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9. ABSTRACT

The method of evaluation used in this report is the synchronization of the cropping time with the probability of rainfall in order to minimize the rick of wet-season cropping and to maximize utilization of the reservoir storage for dry-season cropping. The Huey Si Thon Project was the area studied. During the wet-season cropping, the reservoir storage should remain full for use in the dry-season cropping. If it is not used at that time, much of the water will be lost by evaporation and seepage. Thus the relationship between the irrigable area for the wet-season cropping and the optimal capacity should be determined by the mean rainfall during the cropping period. Increasing reservoir capacity to reduce the risk of wet-season cropping also will increase the service area for dry-season cropping. The irrigable area for wet-season cropping may be enlarged in the future, if further research indicates that watershed runoff successfully can be diverted and stored in the rice paddies.

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The method of evaluation used in this report is to synchronize the cropping time with the probability of rainfall in order to minimize the risk of wet-season cropping and to maximize utilization of the reservoir storage for dry-season cropping.

WATER MANAGEMENT FOR SMALL IRRIGATION RESERVOIRS
IN NORTHEAST THAILAND

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ABSTRACT

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The primary aim of this report is to evaluate the water use efficiency of small irrigation reservoirs in Northeast Thailand. These reservoirs are necessary for consistent agricultural production in this region. Reservoir capacities are restricted by topography and rainfall runoff is their source of water. Water management of these reservoirs has to take into consideration the risk of a varying rainfall distribution.

The method of evaluation used in this report is to synchronize the cropping time with the probability of rainfall in order to minimize the risk of wet-season cropping and to maximize utilization of the reservoir storage for dry-season cropping.

The Huey Si Thon Project is used as a study area in this report. An analysis of the data indicates that the wet-season cropping schedule should depend on the amount of rainfall during May to June. Generally, the suitable cropping schedule of the wet-season crop (rice) should begin in early July. During the wet-season cropping, the reservoir storage should remain full. The full reservoir storage can then be used for dry-season cropping. If this remaining reservoir storage is not used for dry-season cropping, much of the water will be lost by evaporation and seepage. The relationship between the irrigable area for the wet-season cropping and the optimal capacity should be determined by the mean rainfall during the cropping period. Increasing reservoir capacity to reduce the risk of wet-season cropping will increase the service area for dry-season cropping. The irrigable

area for wet-season cropping may be increased in the future if further research indicates that watershed runoff can be successfully diverted and stored in the rice paddies.

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TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF TABLES

LIST OF TABLES (Continued)

LIST OF TABLES (Continued)

LIST OF FIGURES

LIST OF FIGURES (Continued)

Chapter I

INTRODUCTION

There are over one hundred irrigation projects operating with small reservoirs (tanks) in the Northeast region of Thailand. They are increasing in number every year. These reservoirs depend largely on the occurrence of runoff from their watersheds and the farming operations have to accept the risks of rainfall variation from year to year. The designed capacity of these reservoirs at the present time varies from sixty thousand cubic meters to 59.0 million cubic meters, and the irrigable areas vary from 12 hectares to 4000 hectares.[1] The lands in the project are owned by many farmers with each farm containing about 3-4 hectares on the average.[2] The purpose of the reservoirs is to store the rainfall during rainy season to irrigate the paddy fields. The average annual rainfall of the region is about 1330 mm,[3] which is enough for agricultural cultivation. If the rainfall during the growing period is uniformly distributed, enough water will be left in the reservoir following the wet season growing period to irrigate a portion of the farming area during the dry season.

The region is the high plateau of Thailand, where the topography is undulated. There are few sites suitable for big reservoirs, but it is necessary to supply water to develop the agricultural production of this region. The investments in these projects are such that the government can cope financially. Also, each project will be completed in a short time. Consequently, the number of small reservoirs is increasing each year.

