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Post Eruption Hydrology and Hydraulics of Mount Pinatubo, The Philippines

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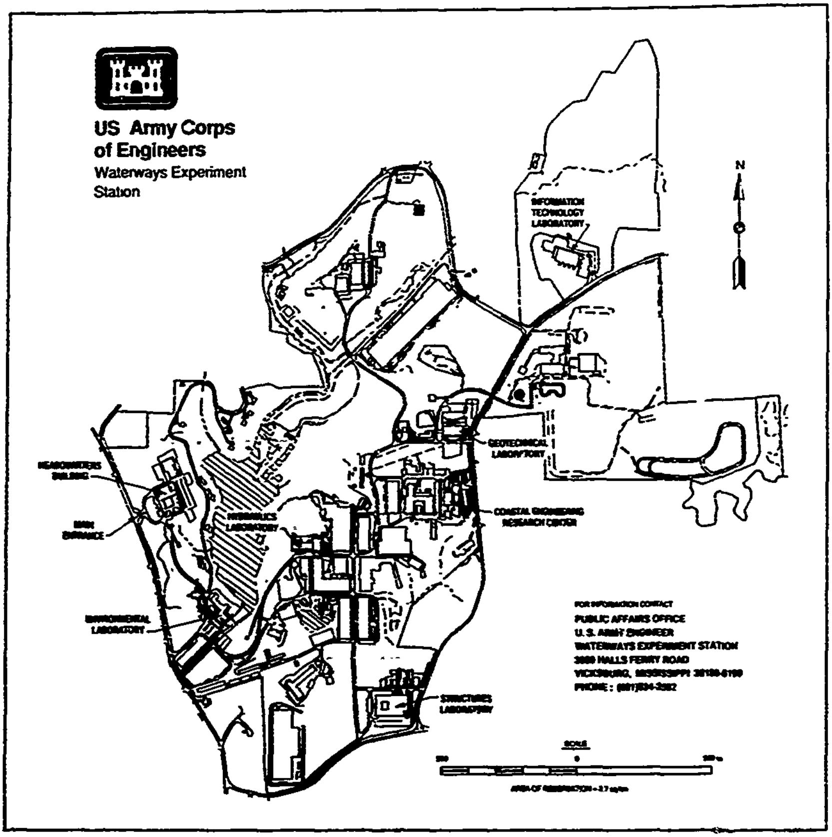

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CONTENTS

[1]This report was initially published as "Appendix A: Hydrology and Hydraulics" to the report entitled "Mount Pinatubo Recovery Action Plan, Long-Term Report," published in March 1994 by the U.S. Army Engineer District, Portland and submitted to the Department of State in March 1994.

PREFACE

Under authority of the Economy Act (31 U.S.C. 1535) and Section 632 of the Foreign Assistance Act (22 U.S.C. 2357), the United States Agency for International Development (USAID) requested the Department of the Army, acting through the U.S. Army Corps of Engineers (USACE), to prepare a comprehensive Recovery Action Plan (RAP) for Mount Pinatubo and subsequent hydrologic events. The RAP is being prepared in accordance with a Participating Agency Service Agreement (PASA) signed on June 18, 1992, between USAID/Philippines and the Department of the Army.

This investigation, "Post Eruption Hydrology and Hydraulics of Mount Pinatubo, The Philippines," was begun and the report was prepared by Mr. Hilaire W. Peck and Mr. Karl W. Eriksen, U.S. Army Engineer District, Portland; MAJ Monte L. Pearson, U.S. Army Engineer Waterways Experiment Station (WES); and Dr. K. Malcolm Leytham, Northwest Hydraulic Consultants, Inc., Kent, Washington, during the period June 1992 to March 1994. Data were collected and analysis was conducted by the authors. A number of field trips were made to the study site, Mount Pinatubo, The Philippines, during the study period.

This report was initially published as Appendix A: Hydrology and Hydraulics to the report entitled "Mount Pinatubo Recovery Action Plan, Long-Term Report," published in March 1994 by the U.S. Army Engineer District, Portland, and submitted to the Department of State in March 1994.

This investigation was performed under the direct supervision of Mr. Ron Mason, Chief, River and Coastal Engineering Branch, and Mr. Mike Roll, Program Manager, U.S. Army Engineer District, Portland, and Mr. Jerry Cornell, Project Manager, U.S. Army Engineer Division, Pacific Ocean; and Drs. W. F. Marcuson III and Paul F. Hadala, Director and Assistant Director, Geotechnical Laboratory, WES, directly supervised MAJ Pearson.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard, EN. Commander of the U.S. Army Engineer District, Portland, was COL Charles Hines, EN.

POST ERUPTION HYDROLOGY AND HYDRAULICS OF MOUNT PINATUBO, THE PHILIPPINS

1. INTRODUCTION

1.1 Authorization

Under authority of the Economy Act (31 U.S.C. 1535) and Section 632 of the Foreign Assistance Act (22 U.S.C. 2357), the United States Agency for International Development (USAID) requested the Department of the Army, acting through the U.S. Army Corps of Engineers (USACE), to prepare a comprehensive Recovery Action Plan (RAP) for controlling sedimentation and flooding resulting from the June 1991 volcanic eruption of Mount Pinatubo, and subsequent hydrologic events. The RAP is being prepared in accordance with a Participating Agency Service Agreement (PASA) signed on June 18, 1992 between USAID/Philippines and the Department of the Army.

1.2 Purpose and Scope

This appendix to the Long-term Action Report is to present hydrology and meteorology pertinent to the design of measures to address long-term flooding and sediment control measures for all eight major river basins impacted by Mount Pinatubo.

1.3 System of Units

The hydrologic output from this study is reported in SI units. Volumes are most often reported in cubic decameters (dam^3). One decameter is equal to 10 meters; therefore, 1 dam^3 is equal to 1,000 m^3. Table 1.3.1 provides SI/English conversions for all SI units used in this appendix.

2. REGIONAL ANALYSES

2.1 Study Area

Mount Pinatubo is located approximately 100 km northwest of Manila in the Zambales Mountains on the west coast of Central Luzon. The eruption of Mount Pinatubo in June 1991 deposited enormous volumes of easily erodible fine-grained pyroclastic material on the flanks of the mountain. Debris flows and shallow flooding worsened by blockage of natural drainages have caused significant economic damage and loss of life.

Mount Pinatubo is drained by eight principal river systems. Clockwise from the north, they are:

O'Donnell-Bangat Rivers (tributary to the Tarlac River)
Sacobia-Bamban Rivers
Abacan River
Pasig-Potrero Rivers
Gumain-Porac Rivers
Santo Tomas River
Maloma River
Bucao River

Drainage basins for these river systems are shown on Plate 1.

The principal drainages can be conveniently split into two groups: west-side and east-side drainages. The west-side drainages (the Santo Tomas, Maloma, and Bucao) drain directly to the South China Sea. Of the east-side drainages, the O'Donnell-Bangat Rivers join the Bulsa River to form the Tarlac River, which flows north to the Agno River and thence to Lingayen Gulf. The remaining east-side drainages (Sacobia-Bamban, Abacan, Pasig-Potrero, and Gumain-Porac) are all tributary to the Pampanga River and the Pampanga Delta which flow south into Manila Bay.

Data used in the analyses were largely obtained from the eight principal drainages and from their immediate surrounding areas. The area considered in the regional analyses generally lies between 14°45' N to 15°45' N and 119°45' E to 121°00' E of each drainage. A small amount of additional data was obtained from more distant locations.

2.2 Physiography

2.2.1 <u>Pre-eruption Conditions</u>. Prior to the June 1991 eruption, the peak of Mount Pinatubo was at 1,745 meters elevation. The upper slopes of the mountain had a dense network of steep and deeply incised drainages. Above 1,000 meters elevation, slopes ranged from 20° to 65° (Pierson et al., op. cit.) with headwater channel gradients in excess of 400 meters per kilometer (m/km). Channel gradients on the lower part of the mountain flatten out to about 10 to 20 m/km at elevations of 200 to 300 meters. Channel gradients in the area of the Pampanga River and the Pampanga Delta are extremely flat, dropping to as low as 0.1 m/km to 0.2 m/km.

The upper slopes of Mount Pinatubo were generally densely covered by shrubs and tall grass before the eruption. The flatter and lower areas on the mountain supported a variety of crops including sugar cane, cassava, and maize.

Much of the low-lying region surrounding the Pampanga River east of Mount Pinatubo is intensively cultivated. This is one of the Philippines' principal rice-growing areas. The more deeply flooded parts of the delta are used for fish-farming and other types of aquaculture.

Little detailed information is available on soils and surficial geology of Mount Pinatubo. However, there is widespread evidence of past eruptions, including large expanses of old pyroclastic deposits in the Sacobia, Abacan, and Pasig-Potrero Rivers on the east side and in the Marella River valley on the southwest side of the mountain (Pierson, et al., op. cit.; JICA, 1978[1]). Analyses of available hydrologic data indicate that soils on Mount Pinatubo are generally highly permeable, though exposures of hard rock have been reported since the eruption in the Gumain and Bangat basins.

2.2.2 Impacts of the June 1991 Eruption. The post-eruption peak of Mount Pinatubo is approximately 1,600 meters, a reduction of more than 130 meters in peak elevation. By necessity the hydrologic analysis is based almost entirely on pre-eruption hydrometeorologic data. The eruption of Mount Pinatubo caused substantial changes in the hydrologic regime of the principal drainages. Some changes (such as reduction in infiltration due to ashfall deposits) are believed to be relatively short-lived and are not reflected in the hydrologic modeling. Other changes, such as in the gross configuration of the drainage systems, are considered to be permanent relative to the life span of possible engineering measures, and are reflected in the modeling effort. The principal hydrologic impacts of the eruption are discussed briefly below.

Changes in Headwater Tributary Areas. The June 1991 eruption filled much of the upper portion of five basins (O'Donnell, Sacobia, Pasig-Potrero, Santo Tomas, and Bucao) with pyroclastic deposits. The drainage patterns that developed in these deposits resulted in numerous changes in sub-basin boundaries within the Bucao Basin and resulted in much of the headwaters of the Sacobia being captured by the Abacan River. However, the Sacobia headcut upstream and recaptured its pre-eruption headwaters plus approximately 4-1/2 km of channel length at the upstream end of the Abacan headwaters (i.e., Abacan above

[1] Japan International Cooperation Agency, 1978, *Planning Report on the Pasig-Potrero River Flood Control and Sabo Project*. Main Report 78-38-1/6.

the Gates of Abacan). It appears that in October 1993 the Pasig-Potrero captured about 21 km² of the Sacobia River headwaters.

In addition to the changes in basin and sub-basin boundaries resulting from new drainage patterns through the pyroclastic deposits, the eruption itself left a 5.9 km² caldera that captured portions of the headwaters of the O'Donnell, Sacobia-Bamban, Gumain-Porac, Santo Tomas, and Bucao Rivers.

With the exception of the headwater drainage areas of the Pasig-Potrero and Sacobia Rivers, hydrologic modeling for post-eruption conditions is based on drainage patterns and drainage areas inferred from aerial photography dated November 1991 and October 1992 and assumes the October 1992 drainage patterns are relatively stable. The portion of the Sacobia River headwaters that was captured by the Pasig-Potrero in October 1993 was determined by District personnel overflights.

<u>Blockages and Lake Breakouts</u>. In the period immediately after the eruption, pyroclastic deposits caused numerous blockages of the drainage system on the upper slopes of Mount Pinatubo. The formation of lakes behind these blockages and their subsequent failure contributed to debris flows along the principal drainages. Given the large amounts of unstable material remaining in the headwater drainages, temporary blockages and sudden breakouts of debris-dammed lakes may be a continuing hazard in some basins. No attempt was made to account for lake breakouts in the hydrologic modeling.

Following the June 1991 eruption, Lake Mapanuepe formed in the Santo Tomas River basin near the mouth of the Mapanuepe River. At the invert elevation of its outlet, Mapanuepe Lake has a surface area of approximately 8 km². The formation of Lake Mapanuepe resulted from a blockage of the Mapanuepe River outlet caused by recurrent lahars and severe aggradation on the Marella River. This lake was the source of repeated lake breakouts in the months immediately following the eruption, but a man-made outlet channel from the lake has now stabilized the situation. Attenuation of the flood wave moving through Mapanuepe Lake due to temporary storage of water in the lake was accounted for in the Santo Tomas hydrologic model.

<u>Channel Degradation and Aggradation</u>. All the principal rivers draining Mount Pinatubo have been affected by extreme channel degradation or aggradation at some point along their course. Channel degradation and aggradation have significantly changed the physical configuration of some of these rivers' drainage systems.

The lower reaches of the Pasig-Potrero, Bamban, and Gumain Rivers have aggraded to the extent that they are now perched between levees approximately three to five meters above the surrounding terrain, and lateral drainage is unable to enter the main channel. These features are reflected in hydrologic modeling.

While beyond the scope of this study, siltation of the Guagua River and other very low-gradient channels leading to the Pampanga Delta has resulted in severe flooding of low-lying land around Bacolor and San Fernando, and is reported to have caused a general increase in the depth and duration of flooding throughout the lower reaches of the Pampanga River and its delta.

Reduction in Infiltration. The June 1991 eruption covered an area of approximately 4,500 km^2 with airfall deposits of fine ash greater than 5 cm in depth, with ash depths of between about 5 and 50 cm on the principal drainages basins covered by this study (Pierson et al., Fig. 2, op. cit.). It is generally believed that deposits of fine ash will reduce pre-eruption infiltration rates, hence causing an increase in the volumes and rates of post-eruption runoff. In the two years since the eruption, much of this widespread deposit of ash has washed off during the monsoon rains, or the low-infiltration crusted surface that forms on these fine grained deposits has been broken up by new plant growth. The reduction in pre-eruption infiltration rates is believed to be a relatively short-lived phenomenon and was not considered in the hydrologic modeling presented in this report.

Loss of Vegetation. The eruption of Mount Pinatubo buried or otherwise destroyed all vegetation over an area of approximately 300 km^2. Loss of vegetation greatly reduces evapotranspiration losses and eliminates the potential for both interception storage and storage in leaf litter and surface soils high in organic material. Loss of vegetation will cause an increase in the volumes and rates of post-eruption runoff. However, the climate of the area around Pinatubo is conducive to rapid plant growth, and it is generally believed that re-vegetation of all but the most unstable parts of the mountain will be relatively rapid. No attempt was made to account for loss of vegetal cover in the hydrologic analyses.

2.3 Climatology

2.3.1 General. The Mount Pinatubo area, on the west coast of Central Luzon, at 15° N latitude, has a tropical climate dominated by the Northeast Monsoon during the winter months (November through May) and by the Southwest Monsoon during the summer months (June through October) which are the rainy-season flood-producing months. The seasonal reversal of airflow results in a pronounced seasonality in prevailing winds and rainfall. Severe weather conditions (high winds and heavy rain) are associated with typhoons, which most commonly occur during the Southwest Monsoon season (June through October).

2.3.2 Climatic Records. Daily rainfall data were available from 15 stations in the vicinity of Mount Pinatubo. Of these, data for 13 stations were obtained from the Philippine Atmospheric, Geophysical, and Astronomical Services Administration (PAGASA). Data for two other stations were obtained from the U.S. Navy (Cubi Point Naval Air Station) and the U.S. Air Force (Clark Air Force Base). The stations, periods of record obtained, and other relevant information are listed in Table 2.3.1. Data availability is summarized in the time-line on Figure 2.3.1. The stations are located on Plate 1. A total of about 330 station years of daily rainfall data was obtained. The majority of the PAGASA stations have a record length of from 15 to 20 years. Longer term records (30 to 40 years of data) are available from Iba, Zambales; Cubi Point NAS; and Clark AFB. Data on station elevations were not available. However, reference to 1:50,000 scale topographic maps published by the National Mapping and Resource Information Authority (NAMRIA) indicate that all daily rainfall stations have elevations in the range of 0 meters to 150 meters (Clark AFB). No daily data were available from stations at higher elevations. The elevation of Mount Pinatubo prior to the eruption was 1,745 meters.

A network of six automatic tipping bucket rain gages was installed at relatively high elevations on Mount Pinatubo by the Philippine Institute of Volcanology and Seismology (PHIVOLCS) after the June 1991 eruption PHIVOLCS high altitude rainfall data were obtained for the period August 1, 1991 to January 10, 1993. Data from these gages were transmitted by radio telemetry either to the Pinatubo Volcano Observatory at the former Clark AFB or to PHIVOLCS main facility in Manila in the format of cumulative bucket tips recorded at pre-selected time intervals. One bucket tip corresponds to 0.635 mm (0.025 inches) of rainfall. The station names, locations, elevations, and other relevant information are listed in Table 2.3.2. The stations are located on Plate 1. There have been considerable difficulties in operating the PHIVOLCS gage network and significant periods of data are missing due to, for example, transmission problems and accumulations of ash in the gages. When these gages are operational, data are reported at least once an hour, and more generally at 20- or 30-minute intervals.

Hourly data were sparse. Gages at Iba, Hacienda Luisita, and Porac provided hourly data, but the record at these stations is described as "fragmentary." Hourly rainfall data were obtained for three storm events at Iba, three events at Hacienda Luisita, and five events at Porac. Information on the data obtained is provided in Table 2.3.3. The stations are located on Plate 1. Hourly rainfall data outside the immediate study area were available for one extreme 24-hour period from *Weather Bureau Technical Paper No. 42*[2], which provided hourly data from Baguio City, located approximately 140 km north-northeast of Mount Pinatubo at 1,370 meters elevation (4,500 feet), for a typhoon-related event in September 1911 which generated the then world's record 24-hour rainfall of 1,168 mm (45.99 inches). The general lack of good hourly rainfall data placed severe limitations on hydrologic modeling for the present study.

Daily pan evaporation data were obtained from three stations in the vicinity of Mount Pinatubo, all operated by PAGASA. The stations, the periods of record obtained, and other relevant information are listed in Table 2.3.1. The stations are located on Plate 1.

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[2] Weather Bureau, U.S. Dept. of Commerce, 1961, *Generalized Estimates of Probable Maximum Precipitation and Rainfall-Frequency Data for Puerto Rico and Virgin Islands for Areas to 400 Square Miles, Durations to 24 Hours, and Return Periods from 1 to 100 Years*. Technical Paper No. 42.

Screening of Daily Data. Daily rainfall data were screened to identify clearly anomalous (high or low) values and to summarize periods of missing data. The completeness of rainfall records is highly variable, with no missing data reported at Clark AFB (station USA02) and over 30 percent of the record missing at Camiling (Station R0315). The records from Cubi Point NAS (USA01), Clark AFB (USA02), and Iba, Zambales (D324), the three stations with the longest records, are all relatively complete.

The following points were noted during screening:

- The maximum reported daily rainfall of 748.5 mm for the period of record at Iba (D324) on July 10, 1980 is suspect. No other neighboring stations reported daily rainfall greater than 150 mm on that date. Examination of hourly data for this event showed that the daily amount for this day was in fact 78.5 mm, and the record was corrected accordingly.

- The rainfall record for Magalang, Pampanga (A020) is too short to be of value. A longer record is available from Bai Magalang (R0312), approximately 5 km east of the Magalang gage.

- The record for Bai Magalang (R0312) is essentially complete between February 1977 and January 1992. However, the maximum recorded daily rainfall of 103.1 mm on November 14, 1977 is significantly lower than that at other neighboring stations.

- The record from Camiling (R0315) is too short and too fragmented to be of value.

- The record for Mayantoc, Tarlac (R0316) is quite fragmented with approximately 20 percent of the daily records reported missing. The record is particularly poor for the period 1978 through 1984, when 27 months are missing, including most records for July, August, and September.

- The record for Palawig, Zambales (R0318) is highly suspect, particularly for 1982 when no rainfall was recorded even though the station was reported to be in operation. Also, the Palawig station does not report nearly as many rainfall events during the relatively dry months of January through April as do other coastal stations. Over the 15 years of record, only nine measurements, including trace rainfalls, were reported in these four months. It is possible the station is only operated on a seasonal basis.

- The record for San Felipe, Zambales (R0319) is suspect. The maximum reported daily rainfall of 162 mm for the period of record is far below that for other coastal stations.

As a result of this basic screening, data from Camiling, Palawig, and Magalang were dropped from further consideration.

Double Mass Analysis. Double mass analyses were conducted on daily rainfall data using the following groups of stations:

Long-term stations

Group 1: Clark AFB (USA02); Cubi Point NAS (USA01); Iba (D324).

West coast stations

Group 2: Cubi Point NAS (USA01); Z-NAS, San Marcelino (R0322); San Felipe (R0319); Santa Rita Elementary School (R0320); Iba (D324).

Northeast stations

Group 3: Mayantoc (R0316); CLSU, Munoz (A017); Hacienda Luisita (A016).

Southeast stations

Group 4: Clark AFB (USA02); Bai Magalang (R0312); Julian Subdivision (R0313); Masantol (R0314).

The entire concurrent rainfall record for each group of stations was used for the double mass analysis. In computing cumulative rainfall amounts, days were ignored for which data were missing for any station in the group. The double mass analyses of the long-term stations indicated that, with the exception of an unusually high rainfall amount recorded at Iba, Zambales (D324) in 1964, the records for these stations are fairly consistent for the period 1961-1990.

The double mass analyses of the west coast stations indicated that, with the exception of San Felipe, the records are relatively consistent over the period 1975-1990. Removing San Felipe from consideration should improve the results for other stations.

The double mass analyses of the northeast stations indicated no obvious long-term changes in slope, although the plot for Mayantoc showed an unusual shape with a number of small slope changes and an overall tendency towards diminished rainfall in later years. Considering these results and the preliminary screening noted earlier, the data from Mayantoc (R0316) are highly suspect.

The double mass analyses of the southeast stations indicated that the data for Bai Magalang underwent several major slope changes between 1977 and 1991. Again, considering the results of the screening and double mass analysis, the data for Bai Magalang are suspect.

For Masantol and Clark AFB the double mass analyses do not indicate any major shifts in recorded rainfall. At Julian Subdivision there is an apparent long-term shift at about 1987. Comparatively less rainfall is recorded at Julian after this date. It is not known if station relocation or other changes took place which might explain this shift.

As a result of the double mass analysis, data from San Felipe, Mayantoc, and Bai Magalang were dropped from further consideration.

Spatial Variation of Daily Data. Spatial variations in rainfall data were examined by computing cross correlations between daily data at all stations and by examining rainfall amounts in individual major storm events. A matrix of cross-correlation coefficients for all stations is shown in Table 2.3.4. Cross-correlations were computed for individual pairs of stations using all available data for which daily rainfall exceeded 50 mm at either or both stations. The maximum cross-correlation is 0.53 between Iba (Station D324) and Santa Rita Elementary School (Station R320), which are approximately 20 km apart. If stations with suspect records are eliminated from the matrix (e.g. Palawig, San Felipe, Bai Magalang), the cross-correlations generally decrease with distance between stations, as might be expected. The low cross-correlations indicate substantial spatial variations in daily rainfall amounts over relatively short distances.

Relationships between daily rainfall amounts at various stations during major storm events were examined qualitatively. Major storms in western Luzon are associated with large weather systems (the Southwest Monsoon or typhoons) which affect the entire area around Mount Pinatubo. However, daily rainfall amounts within individual events show great spatial variability, especially when rainfall depths from stations on the east and west sides of Mount Pinatubo are compared. Spatial variations of rainfall during Typhoon Didang in May 1976 appear to be typical. This event produced the maximum two-day rainfall depth of 988 mm for the 40-year period of record at Iba. Significant rainfall depths were recorded at all other west coast stations, although storm depths were relatively less severe. The maximum two-day rainfall depth at Cubi Point during this event, for example, was 485 mm, a depth exceeded six times in Cubi Point's 33-year record. Comparison of rainfall depths at Iba for this event with rainfall depths from the east side of Pinatubo (for example, at Clark AFB) show even greater variation.

Analysis of PHIVOLCS Data. Review of the daily rainfall records and monthly totals recorded at PHIVOLCS stations indicates significant problems with many of the stations. PHIVOLCS data do not include a flag to indicate missing data or equipment malfunction. Therefore any gaps in the record were filled with a value of 0.0. This may lead to inconsistencies when comparing PHIVOLCS data to PAGASA or other neighboring daily rainfall gages. Following is a review of the available PHIVOLCS data.

Station RG-1 — Mt. Caudrado: Data for August and September 1991 appear to be fairly complete. Monthly totals are not significantly greater than those recorded at lower elevations but individual storm events show increased daily precipitation. Data beyond October 1991 are fragmented and are not useful in the hydrologic analyses.

Station RG-2 — BUGZ: Data for August and September 1991 are relatively complete. Similar to station RG-1, the monthly totals are not substantially larger than the lower elevation PAGASA stations. Data from mid-August 1992 to mid- September 1992 may also be of some value. As was the case for RG-1, the data for much of 1992 were recorded as no rainfall. As noted earlier, there is no way of distinguishing between missing data due to station malfunction and data that actually register 0.0.

Station RG-3 — PI2: Data for all months are unrealistically low. The maximum monthly precipitation recorded was 535 mm in August 1992. This is significantly lower than the 804 mm recorded at Bai Magalang, for instance.

Station RG-4 — Mt. Culianan: Data for all months are unrealistically low. The maximum single day rainfall in 1991 was 37.4 mm. In comparison, the PAGASA station at Iba, Zambales reported six events greater than 100 mm during August and September 1991.

Station RG-5 — Gumain: Rainfall records for the August 20, 1991 event appear to be complete through midday on August 21, 1991. With the exception of this event, the Gumain data are fragmented, unrealistically low, and probably not of value.

Station RG-6 — Sacobia: Data collection did not begin until mid-September 1991. Rainfall totals for July and August 1992 are substantially less than those reported at low elevation stations. The record is fragmented and is not useful in the hydrologic analyses.

The PHIVOLCS records are too short and fragmented to be used for determining variations of rainfall with elevation on Mount Pinatubo.

Evaporation Data. Daily pan evaporation data were obtained from three stations in the vicinity of Mount Pinatubo, all operated by PAGASA. The stations, the periods of record obtained, and other relevant information are listed in Table 2.3.1. The stations are located on Plate 1.

Most of the missing data in the evaporation records can be attributed to pan overflows during wet weather. Examination of the available data showed the record at

Hacienda Luisita to be fragmented and occasionally reporting unusually large (in excess of 30 mm/day) daily evaporation depths. Data from this station were consequently dropped from further consideration. The data from Magalang were also dropped because the record was too fragmented and too short to be of value.

The data from CLSU, Munoz are believed to be the most reliable pan evaporation data available. Missing periods in this record were filled with mean daily values for each month to obtain estimates of annual pan evaporation. The estimated annual pan evaporation is given in Table 2.3.5.

2.3.3 Precipitation. The rainfall regime of the Mount Pinatubo area is highly seasonal, with a pronounced wet season from approximately June through October, coincident with the Southwest Monsoon, and a dry season from approximately November through May. Rainfall amounts along the west coast of Central Luzon are enhanced by orographic uplift during the Southwest Monsoon. Mountains to the west and southwest of Mount Pinatubo, with peaks at about 1,000 meters, act as partial orographic barriers during the Southwest Monsoon, with the result that the west and southwest flanks of Mount Pinatubo probably receive somewhat less rainfall than would otherwise be expected. Mount Pinatubo itself, and the Cabusilan Mountains to the south, present a more significant orographic barrier during the Southwest Monsoon, such that the east and northeast sides of Mount Pinatubo lie in a rain shadow, with low-lying interior areas east of Mount Pinatubo receiving only about half of the total annual rainfall experienced on the coast. Plots of mean monthly rainfall at Cubi Point NAS and Clark AFB (Figures 2.3.2 and 2.3.3) illustrate the seasonal distribution of rainfall totals on the west side and east side of Mount Pinatubo, respectively. The mean annual rainfalls at Cubi Point NAS and Clark AFB are about 3,600 mm and 2,000 mm, respectively.

Maximum daily rainfall amounts at stations in the Mount Pinatubo area are generally caused directly or indirectly by tropical cyclones, which are most prevalent between May and November. Data available from PAGASA indicate that between 1948 and 1991, an average of 16 tropical cyclones per year (tropical depressions, tropical storms, or typhoons) affected weather conditions at various regions in the Philippines. Of these, typically three or four per year affected weather conditions around Mount Pinatubo.

While large one-day rainfall amounts can be caused by the direct passage of a typhoon over the area (the maximum recorded one-day rainfall at Cubi Point NAS of 442 mm in May 1966 is believed to be one such example), rainfall events of longer duration with greater total event volumes and comparable one-day depths may result from intensification (or surges) in the Southwest Monsoon flow during passage of typhoons to the northeast of Luzon.

The Southwest Monsoon flow can bring long periods of near-continuous heavy rain. Intense localized rainfall is associated with intense convective activity in groups or pockets of storm cells embedded in the general southwesterly flow. Surges in the southwesterly flow due to the influence of typhoons may increase wind speeds by 10 to 20 knots with a concomitant increase in rainfall.

Normal Annual Precipitation (NAP) Map. Figure 2.3.4 shows isohyets of mean annual rainfall as determined from assessments of available long-term rainfall and streamflow data. Long-term rainfall records are available only for elevations generally less than 100 meters near the coast and in the interior lowland regions. However, the study area includes much higher elevations: the pre-eruption summit elevation of Mount Pinatubo, for example, was 1,745 meters. Streamflow and evaporation records were used to estimate mean annual rainfall at the higher elevations which correspond to the watershed areas of interest, as described in the following paragraphs:

1) The annual rainfall data, summarized by Table 2.3.6, were sufficient to determine an isohyetal line corresponding to 1,900 mm/yr of rainfall in the lowland areas east of the Zambales and Cabusilan mountain areas, and to show that rainfall decreases with eastward distance from the mountains. Coastal rainfall gages to the west of the mountains indicate rainfall of around 3,600 mm/yr to 4,200 mm/yr.

2) Annual yields from watersheds with streamflow gages were determined in terms of annual depth of runoff over the basin area as summarized by Table 2.3.7. Data for the Bagsit and (upper) Camiling stations, key stations for rainfall assessment because they have relatively high-elevation basins, show average annual runoff amounts of approximately 3,400 mm and 3,700 mm, respectively.

3) Average basin rainfalls were estimated by adjusting the runoff data by 1,550 mm to account for the estimated average annual evapotranspiration in the basins. This evapotranspiration amount was computed as being equal to about 80 percent of pan evaporation reported for lower elevations, assuming there would be no significant moisture deficit in the mountains. In transposing the estimated basin rainfall amounts to the maps, it was assumed that the average basin rainfall would occur at the centroid of the basin, and that rainfall would increase with elevation.

4) Knowing the rainfall at the lower basin elevations from the rain gages, and having assumed the rainfall for the centroid of the basin, rainfall at the upper basin was determined as the amount necessary to generate the observed runoff.

The analysis resulted in findings that, for mountains next to the coast, without any intervening topographic barriers, rainfall isohyetal lines of 5,000 mm/yr and 6,000 mm/yr correspond approximately to elevations of 750 meters and 1,200 meters, respectively. At Mount Pinatubo, which is separated from the coast by other mountains and may experience a rain shadow effect, isohyetal lines of 4,000 mm/yr and 5,000 mm/yr correspond approximately to elevations of 500 meters and 1,000 meters, respectively.

The NAP map in Figure 2.3.4 differs significantly from those published with other studies in the area. Other available NAP maps show no significant increase of rainfall with elevation over Mount Pinatubo. Most of the annual rainfall in this region is associated with the Southwest Monsoon, which brings moist air from the southwest across the South China Sea during the months of June through October, striking the west coast of Luzon. An intensification of monsoon rain on the west side of the Zambales and Cabusilan Mountains due to orographic uplift is expected, and hence an increase of rainfall with elevation. The role of orography in increasing monsoon rainfall has been confirmed by meteorologists formerly stationed at Cubi Point NAS.

Additional support for the role of orography causing increasing rain with elevation is found in *Weather Bureau Technical Paper No. 42*[3]. This paper verified the orographic component of a hurricane model using wind and rain data recorded at Baguio City, Philippines in September 1911. Baguio City is located approximately 140 km NNE of Mount Pinatubo, at elevation 1,370 meters (4,500 feet). The rainfall event was associated with a typhoon and prevailing southwest winds.

2.3.4 <u>Air Temperature</u>. The mean annual air temperature at Cubi Point NAS (at sea level on the southwest of Mount Pinatubo) is approximately 26-28° C[4]. The annual average maximum temperature at Cubi Point NAS is 31.4° C and the annual average minimum is 23.7° C. A plot of mean monthly temperatures at Cubi Point NAS is given in Figure 2.3.5. Temperatures near the summit of Mount Pinatubo (pre-eruption elevation of 1,745 meters) are expected to be about 5 to 10° C cooler than those at Cubi Point and Munoz, by consideration of adiabatic lapse rates.

2.3.5 <u>Winds</u>. Wind speed data are available from Cubi Point NAS and annual monthly wind roses have been published by the Naval Weather Service Environmental Detachment. The annual wind rose is shown in Figure 2.3.6. The numbers shown on the wind rose (e.g. 19.6, 9.9, .9, etc.) represent the percent of time that wind comes from the indicated directions. The various ranges of wind speed and the symbols that represent these ranges are shown in the lower right hand corner of Figure 2.3.6. The percent of time that wind in a given speed range comes from a given direction can be scaled from the appropriate symbol on the wind rose (e.g. 19.6 percent of the time wind comes from the northeast and approximately 4 percent of the time wind comes from the northeast at a speed between 11 and 16 KTS). As indicated in the center of the wind rose, 25.9 percent of the time wind

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[3] See Footnote 2.

[4] Wernstedt, F.L, 1972, *World Climatic Data*, Climatic Data Press.

speed is less than 4 knots (KTS). The direction of winds less than 4 KTS is not indicated by the wind rose. As previously indicated, the winds come from two predominant directions: from the southwest during June through October and from the northeast during November through May

2.4 Hydrology

2.4.1 Discharge Records. Daily streamflow data were available from 18 stations in the vicinity of Mount Pinatubo. Data were obtained from the Department of Public Works and Highways (DPWH) and the Bureau of Research and Standards (BRS), which currently have responsibility for collection and dissemination of streamflow data. Responsibility for streamflow data collection has changed hands several times in past years and most of the data obtained were originally collected by either the Bureau of Public Works or the National Water Resources Council (NWRC). The stations, drainage areas, periods of record obtained, and other relevant information are listed in Table 2.4.1. No daily streamflow data were obtained prior to 1957, although published records indicate that earlier data are available for some stations, as indicated in Table 2.4.1. The last year for which data were officially published was 1972. A small amount of post-1972 data were obtained. Streamflow stations are located on Plate 1.

Peak annual flow data were obtained at the 18 stations providing daily streamflow data. Station names, periods of record, and other relevant information are given in Table 2.4.1. For the most part, peak annual flows were extracted from two publications:

- *Philippine Water Resources Summary Data, Volume 1 — Streamflow and Lake or River Stage Ending December 31, 1970.* Partial copy. Exact title, publisher, and date of publication unknown.

- *Philippine Water Resources Summary Data, Volume 2 — Streamflow and Lake or River Stage Ending December 31, 1980.* Republic of the Philippines, Department of Public Works and Highways, Bureau of Research and Standards, Quezon City, June 1991.

The first of these publications contains peak annual flow data for the period of record through December 1970. The second publication covers the period 1971 through 1980. Some additional peak annual flow data subsequent to 1980 were obtained from unpublished sources.

Most of the streamflow data in the study area were obtained from staff gage readings that were reportedly read two or three times per day. Data at some stations were collected using an automatic water level recorder. Attempts were made to obtain these data for selected flood events. However, no data could be obtained other than mean daily flows and published annual peak flows.

Review of Rating Curves. Discharge measurement data and/or rating curves were available for review for about one half of the stations considered in the analysis. The available information yielded the following general observations which should apply for all stations.

- The rating curves tend to be unstable, and most stations required a number of different rating curves over time as channel conditions changed. Substantial shifts in rating curves were most apparent in rivers subject to aggradation, where vertical shifts of 1 meter or more were observed over the period of record.

- Measured (gaged) discharge points are available only at flows significantly less than peak annual discharges. Measured data were apparently used as the basis for shifting previously defined rating curves to match the measured points as well as to define new rating curves when the extent of shifting exceeded certain (unspecified) limits. In general, the low-flow records are considered to be quite good for those periods when discharge measurements were made on a regular basis.

- Prior to 1970, discharge measurements were made on a regular basis at most stations, typically at least three measurements per year. After 1970, the frequency of discharge measurements decreased significantly, with most stations showing one or more years with no measurements at all.

- Plotted stage-discharge curves appear to be biased towards matching the lower limit of measured discharges for a given stage. If this observation is accurate, the implication is that available water supplies are conservatively reported but that peak discharges tend to be underestimated.

- The basis for extrapolating the rating curves beyond the measured discharges is generally not known. The following three methodologies were indicated in the literature for some of the stations:

1) "The upper portion of the curve was extended by area-velocity method."

2) "Due to the unavailability of the cross-section of the river, the upper portion of the curve was extended by logarithmic plotting."

3) There are infrequent references to some peak discharges as having been determined by "slope-area" method.

In summary, pre-1970 reported low discharges are considered to be quite accurate but the discharges may not reflect natural hydrologic conditions due to irrigation withdrawals on many of the rivers. Peak flows are subject to considerable error due to a lack of data for estimation plus shifting of the stage-discharge relationships during flood events.

Screening of Daily Data. Daily streamflow data were screened to identify clearly anomalous (high and low) values and to summarize periods of missing data. Data availability is summarized in the time-line in Figure 2.4.1.

The principal observations from screening the data are as follows:

- Useful streamflow data are sparse after 1972. Data available after 1972 suggest staff gages were read not on a regular daily basis, but at irregular intervals several times a month. For example, the record for Maloma for 1987 contains a period of 21 days in the wet season with a constant flow of 7.2 m^3/s with an abrupt change on August 17 from 7.2 to 372 m^3/s. The records for 1987 and other years contain similar periods of "constant" flow.

- As can be seen from Figures 2.3.1 and 2.4.1, there is very limited overlap of daily rainfall and daily streamflow data. This makes it impossible to reconstruct storm isohyetal maps for which reliable concurrent streamflow data are available.

- Data from the two stations on the Porac River near Del Carmen and Valdez show inconsistencies. It is possible that the data near Valdez reflect irrigation diversions or diversion of flows into the Gumain Floodway. However, no information is available on the nature of diversions or the physical configuration of the floodway. As a result, data from the Porac River near Valdez and the Gumain Floodway were dropped from further consideration.

- Records from many stations show unreasonable abrupt changes in flow rate. These occur at many places throughout the record and are too numerous to document individually.

Double Mass Analysis. Double mass analysis was conducted on daily streamflow data using, in the first instance, the following group of four stations:

Porac River near Del Carmen (084A)
Gumain River (086A)
Bucao River (093A)
Santo Tomas River (094A)

These stations were selected because they are of direct interest to the hydrologic analyses (all are affected by the eruption of Mount Pinatubo) and have a relatively long common record. The entire concurrent record for the group of stations was used for double mass analysis. The analysis was done in terms of mean monthly cumulative runoff in millimeters using published drainage areas to convert from discharge rate in m^3/s to runoff depth in millimeters. The plot for Porac River near Del Carmen indicates a progressive increase in flows relative to other stations throughout its period of record. The plot for the Santo Tomas indicates a dramatic reduction in flows starting in 1964. The reason for the reduction in flows is not known but could result from gage errors or irrigation diversions. However, no information was available as to whether such diversions occurred. Plots for the Gumain and Bucao Rivers showed a reasonably consistent record.

For completeness, double mass analyses were done for all other available records by plotting cumulative monthly runoff at the station of interest against the cumulative mean monthly runoff from a control group made up of stations on the Porac, Gumain, Bucao, and Santo Tomas Rivers. All plots exhibited inconsistencies in the records. Records for the two gages on the Camiling River appeared to be the most reliable outside the control group.

Review of Peak Annual Flow Data. Table 2.4.2 presents a summary of all available peak flow data expressed in m^3/s. Table 2.4.3 presents the same data on a normalized yield basis computed by dividing each peak flow (m^3/s) by the published basin drainage area (km^2) at the gage. These tables include data found to be unrepresentative of actual annual peak flow amounts.

Some of the published peak annual flow data were determined to be unrepresentative of actual annual peak flow amounts when the peak was published for:

- a year in which there was only a partial record of flow, and for which there were no discharge records for significant portions of the high-flow months of July through December;

- a year or longer period for which there were serious questions as to the adequacy of the rating curve used at the station.

Tables 2.4.4 and 2.4.5 summarize peak flow and normalized peak flow data which have been screened to exclude doubtful records.

Examination of data in Tables 2.4.2 through 2.4.5 show very low peak flow yields for the Pasig-Potrero and O'Donnell Rivers and very high yields for the Caulaman River. The low yields on the Pasig-Potrero and O'Donnell could result from local geologic conditions although no information is available to confirm this. The reason for the unusually high yield on the Caulaman is unknown.

Most streamflow gaging stations used in the hydrologic analyses rely on a staff gage (which is read between once and three times a day, depending on the gage site) and its associated rating curve. The reported "peak annual flow" at these stations appears to be the largest of the discrete number of available observations. There are no known crest-stage gages at the gage sites, and few, if any, of the reported peak flow measurements appear to be based on observed high water marks. The following points are noted:

- Because continuous stage records are lacking at many sites, many reported "peak annual flows" may understate true instantaneous peak annual flows. However, due to the considerable uncertainty in the magnitude of high flows resulting from extrapolation of rating curves, it cannot be determined if the reported "peak annual flows" are in fact understated.

- Measurement procedures appear to be inconsistent from year to year. In some years, some stations report the peak annual flow as having the same value as the maximum daily annual flow, implying that only one stage measurement was made on that day, even though the gage was reported to be read two or three times a day.

Review of Annual Runoff Data. The annual runoff (mm) for each complete year of streamflow record was computed for all stations and is shown in Table 2.3.7. Some serious inconsistencies are evident:

- The Porac River near Valdez (drainage area 118 km^2) shows a significantly lower yield than the Porac River near Del Carmen (drainage area 111 km^2). The Valdez record is presumably affected by irrigation diversions or diversions to the Gumain Floodway.

- The Santo Tomas River shows an abrupt drop in yield in 1967 (drop was also indicated on the double mass plot).

- The Pasig-Potrero River at Hacienda Dolores (drainage area 28 km^2) shows an abrupt drop in yield in 1969.

Because of significant periods of missing data, the annual runoff data from several stations could only be estimated for two or three years and were not considered to be of value to the hydrologic analyses.

Due to lack of overlapping rainfall and streamflow data, only limited comparison of annual runoff and annual rainfall data was possible. Plots of annual rainfall at Clark AFB against annual runoff on the Gumain, Porac, and O'Donnell Rivers are given in Figures 2.4.2 through 2.4.4, and a plot of annual rainfall at Cubi Point NAS against runoff on the Santo Tomas is given in Figure 2.4.5. With the exception of the Gumain River (Figure 2.4.2), these plots do not show a good relationship between annual rainfall and annual runoff. The plot for the Santo Tomas River (Figure 2.4.5) would improve somewhat if suspect data after 1967 were dropped from the analysis.

Review of Gaging Stations. The records available for analyses are listed in Table 2.4.6. The principal findings of the review of stations from which these records were obtained are provided below for each gage site:

Bulsa River (Station W010A): The headwaters for the Bulsa River are on the east slopes of the Zambales Mountains, 15 to 45 km north of Mount Pinatubo. The record shows unusually high yield (i.e. normalized peak flow in $m^3/s/km^2$) relative to other stations whose headwaters originate on Mount Pinatubo, with some periods reporting extreme (and likely erroneous) monthly runoff (e.g. runoff for July 1972 was reported as 3.8 meters, with monthly rainfall at Iba of 1.7 meters and at Hacienda Luisita 1.6 meters). The high yield relative to basins on Mount Pinatubo may result in part from different geologic conditions. However, the Bulsa's double mass curve is concave upward, indicating a progressive increase in flows with time relative to other stations, and its rating curves show a progressive upward shift due to aggradation.

O'Donnell and Bangat Rivers (Stations W011A, W011B, and W012A): The records from the O'Donnell and Bangat Rivers show very significant and irreconcilable inconsistencies. Peak flows on the Bangat (Station W012A, drainage area 90 km^2) are invariably much higher (by as much as a factor of 6) than those recorded at the downstream gage on the O'Donnell (drainage area 240 km^2). A possible high flow diversion exists from the O'Donnell above gage W011B into the Bangat above gage W012A. However, no diversion has been identified out of the system between the Bangat River gage W012A and the O'Donnell River gage W011A. Records for these stations are less than 10 years in length.

Camiling River (Stations W023A and W023B): The headwaters of the Camiling River are on the east slopes of the Zambales Mountains from 40 to 60 km north of Mount Pinatubo. The records show an unusually high yield (i.e. normalized peak flow in $m^3/s/km^2$) relative to other stations originating on Mount Pinatubo. The record for both these stations is less than 10 years in length.

Pasig-Potrero River (Stations W081A and W082A): The record from station W081A (drainage area 242 km^2) may have been tidally affected and stage records only are available for much of the record. Discharge records are available for only five years from Station W081A and six years from Station W082A.

Porac River (Stations W083A and W084A): The records from the two Porac River gages (Station W083A with drainage area 118 km² and W084A with drainage area 111 km²) show significant and irreconcilable inconsistencies, with the downstream gage frequently showing significantly higher peak flows than the upstream gage despite the very small difference in drainage area. It is likely that the records are affected by the operation of both irrigation and flood control projects. However, no information could be obtained on the configuration or operation of these schemes.

Gumain Floodway (Station W085A): This station is at the downstream end of the Gumain Floodway and the record is affected by upstream flood control and irrigation projects. No information could be obtained on the configuration or operation of these projects and how they affect the flow record at gage W085A.

Gumain River (Station W086A): The headwaters for the Gumain River are on the southeast slopes of Mount Pinatubo. The available daily record is 15 years in length. There are no known upstream diversions into or out of the system. The record appears to be of reasonable quality. A water level recorder was in operation for most of the period of record.

Caulaman River (Station W087A): The Caulaman River originates on the east slopes of Mount Bitnung 15 km south of Mount Pinatubo. It has not been possible to determine the exact location of this gage. Assuming the reported drainage area is correct, the records show an extremely high yield relative to other stations. Reported monthly and event runoff is occasionally (and likely erroneously) extremely high. For example, the reported runoff for September 1963 was 1.85 meters with reported rainfall at Cubi Point NAS of 0.93 meters and at Clark AFB of 0.51 meters.

Colo River (Station W088A): The Colo River basin lies approximately 30 km south of Mount Pinatubo. The station is downstream from an irrigation dam. The effect of this dam on the record is not known.

Bagsit River (Station W092A): The Bagsit river originates on the west slopes of the Zambales Mountains approximately 40 km north of Mount Pinatubo. The basin was judged to be too far from Pinatubo to be representative of hydrologic conditions of interest.

Bucao River (Station W093A): The Bucao River originates on the northwest slopes of Mount Pinatubo. The available record of daily flows is 15 years in length. Although the record quality is uncertain because of extreme extrapolation of the available rating curves, the record prior to 1972 appears to be relatively consistent. There are occasional periods of suspiciously high reported daily runoff volumes. A water level recorder was apparently in operation for part of the record.

Santo Tomas (Station W094A): The Santo Tomas River originates on the southwest slopes of Mount Pinatubo. The available record of daily flows is 15 years in length. The double mass curve for the Santo Tomas showed discharge volumes after 1967 to be significantly reduced by irrigation diversions upstream of the gage. However, the 11 years of data prior to 1967 appears to be relatively consistent.

Maloma River (Station W099B): The Maloma River originates on the west slope of Mount Pinatubo. Seven years of flow data are available; however, the record is judged to be exceedingly poor and too unreliable to be of use.

2.4.2 Streamflow Characteristics. Table 2.4.7 lists the 15 streamflow gages considered in the hydrologic analyses, together with rainfall and evaporation gages. The list excludes those gages determined to be unreliable or not useful to the analyses. Gage locations are shown on Plate 1. The data available for each streamflow gage consist of reported mean daily discharges and annual peak instantaneous discharges. No continuous or short-duration flow hydrograph data are available.

The convention adopted to identify streamflow gage data consists of a five-character code:

- the first character is "W" to signify a streamflow gage;

- the second through fourth characters identify the stream gage number, based where possible on gage numbers published by Philippine agencies;

- the fifth (and final) "A" or "B" character signifies whether the gage actually had a published gage number: "A" signifies that the number was published, and "B" signifies that no gage number had been published and that one was arbitrarily assigned for purposes of this analysis.

Periods of record of available daily streamflow data are summarized by Table 2.4.7 and Figure 2.4.6 together with rainfall and evaporation data. Record lengths vary from five to 16 years and are mostly within the period 1957 to 1972. Peak instantaneous streamflow data considered in this analysis are summarized by Table 2.4.8. Record lengths vary from five to 33 years, with very little data available after 1972.

Summary hydrographs at each of the gages are presented on Figures 2.4.7 through 2.4.21. The high points shown on the figures reflect discrete major flood events; differences in the presence or absence of specific peaks from gage to gage are due in part to differences in the periods of record.

Plots of mean monthly minimum, average, and maximum daily discharges are presented on Figures 2.4.22 through 2.4.36. The mean monthly maximum daily discharge for the month of June, for example, was determined by averaging the maximum daily values for June from each year of record.

The plots on Figures 2.4.7 through 2.4.36 indicate a strong seasonal pattern of low flows during the months of January through April and high flows during the months of June through October. High flows indicated for May mostly reflect a major storm in May 1966. The Bucao River (W093A) has no data for this month; hence, the Bucao River data as shown on Figures 2.4.19 and 2.4.34 are misleading by wrongly suggesting that high flows have not occurred on this river in May.

Plots on Figures 2.4.37 through 2.4.51 show the daily flow duration curves for each of the streamflow gages. Plots on Figures 2.4.52 and 2.4.53 show normalized flow duration curves for all gages, in which the curves were normalized by dividing the curve ordinates by the average daily flow for each gage.

The normalized flow duration curves show pronounced differences between the gages at higher discharges. While the reasons for these differences are not known, inaccuracies in the reported peak discharges are probably one factor.

2.4.3 Runoff. Figures 2.4.54 through 2.4.68 summarize the annual runoff for each of the streamflow gages.

2.4.4 Frequency Analyses. The HEC-FFA Flood Frequency Analysis program Version 3.0, which computes flood frequencies using a Log Pierson Type 3 fit in accordance with guidelines described in *Bulletin 17B* of the U.S. Water Resources Council[5], was used to assess frequency characteristics of both flood flow and rainfall data.

Rainfall Data. HEC-FFA frequency analyses of maximum annual 1, 2, 5, 10, and 15-day duration rainfall amounts were conducted for all daily data rain gage stations.

Tables 2.4.9 through 2.4.13 summarize the rainfall frequency data as computed from the raw data and also after multiplication by factors to convert from observational day data to *n*-hour

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[5] U.S. Water Resources Council, March 1982, *Guidelines for Determining Flood Flow Frequencies*. Bulletin 17B.

amounts. The following empirical factors suggested by the U.S. Weather Bureau[6,7] were used:

n-days	n-hours	conversion factor
1	24	1.13
2	48	1.04
5	120	1.02
10	240	1.01
15	360	N/A

The plotted analytical frequency curves fit the data well for all *n*-day durations at all gages as typified by Figures 2.4.69 and 2.4.70.

The frequency data support the earlier observation that daily and multi-day rainfall is significantly greater along the coast than in the interior.

Streamflow Data. The criteria for selecting stations for frequency analysis were generally as follows:

- minimum of 10 years record (excluding periods of clearly erroneous data);
- headwaters originating on Mount Pinatubo (records from streams originating in other areas were not selected for frequency-based calibration because of lack of information on surficial geology and concern about whether such records would be representative of hydrologic conditions on Mount Pinatubo);
- clearly defined drainage area with consistent records and no significant upstream diversions into or out of the system (e.g., for irrigation or flood control).

It was determined in the review of gaging stations in Section 2.4.1 that three stations met the above criteria. These were the Gumain River (W086A), the Bucao River (W093A), and the Santo Tomas River (W094A).

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[6] Weather Bureau, U.S. Dept. of Commerce, no date, *Rainfall Frequency Atlas of the United States for Durations from 30 Minutes to 24 Hours and Return Periods from 1 to 100 Years*. Technical Paper No. 40.

[7] Weather Bureau, U.S. Dept. of Commerce, 1964, *Two- to Ten-Day Precipitation for Return Periods of 2 to 100 Years in the Contiguous United States*. Technical Paper No. 49.

For each of these gages, frequency analyses were conducted on the following maximum annual data:

A) Peak instantaneous discharge
B) Mean daily discharge (and corresponding 1-day volume)
C) Mean 3-day discharge (and corresponding 3-day volume)

Also for each of the gages, different data sets were assessed according to data availability and reliability, as follows:

A) Screened data set within the period 1957 through 1972. As previously discussed, these data were screened by double-mass analysis and other methods to eliminate obviously unreliable data.

B) Extended data set including the screened data plus additional pre-1957 and post-1972 annual maximum peak instantaneous and daily discharges. The extended portion of this data set was obtained from Philippine summary sheets listing only annual maximum peak instantaneous and daily discharges. Data outside the 1957 through 1972 period are considered "not screened" and therefore of unknown quality. Table 2.4.7 shows periods of record available at each gage using the extended data set.

Relative to the screened data set, the extended data set added 16 data points for frequency analyses of peak and daily flows on the Gumain River and nine data points for frequency analysis of peak and daily flows on the Santo Tomas River. No additional data points were gained for the Bucao River or for analysis of multi-day (i.e., 3-day) flows and volumes at any of the gages.

C) Subsets of the above data sets (A and/or B), created by excluding years in which data anomalies were noticed on or near the day of maximum annual flow. In practice, data subsets were analyzed for the Santo Tomas and Bucao Rivers only, and in each case excluded data for year 1962.

Gumain River Frequency Analysis.

Two data sets were analyzed for the Gumain River (W086A): 1) screened data for 1957 through 1971 and 2) extended data for 1947 through 1979. The screened data set is believed to be of high quality because the data were collected using an automatic water level recorder. Post-1971 data, and possibly much of the pre-1957 data, were based on staff gage readings only. Furthermore, all post-1972 data are subject to greater uncertainty due to a significant deterioration in the gaging program after that date. The most significant difference between the two data sets is that the maximum peak instantaneous discharge reported under the extended data set, 740 m^3/s in 1976, is nearly double the highest value reported under the screened data set, 375 m^3/s in 1964.

Figures 2.4.71 through 2.4.76 show the results of the frequency analyses on data for the Gumain River (W086A), plotting the maximum event data together with expected probability frequency curves as computed by the HEC-FFA program. These figures are discussed briefly in the paragraphs which follow.

1) Figure 2.4.71 shows the frequency analyses results arranged to show the peak instantaneous, 1-day, and 3-day flows together for the screened data set. Extended data set results (for which 3-day data were not available) are shown by Figure 2.4.72. Figure 2.4.71 shows that the computed frequency curves fit the peak, 1-day, and 3-day values from the screened data set reasonably well, although the lines are not parallel as might be expected. For the extended data set, Figure 2.4.72 shows a good fit for the 1-day data but only a fair fit for the peak instantaneous data, due to the extraordinarily high peak instantaneous data point for year 1976, which has a considerable influence on the shape of the frequency curve and on estimates of flood flows.

2) Figures 2.4.73 and 2.4.74 show the frequency analyses results arranged to compare the effects of the alternative data sets for the peak instantaneous and 1-day flows respectively. The figures show that flows estimated for a given return period are sensitive to the data set used. The frequency curves computed for the extended data set are steeper than those for the screened data set, and differences between the curves are greatest at higher return periods. For example, expected probability estimates of the 100-year peak instantaneous flow vary from about 500 m^3/s based on the screened data set to 660 m^3/s based on the extended data set. Estimates of the 100-year 1-day flow vary from about 340 m^3/s based on the screened data set to 420 m^3/s based on the extended data set.

3) Figures 2.4.75 and 2.4.76 show the 1- and 3-day volume frequency analyses. These data and curves are the same as for 1- and 3-day flows, after conversion to volume units.

<u>Bucao River Frequency Analysis</u>.

Two data sets were analyzed for the Bucao River (W093A): 1) screened data for 1957-1965 and 1967-1971 and 2) a data subset consisting of the same screened data in (1) but excluding data from year 1962. Data from year 1966 were excluded from both of the data sets because there were no data for that year's peak flow month (based on other gages) of May.

The year 1962 was excluded from the second Bucao River data set because a single value, 2,220 m^3/s, was reported to be both the peak instantaneous discharge and the maximum average daily discharge for the year. As a peak instantaneous discharge, 2,220 m³/s ranks second in the station's history. However, as a maximum average daily discharge, this value would be more than double the second highest daily value of 992 m³/s reported in 1961. Furthermore, total runoff from the basin for the five-day period in 1962 of July 20-24 was 942 mm, compared to a total rainfall at Iba for the same period of only 530 mm. Even allowing for spatial variations in rainfall and increases in rainfall with elevation, the total runoff volume appears unreasonably large in comparison to Iba rainfall.

The Bucao River data are of mixed quality. An automatic water level recorder was in place for 1957 through 1964; post-1964 data are based on staff gage readings made twice daily. The reported maximum annual discharge for year 1962 was measured/computed by the "slope-area" method.

Figures 2.4.77 through 2.4.83 show the results of the frequency analyses on data for the Bucao River (W093A), plotting the maximum event data together with expected probability frequency curves as computed by the HEC-FFA program. These figures are discussed briefly in the paragraphs which follow.

1) Figures 2.4.77 and 2.4.78 show the frequency analyses results arranged to show the peak instantaneous, 1-day, and 3-day flows together for each of the data sets, i.e. the screened data set with and without year 1962 data. The curves generally fit the data best for the data set which excludes year 1962 data.

2) Figures 2.4.79 through 2.4.81 show the frequency analyses results arranged to compare the effects of the alternative data sets for the peak instantaneous, 1-day, and 3-day flows respectively. The figures show that all estimated flows, and the 1- and 3-day flows in particular, are sensitive to the data set used, and that curves computed on the data sets including year 1962 data are steeper than those for which that year was excluded. Differences between the curves are greatest at higher return periods. For example, expected probability estimates of the 100-year peak instantaneous flow vary from about 3,740 m³/s, excluding year 1962 data, to 4,330 m³/s, including 1962 data. Estimates of the 100-year 1-day flow vary from about 1,260 m³/s excluding 1962 data to 2,730 m³/s when including 1962 data.

3) Figures 2.4.82 and 2.4.83 show the 1- and 3-day volume frequency analyses. These data and curves are the same as for 1- and 3-day flows, after conversion to volume units.

Santo Tomas River Frequency Analysis.

Four data sets were analyzed for the Santo Tomas Rive (W094A): 1) screened data for 1957 through 1967; 2) extended data for 1948 through 1967; 3) screened data set (1) excluding year 1962 data; and 4) extended data set (2) excluding year 1962 data.

All Santo Tomas River data are based on staff gage readings. Year 1962, which includes the historical maximum peak instantaneous and daily values, was excluded from the final sets of data because of anomalies in the daily data: the minimum daily discharge for 1962 is reported to occur just two days after the maximum flow. As the Santo Tomas River gage was located 400 meters downstream of a structure that is believed to be a major irrigation project, it is possible that high flows during the flood may have been supplemented by releases of reservoir storage, and that the very low flows after the flood reflect the recovery of reservoir storage.

Figures 2.4.84 through 2.4.92 show the results of frequency analyses on data for the Santo Tomas River (W094A), plotting the maximum event data together with expected probability frequency curves as computed by the HEC-FFA program. These figures are discussed briefly in the paragraphs which follow.

1) Figures 2.4.84 and 2.4.85 show the frequency analyses results arranged to show the peak instantaneous, 1-day and 3-day flows together for the screened data set with and without year 1962 data. Extended data set results (for which 3-day data were not available) are shown by Figures 2.4.86 and 2.4.87. The curves are generally more parallel for the extended data sets than for the screened data sets. The best fit of expected probability curve to the data is for 1-day discharges with the extended data set excluding 1962 (Figure 2.4.87).

2) Figures 2.4.88 through 2.4.90 show the frequency analyses results arranged to compare the effects of the alternative data sets for the peak instantaneous, 1-day, and 3-day flows respectively. The figures show that all estimated flows are sensitive to the data set used, and that curves computed on the data sets including year 1962 data are steeper than those in which that year was excluded. Differences between the curves are greatest at higher return periods. For example, expected probability estimates of the 100-year peak instantaneous flow vary from about 800 m^3/s based on the extended data set excluding year 1962 data to 1,560 m^3/s based on the screened data set including year 1962 data. Estimates of the 100-year 1-day flow vary from about 520 m^3/s based on the extended data set excluding year 1962 data to 1160 m^3/s based on the screened data set including year 1962 data.

3) Figures 2.4.91 and 2.4.92 show the 1- and 3-day volume frequency analyses. These data and curves are the same as for 1- and 3-day flows, after conversion to volume units.

Summary.

Frequency analyses of the maximum streamflow data are greatly complicated by the uncertain quality of the available data and related uncertainty over which of the possible data sets is more representative of "true" conditions. The choice of data set significantly influences estimated high return period flows and volumes.

For all three gages assessed, the fit of the computed curves to the data was generally improved by disregarding high peak values over which there was some justifiable uncertainty. However, a review of rainfall data showed that these and other (uncertain) extreme flows were associated with very heavy rainfall expected to result in extreme flows. It is inappropriate to either fully accept or disregard the extreme value data.

Given the available record of uncertain data and the sensitivity of the analyses to single data points, single-value estimates of 100-year or other return period flows are not made. Instead, the families of expected probability frequency curves shown by Figures 2.4.71 through 2.4.92 are used to indicate a plausible range of reasonable values. Ranges for 2- and 100-year return periods are summarized in Table 2.4.14. The results of this analysis were used to calibrate the hydrologic model, HEC-1, which was used to generate design flood hydrographs.

2.4.5 Design Storms. The objective of the design storm analysis was to develop rainfall hyetographs for 2-, 10-, 50-, 100-, and 500-year hypothetical storms of appropriate duration to result in similar return period flooding of streams affected by the Mount Pinatubo eruption. The assessment was complicated by the fact that no rainfall data are available to describe conditions in the mountain watershed areas of interest.

The approach taken to develop the design storms is described in the following report sections. In summary:

1) Isopluvial maps of 2-, 10-, 50-, 100-, and 500-year rainfall over durations of 1-, 2-, and 5-days were developed from the frequency analysis of available rain data and with the assumption that the ratios of coastal-to-mountain rainfall amounts would be the same as for annual rainfall amounts shown by the NAP map.

2) U.S. Weather Bureau area-reduction factors were reviewed in light of the available rainfall data, and a methodology for applying area-reduction factors jointly with elevation-based variations in rainfall was developed.

3) Short-duration (less than 24-hour) storm characteristics were assessed from available published intensity-duration-frequency data and from the limited available hourly data. A methodology was developed to construct and distribute design storm hyetographs throughout the basins of interest.

Frequency-Duration Isopluvial Maps. Figures 2.4.93 through 2.4.107 show isopluvial maps of 2-, 10-, 50-, 100-, and 500-year rainfall over durations of 1-, 2-, and 5-days.

The isopluvial lines shown for the coast and interior lowlands are based on the rainfall frequency analyses results summarized by Tables 2.4.9 through 2.4.13. Isopluvial lines for the mountain watershed areas are based on the assumption that rainfall near the 1,000-meter contour around the summit of Mount Pinatubo is, for all return periods, equal to the average rainfall at the coastal gages multiplied by a factor of 1.35 for all durations and return periods. The 1,000-meter contour follows the top of a narrow ridge to the south of Mount Pinatubo and an irregular circular path about 5 km in diameter around Pinatubo's 2.5 km diameter (post-eruption) crater rim. The 1.35 factor is based on average annual data for coastal rain gages and on the NAP map.

Tables 2.4.15 through 2.4.17 provide data to examine the assumption that the ratio of same-return-period rainfall at the coast, at high elevations, and in the interior is relatively constant for all durations and return periods. Table 2.4.15 presents data and ratios of interior gages to coastal gages for multi-day duration events. Tables 2.4.16 and 2.4.17 present short-duration data and ratios for stations representing interior, coastal, and high-elevation sites. Figure 2.4.108 plots the ratios for the short-duration data; Figure 2.4.109 plots the ratios between Hacienda Luisita and Iba for both short- and long-duration events.

Several observations are made from the data:

1) For durations of six hours and longer, the ratio of same-frequency-duration rainfall between any two stations is essentially constant, independent of the duration. This ratio is approximately equal to the ratio of average annual rainfall between any two stations.

2) For durations of one hour or less, rainfall depth is essentially independent of station location or elevation. For example, the 100-year 1-hour rainfall depth at coastal sites is essentially the same as the depth at sites in the mountains and the interior.

3) There is no clear indication of the effect of return period on the ratio of same-frequency-duration rainfall between two stations. The short-term data suggest that differences between two stations become slightly greater (ratios further from 1.0) with increasing return period. However, the long-term data suggest the opposite, that differences become slightly less (ratios closer to 1.0) with increasing return period. The discrepancy may result from the fact that the data analyses were conducted using different theoretical distributions. The short-duration data were assessed by PAGASA using a Gumbell distribution, which has a fixed skew. The long-duration data were assessed as part of this

study using a Log Pierson III distribution (HEC-FFA) in which skew is calculated from the data.

In summary, for rainfall durations of six hours and greater, the data show that mountain rainfall of a given frequency can reasonably be estimated as a constant multiple of same-frequency average coastal rainfall. A constant multiplier equal to the ratio of average annual rainfall appears reasonable for durations of six hours or longer. No adjustment, i.e. a multiplier of 1.0 applied to coastal rainfall, is appropriate for durations of one hour or less.

Area Reduction Factors. Area-reduction factors are used to estimate average basin-wide or area rainfall amount from point values. In relatively flat topography, the 100-year 1-hour rainfall over a basin area is expected to be less than the 100-year 1-hour rainfall at any point within the basin.

Area-reduction factors for the continental U.S. have been developed by the U.S. Weather Bureau[8] based on data from dense rain-gage networks. These factors have previously been considered "reasonable" to be applied to conditions in Hawaii[9], despite a lack of data to test the relationships for Hawaiian conditions. After an inconclusive check for reasonableness relative to the available study area data, the Weather Bureau factors were adopted for use in the hydrologic analysis.

Figure 2.4.110 shows distance-reduction curves de-·-ed from the Weather Bureau area-reduction factors. The latter, which were based on circular areas, were converted to distance-reduction factors by assuming that peak rainfall occurs at the center of the circle and that rainfall decreases linearly with radial distance from the center. This conversion was done to facilitate comparison with the available data and to provide a methodology which could be applied jointly with factors to account for elevation-based variations in rainfall.

Construction of Storm Hyetographs. Table 2.4.18 summarizes frequency-depth-duration data for a hypothetical rain gage located near the summit of Mount Pinatubo at about 1000 meters elevation. These data provide the basis for construction of design storms hyetographs.

The 24-hour, 2- and 5-day data in Table 2.4.18 are approximately equal to 1.35 times average coastal gage values shown in Table 2.4.15; the data vary slightly from the 1.35 multiplier due to rounding effects when tabulating hourly data for HEC-1 model input. The 1-, 2-, 3-, 6-, and 12-hour data in Table 2.4.18 are based on the short-duration data of Table 2.4.16 with emphasis given to the high-elevation station at Baguio City.

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[8] See Footnote 7.

[9] Weather Bureau, U.S. Department of Commerce, no date, *Two- to Ten-Day Rainfall for Return Periods of 2 to 100 Years in the Hawaiian Islands*. Technical Paper No. 51.

While peak discharges on rivers draining Mount Pinatubo generally result from heavy rains lasting less than 12 hours, a design storm duration of five days was selected to provide additional data on total runoff volumes as might be required for later design work. Design storms of a specified return period were constructed by embedding same-frequency events; i.e., the 100-year 24-hour rain was embedded within the 100-year 2-day rain, which was embedded within the 100-year 5-day rain. This general approach was consistent with the available daily rainfall data.

During early efforts to calibrate the HEC-1 model to the region, it became apparent that the conservative approach of fully embedding all same-frequency durations within a single design storm yielded excessively high peak discharges. Unfortunately, peak discharges on the basins of interest result from short-duration (typically 3-hour to 12-hour) events, while hourly data were available for only two significant storm events.

Figure 2.4.111 plots hourly data and associated frequency-duration characteristics for a severe storm recorded at Iba (RD324) in May 1976. While the maximum 48-hour rain corresponds to a 200-year storm and the maximum 24-hour rain corresponds to a 25-year storm, the maximum hour corresponds to only a 2-year storm.

Figure 2.4.112 plots hourly data and associated frequency-duration characteristics for a severe storm recorded at Baguio City in September 1911. The rainfall data were obtained from Weather Bureau Technical Report No. 42[10] and reflect a (former) world record 24-hour rainfall amount. While the maximum 24-hour rain corresponds to about a 200-year storm, the maximum hour corresponds to only about a 20-year storm.

The available historic storm data support the proposition that a single design storm should not fully embed all same-frequency depth-durations, i.e., that a 1 in 100 year 24-hour rainfall should not contain a 1 in 100 year 1-hour rainfall. Possible physical explanations for this are that the monsoon or typhoon conditions responsible for large daily rainfalls are not conducive to the formation of intense cloudbursts, or that the monsoon or typhoon winds associated with large daily rainfalls do not allow intense cloudbursts to stay in one place long enough for significant rainfall amounts to accumulate at a point.

Figure 2.4.113 plots the 2-, 10-, 50-, 100-, and 500-year hypothetical storms adopted as "base storms" before adjustments for elevation-based total storm depth and for depth-area reduction. These hyetographs are for a hypothetical station located at approximately 1,000 meters elevation near the summit of Mount Pinatubo, and embed same-frequency events from six hours duration through five days duration. A constant hourly intensity is assumed throughout the maximum 6-hour period.

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[10] See Footnote 2.

A constant hourly intensity over the maximum 6-hour period produces 1-hour to 24-hour characteristics which are similar to those observed in the two historic storms for which hourly data were available. The maximum hourly rain in a 25-year 24-hour storm has a return period of about two years, and the maximum hourly rain in a 200-year 24-hour storm has a return period of about 20 years.

The procedure described below was developed to construct multi-basin rainfall hyetographs for a single storm event. In this description, "summit rain" refers to rainfall characteristics at the hypothetical station at approximately 1,000 meters elevation near the summit of Mount Pinatubo. "Base storms" refer to design rainfall hyetographs for this hypothetical station as shown by Figure 2.4.113.

1) The basin of interest was subdivided into smaller sub-basins, considering isohyetal gradients through the basin as one factor.

2) The average annual rainfall for each sub-basin was determined from the NAP map (Figure 2.3.4), and the ratio of sub-basin rain to summit rain was determined. For any sub-basin, this ratio is a constant for all return periods and for all durations greater than six hours.

3) For each sub-basin, the base storm was adjusted to correct for the ratio of sub-basin rain to summit rain. The ratio was applied directly for all durations of six hours and longer, and factored within the peak 6-hour period so that a single peak hour was not adjusted. The justification for maintaining the peak hourly intensity at the average 6-hour intensity for the base storm is the previously stated observation that peak hourly rainfall intensities appear to be independent of location and elevation. Figure 2.4.114 illustrates this step in sub-basin hyetograph development by showing a 50-year base storm before and after the adjustments for a sub-basin normally receiving 80 percent of the summit rain.

4) A storm center was assumed to be located in the middle of the sub-basin with the highest rainfall. The distances from the assumed storm center to the mid-points of all other sub-basins were determined. For the sub-basin containing the assumed storm center, the average distance to the storm center was estimated as 2/3 of the radius of a circle having an area equal to the sub-basin area.

5) Finally, depth-area corrections were applied to each sub-basin storm (i.e., the base storm after correction for the ratio of sub-basin rain to summit rain). These corrections followed the depth-duration-distance curves shown by Figure 2.4.110 for durations of six hours and greater. The 6-hour adjustment curve of Figure 2.4.110 was applied to all durations within the peak 6-hour period because of the earlier assumption of a constant hourly intensity within the peak 6-hour period for the base storm. Figure 2.4.114 illustrates this final step in sub-basin hyetograph development by showing a 50-year sub-basin storm before and after depth-area corrections for a sub-basin located 10 km from an assumed storm center.

Sub-basin storm hyetographs derived in this manner were used as input to HEC-1 models used in the basin analyses.

3. BASIN ANALYSES

3.1 Introduction

Hydrologic basin analyses were performed on all eight major river basins impacted by the eruption of Mount Pinatubo. Hydrologic analyses products were required at specific locations within the basins for use in the design of mitigation measures. The primary products required from the hydrologic analyses are, for the purposes of the following discussion, grouped as follows: (1) 2-, 10-, 50-, 100-, and 500-year instantaneous flood peaks, 1-day volumes, and 3-day volumes and the hydrographs corresponding to these peaks and volumes, (2) flow duration curves, and (3) flow velocities and depths. The modeling methodologies used to obtain products in groups (1), (2), and (3) are discussed in Sections 3.2, 3.3, and 3.4 respectively. The results of the modeling are presented in Sections 3.5 and 3.6.

3.2 Rainfall/Runoff Modeling Methodology

3.2.1 Introduction. Rainfall/runoff processes were simulated with the use of an HEC-1 computer model. Model runs were made with the 2-, 10-, 50-, 100-, and 500-year hypothetical storm events obtained from the regional analyses in order to obtain estimates of the 2-, 10-, 50-, 100-, and 500-year instantaneous flood peaks, 1-day volumes, and 3-day volumes and the corresponding hydrographs.

Methods used to obtain HEC-1 model parameters are discussed in Section 3.2.2. The methodology used in the calibration of the HEC-1 model is discussed in Section 3.2.3. The methodologies used in the construction of the basin models are described in Section 3.2.4.

3.2.2 HEC-1 Rainfall/Runoff Model Parameters. Hydrologic modeling for this study was done using an extended memory version of HEC-1. The extended memory version of HEC-1 allows event simulation for up to 2,000 computational time steps, as compared to only 300 time steps in earlier releases of the model. The extended memory version, however, assumes the time base of the unit hydrograph is less than 300 time steps. All modeling work was done using metric units. Minor modifications to the extended memory program were made by the Hydrologic Engineering Center (HEC) to allow output of unit hydrograph ordinates to three significant digits when working in metric units.

Computational Time Step. Hydrologic modeling for rivers draining Mount Pinatubo is complicated both by the lack of good hydrometeorologic data and by the flat response of event hydrographs. Storm event hydrographs are often quite flat, with recorded ratios of instantaneous peak to maximum daily average flows of as little as 1.1 or 1.2. Furthermore, major storms affecting this area are frequently several days in duration, resulting in a need to model hydrologic response from a storm event for periods of up to about 10 days.

The fla' sponse of the drainage basins under study naturally produces a flat unit hydrograph with an extended time base. HEC-1 assumes that the length of the unit graph time base is less than 300 time steps. Any volume in a unit hydrograph beyond this point is lost, such that the program fails to conserve mass. In order to model the flat response of these rivers while avoiding unacceptable loss of volume in the tails of the unit hydrographs, modeling had to be done at a 1-hour time step.

While a 1-hour time step is appropriate for modeling most of the larger study basins, modeling was also required to simulate flows from a number of small headwater catchments with drainage areas as small as 4.4 km^2, and with times of concentration as low as 0.4 hour. While this situation would normally require modeling at a time step of perhaps as small as 10 minutes, tests conducted during the analysis found the model response to be relatively insensitive to time step due to the flat response of hydrographs and the relatively large amounts of storage implied. Tests conducted on small sub-basins with modeling time steps from five minutes to one hour showed a difference in simulated peak flows of about 2 percent -- substantially less than the degree of uncertainty in the basic data used for model development.

Unit Hydrograph. Three synthetic unit hydrographs are available in HEC-1:

- Clark Unit Hydrograph
- Snyder Unit Hydrograph
- SCS Dimensionless Unit Hydrograph

The shape of the SCS unit hydrograph is controlled by a single parameter, namely, basin time lag. Preliminary simulations showed it to be incapable of reproducing the peak-to-volume characteristics of observed hydrographs in the Pinatubo region. The SCS unit graph produced a much sharper response than observed, such that it was not possible to maintain both observed peaks *and* volumes. Most of the HEC-1 modeling was therefore done using the Clark Unit hydrograph. This method uses three parameters to compute a unit graph: time of concentration, a storage coefficient, and a time-area curve. The greater flexibility inherent in the Clark method was found to greatly improve modeling results. The Clark storage coefficient provides an avenue for modeling significant attenuation of peak flows in the highly permeable volcanic deposits on Mount Pinatubo. The SCS unit graph was retained and used to represent runoff from the relatively large impervious paved areas of two sub-basins in the Abacan River catchment that incorporate parts of Clark AFB and nearby urban areas.

Parameters for the Clark unit hydrograph were determined as follows:

- Time of Concentration

In the absence of observed data, time of concentration was determined by an empirical equation provided by the U.S. Bureau of Reclamation[11] as:

$$T_c = \left(\frac{11.9 \cdot L^3}{\Delta H} \right)^{0.385}$$

where
T_c = time of concentration (hours)
L = length of longest watercourse from the point of interest to the watershed divide (miles)
ΔH = elevation change along the longest water course (feet)

- Storage Coefficient

The Clark storage coefficient was determined by calibration to available data, as will be discussed in detail in Section 3.2.3, and expressed as a function of T_c to facilitate application to ungaged sub-basins.

- Time-Area Curve

The time-area curve describes the cumulative area of a sub-basin contributing runoff to the sub-basin outlet as a function of time, expressed as a fraction of the time of concentration. The default time-area curve provided by HEC-1 was used for all sub-basins. HEC-1 uses a dimensionless time-area curve given by the following:

$$AI = 1.414T^{1.5} \qquad 0 \leq T < 0.5$$

$$1 - AI = 1.414(1 - T)^{1.5} \qquad 0.5 \leq T < 1$$

where
AI = cumulative area as a fraction of the total sub-basin area
T = fraction of the time of concentration

Parameters for the SCS unit hydrograph were determined as follows:

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[11] United States Department of the Interior, 1977, *Design of Small Dams*, Bureau of Reclamation, Washington D.C.

- Time Lag

The time lag is the lag (in hours) between the center of mass of rainfall excess and the peak of the unit hydrograph. The lag-time was determined using an empirical expression recommended by the U.S. Soil Conservation Service:

$$T_L = 0.6 \cdot T_c$$

where

T_L = lag time, hours

T_c = time of concentration in hours, estimated using the same expression as described above for the Clark unit hydrograph.

Base Flows. Base flows in the context of the basin analyses are representative flood season low flows expected to occur at simulation sites prior to the onset of the flood hydrograph. They are significantly higher than the low base flows which occur during the dry season.

Flood-season base flows at stream gages were estimated by inspection of time series hydrograph plots. Average annual rainfall for each basin was estimated (as before) to be the average annual runoff plus 1,550 mm to account for evapotranspiration. Comparison of these data yielded the following approximate relationship for estimation of flood-season base flows on streams originating on Mount Pinatubo as a function of average annual basin rainfall and basin area:

$$Qbase = A\,(R/17{,}500 - 0.12)$$

where

Qbase = Typical flood season base flow, m^3/s

A = Basin area, km^2

R = Average annual rainfall over basin, mm/yr

Base flows determined by this relationship for each sub-basin were assumed to be constant (without any recession) throughout each event simulated in the HEC-1 modeling.

Loss Rates. The HEC-1 model allows the computation of loss rates by a number of different methods. These methods include:

- initial and uniform loss rate
- exponential loss rate
- SCS Curve Number method
- Holton loss rate

All modeling for this study assumed a uniform loss rate with no initial loss. Major floods in this area occur primarily during the Southwest Monsoon. Significant amounts of rainfall can be expected prior to flood-producing events which are therefore assumed to occur under essentially saturated conditions.

The uniform loss rate was estimated by calibration to available data as will be described in Section 3.2.3.

Routing Parameters. Routing of flood hydrographs through the stream channels in the basins of interest was done in HEC-1 using the Muskingum method. There is a lack of basic data from which to determine channel routing parameters. Only limited information exists on channel cross-sections or floodplain geometry, no information exists on flood wave travel times, and, as discussed earlier, there is considerable uncertainty in discharge rates. In the absence of basic data, all flow routing was done assuming a flood wave velocity of 2.5 m/s and a Muskingum "X" coefficient of 0.2. A detailed description of the routing scheme implemented in HEC-1 is provided in the HEC-1 User's Manual.

3.2.3 Calibration of HEC-1 Model. HEC-1 model calibration for basins draining Mount Pinatubo was limited by the lack of reliable streamflow data. From the review of gaging stations in Section 2.4.1, it was determined that only three stations had data reliable enough for model calibration. These stations were the Gumain River (W086A), the Bucao River (W093A), and the Santo Tomas River (W094A). Model calibration was further limited by the lack of short-interval rainfall data that were concurrent with data from the above three stations.

Figures 3.2.1 through 3.2.3 show the calibration basins as they existed prior to the eruption of Mount Pinatubo. Sub-basins upstream of the stream gages were delineated to reflect major tributaries and to reflect the elevation-related rainfall gradients up the mountain slopes.

Sub-basins and simulation output sites defined for pre-eruption modeling of each of the three calibration basins were assigned a two-letter prefix beginning with "P" (for pre-eruption) for identification purposes. The two-letter prefix for each of the three calibration basins is:

PG — Gumain River (W086A)
PB — Bucao River (W093A)
PT — Santo Tomas River (W094A)

Sub-Basin Identifiers. Identifiers PG1 through PG9 refer to sub-basin areas within the pre-eruption Gumain basin as shown by Figure 3.2.1. The prefix letters "PG" denote the pre-eruption Gumain basin, and the following numbers identify sequentially-numbered sub-basins. These identifiers are used in tables and figures. The convention generally followed for sequential numbering of sub-basins was to start at the most upstream sub-basin and to end at the most downstream sub-basin.

Output Site Identifiers. Identifiers PG5US through PG9DS refer to the simulation output sites located at specific points within the pre-eruption Gumain basin as shown by Figure 3.2.1. The first two characters of the identifier indicate the sub-basin within which the site is located. The last two characters, either "US" or "DS", indicate that the site is located at either the upstream or downstream end of the sub-basin. Calibration output results are provided in tables and figures only for the site corresponding to the stream gage location, this being the most downstream site in each calibration basin.

Tables 3.2.1 through 3.2.3 summarize physical and computed parameters for each of the calibration basins. Some of these computed parameters (Unit hydrograph method, storage coefficient, loss rate) were determined through the calibration process as described in the following sections.

Calibration to Historic Event. Calibration of the HEC-1 runoff model comprises two basic steps:

1) Identifying historic events for which concurrent rainfall and runoff data are available and sufficient to describe rainfall over the basin(s) as well as the shape and volume of the resultant runoff hydrograph from the basin.

2) Running the HEC-1 model with known (historic) basin rainfall events for input, and adjusting model parameters until the model suitably reproduces the known (historic) runoff hydrograph for each event.

Because most of the basins draining Mount Pinatubo have maximum times of concentration of the order of three to 12 hours, hourly data were desirable for calibration.

HEC-1 model calibration for basins draining Mount Pinatubo was complicated by a lack of suitable concurrent rainfall and streamflow data. Available streamflow data are often of poor quality and are limited to average daily discharges and annual peak discharges. Only very limited hourly rainfall data are available from any of the rain gage stations.

There is a general mismatch between available streamflow data and available rainfall data. Streamflow data are very sparse after 1972, and only limited rainfall data are available prior to 1972. Hourly rainfall data could be obtained for only a small number of storm events from three stations in the general vicinity of Mount Pinatubo: Iba, Hacienda Luisita, and Porac.

Only one historic event, on September 1, 1970, was found with (marginally) sufficient concurrent rainfall and streamflow data for model calibration. The data consisted of hourly rainfall at Porac and streamflow data for the Gumain River at Pabanlag (W086A), which included daily flows and a peak instantaneous discharge (NOTE: In the publication *Philippine Water Resources Summary Data, Vol. II Streamflow and Lake or River Stage*, December 31, 1970, the peak instantaneous discharge used for the historic event calibration is reported to have occurred on September 11 at 1:30 p.m. However, no flows of significance were reported on September 11 at any other nearby gages as were reported on September 1. The form on which the date and time of the peak were recorded did not have enough spaces to record a 2-digit date and a 4-digit time. It is believed that the peak reported on September 11 at 1:30 p.m. actually occurred on September 1 at 11:30 p.m.) The stream gage on the Gumain River at Pabanlag is reported to have had a water level recorder in operation during this event, and the estimates of the daily average flows and the peak instantaneous discharge are probably more reliable than those from any other nearby gage. Although a water level recorder was apparently in operation on the Gumain, the recorder strip charts cannot be located and hence no short-interval (e.g., hourly) flow data are available.

The calibration event was the Gumain River (W086A) peak annual flow of 267.5 m^3/s on September 1, 1970, which had a return period of about one in four years. Concurrent hourly rainfall data were available from a gage at Porac, located about 20 km east of headwater areas of the Gumain River basin. Figure 3.2.1 shows the relative locations of the basin and the Porac rain gage.

Ideally, hourly rainfall data for model calibration would be available from rain gages within the watershed, or at least from several gages closely surrounding the watershed. This methodology would allow for an accurate estimation of the spatial and temporal distribution of rainfall over the basin. Unfortunately, hourly data were available for only the Porac rain gage, and there were no daily data rain gages located sufficiently close to the basin to improve estimation of actual basin rainfall.

In the absence of additional information, hourly rainfall at each of the sub-basins was estimated as being hourly rainfall at Porac multiplied by an adjustment factor to account for increasing rainfall with elevation as shown by the 2-year 24-hour isopluvial map of the study area. For each sub-basin, the adjustment factor was computed to be the ratio of the 2-year 24-hour rainfall at the middle of the sub-basin to that at Porac. By this approach, rainfall amounts on the sub-basin varied from 1.3 to 1.9 times the rainfall at Porac, averaging about 1.6 times the Porac rainfall.

Figure 3.2.4 summarizes key results from three simulations for the historic event. Variables considered in these simulations were loss rate and the Clark storage coefficient. In each case these parameters were adjusted iteratively until the historic peak discharge was reproduced.

A Clark unit hydrograph storage coefficient of 15 to 25 times the time of concentration, with appropriate loss rates, provides a fairly good approximation of the historic hydrograph. When considered together with the frequency-event calibration work, a storage coefficient equal to 25 times the time of concentration and a constant loss rate of 3 mm/hour were adopted for subsequent hydrologic analyses of basins throughout the study area.

Calibration to Frequency Characteristics. In the absence of other suitable historical data, additional calibration efforts were limited to frequency events. The frequency-event-based calibration consisted, for example, of adjusting HEC-1 model parameters so that a synthesized 100-year design storm applied over a gaged basin would generate 100-year flow volumes ana peak instantaneous discharge at the gage site.

The stations chosen for the frequency-event-based calibration were the same three chosen for the frequency analyses: the Gumain River (W086A), the Bucao River (W093A), and the Santo Tomas River (W094A). The pre-eruption basins above these gages are shown by Figures 3.2.1 through 3.2.3. Due to irrigation diversions after 1967, post-1967 data from the Santo Tomas were excluded from the frequency-event-based calibration.

Frequency analyses of streamflow data from the calibration basins are described in Section 2.4.4. The results of those analyses, in light of the available record of uncertain data and the sensitivity of the analyses to single data points, were presented as families of flow frequency curves to indicate plausible ranges of reasonable discharges and volumes at various return periods. Ranges of reasonable values for 2- and 100- year return period floods were adopted as the targets to be attained in the frequency event calibration.

The procedure for calibrating the two available parameters, loss rate and storage coefficient, was first to assign a storage coefficient, and then to vary the loss rate until the target value was matched. Tables 3.2.1 through 3.2.3 summarize parameters for the three calibration basins. Table 3.2.4 and Figures 3.2.5 through 3.2.13 summarize the results of the frequency event calibrations, showing the target ranges of reasonable values together with the results obtained from HEC-1 simulations of 2- and 100-year events. The simulations summarized are based on a one-hour time step simulation of design storms of five days in duration.

The 2-year peak instantaneous discharge for the Gumain River (W086A) was taken as the primary target value for calibration, as it was considered to be the most reliable of possible targets. Parameters determined for the Gumain River were then used in models for all three calibration basins for both 2- and 100-year hypothetical storms.

In reviewing the final calibration run outputs, the greatest weight was given to matching peak instantaneous discharge, then to three-day volume. The frequency data and curves for 1-day volumes were given the least weight because the source data were based on arbitrary calendar-day periods (and often on staff gage readings) which would tend to underestimate true 24-hour maximum values.

Based on the calibration results, it was decided to make subsequent runs of the HEC-1 model using a constant loss rate of 3 mm/hr and the Clark unit hydrograph method with storage coefficient computed as 25 times the time of concentration for each sub-basin. These parameters were considered to yield generally good results for both peak flows and total flow volumes for all three calibration basins. The simulated 100-year peak flow for the Bucao River appears low (Figure 3.2.8), but may be within reason when considering that the two extreme high recorded flows may have actual return periods in excess of about 10 to 20 years as suggested by the plotting positions based on the available period of data record.

Sensitivity Analysis. Most of the sensitivity analysis was conducted concurrently with model calibration discussed in the previous sections and as summarized by Table 3.2.4 and Figures 3.2.5 through 3.2.13. That analysis consisted of varying paired combinations of constant loss rate and Clark unit hydrograph storage coefficient.

Increasing (or reducing) the loss rate within reasonable bounds from the adopted 3 mm/hr value has a relatively large impact on total runoff volume and a relatively small impact on peak discharge. A typical 2-year 5-day storm near the summit of Mount Pinatubo, for example, would have an average rainfall intensity of about 6.5 mm/hr considering the full 5-day period, and a peak hour rainfall intensity of about 30 mm/hr. Increasing the loss rate from 3 to 6 mm/hr for determining the rainfall excess would obviously have a far greater impact on the total runoff volume than on the peak hourly flow.

Increasing (or reducing) the Clark unit hydrograph storage coefficient has a significant impact on the peak discharge, but no impact on the total runoff volume. Increasing the storage coefficient dampens the peak flow and flattens the shape of the hydrograph. The impact of the storage coefficient on the shape of the hydrograph is illustrated by Figure 3.2.4.

With the adopted unit hydrograph (Clark), storage coefficient (25 times time of concentration), and loss rate (3 mm/hour), model results were found to be generally insensitive to variations in model time step and routing parameters. Tests using the Gumain Basin of varying the model time step from five to 60 minutes, the Muskingum "X" coefficient from 0.2 to 0.4, and the Muskingum "K" coefficient within a range reflecting flood wave velocities of 1 to 5 m/s all yielded peak discharge results which were within about 2 percent of each other. Again, this lack of sensitivity results from the large storage in the system implied by the large storage coefficient used with the Clark unit hydrograph.

3.2.4 HEC-1 Basin Models

Sub-basin and Output Site Numbering Convention. Sub-basins are designated by a 2- or 3-character alpha-numeric identifier. The first character, which designates one of the eight major basins, is one of the following:

Sacobia-Bamban	- "S"	Pasig-Potrero	- "P"
Abacan	- "A"	Santo Tomas	- "T"
O'Donnell	- "O"	Bucao	- "B"
Gumain/Porac	- "G"	Maloma	- "M"

The second character, which is numeric, identifies the sub-basin within the major basin. The convention generally followed for sequential numbering of the sub-basins within a major basin was to start at the most upstream sub-basin and to end at the most downstream sub-basin.

Output sites are designated by a 4- or 5-character alpha-numeric identifier. The first two or three characters identify the sub-basin in which the site is located. The last two characters, either "US" or "DS", indicate that the site is located at either the upstream or downstream end of the sub-basin.

Structure of Basin Models. In constructing the models, sub-basins were delineated so that output would be provided for at required locations. Some of these sub-basins were further divided to define major tributary streams and to provide better definition of rainfall gradients through the basins. Additionally, (1) sub-basins S7 in the Sacobia-Bamban Basin, P7 in the Pasig-Potrero Basin, and G19 in the Gumain-Porac Basin were delineated to isolate narrow dike-confined sections of the channels, and (2) sub-basin T7 in the Santo Tomas Basin was delineated in order to define Lake Mapanuepe.

Definition of sub-basin boundaries to provide output at desired sites sometimes resulted in the creation of some very small basins. These areas were not given sub-basin numbers or explicitly identified in the HEC-1 models. Instead, for modeling purposes, these small areas were re-allocated to nearby sub-basins such that schematically there would be no intervening areas or routing reaches (e.g., the small areas just upstream of sub-basin S7 in the Sacobia-Bamban Basin (see Figure 3.5.4) were re-allocated to upstream sub-basins S3, S4, and S6 such that, schematically, simulation sites S3DS, S4DS, S6DS, and S7US all exist near site S7US without any intervening areas or routing reaches). Routing reaches through these small areas were ignored because flow travel times are significantly shorter than the one-hour model time step.

Parameter Estimation. Physical and computed parameters at simulation output sites were obtained as described below.

- Stream elevations were determined from 1:50,000 topographic maps dated 1986.

- Basin areas upstream of each site were computed as the sum of all contributing sub-basin areas.

- Basin times of concentration were computed using the formula presented in Section 3.2.2 based on the slope and length characteristics of the entire basin.

- Average annual basin rainfall amounts were estimated based on isohyets of mean annual rainfall over the study area as shown by Figure 2.3.4.

• Average annual streamflows at each site were estimated on the basis of average annual basin rainfall, basin area, and a formula that will be presented in Section 3.3.

• In some basins where simulation output sites do not share a common headwater area, more than one storm pattern is required in order to maximize flows at all sites within a given basin. Maximum flows at each site were assumed to result from storms centered over the headwater sub-basin with the highest rainfall as determined from the isohyetal map.

Physical and computed parameters for sub-basins were obtained as described below.

• Physical parameters of area, internal flow path, channel length, and elevation changes were measured from 1:50,000 scale maps dated 1986. Internal flow path lengths and elevation changes are provided for all sub-basins, as required for determining time of concentration for local sub-basin runoff. Channel lengths through sub-basins, and corresponding elevation changes, are applicable only in cases where there is an upstream basin generating incoming channel flow to be routed through the sub-basin.

• As noted in Section 2.4.5, the ratio of sub-basin event rainfall to summit rainfall was determined to be approximately constant for all return periods and for all durations greater than six hours. For convenience, the design storm parameter of sub-basin rainfall as a percentage of summit rainfall was determined from 50-year 24 hour rainfall isopluvials for the study area as shown by Figure 2.4.95. This parameter is used to correct for elevation-related rainfall variations when constructing sub-basin storm hyetographs.

• The distance of each sub-basin from the center of the design storm(s) is used to determine the depth-area (depth-distance) correction when constructing sub-basin storm hyetographs. These distances were measured from the middle of the sub-basin with the storm center to the middle of each other sub-basin. Distances to other storm locations are given only if the sub-basin contributed to the flows at the sites requiring alternative storm locations.

• Runoff parameters of time of concentration, storage coefficient, infiltration loss, and base flow are all required for input to the HEC 1 model to define runoff from each sub-basin. Times of concentration were computed using the formula presented in Section 3.2.2 together with the slope and length characteristics of each sub-basin. The storage coefficient for the Clark unit hydrograph for each sub-basin was computed as 25 times the time of concentration. Infiltration rates were assumed to be constant at 3 mm/hour for all sub-basins except for (1) the perched S7, P7, and G19 sub-basins for which an artificially high 1,000 mm/hour loss rate was applied to ensure no rainfall excess from the basin; (2) T7 (Lake Mapanuepe) for which no infiltration loss was assumed; and (3) 0.8 km^2 of A2 and 2.6 km^2 of A4 which were assumed impervious due to the effects of urbanization. The high loss rate was applied to the perched sub-basins to reflect high but unquantified losses expected through highly permeable perched channel reaches. Base flows from each sub-basin were estimated on the basis of average annual sub-basin rainfall, area, and the formula presented in Section 3.2.2.

Design Storms. The 2-, 10-, 50-, 100-, and 500-year storms, developed as described in Section 2.4.5, were used for the HEC-1 modeling.

Effects of Eruption. Due to lack of justification for changes to any other parameters such as loss rate or storage coefficient, eruption impacts reflected in the HEC-1 models of post-eruption basins were limited to (1) physical changes in basin areas, (2) the formation of Lake Mapanuepe, and (3) perched channel reaches on the Bamban, Potrero, and Gumain Rivers.

3.2.5 Confidence Limits on Computed Frequency Events. The 5 and 95 percent confidence limits on the HEC-1 computed instantaneous peaks, maximum 1-day volumes, and maximum 3-day volumes were estimated as follows:

1) The 5 and 95 percent confidence limits were obtained on all streamflow gage data sets on which frequency analyses were conducted (see Section 2.4.4). These confidence limits were obtained in accordance with guidelines described in *Bulletin 17B* of the U.S. Water Resources Council.

2) For each streamflow gage data set, the change in percent from the expected value to the 5 and 95 percent confidence limits were calculated and averaged. The average percentage changes obtained from the streamflow gage data sets were applied to the HEC-1 generated instantaneous peaks, maximum 1-day volumes, and maximum 3-day volumes to obtain the 5 and 95 percent limits.

3.3 Flow Duration Curve Modeling Methodology

3.3.1 Flow Duration Curve. Flow duration curves at gaged locations were presented in Section 2.4.2 of the regional analyses portion of this appendix. Computed flow duration curves at hydrologic simulation output sites were computed on the basis of the following flow data and plotting positions:

1) Average annual flow above each simulation output site was estimated from the normal annual precipitation (NAP) map of the study area. Rainfall shown by that map for the mountain watershed areas had been estimated using a water balance approach to match observed average flows from the watersheds. Thus, for the mountain watersheds, the NAP map is functionally equivalent,

after correction for evapotranspiration, to a map of mean annual runoff (and flows) over the study area.

Conversion from average annual basin rainfall shown by the NAP map to average annual flows for specific basins in the vicinity of Mount Pinatubo was accomplished with the following approximate formula derived from data at gaged basins:

$$Q_{avg} = A\,(R/31{,}500 - 0.05)$$

where:

Q_{avg} = Average annual discharge, m^3/s

A = Basin area, km^2

R = Average annual rainfall over basin, mm/yr. In deriving the formula (and also the NAP map), average annual basin rainfall was assumed to be equal to average annual runoff plus 1,550 mm for evapotranspiration losses.

Normalized daily flow duration curves from gaged basins indicate that the average annual flows are exceeded from 15 to 40 percent of the time, averaging about 25 percent (see Figure 2.4.52). For the computed flow duration curves, the average annual flow was plotted to be exceeded about 25 percent of the time.

2) The 2-year 24-hour (average) flow was computed by HEC-1 simulations. The 2-year flow is expected to occur once every two years, on average, based on frequency characteristics of an annual series which considers only the single highest data point for each year of record. However, flow duration curves assume a partial duration series which consider all data points within each year. According to Kite[12], the 2-year return period from an annual series is equivalent to a 1.44-year return period in a partial duration series. For the computed flow duration curves, the 2-year 24-hour (average) flow was plotted to be exceeded about 0.19 percent of the time, corresponding to one day in 1.44 years.

3) The 10-year 24-hour (average) flow was computed by HEC-1 simulations. The 10-year flow is expected to occur once every 10 years, on average. No adjustment was made for the minor difference in partial duration vs. annual series annual return period, 9.5 years vs. 10 years. For the computed flow duration curves, the 10-year 24-hour (average) flow was plotted to be

[12] Kite, G.W., 1977, *Frequency and Risk Analysis in Hydrology*, Water Resources Publications.

exceeded about 0.027 percent of the time, corresponding to one day in 10 years.

Flows and plotting positions were interpolated between and extrapolated beyond the three points described above considering the shape of flow duration curves for gaged streams in the study area, as shown by Figures 2.4.52 and 2.4.53.

3.3.2 Confidence Limits on Flow Duration Curves. The 5 and 95 percent confidence limits on the flow duration curves were estimated as follows:

1) The 5 and 95 percent confidence limits of the 2- and 10-year 24-hour (average) flow and the mean annual flow were obtained on all streamflow gage data sets on which frequency analyses were conducted (see Section 2.4.4). These confidence limits were obtained in accordance with guidelines described in *Bulletin 17B* of the U.S. Water Resources Council.

2) For each streamflow gage data set, the change in percent from the expected value to the 5 and 95 percent confidence limits were calculated and averaged. The average percentage changes obtained from the streamflow gage data sets were applied to the HEC-1 generated 2- and 10-year 24-hour (average) flow and to the mean annual flow that was obtained as described in Section 3.3.1. This resulted in the 5 and 95 percent confidence limit on the 2-year 24-hour flow, 10-year 24-hour flow, and average annual flow. The 5 and 95 percent confidence limit flows thus obtained were used to develop the 5 and 95 percent confidence limit flow duration curves using the same methodology described in Section 3.3.1.

3.4 River Hydraulic Modeling Methodology

Flow depths and velocities were required for the hydraulic design of mitigation measures in seven of the eight major basins. These depths and velocities were obtained through use of the HEC-2, Water Surface Profile Model, normal depth calculations, and critical depth calculations. Channel and cross-section variations, transport of sediment, bed and bank roughness, and spill resistance, all of which create turbulence and energy losses, tend to increase *with increasing discharge*. These energy losses result in flow conditions on steep natural streams that may approach but do not exceed critical flow except in very localized areas of the channel.[13] On reaches that modeling results indicated were of supercritical slope, velocities were obtained from a supercritical flow analysis and depths from a subcritical flow analysis. The velocities and depths thus obtained were, in most cases, approximately equal to the critical depth and velocity because most of these reaches were

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[13] Jarrett, R.D., November 1984, *Hydraulics of High-Gradient Streams*, Journal of Hydraulic Engineering, Vol 110, No. 11, ASCE.

near a critical slope. On reaches that modeling results indicated were of subcritical slope, velocities and depths were obtained from a subcritical flow analysis. A Mannings' "n" value of 0.25 was used for all calculations.

Cross-sectional data for both HEC-2 modeling and normal/critical depth calculations were obtained from a number of sources. In a few instances, detailed surveyed cross-sectional data were available. In many instances, cross-sections were obtained from a digital terrain model (DTM). At some locations that lacked adequate surveyed or DTM data, the data required for input to the HEC-2 model were obtained from aerial photographs, channel centerline profiles, and professional judgement from team members that observed the site of interest. At some locations no depths and velocities were obtained for existing conditions because adequate data could not be obtained.

3.5 Hydrologic Results

3.5.1 Unit Hydrographs. Table 3.5.1 presents the peak discharge of the unit hydrograph for each sub-basin. The unit hydrograph peaks correspond to a rainstorm of one hour duration with a total rain depth of 1 mm. Figure 3.5.1 shows a typical unit hydrograph computed by the HEC-1 program. Most unit hydrographs are very similar to the shape typified in Figure 3.5.1. The exceptions are presented in Figures 3.5.2 and 3.5.3. These plots for sub-basins A2 and A4 show composite unit hydrographs representing the combination of the SCS unit hydrograph (with no storage coefficient) applied for effectively impervious areas and the Clark unit hydrograph applied for non-impervious areas. These two figures dramatically illustrate both the peak flow increases expected from urban development in the Pinatubo region, and the effect of a large storage coefficient on the shape of a unit hydrograph.

3.5.2 Sacobia-Bamban Basin. The Sacobia-Bamban basin is 146 km^2 in area, extending northeasterly from the base of Mount Pinatubo to the interior lowlands of the island of Luzon. Plate 1 shows the location of the basin relative to the study area and hydrometeorological data stations. Figure 3.5.4 shows the basin at a larger scale.

The basin headwater area consists of steep and narrow parallel valleys drained by the Sacobia, Sapang-Cauayan, Marimla, and Malago Rivers. Of these, only the Sacobia and Malago extend to near the base of Mount Pinatubo; the other rivers originate at lower elevations down the mountain's northeastern slope. The Bamban River begins at the confluence of the Sacobia and Marimla Rivers about 25 km northeast of the crater rim, just upstream of the Highway 3 road crossing near the village of Bamban.

Elevations for the Sacobia River and other headwater tributaries range from about 1,100 meters in the headwaters of the Sacobia and Malago Rivers to 55 meters at the confluence defining the start of the Bamban River above the Highway 3 crossing. The Bamban River component of the basin is relatively flat, dropping only about 23 meters over its 12 km long reach. Most of the Bamban River is contained within a diked channel section which is now perched above the surrounding topography. Perching of the Bamban River is a consequence of significant aggradation resulting from the June 1991 eruption. This condition presumably leads to a net water loss resulting from percolation through the channel bed and under the levee system. For modeling purposes, all event rainfall for sub-basin S7 was assumed to be lost to infiltration (i.e., the infiltration rate was set to an arbitrarily high value greater than the maximum rainfall rate).

The 1:50,000 scale maps dated 1986 indicate no significant population centers or urban development within the basin. Clark AFB is located immediately to the south of the basin, but does not affect basin hydrology.

The Sacobia-Bamban basin, located on the northeast slopes of Mount Pinatubo, is in Pinatubo's rain shadow during the Southwest Monsoon or rainy season. Annual rainfall amounts over the basin vary from a maximum of about 4,000 mm/yr in the upper headwater areas near the summit of Mount Pinatubo to a minimum of about 1,800 mm/yr at the downstream end of the basin in the interior lowlands of the island of Luzon. Similar variations in rainfall over the basin are expected during single storm events. Figure 2.3.4 shows isohyets of average annual precipitation over the study area.

<u>Sub-Basin and Output Site Parameters</u>. Physical and computed parameters of sub-basins within the Sacobia-Bamban River Basin are summarized in Table 3.5.2. Physical and computed parameters at simulation output sites in the Sacobia-Bamban River Basin are summarized in Table 3.5.3. As discussed in Section 2.4.5, the flow at a given site was obtained by centering the storm over the contributing sub-basin that has the highest rainfall (usually the highest elevation headwater sub-basin). Because the sites listed in Table 3.5.3 do not all share common headwaters, the storms had to be centered over three sub-basins in order to obtain flows at all sites. The column in Table 3.5.3 labeled "Critical Storm Location" identifies the Sacobia-Bamban sub-basin over which the storm was centered to obtain flows at the indicated site.

<u>Design Flood Hydrographs</u>. Design flood hydrographs computed by the HEC-1 model at Sacobia-Bamban basin simulation output sites for each of the 2-, 10-, 50-, 100-, and 500-year return period hypothetical storms are shown by Figures 3.5.5 through 3.5.11. The hydrographs presented for each site correspond to model(s) with the storm(s) centered over the sub-basin location identified by Table 3.5.3 for maximum flows at each site.

<u>Design Discharge-Frequency Curves</u>. Peak discharge and maximum 24-hour and 3-day flow volumes from each of the 2-, 10-, 50-, 100-, and 500-year design flood hydrographs are summarized by Table 3.5.4.

Flow Duration Curves. Daily flow duration curve data for each of the Sacobia-Bamban basin simulation output sites, computed following the method described in Section 3.3, are summarized by Table 3.5.5 The data shown for site S7DS do not account for seepage losses during low-flow periods from the perched upstream channel, and probably over-estimate the low-flow characteristics.

3.5.3 Abacan River Basin. The Abacan basin is 51 km^2 in area, originating about 4 km east of the crater rim of Mount Pinatubo and extending easterly to the interior lowlands of the island of Luzon. Plate 1 shows the location of the basin relative to the study area and hydrometeorological data stations. Figure 3.5.12 shows the basin at a larger scale.

The basin headwater area consists of two steep and narrow parallel valleys drained by the Abacan River and one major tributary, Sapang-Bayo Creek. The basin headwaters originate on Mount Pinatubo's eastern slope at elevations about 1,000 meters below the crater rim. Sapang-Bayo Creek joins the Abacan River about 4 km upstream of the Highway 3 crossing and about 2 km south of Clark Air Base. The lower portion of the basin below Highway 3 is mostly confined within dikes.

Elevations for Abacan River/Sapang-Bayo Creek range from about 500 meters in the upper headwater areas to 130 meters at Sapang-Bayo/Abacan confluence to 10 meters at the end of the dike-confined channel section. Unlike the Bamban River, the dike-confined channel section is not perched above the surrounding landscape.

The 1:50,000 scale maps dated 1986 indicate significant urban development and "densely built up" areas in the Abacan basin in the vicinity of Clark AFB and Angeles City. Portions of Clark AFB's runways and hangers extend into the basin and also presumably drain to the Abacan River. The extent of urban development relative to the basin size is believed to be sufficient to have a noticeable impact on basin hydrology.

The Abacan basin, located on the eastern slopes of Mount Pinatubo, is in Pinatubo's rain shadow during the Southwest Monsoon or rainy season. Annual rainfall amounts over the basin vary from a maximum of about 3,000 mm/yr in the upper headwater areas on the slopes of Mount Pinatubo to a minimum of about 1,800 mm/yr at the downstream end of the basin in the interior lowlands of the island of Luzon. Similar variations in rainfall over the basin are expected during single storm events. Figure 2.3.4 shows isohyets of average annual precipitation over the study area.

Sub-Basin and Output Site Parameters. Physical and computed parameters of sub-basins within the Abacan River Basin are summarized in Table 3.5.6. Physical and computed parameters at simulation output sites in the Abacan River Basin are summarized in Table 3.5.7. As discussed in Section 2.4.5, the flow at a given site was obtained by centering the storm over the contributing sub-basin that has the highest rainfall (usually the highest elevation headwater sub-basin). Because the sites listed in Table 3.5.7 all share common headwaters, the storms had to be centered over only one sub-basin in order to obtain flows at all sites. The column in Table 3.5.7 labeled "Critical Storm Location" identifies the Abacan sub-basin (A1) over which the storm was centered.

Design Flood Hydrographs. Design flood hydrographs computed by the HEC-1 model at Abacan basin simulation output sites for each of the 2-, 10-, 50-, 100-, and 500-year return period hypothetical storms are shown by Figures 3.5.13 through 3.5.15.

Design Discharge/Volume Frequency Curves. Peak discharge and maximum 24-hour and 3-day flow volume data from each of the 2-, 10-, 50-, 100-, and 500-year design flood hydrographs are summarized by Table 3.5.8.

Flow Duration Curves. Daily flow duration curve data for each of the Abacan basin simulation output sites, computed following the method described in Section 3.3, are summarized by Table 3.5.9.

3.5.4 O'Donnell Basin. The study area considered herein for the O'Donnell basin includes two major rivers, the O'Donnell and the Bulsa. The O'Donnell River drains the northern slopes of Mount Pinatubo, and has a basin area upstream of the confluence with the Bulsa of about 266 km^2. The Bulsa River primarily drains the eastern slopes of the Zambales mountains, and has a basin area upstream of the confluence with the O'Donnell of about 510 km^2. The entire basin extends about 2 km below the O'Donnell-Bulsa confluence and has a total area of about 817 km^2. It is the largest of all basins being assessed under the present work.

Plate 1 shows the location of the basin relative to the study area and hydrometeorological data stations. Figure 3.5.16 shows the basin at a larger scale.

Basin headwater areas on Mount Pinatubo consist of steep and narrow parallel valleys drained primarily by the O'Donnell, Apalong, and Bangat Rivers. Of these three tributaries, only the O'Donnell sub-basin extends fully to Pinatubo's crater rim where the post-eruption elevation is about 1,200 meters. The Apalong and Bangat Rivers originate from a secondary peak on Mount Pinatubo which, with a pre-eruption summit elevation of about 1,500 meters, may now be the highest point on the mountain.

Basin headwater areas for the Bulsa River on the east slopes of the Zambales Mountains reach a maximum elevation of about 1,600 meters. These headwater areas include numerous steep and narrow stream-cut valleys which seem generally less entrenched into the mountain slopes than those on Pinatubo.

The stream elevation at the confluence of the Bulsa and O'Donnell Rivers, located near the downstream end of the basin study area, is about 40 meters.

The 1:50,000 scale maps dated 1986 indicate several small population centers (O'Donnell, Santa Lucia, Moriones), but none of sufficient size or scale to appreciably affect the hydrology at sites of interest within the basin.

The O'Donnell basin, which generally drains in a northeasterly direction, is in the rain shadow of the Zambales Mountains and, to a lesser extent, of Mount Pinatubo, during the Southwest Monsoon or rainy season. Annual rainfall amounts over the basin vary from a maximum of about 6,000 mm/yr in the upper headwater areas of the Bulsa River in the Zambales Mountains, and 5,000 mm/yr in the upper headwater areas of O'Donnell River tributaries draining Mount Pinatubo, to a minimum of about 1,800 mm/yr at the downstream end of the basin in the interior lowlands of the island of Luzon. Similar variations in rainfall over the basin are expected during single storm events. Figure 2.3.4 shows isohyets of average annual precipitation over the study area.

Sub-Basin and Output Site Parameters. Physical and computed parameters of sub-basins within the O'Donnell River Basin are summarized in Table 3.5.10. Physical and computed parameters at simulation output sites in the O'Donnell River Basin are summarized in Table 3.5.11. As discussed in Section 2.4.5, the flow at a given site was obtained by centering the storm over the contributing sub-basin that has the highest rainfall (usually the highest elevation headwater sub-basin). Because the sites listed in Table 3.5.11 do not all share common headwaters, the storms had to be centered over three sub-basins in order to obtain flows at all sites. The column in Table 3.5.11 labeled "Critical Storm Location" identifies the O'Donnell sub-basin over which the storm was centered to obtain flows at the indicated site.

Design Flood Hydrographs. Design flood hydrographs computed by the HEC-1 model at basin simulation output sites for each of the 2-, 10-, 50-, 100-, and 500-year return period hypothetical storms are shown by Figures 3.5.17 through 3.5.27.

Design Discharge/Volume Frequency Curves. Peak discharge and maximum 24-hour and 3-day flow volume data from each of the 2-, 10-, 50-, 100-, and 500-year design flood hydrographs are summarized by Table 3.5.12.

Flow Duration Curves. Daily flow duration curve data for each of the O'Donnell basin simulation output sites, computed following the method described in Section 3.3, are summarized by Table 3.5.13.

3.5.5 Gumain/Porac Basin. The Gumain/Porac basin is 302 km^2 in area, extending in a generally southeasterly direction from Mount Pinatubo to the Pampanga Delta. Plate 1 shows the location of the basin relative to the study area and hydrometeorological data stations. Figure 3.5.28 shows the basin at a larger scale.

The Gumain/Porac basin includes two major rivers, the Gumain and the Porac. The headwaters of the Gumain River consist of steep, well-incised tributaries originating near the crater rim of Mount Pinatubo and along the ridge which extends south from Mount Pinatubo, separating the Gumain/Porac basin from the westerly-flowing Santo Tomas tributaries. The Gumain River flows approximately 32 km southeast from the crater rim of Mount Pinatubo to its confluence with the Porac River at the head of the Gumain Floodway. Elevations within the basin range from about 1,600 meters on the ridge line approximately 4 km south of Mount Pinatubo and about 1,200 meters at the crater rim to about 10 meters at the head of the Gumain Floodway.

The headwaters of the Porac River originate on the southeast slopes of Mount Pinatubo, approximately 5 km southeast of the crater rim. The river flows east and then south some 39 km to its confluence with the Gumain River at the head of the Gumain Floodway. Elevations within the Porac basin range from 1,150 meters at the high point to 10 meters at the head of the Gumain Floodway.

The lower reaches of the Gumain and Porac Rivers contain a number of major irrigation and flood control projects, including the Gumain Floodway. One major aspect of these projects was the diversion of the Porac River into the Gumain Floodway system; the Porac's natural course appears to be in a channel which flows about 4 km north of the floodway. However, it has not been possible to obtain information on the exact configuration and operating policies for these projects or their current (post-eruption) condition. For purposes of hydrologic modeling of post-eruption conditions, it was assumed that flood flows from both the Gumain and Porac Rivers will be directed to and confined within the Gumain Floodway.

The Gumain Floodway begins at the confluence of the Gumain and Porac Rivers and continues downstream approximately 8 km to its outlet in the Pampanga Delta at an approximate elevation of 5 meters. The floodway, represented as sub-basin G19, has aggraded significantly since the eruption and is now perched above the surrounding landscape. This condition presumably leads to a net water loss resulting from percolation through the channel bed and under the levee system. For modeling purposes, all event rainfall for sub-basin G19 was assumed to be lost to infiltration (i.e, the infiltration rate was set to an arbitrarily high value greater than the maximum rainfall rate).

The drainage area delineated during this study for the Gumain/Porac basin at the downstream end of the Gumain Floodway is 302 km^2. This is less than the 370 km^2 basin area previously published for a stream gage located along the floodway. The previously published value is believed to have included areas which can no longer drain to the lower Gumain because of extreme channel aggradation.

The 1:50,000 scale maps dated 1986 indicate several small population centers (i.e. Pabanlag, Del Carmen, and Santa Rita), but none are of sufficient size to appreciably affect the hydrology at sites of interest within the basin.

Annual rainfall amounts over the basin vary from a maximum of about 5,000 mm/yr in the Gumain River headwater region on Mount Pinatubo to 2,000 mm/yr at the downstream end of the basin at the western edge of the Pampanga Delta. Similar variations in rainfall over the basin are expected during single storm events. Figure 2.3.4 shows isohyets of average annual precipitation over the study area.

Sub-Basin and Output Site Parameters. Physical and computed parameters of sub-basins within the Gumain/Porac River Basin are summarized in Table 3.5.14. Physical and computed parameters at simulation output sites in the Gumain/Porac River Basin are summarized in Table 3.5.15. As discussed in Section 2.4.5, the flow at a given site was obtained by centering the storm over the contributing sub-basin that has the highest rainfall (usually the highest elevation headwater sub-basin). Because the sites listed in Table 3.5.15 do not all share common headwaters, the storms had to be centered over two sub-basins in order to obtain flows at all sites. The column in Table 3.5.15 labeled "Critical Storm Location" identifies the Gumain/Porac sub-basin over which the storm was centered to obtain flows at the indicated site.

Design Flood Hydrographs. Design flood hydrographs computed by the HEC-1 model at basin simulation output sites for each of the 2-, 10-, 50-, 100-, and 500-year return period hypothetical storms are shown in Figures 3.5.29 through 3.5.35.

Design Discharge/Volume Frequency Curves. Peak discharge and maximum 24-hour and 3-day flow volume data from each of the 2-, 10-, 50-, 100-, and 500-year design flood hydrographs are summarized in Table 3.5.16.

Flow Duration Curves. Daily flow duration curve data for each of the Gumain/Porac basin simulation output sites, computed following the method described in Section 3.3, are summarized in Table 3.5.17. The data shown for site G19US do not account for seepage losses from the perched upstream channel during low-flow periods and probably over-estimate the low-flow characteristics.

3.5.6 Pasig-Potrero Basin. The Pasig-Potrero basin is 77 km^2 in area, originating at the Mount Pinatubo crater rim and extending first in an easterly direction and then, further downstream, in a southeasterly direction to the Pampanga Delta. Plate 1 shows the location of the basin relative to the study area and hydrometeorological stations. Figure 3.5.36 shows the basin at a larger scale.

The basin headwater area is drained by five streams: the Bucbuc, Yangca, Timbu, and Papatac Rivers, and a stream that prior to the eruption was the uppermost headwater stream of the Sacobia River. The Papatac River is formed at the confluence of the Bucbuc and Yangca. The Pasig River is formed at the confluence of the Papatac and Timbu Rivers. Below the former site of the Mancatian Bridge, the Pasig's name changes to Potrero.

Elevations in the basin range from about 1,200 meters near the crater rim to near zero at the confluence of the Potrero River with the Guagua River. The Potrero River component, which comprises almost half of the basin length, is relatively flat, dropping about 100 meters over its 18 km length.

The 1:50,000 scale maps dated 1986 do not indicate any urban development that would significantly affect basin hydrology. The town of Bacolor near the downstream end of the basin has been affected by shallow flooding from the Potrero River, but is not considered to lie in the basin because the Potrero River is isolated from the surrounding topography by levees and because the channel from about 4-1/2 km below the former site of the Mancatian Bridge to the confluence with the Guagua River is perched above the surrounding topography.

The Pasig-Potrero basin, located on the eastern slopes of Mount Pinatubo, is in Pinatubo's rain shadow during the Southwest Monsoon or rainy season. Annual rainfall amounts vary from a maximum of about 5,000 mm/yr in the upper headwater areas on the slopes of Mount Pinatubo to a minimum of about 1,800 mm/yr at the downstream end of the basin in the Pampanga Delta. Similar variations in rainfall over the basin are expected during single storm events. Figure 2.3.4 shows isohyets of average annual precipitation over the study area.

Sub-Basin and Output Site Parameters. Physical and computed parameters of sub-basins within the Pasig-Potrero River Basin are summarized in Table 3.5.18. Physical and computed parameters at simulation output sites in the Pasig-Potrero River Basin are summarized in Table 3.5.19. As discussed in Section 2.4.5, the flow at a given site was obtained by centering the storm over the contributing sub-basin that has the highest rainfall (usually the highest elevation headwater sub-basin). Because the sites listed in Table 3.5.19 do not all share common headwaters, the storms had to be centered over two sub-basins in order to obtain flows at all sites. The column in Table 3.5.19 labeled "Critical Storm Location" identifies the Pasig-Potrero sub-basin over which the storm was centered to obtain flows at the indicated site.

