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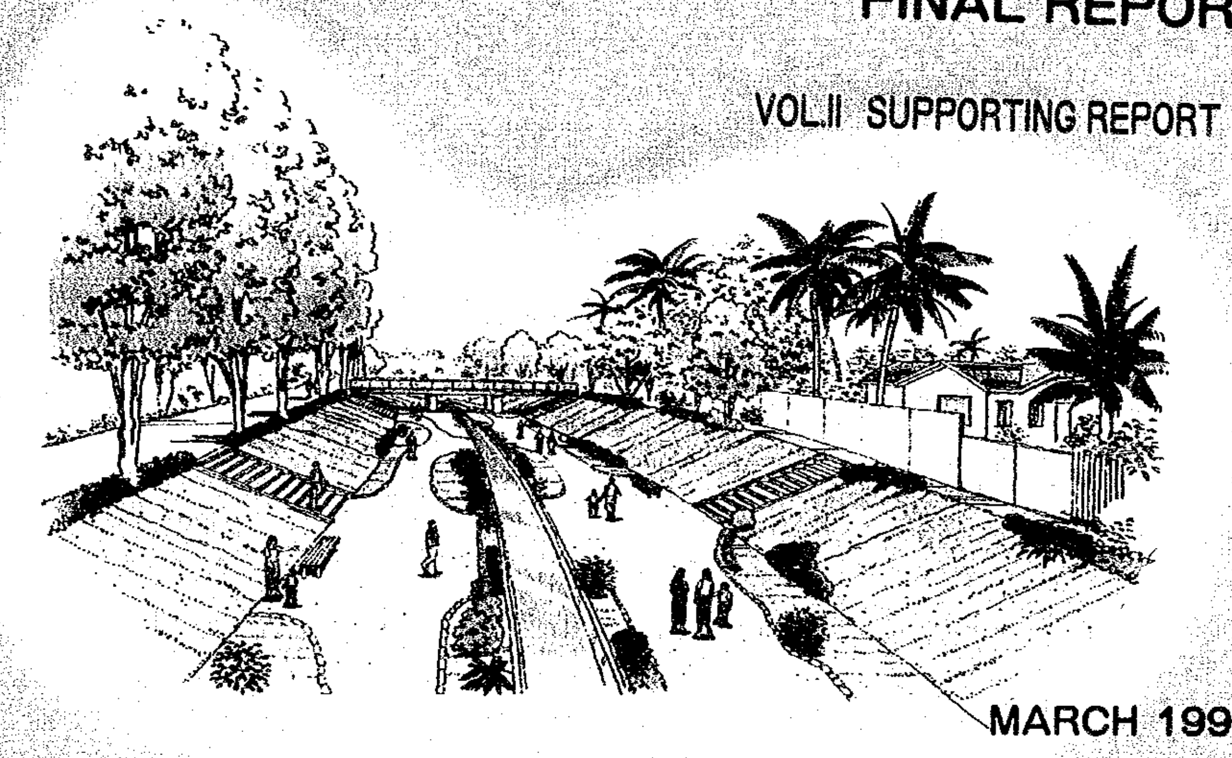
LAO PEOPLE'S DEMOCRATIC REPUBLIC

FEASIBILITY STUDY ON IMPROVEMENT OF DRAINAGE SYSTEM IN VIENTIANE

FINAL REPORT

VOL.II SUPPORTING REPORT (1)



MARCH 1990

JAPAN INTERNATIONAL COOPERATION AGENCY

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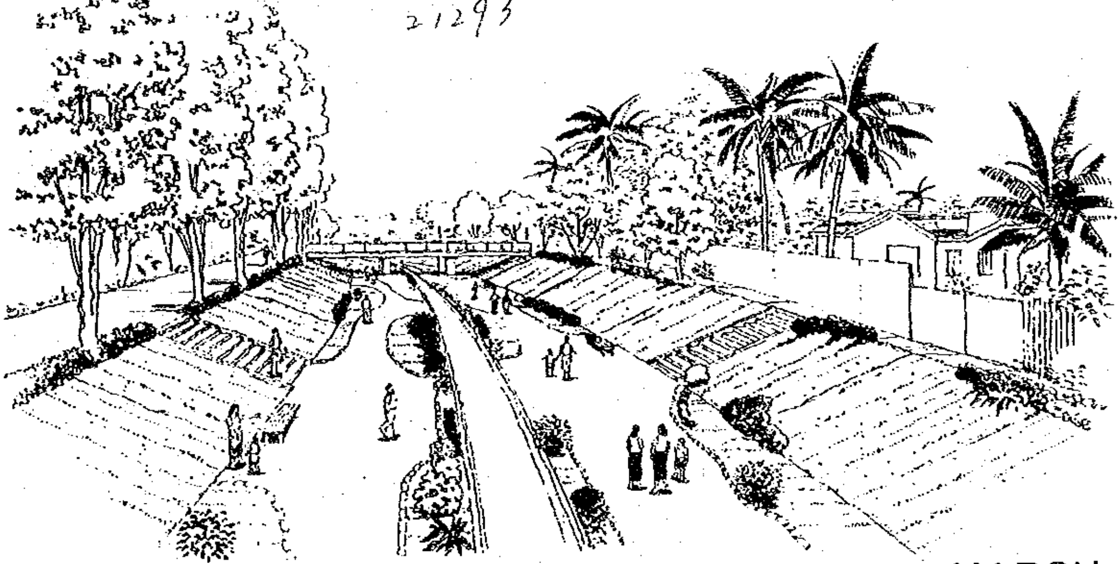

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LIST OF VOLUMES

This is VOLUME II. SUPPORTING REPORT (1).

APPENDIX A

METEOROLOGY AND HYDROLOGY

APPENDIX A METEOROLOGY AND HYDROLOGY

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APPENDIX A. METEOROLOGY AND HYDROLOGY

A.1 Objectives

The objectives of the meteoro-hydrologic study in the present study are as summarized below:

- to collect, review and analyze the existing meteoro-hydrologic data and review the previous studies relevant to this study;
- to collect supplementary data by installing observation instruments and analyze the data;
- to conduct hydrological analysis utilizing the data obtained above and determine the basic design values of the Basic Drainage plan and Feasibility Study.

This Appendix summarizes the results of review and analysis concerning the meteorologic and hydrologic condition of the Study area.

A.2 Review of Existing Data and Reports

A.2.1 Collected Data

The Vientiane Meteorology Station is located near the Wat Tay Airport, west of the central city. The station, which is managed by the Department of Meteorology and Hydrology, the Ministry of Agriculture and Forestry, takes daily recording of various meteorologic data. The basic data of the station are as given below:

Station Name	:	Vientiane, Lao P.D.R.
Latitude	:	17°57' N
Longitude	:	102°34' E
Elevation	:	171.0 m MSL

The daily meteorologic observation has been conducted since around 1900, but some of the old data are not well-maintained. During the field study, the daily rainfall data for the period of 1958 through 1988 have been collected.

The Department also provided the JICA team with in-house material of the annual maximum daily rainfall records since 1900 and monthly meteorologic data for 1969 through 1988.

Besides, the daily rainfall data at the Tha Ngon and Salakam Stations were collected. The data taken at the Salakam Station have frequent interruptions. The basic data of the stations are as given below:

Station Name	:	Tha Ngon, Lao P.D.R.	Salakam, Lao P.D.R.
Latitude	:	18°10' N	17°50' N
Longitude	:	102°40' E	102°40' E
Elevation	:	170.0 m MSL	168.0 m MSL

The water level data of the Mekong related to this study are these recorded at the three gauging stations near and downstream of Vientiane, the location of which are given below:

Station Name	:	Vientiane	Nongkhai	Phon Phisai
Latitude	:	17° 55.61' N	17° 52' 03" N	18° 01.3' N
Longitude	:	102° 37.2' E	102° 42' 11" E	103° 04.7' E
Location	:	Wat Sop village 4 km downstream of Vientiane	At Hydrographic office in Nong Khai	On the right at Chum Phon Phone Phisai
Zero point	:	158.04 m MSL	154.071 m MSL	150.000 m MSL
Distance from River Mouth	:	1,584 km	1,550 km	1,503 km
Catchment area	:	299,000 km^2	302,000 km^2	-

The water level data of other rivers are scarce. On the Houei Makhiao, the daily water level records by a staff gauge located at just downstream from the Makhiao regulator are available for three years. The recording has been disconnected since 1982. The water level records of the Hong Xeng by a staff gauge at Ban Phone Khen are available for 1981 through 1983. The staff gauge was located on the left bank of the Hong Xeng at the bridge site of Route 13, but has been discarded already. The basic data of these two gauges are as given below:

Station Name :	Houei Makhiao at the Regulator	Hong Xeng
Latitude :	17° 59.9' N	17° 59.1'
Longitude :	102° 55.1' E	102° 59.1' E
Location :	Near Ban Makhiao, on the left bank of the river, just downstream of the Houei Makhiao Regulator	On the left bank of the river at Ban Phone Khen at the Route 13 bridge
Zero point :	154.635 m MSL	165.263 m MSL

The following meteoro-hydrologic data have been collected during the field study:

Item	Period
a) Precipitation data	
Daily precipitation data at Vientiane	1958 - 1988
Daily precipitation data at Tha Ngon	1977 - 1988
Annual maximum one-day rainfall at Vientiane	1900 - 1988
Annual maximum rainfall for shorter durations at Vientiane	some
b) Meteorologic data at the Vientiane Station	
Monthly average mean temperature,	1968 - 1988
Monthly average daily maximum temperature,	1968 - 1988
Monthly average daily minimum temperature,	1968 - 1988
Monthly minimum temperature,	1968 - 1988
Monthly average mean relative humidity,	1968 - 1988
Monthly average pan evaporation,	1968 - 1988
c) Water level and discharges of the Mekong	
Daily water level and discharge at Vientiane Station	1923 - 1939
	1942 - 1952
	1961 - 1987
Monthly average discharge at Vientiane Station	1913 - 1987
Daily water level and discharge at Nongkhai Station,	1965 - 1987
Daily water level and discharge at Phon Phisai Station,	1972 - 1987
d) Water levels of other rivers	
Water level data of Houei Makhiao at Ban Makhiao,	1973, 1974, 1981
Water level data of Hong Xeng at Ban Phone Khen,	1981 - 1983

A.2.2 Collected Reports

There have been several studies in which meteoro-hydrologic characteristics of Vientiane and its surrounding regions were scrutinized. The following is the list of the reports which have been collected and reviewed by the study team:

[1] JICA, Feasibility Study on Agricultural and Rural Development Project in the Suburbs of Vientiane, 1989.

[2] Khamthong S. and Sisasvath C., Flood Loss Prevention and Management in the Vientiane Plain, 1988.

[3] Mekong Committee, Flood Protection and Reclamation of Swamp and Marshland in the Vientiane Plain, September 1982.

[4] Mekong Committee, Lower Mekong Hydrologic Year Book, respective volumes.

[5] R.J. Miles for UNDP, Drainage Strategy Study - Urban Development Program, 1987.

[6] Nihon Suido Consultants, Vientiane Drainage Study on Top Priority Project, 1975.

[7] Nippon Koei for the United Nations, Comprehensive Project Feasibility Report on the Nam Ngum Project, Part 2: Lower Nam Ngum Irrigation Project, 1962.

[8] U.S. Agency for International Development, Report on Vientiane Laos Flood Control Project, 1971.

[9] United States Department of the Interior Bureau of Reclamation, Pa Mong Stage One Feasibility Report, Appendix II: Drainage, 1970; and Ditto, Appendix III: Hydrology and Climatology.

Reference [1] contains much of the raw meteoro-hydrologic data in and around Vientiane in the form of a data book. Reference [2] is the latest work by the in-house staff of the Department of Meteorology and Hydrology, and contains the most comprehensive storm rainfall intensity data. Reference [4] is the regular publication of the meteoro-hydrologic data of the Lower Mekong areas. Reference [5] contains the rainfall intensities for durations shorter than 3 hours for 1980 through 1987, with some interruptions. Reference [6] lists the daily rainfall events at Vientiane exceeding 100 mm since 1923 through 1966. Since the daily rainfall data before 1960 are difficult to collect, the data listed in this reference were of some use in determining the one-day probable storms. Reference [8] and [9] contains some of the old data of the floods of the Mekong.

A.3 Overview of Climatic Conditions of Study Area

The climate of the Vientiane is classified as tropical, with distinctive effects of monsoons. The south-western monsoon picks up moisture from the Indian Ocean and causes rainfall in the areas along the lower reaches of the Mekong, starting in mid-May until around mid-October. This period is known commonly as the rainy season. Heavy monsoonal storms occur in this rainy season.

After the rainy season, the north-eastern monsoon will carry over cool air of the Polar Pacific Airmass from Siberia and the mainland of China until mid-February. This period is called the cool season, with generally cool and dry weather in Vientiane. Following this is the hot season characterized by hot and dry weather, which lasts until the next south-western monsoon sets in.

Another factor that influences the storm rainfall is the passing of typhoons. Usually, a typhoon or a tropical depression that originates in the Pacific Ocean or the South China Sea subsides before reaching Lao P.D.R, but very rarely, passes near the Study area. In such an event, with the additional effects of activated fronts, heavy storm rainfall may occur. Most typhoons occur in the south-west monsoon period, when the Study area is generally covered by humid airmass. Table A.1 summarizes the meteorologic conditions of the Study area.

Temperatures in Vientiane ranges from a low of about 16 to 18°C during the coolest months of December and January to a high of 31 to 32°C during the hottest months of March through May. The relative humidity is in general 75 to 80 per cent during the rainy season and 65 to 70 in other periods. Table A.2, A.3 and A.4 respectively summarize the monthly mean, monthly high and monthly low temperatures at Vientiane. Table A.5 summarizes the extreme low temperatures in Vientiane. Table A.6 summarizes the relative humidity at Vientiane. Tables A.7, A.8 and A.9 respectively summarize the pan evaporation, mean wind velocity and sunshine hours at Vientiane.

The annual rainfall at Vientiane ranges from 1,100 mm in a dry year to 2,300 mm in a wet year. The average annual rainfall during 1967 through 1988 is around 1,600 mm, of which about 86 per cent occurs during the period of

May through September. Table A.10 summarizes the monthly rainfall at Vientiane.

At the Tha Ngon Station, about 30 km north of Vientiane along the Route 13 North, the average annual rainfall for the period of 1971 through 1988 was 1,763 mm. Table A.11 summarizes the monthly rainfall at Tha Ngon.

Storms in Vientiane can be classified by the causes into (1) monsoonal and (2) depressional. Rainfall due to monsoonal storms lasts usually for around 3 hours or less with high intensity, and tends to subside soon after the peak.

The annual maximum one-day rainfall is generally in the range of 70 to 140 mm. For 79 years of observation records at Vientiane, the recorded maximum one-day rainfall of 224.2 mm was observed in August 26, 1976. This storm lasted for 14 hours, which is an exceptionally long duration in Vientiane. Another recent heavy storm rainfall occurred in July 20, 1981, with the daily rainfall of 181 mm. This is of the third order in the 79 years of observation. Heavy rainfall intensity lasted for about 3 hours. Table A.12 summarizes the annual maximum daily rainfall at Vientiane.

A.4 Meteoro-Hydrologic Observation Conducted for the Study

A.4.1 Installation and Operation of Meteoro-Hydrologic Instruments

In order to supplement the existing meteoro-hydrologic data, the Study team installed the following recording devices. The location and basic data of the gauges are indicated on Fig. A.1. Plate A.1 shows the instruments as per installed on site. The following is the number of instruments:

Automatic rainfall gauge	:	1 no.
Automatic water level recorders	:	2 nos.
Staff gauges	:	12 nos.

A.4.2 Automatic Rainfall Gauge

The automatic rainfall gauge was installed in the compound of VOM for easy maintenance and convenience of operation. The equipment is mounted on a concrete base, fixed with four anchor bolts, and is protected by a wooden fence. The instrument is a tipping bucket type, Model SKI - I of IKEDA KEIKI for one month reading. The orifice is of standard type of 20 cm in diameter. The gauge part consists of a bucket that tips at every 0.5 mm of rainfall and lets the mercury switch make a closure. The pulse sent from the switch will be transmitted to the recording part, which moves a pen half graduation and records rainfall on a roll paper. The paper needs to be changed once every month. The instrument is driven by four UM-1 batteries. The batteries need to be replace every 6 months. The data taken by the automatic rainfall gauge were used to supplement the hourly storm intensity data.

A.4.3 Automatic Water Level Gauge

Two automatic water level gauges were installed by the Study team. The one is on the Hong Ke downstream of an manual gate at the outlet to the That Luang Marsh, and the other on the Hong Xeng downstream of an irrigation gate near the bridge of Route 13 north.

The instrument used is Model ADR-105 Wp of IKEDA KEIKI, which is of a float-and-weight type with a horizontal drum. For the installation of the instrument, a wooden recorder house was built, mounted on four hard-wood piles installed close to the river bank. One PVC (poly-vinyl chloride) pipe of 15 cm diameter was fixed to the piles for the float. The pipe has holes drilled on its sides so that the water surface within the pipe would respond to the water stage of the river. Another PVC pipe of 10 cm diameter was fixed to the piles for housing the weight, so that the weight would not be affected by winds.

The instrument takes the level of the float and records it automatically on roll paper with two pens. The reading of the instrument has been adjusted to the staff gauge, installed at one of the piles. The paper roll needs to be changed every month. The instrument is driven by one UM-2 dry battery, which usually lasts for 3 months, but it is recommended to replace the battery earlier taking account possible voltage drop. At the time of each paper change, the voltage of the batteries needs to be checked by the battery checker switch placed on the driver. The data taken by the automatic water level recorders were utilized for the analysis of hourly variations of the water levels and discharge at the respective sites. A rough sketch of the gauging stations is shown in Fig. A.2.

A.4.4 Staff Gauges

Twelve staff gauges, including two at the automatic gauge sites, were installed in and around the Study area. The location of the gauges were determined so that the water level profile of water courses in and downstream of the Study area could be clarified. The water levels at the staff gauges were taken simultaneously under different hydraulic conditions and be used chiefly for assessing the head losses and slopes of the water surface within the main channels.