The Purposes of the Study

The soil and climate of Thailand are suitable for year-round production of crops. Although the soil is not well fertilized, it is easy to grow crops when the water is available. Water is the limiting factor in green revolution for this region because after the rainy season, no water is left except in a few main rivers. The construction of the small reservoirs over the region is a strategy to solve the problem.

However, the amount of water is the main constraint for this type of irrigation project since reservoir capacity is limited by the topography of the region. Because of this, the efficiency of water management and reservoir operation is most important if these projects are to develop high production per unit of water use.

The purposes of this study are to evaluate the water use efficiency and corresponding land use patterns in the service areas of small existing reservoirs of Northeast Thailand. More specifically, the objectives are:

1. To determine efficient operation strategies for the existing reservoirs in order to increase the service areas for dry-season crops;

2. To determine the relationship between reservoir capacity and the service area of both the wet-season and the dry-season crops with minimum risk associated with rainfall variations in the wet season;

3. To be a guide for reservoir management from the beginning of the wet-season crops (particularly in a year of below normal rainfall). As a result of this study, the reservoir operator can know the size of the service area for dry-season crops that should be served by the remaining water stored in the reservoir at the beginning of the season; and

4. To serve as a basis for research work to develop water management practices for these projects.

The Scope of the Study

The scope of this study will be limited to reservoir water management where the reservoir storage is derived from the small watershed rainfall-runoff. Also, the water stored for irrigation will be used within the period of a year. There is considerable information needed for such a study, but much is not now known; consequently, much has been assumed for purposes of this study. The assumptions are:

1. The distribution system, drainage and land leveling for the projects have been completed.

2. The selected crops are suitable for the area and are well adapted for irrigation so that high yields will be obtained when they are irrigated properly.

3. A market for the agricultural products is available, and the prices of the selected crops are such that farmers are encouraged to produce the crops and be efficient in the process.

The Huey Si Thon Project in the Kalasin province has been selected as a representative example of these types of reservoirs in the Northeast for this study, because of the following reasons:

1. Rainfall records, daily pan evaporation, daily temperature, etc. for this reservoir are available.

2. The reservoir capacity is about average for this type of reservoir in the Northeast.

3. Location of the project is in the middle of the Northeast.

4. There is an agricultural experiment station in the project area which conducts research on irrigated crops which are suitable for

this area as well as other areas in the Northeast. The demonstration farms of the agricultural experiment station are an excellent place to study and research water management on farms.[4] This information will assist the development of similar reservoirs in the future. However, this study will not delve deeply into the details of irrigation practices and methods.

The aim of Chapter 2 is to present data on soils, crops and climate in the study area. They are the major factors which affect water management of irrigation projects. Knowledge of soil and water relationships is valuable if efficient irrigation practices are to be developed. Each soil type has a different ability to hold water for plant use. This affects the amount of irrigation water applied, number of irrigations in the cropping period and times between irrigation applications. Excessive volumes of water in soils retard or inhibit plant growth and make drainage essential. Also, each type of crop has a different consumptive use rate according to maturity, root zone and physiologic factors, and a suitable cropping time. Climate is the most important factor in this particular study since it determines the magnitude and distribution of precipitation, wind, temperature and humidity. These in turn affect evaporation from the reservoir, evapotranspiration of the crops, and the moisture in the soil.

Chapter 3 presents the hydrologic properties of Huey Si Thon, the study project. The expected reservoir losses and the expected monthly rainfall of the study area are determined in order to obtain the basic information for consideration of water demand and reservoir operation.

In Chapter 4, water demand of the study project is discussed in detail. The suitable crops for wet and dry seasons are selected to determine the water requirements for maximizing reservoir water utilization. Factors involved in determining the water requirements of crops are considered in order to set the cropping time with minimum risk.

Chapter 5 deals with the reservoir operation and analysis. Since, rainfall-runoff is the source of water supply for this type of reservoir and since the study deals with a monsoon country such as Thailand, the distribution, rather than amount of rainfall, is critical for wet-season cropping. So, rainfall, runoff, water balance and the series of short drought periods in the rainy season have been analyzed to determine the optimum reservoir operation with minimum risk and maximum reservoir utilization. As a result of the analysis a proposal is made to develop additional water for this type of reservoir by storing watershed runoff in the rice paddies. The irrigable area for the wet-season crop (rice) may be increased; however, additional research is necessary to determine the benefits of this proposal.