Design Flood Hydrographs. Design flood hydrographs computed by the HEC-1 model at Pasig-Potrero simulation output sites for each of the 2-, 10-, 50-, 100-, and 500-year return period hypothetical storms are shown by Figures 3.5.37 through 3.5.45.

Design Discharge/Volume Frequency Curves. Peak discharge and maximum 24-hour and 3-day flow volume data from each of the 2-, 10-, 50-, 100-, and 500-year design flood hydrographs are summarized in Table 3.5.20.

Flow Duration Curves. Daily flow duration curve data for each of the Pasig-Potrero basin simulation sites, computed following the method described in Section 3.3, are summarized in Table 3.5.21. The data shown for site P7DS do not account for seepage losses from the perched upstream channel during low-flow periods and probably overestimate the low-flow characteristics.

3.5.7 Santo Tomas Basin. The Santo Tomas basin is approximately 262 km^2 in area, extending in a southwesterly direction from Mount Pinatubo to the South China Sea. Plate 1 shows the location of the basin relative to the study area and hydrometeorological data stations. Figure 3.5.46 shows the basin at a larger scale.

The Santo Tomas River system incorporates two major tributaries, the Marella River and the Mapanuepe River, which join to form the Santo Tomas. The headwaters of the Marella River originate near the crater rim of Mount Pinatubo at an elevation of about 1,500 meters and along the ridge extending south from Mount Pinatubo which separates the Santo Tomas basin from the easterly flowing Gumain River tributaries. The Marella River drains the southwest slopes of Mount Pinatubo and combines with the Mapanuepe River at an elevation of about 90 meters. The reach length from the confluence of the Marella and Mapanuepe Rivers to the crater rim is about 28 km.

The headwaters of the Mapanuepe River originate near the divide between the Santo Tomas and Gumain basins at an elevation of around 1,000 meters. The Mapanuepe River sub-basin includes a large mine site, a mine tailings dam, and Lake Mapanuepe. Approximately 4.2 km^2 of the mine site does not contribute surface runoff to the watershed and hence was not included in the hydrologic model. The impoundment behind the tailings dam is small in comparison to Lake Mapanuepe and no flow routing was done through this facility.

Lake Mapanuepe was formed following the June 1991 eruption of Mount Pinatubo as a result of blockage of the Mapanuepe River outlet by recurrent lahars and severe aggradation on the Marella. Under current conditions, the Mapanuepe River joins the Marella River approximately 1.5 km downstream from the outlet of Lake Mapanuepe. The surface area of Lake Mapanuepe at the invert elevation of its current outlet, 121.6 meters, is about 8.0 km^2; topographic contours show that the lake surface area would be about 17 km^2 at a water level elevation of 140 meters. Lake storage volumes between these two elevations were computed using the conic method for reservoir volumes as described in the HEC-1 manual. The following stage/discharge characteristics were used for modeling purposes:

Lake Elevation (m)	Outlet Discharge (m^3/s)
< 121.6	0
121.6 to 129.6	$23.57d[10d/(10+2d)]^{0.667}$
< 129.6	$2.36a\{a/[26+(2.08)(d-8)]\}^{0.667}$

where: d = overflow depth = lake elevation - 121.6
a = flow area = 80 + (7.78+0.28d)(d-8)

The Santo Tomas River begins at the Marella-Mapanuepe confluence. The Santo Tomas is joined by the Santa Fe River approximately 10 km downstream from gage W094A. The Santo Tomas then flows a further 12 km through coastal lowlands to Highway 7, and an additional 1 km to the South China Sea.

The 1:50,000 scale maps dated 1986 indicate several small population centers (San Rafael, Dalanaon and Aglao), but none are of sufficient size or scale to appreciably affect the hydrology at sites of interest within the basin.

Annual rainfall amounts over the basin vary from a maximum of about 5,000 mm/yr in the Marella River headwater region on Mount Pinatubo to a minimum of about 3,600 mm/yr at the downstream end of the basin near the coastline. Similar variations in rainfall over the basin are expected during single storm events. Figure 2.3.4 shows isohyets of average annual precipitation over the study area.

Sub-Basin and Output Site Parameters. Physical and computed parameters of sub-basins within the Santo Tomas River Basin are summarized in Table 3.5.22. Physical and computed parameters at simulation output sites in the Santo Tomas River Basin are summarized in Table 3.5.23. As discussed in Section 2.4.5, the flow at a given site was obtained by centering the storm over the contributing sub-basin that has the highest rainfall (usually the highest elevation headwater sub-basin). Because the sites listed in Table 3.5.23 do not all share common headwaters, the storms had to be centered over two sub-basins in order to obtain flows at all sites. The column in Table 3.5.23 labeled "Critical Storm Location" identifies the Santo Tomas sub-basin over which the storm was centered to obtain flows at the indicated site.

Design Flood Hydrographs. Design flood hydrographs computed by the HEC-1 model at basin simulation output sites for each of the 2-, 10-, 50-, 100-, and 500-year return period hypothetical storms are shown by Figures 3.5.47 through 3.5.51.

Design Discharge/Volume Frequency Curves. Peak discharge and maximum 24-hour and 3-day flow volume data from each of the 2-, 10-, 50-, 100-, and 500-year design flood hydrographs are summarized by Table 3.5.24.

Flow Duration Curves. Daily flow duration curve data for each of the Santo Tomas basin simulation output sites, computed following the method described in Section 3.3, are summarized by Table 3.5.25.

3.5.8 Bucao Basin. The Bucao basin is 656 km² in area, extending in a generally northwesterly direction from Mount Pinatubo and southwesterly from the Zambales Mountains to the South China Sea. Plate 1 shows the location of the basin relative to the study area and hydrometeorological data stations. Figure 3.5.52 shows the basin at a larger scale.

The Bucao basin incorporates the Bucao River and its two major tributaries, the Balin-Buquero River and the Balintawak River. The central portion of the basin includes a large area of relatively flat and low-lying terrain nestled between the mountains which define the basin perimeter: Mount Pinatubo, the Zambales Mountains, and the coastal mountains located between Mount Pinatubo and the South China Sea.

The headwaters of the Bucao River originate on the northwest slopes of Mount Pinatubo 2 to 5 km north of the crater rim at an elevation of about 900 meters. The river flows in a generally westerly direction through rugged terrain for approximately 28 km to its confluence with the Balintawak River at an elevation of about 50 meters. The Bucao then enters a broad flat valley and continues to flow west approximately 4 km to its confluence with the Balin-Buquero and a further 12 km to the Highway 7 crossing. The Bucao enters the South China Sea approximately 2 km below Highway 7.

The headwaters of the Balin-Buquero River originate to the south of the Bucao River headwater areas and extend to the crater rim of Mount Pinatubo at an elevation of about 1,500 meters. The Balin-Buquero and its principal tributaries (such as the Maronut) drain the western slopes of Mount Pinatubo and the northeastern slopes of the coastal mountain range which lies between Mount Pinatubo and the South China Sea. The Balin-Buquero flows in a generally northwesterly direction for approximately 20 km from the crater rim of Mount Pinatubo to its confluence with the Maronut River at an elevation of about 90 meters. Below the confluence with the Maronut, the Balin-Buquero enters a broad flat valley and continues to flow northwest for a further 12 km to its confluence with the Bucao at an elevation of about 40 meters. The drainage area of the Balin-Buquero above its confluence with the Bucao is approximately 217 km².

The headwaters of the Balintawak River originate to the north of the Bucao River headwater areas and drain the southern slopes of the Zambales Mountains at elevations of up to 1,670 meters. The Balintawak River flows in a generally southwesterly direction through rugged terrain for approximately 20 km to its confluence with the Bucao River at an elevation of 90 meters. The drainage area of the Balintawak upstream of its confluence with the Bucao is approximately 166 km².

The headwater areas of the Bucao and Balin-Buquero Rivers were severely disturbed by the June 1991 eruption of Mount Pinatubo, with massive deposits of pyroclastic material filling in entire river channels and destroying much of the pre-eruption drainage system. Post-eruption changes to drainage boundaries occurred to most of the Bucao and Balin-Buquero headwater drainages. The Maronut River was the most affected by the eruption, with a reduction in catchment area from 31 km^2 to 11 km^2 as a result of gross changes in catchment topography.

The 1:50,000 scale maps dated 1986 indicate several small population centers (San Juan, Poonbato and Maguiguis), but none are of sufficient size or scale to appreciably affect the hydrology at sites of interest within the basin.

Annual rainfall amounts over the basin vary from a maximum of about 6,000 mm/yr in the Zambales Mountains and 5,000 mm/yr in upper headwaters on Mount Pinatubo to 3,800 mm/yr in the coastal lowlands. Similar variations in rainfall over the basin are expected during single storm events. Figure 2.3.4 shows isohyets of average annual precipitation over the study area.

Sub-Basin and Output Site Parameters. Physical and computed parameters of sub-basins within the Bucao River Basin are summarized in Table 3.5.26. Physical and computed parameters at simulation output sites in the Bucao River Basin are summarized in Table 3.5.27. As discussed in Section 2.4.5, the flow at a given site was obtained by centering the storm over the contributing sub-basin that has the highest rainfall (usually the highest elevation headwater sub-basin). Because the sites listed in Table 3.5.27 do not all share common headwaters, the storms had to be centered over six sub-basins in order to obtain flows at all sites. The column in Table 3.5.27 labeled "Critical Storm Location" identifies the Bucao sub-basin over which the storm was centered to obtain flows at the indicated site.

Design Flood Hydrographs. Design flood hydrographs computed by the HEC-1 model at simulation output sites for each of the 2-, 10-, 50-, 100-, and 500-year return period hypothetical storms are shown by Figures 3.5.53 through 3.5.63.

Design Discharge/Volume Frequency Curves. Peak discharge and maximum 24-hour and 3-day flow volume data from each of the 2-, 10-, 50-, 100-, and 500-year design flood hydrographs are summarized by Table 3.5.28.

Flow Duration Curves. Daily flow duration curve data for each of the Bucao basin simulation output sites, computed following the method described in Section 3.3, are summarized by Table 3.5.29.

3.5.9 Maloma Basin. The Maloma basin is 150 km^2 in area, originating about 7 km southwest of Mount Pinatubo and extending in a westerly direction to the South China Sea. Plate 1 shows the location of the basin relative to the study area and hydrometeorological data stations. Figure 3.5.63 shows the basin at a larger scale.

The Maloma basin includes two major rivers, the Maloma River and the Gorongoro/Kakilingar River, which join before discharging into the South China Sea. The basin primarily drains the coastal mountains to the west of Mount Pinatubo; drainage of Mount Pinatubo itself is limited to the extreme eastern headwaters of the Maloma River which extend to the lower southwest slopes of Mount Pinatubo at an elevation of only about 600 meters.

The Maloma River flows west from Mount Pinatubo in a narrow canyon through the coastal mountain range which lies between Mount Pinatubo and the South China Sea. It is then joined by the Gorongoro/Kakilingar River about 6 km upstream of the Highway 7 bridge at an elevation of less than 10 meters. Elevations within the Maloma basin range from sea level to about 1,000 meters, with the highest elevations occurring within the coastal mountains.

The Gorongoro/Kakilingar River originates entirely from the coastal mountains to the west of Mount Pinatubo, and flows westward in a deep narrow valley through the coastal mountains. Elevations within the Gorongoro/Kakilingar catchment range from about 800 meters in the upper headwater areas to less than 10 meters at the confluence with the Maloma.

The 1:50,000 scale maps dated 1986 and 1991 indicate several small population centers (Payodpod, Maquineng, and Maloma), but none are of sufficient size to appreciably affect the hydrology at sites of interest within the basin.

Annual rainfall amounts over the basin vary from a maximum of about 5,000 mm/yr in the coastal mountains to a minimum of about 4,000 mm/yr in the low lying area between Mount Pinatubo and the coastal mountains, and along the coast near the South China Sea. Similar variations in rainfall over the basin are expected during single storm events. Figure 2.3.4 shows isohyets of average annual precipitation over the study area.

Sub-Basin and Output Site Parameters. Physical and computed parameters of sub-basins within the Maloma River Basin are summarized in Table 3.5.30. Physical and computed parameters at simulation output sites in the Maloma River Basin are summarized in Table 3.5.31. As discussed in Section 2.4.5, the flow at a given site was obtained by centering the storm over the contributing sub-basin that has the highest rainfall (usually the highest elevation headwater sub-basin). Because the sites listed in Table 3.5.31 do not all share common headwaters, the storms had to be centered over three sub-basins in order to obtain flows at all sites. The column in Table 3.5.31 labeled "Critical Storm Location" identifies the Maloma sub-basin over which the storm was centered to obtain flows at the indicated site.

Design Flood Hydrographs. Design flood hydrographs computed by the HEC-1 model at basin simulation output sites for each of the 2-, 10-, 50-, 100-, and 500-year return period hypothetical storms are shown by Figures 3.5.65 through 3.5.68.

Design Discharge/Volume Frequency Curves. Peak discharge and maximum 24-hour and 3-day flow volume data from each of the 2-, 10-, 50-, 100-, and 500-year design flood hydrographs are summarized by Table 3.5.32.

Flow Duration Curves. Daily flow duration curve data for each of the Maloma basin simulation output sites, computed following the method described in Section 3.3, are summarized by Table 3.5.33.

3.5.10 Confidence Limits.

Frequency Events. Table 3.5.34 presents the 2-, 10-, 50-, 100-, and 500-year peak discharges estimated with the use of the HEC-2 model and the 5 and 95 percent confidence limits about these peak discharges at each hydrologic site considered in this study. On Figure 3.5.69 are plotted the HEC-1 estimated peak discharges for the 2- through 500-year events and the 5 and 95 percent confidence limits about these peaks at a typical hydrologic site (Site O9US in the O'Donnell River basin).

Table 3.5.35 presents the 2-, 10-, 50-, 100-, and 500-year maximum 24-hour volumes estimated with the use of the HEC-2 model and the 5 and 95 percent confidence limits about these volumes at each hydrologic site considered in this study. On Figure 3.5.70 are plotted the HEC-1 estimated peak discharges for the 2- through 500-year events and the 5 and 95 percent confidence limits about these peaks at a typical hydrologic site (Site O9US in the O'Donnell River basin).

Table 3.5.36 presents the 2-, 10-, 50-, 100-, and 500-year maximum 3-day volumes estimated with the use of the HEC-2 model and the 5 and 95 percent confidence limits about these volumes at each hydrologic site considered in this study. On Figure 3.5.71 are plotted the HEC-1 estimated peak discharges for the 2- through 500-year events and the 5 and 95 percent confidence limits about these peaks at a typical hydrologic site (Site O9US in the O'Donnell River basin).

Flow Duration Curves. Table 3.5.37 presents the data for the 5 percent confidence limit about the flow duration curve at each hydrologic site considered in this study. Table 3.5.38 presents the data for the 95 percent confidence limit about these same flow duration curves. On Figure 3.5.72 are plotted the computed flow duration curve and the 5 and 95 percent confidence limit about the computed curve at a typical hydrologic site (Site S7DS in the Sacobia-Bamban River basin).

3.6 River Hydraulic Modeling Results

Table 3.6.1 presents clearwater flow depths. Table 3.6.2 presents bulked flow (i.e., sediment + water flow) depths.[14] In Table 3.6.3 are clearwater flow velocities Table 3.6.4 presents bulked flow velocities. Notes contained in Table 3.6.5 provide information on each reach that is useful for the correct interpretation of the data in Tables 3.6.1 through 3.6.4.

Figures 3.6.1 through 3.6.11 present the results of the hydraulic modeling of clearwater flows at bridges located in the reaches indicated on Tables 3.6.1 through 3.6.5. Figures 3.6.12 through 3.6.22 present the results at these same bridges but for flows that have been increased for suspended sediment.

3.7 HEC-1 Input

Enclosure 1 provides a listing of the HEC-1 input used for the modeling of the 100-year event in the Sacobia-Bamban River basin. Storms were centered over three different sub-basins of the Sacobia-Bamban Basin in order to obtain flow estimates at all required sites (see Section 3.5.2, Sub-Basin and Output Site Parameters). Therefore, Enclosure 1 includes three separate HEC-1 input files, one for each of the three assumed storm centers. HEC-1 input for the 2-, 10-, 50-, and 500-year events on the Sacobia-Bamban Basin are identical to Enclosure 1 except the values on the PI cards, which represent incremental storm precipitation, are different.

The HEC-1 input for other basins was similar to the input provided in Enclosure 1.

[14] Technical Appendix B, Sedimentation, contains information on flow bulking for suspended sediment.

ENCLOSURE, PLATE, AND EXHIBIT A FOR

TECHNICAL APPENDIX A

HYDROLOGY AND HYDRAULICS

ENCLOSURE 1

HEC-1 INPUT FOR THE 100-YEAR EVENT ON THE PASIG-POTRERO BASIN:

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ID PASIG-POTRERO RIVER: 100-YEAR EVENT
ID POST-ERUPTION CONDITIONS
ID US ARMY CORPS OF ENGINEERS
*FREE
*DIAGRAM
IM
IT 60 01JAN00 0100 241
IO 1
IN 60
*
***********************************************************
******************
*  100-Year Storm, 5-Day Event:
*  Ratio of Storm Volume from Isopluvial Maps (Sub-Basin to Summit) : .55
*  Distance from Sub-Basin to Assumed Storm Center : .0 km
*  Distance Assumed for Depth-Area Correction: 0.92 km
*
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PG PT
PI    4.20   4.20   4.20   4.20   4.20   4.20   4.20   4.20   4.20
PI    4.20   4.20   4.20   4.20   4.20   4.20   4.20   4.20   4.20
PI    4.20   4.20   4.20   4.20   4.20   4.20   4.20   4.20   4.20
PI    4.20   4.20   4.20   4.20   4.20   4.20   4.20   4.20   4.20
PI    4.20   4.20   4.20   4.20   4.20   4.20   4.20   6.48   6.48
PI    6.48   6.48   6.48   6.48   5.48   6.48   6.48   6.48   6.48
PI    6.48   6.48   6.48   6.48   6.48   6.45   6.45   6.45  24.93
PI   24.93  24.93  41.55  41.55  41.55  76.39  51.52  43.93  24.93
PI   24.93  24.93   6.45   6.45   6.45   6.45   6.45   6.45   6.45
PI    6.45   6.45   6.48   6.48   6.48   6.48   6.48   6.48   6.48
PI    6.48   4.20   4.20   4.20   4.20   4.20   4.20   4.20   4.20
PI    4.20   4.20   4.20   4.20   4.20   4.20   4.20   4.20   4.20
PI    4.20   4.20   4.20   4.20   4.20   4.20   4.20   4.20   4.20
PI    4.20   4.20   4.20
*
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* 100-Year Storm, 5-Day Event:
* Ratio of Storm Volume from Isopluvial Maps (Sub-Basin to Summit) : .93
* Distance from Sub-Basin to Assumed Storm Center : .0 km
* Distance Assumed for Depth-Area Correction: 1.7 km
*

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PG P0

PI	7.37	7.37	7.37	7.37	7.37	7.37	7.37	7.37	7.37
PI	7.37	7.37	7.37	7.37	7.37	7.37	7.37	7.37	7.37
PI	7.37	7.37	7.37	7.37	7.37	7.37	7.37	7.37	7.37
PI	7.37	7.37	7.37	7.37	7.37	7.37	7.37	7.37	7.37
PI	7.37	7.37	7.37	7.37	7.37	7.37	7.37	11.34	11.34
PI	11.34	11.34	11.34	11.34	11.34	11.34	11.34	11.34	11.34
PI	11.34	11.34	11.34	11.34	11.34	11.26	11.26	11.26	43.48
PI	43.48	43.48	74.75	74.75	74.75	82.17	77.19	76.12	43.48
PI	43.48	43.48	11.26	11.26	11.26	11.26	11.26	11.26	11.26
PI	11.26	11.26	11.34	11.34	11.34	11.34	11.34	11.34	11.34
PI	11.34	7.37	7.37	7.37	7.37	7.37	7.37	7.37	7.37
PI	7.37	7.37	7.37	7.37	7.37	7.37	7.37	7.37	7.37
PI	7.37	7.37	7.37	7.37	7.37	7.37	7.37	7.37	7.37
PI	7.37	7.37	7.37						

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* 100-Year Storm, 5-Day Event:
* Ratio of Storm Volume from Isopluvial Maps (Sub-Basin to Summit) : .70
* Distance from Sub-Basin to Assumed Storm Center : 4.2 km
*

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PG P1

PI	5.40	5.40	5.40	5.40	5.40	5.40	5.40	5.40	5.40
PI	5.40	5.40	5.40	5.40	5.40	5.40	5.40	5.40	5.40
PI	5.40	5.40	5.40	5.40	5.40	5.40	5.40	5.40	5.40
PI	5.40	5.40	5.40	5.40	5.40	5.40	5.40	5.40	5.40
PI	5.40	5.40	5.40	5.40	5.40	5.40	5.40	8.34	8.34
PI	8.34	8.34	8.34	8.34	8.34	8.34	8.34	8.34	8.34

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PI    8.34   8.34   8.34   8.34   8.34   8.14   8.14   8.14  31.44
PI   31.44  31.44  52.60  52.60  52.60  78.53  59.60  53.54  31.44
PI   31.44  31.44   8.14   8.14   8.14   8.14   8.14   8.14   8.14
PI    8.14   8.14   8.34   8.34   8.34   8.34   8.34   8.34   8.34
PI    8.34   5.40   5.40   5.40   5.40   5.40   5.40   5.40   5.40
PI    5.40   5.40   5.40   5.40   5.40   5.40   5.40   5.40   5.40
PI    5.40   5.40   5.40   5.40   5.40   5.40   5.40   5.40   5.40
PI    5.40   5.40   5.40
*
***********************************************************
******************
*  100-Year Storm, 5-Day Event:
*  Ratio of Storm Volume from Isopluvial Maps (Sub-Basin to Summit) : .65
*  Distance from Sub-Basin to Assumed Storm Center : 6.70 km
*
***********************************************************
******************
PG P2
PI    4.93   4.93   4.93   4.93   4.93   4.93   4.93   4.93   4.93
PI    4.93   4.93   4.93   4.93   4.93   4.93   4.93   4.93   4.93
PI    4.93   4.93   4.93   4.93   4.93   4.93   4.93   4.93   4.93
PI    4.93   4.93   4.93   4.93   4.93   4.93   4.93   4.93   4.93
PI    4.93   4.93   4.93   4.93   4.93   4.93   4.93   7.74   7.74
PI    7.74   7.74   7.74   7.74   7.74   7.74   7.74   7.74   7.74
PI    7.74   7.74   7.74   7.74   7.74   7.50   7.50   7.50  28.95
PI   26.95  28.95  43.69  43.69  43.39  74.17  53.38  46.75  28.95
PI   23.95  28.95   7.50   7.50   7.50   7.50   7.50   7.50   7.50
PI    7.50   7.50   7.74   7.74   7.74   7.74   7.74   7.74   7.74
PI    7.74   4.93   4.93   4.93   4.93   4.93   4.93   4.93   4.93
PI    4.93   4.93   4.93   4.93   4.93   4.93   4.93   4.93   4.93
PI    4.93   4.93   4.93   4.93   4.93   4.93   4.93   4.93   4.93
PI    4.93   4.93   4.93
*
***********************************************************
******************
*  100-Year Storm, 5-Day Event:
*  Ratio of Storm Volume from Isopluvial Maps (Sub-Basin to Summit) : .55
*  Distance from Sub-Basin to Assumed Storm Center : 8.7 km
*
***********************************************************
```

```
******************
PG P3
PI   4.11   4.11   4.11   4.11   4.11   4.11   4.11   4.11   4.11
PI   4.11   4.11   4.11   4.11   4.11   4.11   4.11   4.11   4.11
PI   4.11   4.11   4.11   4.11   4.11   4.11   4.11   4.11   4.11
PI   4.11   4.11   4.11   4.11   4.11   4.11   4.11   4.11   4.11
PI   4.11   4.11   4.11   4.11   4.11   4.11   4.11   6.50   6.50
PI   6.50   6.50   6.50   6.50   6.50   6.50   6.50   6.50   6.50
PI   6.50   6.50   6.50   6.50   6.50   6.35   6.35   6.35  24.52
PI  24.52  24.52  35.41  35.41  35.41  65.10  43.91  37.44  24.52
PI  24.52  24.52   6.35   6.35   6.35   6.35   6.35   6.35   6.35
PI   6.35   6.35   6.50   6.50   6.50   6.50   6.50   6.50   6.50
PI   6.50   4.11   4.11   4.11   4.11   4.11   4.11   4.11   4.11
PI   4.11   4.11   4.11   4.11   4.11   4.11   4.11   4.11   4.11
PI   4.11   4.11   4.11   4.11   4.11   4.11   4.11   4.11   4.11
PI   4.11   4.11   4.11
*
*****************************************************************
******************
*  100-Year Storm, 5-Day Event:
*  Ratio of Storm Volume from Isopluvial Maps (Sub-Basin to Summit) : .50
*  Distance from Sub-Basin to Assumed Storm Center : 9.7 km
*
*****************************************************************
******************
PG P4
PI   3.74   3.74   3.74   3.74   3.74   3.74   3.74   3.74   3.74
PI   3.74   3.74   3.74   3.74   3.74   3.74   3.74   3.74   3.74
PI   3.74   3.74   3.74   3.74   3.74   3.74   3.74   3.74   3.74
PI   3.74   3.74   3.74   3.74   3.74   3.74   3.74   3.74   3.74
PI   3.74   3.74   3.74   3.74   3.74   3.74   3.74   5.92   5.92
PI   5.92   5.92   5.92   5.92   5.92   5.92   5.92   5.92   5.92
PI   5.92   5.92   5.92   5.92   5.92   5.79   5.79   5.79  22.37
PI  22.37  22.37  31.99  31.99  31.99  57.64  39.50  33.35  22.37
PI  22.37  22.37   5.79   5.79   5.79   5.79   5.79   5.79   5.79
PI   5.79   5.79   5.92   5.92   5.92   5.92   5.92   5.92   5.92
PI   5.92   3.74   3.74   3.74   3.74   3.74   3.74   3.74   3.74
PI   3.74   3.74   3.74   3.74   3.74   3.74   3.74   3.74   3.74
PI   3.74   3.74   3.74   3.74   3.74   3.74   3.74   3.74   3.74
PI   3.74   3.74   3.74
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* 100-Year Storm, 5-Day Event:
* Ratio of Storm Volume from Isopluvial Maps (Sub-Basin to Summit) : .42
* Distance from Sub-Basin to Assumed Storm Center : 15.0 km
*

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PG P5

PI	3.12	3.12	3.12	3.12	3.12	3.12	3.12	3.12	3.12
PI	3.12	3.12	3.12	3.12	3.12	3.12	3.12	3.12	3.12
PI	3.12	3.12	3.12	3.12	3.12	3.12	3.12	3.12	3.12
PI	3.12	3.12	3.12	3.12	3.12	3.12	3.12	3.12	3.12
PI	3.12	3.12	3.12	3.12	3.12	3.12	3.12	5.01	5.01
PI	5.01	5.01	5.01	5.01	5.01	5.01	5.01	5.01	5.01
PI	5.01	5.01	5.01	5.01	5.01	5.01	5.01	5.01	19.34
PI	19.34	19.34	24.37	24.37	24.37	44.86	30.77	25.88	19.34
PI	19.34	19.34	5.01	5.01	5.01	5.01	5.01	5.01	5.01
PI	5.01	5.01	5.01	5.01	5.01	5.01	5.01	5.01	5.01
PI	5.01	3.12	3.12	3.12	3.12	3.12	3.12	3.12	3.12
PI	3.12	3.12	3.12	3.12	3.12	3.12	3.12	3.12	3.12
PI	3.12	3.12	3.12	3.12	3.12	3.12	3.12	3.12	3.12
PI	3.12	3.12	3.12						

*

****

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* 100-Year Storm, 5-Day Event:
* Ratio of Storm Volume from Isopluvial Maps (Sub-Basin to Summit) : .40
* Distance from Sub-Basin to Assumed Storm Center : 20.8 km
*

****

****

PG P6

PI	2.97	2.97	2.97	2.97	2.97	2.97	2.97	2.97	2.97
PI	2.97	2.97	2.97	2.97	2.97	2.97	2.97	2.97	2.97
PI	2.97	2.97	2.97	2.97	2.97	2.97	2.97	2.97	2.97
PI	2.97	2.97	2.97	2.97	2.97	2.97	2.97	2.97	2.97
PI	2.97	2.97	2.97	2.97	2.97	2.97	2.97	4.79	4.79
PI	4.79	4.79	4.79	4.79	4.79	4.79	4.79	4.79	4.79

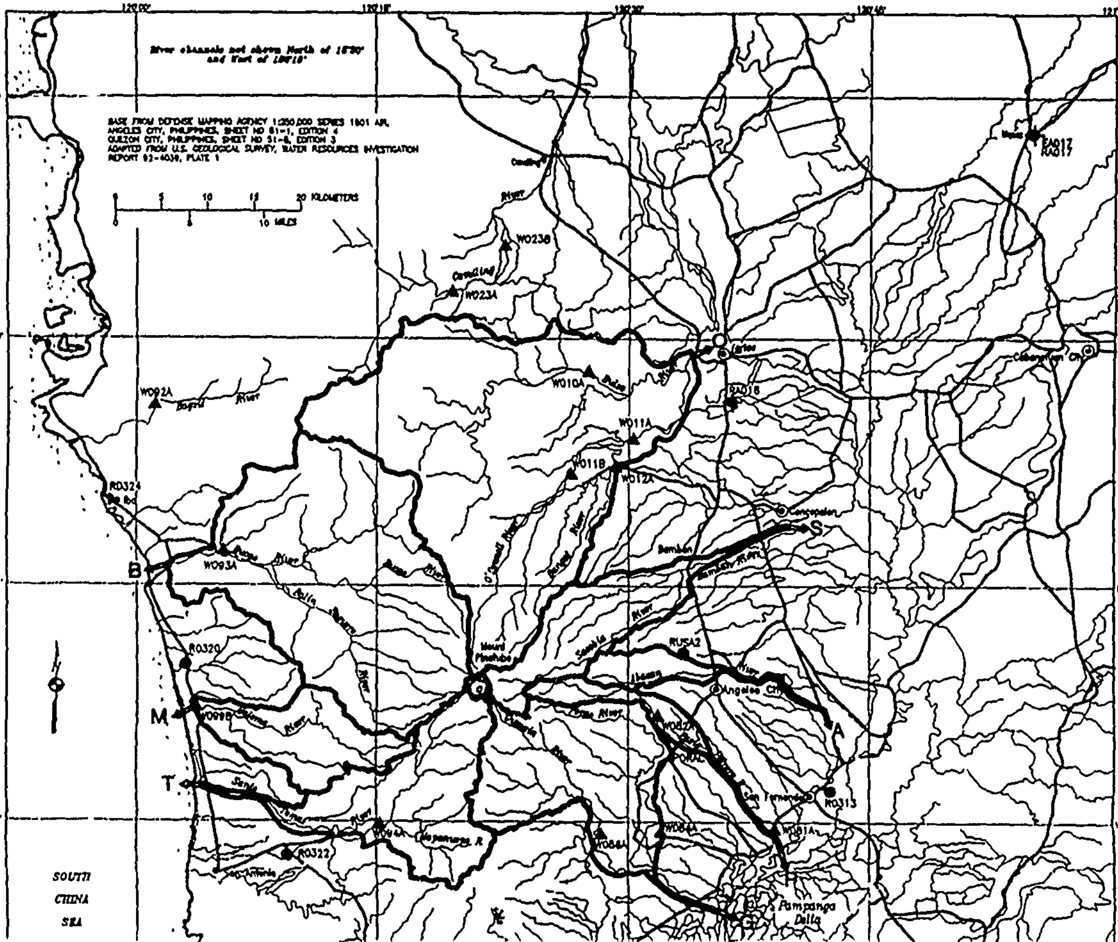
```
PI    4.79   4.79   4.79   4.79   4.79   4.81   4.81   4.81  18.57
PI   18.57  18.57  21.85  21.85  21.85  41.92  28.17  24.11  18.57
PI   18.57  18.57   4.81   4.81   4.81   4.81   4.81   4.81   4.81
PI    4.81   4.81   4.79   4.79   4.79   4.79   4.79   4.79   4.79
PI    4.79   2.97   2.97   2.97   2.97   2.97   2.97   2.97   2.97
PI    2.97   2.97   2.97   2.97   2.97   2.97   2.97   2.97   2.97
PI    2.97   2.97   2.97   2.97   2.97   2.97   2.97   2.97   2.97
PI    2.97   2.97   2.97
*     *********
*
**********************************************************************
*******************
*  100-Year Storm, 5-Day Event:
*  Ratio of Storm Volume from Isopluvial Maps (Sub-Basin to Summit) : .39
*  Distance from Sub-Basin to Assumed Storm Center - 28 km
*
**********************************************************************
*******************
PG P7
PI    2.88   2.88   2.88   2.88   2.88   2.88   2.88   2.88   2.88
PI    2.88   2.88   2.88   2.88   2.88   2.88   2.88   2.88   2.88
PI    2.88   2.88   2.88   2.88   2.88   2.88   2.88   2.88   2.88
PI    2.88   2.88   2.88   2.88   2.88   2.88   2.88   2.88   2.88
PI    2.88   2.88   2.88   2.88   2.88   2.88   2.88   4.67   4.67
PI    4.67   4.67   4.67   4.67   4.67   4.67   4.67   4.67   4.67
PI    4.67   4.67   4.67   4.67   4.67   4.71   4.71   4.71  18.18
PI   18.18  18.18  22.95  22.95  22.95  40.55  27.96  23.21  18.18
PI   18.18  18.18   4.71   4.71   4.71   4.71   4.71   4.71   4.71
PI    4.71   4.71   4.67   4.67   4.67   4.67   4.67   4.67   4.67
PI    4.67   2.88   2.88   2.88   2.88   2.88   2.88   2.88   2.88
PI    2.88   2.88   2.88   2.88   2.88   2.88   2.88   2.88   2.88
PI    2.88   2.88   2.88   2.88   2.88   2.88   2.88   2.88   2.88
PI    2.88   2.88   2.88
*  *********
*  KM For the following hydrographs: Stations that begin with a "P"
*  KM (e.g., P1DS, P5US. etc.) are the total hydrograph at the
*  KM indicated location but may (on the upper sub-basins) also be
*  KM a sub-basin runoff hydrograph.  Stations that begin with an "RF"
*  KM are sub-basin runoff hydrographs for the indicated area and do not
*  KM represent a hydrograph at any location.  Stations that begin with
```

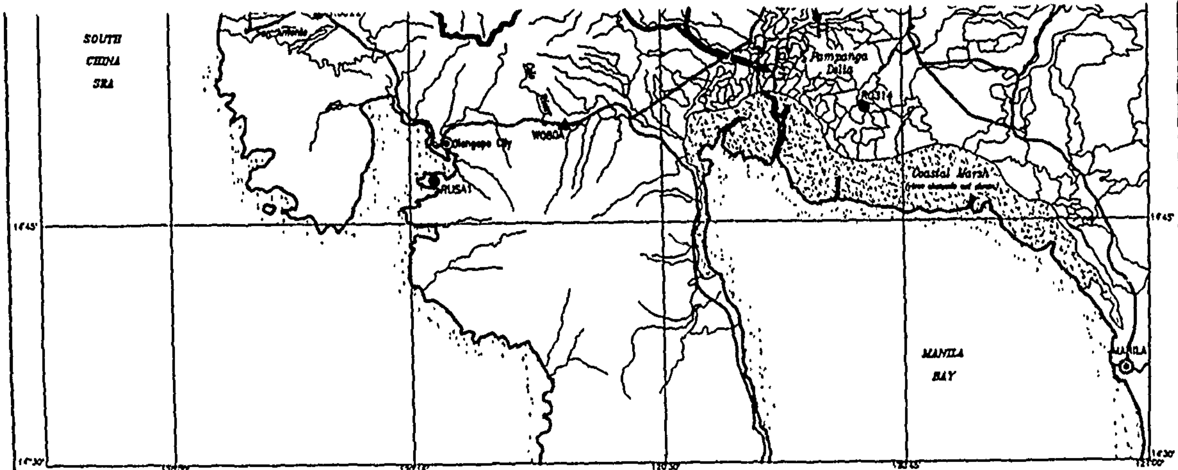
```
* KM an "RT" are the resulting hydrograph after being routed from the
* KM indicated location to the next downstream location and do not
* KM represent a hydrograph at any location.
* KM
* KM Two storms were applied over P3 (Timbu). One to obtain the
* KM hydrograph at P3DS, the other for use in obtaining hydrographs
* KM at other locations since a storm centered over P0 gives greater
* KM flow at these other locations than a storm centered over P3
*       **********
KK P3DS
KM Hydrograph for P3DS
BA 6.0
BF 0.3
PR PT
LU 0,3
ZW A=PINATUBO_DESIGN B=PASIG P3DS C=FLOW F=100-YR COMPUTED
UC 1.0,25.5
*       ************
KK P0DS
KM Hydrograph calculation for P0DS.
BA 21.3
BF 3.0
PR P0
LU 0,3
ZW A=PINATUBO_DESIGN B=PASIG P0DS C=FLOW F=100-YR COMPUTED
UC 0.7,17.5
*       *************
KK RTP0DS
KM Muskingum routing of P0DS to P1DS.
RM 1,.7,.2
*       ********
KK RFP1
KM Sub-basin runoff calculation for P1DS.
BA 9.3
BF 0.7
PR P1
LU 0,3
UC .8,20.8
*       **********
KK P1DS
```

```
KM Hydrograph calculation for P1DS.
ZW A=PINATUBO_DESIGN B=PASIG P1DS C=FLOW F=100-YR COMPUTED
HC 2
*      **********
KK P2DS
KM Hydrograph calculation for P2DS.
BA 4.4
BF 0.3
PR P2
LU 0,3
ZW A=PINATUBO_DESIGN B=PASIG P2DS C=FLOW F=100-YR COMPUTED
UC .4,11.0
*      *********
KK P4US
KM Hydrograph calculation for P4US.
ZW A=PINATUBO_DESIGN B=PASIG P4US C=FLOW F=100-YR COMPUTED
HC 2
*      *********
KK RTP4US
KM Muskingum routing from P4US to P4DS
RM 1,.4,.2
*      *********
KK RFP4
KM Sub-basin runoff calculation for P4.
BA 3.1
BF 0.1
PR P4
LU 0,3
UC .9,23.5
*      *********
KK P4DS
KM Hydrograph calculation for P4DS.
ZW A=PINATUBO_DESIGN B=PASIG P4DS C=FLOW F=100-YR COMPUTED
HC 2
*      **********
KK P3DS
KM Hyd. calc. for P3DS for use at pts. other than P3DS
BA 6.0
BF 0.3
PR P3
```

```
LU 0,3
UC 1.0,25.5
*      **********
KK P5US
KM Hydrograph calculation for P5US.
ZW A=PINATUBO_DESIGN B=PASIG P5US C=FLOW F=100-YR COMPUTED
HC 2
*      **********
KK RTP5US
KM Muskingum routing from P5US to P5DS
RM 1,1.1,.2
*      **********
KK RFP5
KM Sub-basin runoff calculation for P5.
BA 12.6
BF 0.0
PR P5
LU 0,3
UC 1.9,48.3
*      **********
KK P5DS
KM Hydrograph calculation for P5DS.
ZW A=PINATUBO_DESIGN B=PASIG P5DS C=FLOW F=100-YR COMPUTED
HC 2
*      **********
KK RTP5DS
KM Muskingum routing from P5DS to P6DS.
RM 1,.5,.2
*      **********
KK RFP6
KM Sub-basin runoff calculation for P6.
BA 17.7
BF 0.0
PR P6
LU 0,3
UC 2.2,55.
*      **********
KK P6DS
KM Hydrograph calculation for P6DS
HC 2
```

```
*       **********
KK RTP6DS
KM Muskingum routing from P6DS to P7DS.
RM 2,1.56,.2
*       *********
KK RFP7
KM Sub-basin runoff calculation for P7.
BA 2.4
BF 0.0
PR P7
LU 0,1000
UC 4.82,121
*       ********
KK P7DS
KM Hydrograph calculation for P7DS
ZW A=PINATUBO_DESIGN B=PASIG P7DS C=FLOW F=100-YR COMPUTED
HC 2
*       ********
ZZ
```


River channels not shown North of 15°30' and West of 120°15'
BASE FROM DEFENSE MAPPING AGENCY 1:250,000 SERIES 1501 AIR,
ANGELES CITY, PHILIPPINES, SHEET NO 51-1, EDITION 4
QUEZON CITY, PHILIPPINES, SHEET NO 51-6, EDITION 3
ADAPTED FROM U.S. GEOLOGICAL SURVEY, WATER RESOURCES INVESTIGATION
REPORT 92-4039, PLATE 1
0 5 10 15 20 KILOMETERS
0 5 10 MILES
120°00'
120°15'
120°30'
120°45'
121°00'
15°45'
15°30'
15°15'
15°00'
RA017
Capas
Concepcion
Tarlac
RA018
W023B
W023A
W092A
W010A
W011A
W011B
W012A
W093A
RO324
RO320
RO322
RO313
RU5A2
W084A
W081A
W082A
W098B
W094A
B
M
T
S
A
Mount Pinatubo
Angeles City
San Fernando
Bamban
Sacobia River
Abacan
Porac River
Pasig
Gumain
Pampanga Delta
SOUTH
CHINA
SEA



STATION KEY

Daily Rainfall Data

RA016 Hacienda Luisita, Tarlac
RA017 CLSU, Munoz, Nueva Ecija
RO324 Iba, Zambales
RO313 Julian Sukil, San Fernando, Pampanga
RO314 Masantol, Pampanga
RO320 Sta Rita Dam Sch. Cabangan, Zambales
RO322 Zvea, San Marcelino, Zambales
RUSA1 Cubi Point Naval Air Station
RUSA2 Clark Air Force Base

Hourly Rainfall Data

RA016 Hacienda Luisita, Tarlac
RO324 Iba, Zambales
PORAC Santa Cruz, Porac, Pampanga
(limited hourly data available)

Daily Evaporation Data

EA017 CLSU, Munoz, Nueva Ecija

Streamflow Data

WO10A Bulsa R.
WO11A O'Donnell R., Palukkab
WO11B O'Donnell R., Patling
WO12A Bangat R.
WO23A Camiling R., Nambalan
WO23B Camiling R., Poblacion
WO81A Pasig-Potrero R., Cabalsaan
WO82A Pasig-Potrero R., Nia Dolores
WO84A Porac R., Del Carmen
WO86A Gumain R.
WO88A Cale R.
WO92A Bagali R.
WO93A Bueno R.
WO94A Sta. Tomas R.
WO99B Malarno R.

DRAINAGE BASIN KEY

(listed clockwise from north)

O O'Donnell
S Sacobia - Bamban
A Abacan
P Pasig - Potrero
G Gumain / Porac
T Santo Tomas
M Malarno
B Bucao

SYMBOL KEY

- ▲ Streamflow data
- ● Daily rainfall data
- ◐ Daily and hourly rainfall data
- ○ Hourly rainfall only
- ✦ Daily rainfall and evaporation data
- ⇨ Basin outlet

northwest hydraulic consultants Kent, Washington	Portland District U.S. Army Corps of Engineers Portland, Oregon

Locations of Drainage Basins and Hydrometeorological Data Stations

SUBMITTED	DESIGNED	DRAWN	CHECKED
CADD FILE 20682.3 1.1	DATE June 1993		PLATE 1

TECHNICAL APPENDIX A

EXHIBIT A
DATA PRIOR TO THE OCTOBER 1993 CHANGE IN PASIG/SACOBIA BASIN CONFIGURATION

A headwater basin of the Sacobia-Bamban River (formerly identified as sub-basin S1) was captured by the Pasig-Potrero River in October of 1993 and is now assigned a sub-basin identifier of P0. In the Sacobia-Bamban Basin, this change in basin configuration reduces the runoff through sub-basins S2, S3, and S4 thereby reducing the runoff at simulation output sites S2DS, S3DS, S3DS+S4DS, S7US, and S7DS. In the Pasig-Potrero Basin, this change in basin configuration increases the runoff through sub-basins P1, P4, P5, P6, and P7 thereby increasing the runoff at simulation output sites P1DS, P4US, P4DS, P5US, P5DS, and P7DS. Runoff was not affected through sub-basins or at simulation output sites not listed above.

Figures A-1 through A-4 are flood hydrographs at two simulation output sites on the Sacobia-Bamban River and two simulation output sites on the Pasig-Potrero River that were affected by the change in basin configuration. These hydrographs were computed for conditions that existed prior to the October 1993 capture of a Sacobia-Bamban headwater basin by the Pasig-Potrero River. Relative changes in the hydrology of these sub-basins and other affected sub-basins can be estimated by comparing Figures A-1 through A-4 to the appropriate post-October 1993 figures described in the text of Technical Appendix A (Figures 3.5.6, 3.5.11, 3.5.43, and 3.5.45).

Table A-1 shows flow duration curves at the same simulation output sites indicated on Figures A-1 through A-4 computed for conditions that existed prior to the October 1993 capture of a Sacobia-Bamban headwater basin by the Pasig-Potrero River. Relative changes in the hydrology of these sub-basins and other affected sub-basins can be estimated by comparing the data in Table A-1 to the appropriate post-October 1993 data in tables described in the text of Technical Appendix A (Tables 3.5.5 and 3.5.21).

Prior to October 1993 Loss of Headwater Basin to Pasig - Potrero River Computed Flood Hydrographs Sacobia-Bamban Basin at Site S3DS

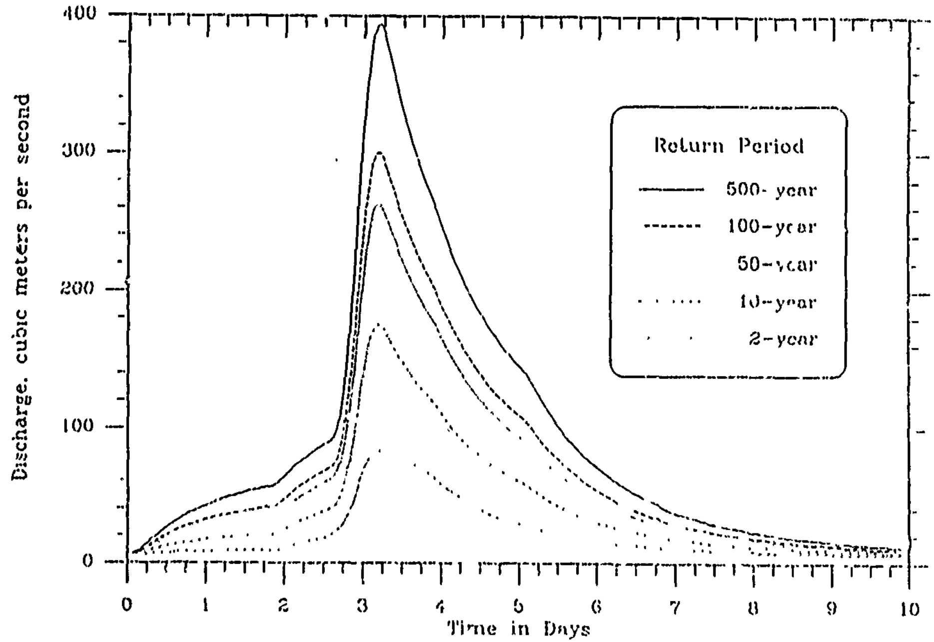


Figure A-1

Prior to October 1993 Loss of Headwater Basin to Pasig - Potrero River Computed Flood Hydrographs Sacobia-Bamban Basin at Site S7DS

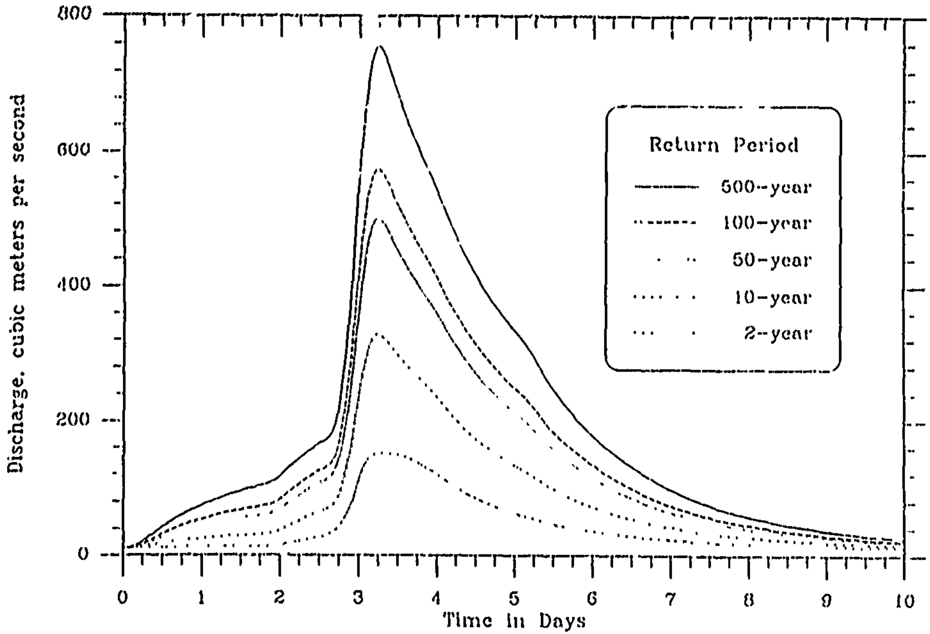


Figure A-2

Prior to October 1993 Capture of Sacobia Headwater Basin
Computed Flood Hydrographs
Pasig-Potrero Basin at Site P5US

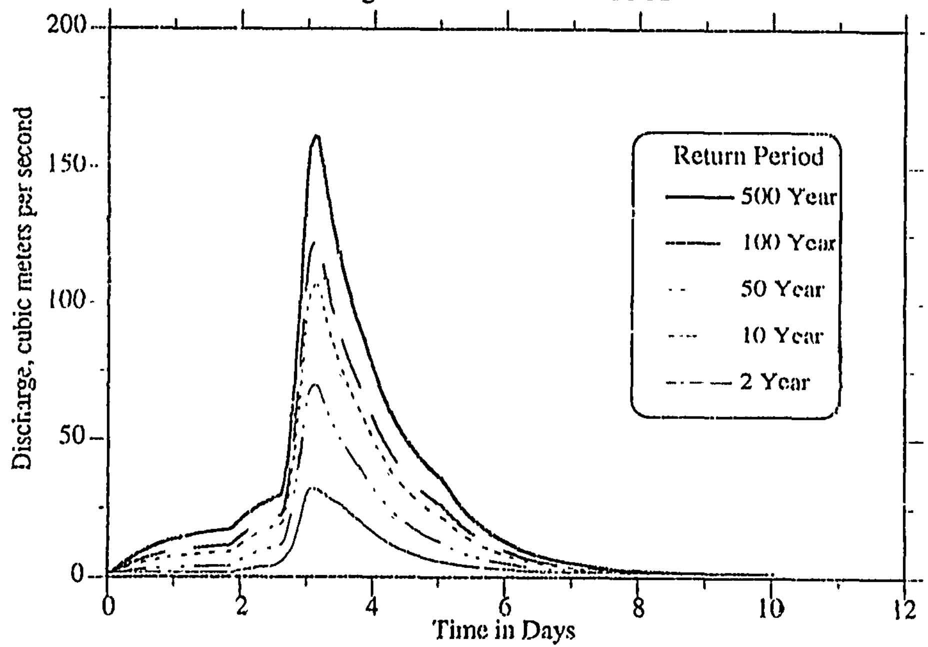


Figure A-3

Prior to October 1993 Capture of Sacobia Headwater Basin

Computed Flood Hydrographs
Pasig-Potrero Basin at Site P7DS

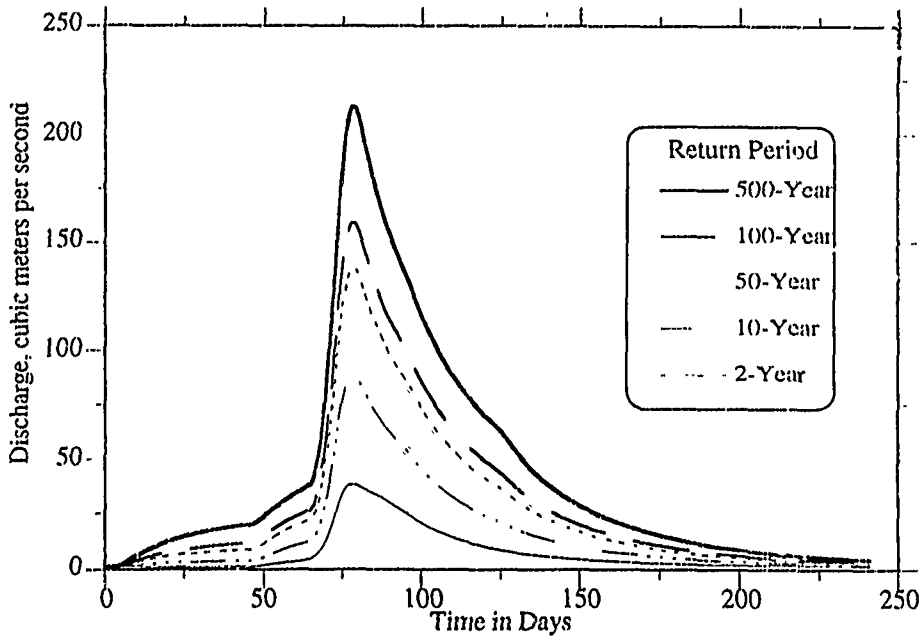


Figure A-4

Table A-1
Prior to October 1993 Change in Basin Configuration

Sample Computed Flow Duration Curves

Sacobia-Bamban and Pasig-Potrero Basins

Data in cubic meters per second

% OF TIME EXCEEDED	S3DS	S7DS	P5US	P7DS
100	0	0	0	0
50	1.5	3.4	0.5	0.7
25	*	*	1.2	1.7
20	4.8	10.7	1.6	2.2
10	7.9	17.8	2.8	3.7
5	11.8	25.9	5	5.5
2	20.1	43.4	8.8	9.3
1	29.8	63.1	12.6	13.7
0.5	42.4	88.3	17.3	19.4
0.2	68.1	142	26.5	32.1
0.1	91.7	195.4	36.5	45
0.05	115.4	249.3	46.6	58.2
0.02	140.6	305.9	57.2	71.8

* Not calculated.

TABLES FOR

TECHNICAL APPENDIX A

HYDROLOGY AND HYDRAULICS

Table 1.3.1
Conversion, SI to English Units

Units of Length	mm	m	dam	km	inches (in)	feet (ft)	yard (yd)	miles (mi)
1 millimeter (mm) =	1	0.001	0.0001	(10)^-6	0.0394	0.0033	-	-
1 meter (m) =	1,000	1	0.1	0.001	39.37	3.281	1.094	-
1 decameter (dam) =	10,000	10	1	0.01	393.7	32.81	10.94	-
1 kilometer (km) =	(10)^6	1,000	100	1	39,370	3,281	1,094	0.6214
Units of Area	**m^2**	**km^2**	**in^2**	**ft^2**	**acres**	**mi^2**		
1 square meter (m^2) =	1	(10)^-6	1550	10.76	-	-		
1 square kilometer (km^2) =	(10)^6	1	-	-	247	0.3861		
Units of Volume	**m^3**	**dam^3**	**ft^3**	**yd^3**	**acre-ft**			
1 cubic meter (m^3) =	1	0.001	35.32	1.307	-			
1 cubic decameter (dam^3) =	1,000	1	35,320	1,307	0.8108			

Note: Dash mark (-) indicates very small or very large conversion that is not commonly used.

TABLE 2.3.1
Daily Rainfall and Evaporation Data

Station ID	Station Name	Station Location		Available Record		Agency	Parameters Available[1]
		Latitude	Longitude	Start Date	End Date		
D324	Iba, Zambales	15°20' N	119°58' E	1951-01-01	1992-10-31	Pagasa	R
A016	Hacienda Luisita, Tarlac	15°26' N	120°36' E	1968-01-01	1992-09-30	Pagasa	R,E
A017	CLSU, Munoz, Neuva Ecija	15°43' N	120°54' E	1974-01-01	1992-09-30	Pagasa	R,E
A020	Magalang, Pampanga	15°13' N	120°39' E	1988-01-01	1991-09-30	Pagasa	R,E
R0312	Bai Magalang, Pampanga	15°13' N	120°42' E	1977-01-01	1992-09-30	Pagasa	R
R0313	Julian Subd, San Fernando, Pampanga	15°02' N	120°42' E	1970-01-01	1991-12-31	Pagasa	R
R0314	Masantol, Pampanga	14°52' N	120°42' E	1970-01-01	1992-09-30	Pagasa	R
R0315	Camiling, Tarlac	15°42' N	120°24' E	1976-01-01	1990-05-01	Pagasa	R
R0316	Mayantoc, Tarlac	15°36' N	120°21' E	1972-01-01	1990-11-30	Pagasa	R
R0318	Palawig, Zambales	15°26' N	119°54' E	1975-01-01	1991-09-30	Pagasa	R
R0319	San Felipe, Zambales	15°04' N	120°04' E	1975-10-01	1990-06-30	Pagasa	R
R0320	Sta Rita Elem Sch, Cabangan, Zamb-ales	15°10' N	120°03' E	1975-10-01	1992-11-30	Pagasa	R
R0322	Znas, San Marcelino, Zambales	14°58' N	120°09' E	1975-10-01	1992-11-30	Pagasa	R
USA01[2]	Cubi Point Naval Air Station	14°48' N	120°17' E	1958-04-01	1990-12-31	U.S.N.	R
USA02[2]	Clark Air Force Base	15°11' N	120°35' E	1950-01-01	1991-09-30	U.S.A.F.	R

[1] R — daily rainfall; E — daily pan evaporation

[2] For purposes of this study, USA01 and USA02 are station identifiers given to the daily raingauges operated by the U.S. Navy and U.S. Air Force.

TABLE 2.3.2
PHIVOLCS Rainfall Stations

STATION I.D.	STATION NAME	LOCATION FROM MT. PINATUBO	ELEVATION (m)	DATE INSTALLED
RG-1 (201)	Mt. Cuadrado	South	1070	July 1991
RG-2 (202)	BUGZ	Southwest	600	July 1991
RG-3 (203)	PI2	Northeast	640	July 1991
RG-4 (204)	Mt. Culianan	Northwest	550	Aug. 1991
RG-5 (205)	Gumain	Southeast	820	Aug. 1991
RG-6 (206)	Sacobia	East/Northeast	510	Sept. 1991

TABLE 2.3.3
Hourly Rainfall Data

Station ID	Station Name	Station Location		Periods of Data Obtained
		Latitude	Longitude	
D324	Iba, Zambales	15°20' N	119°58' E	1972-07-14 to 1972-08-10 1976-05-17 to 1976-05-31 1980-07-08 to 1980-07-11
A016	Hacienda Luisita, Tarlac	15°26' N	120°36' E	1970-08-28 to 1970-09-06 1972-07-14 to 1972-08-10 1974-08-12 to 1974-08-19
PORAC[1]	Santa Cruz, Porac Pampanga	15°05' N	120°33' E	1970-08-28 to 1970-09-03 1972-07-14 to 1970-08-05 1974-08-12 to 1974-08-19 1976-05-19 to 1976-05-29 1977-11-11 to 1977-11-16

[1] Official Station ID unknown.

TABLE 2.3.4

Cross Correlations of Daily Rainfall Data

	Station ID														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	1.00	0.08	0.08	-0.17	0.10	0.18	0.12	0.06	0.07	0.29	-0.07	0.53	0.31	0.25	0.13
2	0.08	1.00	0.06	-0.20	-0.16	0.37	0.14	0.23	0.08	-0.15	-0.40	0.16	0.04	0.02	0.32
3	0.08	0.06	1.00	-0.30	-0.06	-0.14	-0.15	-0.07	-0.20	-0.24	-0.46	0.05	-0.06	-0.08	-0.13
4	-0.17	-0.20	-0.30	1.00	-0.02	-0.20	0.02	-0.09	-0.27	-0.54	-0.42	-0.16	-0.34	-0.22	-0.17
5	0.10	-0.16	-0.06	-0.02	1.00	-0.22	-0.12	-0.11	-0.24	-0.13	-0.24	0.11	0.06	0.08	-0.16
6	0.18	0.37	-0.14	-0.20	-0.22	1.00	0.38	0.04	0.11	-0.21	-0.30	0.14	0.11	0.20	0.40
7	0.12	0.14	-0.15	0.02	-0.12	0.38	1.00	0.01	-0.04	-0.24	-0.22	0.18	0.11	0.27	0.26
8	0.06	0.23	-0.07	-0.09	-0.11	0.04	0.01	1.00	-0.33	-0.16	-0.32	0.12	0.17	-0.03	0.21
9	0.07	0.08	-0.20	-0.27	-0.24	0.11	-0.04	-0.33	1.00	-0.18	-0.38	0.02	-0.11	0.04	0.07
10	0.29	-0.15	-0.24	-0.54	-0.13	-0.21	-0.24	-0.16	-0.18	1.00	-0.37	0.32	0.21	0.11	-0.06
11	-0.07	-0.40	-0.46	-0.42	-0.24	-0.30	-0.22	-0.32	-0.38	-0.37	1.00	-0.01	-0.06	-0.05	-0.28
12	0.53	0.16	0.05	-0.16	0.11	0.14	0.18	0.12	0.02	0.32	-0.01	1.00	0.42	0.37	0.19
13	0.31	0.04	-0.06	-0.34	0.06	0.11	0.11	0.17	-0.11	0.21	-0.06	0.42	1.00	0.38	0.20
14	0.25	0.02	-0.08	-0.22	0.08	0.20	0.27	-0.03	0.04	0.11	-0.05	0.37	0.38	1.00	0.28
15	0.13	0.32	-0.13	-0.17	-0.16	0.40	0.26	0.21	0.07	-0.06	-0.28	0.19	0.20	0.28	1.00

Station Key

ID	File Name	Station Name
1	D3245192.WAT	Iba, Zambales
2	A0166892.WAT	Hacienda Luisita, Tarlac
3	A0177492.WAT	CLSU, Munoz, Nueva Ecija
4	A0208892.WAT	Magalang, Pampanga
5	R3127792.WAT	Bai Magalang, Pampanga
6	R3137091.WAT	Julian Subd, San Fernando, Pampanga
7	R3147092.WAT	Masantol, Pampanga
8	R3157690.WAT	Camiling, Tarlac
9	R3167290.WAT	Mayantoc, Tarlac
10	R3187591.WAT	Palawig, Zambales
11	R3197590.WAT	San Felipe, Zambales
12	R3207592.WAT	Sta Rita Elem Sch, Cabangan, Zambales
13	R3227592.WAT	Znas, San Marcelino, Zambales
14	USNRPMB.WAT	Cubi Point Naval Air Station
15	CLARK.WAT	Clark Air Force Base

TABLE 2.3.5
Estimated Annual Pan Evaporation (mm)
CLSU, Munoz

Year	Pan Evaporation (mm)
1974	1855
1975	2084
1976	1972
1977	2109
1978	1731
1979	1842
1980	1968
1981	1796
1982	1921
1983	2153
1984	1895
1985	2010
1986	1852
1987	2006
1988	2008
1989	1943
1990	1914
1991	2049
1992	1919

Table 2.3.6
Annual Rainfall, mm

RAIN GAGE	Iba RD324	Luisita RA016	CLSU RA017	Julian R0313	Masantol R0314	Sta Rita R0320	Znas R0322	Cubi RUSA1	Clark RUSA2
YEAR									
1950									2207
1951	3039								1782
1952	4073								1756
1953	2916								2167
1954	2716								1315
1955	1927								1439
1956	3531								1761
1957									1441
1958									1732
1959								2500	1097
1960	5088							3829	2331
1961	5481							3794	2079
1962								3535	1970
1963	3784							3477	2205
1964	8594							3075	1966
1965	3739							3539	2054
1966	3747							3302	2773
1967	5072							4396	2001
1968	1972	1754						2146	1694
1969	3585	1465						2688	1727
1970	4272				1796				2346
1971	2745	1887		1669	1625			2964	2191
1972	4659	3526		3678	3128			4308	4120
1973	3324	1300		1459	1368			2572	1604
1974	4124	2384	2526	26.9	2172			4138	2619
1975	2528		2045	1438	1638			2868	1516
1976	4374	2475	2650	2654	2232	4888	4154	4226	2705
1977	3901	1713	1505	1410	1472	4112	4250	3768	1765
1978	5227	2011	1998	2119	2212		5099	5402	2347
1979	3551	1518	1522	1483	1558	4131	3293	4058	1817
1980	3960	1742	1675	1885	2072	3946	2564	2585	1742
1981		1692	1788	1393	1580			3233	1775
1982		1562	1789				3446	3857	1389
1983	2120	1305	1347	985	1685	2467	2260	2566	1034
1984	4137	2107		2126	2428	4277	3025	4758	1920
1985	4119		2211	2264		5154	3561	4944	2391
1986	4024	1983	2292	2312		4930	3983	4612	2313
1987	2562	1171	1337	875	1864	2849		2590	1446
1988	3874		2042	1060	2222	4025	2984	3303	1807
1989		1524	2056	1381	1989	4133	3424	3556	1971
1990	3509		2294	1884	2575	4833	3688	4245	2298
1991	4021		1760	1334	2038	4355	3928		
# OBS	34	18	17	20	19	13	14	31	41
MEAN	3832	1840	1932	1802	1982	4162	3547	3575	1966
STD	1211	536	378	663	426	748	703	801	526

TABLE 2.3.7
Annual Runoff from Basin, mm

RIVER DA (km²)	BULSA 405	O'DONNEL 240	O'DONNEL 112	BANGAT 90	CAMILING 142	CAMILING 280	PASIG-P 242	PASIG-P 28	PORAC 118	PORAC 111	GUMAIN FW 370	GUMAIN 128	CAULAMAN 72	COLO 76	BAGSIT 68	BUCAO 615	STO TOMAS 177	MALOMA 151
YEAR																		
1955																		
1956																		
1957						1294				475		2052	3109	1688		3080	1331	
1958						1520				407		2591	2997	2387		3762	3647	
1959			1012			576			205	646	476	912	820	691		1681	1331	
1960			2767						1262	1773	3968	3362		2225		3340	4242	
1961	1918		1906						1138	935	1313	2796		1782		3321	3069	
1962	1896		781			1981				1586	2485	2241	2781		2956	3267	3870	
1963						2217			1891	1084	3192	2131	3627			3605	3628	
1964	2284		1197		3928	1387			1104	1401	2242	2451	2161	1493	4876	1764	1802	
1965	1521		1150		3467	1050			635	1317	678	2163	1956	1937		1583	1269	
1966	2866		1460		3687					2660	3384	3643	2433	2820	2018	3233	2212	
1967	2538			1957	4710			1423		2046	3186	3065		2920	3755	4003	677	
1968	2767	1146		1509	3867		179	1092	380	1434	3640	2065		2307	3050	2670		
1969	1675	1017		1714	3324		130	232	203	2271	1925	1399			3566	1532	201	
1970	2625	882		3008	3988			359	341	1730	3132	2314	1624	3237	3849	2386	258	
1971	1694		1824	2721	3199			885	296	874	3379	2698	645	3910		2349		
1972	5140				2870						2146							
1973											4605							
1974											528							
1975																		
1976																		
1977																		
1978											461							
1979																		
1980																		
1981																		
1982																		
1983																		
1984			2722															5205
1985																		
1986											3939							
1987																		
1988																		
1989											2657							
1990											1047							3823
1991																		
# OBS.	11	3	9	5	9	7	2	5	10	15	20	15	10	12	7	15	13	2
MEAN	2448	1015	1647	2182	3671	1432	154	798	746	1443	2419	2392	2215	2283	3439	2772	2118	4514
STD	963	108	679	582	507	511	25	447	544	688	1270	674	928	824	824	811	1369	691

TABLE 2.4.1
Streamflow Data

STATION ID[3]	STATION NAME	DRAINAGE AREA (km²)	DATE RECORDS REPORTED TO START	AVAILABLE RECORDS	
				DAILY DATA	MAXIMUM ANNUAL FLOW DATA
10A	Bulsa	405	Aug 60	Aug 60 - Dec 72	1960 - 1972
11A	O'Donnell, Palublub	240	Jan 65	Jan 65 - Dec 72[1]	1964 - 1972[2]
11B	O'Donnell, Capas	112	Nov 58	Nov 58 - Dec 67	1962 - 1967
12A	Bangat	90	Nov 66	Nov 66 - Dec 72	1967 - 1972
23A	Camiling, Nambalan	142	Mar 64	Mar 64 - Dec 72	1964 - 1972[2]
23B	Camiling, Poblacion	280	Dec 54	Jan 57 - Nov 66	1957 - 1966
81A	Pasig-Potrero, Cabetican	242	Apr 65	Apr 65 - Dec 69	1965 - 1969
82A	Pasig-Potrero, Hda Dolores	28	Sep 66	Sep 66 - Jul 72	1966 - 1972
83A	Porac, Valdez	118	Oct 58	Oct 58 - Dec 71	1959 - 1975[2]
84A	Porac, Del Carmen	111	Oct 45	Jan 57 - May 72	1946 - 1971[2]
85A	Gumain Floodway	370	Sep 58	Sep 58 - Dec 72[1]	1959 - 1990[2]
86A	Gumain, Pabanlag	128	Oct 45	Jan 57 - Dec 71	1946 - 1979[2]
87A	Caulaman	72	Aug 54	Jan 57 - Dec 72	1955 - 1973[2]
88A	Colo	76	Mar 55	Jan 57 - Dec 71	1955 - 1979[2]
92A	Bagsit	68	Jul 60	Jul 60 - Jun 72	1960 - 1972
93A	Bucao	315	Oct 55	Jan 57 - Dec 70	1956 - 1971
94A	Santo Tomas	177	Apr 47	Jan 57 - Dec 72[1]	1947 - 1971
99B	Maloma	151	not known	Jan 84 - Apr 91	1984 - 1990

[1] Limited data exists after 1972
[2] Some years missing within period of record.
[3] Station ID's '*nn*B' are unofficial ID's

TABLE 2.4.2

Peak Discharges in m³/s, Including Records of Doubtful Quality

RIVER DA (km²)	DULSA 405	O'DONNEL 240	O'DONNEL 112	BANGAT 90	CAMILING 142	CAMILING 280	PASIG-P 242	PASIG-P 28	PORAC 118	PORAC 111	GUMAIN FN 370	GUMAIN 128	CAULAMAN 72	COLO 76	BAGSIT 68	BUCAO 615	STO TOMAS 177	MALOMA 151
YEAR																		
1946										509		187						
1947										199		116					287	
1948										484		198					432	
1949										232		127					279	
1950										400		155					373	
1951										232		75					242	
1952										283		139					312	
1953										481		108					279	
1954										202		94					250	
1955										268		218	669	140		43	327	
1956												218	97	95		1092	172	
1957						376				5		247	571	102		766	274	
1958						316				7		192	339	119		1088	315	
1959									24	21	366	151	629	73		701	328	
1960	752		210						168	129	491	255	[illegible]	112	94	2525	662	
1961	1958								155	68	455	206	[illegible]	112	55	1140	576	
1962	2259		45						30	400	860	310	850	145	106	2220	855	
1963	1757		18			928			333	55	759	310	669	94	225	1380	346	
1964	1087	24	29		644	1280			330	124	762	375	709	118	107	1079	288	
1965	704	18	18		353	213	48		255	134	612	165	755	76	84	607	289	
1966	1087	36	73	65	443	610	73	4.3	321	227	742	283	960	102	111	494	270	
1967	692	103	18	353	1262		71	7.2	153	225	814	253	181	68	60	529	225	
1968	1958	115		423	474		61	8.9	38	36	399	327	40	102	94	744	10	
1969	1221	64		365	675		49	6.0	45	72	879	48	158	111	86	705	5	
1970	2082	176		414	646			2.2	83	146	857	268	677	108	91	885	14	
1971	452	70		339	58			8.8	56	43	720	216	103	108	42	190	5	
1972	1542	205		540	166			8.9		12	641	222	189		154		5	
1973	219	34			40				22		641	194	6	57		90		
1974									132		255	292		88				
1975					2				470		30	68		59		78		
1976					17							740		81		94		
1977											162		3	103		95		
1978					17						300	268	2	81		46		
1979					12						162	64	3	66		212		
1980																		
1981																		
1982																		
1983		421															65	
1984		97																145
1985		3									318							46
1986											8014							1375
1987											344							373
1988											237							188
1989											237							149
1990											286							615
1991											144							5
# OBS.	14	13	7	7	14	6	5	7	16	26	27	33	22	24	13	23	27	8
MEAN	1269	105	59	357	345	620	60	6.6	163	192	751	211	370	97	107	710	277	362
STD. DEV.	636	100	64	134	361	376	11	2.4	135	154	1448	122	313	24	50	649	196	424

TABLE 2.4.3

Normalized Peak Flows in m³/s / km², Including Records of Doubtful Quality

RIVER	BULSA	O'DONNEL	O'DONNEL	BANGAT	CAMILING	CAMILING	PASIG-P	PASIG-P	PORAC	POHAC	GUMAIN FH	GUMAIN	CAULAMAN	CULO	DAGSIT	BUCAO	STO TOMAS	MALOMA
DA (km²)	405	240	112	90	142	280	242	28	118	111	370	128	72	76	68	615	177	151
YEAR																		
1946										4.59		1.46						
1947										1.79		0.90					1.62	
1948										4.36		1.54					2.44	
1949										2.09		0.99					1.57	
1950										3.60		1.21					2.10	
1951										2.09		0.58					1.37	
1952										2.55		1.08					1.76	
1953										4.34		1.47					1.58	
1954										1.82		0.73					1.41	
1955										2.41		1.70	9.29	1.94		0.07	1.85	
1956												1.70	1.35	1.25		1.78	0.97	
1957						1.34				0.05		1.93	7.92	1.34		1.25	1.55	
1958						1.13				0.06		1.50	4.70	1.56		1.77	1.78	
1959									0.21	0.19	0.99	1.18	8.74	0.97		1.14	1.85	
1960	1.86		1.88						1.42	1.16	1.33	1.99	3.14	1.47	1.39	4.11	3.74	
1961	4.83								1.31	0.61	1.23	1.61	3.94	1.47	0.81	1.85	3.25	
1962	5.58		0.40						0.26	3.60	2.32	2.43	11.80	1.91	2.73	3.61	4.83	
1963	4.34		0.16			3.31			2.82	0.49	2.05	2.43	9.29	1.23	3.31	2.24	1.95	
1964	2.68	0.11	0.26		4.54	4.57			2.80	1.12	2.06	2.93	9.83	1.56	1.57	1.75	1.63	
1965	1.74	0.07	0.16		2.49	0.76	0.20		2.16	1.21	1.65	1.29	10.49	1.00	1.23	0.99	1.63	
1966	2.68	0.15	0.65	0.73	3.12	2.18	0.30	0.15	2.72	2.05	2.00	2.21	13.33	1.34	1.64	0.80	1.53	
1967	1.71	0.43	0.16	3.92	8.89		0.29	0.26	1.29	2.02	2.20	1.98	2.52	0.90	0.88	0.86	1.27	
1968	4.83	0.48		4.70	3.34		0.25	0.32	0.32	0.32	1.08	0.99	0.55	1.34	1.39	1.21	0.06	
1969	3.01	0.27		4.05	4.75		0.20	0.21	0.38	0.65	2.37	0.37	2.19	1.47	1.26	1.15	0.03	
1970	5.14	0.74		4.60	4.69			0.08	0.70	1.37	2.32	2.09	9.40	1.42	1.34	1.44	0.08	
1971	1.32	0.29		3.77	0.41			0.31	0.47	0.39	1.94	1.68	1.43	1.42	0.62	0.31	0.03	
1972	3.81	0.86		5.99	1.17			0.32		0.11	1.73	1.73	2.63		2.27		0.03	
1973	0.54	0.14			0.28				0.18		1.73	1.52	0.08	0.75		0.15		
1974									1.12		0.69	2.28		1.16				
1975					0.02				3.98		0.08	0.53		0.77		0.13		
1976					0.12							5.78		1.06		0.15		
1977											0.44		0.04	1.36		0.15		
1978					0.12						0.27	2.09	0.03	1.06		0.07		
1979					0.08						0.44	0.50	0.04	0.86		0.34		
1980																		
1981																		
1982																		
1983		1.75															0.37	
1984		0.40																0.96
1985		0.01									0.06							0.30
1986											21.66							9.11
1987											0.93							2.47
1988											0.64							1.25
1989											0.64							0.99
1990											0.77							4.07
1991											0.39							0.03
# OBS.	14	13	7	7	14	6	5	7	16	26	27	33	22	24	13	23	27	8
MEAN	3.13	0.44	0.53	3.96	2.43	2.22	0.25	0.24	1.38	1.73	2.03	1.65	5.13	1.28	1.57	1.19	1.57	2.40
STD. DEV.	1.57	0.45	0.57	1.49	2.54	1.34	0.04	0.09	1.14	1.39	3.91	0.95	4.34	0.31	0.74	1.06	1 11	2.81

TABLE 2.4.4

Peak Discharges in m³/s, Excluding Records of Doubtful Quality

RIVER DA (km²)	BULSA 405	O'DONNEL 240	O'DONNEL 112	BANGAT 90	CAMILING 142	CAMILING 280	PASIG-P 242	PASIG-P 28	PORAC 118	PORAC 111	GUMAIN FW 370	GUMAIN 128	CAULAMAN 72	COLO 76	BAGSIT 68	BUCAO 615	STO TOMAS 177	MALOMA 151
YEAR																		
1946										509		187						
1947										199		116					287	
1948										484		198					432	
1949										232		127					279	
1950										400		155					373	
1951										272		75					242	
1952										283		139					312	
1953										481		180					279	
1954										202		94					250	
1955										268		218	669	140			327	
1956												218	97	95		1092	172	
1957						376				5		247	571	102		766	274	
1958						316				7		192	339	119		1088	315	
1959									24	21	366	151	629	73		701	328	
1960	752		210						168	129	491	255	240	112	94	2525	662	
1961	1958								155	68	455	206	284	112	55	1140	576	
1962	2259		45							400	860	310	850	145	186	2220	855	
1963	1757		18			928			333	55	759	310	669	94	225	1380	346	
1964	1087	26	29		644	1280			330	124	762	375	708	118	107	1078	288	
1965	704		18		353	213	48		255	134	612	165	755	76	84	607	289	
1966	1087	36	73		443	610	73		321	227	742	283	960	102	111	494	270	
1967	692	103	10	353	1262		71	7.2	153	225	814	253	181	68	60	529	225	
1968	1958	115		423	474		61	8.9	38	36	399	127	40	102	94	744		
1969	1221	64		365	675		49	6.0	45	72	879	48	158	111	86	705		
1970	2082	176		414	666			2.2	83	146	857	268	677	108	91	885		
1971	452	70		339	58			8.8	56	43	720	216	103	108	42	190		
1972	1542	205		540	166			8.9			641	222	189		154			
1973		34							22		641	194		57				
1974									132		255	292		88				
1975									470			68		59				
1976												740		81				
1977											162			103				
1978											100	268		81				
1979											162	64		66				
1980																		
1981																		
1982																		
1983		421																
1984		97																145
1985											318							46
1986																		1375
1987											344							373
1988											237							188
1989											237							149
1990											286							615
1991																		
# OBS.	13	11	7	6	9	6	5	6	15	25	24	33	18	24	13	16	21	7
MEAN	1350	122	59	405	527	620	60	7.0	172	199	504	211	451	97	107	1009	351	413
STD. DEV.	587	109	64	67	331	376	11	2.4	134	153	251	122	288	24	50	592	157	430

TABLE 2.4.5
Normalized Peak Flows in m^3/s / km^2, Excluding Records of Doubtful Quality

RIVER DA (km^2)	BULSA 405	O'DONNEL 240	O'DONNEL 112	BANGAT 90	CAMILING 142	CAMILING 280	PASIG-P 242	PASIG-P 28	PORAC 118	PORAC 111	GUMAIN FW 370	GUMAIN 128	CAULAMAN 72	COLO 76	BAGSIT 68	BUCAO 615	STO TOMAS 177	MALOMA 151
YEAR																		
1946										4.58		1.46						
1947										1.79		0.90					1.62	
1948										4.36		1.54					2.44	
1949										2.09		0.99					1.57	
1950										3.60		1.21					2.10	
1951										2.09		0.58					1.37	
1952										2.55		1.08					1.76	
1953										4.34		1.47					1.58	
1954										1.82		0.73					1.41	
1955										2.41		1.70	9.29	1.94			1.85	
1956												1.70	1.35	1.25		1.78	0.97	
1957						1.34				0.05		1.93	7.92	1.34		1.25	1.55	
1958						1.13				0.06		1.50	4.70	1.56		1.77	1.78	
1959									0.21	0.19	0.99	1.18	8.74	0.97		1.14	1.85	
1960	1.86		1.88						1.42	1.16	1.33	1.99	3.34	1.47	1.39	4.11	3.74	
1961	4.83								1.31	0.61	1.23	1.61	3.94	1.47	0.81	1.85	3.25	
1962	5.58		0.40							3.60	2.32	2.43	11.80	1.91	2.73	3.61	4.83	
1963	4.34		0.16			3.31			2.82	0.49	2.05	2.43	9.29	1.23	3.31	2.24	1.95	
1964	2.68	0.11	0.26		4.54	4.57			2.80	1.12	2.06	2.93	9.83	1.56	1.57	1.75	1.63	
1965	1.74		0.16		2.49	0.76	0.20		2.16	1.21	1.65	1.29	10.49	1.00	1.23	0.99	1.63	
1966	2.68	0.15	0.65		3.12	2.18	0.30		2.72	2.05	2.00	2.21	13.33	1.34	1.64	0.80	1.53	
1967	1.71	0.43	0.16	3.92	8.89		0.29	0.26	1.29	2.02	2.20	1.98	2.52	0.90	0.88	0.86	1.27	
1968	4.83	0.48		4.70	3.34		0.25	0.32	0.32	0.32	1.08	0.99	0.55	1.34	1.39	1.21		
1969	3.01	0.27		4.05	4.75		0.20	0.21	0.38	0.65	2.37	0.37	2.19	1.47	1.26	1.15		
1970	5.14	0.74		4.60	4.69			0.08	0.70	1.32	2.32	2.09	9.40	1.42	1.34	1.44		
1971	1.12	[illegible]		3.77	0.41			0.31	0.47	0.39	1.94	1.68	1.43	1.42	0.62	0.31		
1972	3.81	[illegible]		5.99	1.17			0.32			1.73	1.73	2.63		2.27			
1973		[illegible]							0.18		1.73	1.52		0.75				
1974									1.12		0.69	2.28		1.16				
1975									3.98			0.53		0.77				
1976												5.78		1.06				
1977											0.44			1.36				
1978											0.27	2.09		1.06				
1979											0.44	0.50		0.86				
1980																		
1981																		
1982																		
1983		1.75																
1984		0.40																0.96
1985											0.86							0.30
1986																		9.11
1987											0.93							2.47
1988											0.64							1.25
1989											0.64							0.99
1990											0.77							4.07
1991																		
# OBS.	13	11	7	6	9	6	[illegible]	5	15	25	24	33	18	24	13	16	21	7
MEAN	3.33	0.51	0.53	4.50	3.71	2.22	0.25	[illegible]	1.46	[illegible]	1.36	1.65	6.26	1.28	1.57	1.64	1.98	2.73
STD. DEV.	1.45	0.45	0.57	0.75	2.33	1.34	0.04	[illegible]	1.14	[illegible]	0.68	0.95	4.00	0.31	0.74	0.96	0.89	2.85

TABLE 2.4.6

Streamflow Data

River	Station ID	Drainage Area (km²)	Approximate Period of Daily Record	[illegible]	Originates on Mount Pinatubo	Comments
Bulsa	W10A	405	1960-1972	none	no	
O'Donnell at Palubiub	W11A	240	1947-1977, 1984	none	yes	Significant inconsistencies between this record and upstream gages W11B and W12A
O'Donnell at Patling	W1 B	112	1959-1967	None	yes	Possible diversion above this gage into the Bangat above gage W12A
Bangat	W12A	93	1967-1972	1967-1970	yes	See comments for stations W11A and W11B
Camiling at Nambalan	W22A	147	1964-1972	1949	no	
Camiling at Poblacion	W23B	290	1957-1966	1957-1963 1965-1966	no	
Pasig-Potrero at Cabetican	W81A	242	1965-1969	none	yes	Gage tidally affected
Pasig-Potrero at Hda. Dolores	W82A	28	1957-1972	none	yes	
Porac at Valdez	W83A	118	1959-1971	none	yes	Significant inconsistencies between this record and upstream gage W84A
Porac at Del Carmen	W84A	111	1957-1971	none	yes	See comments for Station W83A
Gumain Floodway	W85A	370	1959-1973 1977-1979 1986-1990	none	yes	Record affected by operation of flood control projects
Gumain	[illegible]	128	1957-1973	1957-1971	yes	
Caulaman	W87A	72	1957-1972	1957-1971	no	
Colo	W88A	76	1957-1971	none	no	
Bagsit	W92A	68	1960-1971	none	no	
Bucao	W93A	615	1957-1971	1957-1964	yes	
Santo Tomas	W94A	177	1957-1971	none	yes	Post-1967 record affected by upstream irrigation diversions
Maloma	W99B	151	1984-1990	none	yes	

Notes:

1. The period of available daily record is generally shorter than the period of record for peak instantaneous flows.
2. In absence of stage recorder, water level determined by staff gauge read 2 or 3 times per day.

Table 2.4.7
Daily Data Rainfall, Evaporation, and Streamflow Stations

Type	ID #	Station Name	Record Considered
RAIN	RD324	Iba, Zambales	1951 - 1992
"	RA016	Hacienda Luisita, Tarlac	1968 - 1992
"	RA017	CLSU, Munoz, Neuva Ecija	1974 - 1992
"	R0313	Julian Subd., San Fernando, Pampanga	1970 - 1991
"	R0314	Masantol, Pampanga	1970 - 1992
"	R0320	Sta Rita Elem Sch, Cabangan, Zambales	1975 - 1992
"	R0322	Znas, San Marcelino, Zambales	1975 - 1992
"	RUSA1	Cubi Point Naval Air Station	1958 - 1990
"	RUSA2	Clark Air Force Base	1950 - 1991
EVAP	EA017	CLSU, Munoz, Neuva Ecija	1974 - 1992
FLOW	W010A	Bulsa River, Villa Aglipay; (405 km²)	1960 - 1972
"	W011A	O'Donnell River, Palublub; (240 km²)	1965 - 1972
"	W011B	O'Donnell River, Patling; (112 km²)	1958 - 1967
"	W012A	Bangat River, Sta Lucia; (90 km²)	1966 - 1972
"	W023A	Camiling River, Nambalan; (142 km²)	1964 - 1972
"	W023B	Camiling River, Poblacion; (280 km²)	1957 - 1966
"	W081A	Pasig-Potrero River, Cabetican; (242 km²)	1965 - 1969
"	W082A	Pasig Potrero River, Hda Dolores; (28 km²)	1966 - 1972
"	W084A	Porac River, Del Carmen; (111 km²)	1957 - 1972
"	W086A	Gumain River, Pabanlag; (128 km²)	1957 - 1971
"	W088A	Colo River, San Benito; (76 km²)	1957 - 1971
"	W092A	Bagsit River, Dampai; (68 km²)	1960 - 1972
"	W093A	Bucao River, San Juan; (615 km²)	1957 - 1971
"	W094A	Santo Tomas River, Dalanawan; (177 km²)	1957 - 1967
"	W099B	Maloma River, Maloma; (151 km²)	1984 - 1991

Table 2.4.8

Peak Instantaneous Discharges, m³/s

RIVER DA (km2)	BULSA 405	O'DONNELL 240	O'DONNELL 112	BANGAT 90	CAMILING 142	CAMILING 280	PASIG-P 242	PASIG-P 28	PORAC 111	GUMAIN 128	COLO 76	BAGSIT 68	BUCAO 615	STO TOMAS 177	MALOMA 151
YEAR															
1946									509	187					
1947									199	116				287	
1948									484	198				432	
1949									232	127				279	
1950									400	155				373	
1951									232	75				242	
1952									283	139				312	
1953									481	188				279	
1954									202	94				250	
1955									268	218	148			327	
1956										218	95		1092	172	
1957						376			5	247	102		766	274	
1958						316			7	192	119		1088	315	
1959									21	151	73		701	328	
1960	752		210						129	255	112	94	2525	662	
1961	1950								68	206	112	55	1140	576	
1962	2259		45						400	310	145	186	2220	855	
1963	1757		18			928			55	310	94	225	1380	346	
1964	1087	26	29		644	1280			124	375	118	107	1078	280	
1965	704		18		353	213	48		134	165	76	84	607	289	
1966	1087	36	73		443	610	73		227	283	102	111	494	270	
1967	692	103	18	353	1262		71	7.2	225	253	68	60	529	225	
1968	1958	115		423	474		61	8.9	36	127	102	94	744		
1969	1221	64		365	675		49	6.0	72	48	111	86	705		
1970	2082	176		414	666			2.2	146	268	108	91	885		
1971	452	70		339	58			8.8	43	216	108	42			
1972	1542	205		540	166			8.9		222		154			
1973		34								194	57				
1974										292	88				
1975										68	59				
1976										740	81				
1977											103				
1978										268	81				
1979										64	66				
1980															
1981															
1982															
1983		421													
1984		97													145
1985															46
1986															1375
1987															373
1988															198
1989															149
1990															615
# OBS.	13	11	7	6	9	6	5	6	25	33	24	13	15	21	7
MEAN	1350	122	59	405	527	620	60	7.0	199	211	97	107	1064	351	413
STD. DEV.	587	109	64	67	331	376	11	2.4	153	122	24	50	571	157	430

Table 2.4.9
Frequency Analysis of 1-Day Maximum Annual Rainfall

Return Period: (Chance of Exceedance in any one year)

Rain Gages (Rainfall, mm)	Years of Record	2-years (50%)	10-years (10%)	50-years (2%)	100-years (1%)	500-years (0.2%)
RD324 Iba	38	247	399	545	610	772
RA016 Hda Luisita	20	123	210	292	329	420
RA017 CLSU	18	127	204	286	324	425
R0313 Julian Subd.	22	144	273	417	488	678
R0314 Masantol	22	151	240	331	374	482
R0320 Sta Rita Sch	17	231	419	608	696	915
R0322 Znas	18	200	346	504	580	783
RUSA1 Cubi Point NAS	33	246	375	489	537	653
RUSA2 Clark AFB	41	140	255	376	433	580

1-day data (above) multiplied by 1.13 to obtain 24-hour duration amounts

Rain Gages (Rainfall, mm)	Years of Record	2-years (50%)	10-years (10%)	50-years (2%)	100-years (1%)	500-years (0.2%)
RD324 Iba	38	279	451	616	689	872
RA016 Hda Luisita	20	139	237	330	372	475
RA017 CLSU	18	144	231	323	366	480
R0313 Julian Subd.	22	163	308	471	551	766
R0314 Masantol	22	171	271	374	423	545
R0320 Sta Rita Sch	17	261	473	687	786	1034
R0322 Znas	18	226	391	570	655	885
RUSA1 CubiPoint NAS	33	278	424	553	607	738
RUSA2 Clark AFB	41	158	288	425	489	655

Table 2.4.10
Frequency Analysis of 2-Day Maximum Annual Rainfall

Return Period: (Chance of Exceedance in any one year)

Rain Gages (Rainfall, mm)	Years of Record	2-years (50%)	10-years (10%)	50-years (2%)	100-years (1%)	500-years (0.2%)
R0324 Iba	38	375	600	820	920	1173
RA016 Hda Luisita	20	170	297	417	470	599
RA017 CLSU	18	168	298	447	521	724
R0313 Julian Subd.	22	203	402	625	735	1026
R0314 Masantol	22	219	359	494	554	705
R0320 Sta Rita Sch	17	369	617	851	955	1209
R0322 Znas	18	323	524	723	814	1044
RUSA1 Cubi Point NAS	33	359	543	709	782	957
RUSA2 Clark AFB	41	196	364	543	628	850

2-day data (above) multiplied by 1.04 to obtain 48-hour duration amounts

Rain Gages (Rainfall, mm)	Years of Record	2-years (50%)	10-years (10%)	50-years (2%)	100-years (1%)	500-years (0.2%)
R0324 Iba	38	390	624	853	957	1220
RA016 Hda Luisita	20	177	309	434	489	623
RA017 CLSU	18	175	310	465	542	753
R0313 Julian Subd.	22	211	418	650	764	1067
R0314 Masantol	22	228	373	514	576	733
R0320 Sta Rita Sch	17	384	642	885	993	1257
R0322 Znas	18	336	545	752	847	1086
RUSA1 Cubi Point NAS	33	373	565	737	813	995
RUSA2 Clark AFB	41	204	379	565	653	884

Table 2.4.11
Frequency Analysis of 5-Day Maximum Annual Rainfall

Return Period; (Chance of Exceedance in any one year)

Rain Gages (Rainfall, mm)	Years of Record	2-years (50%)	10-years (10%)	50-years (2%)	100-years (1%)	500-years (0.2%)
RD324 Iba	38	590	892	1164	1282	1567
RA016 Hda Luisita	20	239	428	624	715	950
RA017 CLSU	18	241	435	660	773	1084
R0313 Julian Subd.	22	287	567	892	1055	1498
R0314 Masantol	22	317	560	808	924	1219
R0320 Sta Rita Sch	17	597	939	1256	1396	1740
R0322 Znas	18	502	811	1125	1274	1652
RUSA1 Cubi Point NAS	33	570	872	1137	1250	1520
RUSA2 Clark AFB	41	271	502	765	895	1251
5-day data (above) multiplied by 1.02 to obtain 120-hour duration amounts						
RD324 Iba	38	602	910	1187	1308	1598
RA016 Hda Luisita	20	244	437	636	729	969
RA017 CLSU	18	246	444	673	788	1106
R0313 Julian Subd.	22	293	578	910	1076	1528
R0314 Masantol	22	323	571	824	942	1243
R0320 Sta Rita Sch	17	609	958	1281	1424	1775
R0322 Znas	18	512	827	1149	1299	1685
RUSA1 Cubi Point NAS	33	581	889	1160	1275	1550
RUSA2 Clark AFB	41	276	512	780	913	1276

Table 2.4.12
Frequency Analysis of 10-Day Maximum Annual Rainfall

		Return Period: (Chance of Exceedance in any one year)				
Rain Gages (Rainfall, mm)	Years of Record	2-years (50%)	10-years (10%)	50-years (2%)	100-years (1%)	500-years (0.2%)
RD324 Iba	38	834	1291	1710	1895	2344
RA016 Hda Luisita	20	342	585	818	922	1180
RA017 CLSU	18	338	547	766	871	1145
R0313 Julian Subd.	22	392	801	1270	1755	2127
R0314 Masantol	22	450	760	1076	1224	1603
R0320 Sta Rita Sch	17	909	1422	1914	2137	2691
R0322 Znas	18	729	1108	1463	1622	2012
RUSA1 Cubi Point NAS	33	860	1289	1646	1794	2136
RUSA2 Clark AFB	41	365	662	983	1137	1546

10-day data (above) multiplied by 1.01 to obtain 240-hour duration amounts

RD324 Iba	38	842	1304	1727	1914	2367
RA016 Hda Luisita	20	345	591	826	931	1192
RA017 CLSU	18	341	552	774	880	1156
R0313 Julian Subd.	22	396	809	1283	1773	2148
R0314 Masantol	22	455	768	1087	1236	1619
R0320 Sta Rita Sch	17	918	1436	1933	2158	2718
R0322 Znas	16	736	1119	1473	1638	2032
RUSA1 Cubi Point NAS	33	869	1302	1662	1812	2157
RUSA2 Clark AFB	41	369	669	993	1148	1561

Table 2.4.13
Frequency Analysis of 15-Day Maximum Annual Rainfall

Return Period: (Chance of Exceedance in any one year)

Rain Gages (Rainfall, mm)	Years of Record	2-years (50%)	10-years (10%)	50-years (2%)	100-years (1%)	500-years (0.2%)
R0324 Iba	38	1020	1561	2014	2204	2645
RA016 Hda Luisita	20	400	674	953	1083	1417
RA017 CLSU	18	404	620	839	940	1201
R0313 Julian Subd.	22	442	897	1414	1670	2357
R0314 Masantol	22	528	883	1230	1388	1784
R0320 Sta Rita Sch	17	1100	1737	2332	2597	3246
R0322 Znas	18	905	1373	1750	1903	2251
RUSA1 Cubi Point NAS	33	1030	1528	1941	2113	2507
RUSA2 Clark AFB	41	427	779	1188	1395	1967

Table 2.4.14

Streamflow Data Frequency Analyses Summary
Expected Probability Discharges in m^3/s

(ranges correspond to alternative data sets)

Gumain River (W086A)

Return Period	2-year	100-year
Peak Instantaneous Q	186 to 226	495 to 663
1-Day Average Q	128 to 152	337 to 417
3-Day Average Q	(n/a) to 109	312 to (n/a)

Bucao River (W093A)

Return Period	2-year	100-year
Peak Instantaneous Q	895 to 962	3740 to 4330
1-Day Average Q	656 to 697	1260 to 2730
3-Day Average Q	521 to 548	891 to 1870

Santo Tomas River (W094A)

Return Period	2-year	100-year
Peak Instantaneous Q	307 to 356	798 to 1560
1-Day Average Q	251 to 299	524 to 1160
3-Day Average Q	207 to 221	562 to 1080

Table 2.4.15
Composite Analysis of Rainfall Frequency Data

Return Period: (Chance of Exceedance in any one year)

AVERAGE RAINFALL (mm) FOR	DURATION	2-years (50%)	10-years (10%)	50-years (2%)	100-years (1%)	500-years (0.2%)
COASTAL GAGES	24-HR	261	435	606	684	882
COASTAL GAGES	2-DAY	371	594	807	902	1140
COASTAL GAGES	5-DAY	576	896	1194	1327	1652
COASTAL GAGES	10-DAY	841	1290	1700	1881	2319
COASTAL GAGES	15-DAY	1014	1550	2009	2204	2662
INTERIOR GAGES	24-HR	155	267	385	440	584
INTERIOR GAGES	2-DAY	199	358	525	605	812
INTERIOR GAGES	5-DAY	276	508	765	890	1224
INTERIOR GAGES	10-DAY	381	678	992	1194	1535
INTERIOR GAGES	15-DAY	440	771	1125	1295	1745

Ratio of Interior to Coastal Rainfall for same Frequency-Duration Events

INTERIOR/COASTAL	24-HR	0.59	0.61	0.63	0.64	0.66
INTERIOR/COASTAL	2-DAY	0.53	0.60	0.65	0.67	0.71
INTERIOR/COASTAL	5-DAY	0.47	0.56	0.64	0.67	0.74
INTERIOR/COASTAL	10-DAY	0.45	0.52	0.58	0.63	0.66
INTERIOR/COASTAL	15-DAY	0.43	0.49	0.55	0.58	0.65
INTERIOR/COASTAL	Average	0.49	0.56	0.61	0.64	0.68

NOTES:

1) Ratio of Interior/Coastal Mean Annual Rain: 1904 mm / 3779 mm - 0.50

2) Peak high-elevation rainfall on Mount Pinatubo estimated to be approximately 1.4 times the average coastal rainfall for all frequency-duration amounts. Higher rainfalls, to approximately 1.7 times the average coastal rainfall, are estimated to occur at higher elevations coastal mountains located approximately 40 km north of Mount Pinatubo.

Coastal Gages:
- RO324 Iba
- RO320 Sta. Rita Elem. School
- RO322 Znas
- RUSA1 Cubi Point NAS

Interior Gages:
- RAO16 Hda Luisita
- RAO17 CLSU
- RO313 Julian Subdivision
- RO314 Masantol
- RUSA2 Clark AFB

Table 2.4.16
Short-Duration Rainfall Frequency Data
For Representative Interior, Coastal, and High-Elevation Stations
Data in mm

Return Period: (Chance of Exceedance in any one year)

Station	DURATION	2-years (50%)	10-years (10%)	50-years (2%)	100-years (1%)	500-years (0.2%)
LOWLAND INTERIOR						
Hda. Luisita	1 HOUR	52	85	114	126	n/a
Hda. Luisita	2 HOURS	60	102	139	154	n/a
Hda. Luisita	3 HOURS	69	115	155	172	n/a
Hda. Luisita	6 HOURS	84	130	171	188	n/a
Hda. Luisita	12 HOURS	101	179	248	277	n/a
Hda. Luisita	24 HOURS	127	246	350	394	n/a
WINDWARD COAST						
Iba	1 HOUR	61	87	109	119	n/a
Iba	2 HOURS	83	126	164	180	n/a
Iba	3 HOURS	98	152	200	220	n/a
Iba	6 HOURS	138	224	300	332	n/a
Iba	12 HOURS	187	372	533	601	n/a
Iba	24 HOURS	238	482	697	788	n/a
HIGH ELEVATIONS						
Baguio City	1 HOUR	56	80	102	111	n/a
Baguio City	2 HOURS	80	145	203	227	n/a
Baguio City	3 HOURS	100	197	281	317	n/a
Baguio City	6 HOURS	157	340	500	568	n/a
Baguio City	12 HOURS	231	528	789	900	n/a
Baguio City	24 HOURS	319	674	985	1117	n/a

Data extracted from Hydrology and Flood Forecast Center, PAGASA, 1981: "Rainfall Intensity-Duration-Frequency Data of the Philippines" Volume 1, First Edition.

Baguio City is located approximately 140 km NNE of Mt. Pinatubo, at elevation 1370 m (4500 feet).

Table 2.4.17

Analysis of Short-Duration Rainfall Frequency Data From Representative Interior, Coastal, and High-Elev. Stations For Same-Frequency-Duration Events

Return Period; (Chance of Exceedance in any one year)

Ratio of Stations	DURATION	2-years (50%)	10-years (10%)	50-years (2%)	100-years (1%)	AVERAGE
INTERIOR TO COAST						
Luisita/Iba	1 HOUR	0.86	0.98	1.04	1.06	0.98
Luisita/Iba	2 HOURS	0.72	0.81	0.85	0.86	0.80
Luisita/Iba	3 HOURS	0.70	0.75	0.77	0.78	0.75
Luisita/Iba	6 HOURS	0.61	0.58	0.57	0.57	0.58
Luisita/Iba	12 HOURS	0.54	0.49	0.46	0.46	0.48
Luisita/Iba	24 HOURS	0.53	0.51	0.50	0.50	0.51
INTERIOR TO HIGH ELEVATIONS						
Luisita/Baguio	1 HOUR	0.94	1.06	1.12	1.13	1.06
Luisita/Baguio	2 HOURS	0.75	0.70	0.68	0.68	0.70
Luisita/Baguio	3 HOURS	0.68	0.58	0.55	0.54	0.58
Luisita/Baguio	6 HOURS	0.53	0.38	0.34	0.33	0.39
Luisita/Baguio	12 HOURS	0.44	0.34	0.31	0.31	0.33
Luisita/Baguio	24 HOURS	0.40	0.36	0.36	0.35	0.36
COAST TO HIGH ELEVATIONS						
Iba/Baguio	1 HOUR	1.10	1.08	1.07	1.07	1.07
Iba/Baguio	2 HOURS	1.04	0.87	0.81	0.79	0.87
Iba/Baguio	3 HOURS	0.98	0.77	0.71	0.69	0.78
Iba/Baguio	6 HOURS	0.88	0.66	0.60	0.58	0.68
Iba/Baguio	12 HOURS	0.81	0.70	0.68	0.67	0.71
Iba/Baguio	24 HOURS	0.75	0.72	0.71	0.71	0.71

Table 2.4.18

Depth-Duration Data for Design Storms
Hypothetical Station Located near Summit of Mount Pinatubo
Data in mm

Return Period; (Chance of Exceedance in any one year)

DURATION	2-years (50%)	10-yrs (10%)	50-yrs (2%)	100-yrs (1%)	500-yrs (.2%)
1-Hour	57	81	103	113	146
2-Hours	82	140	193	215	280
3-Hours	102	186	261	293	381
6-Hours	159	311	446	505	655
12-Hours	240	478	694	789	1022
24-Hours	352	587	830	936	1196
2-Days	501	802	1101	1230	1544
5-Days	777	1209	1624	1804	2236

NOTES

1. The depth-duration-frequency data summarized above are for a hypothetical station located at approximately 1000 meters elevation near the summit of Mount Pinatubo. This station has a mean annual rainfall of about 5000 mm.

2. The 1-hour duration depth-frequency data are effectively independent of station location. The 1-hour data presented above are directly applicable to any site (coastal, mountain, or interior) throughout the study area.

3. Depth-frequency data for durations of 6 hours and longer may be transposed to other sites throughout the study area after multiplication by a site-specific factor. The factor is equal to the ratio of the desired site's mean annual rainfall in millimeters to 5000 mm, the mean annual rainfall for the hypothetical station.

4. Same-frequency durations are not fully embedded in a single storm; i.e., a 100-year 24-hour storm is not expected to include a 100-year 1-hour duration. The available data showed a maximum 20-year 1-hour rain within a 200-year 24-hour storm, and a maximum 2-year 1-hour rain within a 25-year 24-hour storm. This relationship of 1-hour to 24-hour return periods can be approximated by assuming a constant rainfall intensity over the peak six-hour duration.

Table 3.2.1

Sub-Basin Parameters

Gumain Basin, Pre-Eruption

Sub-Basin ID	PG1	PG2	PG3	PG4	PG5	PG6	PG7	PG8	PG9
Physical Parameters									
Area (km2)	9.2	16.5	6.7	22.8	11.0	13.1	12.3	19.0	6.1
Longest Flow Path within Sub-Basin (km)	4.3	8.3	3.9	9.0	7.0	7.8	7.9	11.9	6.4
Elevation Change along Flow Path (m)	665	865	925	575	700	1,323	1,060	1,050	190
Channel Length to Upstream Basin (km)	N/A	7.9	N/A	7.4	4.7	N/A	N/A	9.2	5.3
Elevation Change along Channel (m)	N/A	290	N/A	290	60	N/A	N/A	210	30
Design Storm Parameters									
Estimated Annual Rainfall (mm)	4,280	3,920	4,370	4,070	3,610	4,220	4,160	3,670	3,310
Percent of Rainfall near Pinatubo Summit	86	78	87	81	72	84	83	73	66
Distance to Assumed Storm Center (km)	10.4	10.0	6.2	6.7	8.7	2.5	1.3	4.4	14.2
Runoff Parameters									
Time of Concentration (hrs)	0.4	0.8	0.3	1.0	0.7	0.6	0.7	1.1	1.1
Clark Storage Coefficient (hrs)	10.0	20.0	7.5	25.0	17.5	15.0	17.5	27.5	27.5
Uniform Infiltration Loss (mm/hr)	3	3	3	3	3	3	3	3	3
Baseflow (cms)	1.2	2.1	0.9	2.9	1.4	1.7	1.6	2.4	0.8
Flow Routing Parameters									
Travel Time (hrs)	N/A	0.9	N/A	0.8	0.5	N/A	N/A	1.0	0.6
Number of Sub-Reaches	N/A	1	N/A	1	1	N/A	N/A	1	1

Table 3.2.2

Sub-Basin Parameters

Bucao Basin, Pre-Eruption

Sub-Basin ID	PB1	PB2	PB3	PB4	PB5	PB6	PB7
Physical Parameters							
Area (km2)	72.3	62.0	23.7	67.0	39.1	12.5	43.3
Longest Flow Path within Sub-Basin (km)	16.8	17.4	8.3	13.9	14.3	10.3	15.6
Elevation Change along Flow Path (m)	940	1,600	875	980	620	440	700
Channel Length to Upstream Basin (km)	N/A	N/A	2.9	12.5	N/A	N/A	5.8
Elevation Change along Channel (m)	N/A	N/A	35	105	N/A	N/A	80
Design Storm Parameters							
Estimated Annual Rainfall (mm)	4,100	4,200	4,200	4,200	3,900	4,100	4,050
Percent of Rainfall near Pinatubo Summit	82	84	84	84	78	82	81
Distance to Assumed Storm Center (km)	6.0	3.0	10.5	13.6	9.2	5.4	7.6
Runoff Parameters							
Time of Concentration (hrs)	1.8	1.5	.8	1.4	1.7	1.3	1.8
Clark Storage Coefficient (hrs)	45.0	37.5	20.0	35.0	42.5	32.5	45.0
Uniform Infiltration Loss (mm/hr)	3	3	3	3	3	3	3
Baseflow (m^3/s)	9	8	3	9	5	2	6
Flow Routing Parameters							
Travel Time (hrs)	N/A	N/A	0.3	1.4	N/A	N/A	0.6
Number of Sub-Reaches	N/A	N/A	0	1	N/A	N/A	1

Table 3.2.3

Sub-Basin Parameters

Santo Tomas Basin, Pre-Eruption

Sub-Basin ID	PT1	PT2	PT3	PT4	PT5
Physical Parameters					
Area (km2)	45.6	34.6	9.4	20.0	75.7
Longest Flow Path within Sub-Basin (km)	*10.5*	*9.2*	*8.3*	*5.5*	*11.0*
Elevation Change along Flow Path (m)	1,471	1,027	250	770	965
Channel Length to Upstream Basin (km)	N/A	5.0	6.1	N/A	8.1
Elevation Change along Channel (m)	N/A	116	68	N/A	20
Design Storm Parameters					
Estimated Annual Rainfall (mm)	4,820	4,370	4,070	4,280	4,100
Percent of Rainfall near Pinatubo Summit	*96*	87	81	86	82
Distance to Assumed Storm Center (km)	0.0	6.0	10.1	14.2	13.1
Runoff Parameters					
Time of Concentration (hrs)	0.9	0.9	1.3	0.5	1.1
Clark Storage Coefficient (hrs)	22.5	22.5	32.5	12.5	27.5
Uniform Infiltration Loss (mm/hr)	3	3	3	3	3
Baseflow ($cm^{3/s}$)	4	3	1	2	6
Flow Routing Parameters					
Travel Time (hrs)	N/A	0.6	0.7	N/A	0.9
Number of Sub-Reaches	N/A	1	1	N/A	1

Table 3.2.4

HEC-1 Calibration and Sensitivity Analysis
Simulations with Clark Unit Hydrograph

Stream gauge	Parameter Set	Peak Inst. Q m³/s		24-hr Vol. dam³		3-day Vol. dam³	
		2-yr	100-yr	2-yr (000 s)	100-yr (000 s)	2-yr (000 s)	100-yr (000 s)
Gumain (W086A)	Target	180-230	490-670	11-13	29-36	(n/a)-28	81-(n/a)
	A	220	940	12	54	18	78
	B	220	790	16	53	28	96
	C	220	680	17	49	36	101
Bucao (W093A)	Target	890-960	3750-4350	56-60	108-235	135-142	230-484
	A	731	3370	52	232	93	406
	B	786	2772	64	214	140	471
	C	811	2358	67	191	168	467
Santo Tomas (W094A)	Target	310-360	800-1560	22-26	45-100	54-57	145-280
	A	320	1580	21	102	31	174
	B	330	1190	26	84	49	164
	C	320	970	27	73	60	154

* Target values (range) from HEC-FFA analyses of recorded data; ranges correspond to alternative data sets.