A.4.5 Discharge Measurement

At the automatic gauge sites at Hong Ke and Hong Xeng, the Study team have measured the river flow regularly, using a direct-reading water current meter. The water current meter being used is NAKAASA Model J-072. This current meter has a Price type transmitter with a screw that rotates in the flow. The flow velocity will be shown on the analogue scale for direct reading. The measuring range is 0.2 to 4 m/sec, which is considered to be appropriate for the discharge measurement requirements in this Study.

For the convenience of discharge measurement, wooden bridges were constructed at the automatic water level gauge sites as part of the hydrologic observation activities. The bridge at Hong Xeng site is approximately 15 meters in total length with three hard-wood piles, and the bridge at Hong Ke is about 6 meter in total length with two piles. With the bridges, discharge measurement were done very effectively and safely even in high flow periods.

A.5 Regional Hydrology

A.5.1 Overview

The major rivers relevant to the Study area are the Mekong, Nam Ngum and Houei Makhiao. The Mekong, which bounds the Study area on the south and west, is the principal water source of municipal supply and irrigation. The Nam Ngum is a tributary of the Mekong which drains most of the northern Part of the Vientiane Plain. The Houei Makhiao, a minor tributary of the Mekong, drains areas in-between the Mekong and lower reaches of the Nam Ngum. The Study area is located at the western end of the Houei Makhiao basin. Fig. A.3 shows the Vientiane Plain and the rivers.

The Mekong rises at the rim of the Great Tibetan plateau. It enters its lower basin at the common Burma-Laos-Thailand boundary point and flows for some 2,380 km to the ocean. Almost the whole of Lao P.D.R. is located on the left bank of the Mekong, and drains into the Mekong. At the Vientiane gauging station at Wat Sop, about 4 km downstream of Vientiane, the Mekong river has the drainage area of 299,000 km^2. The discharge of the Mekong is in the range of 1,000 to 2,000 m^3/sec for most of the time in January to May, then increases gradually during the months of June and July. In August and September, the discharge often exceeds 10,000 m^3/sec, and in October onwards, the discharge returns to its initial range. The average discharge at Vientiane station for the period of 1913 through 1986 is 4,594 m^3/sec, which corresponds to the annual run-off depth of 484 mm. Table A.13 summarizes the monthly discharge of the Mekong at Vientiane.

On the regional scale, the Study area is located in the middle of the southern rim of the Vientiane plain, which is chiefly drained by the lower reaches of the Nam Ngum and Houei Makhiao. The Vientiane plain extends in the elevations ranging from 160 to 180 m with mild undulations gently sloped toward the south and southeast. The soil in the Vientiane plain can be classified into the two groups; brown lateritic old alluvial soil group, which is accumulated on residuals of sand stonea and silt stonea; and grey brown hydromorphic alluvial soil, recently transported by the Nam Ngum and Mekong.

The Houei Makhiao drains to the Mekong near Ban Makhiao village. The confluence of the Makhiao with the Mekong is located about 64 km downstream of Vientiane along the Mekong, or about 1,524 km from the river mouth. The main water courses in the Study area such as the Nam Pasak, Hong Ke and Hong Xeng are all tributaries of the Houei Makhiao. Near the confluence of the Houei Makhiao to the Mekong, there is a gate to prevent the backwater of the Mekong in the high flow period. The Houei Makhiao has the drainage area of 441 km^2 at the outlet to the Mekong.

A.5.2 Hydrology of Study Area

The Study area is drained by the Nam Pasak, Hong Xeng and Hong Ke through the Houei Makhiao to the Mekong. The Nam Pasak river used to flush to the Mekong near the Vientiane city, but the outlet is clogged now. Most of the upstream Nam Pasak basin forms a flat area with an extensive swamp/marsh topography. There is an area of 575 ha in this basin below the elevation 167.0 m which is mostly either swamp or paddy fields. This area thus has a distinctive natural retardation effect. The former downstream reach of the Nam Pasak river close to the central city is now redirected to the Hong Xeng. This reach is about 15 to 30 m wide bank-to-bank, with several ox-bows near the former outlet to the Mekong.

The western part of the Study area is drained to the upstream Nam Pasak through irrigation/drainage canals. The Nong Douang Marsh is a natural pond that stretches a water surface area of 11.0 ha at El. 168 m. Despite its potential capacity as a retardation basin, the Nong Douang Marsh is not fully utilized for this purpose due mainly to insufficient inlet/outlet capacities.

The Hong Xeng starts at the confluence with the upstream Nam Pasak and flows eastward. The channel is about 10 to 30 meters wide and is fairly straight. There is a bridge of Route 13, and at about 300 m downstream of the bridge, a gated irrigation intake exists, which diverts the flow south to the Northern part of the That Luang Marsh in the dry season. The Hong Xeng is then joined by a drainage canal from the That Luang Marsh and connects to Bueng Khat Khao swamp, which drains to the Houei Makhiao near the Ban Xok Noy village.

The Hong Ke river conveys the outflow of the Nong Chanh Marsh to the That Luang Marsh for about 2.7 km. The Nong Chanh Marsh has water surface of 12.3 ha at El. 167.0 m, and 23.4 ha at El. 168.0 m. The Nong Chanh Marsh receives the discharge of the Hong Thong and Khoua Khao. The Hong Thong, about 10 to 30 m wide, most of the central city areas and Thong Kham Kham area. The Khoua Khao usually outflows to the Mekong by gravity. When the water level of the Mekong rises to the level of the sill of the stop-log (about 166.0 m), the outlet is closed manually to disconnect the Mekong. In this condition, the Khoua Khao flows backward to the Nong Chanh Marsh.

A.5.3 Water Levels of Main Canals

(1) Simultaneous Observation of Water Levels

For the purpose of clarifying the water surface profiles in the main channels, water levels at the 12 staff gauges are observed several times during the study period. The results of the gauge reading are summarized in Table A.14.

The water levels of the Hong Thong (Point 3 in Fig A.1) were the highest among the observed water courses, which are in the range of 167.5 to 167.9 el.m. The water levels of the upstream (Point 2) and downstream (Point 5) of the Nong Chanh Marsh were both in the range of 166.9 to 167.4 el.m. The water levels of the Nam Pasak at the confluence with the Hong Thong (Point 4) were in the range of 166.7 to 166.8 el.m, which are about 0.8 to 1.1 m lower than those of the Hong Thong. Near the boundary of the Study area, the water levels of the Hong Ke were normally slightly higher than the water levels of the Hong Xeng. The water levels of the That Luang drainage canal (Point 11) were in the range of 164.4 to 165.2 m (Point 11). The water level of the Bueng Khat Khao at a bridge near Ban Xok Noy (Point 12) were in the range of 163.4 to 164.1 el.m, or about 1.1 m below the level of the That Luang drainage canal (Point 11).

Maximum and Minimum water levels of Main Canals

Point No.	Canal	Minimum (el.m)	Maximum (el.m)
1	Khoua Khao	165.77	165.97
2	Khoua Khao	166.98	167.35
3	Hong Thong	167.54	167.94
4	Nam Pasak	166.71	166.88
5	Hong Ke	166.93	167.35
6	Hong Ke	165.69	165.91
7	Hong Ke	165.25	165.69
8	Upstream Nam Pasak	165.83	166.50
9	Hong Xeng	165.03	166.02
10	Hong Xeng	164.21	165.23
11	That Luang drainage	164.44	165.20
12	Houei Makhiao	163.39	164.07

(2) Water Level Records of Hong Xeng

Daily water level records of the Hong Xeng river at Ban Phon Khen (near the bridge of the route 13) exist for the years 1961, 1980, 1981 and 1982. Fig. A.4 shows the fluctuation of the water level during the rainy season. The following table shows the monthly maximum water levels of the observed daily data.

Maximum water level of Hong Xeng at B. Phone Khen

	May	June	July	Aug.	Sep.	Oct.	Nov.
1961	-	165.7	165.7	166.4	166.6	166.6	164.8
1980	-	-	-	166.5	166.6	166.2	-
1981	-	-	166.7	166.6	166.5	166.2	-
1982	166.2	166.2	-	-	-	-	-

Note: - indicates no observed data

It should be noted that the water levels of the Hong Xeng at Ban Phone Khen are affected by the operation of the gates for irrigation water supply downstream of the bridge of Route 13.

(3) Water Levels Recorded by Automatic Water Level Gauges

At the automatic water level gauges installed by the Study team, the water levels are recorded from June onwards. The Hong Ke site is located downstream of a gate on the Hong Ke at the That Luang Marsh. Farmers often close the canal for intaking water for irrigation downstream of the gauge. Water levels are affected sometimes by the backwater from the clogging. The Hong Xeng site is located downstream of an irrigation gate on the Hong Xeng, downstream of the bridge of Route 13. Condition of flow at the Hong Xeng site is relatively good.

The water levels recorded by the two automatic gauges, together with the daily rainfall recorded by the automatic rain gauge, are summarized in Table A.5 and shown in Fig. A.5. The water level at the Hong Ke site is 0.5 to 1 m higher than the water level at the Hong Xeng site. The water level of the Hong Xeng is more susceptible to the rainfall than the Hong Ke, presumably because the catchment of the Hong Xeng is larger than that of the Hong Ke. The water levels taken by the automatic gauges are summarized in Table A.15

(4) Water Level of End-Points of Priority Project

For the designing of the priority projects, the water levels in the water course at their respective end-points are important, since the backwater from the downstream water bodies may affect the water levels in the main canals.

For the Hong Ke system, the boundary condition of the flow in the main canals will be given by the water level of the That Luang marsh. Unfortunately, there are no reliable records of the water levels in the That Luang Marsh. The study team conducted a hearing survey in the area to estimate the water level. The location of No. 11 staff gauge was chosen for the survey. This site at the outlet of a drainage canal from the Marsh to the Hoei Makhiao, just downstream of the pier of a bridge that crosses the canal. The survey was conducted on June 9, 1989, in which local residents familiar with the water level conditions at the location were asked to point the highest water level in the last five years on one of the existing structures on site. Based on the water level reading of the staff gauge at the time of the survey, the pointed level was converted to the elevation by adding the difference between the pointed level and the water surface.

For the Hong Xeng system, the flow condition of the Nam Pasak will be affected by the backwater of the Hong Xeng. A hearing survey was conducted on 26/10/1989 in the same format.

The water levels thus determined by the hearing surveys at the two points are summarized in Table A.16. The water levels of That Luang at Point 11 range from 165.0 to 165.4 m. With the possible error in such hearing survey take into consideration, HWL at Point 11 was assumed on the safe side as 165.5 m. The water levels of the Hong Xeng at Dongdeng (Point 8) range between 167.3 and 167.5 m. HWL at Point 8 was thus determined as 167.5 m.

A.5.4 Past Floods of the Mekong

The recorded maximum flood during the 73 years of observation was recorded in 1966. At the Vientiane station, the water surface exceeded the flood level (gauge height of 11.5 m) for 19 consecutive days from August 28 to September 15. The highest daily gauge height of 12.70 (El. 170.74 m) was obtained on September 4, 1966, with the estimated daily average flood discharge of 25,900 m^3/sec, after being adjusted for the overbank flow. The estimated peak discharge was 26,000 m^3/sec. The recurrence interval of this flood is estimated to be around 50 years. Table A.17 presents the annual maximum discharges of the Mekong at Vientiane since 1900.

An extensive flood damage occurred along the Mekong river. The river dikes were topped at several locations including one upstream of the Wat Tay airport, and flooded most of the areas in Vientiane below 170 m in elevation. Some 200,000 people had to be evacuated in Thailand also due to flooding, according to a USBR survey.

Another large flood was experienced in 1971. The Vientiane station's gauge reading exceeded the flood level for 23 days from August 17 through September 8. The daily peak discharge occurred on August 22, with the gauge height of 12.51 m (El. 170.55 m). This flood was not confined by the dikes, either, and caused extensive flooding throughout the Study area. This flood is the fourth largest flood in terms of the peak discharge in the 73 years of observation. The recurrence interval of this flood is estimated to be around 20 years.

The present flood dyke, constructed by the Mekong Committee under phase I of the Flood Protection and Reclamation of Swamp and Marshland in the Vientiane Plain, will result in a top elevation of 170.8 m MSL at Chinaimo. This top level of the dykes is slightly above the 10-year flood level (fully-dyked). The Mekong Committee is proposing Phase II of the same project, which will protect the whole areas of Vientiane and Nong Khai against the 25-year flood.

A.5.5 Water Level of the Mekong and Rainfall

The water levels of the Mekong and occurrence of the storm rainfall are the two probabilistic events which are not independent. In this section, the water levels of the Mekong at Vientiane and storm rainfall intensities at Vientiane will be discussed as correlated probabilistic events.

The cause of the correlation comes chiefly from the seasonality of the two events embedded in the regular changes in the climatological conditions. The following analysis is intended to clarify the underlying seasonal characteristics of the two events.

(1) Seasonality of Maximum Water Level of Mekong

The following table summarizes the monthly distribution of the occurrence of annual maximum water level of the Mekong at Vientiane for the 73 years of observation period.

Month	July	Aug.	Sept.	Oct.	Total
No. occurrence of annual max.	3	47	18	5	73

This indicates that for most of the years the annual maximum water level of the Mekong at Vientiane occurs in either August or September.

(2) Seasonality of Storm Rainfall in Vientiane

Monthly distribution of the occurrence of annual maximum one-day rainfall at Vientiane is summarized in the following table:

Month	Apr.	May	June	July	Aug.	Sept.	Oct.	Total
No. occurrence of annual max.	2	13	12	18	15	16	3	79

Compared with the monthly distribution of annual maximum water levels of the Mekong as discussed in item (1) above, the occurrence of the annual maximum rainfall in Vientiane tends to be distributed more evenly over the longer period of April through October. In July, August and September, when the water levels of the Mekong is generally high, only 49 years out of 79 sample years experienced annual maximum one-day rainfall.

(3) Characteristics of Correlation of Two Events

There are 47 years when the water levels of the Mekong at Vientiane is known for the day on which the annual maximum daily rainfall occurred in Vientiane. A histogram was made of the water levels of the Mekong at Vientiane for these 47 samples. The following table summarizes the histogram:

Periods	< el. 159 m	159 - 161	161 - 163	163 - 165	165 - 167	167 - 169	> el. 169 m
July through Sept.	0	0	1	7	12	9	1
Other months	2	10	1	3	1	0	0
Total	2	10	2	10	13	9	1

As seen from the above, the histogram has two peaks. One peak is in the range between el. 159 to 161 m and the other is in the range el. 165 and 167 m. This seemingly unnatural two peak histogram can best be explained by dividing the period in which the annual maxima occurred. For the years in which the annual maximum rain occurred in July through September, the separated histogram shows a clear peak in the relatively high range of el. 165 and 167 m, whereas for the years in which the maximum occurred in other months, the histogram has a peak at a low range of el. 159 to 161 m.

A.6 Analysis of Storm Rainfall

A.6.1 Storm Rainfall Recorded by Automatic Gauge

The automatic rainfall gauge, which was installed by the Study team in the compound of the MOV, recorded rainfall for the months of June through September 1989. The maximum rainfall recorded by the automatic gauge is the rainfall of 4th of August, with the daily rainfall of 73.0 mm. Most of the rainfalls have high intensity of more than 50 mm/hr for less than an hour at the beginning of the rainfall event, and the continuous downpour continues only for around one to two hours. After that, light rainfall may follow with interruptions. Fig. A.6 shows some of the representative rainfalls recorded by the automatic gauge.

In order to clarify the characteristics of storm rainfalls at Vientiane, mass curves (cumulative rainfall plotted against the time) were prepared for the storm rainfalls recorded by the automatic gauge. In a typical storm rainfall event, high intensity rainfall usually comes at the beginning of each rainfall event, and the rainfall tends to subside quickly after the peak. The mass curves show this characteristic of storm rainfall at Vientiane clearly. In about 3 hours after the beginning of the rainfall, more than 80 per cent of the total rainfall occurs. Fig. A.7 shows the mass curves of the storm rainfalls.

A.6.2 One-Day Storm Rainfall Intensity

Daily rainfall records at the Vientiane station are said to exist since 1900 and onwards, but older records are hard to locate today. Based on four different sources, the annual maximum daily rainfall at Vientiane are collected for 1900 through 1987, with 1911, 1912 and 1942 through 1948 interrupted. For the period of 79 years, the recorded maximum daily rainfall occurred in August 26, 1976 with the daily rainfall of 224.2 mm.

On the basis of these data, a frequency analysis was conducted for estimating the probable rainfalls. The following table summarizes the results of the analysis:

Probable One-Day Rainfall

Method	Probable rainfall (mm/day) with the return period of				
	2 years	5 years	10 years	20 years	50 years
Gumbel*	104.0	132.1	150.6	168.4	191.4
Pearson III	102.3	128.5	147.2	166.0	191.9
Iwai	105.3	132.2	150.9	169.5	194.5

*: Selected for use

On the whole, the three methods agrees within the range of 3 per cent. Since the previous studies all used the Gumbel's method, the present study will also adopt this method for the probable rainfall estimation. Fig. A.8 shows the frequency curve of the one-day rainfall by the Gumbel's method.

In order to compare the result of the frequency analysis for the present study with the results of the previous studies, the one-day probable rainfall estimates of the four other studies are tabulated for comparison below:

Comparison of Probable One-day Rainfall in Previous Studies

(Unit : mm)

Source of Study	Probable Rainfall for the Return Period of:							Length of data (years)
	2	5	10	20	25	50	100	
Present Study	104.0	132.1	150.6	168.4	174.0	191.4	208.7	79
Khamtong et al. [2]	-	131.5	151.0	-	175.0	194.0	212.0	78
R. J. Miles [5]	102.0	130.0	149.0	-	173.01	191.0	208.0	78
Nihon Suido [6]	-	125.0	133.8	-	-	-	-	46
Nippon Koei [7]	96.0	120.0	131.0	142.0	-	154.0	162.0	25

The probable rainfall for the present study agree very well with Khamtong et al. [2], R.J. Miles [5] and Nihon Suido [6], all of which based on more than 78 years of data. Nippon Koei [7] was done in 1962 and used only 25 years of the then available data.