Chapter 6 is the summary and conclusions for the study. Conclusions are presented on hydrology, reservoir capacity, reservoir operation and limitations of results to application of the results of the study.

Figure 1 shows the study site (after the Royal Irrigation Department--R.I.D.).

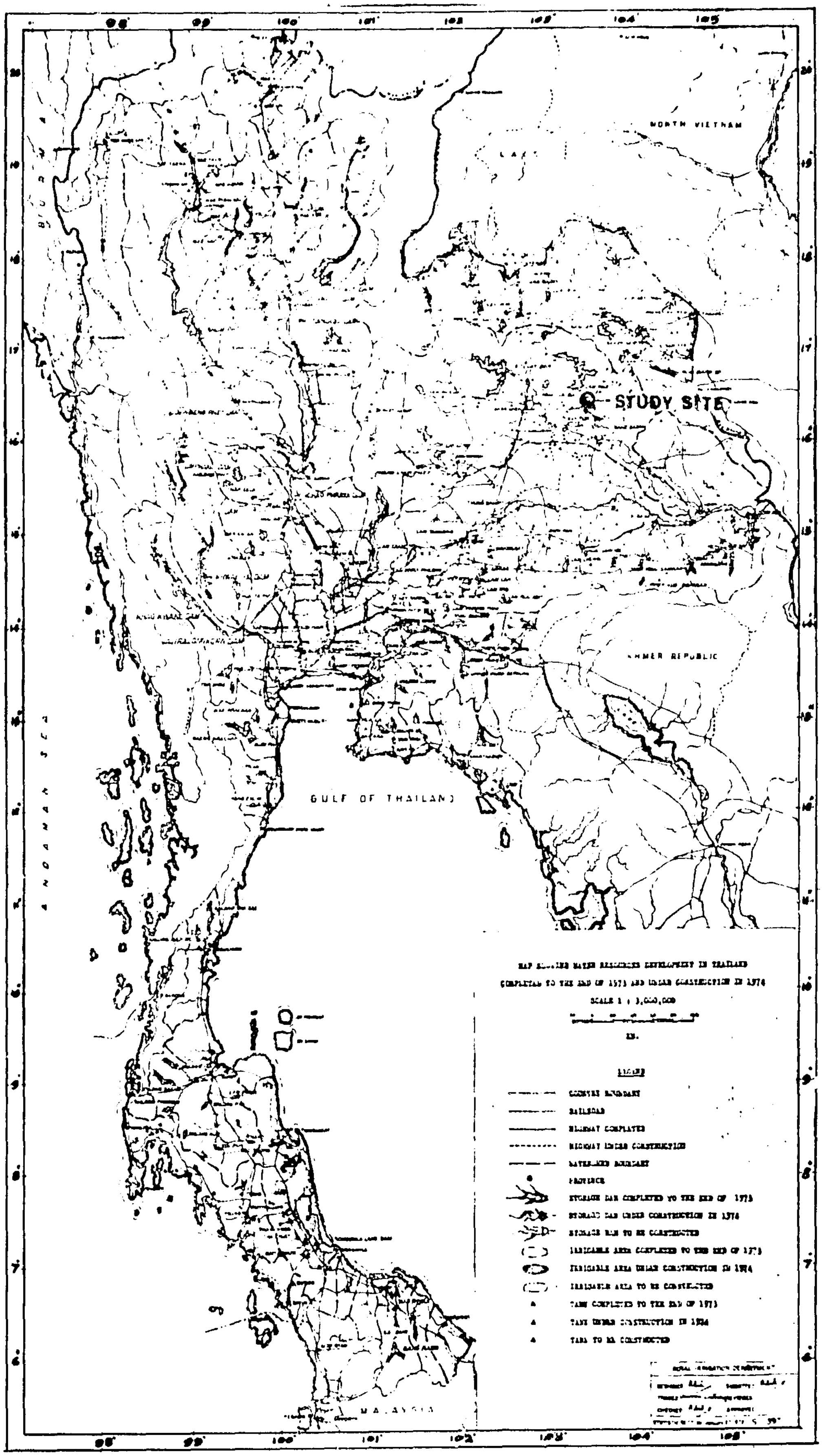


FIGURE 1. STUDY SITE (AFTER R.I.D.)

As mentioned already, experimentation with irrigated agriculture would give results that can be generalized over wide areas in the Northeast. Experimentation on dry land crops, garden crops and vegetables would equally find representative soil conditions, though certain soil series, and especially the Korat series seem to occupy relatively less surface than in the Northeast as a whole. ---------- "

Field Capacity of the Soils

Data on field capacity of soils is not available in Thailand. For the purposes of this study, the average values of field capacity from a graph in the 1955 yearbook of Agriculture entitled "Water", will be used,

TABLE 1. VALUES OF FIELD CAPACITY OF THREE MAJOR SOIL SERIES

Type of soils	Soil classification	Water content in inches per foot of soils
Ubon soils	sandy	1.2" - 2" (10-17 cm/m)
Roi Et Soils	loamy	2" - 3" (17-25 cm/m)
Korat soils	sandy loam	2" - 2.5" (17-20 cm/m)

Crops

Agriculture in the Northeast for the most part has been of a simple type and used mainly to grow crops for family consumption. This was partly because there were no ready markets for sale of the agricultural products and partly because there were no easy means of transporting products from villages to towns. The agricultural practices were those traditionally handed down from one generation to another; season crops were grown in small plots next to or near homes on a subsistence basis.[8]

Gradually, with increased population and development of communication facilities, agriculture on a subsistence basis changed somewhat to agriculture on a market basis in order to meet the increasing needs of people in towns. However, much of the agricultural production of the region is still on a subsistence basis.