Parameter Set	Constant Loss Rate mm/hr	Unit Hydrograph Storage Coefficient
A	5.75	15 x T_c
B	3.0	25 x T_c
C	1.8	35 x T_c

(T_c = Basin Time of Concentration)

Table 3.5.1

Sub-Basin Unit Hydrograph Peaks

Basin, Sub-Basin	Unit Hydrograph Peak (cms)	Basin, Sub-basin	Unit Hydrograph Peak (cms)	Basin, Sub-basin	Unit Hydrograph Peak (cms)
Abacan, A1	0.093	Gumain-Porac, G6	0.232	O'Donnell, O14	0.427
Abacan,A2	0.169	Gumain-Porac, G7	0.174	O'Donnell, O15	0.518
Abacan, A3	0.081	Gumain-Porac, G8	0.184	O'Donnell, O16	0.354
Abacan, A4	0.323	Gumain-Porac, G9	0.060	O'Donnell, O17	0.175
Abacan, A5	0.038	Gumain-Porac, G10	0.061	Pasig/Potrero, P0	0.320
Bucao, B1	0.431	Gumain-Porac, G11	0.155	Pasig/Potrero, P1	0.118
Bucao, B2	0.330	Gumain-Porac, G12	0.196	Pasig/Potrero, P2	0.102
Bucao, B3	0.086	Gumain-Porac, G13	0.155	Pasig/Potrero, P3	0.063
Bucao, B4	0.313	Gumain-Porac, G14	0.120	Pasig/Potrero, P4	0.035
Bucao, B5	0.505	Gumain-Porac, G15	0.189	Pasig/Potrero, P5	0.070
Bucao, B6	0.246	Gumain-Porac, G16	0.196	Pasig/Potrero, P6	0.086
Bucao, B7	0.140	Gumain-Porac, G17	0.081	Sacobia, S2	0.180
Bucao, B8	0.262	Gumain-Porac, G18	0.141	Sacobia, S3	0.084
Bucao, B9	0.143	O'Donnell, O1	0.162	Sacobia, S4	0.110
Bucao, B10	0.544	O'Donnell, O2	0.286	Sacobia, S5	0.334
Bucao, B11	0.429	O'Donnell, O3	0.201	Sacobia, S6	0.176
Bucao, B12	0.317	O'Donnell, O4	0.156	Santo Tomas, T1	0.452
Bucao, B13	0.107	O'Donnell, O5	0.307	Santo Tomas, T2	0.398
Bucao, B14	0.256	O'Donnell, O6	0.185	Santo Tomas, T3	0.083
Bucao, B15	0.551	O'Donnell, O7	0.166	Santo Tomas, T4	0.896
Bucao, B16	0.342	O'Donnell, O8	0.134	Santo Tomas, T5	0.317
Gumain-Porac, G1	0.237	O'Donnell, O9	0.075	Santo Tomas, T6	0.534
Gumain-Porac, G2	0.221	O'Donnell, O10	0.075	Santo Tomas, T7	1.111
Gumain-Porac, G3	0.221	O'Donnell, O11	0.383	Santo Tomas, T8	0.181
Gumain-Porac, G4	0.246	O'Donnell, O12	0.224	Santo Tomas, T9	0.160
Gumain-Porac, G5	0.170	O'Donnell, O13	0.447	Santo Tomas, T10	0.029

Table 3.5.2

Sub-Basin Parameters
Sacobia-Bamban Basin

Sub-Basin ID	S2	S3	S4	S5	S6	S7
Physical Parameters						
Area (km2)	30.2	13.4	22.7	41.3	26.4	11.6
Longest Flow Path within Sub-Basin (km)	15.6	11.8	18.9	13.3	11.6	15.6
Elevation Change along Flow Path (m)	720	336	785	945	425	186
Channel Length to Upstream Basin (km)	N/A	9.8	N/A	N/A	10.9	12.5
Elevation Change along Channel (m)	N/A	125	N/A	N/A	100	23
Design Storm Parameters						
Estimated Annual Rainfall (mm)	3,250	2,650	2,860	3,490	2,710	2,110
Percent of Rainfall near Pinatubo Summit	65	53	57	70	54	42
Distance to Assumed Storm Center (km)						
Storm 1 at Sub-Basin S2	0	9	5.5	N/A	N/A	N/A
Storm 2 at Sub-Basin S4	N/A	N/A	0	N/A	N/A	N/A
Storm 3 at Sub-Basin S5	4.4	12.2	7.5	0	10.9	20
Runoff Parameters						
Time of Concentration (hrs)	1.8	1.7	2.2	1.3	1.6	3
Clark Storage Coefficient (hrs)	45	42.5	55	32.5	40	75
Uniform Infiltration Loss (mm/hr)	3	3	3	3	3	1000
Baseflow (cms)	2	1	1	3.3	0.9	0
Flow Routing Parameters						
Travel Time of Flood Wave (hrs)	N/A	1.1	N/A	N/A	1.2	1.4
Number of Sub-Reaches (1-hr time step)	N/A	1	N/A	N/A	1	1

Table 3.5.3
Simulation Output Sites
Sacobia-Bamban Basin

Site ID	Corps-Specified Site	Site Description	Stream Elevation (m)	Upstream Basin area (km2)	Time of Concentration (hours)	Average Annual Basin Rain (mm)	Average Annual Flow (cms)	Critical Storm Location	Critical Storm ID
S2DS	Yes	Sacobia River 10 km above confluence with Sapang Cauyan River	180	30.2	1.8	3,250	1.6	S2	1
S3DS	Yes	Sacobia River above confluence with Sapang Cauyan River	55	43.6	3	3,065	2.1	S2	1
S4DS	Yes	Sapang Cauyan River above confluence with Sacobia River	55	22.7	2.2	2,860	0.9	S4	2
S3DS+S4DS	Yes	Sacobia River below confluence with Sapang Cauyan River	55	66.3	3	2,995	3	S2	1
S6DS	Yes	Marimia River above confluence with Sacobia River	55	67.7	2.6	3,190	3.5	S5	3
S7US	Yes	Bamban River below confluence with Sacobia and Marimia Rivers	55	133.9	3	3,095	6.5	S5	3
S7DS	Yes	Bamban River near Concepcion City	32	145.5	4.7	3,016	6.7	S5	3

Table 3.5.4

Computed Maximum Annual Peak Discharge and Volume Frequency Data
Sacobia-Bamban Basin

Site I D	Maximum Annual Peak Discharge (cms)				
	2-year	10-year	50-year	100-year	500-year
S2DS	25	54	82	95	125
S3DS	32	71	109	125	166
S4DS	13	29	45	52	70
S3DS+S4DS	44	98	152	175	232
S6DS	62	138	211	243	321
S7US	102	233	358	413	547
S7DS	102	230	354	409	541

Site I D	Maximum Annual 24-hr Volume (cubic decameters)				
	2-year	10-year	50-year	100-year	500-year
S2DS	2,100	4,200	6,500	7,400	9,800
S3DS	2,700	5,600	8,500	9,800	13,000
S4DS	1,100	2,300	3,600	4,200	5,500
S3DS+S4DS	3,700	7,700	11,900	13,800	18,300
S6DS	5,000	10,500	16,000	18,400	24,300
S7US	8,300	17,900	27,600	31,800	42,000
S7DS	8,300	17,900	27,500	31,700	41,900

Site I D	Maximum Annual 3-Day Volume (cubic decameters)				
	2-year	10-year	50-year	100-year	500-year
S2DS	4,500	9,400	14,500	16,800	22,200
S3DS	5,900	12,200	19,100	22,100	29,400
S4DS	2,500	5,200	8,400	9,800	13,100
S3DS+S4DS	8,200	17,100	27,000	31,400	41,900
S6DS	10,200	21,400	33,400	38,600	51,200
S7US	17,600	38,000	59,600	69,100	92,000
S7DS	17,600	37,900	59,600	69,100	92,000

Table 3.5.5
Computed Flow Duration Curves
Sacobia-Bamban Basin
Data in cubic meters per second

% OF TIME EXCEEDED	S2DS	S3DS	S3DS+S4DS	S4DS	S6DS	S7US	S7DS
100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
50.0	0.6	0.8	1.2	0.4	1.4	2.6	2.7
25.0	1.6	2.1	3.0	0.9	3.5	6.5	6.7
20.0	2.0	2.6	3.7	1.1	4.4	8.0	8.2
10.0	3.3	4.3	6.1	1.8	7.3	13.3	13.6
5.0	4.7	6.2	8.7	2.6	10.7	19.0	19.4
2.0	7.8	10.1	14.2	4.2	17.9	31.3	31.7
1.0	11.2	14.5	20.1	6.0	26.0	44.7	45.1
0.5	15.5	20.0	27.6	8.2	36.5	61.6	61.8
0.2	23.6	30.5	42.1	12.5	59.1	98.9	95.4
0.1	31.7	41.3	57.4	17.1	82.1	138.7	131.9
0.05	40.9	53.5	74.7	22.3	105.3	179.0	173.1
0.02	52.0	68.1	95.3	28.5	129.5	220.8	221.6

Table 3.5.6
Sub-Basin Parameters
Abacan Basin

Sub-Basin ID	A1	A2	A3	A4	A5
Physical Paramters					
Area (km2)	7.9	12.7	15.8	9.9	5.1
Longest Flow Path within Sub-Basin (km)	6.4	7.9	14.7	9.2	12.7
Elevation Change along Flow Path (m)	305	190	415	85	75
Channel Length to Upstream Basin (km)	N/A	6.7	2.4	2.6	12.5
Elevation Change along Channel (m)	N/A	80	30	20	70
Design Storm Parameters					
Estimated Annual Rainfall (mm)	3,160	2,860	3,010	2,530	1,990
Percent of Rainfall near Pinatubo Summit	63	57	60	51	40
Distance to Assumed Storm Center (km)					
Strom 1 at Sub-Basin A1	0.0	3.6	2.5	9.5	17.9
Runoff Paramters					
Time of Concentration (hrs)	0.9	1.4	2.1	2.2	1.4
Clark Storage Coefficient (hrs)	22.5	35.0	52.5	55.0	35.0
Uniform Infiltration Loss (mm/hr)	3	3	3	3	3
Baseflow (cms)	0.5	0.6	0.8	0.2	0.0
Flow Routing Parmaters					
Travel Time of Flood Wave (hrs)	N/A	0.7	0.3	0.3	1.4
Number of Sub-Reaches (1-hr time step)	N/A	1	1	1	1

Table 3.5.7
Simulation Output Sites
Abacan Basin

Site ID	Corps-Specified Site	Site Description	Stream Elevation (m)	Upstream Basin Area (km2)	Time of Concentration (hours)	Average Annual Basin Rain (mm)	Average Annual Flow (cms)	Critical Storm Location
A1DS	Yes	Abacan River approximately 7 km above Sapang-Bayo creek confluence	210	7.9	0.9	3,160	0.4	A1
A3DS	Yes	Abacan River approximately 1.3 km above Highway 3 bridge	100	36.4	2.1	2,990	1.6	A1
A5DS	Yes	Abacan River at Highway 329	10	51.4	4.5	2,800	2.0	A1

Table 3.5.8

Computed Maximum Annual Peak Discharge and Volume Frequency Data
Abacan Basin

Maximum Annual Peak Discharge (cms)

Site ID	2-year	10-year	50-year	100-year	500-year
A1DS	10	23	35	40	52
A3DS	31	69	106	122	161
A5DS	41	90	138	159	211

Maximum Annual 24-hr Volume (dam3)

Site ID	2-year	10-year	50-year	100-year	500-year
A1DS	800	1,600	2,400	2,800	3,600
A3DS	2,500	5,100	7,800	9,000	11,900
A5DS-	3,100	6,500	10,000	11,500	15,300

Maximum Annual 3-Day Volume (dam3)

Site ID	2-year	10-year	50-year	100-year	500-year
A1DS	1,300	2,800	4,300	5,000	6,700
A3DS	4,900	10,300	16,200	18,800	25,000
A5DS	6,300	13,100	21,000	23,900	21,900

Table 3.5.9
Computed Flow Duration Curves
Abacan Basin
Data in cubic meters per second

% OF TIME EXCEEDED	A1DS	A3DS	A5DS
100	0.0	0.0	0.0
50	0.2	0.6	0.8
20	0.5	2.1	2.6
10	0.9	3.4	4.3
5	1.7	5.1	6.3
2	3.0	8.6	10.7
1	4.3	12.7	15.8
0.5	6.0	18.0	22.4
0.2	9.3	29.3	36.6
0.1	12.7	40.3	50.8
0.05	16.1	51.3	65.2
0.02	19.7	62.9	80.2

Table 3.5.10 (sheet 1 of 2)

Sub-Basin Parameters

O'Donnell Basin

Sub-Basin ID	O1	O2	O3	O4	O5	O6	O7	O8	O9
Physical Parameters									
Area (km2)	22.9	47.9	15.2	26.2	57.0	12.3	38.8	27.6	18.1
Longest Flow Path within Sub-Basin (km)	13.1	15.0	8.5	15.0	15.5	7.3	21.6	16.4	16.3
Elevation Change along Flow Path (m)	700	633	1,070	628	510	1,040	817	520	328
Channel Length to Upstream Basin (km)	N/A	11.2	N/A	14.5	13.3	N/A	20.6	N/A	9.9
Elevation Change along Channel (m)	N/A	160	N/A	250	60	N/A	280	N/A	30
Design Storm Parameters									
Estimated Annual Rainfall (mm)	4,160	3,460	4,160	3,460	2,860	3,920	3,310	3,160	2,710
Percent of Rainfall near Pinatubo Summit	83	69	83	69	57	78	66	63	54
Distance to Assumed Storm Center (km)									
Storm 1 at Sub-Basin O1	0.0	9.4	2.7	8.3	20.0	5.2	9.8	12.9	19.6
Storm 2 at Sub-Basin O6	N/A	N/A	N/A	N/A	N/A	0.0	9.4	11.8	N/A
Storm 3 at Sub-Basin O13	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Runoff Parameters									
Time of Concentration (hrs)	1.5	1.8	0.8	1.8	2.0	0.7	2.5	2.2	2.6
Clark Storage Coefficient (hrs)	37.5	45.0	20.0	45.0	50.0	17.5	62.5	55.0	65.0
Uniform Infiltration Loss (mm/hr)	3	3	3	3	3	3	3	3	3
Baseflow (cms)	2.7	3.7	1.8	2.0	2.5	1.3	2.7	1.7	0.6
Flow Routing Parameters									
Travel Time of Flood Wave (hrs)	N/A	1.2	N/A	1.6	1.5	N/A	2.3	N/A	1.1
Number of Sub-Reaches (1-hr time step)	N/A	1	N/A	2	1	N/A	2	N/A	1

Table 3.5.10 (sheet 2 of 2)

Sub-Basin Parameters
O'Donnell Basin

Sub-Basin ID	O10	O11	O12	O13	O14	O15	O16	O17
Physical Parameters								
Area (km2)	40.9	74.3	43.8	33.8	79.1	148.7	56 3	74.3
Longest Flow Path within Sub-Basin (km)	18.9	16.0	16.7	9.1	19.1	27.1	12.3	35 2
Elevation Change along Flow Path (m)	60	530	626	1248	974	925	420	714
Channel Length to Upstream Basin (km)	15.8	N/A	10.9	N/A	14 2	13 7	5.6	18.9
Elevation Change along Channel (m)	40	N/A	79	N/A	206	79	15	30
Design Storm Parameters								
Estimated Annual Rainfall (mm)	2,410	3,770	3,460	5,420	4,220	3,770	2,950	2,710
Percent of Rainfall near Pinatubo Summit	48	75	69	108	84	75	59	54
Distance to Assumed Storm Center (km)								
Storm 1 at Sub-Basin O1	27.9	10.4	16.7	28.0	22.9	27.1	28.3	28.1
Storm 2 at Sub-Basin O6	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Storm 3 at Sub-Basin O13	N/A	16.9	15.6	0.0	7.8	14.7	23.5	29.7
Runoff Parameters								
Time of Concentration (hrs)	5.9	2.1	2.1	0.8	2 0	3.1	1.7	4.6
Clark Storage Coefficient (hrs)	147.5	52.5	52.5	20.0	50.0	77.5	42.5	115.0
Uniform Infiltration Loss (mm/hr)	3	3	3	3	3	3	3	3
Baseflow (cms)	0.7	7.1	3.4	6.4	9 6	14 2	2 7	2 6
Flow Routing Parameters								
Travel Time of Flood Wave (hrs)	1.8	N/A	1.2	N/A	1 6	1 5	0 6	2.1
Number of Sub-Reaches (1-hr time step)	2	N/A	1	N/A	2	2	1	2

Table 3.5.11
Simulation Output Sites
O'Donnell Basin

Site ID	Corps-Specified Site	Site Description	Stream Elevation (m)	Upstream Basin Area (km2)	Time of Concentration (hours)	Average Annual Basin Rain (mm)	Average Annual Flow (cms)	Critical Storm Location
O1DS	Yes	O'Donnell River approximately 1 km below pyroclastic flow deposit	300	22.9	1.5	4,160	1.9	O1
O5US	No	O'Donnell River below confluence with Apalong River	150	112.2	2.8	3,700	7.6	O1
O5DS	Yes	O'Donnell River above confluence with Bangat River	90	169 1	4.5	3,420	9.9	O1
O7DS	Yes	Bangat River above road crossing approximately 1km southeast of O'Donnell village	120	51.1	2.8	3,460	3.1	O6
O9US	No	Bangat River below road crossing (and unnamed tributary) approximately 1 km southeast of O'Donnell village	120	78.8	2.8	3,350	4.4	O6
O10US	Yes	O'Donnell River below confluence with Bangat River	90	266.0	4.5	3,350	15 0	O1
O10DS	No	O'Donnell River above confluence with Bulsa River	50	305.1	6.5	3,230	16.0	O1
O15US	No	Bulsa River approximately 20 km above streamflow gage W010A	174	231.0	3.9	4,110	18.6	O13
O16DS	No	Bulsa River at streamflow gage W010A	80	436.0	6.8	3,840	31.4	O13
O17DS	No	Bulsa River above confluence with O'Donnell River	50	508.5	9.6	3,680	34.0	O13
O18DS	Yes	O'Donnell River above Highway 13	40	817.2	9.9	3,500	49.9	O1

Table 3.5.12

Computed Maximum Annual Peak Discharge and Volume Frequency Data
O' Donnell Basin

Maximum Annual Peak Discharge (cms)

Site ID	2-year	10-year	50-year	100-year	500-year
O1DS	31	65	97	110	144
O5US	121	258	389	446	585
O5DS	150	321	490	563	741
O7DS	47	102	154	177	233
O9US	63	137	210	241	318
O10US	218	468	714	822	1,084
O10DS	223	477	730	841	1,110
O15US	264	546	815	932	1,216
O16DS	392	799	1,201	1,377	1,802
O17DS	409	830	1,251	1,435	1,881
O18DS	616	1,273	1,933	2,221	2,922

Maximum Annual 24-hr Volume (dam3)

Site ID	2-year	10-year	50-year	100-year	500-year
O1DS	2,600	5,000	7,400	8,500	11,000
O5US	9,900	19,800	29,700	34,000	44,500
O5DS	12,200	25,000	38,000	43,700	57,400
O7DS	3,8[illegible]	7,600	11,500	13,200	17,400
O9US	5,100	10,500	16,000	18,400	24,200
O10US	17,800	36,500	55,700	64,000	84,300
O10DS	18,200	37,600	57,400	66,100	87,200
O15US	21,900	42,600	63,100	72,000	93,700
O16DS	32,400	64,200	96,100	110,000	143,600
O17DS	33,700	67,300	101,100	115,800	151,500
O18DS	50,600	102,600	155,300	178,400	234,200

Maximum Annual 3-Day Volume (dam3)

Site ID	2-year	10-year	50-year	100-year	500-year
O1DS	5,600	11,000	16,400	18,700	24,300
O5US	20,900	42,400	64,300	73,800	96,800
O5DS	26,300	54,100	83,600	96,400	127,200
O7DS	7,800	16,000	24,500	28,300	37,200
O9US	10,900	22,700	35,200	40,600	53,700
O10US	38,300	79,400	123,100	142,200	188,200
O10DS	39,600	82,500	128,300	148,400	196,900
O15US	48,200	95,200	141,900	162,000	211,100
O16DS	74,400	149,000	224,900	258,000	337,600
O17DS	78,300	157,600	239,100	274,800	360,400
O18DS	115,500	236,100	362,100	417,200	549,800

Table 3.5.13

Computed Flow Duration Curves

O'Donnell Basin

Data in cubic meters per second

% OF TIME EXCEEDED	O1DS	O5US	O5DS	O7DS	O9US	O10US
100	0.0	0.0	0.0	0.0	0.0	0.0
50	0.8	3.0	4.0	1.2	1.8	6.0
20	2.4	9.4	12.1	3.8	5.3	18.2
10	3.9	15.6	20.1	6.3	8.8	30.3
5	5.7	22.4	28.6	8.9	12.4	42.8
2	9.5	36.9	46.8	14.6	19.9	69.4
1	13.7	53.0	66.5	20.7	28.0	98.0
0.5	19.0	73.2	91.2	28.3	37.9	133.4
0.2	28.9	111.3	138.5	42.6	56.8	201.5
0.1	38.5	149.5	187.6	57.5	77.1	273.4
0.05	49.3	193.0	243.2	74.3	100.1	354.9
0.02	62.5	245.3	309.8	94.5	127.5	452.2

% OF TIME EXCEEDED	O10DS	O15US	O16DS	O17DS	O18DS
100	0.0	0.0	0.0	.0	0.0
50	6.4	7.4	12.6	13.6	20.0
20	19.2	22.5	37.1	39.8	58.7
10	32.1	37.5	61.9	66.7	98.2
5	45.0	52.9	85.5	91.5	135.2
2	72.5	85.7	135.5	144.1	213.6
1	101.7	120.8	186.9	197.5	294.0
0.5	137.5	164.3	248.5	260.9	389.8
0.2	206.5	244.0	363.0	379.0	571.1
0.1	280.8	324.5	486.2	508.5	771.1
0.05	364.8	416.3	626.3	655.7	998.0
0.02	465.1	527.5	795.2	832.9	1270.0

Table 3.5.14 (sheet 1 of 3)

Sub-Basin Parameters

Gumain/Porac Basin

Sub-Basin ID	G1	G2	G3	G4	G5	G6	G7
Physical Parameters							
Area (km2)	9.4	16.7	6.8	23.0	11.3	13.4	13.2
Longest Flow Path within Sub-Basin (km)	4.3	8.3	3.9	9.0	7.0	7.8	8.5
Elevation Change along Flow Path (m)	665	865	925	575	700	1,323	900
Channel Length to Upstream Basin (km)	N/A	7.9	N/A	7.4	4.7	N/A	N/A
Elevation Change along Channel (m)	N/A	290	N/A	290	60	N/A	N/A
Design Storm Parameters							
Estimated Annual Rainfall (mm)	4,300	3,900	4,350	4,050	3,600	4,200	4,150
Percent of Rainfall near Pinatubo Summit	86	78	87	81	72	84	83
Distance to Assumed Storm Center (km)							
Storm 1 at Sub-Basin G7	10.4	10.0	6.2	6.7	8.7	2.5	0.0
Storm 2 at Sub-Basin G11	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Runoff Parameters							
Time of Concentration (hrs)	0.4	0 8	0.3	1.0	0.7	0.6	0.8
Clark Storage Coefficient (hrs)	10.0	20.0	7.5	25 0	17.5	15 0	20 0
Uniform Infiltration Loss (mm/hr)	3	3	3	3	3	3	3
Baseflow (cms)	1.2	1.7	0.9	2.6	1.0	1.6	1 5
Flow Routing Parameters							
Travel Time of Flood Wave (hrs)	N/A	0.9	N/A	0.8	0.5	N/A	N/A
Number of Sub-Reaches (1-hr time step)	N/A	1	N/A	1	1	N/A	N/A

Table 3.5.14 (sheet 2 of 3)

Gumain/Porac Basin

Sub-Basin ID	G8	G9	G10	G11	G12	G13	G14
Physical Parameters							
Area (km2)	19.3	6.3	21.6	11.7	29.4	10.3	18.0
Longest Flow Path within Sub-Basin (km)	11.9	6.4	12.8	7.8	13.2	6.4	10.3
Elevation Change along Flow Path (m)	1,050	190	55	860	565	485	295
Channel Length to Upstream Basin (km)	9.2	5.3	9.5	N/A	11.5	N/A	5.8
Elevation Change along Channel (m)	210	30	20	N/A	165	N/A	30
Design Storm Parameters							
Estimated Annual Rainfall (mm)	3,650	3,300	3,300	3,750	3,150	3,300	3,150
Percent of Rainfall near Pinatubo Summit	73	66	66	75	63	66	63
Distance to Assumed Storm Center (km)							
Storm 1 at Sub-Basin G7	4.4	14.2	18.4	4.4	11.9	9.4	13.8
Storm 2 at Sub-Basin G11	N/A	N/A	N/A	0.0	8.1	6.2	10.9
Runoff Parameters							
Time of Concentration (hrs)	1.1	1.1	3.8	0.8	1.6	0.7	1.6
Clark Storage Coefficient (hrs)	27.5	27.5	95.0	20.0	40.0	17.5	40.0
Uniform Infiltration Loss (mm/hr)	3	3	3	3	3	3	3
Baseflow (cms)	1.7	0.4	1.5	1.1	1.8	0.7	1.1
Flow Routing Parameters							
Travel Time of Flood Wave (hrs)	1.0	0.6	1.1	N/A	1.3	N/A	0.6
Number of Sub-Reaches (1-hr time step)	1	1	1	N/A	1	N/A	1

Table 3.5.14 (sheet 3 of 3)

Sub-Basin Parameters

Gumain/Porac Basin

Sub-Basin ID	G15	G16	G17	G18	G19
Physical Parameters					
Area (km2)	14.3	20.5	18.2	36.6	2.3
Longest Flow Path within Sub-Basin (km)	8.3	9.3	12.3	14.4	7.9
Elevation Change along Flow Path (m)	940	535	175	180	5
Channel Length to Upstream Basin (km)	N/A	6.6	7.7	5.8	7.9
Elevation Change along Channel (m)	N/A	115	35	5	5
Design Storm Parameters					
Estimated Annual Rainfall (mm)	3,600	3,450	3,150	3,150	3,150
Percent of Rainfall near Pinatubo Summit	72	69	63	63	63
Distance to Assumed Storm Center (km)					
Storm 1 at Sub-Basin G7	5.3	9.7	15.6	18.1	27.8
Storm 2 at Sub-Basin G11	2.8	7.5	13.8	17.2	N/A
Runoff Parameters					
Time of Concentration (hrs)	0.8	1.1	2.4	2.8	0.9
Clark Storage Coefficient (hrs)	20.0	27.5	60.0	70.0	22.5
Uniform Infiltration Loss (mm/hr)	3	3	3	3	1000
Baseflow (cms)	1.2	1.6	1.1	2.2	0.1
Flow Routing Parameters					
Travel Time of Flood Wave (hrs)	N/A	0.7	0.9	0.6	0.9
Number of Sub-Reaches (1-hr time step)	N/A	1	1	1	1

Table 3.5.15
Simulation Output Sites
Gumain/Porac Basin

Site ID	Corps-Specified Site	Site Description	Stream Elevation (m)	Upstream Basin Area (km2)	Time of Concentration (hours)	Average Annual Basin Rainfall (mm)	Average Annual Flow (cms)	Critical Storm Location
G9DS	Yes	Gumain River at streamflow gage W036A	30	119.5	2.4	3,950	9.0	G7
G10DS	Yes	Gumain River above confluence with Porac River	10	141.1	3.5	3,850	10.2	G7
G12DS	Yes	Porac River approximately 13.5 km above streamflow gage W084A	75	41.1	2.0	3,320	2.3	G11
G17DS	Yes	Porac River at streamflow gage W084A	15	122.4	3.6	3,320	5.8	G11
G18DS	Yes	Porac River above confluence with Gumain River	10	159.0	4.3	3,280	8.6	G11
G19US	Yes	Gumain/Porac River above levee	10	300.1	4.3	3,550	18.8	G7
G19DS	Yes	Gumain/Porac River below levee	5	302.4	5.4	3,550	18.3	G7

Table 3.5.16

Computed Maximum Annual Peak Discharge and Volume Frequency Data
Gumain/Porac Basin

Maximum Annual Peak Discharge (cms)

Site ID	2-year	10-year	50-year	100-year	500-year
G9DS	220	470	700	801	1,048
G10DS	228	485	723	828	1,083
G12DS	43	95	145	166	219
G17DS	128	283	430	494	651
G18DS	146	320	488	561	740
G19US	367	794	1,196	1,371	1,801
G19DS	366	790	1,191	1,366	1,793

Maximum Annual 24-hr Volume (dam3)

Site ID	2-year	10-year	50-year	100-year	500-year
G9DS	16,200	31,800	47,200	53,900	70,300
G10DS	16,900	33,300	49,500	56,600	73,800
G12DS	3,400	7,000	10,600	12,200	16,000
G17DS	10,000	20,700	31,400	36,000	47,400
G18DS	11,500	23,400	36,300	41,700	54,900
G19US	28,000	56,400	84,800	97,200	127,300
G19DS	28,000	56,300	84,700	97,000	127,100

Maximum Annual 3-Day Volume (dam3)

Site ID	2-year	10-year	50-year	100-year	500-year
G9DS	28,600	57,300	85,700	98,000	127,700
G10DS	30,500	61,100	91,800	105,100	137,200
G12DS	6,600	13,800	21,400	24,600	32,600
G17DS	19,400	40,300	62,500	72,200	95,600
G18DS	24,000	48,000	74,900	86,500	114,600
G19US	52,800	107,700	164,500	189,300	248,900
G19DS	52,700	107,000	164,500	189,300	248,900

Table 3.5.17

Computed Flow Duration Curves
Gumain/Porac Basin
Data in cubic meters per second

% OF TIME EXCEEDED	G9DS	G10DS	G12DS	G17DS
100	0.0	0.0	0.0	0.0
50	3.6	4.1	0.9	2.7
20	11.6	13.0	2.9	8.7
10	21.0	23.6	4.8	14.3
5	36.6	40.7	7.1	21.0
2	64.6	71.0	12.0	35.3
1	92.0	99.8	17.5	51.7
0.5	125.3	133.5	24.7	72.7
0.2	187.9	196.2	40.0	117.7
0.1	254.3	266.0	55.1	162.6
0.05	321.3	336.3	70.3	207.9
0.02	392.2	410.7	86.3	255.3

% OF TIME EXCEEDED	G18DS	G19US	G19DS
100	0.0	0.0	0.0
50	3.4	7.5	7.5
20	10.7	24.0	24.0
10	17.7	39.6	39.6
5	25.6	58.4	58.4
2	42.4	98.4	98.4
1	61.1	144.2	144.2
0.5	84.7	203.2	203.2
0.2	129.9	327.1	326.9
0.1	175.7	447.1	446.5
0.05	227.6	568.1	567.2
0.02	289.7	695.6	694.3

Table 3.5.18

Sub-Basin Parameters

Pasig-Potrero Basin

Sub-Basin ID	P0	P1	P2	P3	P4	P5	P6	P7
Physical Parameters								
Area (km2)	21.3	9.3	4.4	6	3.1	12.6	17.7	2.4
Longest Flow Path within Sub-Basin (km)	5.9	8.2	4	8	4	9.5	11.5	14
Elevation Change along Flow Path (m)	460	772	480	420	65	135	180	40
Channel Length to Upstream Basin (km)	N/A	6.5	N/A	N/A	4	9.5	4.5	14
Elevation Change along Channel (m)	N/A	140	N/A	N/A	65	135	65	35
Design Storm Parameters								
Estimated Annual Rainfall (mm)	4,670	3,500	3,500	3,000	2,500	2,300	1,950	1,950
Percent of Rainfall near Pinatubo Summit	93	70	65	55	50	42	40	39
Distance to Assumed Storm Center (km)								
Storm 1 at Sub-Basin P0	0	4.2	6.7	8.7	9.7	15	20.8	28
Storm 2 at Sub-Basin P3	N/A	N/A	N/A	0	N/A	N/A	N/A	N/A
Runoff Parameters								
Time of Concentration (hrs)	0.7	0.8	0.4	1	0.9	1.9	2.2	4.8
Clark Storage Coefficient (hrs)	17.5	20.8	11	25.5	23.5	48.3	55	120
Uniform Infiltration Loss (mm/hr)	3	3	3	3	3	3	3	1000
Baseflow (cms)	3.1	0.7	0.3	0.3	0.1	0	0	0
Flow Routing Parameters								
Travel Time of Flood Wave (hrs)	N/A	0.7	N/A	N/A	0.4	1.1	0.5	1.6
Number of Sub-Reaches (1-hr time step)	N/A	1	N/A	N/A	1	1	1	2

Table 3.5.19
Simulation Output Sites
Pasig-Potrero Basin

Site ID	Corps-Specified Site	Site Description	Stream Elevation (m)	Upstream Basin area (km2)	Time of Concen-tration (hours)	Average Annual Basin Rain (mm)	Average Annual Flow (cms)	Critical Storm Location	Critical Storm ID
P0DS	Yes	Upper sub-basin of the Sacobia captured by Pasig	640	21.3	0.7	4,670	2.1	P0	1
P1DS	Yes	Bucbuc River above confluence with Yangca River	300	30.6	1.5	4,310	2.7	P0	1
P2DS	Yes	Yangca River above confluence with Bucbuc River	300	4.4	0.4	3,500	0.27	P0	1
P3DS	Yes	Timbu River above confluence with Papatac River	240	6	1	3,030	0.28	P3	2
P4US	Yes	Papatac River below confluence of Bucbuc and Yangca Rivers	300	35	1.5	4,210	2 9	P0	1
P4DS	Yes	Papatac River above confluence with Timbu River	240	38.1	2	4,080	3	P0	1
P5US	Yes	Pasig River below confluence of Papatac and Timbu Rivers	240	44.1	2	3,930	3.3	P0	1
P5DS	Yes	Pasig River at Mancatian Bridge	100	56.6	3.1	3,780	4	P0	1
P7DS	Yes	Potrero River above confluence with Guagua River	0	76.7	5.5	3,150	4.9	P0	1

Table 3.5.20

Computed Maximum Annual Peak Discharge and Volume Frequency Data
Pasig-Potrero Basin

Site I D	Maximum Annual Peak Discharge (cms)				
	2-year	10-year	50-year	100-year	500-yr
P0DS	55	112	166	189	246
P1DS	69	143	211	241	314
P2DS	8.5	19	28	32	42
P3DS	5.9	13	21	24	32
P4US	77	161	238	272	355
P4DS	79	166	247	282	369
P5US	84	178	265	304	397
P5DS	87	186	279	319	419
P7DS	90	195	294	337	444

Site I D	Maximum Annual 24-hr Volume (cubic decameters)				
	2-year	10-year	50-year	100-year	500-yr
P0DS	4,100	7,700	11,200	12,700	16,500
P1DS	5,100	9,800	14,400	16,400	21,300
P2DS	500	1,100	1,700	1,900	2,500
P3DS	400	900	1,500	1,700	2,200
P4US	5,700	10,900	16,000	18,300	23,700
P4DS	5,800	11,300	16,600	19,000	24,700
P5US	6,200	12,100	18,000	20,500	26,700
P5DS	6,400	12,800	19,100	21,900	28,600
P7DS	6,700	13,600	20,400	23,400	30,800

Site I D	Maximum Annual 3-Day Volume (cubic decameters)				
	2-year	10-year	50-year	100-year	500-yr
P0DS	7,400	13,900	20,200	23,000	29,600
P1DS	9,200	17,700	26,000	29,600	38,400
P2DS	800	1,600	2,500	2,900	3,900
P3DS	800	1,700	2,700	3,100	4,200
P4US	10,000	19,300	28,500	32,500	42,200
P4DS	10,300	19,900	29,600	33,800	44,000
P5US	10,900	21,400	32,000	36,600	47,800
P5DS	11,500	22,800	34,400	39,500	51,900
P7DS	12,100	24,500	37,400	43,000	57,000

Table 3.5.21

Computed Flow Duration Curves

Pasig-Potrero Basin

Data in cubic meters per second

% OF TIME EXCEEDED	P0DS	P1DS	P2DS	P3DS	P4US	P4DS	P5US	P5DS	P7DS
100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
50.0	0.8	1.1	0.1	0.1	1.2	1.2	1.3	1.6	2.0
25.0	2.1	2.7	0.3	0.3	2.9	3.0	3.3	4.0	4.9
20.0	2.7	3.5	0.3	0.4	3.8	3.9	4.3	5.2	6.1
10.0	4.9	6.3	0.6	0.6	6.8	7.0	7.7	8.6	10.2
5.0	8.7	11.1	1.1	0.9	12.0	12.4	13.6	12.8	14.7
2.0	15.6	19.7	2.0	1.4	21.5	22.1	24.1	21.8	24.4
1.0	22.5	28.3	2.8	2.1	31.1	31.9	34.5	32.3	35.3
0.5	31.1	39.0	3.8	2.9	43.1	44.1	47.4	46.0	49.2
0.2	47.0	58.8	6.0	4.8	65.6	67.1	71.8	74.6	78.4
0.1	62.5	79.0	8.5	6.9	88.0	90.6	97.0	101.7	107.5
0.05	78.2	99.2	11.0	9.0	110.4	114.3	122.3	129.0	136.9
0.02	95.0	120.9	13.6	11.1	134.4	139.4	149.2	157.9	167.7

Table 3.5.22 (sheet 1 of 2)
Sub-Basin Parameters
Santo Tomas Basin

Sub-Basin ID	T1	T2	T3	T4	T5	T6
Physical Parameters						
Area (km2)	42.3	33.7	11.0	43.6	18.3	26.0
Longest Flow Path within Sub-Basin (km)	9.8	9.2	8.3	5.4	6.0	4.8
Elevation Change along Flow Path (m)	886	1027	220	714	690	721
Channel Length to Upstream Basin (km)	N/A	5.0	6.1	N/A	N/A	N/A
Elevation Change along Channel (m)	N/A	118	68	N/A	N/A	N/A
Design Storm Parameters						
Estimated Annual Rainfall (mm)	4,800	4,350	4,050	4,200	4,250	3,950
Percent of Rainfall near Pinatubo Summit	96	87	81	84	85	79
Distance to Assumed Storm Center (km)						
Storm 1 at Sub-Basin T1	0.0	5.7	9.4	10.4	14.6	16.8
Storm 2 at Sub-Basin T5	N/A	N/A	N/A	5.7	0.0	5.7
Runoff Parameters						
Time of Concentration (hrs)	1.0	0.9	1.4	0.5	0.6	0.5
Clark Storage Coefficient (hrs)	25.0	22.5	35.0	12.5	15.0	12.5
Uniform Infiltration Loss (mm/hr)	3	3	3	3	3	3
Baseflow (cms)	6.5	4.3	1.2	5.2	2.2	2.7
Flow Routing Parameters						
Travel Time of Flood Wave (hrs)	N/A	0.6	0.7	N/A	N/A	N/A
Number of Sub-Reaches (1-hr time step)	N/A	1	1	N/A	N/A	N/A

Table 3.5.22 (sheet 2 of 2)

Sub-Basin Parameters

Santo Tomas Basin

Sub-Basin ID	T7 (lake)	T8	T9	T10
Physical Parameters				
Area (km2)	8.0	42.3	31.4	4.9
Longest Flow Path within Sub-Basin (km)	N/A	16.2	15.6	8.4
Elevation Change along Flow Path (m)	N/A	330	481	110
Channel Length to Upstream Basin (km)	N/A	N/A	13.7	8.4
Elevation Change along Channel (m)	N/A	N/A	81	7
Design Storm Parameters				
Estimated Annual Rainfall (mm)	4,050	3,850	3,700	3,550
Percent of Rainfall near Pinatubo Summit	81	77	74	71
Distance to Assumed Storm Center (km)				
Storm 1 at Sub-Basin T1	14.0	13.7	17.1	24.4
Storm 2 at Sub-Basin T5	6.0	N/A	N/A	N/A
Runoff Parameters				
Time of Concentration (hrs)	0.0	2.5	2.1	1.8
Clark Storage Coefficient (hrs)	0.0	62.5	52.5	45.0
Uniform Infiltration Loss (mm/hr)	0	3	3	3
Baseflow (cms)	0.0	4.2	2.9	0.4
Flow Routing Parameters				
Travel Time of Flood Wave (hrs)	N/A	N/A	1.5	0.9
Number of Sub-Reaches (1-hr time step)	N/A	N/A	2	1

Table 3.5.24

Computed Maximum Annual Peak Discharge and Volume Frequency Data
Santo Tomas Basin

Maximum Annual Peak Discharge (cms)

Site ID	2-year	10-year	50-year	100-year	500-year
T2DS	156	320	472	538	699
T3DS	169	347	512	584	760
T7DS	84	172	259	296	384
T9US	224	457	684	783	1,023
T10DS	285	578	867	993	1,297

Maximum Annual 24-hr Volume (dam3)

Site ID	2-year	10-year	50-year	100-year	500-year
T2DS	12,300	23,200	34,000	38,600	50,000
T3DS	13,400	25,400	37,200	42,400	54,900
T7DS	7,000	14,500	21,800	25,000	32,500
T9US	18,600	36,800	54,700	62,500	81,300
T10DS	23,600	47,000	70,100	80,200	104,400

Maximum Annual 3-Day Volume (dam3)

Site ID	2-year	10-year	50-year	100-year	500-year
T2DS	24,100	45,700	66,900	76,000	98,200
T3DS	26,400	50,500	74,000	84,200	108,800
T7DS	18,100	37,600	56,600	64,900	84,600
T9US	42,100	84,200	125,300	143,200	186,100
T10DS	54,300	109,300	163,500	187,000	243,500

Table 3.5.25
Computed Flow Duration Curves
Santo Tomas Basin
Data in cubic meters per second

% OF TIME EXCEEDED	T2DS	T3DS	T7DS	T9US	T10DS
100	0.0	0.0	0.0	0.0	0.0
50	2.9	3.3	3.1	6.3	8.6
20	9.3	10.7	9.0	19.1	25.6
10	16.9	17.6	15.1	31.8	42.7
5	29.2	26.4	20.4	44.9	59.6
2	51.1	45.2	31.6	72.7	95.4
1	71.9	67.2	42.7	102.6	133.2
0.5	96.6	95.9	55.4	139.4	179.2
0.2	140.9	153.7	79.8	208.1	265.1
0.1	188.2	205.6	108.4	278.7	355.7
0.05	235.7	257.8	140.8	356.9	458.6
0.02	286.6	313.5	179.5	455.7	582.5

Table 3.5.26 (sheet 1 of 2)
Sub-Basin Parameters
Bueno Basin

Sub-Basin ID	B1	B2	B3	B4	B5	B6	B7	B8
Pysical Parameters								
Area (km2)	72.3	43.8	10 6	23.7	67 0	39 1	17 3	43.9
Longest Flow Path within Sub-Basin (km)	16.8	15.2	9 2	8.3	13.9	14.3	12.9	15.6
Elevation Change along Flow Path (m)	940	1,165	355	875	980	620	860	700
Channel Length to Upstream Basin (km)	N/A	N/A	N/A	2 9	12 5	N/A	N/A	5.8
Elevation Change along Channel (m)	N/A	N/A	N/A	35	105	N/A	N/A	80
Design Storm Parameters								
Estimated Annual Rainfall (mm)	4,100	4,200	4,050	4,200	4,200	3,900	4,100	4 050
Percent of Rainfall near Pinatubo Summit	82	84	81	84	84	78	82	81
Distance to Assumed Storm Center (km)								
Storm 1 at Sub-Basin B1	3 2	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Storm 2 at Sub-Basin B2	6.0	2.5	4.8	10.5	13.6	9.2	5 4	7 6
Storm 3 at Sub-Basin B3	N/A	N/A	1 2	N/A	N/A	N/A	N/A	N/A
Storm 4 at Sub-Basin B6	N/A	N/A	N/A	N/A	N/A	2 4	N/A	N/A
Storm 5 at Sub-Basin B7	N/A	N/A	N/A	N/A	N/A	N/A	1.6	N/A
Storm 6 at Sub-Basin B11	N/A	N/A	N/A	N/A	N/A	14.6	16 2	14 0
Runoff Parameters								
Time of Concentration (hrs)	1 8	1.4	1.3	8	1 4	1 7	1 3	1 8
Clark Storage Coefficient (hrs)	45.0	35.0	32.5	20 0	35.0	42.5	32 5	45 0
Uniform Infiltration Loss (mm/hr)	3	3	3	3	3	3	3	3
Baseflow (m3/s)	8.3	5.3	1.2	2 8	8 0	4 0	2 0	4 9
Flow Routing Parameters								
Travel Time (hrs)	N/A	N/A	N/A	0.3	1 4	N/A	N/A	0 6
Number of Sub-Reaches	N/A	N/A	N/A	0	1	N/A	N/A	1

Table 3.5.26 (sheet 2 of 2)

Sub-Basin Parameters

Bucno Basin

Sub-Basin ID	B9	B10	B11	B12	B13	B14	B15	B16
Pysical Parameters								
Area (km2)	25.2	72.1	56.9	36.5	10 0	29.4	63.4	45 3
Longest Flow Path within Sub-Basin (km)	11.1	14 0	16.4	8.3	5.6	11 7	14.7	12.5
Elevation Change along Flow Path (m)	234	945	1,535	325	160	821	1,655	655
Channel Length to Upstream Basin (km)	7.9	N/A	N/A	5.8	4 0	5.9	N/A	5.7
Elevation Change along Channel (m)	65	N/A	N/A	40	10	30	N/A	10
Design Storm Parameters								
Estimated Annual Rainfall (mm)	4,000	4,050	4,500	4,050	4,050	4,050	4,600	4,100
Percent of Rainfall near Pinatubo Summit	80	81	90	81	81	81	92	82
Distance to Assumed Storm Center (km)								
Storm 1 at Sub-Basin B1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Storm 2 at Sub-Basin B2	12 1	17.8	21.6	17.8	18 1	21 0	24.4	26.7
Storm 3 at Sub-Basin B3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Storm 4 at Sub-Basin B6	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Storm 5 at Sub-Basin B7	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Storm 6 at Sub-Basin B11	12 1	6.4	2.8	6.7	10.2	N/A	N/A	N/A
Runoff Parameters								
Time of Concentration (hrs)	1.9	1.4	1.4	1 2	1.0	1 2	1 2	1.4
Clark Storage Coefficient (hrs)	47.5	35.0	35.0	30 0	25.0	30 0	30 0	35 0
Uniform Infiltration Loss (mm/hr)	3	3	3	3	3	3	3	3
Baseflow (m^3/s)	2.7	8.0	7 8	4 1	1.1	3 3	9.1	5.2
Flow Routing Parameters								
Travel Time (hrs)	0.9	N/A	N/A	0 6	0.4	0 7	N/A	0 6
Number of Sub-Reaches	1	N/A	N/A	1	0	1	N/A	1

Table 3.5.27
Simulation Output Sites
Bucao Basin

Site ID	Corps-Specified Site	Site Description	Stream Elevation (m)	Upstream Basin Area (km2)	Time of Concentration (hours)	Average Annual Basin Rain (mm)	Average Annual Flow (cms)	Critical Storm Location
B1DS	Yes	Balin-Buquero River headwater basin	180	72.3	1.8	4,100	5.8	B1
B2DS	Yes	Headwater basin originating as the Maronut River near Mt Pinatubo, channel direction shifted above basin B3 as a result of depositions	145	43.8	1.4	4,200	3.7	B2
B3DS	Yes	Maronut River downstream of channel shift noted in sub-basin B2.	145	10 6	1 3	4,200	0 9	B3
B5US	Yes	Balin-Buquero River below confluence with Maronut River	145	150.4	2.1	4,150	12.3	B2
B5DS	Yes	Balin-Buquero River above confluence with Bucao River	40	217.4	3.5	4,150	17.8	B2
B6DS	Yes	Bucao River headwater basin	200	39.1	1.7	3,900	2.9	B6
B7DS	Yes	Kayanga Creek above confluence with Bucao River	120	17 3	1 3	4,100	1.4	B7
B13DS	Yes	Bucao River above confluence with the Balin-Buquero River	40	301 0	4 0	4,100	24.1	B11
B14US	Yes	Bucao River below confluence with the Balin-Buquero River	40	518.4	4.0	4,150	42 4	B2
B16US	No	Bucao River at streamflow gage W093A	15	611 2	4.8	4,200	50 9	B2
B16DS	Yes	Bucao River at Hwy 7 bridge. (approximately 2 5 km upstream of South China Sea)	5	656.5	5.6	4,150	53 7	B2

Table 3.5.28

Computed Maximum Annual Peak Discharge and Volume Frequency Data

Busao Basin

Maximum Annual Peak Discharge (cms)

Site ID	2-year	10-year	50-year	100-year	500-year
B1DS	86	175	260	297	387
B2DS	63	132	195	223	290
B3DS	15	32	48	55	72
B5US	200	421	626	716	933
B5DS	283	592	881	1,007	1,314
B6DS	45	93	139	160	208
B7DS	26	54	80	91	119
B13DS	376	787	1,173	1,342	1,752
B14US	643	1,345	2,007	2,296	2,998
B16US	780	1,623	2,420	2,768	3,613
B16DS	834	1,737	2,591	2,963	3,869

Maximum Annual 24-hr Volume (dam3)

Site ID	2-year	10-year	50-year	100-year	500-year
B1DS	7,100	13,900	20,600	23,400	30,400
B2DS	5,200	10,100	14,900	17,000	22,000
B3DS	1,300	2,500	3,600	4,100	5,400
B5US	16,400	32,200	47,500	54,200	70,400
B5DS	23,300	45,800	67,800	77,300	100,500
B6DS	3,700	7,300	10,900	12,500	16,200
B7DS	2,100	4,100	6,000	6,900	8,900
B13DS	31,000	61,200	90,700	103,500	134,700
B14US	53,000	104,700	155,200	177,200	230,600
B16US	64,100	126,300	187,100	213,600	277,800
B16DS	68,600	135,200	200,400	228,700	297,600

Maximum Annual 3-Day Volume (dam3)

Site ID	2-year	10-year	50-year	100-year	500-year
B1DS	16,100	32,000	47,500	54,300	70,500
B2DS	11,100	21,800	32,300	36,800	47,700
B3DS	2,600	5,100	7,600	8,700	11,300
B5US	34,800	69,300	103,000	117,600	152,800
B5DS	49,800	99,400	147,800	168,900	219,600
B6DS	8,200	16,500	24,700	28,300	36,800
B7DS	4,300	8,600	12,700	14,500	18,800
B13DS	66,900	134,100	199,800	228,400	297,200
B14US	114,000	229,200	341,700	390,600	508,500
B16US	137,500	275,200	409,800	468,400	609,400
B16DS	147,100	294,700	439,000	501,800	652,900

Table 3.5.29
Computed Flow Duration Curves
Bucao Basin
Data in cubic meters per second

% OF TIME EXCEEDED	B1DS	B2DS	B3DS	B5US	B5DS	B6DS
100	0.0	0.0	0.0	0.0	0.0	0.0
50	2.3	1.5	0.4	4.9	7.1	1.2
20	7.1	4.7	1.1	15.3	22.1	3.6
10	11.8	7.7	1.9	25.4	36.6	5.9
5	16.7	11.2	2.7	36.6	52.6	8.5
2	27.3	18.8	4.5	60.5	86.8	13.9
1	38.7	27.3	6.6	87.2	124.6	19.9
0.5	53.0	38.2	9.2	120.9	172.3	27.4
0.2	79.4	58.2	14.0	183.4	261.0	41.5
0.1	105.8	77.2	18.7	244.4	348.1	55.6
0.05	135.9	98.9	23.9	314.0	447.4	71.6
0.02	172.3	125.3	30.4	398.1	567.4	91.0

% OF TIME EXCEEDED	B7DS	B13DS	B14US	B16US	B16DS
100	0.0	0.0	0.0	0.0	0.0
50	0.6	9.6	17.0	20.4	21.5
20	1.8	29.8	52.0	62.6	66.2
10	3.0	49.4	86.4	103.9	109.9
5	4.4	70.8	123.2	148.3	157.2
2	7.4	116.4	201.5	243.0	258.2
1	10.8	166.6	287.2	346.7	369.[illegible]
0.5	15.2	229.8	394.2	476.5	508.7
0.2	24.3	347.5	593.6	717.9	768.0
0.1	32.8	464.3	793.7	958.7	1026.0
0.05	41.3	597.3	1021.4	1232.8	1319.6
0.02	50.4	757.9	1296.2	1564.0	1674.3

Table 3.5.30

Sub-Basin Parameters
Maloma Basin

Sub-Basin ID	M1	M2	M3	M4	M5	M6
Physical Parameters						
Area (km2)	6.0	68.2	23.2	20 8	18.7	13.0
Longest Flow Path within Sub-Basin (km)	6.2	17.8	7.9	7.7	11.5	6.4
Elevation Change along Flow Path (m)	430	325	401	845	620	383
Channel Length to Upstream Basin (km)	N/A	15.0	N/A	7.0	10.7	5.7
Elevation Change along Channel (m)	N/A	195	N/A	20	90	3
Design Storm Parameters						
Estimated Annual Rainfall (mm)	4,100	4,400	4,250	4,500	4,300	4,200
Percent of Rainfall near Pinatubo Summit	82	88	85	90	86	84
Distance to Assumed Storm Center (km)						
Storm 1 at Sub-Basin M1	0.0	N/A	N/A	N/A	N/A	N/A
Storm 2 at Sub-Basin M3	N/A	N/A	6.9	N/A	0.0	N/A
Storm 3 at Sub-Basin M4	15.0	7.2	7.7	0.0	2.5	5.3
Runoff Parameters						
Time of Concentration (hrs)	0.8	2.8	1.0	0.7	1 3	0.8
Clark Storage Coefficient (hrs)	20.0	70.0	25.0	17 5	32.5	20 0
Uniform Infiltration Loss (mm/hr)	3	3	3	3	3	3
Baseflow (cms)	0.7	9'	2.9	2.9	2 4	1.6
Flow Routing Parameters						
Travel Time of Flood Wave (hrs)	N/A	1.7	N/A	0.8	1 2	0 6
Number of Sub-Reaches (1-hr time step)	N/A	1	N/A	1	1	1

Table 3.5.31
Simulation Output Sites
Maloma Basin

Site ID	Corps-Specified Site	Site Description	Stream Elevation (m)	Upstream Basin Area (km2)	Time of Concentration (hours)	Average Annual Basin Rain (mm)	Average Annual Flow (cms)	Critical Storm Location
M1DS	Yes	Headwater tributary of Maloma River approximately 0.25 km upstream of Payodpod	220	6.0	0.8	4,100	0.5	M1
M4DS	No	Maloma River upstream of confluence with Gorongoro River	5	74.2	4.1	4,400	6.7	M4
M5DS	No	Gorongoro tributary upstream of confluence with Maloma River	5	41.9	2.5	4,250	3.6	M5
M6DS	Yes	Maloma River at streamflow gage W099B	2	150.0	5.1	4,350	13.2	M4

Table 3.5.32

Computed Maximum Annual Peak Discharge and Volume Frequency Data
Maloma Basin

Maximum Annual Peak Discharge (cms)

Site ID	2-year	10-year	50-year	100-year	500-year
M1DS	12	26	38	44	57
M4DS	119	244	360	411	534
M5DS	69	143	212	242	315
M6DS	212	437	646	738	960

Maximum Annual 24-hr Volume (dam3)

Site ID	2-year	10-year	50-year	100-year	500-year
M1DS	900	1,800	2,600	3,000	3,900
M4DS	9,700	18,700	27,400	31,200	40,400
M5DS	5,500	10,700	15,700	17,900	23,200
M6DS	17,100	33,000	48,400	55,200	71,600

Maximum Annual 3-Day Volume (dam3)

Site ID	2-year	10-year	50-year	100-year	500-year
M1DS	1,700	3,300	4,800	5,500	7,200
M4DS	21,500	41,700	61,200	69,700	90,200
M5DS	11,100	21,700	32,100	36,600	47,500
M6DS	36,000	70,000	103,200	117,600	152,300

Table 3.5.33
Computed Flow Duration Curves
Maloma Basin
Data in cubic meters per second

% OF TIME EXCEEDED	M1DS	M4DS	M5DS	M6DS
100	0.0	0.0	0.0	0.0
50	0.2	2.7	1.4	5.3
20	0.6	8.5	4.6	16.3
10	1.2	14.1	7.6	27.1
5	2.0	20.6	11.3	38.9
2	3.6	34.6	19.1	64.0
1	5.2	50.5	28.2	91.7
0.5	7.1	71.0	39.9	126.7
0.2	10.7	112.4	63.6	190.4
0.1	14.4	150.8	85.5	252.1
0.05	18.2	189.4	107.5	322.6
0.02	22.2	230.6	131.0	408.2

Table 3.5.34 (sheet 1 of 2)

Estimated Peak Instantaneous Discharges and Confidence Limits at Hydrologic Output Sites

Site ID	HEC-2 Estimated Peak Discharge					Peak Discharge, Estimated 5% Confidence Limit					Peak Discharge, Estimated 95% Confidence Limit				
	2-Year (cms)	10-Year (cms)	50-Year (cms)	100-Year (cms)	500-Year (cms)	2-Year (cms)	10-Year (cms)	50-Year (cms)	100-Year (cms)	500-Year (cms)	2-Year (cms)	10-Year (cms)	50-Year (cms)	100-Year (cms)	500-Year (cms)
A1DS	10	23	35	40	52	12	30	48	54	67	8	18	24	25	26
A3DS	31	69	108	122	161	37	90	145	166	206	26	54	71	76	81
A5DS	41	90	138	159	211	49	117	188	216	270	34	70	93	99	106
B1DS	86	175	260	297	387	103	228	355	404	495	72	137	175	185	194
B2DS	63	132	195	223	290	75	172	266	303	371	53	103	131	139	146
B3DS	15	32	48	55	72	18	42	65	75	92	13	25	32	34	36
B5US	200	421	626	716	033	239	550	854	974	1,194	167	329	421	446	469
B5DS	283	592	881	1,007	1,314	339	773	1,202	1,370	1,681	236	463	593	627	660
B6DS	45	93	139	160	208	54	121	190	218	266	38	73	94	100	105
B7DS	26	54	80	91	119	31	70	109	124	152	22	42	54	57	60
B13DS	376	787	1,173	1,342	1,752	450	1,027	1,601	1,826	2,242	314	616	789	835	880
B14US	643	1,345	2,007	2,298	2,998	770	1,756	2,739	3,124	3,836	536	1,052	1,351	1,429	1,506
B16US	780	1,623	2,420	2,768	3,613	934	2,119	3,302	3,766	4,622	651	1,270	1,628	1,723	1,816
B16DS	834	1,737	2,591	2,963	3,869	999	2,268	3,535	4,031	4,950	696	1,359	1,743	1,844	1,944
G9DS	220	470	700	801	1,046	263	614	955	1,090	1,341	184	368	471	499	527
G10DS	228	485	723	828	1,083	273	633	987	1,127	1,386	190	380	487	515	544
G12DS	43	95	145	166	219	51	124	198	226	280	36	74	98	103	110
G17DS	128	283	430	494	651	153	369	587	672	833	107	221	289	308	327
G18DS	146	320	488	561	740	175	418	666	763	947	122	250	328	349	372
G19US	367	794	1,196	1,371	1,801	439	1,037	1,632	1,865	2,304	306	621	805	853	905
G19DS	366	790	1,191	1,366	1,793	438	1,031	1,625	1,859	2,294	305	618	801	850	901
M1DS	12	28	38	44	57	14	34	52	60	73	10	20	26	27	29
M4DS	119	244	360	411	534	142	319	491	559	683	99	191	242	256	268
M5DS	69	143	212	242	315	83	187	289	329	403	58	112	143	151	158
M6DS	212	437	646	738	960	254	571	881	1,004	1,228	177	342	435	459	482

Table 3.5.34 (sheet 2 of 2)

Estimated Peak Instantaneous Discharges and Confidence Limits at Hydrologic Output Sites

Site ID	HFC-2 Estimated Peak Discharge					Peak Discharge, Estimated 5% Confidence Limit					Peak Discharge, Estimated 95% Confidence Limit				
	2-Year (cms)	10-Year (cms)	50-Year (cms)	100-Year (cms)	500-Year (cms)	2-Year (cms)	10-Year (cms)	50-Year (cms)	100-Year (cms)	500-Year (cms)	2-Year (cms)	10-Year (cms)	50-Year (cms)	100-Year (cms)	500-Year (cms)
O1DS	31	65	97	110	144	37	85	132	150	184	26	51	65	68	72
O5US	121	258	389	446	585	145	337	531	607	748	101	202	262	278	294
O5DS	150	321	490	563	741	180	419	669	766	948	125	251	330	350	372
O7DS	47	102	154	177	233	56	133	210	241	298	39	80	104	110	117
O9US	63	137	210	241	318	75	179	287	328	407	53	107	141	150	160
O10US	218	468	714	822	1,084	261	611	974	1,118	1,387	182	366	480	512	545
O10DS	223	477	730	841	1,110	267	623	998	1,144	1,420	186	373	491	524	558
O15US	264	546	815	932	1,216	316	713	1,112	1,268	1,556	220	427	548	580	611
O16DS	392	799	1,201	1,377	1,802	469	1,043	1,639	1,874	2,305	327	625	808	857	906
O17DS	409	830	1,251	1,435	1,881	490	1,084	1,707	1,952	2,407	341	649	842	893	945
O18DS	616	1,273	1,933	2,221	2,922	738	1,662	2,638	3,022	3,738	514	996	1,301	1,383	1,468
P1DS	15	32	49	56	73	18	42	67	76	93	13	25	33	35	37
P2DS	9	20	30	34	45	11	26	41	46	58	8	16	20	21	23
P3DS	6	13	21	24	32	7	17	29	33	41	5	10	14	15	16
P4US	24	52	78	90	118	29	68	106	122	151	20	41	52	56	59
P4DS	27	57	87	100	131	32	74	119	136	168	23	45	59	62	66
P5US	32	70	107	122	161	38	91	146	166	206	27	55	72	76	81
P5DS	35	79	121	140	186	42	103	165	190	238	29	62	81	87	93
P7DS	39	89	138	159	213	47	116	188	216	273	33	70	93	99	107
S1DS	55	112	166	189	246	66	146	227	257	315	46	88	112	118	124
S2DS	76	159	238	273	357	91	208	325	371	457	63	124	160	170	179
S3DS	83	175	262	300	394	99	228	357	408	504	69	137	176	187	198
S4DS	13	29	45	52	70	16	38	61	71	90	11	23	30	32	35
S6DS	62	138	211	243	321	74	180	288	331	411	52	108	142	151	161
S7US	153	332	505	580	764	183	433	689	789	977	128	260	340	361	384
S7DS	152	329	500	575	757	182	430	682	782	969	127	257	336	358	380
T2DS	156	320	472	538	699	187	418	644	732	894	130	250	318	335	351
T3DS	169	347	512	584	760	202	453	699	795	972	141	272	345	364	382
T7DS	84	172	259	296	384	101	225	353	403	491	70	135	174	184	193
T9US	224	457	684	783	1,023	268	597	933	1,065	1,309	187	358	460	487	514
T10DS	285	578	867	993	1,297	341	755	1,183	1,361	1,659	238	452	583	618	652

Table 3.5.35 (sheet 1 of 2)

Estimated Maximum Annual 24-Hour Volume and Confidence Limits at Hydrologic Output Sites

Site ID	HEC-2 Estimated 24-Hour Volume					24-Hour Volume, Estimated 5% Confidence Limit					24-Hour Volume, Estimated 95% Confidence Limit				
	2-Year (dam^3)	10-Year (dam^3)	50-Year (dam^3)	100-Year (dam^3)	500-Year (dam^3)	2-Year (dam^3)	10-Year (dam^3)	50-Year (dam^3)	100-Year (dam^3)	500-Year (dam^3)	2-Year (dam^3)	10-Year (dam^3)	50-Year (dam^3)	100-Year (dam^3)	500-Year (dam^3)
A1DS	800	1,600	2,400	2,800	3,600	958	2,089	3,275	3,810	4,606	667	1,252	1,615	1,743	1,809
A3DS	2,500	5,100	7,800	9,000	11,900	2,994	6,656	10,643	12,245	15,225	2,085	3,991	5,249	5,603	5,980
A5DS	3,100	6,500	10,000	11,500	15,300	3,712	8,486	13,645	15,647	19,575	2,586	5,086	6,729	7,159	7,686
B1DS	7,099	13,919	20,553	23,430	30,438	8,500	18,171	28,045	31,879	38,942	5,921	10,892	13,830	14,585	15,295
B2DS	5,221	10,121	14,899	16,983	22,032	6,252	13,213	20,330	23,107	28,188	4,355	7,920	10,026	10,572	11,071
B3DS	1,254	2,452	3,621	4,130	5,367	1,502	3,201	4,941	5,619	6,867	1,046	1,919	2,437	2,571	2,697
B5US	16,403	32,152	47,507	54,189	70,424	19,641	41,974	64,823	73,730	90,100	13,682	25,159	31,967	33,733	35,388
B5DS	23,330	45,828	67,779	77,346	100,544	27,935	59,828	92,484	105,237	128,636	19,460	35,860	45,608	48,148	50,523
B6DS	3,700	7,346	10,908	12,458	16,223	4,430	9,590	14,884	16,950	20,756	3,086	5,748	7,340	7,755	8,152
B7DS	2,097	4,084	6,022	6,863	8,917	2,511	5,332	8,217	9,338	11,408	1,749	3,196	4,052	4,272	4,481
B13DS	31,032	61,210	90,701	103,534	134,667	37,158	79,910	123,762	140,868	172,319	25,884	47,897	61,033	64,450	67,680
B14US	52,987	104,669	155,204	177,211	230,593	63,447	136,671	211,776	241,113	295,021	44,196	81,919	104,437	110,314	115,873
B16US	64,131	126,315	187,114	213,596	277,846	76,790	164,904	255,317	290,619	355,476	53,492	98,841	125,909	132,964	139,618
B16DS	68,594	135,229	200,375	228,743	297,584	82,134	176,541	273,412	311,228	380,729	57,214	105,817	134,832	142,393	149,536
G9DS	16,200	31,600	47,200	53,900	70,300	19,398	41,515	64,404	73,336	89,942	13,512	24,884	31,761	33,553	35,326
G10DS	16,900	33,300	49,500	56,600	73,800	20,236	43,473	67,543	77,010	94,420	14,096	26,057	33,309	35,234	37,085
G12DS	3,400	7,000	10,600	12,200	16,000	4,071	9,139	14,464	16,599	20,470	2,836	5,478	7,133	7,595	8,040
G17DS	10,000	20,700	31,400	36,000	47,400	11,974	27,024	42,845	48,982	60,644	8,341	16,198	21,129	22,410	23,819
G18DS	11,500	23,400	36,300	41,700	54,900	13,770	30,549	49,531	56,737	70,239	9,592	18,311	24,426	25,958	27,587
G19US	28,000	56,400	84,800	97,200	127,300	33,527	73,630	115,710	132,250	162,868	23,355	44,133	57,062	60,507	63,968
G19DS	28,000	56,300	84,700	97,000	127,100	33,527	73,500	115,573	131,978	162,612	23,355	44,055	56,995	60,383	63,868
M1DS	930	1,796	2,643	3,012	3,913	1,114	2,345	3,606	4,098	5,006	776	1,405	1,778	1,875	1,966
M4DS	9,751	18,695	27,403	31,189	40,393	11,676	24,406	37,391	42,436	51,679	8,133	14,629	18,439	19,415	20,297
M5DS	5,511	10,662	15,692	17,886	23,214	6,599	13,919	21,412	24,336	29,700	4,597	8,343	10,559	11,134	11,665
M6DS	17,120	32,071	48,428	55,156	71,511	20,499	43,044	66,080	75,045	91,491	14,280	25,800	32,587	34,335	35,934

Table 3.5.35 (sheet 2 of 2)

Estimated Maximum Annual 24-Hour Volume and Confidence Limits at Hydrologic Output Sites

Site ID	HEC-2 Estimated 24-Hour Volume					24-Hour Volume, Estimated 5% Confidence Limit					24-Hour Volume, Estimated 95% Confidence Limit				
	2-Year (dam^3)	10-Year (dam^3)	50-Year (dam^3)	100-Year (dam^3)	500-Year (dam^3)	2-Year (dam^3)	10-Year (dam^3)	50-Year (dam^3)	100-Year (dam^3)	500-Year (dam^3)	2-Year (dam^3)	10-Year (dam^3)	50-Year (dam^3)	100-Year (dam^3)	500-Year (dam^3)
O1DS	2,593	5,049	7,442	8,480	11,010	3,105	6,591	10,155	11,538	14,086	2,163	3,951	5,008	5,279	5,533
O5US	9,894	19,809	29,707	34,010	44,471	11,847	25,661	40,535	46,274	56,696	8,253	15,501	19,990	21,171	22,347
O5DS	12,237	25,020	38,025	43,683	57,420	14,653	32,664	51,885	59,435	73,463	10,207	19,578	25,587	27,193	28,854
O7DS	3,785	7,629	11,525	13,222	17,344	4,532	9,960	15,726	17,990	22,190	3,157	5,970	7,755	8,231	8,715
O9US	5,132	10,498	15,990	18,381	24,187	6,145	13,705	21,818	25,009	30,945	4,281	8,215	10,760	11,442	12,154
O10US	17,780	36,523	55,685	64,033	84,300	21,290	47,681	75,982	87,123	107,853	14,830	28,579	37,470	39,861	42,361
O10DS	18,205	37,564	57,406	66,088	87,156	21,799	49,040	78,330	89,919	111,507	15,185	29,394	38,628	41,140	43,796
O15US	21,869	42,603	63,094	72,030	93,664	26,186	55,618	86,092	98,004	119,834	18,241	33,337	42,456	44,839	47,066
O16DS	32,357	64,222	96,099	109,985	143,602	38,744	83,842	131,127	149,646	183,724	26,989	50,254	64,665	68,466	72,160
O17DS	33,736	67,270	101,071	115,826	151,526	40,395	87,821	137,911	157,593	193,862	28,139	52,639	68,011	72,102	76,142
O18DS	50,606	102,570	155,345	178,388	234,218	60,596	133,905	211,968	242,712	299,659	42,210	80,261	104,532	111,045	117,695
P1DS	1,100	2,200	3,300	3,800	5,000	1,317	2,872	4,503	5,170	6,397	918	1,722	2,221	2,366	2,513
P2DS	600	1,200	1,800	2,000	2,700	718	1,567	2,456	2,721	3,454	500	939	1,211	1,245	1,357
P3DS	400	900	1,500	1,700	2,200	479	1,175	2,047	2,313	2,815	334	704	1,009	1,058	1,106
P4US	1,700	3,400	5,100	5,800	7,600	2,036	4,439	6,959	7,891	9,723	1,418	2,661	3,432	3,611	3,819
P4DS	1,900	3,800	5,700	6,600	8,600	2,275	4,961	7,778	8,980	11,003	1,585	2,974	3,836	4,109	4,322
P5US	2,300	4,600	7,100	8,100	10,700	2,754	6,005	9,688	11,021	13,690	1,918	3,600	4,778	5,042	5,377
P5DS	2,500	5,400	8,300	9,500	12,700	2,994	7,050	11,325	12,926	16,248	2,085	4,226	5,585	5,914	6,382
P7DS	2,800	6,200	9,600	11,100	14,900	3,353	8,094	13,099	15,103	19,063	2,335	4,852	6,460	6,910	7,487
S1DS	4,100	7,700	11,200	12,700	16,500	4,909	10,052	15,282	17,280	21,110	3,420	6,025	7,536	7,906	8,291
S2DS	5,900	11,400	17,000	19,400	25,300	7,065	14,883	23,197	26,396	32,369	4,921	8,921	11,439	12,077	12,713
S3DS	6,400	12,700	19,000	21,700	28,400	7,663	16,580	25,926	29,525	36,335	5,338	9,938	12,785	13,508	14,271
S4DS	1,100	2,300	3,600	4,200	5,500	1,317	3,003	4,912	5,715	7,037	918	1,800	2,422	2,615	2,764
S6DS	5,000	10,500	16,000	18,400	24,300	5,987	13,708	21,832	25,035	31,089	4,171	8,216	10,766	11,454	12,211
S7US	12,200	24,900	37,700	43,300	57,000	14,608	32,507	51,442	58,914	72,926	10,176	19,484	25,368	26,954	28,643
S7DS	12,100	24,800	37,600	43,200	56,900	14,489	32,376	51,305	58,778	72,798	10,093	19,406	25,301	26,892	28,592
T2DS	12,270	23,238	33,975	38,642	50,036	14,692	30,337	46,359	52,576	64,016	10,234	18,184	22,862	24,055	25,143
T3DS	13,366	25,423	37,236	42,372	54,893	16,004	33,190	50,809	57,651	70,230	11,149	19,893	25,056	26,377	27,584
T7DS	7,031	14,501	21,828	24,983	32,477	8,419	18,931	29,784	33,992	41,551	5,865	11,347	14,688	15,552	16,320
T9US	18,553	36,807	54,727	62,514	81,298	22,215	48,052	74,675	85,057	104,013	15,475	28,801	36,826	38,915	40,852
T10DS	23,608	47,044	70,146	80,176	104,403	28,268	61,416	95,714	109,087	133,573	19,691	36,812	47,201	49,910	52,463

Table 3.5.36 (sheet 1 of 2)

Estimated Maximum 3-Day Volume and Confidence Limits at Hydrologic Output Sites

Site ID	HEC-2 Estimated 3-Day Volume					3-Day Volume, Estimated 5% Confidence Limit					3-Day Volume, Estimated 95% Confidence Limit				
	2-Year (dam^3)	10-Year (dam^3)	50-Year (dam^3)	100-Year (dam^3)	500-Year (dam^3)	2-Year (dam^3)	10-Year (dam^3)	50-Year (dam^3)	100-Year (dam^3)	500-Year (dam^3)	2-Year (dam^3)	10-Year (dam^3)	50-Year (dam^3)	100-Year (dam^3)	500-Year (dam^3)
A1DS	1,300	2,800	4,300	5,000	6,700	1,557	3,855	5,867	6,803	8,572	1,084	2,191	2,893	3,113	3,367
A3DS	4,900	10,300	16,200	18,800	25,000	5,867	13,447	22,105	25,579	31,985	4,087	8,060	10,901	11,703	12,563
A5DS	6,300	13,100	21,000	23,900	21,900	7,544	17,102	28,655	32,518	28,019	5,255	10,251	14,131	14,878	11,005
B1DS	16,104	32,032	47,533	54,246	70,505	19,283	41,818	64,859	73,807	90,204	13,432	25,065	31,985	33,768	35,429
B2DS	11,132	21,819	32,257	36,804	47,730	13,329	28,485	44,015	50,076	61,066	9,285	17,073	21,706	22,910	23,984
B3DS	2,589	5,146	7,643	8,729	11,343	3,100	6,718	10,429	11,877	14,512	2,159	4,027	5,143	5,434	5,700
B5US	34,825	69,309	102,962	117,583	152,847	41,699	90,483	140,492	159,983	195,552	29,048	54,234	69,283	73,195	76,806
B5DS	49,602	99,429	147,828	168,892	219,579	59,833	129,805	201,711	229,794	280,929	41,540	77,803	99,473	105,135	110,338
B6DS	8,174	16,526	24,707	28,263	36,846	9,788	21,575	33,713	38,455	47,141	6,818	12,932	16,625	17,594	18,515
B7DS	4,340	8,576	12,710	14,500	18,839	5,197	11,196	17,343	19,729	24,103	3,620	6,711	8,553	9,026	9,467
B13DS	66,895	134,064	199,807	228,368	297,224	80,100	175,021	272,637	310,718	380,268	55,797	104,905	134,450	142,159	149,355
B14US	114,060	229,161	341,669	390,617	508,472	136,576	299,170	466,207	531,473	650,539	95,137	179,318	229,909	243,159	255,507
B16US	137,539	276,206	409,807	468,360	609,360	164,689	359,281	559,182	637,251	779,615	114,721	215,349	275,759	291,554	306,203
B16DS	147,106	294,700	438,995	501,754	652,913	176,145	384,731	599,009	682,686	835,337	122,701	230,603	295,400	312,342	328,089
G9DS	28,600	57,300	85,700	98,000	127,700	34,246	74,805	116,938	133,339	163,379	23,855	44,837	57,668	61,005	64,169
G10DS	30,500	61,100	91,800	105,100	137,200	36,521	79,766	125,261	142,999	175,534	25,440	47,811	61,772	65,425	63,943
G12DS	6,600	13,800	21,400	24,600	32,600	7,903	18,016	29,200	33,471	41,708	5,505	10,799	14,400	15,314	16,382
G17DS	19,400	40,300	62,500	72,200	95,600	23,230	52,612	85,281	98,235	122,311	1[illegible],182	31,535	42,056	44,945	48,039
G18DS	24,000	48,000	74,900	86,500	114,600	28,738	62,664	102,201	117,692	146,619	20,018	37,560	50,400	53,846	57,587
G19US	52,800	107,700	164,500	189,300	248,900	63,223	140,602	224,460	257,562	318,443	44,040	84,275	110,692	117,839	125,072
G19DS	52,700	107,000	164,500	189,300	248,900	63,103	139,689	224,460	257,562	318,443	43,957	83,728	110,692	117,839	125,072
M1DS	1,667	3,271	4,840	5,518	7,162	1,996	4,270	6,604	7,606	9,163	1,390	2,560	3,257	3,435	3,599
M4DS	21,533	41,658	61,217	69,711	90,200	25,784	54,385	83,531	94,849	115,402	17,961	32,597	41,193	43,395	45,326
M5DS	11,123	21,749	32,121	36,638	47,507	13,319	28,393	43,829	49,850	60,780	9,278	17,019	21,614	22,807	23,872
M6DS	36,020	70,036	103,176	117,581	152,301	43,130	91,432	140,784	159,981	194,854	30,044	54,603	69,427	73,194	76,531

Table 3.5.36 (sheet 2 of 2)

Estimated Maximum 3-Day Volume and Confidence Limits at Hydrologic Output Sites

Site ID	HEC-2 Estimated 3-Day Volume					3-Day Volume, Estimated 5% Confidence Limit					3-Day Volume, Estimated 95% Confidence Limit				
	2-Year (dam^3)	10-Year (dam^3)	50-Year (dam^3)	100-Year (dam^3)	500-Year (dam^3)	2-Year (dam^3)	10-Year (dam^3)	50-Year (dam^3)	100-Year (dam^3)	500-Year (dam^3)	2-Year (dam^3)	10-Year (dam^3)	50-Year (dam^3)	100-Year (dam^3)	500-Year (dam^3)
O1DS	5,616	11,077	16,398	18,705	24,279	6,725	14,461	22,375	25,450	31,063	4,684	8,668	11,034	11,644	12,200
O5US	20,914	42,390	64,307	73,828	96,782	25,042	55,340	87,747	100,450	123,797	17,444	33,170	43,272	45,958	48,623
O5DS	26,280	54,082	83,583	96,379	127,249	31,468	70,604	114,022	131,133	162,602	21,920	42,319	56,230	59,996	63,943
O7DS	7,793	15,971	24,533	28,254	37,236	9,331	20,850	33,475	38,442	47,640	6,500	12,497	16,508	17,588	18,711
O9US	10,946	22,655	35,152	40,592	53,710	13,107	29,576	47,965	55,229	68,717	9,130	17,728	23,654	25,269	26,989
O10US	38,340	79,363	123,148	142,220	188,181	45,908	103,608	168,035	193,505	240,759	31,979	62,102	82,866	88,532	94,561
O10DS	39,629	82,501	128,337	148,447	196,916	47,452	107,705	175,116	201,977	251,934	33,055	64,557	86,358	92,408	98,950
O15US	48,234	95,225	141,884	162,030	211,084	57,755	124,316	193,601	220,458	270,061	40,232	74,514	95,474	100,864	106,070
O16DS	74,372	148,996	224,919	257,988	337,589	89,053	194,514	306,902	351,018	431,911	62,034	116,589	151,348	160,598	169,638
O17DS	78,266	157,592	239,134	274,762	360,440	93,716	205,736	326,298	373,841	461,147	65,282	123,316	160,913	171,039	181,121
O18DS	115,455	236,108	362,103	417,183	549,828	138,246	308,239	494,090	567,592	703,450	96,301	184,755	243,659	259,684	276,289
P1DS	1,900	4,000	6,000	6,900	9,100	2,275	5,222	8,187	9,388	11,643	1,585	3,130	4,037	4,295	4,573
P2DS	800	1,700	2,700	3,100	4,100	958	2,219	3,684	4,218	5,246	667	1,330	1,817	1,930	2,060
P3DS	800	1,700	2,700	3,100	4,200	958	2,219	3,684	4,218	5,373	667	1,330	1,817	1,930	2,111
P4US	2,800	5,700	8,700	10,000	13,100	3,353	7,441	11,871	13,606	16,760	2,335	4,460	5,854	6,225	6,583
P4DS	3,100	6,300	9,800	11,300	14,900	3,712	8,225	13,372	15,375	19,063	2,586	4,930	6,594	7,034	7,487
P5US	3,800	7,900	12,300	14,200	18,900	4,550	10,313	16,783	19,321	24,181	3,170	6,182	8,277	8,840	9,497
P5DS	4,300	9,300	14,800	17,200	23,100	5,149	12,141	20,195	23,402	29,554	3,587	7,277	9,959	10,707	11,608
P7DS	5,000	11,100	17,800	20,800	28,300	5,987	14,491	24,288	28,300	36,207	4,171	8,686	11,978	12,948	14,221
S1DS	7,400	13,900	20,200	23,000	29,600	8,861	18,146	27,563	31,294	37,870	6,172	10,877	3,593	14,318	14,874
S2DS	11,300	22,100	33,200	38,000	49,600	13,531	28,852	45,301	51,703	63,458	9,425	17,293	22,340	23,655	24,924
S3DS	12,500	24,800	37,500	43,100	56,500	14,968	32,376	51,169	58,642	72,286	10,426	19,406	25,234	26,830	28,391
S4DS	2,500	5,200	8,400	9,800	13,100	2,994	6,789	11,462	13,334	16,760	2,085	4,069	5,652	6,101	6,583
S6DS	10,200	21,400	33,400	38,600	51,200	12,213	27,938	45,574	52,519	65,505	8,508	16,746	22,475	24,029	25,728
S7US	24,600	50,500	78,000	90,000	119,000	29,456	65,928	106,431	122,454	152,249	20,519	39,516	52,486	56,025	59,798
S7DS	24,600	50,400	77,900	90,000	118,900	29,456	65,797	106,295	122,454	152,121	20,519	39,438	52,419	56,025	59,747
T2DS	24,118	45,746	66,888	76,051	98,171	28,870	59,721	91,269	103,475	125,600	20,117	35,796	45,009	47,342	49,331
T3DS	26,442	50,477	73,976	84,169	108,760	31,662	65,898	100,940	114,520	139,148	22,055	39,498	49,778	52,395	54,652
T7DS	18,060	37,557	56,537	64,908	84,614	21,625	49,031	77,281	88,314	108,255	15,064	29,388	38,111	40,405	42,519
T9US	42,136	84,159	125,318	143,202	186,067	50,454	109,870	170,996	194,841	238,054	35,146	65,854	84,326	89,143	93,499
T10DS	54,326	109,255	163,455	186,984	243,521	65,052	142,632	223,034	254,410	311,561	45,315	85,492	109,989	116,398	122,369

Table 3.5.37 (sheet 1 of 2)

Flow Duration Curve, 5 Percent Confidence Limit Data at Hydrologic Sites (cms)

Site Number	Percent of Time Exceeded												
	100	50	25	20	10	5	2	1	0.50	0.20	0.10	0.05	0.02
A1DS	0	0.2	0.5	0.6	1.1	2.0	3.5	5.1	7.1	11.1	15.6	20.1	24.7
A3DS	0	0.8	1.9	2.5	4.1	6.0	10.2	14.9	21.1	34.9	49.3	63.8	78.9
A5DS	0	1.0	2.4	3.1	5.1	7.5	12.7	18.6	26.2	43.6	62.2	81.1	100.5
B1DS	0	2.8	7.0	8.5	14.1	19.9	32.3	45.6	62.1	94.5	129.5	169.1	216.1
B2DS	0	1.8	4.5	5.6	9.2	13.4	22.2	32.1	44.7	71.8	99.4	127.4	156.5
B3DS	0	0.4	1.1	1.3	2.2	3.2	5.4	7.7	10.7	17.3	24.0	30.8	37.9
B5US	0	5.9	14.8	18.3	30.4	43.5	71.6	102.6	141.6	218.3	299.2	390.7	499.1
B5DS	0	8.6	21.4	26.4	43.8	62.6	102.7	146.7	201.9	310.7	426.2	556.7	711.4
B6DS	0	1.4	3.5	4.3	7.1	10.1	16.5	23.5	32.1	49.4	68.1	89.1	114.0
B7DS	0	0.7	1.7	2.1	3.5	5.2	8.7	12.7	17.8	28.9	40.1	51.4	63.2
B13DS	0	11.6	29.0	35.6	59.1	84.2	137.7	196.2	269.2	413.8	568.5	743.2	950.2
B14US	0	20.4	51.0	62.2	103.4	146.6	238.6	338.2	461.8	706.9	971.8	1271.0	1625.2
B16US	0	24.5	61.3	74.8	124.3	176.5	287.6	408.2	558.3	854.8	1173.7	1534.0	1960.9
B16DS	0	25.9	64.6	79.1	131.5	187.1	305.6	434.7	595.8	914.5	1256.1	1642.1	2099.3
G9DS	0	4.3	10.8	13.9	25.2	43.7	76.8	108.8	147.2	223.5	311.1	399.6	491.7
G10DS	0	4.9	12.3	16.0	26.3	39.3	67.1	99.5	141.6	233.5	325.3	418.3	514.9
G12DS	0	1.1	2.8	3.5	5.8	8.5	14.2	20.6	28.9	47.6	67.4	87.5	108.2
G17DS	0	3.3	8.2	10.4	17.1	25.0	41.8	60.8	85.1	140.2	199.0	258.7	
G18DS	0	4.1	10.4	12.8	21.2	30.5	50.1	71.9	99.2	160.4	226.2	293.0	361.8
G19US	0	9.1	22.8	28.7	47.4	69.4	116.3	169.6	237.9	389.3	547.1	706.8	872.1
G19DS	0	9.1	22.8	28.7	47.4	69.4	116.3	169.6	237.9	389.1	546.4	705.7	870.6
M1DS	0	0.2	0.6	0.8	1.4	2.4	4.3	6.1	8.4	12.8	17.7	22.6	27.8
M4DS	0	3.2	8.1	10.2	16.8	24.5	40.8	59.4	83.1	133.7	184.3	235.5	289.1
M5DS	0	1.7	4.3	5.5	9.1	13.4	22.6	33.1	46.8	75.7	104.8	134.2	164.9
M6DS	0	6 4	15.9	19.5	32.4	46.2	75.7	108.0	148.4	226.7	308.6	401.3	511.8

Table 3.5.37 (sheet 2 of 2)

Flow Duration Curve, 5 Percent Confidence Limit Data at Hydrologic Sites (cms)

Site Number	Percent of Time Exceeded												
	100	50	25	20	10	5	2	1	0.50	0.20	0.10	0.05	0.02
O1DS	0	0.9	2.3	2.8	4.7	6.8	11.2	16.1	22.3	35.7	49.5	63.5	78.1
O5US	0	4.8	11.9	14.5	24.1	34.1	55.4	78.4	106.8	165.0	229.8	302.7	388.4
O5DS	0	4.8	11.9	14.5	24.1	34.1	55.4	78.4	106.8	165.0	229.8	302.7	388.4
O7DS	0	1.5	3.7	4.5	7.5	10.6	17.2	24.3	33.1	50.8	70.4	92.4	118.4
O9US	0	2.1	5.3	6.4	10.6	14.9	23.9	33.5	45.2	69.2	96.4	127.0	163.0
O10US	0	7.2	18.1	21.8	30.3	50.9	82.2	115.4	156.3	240.0	334.9	441.7	567.0
O10DS	0	7.7	19.3	23.0	38.4	53.6	85.8	119.8	161.1	246.1	344.0	454.1	583.1
O15US	0	9.0	22.4	26.9	44.9	63.0	101.4	142.3	192.5	290.5	397.3	518.0	661.4
O16DS	0	15.1	37.8	44.3	74.2	101.9	160.6	220.4	291.4	432.3	595.3	779.3	997.0
O17DS	0	16.4	40.9	47.7	79.9	109.1	170.9	233.0	306.0	451.3	622.6	815.9	1044.3
O18DS	0	24.0	60.1	70.3	117.6	161.1	253.3	346.7	457.1	680.4	944.5	1242.1	1592.3
P1DS	0	0.3	0.7	0.9	1.6	2.8	5.0	7.2	9.8	15.3	21.4	27.6	34.0
P2DS	0	0.1	0.3	0.4	0.8	1.4	2.5	3.7	5.2	8.3	11.7	15.1	18.6
P3DS	0	0.1	0.3	0.4	0.7	1.0	1.7	2.5	3.4	5.7	8.4	11.2	13.9
P4US	0	0.4	1.0	1.3	2.4	4.2	7.5	10.8	15.0	23.6	33.1	42.6	52.6
P4DS	0	0.4	1.1	1.5	2.8	4.7	8.3	12.1	16.7	26.4	36.9	47.7	58.8
P5US	0	0.6	1.5	1.9	3.4	6.0	10.6	15.1	20.6	31.9	44.7	57.7	71.1
P5DS	0	0.7	1.8	2.4	3.9	5.8	9.9	14.7	20.9	35.5	51.2	67.2	83.5
P7DS	0	0.8	2.1	2.7	4.4	6.6	11.2	16.6	23.5	40.1	58.4	77.0	95.9
S1DS	0	1.0	2.5	3.3	5.9	10.4	18.5	26.6	36.8	55.9	76.4	97.2	119.1
S2DS	0	1.8	4.6	5.7	9.5	14.0	23.8	35.1	49.7	81.1	112.1	143.5	176.?
S3DS	0	2.0	4.9	6.3	10.4	15.4	26.1	38.3	54.0	88.6	123.8	159.4	196.4
S4DS	0	0.4	1.1	1.3	2.2	3.1	6.0	7.1	9.6	14.9	21.0	27.8	35.7
S6DS	0	1.7	4.2	5.3	8.7	12.7	21.1	30.6	42.7	70.4	100.5	131.0	162.4
S7US	0	4.1	10.2	12.9	21.3	30.9	51.5	74.7	104.2	170.3	240.5	311.6	385.0
S7DS	0	4.1	10.2	12.8	21.2	30.8	51.3	74.2	103.4	169.1	239.2	310.2	383.5
T2DS	0	3.5	8.8	11.5	18.9	28.3	48.4	71.9	102.7	167.6	230.1	293.1	359.3
T3DS	0	3.9	9.9	12.8	21.1	31.4	53.4	79.0	112.2	182.8	251.3	320.5	393.1
T7DS	0	3.8	9.4	11.0	18.4	25.2	39.5	54.1	71.3	103.0	137.8	177.4	225.1
T9US	0	7.6	19.0	22.9	38.1	53.5	86.1	120.8	163.3	247.8	341.2	446.7	571.4
T10DS	0	10.3	25.8	30.0	51.1	71.0	113.1	157.0	210.0	315.8	435.5	570.7	730.3

TABLE 3.5.38 (sheet 1 of 2)

Flow Duration Curve, 95 Percent Confidence Limit Data at Hydrologic Sites (cms)

Site Number	Percent of Time Exceeded												
	100	50	25	20	10	5	2	1	0.50	0.20	0.10	0.05	0.02
A1DS	0	0.1	0.3	0.4	0.8	1.4	2.5	3.7	5.1	7.9	10.5	13.2	16.0
A3DS	0	0.5	1.3	1.7	2.9	4.3	7.3	10.8	15.4	24.8	33.3	42.0	51.1
A5DS	0	0.7	1.7	2.2	3.6	5.3	9.1	13.5	19.1	31.0	42.1	53.3	65.2
B1DS	0	1.9	4.9	6.0	9.9	14.1	23.1	33.0	45.3	67.1	87.6	111.1	140.1
B2DS	0	1.2	3.1	3.9	6.5	9.5	15.9	23.2	32.8	49.2	64.0	80.9	101.8
B3DS	0	0.3	0.8	0.9	1.6	2.3	3.8	5.6	7.8	11.8	15.4	19.6	24.7
B5US	0	4.1	10.3	12.9	21.3	30.9	51.3	74.2	103.3	155.0	202.4	256.7	323.6
B5DS	0	5.9	14.0	18.6	30.7	44.4	73.6	106.1	147.3	220.6	288.2	365.8	461.1
B6DS	0	1.0	2.4	3.0	5.0	7.2	11.8	17.0	23.5	35.1	46.0	58.6	73.9
B7DS	0	0.5	1.2	1.5	2.6	3.7	6.2	9.2	13.0	20.5	27.1	33.8	40.9
B13DS	0	8.1	20.1	25.0	41.5	59.7	98.7	141.9	196.5	293.7	384.4	488.3	615.9
B14US	0	14.2	35.4	43.7	72.5	103.9	170.8	244.4	337.0	501.8	667.1	835.0	1059.4
B16US	0	17.0	42.5	52.6	87.2	125.1	205.9	295.1	407.3	606.8	793.7	1007.9	1271.0
B16DS	0	17.9	44.9	55.7	92.3	132.7	218.9	314.3	434.8	649.2	849.5	1078.9	1360.7
G9DS	0	3.0	7.5	9.7	17.6	30.8	54.5	78.0	106.8	158.9	210.7	282.7	313.7
G10DS	0	3.4	8.5	10.9	19.7	34.2	59.9	84.5	113.8	166.0	220.3	275.0	333.8
G12DS	0	0.8	1.9	2.5	4.1	0.0	10.2	14.9	21.1	33.8	45.6	57.5	70.2
G17DS	0	2.3	5.7	7.3	12.0	17.7	30.0	44.0	62.2	99.5	134.6	170.0	207.6
G18DS	0	2.9	7.2	9.0	14.9	21.6	35.9	52.0	72.4	109.8	145.4	186.0	235.5
G19US	0	6.3	15.7	20.2	33.5	49.3	83.5	122.8	173.8	276.6	370.3	464.6	565.3
G19DS	0	6.3	15.7	20.2	33.3	49.3	83.5	122.8	173.8	276.4	369.0	463.8	564.3
M1DS	0	0.2	0.4	0.5	1.0	1.7	3.1	4.4	6.1	9.1	12.0	14.9	18.0
M4DS	0	2.2	5.6	7.2	11.8	17.4	29.4	43.1	60.7	91.6	118.6	149.6	188.1
M5DS	0	1.2	3.0	3.9	6.4	9.5	16.2	24.0	34.1	53.9	71.0	88.2	106.9
M6DS	0	4.4	11.0	13.7	22.7	32.8	54.2	78.1	108.3	161.0	208.8	263.8	331.8

TABLE 3.5.38 (sheet 2 of 2)

Flow Duration Curve, 95 Percent Confidence Limit Data at Hydrologic Sites (cms)

Site Number	Percent of Time Exceeded												
	100	50	25	20	10	5	2	1	0.50	0.20	0.10	0.05	0.02
O1DS	0	0.8	1.6	2.0	3.3	4.8	8.0	11.7	16.3	24.5	31.8	40.3	50.8
C5US	0	2.5	6.4	7.9	13.7	18.9	31.3	45.1	62.5	94.0	123.8	157.8	199.3
O5DS	0	3.3	8.3	10.2	16.9	24.2	39.6	56.6	77.9	117.0	155.2	198.8	251.8
O7DS	0	1.0	2.6	3.2	5.3	7.5	12.3	17.6	24.2	36.0	47.6	60.7	76.8
O9US	0	1.5	3.7	4.5	7.4	10.5	17.1	24.2	33.0	49.1	65.1	83.4	105.8
O10US	0	5.0	12.6	15.3	26.4	36.1	58.8	83.4	114.0	170.2	226.2	290.1	367.5
O10DS	0	5.3	13.4	16.2	28.9	37.9	61.4	86.5	117.5	174.5	232.3	298.2	378.0
O15US	0	6.2	15.5	18.9	31.5	44.6	72.6	102.8	140.4	206.3	268.7	340.4	428.7
O16DS	0	10.6	26.2	31.1	62.0	72.0	114.6	158.9	212.3	308.8	402.5	512.0	646.2
O17DS	0	11.4	28.4	33.6	65.9	77.1	121.9	167.9	222.8	320.3	420.9	536.0	676.9
O18DS	0	16.7	41.7	49.3	82.4	113.9	180.6	249.9	332.9	482.6	638.2	815.8	1032.[illegible]
P1DS	0	0.2	0.5	0.6	1.1	2.0	3.6	5.2	7.3	10.8	14.5	18.1	22.1
P2DS	0	0.1	0.2	0.3	0.6	1.0	1.8	2.7	3.6	5.9	7.8	9.9	12.0
P3DS	0	0.1	0.2	0.3	0.5	0.7	1.2	1.8	2.5	4.1	5.7	7.3	9.0
P4US	0	0.3	0.7	0.9	1.7	2.9	5.3	7.8	10.9	16.6	22.4	26.0	34.1
P4DS	0	0.3	0.8	1.0	1.8	3.3	5.9	8.7	12.2	18.7	25.0	31.3	38.1
P5US	0	0.4	1.0	1.3	2.4	4.2	7.5	10.8	15.0	22.7	30.3	37.9	46.1
P5DS	0	0.5	1.3	1.6	2.9	5.0	8.8	12.5	16.8	25.2	34.6	44.1	54.1
P7DS	0	0.6	1.5	1.8	3.4	5.8	10.1	14.2	19.0	28.4	39.4	50.5	62.1
S1DS	0	0.7	1.8	2.3	4.1	7.3	13.1	19.0	28.5	39.6	51.9	64.0	77.2
S2DS	0	1.2	3.1	3.9	7.1	12.3	21.4	30.0	40.1	57.6	70.0	94.4	114.3
S3DS	0	1.4	3.4	4.6	7.3	11.0	18.7	27.7	39.6	63.0	83.8	104.8	127.3
S4DS	0	0.3	0.8	0.9	1.5	2.2	3.6	5.1	7.0	10.6	14.2	18.2	23.1
S6DS	0	1.2	2.9	3.7	6.1	9.0	15.2	22.2	31.2	49.9	67.9	86.1	105.2
S7US	0	2.6	7.1	9.1	14.9	22.0	38.9	54.1	76.1	120.9	162.7	204.8	249.6
S7DS	0	2.8	7.1	9.0	14.9	21.9	38.8	53.7	75.5	120.1	161.8	203.9	248.6
T2DS	0	2.4	6.1	7.6	14.2	24.6	43.1	61.0	82.3	119.3	156.0	192.8	232.9
T3DS	0	2.7	6.9	8.7	15.9	27.4	47.9	67.4	90.4	130.1	170.4	210.8	254.8
T7DS	0	2.0	6.5	7.5	12.7	17.2	28.8	36.3	47.3	67.4	89.7	115.1	145.9
T9US	0	5.3	13.2	16.1	26.7	37.9	61.6	67.3	119.1	175.9	230.7	293.4	370.4
T10DS	0	7.2	17.9	21.5	36.5	50.2	80.8	113.3	153.1	224.1	294.4	374.9	473.4

Table 3.6.1

Estimated Depths of Clearwater flows

River	Reach of River Modeled (river km)	Maximum and minimum depths in meters estimated to occur within the reach for the 2- through 500-year floods. Following the min and max is the estimated average depth within the reach (in parentheses). Normal depth is indicated for reaches for which only one depth is shown: 2-year	10-year	50-year	100-year	500-year
Abacan	1.0	0.[illegible]	0.7	0.8	0.9	1.1
Abacan	8.0	0.4	0.7	0.9	0.[illegible]	1.1
Abacan						
Downstr. of Expressway Br.	16.7-17.6	0.3-0.6 (0.5)	0.5-0.8 (0.7)	0.6-1.0 (0.8)	0.6-1.1 (0.9)	0.7-1.3 (1.0)
Betw. Expr. and Friendship Br.	17.6-25.4	0.3-0.9 (0.5)	0.5-1.[illegible] (0.7)	0.7-1.3 (0.9)	0.7-1.4 (1.0)	0.8-1.5 (1.1)
Upstream of Friendship Br.	25.4-26.4	0.4-0.6 (0.5)	0.6-0.8 (0.7)	0.7-1.0 (0.9)	0.8-1.1 (0.9)	0.9-1.2 (1.1)
Bamban						
Sacobia and Marimla flow	14-19	0.4	0.7	0.9	0.9	1.1
Sacobia flow only	14-19	0.3	0.4	0.5	0.6	0.7
Bangat						
downstream site	9.0	1.0	1.3	1.5	1.6	1.8
middle site	9.0	1.2	1.7	2.1	2.3	2.7
upstream site	9.0	2.1	2.8	3.3	3.5	3.9
Bucao						
downstream of bridge	0-3	1.1	1.7	2.2	2.3	2.7
upstream of bridge	0-3	0.4-2.6 (1.7)	1.[illegible]-3.7 (2.7)	2.1-4.5 (3.5)	2.4-4.8 (3.8)	3.1-5.5 (4.7)
Gumain						
Downstream of river km 16	14.5-16.0	1.2	1.7	2.0	2.1	2.3
Upstream of river km 16	16.0-18.0	0.2-2.3 (1.0)	0.4-2.5 (1.2)	0.5-2.7 (1.4)	0.5-2.7 (1.4)	0.6-2.9 (1.6)
O'Donnell	25.0	0.4	0.6	0.[illegible]	1.1	1.1
O'Donnell	29.0	0.4	0.7	0.9	1.0	1.2
Pasig						
Downstream of lower bridge	1-2.3	0.9-1.5 (1.1)	1.4-2.0 (1.6)	1.8-2.3 (1.9)	1.9-2.5 (2.1)	2.[illegible]-2.8 (2.4)
Betw. lower and Bypass Br.	2.3-4.1	0.6-1.1 (0.8)	0.8-1.6 (1.2)	1.0-2.0 (1.6)	1.1-2.2 (1.7)	1.2-2.5 (2.0)
Upstream of Bypass Bridge	4.1-4.6	0.6-0.9 (0.7)	0.9-1.2 (1.[illegible])	1.2-1.5 (1.3)	1.3-1.6 (1.4)	1.6-1.9 (1.7)
Pasig	19-21	0.6-2.1 (1.4)	0.9-2.9 (1.9)	1.1-3.3 (2.2)	1.2-3.8 (2.3)	1.4-4.0 (2.5)
Porac						
Near Floridablanca	5-7	1.1-1.9 (1.6)	1.4-2.8 (2.2)	1.7-3.5 (2.7)	1.9-3.7 (2.9)	2.0-4.2 (3.2)
Downstream of bridge	18-20	0.2-1.8 (0.9)	0.3-2.5 (1.2)	0.4-2.9 (1.4)	0.5-3.1 (1.5)	0.5-3.4 (1.6)
Upstream of bridge	20-22.7	0.5-2.3 (1.0)	0.7-3.2 (1.4)	0.9-3.7 (1.7)	1.0-3.9 (1.9)	1.1-4.3 (2.2)
Santo Tomas						
Downstream of Macolcol Br.	0-1.6	0.6-1.0 (0.8)	0.8-1.6 (1.2)	1.0-1.6 (1.3)	1.1-1.7 (1.3)	1.1-2.0 (1.5)
Upstream of Macolcol Bridge	1.6-3.6	0.7-1.5 (1.0)	1.3-1.9 (1.5)	1.5-2.2 (1.[illegible])	1.6-2.3 (1.8)	1.7-2.4 (2.0)
Tarlac						
Downstream of Aquino Br.	town of Tarlac	0.5-1.2 (0.7)	0.7-1.7 (1.1)	0.9-2.1 (1.4)	1.0-2.2 (1.5)	1.2-2.6 (1.8)
Betw. Aquino and Agana Br.	town of Tarlac	0.8-1.9 (1.3)	1.3-2.8 (2.0)	1.8-3.5 (2.5)	2.0-3.7 (2.7)	2.6-4.3 (3.3)
Upstream of Agana Bridge	town of Tarlac	0.5-2.5 (1.3)	1.0-3.7 (2.1)	1.6-4.7 (2.5)	1.9-5.2 (3.4)	2.9-6.6 (4.7)

Table 3.6.2

Estimated Depths for Sediment + Water Flows

River	Reach of River Modeled (kilometers)	Maximum and minimum depths in meters estimated to occur within the reach for the 2- through 500-year floods. Following the min and max is the estimated average depth within the reach (in parentheses). Normal depth is indicated for reaches for which only one depth is shown. 2-year	10-year	50-year	100-year	500-year
Abacan	1.0	0.4	0.7	0.9	1.0	1.2
Abacan	8.0	0.4	0.7	0.9	1.0	1.2
Abacan						
Downstr. of Expressway Br.	16.7-17.6	0.3-0.6 (0.5)	0.5-0.9 (0.7)	0.6-1.1 (0.9)	0.7-1.2 (0.9)	0.8-1.3 (1.1)
Betw. Expr. and Friendship Br.	17.6-25.4	0.3-0.9 (0.5)	0.5-1.2 (0.8)	0.7-1.4 (0.9)	0.8-1.4 (1.0)	0.9-1.6 (1.2)
Upstream of Friendship Br.	25.4-26.4	0.4-0.6 (0.5)	0.6-0.9 (0.7)	0.8-1.0 (0.9)	0.8-1.1 (1.0)	0.9-1.2 (1.1)
Bamban						
Sacobia and Marimla	14-19	0.5	0.8	1.0	1.1	1.3
Sacobia flow only	14-19	0.3	0.5	0.7	0.7	0.9
Bangat						
downstream site	9.0	1.0	1.3	1.5	1.6	1.8
middle site	9.0	1.2	1.8	2.2	2.4	2.8
upstream site	9.0	2.2	2.9	3.4	3.6	4.0
Bucao						
downstream of bridge	0-3	1.3	2.1	2.6	2.9	3.4
upstream of bridge	0-3	0.7-3.0 (2.1)	1.9-4.3 (3.3)	2.9-5.3 (4.3)	3.3-5.7 (4.7)	4.3-6.6 (5.6)
Gumain						
Downstream of river km 16	14.5-16.0	0.3	0.5	0.6	0.6	0.7
Upstream of river km 16	16.0-18.0	0.3-2.3 (1.0)	0.4-2.6 (1.3)	0.5-2.7 (1.4)	0.6-2.8 (1.5)	0.7-3.1 (1.6)
	26.0	0.5	1.0	1.1	1.2	1.2
O'Donnell	29.0	0.4	0.7	1.0	1.1	1.3
Pasig						
Downstream of lower bridge	1-2.3	1.2-1.8 (1.4)	1.9-2.4 (2.0)	2.3-2.9 (2.5)	2.5-3.1 (2.7)	2.9-3.5 (3.1)
Betw. lower and Bypass Br.	2.3-4.1	0.7-1.4 (1.1)	1.0-2.1 (1.7)	1.3-2.6 (2.1)	1.4-2.8 (2.3)	1.7-3.3 (2.6)
Upstream of Bypass Bridge	4.1-4.6	0.8-1.0 (0.9)	1.3-1.6 (1.4)	1.6-2.0 (1.7)	1.7-2.1 (1.9)	2.0-2.4 (2.2)
Pasig	19-21	This reach was not modeled for bulked flow as the estimated concentration of the bulked flow was such that the resulting mixture would be a non-Newtonian fluid.				
Porac						
Near Floridablanca	5-7	1.1-2.0 (1.6)	1.4-3.0 (2.3)	1.8-3.6 (2.8)	1.9-3.9 (3.0)	2.1-4.4 (3.4)
Porac						
Downstream of bridge	18-20	0.2-1.9 (1.0)	0.3-2.6 (1.3)	0.4-3.1 (1.4)	0.5-3.2 (1.5)	0.6-3.6 (1.7)
Upstream of bridge	20-22.7	0.5-2.4 (1.0)	0.7-3.3 (1.5)	1.0-3.9 (1.8)	1.0-4.1 (2.0)	1.1-4.5 (2.3)
Santo Tomas						
Downstream of Macolcol Br.	0-1.6	0.7-1.2 (0.9)	1.0-1.6 (1.3)	1.1-1.9 (1.5)	1.2-2.0 (1.5)	1.2-2.2 (1.6)
Upstream of Macolcol Bridge	1.6-3.6	0.9-1.6 (1.1)	1.5-2.2 (1.7)	1.7-2.4 (2.0)	1.8-2.5 (2.1)	2.0-2.9 (2.4)
Tarlac						
Downstream of Aquino Br.	town of Tarlac	0.5-1.3 (0.8)	0.8-1.8 (1.2)	1.3-2.2 (1.5)	1.1-2.4 (1.6)	1.3-2.8 (1.9)
Betw. Aquino and Agana Br.	town of Tarlac	0.9-2.0 (1.4)	1.5-3.0 (2.1)	2.0-3.7 (2.7)	2.2-4.0 (2.9)	3.0-4.7 (3.8)
Upstream of Agana Bridge	town of Tarlac	0.7-2.7 (1.4)	1.2-4.0 (2.3)	1.8-5.2 (3.3)	2.3-5.9 (3.9)	3.5-7.3 (5.3)

Table 3.6.3

Estimated Velocities for Clear-Water Flows

River	Reach of River Modeled	Maximum and minimum velocities in meters per second estimated to occur within the reach for the 2- through 500-year floods. Following the min and max is the estimated average velocity within the reach (in parentheses). Velocity at normal depth is indicated for reaches for which only one depth is shown				
	(river km)	2-year	10-year	50-year	100-year	500-year
Abacan	1.0	0.9	1.2	1.4	1.5	1.7
Abacan	8.0	1.2	1.5	1.8	1.9	2.1
Abacan						
Downstr. of Expressway Br.	16.7-17.6	1.4-1.9 (1.7)	1.7-2.3 (2.1)	1.9-2.6 (2.4)	2.0-2.8 (2.5)	2.1-3.2 (2.7)
Betw. Expr. and Friendship Br.	17.6-25.4	1.4-7.5 (2.0)	0.3-1.1 (0.7)	1.9-6.1 (2.8)	1.9-6.0 (2.9)	2.1-6.1 (3.2)
Upstream of Friendship Br.	25.4-26.4	1.6-2.7 (2.0)	2.0-3.3 (2.6)	2.4-3.4 (2.9)	2.5-3.6 (3.1)	2.7-3.9 (3.4)
Bamban						
Sacobia and Marimla flow	14-19	1.6	2.2	2.5	2.7	3.0
Sacobia flow only	14-19	1.1	1.5	1.9	1.9	2.2
Bangat						
downstream site	9.0	1.8	2.3	2.6	2.7	2.9
middle site	9.0	3.1	4.1	4.7	4.9	5.4
upstream site	9.0	2.5	3.2	3.7	3.9	4.2
Bucao						
downstream of bridge	0-3	2.6	3.5	4.0	4.2	4.7
upstream of bridge	0-3	0.7-2.9 (1.3)	1.0-3.5 (1.4)	0.9-4.0 (1.6)	0.9-4.1 (1.6)	0.9-4.4 (1.8)
Gumain						
Downstream of river km 16	14.5-16.0	0.3	0.4	0.5	0.6	0.7
Upstream of river km 16	16.0-18.0	1.2-2.1 (1.6)	1.6-2.6 (2.2)	1.9-3.0 (2.5)	2.0-3.1 (2.6)	2.2-3.4 (2.8)
O'Donnell	26.0	1.6	2.1	2.4	1.5	1.8
O'Donnell	29.0	2.0	2.8	3.3	3.5	3.9
Pasig						
Downstream of lower bridge	1-2.3	0.9-1.1 (0.9)	1.2-1.4 (1.3)	1.4-1.6 (1.5)	1.5-1.7 (1.6)	1.6-1.9 (1.7)
Betw. lower and Bypass Br	2.3-4.1	0.7-1.8 (1.0)	1.0-1.8 (1.4)	1.2-2.3 (1.6)	1.2-2.4 (1.7)	1.2-2.5 (2.0)
Upstream of Bypass Bridge	4.1-4.6	0.9-1.9 (1.3)	1.1-2.3 (1.7)	1.3-2.3 (1.9)	1.4-2.4 (2.0)	1.6-2.5 (2.2)
Pasig	19-21	1.9-3.2 (2.5)	2.4-3.5 (2.8)	2.6-3.8 (3.0)	2.6-3.4 (3.0)	2.8-3.5 (3.1)
Porac						
Near Floridablanca	5-7	1.1-2.0 (1.6)	1.3-2.9 (2.1)	1.3-3.2 (2.3)	1.3-3.4 (2.4)	1.3-3.8 (2.6)
Porac						
Downstream of bridge	18-20	1.1-4.9 (2.0)	1.4-5.4 (2.3)	1.5-5.5 (2.5)	2.6-5.2 (3.7)	1.8-5.7 (2.8)
Upstream of bridge	20-22.7	1.7-3.2 (2.4)	2.0-4.3 (3.1)	2.6-5.0 (3.5)	1.5-5.5 (2.5)	2.6-5.7 (4.0)
Santo Tomas						
Downstream of Macolcol Br.	0-1.6	0.9-2.0 (1.5)	0.9-2.4 (1.7)	0.6-2.7 (1.9)	0.7-2.8 (2.0)	0.9-3.3 (1.9)
Upstream of Macolcol Bridge	1.6-3.6	1.3-3.7 (2.1)	1.3-2.2 (1.7)	1.5-2.4 (2.0)	1.5-2.6 (2.1)	1.6-2.6 (2.3)
Tarlac						
Downstream of Aquino Br	town of Tarlac	0.8-2.5 (1.3)	1.1-3.5 (1.9)	1.2-4.1 (2.1)	1.3-4.3 (2.2)	1.4-4.6 (2.5)
Betw. Aquino and Agana Br.	town of Tarlac	1.2-3.0 (2.0)	1.6-4.2 (2.8)	1.9-4.9 (3.3)	2.0-5.1 (3.4)	2.2-5.[illegible] (3.6)
Upstream of Agana Bridge	town of Tarlac	0.5-2.5 (1.3)	0.8-3.1 (1.8)	1.0-3.7 (1.8)	1.0-3.6 (1.9)	1.1-3.4 (1.7)

Table 3.6.4

Estimated Velocities for Sediment + Water Flows

River	Reach of River Modeled (river km)	Maximum and minimum velocities in meters per second estimated to occur within the reach for the 2- through 500-year floods. Following the min and max is the estimated average velocity within the reach (in parentheses). Velocity at normal depth is indicated for reaches for which only one depth is shown. 2-year	10-year	50-year	100-year	500-year
Abacan	1.0	0.9	1.3	1.5	1.6	1.8
Abacan	8.0	1.2	1.6	1.9	2.0	2.2
Abacan						
Downstr. of Expressway Br.	16.7-17.6	0.3-0.6 (0.4)	0.5-0.8 (0.6)	0.6-0.9 (0.8)	0.7-1.0 (0.8)	0.8-1.1 (0.9)
Betw. Expr. and Friendship Br.	17.6-25.4	0.2-0.9 (0.5)	0.4-1.2 (0.7)	0.5-1.3 (0.9)	0.5-1.4 (0.9)	0.6-1.6 (1.1)
Upstream of Friendship Br.	25.4-26.4	0.3-0.6 (0.4)	0.4-0.9 (0.6)	0.5-1.0 (0.8)	0.6-1.1 (0.8)	0.7-1.3 (0.9)
Bamban						
Sacobia and Marimla flow	14-19	1.7	2.4	2.8	3.0	3.3
Sacobia flow only	14-19	1.5	1.8	2.1	2.3	2.6
Bangat						
downstream site	9.0	1.9	2.4	2.7	2.8	3.1
middle site	9.0	3.2	4.2	4.9	5.1	5.6
upstream site	9.0	2.6	3.3	3.8	4.0	4.3
Bucao						
downstream of bridge	0-3	2.9	3.9	4.5	4.8	5.4
upstream of bridge	0-3	0.8-3.2 (1.3)	0.9-3.9 (1.6)	0.9-4.3 (1.7)	0.9-4.5 (1.8)	0.9-4.7 (1.9)
Gumain						
Downstream of river km 16	14.5-16.0	1.3	1.8	2.0	2.1	2.4
Upstream of river km 16	16.0-18.0	1.2-2.2 (1.6)	1.7-2.7 (2.2)	2.0-3.1 (2.6)	2.1-3.2 (2.7)	2.3-3.4 (2.9)
O'Donnell	26.0	1.9	1.7	1.8	1.8	2.0
O'Donnell	29.0	2.1	2.9	3.4	3.6	4.0
Porac						
Near Floridablanca	5-7	1.2-2.3 (1.7)	1.3-3.0 (2.2)	1.3-3.3 (2.4)	1.3-3.6 (2.5)	1.3-4.0 (2.7)
Pasig						
Downstream of lower bridge	1-2.3	1.1-1.3 (1.1)	1.4-1.7 (1.5)	1.6-1.9 (1.8)	1.7-2.0 (1.9)	1.9-2.2 (2.1)
Betw. lower and Bypass Br.	2.3-4.1	0.9-1.8 (1.2)	1.2-2.4 (1.6)	1.4-2.8 (1.9)	1.5-2.9 (2.0)	1.6-3.1 (2.2)
Upstream of Bypass Bridge	4.1-4.6	1.0-2.3 (1.6)	1.4-2.3 ([illegible])	1.5-2.6 (2.3)	1.7-2.8 (2.4)	2.0-3.0 (2.6)
Pasig	19-21	This reach was not modeled for bulked flow as the estimated concentration of the bulked flow was such that the resulting mixture would be a non-Newtonian fluid.				
Porac						
Downstream of bridge	18-20	1.8-3.3 (2.5)	2.1-4.5 (3.2)	2.7-5.2 (3.6)	2.8-5.4 (3.8)	2.9-5.9 (4.2)
Upstream of bridge	20-22.7	1.0-5.0 (2.0)	1.4-5.5 (2.3)	1.6-5.6 (2.6)	1.7-5.7 (2.7)	1.8 (2.6)
Santo Tomas						
Downstream of Macolcol Br.	0-1.6	1.2-2.4 (1.8)	0.6-2.7 (1.8)	0.9-3.2 (1.8)	1.0-3.3 (2.0)	1.3-3.7 (2.4)
Upstream of Macolcol Bridge	1.6-3.6	1.5-3.4 (2.1)	1.5-2.4 (2.0)	1.8-2.6 (2.3)	1.9-3.0 (2.4)	[illegible]-3.5 (2.6)
Tarlac						
Downstream of Aquino Br.	town of Tarlac	0.9-2.7 (1.4)	1.1-3.7 (1.9)	1.3-4.2 (2.2)	1.3-4.4 (2.4)	1.5-4.8 (2.7)
Betw. Aquino and Agana Br.	town of Tarlac	1.2-3.2 (2.1)	1.7-4.4 (2.9)	2.0-5.1 (3.4)	2.1-5.3 (3.6)	2.2-5.8 (3.7)
Upstream of Agana Bridge	town of Tarlac	0.6-2.5 (1.5)	0.9-3.3 (1.5)	1.0-3.6 (1.9)	1.1-3.5 (1.8)	1.1-3.5 (1.7)

Table 3.6.5 (sheet 1 of 2)
Hydraulic Modeling Notes

River	Reach of River Modeled (kilometers)	Notes
Abacan	1.0	(1) Normal depth calculation. *(2) Sediment + water flows are 10% sediment. (3) Cross-section data from **DTM.
Abacan	8.0	(1) Normal depth calculation. (2) Sediment + water flows are 10% sediment. (3) Cross-section data from DTM.
Abacan	17-26	(1) Slope very close to critical, therefore, depths taken from sub-critical run and velocities from super-critical run. (2) Sediment + water flows are 10% sediment. (3) Cross-section data from ***DPWH 2 March - 21 April 1992 topographic/hydrographic survey.
Bamban	14-19	(1) Depths and velocities were estimated for two possible conditions: (a) Sacobia and Marimla flow occur together. (b) Sacobia flow only (flow from the Marimla is kept separate). (2) Sediment + water flows are 22% sediment for the combined flow and 35% for the Sacobia flow by itself (3) Cross-section data: A constant width between levees (est. by District personnel) was assumed and a constant slope (measured in the field by District personnel) was also assumed, therefore, although an HEC-2 model was run, the results are normal depth and velocity except in the vicinity of the bridge.
Bangat	9.0	(1) Normal depth calculated at 3 sites within river kilometer 9. (2) Sediment + water flows are 10% sediment. (3) Data from DTM.
Bucao	0-3.5	(1) Sediment + water flows are 28% sediment. (2) Cross-section data: Average slope from DTM data used. Levees downstream of bridge assumed 300 m wide. Right levee upstream of bridge assumed to vary linearly such that channel width at bridge is 290 m and channel width 860 m upstream of bridge is 1400 m. Due to these assumptions, results are normal depth and velocity except in the vicinity of the bridge. However, upstream of the bridge results are reported as min, max, and average to reflect the assumed change in channel width.

*All sediment concentrations are by total volume.
** DTM (Digital Terrain Model).
*** DPWH (Department of Public Works and Highways).

Table 3.6.5 (sheet 2 of 2)

Hydraulic Modeling Notes

River	Reach of River Modeled (kilometers)	Notes
Gumain	14.5-18.0	(1) Sediment + water flows are 10% sediment. (2) DTM data used from river km 17.0 to 18.0. From river km 14.5 to 17.0 the average slope between river km 17.0 and 18.0 obtained from the DTM data was assumed and the width between levees was assumed to be 700 meters. Therefore, depths and velocities reported for river km 14.5 to 17.0 are normal depths and velocities.
O'Donnell	26.0	(1) Normal depth calculated at constriction using cross-section and slope data from the DTM. (2) Sediment + water flows are 38% sediment
O'Donnell	29.0	(1) Normal depth calculated at constriction using cross-section and slope data from the DTM model. (2) Model flow is supercritical, therefore estimated depths at critical and velocities at supercritical.
Pasig	0.3-5	(1) Obtained cross-section and slope data from the DTM model. (2) Sediment + water flows are 40% sediment.
Pasig	19-21	(1) Obtained cross-section and slope data from the DTM model. (2) Model results apply from 0.5 to 3.0 km upstream of the former location of the Mancatian bridge. (3) Assumed no backwater effects from Mancatian bridge. (4) Sediment + water flows are 67% sediment, however, this was not modeled as this high of a sediment concentration would cause the flow to be non-Newtonian thus violating a basic assumption of the analyses procedures used.
Porac	5-7	(1) Obtained cross-section and slope data from the DTM model. (2) For clearwater flows, the water surface elevation of the 500-year flood was approximately 0.25 meters above the highest left overbank elevation. (3) For sediment + water flows, the water surface elevation of the 500-year flood was approximately 0.5 meters above the highest left overbank elevation. (4) Sediment + water flows are 10% sediment.
Porac	19.5-20.5	(1) Slope very close to critical, therefore, depths taken from sub-critical run and velocities from super-critical run. (2) Sediment + water flows are 10% sediment. (3) Data from DTM.
Santo Tomas	0-3	(1) Sediment + water flows are 30% sediment. (2) Cross-section data from March 1992 DPWH topographic/hydrographic survey.
Tarlac	town of Tarlac	(1) Sediment + water flows are 12% sediment. (2) Cross-section data: Width between levees and slopes obtained from 1992 DPWH drawings of the Location Plan and river profile for O'Donnell River Dredging.

*All sediment concentrations are by total volume.

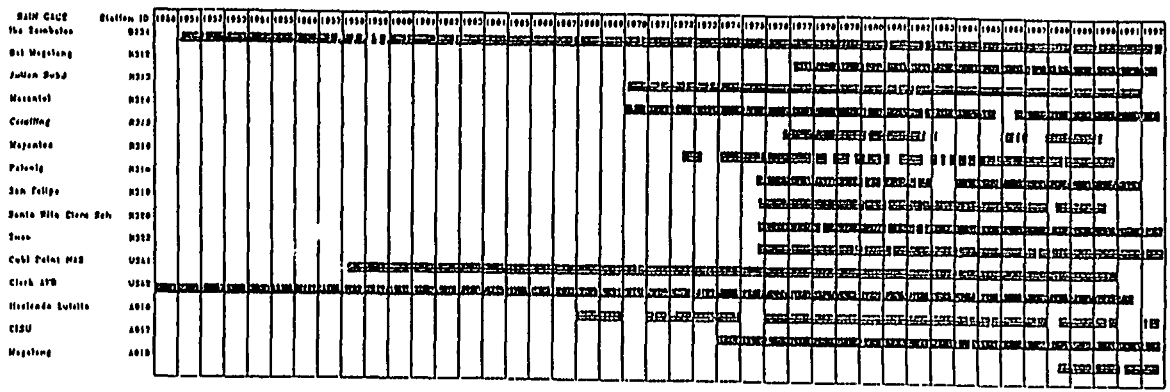
** DTM (Digital Terrain Model).