A.6.3 Storm Rainfall Intensities for Short Durations

The Vientiane Meteorologic stations is equipped with an automatic rainfall gauge, and has some accumulation of rainfall intensity data for the durations of 15, 30, 60, 120 and 180 minutes, but the measurement is limited to rainy season. Khamthong et al. [2] contains the most comprehensive data of rainfall intensities for short durations.

A frequency analysis was conducted for storm rainfalls based on the data given in the studies [2], [5], [6] and [7]. The Gumbel's method is adopted to be consist with the frequency analysis for the one-day rainfall. Fig. A.9 shows the frequency curves for each duration. The results of the analysis are summarized below:

Probable Rainfall for Short Duration

(Unit : mm)

Duration in minutes	Return Period in Years				
	2	5	10	20	50
15	19.2	25.8	30.1	34.3	39.7
30	30.8	43.9	52.5	60.8	71.6
60	44.9	70.4	87.2	103.4	124.4
120	58.5	88.6	108.6	127.7	152.5
180	65.9	95.9	115.8	134.9	159.5

A.6.4 Analysis of Rainfall Intensity and Duration

Based on the probable rainfall estimates in the previous sections, an analysis of storm rainfall intensities for varying durations was conducted. The Talbot's formula, as given below, was used.

$$i = \frac{a}{t^n + b}$$

where, i : rainfall intensity in mm/hr

t : duration in minutes

n, a, b : constants

The constants were determined for each return period by the least square error, as given below:

Constants in Talbot's Formula

Return Period (years)	Constants		
	n	a	b
2	1.0	5,835	65.40
5	1.0	8,171	63.90
10	1.0	9,629	62.15
20	1.0	10,983	60.43
50	1.0	12,685	58.31

Fig. A.10 shows shows the determined Talbot's curve for each return period.

A.7 Analysis of the Water Level of the Mekong

A.7.1 Water Level of the Mekong at Vientiane

The present study does not deal with the flooding of the Mekong. The following analysis, therefore, is intended to clarify the condition of the Mekong only as the reference for the planning of the drainage facility in Vientiane.

The annual maximum daily discharge data of the Mekong at the Vientiane station are available for the period of 1913 onwards (1919 interrupted). A study by the U.S.A.I.D. [8] , stated that the water surface level of the Mekong at Vientiane has been recorded daily since 1913; but there was no discharge measurement until 1959, when a hydrologic data program was established; and that the Harza Engineers estimated streamflow for prior years using the available river stage records. It also noted that the gauge at Vientiane was moved two or three times during the period 1913 - 1959; that there was some question as to how closely these gauges were tied to basic datum; and that the rating of the station for high flows was difficult due to possible overbank flow. The data cited in U.S.A.I.D. [8] were not adjusted for overbank flow except for 1966 and 1971.

U.S. Dept. of Interior, Bureau of Reclamation [9] adjusted for the estimated overbank flow for the discharge exceeding Vientiane gauge height of 11.00 m, and modified the flood discharge of U.S.A.I.D. [8] for the period of 1913 through 1966.

The flood analysis of the Mekong in this study is based on the discharge data as published in U.S.B.R. [9] for the period before 1966, and the Mekong Committee [4] for the period thereafter, with some in-house data of the Department of Meteorology and Hydrology as supplements.

A frequency analysis was conducted for the annual maximum daily discharge of the Mekong at Vientiane. Fig. A.11 shows the frequency curve by Pearson type III distribution. The following table summarizes the results of the analysis

Probable Discharge of the Mekong

(Unit: m^3/sec)

Method	Return period in years						
	1.01	2	5	10	20	50	100
Gumbel	11,860	16,725	19,632	21,558	23,404	25,795	27,586
Pearson III*	11,265	16,880	19,653	21,306	22,790	24,602	25,900

* : Selected for use

Based on the rating curves of the Mekong as given in the Mekong Committee [4], the probable water levels of the Mekong at Vientiane (Watsop) were estimated as follows:

Probable Water Level of the Mekong

(Unit: El. m)

Method	Return period in years						
	1.01	2	5	10	20	50	100
Gumbel	166.9	169.0	170.0	170.7	171.3	172.1	172.6
Pearson III*	166.6	169.0	170.0	170.6	171.1	171.7	172.1

* : Selected for use

Concerning the recent large floods of the Mekong in 1966 and 1972, the return periods were estimated below:

Return Periods of Recent Floods

Flood	Peak discharge (m^3/sec)	Return Period (years)
1966	26,000	50
1972	23,000	20

Note: Based on Pearson's Type III distribution.

A.7.2 Water Level of the Mekong at Makhiao

The water level of the Makhiao river was recorded for the years 1973, 1974 and 1981. According to the Hydrological Yearbook of the Mekong Committee [4], the data are taken at a staff gauge located at the downstream of the regulator near the village of Ban Makhiao, less than 1 km from the confluence of the Makhiao to the Mekong. Figs. A.12, A.13 and A.14 show the water levels of the Makhiao in comparison with the water levels of the Mekong at Vientiane, Nongkhai (Thailand) and Phonphisai (Thailand). Water levels of the Hong Xeng at Ban Phon Khen are also given in Fig. A.14 for 1981.

Table A.18 summarizes the annual maximum water levels of the Mekong at Vientiane, Nongkhai and Phonphisai. The confluence of the Houei Makhiao river to the Mekong is located at about halfway between the Nongkhai and Phonphisai stations; about 21 km upstream of the Phonphisai station and 26 km downstream of the Nongkhai station. The annual maximum water levels at the confluence were thus estimated by interpolation. The estimated annual maximum water levels at the confluence are plotted against the annual maximum water level of the Mekong at Vientiane of the same year, as shown in Fig. A.15.

As seen in the Figure, the annual maximum water levels of the Mekong at the confluence with the Makhiao and at Vientiane are well-correlated. Following regression line was obtained :

$$Y = 0.9571 \cdot X + 2.13$$

where, Y ; Annual maximum water level at Makhiao (el.m)
X; Annual maximum water level at Vientiane (el.m)

The correlation coefficient for the two variables (R^2) was 0.891.

Based on the frequency analysis of the annual maximum discharges of the Mekon at Vientiane and the corresponding water levels, as given in Section A.7.1, the water levels at Makhiao at the time of annual maximum discharge of the Mekong are estimated as follows:

Probable High Water Levels of the Mekong at Mohiao and Vientiane

(Unit : el.m)

Return Period (years)	1.01	2	5	10
Mekong at Vientiane	166.6	169.0	170.0	170.6
Mekong at Makhiao	161.6	163.9	164.8	165.4

Note: Based on Pearson's Type III distribution.

A.8 Analysis of Discharges in the Study Area

A.8.1 Discharge Measurement in Previous Studies

Measurement of streamflow has been conducted in and around the Study area by several parties. In the hydrological year of 1961, Nippon Koei [7] conducted discharge measurement of the Hong Xeng at Phon Khen(Point 9 of our study) and at the bridge of Nong Nieng. The following table summarizes the results of streamflow measurements:

Discharge of the Hong Xeng Observed in 1961 in Nippon Koei [7]

m³Unit : m³/sec)

Location/item	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.
Nong Nieng(Catchment 161.7 km²)										
Discharge(m³/sec)	-	2.7	5.3	2.5	5.0	14.5	11.4	3.1	0.8	0.1
Runoff depth (mm)	-	44.7	84.4	41.8	82.3	233.0	189.2	49.1	14.1	1.9
Phon Khen (Catchment 79.1 km²)										
Discharge(m³/sec)	-	2.0	3.6	2.0	4.1	7.2	5.3	0.3	0.1	-
Runoff depth (mm)	-	66.7	117.3	67.8	137.6	236.8	180.6	10.7	3.9	-

Note : - indicates no flow

Nippon Koei [7] also reports that the maximum discharge observed at Phone Khen and Nong Nieng in the hydrologic year 1961 were 10.4 m³/sec (September 27) and 21.0 m³/sec (September 30), respectively.

JICA Study Team for KM-6 Project [1] installed three staff gauges on the drainage canal from the That Luang Marsh and Houei Makhiao. The Team conducted discharge measurement at these three sites in August and September 1988. The results of the discharge measurement are as summarized below:

Results of Discharge measurement in JICA [1]

Date	No.1 Gauge			No.2 Gauge			No.3 Gauge		
	W.L. (el.m)	Q (m^3/s)	v (m/s)	W.L. (el.m)	Q (m^3/s)	v (m/s)	W.L. (el.m)	Q (m^3/s)	v (m/s)
Aug. 27 1988	164.02	5.96	0.189	164.52	5.93	0.312	164.89	1.08	0.420
Aug. 30 1988	163.92	6.38	0.205	164.47	5.13	0.276	164.83	1.75	0.611
Sep. 1 1988	163.94	6.00	0.192	164.45	4.75	0.276	164.77	1.11	0.600
Sep. 6 1988	164.27	16.32	0.442	164.71	8.16	0.393	164.97	0.63	0.197
Sep. 7 1988	164.37	19.27	0.622	164.77	10.30	0.467	165.15	1.22	no flow

JICA [1] also summarized the results of discharge measurements conducted by Nippon Koei in 1960/1961 and by Vientiane Municipality in 1980 and 1981.

A.8.2 Discharge Measurement in This Study

Discharge measurement was conducted regularly by the discharge measurement team in the months of June through September. The equipment used was a direct reading Price type current meter, mentioned in Section A.4.5. The discharge measurement team consisted of three staff of the MOV and the Hydrologist of the Study Team.

Streamflow of the Hong Xeng river was measured at a bridge newly built by the Study team just downstream of the automatic water level gauge house on the Hong Xeng. At the Hong Xeng site, 31 times of measurements were conducted. The results of the measurement are summarized in Table A.19.

The maximum discharge measure by the team was 16.98 m^3/sec on September 12, 1989. In this occasion, the average flow velocity were respectively 0.61 and the maximum flow depth were 3.2 m. The measured discharges were below 10 m^3/sec most of the time, except after heavy rainfalls.

Streamflow of the Hong Ke river was measured at a bridge newly constructed just downstream of the automatic gauge house on the Hong Ke. In 33 times of discharge measurement, the maximum discharge measured by the team was 3.9 m^3/sec on September 12, 1989. In this occasion, average flow velocity was 0.55 m/sec and the maximum flow depth were 1.15 m. The measured discharges were below 1 m^3/sec most of the time, except for after heavy rainfalls. Flow velocity at the Hong Ke site was in the range of 0.05 to 0.5 m/sec. The results of the measurement are summarized in Table A.20.

A.8.3 Rating Curves

(1) Hong Xeng Site

The discharge and the water level are well-correlated at the Hong Xeng site. Fig. A.16 shows the relationship between the square root of the discharges and the gauge heights. As seen in the figure, the two variables have a clear linear correlation. The correlation coefficient between the two variables (R^2) was 0.991. The following conversion formula was estimated in a linear regression:

$$Q = (2.133 \cdot H + 0.257)^2$$

where, Q ; discharge in m^3/sec
H ; gauge height in m

Fig. A.17 shows the estimated rating curve and the results of the discharge measurement at the Hong Xeng site.

(2) Hong Ke Site

Unlike the Hong Xeng site, the measured discharges and the water levels do not show high correlation. The canal downstream of the Hong Ke site is often clogged by local farmers for intaking water to paddy fields. When the downstream canal was reconnoitered by the Hydrologist of the Study team, one section of the canal was clogged about 300 m downstream of the discharge measurement site, presumably for taking the water to a paddy field for the ploughing. Backwater of the clogging reaches the discharge measurement site. Fig. A.18 shows the relationship between the square root of the discharges and the gauge heights.

A group of points appear above the regression line, meaning that the water levels are too high for the flow. These points are apparently affected by the backwater of the clogging. A linear regression was taken on the square root of discharge (Q) and gauge height (H), excluding the points affected by the backwater effect. The correlation coefficient (R^2) between the two variables was 0.919. The following conversion formula was estimated in a linear regression:

$$Q = (1.769 \cdot H - 0.125)^2$$

where, Q ; discharge in m^3/sec
H ; gauge height in m

Fig. A.19 shows the relationship between the measured discharges and the water levels.

A.8.4 Evaluation of Rating Curves at Hong Xeng and Hong Ke

For the purpose of verifying the obtained rating curves of the Hong Xeng and Hong Ke respectively at the automatic gauges, comparison was made between the discharge converted by the rating curves and the discharge calculated by the Manning's formula. The following are the parameters used in the Manning's formula :

Parameters in Manning's Formula

Parameter	Hong Xeng	Hong Ke
Hydraulic gradient (s)	1/6,500	1/5000
Coefficient of roughness (n)	0.035	0.035

For the Hong Xeng, the hydraulic gradient is estimated from the results of the simultaneous water level reading on September 13. There was a stage difference of 1.16 m between the Hong Xeng Gauge (Point 10) and the staff gauge at ban Xok Noy (Point 12). Since the distance between the two points are about 7,500 m, the gradient of 1/6,500 was obtained.

For the Hong Ke river downstream of the Gauge, there is a stage difference of 70 to 150 cm in a 1,500 m stretch between the Gauge and the outlet of the That Luang drainage canal (Point 11). Since the canal is often clogged downstream of the Gauge, as mentioned in the previous section, there is some substantial head loss at the clogging. Taking this into consideration, the hydraulic gradient of 1,5,000 was assumed for the Hong Ke gauge.

The following table summarizes the results of the comparison :

Comparison of Calculated Discharge and Rating Curve

(Unit : m^3/s)

Site/ Gauge height	Rating curve	Manning's formula	Remarks
Hong Xeng			
G.H. 1.5 m	1.8	2.1	Based on measurement on 15/9/89
G.H. 1.0 m	5.7	5.9	Based on measurement on 4/9/89
G.H. 0.5 m	11.9	10.3	Based on measurement on 5/6/89
Hong Ke			
G.H. 1.0 m	2.70	2.55	Based on measurement on 25/9/89
G.H. 0.6 m	0.88	1.18	Based on measurement on 9/9/89

The above comparison indicates that the rating curves constructed by actual discharge measurement for the present study fit the discharges calculated by the Manning's formula, with the margin of errors not more that 30% for low flows, and 15% for high flows (gauge height less than 1 m at respective sites). We thus conclude that the rating curves at these two sites are appropriate.

A.8.5 Daily Discharges of the Hong Xeng and Hong Ke

Based on the rating curves estimated and verified above, the water levels of the Hong Xeng and Hong Ke taken by the automatic gauges were converted to the the daily discharges. Table A.21 summarizes the daily discharges thus calculated. Fig. A.20 illustrates the discharges at the gauges.

A.9 Analysis of Design Flood Discharges

A.9.1 Design Hyetograph

The present study will use the following probable rainfalls as the design rainfall:

Type of canal	Return period (years)	Method of runoff analysis
Main canals		
Hong Xeng	10	Tank model
Hong Ke	10	Rational formula and Tank model
Others	10	Rational formula
Lateral canals	2	Rational formula

On 1st of June, 1987, a heavy rainfall occurred in Vientiane. The automatic rain gauge at the Vientiane Meteorologic Station recorded the hyetograph of this rainfall. The daily rainfall at the station was 162.0 mm. Since this rainfall is close to the probable rainfall with a 10-year return period, the design hyetograph was constructed by adjusting the recorded hyetograph of this rainfall.

This rainfall, like most of rainfalls recorded by our automatic gauge, has the high intensity part at the beginning of the rainfall event. The total rainfall in the first two hours was 126.0 mm. The recorded rainfall was adjusted by a multiplier so that the design hyetograph would have the same rainfall for the duration of 2 hours as the 2-hour probable rainfall of 108.6 mm. For the periods after the two hours, a multiplier was applied so that the one-day rainfall would be adjusted to the probable one-day rainfall of 150.6 mm.

The design hyetograph thus constructed, with the return period of 10 years, is shown in Fig. A.21. Table A.22 summarizes the design hyetographs with different return periods. The following table summarizes the hourly rainfall in the design hyetograph:

Design Hyetograph

Hour	Recorded rainfall (mm)	Multi-plier	Design hyetograph (mm)
1	80.5	0.862	69.4
2	45.5	0.862	39.2
3	6.0	3.230	19.4
4	5.5	3.230	17.8
5	1.5	3.230	4.8
Total	139.0		150.6

A.9.2 Catchment Area

The Hong Xeng river has the catchment area of 79.1 km^2 at the automatic water level gauge. The catchment area extends westwards to the eastern slopes of the hills west of the Vientiane city and includes paddy fields along the Upstream Nam Pasak and Hong Xeng. According to the land use plan adopted for this study, this catchment area now include 36.8 km^2 of paddy fields, of which 32.3 km^2 will remain as paddy fields in 2020.

The Hong Xeng at Nong Nieng has a drainage area of 155.6 km^2 and includes the entire catchment of the Hong Xeng at the automatic gauge and additionally the catchment areas of the That Luang Marsh. All the main canals in the Study area flow into the That Luang Marsh, except for the Khoua Khao canal at the time when the outlet gate to the Mekong is open.

The catchment area of the Hong Ke at the automatic gauge is mostly urban. It includes most of the central city areas of Vientiane. In the total catchment of 8.98 km^2, paddy fields occupy an area of 1.11 km^2 as of now, of which 0.34 km^2 will remain as paddy fields in the year 2020.