Total seasonal rainfall in the general vicinity of the Northeast is usually adequate for several of the more important crops grown during the wet season; however, rainfall distribution is irregular, and crops frequently have insufficient water for optimum production. The dry season is too dry for crop production without irrigation. Because of the moisture deficiencies, big irrigation projects were constructed, as well as several small reservoir irrigation systems in the general vicinity of the Northeast.[8]

The following items are the main agricultural products in the Northeast region.

1. Rice

Rice is the main crop of Thai people because they need it for family consumption. It no doubt will continue to be one of the important crops grown during the wet season until the government can convince the farmers to grow the more economic crops that are suitable for the region. Nearly all the rice grown, about 96%, is of the glutinous type; the remaining rice is of the non-glutinous type.[6] All of the rice grown is by transplanting, essentially none by broadcasting. No dry-season rice of any significance was produced prior to irrigation development.

There has been very little development in mechanized rice farming in the Northeast. Cattle are still used for the most part. This is mainly because of: (a) small size of farms; (b) enough labor is available to do the work needed; and (c) each family has a small amount of land. The yield of rice depends on the type of soils at each location.

2. Kenaf

Kenaf is adapted to a rather wide range of soil conditions, and is able to withstand drought more than many upland crops. Because of this, and because of the demand for fiber, kenaf has been grown extensively in the Northeast for some time. It is now one of the important crops grown for market and export.