*** DPWH (Department of Public Works and Highways).

FIGURES FOR

TECHNICAL APPENDIX A

HYDROLOGY AND HYDRAULICS



Legend:
Complete data for period
Partial data for period
No data for period
See Plate 1 for station locations

Available Daily Rainfall Data

Figure 2.3.1

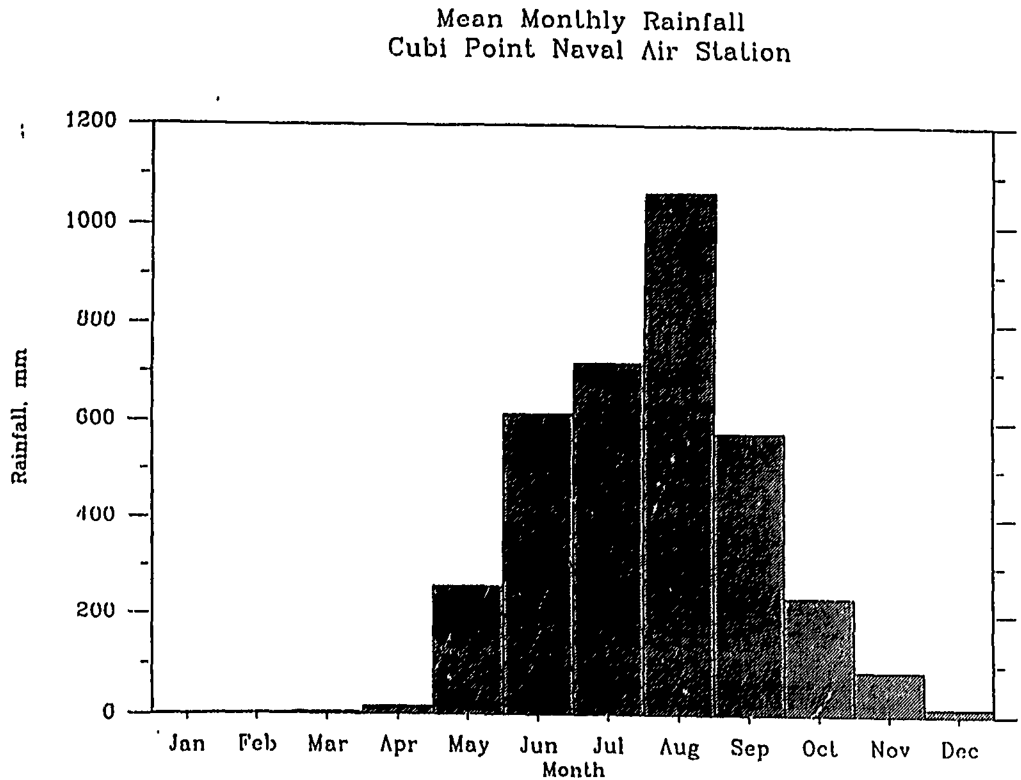

Mean Monthly Rainfall
Cubi Point Naval Air Station
Rainfall, mm
1200
1000
800
600
400
200
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month

Figure 2.3.2

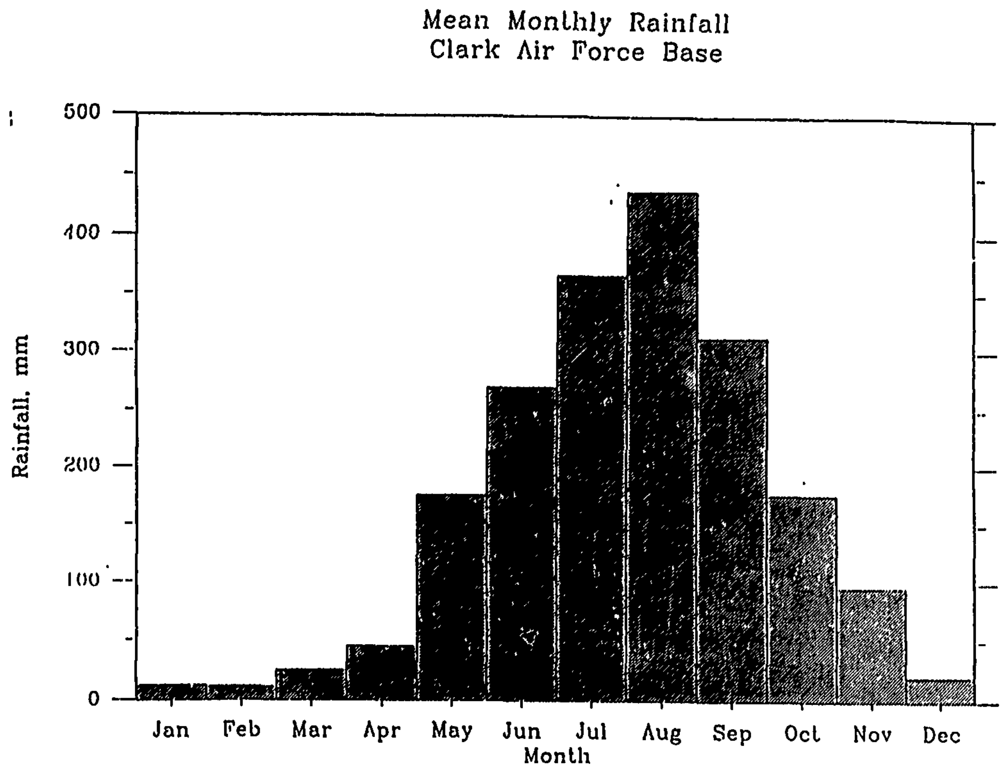
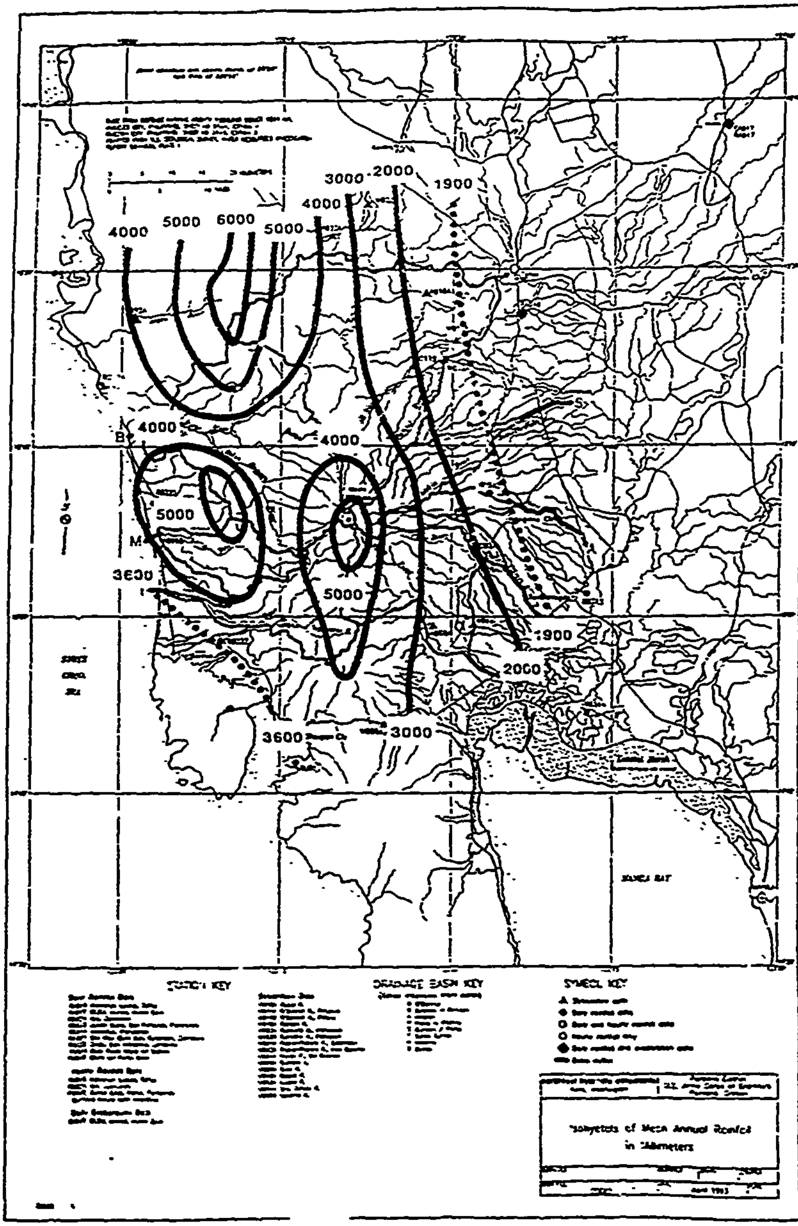

Mean Monthly Rainfall
Clark Air Force Base
Rainfall, mm
500
400
300
200
100
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month

Figure 2.3.3



3000
2000
1900
4000
5000
6000
5000
4000
4000
4000
5000
3600
5000
1900
2000
3600
3000
STATION KEY
DRAINAGE BASIN KEY
SYMBOL KEY
Isohyets of Mean Annual Rainfall
in Millimeters

Figure 2.3.4

Mean Monthly Air Temperature
Cubi Point Naval Air Station

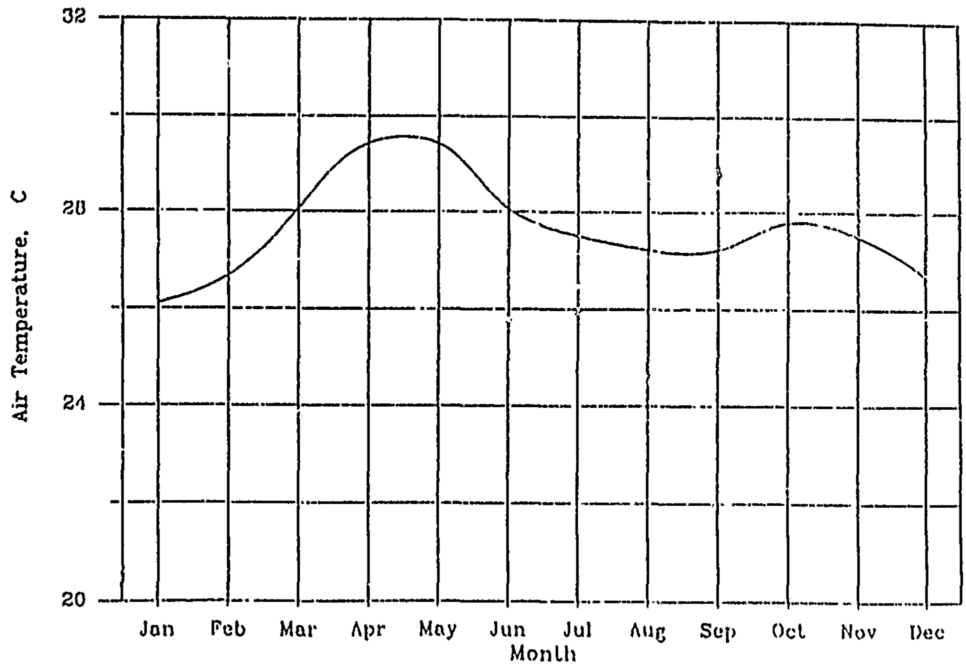


Figure 2.3.5

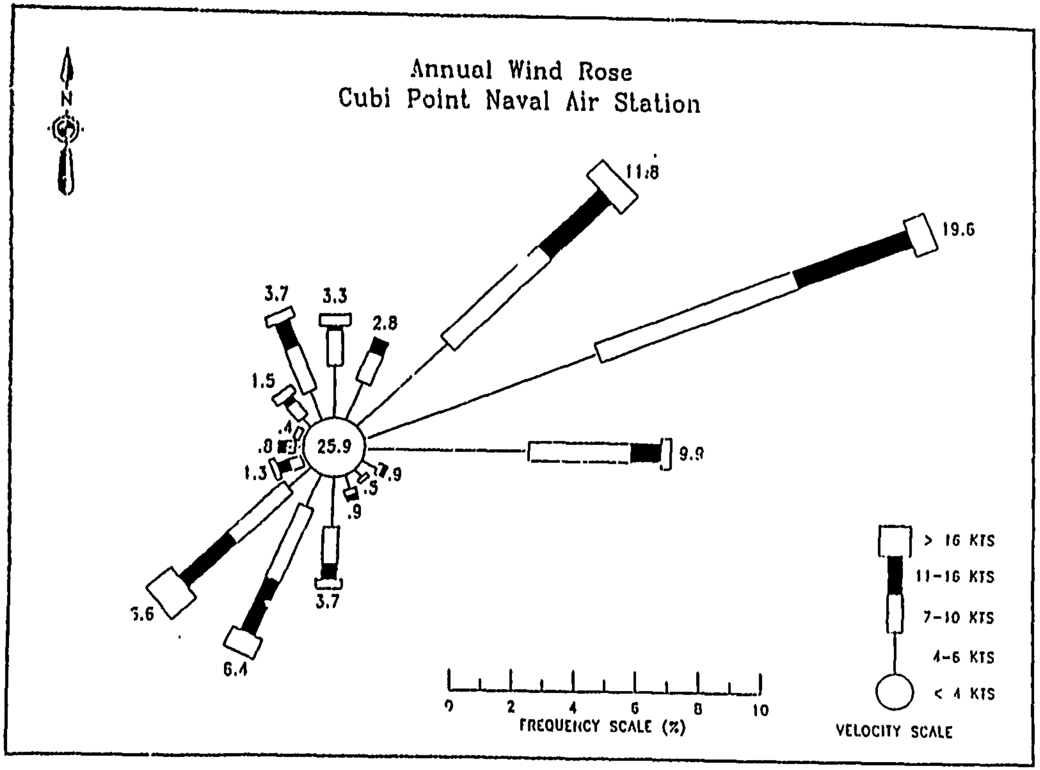
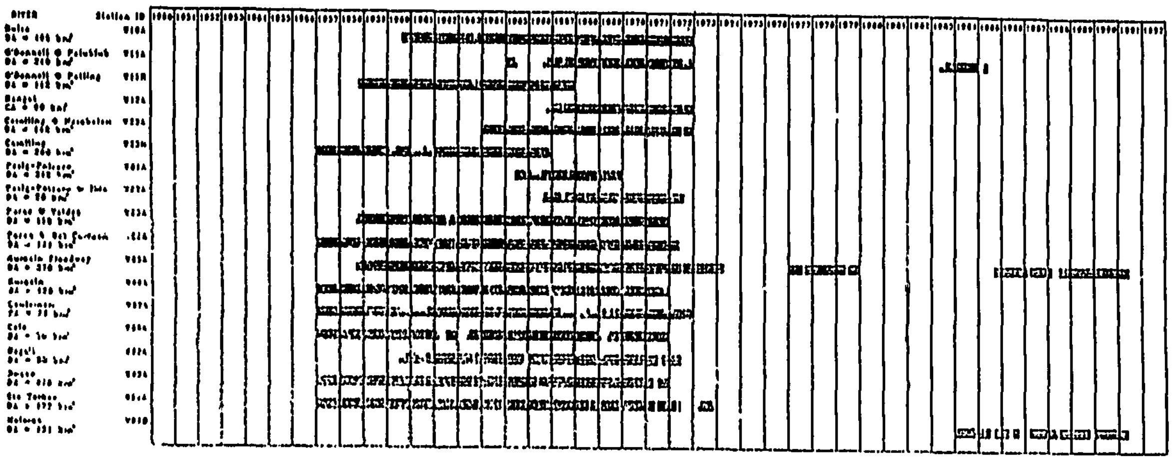

Annual Wind Rose
Cubi Point Naval Air Station
N
11.8
19.6
3.7
3.3
2.8
1.5
.4
.8
25.9
9.9
1.3
.9
.5
.9
3.7
5.6
6.4
> 16 KTS
11-16 KTS
7-10 KTS
4-6 KTS
< 4 KTS
VELOCITY SCALE
0 2 4 6 8 10
FREQUENCY SCALE (%)

Figure 2.3.6



Legend.
Complete data for period
Partial data for period
No data for period

See Plate 1 for station locations

Available Daily Streamflow Data

Figure 2.4.1

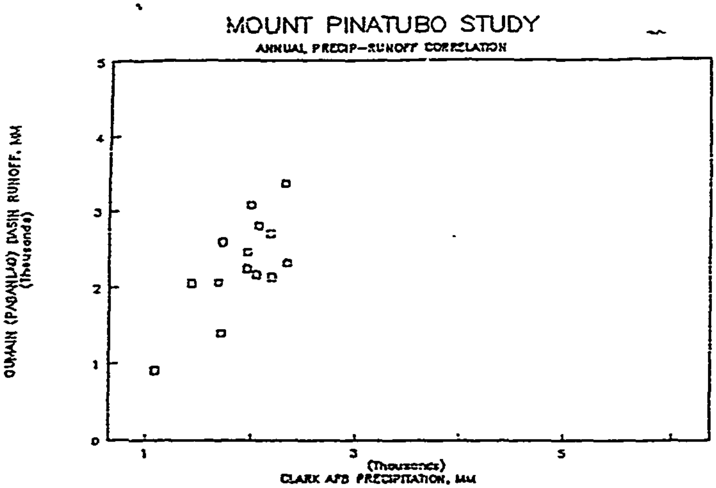
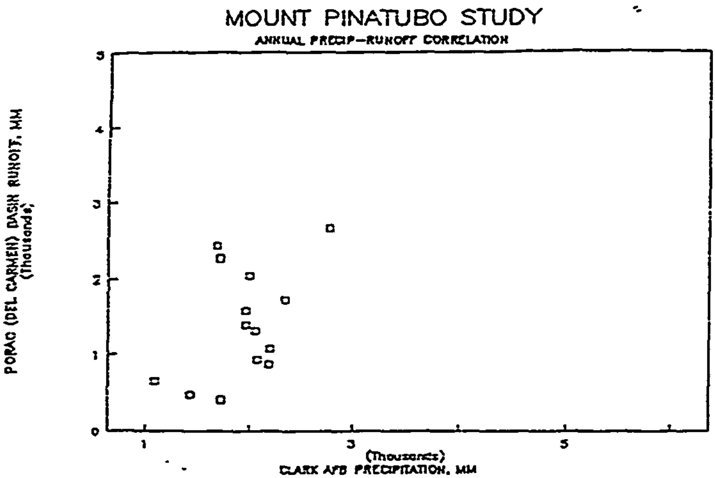

MOUNT PINATUBO STUDY
ANNUAL PRECIP-RUNOFF CORRELATION
(Thousands)
CLARK AFB PRECIPITATION, MM
BASIN RUNOFF, MM
(Thousands)

Figure 2.4.2



MOUNT PINATUBO STUDY
ANNUAL PRECIP—RUNOFF CORRELATION
PORAC (DEL CARMEN) BASIN RUNOFF, MM
(Thousands)
0
1
2
3
4
5
1
3
5
(Thousands)
CLARK AFB PRECIPITATION, MM

Figure 2.4.3

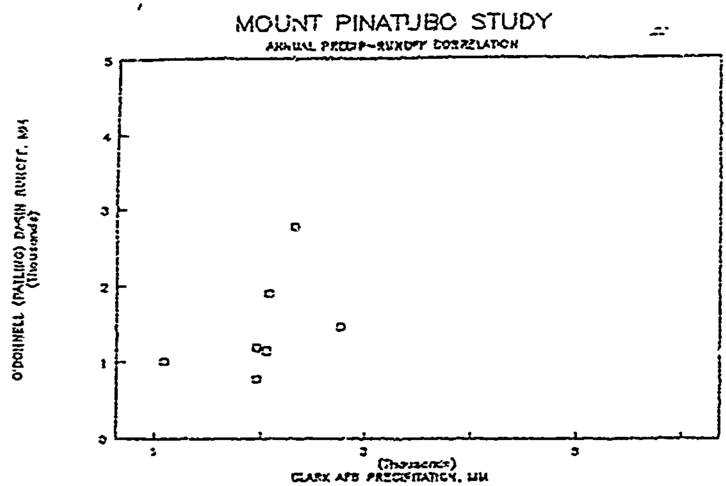
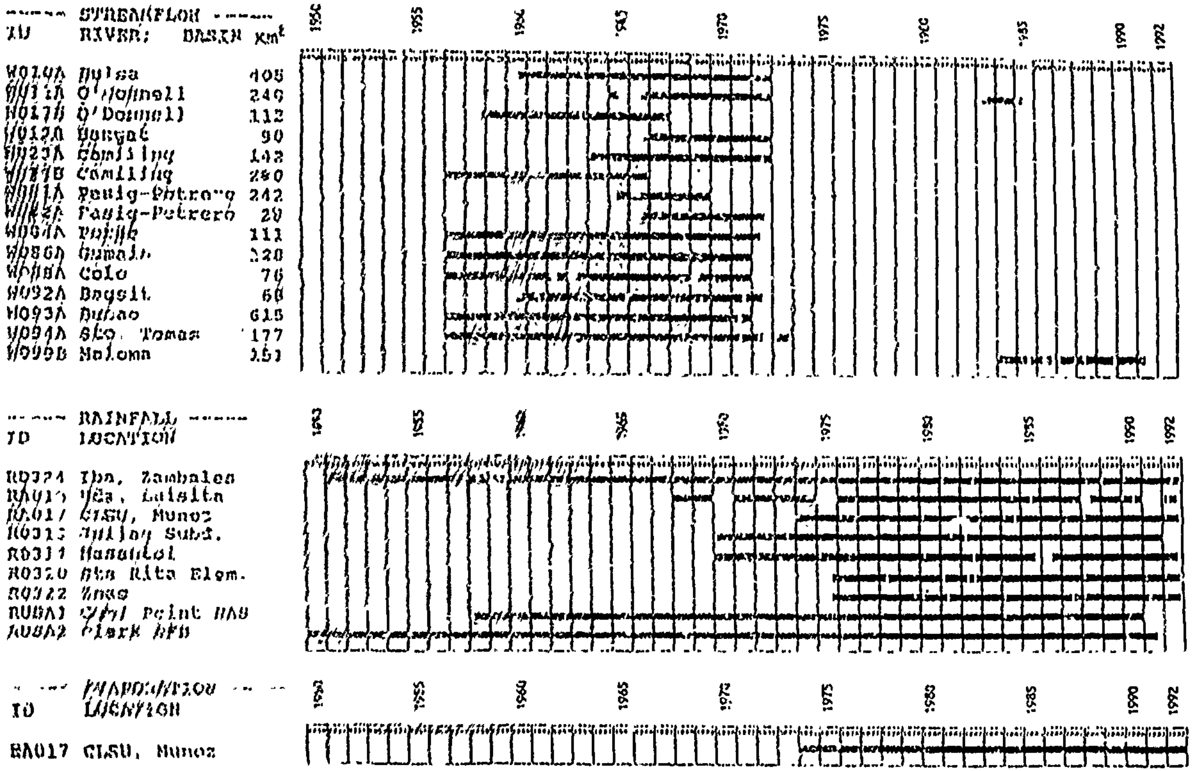


Figure 2.4.4



Legend:
Complete data for period
Partial data for period
No data for period

See Plate 1 for station locations

Available Daily Data

Figure 2.4 6

Summary Hydrographs
Station W010A; Bulsa River, Villa Aglipay
Basin Area = 405 sq. km

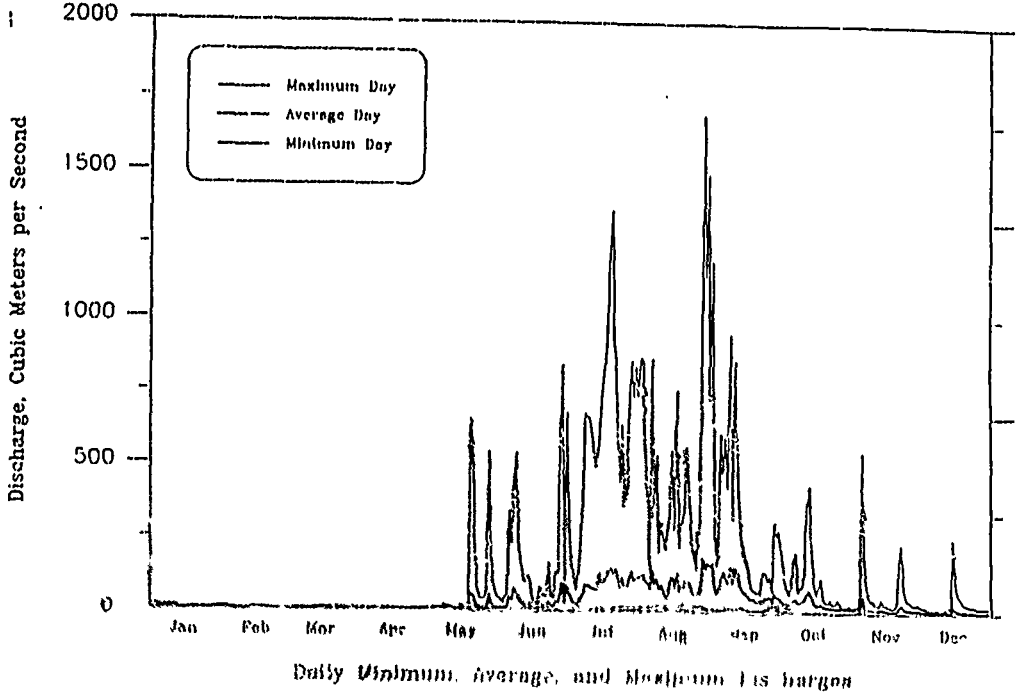


Figure 2.4.7

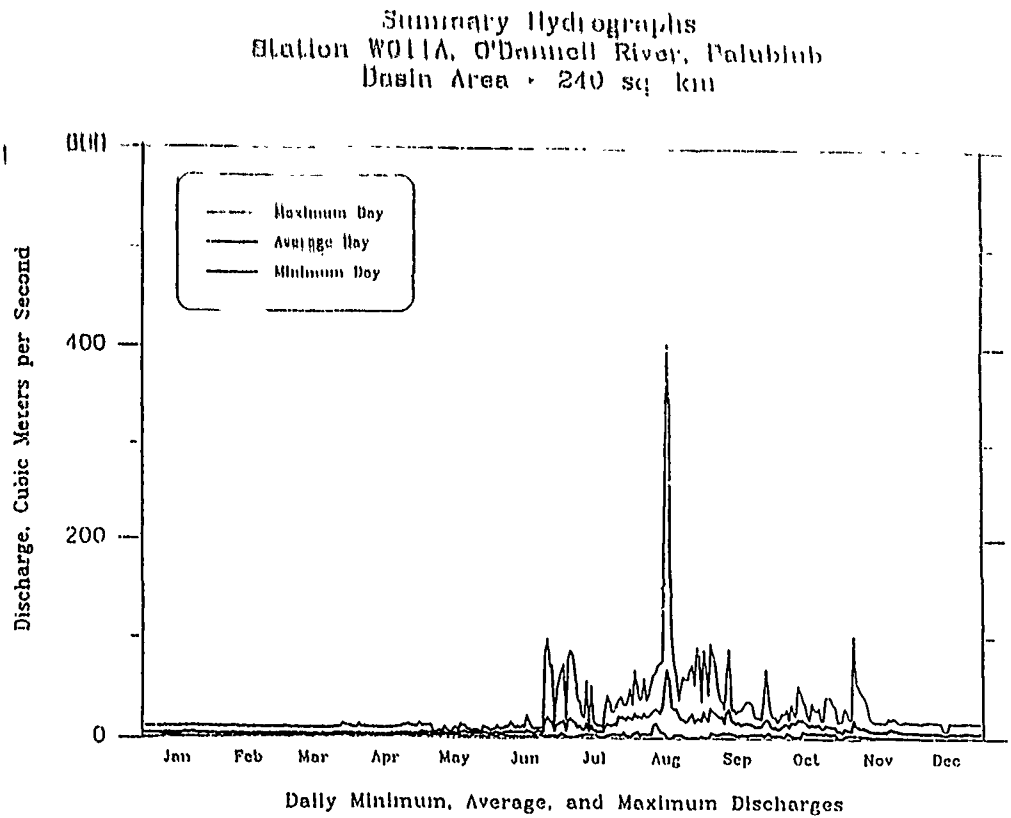

Summary Hydrographs
Station W011A, O'Donnell River, Palublub
Basin Area - 240 sq km
Maximum Day
Average Day
Minimum Day
Discharge, Cubic Meters per Second
600
400
200
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Daily Minimum, Average, and Maximum Discharges

Figure 2.4.8

Summary Hydrographs
Station W011B; O'Donnell River, Patling
Basin Area = 112 sq. km

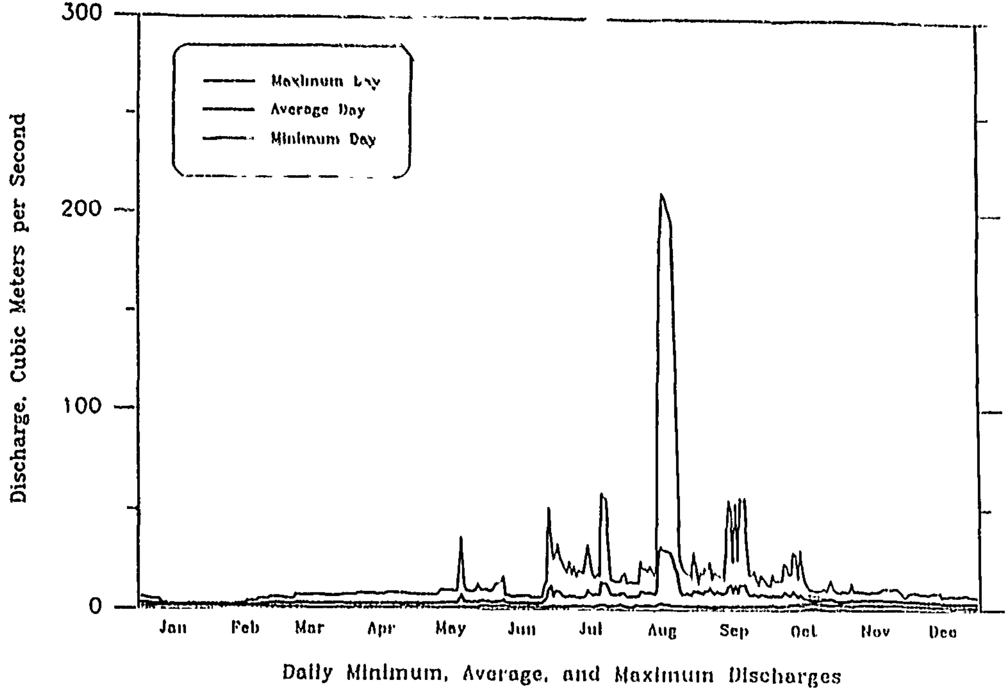


Figure 2.4.9

Summary Hydrographs
Station W012A; Bangal River, Stn Lucia
Basin Area = 90 sq. km

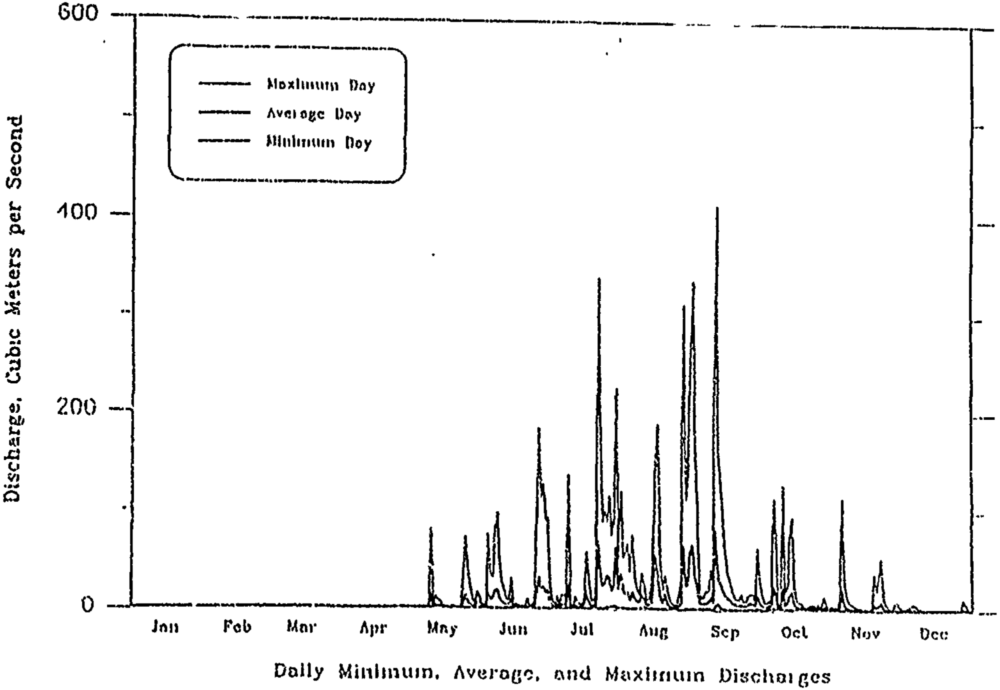


Figure 2.4.10

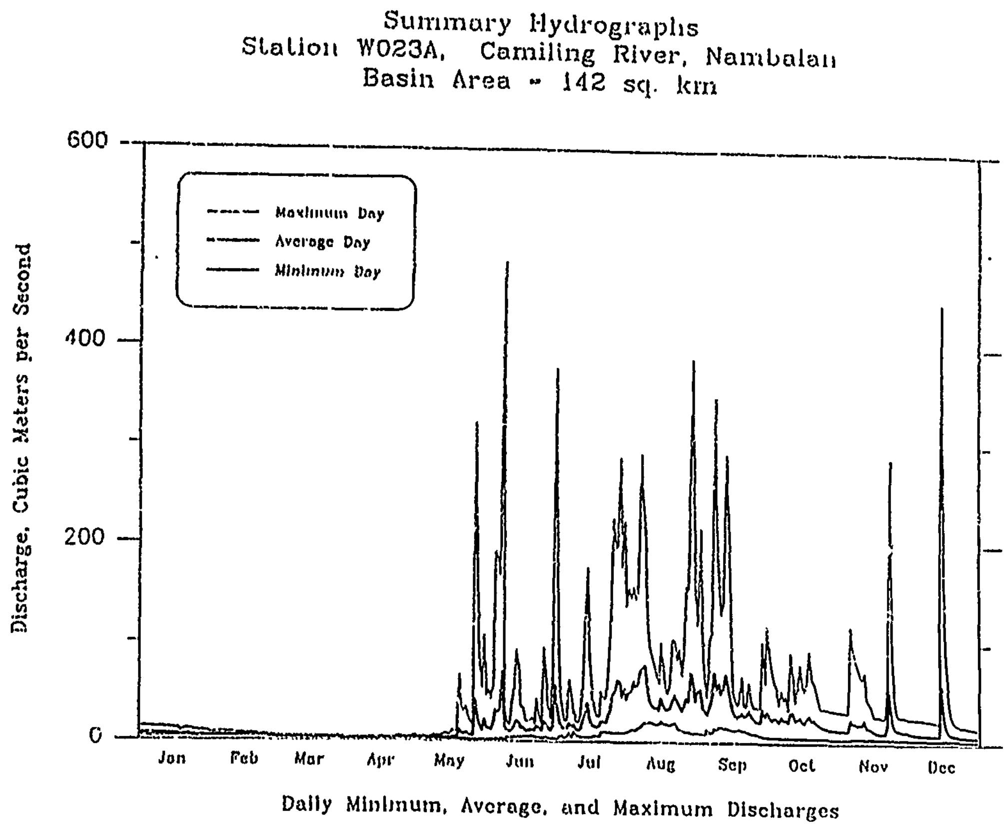

Summary Hydrographs
Station W023A, Camiling River, Nambalan
Basin Area = 142 sq. km
Discharge, Cubic Meters per Second
600
400
200
0
Maximum Day
Average Day
Minimum Day
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Daily Minimum, Average, and Maximum Discharges

Figure 2.4.11

Summary Hydrographs
Station W023B; Camiling River, Poblacion
Basin Area = 280 sq. km

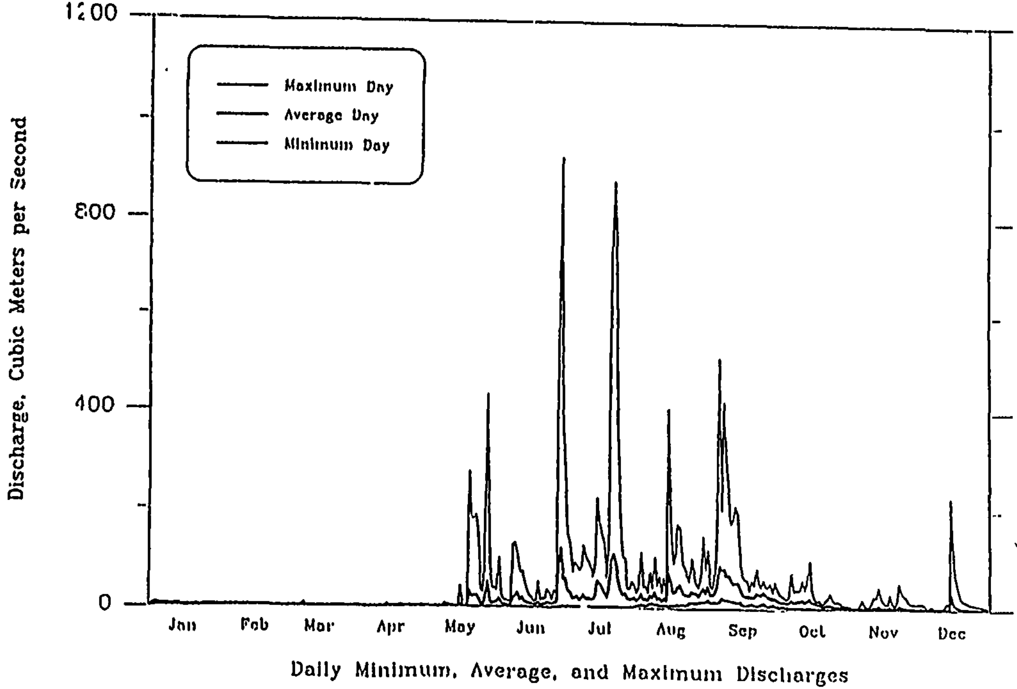


Figure 2.4.12

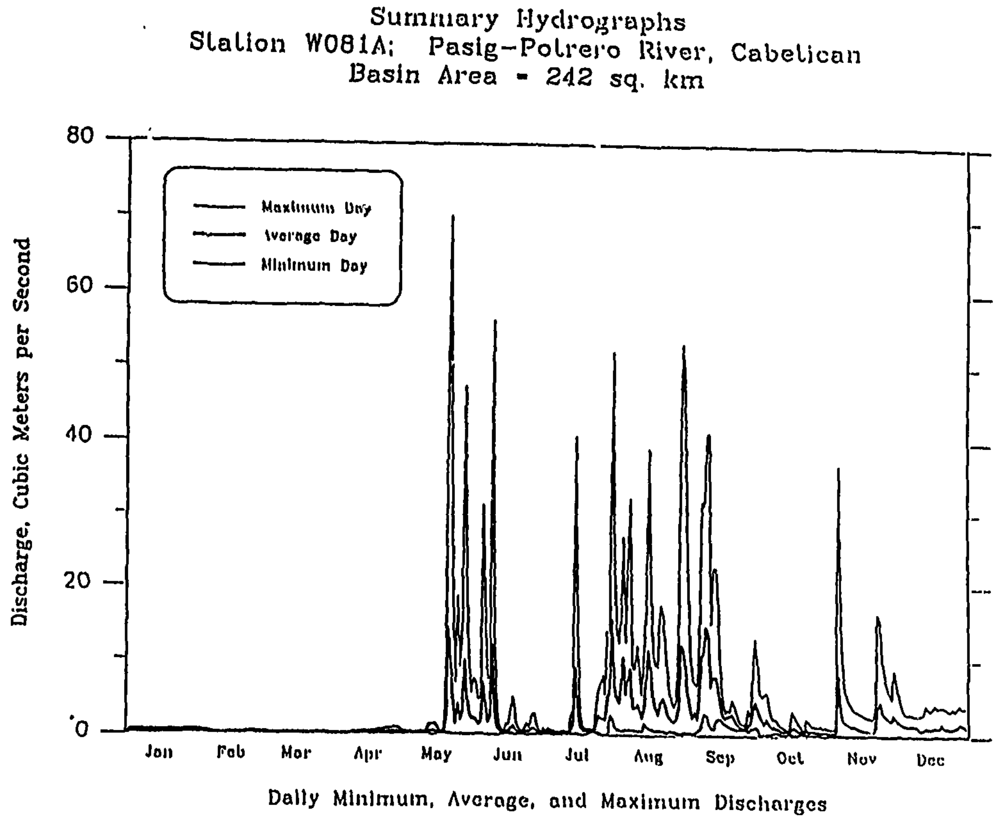

Summary Hydrographs
Station W081A; Pasig-Potrero River, Cabelican
Basin Area = 242 sq. km
Maximum Day
Average Day
Minimum Day
80
60
40
20
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Discharge, Cubic Meters per Second
Daily Minimum, Average, and Maximum Discharges

Figure 2.4.13

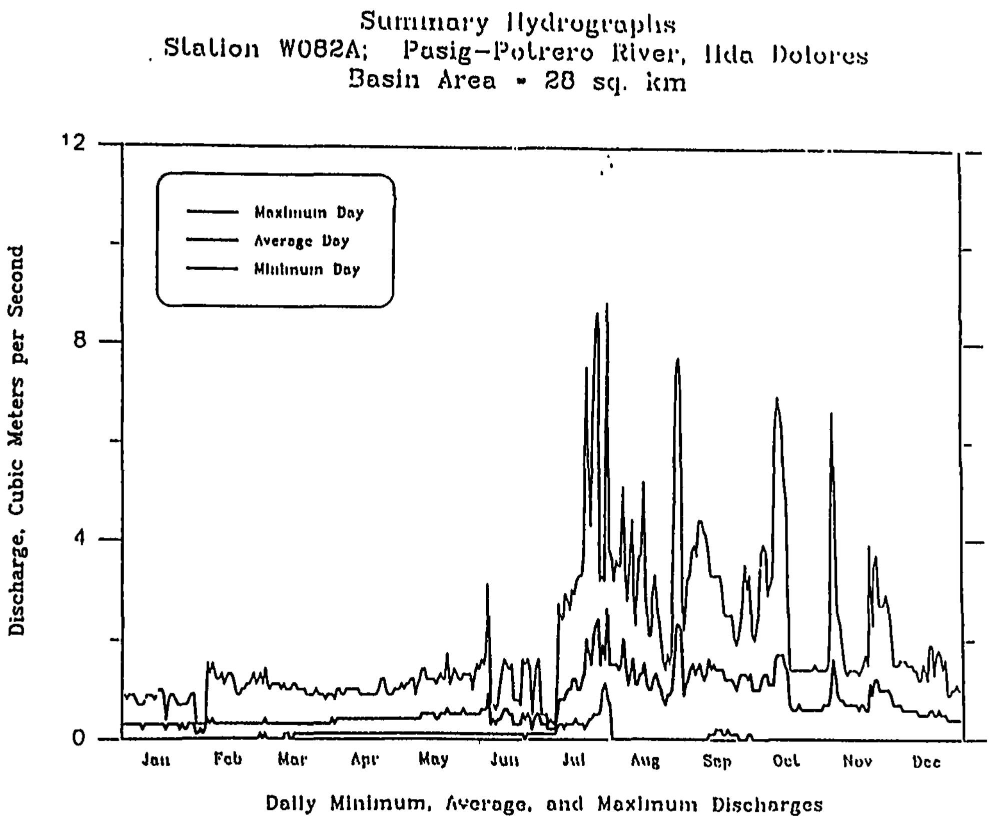

Summary Hydrographs
Station W082A; Pasig-Potrero River, Ilda Dolores
Basin Area = 28 sq. km
12
8
4
0
Discharge, Cubic Meters per Second
Maximum Day
Average Day
Minimum Day
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Daily Minimum, Average, and Maximum Discharges

Figure 2.4.14

Summary Hydrographs
Station W084A; Porac River, Del Carmen
Basin Area = 111 sq. km

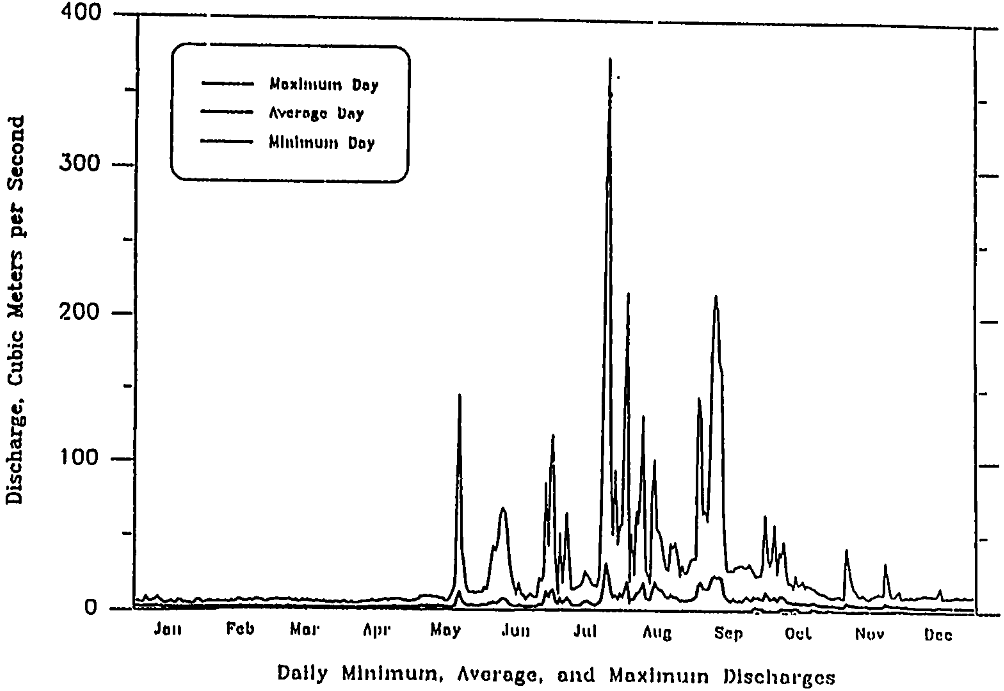


Figure 2.4.15

Summary Hydrographs
Station W086A; Gumain River, Pabanlag
Basin Area = 128 sq. km

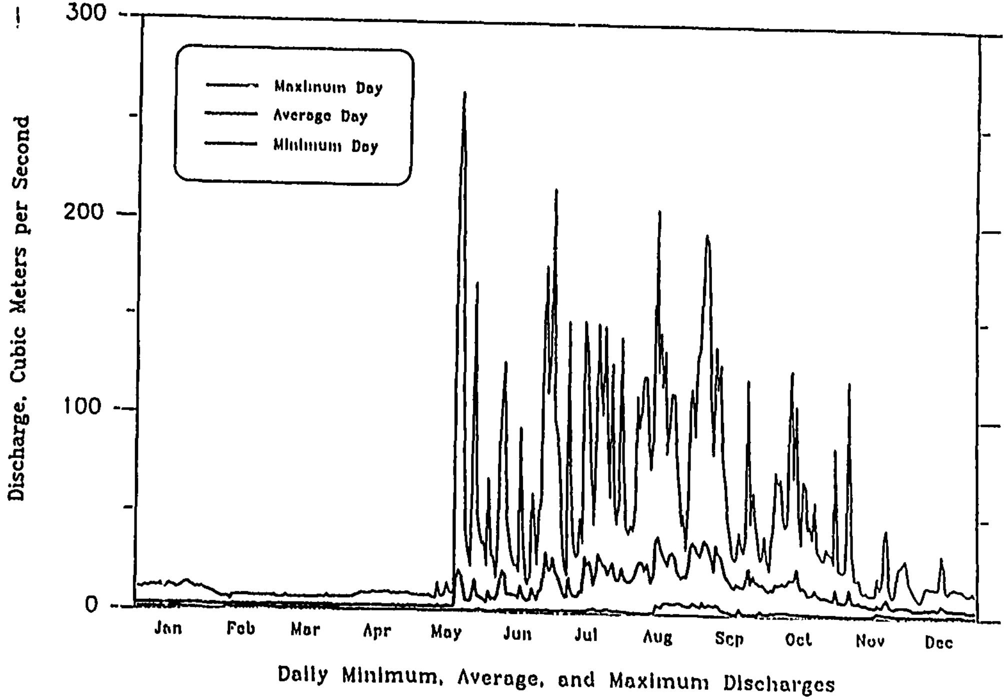


Figure 2.4.16

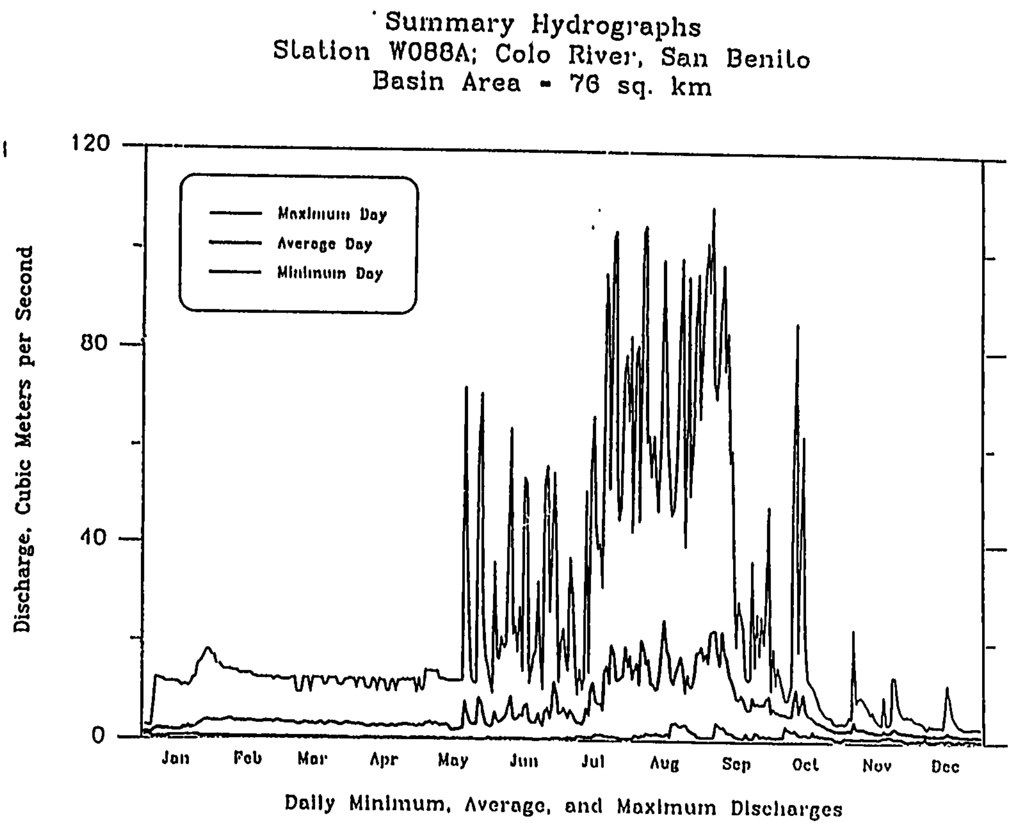
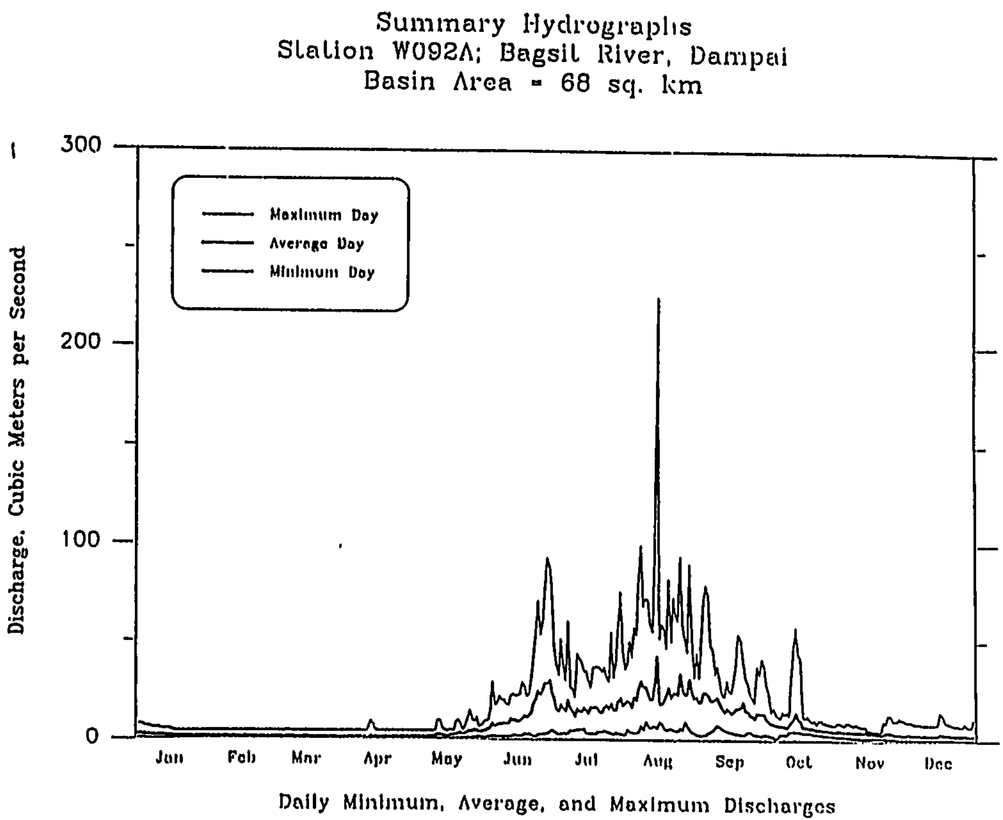

Summary Hydrographs
Station W088A; Colo River, San Benito
Basin Area = 76 sq. km
Maximum Day
Average Day
Minimum Day
120
80
40
0
Discharge, Cubic Meters per Second
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Daily Minimum, Average, and Maximum Discharges

Figure 2.4.17



Summary Hydrographs
Station W092A; Bagsil River, Dampai
Basin Area = 68 sq. km
Discharge, Cubic Meters per Second
300
200
100
0
Maximum Day
Average Day
Minimum Day
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Daily Minimum, Average, and Maximum Discharges

Figure 2.4.18

Summary Hydrographs
Station W093A; Bucao River, San Juan
Basin Area = 615 sq. km

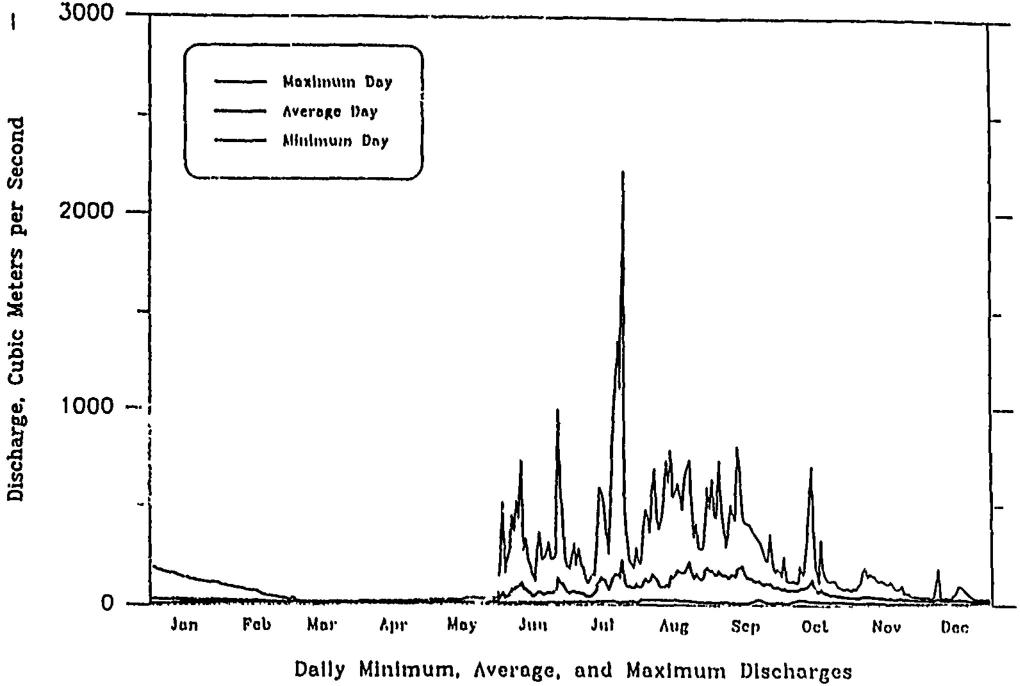
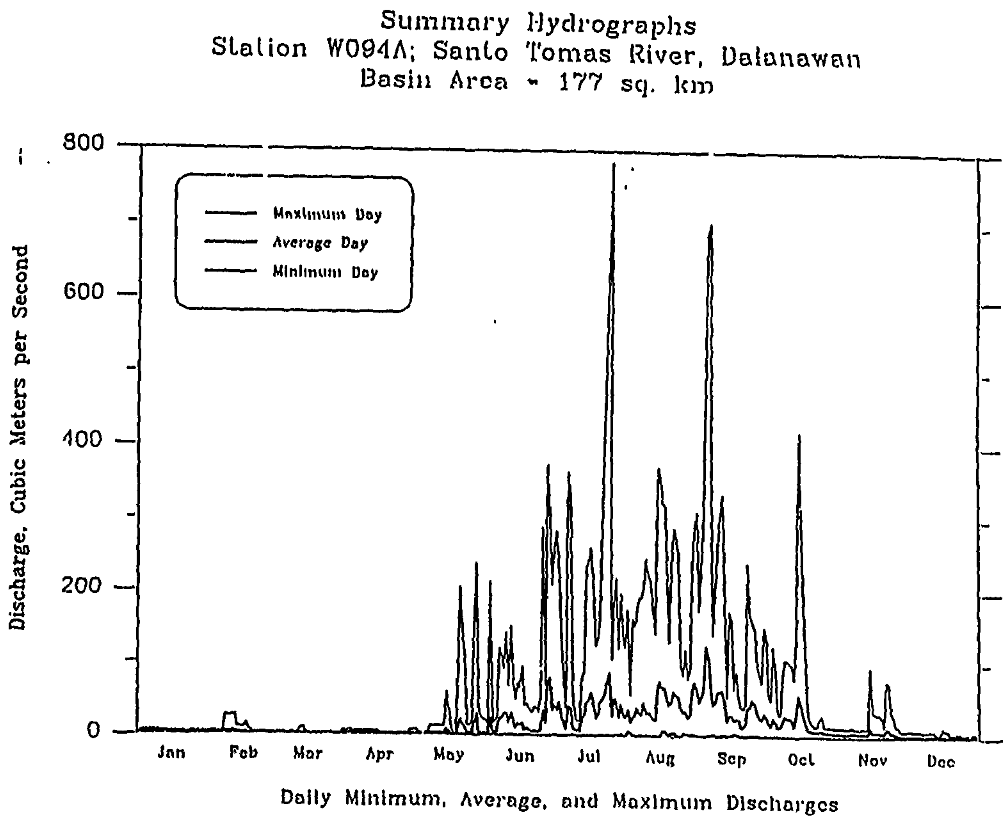


Figure 2.4.19



Summary Hydrographs
Station W094A; Santo Tomas River, Dalanawan
Basin Area = 177 sq. km
800
600
400
200
0
Discharge, Cubic Meters per Second
Maximum Day
Average Day
Minimum Day
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Daily Minimum, Average, and Maximum Discharges

Figure 2.4.20

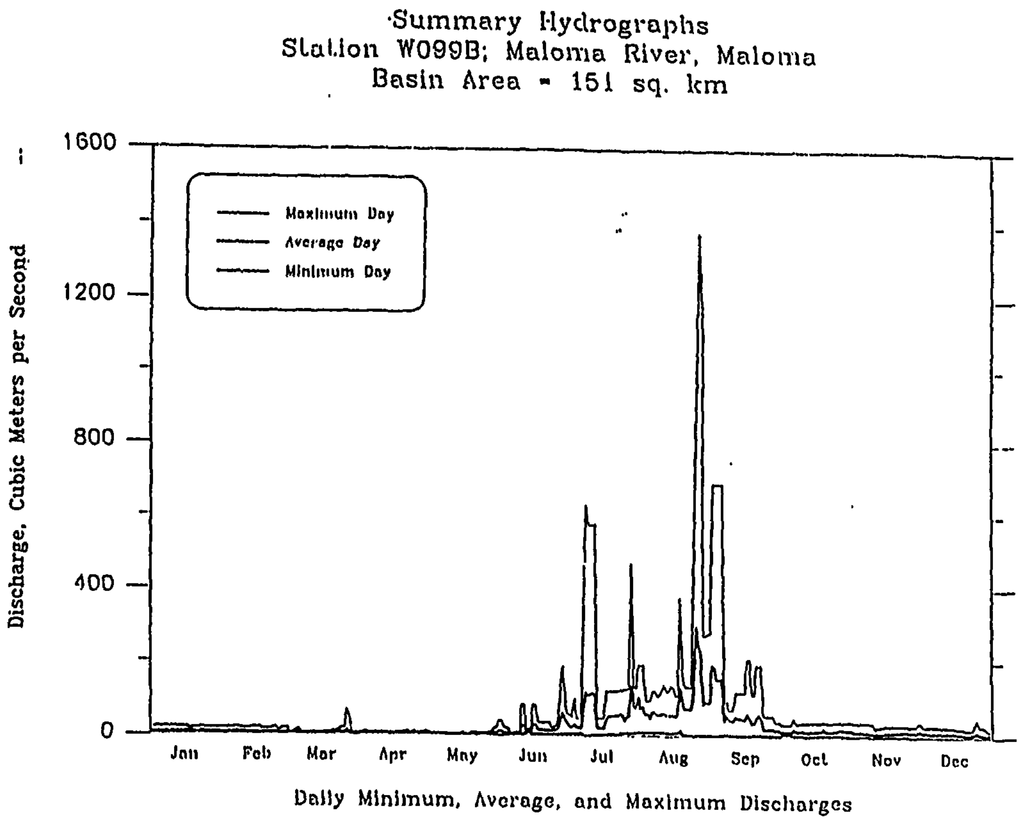
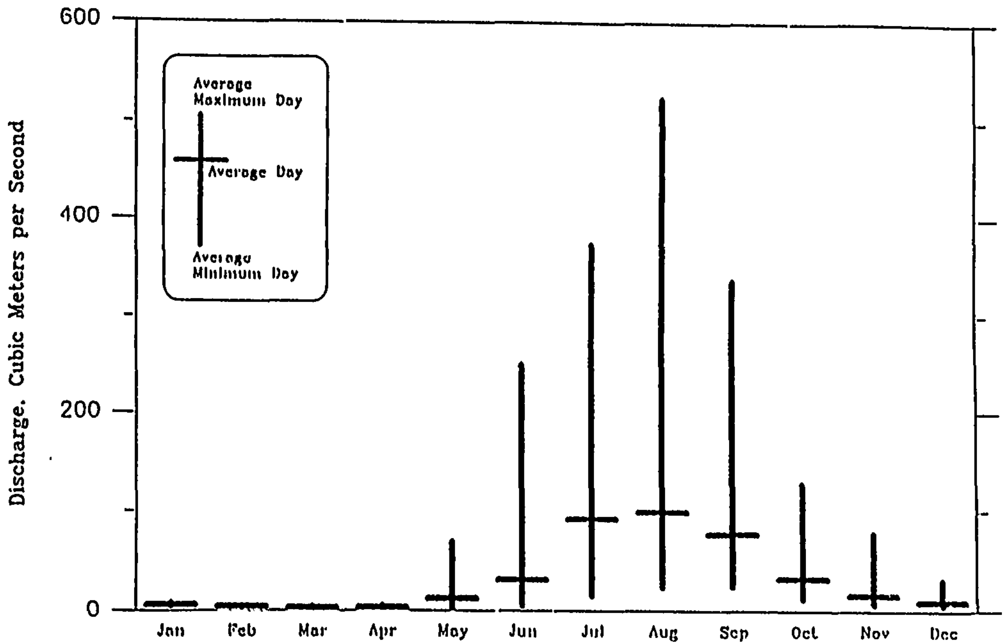

Summary Hydrographs
Station W099B; Maloma River, Maloma
Basin Area = 151 sq. km
Maximum Day
Average Day
Minimum Day
1600
1200
800
400
0
Discharge, Cubic Meters per Second
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Daily Minimum, Average, and Maximum Discharges

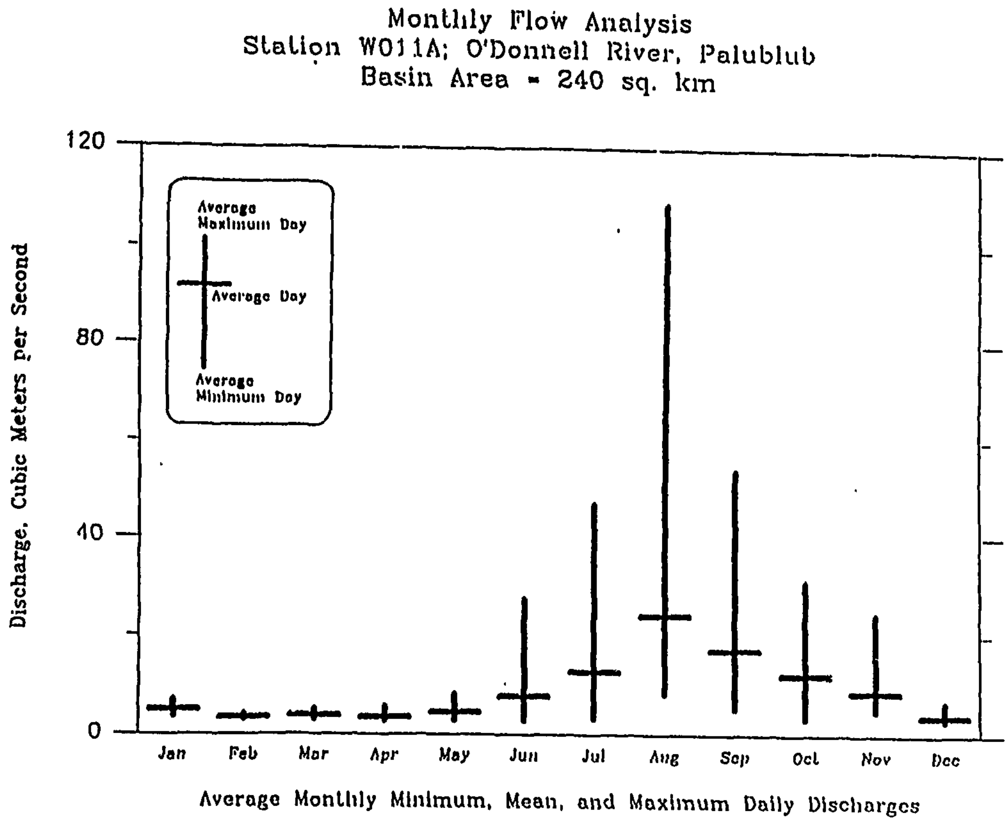
Figure 2.4.21

Monthly Flow Analysis
Station W010A; Bulsa River, Villa Aglipay
Basin Area = 405 sq. km



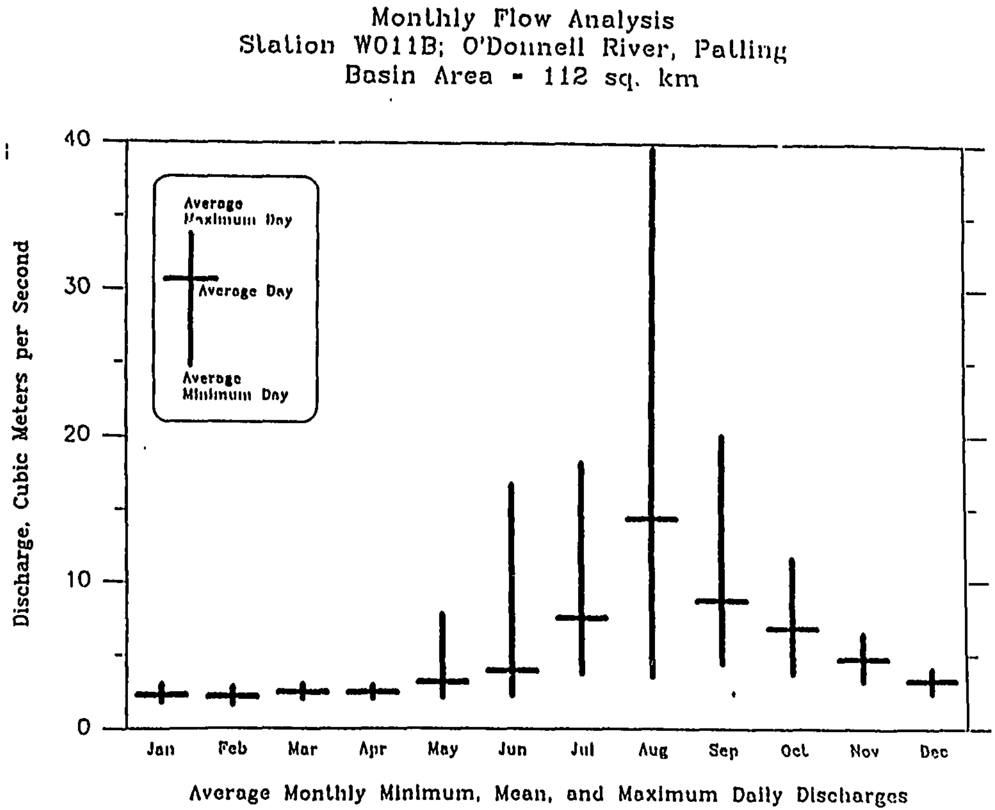
Average Monthly Minimum, Mean, and Maximum Daily Discharges

Figure 2.4.22



Monthly Flow Analysis
Station W011A; O'Donnell River, Palublub
Basin Area = 240 sq. km
120
80
40
0
Discharge, Cubic Meters per Second
Average Maximum Day
Average Day
Average Minimum Day
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Average Monthly Minimum, Mean, and Maximum Daily Discharges

Figure 2.4.23



Monthly Flow Analysis
Station W011B; O'Donnell River, Palling
Basin Area = 112 sq. km
Discharge, Cubic Meters per Second
0
10
20
30
40
Average Maximum Day
Average Day
Average Minimum Day
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Average Monthly Minimum, Mean, and Maximum Daily Discharges

Figure 2.4.24

Monthly Flow Analysis
Station W012A; Bangat River, Sta Lucia
Basin Area = 90 sq. km.

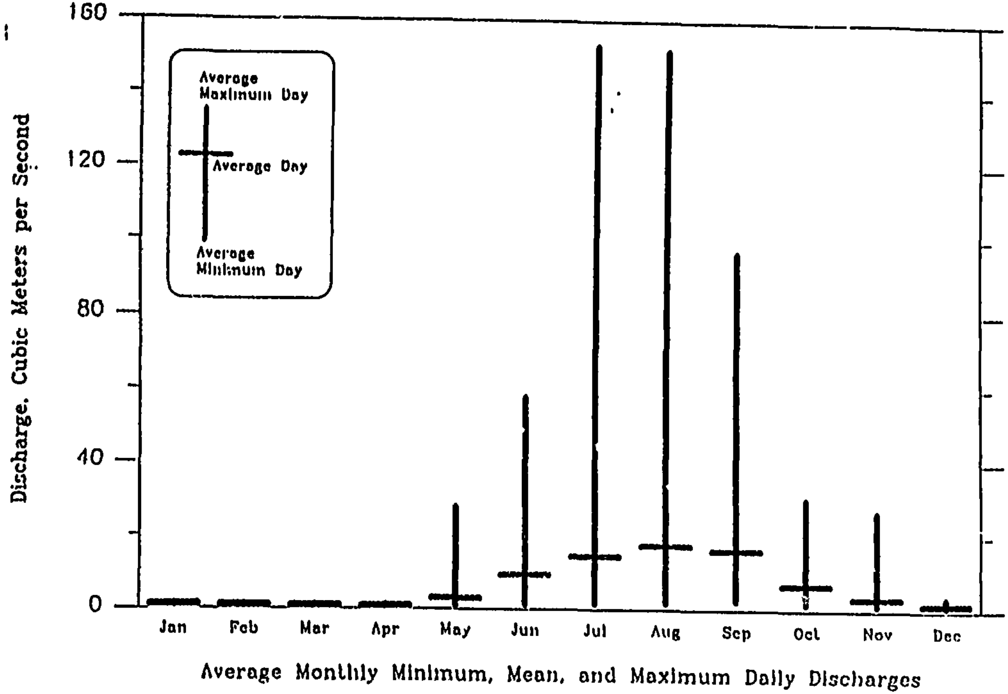


Figure 2.4.25

Monthly Flow Analysis
Station W023A; Camiling River, Nambalan
Basin Area = 142 sq. km.

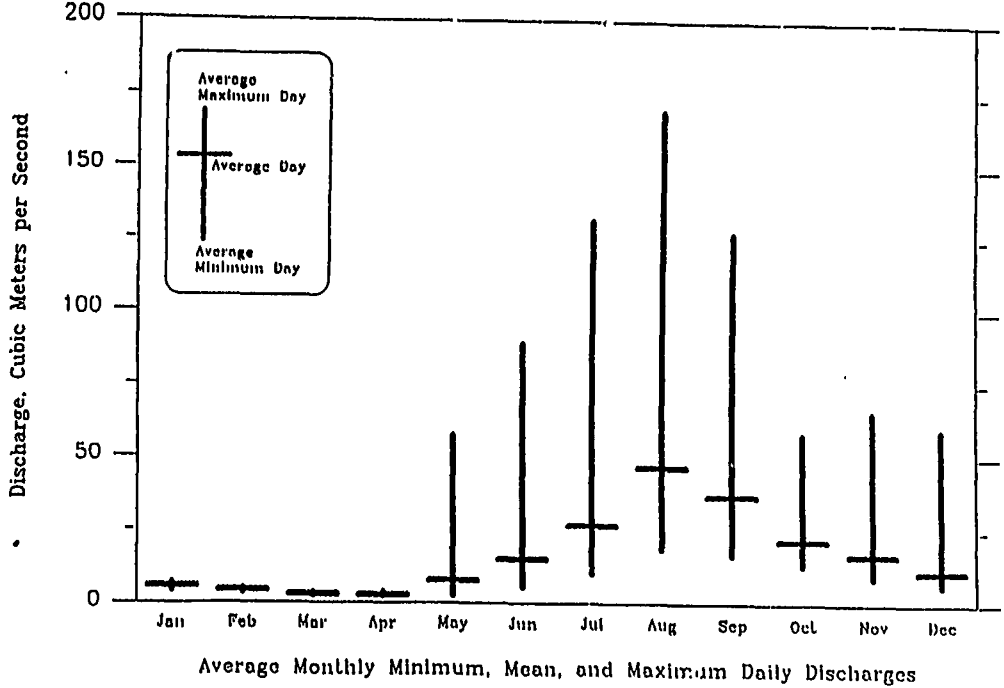


Figure 2.4.26

Monthly Flow Analysis
Station W023B; Camiling River, Poblacion
Basin Area = 280 sq. km.

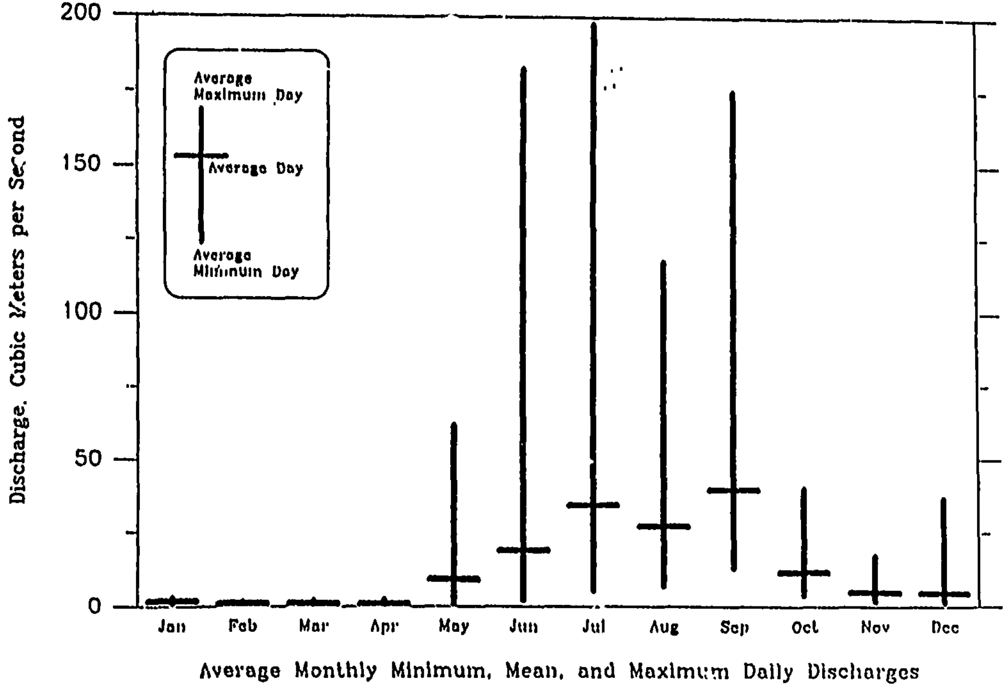


Figure 2.4.27

Monthly Flow Analysis
Station W081A; Pasig-Potrero River, Cabelican
Basin Area = 242 sq. km.

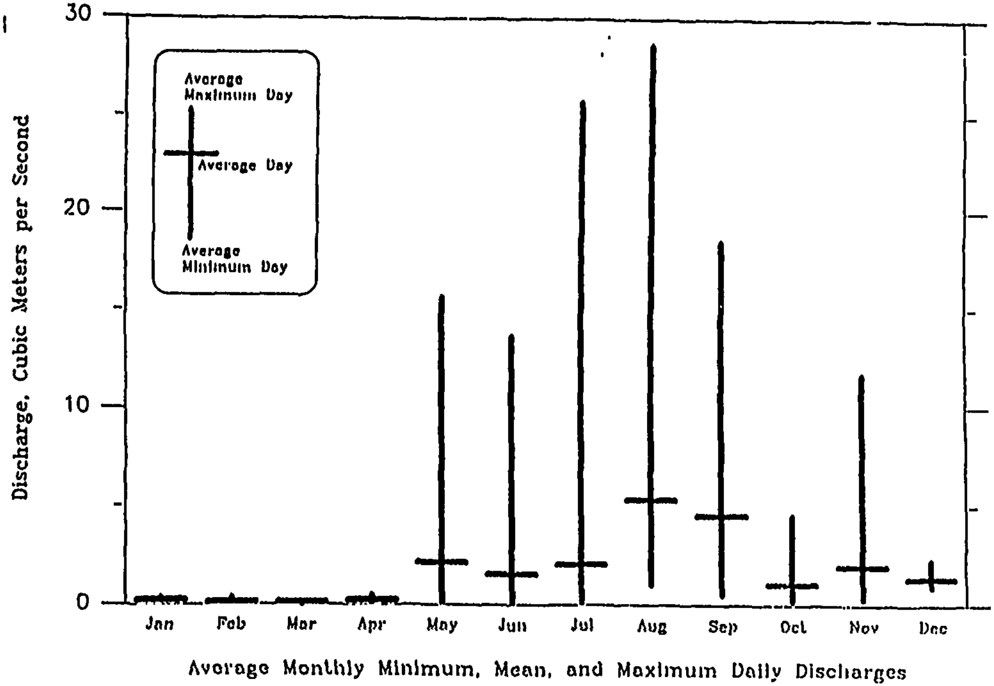


Figure 2.4.28

Monthly Flow Analysis
Station W082A; Pasig-Potrero River, Hda Dolores
Basin Area = 28 sq. km.

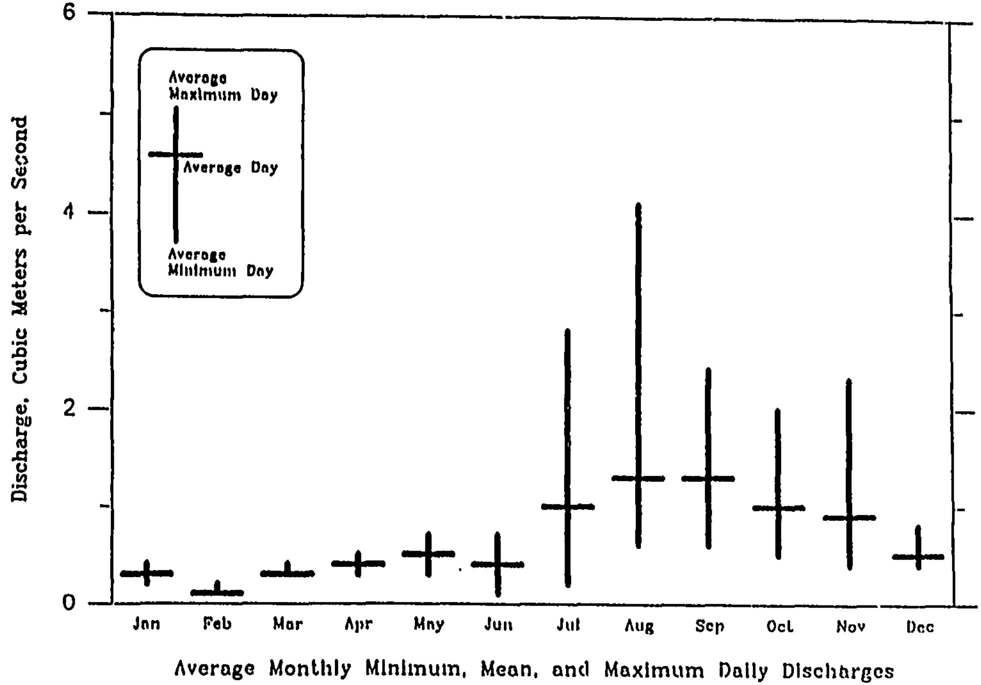


Figure 2.4.29

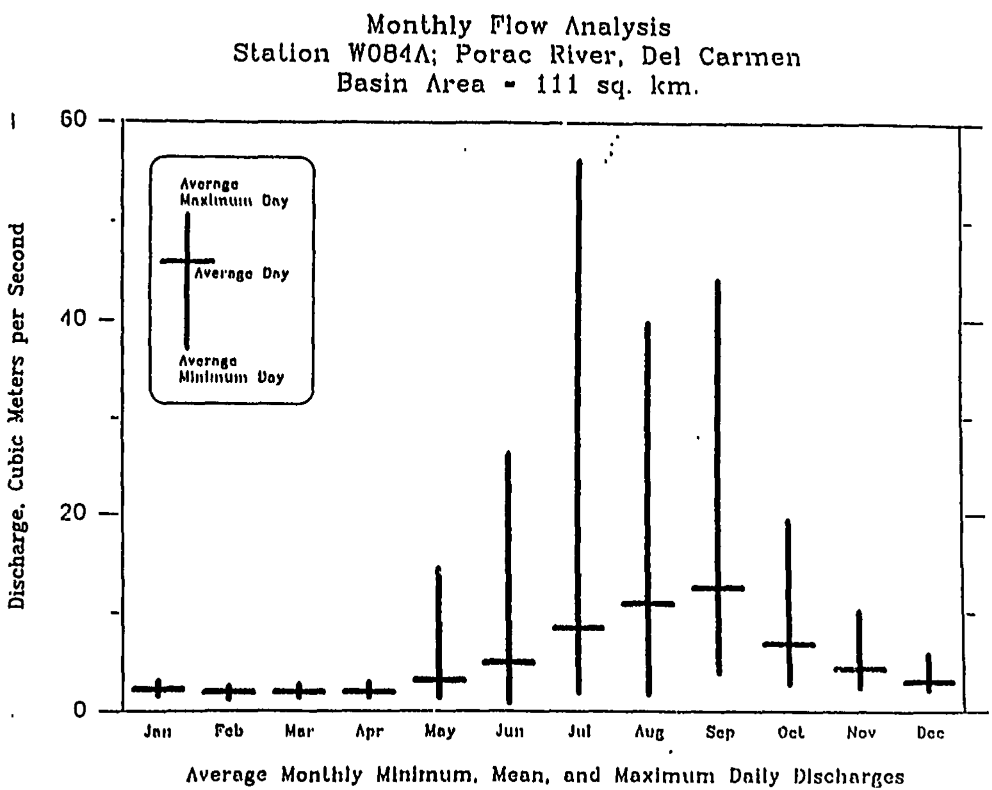

Monthly Flow Analysis
Station W084A; Porac River, Del Carmen
Basin Area = 111 sq. km.
Discharge, Cubic Meters per Second
60
40
20
0
Average Maximum Day
Average Day
Average Minimum Day
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Average Monthly Minimum, Mean, and Maximum Daily Discharges

Figure 2.4.30

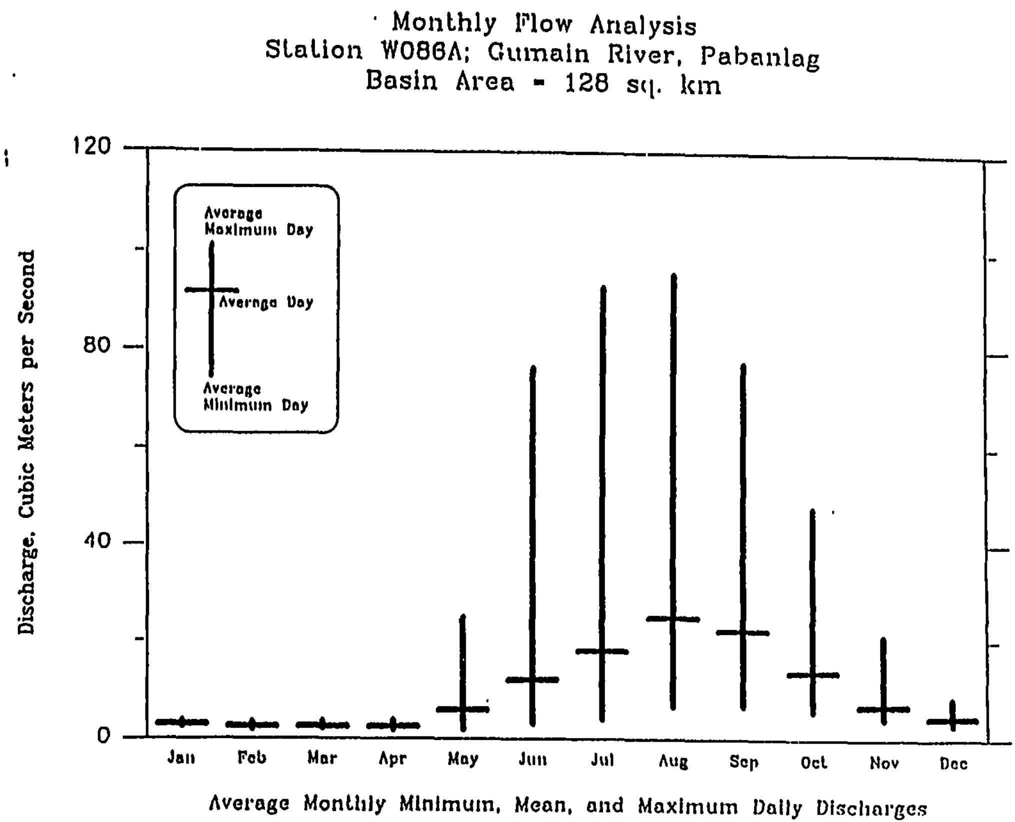

Monthly Flow Analysis
Station W086A; Gumain River, Pabanlag
Basin Area = 128 sq. km
Discharge, Cubic Meters per Second
120
80
40
0
Average Maximum Day
Average Day
Average Minimum Day
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Average Monthly Minimum, Mean, and Maximum Daily Discharges

Figure 2.4.31

Monthly Flow Analysis
Station W088A; Colo River, San Benito
Basin Area = 76 sq. km

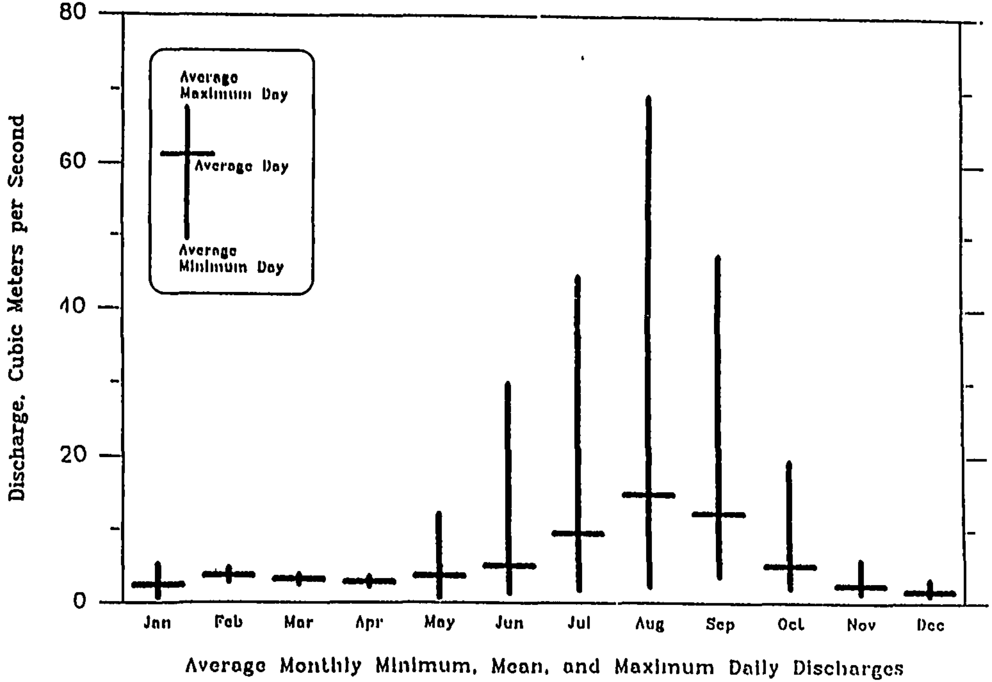


Figure 2.4.32

Monthly Flow Analysis
Station W092A; Bagsit River, Dampai
Basin Area = 68 sq. km

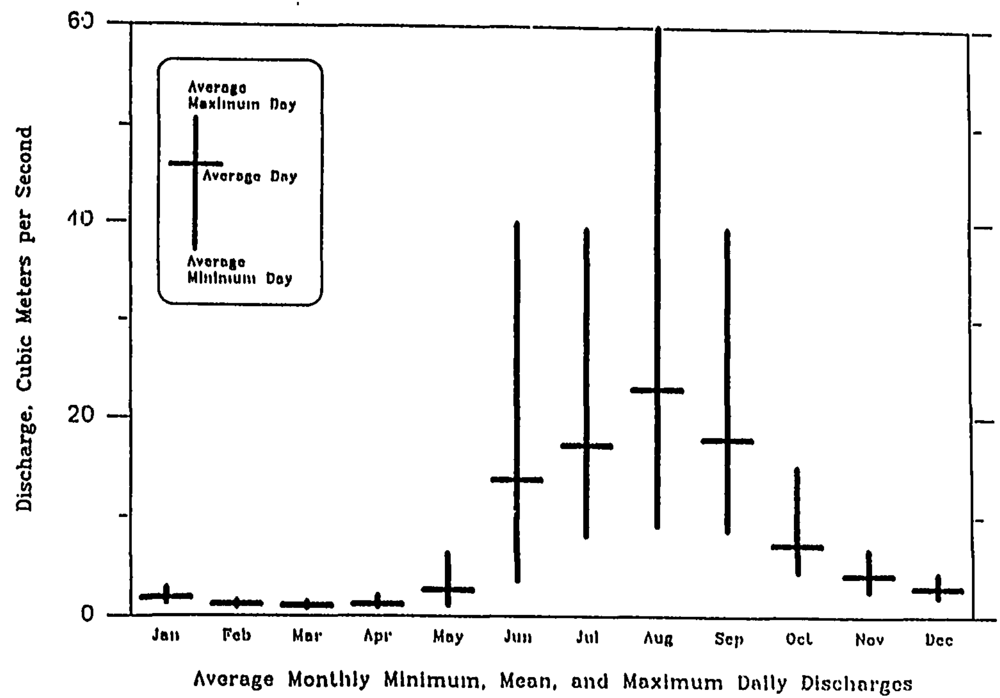


Figure 2.4.33

Monthly Flow Analysis
Station W093A; Bucao River, San Juan
Basin Area - 615 sq. km

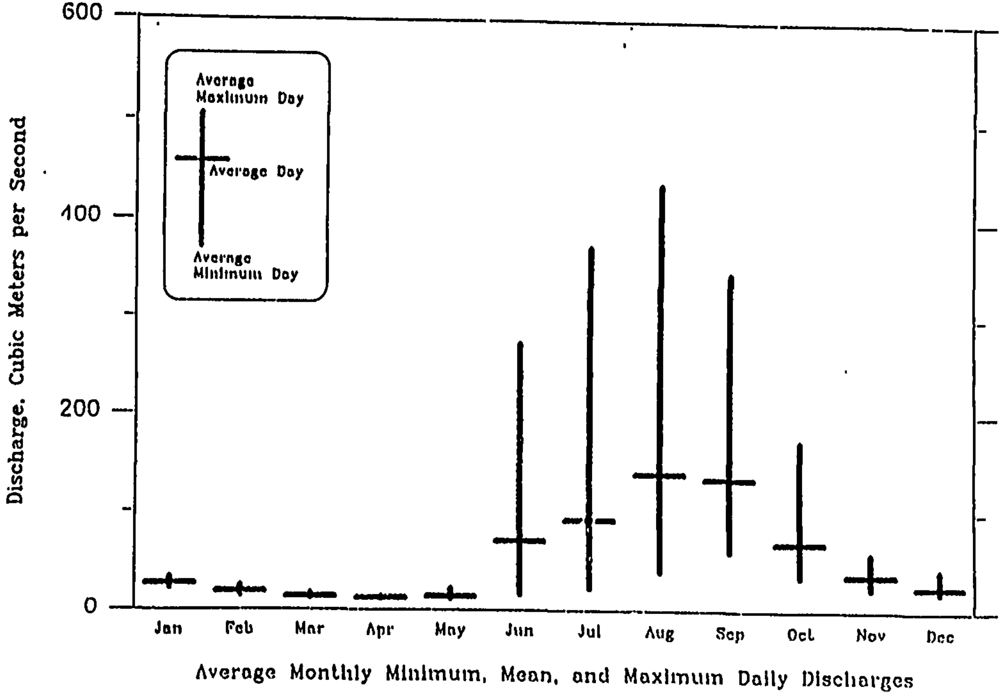


Figure 2.4.34

Monthly Flow Analysis
Station W094A; Santo Tomas River, Dalanawan
Basin Area = 177 sq. km.

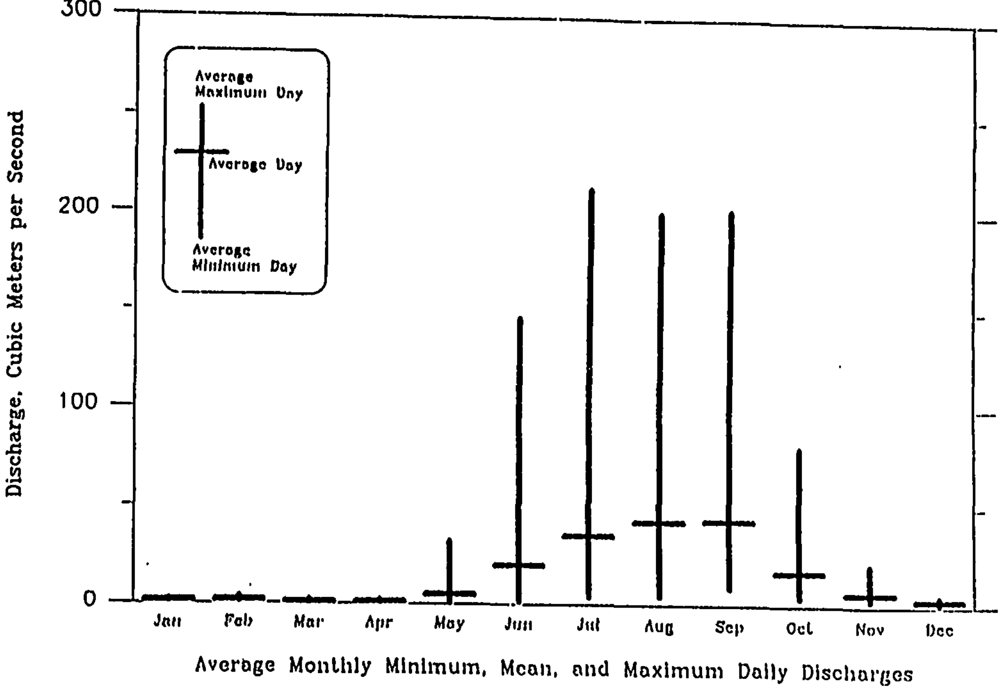


Figure 2.4.35

Monthly Flow Analysis
Station W099B; Maloma River, Maloma
Basin Area = 151 sq. km.

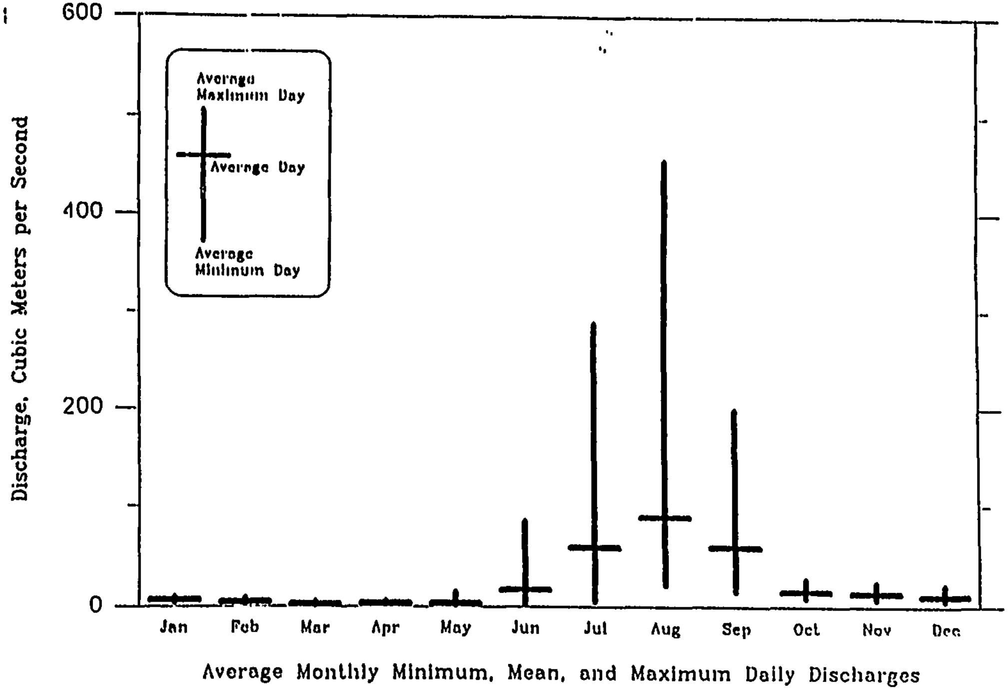


Figure 2.4.36

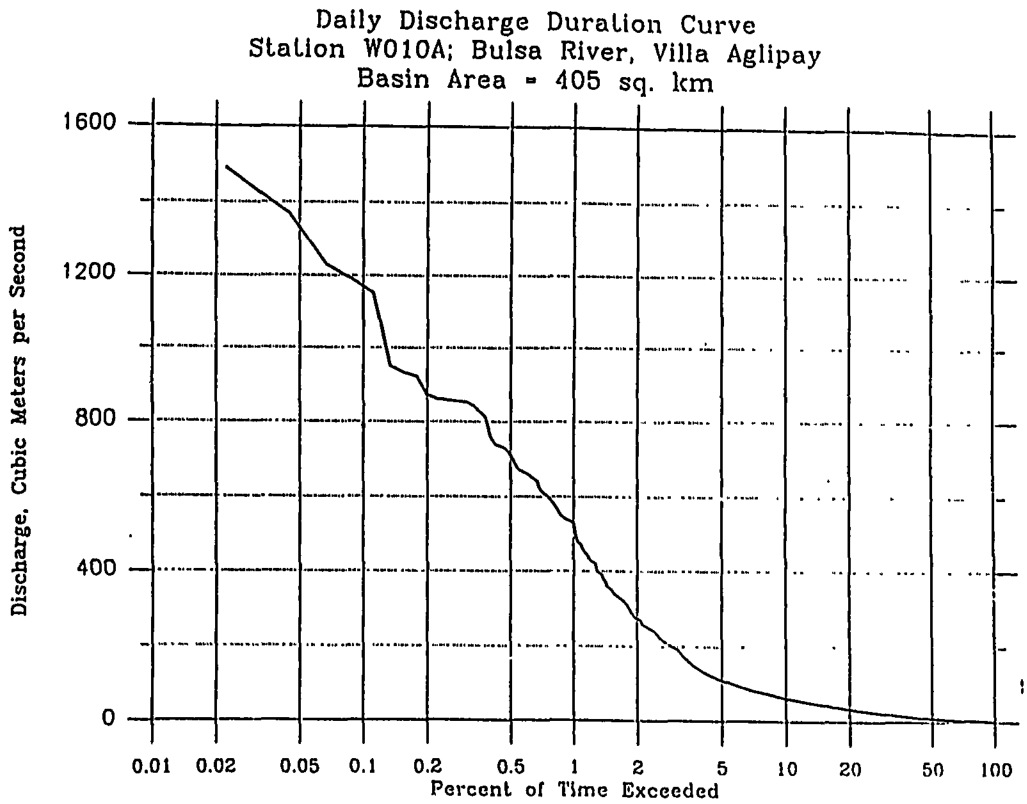

Daily Discharge Duration Curve
Station W010A; Bulsa River, Villa Aglipay
Basin Area = 405 sq. km
1600
1200
800
400
0
Discharge, Cubic Meters per Second
0.01
0.02
0.05
0.1
0.2
0.5
1
2
5
10
20
50
100
Percent of Time Exceeded

Figure 2.4.37

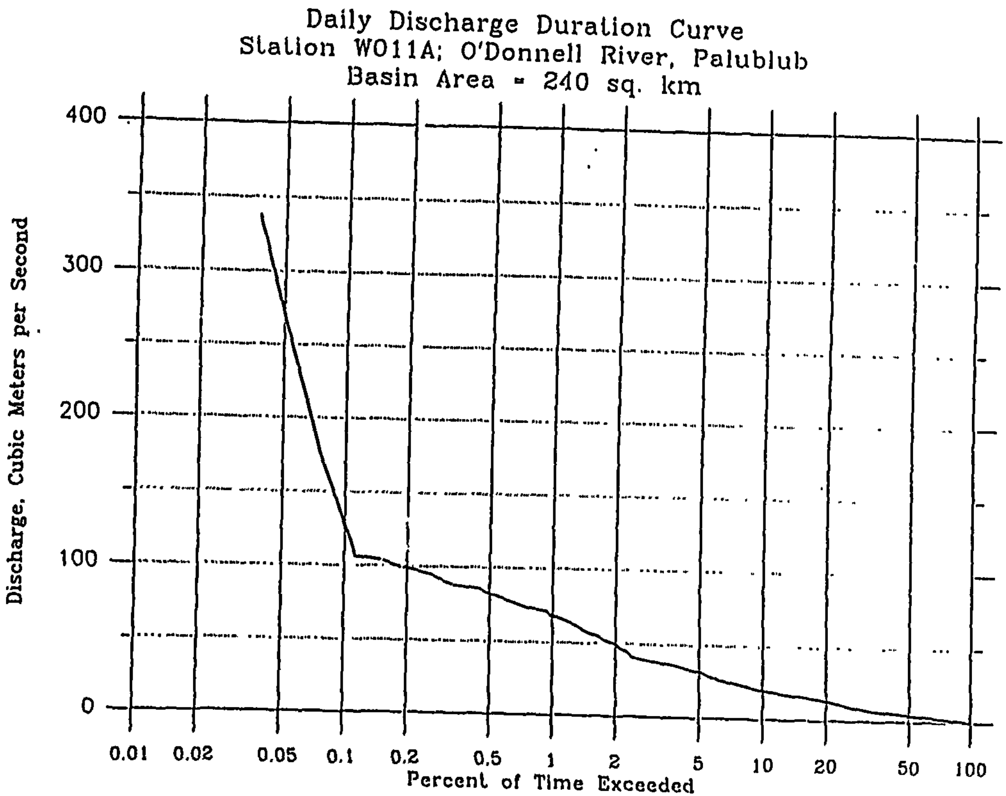

Daily Discharge Duration Curve
Station W011A; O'Donnell River, Palublub
Basin Area = 240 sq. km
Discharge, Cubic Meters per Second
400
300
200
100
0
0.01
0.02
0.05
0.1
0.2
0.5
1
2
5
10
20
50
100
Percent of Time Exceeded

Figure 2.4.38

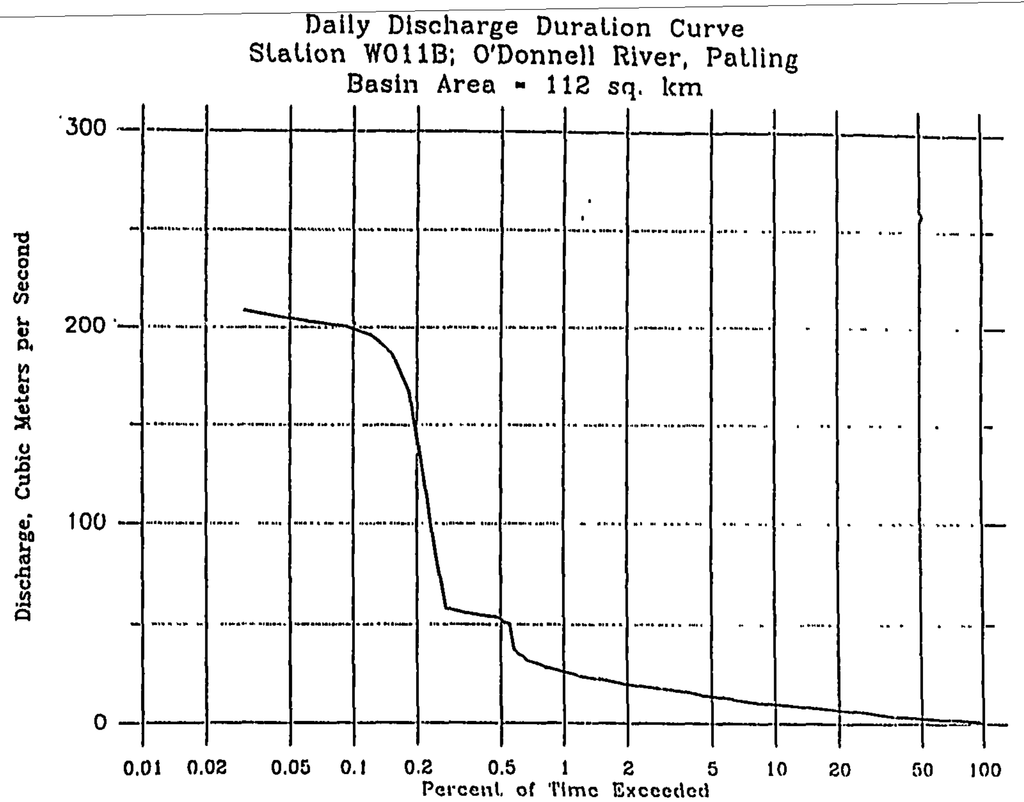

Daily Discharge Duration Curve
Station W011B; O'Donnell River, Patling
Basin Area = 112 sq. km
300
200
100
0
Discharge, Cubic Meters per Second
0.01
0.02
0.05
0.1
0.2
0.5
1
2
5
10
20
50
100
Percent of Time Exceeded

Figure 2.4.39

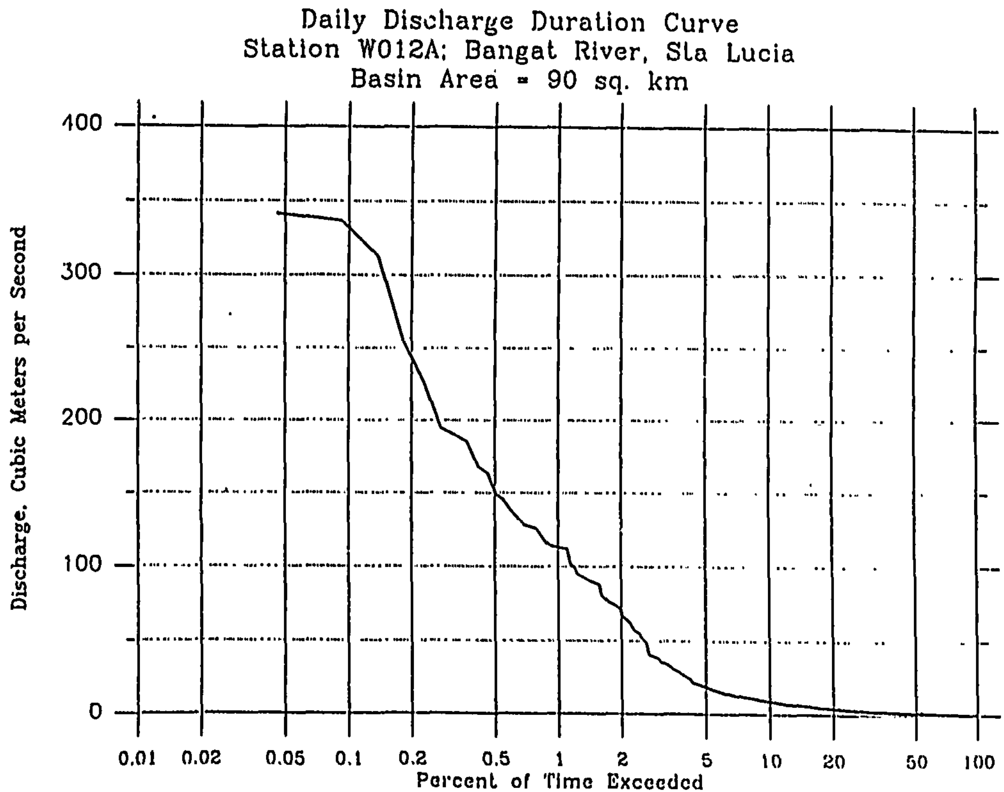
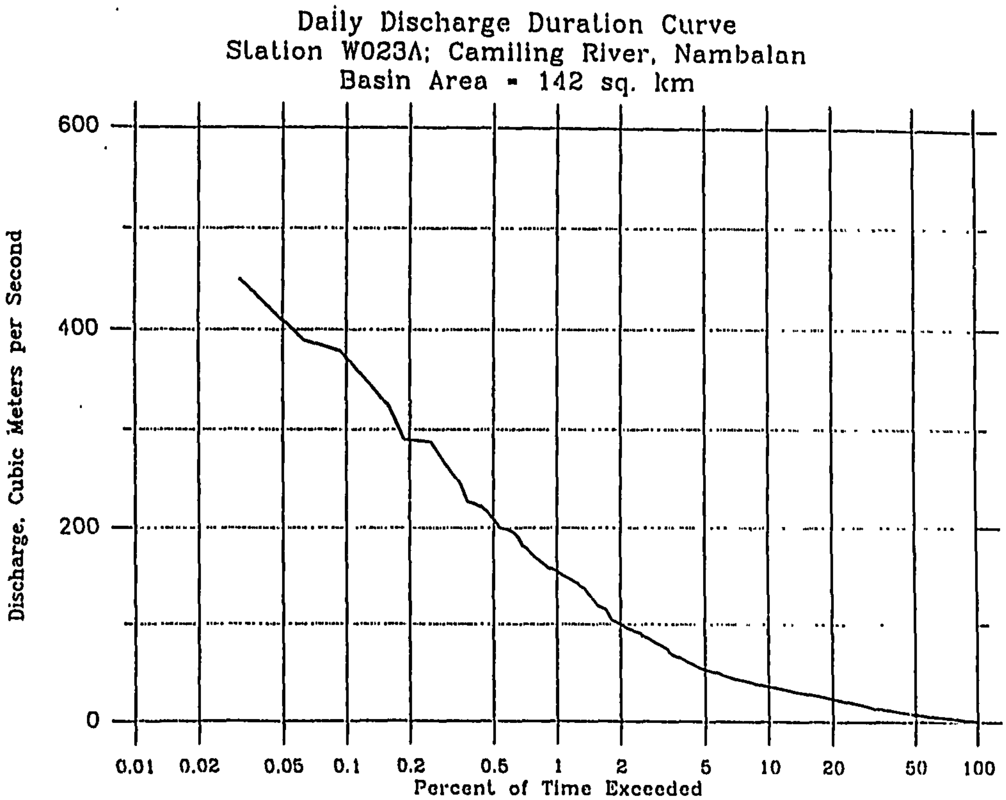

Daily Discharge Duration Curve
Station W012A; Bangat River, Sta Lucia
Basin Area = 90 sq. km
Discharge, Cubic Meters per Second
400
300
200
100
0
0.01
0.02
0.05
0.1
0.2
0.5
1
2
5
10
20
50
100
Percent of Time Exceeded

Figure 2.4.40



Daily Discharge Duration Curve
Station W023A; Camiling River, Nambalan
Basin Area = 142 sq. km
Discharge, Cubic Meters per Second
600
400
200
0
0.01
0.02
0.05
0.1
0.2
0.5
1
2
5
10
20
50
100
Percent of Time Exceeded

Figure 2.4.41

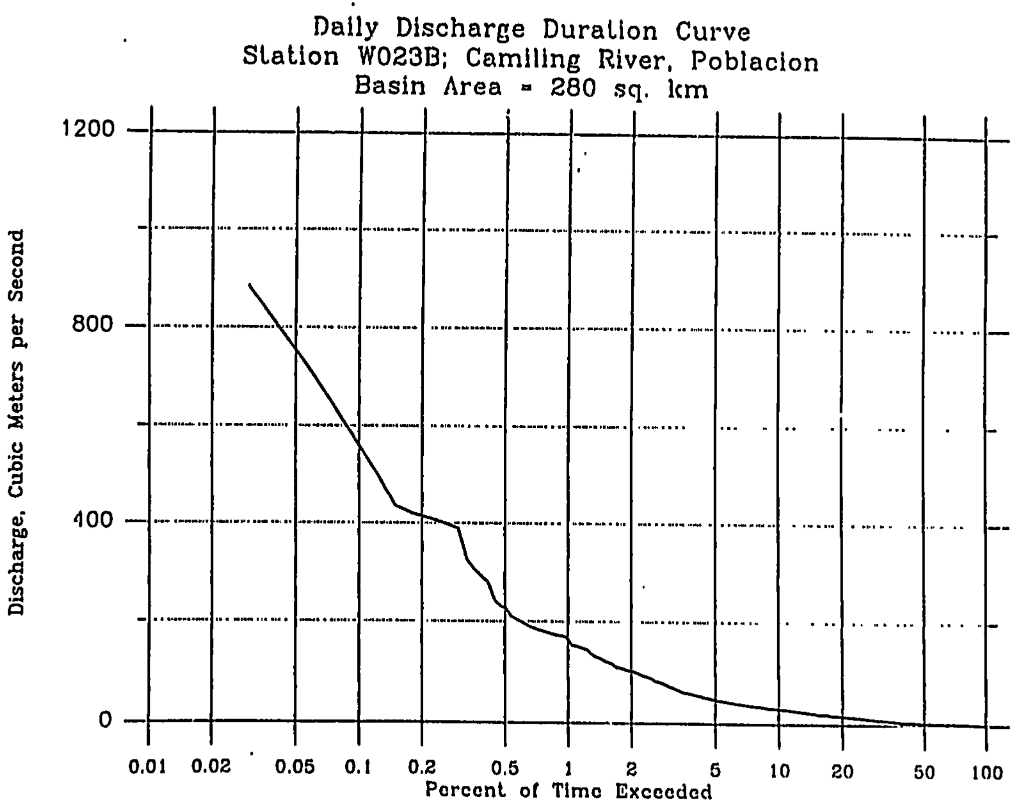

Daily Discharge Duration Curve
Station W023B; Camiling River, Poblacion
Basin Area = 280 sq. km
1200
800
400
0
Discharge, Cubic Meters per Second
0.01
0.02
0.05
0.1
0.2
0.5
1
2
5
10
20
50
100
Percent of Time Exceeded

Figure 2.4.42

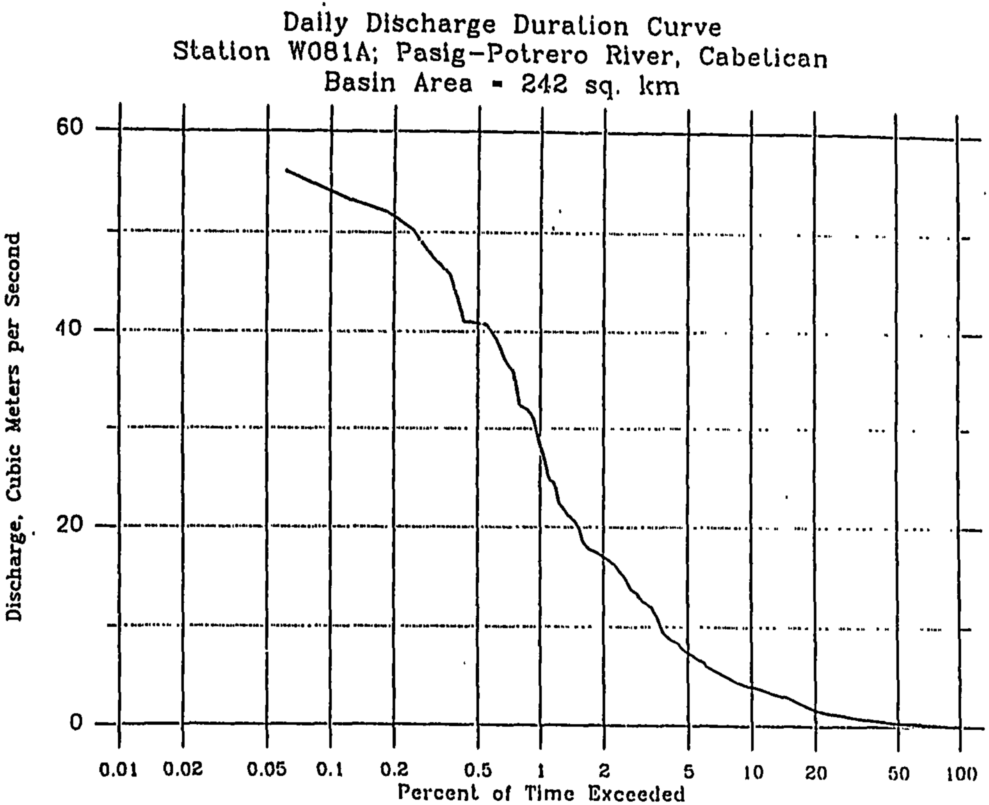

Daily Discharge Duration Curve
Station W081A; Pasig-Potrero River, Cabelican
Basin Area = 242 sq. km
Discharge, Cubic Meters per Second
60
40
20
0
0.01
0.02
0.05
0.1
0.2
0.5
1
2
5
10
20
50
100
Percent of Time Exceeded

Figure 2.4.43

Daily Discharge Duration Curve
Station W082A; Pasig-Potrero River, Hda Dolores
Basin Area = 28 sq. km

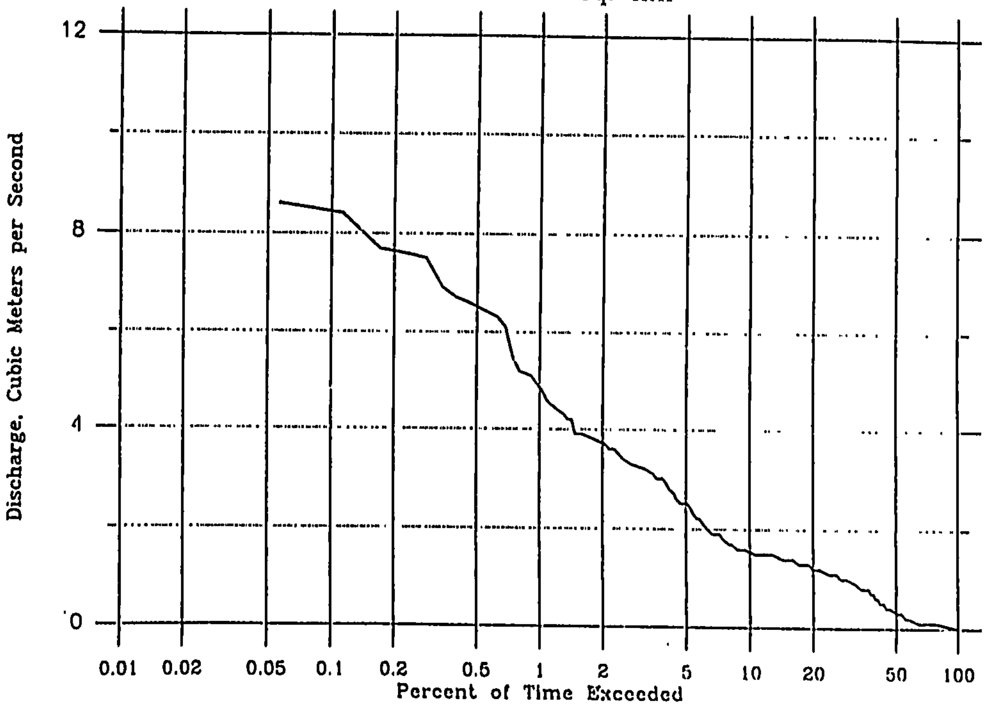


Figure 2.4.44

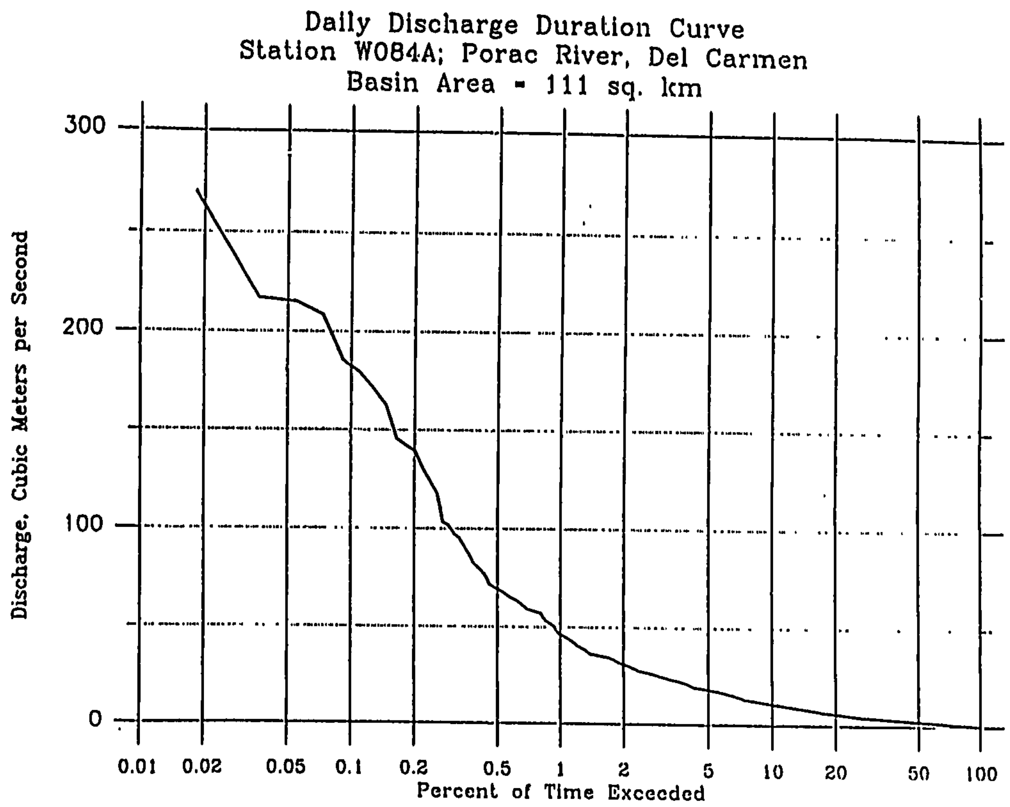
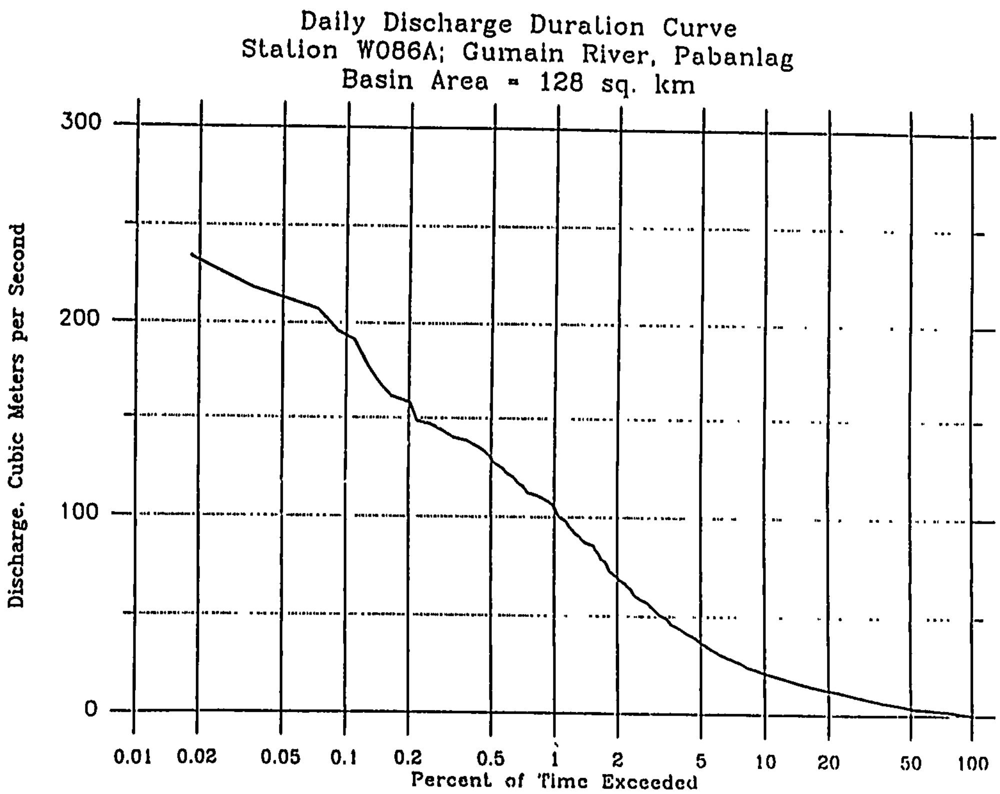

Daily Discharge Duration Curve
Station W084A; Porac River, Del Carmen
Basin Area = 111 sq. km
300
200
100
0
Discharge, Cubic Meters per Second
0.01
0.02
0.05
0.1
0.2
0.5
1
2
5
10
20
50
100
Percent of Time Exceeded