The demarcation of the catchment areas is as shown in Fig. A.22. The land use within each sub-catchment area is summarized in Table A.23. The land use in the Hong Xeng and Hong Ke basins are summarized below:

Catchment areas and land use

(Unit : km^2)

Land use	Hong Xeng at Gauge		Hong Xeng at Nong Nieng		Hong Ke at Gauge	
	Present	2020	Present	2020	Present	2020
Paddy	36.8	32.3	80.4	75.6	1.11	0.34
Hilly	31.0	31.0	50.9	48.3	-	-
Urban	11.4	15.9	24.2	31.6	7.87	8.64
Total	79.1	79.1	155.6	155.6	8.98	8.98

A.9.3 Effective Rainfall Model

In order to reflect land use patterns of the catchment areas into the flood runoff characteristics in the modeling, an effective rainfall model that utilizes different parameters for areas of different land use was used. The effective rainfall model used in this study follows the assumption that at the beginning of a storm rainfall the runoff coefficient is constant at f_1, which is called the initial runoff coefficient, until the total rainfall reaches a saturation level of R_{sa}. After reaching this level, the runoff coefficient will be constant at f_{sa}. Therefore, the following formula applies:

$$R_e = f_1 \cdot R \qquad \text{(for } R < R_{sa}\text{)}$$

$$R_e = f_1 \cdot R_{sa} + (R - R_{sa}) \cdot f_{sa} \qquad \text{(for } R > R_{sa}\text{)}$$

where,
- Re; Effective rainfall in mm
- R; Cumulative rainfall in mm
- f_1; Initial runoff coefficient
- R_{sa}; Saturation rainfall in mm
- f_{sa}; Saturation runoff coefficient

The model adopted in this study used the following parameters:

Parameters in the Effective Rainfall Model

Land use	f1	Rsa (mm)	fsa
Paddy	0.0	50.0	1.0
Hilly	0.25	150.0	1.0
Urban	0.4	50.0	1.0

The effective rainfall of the Hong Xeng and Hong Ke at the automatic gauges can be calculated by the weighted sum of the effective rainfalls from each land use category. The following table shows the effective rainfalls at these two catchment areas when the design hyetograph occurs:

Hour	Design rainfall (mm)	Effective rainfall	
		Hong Xeng System (mm)	Hong Ke System (mm)
1	69.4	23.4	38.6
2	39.2	27.7	39.2
3	19.4	13.7	19.4
4	17.8	12.6	17.8
5	4.8	3.4	4.8
Total	150.6	80.8	119.8
Runoff coefficient		(0.534)	(0.795)

A.9.4 Flood Runoff Model

For estimating the flood discharges for the priority projects, a rainfall-runoff model was constructed. The so-called "Tank Model" transforms the effective rainfall into stream flow through imaginary tanks with outlets on the sides and bottom, which drain the stored stormwater in proportion to the height of the water surface. Fig. A.23 presents the schematic structure of the tank models used for the estimation of flood discharges.

The model utilized in the present study consists basically of four tank in a series. The top tank receives the effective rainfall and produces some surface runoff from its side holes and infiltration (or conveyance to the 2nd tank) through its bottom hole. The 2nd tank, which roughly models the intermediate runoff, receives water from the Top tank and produces the runoff through its side hole and conveyance to the sub-surface layers, modeled by the 3rd and 4th tanks. For the Hong Ke basin, one extra tank is added to simulate the retardation effect of the Nong Chanh Marsh.

In each tank, the outflow from a hole is calculated as a linear function of the depth of the water surface in the tank above the level of the hole. The following formula applies to any tank:

$$q = C \cdot (h - H)$$

where,
- q ; runoff in mm
- h ; water level in the tank in mm
- H ; height of the hole from the bottom in mm
- C ; coefficient

Each hole has two parameters, namely H and C, which are determined through a calibration using a recorded flood hydrograph and hourly rainfall.

A.9.5 Calibration of the model

The tank models for the Hong Xeng and Hong Ke basin were calibrated by using the hourly rainfalls and discharges recorded by the instruments installed by the study team. The parameters of the models were adjusted so that the simulated discharges would trace the recorded discharges closely.

The following table summarizes the results of the calibration:

Calibration Results

Item	Hong Xeng at Gauge	Hong Ke at Gauge
Period	4/8-5/8/1989	24/9-26/9/1989
Observed peak Discharge (m^3/s)	11.5	2.88
Simulated peak Discharge (m^3/s)	11.6	2.90

Figs. A.24 and A.25 show the simulated and observed runoff of the Hong Xeng and Hong Ke respectively at the automatic gauges. The simulated discharge follow the observed discharge closely. These calibrated tank models were used in the estimation of design flood discharges of the Hong Xeng and Hong Ke.

A.9.6 Simulated 10-year Flood Discharge

For the Hong Xeng and Hong Ke, the 10-year flood discharges were simulated by the tank model with the input of the estimated 10-year storm rainfall. Since the model was calibrated by the actual discharges recorded at the automatic gauges, these simulated flood discharges would show the 10-year probable flood peak discharge under the present condition of the river channels.

Since the channels of the both rivers do not have the capacities enough to accommodate large floods, the observed flood hydrographs are already affected by the overbank flow which flattens the peak discharge. The simulated hydrograph by the tank model, thus, shows the 10-year probable floods under the present condition of the river channel.

Fig. A.26 shows the simulated 10-year flood hydrograph of the Hong Xeng at the automatic gauge. The peak discharge is estimated as 35.5 m^3/s. Fig. A.27 shows the simulated 10-year flood hydrograph of the Hong Ke at the automatic gauge. The peak discharge is estimated as 10.1 m^3/s.

A.9.7 Design Flood Discharges of Hong Ke System

(1) Alternative Drainage Plans for Hong Ke System

The Hong Ke system comprises the Hong Thong Canal which collects the discharge mostly from Sub-area C; the Nong Chanh Marsh and the Hong Ke river from the outlet from the Nong Chanh Marsh to the That Luang Marsh.

The following five (5) alternatives were considered in the storage capacities to be secured in the Hong Thong, Khoua Khao and Nong Chanh Marsh. In this comparison, the alignment of the secondary canals are assumed to be the same as the present conditions.

<u>Alternative Drainage Plans for Hong Ke system</u>

Case	Storage capacity (1,000 m^3).			
	H Thong	K. Khao	N. Chanh	Total
Case 0	Base Case (no improvement)			
Case 1	0	0	0	0
Case 2	0	0	80	80
Case 3	16	32	60	108
Case 4	0	0	120	120
Case 5	16	32	120	168

(2) Design Flood Discharge for Alternative Drainage Plans

On determining the design discharges for the Hong Ke system for each of the alternative drainage plans, the following methods and assumptions were made.

(a) For the Hong Thong and Khoua Khao canals, the rational formula was used in combination with the effective rainfall model mentioned in Section A.9.3

(b) A hydrograph was synthesized for each canal based on the peak discharges estimated by 1) above.

(c) For the Hong Thong canal with a channel storage plan (Cases 3 and 5), deformation of flood hydrograph was simulated by a model that utilizes the height-discharge characteristics (H-Q curve) of the Morning Market culvert. The following flood water level and low water levels in the routine model :

FWL for Hong Thong storage : el. 168.0 m
LWL for Hong Thong storage : el.167.0 m

H-Q curve of the Morning Market culvert was constructed by the following assumptions :

Flow condition	:	Free flow (unpressurized)
Slope	:	1 o/oo (1/1000)
Length	:	270 m
Sill elevation at inlet	:	el.166.3 m
Coefficient of roughness	:	0.016

(d) For Nong Chanh marsh with a storage plan (Cases 2 through 5), deformation of flood hydrograph was simulated by a flood routine model. The following water levels were assumed:

FWL for Nong Chanh storage : el. 167.0 m
LWL for Nong Chanh storage : el.166.0 m

The H-Q curve at the outlet to the Hong Ke is given by an assumed free overflow section with the crest at e.166.0 m. The length of the crest were determined so that the 10-year flood is accommodated without exceeding FWL.

(e) For Khoua Khao canal with a storage plan (Cases 3 and 5), the storage at Khoua Khao was dealt with as an integrated storage combined with the storage at the Nong Chanh marsh.

The following table summarizes the design flood discharges of the main canals in the Hong Ke system thus determined.

Design Flood Discharges of the Hong Ke System

(Unit : m^3/s)

Canal/ Chainage	Case 1	Case 2	Case 3	Case 4	Case 5
<u>Hong Thong</u>					
HT/1220 - 1800	6.6	6.6	-	6.6	-
HT/670 - 1220	11.1	11.1	-	11.1	-
HT/400 - 670	16.7	16.7	15.5	16.7	15.5
HT/0 - 400	20.9	20.9	19.4	20.9	19.4
<u>Khoua Khao</u>					
KK/2000 - 2200	9.2	9.2	-	9.2	-
KK/950 - 2000	11.3	11.3	-	11.3	-
KK/400 - 950	13.2	13.2	-	13.2	-
KK/0 - 400	17.5	17.5	-	17.5	-
<u>Hong Ke</u>					
HK2/2570 - 3020	42.9	-	-	-	-
HK2/2200 - 2570	42.9	39.5	37.6	35.8	31.8
HK2/800 - 2200	61.2	59.6	57.8	56.0	51.9
HK2/0 - 800	70.5	66.2	64.4	62.5	58.1
HK1/0 - 615	70.5	66.2	64.4	62.5	58.1

Note : "-" indicates that the design discharge is not applicable (storage plan)

Fig. A.28 illustrates the design discharges at major points in the Hong Ke system. Figs. A.29 and A.30 show the inflow and outflow hydrographs respectively of the Hong Thong storage pond at the Morning Market culvert and of the Nong Chanh Retarding Basin.

A.9.8 Design Flood Discharge of System for Sub-area L (Nam Pasak)

(1) Alternative Drainage Plans for the System

The drainage plans for the right branch of the System for Sub-area L (Nam Pasak-R) consist of the realignment of the channel (Case 1) and utilization of the present channel as it is (Case 2). The base case (Case 0) refers to a case without any improvement. The drainage plans are summarized in the following:

Alternative Drainage Plans for Hong Ke system

Case	Nam Pasak-R	Hong Xeng
Case 0 (Base case)	No improvement	No improvement
Case 1 (Realignment)	Realignment of river channel	- " -
Case 2 (No realignment)	Improvement of channel with the present alignment	- " -

(3) Design Flood Discharge for Alternative Drainage Plans

The design flood discharge for the Hong Xeng System were determined through the following steps :

(a) The catchment area is divided into the areas by the time to reach the Confluence (Chainage 0). For each area, the flood hydrograph was constructed from the peak discharges estimated by the rational formula from the design hyetograph in the effective term.

(b) The hydrographs of each areas were overlaid with the lag time of 1 hour between each area.

(c) The above process was repeated for Case 0, Case 1 and Case 2, as described in (1) above.

Fig. A.31 illustrates the design discharges of the main canal in the System. The following table summarizes the design flood discharges of the Nam Pasak-R at different chainages :

Peak discharge for Nam Pasak-R

Case/ chainage	Catchment area (ha)	Peak discharge (m^3/s)
Case 0		
0 - 1800	110	18.5
1800 - 3600	60	11.4
3600 - 4750	44	4.8
Case 1		
0 - 1920	152	23.3
1920 - 3220	62	6.8
Case 2		
0 - 1920	138	23.3
1920 - 4750	82	8.9

A.9.9 Design Flood Discharge of System for Sub-area I (Hong Kai Keo)

The system for Sub-area I consists of the Nong Bon retarding basin and the Hong Kai Keo main canal which drains the Nong Bon to the Hong Xeng. The present water surface of the Nong Bon is 5 ha, and assuming the usable depth of 1 m, the storage capacity of 50,000 m^3/s is estimated for Nong Bon retardation basin.

The design discharges of the Nong Bon and Hong Kai Keo is estimated through the retardation calculation similar to the Hong Ke System. Fig. A.32 shows the design discharges of the System. The following table summarizes the results:

Design Flood Discharge of Hong Kai Keo

Canal, pond chainage	Catchment (ha)	Design discharge (m^3/s)
Nong Bon Pond		
Outlet	160.8	16.8
Hong Kai Keo		
HKK 840 - 1,340	32.8	20.2
HKK 0 - 840	31.2	23.5

A.9.10 Evaluation of Design Flood Discharges

On the last two sections, the design flood discharges for the main canals were estimated. The following table summarizes the design flood discharges in nominal and specific terms, with some of the flood discharges of nearby rivers:

Comparison of Flood Discharges

River	Place	Catchment area (km^2)	10-yr flood discharge (m^3/s)	Specific discharge ($m^3/s/km^2$)
Mekong	Vientiane	299,000	21,306	0.071
Nam Ngum	Tha Ngon	16,500	3,650	0.221
Hong Xeng 1/	Gauge	79.1	35.5	0.449
Hong Ke 1/	Gauge	8.98	10.1	1.125

Note 1/: Denotes the base cases (natural conditions)

Nippon Koei [7] cites the annual maximum discharges of some of the rivers in the Vientiane Plain for the hydrologic year of 1961. The following table summarizes the cross drainage comparison of annual maximum discharges in Vientiane Plain.

Comparison of Annual Max. Discharges

River/site	Catchment area (km^2)	Year	Annual max. discharge (m^3/s)	Specific discharge ($m^3/s/km^2$)
Mountainous catchment				
Na Nga	107	1961	46.4	43.4
Song Phouai	78	1961	38.6	49.5
Y Lai	42	1961	15.7	37.4
Hot Khoua	36	1961	22.4	62.3
Na Sai	47	1961	11.1	23.6
Flat catchment				
Hong Xeng at Nong Nieng	155.6	1961	21.0	13.5
Hong Xeng at Phone Khen	79.1	1961	10.4	13.1
Hong Xeng at Gauge	79.1	1989	14.4	18.2
Hong Ke at Gauge	8.98	1989	3.65	40.6

Fig. A.31 illustrates the cross drainage comparisons above. The catchment of the Hong Xeng and Hong Ke is predominantly gently-sloped plain with swamps and paddy fields. The annual maximum discharge observed at the automatic gauge is substantially lower than the regression curve obtained for the rivers with mountainous catchments. The flood discharges for the Hong Xeng and Hong Ke reflect the natural conditions of the catchment areas through the effective rainfall and retardation in the tank models, and are judged to be justifiable in view of the cross drainage comparison given above.

A.9.11 Design Discharge for Basic Plan

For the main canals in the Basic Plan, the design discharges were estimated. Adaptability to the design discharges of the canals in the Priority Project was allowed for in this calculation. The following sub-sections summarize the process of the design discharge estimation.

(1) Assumptions for Estimation

The design discharges for the Basic Plan were calculated by the rational formula, given below:

$$Q=\frac{CIA}{360}$$

where, C : Runoff coefficient
I : Rainfall intensity (mm/hr)
A : Catchment area (ha)

For the design discharge of the Basic Plan, the following assumptions were made:

(a) Runoff coefficient

Unoccupied land 0.35 - 0.50
Building 0.90
Road 0.85
Paddy field 0.70

The runoff coefficient for an area is calculated by the weighted sum of the coefficients above.

(b) Time of concentration

Time of concentration (Tc) in minutes is given by:

$$T_c = T_{in} + \frac{L}{V}$$

where, Tin : Inflow time of rain water from the most remote point in the sub-drainage area to the drainage canal (min.)

L : Length of drainage canal (m)

V : Average velocity in drainage canal (m/sec)

For the Basic Plan, the design velocity was assumed to be 0.8 m/s throughout the study area. T_{in} was estimated to be 52.3 min. by the Kerby's formula.

(2) Other Considerations

(a) Retardation in Left Branch of Nam Pasak

Areas along the upstream reaches of the left branch of the Nam Pasak are mostly backswamps and marshes. According to the land use plan adopted in this Study, these areas will remain to be the present natural conditions. IN estimating the design discharges of the Basic Plan, the retarding effects of these areas were considered to stay.

On topographic maps of 1 to 10,000, the following relationship between the elevation and area was clarified.

Elevation interval	Area (ha)	Internal volume (1,000 m^3)	Cumulative volume (1,000 m^3)
Below 165	0	0	0
165 - 166	144	720	720
166 - 166.5	290	1,085	1,805
166.5 - 167	575	2,163	3,968
167 - 167.5	824	3,498	7,460

The effective storage in these areas were calculated based on the following assumptions:

- The high water level at the time of 10-year flood is El. 167.5 m; based on the results of the hearing survey at Point 8 (Ref. Table A.16).

- The initial water level is El. 166.9; based on the results of the simultaneous water level observation at Point 8, max. El. 166.5 (Ref. Table A.14) + 0.4 m for the hydraulic gradient.

The effective storage was calculated to be 4,080 x 10^3 m^3 between El. 166.9 and 167.5. The catchment area is 4,805 ha, with the runoff coefficient of 0.66 (rural area). By using the formula for estimating the retardation effect (Ref. Annex A.1), the regulated peak outflow downstream was estimated to be 30 m^3/s at he confluence of left and right branches of the Nam Pasak.

(b) Retardation in Nong Douang Marsh

The Nong Douang marsh is located north of the Luang Prabang road. It is a natural marsh, utilized now for the cultivation of water plants.

The area-elevation data of the Nong Douang marsh was measured on the map of 1 to 1,000 provided by MOV. The following table summarize the data.

Elevation interval	Area (ha)	Internal volume (1,000 m^3)	Cumulative volume (1,000 m^3)
Below 166.5	0.06	0.3	0.3
166.5 - 167	1.46	7.6	7.9
167 - 167.5	4.82	31.4	39.3
167.5 - 168	9.38	71.0	110.3

Assuming that the storage volume between El. 167.5 and 168.0 is effective for retardation, the effective storage capacity of the Nong Douang marsh was estimated to be 70×10^3 m^3. The catchment area of the Nong Douang marsh is 185 ha, with the runoff coefficient of 0.57. The regulated 10-year flood outflow was estimated to be 8.2 m^3/s by the formula in Annex A.1.

(3) Results of Estimation

For the main canals outside of the areas covered by the Priority Project, the design discharges were estimated by the methods detailed in items (1) and (2) above. The following table summarizes the calculation results:

Design Discharge Calculation for Basic Plan

(System)/ Sub-area	Area A (ha)	Length L (m)	Tc (min)	Runoff coefficient D	Rainfall (I_{tc}) (m/hr)	Peak discharge Q (m3/s)	
Nong Hay System							
A_1	236	1,370	80.8	0.48	67.3	21.2	
A_2	185	1,360	109.2	0.48	56.2	31.5	
A_3	140	1,370	137.7	0.48	48.2	36.0	
Souane Mone System							
B_1	219	1,350	80.4	0.47	67.5	19.3	
B_2	169	1,350	108.6	0.47	56.4	28.6	
B_3	239	1,700	144.0	0.47	46.7	38.2	
Wat Tay System							
M_1	280	2,075	95.5	0.57	61.1	27.1	
M_2	339	2,350	144.5	0.57	46.6	45.7	
M_3	165	1,120	75.6	0.57	69.9	18.3	(8.2)
M_4	292	3,025	207.0	0.57	35.8	61.0	(55.8)

Note: Figures in ( ) are after regulation at the Nong Douang marsh.