At the present time, two methods are used in growing kenaf, one by broadcasting and one by transplanting. Broadcasting is more commonly used. Fertilizers have not been used. Usually, kenaf is grown on the slope or upland. The yield is about 800-1500 kg/hectare.(8)

3. Maize

Maize has been grown on the upland in some parts of the Northeast. Yield is about 1500-2000 kg/hectare in years with normal rainfall.(8)

4. Cotton

At the present time, cotton is still grown in some parts of the area. However, because it needs additional treatment to protect from diseases and requires high investment, farmers have had to assume extra risk, above that created by irregular distribution of the rainfall and unstable marketing. Yield is about 750-1000 kg/hectare.(8)

5. Groundnuts (peanuts)

Groundnuts of a native type have been grown in Thailand for a long time. In some areas, it is one of the important crops grown during either the wet season or the early part of the dry season. May to August is usually the growing period during the wet season, and October to January usually is the period during the dry season. Experimental trials have shown that groundnuts are well adapted to follow a wet-season rice crop in paddy checks.(8)

6. Mungbean

In the past, mungbean was not a popular crop grown in the Northeast because a strong, stable local market was not available. It is desired by the local market once a year during a ceremony. At present, mungbean is one of the crops that can be exported.

7. Cattle

Most of the Northeast farms have their own cattle, such as water-buffaloes. Because they raise oxen and buffaloes for draft work and tilling the paddy fields, they are a by-product of the farms.

Recommended Crops in Kalasin Area

In 1965, an experimental and demonstration farm for irrigated agriculture was established in the irrigable area of Huey Si Thon Project near Kalasin province. The experimental station has recommended the following main crops to be suitable for the area.(9)

1. Groundnuts (peanuts)

This crop is not only the most promising crop in the region for dry season cropping, but it is also grown successfully in the rainy season. It can be planted year-round. Yields, with hull, of about

3100-5000 kg/hectare have been obtained when fertilizers are used. Maturity is about 95-115 days.

2. Mungbean

Mungbean is a good price crop both in the local market and for export. It can be grown all year-round if irrigation water is available and if drained properly for rainy season cropping. Yield is about 900-1300 kg/hectare. Fertilizer is required. The growth period is about 70 days.

3. Cotton

Cotton can be grown successfully in irrigated paddy fields during the dry season, but the plant protection supervision must be well organized. The expected income is higher than other field crops if a good yield is achieved. Yields are about 1500-1800 kg/hectare in the dry season and about 1800-2000 kg/hectare in the rainy season. Fertilizer is necessary. The growth period is about 110 days.

4. Maize

Maize can be grown in the irrigation project in the dry season with yields of about 3000 kg/hectare, but the price is low in this area since it is far from the market in Bangkok. The growth duration is about 120 days.

5. Watermelon (Sugar baby)

Watermelon is able to be planted in the rice field after the harvest of rice. Yield is about 3700 melons/hectare. Average weight is about 5-7 kg/melon. Growth duration is about 80-95 days.

There are other recommended crops and vegetables but there needs to be more research on the consumptive use of these crops.

They are omitted in this study due to a lack of crop production data that would allow for analysis of yields relative to specific kinds of soils.

Suitable Cropping Time for the Northeast Region

The chart in Figure 2 depicts the recommended crops and their suitable cropping time in the Northeast region. This chart was received by courtesy of the Northeast Agricultural Research Center. It will be used as a guideline in selecting crops for the study area.

Climate of the Northeast Region

Climate of the Northeast is typically tropical. It is clearly influenced by two prevailing winds: the monsoon from the southwest, from June to September (the rainy season); and the monsoon from the northeast, from November to February (the dry season).[2]

1. Temperature distribution

The temperature range of the Northeast is extreme. The minimum temperature in January has been recorded as 4.9°C (41°F), maximum temperature in April at 42°C (109°F) and mean in summer monsoon is 30°C (85°F).[3]

2. Rainfall

The distribution of rainfall in the Northeast varies from part to part according to the local topographic features. The belt of relatively less rainfall, i.e., 800-1000 mm. annually, extends through the entire western strip of the Northeast Plateau, for the mountain ranges along the western divide of the Plateau act as high barriers to the wet summer monsoon. The mean annual rainfall in the Northeast is about 1 330.7 mm. The extreme maximum deviates from the mean by 27%