Figure 2.4.45



Daily Discharge Duration Curve
Station W086A; Gumain River, Pabanlag
Basin Area = 128 sq. km
300
200
100
0
Discharge, Cubic Meters per Second
0.01
0.02
0.05
0.1
0.2
0.5
1
2
5
10
20
50
100
Percent of Time Exceeded

Figure 2.4.46

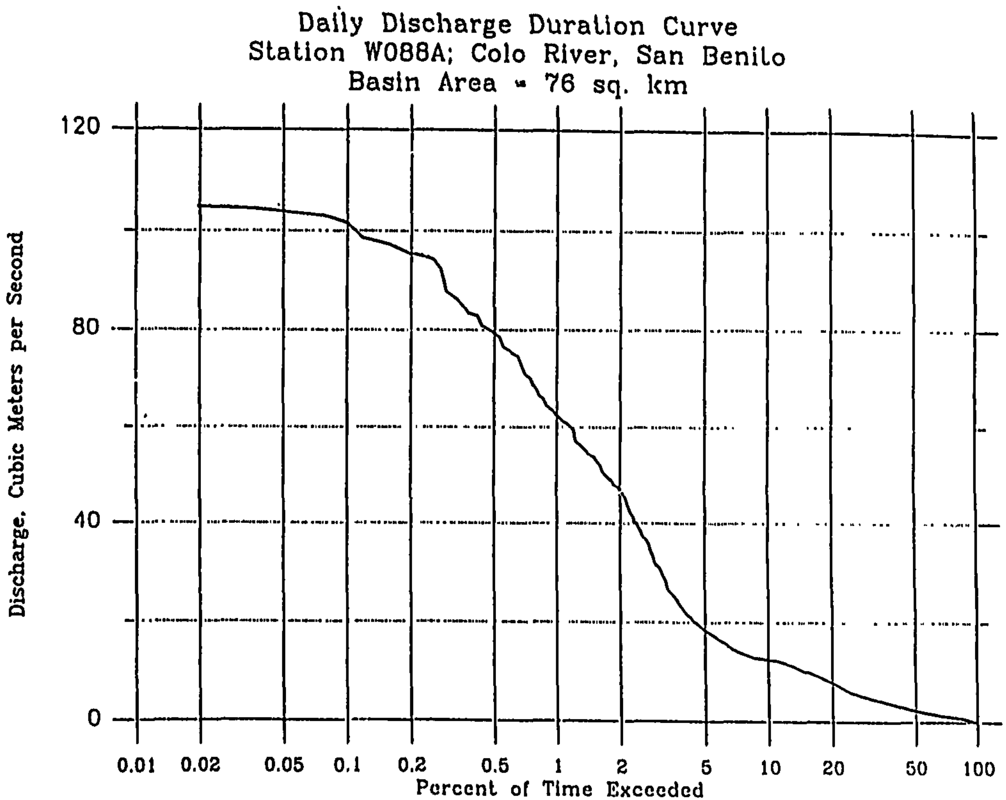

Daily Discharge Duration Curve
Station W088A; Colo River, San Benito
Basin Area = 76 sq. km
120
80
40
0
Discharge, Cubic Meters per Second
0.01
0.02
0.05
0.1
0.2
0.5
1
2
5
10
20
50
100
Percent of Time Exceeded

Figure 2.4.47

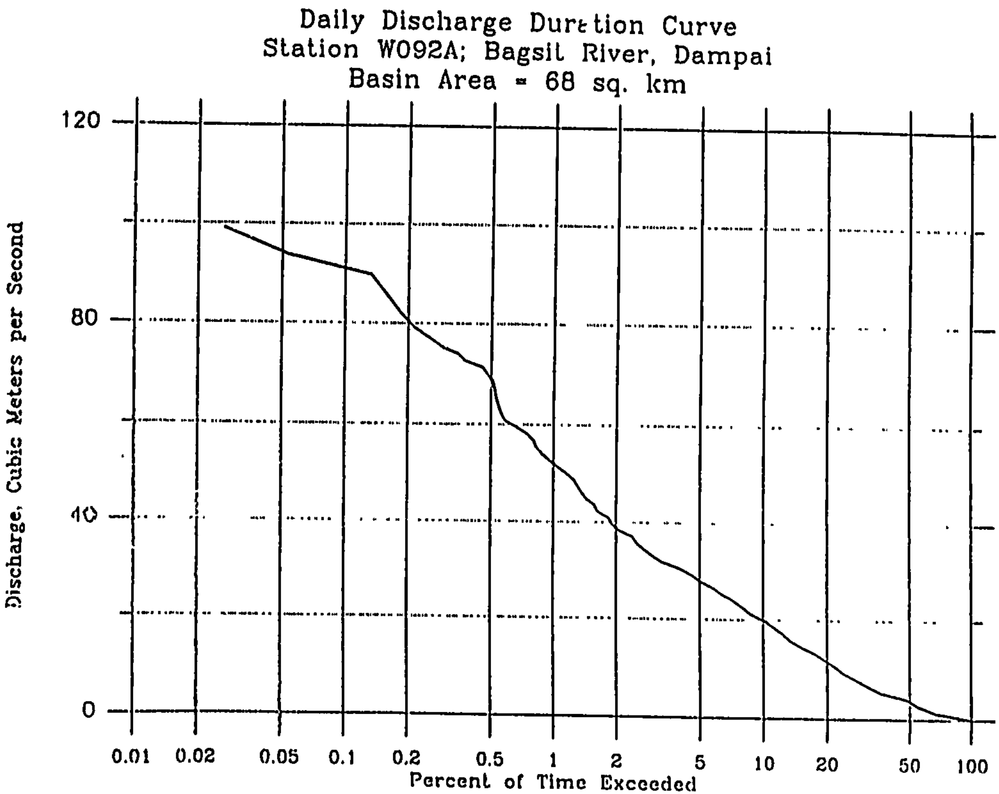

Daily Discharge Durtion Curve
Station W092A; Bagsil River, Dampai
Basin Area = 68 sq. km
120
80
40
0
Discharge, Cubic Meters per Second
0.01
0.02
0.05
0.1
0.2
0.5
1
2
5
10
20
50
100
Percent of Time Exceeded

Figure 2.4.48

Daily Discharge Duration Curve
Station W093A; Bucao River, San Juan
Basin Area = 615 sq. km

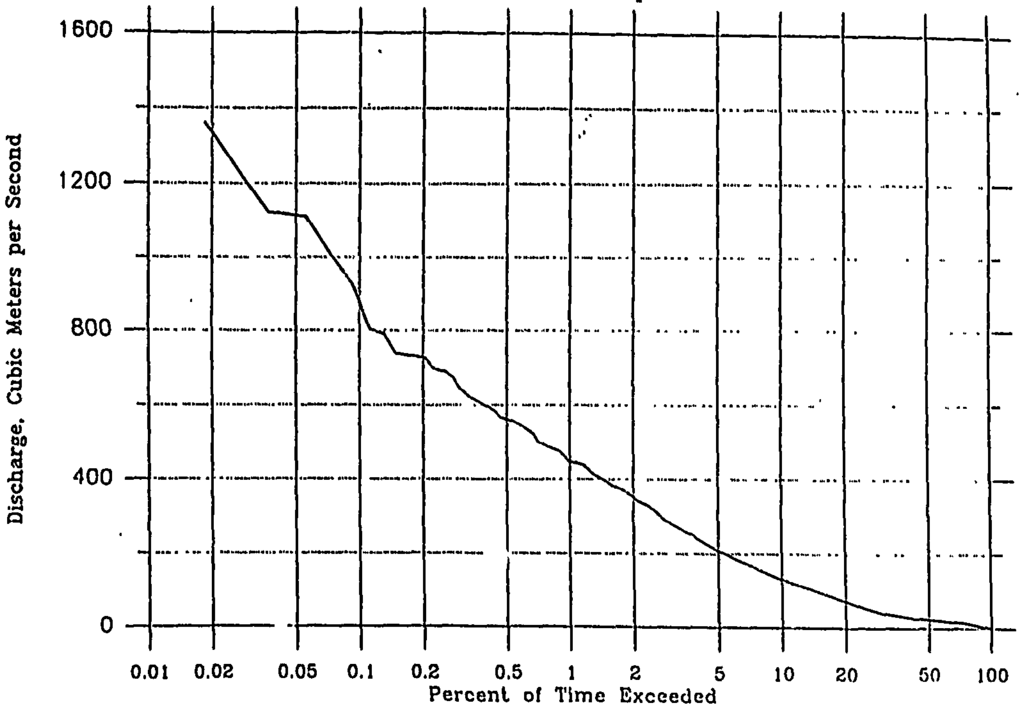
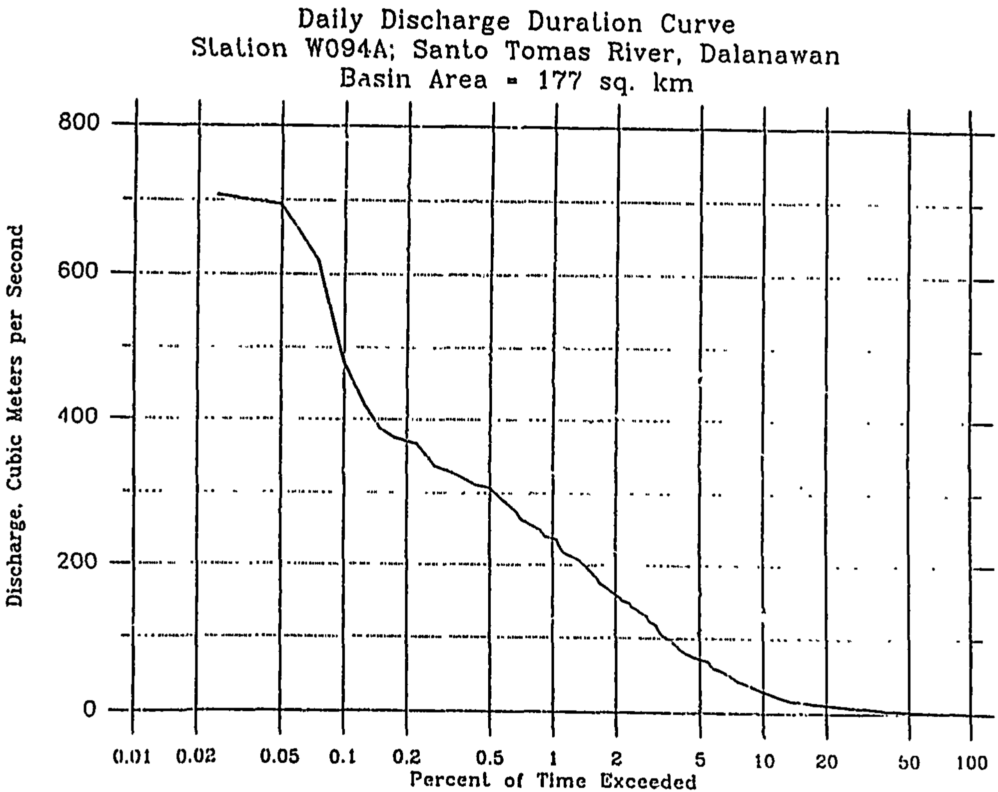


Figure 2.4.49



Daily Discharge Duration Curve
Station W094A; Santo Tomas River, Dalanawan
Basin Area = 177 sq. km
800
600
400
200
0
Discharge, Cubic Meters per Second
0.01
0.02
0.05
0.1
0.2
0.5
1
2
5
10
20
50
100
Percent of Time Exceeded

Figure 2.4.50

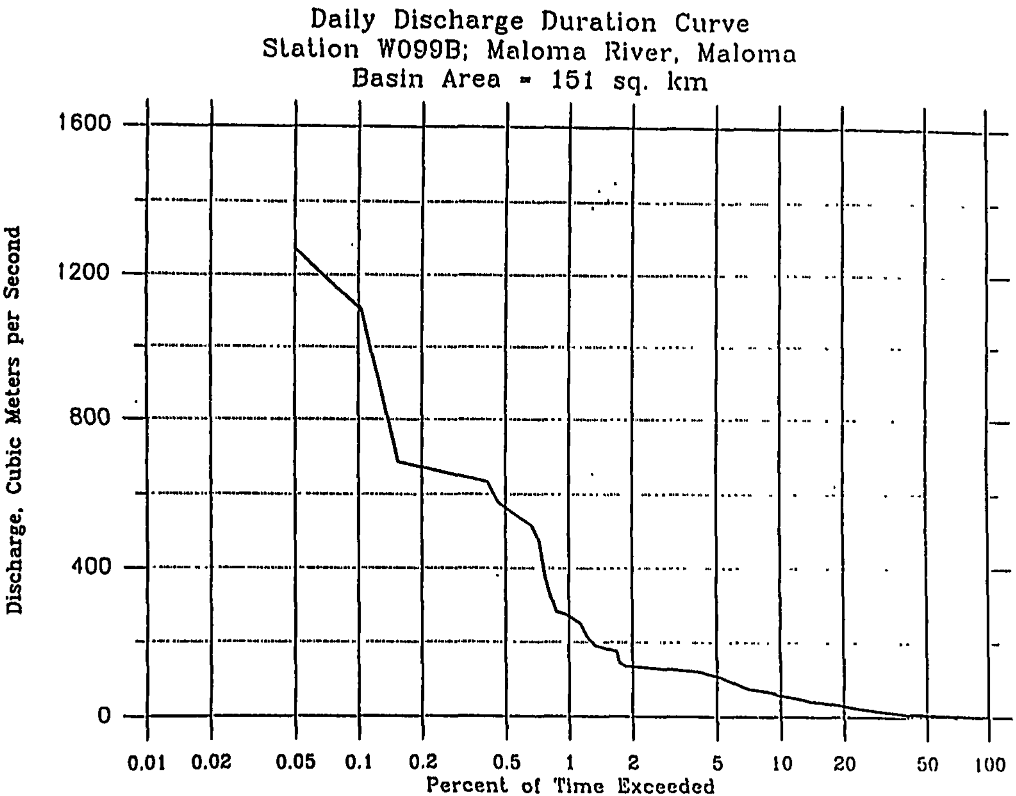

Daily Discharge Duration Curve
Station W099B; Maloma River, Maloma
Basin Area = 151 sq. km
Discharge, Cubic Meters per Second
1600
1200
800
400
0
0.01
0.02
0.05
0.1
0.2
0.5
1
2
5
10
20
50
100
Percent of Time Exceeded

Figure 2.4.51

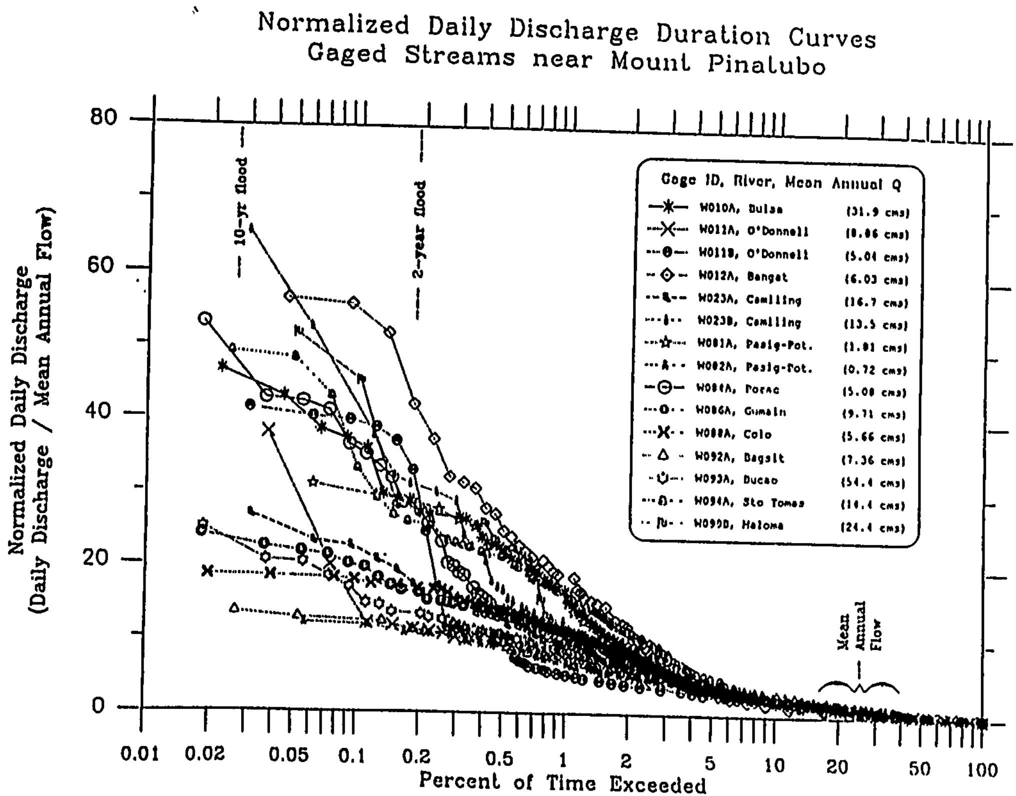
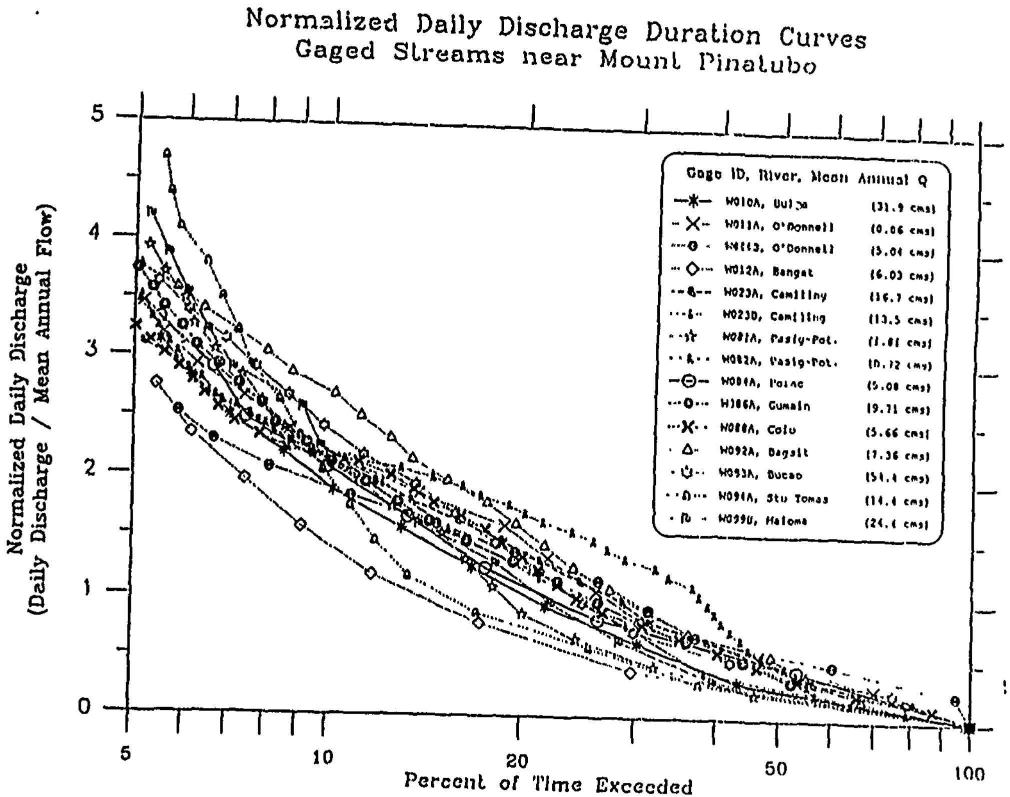

Normalized Daily Discharge Duration Curves
Gaged Streams near Mount Pinatubo
Normalized Daily Discharge
(Daily Discharge / Mean Annual Flow)
Percent of Time Exceeded
10-yr flood
2-year flood
Mean Annual Flow
Gage ID, River, Mean Annual Q
W010A, Bulsa (31.9 cms)
W011A, O'Donnell (8.86 cms)
W011B, O'Donnell (5.04 cms)
W012A, Bangat (6.03 cms)
W023A, Camiling (16.7 cms)
W023B, Camiling (13.5 cms)
W081A, Pasig-Pot. (1.81 cms)
W082A, Pasig-Pot. (0.72 cms)
W084A, Porac (5.08 cms)
W086A, Gumain (9.71 cms)
W088A, Colo (5.66 cms)
W092A, Bagsit (7.36 cms)
W093A, Ducao (54.4 cms)
W094A, Sto Tomas (14.4 cms)
W099D, Maloma (24.4 cms)
0
20
40
60
80
0.01
0.02
0.05
0.1
0.2
0.5
1
2
5
10
20
50
100

Figure 2.4.52



Normalized Daily Discharge Duration Curves
Gaged Streams near Mount Pinatubo
Gage ID, River, Mean Annual Q
W010A, Bulsa (31.9 cms)
W011A, O'Donnell (0.06 cms)
O'Donnell (3.04 cms)
W012A, Bangat (6.03 cms)
W023A, Camiling (16.7 cms)
W023D, Camiling (13.5 cms)
W081A, Pasig-Pot. (1.81 cms)
W082A, Pasig-Pot. (0.72 cms)
W084A, Porac (5.08 cms)
Gumain (9.71 cms)
W088A, Colo (5.66 cms)
W092A, Bagsit (7.36 cms)
W093A, Bucao (51.4 cms)
W094A, Sto Tomas (14.4 cms)
W099U, Maloma (24.4 cms)
Normalized Daily Discharge
(Daily Discharge / Mean Annual Flow)
5
4
3
2
1
0
5
10
20
50
100
Percent of Time Exceeded

Figure 2.4.53

Annual Basin Runoff
Station W010A; Bulsa River, Villa Aglipay
Basin Area 405 sq. km

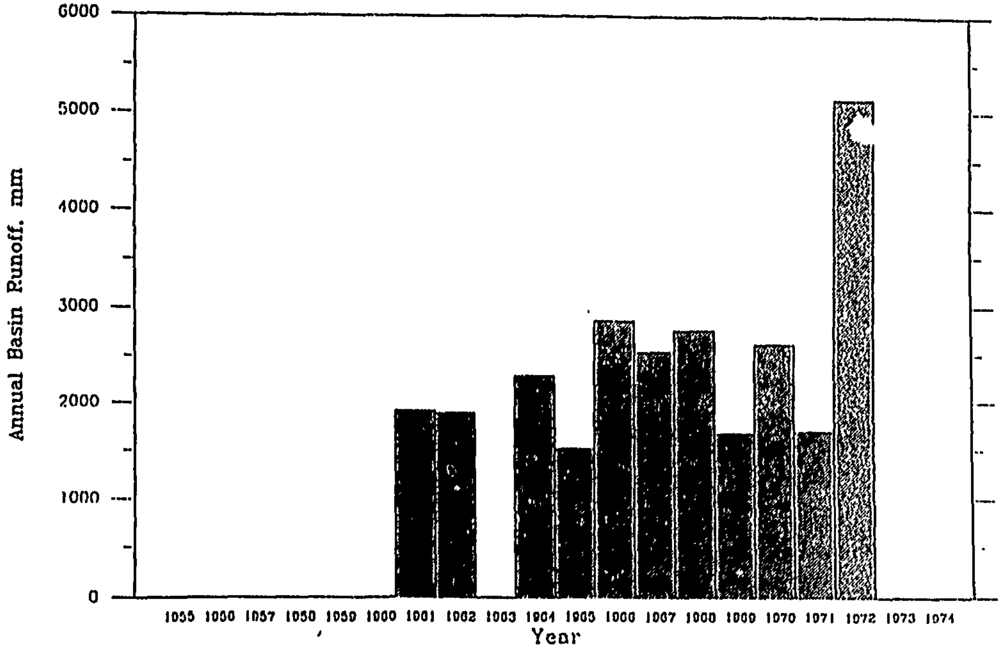


Figure 2.4.54

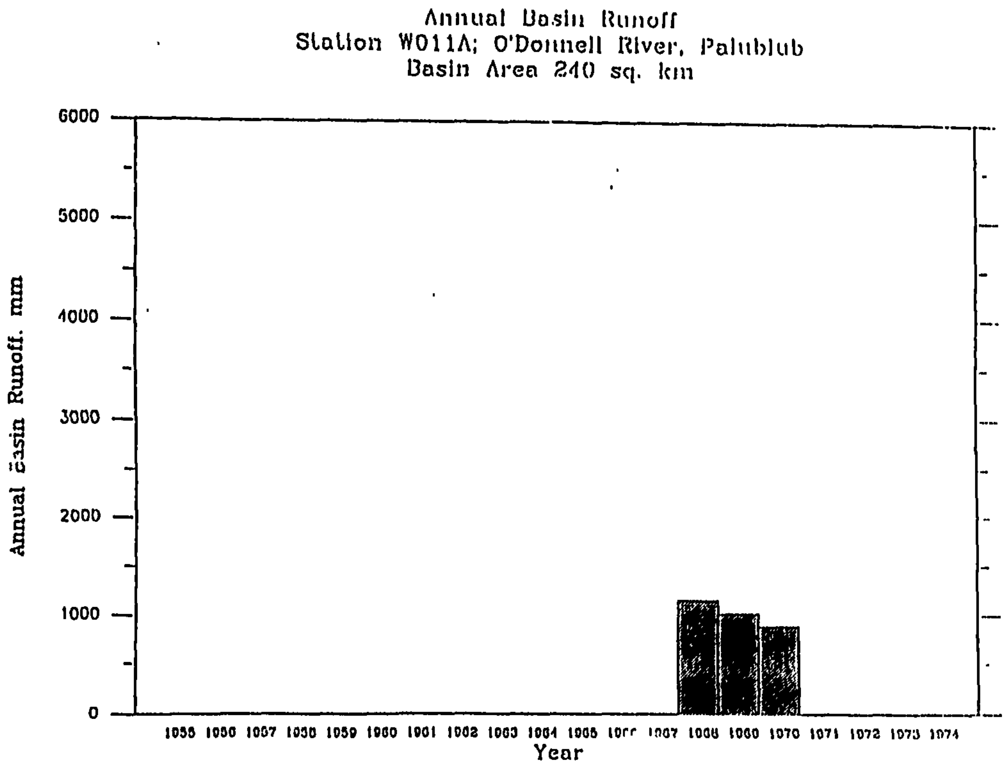

Annual Basin Runoff
Station W011A; O'Donnell River, Palublub
Basin Area 240 sq. km
6000
5000
4000
3000
2000
1000
0
Annual Basin Runoff. mm
Year

Figure 2.4.55

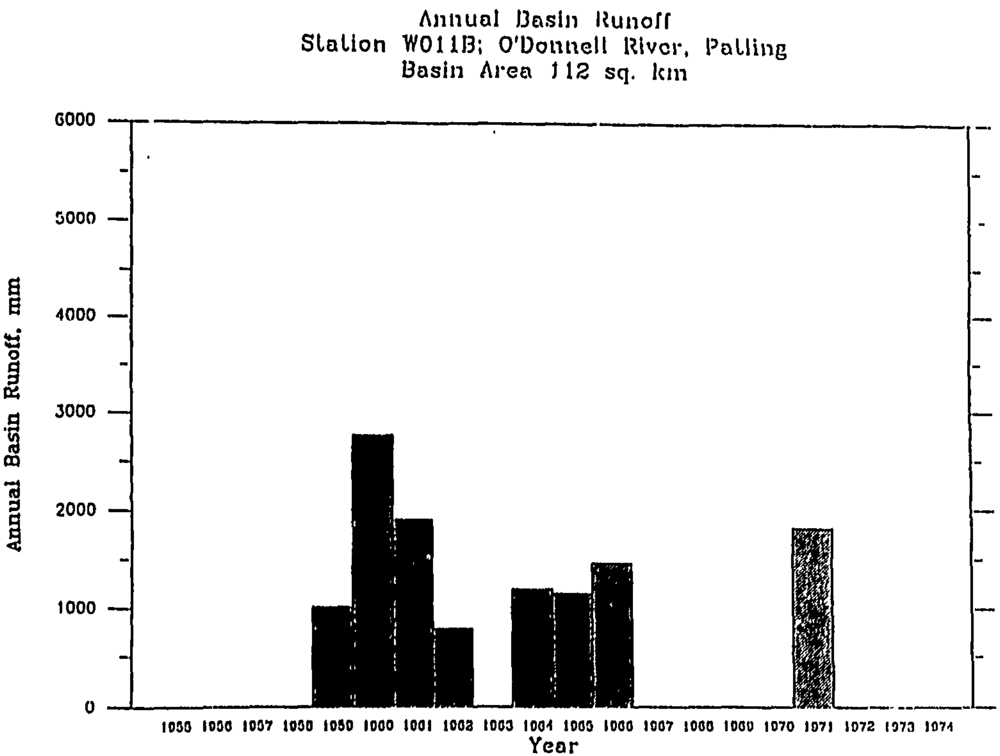

Annual Basin Runoff
Station W011B; O'Donnell River, Palling
Basin Area 112 sq. km
Annual Basin Runoff, mm
6000
5000
4000
3000
2000
1000
0
1955 1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974
Year

Figure 2.4.56

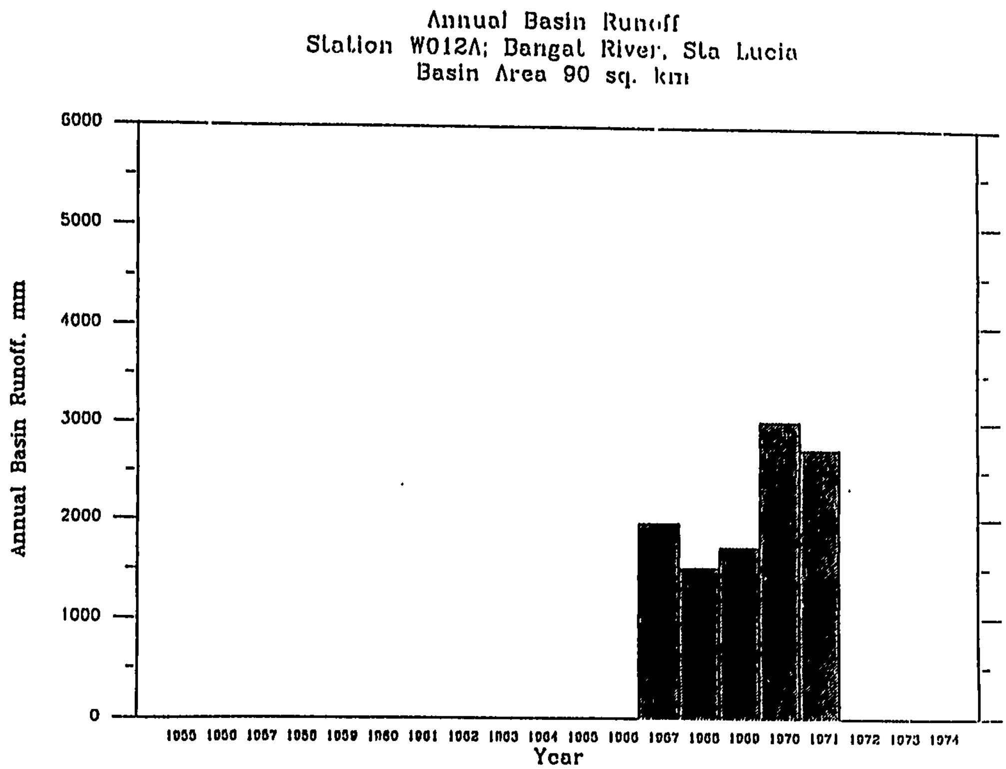

Annual Basin Runoff
Station W012A; Bangal River, Sta Lucia
Basin Area 90 sq. km
Annual Basin Runoff, mm
6000
5000
4000
3000
2000
1000
0
1955 1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974
Year

Figure 2.4.57

Annual Basin Runoff
Station W023A; Camiling River, Nambalan
Basin Area 142 sq. km

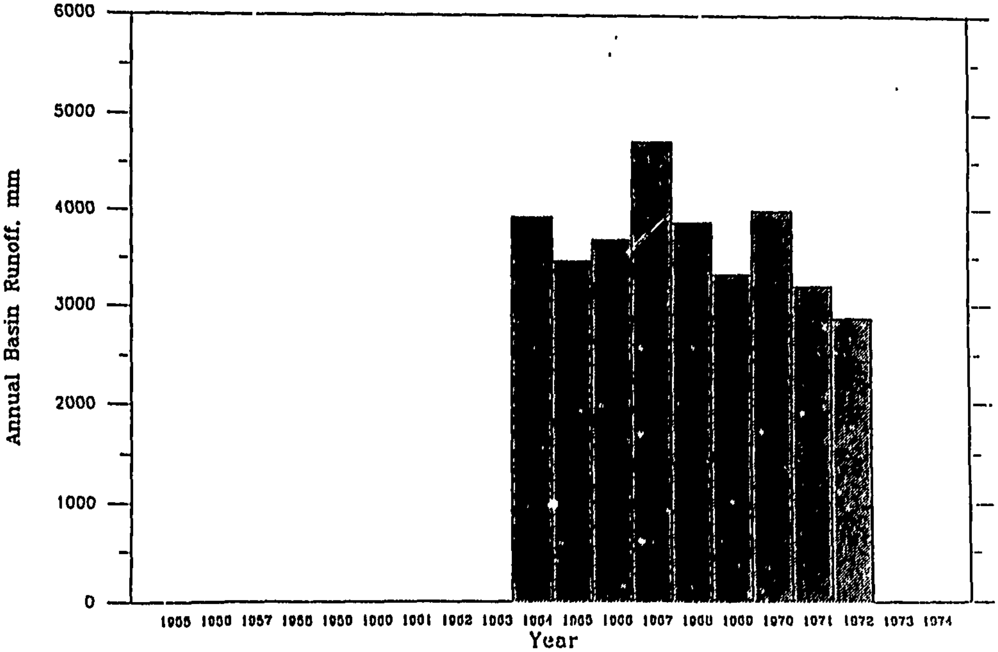


Figure 2.4.58

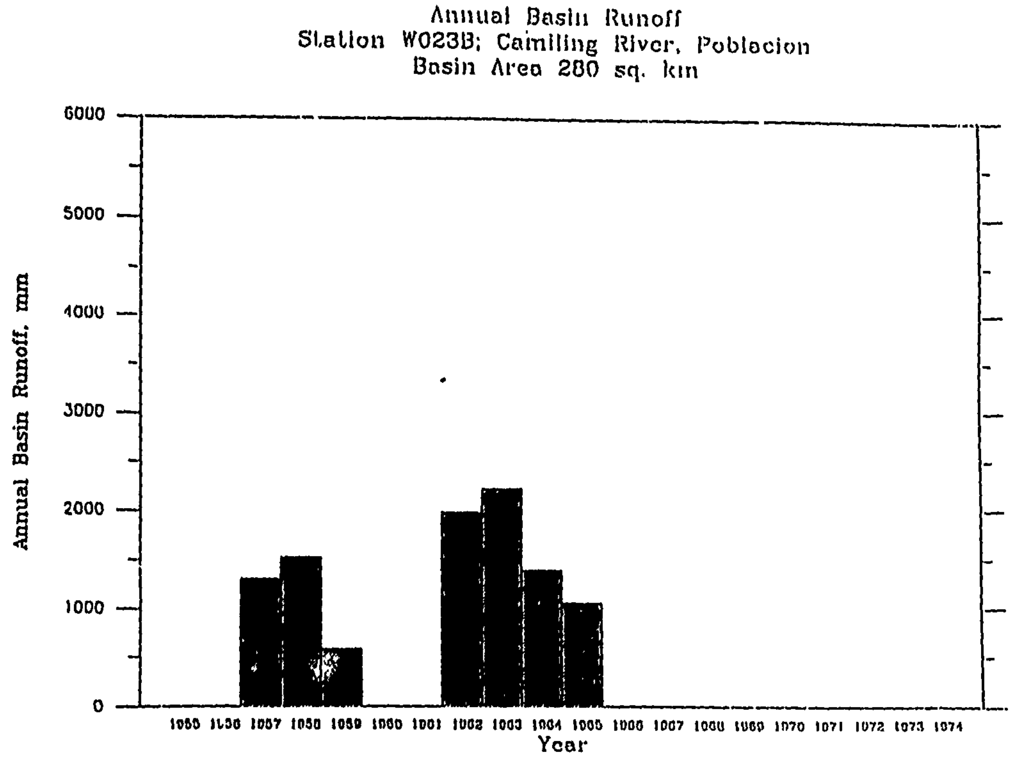

Annual Basin Runoff
Station W023B; Camiling River, Poblacion
Basin Area 280 sq. km
Annual Basin Runoff, mm
6000
5000
4000
3000
2000
1000
0
Year

Figure 2.4.59

Annual Basin Runoff
Station W081A; Pasig-Potrero River, Cabetican
Basin Area 242 sq. km

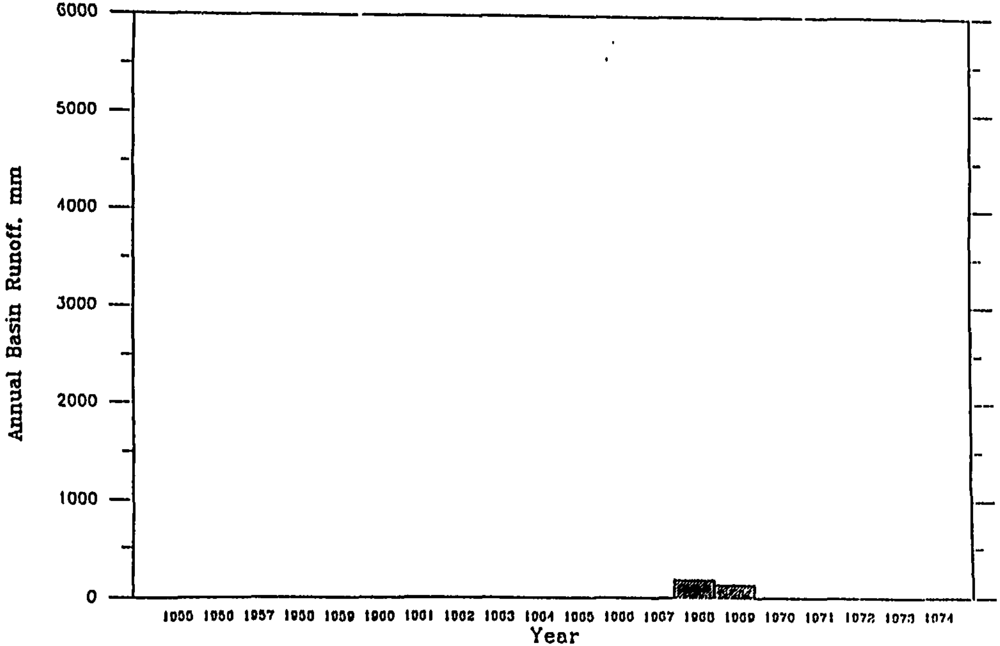


Figure 2.4.60

Annual Basin Runoff
Station W082A; Pasig-Potrero River, Ilda Dolores
Basin Area 28 sq. km

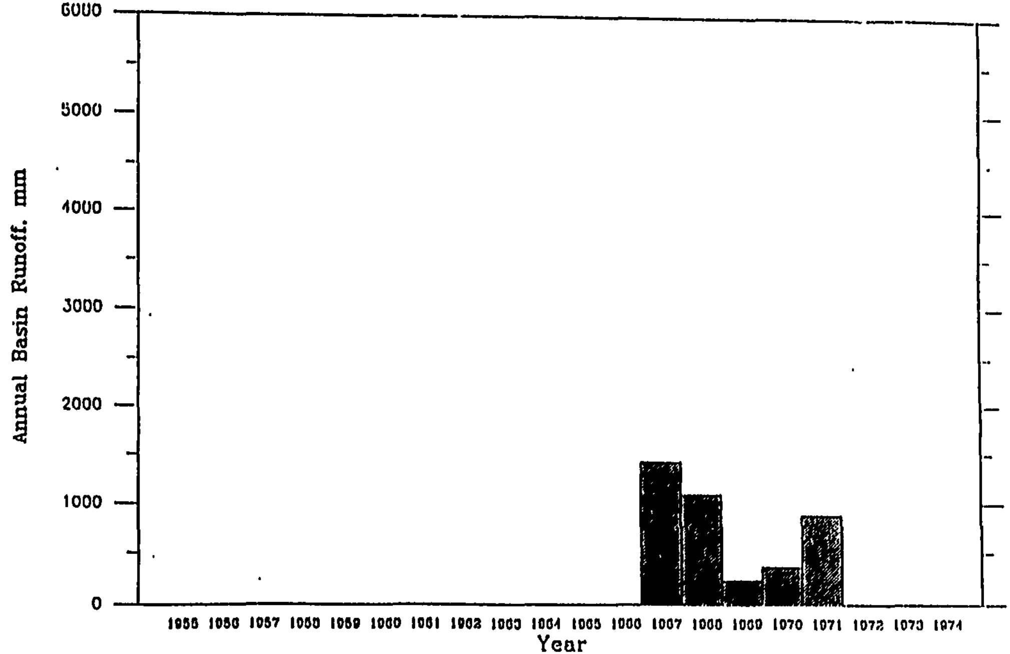


Figure 2.4.61

Annual Basin Runoff
Station W084A; Porac River, Del Carmen
Basin Area 111 sq. km

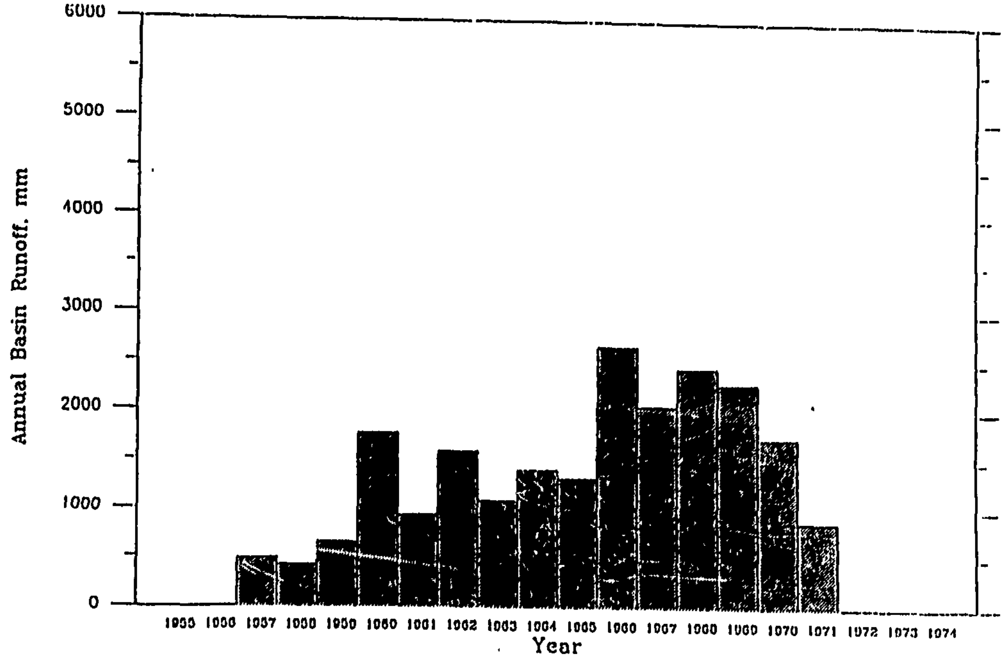


Figure 2.4.62

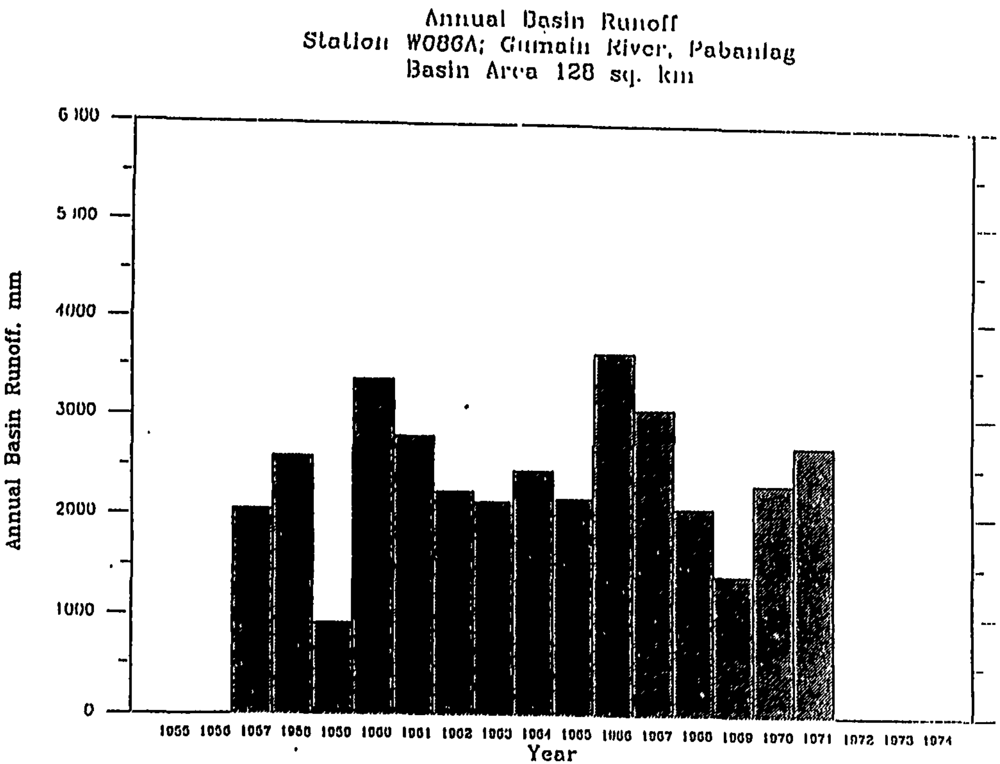

Annual Basin Runoff
Station W086A; Gumain River, Pabanlag
Basin Area 128 sq. km
Annual Basin Runoff, mm
6000
5000
4000
3000
2000
1000
0
1955 1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974
Year

Figure 2.4.63

Annual Basin Runoff
Station W088A; Colo River, San Benito
Basin Area 76 sq. km

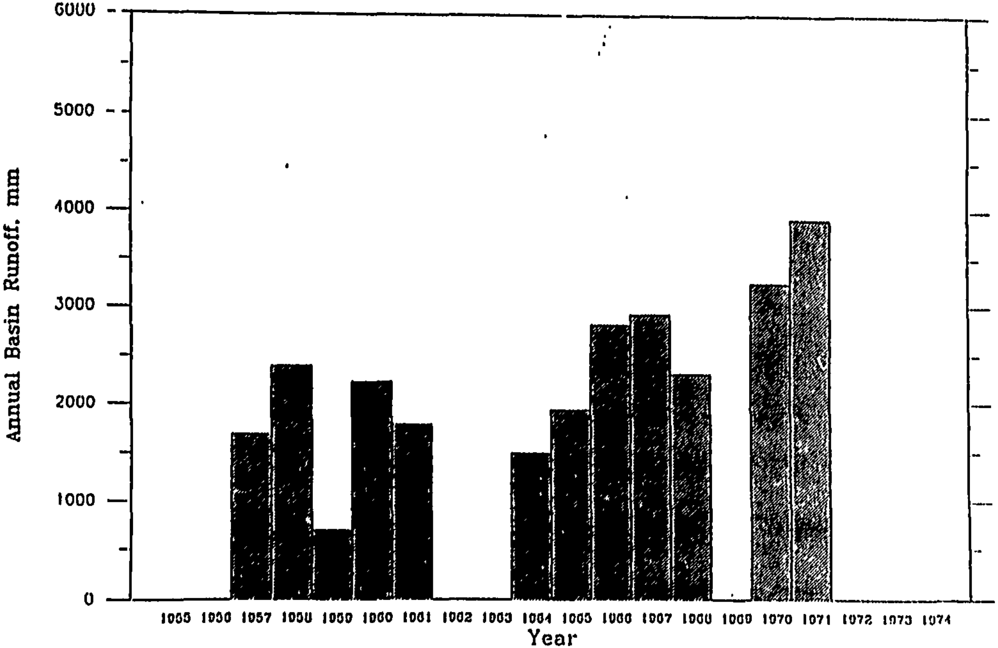
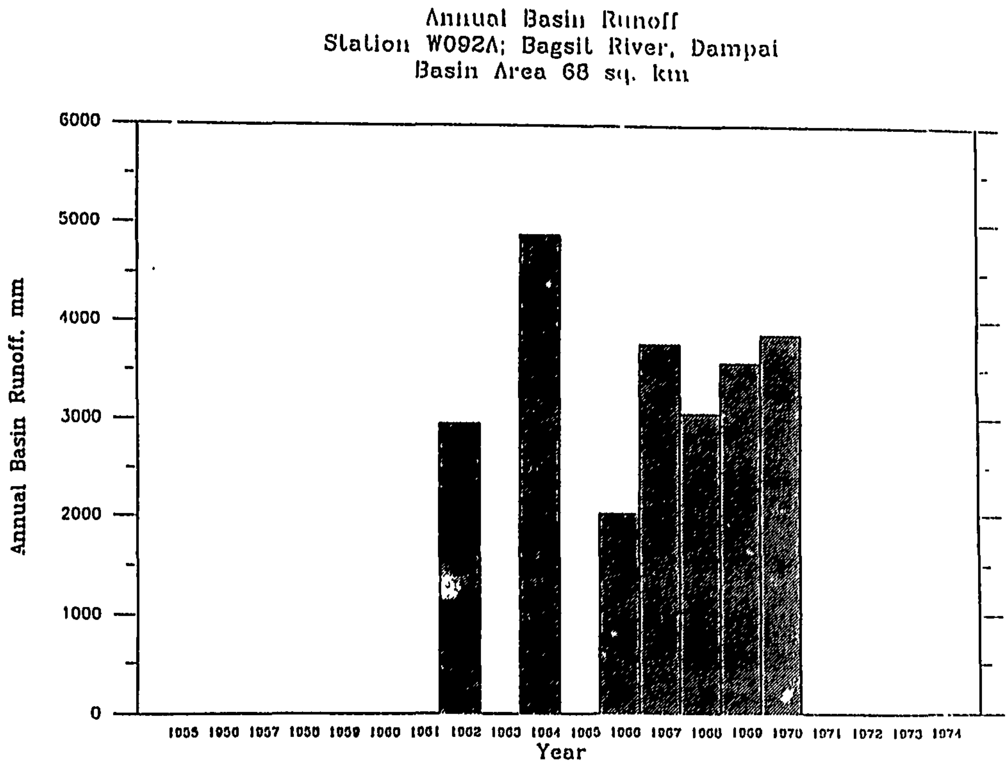


Figure 2.4.64



Annual Basin Runoff
Station W092A; Bagsit River, Dampai
Basin Area 68 sq. km
Annual Basin Runoff, mm
6000
5000
4000
3000
2000
1000
0
Year

Figure 2.4.65

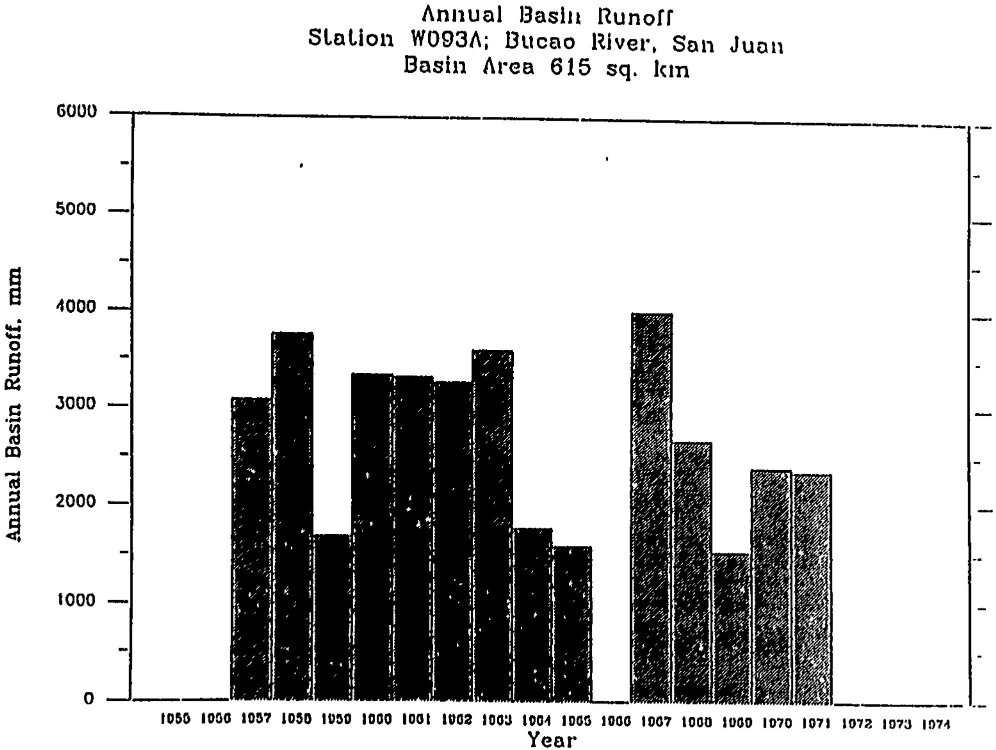

Annual Basin Runoff
Station W093A; Bucao River, San Juan
Basin Area 615 sq. km
Annual Basin Runoff, mm
6000
5000
4000
3000
2000
1000
0
Year

Figure 2.4.66

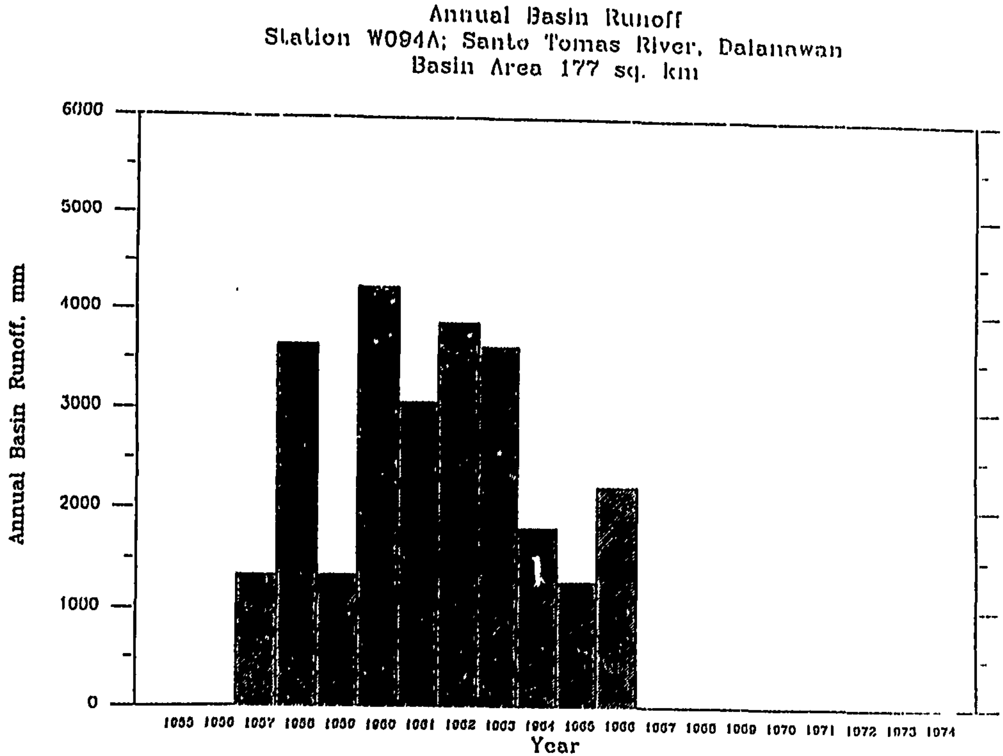

Annual Basin Runoff
Station W094A; Santo Tomas River, Dalanawan
Basin Area 177 sq. km
Annual Basin Runoff, mm
6000
5000
4000
3000
2000
1000
0
Year

Figure 2.4.67

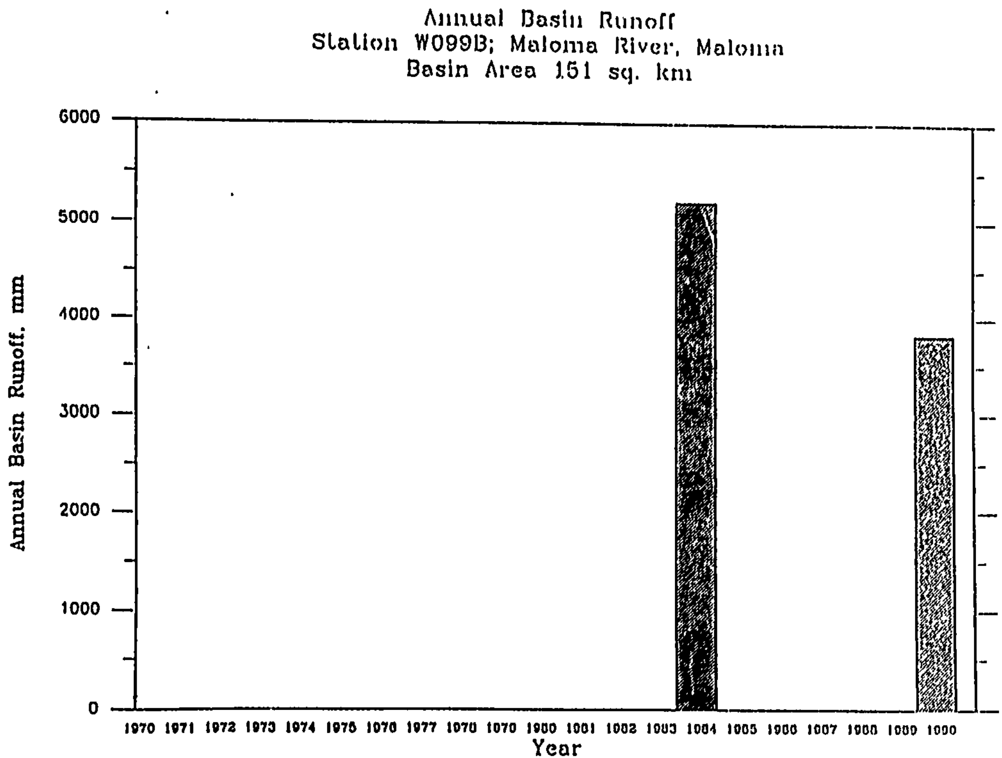

Annual Basin Runoff
Station W099B; Maloma River, Maloma
Basin Area 151 sq. km
Annual Basin Runoff, mm
6000
5000
4000
3000
2000
1000
0
1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990
Year

Figure 2.4.68

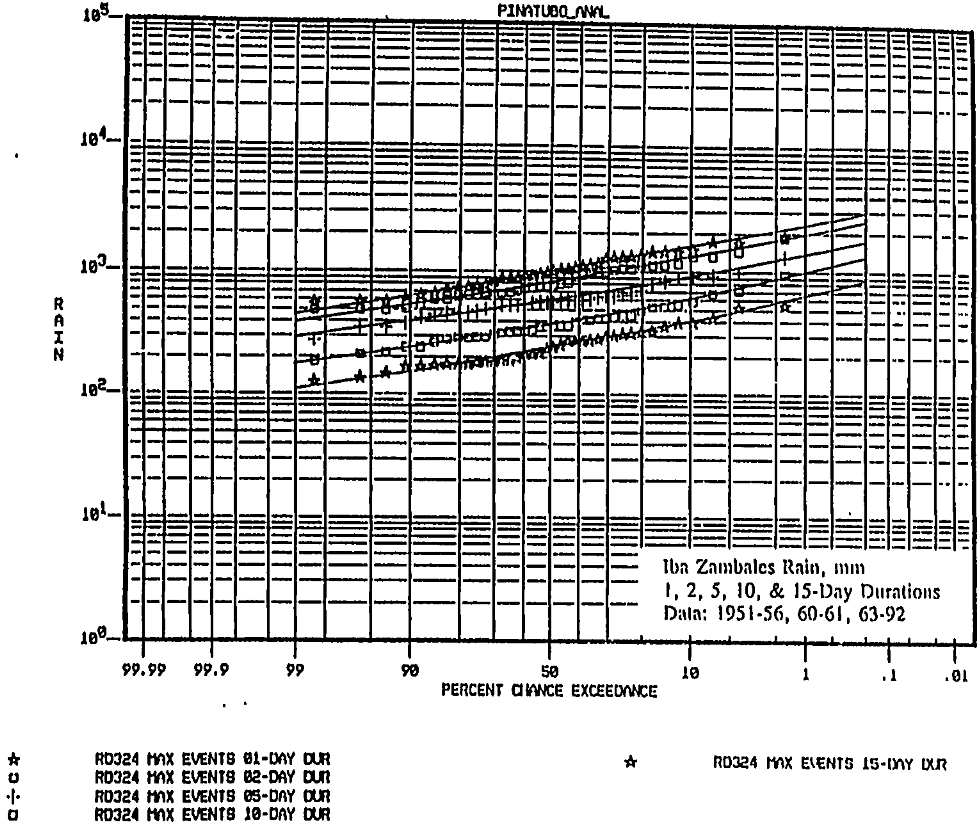

PINATUBO_ANAL
RAIN
10^5
10^4
10^3
10^2
10^1
10^0
99.99
99.9
99
90
50
10
1
.1
.01
PERCENT CHANCE EXCEEDANCE
Iba Zambales Rain, mm
1, 2, 5, 10, & 15-Day Durations
Data: 1951-56, 60-61, 63-92
RD324 MAX EVENTS 01-DAY DUR
RD324 MAX EVENTS 02-DAY DUR
RD324 MAX EVENTS 05-DAY DUR
RD324 MAX EVENTS 10-DAY DUR
RD324 MAX EVENTS 15-DAY DUR

Figure 2.4.69

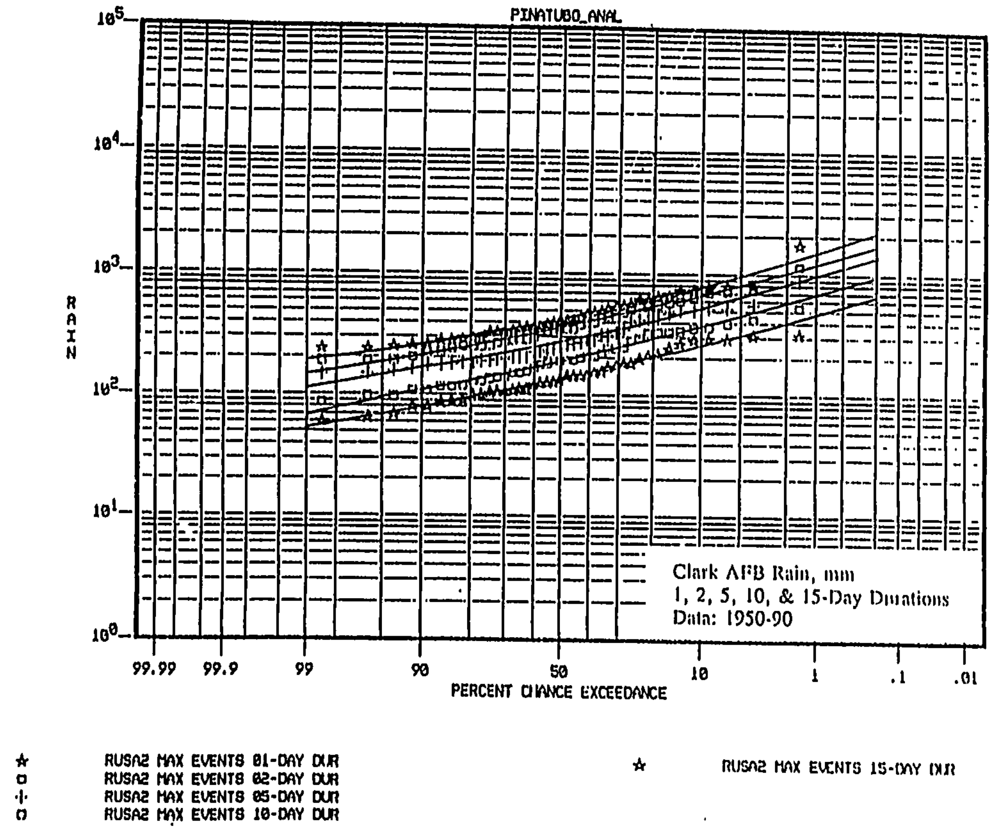
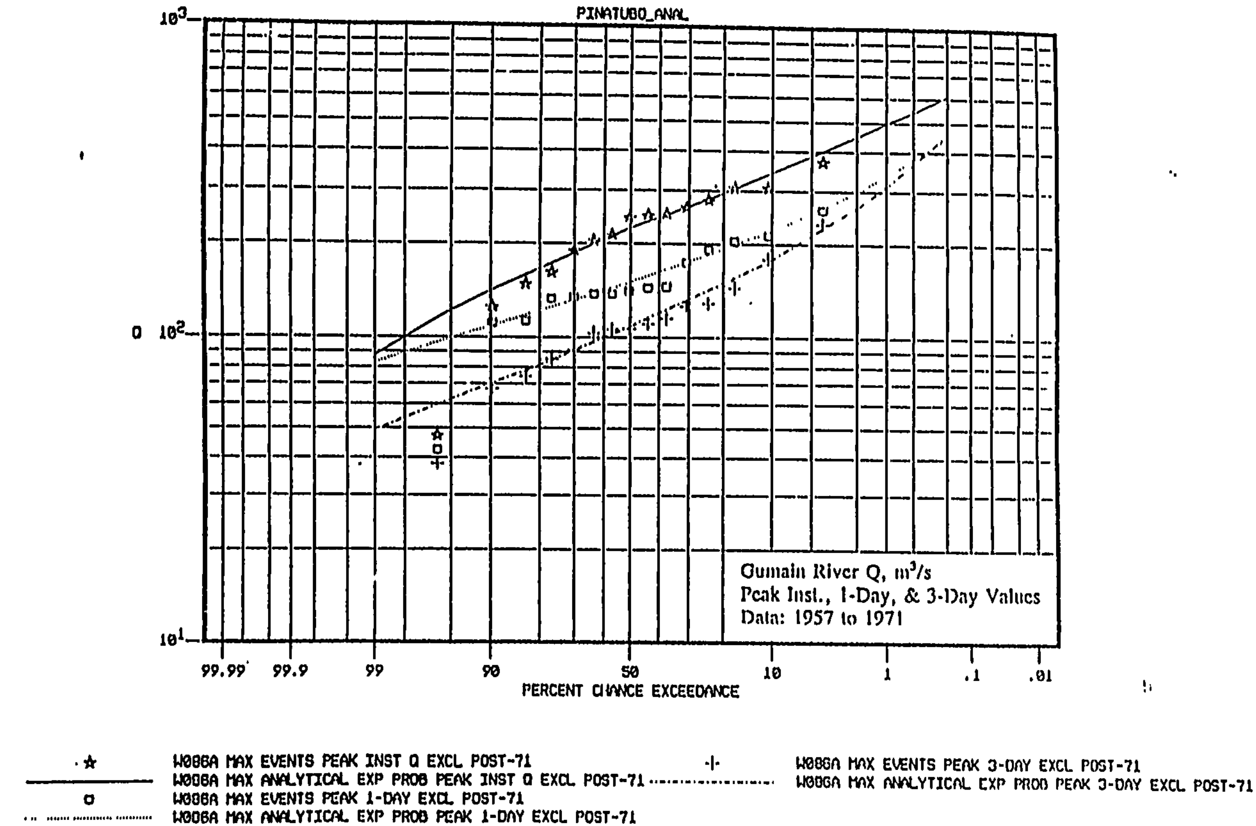

PINATUBO_ANAL
RAIN
10^0
10^1
10^2
10^3
10^4
10^5
99.99
99.9
99
90
50
10
1
.1
.01
PERCENT CHANCE EXCEEDANCE
Clark AFB Rain, mm
1, 2, 5, 10, & 15-Day Durations
Data: 1950-90
RUSA2 MAX EVENTS 01-DAY DUR
RUSA2 MAX EVENTS 02-DAY DUR
RUSA2 MAX EVENTS 05-DAY DUR
RUSA2 MAX EVENTS 10-DAY DUR
RUSA2 MAX EVENTS 15-DAY DUR

Figure 2.4.70



PINATUBO_ANAL
10³
Q 10²
10¹
99.99
99.9
99
90
50
10
1
.1
.01
PERCENT CHANCE EXCEEDANCE
Gumain River Q, m³/s
Peak Inst., 1-Day, & 3-Day Values
Data: 1957 to 1971
W086A MAX EVENTS PEAK INST Q EXCL POST-71
W086A MAX ANALYTICAL EXP PROB PEAK INST Q EXCL POST-71
W086A MAX EVENTS PEAK 1-DAY EXCL POST-71
W086A MAX ANALYTICAL EXP PROB PEAK 1-DAY EXCL POST-71
W086A MAX EVENTS PEAK 3-DAY EXCL POST-71
W086A MAX ANALYTICAL EXP PROB PEAK 3-DAY EXCL POST-71

Figure 2.4.71

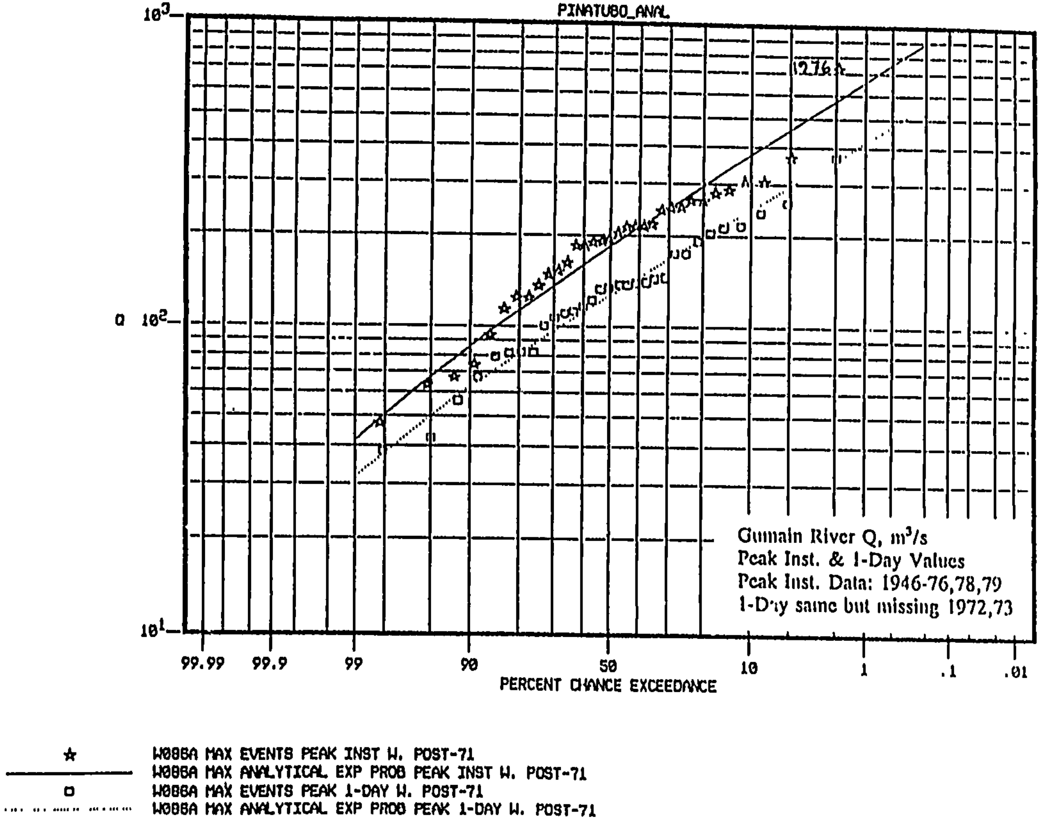

PINATUBO_ANAL
Q
10^3
10^2
10^1
1276
Gumain River Q, m³/s
Peak Inst. & 1-Day Values
Peak Inst. Data: 1946-76,78,79
1-Day same but missing 1972,73
99.99
99.9
99
90
50
10
1
.1
.01
PERCENT CHANCE EXCEEDANCE
W08BA MAX EVENTS PEAK INST W. POST-71
W08BA MAX ANALYTICAL EXP PROB PEAK INST W. POST-71
W08BA MAX EVENTS PEAK 1-DAY W. POST-71
W08BA MAX ANALYTICAL EXP PROB PEAK 1-DAY W. POST-71

Figure 2.4.72

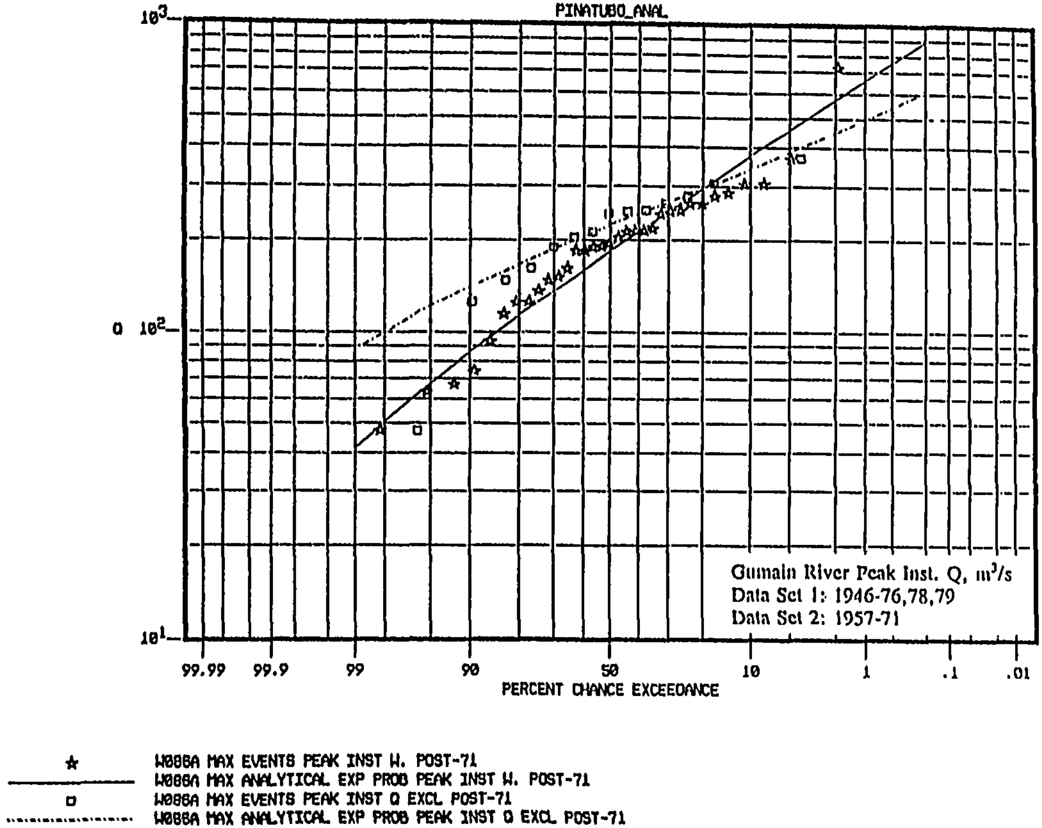

PINATUBO_ANAL
Q
10^3
10^2
10^1
99.99
99.9
99
90
50
10
1
.1
.01
PERCENT CHANCE EXCEEDANCE
Gumain River Peak Inst. Q, m³/s
Data Set 1: 1946-76,78,79
Data Set 2: 1957-71
★ W088A MAX EVENTS PEAK INST W. POST-71
——— W088A MAX ANALYTICAL EXP PROB PEAK INST W. POST-71
□ W088A MAX EVENTS PEAK INST Q EXCL POST-71
-·-·-·- W088A MAX ANALYTICAL EXP PROB PEAK INST Q EXCL POST-71

Figure 2.4.73

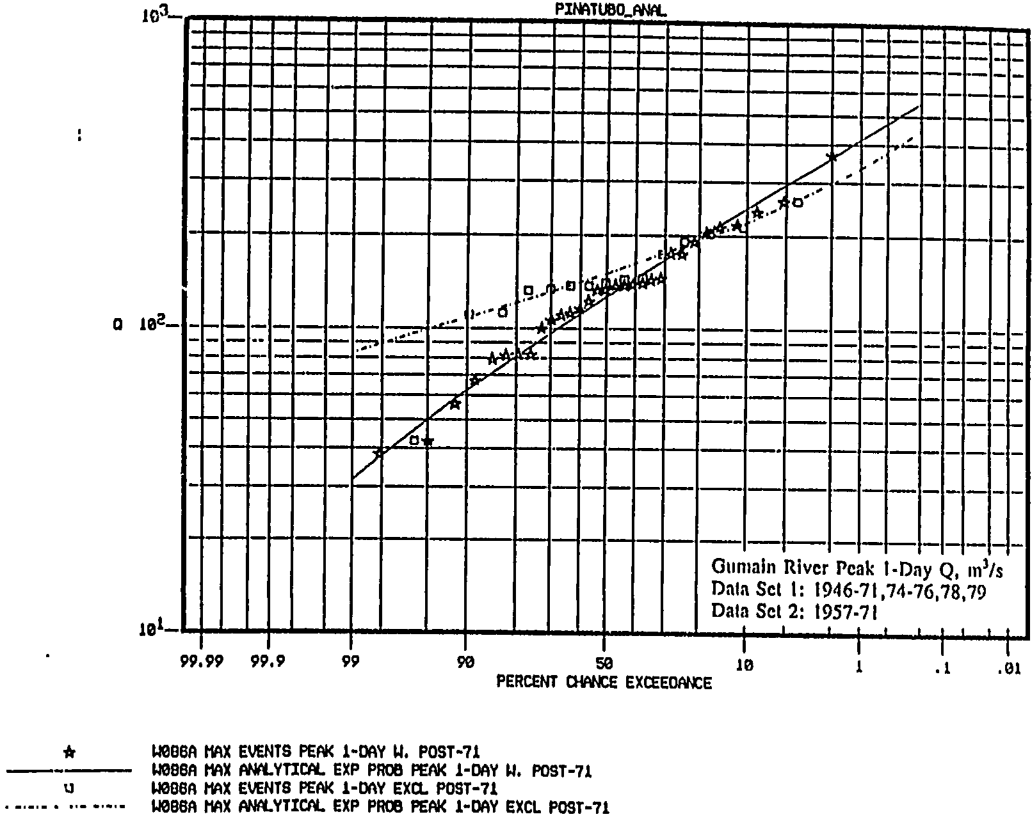

PINATUBO_ANAL
Q
10^3
10^2
10^1
99.99
99.9
99
90
50
10
1
.1
.01
PERCENT CHANCE EXCEEDANCE
Gumain River Peak 1-Day Q, m³/s
Data Set 1: 1946-71,74-76,78,79
Data Set 2: 1957-71
W088A MAX EVENTS PEAK 1-DAY W. POST-71
W088A MAX ANALYTICAL EXP PROB PEAK 1-DAY W. POST-71
W088A MAX EVENTS PEAK 1-DAY EXCL POST-71
W088A MAX ANALYTICAL EXP PROB PEAK 1-DAY EXCL POST-71

Figure 2.4.74

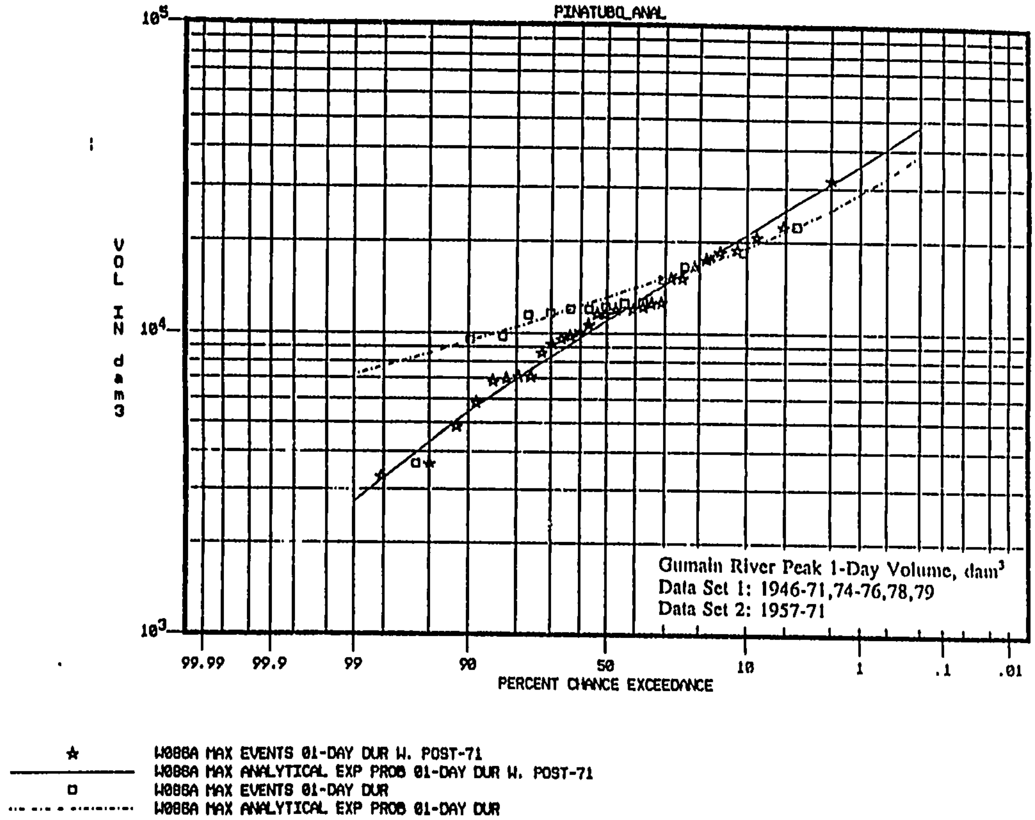

PINATUBO_ANAL
VOL IN dam3
10^5
10^4
10^3
99.99
99.9
99
90
50
10
1
.1
.01
PERCENT CHANCE EXCEEDANCE
Gumain River Peak 1-Day Volume, dam³
Data Set 1: 1946-71,74-76,78,79
Data Set 2: 1957-71
W088A MAX EVENTS 01-DAY DUR W. POST-71
W088A MAX ANALYTICAL EXP PROB 01-DAY DUR W. POST-71
W088A MAX EVENTS 01-DAY DUR
W088A MAX ANALYTICAL EXP PROB 01-DAY DUR

Figure 2.4.75

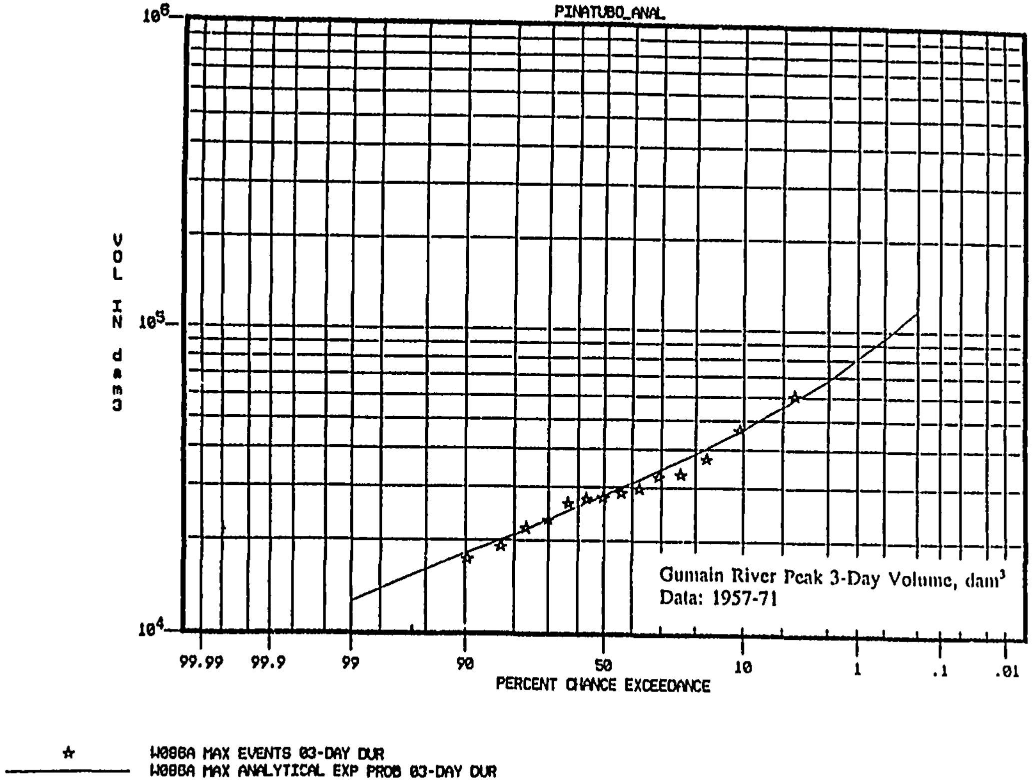

PINATUBO_ANAL
VOL IN dam3
10^6
10^5
10^4
99.99
99.9
99
90
50
10
1
.1
.01
PERCENT CHANCE EXCEEDANCE
Gumain River Peak 3-Day Volume, dam³
Data: 1957-71
W088A MAX EVENTS 03-DAY DUR
W088A MAX ANALYTICAL EXP PROB 03-DAY DUR

Figure 2.4.76

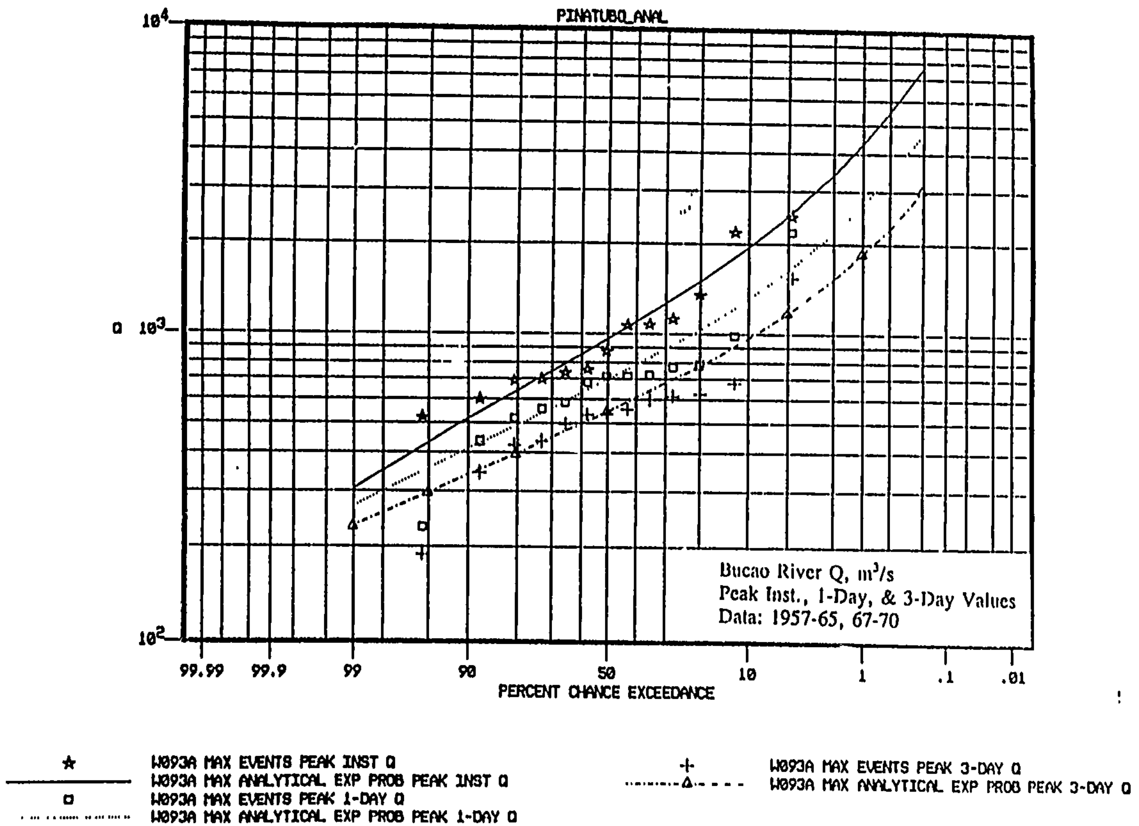

PINATUBO_ANAL
Q
10^4
10^3
10^2
99.99
99.9
99
90
50
10
1
.1
.01
PERCENT CHANCE EXCEEDANCE
Bucao River Q, m^3/s
Peak Inst., 1-Day, & 3-Day Values
Data: 1957-65, 67-70
W093A MAX EVENTS PEAK INST Q
W093A MAX ANALYTICAL EXP PROB PEAK INST Q
W093A MAX EVENTS PEAK 1-DAY Q
W093A MAX ANALYTICAL EXP PROB PEAK 1-DAY Q
W093A MAX EVENTS PEAK 3-DAY Q
W093A MAX ANALYTICAL EXP PROB PEAK 3-DAY Q

Figure 2.4.77

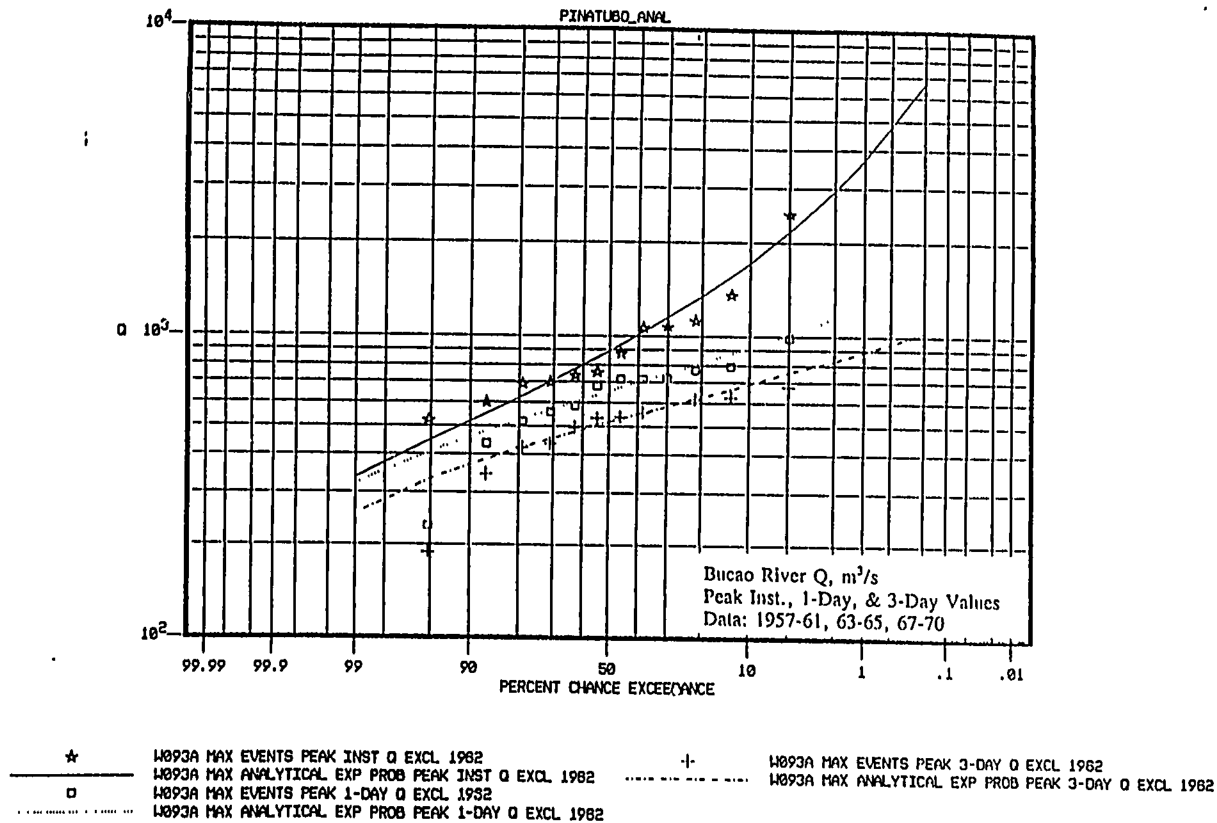
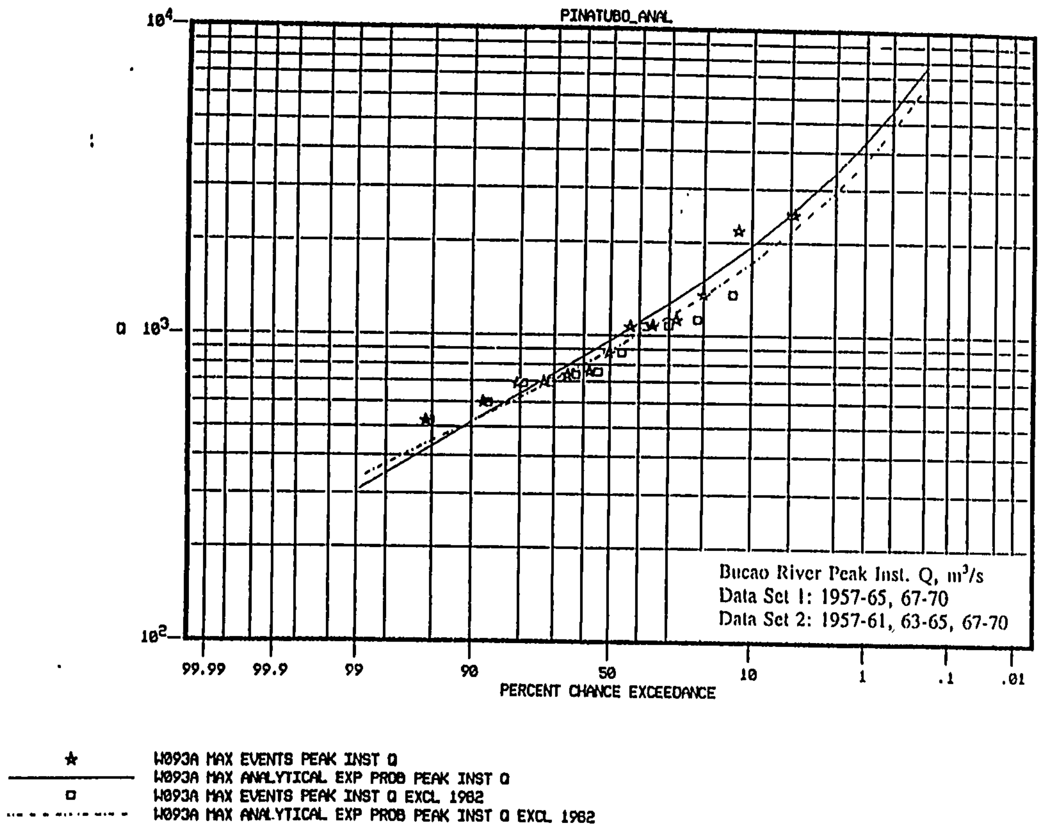

PINATUBO_ANAL
Q
10^4
10^3
10^2
99.99
99.9
99
90
50
10
1
.1
.01
PERCENT CHANCE EXCEEDANCE
Bucao River Q, m³/s
Peak Inst., 1-Day, & 3-Day Values
Data: 1957-61, 63-65, 67-70
W093A MAX EVENTS PEAK INST Q EXCL 1982
W093A MAX ANALYTICAL EXP PROB PEAK INST Q EXCL 1982
W093A MAX EVENTS PEAK 1-DAY Q EXCL 1982
W093A MAX ANALYTICAL EXP PROB PEAK 1-DAY Q EXCL 1982
W093A MAX EVENTS PEAK 3-DAY Q EXCL 1982
W093A MAX ANALYTICAL EXP PROB PEAK 3-DAY Q EXCL 1982

Figure 2.4.78



PINATUBO_ANAL
Q
10^4
10^3
10^2
99.99
99.9
99
90
50
10
1
.1
.01
PERCENT CHANCE EXCEEDANCE
Bucao River Peak Inst. Q, m³/s
Data Set 1: 1957-65, 67-70
Data Set 2: 1957-61, 63-65, 67-70
W093A MAX EVENTS PEAK INST Q
W093A MAX ANALYTICAL EXP PROB PEAK INST Q
W093A MAX EVENTS PEAK INST Q EXCL 1982
W093A MAX ANALYTICAL EXP PROB PEAK INST Q EXCL 1982

Figure 2.4.79

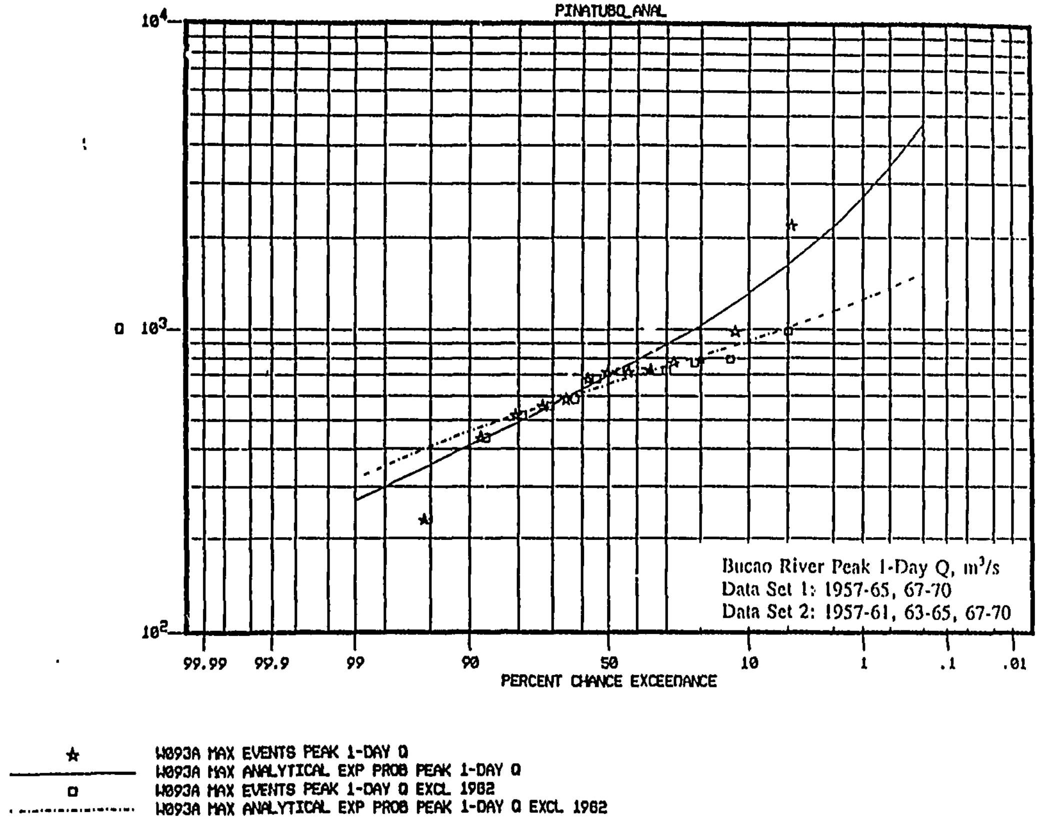

PINATUBO_ANAL
Q
10^4
10^3
10^2
99.99
99.9
99
90
50
10
1
.1
.01
PERCENT CHANCE EXCEEDANCE
Bucao River Peak 1-Day Q, m³/s
Data Set 1: 1957-65, 67-70
Data Set 2: 1957-61, 63-65, 67-70
W093A MAX EVENTS PEAK 1-DAY Q
W093A MAX ANALYTICAL EXP PROB PEAK 1-DAY Q
W093A MAX EVENTS PEAK 1-DAY Q EXCL 1962
W093A MAX ANALYTICAL EXP PROB PEAK 1-DAY Q EXCL 1962

Figure 2.4.80

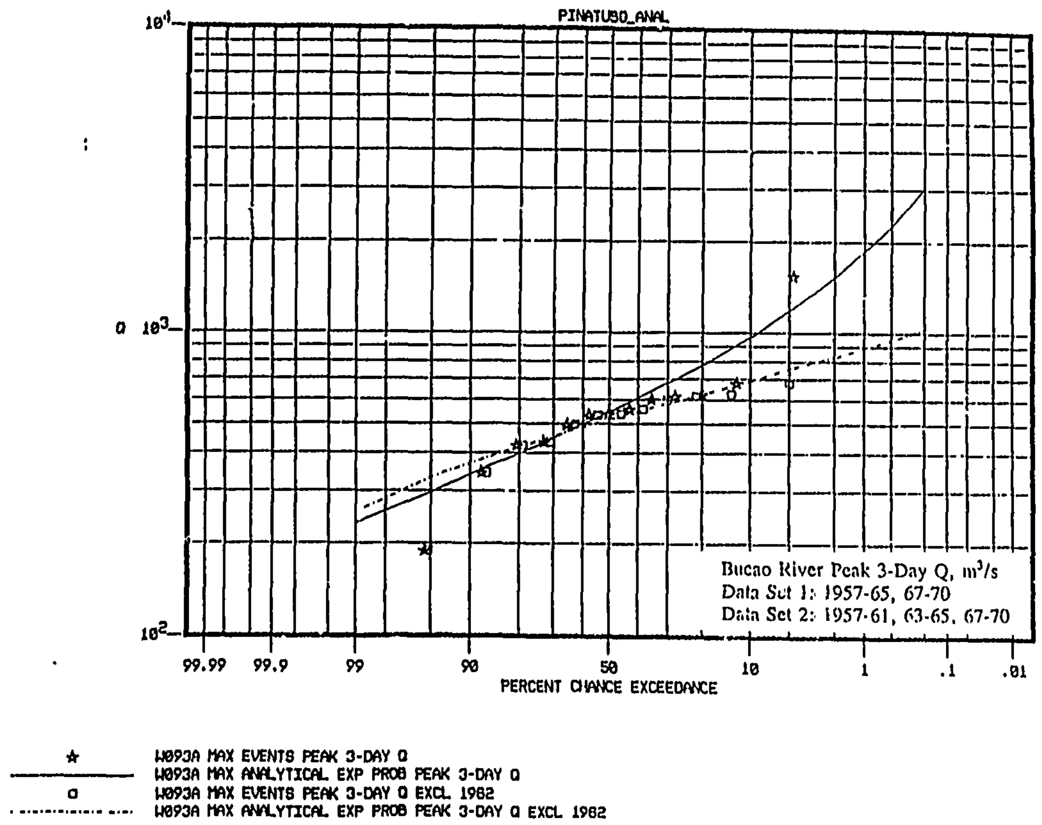

PINATUBO_ANAL
10⁴
Q 10³
10²
99.99
99.9
99
90
50
10
1
.1
.01
PERCENT CHANCE EXCEEDANCE
Bucao River Peak 3-Day Q, m³/s
Data Set 1: 1957-65, 67-70
Data Set 2: 1957-61, 63-65, 67-70
W093A MAX EVENTS PEAK 3-DAY Q
W093A MAX ANALYTICAL EXP PROB PEAK 3-DAY Q
W093A MAX EVENTS PEAK 3-DAY Q EXCL 1982
W093A MAX ANALYTICAL EXP PROB PEAK 3-DAY Q EXCL 1982

Figure 2.4.81

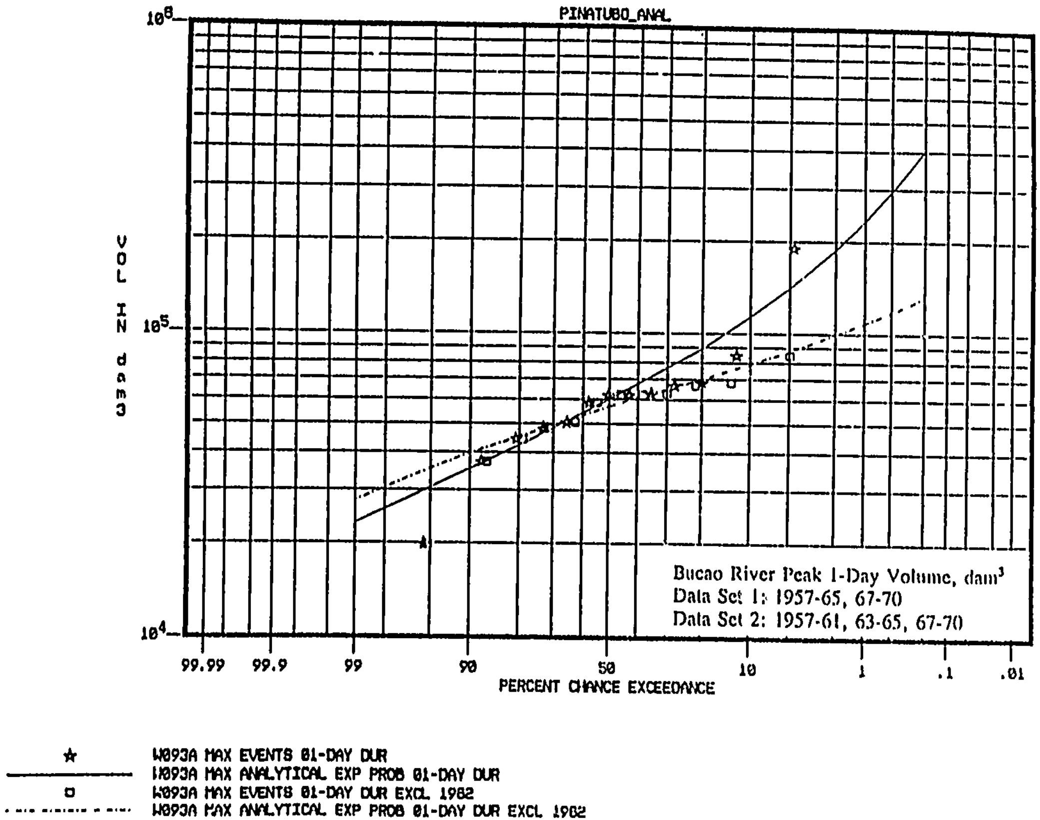

PINATUBO_ANAL
VOL IN dam3
10^6
10^5
10^4
99.99
99.9
99
90
50
10
1
.1
.01
PERCENT CHANCE EXCEEDANCE
Bucao River Peak 1-Day Volume, dam³
Data Set 1: 1957-65, 67-70
Data Set 2: 1957-61, 63-65, 67-70
W093A MAX EVENTS 01-DAY DUR
W093A MAX ANALYTICAL EXP PROB 01-DAY DUR
W093A MAX EVENTS 01-DAY DUR EXCL 1962
W093A MAX ANALYTICAL EXP PROB 01-DAY DUR EXCL 1962

Figure 2.4.82

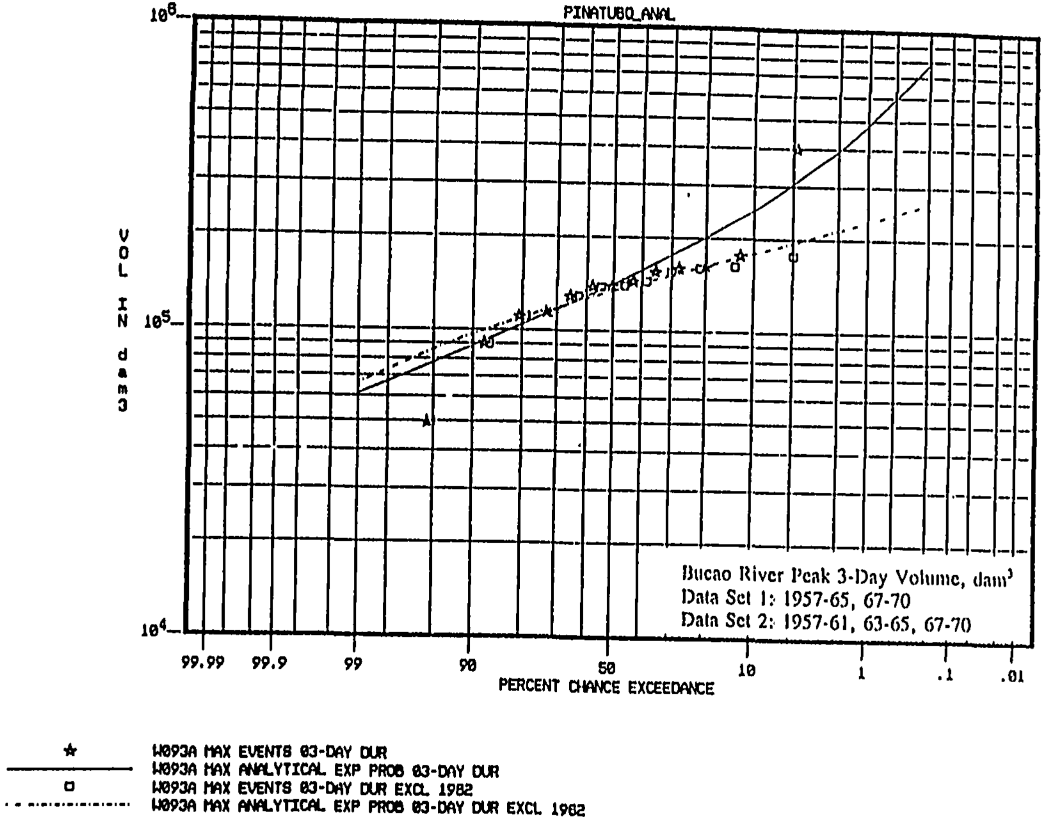

PINATUBO_ANAL
VOL IN dam3
10^6
10^5
10^4
99.99
99.9
99
90
50
10
1
.1
.01
PERCENT CHANCE EXCEEDANCE
Bucao River Peak 3-Day Volume, dam³
Data Set 1: 1957-65, 67-70
Data Set 2: 1957-61, 63-65, 67-70
W093A MAX EVENTS 03-DAY DUR
W093A MAX ANALYTICAL EXP PROB 03-DAY DUR
W093A MAX EVENTS 03-DAY DUR EXCL 1982
W093A MAX ANALYTICAL EXP PROB 03-DAY DUR EXCL 1982

Figure 2.4.83

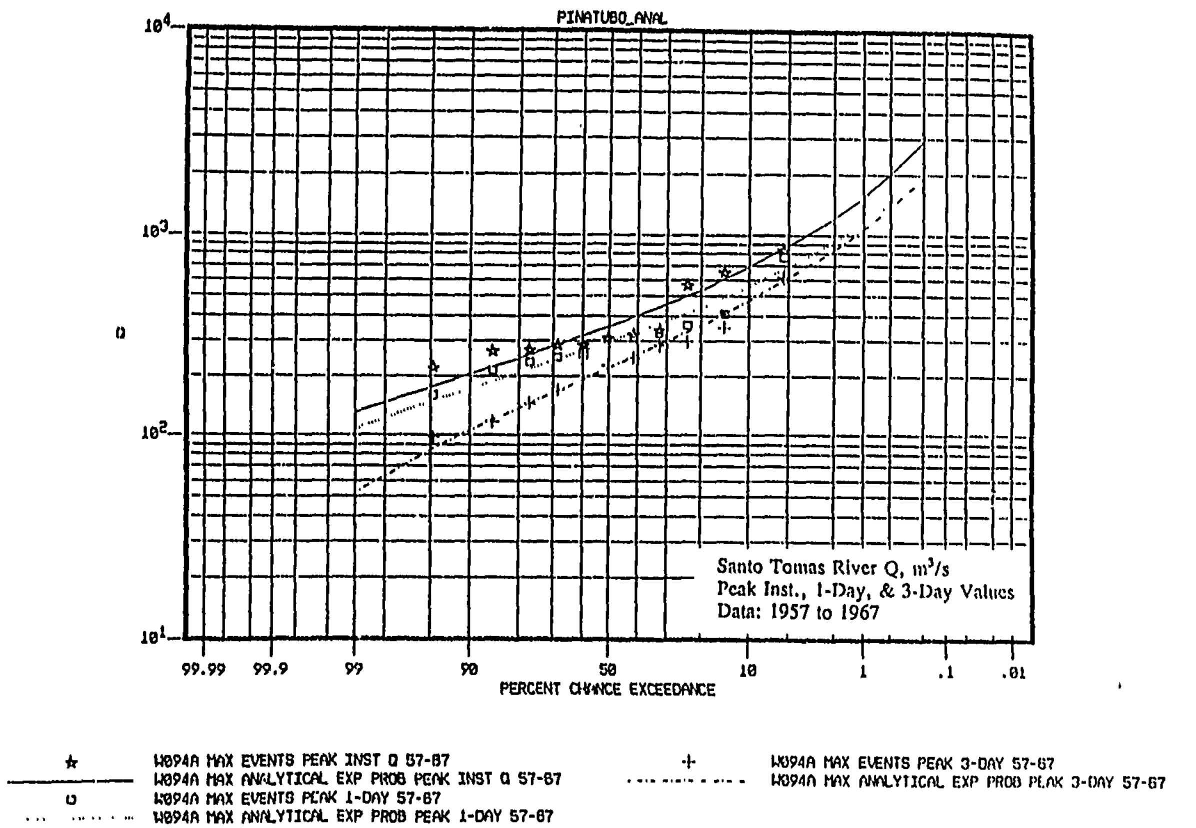

PINATUBO_ANAL
Q
10^4
10^3
10^2
10^1
99.99
99.9
99
90
50
10
1
.1
.01
PERCENT CHANCE EXCEEDANCE
Santo Tomas River Q, m³/s
Peak Inst., 1-Day, & 3-Day Values
Data: 1957 to 1967
W094A MAX EVENTS PEAK INST Q 57-67
W094A MAX ANALYTICAL EXP PROB PEAK INST Q 57-67
W094A MAX EVENTS PEAK 1-DAY 57-67
W094A MAX ANALYTICAL EXP PROB PEAK 1-DAY 57-67
W094A MAX EVENTS PEAK 3-DAY 57-67
W094A MAX ANALYTICAL EXP PROB PEAK 3-DAY 57-67

Figure 2.4.84

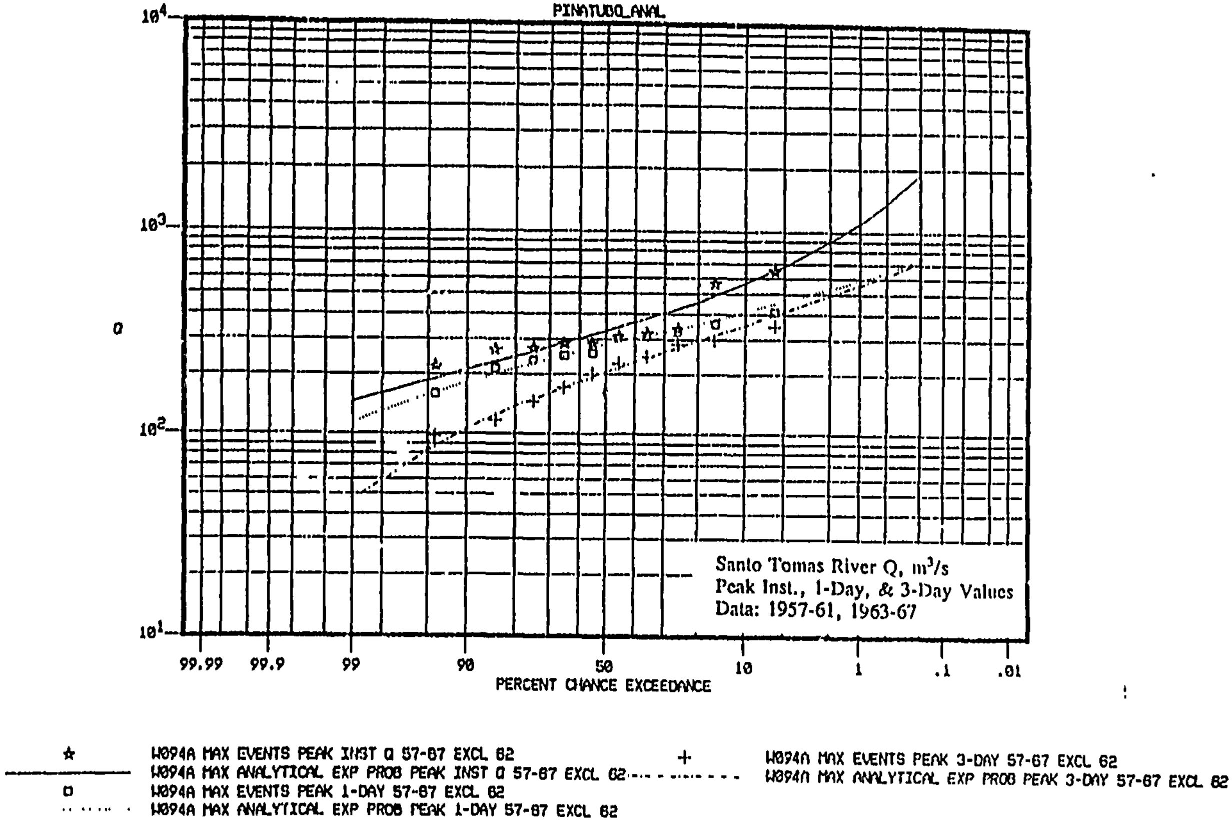
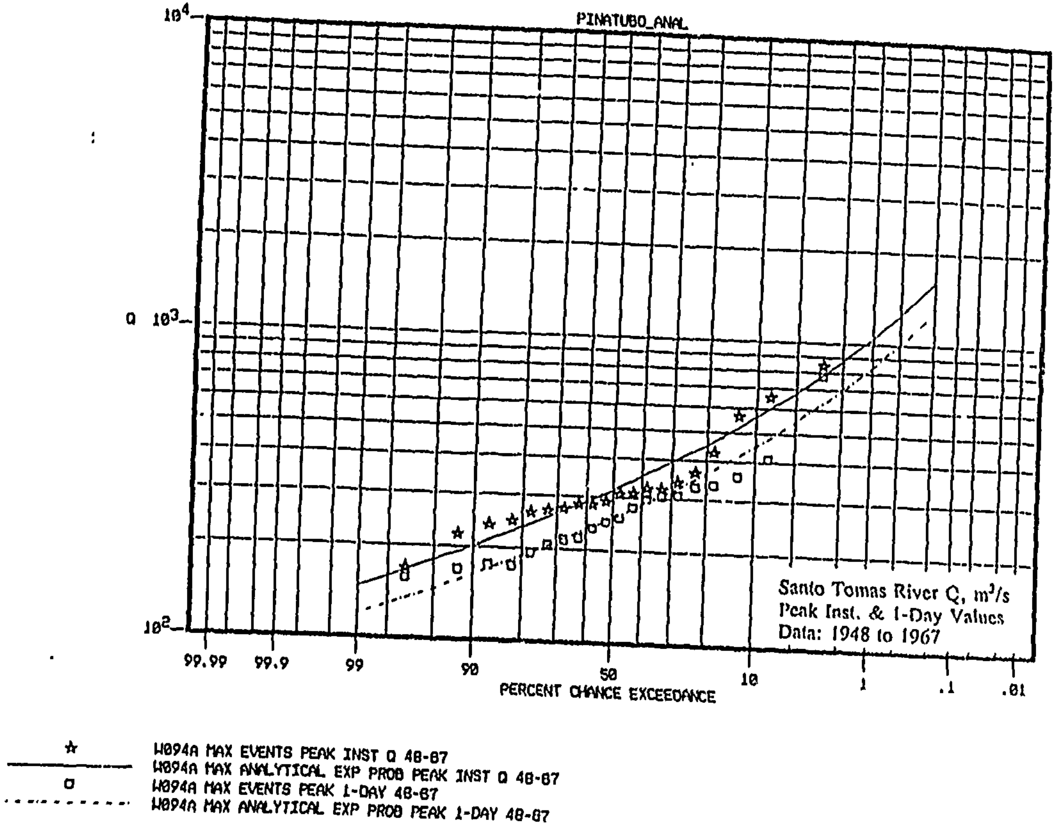

PINATUBO_ANAL
Q
10^4
10^3
10^2
10^1
99.99
99.9
99
90
50
10
1
.1
.01
PERCENT CHANCE EXCEEDANCE
Santo Tomas River Q, m³/s
Peak Inst., 1-Day, & 3-Day Values
Data: 1957-61, 1963-67
W094A MAX EVENTS PEAK INST Q 57-67 EXCL 62
W094A MAX ANALYTICAL EXP PROB PEAK INST Q 57-67 EXCL 62
W094A MAX EVENTS PEAK 1-DAY 57-67 EXCL 62
W094A MAX ANALYTICAL EXP PROB PEAK 1-DAY 57-67 EXCL 62
W094A MAX EVENTS PEAK 3-DAY 57-67 EXCL 62
W094A MAX ANALYTICAL EXP PROB PEAK 3-DAY 57-67 EXCL 62

Figure 2.4.85



PINATUBO_ANAL
Q
10^4
10^3
10^2
99.99
99.9
99
90
50
10
1
.1
.01
PERCENT CHANCE EXCEEDANCE
Santo Tomas River Q, m³/s
Peak Inst. & 1-Day Values
Data: 1948 to 1967
W094A MAX EVENTS PEAK INST Q 48-67
W094A MAX ANALYTICAL EXP PROB PEAK INST Q 48-67
W094A MAX EVENTS PEAK 1-DAY 48-67
W094A MAX ANALYTICAL EXP PROB PEAK 1-DAY 48-67