The demarcation of divided sub-areas and the design discharges are shown in Fig. A.33.

A.10 Analysis of Inundation in Sample Area

In this chapter, the expected conditions of inundation due to heavy rainfalls will be clarified quantitatively within the Sample area.

A.10.1 Estimation of Present Drainage Capacity

During the periods of June through October 1989, the Study team installed an automatic rain gauge and recorded rainfalls in Vientiane (refer to Section A.4.2). In order to assess the capacity of existing storm water drainage facilities, the Study team observed inundation conditions in the Study area caused by various intensities of storm rainfalls. Table A.23 summarizes the heavy rainfalls recorded by the automatic gauge and the inundation conditions seen in the Study area.

The maximum hourly rainfall recorded by the gauge was 62.0 mm on 12th of September. At the time of this rainfall, inundation occurred in a number of places in the Study area. Plate A.1 presents the inundated areas in and near the Study area caused by this rainfall. The second largest was 36 mm on 4th of August, preceded by 28.5 mm in the previous hour. This storm also caused an extensive inundation in the Study area. On 2nd of September, there was a storm rainfall of 23.5 mm hourly, which caused some minor local inundations. Table A.24 summarizes the recorded heavy rainfall and corresponding inundation in the Study area.

Based on the above observation of rainfall and inundation, the existing capacity of storm water drainage system was estimated to be 20 mm/hr. By applying the effective rainfall model for an urban area, (refer to Section A.9.3), the effective rainfall corresponding to this existing capacity was estimated to be 8 mm/hr.

A.10.2 Estimation of Excess Rainfall

With the implementation of the proposed project, the priority area would have the storm water drainage capacity enough to accommodate the design floods. In this section, the inundation conditions under the protection levels of 2 years and 5 years are examined. These will correspond to the design rainfall of 21 mm/hr for 2-year storm and 82 mm for 5-year storm, both on the effective basis. The table below summarizes the rainfall depths in excess of the existing drainage capacity with and without the implementation of the project:

Return Period (years)	Design Rainfall (mm)	Effective Rainfall (mm)	Inundated volume (mm)		
			Without Project	With Project	
				2-yr P.L	5-yr P.L
50	191.4	161.4	124.9	80.5	58.5
20	168.4	138.4	101.7	55.7	33.7
10	150.6	120.6	83.8	36.6	14.6
5	132.1	102.1	65.1	16.6	0
2	104.0	46.7	12.9	0	0

Note: P.L = protection level

The Sample area comprises of the area within the dyke road in sub-area H. The Sample area comprises the total area of 110 ha, with exclusively urban land use. By applying the area, the excess storm rainfalls with different return periods are calculated as follows:

Return Period (Years)	Excess rain (1,000 m^3)		
	Without Project	With Project	
		2-yr P.L	5-yr P.L
50	124.9	88.6	64.4
20	101.7	61.3	37.1
10	83.8	40.3	16.1
5	65.1	18.3	0
2	12.0	0	0

A.10.3 Estimation of Inundated Area by Heavy Storms

The Sample area stretches in the elevations of 168 to 172 meters MSL. Near the Hong Thong canal, there is a 30 ha area in the elevation between 168 to 189 meters, which is close to the area prone to frequent flooding. The following table summarizes the area and corresponding cumulative volume below each contour line.

Contour Interval	Area (ha)	Internal Volume (1,000 m^3)	Cumulative Volume (1,000 m^3)
167 - 168	0	0	0
168 - 169	30.0	150	150
169 - 170	36.1	331	481

The excess storm water estimated in the previous section would presumably cause inundation in the Sample area. The areas to be inundated by storm rainfalls with different return periods are estimated from the volume of excess storm water and area-volume relationship as clarified in this section. The results are summarized below:

Return Period (Years)	Inundation Area (ha)		
	Without Project	With Project	
		2-yr P.L	5-yr P.L
50	28.0	21	16
20	24.0	15	11
10	21.0	11	5
5	18.0	5	0
2	4.5	0	0

A.10.4 Estimation of Inundation Area by Small Storms

In addition to the inundation by heavy storms larger than the probable storm rainfalls of 2-year return periods, the Study area suffers from minor inundations frequently caused by smaller storm rainfalls.

In order to estimate the benefit of relieving the Study area from such minor, but frequently-caused inundation, a case study was conducted for a typical minor storms.

Table A.24 shows some of the heavy storms recorded by the automatic gauge. The Study team observed local inundation in four occasions, as listed in the table. Based on the automatic gauge records a storm that occurs four times a year would have the following intensities.

1-hour rainfall	:	30 - 35 mm
2-hour rainfall	:	35 - 40 mm

In this case study, a storm with 35 mm/hr, followed by 5 mm/hr, in the second hour was assumed to be a typical storm that occurs 4 times a year.

The inundation caused by this storm rainfall is estimated to be as follows:

Effective rainfall	: 16 mm
Excess rainfall	: 8 mm
Inundation volume	: 8.8 x 10^3 m^3 in Sample area
Inundation area	: 2 ha

The inundation area is estimated to occur in the central city area.

A.11 Analysis of Low Flow

For the purpose of determining the design discharges of the low flow channels of drainage canals, a supplementary study was conducted on the low flow discharges of the main canals in the Study area. The analysis here are based on discharges observed on two occasions due to the lack of data, and the reader is cautioned that the dependability is not implied in this analysis.

A.11.1 Discharge Measurement in Dry Season

In conjunction with the water sampling for water quality analysis, discharges of the main canals were measured on two occasions in May and June. The first set of discharges were taken on 24 and 25th of May, 1989, which are considered to be indicative of discharges during the dry season. The second set of data were taken on the same locations as the first set on 31st of May and 2nd of June, 1989. Between 25th and 29th of May, there was a total rainfall of 72.5 mm, and therefore the second set of data show the discharges somewhat affected by the starting rainy season. Fig. A.34 shows the location of the discharge measurement.

Table A.25 summarizes the observed discharges on the nominal and specific terms. The specific discharges rang from 0.4 to 10.6 $m^3/sec/100\ km^2$ for the first set and 0.7 to 17.7 $m^3/sec/100\ km^2$ for the second set. The increase between the two ranges is presumably caused by the downpour of rainfall between the two occasions.

A.11.2 Design Discharge for Low Flow Channel

The Observed discharges of the main canals are plotted against the catchment areas in Fig. A.35. The figure shows the effects of the rainfall clearly. The design discharges for the low flow channels are determined as an envelop curve for the dry season discharges as represented by the data of the first set.

The following table summarizes the estimated design discharges for the low flow channels for typical catchment areas:

Design Discharges of Low Flow Channels

Catchment area (km^2)	Design flood discharge (m^3/s)
1	0.021
5	0.038
10	0.068
50	0.15
100	0.22

Annex A.1 Formula for Retardation Effect

This annex will give a brief description of the formula that calculates the outflow discharge with retardation storage. The attached figure depicts the simplified rainfall pattern for the time of concentration tc. The peak rainfall for this tc is given b the Talbot's formula. namely:

$$I_{tc} = \frac{a}{t^n + b} \quad \text{.......} \quad (1)$$

where a, b and n are constants. The maximum outflow is assumed to be qc (m3/s), which can be converted to the unit adaptable to the rainfall by the following conversion equation.

$$r_c = \frac{360\ qc}{f \cdot A} \quad \text{.......} \quad (2)$$

where f : runoff coefficient
qc : Peak discharge downstream (m^3/s)
A : catchment area (ha)

Actual outflow curve would be affected by the topographic and facility-related conditions, but may be approximated by a doted straight line between (0,0) and ($2 \cdot t_c, r_c$) as shown in the figure. The formula to be presented here further approximates the required storage by the area of the triangle above the horizontal line at (r_c,2).

The required storage for an arbitrary time of concentration can be expressed by the following formula:

$$V(t_c) = \left(\frac{a}{t_c^n + b}\right) \cdot 60 \cdot tc \cdot f \cdot A \cdot \frac{1}{360} \quad \text{.......} \quad (3)$$

To find out the maximum required storage capacity for a specific tc, we take the derivatives of Eq. (3) and set it as 0. Consequently, letting $x = t^{1/n}$, we can find the maximizer of V in Eq. (3) by solving the following quadratic form:

$$(\frac{r_c}{2})x2 + \{2\frac{r_c}{2}\cdot b + a(n-1)\}x + b(\frac{r_c}{2}\cdot b - a) = 0 \quad \text{.........} \quad (4)$$

Denoting a positive root of (4) as x^*, the maximizer of (3) is calculated by

$$t^* = (x^*)^{1/n}$$

By plugging t^* as given by Eq. (5) in Eq. (3), we get the maximum required storage capacity V^*.

The required maximum storage V^* is dependent on the peak outflow downstream q_c.

By changing q_c, we can clarify the relationship between the required storage and the peak discharge downstream.

TABLES

Table A.1 Summary of Meteorologic Conditions of Study Area

Item	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1) Monthly Mean Temperature in Vientiane (degrees Centigrade)													
	22.4	24.7	27.4	29.0	28.7	28.4	28.1	27.6	27.6	27.0	24.8	22.3	26.5
2) Monthly Mean Maximum Temperature in Vientiane (degrees Centigrade)													
	28.2	30.4	33.0	34.1	32.8	31.9	31.4	30.8	31.0	30.8	29.4	27.9	31.0
3) Monthly Mean Minimum Temperature in Vientiane (degrees Centigrade)													
	16.7	19.0	21.8	24.0	24.6	25.1	24.9	24.8	24.2	23.2	20.3	16.8	22.1
4) Extreme Minimum Temperature in Vientiane (degrees Centigrade)													
	12.6	14.6	17.3	20.5	22.0	23.0	22.7	23.0	22.6	20.1	15.5	12.3	
5) Monthly Mean Relative Humidity at Vientiane (%)													
	68	66	64	66	74	77	78	80	78	74	69	67	72
6) Monthly Class-A Pan Evaporation at Vientiane (mm/day)													
	3.7	4.2	4.6	5.1	4.7	4.3	4.1	3.7	4.1	4.3	4.4	3.9	4.2
7) Monthly Mean Wind Velocity at Vientiane (m/sec)													
	1.6	1.6	1.7	1.9	2.0	1.7	1.8	1.8	1.6	1.6	1.6	1.6	4.2
8) Monthly Mean Sunshine Hours at Vientiane (hours/day)													
	8.4	7.6	6.9	7.5	6.7	5.0	4.7	4.3	5.8	7.2	7.9	8.3	6.7
9) Monthly Rainfall at Vientiane (mm; share in %)													
	6.4	12.0	35.8	80.3	243.4	271.3	285.2	303.0	282.5	84.4	9.6	3.5	1617.0
Share	0.4	0.7	2.2	5.0	15.1	16.8	17.6	18.7	17.5	5.2	0.6	0.2	100.0
10) Monthly Rainfall at Tha Ngon (mm; share in %)													
	7.8	12.6	45.5	83.2	251.3	295.5	330.2	339.4	268.8	92.0	14.3	1.7	1763
Share	0.4	0.7	2.6	4.7	14.3	16.8	18.7	19.3	15.2	5.2	0.8	0.1	100.0

Table A.2 Monthly Mean Temperature at Vientiane

unit : degrees Centigrade

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1968	21.5	22.6	27.0	27.2	27.7	27.4	28.4	28.0	28.0	26.7	25.8	24.2	26.2
1969	24.5	25.3	27.9	29.5	28.9	28.3	28.1	28.0	27.2	27.0	23.6	20.8	26.6
1970	22.5	24.9	27.8	28.0	28.5	27.4	27.8	27.1	27.2	26.6	24.7	23.9	26.4
1971	21.0	23.4	26.7	29.4	28.5	27.7	27.4	26.9	27.5	25.5	22.9	22.5	25.8
1972	21.1	24.8	25.8	27.6	29.6	28.7	28.5	27.5	28.0	27.4	26.1	23.9	26.6
1973	22.9	26.3	28.2	30.6	28.8	28.9	27.9	27.3	27.1	27.2	23.8	20.5	26.6
1974	21.4	22.4	26.1	27.6	28.6	28.4	27.9	27.5	27.7	27.1	24.9	23.4	26.1
1975	23.0	25.2	28.0	30.9	27.6	28.1	27.9	27.6	27.6	27.3	24.3	19.8	26.4
1976	20.9	24.6	26.7	28.0	27.8	28.3	28.3	27.4	27.7	27.3	23.8	22.9	26.1
1977	22.5	22.8	26.8	28.7	29.1	30.2	28.3	28.4	27.7	27.6	24.0	23.6	26.6
1978	23.4	24.0	28.2	29.0	28.5	28.7	27.4	27.8	27.3	27.0	25.3	23.1	26.6
1979	24.6	25.8	28.5	29.3	28.6	28.0	29.4	28.0	28.1	26.4	24.0	22.7	27.0
1980	23.2	24.3	28.2	29.8	28.9	28.0	28.4	28.3	27.3	27.8	25.9	23.8	27.0
1981	22.2	26.2	28.3	28.7	28.5	28.2	27.7	28.2	28.3	27.3	25.9	21.4	26.7
1982	22.7	25.2	28.8	27.9	29.7	29.2	28.4	27.5	27.2	27.4	26.4	20.9	26.8
1983	20.9	25.5	27.0	31.0	29.4	28.9	28.9	28.0	27.0	27.2	23.4	21.1	26.5
1984	21.6	25.4	27.6	30.0	28.3	28.6	27.4	27.6	27.4	25.8	25.2	22.8	26.5
1985	23.0	25.2	26.4	28.9	28.9	28.0	27.7	27.9	27.5	26.9	26.1	22.3	26.6
1986	21.5	24.8	26.4	29.5	28.3	28.8	27.9	25.6	27.6	27.3	24.8	22.8	26.3
1987	23.0	25.0	27.0	28.8	29.9	28.8	28.9	28.0	27.9	27.6	27.0	20.4	26.9
1988	23.6	25.6	27.6	29.2	28.4	28.1	27.9	27.4	27.9	26.3	23.0	21.4	26.4
Ave.	22.4	24.7	27.4	29.0	28.7	28.4	28.1	27.6	27.6	27.0	24.8	22.3	26.5

Data are provided by Dept. of Meteorology and Hydrology, Min. Agriculture and Forestry.

Table A.3 Monthly Mean Maximum Temperature at Vientiane

unit : degrees Centigrade

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1968	27.0	28.1	32.4	31.9	31.8	30.5	32.0	30.9	31.7	30.7	30.7	30.3	30.7
1969	29.8	31.8	32.9	34.7	33.4	31.4	31.1	31.0	30.6	31.0	28.0	26.5	31.0
1970	27.7	31.2	33.8	32.7	32.4	30.2	30.7	29.8	30.2	30.4	29.2	29.0	30.6
1971	26.9	28.9	31.9	34.9	32.7	30.8	30.2	29.4	30.8	29.0	28.4	27.4	30.1
1972	26.9	30.4	31.2	32.0	34.4	32.4	31.7	30.4	31.5	31.1	30.0	29.2	30.9
1973	29.4	32.9	33.8	36.2	32.7	32.4	31.0	30.1	29.9	31.3	28.3	26.3	31.2
1974	27.9	28.1	30.9	32.2	32.8	31.9	31.3	30.4	31.2	30.7	29.2	27.9	30.4
1975	27.3	31.0	33.5	36.5	31.8	31.3	31.2	30.6	31.1	31.1	28.9	25.8	30.8
1976	27.5	30.8	32.3	32.3	31.2	32.1	31.7	30.4	31.2	31.0	28.3	28.6	30.6
1977	27.8	28.4	32.2	33.8	33.6	34.5	31.6	31.8	31.3	31.4	29.0	28.9	31.2
1978	28.9	28.4	33.9	34.0	32.3	32.4	30.7	30.8	30.7	31.3	30.1	28.9	31.0
1979	30.5	31.7	35.0	34.5	32.6	31.2	33.3	31.2	31.6	31.1	29.7	29.0	31.8
1980	29.7	30.2	34.3	35.1	33.0	31.3	31.5	31.3	30.3	31.7	30.8	29.3	31.5
1981	28.6	32.3	34.5	33.4	32.3	31.5	30.6	31.2	31.7	30.8	30.0	26.7	31.1
1982	28.5	30.8	34.3	32.6	34.1	32.8	31.7	30.2	30.4	31.2	30.8	26.6	31.2
1983	25.8	31.0	32.8	36.8	33.5	32.7	32.4	31.1	30.9	30.6	28.4	27.0	31.1
1984	27.5	30.5	33.7	35.3	32.7	32.3	30.7	30.8	31.0	29.4	29.7	28.3	31.0
1985	28.1	30.2	31.5	33.8	32.8	31.1	31.2	30.9	31.0	30.8	30.3	27.9	30.8
1986	27.3	30.4	32.7	34.7	31.8	32.0	30.7	32.2	31.2	31.0	29.1	27.8	30.9
1987	28.4	30.1	32.4	33.8	34.6	32.3	32.1	31.2	31.2	31.5	30.8	26.3	31.2
1988	30.0	30.9	33.2	34.0	32.3	32.0	31.6	31.0	31.8	29.7	28.0	27.4	31.0
Ave.	28.2	30.4	33.0	34.1	32.8	31.9	31.4	30.8	31.0	30.8	29.4	27.9	31.0

Data are provided by Dept. of Meteorology and Hydrology, Min. Agriculture and Forestry.