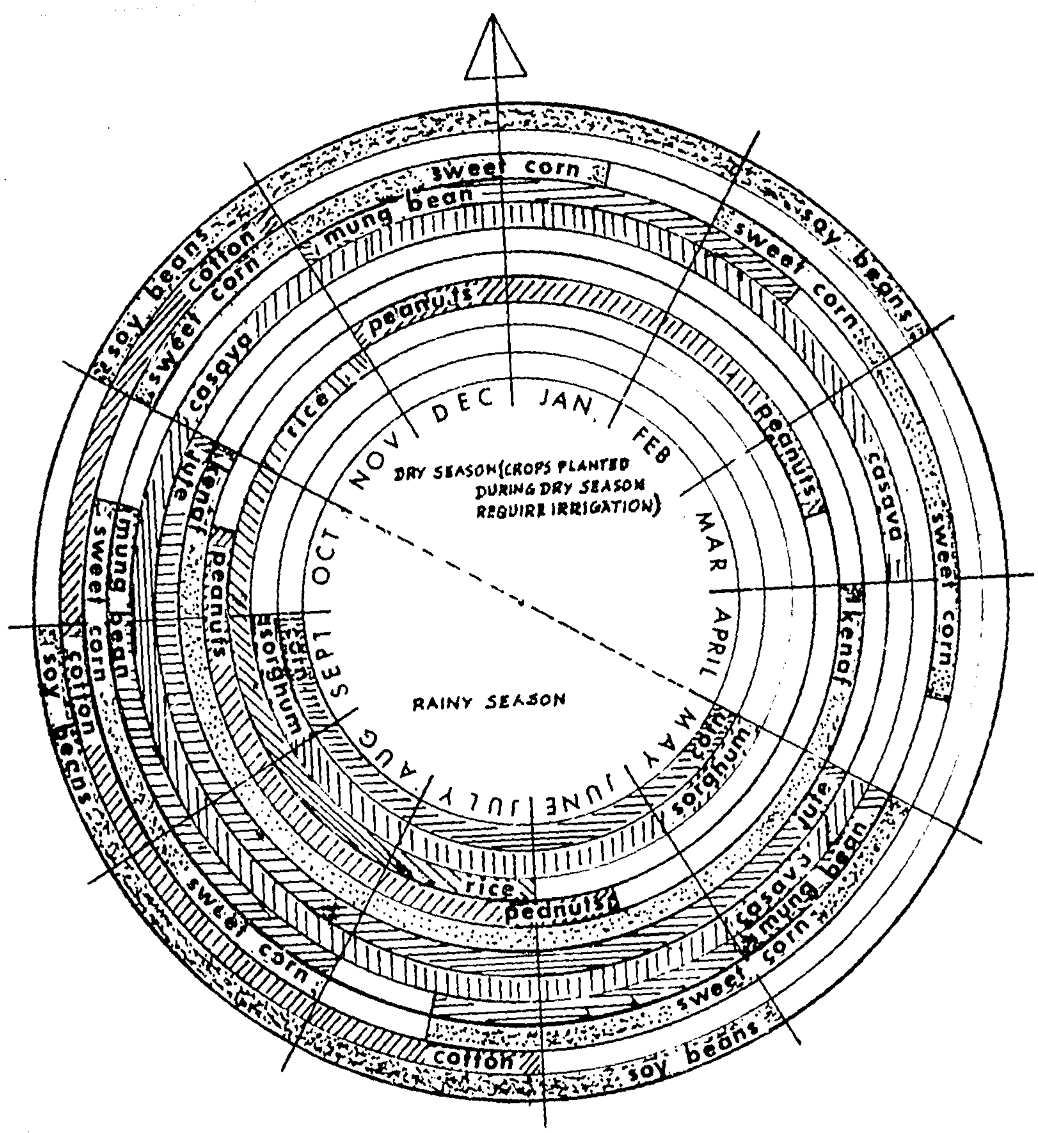


FIGURE 2 CROPPING TIME CHART

and the extreme minimum by 23%.[3] The tabulation below shows the average monthly rainfall in the Northeast.