Figure 2.4.86

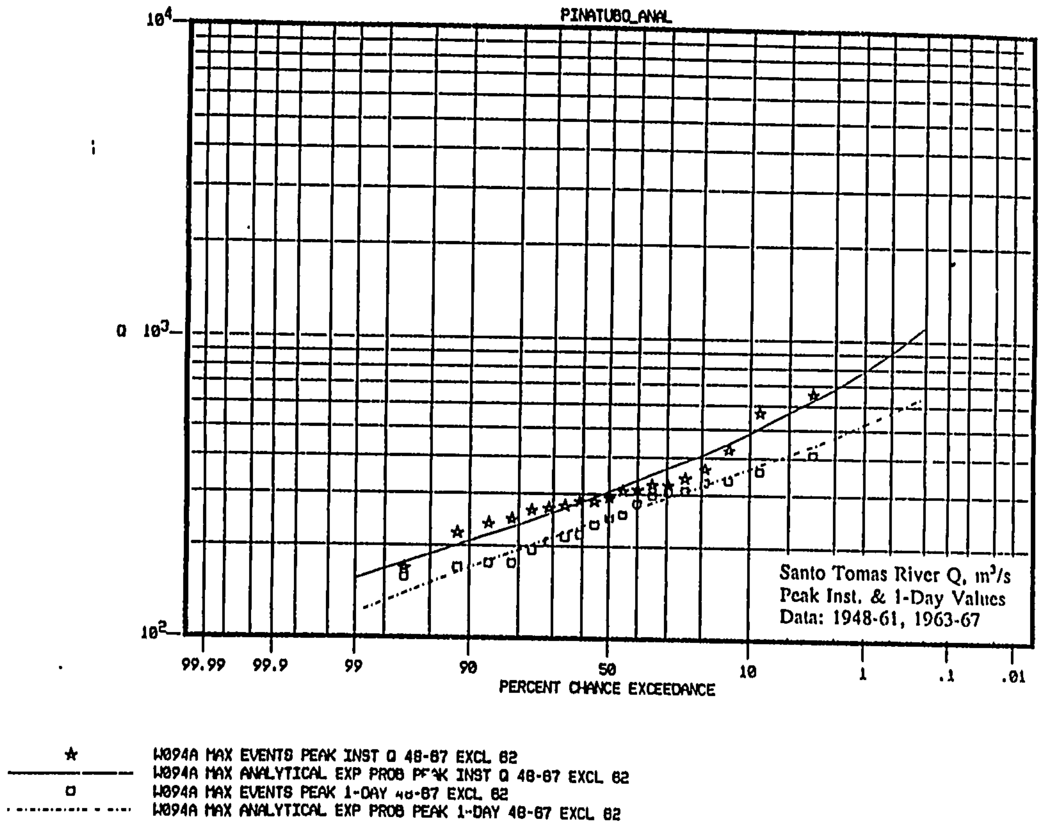
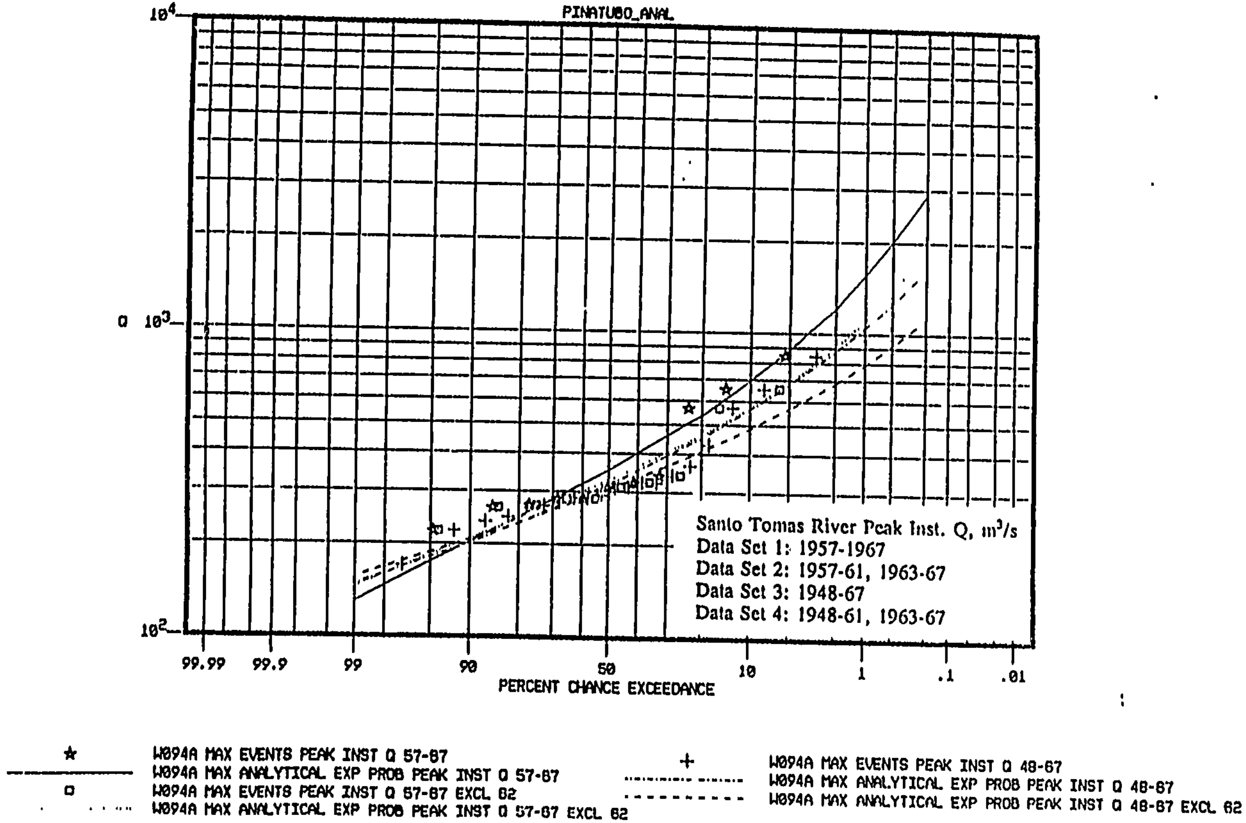

PINATUBO_ANAL
Q
10^4
10^3
10^2
99.99
99.9
99
90
50
10
1
.1
.01
PERCENT CHANCE EXCEEDANCE
Santo Tomas River Q, m³/s
Peak Inst. & 1-Day Values
Data: 1948-61, 1963-67
W094A MAX EVENTS PEAK INST Q 48-67 EXCL 62
W094A MAX ANALYTICAL EXP PROB PEAK INST Q 48-67 EXCL 62
W094A MAX EVENTS PEAK 1-DAY 48-67 EXCL 62
W094A MAX ANALYTICAL EXP PROB PEAK 1-DAY 48-67 EXCL 62

Figure 2.4.87



PINATUBO_ANAL
Q
10^4
10^3
10^2
99.99
99.9
99
90
50
10
1
.1
.01
PERCENT CHANCE EXCEEDANCE
Santo Tomas River Peak Inst. Q, m³/s
Data Set 1: 1957-1967
Data Set 2: 1957-61, 1963-67
Data Set 3: 1948-67
Data Set 4: 1948-61, 1963-67
W094A MAX EVENTS PEAK INST Q 57-67
W094A MAX ANALYTICAL EXP PROB PEAK INST Q 57-67
W094A MAX EVENTS PEAK INST Q 57-67 EXCL 62
W094A MAX ANALYTICAL EXP PROB PEAK INST Q 57-67 EXCL 62
W094A MAX EVENTS PEAK INST Q 48-67
W094A MAX ANALYTICAL EXP PROB PEAK INST Q 48-67
W094A MAX ANALYTICAL EXP PROB PEAK INST Q 48-67 EXCL 62

Figure 2.4.88

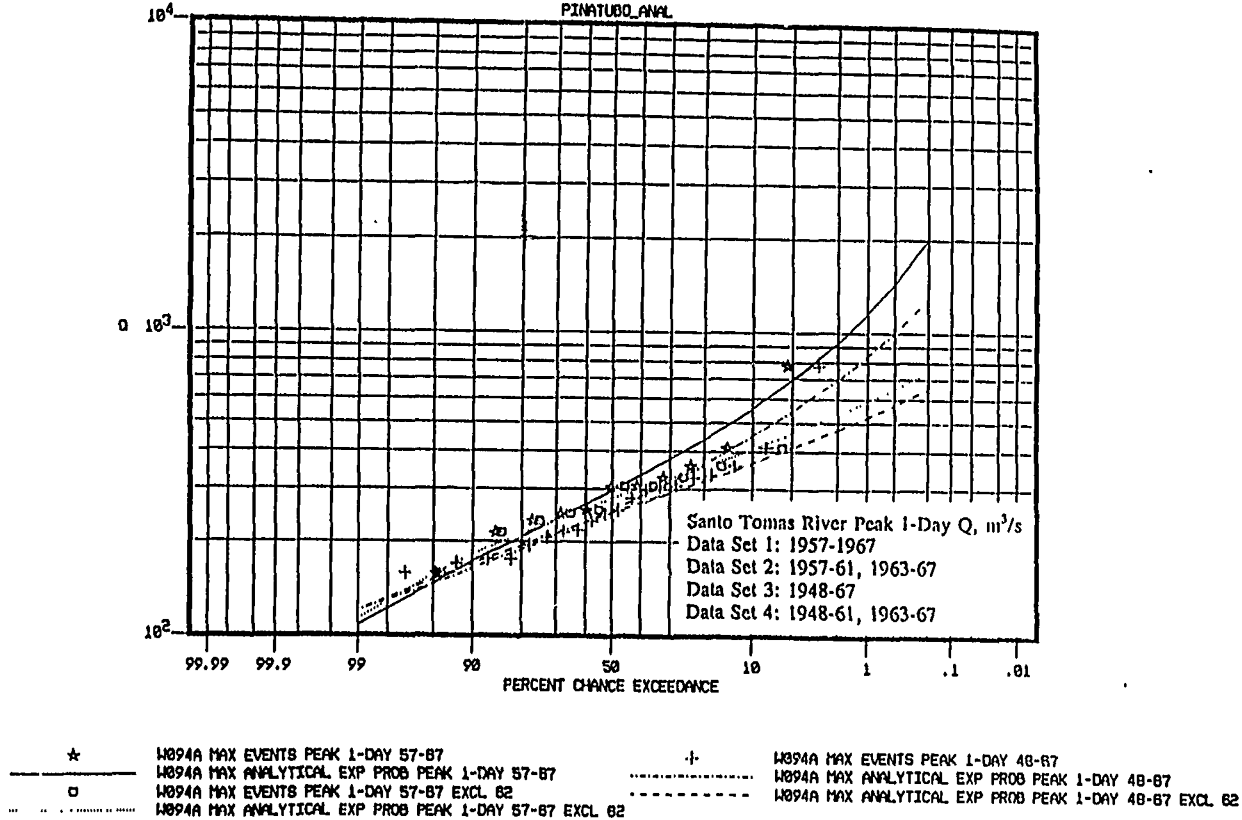

PINATUBO_ANAL
Q
10^4
10^3
10^2
99.99
99.9
99
90
50
10
1
.1
.01
PERCENT CHANCE EXCEEDANCE
Santo Tomas River Peak 1-Day Q, m³/s
Data Set 1: 1957-1967
Data Set 2: 1957-61, 1963-67
Data Set 3: 1948-67
Data Set 4: 1948-61, 1963-67
W094A MAX EVENTS PEAK 1-DAY 57-67
W094A MAX ANALYTICAL EXP PROB PEAK 1-DAY 57-67
W094A MAX EVENTS PEAK 1-DAY 57-67 EXCL 62
W094A MAX ANALYTICAL EXP PROB PEAK 1-DAY 57-67 EXCL 62
W094A MAX EVENTS PEAK 1-DAY 48-67
W094A MAX ANALYTICAL EXP PROB PEAK 1-DAY 48-67
W094A MAX ANALYTICAL EXP PROB PEAK 1-DAY 48-67 EXCL 62

Figure 2.4.89

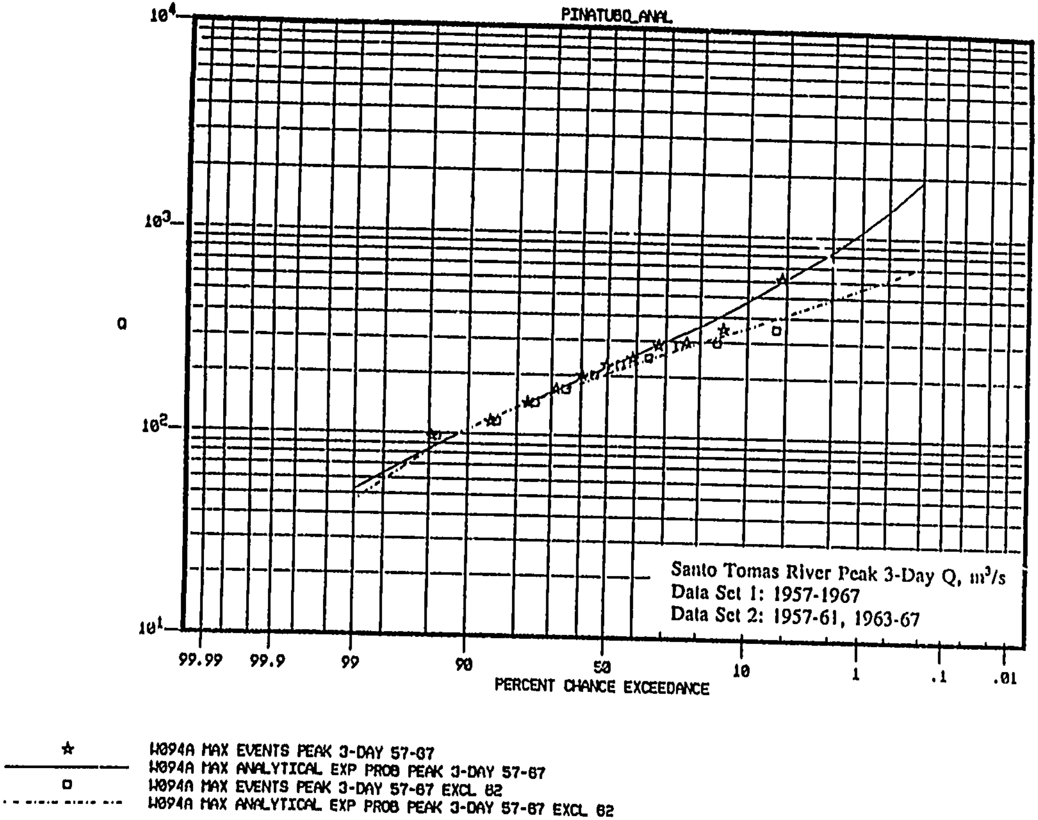

PINATUBO_ANAL
10^4
10^3
10^2
10^1
Q
99.99
99.9
99
90
50
10
1
.1
.01
PERCENT CHANCE EXCEEDANCE
Santo Tomas River Peak 3-Day Q, m³/s
Data Set 1: 1957-1967
Data Set 2: 1957-61, 1963-67
W094A MAX EVENTS PEAK 3-DAY 57-67
W094A MAX ANALYTICAL EXP PROB PEAK 3-DAY 57-67
W094A MAX EVENTS PEAK 3-DAY 57-67 EXCL 62
W094A MAX ANALYTICAL EXP PROB PEAK 3-DAY 57-67 EXCL 62

Figure 2.4.90

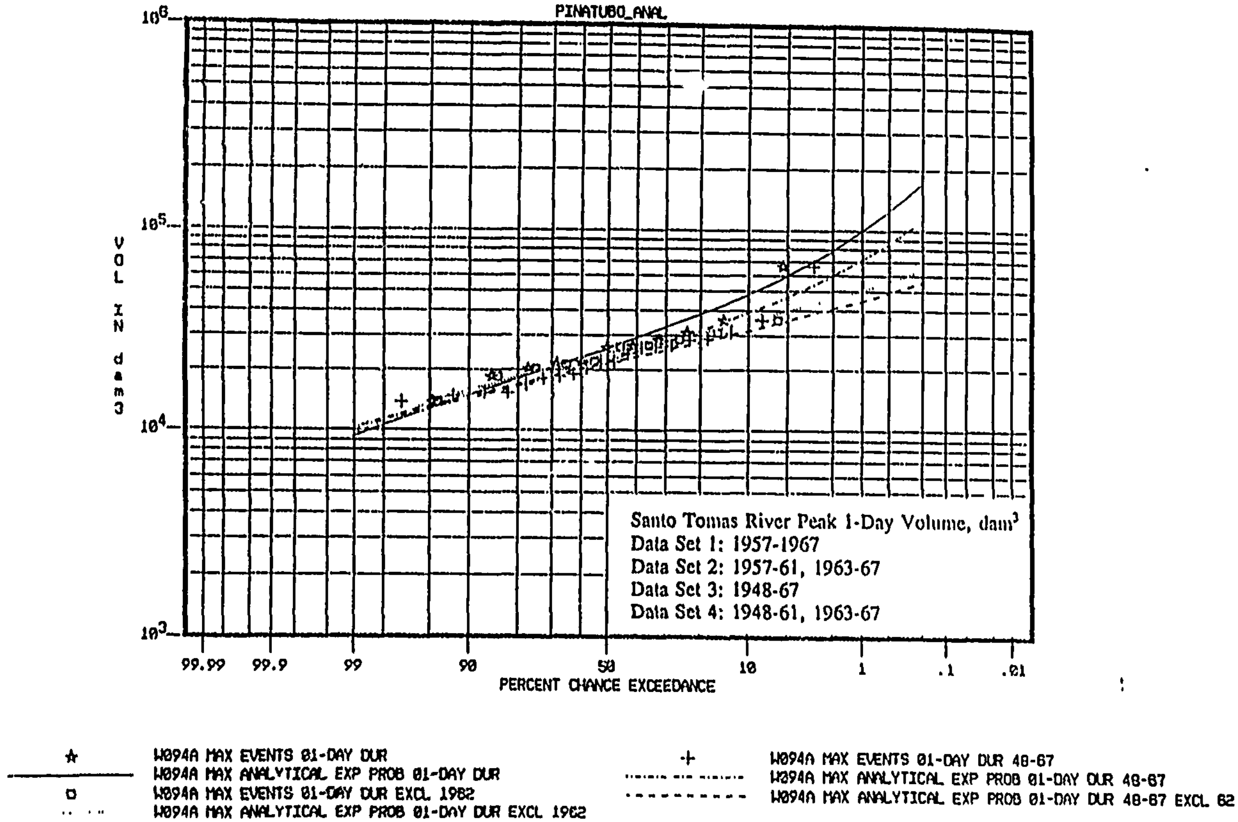

PINATUBO_ANAL
VOL IN dam3
10^6
10^5
10^4
10^3
99.99
99.9
99
90
50
10
1
.1
.01
PERCENT CHANCE EXCEEDANCE
Santo Tomas River Peak 1-Day Volume, dam^3
Data Set 1: 1957-1967
Data Set 2: 1957-61, 1963-67
Data Set 3: 1948-67
Data Set 4: 1948-61, 1963-67
W094A MAX EVENTS 01-DAY DUR
W094A MAX ANALYTICAL EXP PROB 01-DAY DUR
W094A MAX EVENTS 01-DAY DUR EXCL 1962
W094A MAX ANALYTICAL EXP PROB 01-DAY DUR EXCL 1962
W094A MAX EVENTS 01-DAY DUR 48-67
W094A MAX ANALYTICAL EXP PROB 01-DAY DUR 48-67
W094A MAX ANALYTICAL EXP PROB 01-DAY DUR 48-67 EXCL 62

Figure 2.4.91

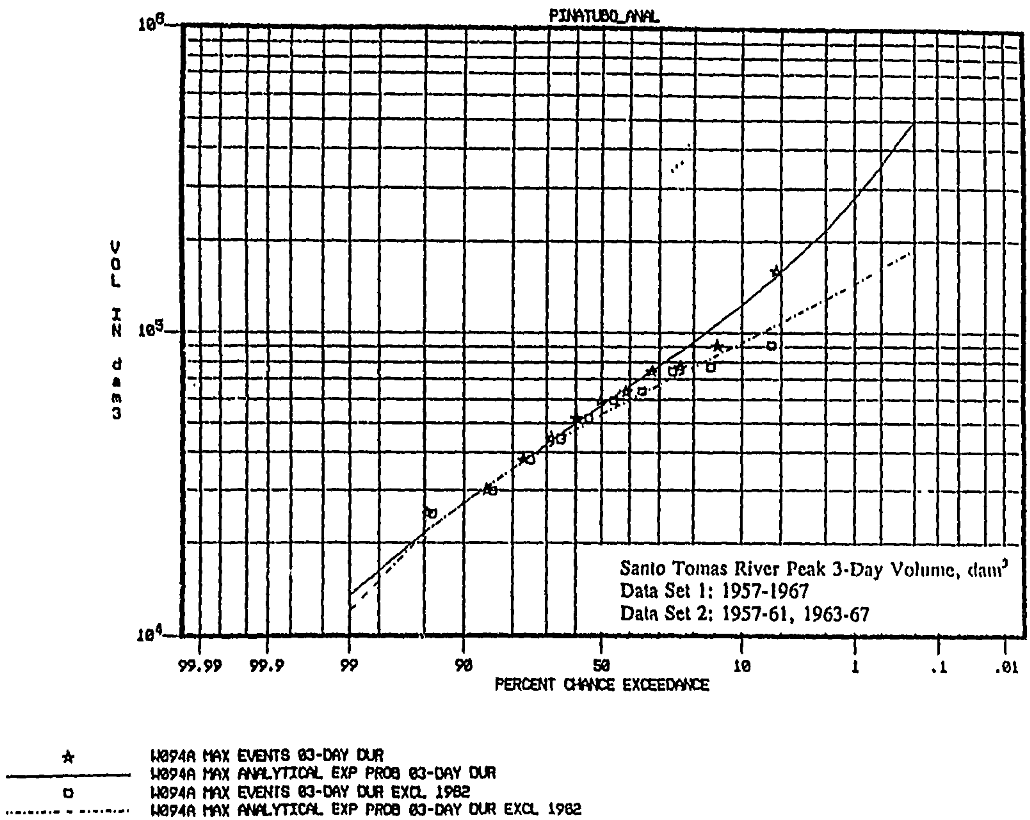
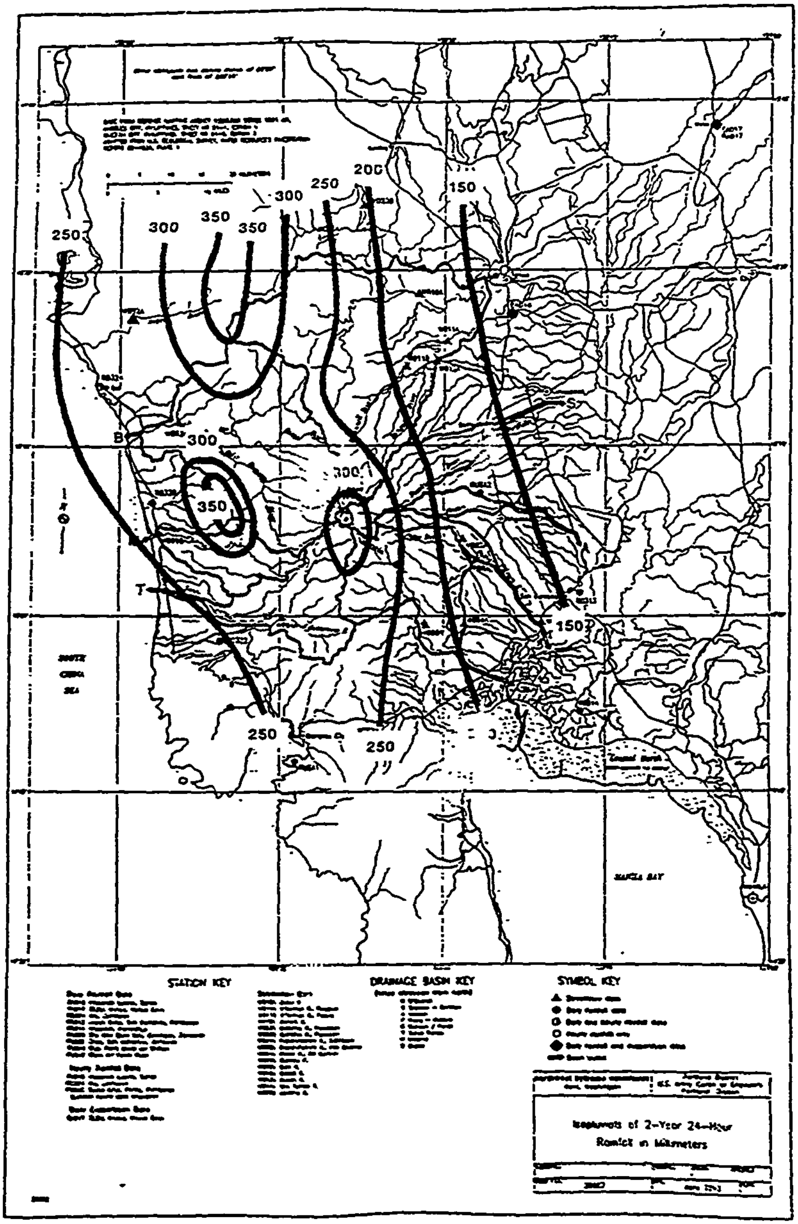
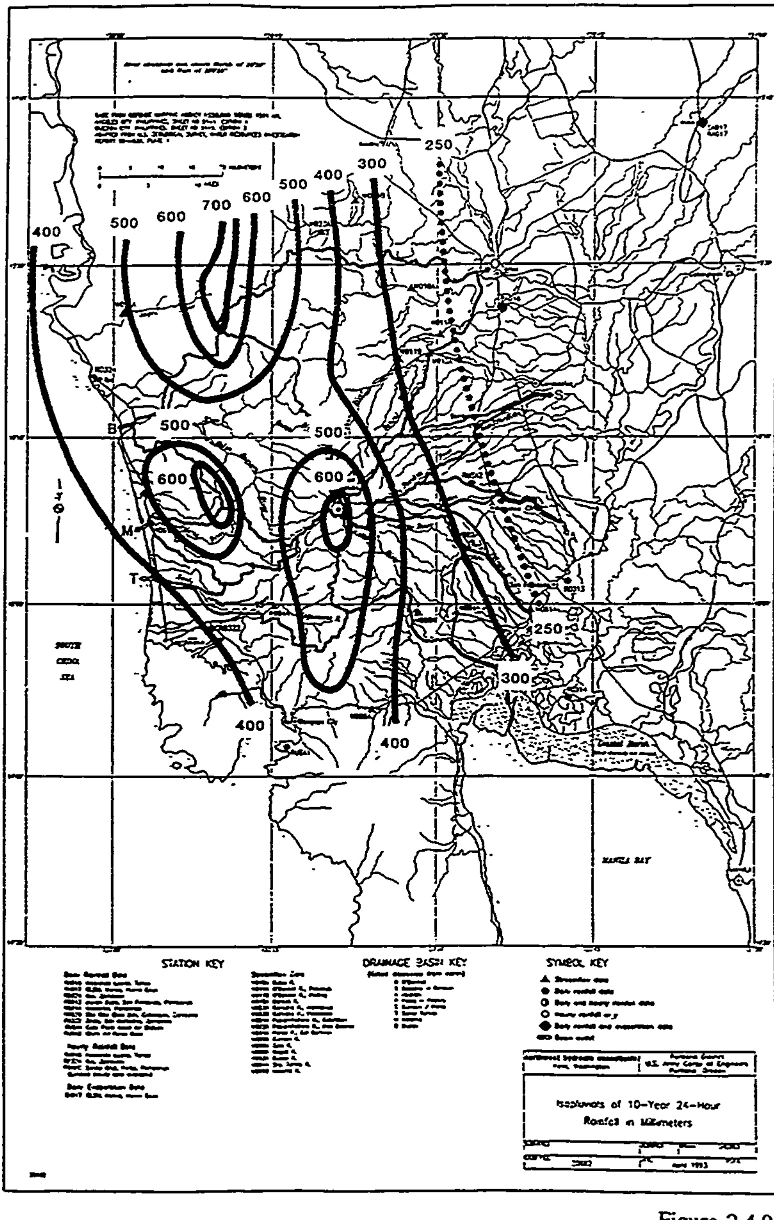

PINATUBO_ANAL
VOL IN dam3
10^6
10^5
10^4
99.99
99.9
99
90
50
10
1
.1
.01
PERCENT CHANCE EXCEEDANCE
Santo Tomas River Peak 3-Day Volume, dam³
Data Set 1: 1957-1967
Data Set 2: 1957-61, 1963-67
W094A MAX EVENTS 03-DAY DUR
W094A MAX ANALYTICAL EXP PROB 03-DAY DUR
W094A MAX EVENTS 03-DAY DUR EXCL 1982
W094A MAX ANALYTICAL EXP PROB 03-DAY DUR EXCL 1982

Figure 2.4.92



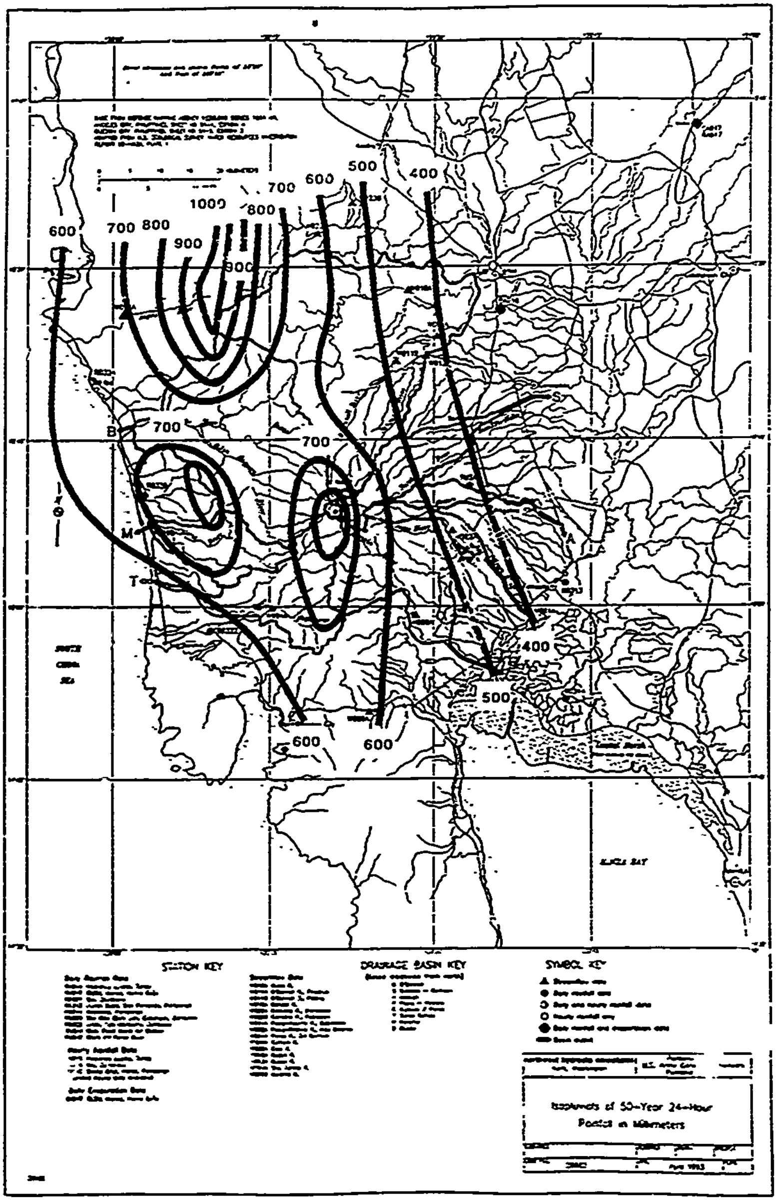
250
300
350
350
300
250
200
150
300
300
350
150
250
250
SOUTH CHINA SEA
MANILA BAY
STATION KEY
DRAINAGE BASIN KEY
SYMBOL KEY
Isopluvials of 2-Year 24-Hour Rainfall in Millimeters

Figure 2.4.93



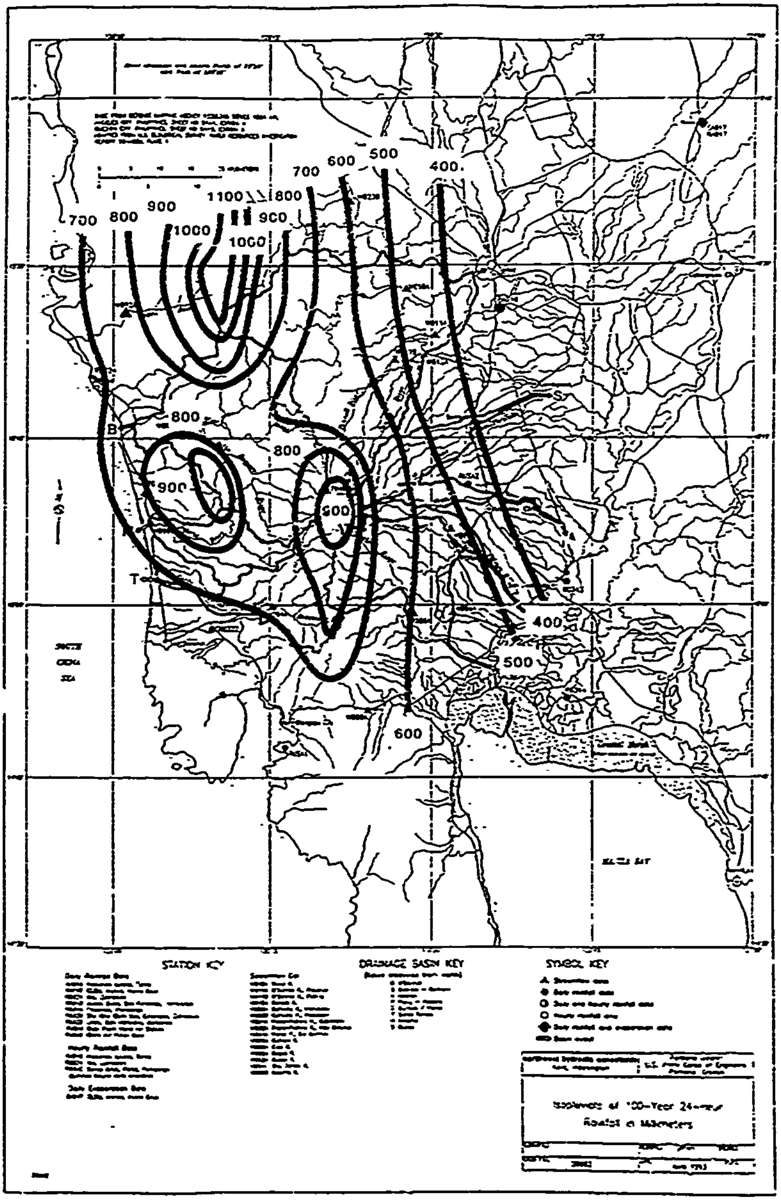
STATION KEY
DRAINAGE BASIN KEY
SYMBOL KEY
Isopluvials of 10-Year 24-Hour
Rainfall in Millimeters

Figure 2.4.94



600
700
800
900
1000
700
800
900
600
500
400
700
700
400
500
600
600
B
M
T
S
A
SOUTH CHINA SEA
STATION KEY
DRAINAGE BASIN KEY
SYMBOL KEY
Isopluvials of 50-Year 24-Hour Precip in Millimeters

Figure 2.4.95



700
800
900
1000
1100
800
900
1000
700
600
500
400
800
800
900
900
400
500
600
B
STATION KEY
DRAINAGE BASIN KEY
SYMBOL KEY

Figure 2.4.96

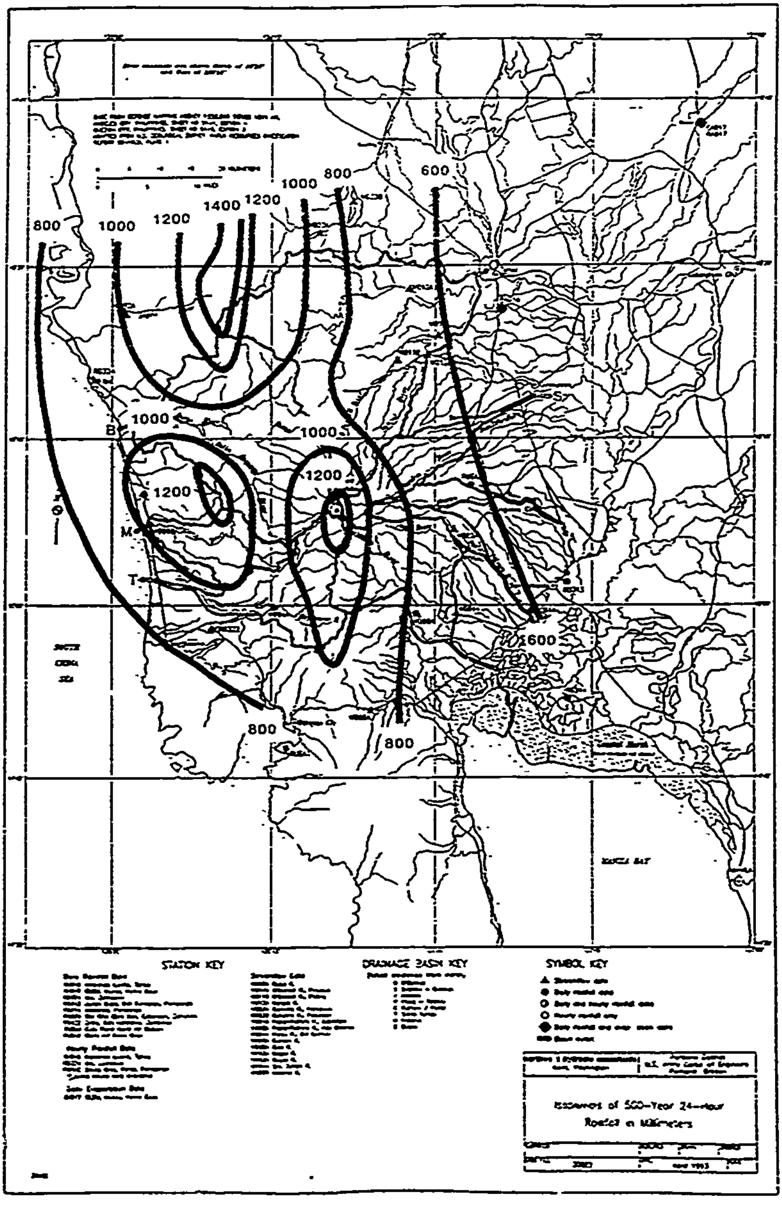
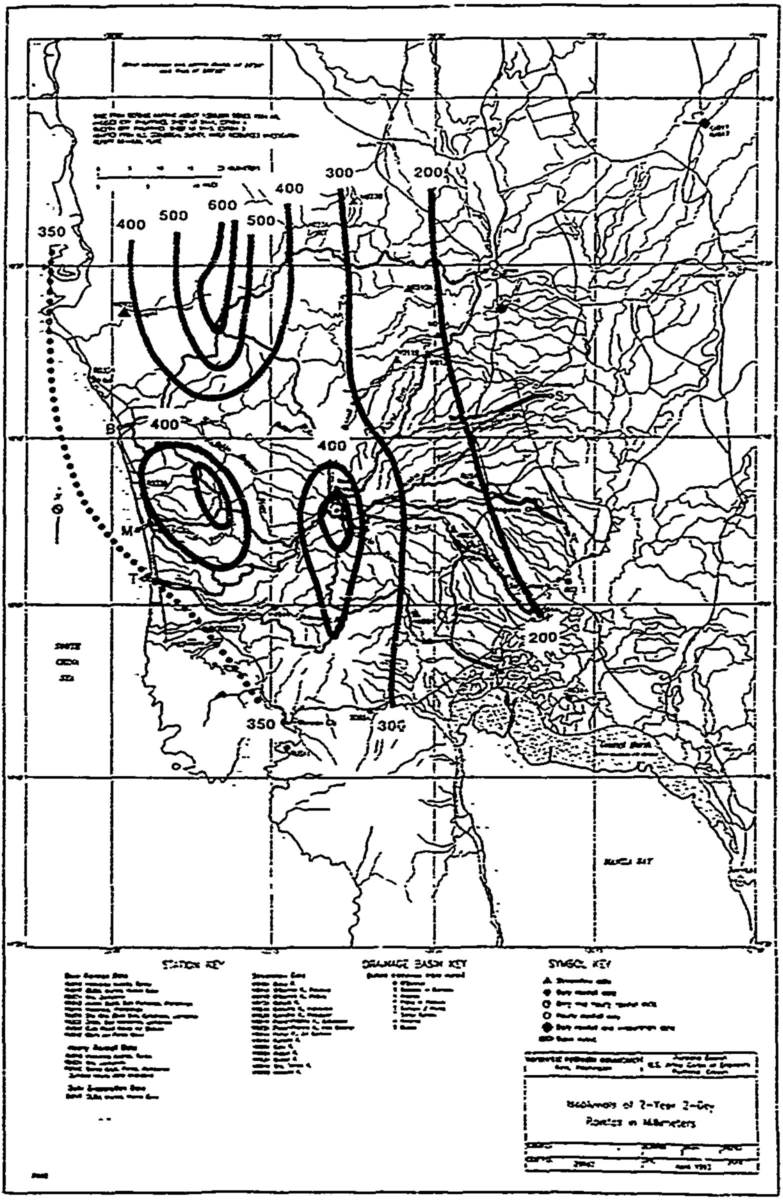
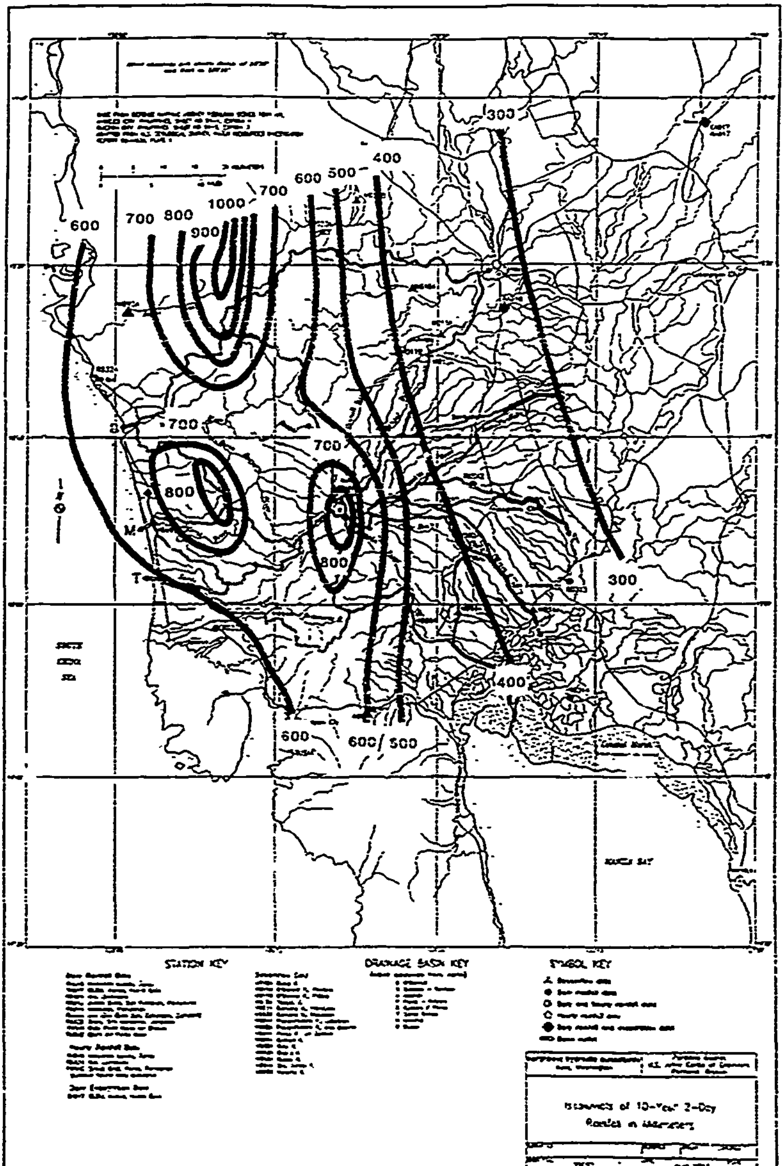

800
1000
1200
1400
1200
1000
800
600
1000
1000
1200
1200
800
800
600
B
M
T
STATION KEY
DRAINAGE BASIN KEY
SYMBOL KEY
Isohyets of 500-Year 24-Hour
Rainfall in Millimeters

Figure 2.4.97



400
500
600
500
400
300
200
350
400
400
200
350
300
B
M
T
S
A
STATION KEY
DRAINAGE BASIN KEY
SYMBOL KEY

Figure 2.4.98



300
400
500
600
700
1000
800
900
600
700
700
700
800
800
300
400
600
600
500
STATION KEY
DRAINAGE BASIN KEY
SYMBOL KEY

Figure 2.4.99

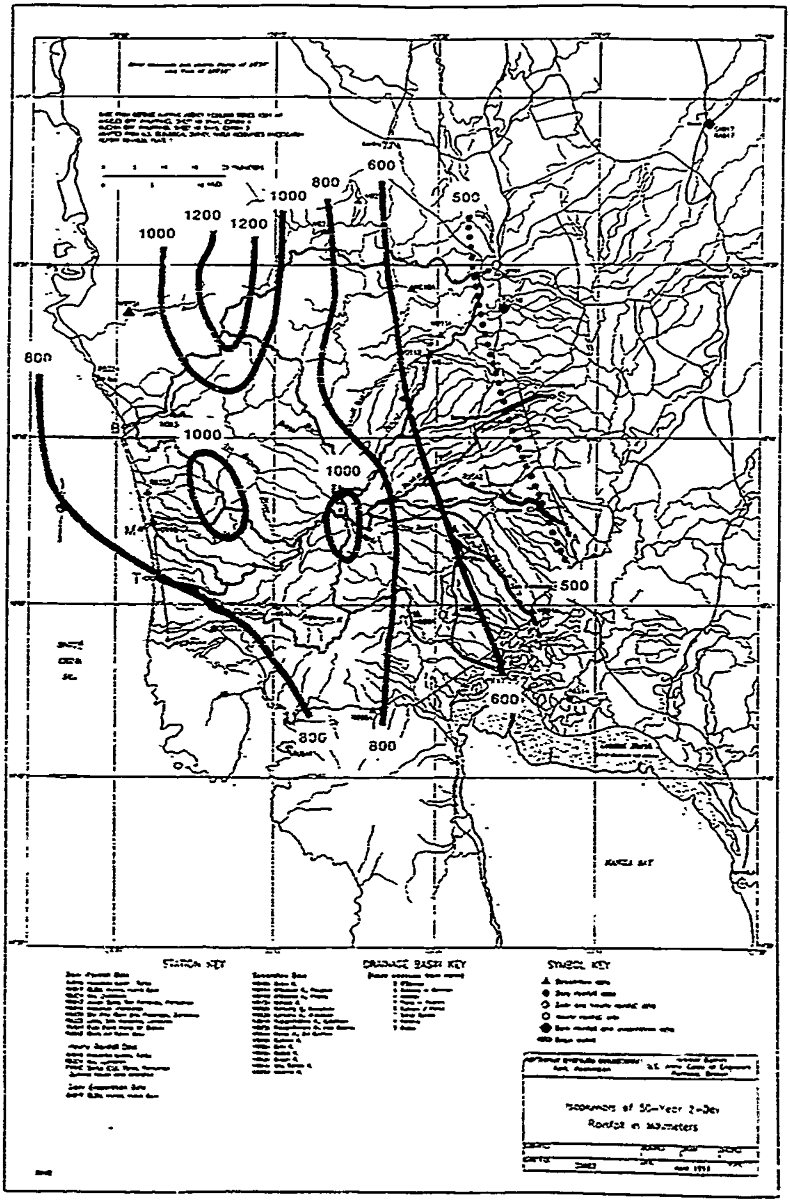


Figure 2.4.100

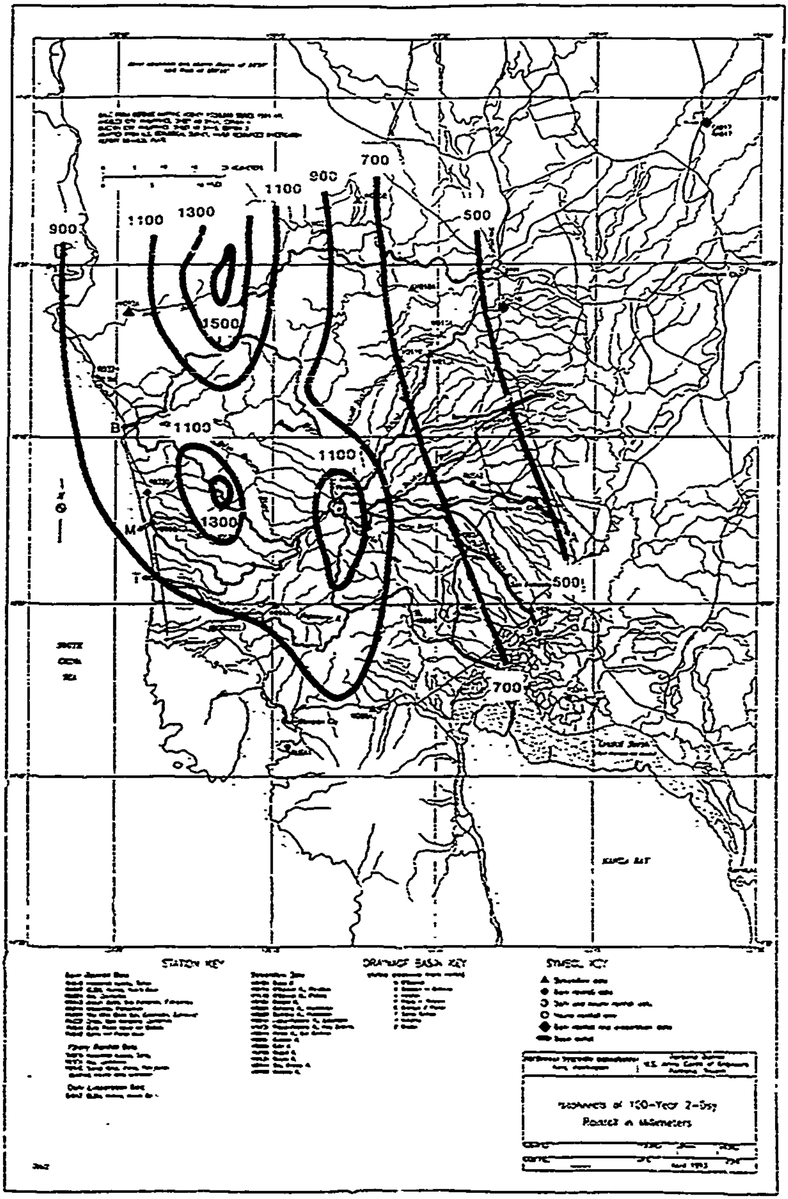


Figure 2.4.101

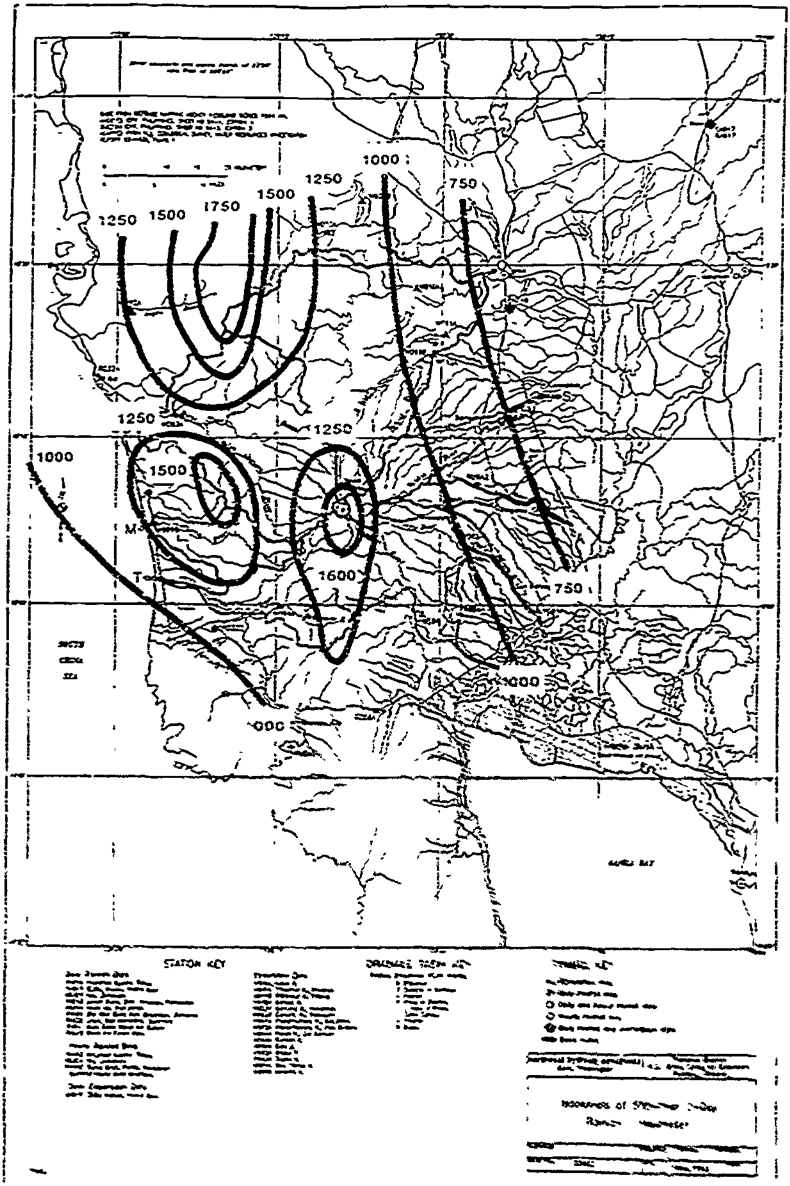


Figure 2.4.702

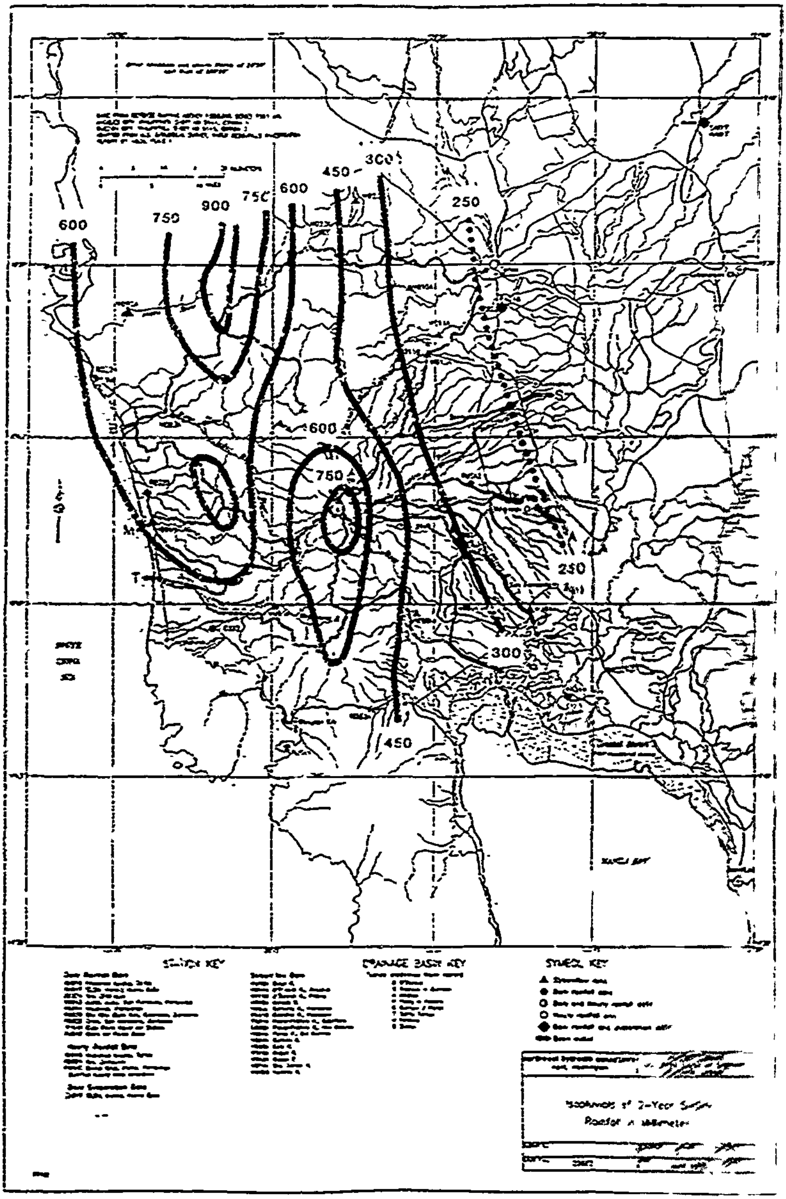

600
750
900
750
600
450
300
250
600
750
250
300
450
STATION KEY
DRAINAGE BASIN KEY
SYMBOL KEY

Figure 2.4 03

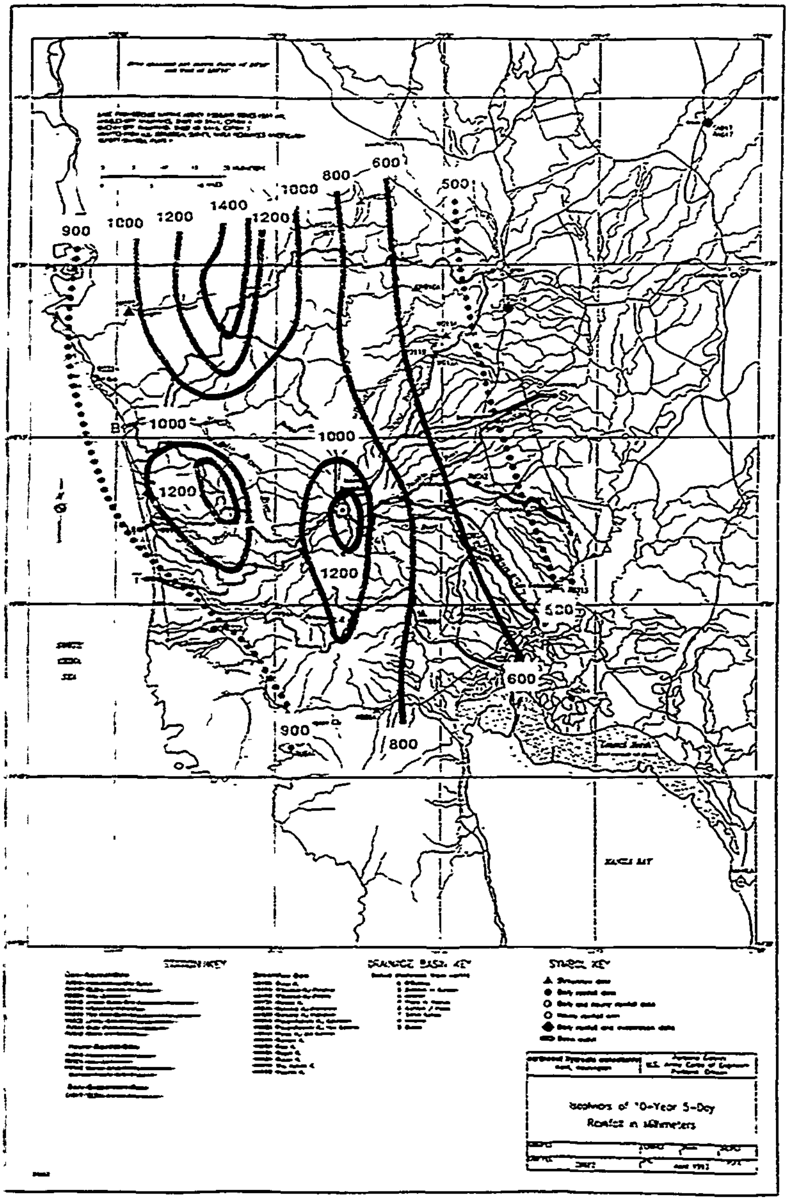


Figure 2.4.104

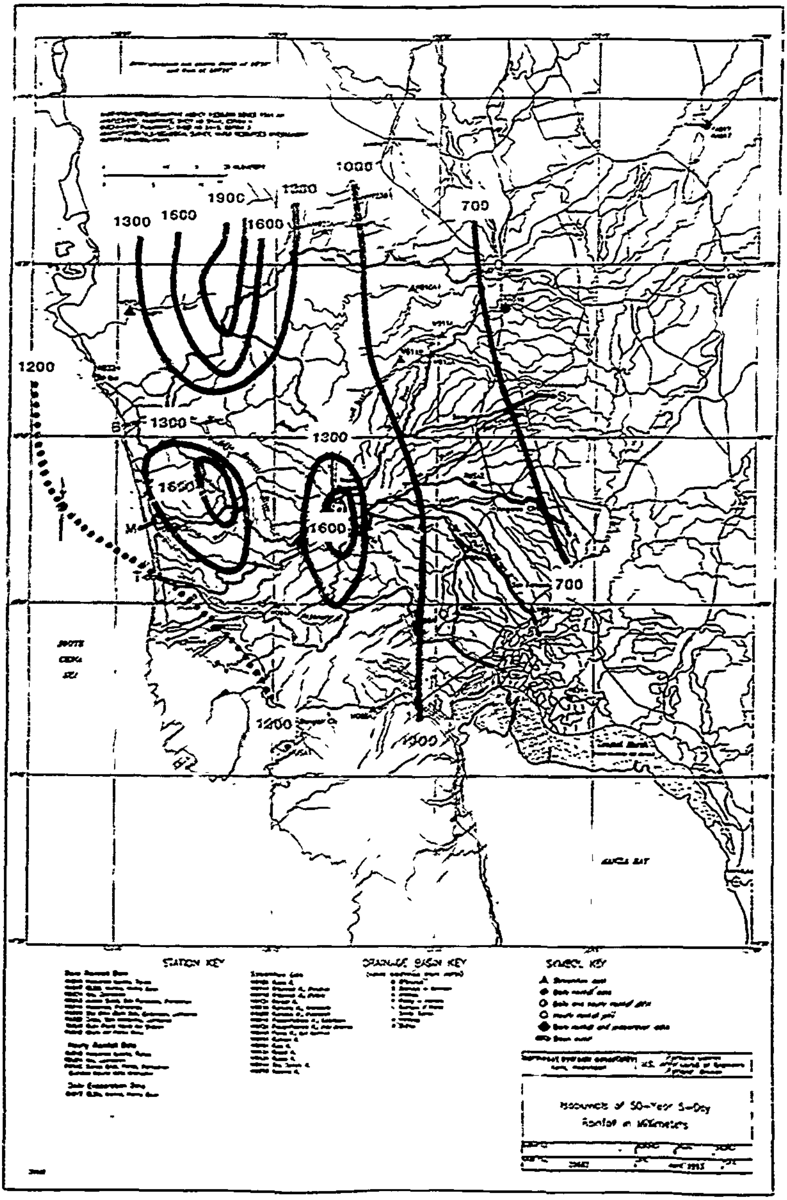


Figure 2.4.105

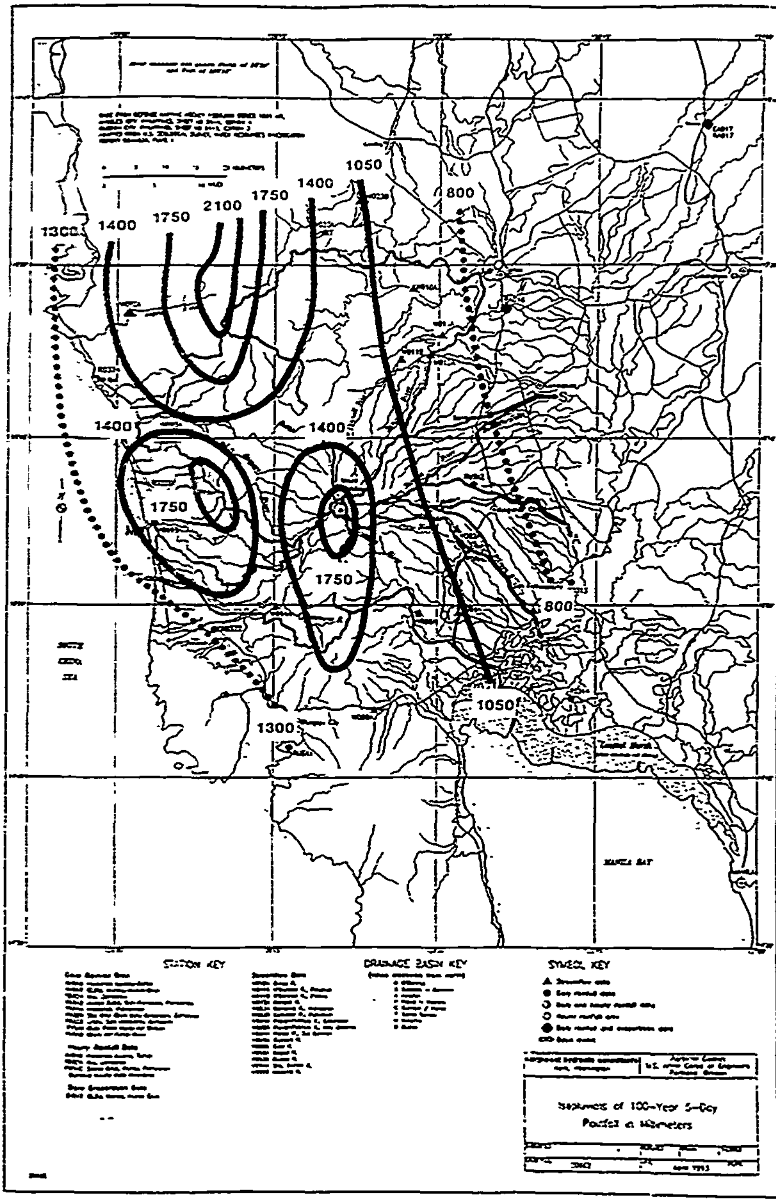


Figure 2.4.106

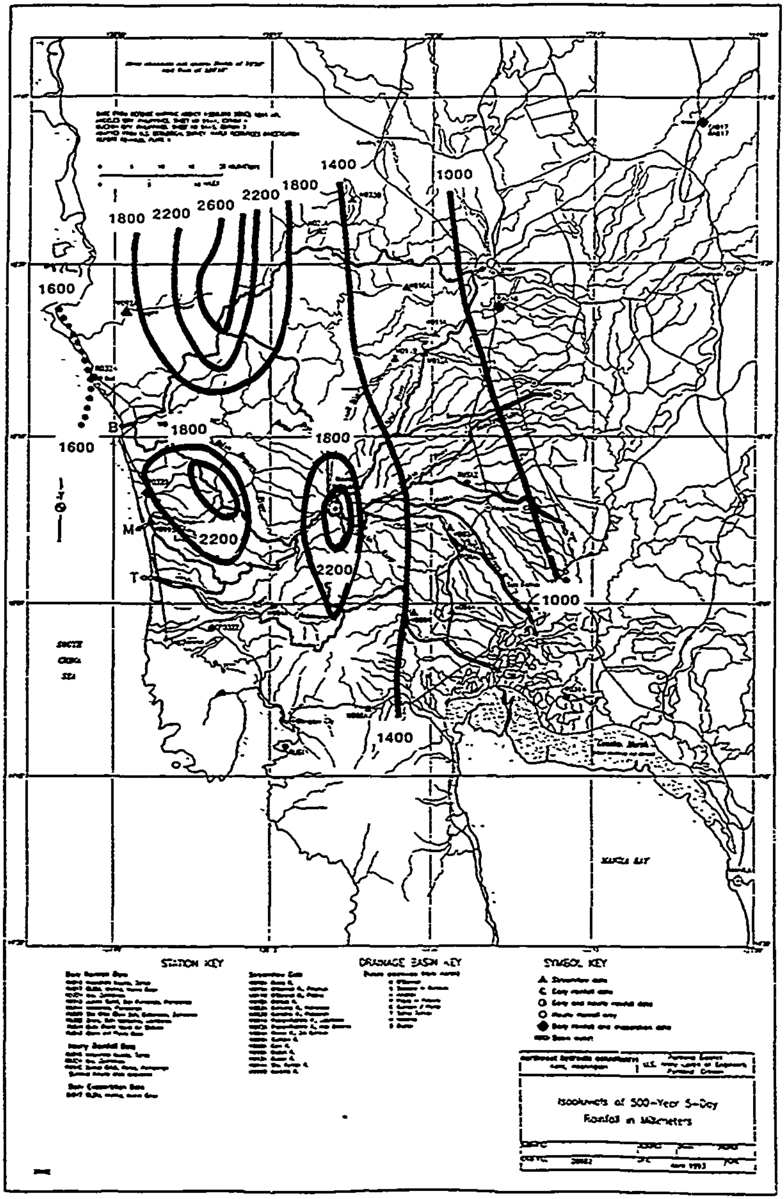
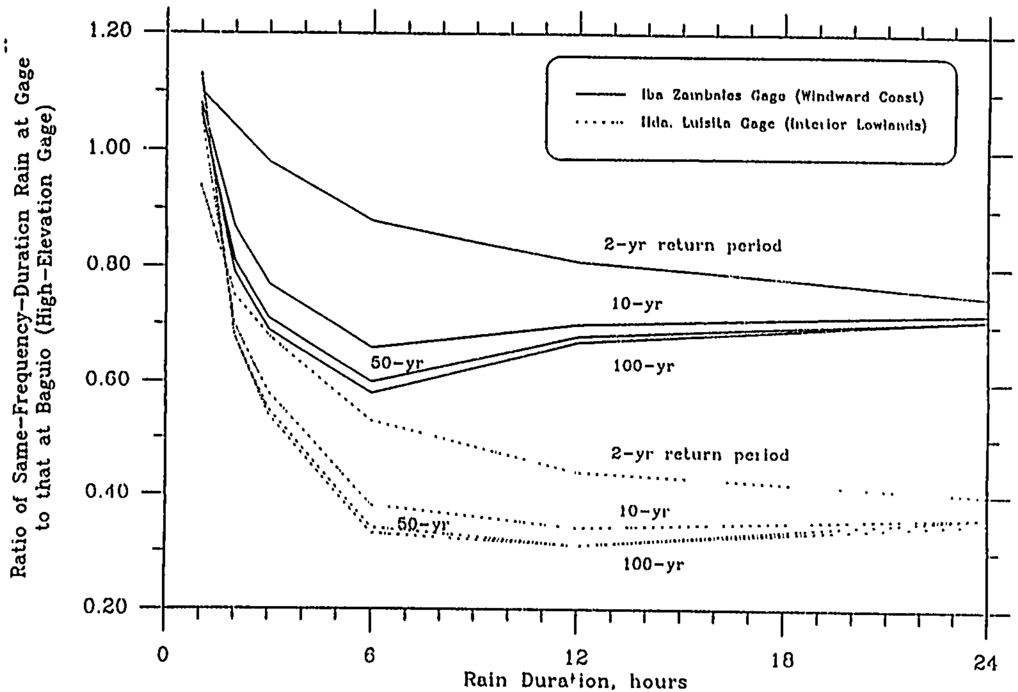


Figure 2.4.107

Effect of Elevation/Location/Return Period on Point Rain Frequency-Duration Characteristics



NOTE. Ratios derived from Hydrology and Flood Forecast Center, PAGASA, 1981 'Rainfall Intensity-Duration-Frequency Data of the Philippines' Volume 1, First Edition.

Figure 2.4.108

Effect of Return Period on Station-to-Station Point Rain Frequency-Duration Characteristics

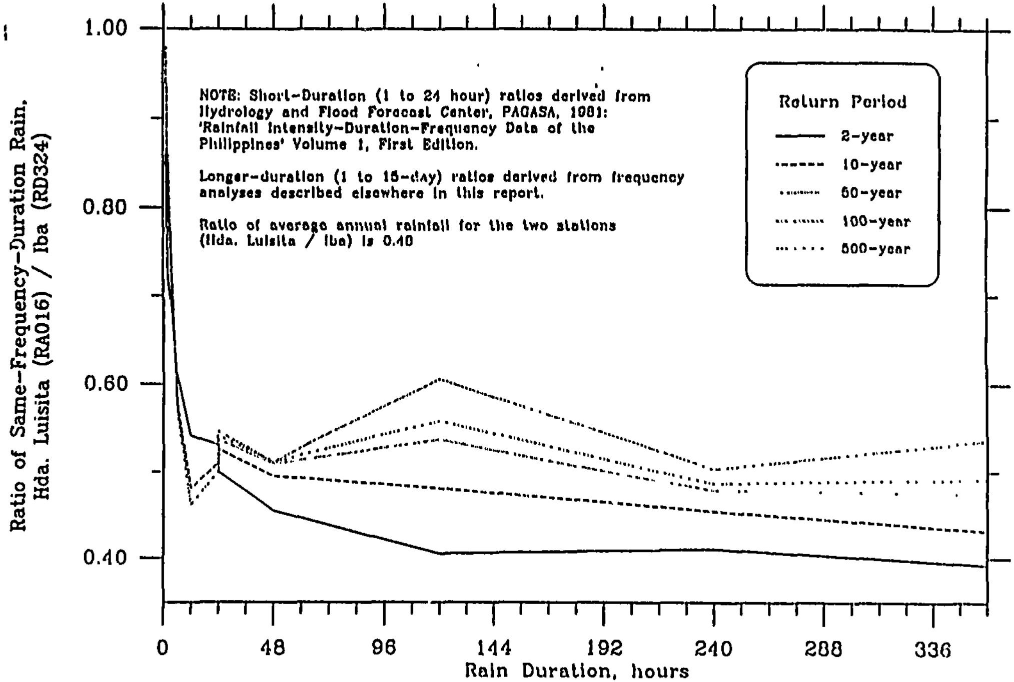


Figure 2.4.109

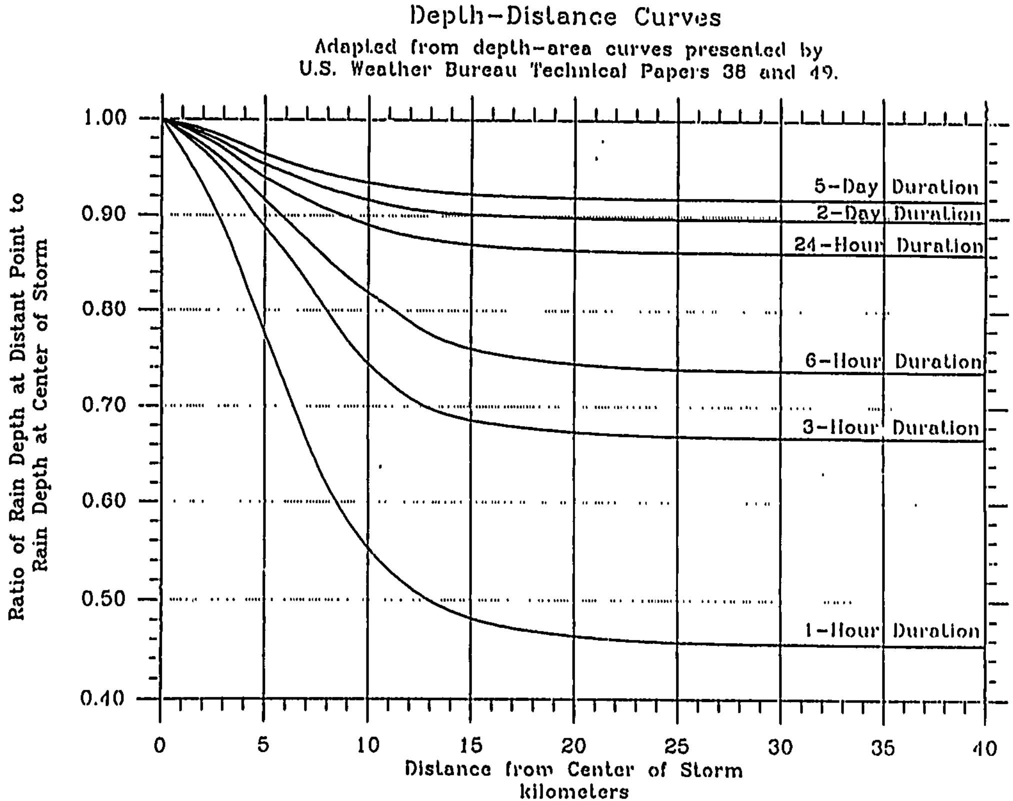


Figure 2.4.110

Historic Rainfall Event @ Iba Zambales, Station RD324
Storm of May 17 – May 29, 1976

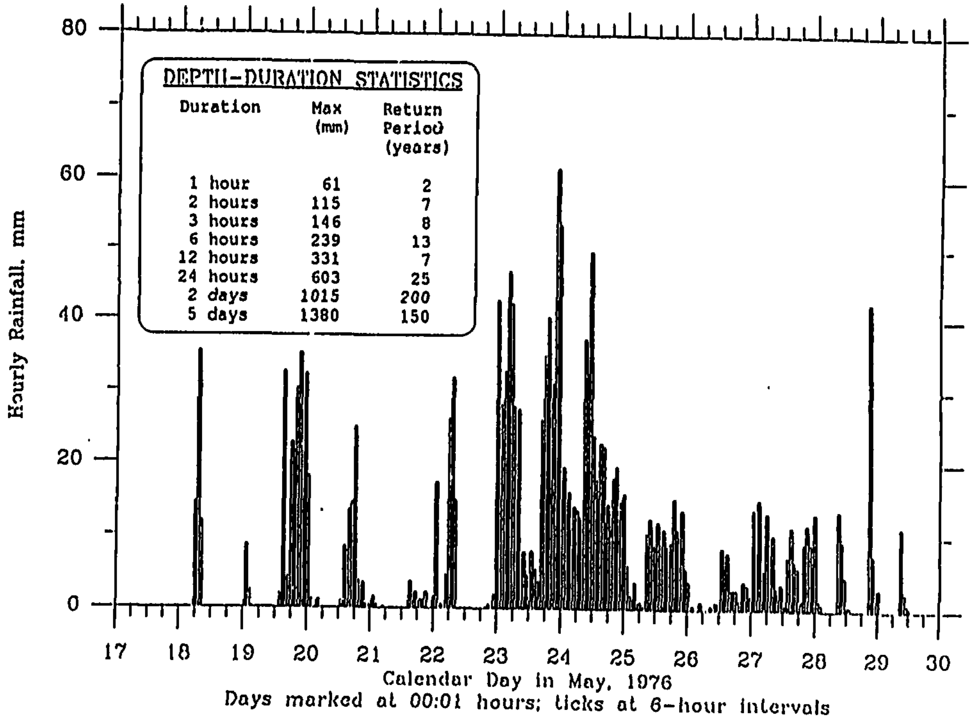


Figure 2.4.111

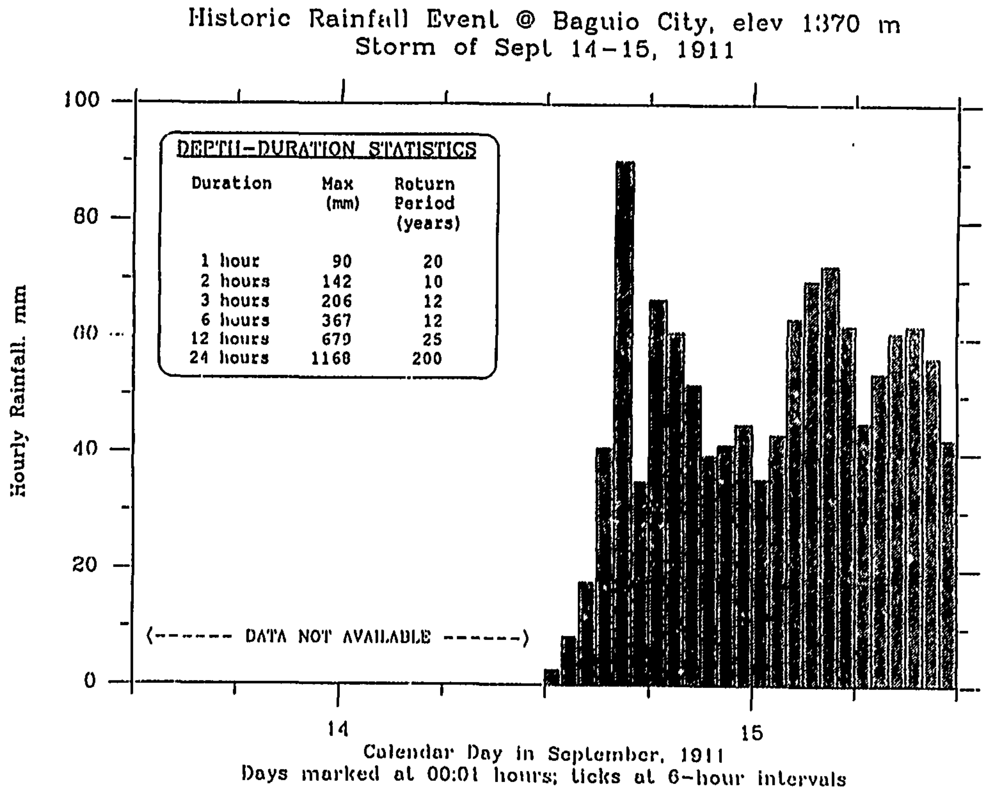


Figure 2.4.112

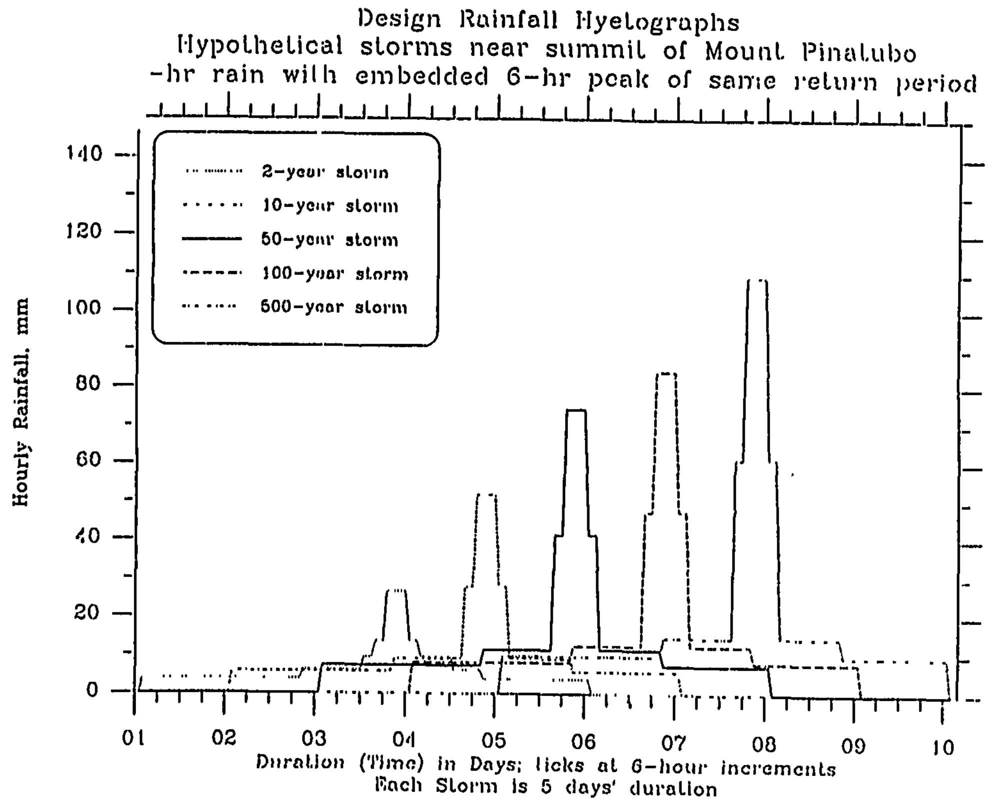


Figure 2.4.113

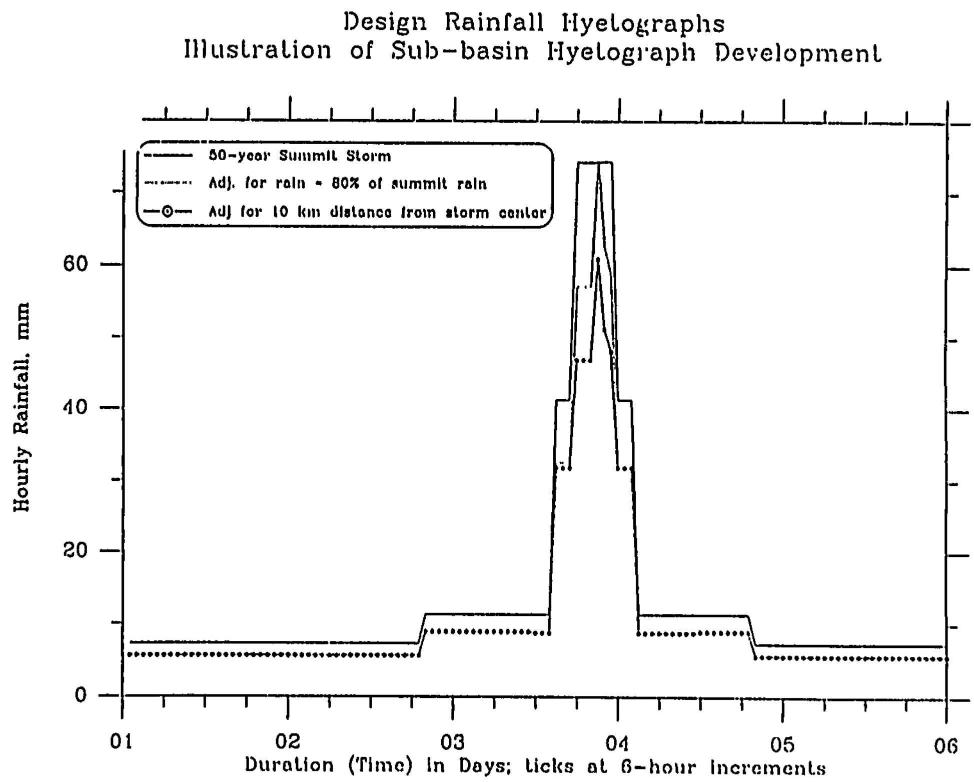


Figure 2.4.114

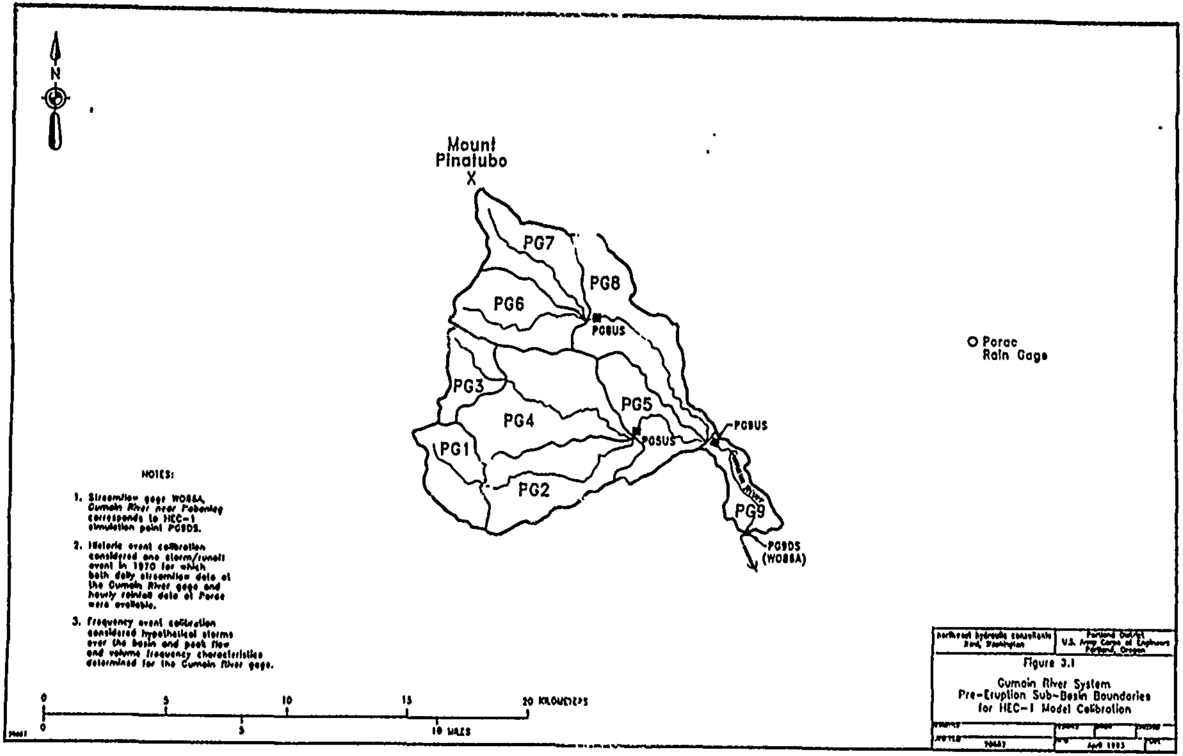
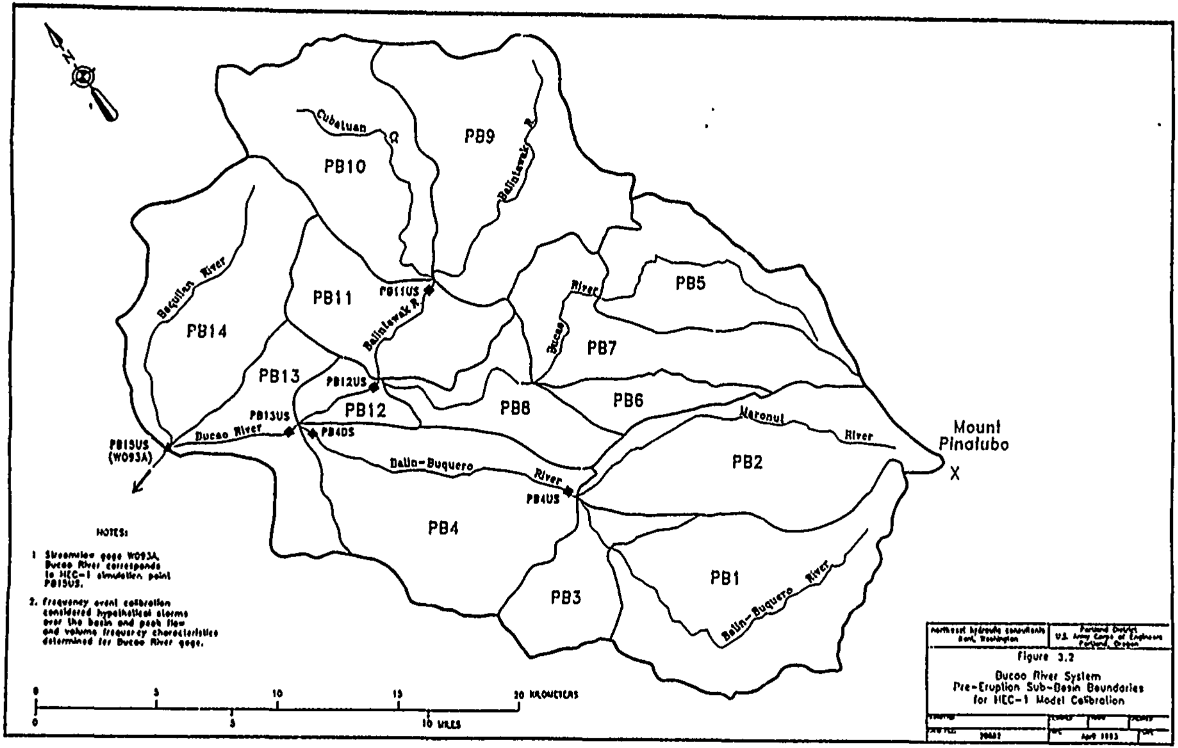

N
Mount Pinatubo
PG1
PG2
PG3
PG4
PG5
PG6
PG7
PG8
PG9
PG5US
PG8US
PG9US
PG9DS (WO88A)
Cumain River
Porac Rain Gage
NOTES:
1. Streamflow gage WO88A, Cumain River near Pabanlag corresponds to HEC-1 simulation point PG9DS.
2. Historic event calibration considered one storm/runoff event in 1970 for which both daily streamflow data at the Cumain River gage and hourly rainfall data at Porac were available.
3. Frequency event calibration considered hypothetical storms over the basin and peak flow and volume frequency characteristics determined for the Cumain River gage.
0 5 10 15 20 KILOMETERS
0 5 10 MILES
Figure 3.1
Cumain River System
Pre-Eruption Sub-Basin Boundaries
for HEC-1 Model Calibration

Figure 3.2.1



PB1
PB2
PB3
PB4
PB5
PB6
PB7
PB8
PB9
PB10
PB11
PB12
PB13
PB14
Mount Pinatubo
X
Cabatuan R
Balintawak R.
Bucao River
Baquilan River
Maronut River
Balin-Buquero River
PB11US
PB12US
PB13US
PB4DS
PB4US
PB15US (W093A)
N
NOTES:
1 Streamflow gage W093A, Bucao River corresponds to HEC-1 simulation point PB15US.
2. Frequency event calibration considered hypothetical storms over the basin and peak flow and volume frequency characteristics determined for Bucao River gage.
0 5 10 15 20 KILOMETERS
0 5 10 MILES
Figure 3.2
Bucao River System
Pre-Eruption Sub-Basin Boundaries
for HEC-1 Model Calibration
April 1993

Figure 3.2.2

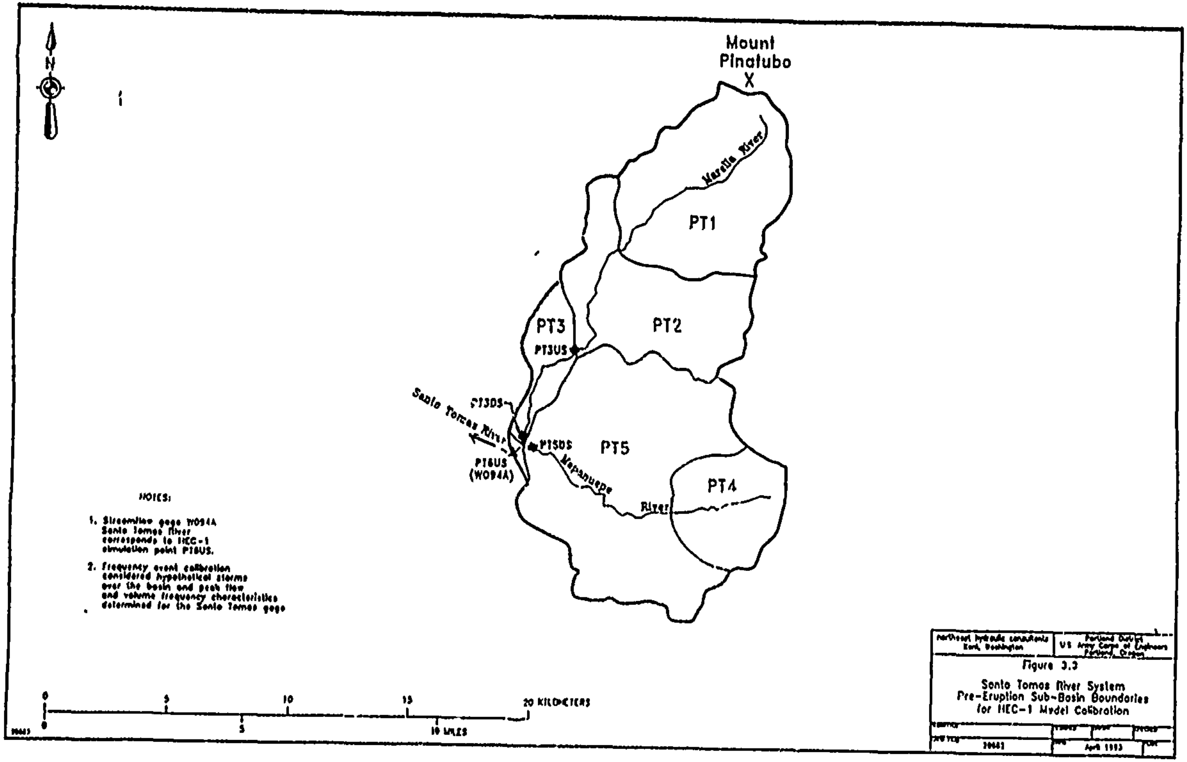

Mount Pinatubo
X
Marella River
PT1
PT2
PT3
PT3US
PT3DS
Santo Tomas River
PT5DS
PT5
PT6US
(W094A)
Mapanuepe
River
PT4
N
NOTES:
1. Streamflow gage W094A Santo Tomas River corresponds to HEC-1 simulation point PT6US.
2. Frequency event calibration considered hypothetical storms over the basin and peak flow and volume frequency characteristics determined for the Santo Tomas gage
0 5 10 15 20 KILOMETERS
0 5 10 MILES
Northwest hydraulic consultants Kent, Washington
US Army Corps of Engineers Portland District Portland, Oregon
Figure 3.3
Santo Tomas River System Pre-Eruption Sub-Basin Boundaries for HEC-1 Model Calibration
April 1993

Figure 3.2.3

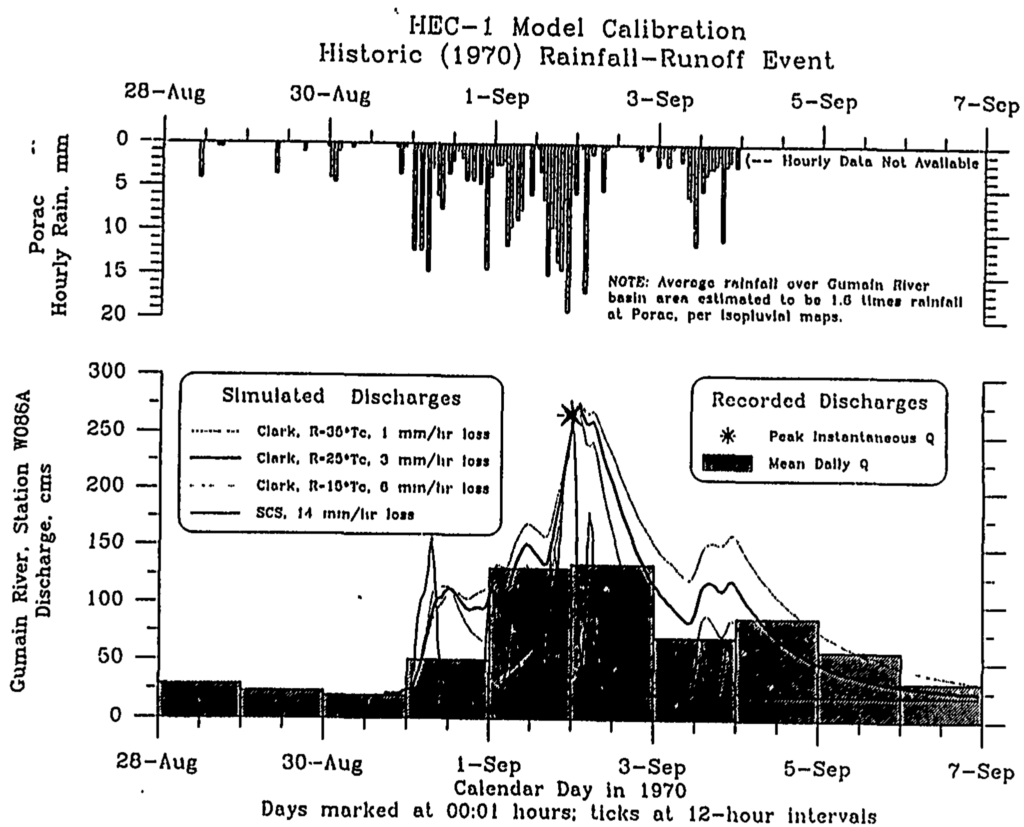

HEC-1 Model Calibration
Historic (1970) Rainfall-Runoff Event
28-Aug
30-Aug
1-Sep
3-Sep
5-Sep
7-Sep
Porac
Hourly Rain, mm
0
5
10
15
20
(-- Hourly Data Not Available
NOTE: Average rainfall over Gumain River basin area estimated to be 1.6 times rainfall at Porac, per isopluvial maps.
Gumain River, Station W086A
Discharge, cms
300
250
200
150
100
50
0
Simulated Discharges
Clark, R=35*Tc, 1 mm/hr loss
Clark, R=25*Tc, 3 mm/hr loss
Clark, R=15*Tc, 6 mm/hr loss
SCS, 14 mm/hr loss
Recorded Discharges
Peak Instantaneous Q
Mean Daily Q
Calendar Day in 1970
Days marked at 00:01 hours; ticks at 12-hour intervals

Figure 3.2.4

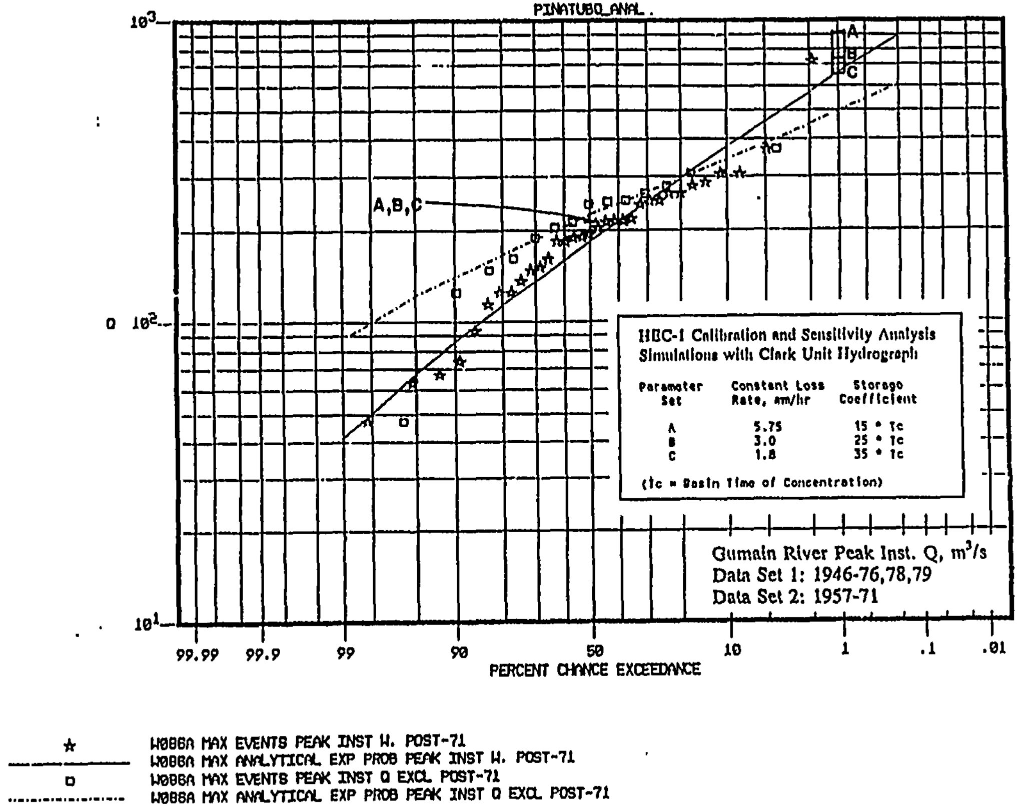
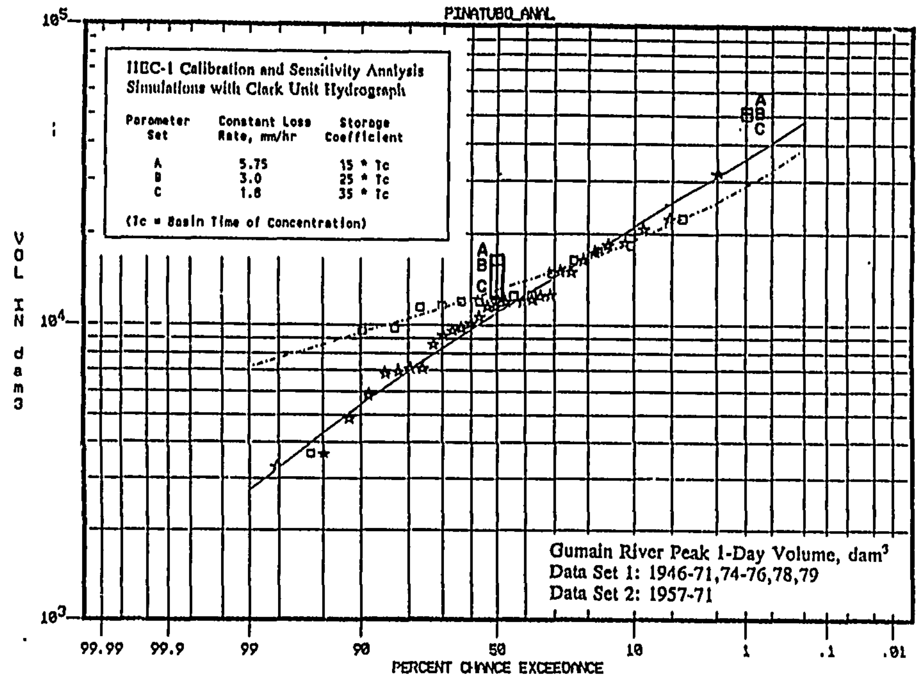
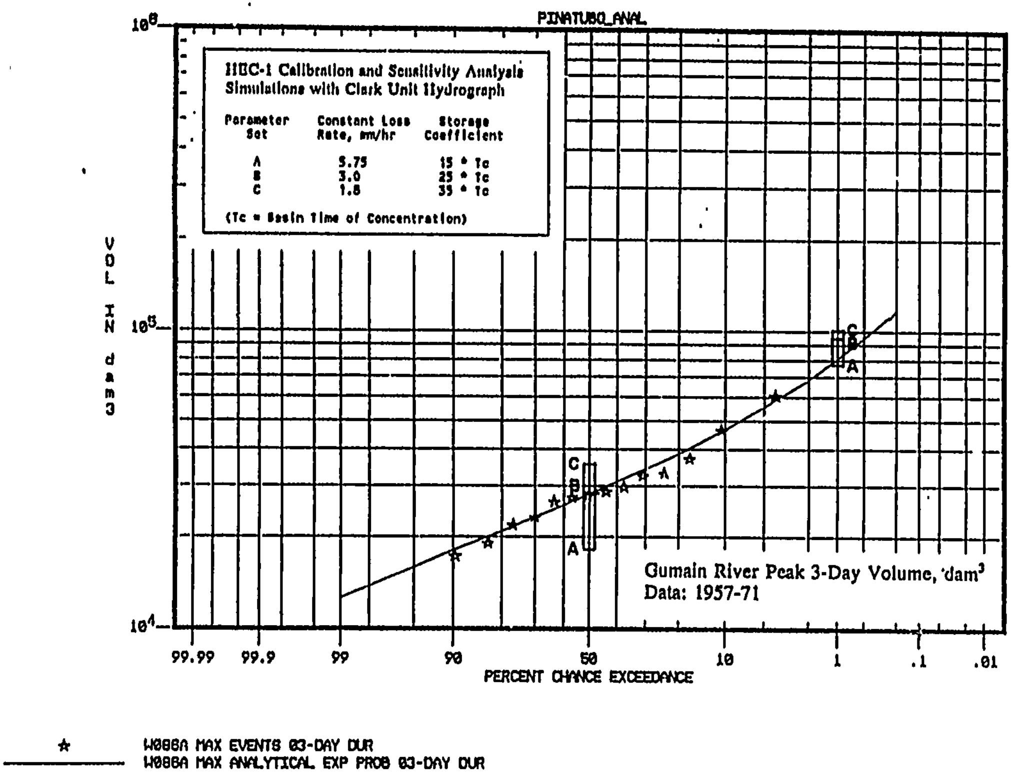

PINATUBO_ANAL.
10^3
Q 10^2
10^1
A,B,C
A
B
C
HEC-1 Calibration and Sensitivity Analysis
Simulations with Clark Unit Hydrograph
Parameter Set
Constant Loss Rate, mm/hr
Storage Coefficient
A 5.75 15 * Tc
B 3.0 25 * Tc
C 1.8 35 * Tc
(Tc = Basin Time of Concentration)
Gumain River Peak Inst. Q, m³/s
Data Set 1: 1946-76,78,79
Data Set 2: 1957-71
99.99
99.9
99
90
50
10
1
.1
.01
PERCENT CHANCE EXCEEDANCE
WOBBA MAX EVENTS PEAK INST W. POST-71
WOBBA MAX ANALYTICAL EXP PROB PEAK INST W. POST-71
WOBBA MAX EVENTS PEAK INST Q EXCL POST-71
WOBBA MAX ANALYTICAL EXP PROB PEAK INST Q EXCL POST-71

Figure 3.2.5



☆	W086A MAX EVENTS 01-DAY DUR W. POST-71
———	W086A MAX ANALYTICAL EXP PROB 01-DAY DUR W. POST-71
□	W086A MAX EVENTS 01-DAY DUR
·-·-·-·	W086A MAX ANALYTICAL EXP PROB 01-DAY DUR

Figure 3.2.6



PINATUBO_ANAL
HEC-1 Calibration and Sensitivity Analysis Simulations with Clark Unit Hydrograph
Parameter Set
Constant Loss Rate, mm/hr
Storage Coefficient
A 5.75 15 * Tc
B 3.0 25 * Tc
C 1.8 35 * Tc
(Tc = Basin Time of Concentration)
Gumain River Peak 3-Day Volume, dam³
Data: 1957-71
VOL IN dam3
PERCENT CHANCE EXCEEDANCE
99.99
99.9
99
90
50
10
1
.1
.01
W086A MAX EVENTS 03-DAY DUR
W086A MAX ANALYTICAL EXP PROB 03-DAY DUR

Figure 3.2.7

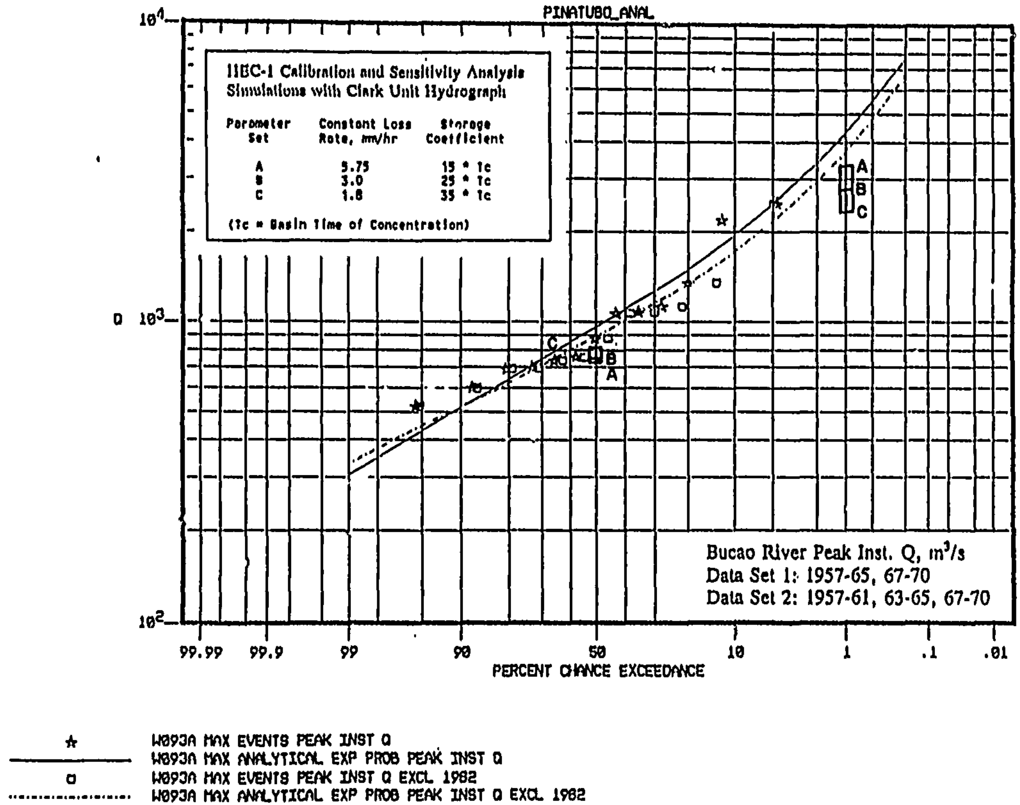

PINATUBO_ANAL
HEC-1 Calibration and Sensitivity Analysis
Simulations with Clark Unit Hydrograph
Parameter Set
Constant Loss Rate, mm/hr
Storage Coefficient
A 5.75 15 * Tc
B 3.0 25 * Tc
C 1.8 35 * Tc
(Tc = Basin Time of Concentration)
Q
10^4
10^3
10^2
99.99
99.9
99
90
50
10
1
.1
.01
PERCENT CHANCE EXCEEDANCE
Bucao River Peak Inst. Q, m^3/s
Data Set 1: 1957-65, 67-70
Data Set 2: 1957-61, 63-65, 67-70
W093A MAX EVENTS PEAK INST Q
W093A MAX ANALYTICAL EXP PROB PEAK INST Q
W093A MAX EVENTS PEAK INST Q EXCL 1982
W093A MAX ANALYTICAL EXP PROB PEAK INST Q EXCL 1982

Figure 3.2.8

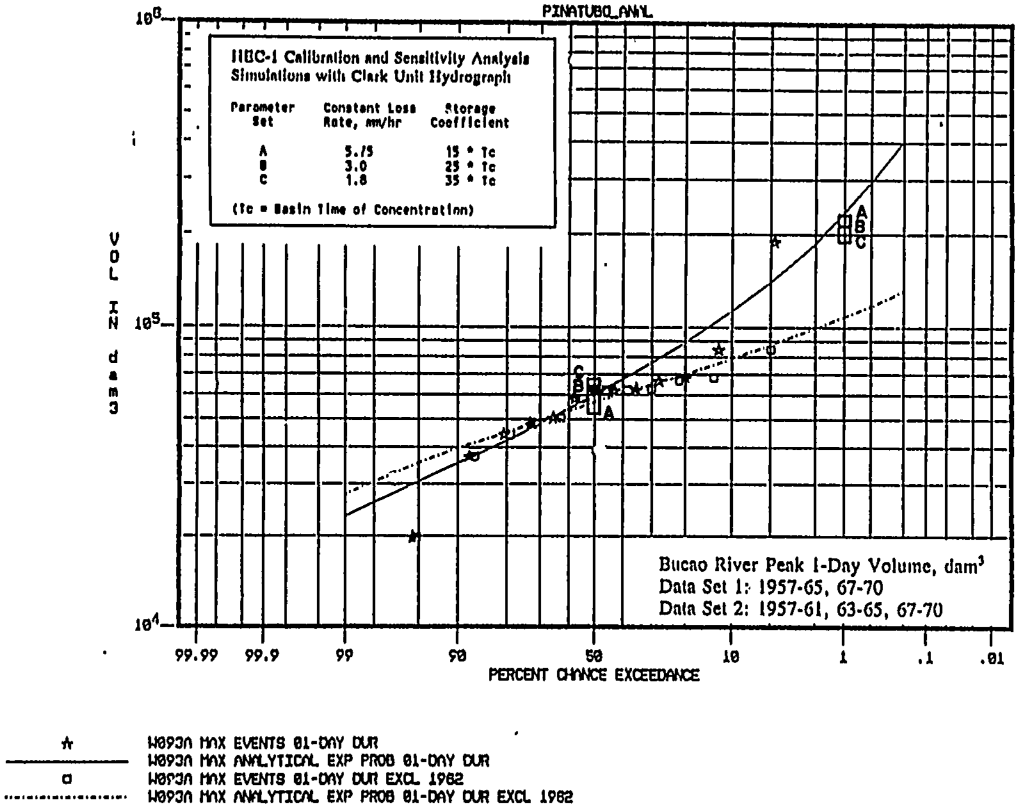

PINATUBO_ANAL
HEC-1 Calibration and Sensitivity Analysis Simulations with Clark Unit Hydrograph
Parameter Set
Constant Loss Rate, mm/hr
Storage Coefficient
A 5.75 15 * Tc
B 3.0 25 * Tc
C 1.8 35 * Tc
(Tc = Basin Time of Concentration)
VOL IN dam3
Bucao River Peak 1-Day Volume, dam³
Data Set 1: 1957-65, 67-70
Data Set 2: 1957-61, 63-65, 67-70
PERCENT CHANCE EXCEEDANCE
W093A MAX EVENTS 01-DAY DUR
W093A MAX ANALYTICAL EXP PROB 01-DAY DUR
W093A MAX EVENTS 01-DAY DUR EXCL 1962
W093A MAX ANALYTICAL EXP PROB 01-DAY DUR EXCL 1962

Figure 3.2.9

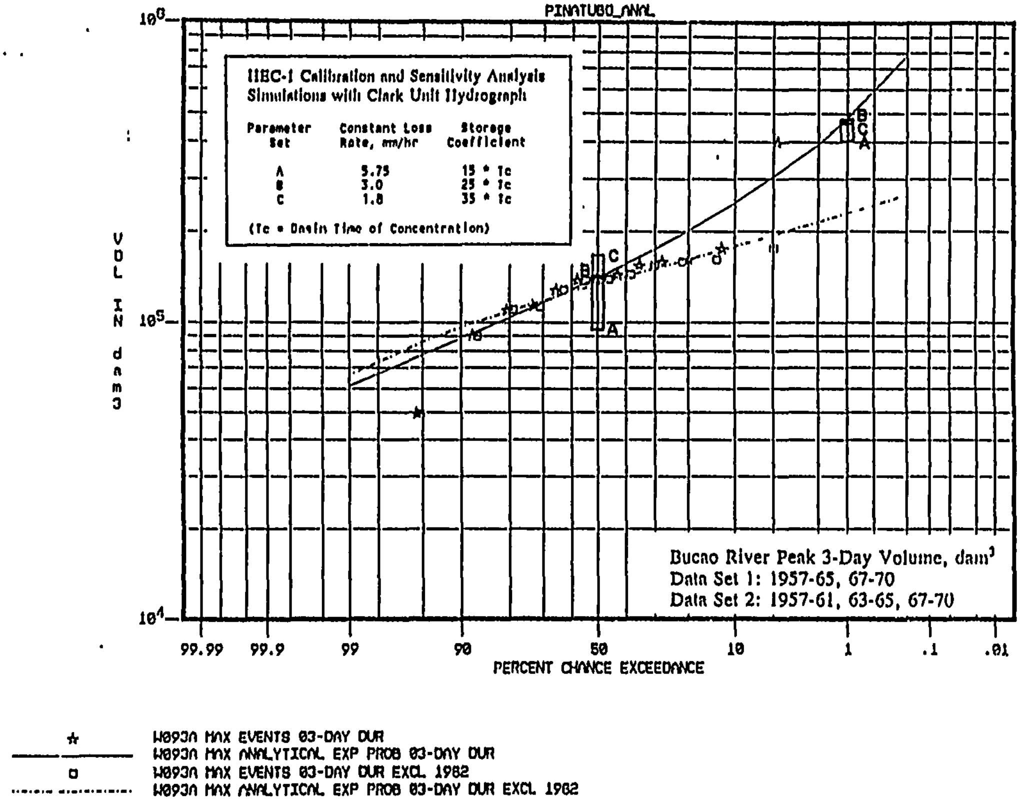
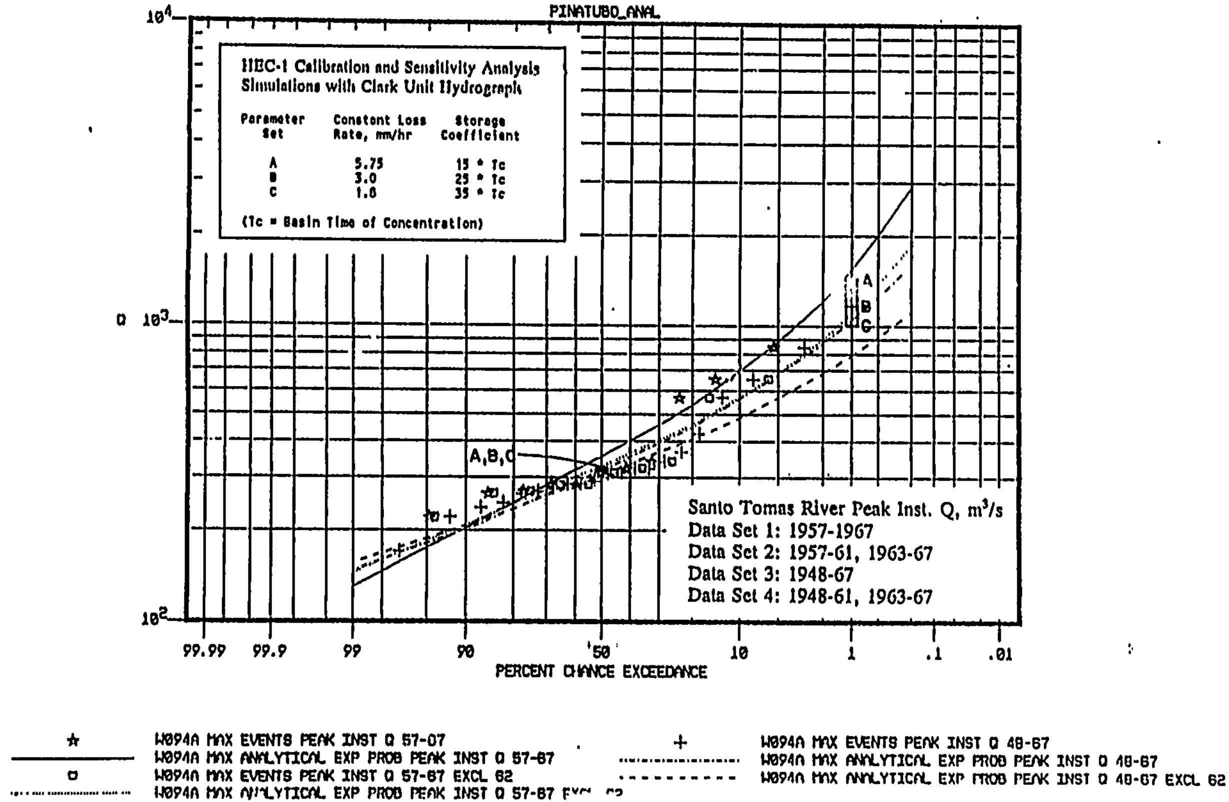