Table A.4 Monthly Mean Minimum Temperature at Vientiane

unit : degrees Centigrade

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1968	16.0	17.2	21.6	22.5	23.7	24.4	24.7	25.2	24.4	22.7	21.0	18.1	21.8
1969	19.2	18.8	22.9	24.3	24.4	25.2	25.1	24.9	23.8	23.1	19.2	15.0	22.2
1970	17.2	18.5	21.8	23.3	24.6	24.6	25.0	24.5	24.2	22.9	20.1	18.9	22.1
1971	15.1	17.9	21.5	23.9	24.3	24.7	24.6	24.4	24.2	21.9	17.4	17.6	21.5
1972	15.4	19.3	20.4	23.2	24.9	25.0	25.3	24.6	24.6	23.8	22.2	18.6	22.3
1973	16.5	19.8	22.6	25.1	25.0	25.5	24.9	24.5	24.3	23.1	19.4	14.8	22.1
1974	14.9	16.8	21.4	23.1	24.5	25.0	24.5	24.6	24.3	23.6	20.7	18.9	21.9
1975	18.7	19.4	22.6	25.3	24.1	24.9	24.7	24.6	24.2	23.6	19.7	13.9	22.1
1976	14.3	18.5	21.1	23.7	24.4	24.6	24.9	24.4	24.2	23.6	19.4	17.2	21.7
1977	17.3	17.1	21.5	23.6	24.7	26.0	25.1	25.0	24.2	23.7	19.1	18.2	22.1
1978	18.0	19.6	22.4	24.0	24.7	25.0	24.2	24.8	24.0	22.7	20.5	17.3	22.3
1979	18.7	19.9	22.0	24.2	24.5	24.8	25.5	24.9	24.5	21.8	18.3	16.4	22.1
1980	16.6	18.4	22.2	24.6	24.8	24.7	25.2	25.3	24.2	23.8	21.0	18.2	22.4
1981	15.8	20.0	22.2	24.0	24.7	25.0	24.8	25.2	24.9	23.8	21.8	16.0	22.4
1982	16.9	19.6	23.2	23.2	25.3	25.7	25.1	24.9	24.0	23.6	22.0	15.2	22.4
1983	16.0	20.0	21.2	25.2	25.4	25.1	25.4	24.8	24.3	23.8	18.4	15.1	22.1
1984	15.7	20.2	21.6	24.8	23.9	25.0	24.0	24.3	23.7	22.2	20.7	17.3	22.0
1985	17.9	20.1	21.2	24.0	25.0	25.0	24.2	24.9	24.0	23.0	21.9	16.7	22.3
1986	15.7	19.1	20.0	24.3	24.8	25.5	25.2	25.1	23.9	23.6	20.6	17.8	22.1
1987	17.6	19.9	21.7	23.9	25.2	25.4	25.7	24.9	24.6	23.6	23.3	14.4	22.5
1988	18.3	21.1	22.8	24.9	25.4	25.5	25.1	24.7	24.5	23.6	18.6	16.6	22.6
Ave.	16.7	19.0	21.8	24.0	24.6	25.1	24.9	24.8	24.2	23.2	20.3	16.8	22.1

Data are provided by Dept. of Meteorology and Hydrology, Min. Agriculture and Forestry.

Table A.5 Extreme Minimum Temperature at Vientiane

unit : degrees Centigrade

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1968	12.2	13.8	17.0	20.0	21.0	22.0	22.0	23.4	22.5	19.8	17.5	15.0
1969	16.0	11.8	20.5	17.5	19.5	23.3	22.8	23.0	21.1	20.8	13.2	11.0
1970	14.5	13.8	20.0	18.1	22.7	23.3	22.8	22.1	22.8	20.0	16.0	14.5
1971	7.3	13.1	16.0	21.3	21.6	23.0	22.7	22.9	22.7	16.8	10.6	14.3
1972	11.9	15.5	14.2	21.2	22.9	22.6	23.7	22.1	23.0	22.2	19.4	15.5
1973	14.8	16.2	19.5	21.9	22.9	22.9	23.0	21.7	23.2	17.7	12.8	7.6
1974	4.7	10.7	14.2	20.2	22.5	23.4	22.5	22.9	22.8	21.6	18.0	15.7
1975	14.1	15.4	20.1	21.0	22.3	23.0	22.8	22.8	22.0	21.5	11.7	5.3
1976	7.3	13.8	16.8	20.3	18.9	21.8	22.8	22.9	23.0	21.9	13.3	12.9
1977	15.5	13.9	14.0	20.3	21.8	24.0	22.0	23.0	21.8	20.8	13.1	14.6
1978	14.5	15.1	18.8	20.0	21.2	23.4	22.8	23.0	22.7	15.3	15.9	11.8
1979	17.2	15.2	19.1	22.3	22.0	22.3	23.5	23.0	23.0	18.6	14.4	12.7
1980	14.0	15.2	18.2	18.5	21.0	23.0	22.6	23.2	23.0	18.7	18.7	13.7
1981	10.9	16.6	18.7	20.5	22.1	23.1	22.0	23.0	22.4	21.0	15.4	11.8
1982	14.4	14.8	20.5	18.8	23.0	23.7	23.3	22.7	22.5	21.8	18.8	9.1
1983	10.8	16.4	17.0	22.9	23.8	22.2	22.7	22.9	21.6	20.5	10.9	10.9
1984	10.9	13.4	15.5	21.7	21.3	23.0	22.0	22.5	22.0	18.2	17.5	14.0
1985	15.7	15.7	16.2	21.7	22.8	22.5	22.5	23.5	21.2	20.0	19.3	9.8
1986	9.0	16.5	11.5	20.9	22.0	23.7	22.9	23.0	21.7	20.0	16.2	15.0
1987	14.5	14.8	19.0	21.0	23.0	23.4	23.7	22.3	21.5	19.0	19.3	10.0
1988	15.0	15.0	17.0	21.3	23.2	23.6	22.6	27.4	27.9	26.3	14.5	13.2
Ave.	12.6	14.6	17.3	20.5	22.0	23.0	22.7	23.0	22.6	20.1	15.5	12.3

Data are provided by Dept. of Meteorology and Hydrology, Min. Agriculture and Forestry.

Table A.6 Monthly Mean Relative Humidity at Vientiane

unit : %

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1968	65	64	64	65	76	81	78	81	80	74	72	69	72
1969	71	64	70	66	74	81	81	80	79	74	70	71	73
1970	75	70	73	76	82	88	86	82	80	73	69	68	77
1971	64	64	61	64	72	78	79	80	75	71	65	67	70
1972	65	65	65	66	68	74	75	79	76	74	71	70	71
1973	65	62	60	59	68	75	79	80	80	72	67	66	69
1974	65	63	66	69	71	75	76	80	76	74	70	68	71
1975	72	64	64	57	74	74	73	76	76	71	68	63	69
1976	62	63	63	71	76	75	75	78	82	74	67	64	71
1977	69	60	60	67	70	69	76	76	76	72	66	68	69
1978	66	67	66	69	76	77	80	80	79	74	69	67	73
1979	67	66	61	65	74	79	75	79	77	68	62	65	70
1980	65	64	57	64	72	79	78	78	80	72	70	68	71
1981	66	65	62	69	74	76	79	77	75	74	69	66	71
1982	68	69	66	69	70	72	72	79	80	76	72	69	72
1983	72	68	63	64	73	78	80	82	81	79	69	70	73
1984	69	68	62	64	72	76	80	78	78	77	71	69	72
1985	72	70	64	65	74	80	80	82	81	79	72	70	74
1986	67	65	58	66	79	79	78	78	76	74	70	64	71
1987	68	67	66	67	70	77	74	81	80	77	74	63	72
1988	67	68	66	66	81	81	83	85	80	79	68	68	74
Ave.	68	66	64	66	74	77	78	80	78	74	69	67	72

Data are provided by Dept. of Meteorology and Hydrology, Min. Agriculture and Forestry.

Table A.7 Monthly Mean Pan Evaporation at Vientiane

(Class A pan) unit :mm

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1968	3.0	4.0	4.1	4.2	5.8	4.6	8.2	3.7	6.7	5.0	4.8	4.0	4.8
1969	3.6	5.0	4.8	5.2	3.7	4.1	5.1	5.1	3.6	4.6	4.2	4.0	4.4
1970	4.0	5.0	5.3	5.4	5.3	4.4	4.0	3.8	4.7	6.8	6.0	5.0	5.0
1971	5.0	4.9	6.5	6.8	7.0	4.9	4.1	4.6	4.5	4.4	4.6	3.8	5.1
1972	3.6	4.4	4.4	5.7	6.3	5.1	4.6	4.3	6.1	5.3	6.0	5.1	5.1
1973	4.7	5.9	6.3	6.8	5.5	4.3	3.5	3.5	3.3	4.1	4.0	4.2	4.7
1974	3.6	4.5	4.4	5.2	5.3	4.0	4.1	3.3	3.7	4.4	3.8	3.6	4.2
1975	3.1	4.3	4.2	6.4	3.2	3.3	3.6	3.3	3.9	4.2	4.0	3.5	3.9
1976	3.7	3.8	4.4	4.0	3.4	4.8	3.4	3.5	3.8	4.2			3.9
1977	3.2	4.0	4.2	4.7	4.9	5.2	4.1	3.3	4.7	4.0	4.1	3.5	4.2
1978	3.8	3.3	4.2	4.0	4.5	4.1	3.6	3.3	4.9	4.3	4.1	3.8	4.0
1979	3.7	3.8	4.3	5.2	4.1	4.0	4.6	3.7	3.6	4.3	4.5	4.0	4.2
1980	3.5	4.0	4.9	4.5	3.4	2.9	3.1	3.7	3.0	4.2	4.0	4.3	3.8
1981	4.2	4.3	4.9	5.0	4.4	3.7	3.4	4.2	3.6	4.0	3.9	4.1	4.1
1982	4.0	3.8	3.6	3.8	4.2	6.6	3.3	2.7	2.8	3.6	4.0	3.0	3.8
1983	3.1	3.6	4.0	6.0	4.8	3.5	3.6	2.7	3.1	3.3	3.4	3.0	3.7
1984	3.3	4.3	4.8	4.7	3.6	3.4	2.7	2.6	2.6	3.0	3.9	3.7	3.6
1985	3.4	3.7	4.4	5.0	3.9	3.1	3.4	3.2	3.7	3.8	3.9	3.6	3.8
1986	3.5	3.8	4.0	4.7	3.4	3.2	2.7	4.3	4.5	4.4	4.5	3.7	3.9
1987	4.0	4.0	4.6	5.0	6.2	4.9	5.1	4.6	4.4	5.1	4.7	4.2	4.7
1988	4.4	4.4	5.0	5.7	5.7	5.3	5.1	4.3	5.2	4.1	4.6	4.2	4.8
Ave.	3.7	4.2	4.6	5.1	4.7	4.3	4.1	3.7	4.1	4.3	4.4	3.9	4.2

Data are provided by Dept. of Meteorology and Hydrology, Min. Agriculture and Forestry.

Table A.8 Monthly Mean Wind Velocity at Vientiane

unit :m/sec

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1968	1.3	1.5	1.6	1.5	1.7	1.9	1.6	1.6	1.5	1.6	1.5	1.3	1.6
1969	1.5	1.7	1.8	1.5	1.9	1.6	1.6	1.4	1.3	1.3	1.6	1.6	1.6
1970	1.7	1.6	1.6	1.5	1.7	1.7	1.4	1.5	1.6	1.5	1.4	1.4	1.6
1971	1.5	1.4	1.6	1.6	2.1	1.3	1.5	1.5	1.5	1.2	1.6	1.5	1.5
1972	1.2	1.3	1.2	1.8	1.4	1.3	1.2	1.3	1.2	1.2	1.1	1.2	1.3
1973	1.1	1.1	1.4	1.5	1.5	1.3	1.5	1.4	1.2	1.2	1.5	1.8	1.4
1974													-
1975							1.7						-
1976													-
1977									1.8	1.8	1.8	1.8	1.8
1978				2.2	2.2	1.8	2.0	2.4		1.9	1.2		2.0
1979	3.4	1.7	1.4	2.3	1.9	1.6	1.9	2.0	1.8	1.5	2.0	1.8	1.9
1980	1.6	1.7	1.8	3.3	3.6	1.7	1.8	1.6	1.9	1.4	1.3	1.4	1.9
1981	1.4	1.5	1.5	1.6	1.8	1.6	1.9	1.8	1.5	1.8	1.8	1.9	1.7
1982	1.3	1.7	1.6	1.7	1.8	1.7	2.0	1.8	2.0	1.5	1.6	1.8	1.7
1983	1.7	1.3	2.0	1.4	2.5	2.0	1.8	1.4	1.5	1.7	1.6	1.6	1.7
1984	1.8	2.2	1.8	2.2	2.3	2.8	2.3	2.5	1.7	1.6	1.7	1.5	2.0
1985	1.6	1.8	2.1	2.4	1.7	1.8	1.9	2.4	1.7	1.8	1.3	1.5	1.8
1986	1.5	1.9	1.7	2.2	2.2	2.1	2.0	2.2	1.9	1.8	1.7	1.3	1.9
1987	1.7	1.8	1.6	2.0	1.8	1.9	1.9	2.3	1.4	1.4	1.7	1.7	1.8
1988	1.5	1.8	1.7	2.0	1.6	1.6	1.8	1.7	1.6	2.0	2.0	1.5	1.7
Ave.	1.6	1.6	1.7	1.9	2.0	1.7	1.8	1.8	1.6	1.6	1.6	1.6	4.2

Data are provided by Dept. of Meteorology and Hydrology, Min. Agriculture and Forestry.

Table A.9 Monthly Mean Sunshine Hours at Vientiane

unit : hours

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1968	8.6	6.6	6.4	6.4	7.4	3.3	6.6	4.2	6.2	7.6	8.8	8.9	6.8
1969	6.9	7.4	5.9	7.7	6.2	4.1	3.6	5.5	5.0	8.6	7.7	8.3	6.4
1970	7.2	7.7	5.6	6.3	6.4	3.6	3.6	3.8	4.2	6.9	6.9	7.4	5.8
1971	8.6	7.2	7.1	7.7	6.6	3.9	3.7	3.3	6.8	6.0		7.6	6.2
1972	8.2	6.7	8.4	8.0	7.6	6.4	4.6	3.3	7.4	7.1	7.2	7.8	6.9
1973	9.6	9.2	7.5	8.9	6.6	5.8	3.9	3.2	4.0	7.2	7.0	9.0	6.8
1974	8.3	7.4	6.2	6.8	7.2	4.7	5.0	3.9	6.7	7.0	7.5	7.8	6.5
1975	5.4	8.8	7.5	8.7	5.5	4.4	6.0	3.9	5.7	7.3	8.2	8.1	6.6
1976	9.6	8.7	7.6	8.1	5.7	7.2	4.3	4.7	5.8	7.8	8.9	8.3	7.2
1977	8.1	8.8	7.0	8.0		7.8	4.8	5.7	6.7	8.6			7.3
1978			7.8	8.0	6.4	5.6	4.1	4.0	4.8	8.3	8.8	8.5	6.6
1979	9.5	8.5	8.8	7.3	6.5	3.8	7.4	4.3	5.7	8.0	9.1	8.6	7.3
1980	8.4	6.7	5.4	7.2	7.3	4.2	3.8	4.6	4.1	7.6	8.3	8.7	6.4
1981	9.0	7.7	6.7	6.4	6.1	4.0	4.1	4.7	6.3	5.3	6.9	7.8	6.3
1982	8.6	6.8	5.7	7.3	7.6	5.3	3.9	2.9	4.2	7.5	8.3	8.4	6.4
1983	6.7	8.2	7.5	8.1	7.4	6.2	6.0	5.0	5.9	6.3	7.8	8.2	6.9
1984	8.4	7.5	6.7	7.6	7.0	5.3	5.1	4.6	7.0	6.5	7.8	8.8	6.9
1985	8.0	7.0	8.2	7.2	6.4	5.1	5.2	3.2	6.6	7.0	7.9	8.0	6.7
1986	9.9	4.9	5.3	6.7	4.7	4.6	3.6	6.0	6.6	7.1	8.1	7.7	6.3
1987	8.8	8.2	7.8	7.8	8.3	5.5	4.0	4.8	4.6	8.9	7.1	9.7	7.1
1988	9.3	7.1	6.3	7.8	6.5	5.1	5.8	3.8	7.2	4.5	7.4	8.1	6.6
Ave.	8.4	7.6	6.9	7.5	6.7	5.0	4.7	4.3	5.8	7.2	7.9	8.3	6.7

Data are provided by Dept. of Meteorology and Hydrology, Min. Agriculture and Forestry.

Table A.10 Monthly Rainfall at Vientiane

unit : mm

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1958	0.0	0.0	0.0	0.0	57.3	246.2	165.1	344.3	0.0	6.0	0.9	0.0	820
1959	0.0	16.2	78.9	125.4	228.7	210.6	435.7	219.4	677.7	0.0	0.0	0.0	1,993
1960	10.3	0.0	6.8	40.1	134.4	106.8	264.5	420.2	609.1	48.4	16.9	0.0	1,658
1961	0.0	29.9	43.7	59.7	377.7	430.7	137.2	372.7	518.5	138.8	0.0	0.0	2,109
1962	0.0	0.0	0.0	118.3	253.1	196.4	207.4	419.1	356.0	111.7	0.0	2.7	1,665
1963	0.0	0.0	17.4	56.5	156.0	309.5	279.2	188.7	182.3	106.1	30.3	6.3	1,332
1964	0.0	11.6	28.5	100.1	407.3	213.1	306.0	238.5	400.1	152.1	1.0	0.0	1,858
1965	0.0	8.4	0.0	241.5	309.8	298.5	265.8	391.8	327.7	64.6	12.5	0.0	1,921
1966	2.4	18.7	78.4	109.5	349.3	232.7	172.3	656.7	119.5	33.5	6.0	0.0	1,779
1967	2.3	12.6	6.0	94.2	159.5	221.8	327.3	209.8	488.9	0.0	21.2	0.0	1,544
1968	0.9	0.0	100.6	88.8	301.8	243.5	258.2	206.8	272.0	27.7	0.0	0.0	1,500
1969	19.6	0.0	42.4	40.9	204.3	295.9	402.1	128.9	247.9	49.9	14.3	0.0	1,446
1970	0.5	0.0	31.2	56.9	306.4	377.2	215.8	624.9	420.5	53.8	0.0	0.1	2,087
1971	0.0	7.3	13.9	34.1	294.0	274.8	289.4	226.4	163.4	103.5	0.8	18.2	1,426
1972	0.0	6.8	36.8	167.6	115.6	312.8	246.1	306.7	166.3	148.4	8.2	5.8	1,521
1973	0.0	0.0	37.0	36.4	308.3	200.7	298.6	263.9	361.3	25.7	0.0	0.0	1,532
1974	0.0	1.6	36.7	97.4	100.5	159.2	255.7	368.4	187.1	92.6	29.7	0.2	1,329
1975	23.5	26.3	13.2	21.8	347.0	473.9	177.5	430.4	289.7	194.4	8.5	0.0	2,006
1976	0.0	23.0	111.9	126.9	121.7	167.3	167.6	403.1	416.7	76.7	0.0	0.0	1,615
1977	15.2	0.0	35.1	69.0	151.9	231.0	211.1	174.8	190.3	26.5	16.5	22.8	1,144
1978	1.6	17.8	51.1	145.9	328.4	254.9	354.6	293.6	381.4	128.9	28.5	0.0	1,987
1979	0.0	21.0	0.1	61.8	344.7	333.3	150.1	117.8	253.1	19.2	0.0	0.0	1,301
1980	0.0	18.6	68.8	61.0	319.5	611.0	461.5	342.9	353.4	54.7	0.0	0.0	2,291
1981	0.0	0.3	19.6	124.2	311.1	238.5	635.0	210.0	224.8	117.8	40.5	0.0	1,922
1982	0.0	6.1	60.8	69.6	239.3	95.4	253.8	484.0	319.5	90.2	22.2	0.6	1,642
1983	53.1	5.7	9.0	58.1	97.6	243.8	217.9	360.8	247.1	67.9	0.0	7.2	1,368
1984	0.0	10.6	3.4	88.9	148.3	148.1	421.0	388.9	267.1	142.1	17.3	0.0	1,636
1985	24.8	64.7	4.9	10.8	135.3	223.5	257.4	191.9	258.8	81.4	0.0	0.0	1,254
1986	0.0	3.2	1.5	118.8	383.4	256.2	308.9	318.3	275.3	66.7	0.0	21.0	1,753
1987	0.0	13.9	100.6	127.0	63.6	473.8	175.0	356.0	260.7	93.4	3.2	0.0	1,667
1988	0.0	23.4	2.8	66.0	573.2	131.5	188.9	257.6	170.4	194.6	0.0	0.0	1,608
Ave.	6.4	12.0	35.8	80.3	243.4	271.3	285.2	303.0	282.5	84.4	9.6	3.5	1,617

Data are provided by Dept. of Meteorology and Hydrology, Min. Agriculture and Forestry.

Table A.11 Monthly Rainfall at Tha Ngon

unit : mm

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1971	0.0	2.3	10.7	20.5	254.2	343.9	255.8	236.2	234.1	123.6	3.0	12.4	1,497
1972	0.0	11.2	93.2	74.1	125.6	216.0	180.4	317.6	120.5	233.9	12.9	2.6	1,388
1973	0.0	0.0	66.8	61.7	242.7	276.6	321.5	310.8	309.6	21.0	0.0	0.0	1,611
1974	0.0	0.1	57.0	60.3	121.9	304.9	280.5	453.9	157.3	0.0	39.5	0.8	1,476
1975	29.5	17.1	57.4	30.6	417.7	402.9	224.5	494.7	325.0	187.3	7.1	0.0	2,194
1976	0.0	31.8	83.0	106.6	268.4	251.8	337.8	265.9	344.6	28.6	8.7	0.0	1,727
1977	16.4	0.0	7.8	142.2	227.6	235.9	338.8	354.0	214.7	50.0	9.0	6.2	1,603
1978	8.5	5.6	71.4	171.3	360.4	256.4	434.0	261.1	247.1	53.6	28.2	0.0	1,898
1979	0.0	12.4	1.2	74.3	470.9	260.5	183.6	76.2	192.4	2.8	0.0	0.0	1,274
1980	0.0	3.0	97.4	74.5	289.4	543.5	443.0	341.5	430.8	71.2	0.0	0.0	2,294
1981	0.0	0.0	17.4	138.7	347.6	227.2	707.7	249.4	362.7	146.8	18.1	0.0	2,216
1982	0.0	6.4	36.2	105.1	177.8	204.0	369.5	548.3	495.5	92.2	6.4	0.0	2,041
1983	53.2	10.8	15.6	30.6	67.3	264.9	269.5	399.9	258.0	84.7	0.0	5.7	1,460
1984	0.0	39.8	5.4	33.3	358.0	199.4	396.6	461.6	192.4	140.6	10.9	0.0	1,838
1985	31.9	20.4	31.0	56.5	191.2	491.2	359.8	214.2	249.5	170.3	2.2	0.0	1,818
1986	0.0	0.0	0.0	173.8	-	300.3	-	-	-	-	-	-	-
1987	0.0	42.4	134.7	58.4	63.6	385.9	327.9	382.0	329.3	64.7	83.0	0.0	1,872
1988	0.0	22.9	33.0	85.0	288.6	153.6	182.1	403.1	105.4	-	-	-	-
Ave.	7.8	12.6	45.5	83.2	251.3	295.5	330.2	339.4	268.8	92.0	14.3	1.7	1762.9

Data are provided by Dept. of Meteorology and Hydrology, Min. Agriculture and Forestry.
Note : "-" indicates no data available.

Table A.12 Annual Maximum Discharge of the Mekong at Vientiane (1/2)

(Unit: cu.m/sec)

Year	Source [1]			Source [2]			Source [3]		Source [4]	Adopted
	Level	Discharge	Date	Level	Discharge	Date	Discharge	Date	Discharge	discharge
1913							17,300	8-24	17,400	17,400
1914							18,400	9-14	19,000	19,000
1915							13,900	8-23	13,900	13,900
1916							12,300	9-13	12,300	12,300
1917							19,000	8-12	20,000	20,000
1918							18,100	8-16	18,400	18,400
1919									14,200	14,200
1920							12,600	9-21	12,600	12,600
1921							16,800	10-03	16,900	16,900
1922							18,300	8-31	18,800	18,800
1923				169.98	19,300	8-22	19,300	8-22	20,600	20,600
1924				170.70	21,400	8-29	21,200	8-29	25,600	25,600
1925				167.76	13,600	8-01	14,000	8-01	14,000	14,000
1926				169.33	17,600	8-20	17,700	8-20	17,900	17,900
1927				169.26	17,400	8-02	17,500	8-02	17,700	17,700
1928				168.42	15,200	7-20	15,500	7-20	15,500	15,500
1929				170.46	20,700	8-23	20,500	8-23	23,500	23,500
1930				169.52	18,100	8-13	18,100	8-13	18,400	18,400
1931				168.56	15,600	9-19	15,800	8-19	15,800	15,800
1932				168.04	14,300	8-11	14,900	10-17	14,900	14,900
1933				168.78	16,100	8-26	16,300	8-26	16,300	16,300
1934				167.96	14,100	8-27	14,900	8-27	14,900	14,900
1935				169.30	17,500	8-16	17,600	8-16	17,800	17,800
1936				169.08	16,900	9-13	17,000	8-13	17,100	17,100
1937				169.18	17,200	9-08	17,300	9-08	17,400	17,400
1938				169.60	18,300	8-28	18,300	8-28	18,800	18,800
1939				169.90	19,100	8-22	19,100	8-22	20,200	20,200
1940							17,900	8-09	17,900	17,900
1941							19,400	8-13	20,900	20,900
1942				170.30	20,200	8-13	20,100	8-13	22,600	22,600
1943				168.53	15,500	8-26	15,800	8-26	15,800	15,800
1944				167.87	13,900	9-02	14,300	9-02	14,300	14,300
1945							20,300	8-21	23,000	23,000
1946							19,400	9-18	20,900	20,900
1947				169.52	18,100	8-13	18,100	8-14	18,400	18,400
1948				168.58	15,600	10-02	15,600	9-07	15,600	15,600
1949				168.08	14,400	10-01	14,800	10-01	14,800	14,800
1950				168.27	14,900	9-05	15,200	9-05	15,200	15,200
1951				168.78	16,100	8-25	16,300	8-25	16,300	16,300
1952				169.20	17,200	9-10	17,300	9-10	17,400	17,400
1953							14,100	8-29	14,100	14,100
1954							15,700	9-02	15,700	15,700
1955							18,000	9-05	18,300	18,300
1956							16,300	8-24	16,300	16,300
1957							11,300	10-02	11,300	11,300

Table A.12 Annual Maximum Discharge of the Mekong at Vientiane (2/2)

(Unit: cu.m/sec)

Year	Source [1]			Source [2]			Source [3]		Source [4]	Adopted
	Level	Discharge	Date	Level	Discharge	Date	Discharge	Date	Discharge	discharge
1958							11,500	7-28	11,500	11,500
1959							17,600	8-30	18,300	18,300
1960							17,800	8-20	18,600	18,600
1961	169.21	18,300	9-10				17,900	9-10	18,800	18,800
1962	168.34	15,400	8-26				15,300	8-26	15,400	15,400
1963	168.51	15,800	8-11				15,700	8-11	15,800	15,800
1964	169.03	17,200	8-27				16,900	8-27	17,300	17,300
1965	167.18	12,800	10-31				12,800	10-31	13,000	13,000
1966	170.74	21,300	9-04				25,900	9-04	26,000	26,000
1967	167.21	12,900	8-24				12,400	8-24		12,900
1968	168.20	14,700	8-18				14,600	8-18		14,700
1969	169.92	19,100	8-20				18,800	8-21		19,100
1970	169.89	19,000	8-15							19,000
1971	170.55	22,900	8-22				23,000	8-22		23,000
1972	167.90	14,200	8-27							14,200
1973	169.72	19,700	8-29							19,700
1974	168.36	15,900	9-03							15,900
1975	168.80	16,400	9-05							16,400
1976	168.80	18,200	8-17							18,200
1977	167.94	14,400	8-02							14,400
1978	170.12	21,300	8-16							21,300
1979	168.24	15,200	9-16							15,200
1980	169.94	20,600	9-06							20,600
1981	168.76	16,600	8-08							16,600
1982	168.78	16,600	8-26							16,600
1983	168.01	14,600	8-08							14,600
1984	168.32	15,400	7-18							15,400
1985	169.54	17,100	9-02							17,100
1986	167.88	13,400	8-12							13,400

Source: [1] Mekong Committee, Lower Mekong Hydrologic Yearbook.
[2] Water levels by Dept. of Meteology;
conversion to discharge by 1971 rating curve.
[3] U.S.A.I.D., Report on Vientiane Laos Flood Control Project, 1971.
[1966 and 1971 discharges are adjusted for overbank flow.]
[4] U.S.Depatment of the Interior, Bureau of Reclamation, Pa Mong Appendix III, 1972. [All data above Gauge Height 11 m adjusted for possible overbank flow]

Table A.13 Monthly Average Discharge of Mekong at Vientiane (1/2)

(Unit: cu.m/sec)

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	AVE.
1913	1,728	1,430	1,265	1,191	2,186	3,429	6,361	11,833	9,187	7,084	5,645	3,171	4,542
1914	1,949	1,401	1,168	1,290	1,488	3,196	7,550	12,375	10,345	6,462	3,682	2,337	4,437
1915	1,726	1,344	1,184	1,244	2,563	4,595	7,704	11,972	9,280	6,693	4,086	2,467	4,571
1916	1,679	1,414	1,220	1,245	1,265	3,188	6,700	8,771	10,127	7,802	3,817	2,144	4,114
1917	1,639	1,287	1,123	1,068	1,249	3,407	7,456	14,343	9,223	5,745	3,364	2,252	4,346
1918	1,632	1,438	1,296	1,200	2,486	5,867	5,774	14,791	13,453	9,643	4,538	3,320	5,453
1919	-	-	-	-	-	-	-	-	-	-	-	-	-
1920	1,651	1,373	1,180	1,187	1,698	2,188	5,167	7,144	10,688	6,557	3,253	2,077	3,680
1921	1,600	1,296	1,147	1,093	1,530	2,898	7,107	10,791	11,840	11,912	4,701	2,593	4,876
1922	1,890	1,520	1,407	1,336	1,798	2,523	7,060	12,479	10,889	5,370	3,759	2,538	4,381
1923	1,805	1,464	1,271	1,397	1,968	4,263	7,215	15,216	11,326	6,371	3,795	2,364	4,871
1924	1,936	1,526	1,324	1,343	1,323	2,870	9,774	19,684	12,485	5,934	3,864	2,208	5,356
1925	1,739	1,539	1,341	1,400	1,703	3,938	7,607	11,093	10,372	6,448	3,565	2,319	4,422
1926	1,688	1,424	1,223	1,138	1,105	2,724	5,667	15,103	11,126	7,048	5,312	3,280	4,737
1927	2,064	1,597	1,311	1,367	2,267	4,708	7,508	13,977	10,015	10,141	4,783	2,964	5,225
1928	2,022	1,690	1,523	1,416	1,583	3,470	9,669	9,503	6,981	5,439	3,681	2,226	4,100
1929	1,422	1,233	1,047	1,081	1,453	4,237	9,620	18,545	12,283	6,980	3,306	2,368	5,298
1930	1,722	1,426	1,233	1,470	2,401	4,951	6,392	14,627	10,640	6,429	3,289	2,236	4,734
1931	1,564	1,331	1,132	1,128	1,292	1,746	3,532	8,987	9,560	4,407	2,342	1,386	3,201
1932	1,162	961	917	1,029	1,009	2,916	6,413	8,847	11,834	11,354	4,047	2,602	4,424
1933	1,810	1,152	921	831	994	3,370	8,006	11,215	8,607	5,285	3,205	2,037	3,953
1934	1,475	1,122	1,002	1,019	1,009	1,988	6,546	12,720	10,064	5,722	3,313	2,063	4,004
1935	1,607	1,243	1,098	1,053	1,460	3,185	4,594	13,993	9,438	8,010	5,291	2,834	4,484
1936	1,920	1,576	1,279	1,439	1,809	4,968	6,944	12,076	12,927	4,772	2,589	1,710	4,501
1937	1,312	1,129	1,028	885	1,429	3,390	7,633	13,887	13,658	6,724	3,534	2,913	4,794
1938	2,196	1,635	1,537	1,601	3,194	6,690	9,042	15,384	12,577	8,962	5,186	3,059	5,922
1939	2,271	1,756	1,515	1,583	2,221	6,078	10,680	15,961	11,652	8,524	4,193	2,961	5,783
1940	2,088	1,673	1,400	1,322	1,875	4,603	7,749	13,094	11,065	5,291	3,184	2,162	4,626
1941	1,572	1,307	1,130	1,077	1,457	4,157	6,145	12,105	13,827	10,903	5,205	2,953	5,153
1942	2,075	1,554	1,246	1,183	2,074	4,411	10,616	18,674	10,257	5,285	3,699	2,350	5,285
1943	1,730	1,335	1,249	1,312	1,402	3,186	5,806	12,247	12,823	7,987	3,346	2,155	4,548
1944	1,701	1,470	1,197	1,033	1,595	3,346	7,719	10,668	11,090	6,747	4,389	2,427	4,448
1945	1,804	1,485	1,312	1,371	2,059	4,064	7,733	16,770	14,109	5,656	3,103	2,382	5,154
1946	1,709	1,349	1,172	1,301	2,138	4,970	7,329	13,966	17,473	9,656	4,973	2,796	5,736
1947	2,062	1,721	1,438	1,397	2,059	4,183	10,904	14,126	14,563	8,109	4,171	2,380	5,593
1948	1,813	1,452	1,261	1,302	2,064	3,811	8,274	12,843	13,455	9,633	4,879	2,899	5,307
1949	2,073	1,606	1,327	1,550	2,130	3,081	7,035	10,329	11,337	8,955	4,207	2,759	4,699
1950	2,046	1,697	1,341	1,181	1,614	2,242	6,161	10,438	9,590	5,291	3,082	2,147	3,902
1951	1,768	1,467	1,091	1,070	1,356	5,324	7,167	13,781	10,630	7,725	3,284	2,400	4,755
1952	1,834	1,322	1,210	1,113	1,476	2,440	6,450	13,381	14,647	7,639	3,258	1,605	4,698
1953	1,181	1,203	907	968	1,564	2,796	6,073	9,714	10,297	4,499	3,196	2,132	3,711
1954	1,497	1,050	852	910	1,320	2,671	4,642	10,694	12,391	5,612	3,182	2,202	3,919
1955	1,604	1,222	996	1,082	1,271	2,492	7,900	14,684	13,203	3,844	3,933	2,260	4,541
1956	1,638	1,116	897	782	1,099	2,855	4,651	13,657	10,400	4,131	1,989	1,431	3,720

Table A.13 Monthly Average Discharge of Mekong at Vientiane (2/2)

(Unit: cu.m/sec)