PINATUBO_ANAL
HEC-1 Calibration and Sensitivity Analysis
Simulations with Clark Unit Hydrograph
Parameter Set
Constant Loss Rate, mm/hr
Storage Coefficient
A 5.75 15 * Tc
B 3.0 25 * Tc
C 1.8 35 * Tc
(Tc = Basin Time of Concentration)
Bucno River Peak 3-Day Volume, dam³
Data Set 1: 1957-65, 67-70
Data Set 2: 1957-61, 63-65, 67-70
VOL IN dam3
10⁶
10⁵
10⁴
99.99
99.9
99
90
50
10
1
.1
.01
PERCENT CHANCE EXCEEDANCE
W093A MAX EVENTS 03-DAY DUR
W093A MAX ANALYTICAL EXP PROB 03-DAY DUR
W093A MAX EVENTS 03-DAY DUR EXCL 1982
W093A MAX ANALYTICAL EXP PROB 03-DAY DUR EXCL 1982

Figure 3.2.10



PINATUBO_ANAL
HEC-1 Calibration and Sensitivity Analysis Simulations with Clark Unit Hydrograph
Parameter Set | Constant Loss Rate, mm/hr | Storage Coefficient
A 5.75 15 * Tc
B 3.0 25 * Tc
C 1.8 35 * Tc
(Tc = Basin Time of Concentration)
Santo Tomas River Peak Inst. Q, m³/s
Data Set 1: 1957-1967
Data Set 2: 1957-61, 1963-67
Data Set 3: 1948-67
Data Set 4: 1948-61, 1963-67
A,B,C
A
B
C
Q
10⁴
10³
10²
99.99
99.9
99
90
50
10
1
.1
.01
PERCENT CHANCE EXCEEDANCE
W094A MAX EVENTS PEAK INST Q 57-67
W094A MAX ANALYTICAL EXP PROB PEAK INST Q 57-67
W094A MAX EVENTS PEAK INST Q 57-67 EXCL 62
W094A MAX ANALYTICAL EXP PROB PEAK INST Q 57-67
W094A MAX EVENTS PEAK INST Q 48-67
W094A MAX ANALYTICAL EXP PROB PEAK INST Q 48-67
W094A MAX ANALYTICAL EXP PROB PEAK INST Q 48-67 EXCL 62

Figure 3.2.11

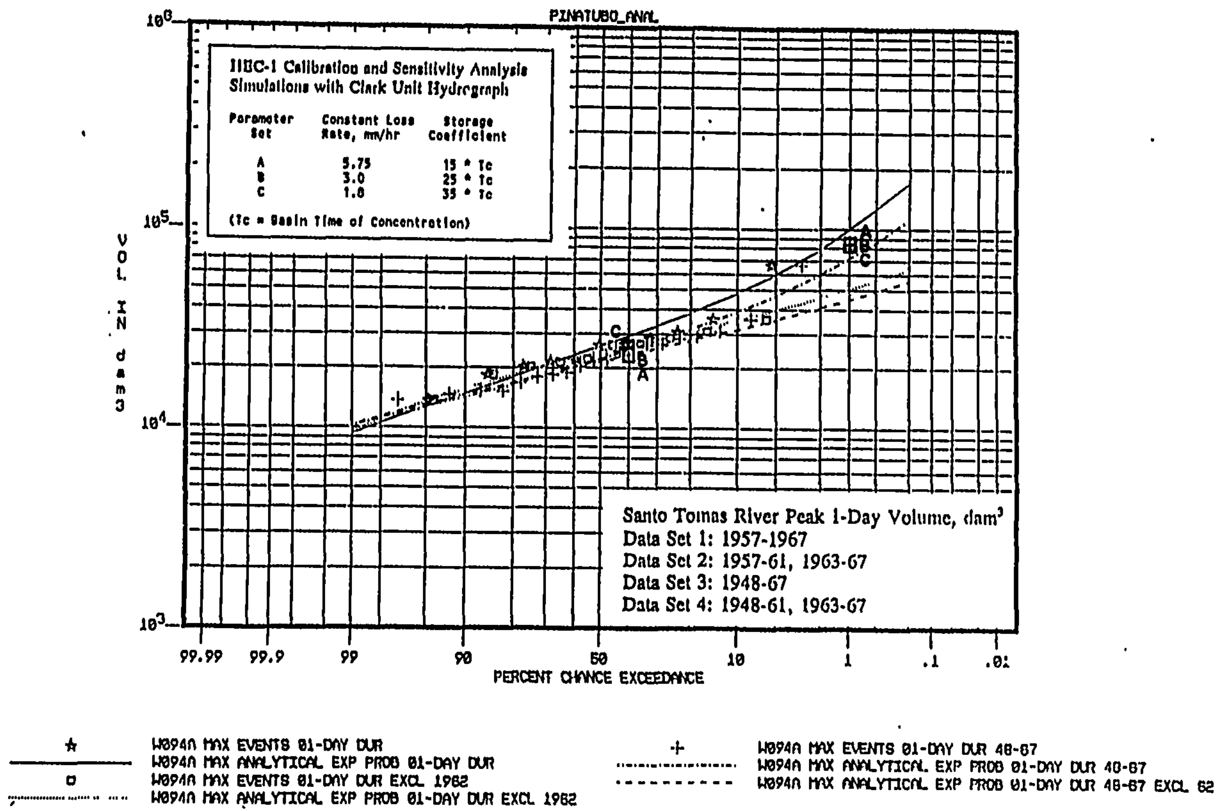

PINATUBO_ANAL
HEC-1 Calibration and Sensitivity Analysis Simulations with Clark Unit Hydrograph
Parameter Set
Constant Loss Rate, mm/hr
Storage Coefficient
A 5.75 15 * Tc
B 3.0 25 * Tc
C 1.8 35 * Tc
(Tc = Basin Time of Concentration)
Santo Tomas River Peak 1-Day Volume, dam³
Data Set 1: 1957-1967
Data Set 2: 1957-61, 1963-67
Data Set 3: 1948-67
Data Set 4: 1948-61, 1963-67
VOL IN dam3
10⁶
10⁵
10⁴
10³
99.99
99.9
99
90
50
10
1
.1
.01
PERCENT CHANCE EXCEEDANCE
W094A MAX EVENTS 01-DAY DUR
W094A MAX ANALYTICAL EXP PROB 01-DAY DUR
W094A MAX EVENTS 01-DAY DUR EXCL 1962
W094A MAX ANALYTICAL EXP PROB 01-DAY DUR EXCL 1962
W094A MAX EVENTS 01-DAY DUR 48-67
W094A MAX ANALYTICAL EXP PROB 01-DAY DUR 48-67
W094A MAX ANALYTICAL EXP PROB 01-DAY DUR 48-67 EXCL 62

Figure 3.2.12

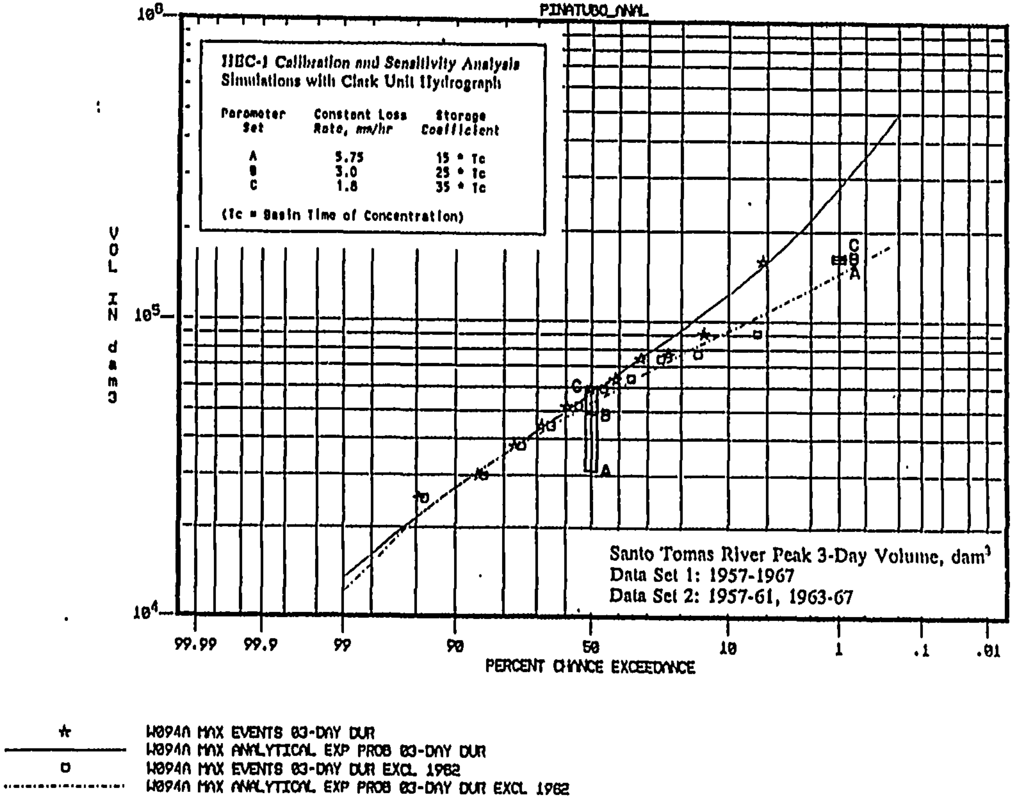

PINATUBO_ANAL
HEC-1 Calibration and Sensitivity Analysis
Simulations with Clark Unit Hydrograph
Parameter Set
Constant Loss Rate, mm/hr
Storage Coefficient
A 5.75 15 * Tc
B 3.0 25 * Tc
C 1.8 35 * Tc
(Tc = Basin Time of Concentration)
Santo Tomas River Peak 3-Day Volume, dam³
Data Set 1: 1957-1967
Data Set 2: 1957-61, 1963-67
VOL IN dam3
10^6
10^5
10^4
99.99
99.9
99
90
50
10
1
.1
.01
PERCENT CHANCE EXCEEDANCE
W094A MAX EVENTS 03-DAY DUR
W094A MAX ANALYTICAL EXP PROB 03-DAY DUR
W094A MAX EVENTS 03-DAY DUR EXCL 1962
W094A MAX ANALYTICAL EXP PROB 03-DAY DUR EXCL 1962

Figure 3.2.13

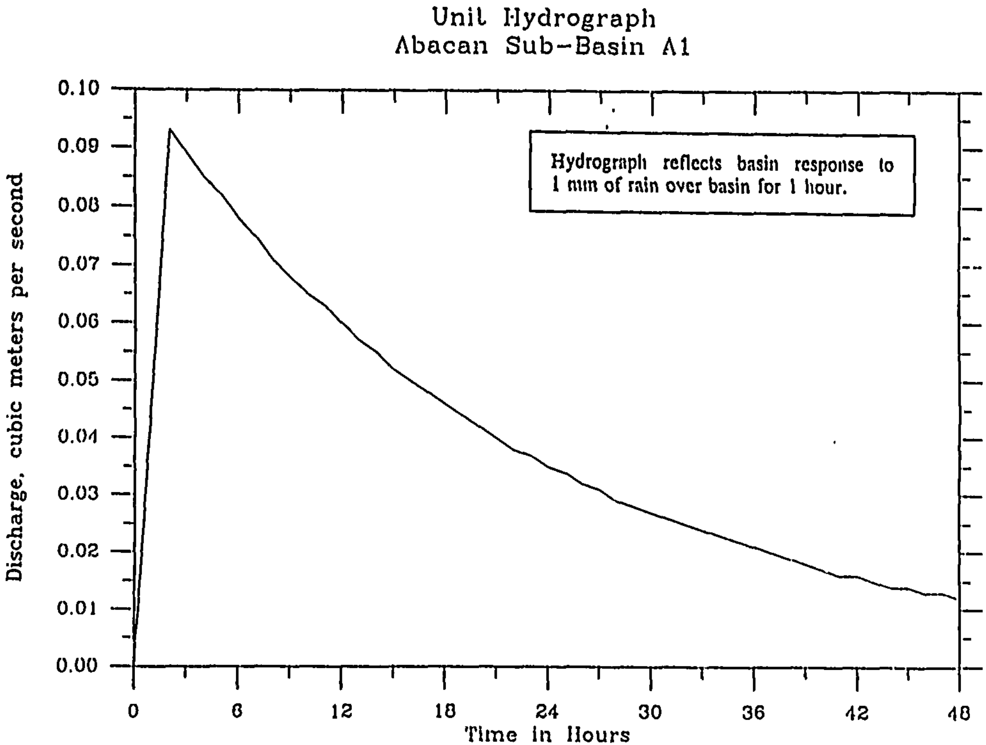

Unil Hydrograph
Abacan Sub-Basin A1
Hydrograph reflects basin response to
1 mm of rain over basin for 1 hour.
Discharge, cubic meters per second
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
0
6
12
18
24
30
36
42
48
Time in Hours

Figure 3.5.1

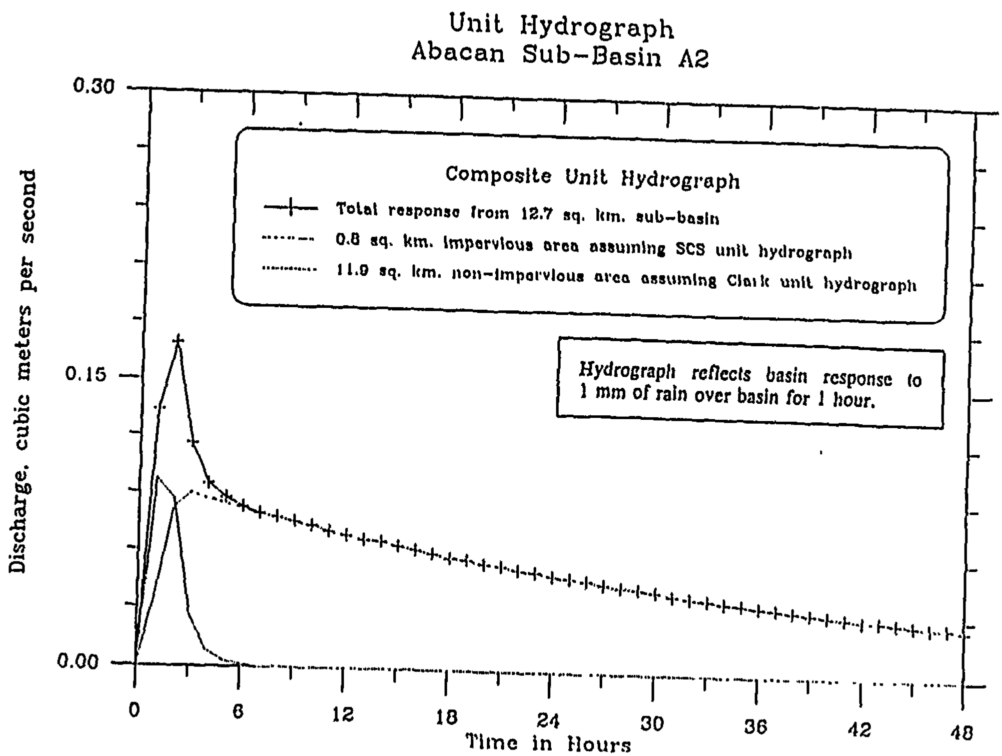

Unit Hydrograph
Abacan Sub-Basin A2
Composite Unit Hydrograph
Total response from 12.7 sq. km. sub-basin
0.8 sq. km. impervious area assuming SCS unit hydrograph
11.9 sq. km. non-impervious area assuming Clark unit hydrograph
Hydrograph reflects basin response to 1 mm of rain over basin for 1 hour.
Discharge, cubic meters per second
0.30
0.15
0.00
0
6
12
18
24
30
36
42
48
Time in Hours

Figure 3.5.2

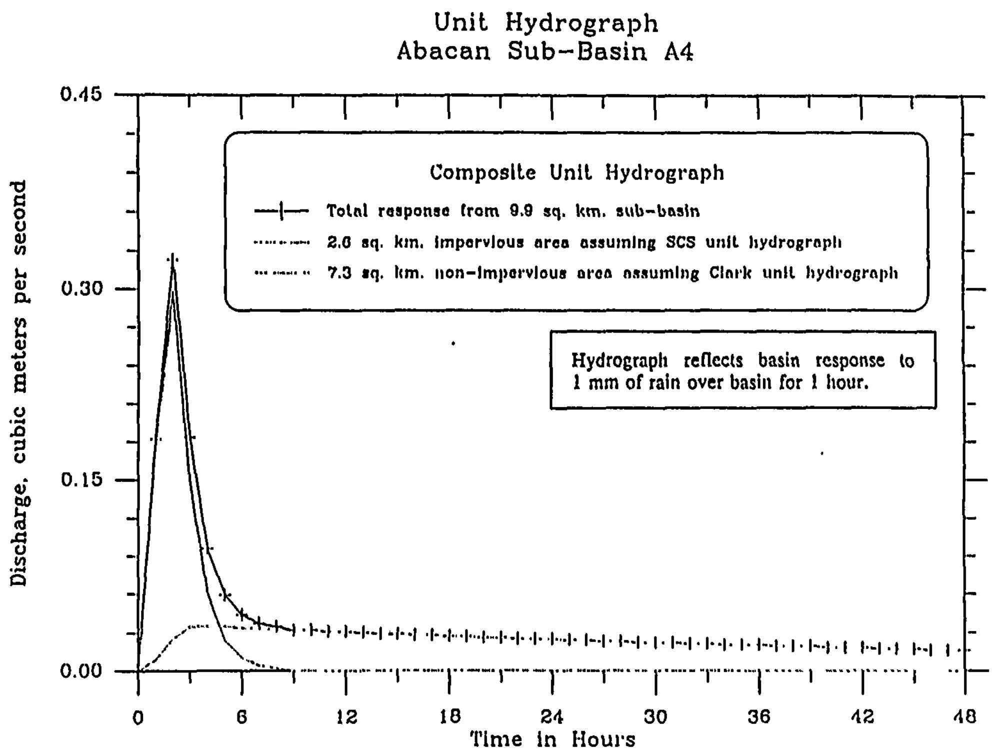
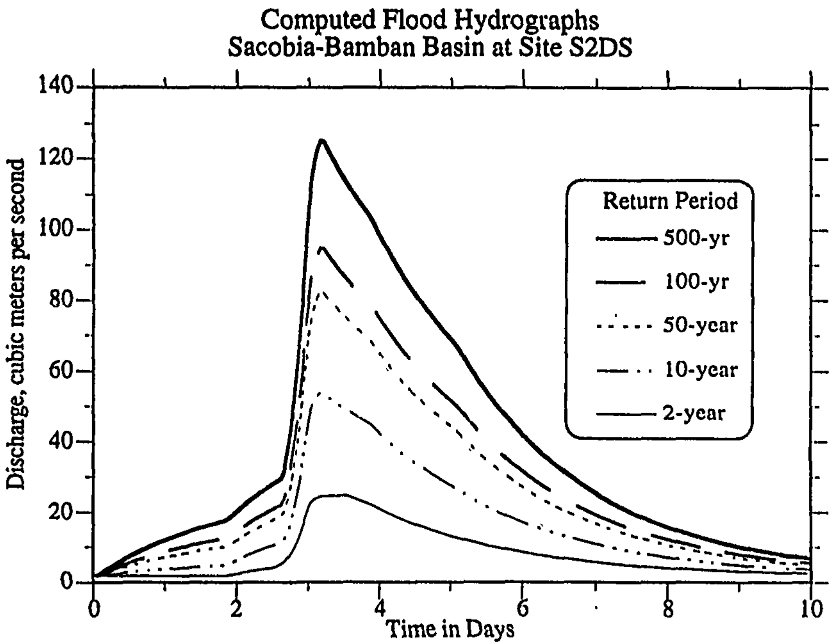

Unit Hydrograph
Abacan Sub-Basin A4
Composite Unit Hydrograph
Total response from 9.9 sq. km. sub-basin
2.6 sq. km. impervious area assuming SCS unit hydrograph
7.3 sq. km. non-impervious area assuming Clark unit hydrograph
Hydrograph reflects basin response to 1 mm of rain over basin for 1 hour.
Discharge, cubic meters per second
0.45
0.30
0.15
0.00
0
6
12
18
24
30
36
42
48
Time in Hours

Figure 3.5.3



Computed Flood Hydrographs
Sacobia-Bamban Basin at Site S2DS
Discharge, cubic meters per second
Time in Days
Return Period
500-yr
100-yr
50-year
10-year
2-year
0
20
40
60
80
100
120
140
0
2
4
6
8
10

Figure 3.5.5

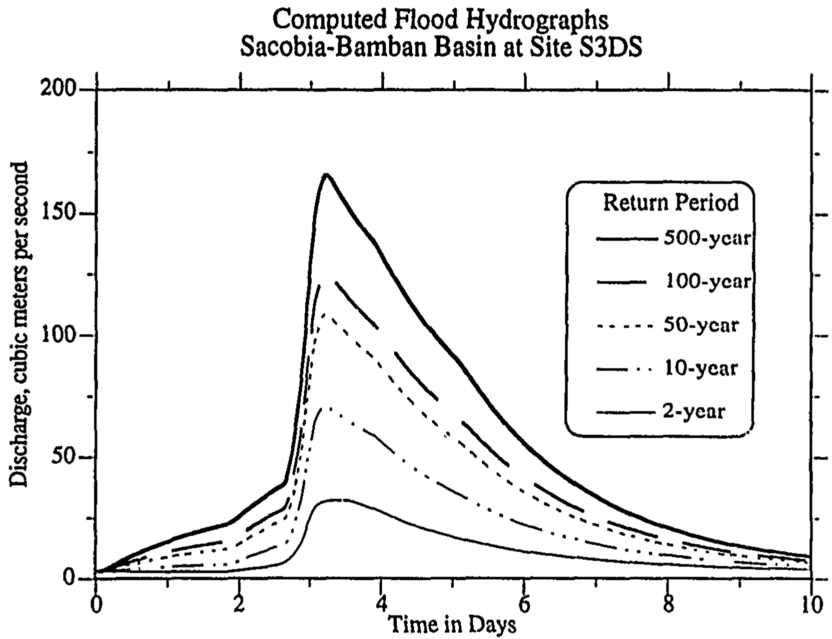

Computed Flood Hydrographs
Sacobia-Bamban Basin at Site S3DS
Discharge, cubic meters per second
200
150
100
50
0
0
2
4
6
8
10
Time in Days
Return Period
500-year
100-year
50-year
10-year
2-year

Figure 3.5.6

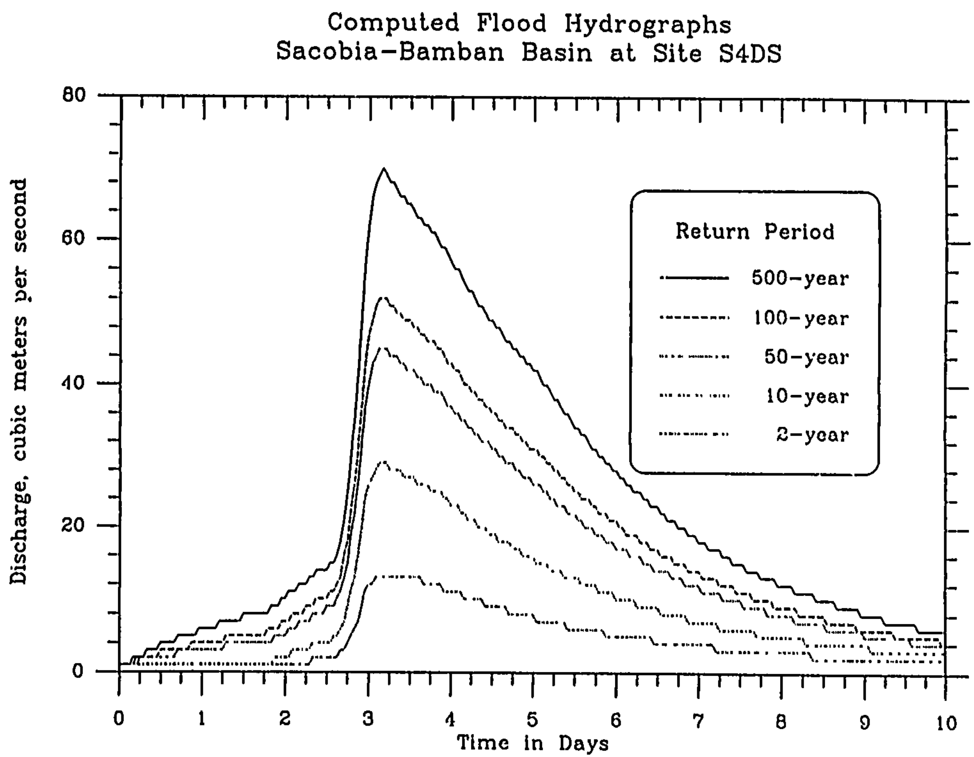

Computed Flood Hydrographs
Sacobia-Bamban Basin at Site S4DS
Discharge, cubic meters per second
0
20
40
60
80
Time in Days
0
1
2
3
4
5
6
7
8
9
10
Return Period
500-year
100-year
50-year
10-year
2-year

Figure 3.5.7

Computed Flood Hydrographs
Site S3DS and S4DS Hydrographs Combined
Sacobia-Bamban Basin

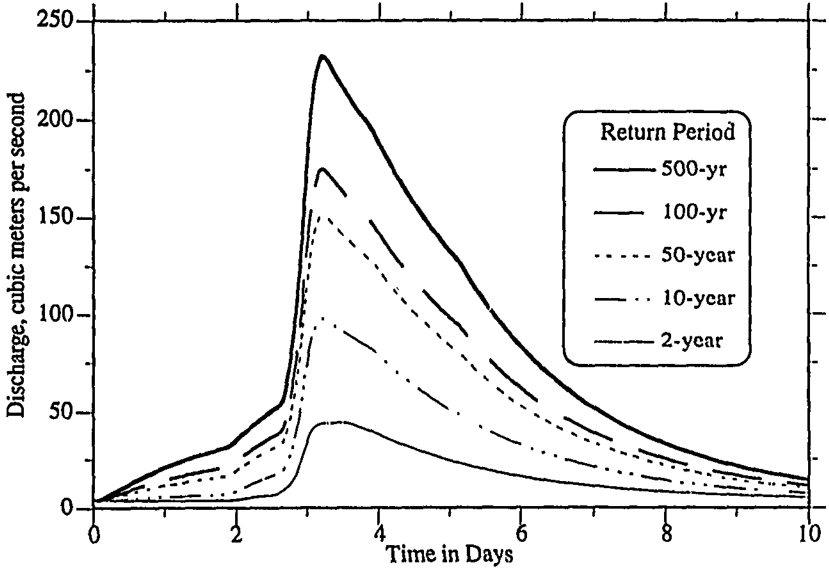


Figure 3.5.8

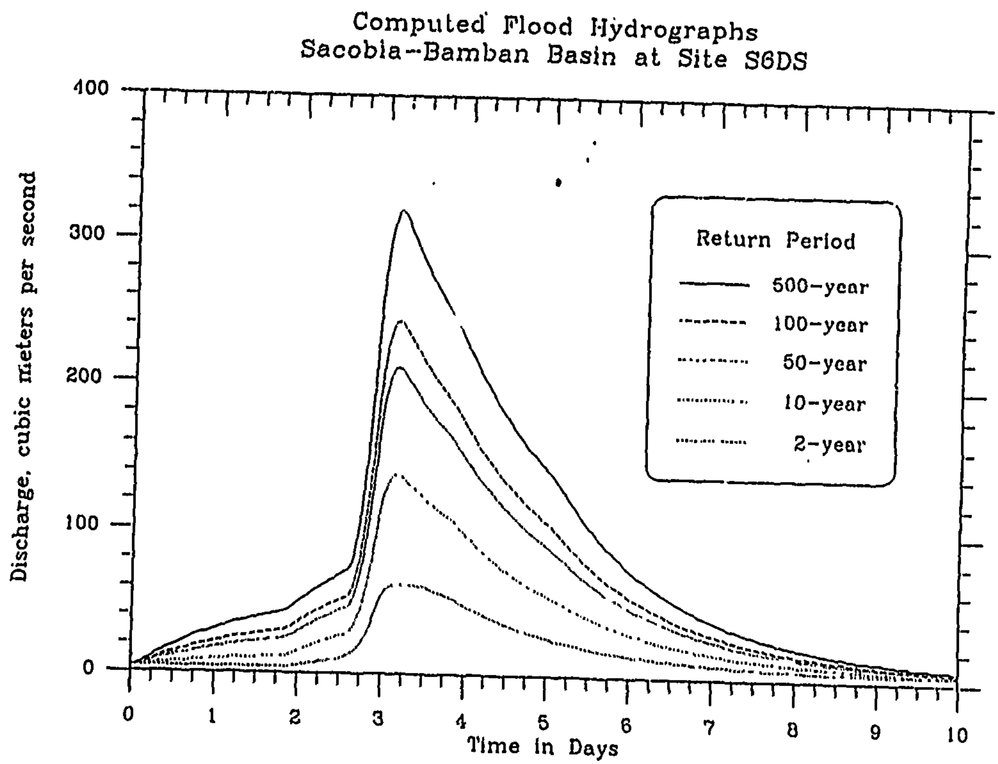

Computed Flood Hydrographs
Sacobia--Bamban Basin at Site S6DS
Discharge, cubic meters per second
400
300
200
100
0
Time in Days
0
1
2
3
4
5
6
7
8
9
10
Return Period
500-year
100-year
50-year
10-year
2-year

Figure 3.5.9

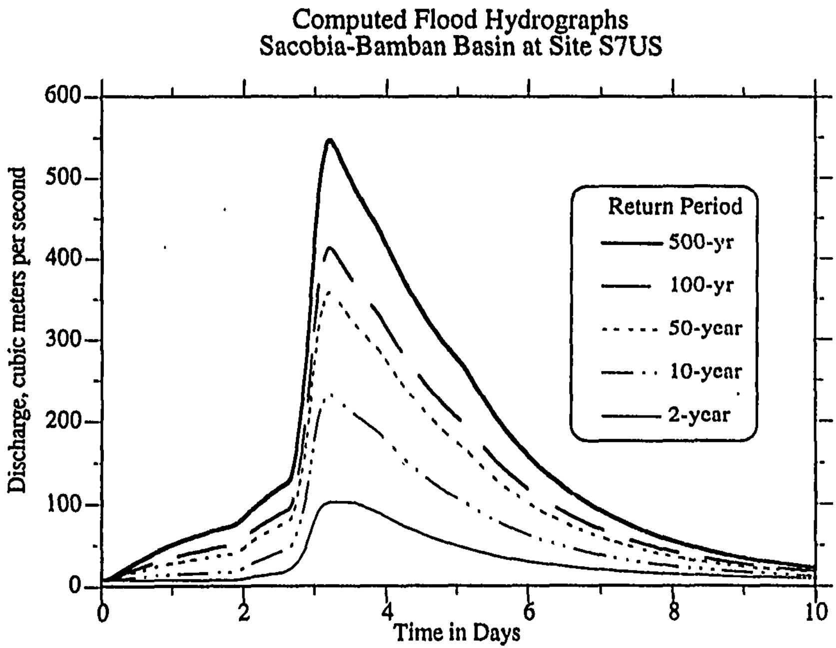

Computed Flood Hydrographs
Sacobia-Bamban Basin at Site S7US
Discharge, cubic meters per second
0
100
200
300
400
500
600
Time in Days
0
2
4
6
8
10
Return Period
500-yr
100-yr
50-year
10-year
2-year

Figure 3.5.10

Computed Flood Hydrographs
Sacobia-Bamban Basin at Site S7DS

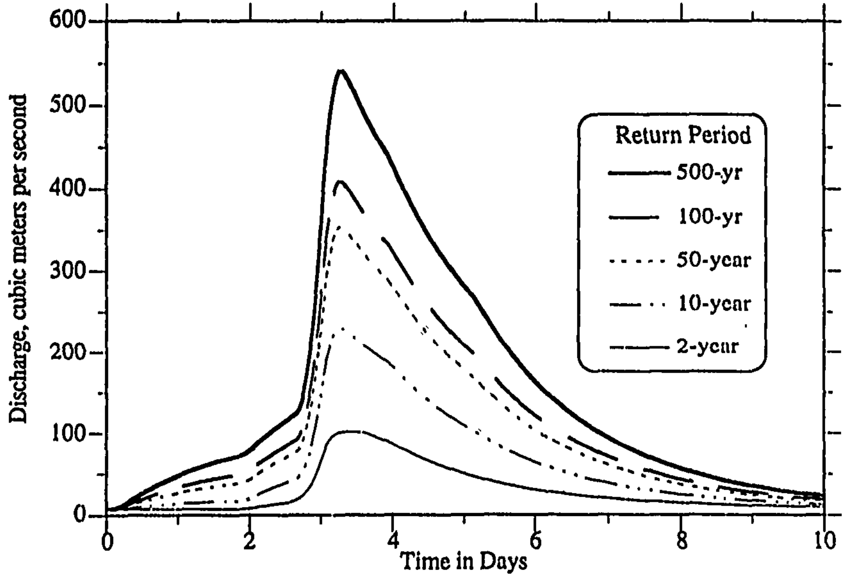


Figure 3.5.11

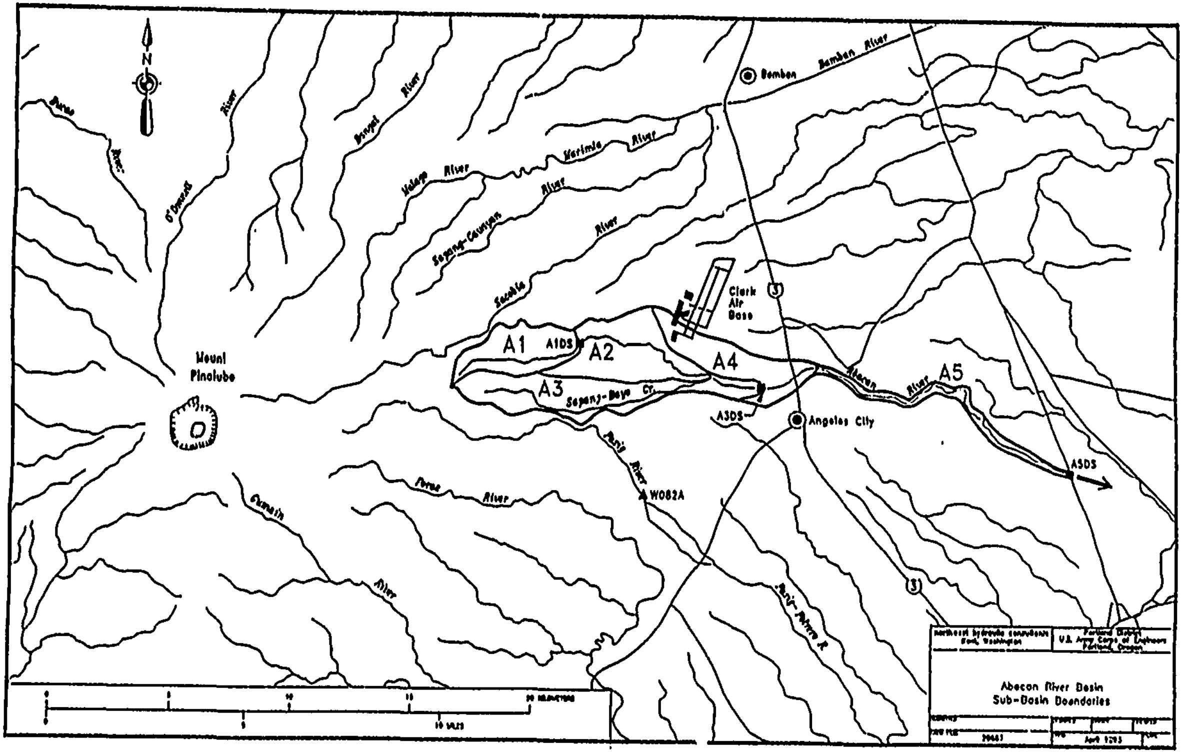

N
Mount
Pinatubo
Bamban
Bamban River
Sacobia
River
A1
A1DS
A2
A3
A4
A5
Sapang-Bayo Cr.
Clark
Air
Base
A3DS
Angeles City
A5DS
W082A
Abacan River Basin
Sub-Basin Boundaries

Figure 3.5.12

Computed Flood Hydrographs
Abacan Basin at Site A1DS

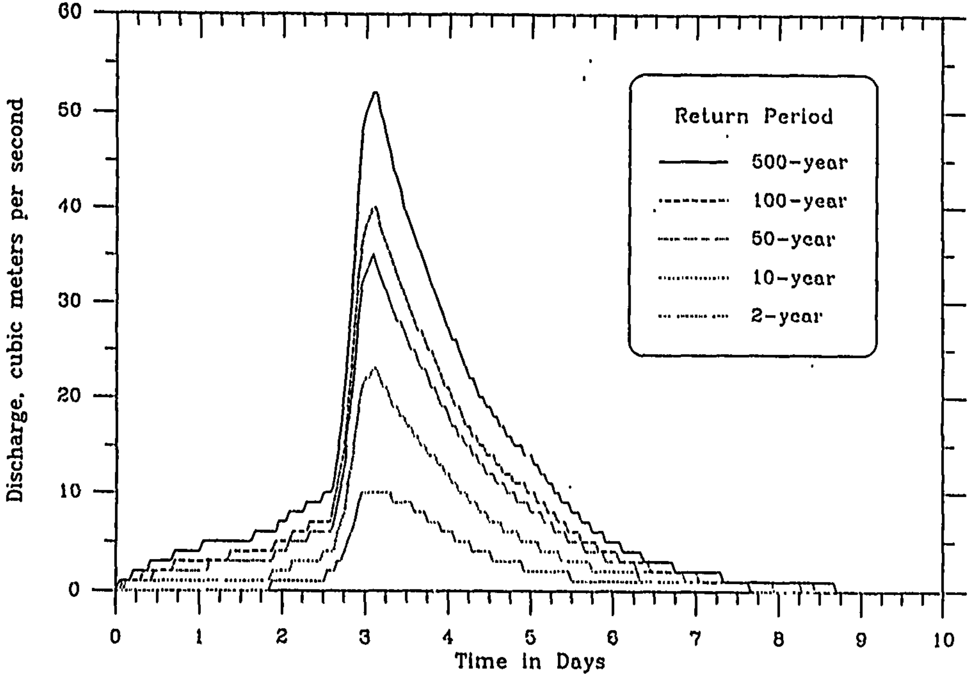
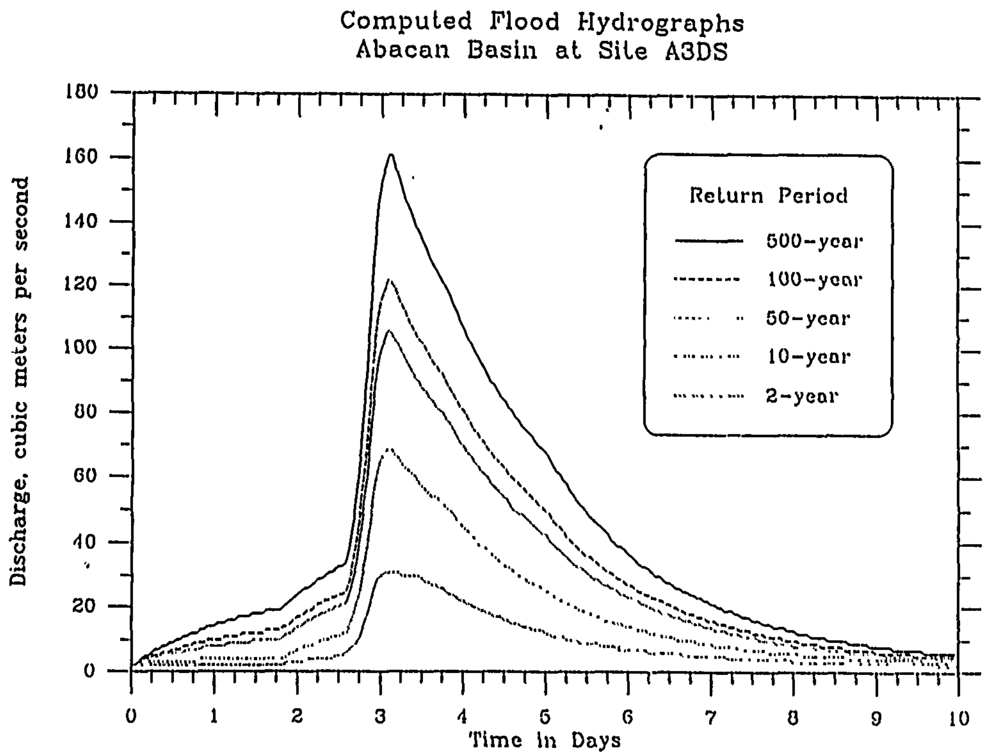


Figure 3.5.13



Computed Flood Hydrographs
Abacan Basin at Site A3DS
Return Period
500-year
100-year
50-year
10-year
2-year
Discharge, cubic meters per second
0
20
40
60
80
100
120
140
160
180
Time in Days
0
1
2
3
4
5
6
7
8
9
10

Figure 3.5.14

Computed Flood Hydrographs
Abacan Basin at Site A5DS

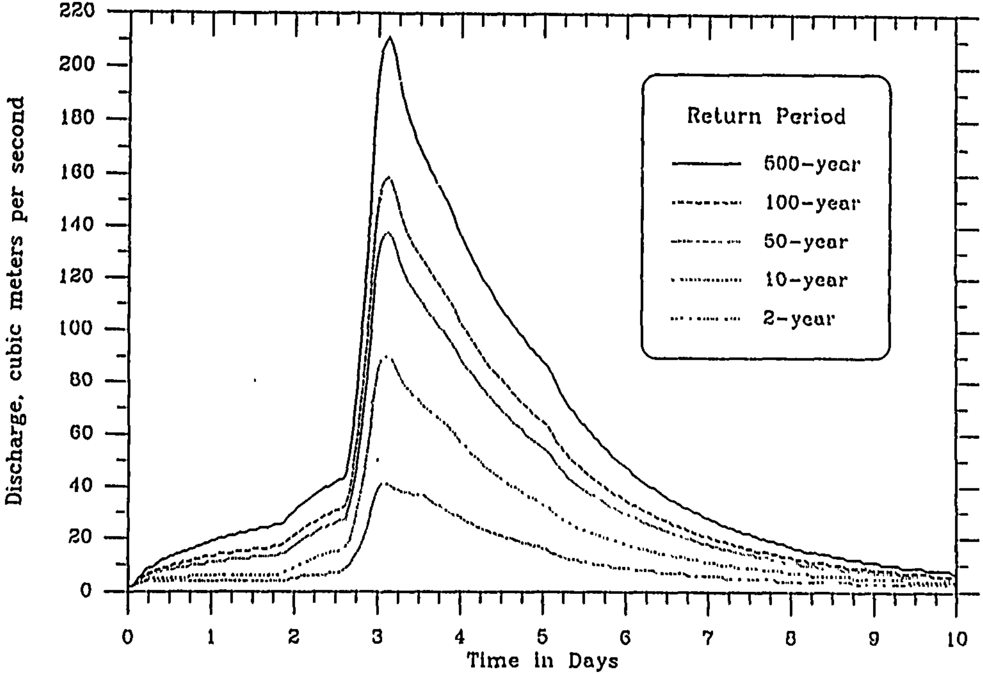


Figure 3.5.15

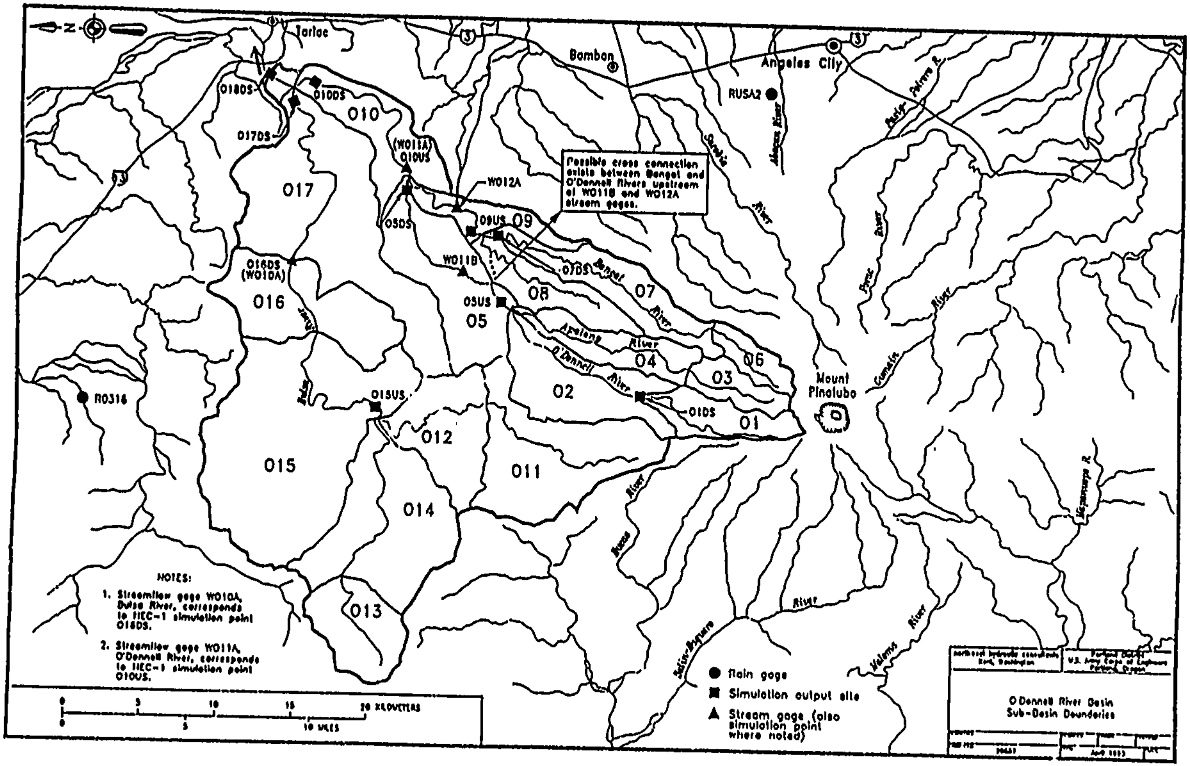
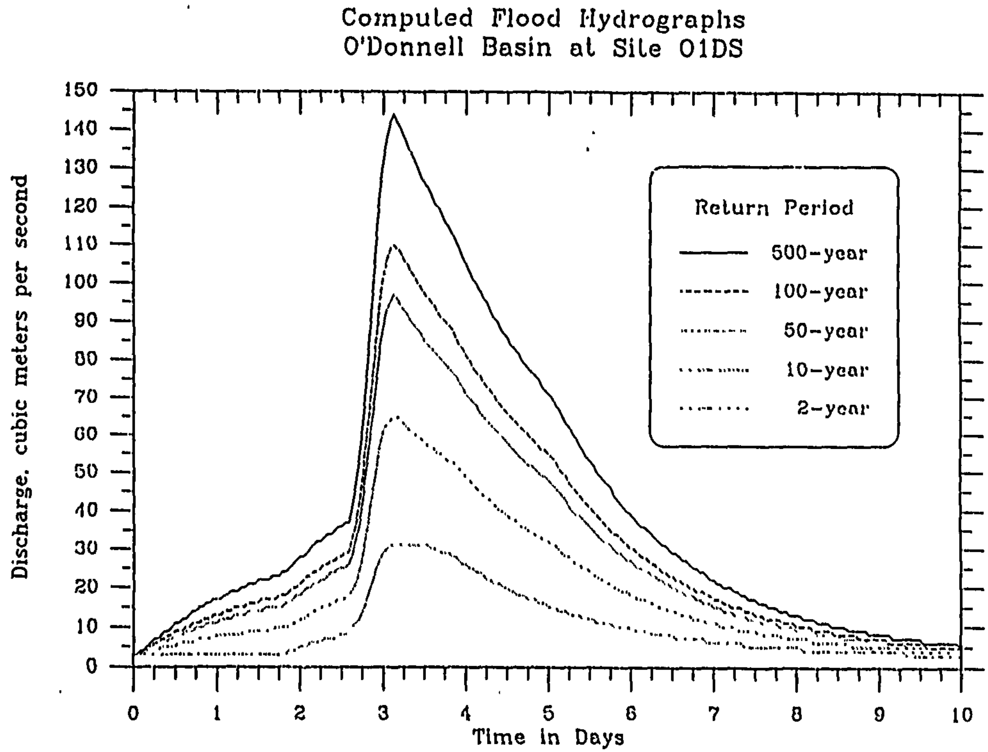

Tarlac
Bombon
Angeles City
RUSA2
Mount Pinatubo
Possible cross connection exists between Bangat and O'Donnell Rivers upstream of WO11B and WO12A stream gages.
O18DS
O10DS
O17DS
O10
(WO11A) O10US
WO12A
O9US
O9
O5DS
WO11B
O7DS
O8
O7
O5US
O5
O4
O3
O6
O2
O1DS
O1
O17
O16DS (WO10A)
O16
O15US
O15
O12
O11
O14
O13
RO316
NOTES:
1. Streamflow gage WO10A, Bulsa River, corresponds to HEC-1 simulation point O16DS.
2. Streamflow gage WO11A, O'Donnell River, corresponds to HEC-1 simulation point O10US.
Rain gage
Simulation output site
Stream gage (also simulation point where noted)
O'Donnell River Basin Sub-Basin Boundaries

Figure 3.5.16



Computed Flood Hydrographs
O'Donnell Basin at Site 01DS
Discharge, cubic meters per second
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
0
1
2
3
4
5
6
7
8
9
10
Time in Days
Return Period
500-year
100-year
50-year
10-year
2-year

Figure 3.5.17

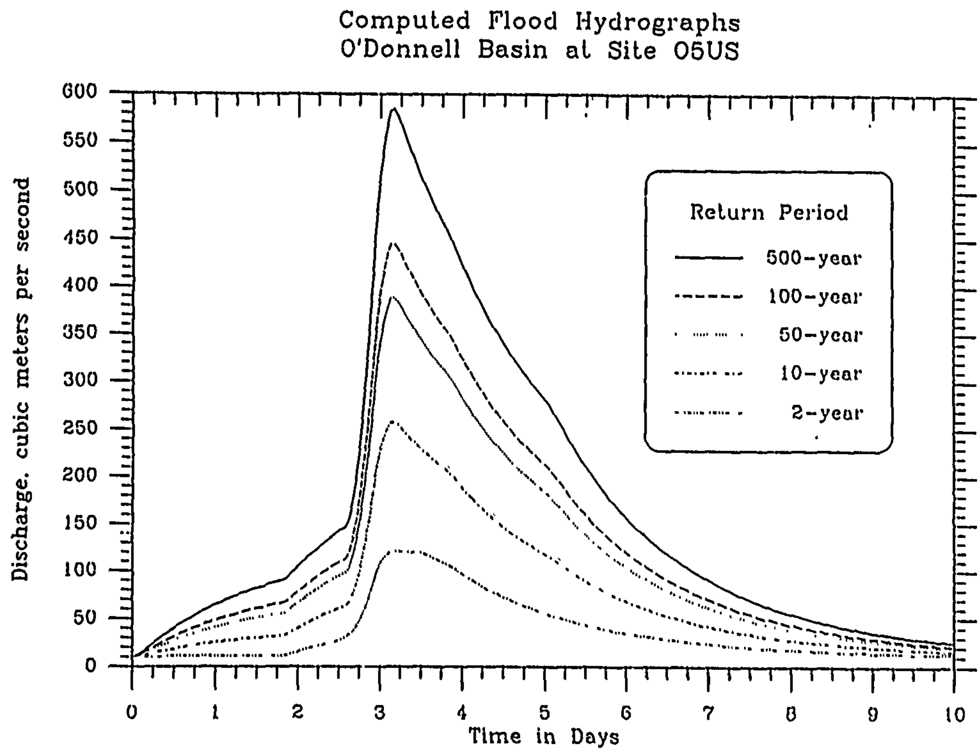

Computed Flood Hydrographs
O'Donnell Basin at Site O5US
Discharge, cubic meters per second
600
550
500
450
400
350
300
250
200
150
100
50
0
0
1
2
3
4
5
6
7
8
9
10
Time in Days
Return Period
500-year
100-year
50-year
10-year
2-year

Figure 3.5.18

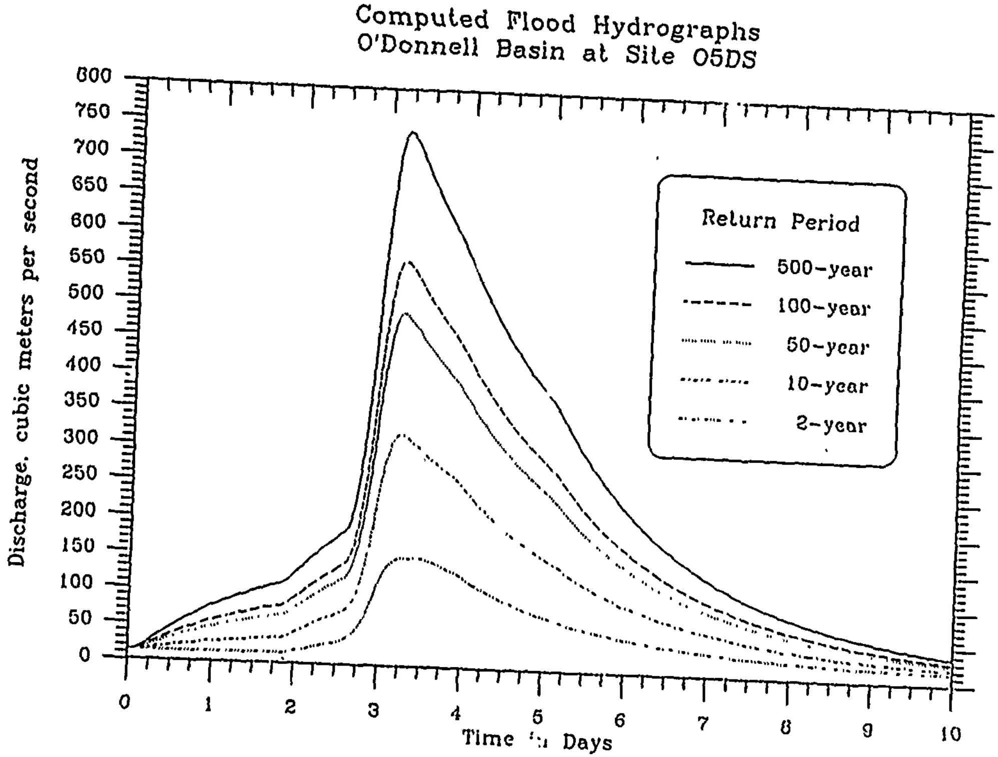

Computed Flood Hydrographs
O'Donnell Basin at Site O5DS
Discharge, cubic meters per second
800
750
700
650
600
550
500
450
400
350
300
250
200
150
100
50
0
Return Period
500-year
100-year
50-year
10-year
2-year
0
1
2
3
4
5
6
7
8
9
10
Days

Figure 3.5.19

Computed Flood Hydrographs
O'Donnell Basin at Site 07DS

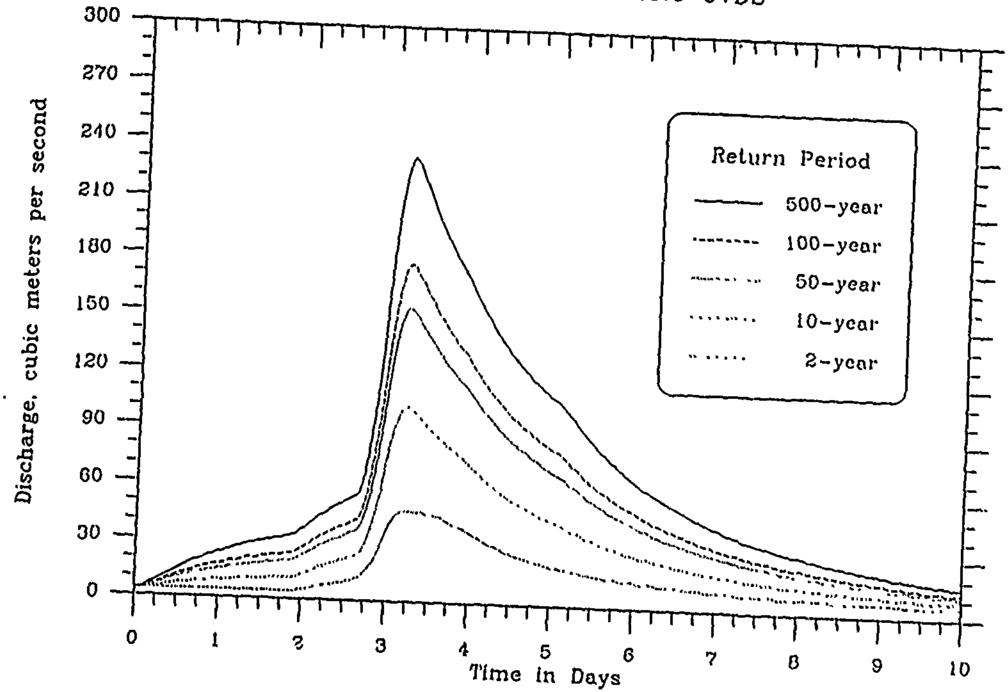


Figure 3.5.20

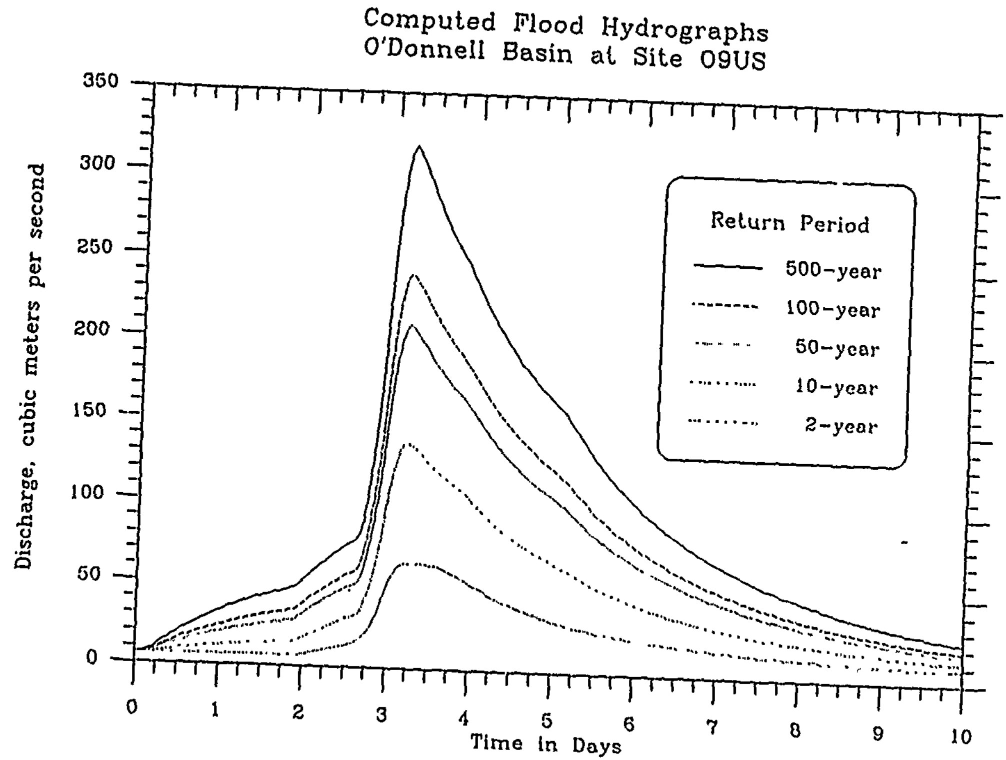
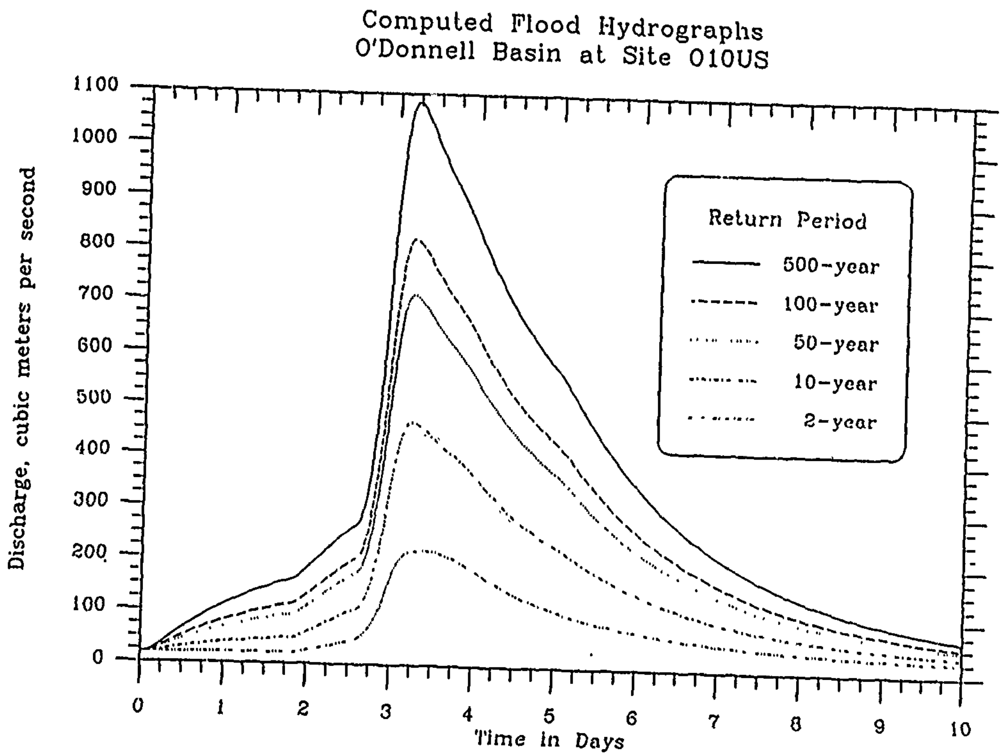

Computed Flood Hydrographs
O'Donnell Basin at Site 09US
Discharge, cubic meters per second
350
300
250
200
150
100
50
0
0
1
2
3
4
5
6
7
8
9
10
Time in Days
Return Period
500-year
100-year
50-year
10-year
2-year

Figure 3.5.21



Computed Flood Hydrographs
O'Donnell Basin at Site 010US
Discharge, cubic meters per second
0
100
200
300
400
500
600
700
800
900
1000
1100
Time in Days
0
1
2
3
4
5
6
7
8
9
10
Return Period
500-year
100-year
50-year
10-year
2-year

Figure 3.5.22

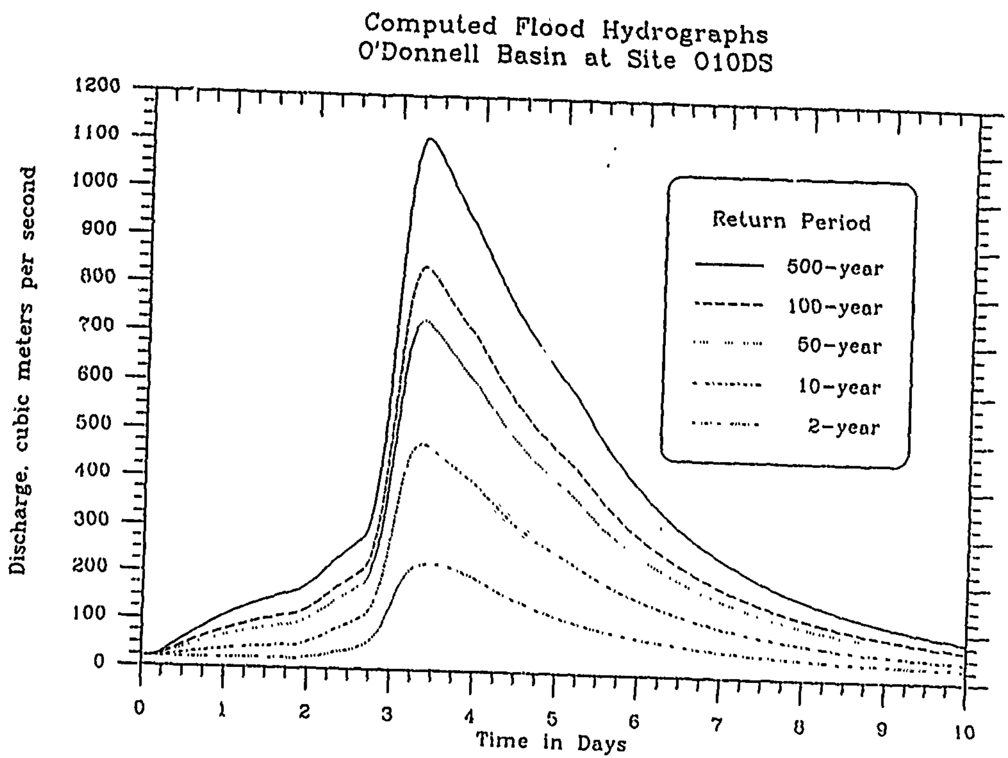

Computed Flood Hydrographs
O'Donnell Basin at Site 010DS
Discharge, cubic meters per second
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
0
1
2
3
4
5
6
7
8
9
10
Time in Days
Return Period
500-year
100-year
50-year
10-year
2-year

Figure 3.5.23

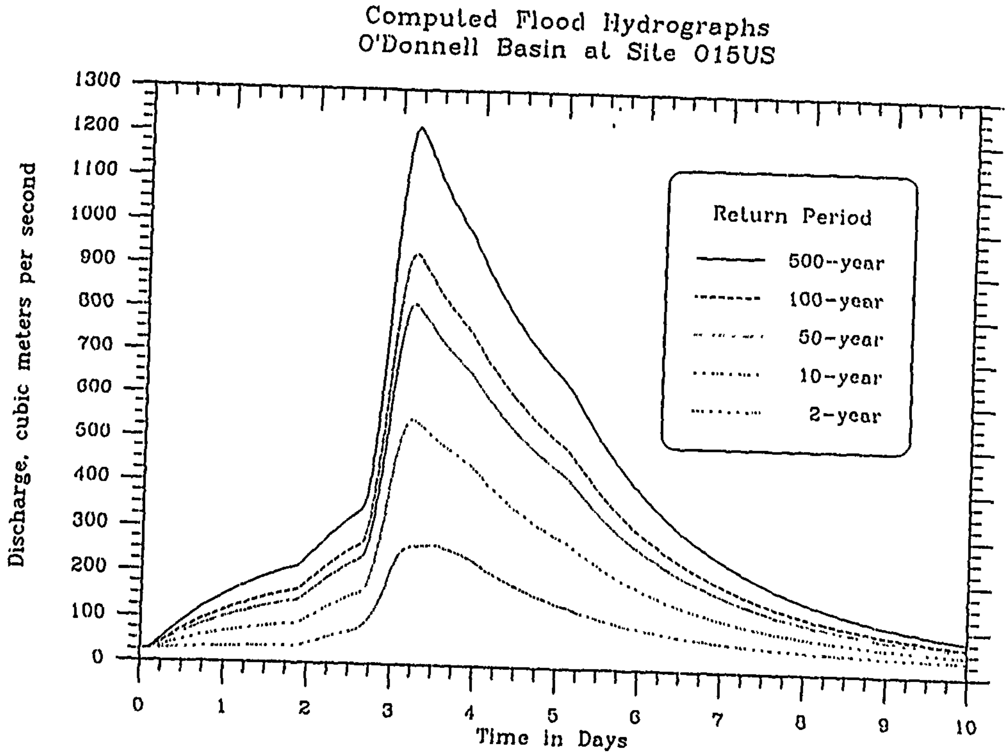

Computed Flood Hydrographs
O'Donnell Basin at Site 015US
Discharge, cubic meters per second
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
0
1
2
3
4
5
6
7
8
9
10
Time in Days
Return Period
500-year
100-year
50-year
10-year
2-year

Figure 3.5.24

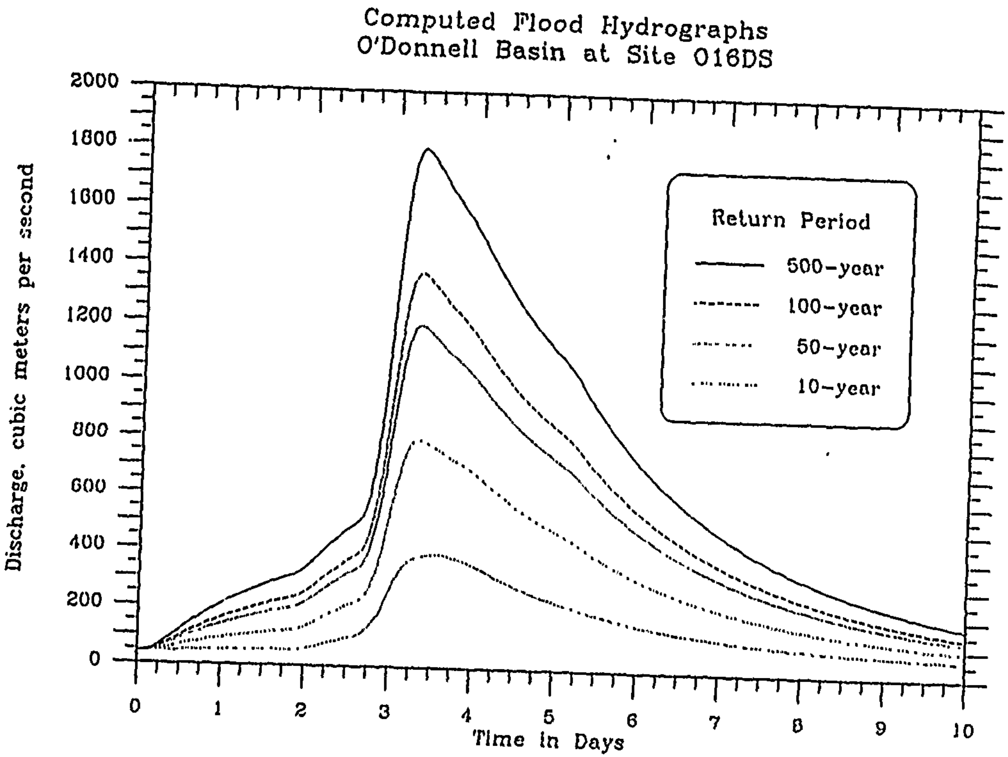

Computed Flood Hydrographs
O'Donnell Basin at Site 016DS
Discharge, cubic meters per second
2000
1800
1600
1400
1200
1000
800
600
400
200
0
Time in Days
0
1
2
3
4
5
6
7
8
9
10
Return Period
500-year
100-year
50-year
10-year

Figure 3.5.25

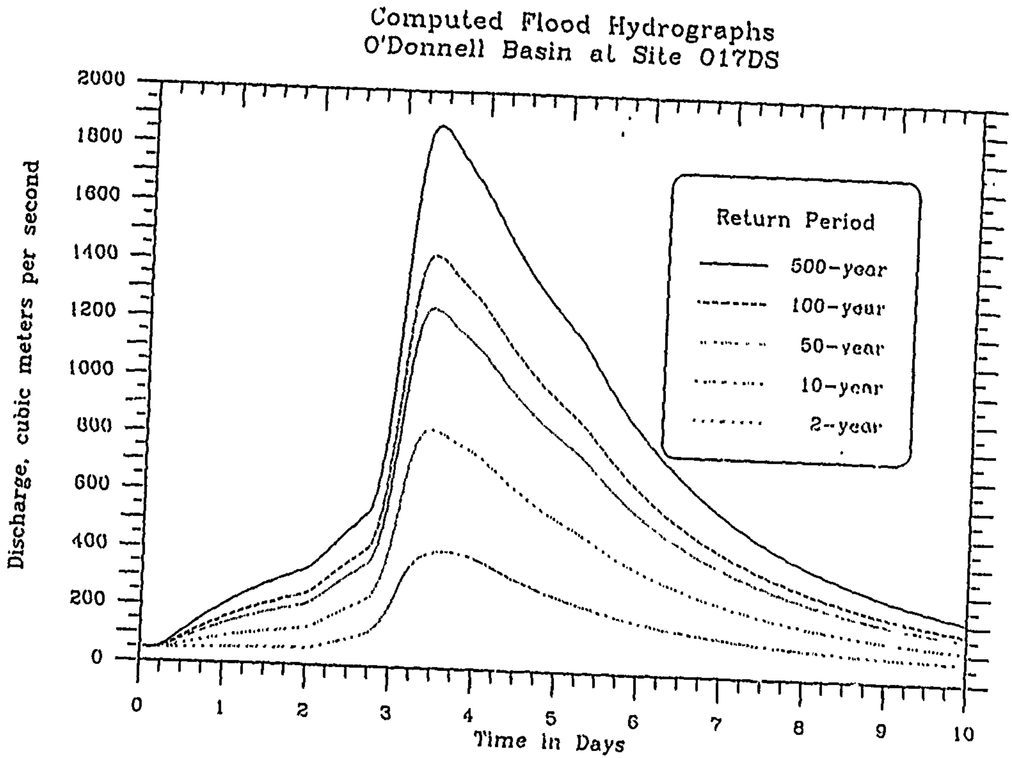

Computed Flood Hydrographs
O'Donnell Basin al Site 017DS
Discharge, cubic meters per second
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0
1
2
3
4
5
6
7
8
9
10
Time in Days
Return Period
500-year
100-year
50-year
10-year
2-year

Figure 3.5.26

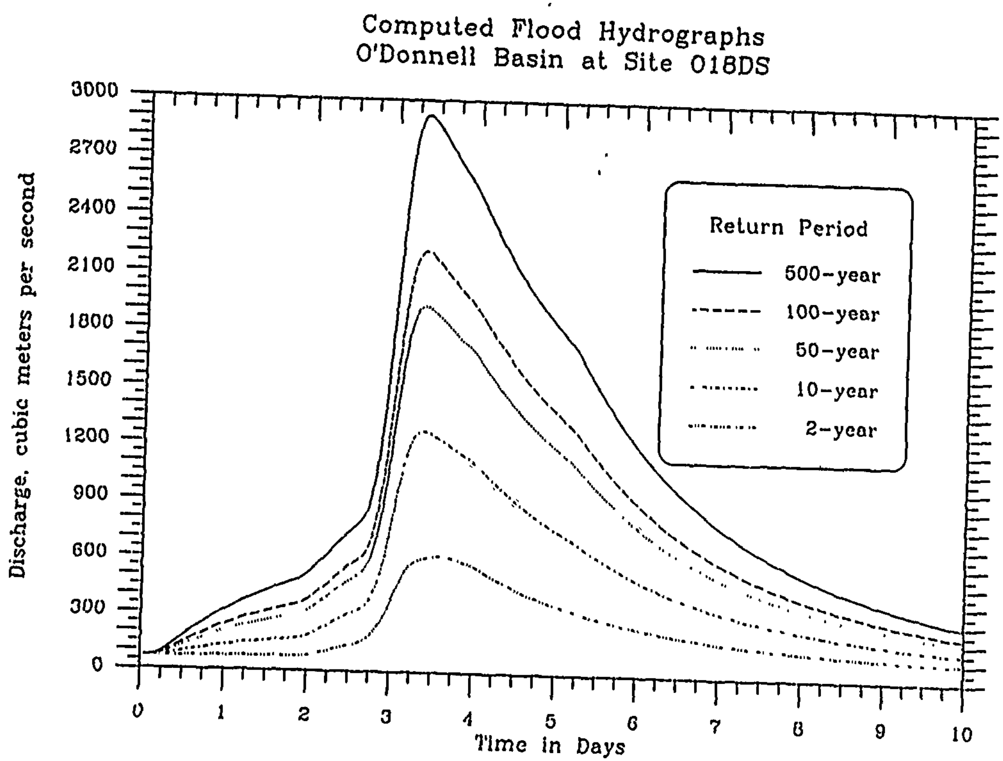

Computed Flood Hydrographs
O'Donnell Basin at Site 018DS
Discharge, cubic meters per second
3000
2700
2400
2100
1800
1500
1200
900
600
300
0
Time in Days
0
1
2
3
4
5
6
7
8
9
10
Return Period
500-year
100-year
50-year
10-year
2-year

Figure 3.5.27

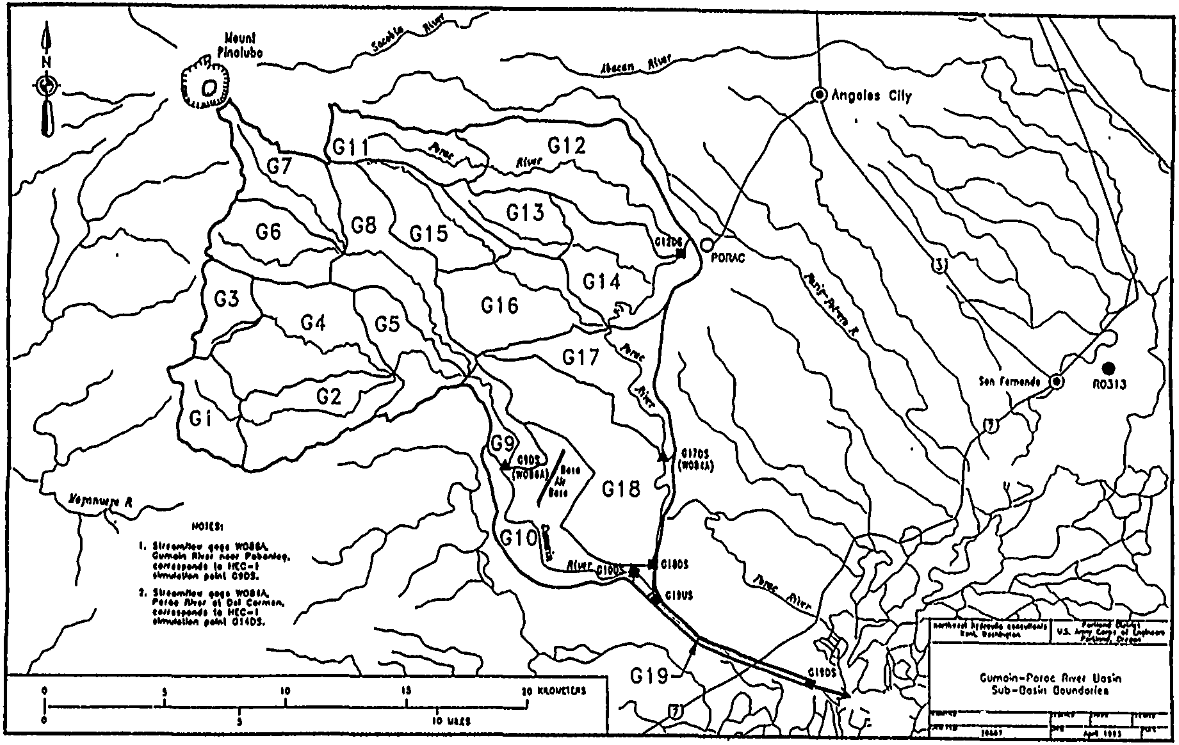

Mount Pinatubo
N
Sacobia River
Abacan River
Angeles City
PORAC
San Fernando
RO313
Porac River
Pasig-Potrero R.
G1
G2
G3
G4
G5
G6
G7
G8
G9
G10
G11
G12
G13
G14
G15
G16
G17
G18
G19
G9DS (WO86A)
Base Air Base
G12DS
G17DS (WO84A)
G18DS
G19US
G19DS
Nayanwaya R.
NOTES:
1. Streamflow gage WO86A, Gumain River near Pabanlag, corresponds to HEC-1 simulation point G9DS.
2. Streamflow gage WO84A, Porac River at Del Carmen, corresponds to HEC-1 simulation point G14DS.
0 5 10 15 20 KILOMETERS
0 5 10 MILES
Gumain-Porac River Basin
Sub-Basin Boundaries
April 1993

Figure 3.5.28

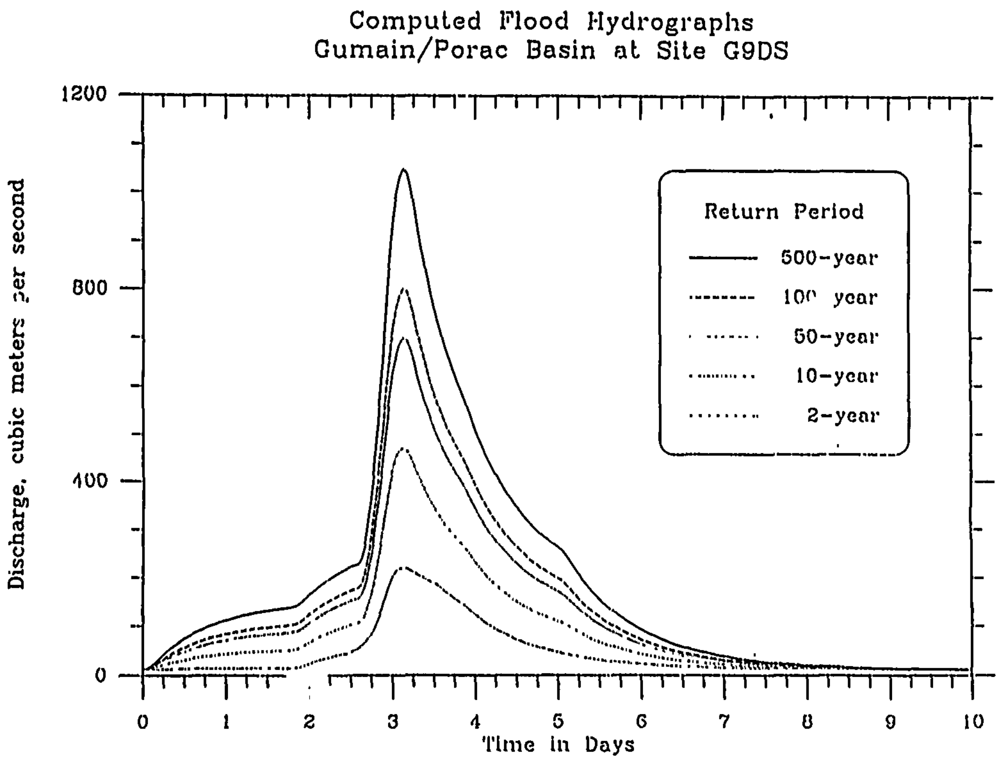
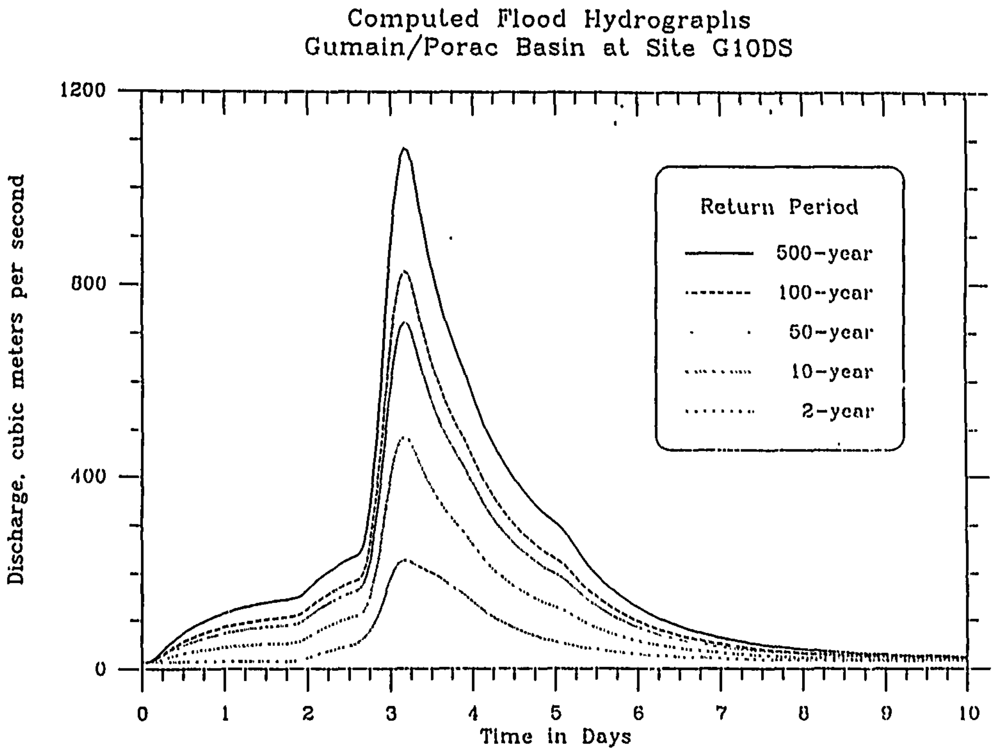

Computed Flood Hydrographs
Gumain/Porac Basin at Site G9DS
Discharge, cubic meters per second
1200
800
400
0
0
1
2
3
4
5
6
7
8
9
10
Time in Days
Return Period
500-year
10 year
50-year
10-year
2-year

Figure 3.5.29



Computed Flood Hydrographs
Gumain/Porac Basin at Site G10DS
Return Period
500-year
100-year
50-year
10-year
2-year
Discharge, cubic meters per second
1200
800
400
0
0
1
2
3
4
5
6
7
8
9
10
Time in Days

Figure 3.5.30

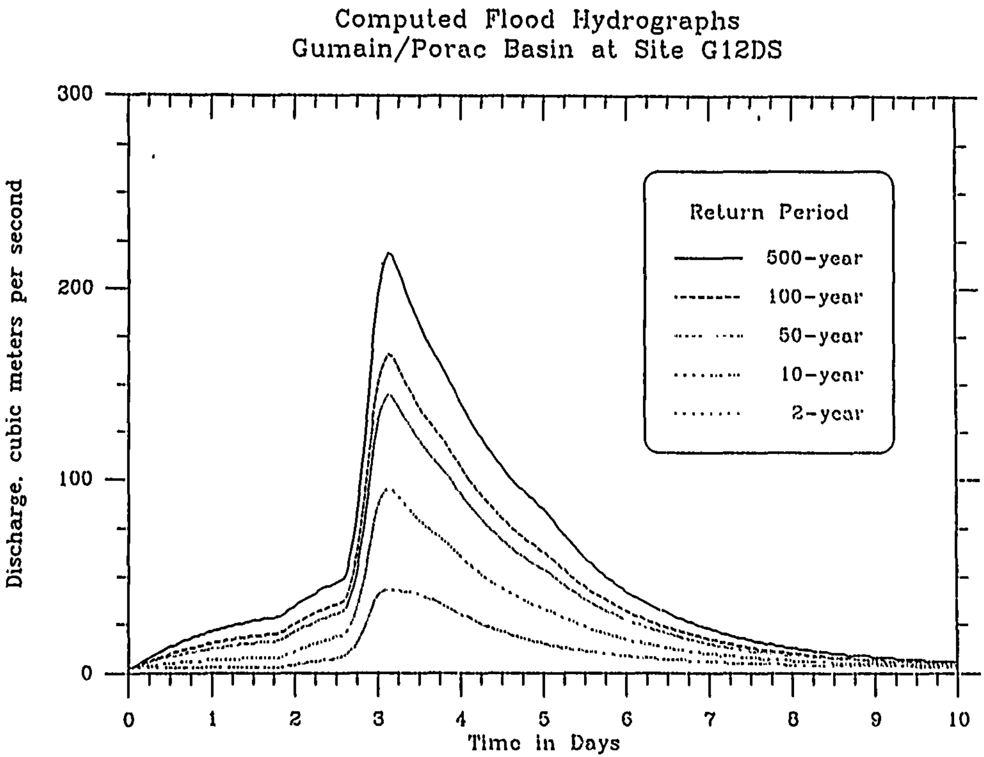

Computed Flood Hydrographs
Gumain/Porac Basin at Site G12DS
Return Period
500-year
100-year
50-year
10-year
2-year
Discharge. cubic meters per second
300
200
100
0
0
1
2
3
4
5
6
7
8
9
10
Time in Days

Figure 3.5.31

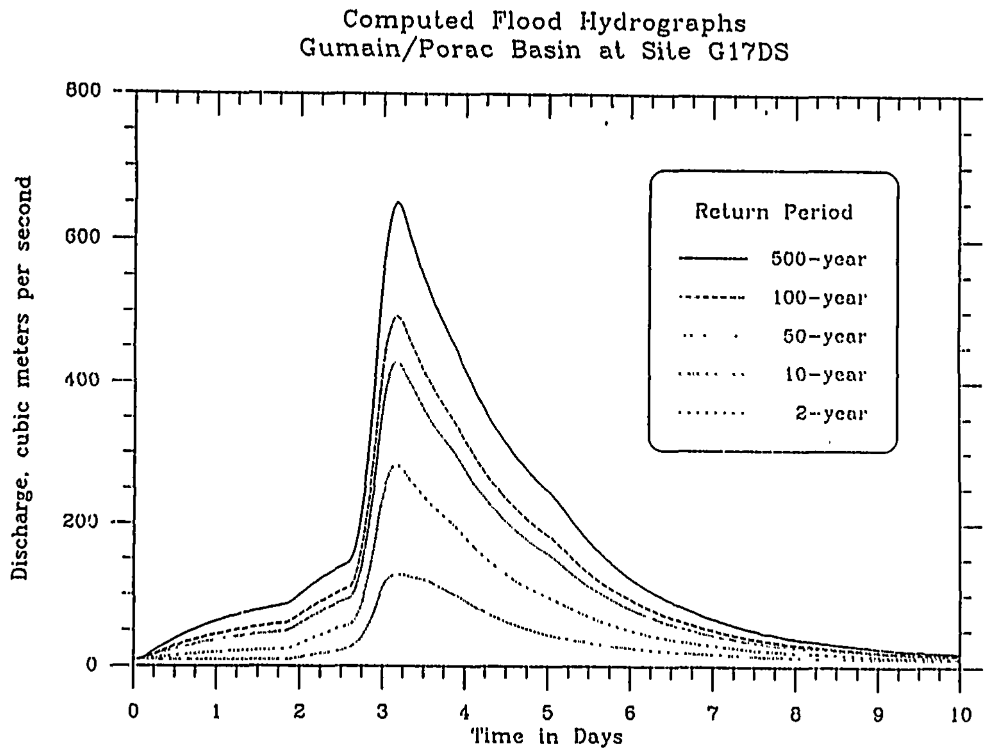
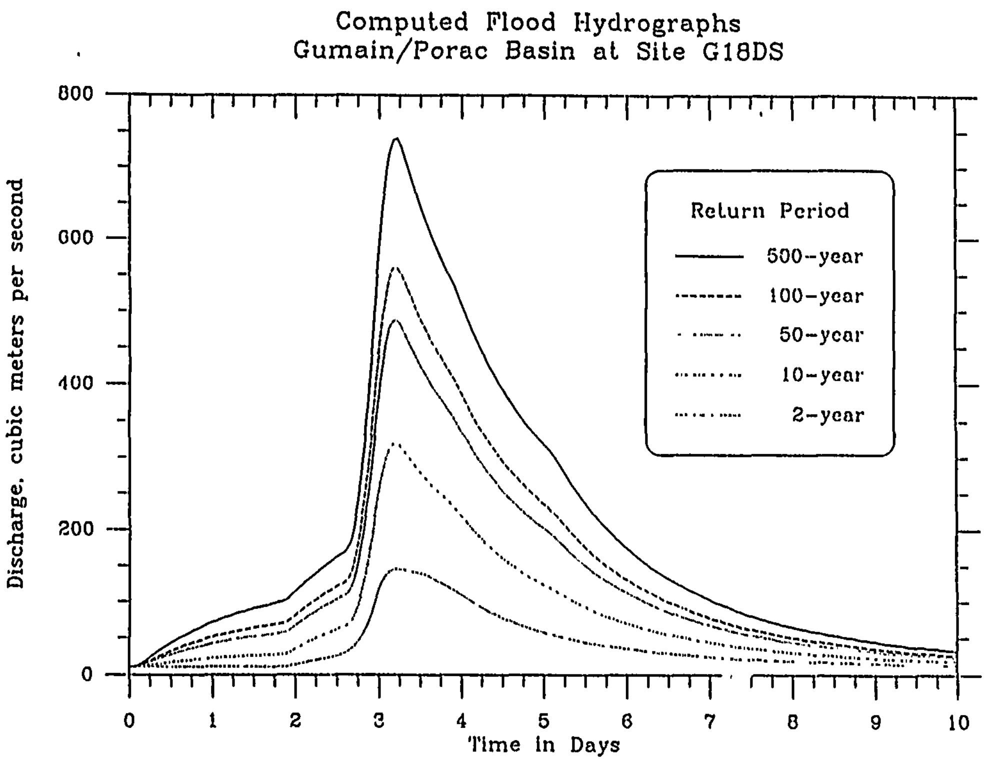

Computed Flood Hydrographs
Gumain/Porac Basin at Site G17DS
Discharge, cubic meters per second
0
200
400
600
800
0
1
2
3
4
5
6
7
8
9
10
Time in Days
Return Period
500-year
100-year
50-year
10-year
2-year

Figure 3.5.32



Computed Flood Hydrographs
Gumain/Porac Basin at Site G18DS
Discharge, cubic meters per second
0
200
400
600
800
Time in Days
0
1
2
3
4
5
6
7
8
9
10
Return Period
500-year
100-year
50-year
10-year
2-year

Figure 3.5.33

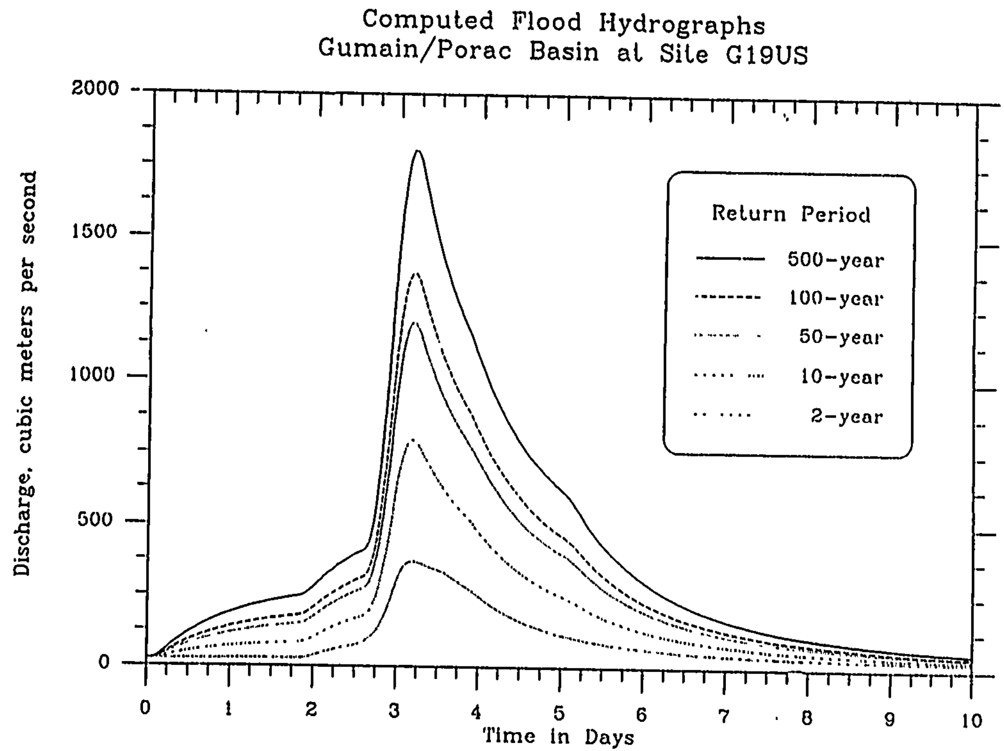
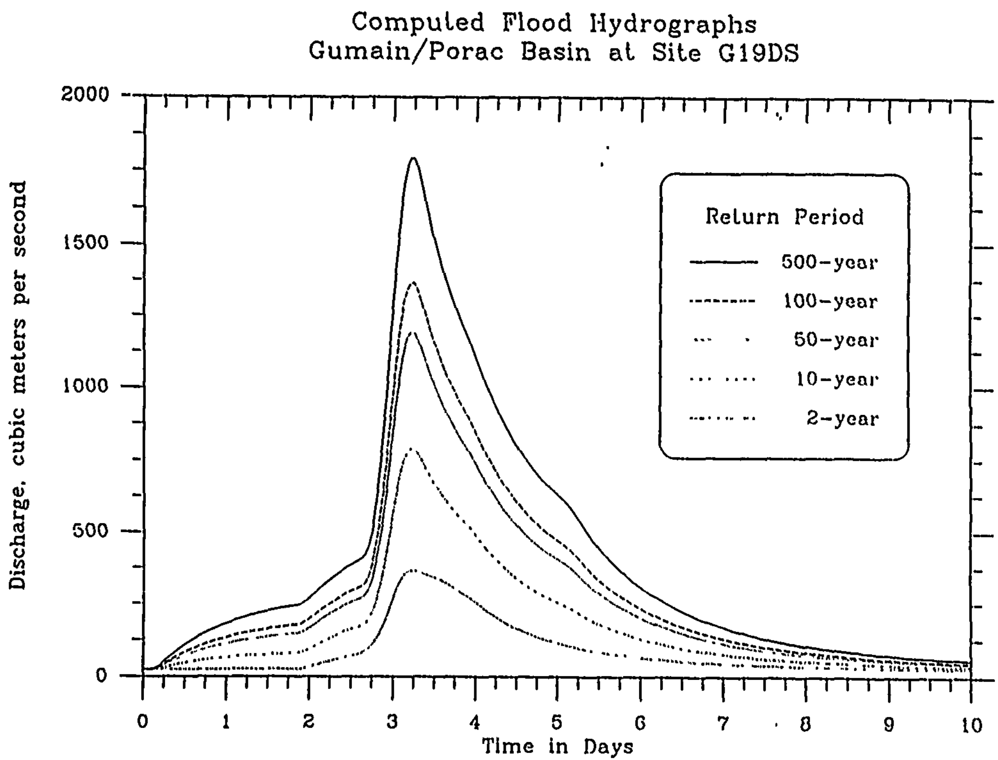
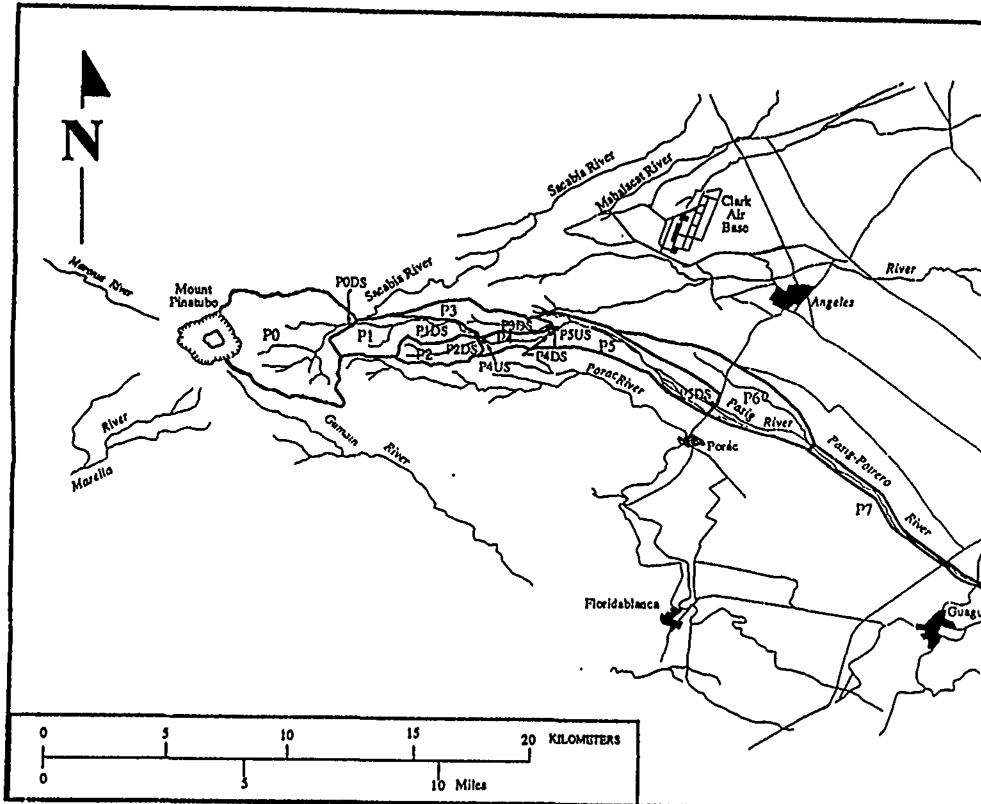

Computed Flood Hydrographs
Gumain/Porac Basin al Sile G19US
Discharge, cubic meters per second
2000
1500
1000
500
0
Time in Days
0
1
2
3
4
5
6
7
8
9
10
Return Period
500-year
100-year
50-year
10-year
2-year

Figure 3.5.34



Computed Flood Hydrographs
Gumain/Porac Basin at Site G19DS
Discharge, cubic meters per second
2000
1500
1000
500
0
Time in Days
0
1
2
3
4
5
6
7
8
9
10
Return Period
500-year
100-year
50-year
10-year
2-year

Figure 3.5.35

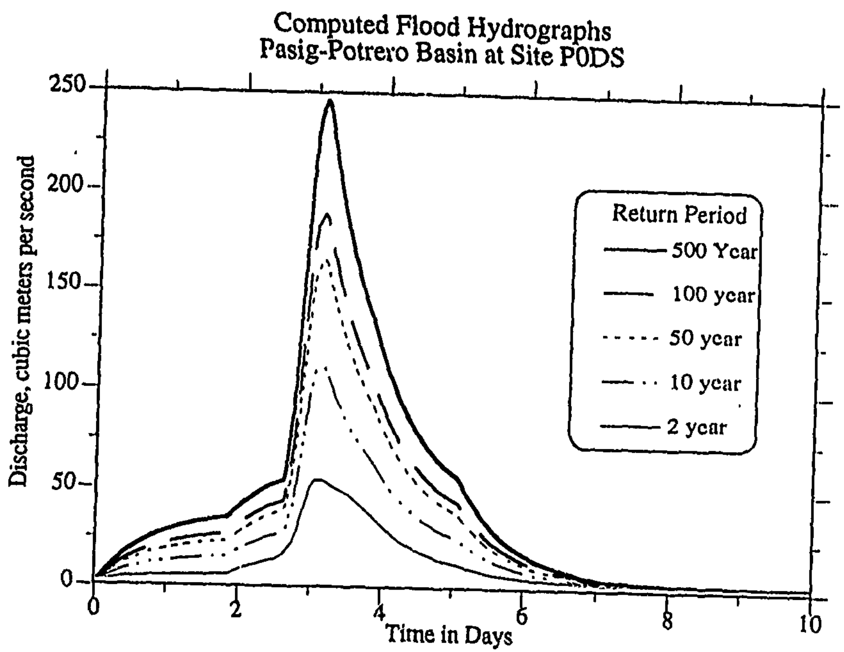


Portland District
U S Army Corps of Engineers
Portland, Oregon

Figure: 3.5.36

Pasig-Potrero River Basin
&
Sub-Basin Boundaries

December 16, 1993



Computed Flood Hydrographs
Pasig-Potrero Basin at Site P0DS
Discharge, cubic meters per second
250
200
150
100
50
0
0
2
4
6
8
10
Time in Days
Return Period
500 Year
100 year
50 year
10 year
2 year

Figure 3.5.37

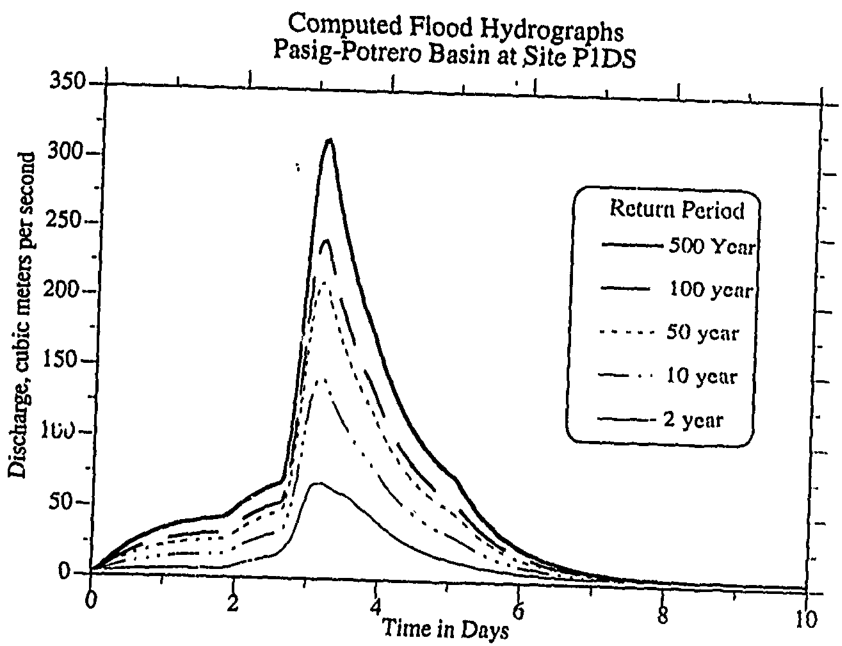

Computed Flood Hydrographs
Pasig-Potrero Basin at Site P1DS
350
300
250
200
150
100
50
0
Discharge, cubic meters per second
0
2
4
6
8
10
Time in Days
Return Period
500 Year
100 year
50 year
10 year
2 year

Figure 3.5.38

Computed Flood Hydrographs
Pasig-Potrero Basin at Site P2DS

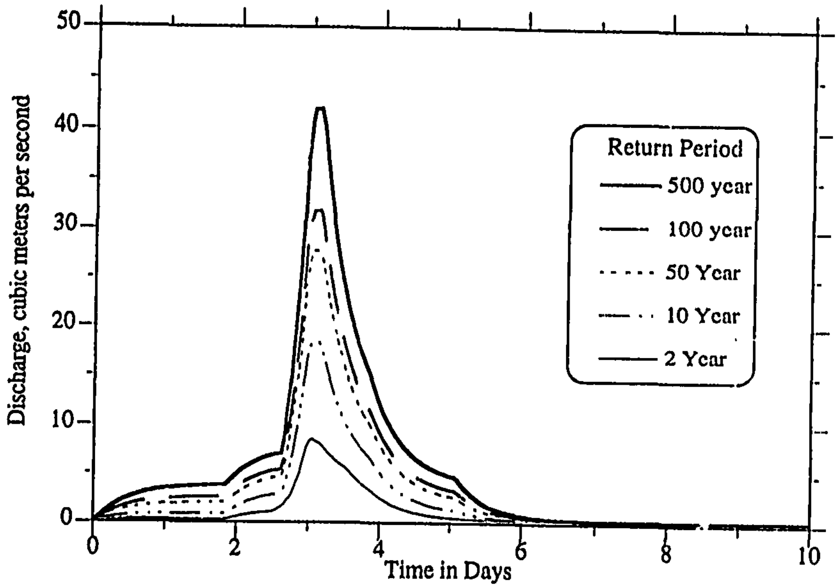


Figure 3.5.39

Computed Flood Hydrographs
Pasig-Potrero Basin at Site P3DS

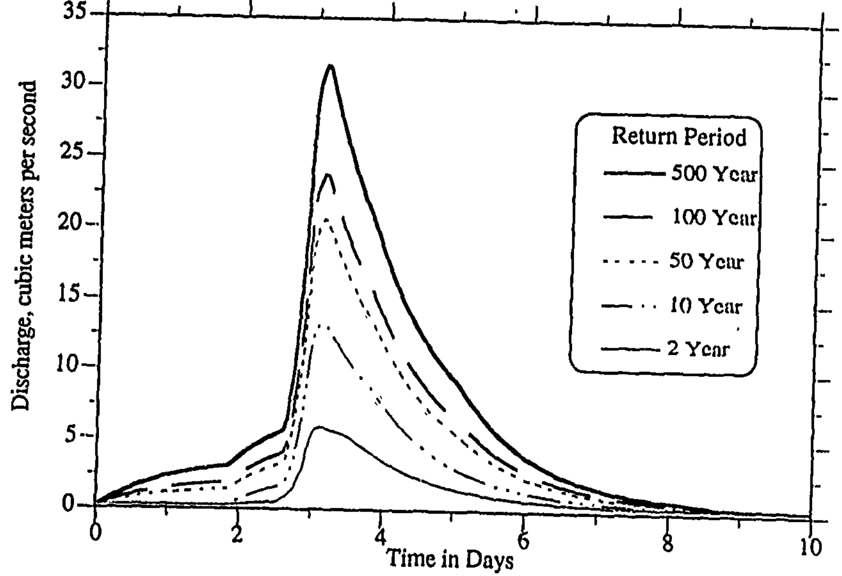
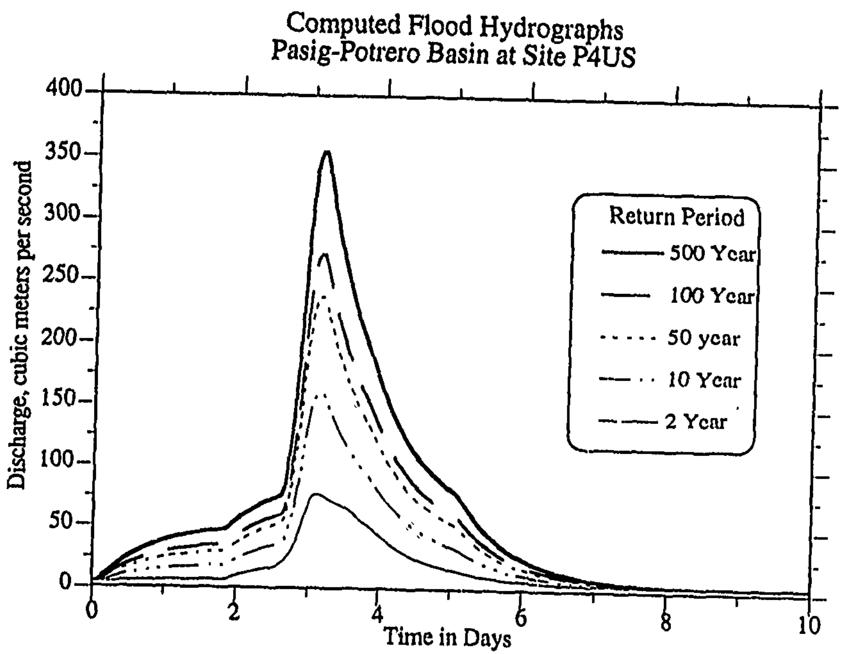


Figure 3.5.40



Computed Flood Hydrographs
Pasig-Potrero Basin at Site P4US
Discharge, cubic meters per second
400
350
300
250
200
150
100
50
0
0
2
4
6
8
10
Time in Days
Return Period
500 Year
100 Year
50 year
10 Year
2 Year

Figure 3.5.41

Computed Flood Hydrographs
Pasig-Potrero Basin at Site P4DS

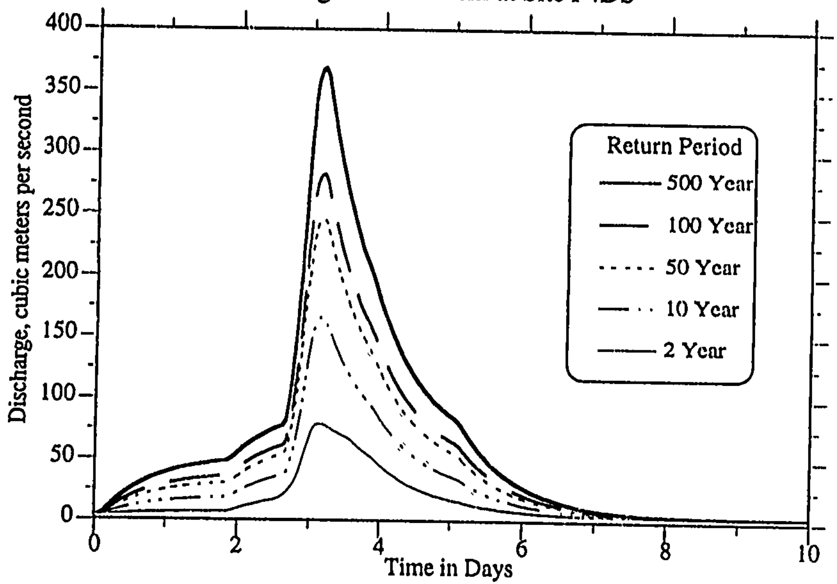


Figure 3.5.42

Computed Flood Hydrographs
Pasig-Potrero Basin at Site P5US

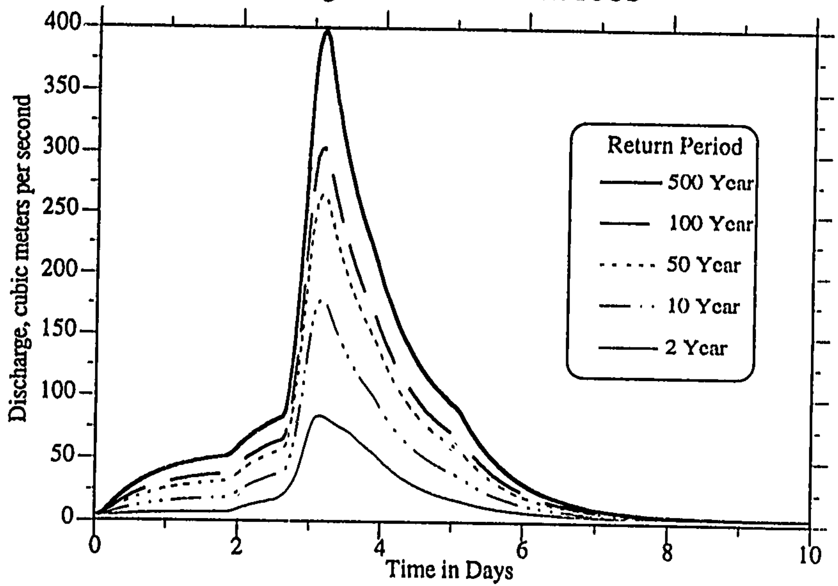


Figure 3.5.43

Computed Flood Hydrographs
Pasig-Potrero Basin at Site P5DS

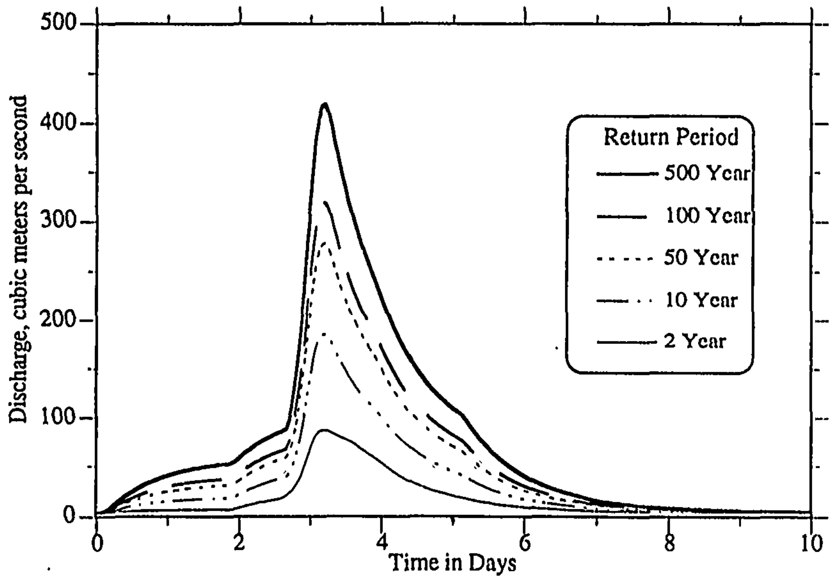


Figure 3.5.44

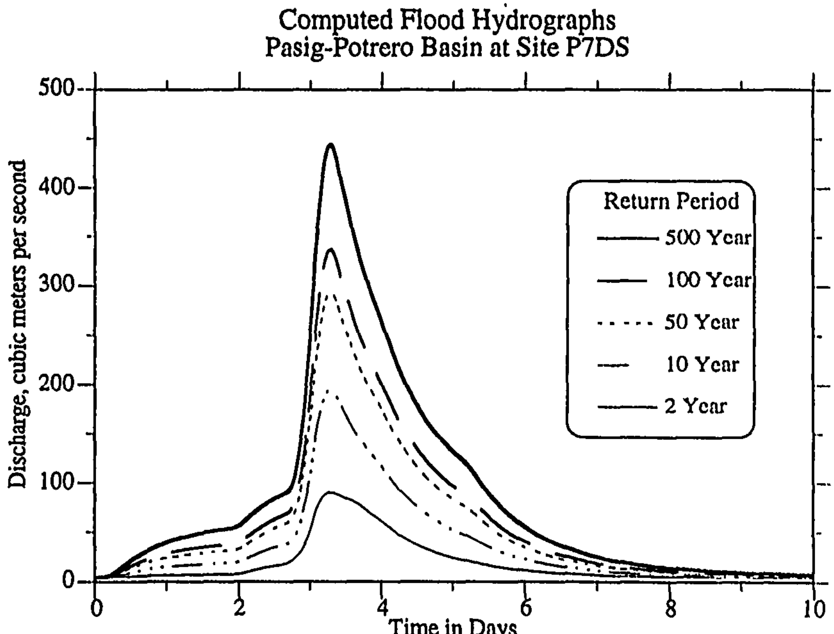

Computed Flood Hydrographs
Pasig-Potrero Basin at Site P7DS
Discharge, cubic meters per second
500
400
300
200
100
0
0
2
4
6
8
10
Time in Days
Return Period
500 Year
100 Year
50 Year
10 Year
2 Year

Figure 3.5.45

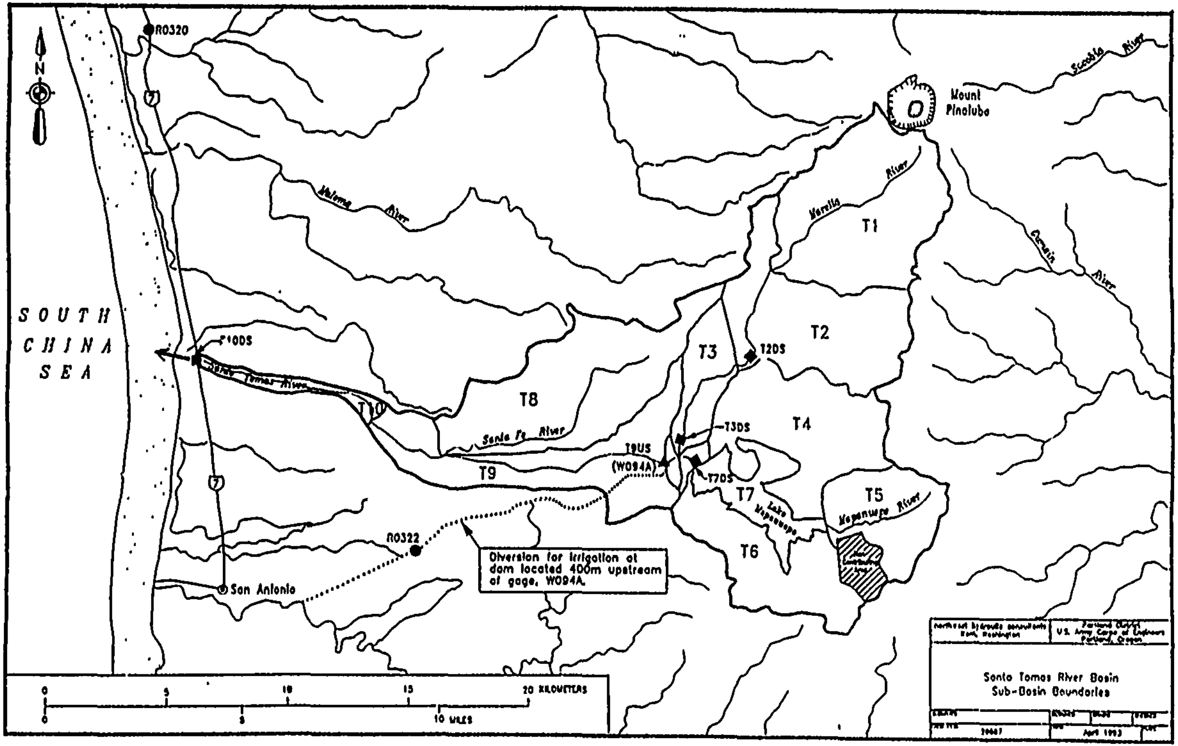

SOUTH CHINA SEA
N
R0320
Mount Pinatubo
Scabla River
Malama River
Marella River
Camsin River
Santa Fe River
Santo Tomas River
Mapanuepe River
Lake Mapanuepe
T1
T2
T3
T4
T5
T6
T7
T8
T9
T10
T2DS
T3DS
T7DS
T9US
(W094A)
T10DS
R0322
San Antonio
7
Diversion for irrigation at dam located 400m upstream of gage, W094A.
0 5 10 15 20 KILOMETERS
0 5 10 MILES
Santo Tomas River Basin
Sub-Basin Boundaries
April 1993