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	AVE.
1957	1,260	1,143	1,018	926	1,132	2,095	5,027	4,693	5,671	5,744	1,936	1,263	2,659
1958	989	884	770	822	1,061	2,198	6,277	9,969	8,290	4,009	2,793	1,704	3,314
1959	1,281	1,269	1,216	1,166	1,495	3,721	5,525	11,043	12,027	7,266	4,003	2,215	4,352
1960	1,635	1,472	1,064	867	1,119	2,416	5,743	12,983	11,950	6,215	3,377	2,407	4,271
1961	1,560	1,320	1,080	1,320	1,660	4,230	5,580	10,800	13,700	9,180	4,280	2,830	4,795
1962	1,920	1,490	1,230	1,190	1,720	4,470	6,300	11,400	9,350	6,040	3,290	2,010	4,201
1963	1,450	1,200	1,070	969	1,120	2,440	7,530	13,300	9,820	6,260	7,260	3,040	4,622
1964	1,920	1,470	1,290	1,330	2,090	3,020	9,520	11,300	12,200	8,290	4,340	2,900	4,973
1965	1,990	1,580	1,270	1,150	1,310	3,910	7,640	9,750	9,620	6,560	7,580	3,610	4,664
1966	2,345	1,749	1,329	1,250	1,660	4,250	8,560	15,500	17,200	8,700	5,240	3,340	5,927
1967	2,380	1,790	1,510	1,350	1,650	2,710	4,690	8,840	8,990	7,030	3,800	2,640	3,948
1968	1,890	1,450	1,240	1,180	2,180	2,850	5,890	9,370	10,000	7,070	5,120	2,530	4,231
1969	1,760	1,340	1,030	919	931	2,980	6,420	14,300	8,550	4,930	3,500	2,020	4,057
1970	1,470	1,190	985	1,130	2,350	4,640	10,600	15,500	12,000	6,370	3,880	3,710	5,319
1971	2,220	1,670	1,310	1,170	1,420	4,000	11,300	18,300	14,500	7,000	4,510	2,510	5,826
1972	1,780	1,350	1,060	1,210	1,360	2,240	3,760	10,800	8,150	6,310	4,190	3,700	3,826
1973	1,810	1,280	1,290	1,300	1,890	3,970	8,000	13,100	16,100	7,390	5,040	3,180	5,363
1974	1,890	1,370	1,140	1,380	1,850	3,510	5,420	11,000	12,600	6,220	3,620	2,160	4,347
1975	1,860	1,330	1,070	1,110	1,490	4,120	6,030	8,830	10,800	6,120	3,760	2,280	4,067
1976	1,610	1,510	1,190	1,280	1,770	3,630	5,800	12,700	8,920	7,630	4,570	2,590	4,433
1977	1,860	1,420	1,300	1,470	1,680	2,190	6,120	9,460	9,800	6,610	4,700	2,500	4,093
1978	2,190	1,450	1,330	1,210	2,360	4,020	9,930	14,500	11,600	7,980	3,620	2,200	5,199
1979	1,590	1,310	1,110	1,100	1,530	3,290	4,510	8,330	11,200	7,090	3,290	2,150	3,875
1980	1,530	1,330	1,230	1,360	1,780	3,850	8,060	12,700	15,300	8,200	4,110	2,500	5,163
1981	1,780	1,470	1,270	1,280	2,780	5,880	10,200	12,000	10,700	6,610	5,330	3,370	5,223
1982	2,130	1,600	1,300	1,470	1,430	3,550	6,040	12,400	9,320	8,700	3,950	2,510	4,533
1983	1,770	1,470	1,390	1,370	1,590	2,760	4,580	9,370	11,800	6,760	5,970	3,220	4,338
1984	2,320	1,610	1,260	1,220	1,460	2,670	9,010	9,310	9,860	6,740	3,950	2,280	4,308
1985	1,410	1,150	957	1,020	1,330	3,850	6,650	10,500	13,300	6,520	5,090	3,200	4,581
1986	1,980	1,400	1,130	1,090	2,290	3,230	5,770	8,910	7,620	6,280	3,650	2,160	3,793
Avera	1,767	1,403	1,194	1,200	1,678	3,563	7,076	12,294	11,269	6,967	4,041	2,501	4,579

Source : For the data of 1913 through 1960 and January through March of 1966, U.S. Dept of the Interior, Pa Mong Phase II, 1972; with conversion of units.
For the data of 1961 onwards, Mekong Committee, Hydrology Year Book of the Mekong, each year.

Table A.14 Results of Simultaneous Observation of Water Levels

Gauge No.	River/Canal	Zero level	June 8 Gauge height (m)	June 8 Water level (el.m)	June 20 Gauge height (m)	June 20 Water level (el.m)	July 7 Gauge height (m)	July 7 Water level (el.m)	August 3 Gauge height (m)	August 3 Water level (el.m)	August 15 Gauge height (m)	August 15 Water level (el.m)	September 13 Gauge height (m)	September 13 Water level (el.m)
1	Khou Kao	165.865	-0.06	165.81	-0.10	165.77	0.01	165.88	0.10	165.97	0.08	165.95	0.10	165.97
2	Khou Kao	166.863	0.14	167.00	0.12	166.98	0.27	167.13	0.43	167.29	0.24	167.10	0.49	167.35
3	Hong Thong	167.465	0.12	167.59	0.08	167.55	0.07	167.54	0.47	167.94	0.08	167.55	0.18	167.65
4	Nam Pasak	166.622	0.20	166.82	0.18	166.80	0.26	166.88	0.22	166.84	0.09	166.71	0.09	166.71
5	Hong Ke	166.591	0.36	166.95	0.34	166.93	0.54	167.13	0.68	167.27	0.51	167.10	0.76	167.35
6	Hong Ke	165.484	0.43	165.91	0.26	165.74	0.21	165.69	0.29	165.77	-	-	0.22	165.70
7	Hong Ke	164.724	0.53	165.25	0.56	165.28	0.58	165.30	0.97	165.69	0.57	165.29	0.94	165.66
8	Upstream Nam Pasak	165.452	0.50	165.95	0.38	165.83	0.82	166.27	0.81	166.26	1.05	166.50	0.46	165.91
9	Hong Xeng	165.087	0.02	165.11	-0.06	165.03	0.80	165.89	0.93	166.02	0.77	165.86	-	-
10	Hong Xeng	163.950	0.48	164.43	0.26	164.21	0.71	164.66	0.53	164.48	1.28	165.23	0.98	164.93
11	That Luang drain canal	163.967	0.62	164.59	0.58	164.55	0.86	164.83	0.72	164.69	1.23	165.20	0.47	164.44
12	Houei Mak Hiao	162.928	0.61	163.54	0.46	163.39	0.84	163.77	0.54	163.47	1.14	164.07	-	-

Table A.15 Results of Rainfall and Water Level Observations at Automatic Gauges

	June			July			August			September			October		
	Daily rain-fall	Water levels		Daily rain-fall	Water levels		Daily rain-fall	Water levels		Daily rain-fall	Water levels		Daily rain-fall	Water levels	
Day	(mm)	Hong Ke (el.m)	Hong Xeng (el.m)	(mm)	Hong Ke (el.m)	Hong Xeng (el.m)	(mm)	Hong Ke (el.m)	Hong Xeng (el.m)	(mm)	Hong Ke (el.m)	Hong Xeng (el.m)	(mm)	Hong Ke (m3/s)	Hong Xeng (m3/s)
1	24.0	164.91	164.46	0.0	165.28	164.16	0.0	165.26	164.15	0.0	-	165.01	1.0	165.39	165.15
2	0.5	164.92	164.58	13.5	165.28	164.16	0.0	165.20	164.15	27.0	-	164.99	2.0	165.37	165.11
3	5.0	165.11	164.36	8.0	165.34	164.44	48.5	165.35	164.34	0.0	-	164.99	0.0	165.34	165.02
4	0.0	165.06	164.26	0.0	165.37	164.62	73.0	165.28	164.73	0.0	-	164.77	0.5	165.32	164.98
5	5.5	165.11	164.55	0.0	165.35	164.33	22.0	165.74	165.18	0.0	-	164.71	2.5	165.55	164.98
6	0.5	165.23	164.43	34.0	165.39	164.47	0.0	165.63	165.12	28.5	-	164.64	39.0	165.41	165.14
7	0.5	165.21	164.43	0.0	165.38	164.66	0.0	165.33	165.05	9.5	-	165.13	0.0	165.34	165.10
8	0.5	165.24	164.43	20.5	165.39	164.66	34.0	165.18	164.99	34.5	165.28	165.32	0.0	165.31	165.09
9	0.0	165.15	164.26	0.0	165.36	164.66	31.0	165.38	165.03	2.0	165.32	165.42	0.0	165.28	165.12
10	1.0	165.19	164.16	0.0	165.29	164.70	1.5	165.51	165.13	0.0	165.29	165.42	0.0	165.26	165.07
11	8.0	165.22	164.30	11.0	165.27	164.51	51.0	165.71	165.30	0.0	165.28	165.39	2.0	165.24	165.11
12	4.0	165.29	164.37	3.0	165.26	164.62	0.5	165.55	165.27	84.0	165.65	165.49	0.0	165.21	165.00
13	23.0	165.26	164.34	1.0	165.27	164.49	30.0	165.37	165.34	9.5	165.68	165.49	3.0	165.21	164.98
14	18.0	165.17	164.34	0.0	165.31	164.38	7.5	165.41	165.31	0.0	165.54	165.48	0.0	165.19	165.03
15	10.0	165.17	164.51	0.0	165.16	164.31	0.5	165.31	165.24	1.0	165.45	165.41	2.5	165.18	165.16
16	0.0	165.07	164.49	-	165.14	164.16	0.0	165.24	165.20	0.0	165.41	165.34	4.0	165.15	165.20
17	0.0	165.04	164.45	-	165.08	164.16	0.0	165.19	165.15	0.0	165.37	165.23	0.0	165.14	165.16
18	0.0	165.24	164.39	-	165.09	164.19	0.0	165.16	165.05	8.0	165.35	165.13	0.0	165.12	165.17
19	0.0	165.26	164.33	-	165.22	164.29	11.5	165.13	164.93	4.5	165.36	165.09	0.0	165.09	165.15
20	0.0	165.27	164.24	-	165.22	164.29	0.0	165.12	164.77	3.0	165.36	165.15	0.0	165.07	165.13
21	0.0	165.24	164.23	-	165.24	164.16	4.5	165.11	164.63	5.5	165.34	165.12	0.0	165.05	165.08
22	0.0	165.27	164.18	0.0	165.26	164.16	7.5	165.10	164.81	9.0	165.36	165.10	0.0	165.02	164.90
23	3.0	165.25	164.17	33.0	165.24	164.16	20.5	165.15	164.69	32.5	165.38	165.09	0.0	165.00	164.70
24	0.5	165.26	164.16	8.5	165.34	164.16	20.5	-	164.80	52.0	165.63	165.27	0.0	164.98	164.91
25	0.0	165.27	164.18	0.5	165.27	164.15	4.0	-	164.99	15.5	165.73	165.48	0.0	164.96	164.73
26	7.5	165.32	164.16	0.0	165.05	164.15	58.0	-	165.01	0.0	165.65	165.46	0.0	164.94	164.71
27	29.0	165.33	164.16	10.5	164.97	164.15	4.5	-	165.16	0.0	165.54	165.42	0.0	164.94	164.70
28	2.5	165.41	164.16	0.0	165.01	164.15	1.0	-	165.14	0.0	165.50	165.38	0.0	164.93	164.54
29	0.0	165.15	164.34	0.0	165.15	164.18	0.0	-	165.12	0.0	165.48	165.31	0.0	164.93	164.60
30	0.0	165.31	164.21	0.5	165.23	164.36	3.0	-	165.10	0.0	165.45	165.24	0.0	164.93	164.32
31				1.0	165.28	164.26	1.0	-	165.07				0.0	164.93	164.46
Total	143.0	-	-	145.0	-	-	435.5	-	-	326.0	-	-	56.5	-	-
Ave.	-	165.20	164.32	-	165.24	164.33	-	165.32	164.96	-	165.45	165.22	-	165.16	164.97

Table A.16 Results of Water Level Hearing Survey of Main Canals

Sample No.	Description of the sample	Lived here since:	Highest water level in last 5 years (El. m)
1) Khoua Khao at Gate to Mekong (Point 1)			
	(Date: 3 November, 1989)		
1	Public servant	1983	168.6
2	Farmer	1976	168.7
3	Public servant	1981	168.8
4	Public servant	1984	168.8
5	Rice cultivation	1960	168.9
Adopted HWL for Point 8			168.8
2) Hong Thong at Gas Station (Point 3)			
	(Date: 2 November, 1989)		
1	Mechanic near the river	1950	168.4
2	Officer	1954	168.3
3	Rice cultivation	1940	168.3
4	Rice cultivation	1940	168.3
5	Officer	1952	168.2
Adopted HWL for Point 8			168.5
3) Nam Pasak at Wat Khao Vieng (Point 4)			
	(Date: 2 November, 1989)		
1	Monk at Khao Vieng	1981	168.0
2	Public servant	1950	168.0
3	Monk at Khao Vieng	1985	168.1
Adopted HWL for Point 8			168.1
4) Hong Ke at Ban Fay Bridge (Point 5)			
	(Date: 2 November, 1989)		
1	Unemployed	1953	168.2
2	Rice cultivation	1945	168.2
3	Unemployed	1943	168.2
4	Public servant	1944	168.4
Adopted HWL for Point 8			168.4

Sample No.	Description of the sample	Lived here since:	Highest water level in last 5 years (El. m)
6) That Luang at outlet of drainage canal (Point 11)			
	(Date: 9 June, 1989)		
1	Farmer	1979	165.2
2	Remedy physician	1976	165.2
3	Farmer	1977	165.4
4	Cigarette factory worker	1979	165.0
5	Farmer	1973	165.3
6	Farmer	1950	165.0
7	Officer at irrigation dept.	1986	165.2
8	Officer at irrigation dept.	1930	165.2
9	Farmer	1960	165.2
10	Farmer	1970	165.3
Adopted HWL for Point 11			165.5
7) Hong Xeng at Dong Deng bridge (Point 8)			
	(Date: 26 October, 1989)		
1	Farming near the river	1983	167.5
2	Farming near the river	1945	167.4
3	Farming near the river	1950	167.3
4	Rice cultivation nearby	1980	167.5
5	Staff of Vientiane Prefecture	1980	167.4
6	Rice cultivation	1986	167.5
7	Farming nearby	1970	167.4
8	Farming nearby	1983	167.3
9	Unemployed	1986	167.3
Adopted HWL for Point 8			167.5

Table A.17 Annual Maximum One-day Rainfall (1/2)

Year	Month	Day	[1]	[2]	[3]	[4]	Adopted one-day rainfall in mm	Remarks
1900	7	12				93	93.0	
1901	5	3				177	177.0	
1902	8	22				36	36.0	
1903	7	29				98	98.0	
1904	5	18				132	132.0	
1905	7	23				182	182.0	
1906	9	8				86	86.0	
1907	5	24				79	79.0	
1908	5	30				138	138.0	
1909	6	5				163	163.0	
1910	5	26				83	83.0	
1913	7	12				104	104.0	
1914	5	25	48.0			78	78.0	
1915	9	9				73	73.0	
1916	7	17				99	99.0	
1917	8	15				92	92.0	
1918	6	8				118	118.0	
1919	6	7				139	139.0	
1920	6	8	126.9			127	126.9	
1921	5	23				80	80.0	
1922	9	13	99.0			99	99.0	
1923	6	25		155.9		84	155.9	
1924	7	6		129.5		130	129.5	
1925	6	2		104.5		105	104.5	
1926	8	10				95	95.0	
1927	7	24		100.3		100	100.3	
1928	7	22				93	93.0	
1929	9	7				76	76.0	
1930	10	2		130.2		130	130.2	
1931	9	16	73.0			73	73.0	
1932	10	20	72.8			82	82.0	
1933	7	30	109.8	109.8		110	109.8	
1934	7	26	79.4	117.5		116	117.5	[1] lists the date as 7/28
1935	9	28	75.7			76	75.7	
1936	5	21	100.7	100.7		84	100.7	[2] lists the date as 5/29
1937	5	3	115.6	115.6		103	115.6	
1938	8	24	131.2	131.2		131	131.2	
1939	7	12	68.3			93	93.0	
1940	8	20	87.7			88	87.7	
1941	8	11	105.5			106	105.5	

Source: [1] Nippon Koei for the United Nations, Comprehensive Project Feasibility Report on th Nam Ngun Project Part II: Lower Nam Ngun Irrigation Project, 1962

[2] Department of the Interior Bureau of Reclamation, Pa Mong Stage One Feasibility Report, 1970

[3] Mekong Committee, Lower Mekong Hydrologic Yearbook, respective volumes

[4] Department of Meteology and Hydrology, in-house data

Table A.17 Annual Maximum One-day Rainfall (2/2)

Year	Month	Day	[1]	[2]	[3]	[4]	Adopted one-day rainfall in mm	Remarks
1949	7	30	81.8				81.8	
1950	8	5	80.7			81	80.7	
1951	10	23	73.2			73	73.2	
1952	9	17		130.0		130	130.0	
1953	9	6	101.4	101.4		101	101.4	
1954	8	15	106.7	106.7		107	106.7	
1955	7	30	132.9	132.9		133	132.9	
1956	8	2	101.3			101	101.3	
1957	7	5	80.5			85	80.5	
1958	6	26	92.5	138.7	92.5	93	92.5	[2] lists the date as 9/2 (may be mistaken for 1959)
1959	9	2	138.7		138.7	139	138.7	
1960	9	27	109.8	109.8	109.8	110	109.8	
1961	6	3	111.7	111.7	111.7	112	111.7	[2] lists the date as 7/3
1962	5	18		100.2		100	100.2	
1963	6	3		106.6	106.6	107	106.6	
1964	9	6			91.1	91	91.1	
1965	9	13		112.0	112.0	112	112.0	
1966	8	13			110.5	111	110.5	
1967	9	20			137.3	137	137.3	
1968	7	23			93.1	93	93.1	
1969	7	11			134.8	135	134.8	
1970	8	17			116.3	116	116.3	
1971	5	5			84.7	85	84.7	
1972	4	12			75.9	76	75.9	
1973	5	28			96.2	96	96.2	
1974	4	16			133.5	134	133.5	
1975	6	19			94.0	94	94.0	
1976	8	26			224.2	224	224.2	
1977	6	20			95.4	95	95.4	
1978	9	16			82.7	83	82.7	
1979	5	24			81.2	81	81.2	
1980	7	24			86.8	87	86.8	
1981	7	20			181.0	181	181.0	
1982	8	10			133.2	133	133.2	
1983	9	10			115.0	80	115.0	
1984	8	18			73.9	74	73.9	
1985	9	12			82.2	82	82.2	
1986	8	25			119.7	120	119.7	
1987	6	1			162.0	162	162.0	
1988	5	14				162.2	162.2	

Source: [1] Nippon Koei for the United Nations, Comprehensive Project Feasibility Report on th Nam Ngun Project Part II: Lower Nam Ngun Irrigation Project, 1962

[2] Department of the Interior Bureau of Reclamation, Pa Mong Stage One Feasibility Report, 1970

[3] Mekong Committee, Lower Mekong Hydrologic Yearbook, respective volumes

[4] Department of Meteology and Hydrology, in-house data