Figure 3.5.46

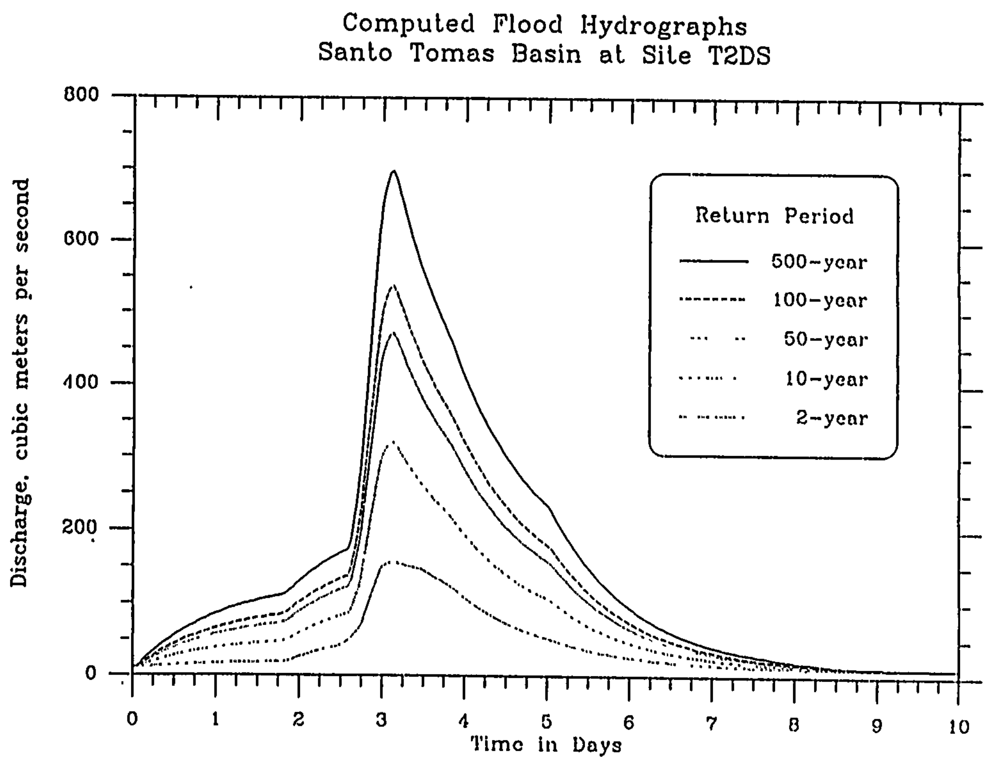

Computed Flood Hydrographs
Santo Tomas Basin at Site T2DS
Discharge, cubic meters per second
0
200
400
600
800
0
1
2
3
4
5
6
7
8
9
10
Time in Days
Return Period
500-year
100-year
50-year
10-year
2-year

Figure 3.5.47

Computed Flood Hydrographs
Santo Tomas Basin at Site T3DS

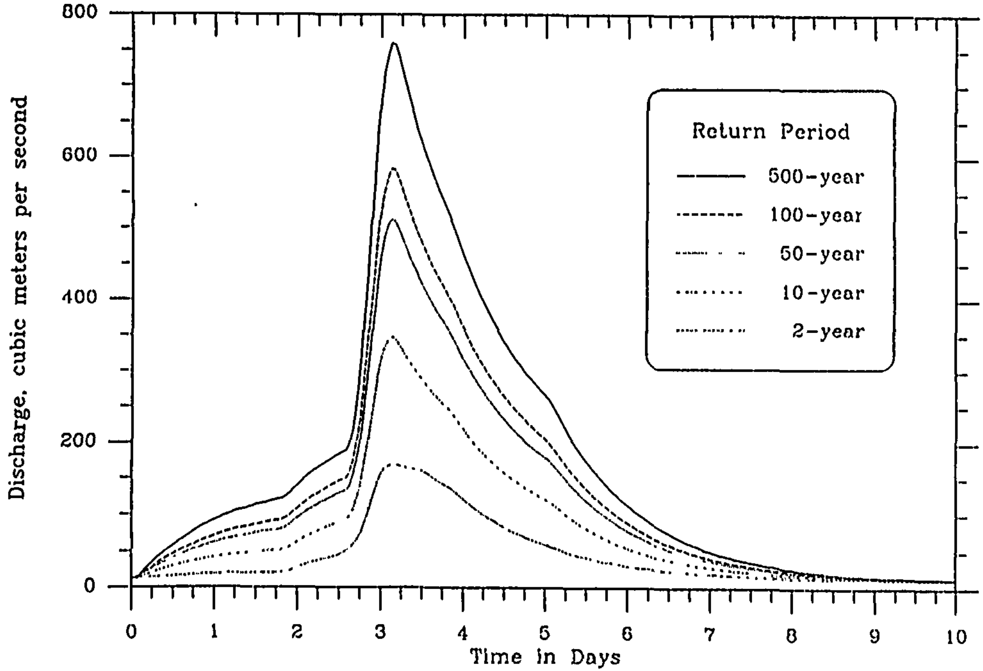


Figure 3.5.48

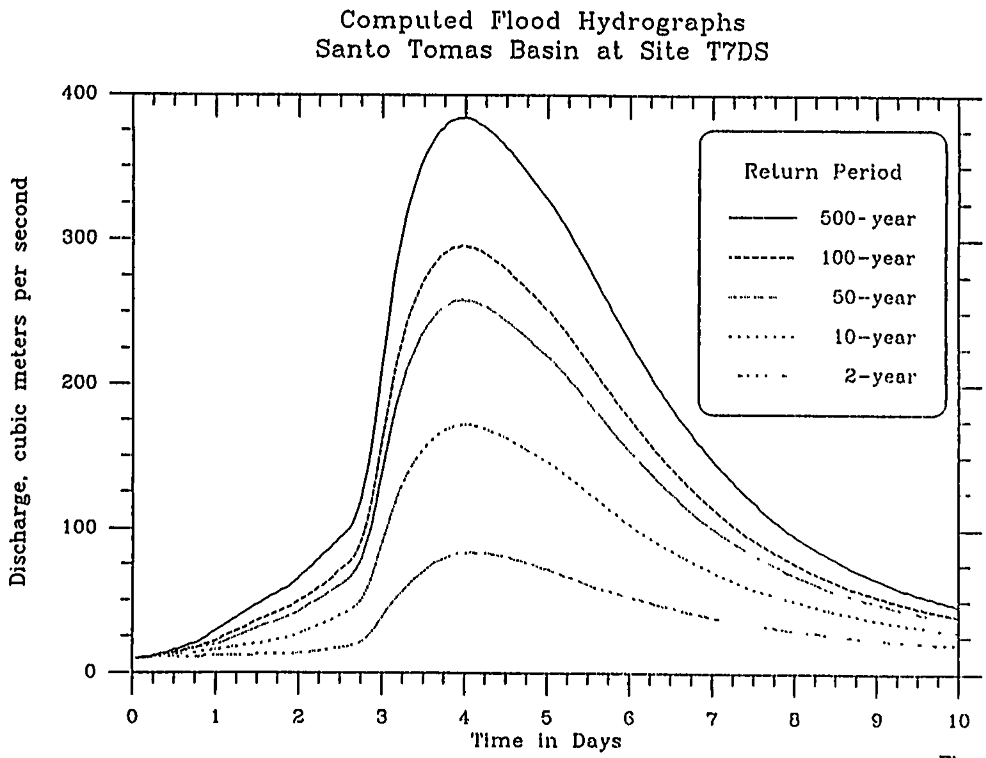

Computed Flood Hydrographs
Santo Tomas Basin at Site T7DS
Discharge, cubic meters per second
0
100
200
300
400
Time in Days
0
1
2
3
4
5
6
7
8
9
10
Return Period
500-year
100-year
50-year
10-year
2-year

Figure 3.5.49

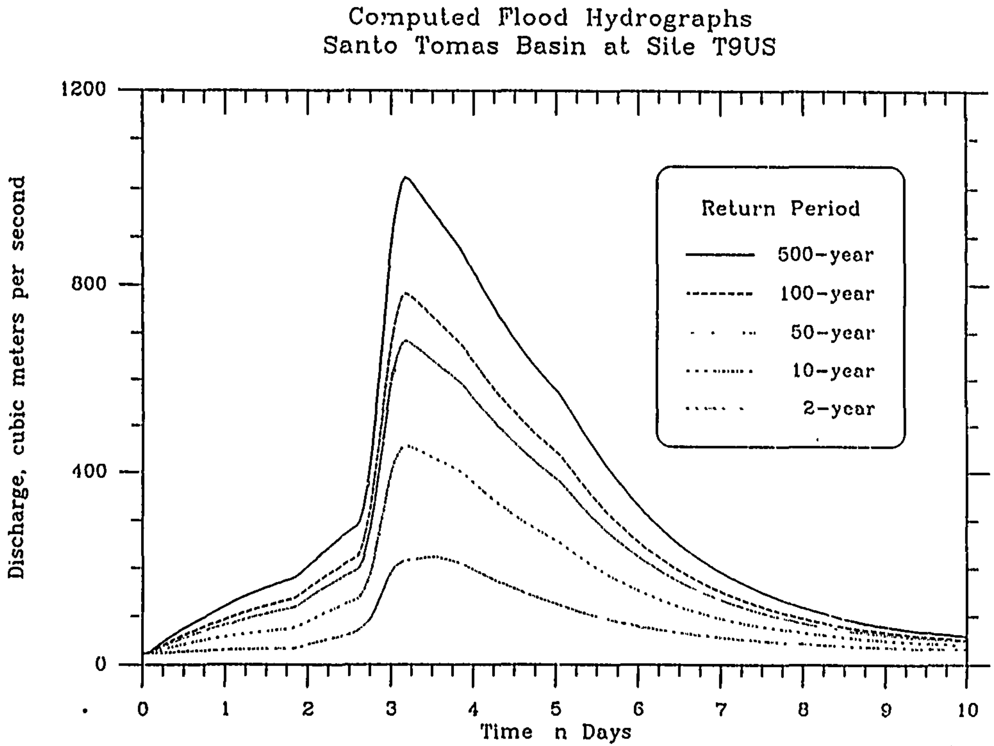

Computed Flood Hydrographs
Santo Tomas Basin at Site T9US
Discharge, cubic meters per second
1200
800
400
0
0
1
2
3
4
5
6
7
8
9
10
Time n Days
Return Period
500-year
100-year
50-year
10-year
2-year

Figure 3.5.50

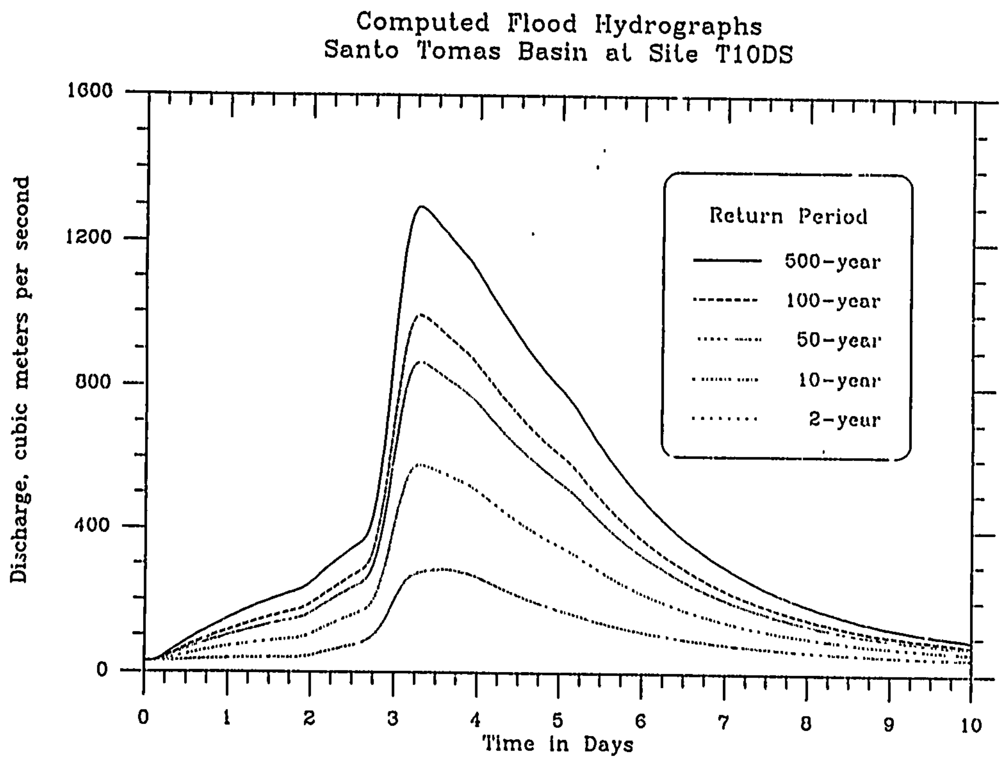

Computed Flood Hydrographs
Santo Tomas Basin at Site T10DS
Discharge, cubic meters per second
1600
1200
800
400
0
0
1
2
3
4
5
6
7
8
9
10
Time in Days
Return Period
500-year
100-year
50-year
10-year
2-year

Figure 3.5.51

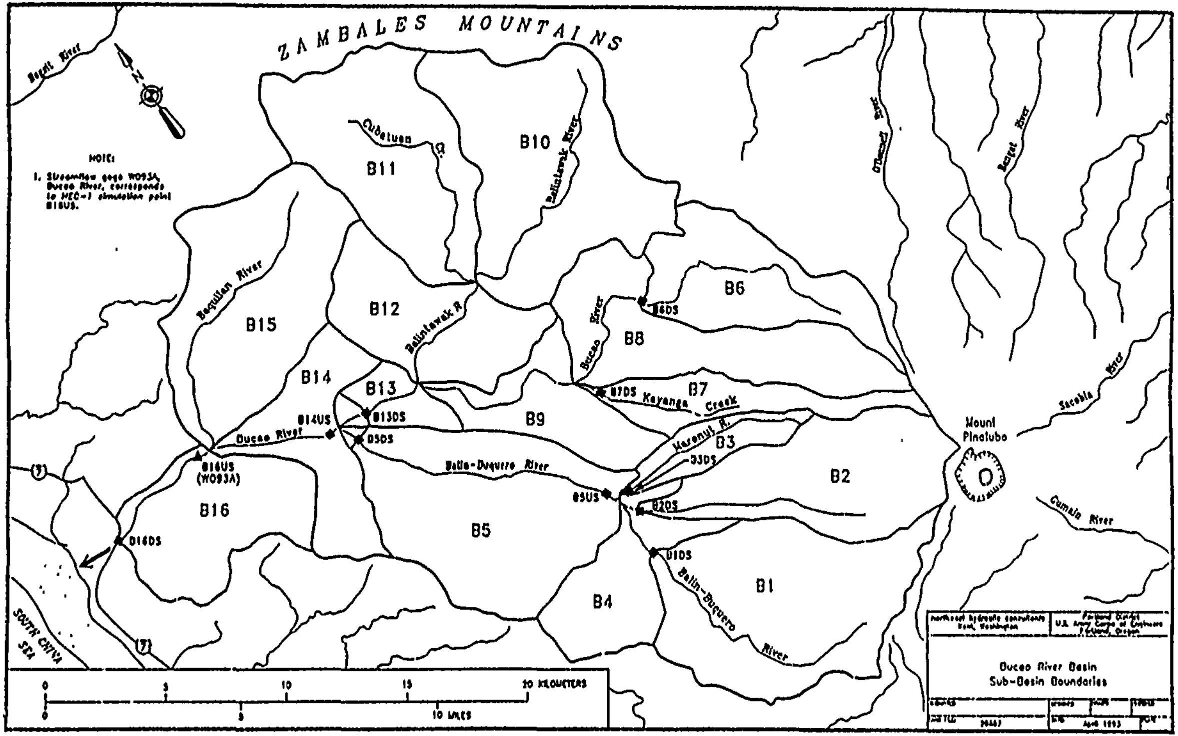
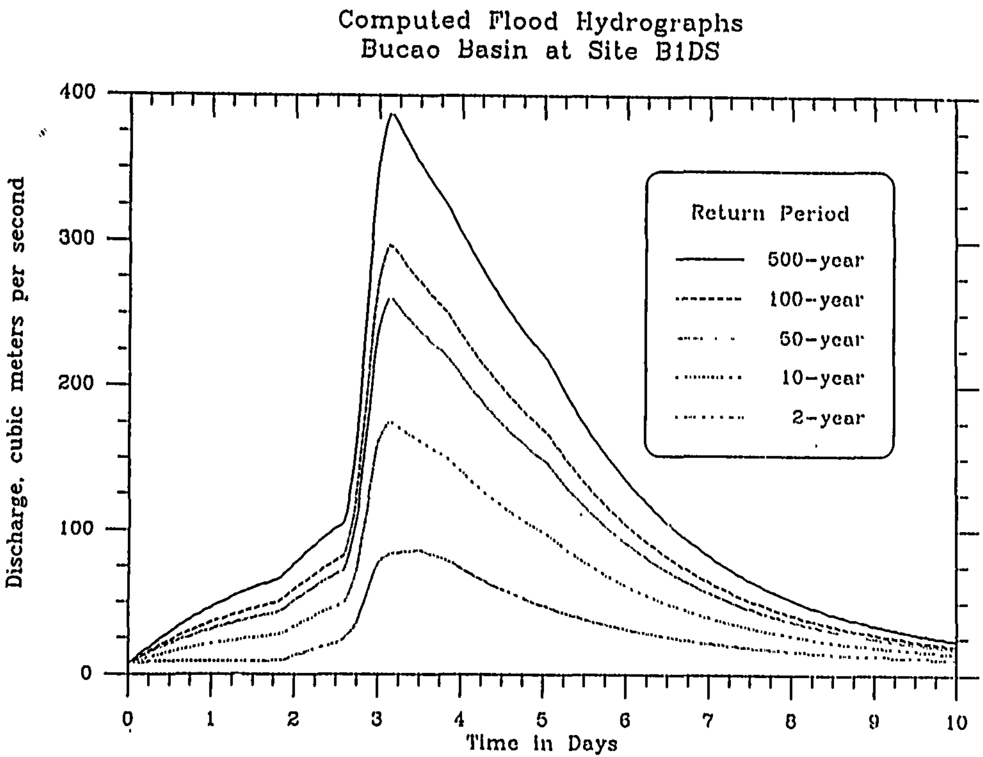

ZAMBALES MOUNTAINS
NOTE:
1. Streamflow gage WO93A, Ducao River, corresponds to HEC-1 simulation point B16US.
B1
B2
B3
B4
B5
B6
B7
B8
B9
B10
B11
B12
B13
B14
B15
B16
B1DS
B2DS
B3DS
B5US
B5DS
B6DS
B7DS
B13DS
B14US
B16US
(WO93A)
B16DS
Mount Pinatubo
Kayanga Creek
Marenut R.
Balin-Buquero River
Balintawak R.
Balintawak River
Cubatuan Cr.
Baquilan River
Ducao River
Gumain River
Sacobia River
Bucao River
SOUTH CHINA SEA
0
5
10
15
20 KILOMETERS
0
5
10 MILES
Ducao River Basin
Sub-Basin Boundaries

Figure 3.5.52



Computed Flood Hydrographs
Bucao Basin at Site B1DS
Discharge, cubic meters per second
0
100
200
300
400
Time in Days
0
1
2
3
4
5
6
7
8
9
10
Return Period
500-year
100-year
50-year
10-year
2-year

Figure 3.5.53

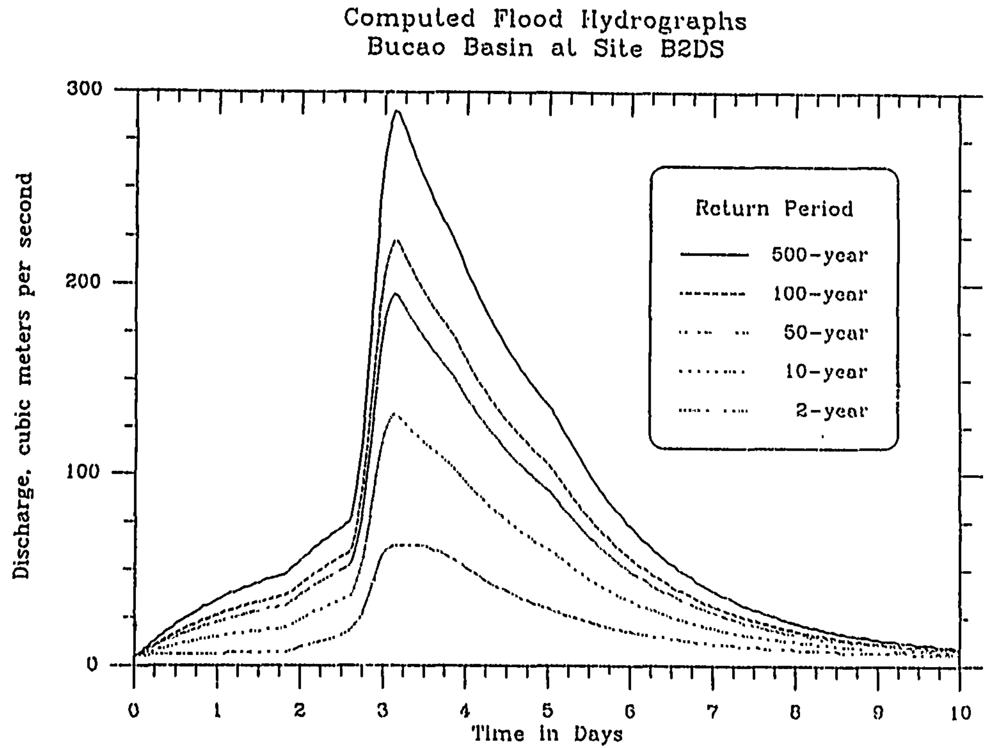

Computed Flood Hydrographs
Bucao Basin al Site B2DS
Discharge, cubic meters per second
300
200
100
0
0
1
2
3
4
5
6
7
8
9
10
Time in Days
Return Period
500-year
100-year
50-year
10-year
2-year

Figure 3.5.54

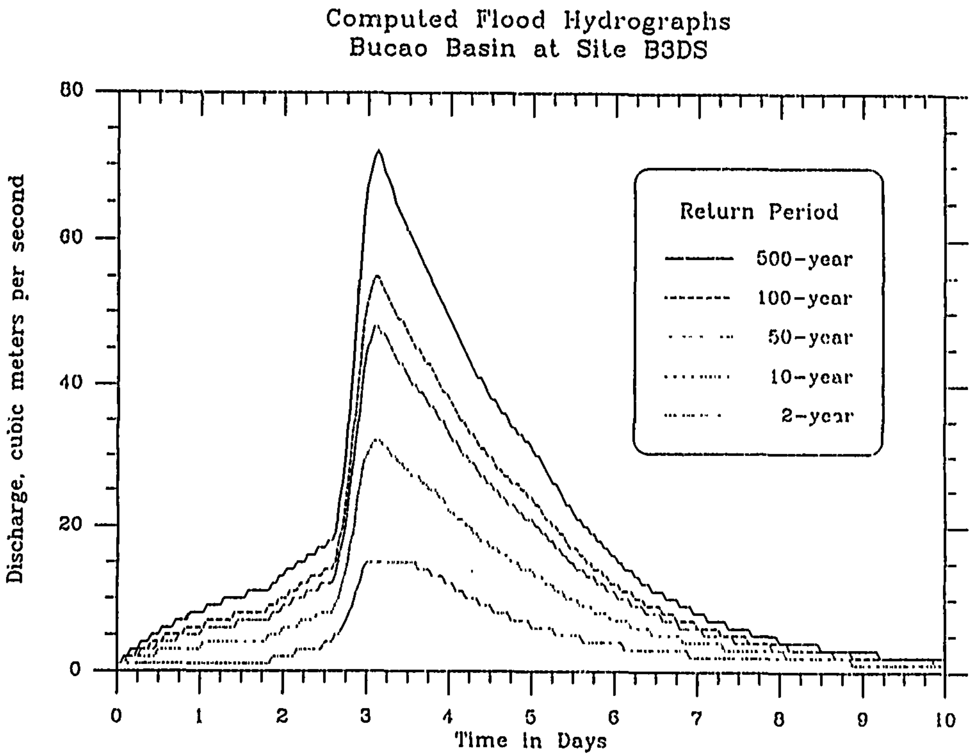
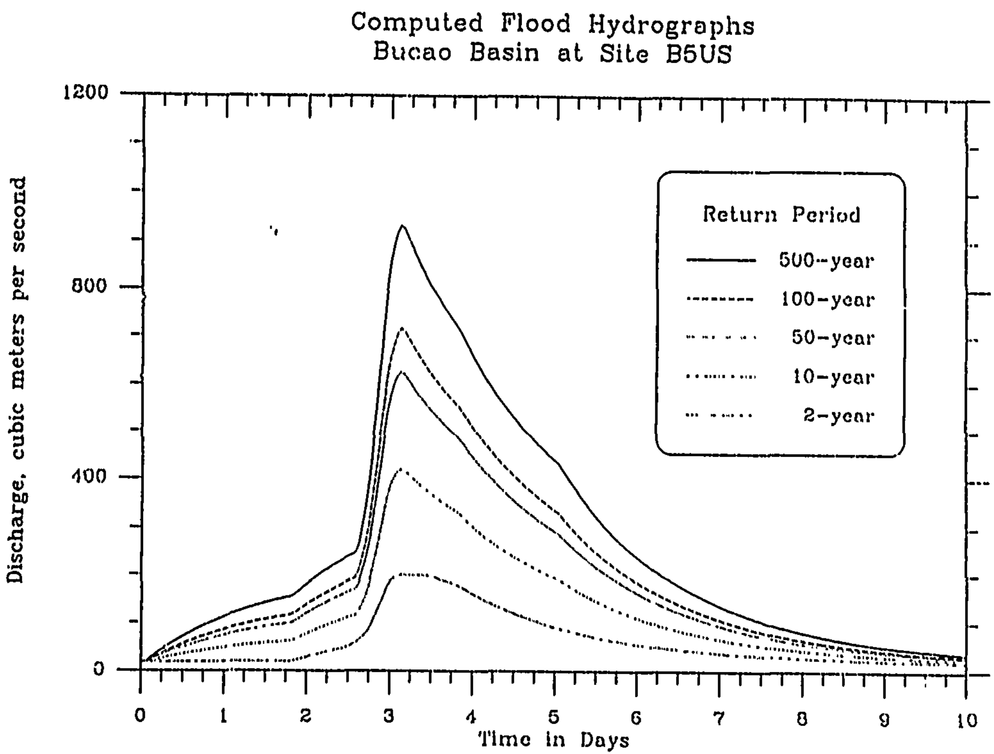
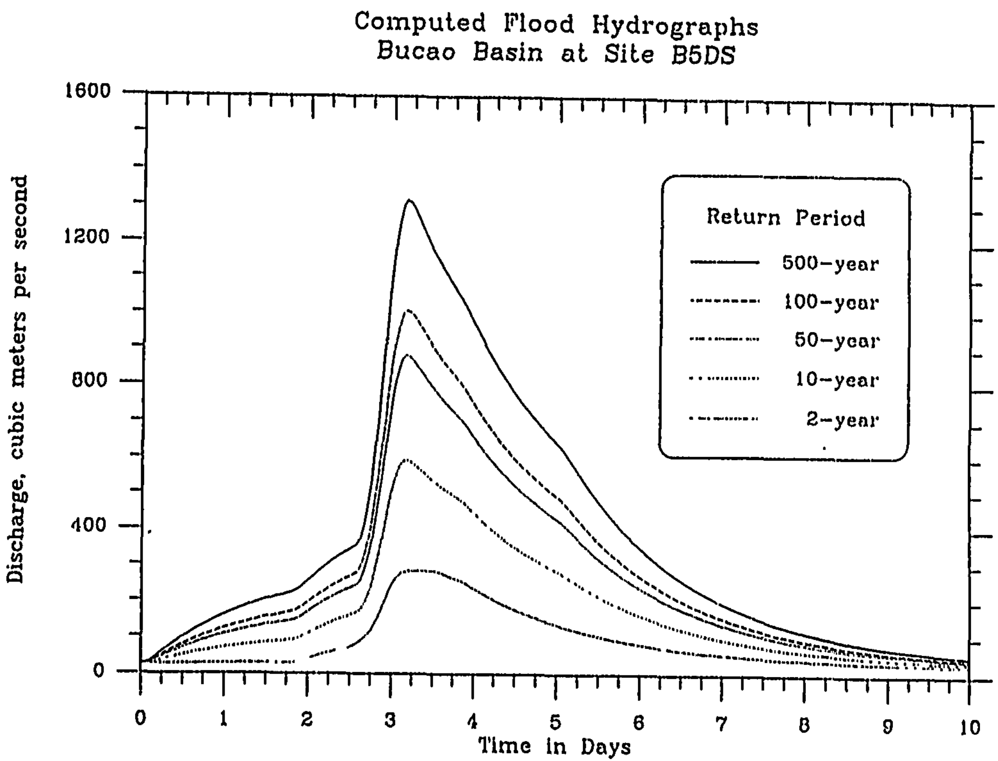

Computed Flood Hydrographs
Bucao Basin at Site B3DS
Discharge, cubic meters per second
0
20
40
60
80
Time In Days
0
1
2
3
4
5
6
7
8
9
10
Return Period
500-year
100-year
50-year
10-year
2-year

Figure 3.5.55



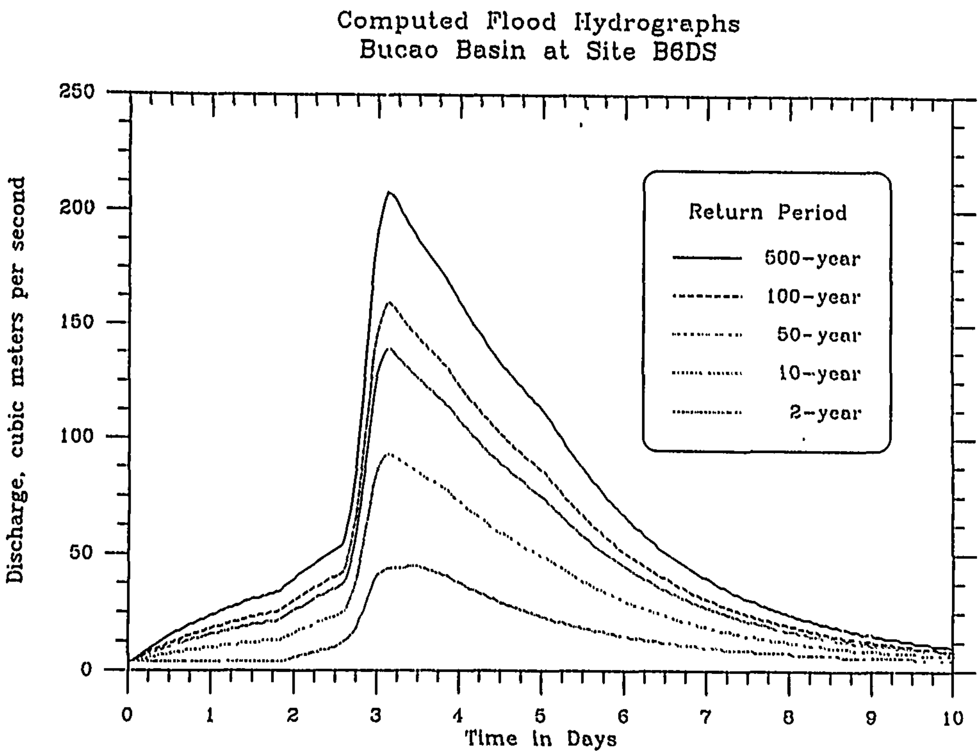
Computed Flood Hydrographs
Bucao Basin at Site B5US
1200
800
400
0
Discharge, cubic meters per second
0
1
2
3
4
5
6
7
8
9
10
Time in Days
Return Period
500-year
100-year
50-year
10-year
2-year

Figure 3.5.56



Computed Flood Hydrographs
Bucao Basin at Site B5DS
Return Period
500-year
100-year
50-year
10-year
2-year
Discharge, cubic meters per second
1600
1200
800
400
0
0
1
2
3
4
5
6
7
8
9
10
Time in Days

Figure 3.5.57



Computed Flood Hydrographs
Bucao Basin at Site B6DS
Return Period
500-year
100-year
50-year
10-year
2-year
Discharge, cubic meters per second
Time in Days
0
50
100
150
200
250
0
1
2
3
4
5
6
7
8
9
10

Figure 3.5.58

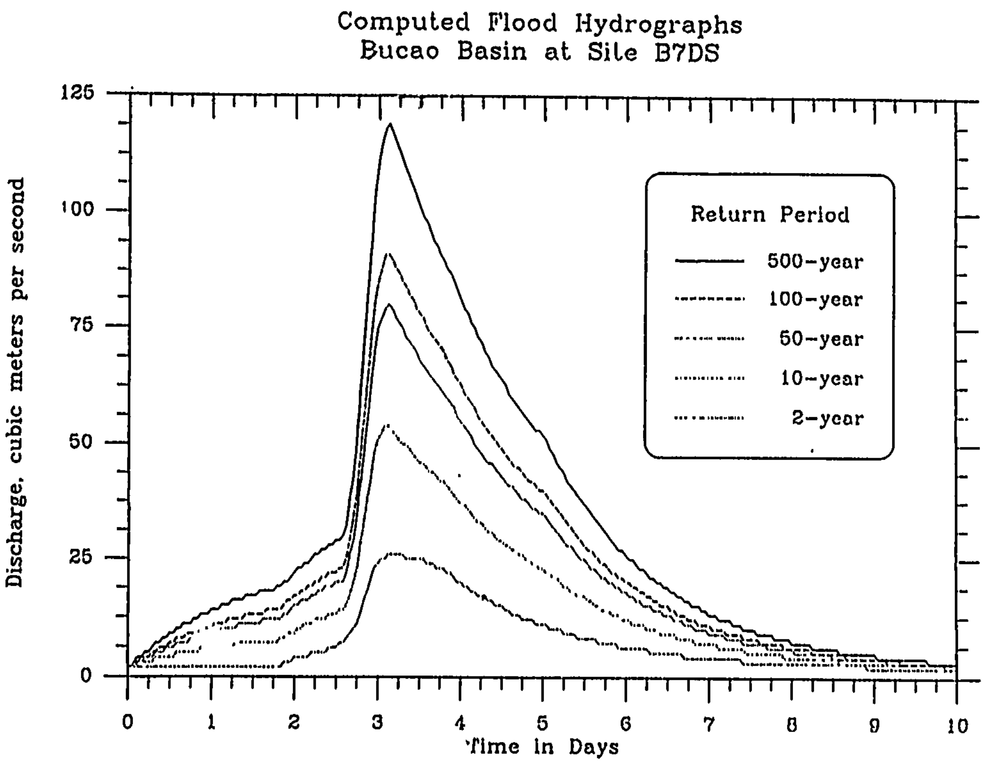
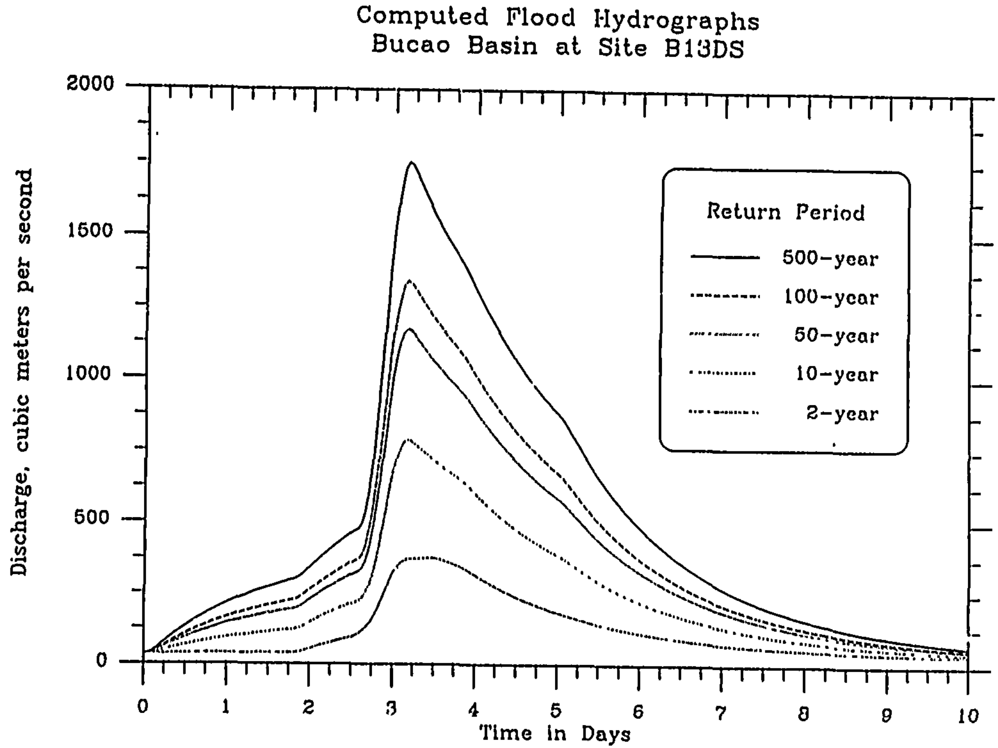
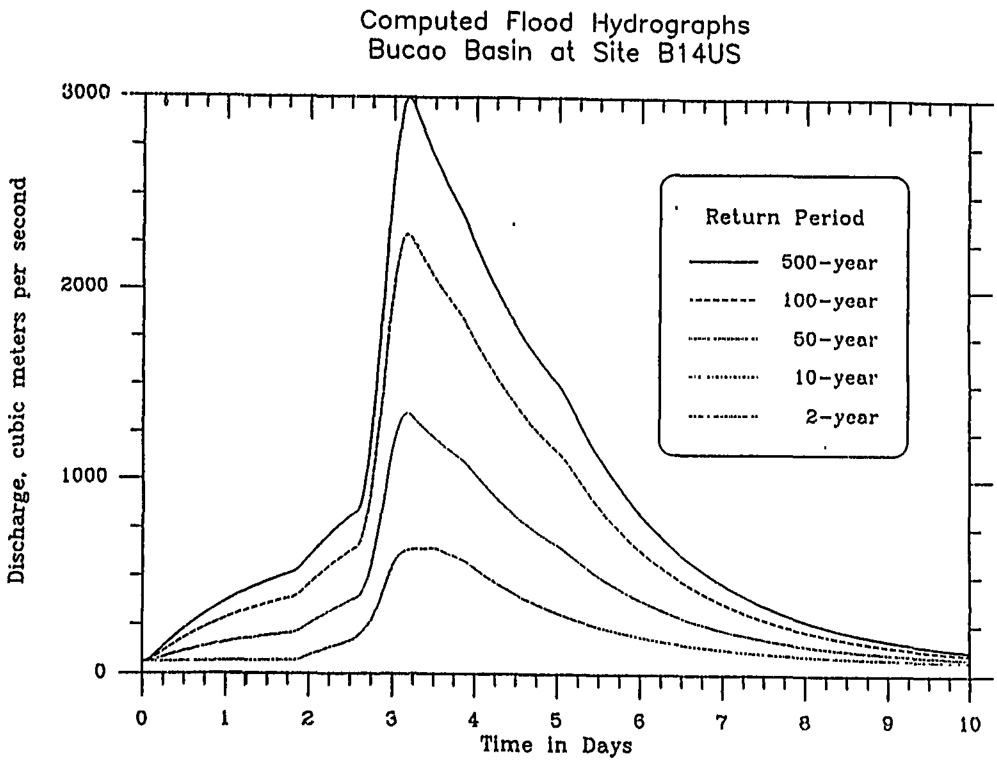

Computed Flood Hydrographs
Bucao Basin at Sile B7DS
Discharge, cubic meters per second
125
100
75
50
25
0
0
1
2
3
4
5
6
7
8
9
10
Time In Days
Return Period
500-year
100-year
50-year
10-year
2-year

Figure 3.5.59



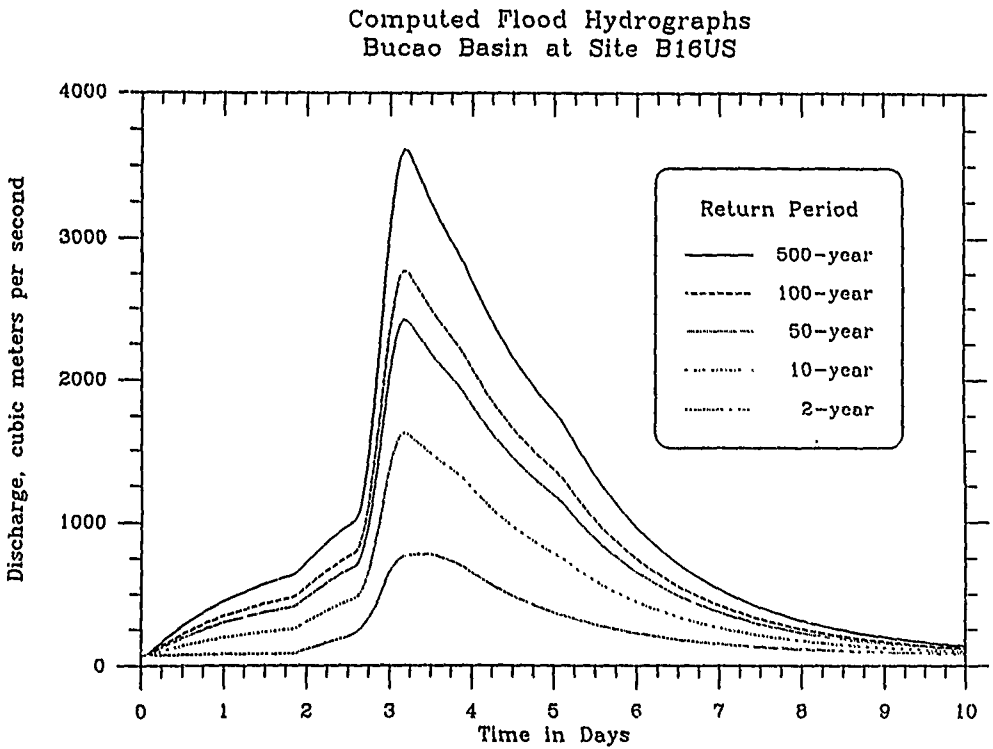
Computed Flood Hydrographs
Bucao Basin at Site B13DS
Discharge, cubic meters per second
2000
1500
1000
500
0
Time in Days
0
1
2
3
4
5
6
7
8
9
10
Return Period
500-year
100-year
50-year
10-year
2-year

Figure 3.5.60



Computed Flood Hydrographs
Bucao Basin at Site B14US
Discharge, cubic meters per second
3000
2000
1000
0
0
1
2
3
4
5
6
7
8
9
10
Time in Days
Return Period
500-year
100-year
50-year
10-year
2-year

Figure 3.5.61



Computed Flood Hydrographs
Bucao Basin at Site B16US
Discharge, cubic meters per second
4000
3000
2000
1000
0
0
1
2
3
4
5
6
7
8
9
10
Time in Days
Return Period
500-year
100-year
50-year
10-year
2-year

Figure 3.5.62

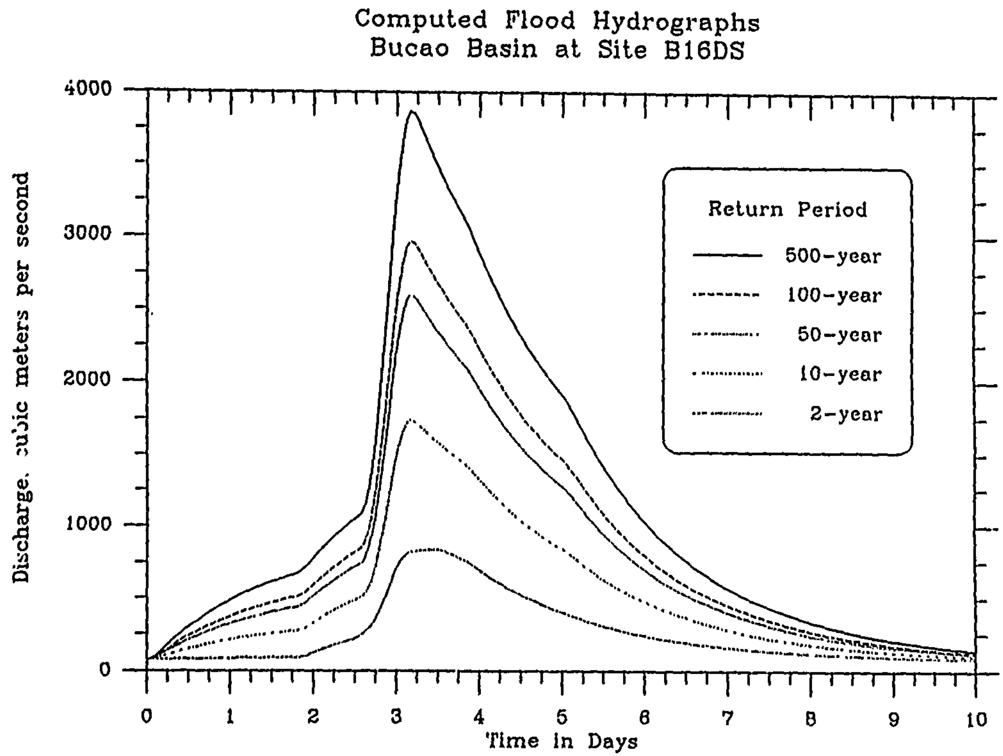
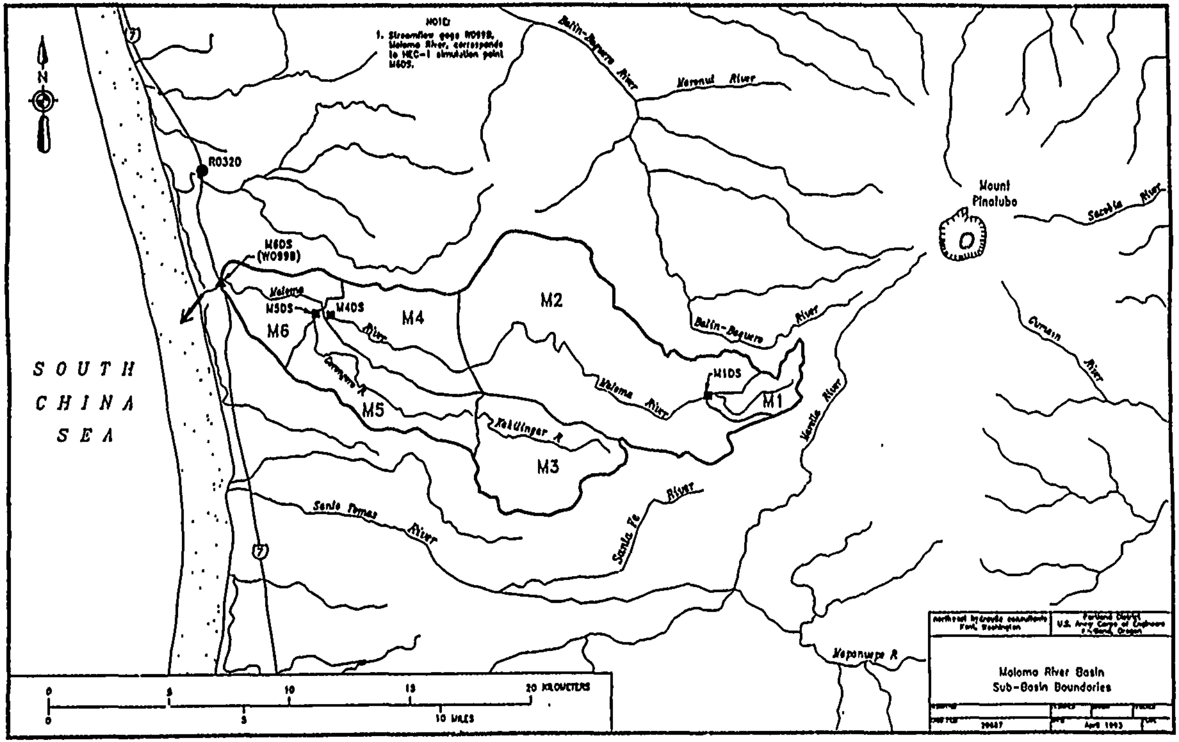

Computed Flood Hydrographs
Bucao Basin at Site B16DS
Discharge, cubic meters per second
4000
3000
2000
1000
0
0
1
2
3
4
5
6
7
8
9
10
Time in Days
Return Period
500-year
100-year
50-year
10-year
2-year

Figure 3.5.63



N
SOUTH
CHINA
SEA
Mount
Pinatubo
M1
M2
M3
M4
M5
M6
M1DS
M4DS
M5DS
M6DS
(W099B)
R0320
Balin-Baquero River
Marella River
Santa Fe River
Santo Tomas River
Kakilingan R
Cumasin River
Sacobia River
Malama River
7
0
5
10
15
20 KILOMETERS
10 MILES
Malama River Basin
Sub-Basin Boundaries
April 1993

Figure 3.5.64

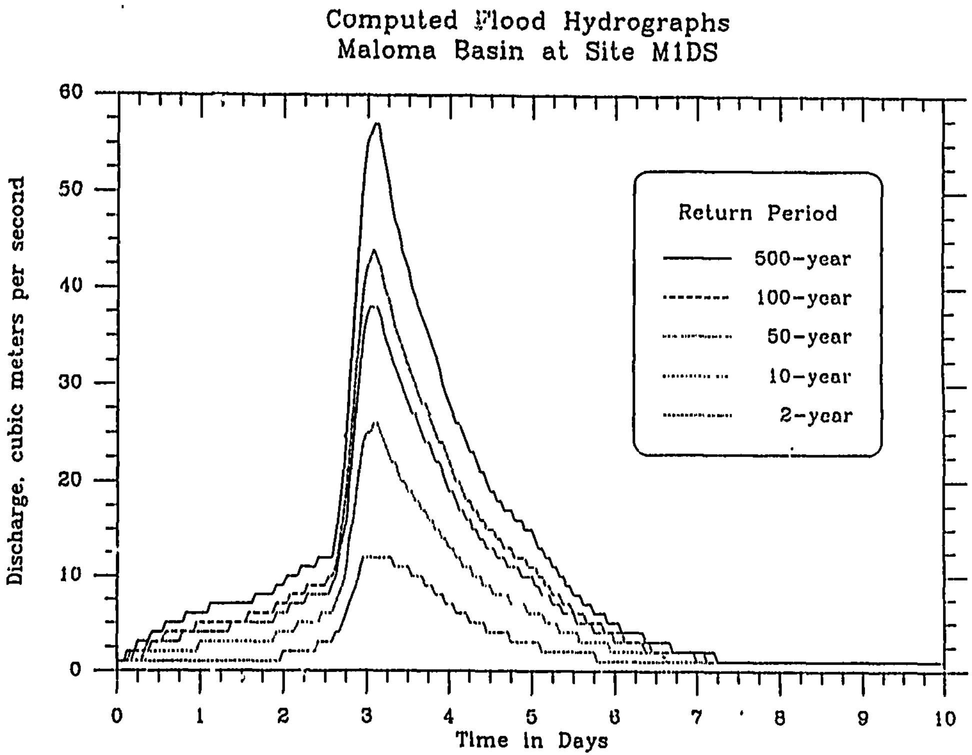

Computed Flood Hydrographs
Maloma Basin at Site M1DS
Return Period
500-year
100-year
50-year
10-year
2-year
Discharge, cubic meters per second
Time In Days
0
10
20
30
40
50
60
0
1
2
3
4
5
6
7
8
9
10

Figure 3.5.65

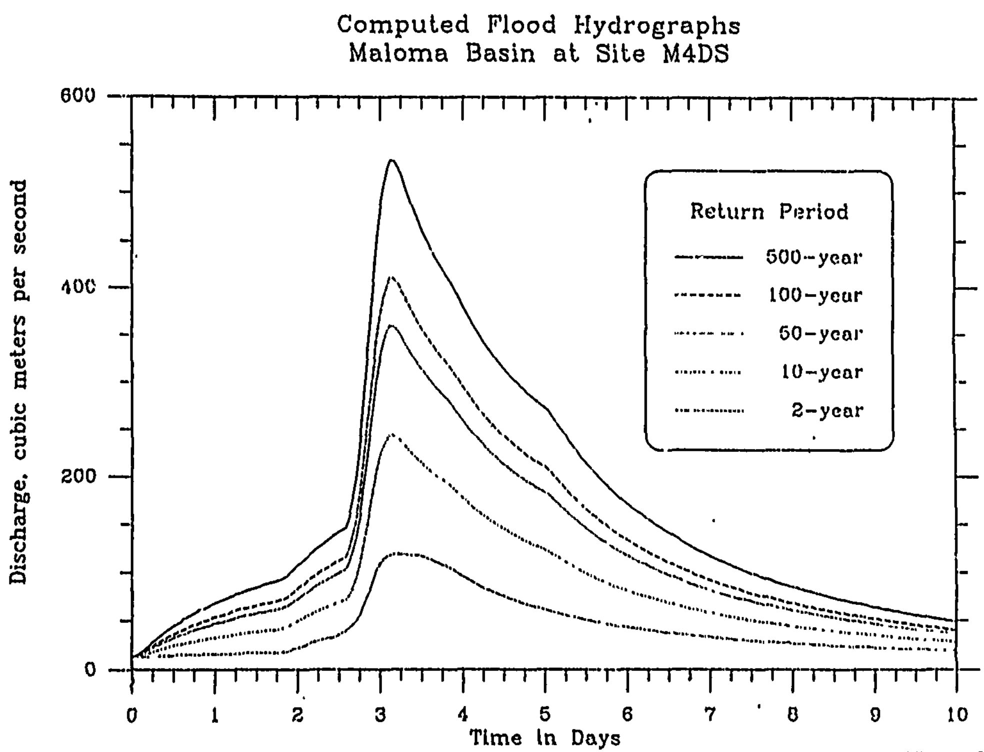

Computed Flood Hydrographs
Maloma Basin at Site M4DS
Return Period
500-year
100-year
50-year
10-year
2-year
Discharge, cubic meters per second
600
400
200
0
0
1
2
3
4
5
6
7
8
9
10
Time In Days

Figure 3.5.66

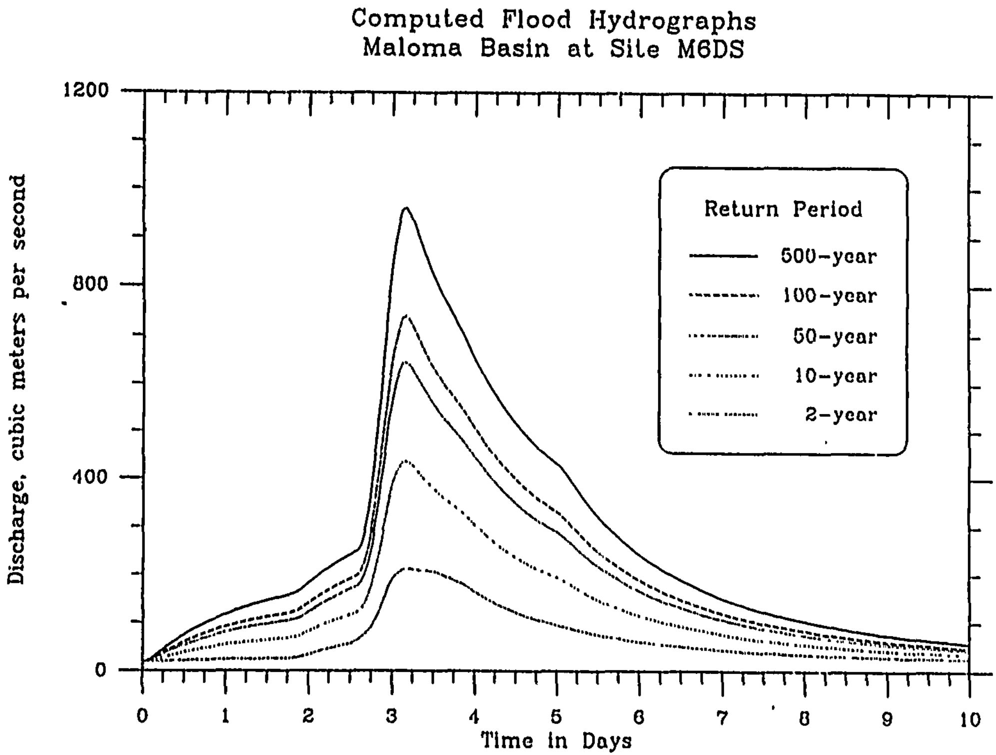
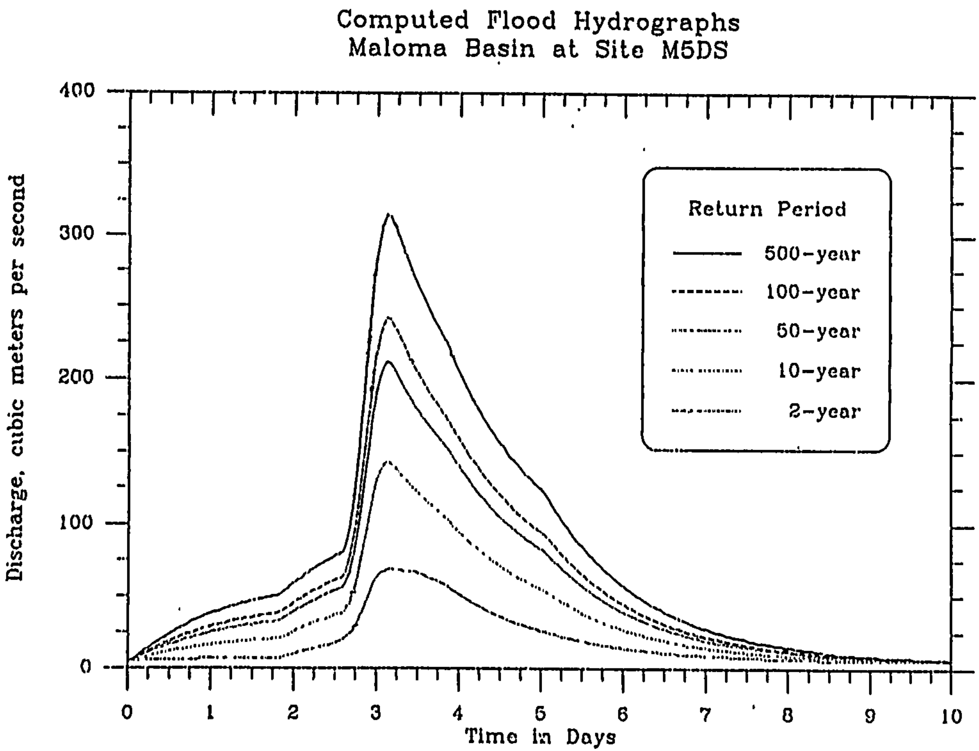

Computed Flood Hydrographs
Maloma Basin at Site M6DS
Discharge, cubic meters per second
1200
800
400
0
0
1
2
3
4
5
6
7
8
9
10
Time in Days
Return Period
500-year
100-year
50-year
10-year
2-year

Figure 3.5.67



Computed Flood Hydrographs
Maloma Basin at Site M5DS
Discharge, cubic meters per second
0
100
200
300
400
Time in Days
0
1
2
3
4
5
6
7
8
9
10
Return Period
500-year
100-year
50-year
10-year
2-year

Figure 3.5.68

Site O9US, HEC-1 Estimated Peak Discharge and Estimated Confidence Limits

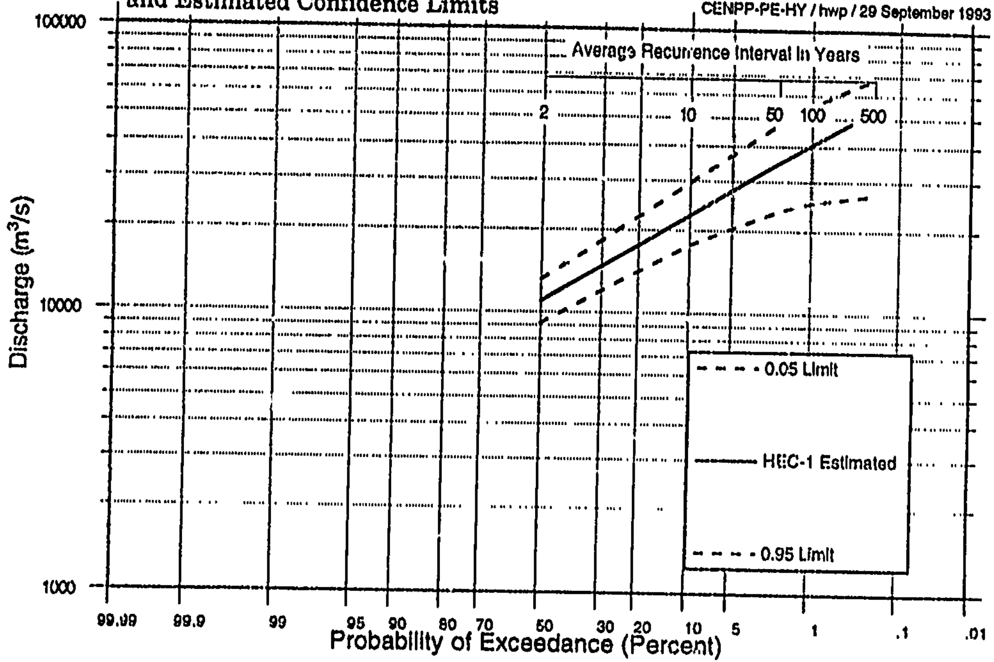


Figure 3.5.69

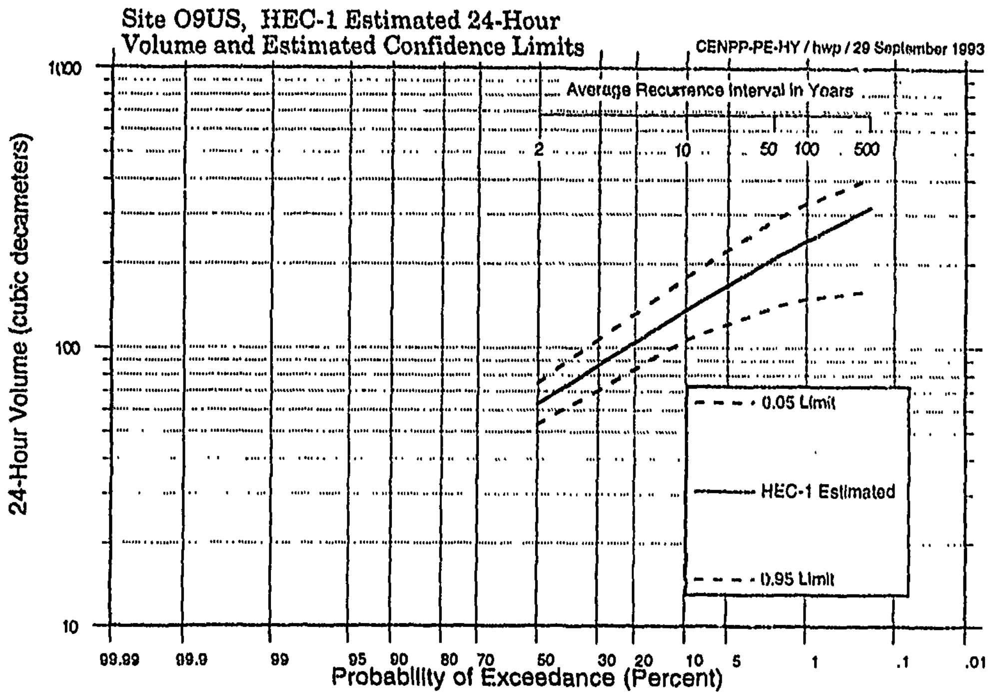
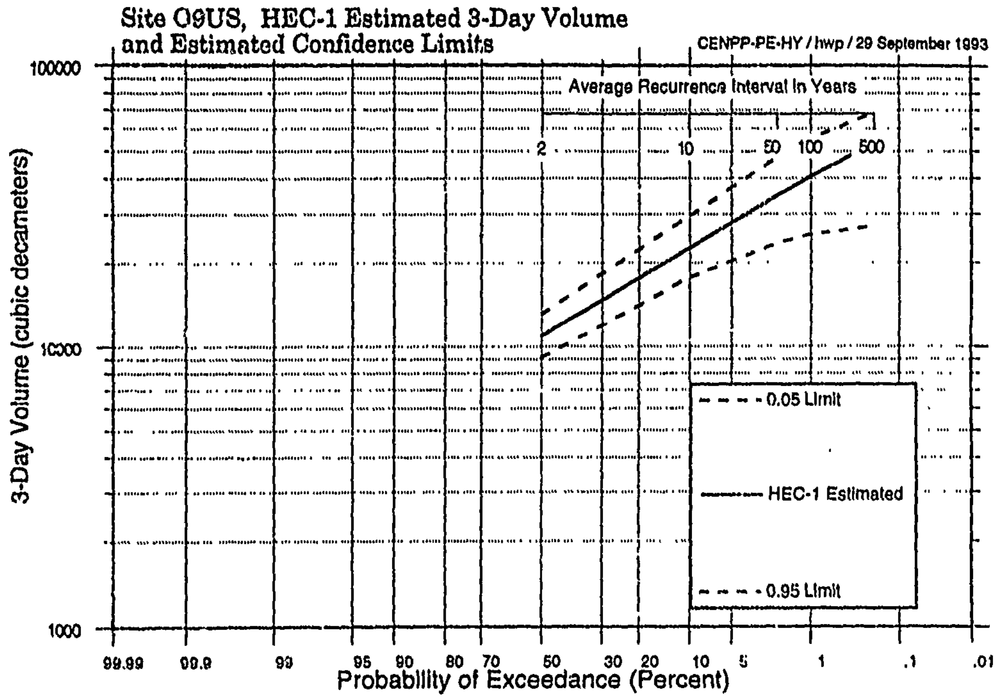

Site O9US, HEC-1 Estimated 24-Hour
Volume and Estimated Confidence Limits
CENPP-PE-HY / hwp / 29 September 1993
Average Recurrence Interval in Years
2
10
50
100
500
24-Hour Volume (cubic decameters)
1000
100
10
0.05 Limit
HEC-1 Estimated
0.95 Limit
99.99
99.9
99
95
90
80
70
50
30
20
10
5
1
.1
.01
Probability of Exceedance (Percent)

Figure 3.5.70



Site O9US, HEC-1 Estimated 3-Day Volume and Estimated Confidence Limits
CENPP-PE-HY / hwp / 29 September 1993
Average Recurrence Interval In Years
2
10
50
100
500
- - - 0.05 Limit
HEC-1 Estimated
- - - 0.95 Limit
3-Day Volume (cubic decameters)
100000
10000
1000
99.99
99.9
99
95
90
80
70
50
30
20
10
5
1
.1
.01
Probability of Exceedance (Percent)

Figure 3.5.71

Site S7DS, Computed Flow Duration Curve and Estimated Confidence Limits

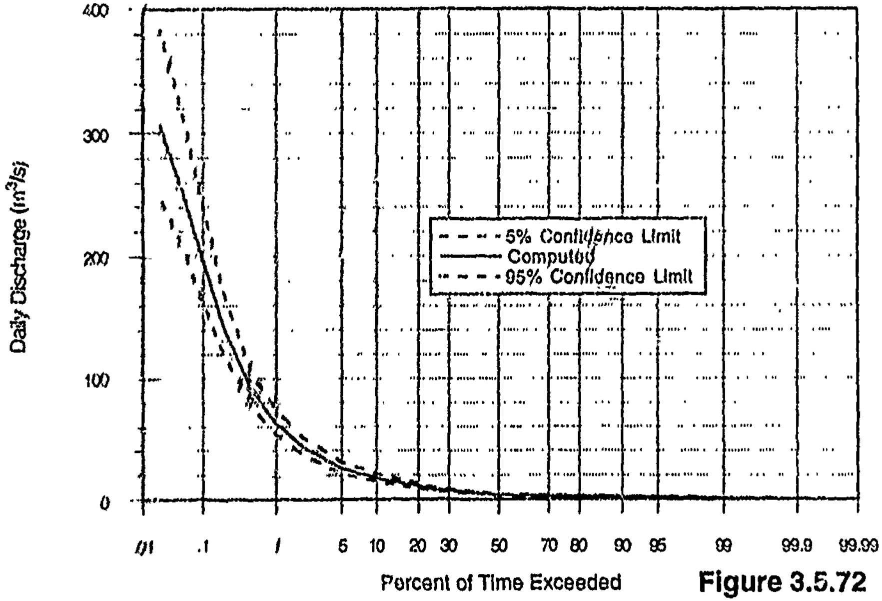


Figure 3.5.72

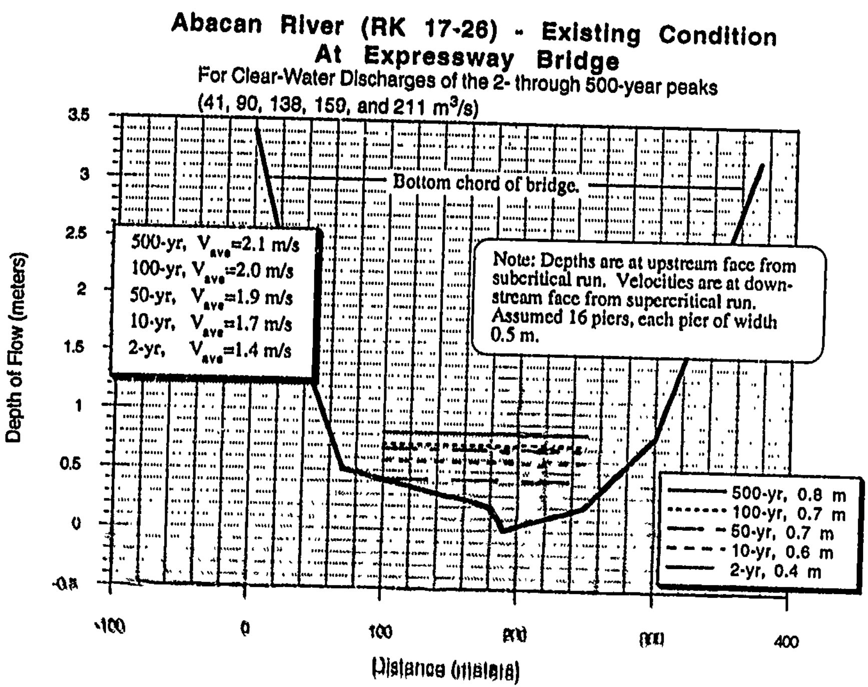

Abacan River (RK 17-26) - Existing Condition
At Expressway Bridge
For Clear-Water Discharges of the 2- through 500-year peaks
(41, 90, 138, 159, and 211 m3/s)
Bottom chord of bridge.
500-yr, Vave=2.1 m/s
100-yr, Vave=2.0 m/s
50-yr, Vave=1.9 m/s
10-yr, Vave=1.7 m/s
2-yr, Vave=1.4 m/s
Note: Depths are at upstream face from subcritical run. Velocities are at downstream face from supercritical run. Assumed 16 piers, each pier of width 0.5 m.
500-yr, 0.8 m
100-yr, 0.7 m
50-yr, 0.7 m
10-yr, 0.6 m
2-yr, 0.4 m
Depth of Flow (meters)
3.5
3
2.5
2
1.5
1
0.5
0
-100
0
100
400
Distance

Figure 3.6.1

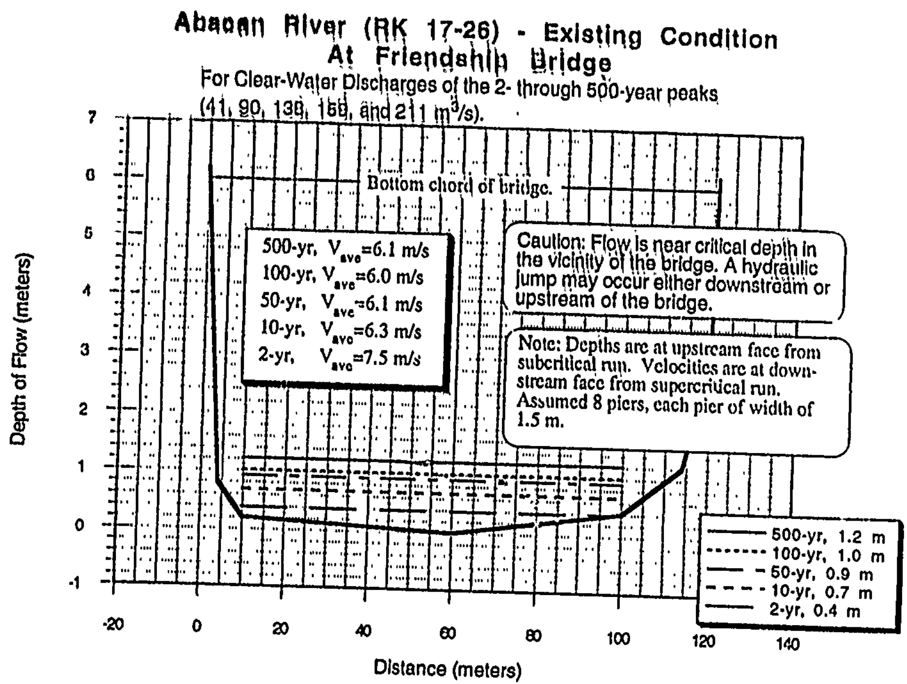

Abacan River (RK 17-26) - Existing Condition At Friendship Bridge
For Clear-Water Discharges of the 2- through 500-year peaks (41, 90, 139, 158, and 211 m³/s).
Bottom chord of bridge.
500-yr, Vave=6.1 m/s
100-yr, Vave=6.0 m/s
50-yr, Vave=6.1 m/s
10-yr, Vave=6.3 m/s
2-yr, Vave=7.5 m/s
Caution: Flow is near critical depth in the vicinity of the bridge. A hydraulic jump may occur either downstream or upstream of the bridge.
Note: Depths are at upstream face from subcritical run. Velocities are at downstream face from supercritical run. Assumed 8 piers, each pier of width of 1.5 m.
500-yr, 1.2 m
100-yr, 1.0 m
50-yr, 0.9 m
10-yr, 0.7 m
2-yr, 0.4 m
Depth of Flow (meters)
Distance (meters)
7
6
5
4
3
2
1
0
-1
-20
0
20
40
60
80
100
120
140

Figure 3.6.2

Bamban River (RK 14-19) - Existing Condition At San Francisco Bridge (Sacobia and Marimla flow)

For Clear-Water Discharges of the 2- through 500-year floods (102, 230, 354, 409, and 541 m^3/s).

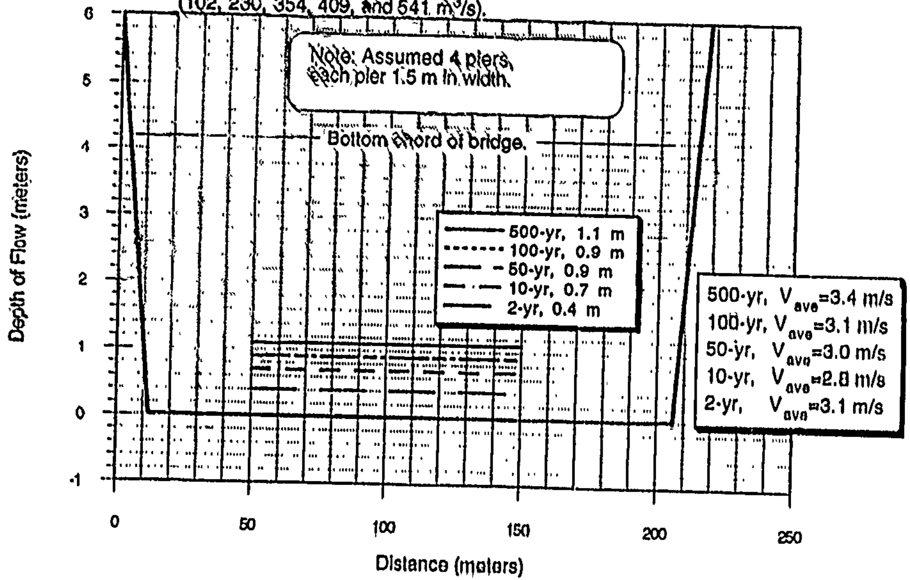


Figure 3.6.3

Bamban River (RK 14-19) - Existing Condition At San Francisco Bridge (Sapobia flow only)

For Clear-Water Discharges of the 2- through 500-year floods (44, 98, 152, 175, and 232m^3/s).

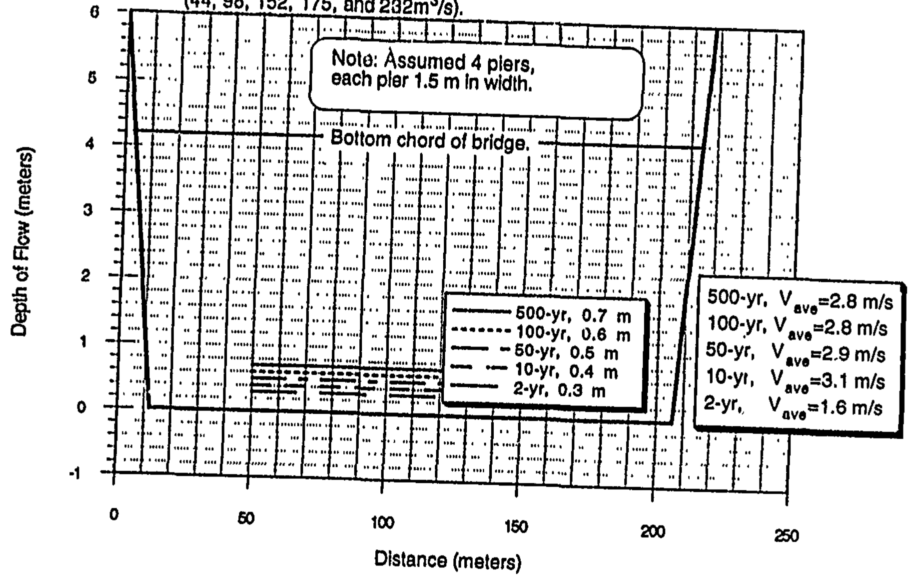


Figure 3.6.4

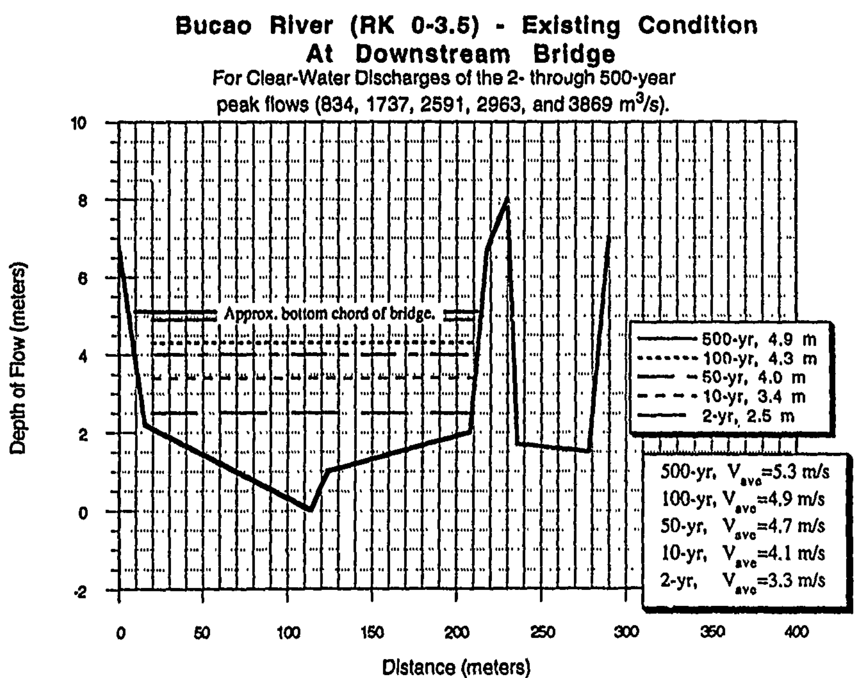

Bucao River (RK 0-3.5) - Existing Condition
At Downstream Bridge
For Clear-Water Discharges of the 2- through 500-year
peak flows (834, 1737, 2591, 2963, and 3869 m³/s).
Depth of Flow (meters)
10
8
6
4
2
0
-2
0
50
100
150
200
250
300
350
400
Distance (meters)
Approx. bottom chord of bridge.
500-yr, 4.9 m
100-yr, 4.3 m
50-yr, 4.0 m
10-yr, 3.4 m
2-yr, 2.5 m
500-yr, Vave=5.3 m/s
100-yr, Vave=4.9 m/s
50-yr, Vave=4.7 m/s
10-yr, Vave=4.1 m/s
2-yr, Vave=3.3 m/s

Figure 3.6.5.

Pasig-Potrero River (RK 1-5) - Existing Condition At Lower (D/S) Bridge

For Clear-Water Discharges of the 2- Through 500Year Floods (90, 195, 294, 337, and 444 m^3/s).

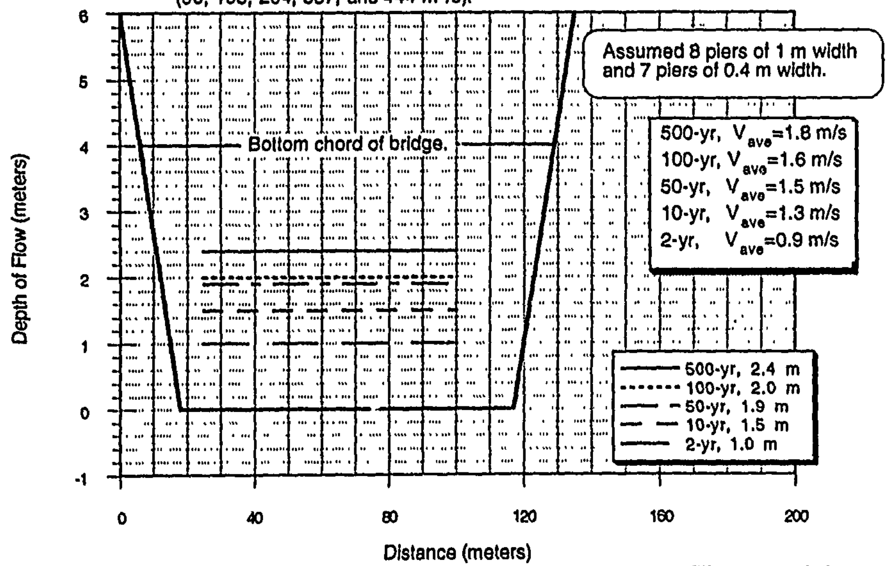


Figure 3.6.6

Pasig-Potrero River (RK 1-5) - Existing Condition At Bypass Bridge

For Clear-Water Discharges of the 2- Through 500-Year Floods (90, 195, 294, 337, and 444 m^3/s).

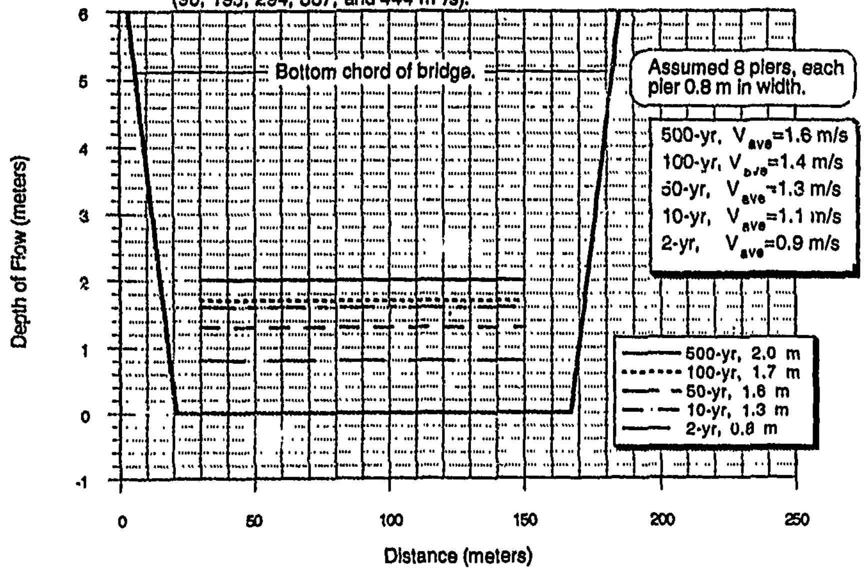


Figure 3.6.7

Porac River (RK 19.5 - 20.5) - Existing Condition At Bridge in Town of Porac

For Clear-Water Discharges of the 2- through 500-year peaks (43, 95, 145, 166, and 219 m^3/s)

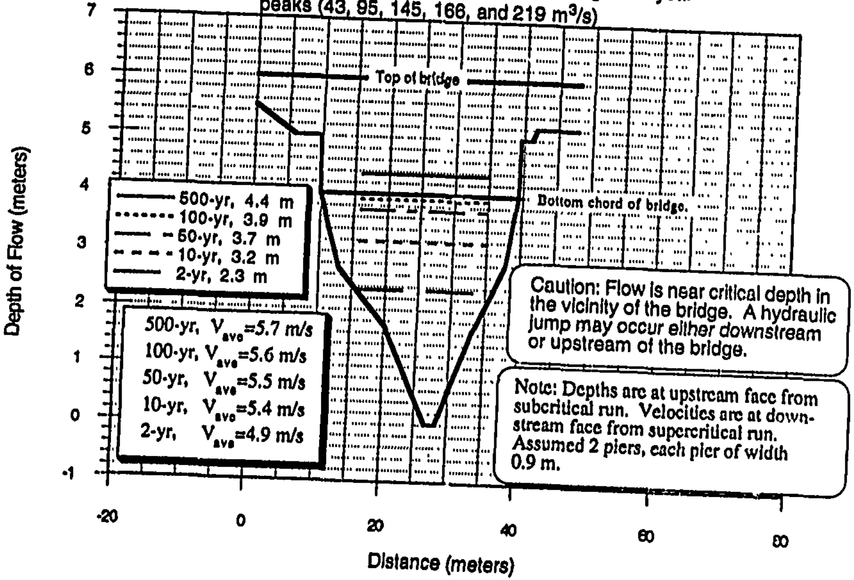


Figure 3.6.8

Santo Tomas River (RK 0-3) - Existing Condition At Macolcol Bridge

For Clear-Water Discharges of the 2- through 500-year peak flows (285,578,867,993, and 1,297 m^3/s)

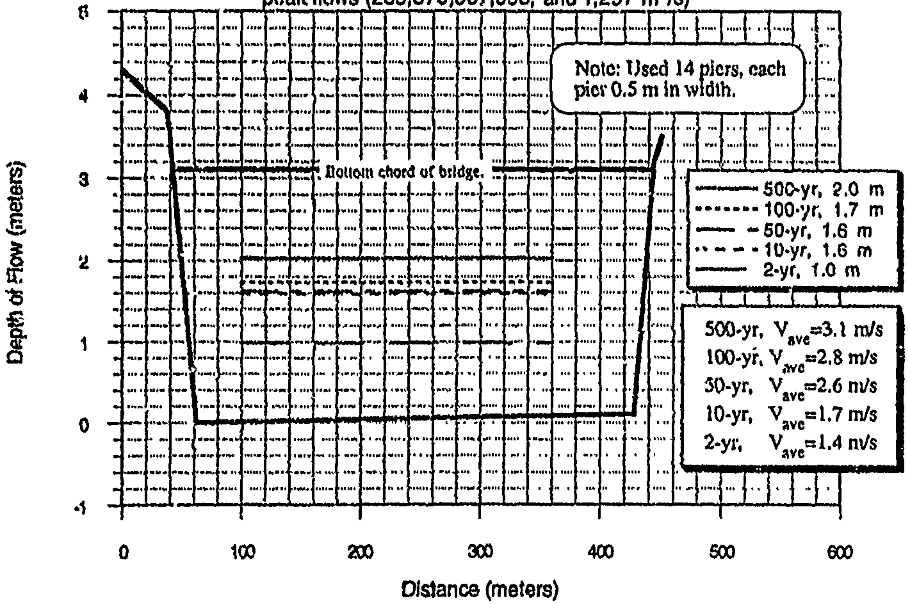


Figure 3.6.9

Tarlac River through Tarlac - Existing Condition
At Agana Bridge

For Clear-Water Discharges of the 2- through 500-year peaks (616, 1273, 1933, 2221, and 2922 m^3/s)

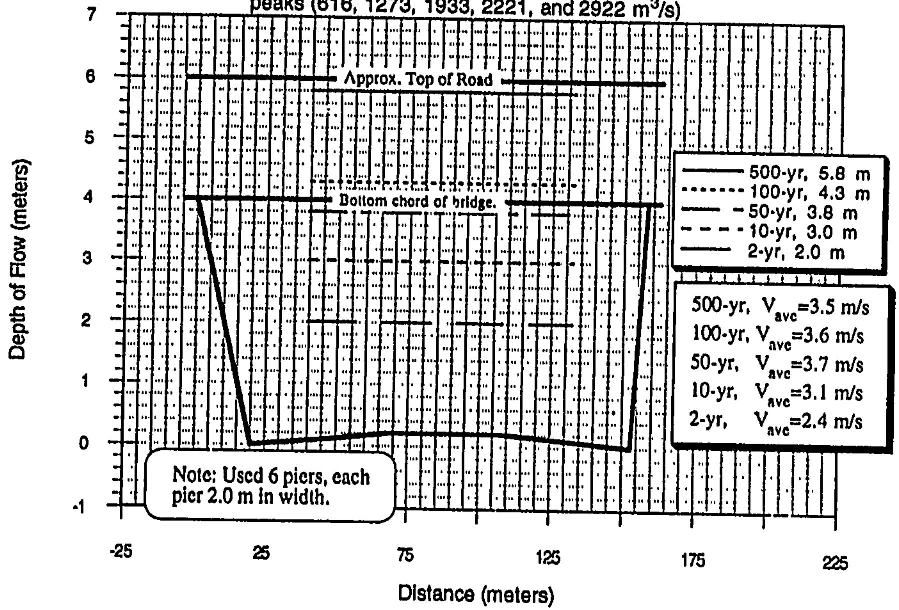


Figure 3.6.10

Tarlac River through Tarlac - Existing Condition At Aquino Bridge

For Clear-Water Discharges of the 2- through 500-year peaks (616, 1273, 1933, 2221, and 2922 m^3/s)

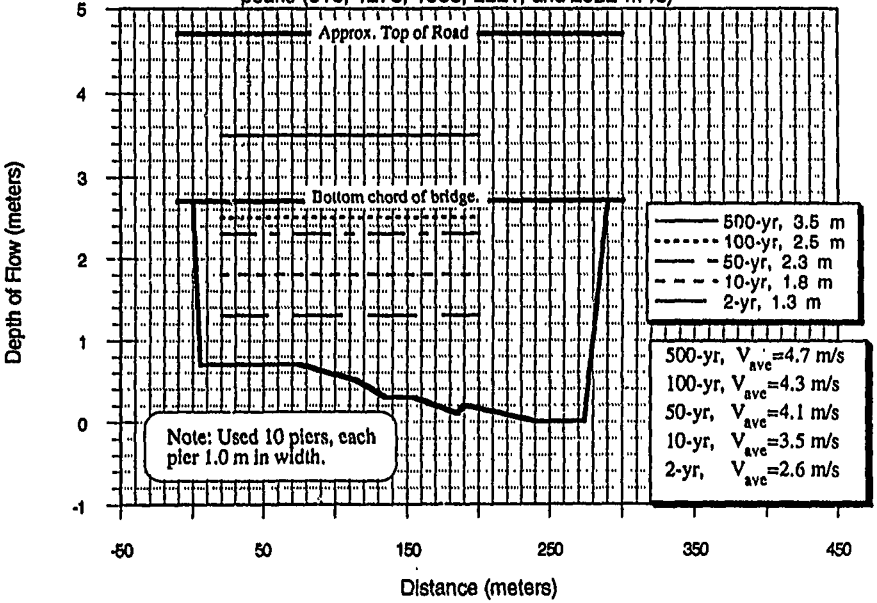


Figure 3.6.11

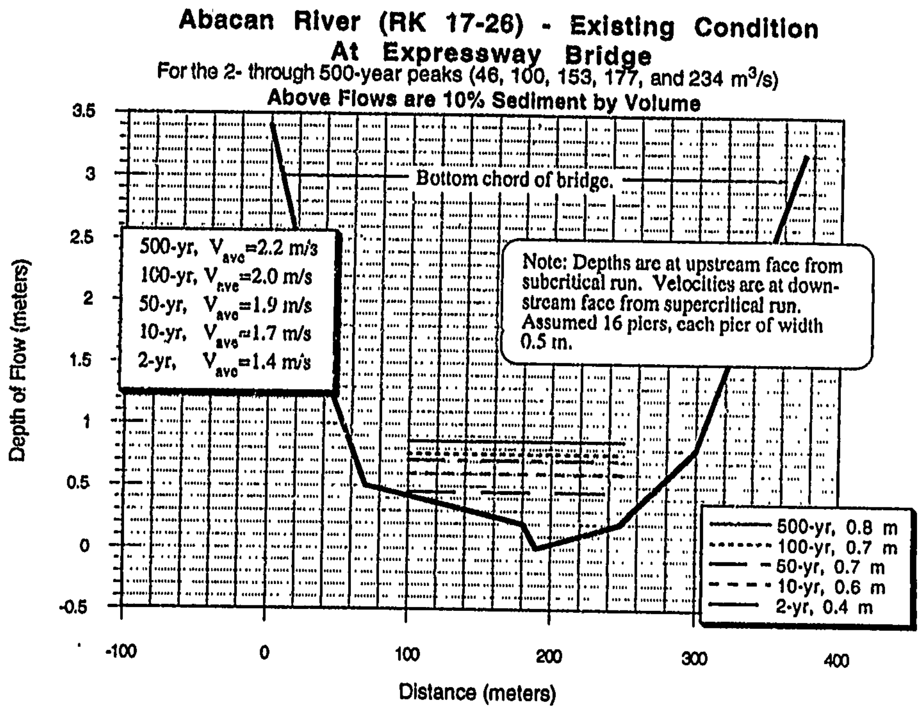

Abacan River (RK 17-26) - Existing Condition
At Expressway Bridge
For the 2- through 500-year peaks (46, 100, 153, 177, and 234 m³/s)
Above Flows are 10% Sediment by Volume
Bottom chord of bridge.
500-yr, Vave=2.2 m/s
100-yr, Vave=2.0 m/s
50-yr, Vave=1.9 m/s
10-yr, Vave=1.7 m/s
2-yr, Vave=1.4 m/s
Note: Depths are at upstream face from subcritical run. Velocities are at downstream face from supercritical run. Assumed 16 piers, each pier of width 0.5 m.
500-yr, 0.8 m
100-yr, 0.7 m
50-yr, 0.7 m
10-yr, 0.6 m
2-yr, 0.4 m
Depth of Flow (meters)
Distance (meters)
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
-100
0
100
200
300
400

Figure 3.6.12

Abacan River (RK 17-26) - Existing Condition At Friendship Bridge

For the 2- through 500-year peaks (46, 100, 153, 177, and 234 m^3/s).

Above Flows are 10% Sediment by Volume

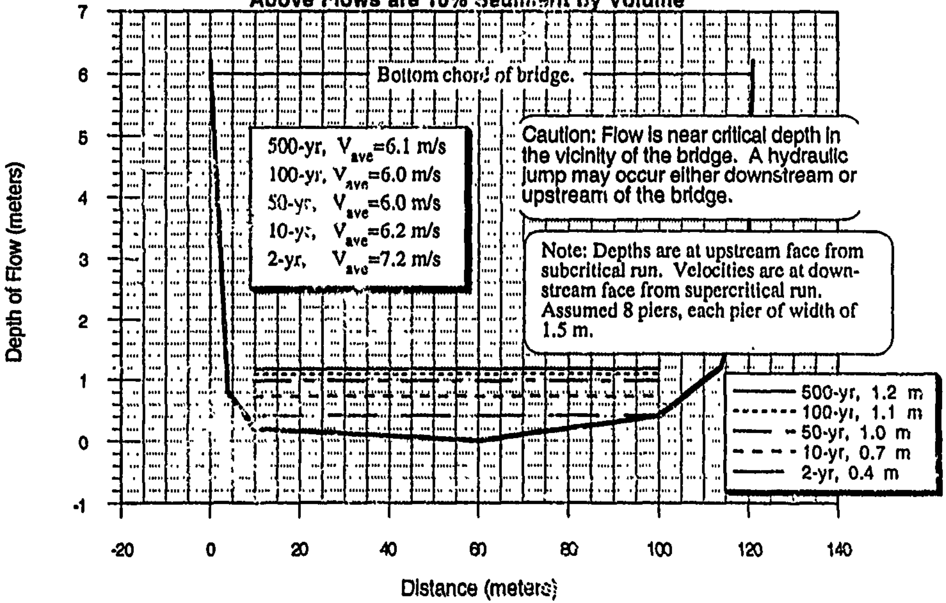


Figure 3.6.13

Bamban River (RK 14-19) - Existing Condition
At San Francisco Bridge (Sacobia and Marimla Flow)
For the 2- through 500-year Floods (131, 298, 458, 528, and 700 m^3/s).
Flow is 22% Sediment by Volume

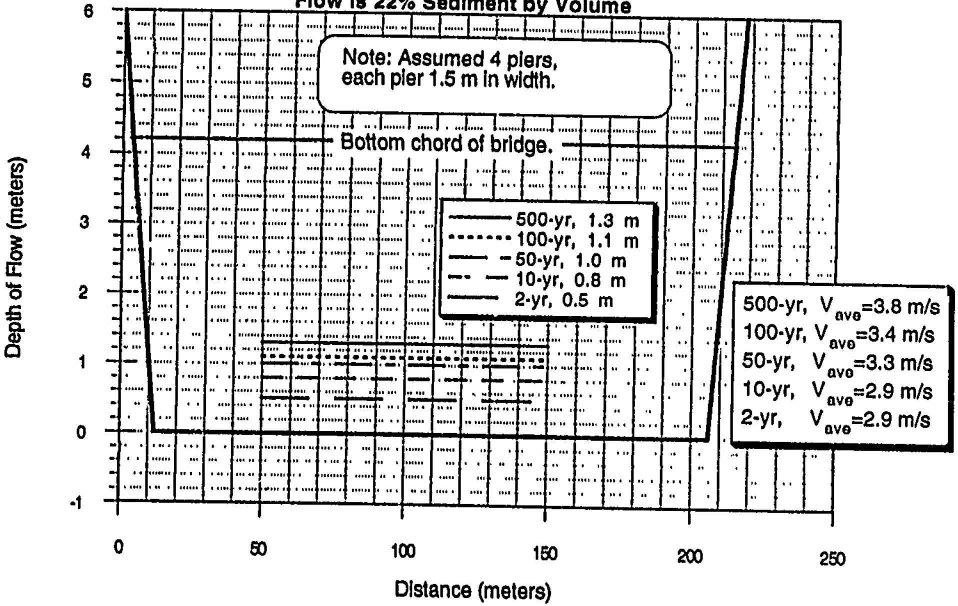


Figure 3.6.14

Bamban River (RK 14-19) - Existing Condition At San Francisco Bridge (Sacobia flow only)

For the 2- through 500-year Floods (68, 151, 232, 266, and 355 m^3/s).

Flow is 35% Sediment by Volume

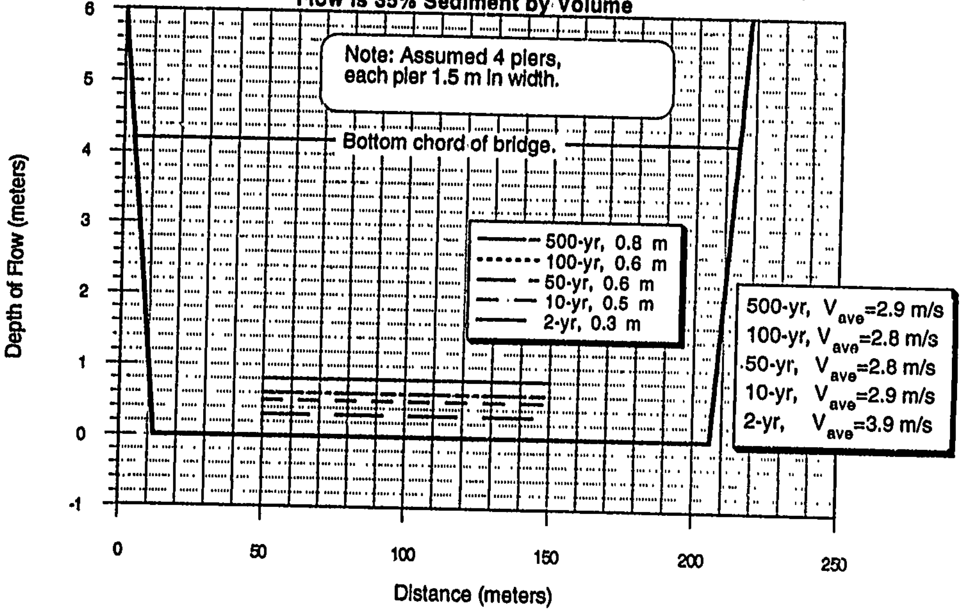


Figure 3.6.15

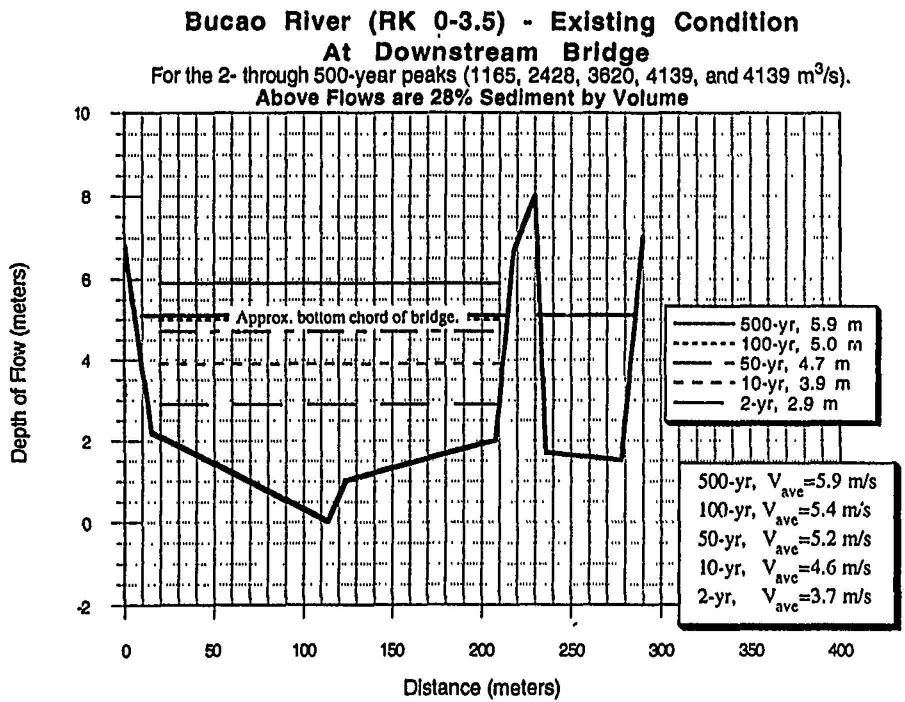

Bucao River (RK 0-3.5) - Existing Condition
At Downstream Bridge
For the 2- through 500-year peaks (1165, 2428, 3620, 4139, and 4139 m3/s).
Above Flows are 28% Sediment by Volume
Approx. bottom chord of bridge.
500-yr, 5.9 m
100-yr, 5.0 m
50-yr, 4.7 m
10-yr, 3.9 m
2-yr, 2.9 m
500-yr, Vave=5.9 m/s
100-yr, Vave=5.4 m/s
50-yr, Vave=5.2 m/s
10-yr, Vave=4.6 m/s
2-yr, Vave=3.7 m/s
Depth of Flow (meters)
Distance (meters)
10
8
6
4
2
0
-2
0
50
100
150
200
250
300
350
400

Figure 3.6.16

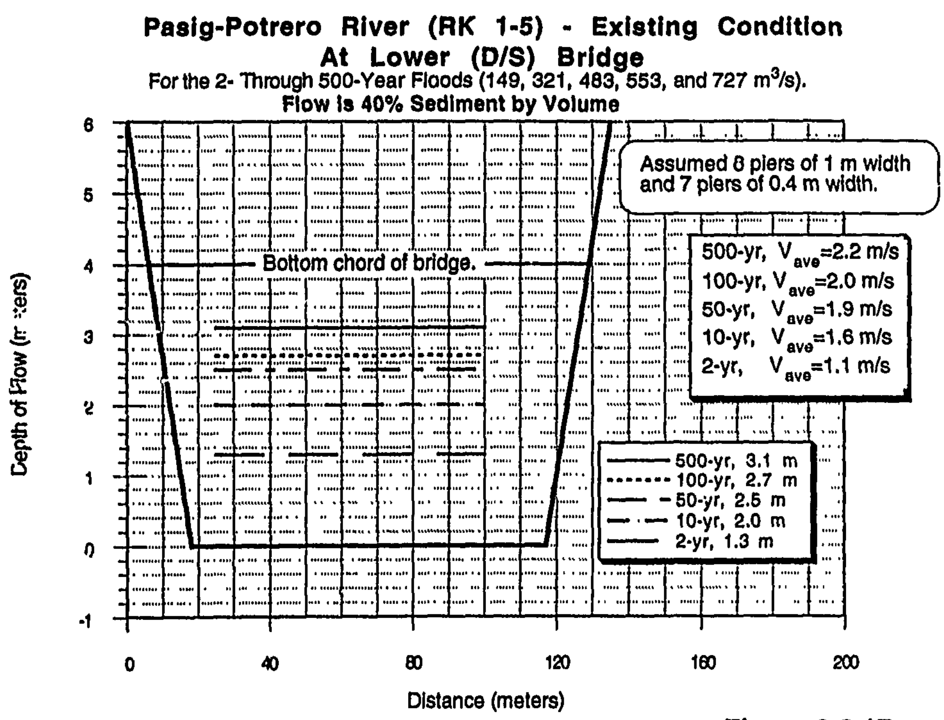
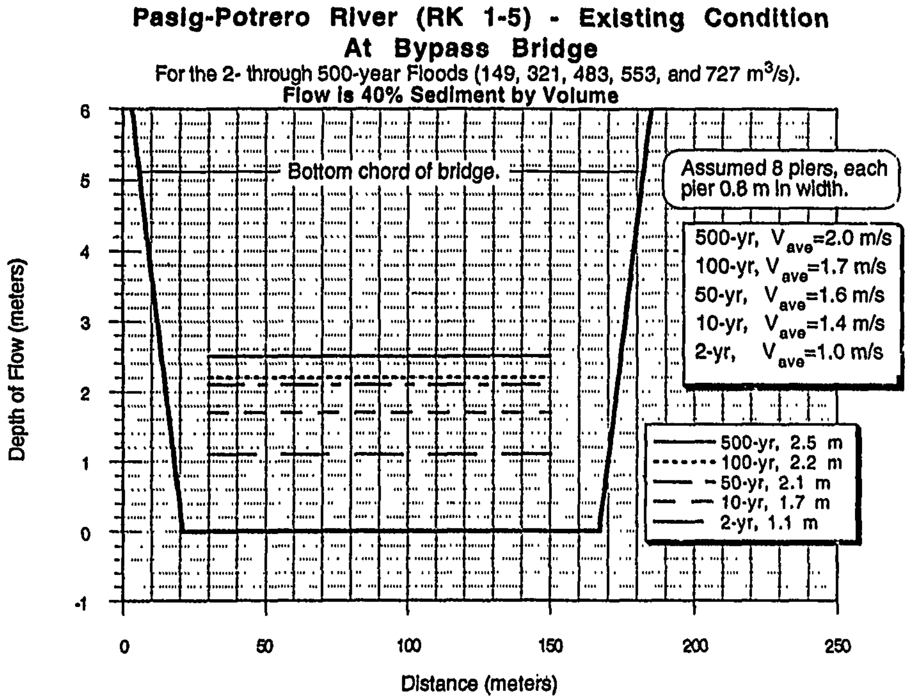

Pasig-Potrero River (RK 1-5) - Existing Condition
At Lower (D/S) Bridge
For the 2- Through 500-Year Floods (149, 321, 483, 553, and 727 m3/s).
Flow is 40% Sediment by Volume
Assumed 8 piers of 1 m width and 7 piers of 0.4 m width.
500-yr, Vave=2.2 m/s
100-yr, Vave=2.0 m/s
50-yr, Vave=1.9 m/s
10-yr, Vave=1.6 m/s
2-yr, Vave=1.1 m/s
Bottom chord of bridge.
500-yr, 3.1 m
100-yr, 2.7 m
50-yr, 2.5 m
10-yr, 2.0 m
2-yr, 1.3 m
6
5
4
3
2
1
0
-1
0
40
80
120
160
200
Distance (meters)
Depth of Flow (meters)

Figure 3.6.17



Pasig-Potrero River (RK 1-5) - Existing Condition
At Bypass Bridge
For the 2- through 500-year Floods (149, 321, 483, 553, and 727 m³/s).
Flow is 40% Sediment by Volume
Depth of Flow (meters)
6
5
4
3
2
1
0
-1
0
50
100
150
200
250
Distance (meters)
Bottom chord of bridge.
Assumed 8 piers, each pier 0.8 m in width.
500-yr, Vave=2.0 m/s
100-yr, Vave=1.7 m/s
50-yr, Vave=1.6 m/s
10-yr, Vave=1.4 m/s
2-yr, Vave=1.0 m/s
500-yr, 2.5 m
100-yr, 2.2 m
50-yr, 2.1 m
10-yr, 1.7 m
2-yr, 1.1 m

Figure 3.6.18

Porac River (RK 19.5 - 20.5) - Existing Condition
At Bridge in Town of Porac
For the 2- through 500-year peaks (48, 106, 161, 184, and 243m^3/s)
Above Flows are 10% Sediment by Volume

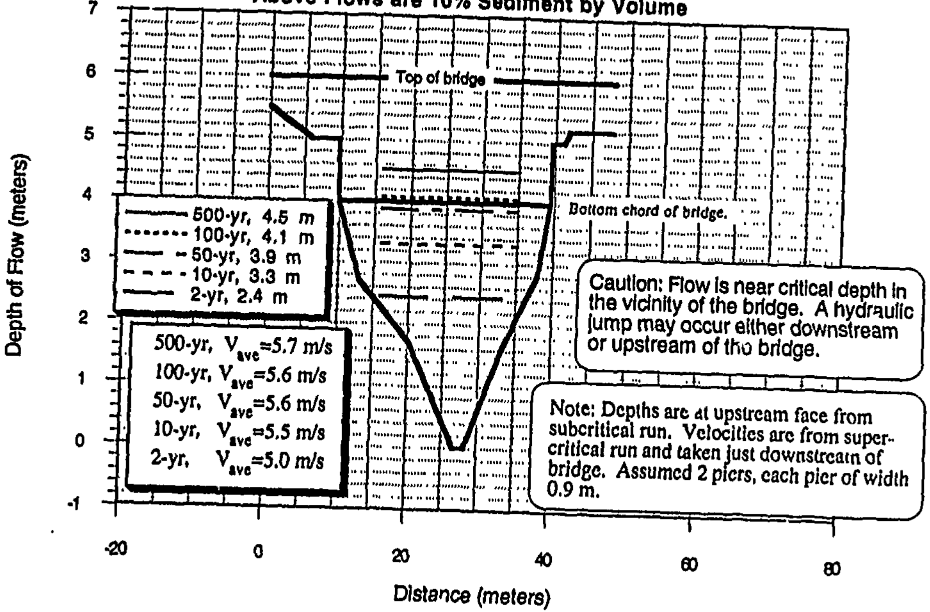


Figure 3.6.19

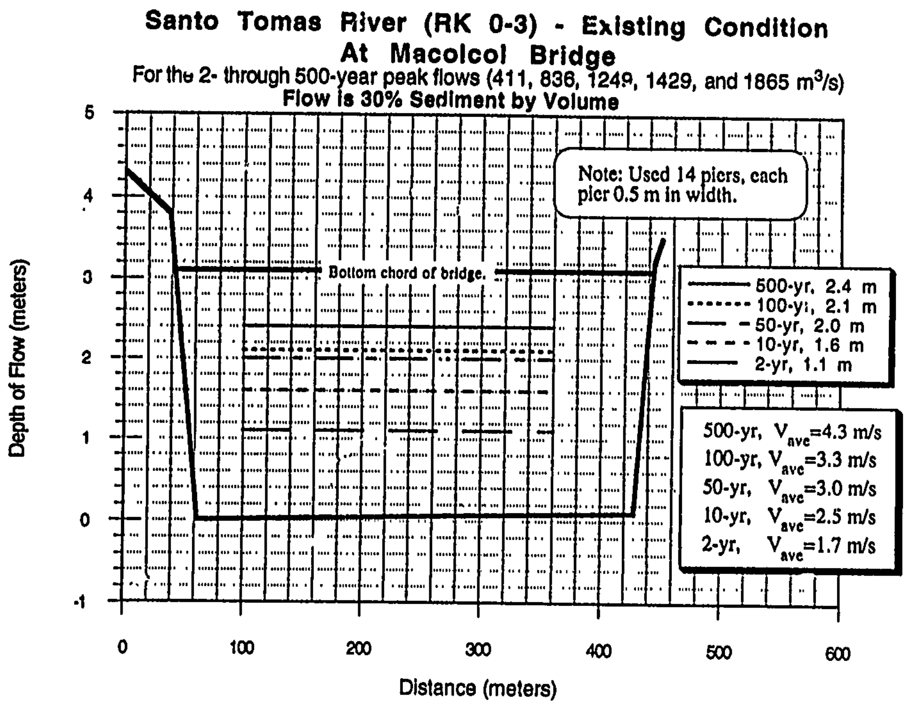

Santo Tomas River (RK 0-3) - Existing Condition
At Macolcol Bridge
For the 2- through 500-year peak flows (411, 836, 1249, 1429, and 1865 m3/s)
Flow is 30% Sediment by Volume
Note: Used 14 piers, each pier 0.5 m in width.
Bottom chord of bridge.
500-yr, 2.4 m
100-yr, 2.1 m
50-yr, 2.0 m
10-yr, 1.6 m
2-yr, 1.1 m
500-yr, Vave=4.3 m/s
100-yr, Vave=3.3 m/s
50-yr, Vave=3.0 m/s
10-yr, Vave=2.5 m/s
2-yr, Vave=1.7 m/s
Depth of Flow (meters)
5
4
3
2
1
0
-1
0
100
200
300
400
500
600
Distance (meters)

Figure 3.6.20

Tarlac River through Tarlac - Existing Condition At Agana Bridge

For the 2- through 500-year peaks (701, 1449, 2200, 2527, and 3324 m^3/s)

Flow is 12% Sediment by Volume

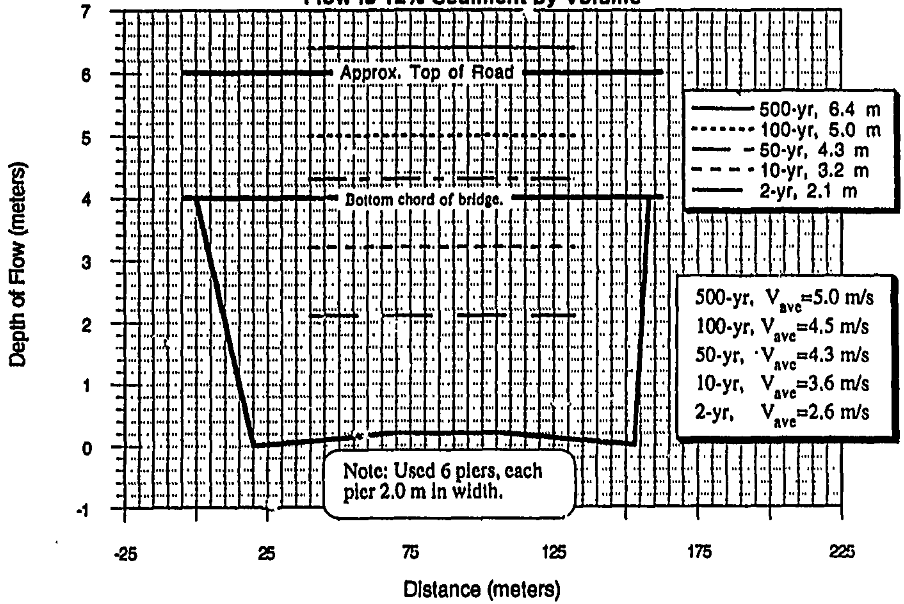
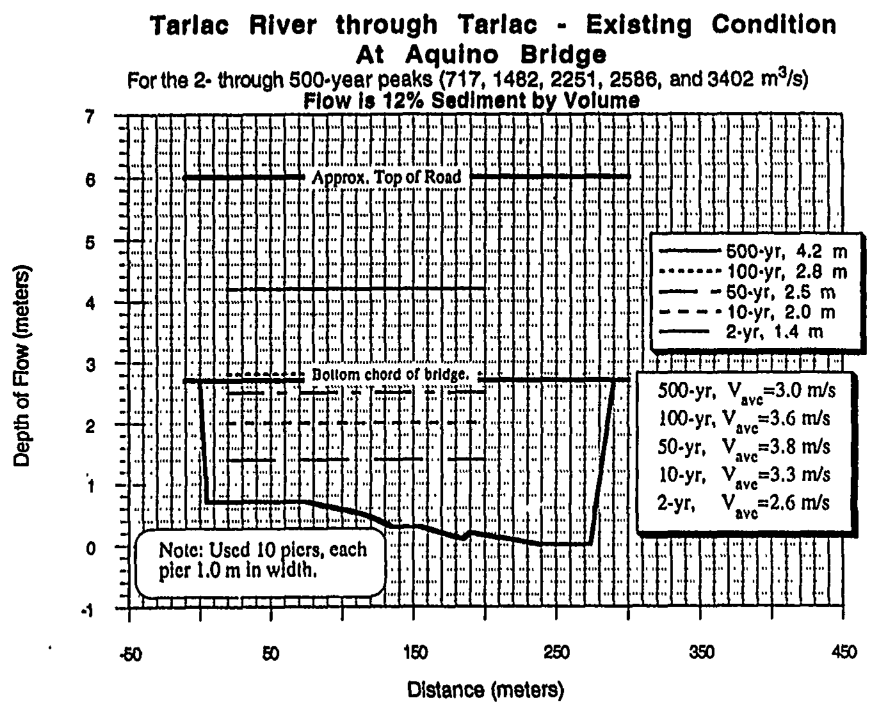


Figure 3.6.21



Tarlac River through Tarlac - Existing Condition
At Aquino Bridge
For the 2- through 500-year peaks (717, 1482, 2251, 2586, and 3402 m3/s)
Flow is 12% Sediment by Volume
Approx. Top of Road
Bottom chord of bridge.
500-yr, 4.2 m
100-yr, 2.8 m
50-yr, 2.5 m
10-yr, 2.0 m
2-yr, 1.4 m
500-yr, Vave=3.0 m/s
100-yr, Vave=3.6 m/s
50-yr, Vave=3.8 m/s
10-yr, Vave=3.3 m/s
2-yr, Vave=2.6 m/s
Note: Used 10 piers, each pier 1.0 m in width.
Depth of Flow (meters)
7
6
5
4
3
2
1
0
-1
-50
50
150
250
350
450
Distance (meters)

Figure 3.6.22

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13. ABSTRACT *(Maximum 200 words)*

The investigation presented in this report provides a hydrology and hydraulics analysis for the eight basins affected by the catastrophic eruption of Mount Pinatubo, The Philippines, on 15 June 1991. Approximately 5.6 billion cubic meters of medium- to fine-grained pyroclastic-flow material was deposited in the upper watershed areas around Mount Pinatubo. Rainfall-runoff has rapidly eroded eruption materials, causing lahars that have flooded low-lying areas. Flooding and sedimentation from Mount Pinatubo lahars have displaced tens of thousands of people from their homes, destroyed bridges and crops, and decreased the amount of land available to agriculture in the lower basin. The analysis of this report presents the hydrology and meteorology pertinent to the design of measures to address long-term flooding and sediment control measures for all eight major river basins impacted by Mount Pinatubo.

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