TABLE 2.[3] AVERAGE MONTHLY RAINFALL IN MM

Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
4.5	16.5	51.6	94.4	175.8	177.0	183.0	211.5	255.9	123.6	33.9	3.0

3. Relative humidity

The mean monthly relative humidity in the Northeast is influenced directly by the prevailing wind. During the southwest monsoon season, the relative humidity is high - between 75-85 percent and is lower during the northeast monsoon - between 55-70 percent. The following Table is the mean relative humidity in the Northeast region.

TABLE 3.[13] 1951 TO 1969 MEAN MONTHLY RELATIVE HUMIDITY (in percentage)

Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
64	62	61	64	74	76	77	80	82	77	72	67

Local Climate of the Study Area

1. Rainfall

Generally, the climate at Huey Si Thon Project is the same as the western strip of the Northeast region. In the following Tables, the specifics taken into consideration are those of the rainfall recorded in the city of Kalasin, (from the year 1939-1971), which is only seven kilometers' distance from the dam site. These figures have been adopted since they constitute a longer series of years, as against the figures recorded in the vicinity of the dam itself (1957-1973).

TABLE 4. TOTAL ANNUAL RAINFALL IN MM.*

At the city of Kalasin		At the Huey Si Thon Dam	
Year	Rainfall in mm.	Year	Rainfall in mm.
1939	1691	-	-
1940	1010	-	-
1941	1225	-	-
1942	760	-	-
1943	1223	-	-
1944	1313	-	-
1945	1115	-	-
1946	1325	-	-
1947	1522	-	-
1948	1619	-	-
1949	Lack of data	-	-
1950	1467	-	-
1951	1484	-	-
1952	1433	-	-
1953	1200	-	-
1954	1076	-	-
1955	1409	-	-
1956	1535	-	-
1957	1023	1957	1145.3
1958	1052	1958	1326.5
1959	1427	1959	1459.9
1960	1106	1960	1321.6
1961	1600	1961	1915.9
1962	1535	1962	1730.9
1963	980	1963	1170.9
1964	1435	1964	1400.0
1965	1478	1965	1617.2
1966	1951	1966	1714.4
1967	1353	1967	1093.5
1968	1255	1968	1112.9
1969	1335	1969	1338.5
1970	1546	1970	1388.4
1971	1356	1971	1401.6
-	-	1972	1429.6
-	-	1973	1233.2
Mean	1338.63	Mean	1400.02

* - Data were supplied by Mr. Prasert Milintrangkul, Engineer, the Royal Irrigation Department, Bangkok, Thailand.

TABLE 5.* MONTHLY PRECIPITATION IN MM.

AMPHUR MUANG STATION - KALASIN PROVINCE

	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Total	No. of Rainy Days
1939	204	411	26	101	159	464	172	-	-	-	80	74	1691	47
1940	-	302	94	97	396	121	-	-	-	-	-	-	1010	29
1941	106	325	112	150	289	243	-	-	-	-	-	-	1225	20
1942	85	185	213	52	-	225	-	-	-	-	-	-	760	22
1943	97	239	265	289	231	52	-	-	-	-	-	-	1223	34
1944	59	162	293	121	235	251	126	59	-	-	7	-	1313	51
1945	57	119	202	137	121	352	3	2	79	-	5	33	1115	70
1946	54	519	125	47	175	179	200	-	-	13	-	13	1325	42
1947	139	306	123	171	472	231	-	-	-	-	-	80	1522	55
1948	86	266	400	252	141	312	72	90	-	-	-	-	1619	56
1949	------------------------------ Lack of data ------------------------------													
1950	136	-	-	-	282	633	293	-	-	-	-	123	1467	31
1951	254	121	-	379	90	359	277	4	-	-	-	-	1434	36
1952	-	169	324	271	300	79	178	-	-	10	99	-	1430	41
1953	41	160	380	230	68	209	22	-	-	70	-	-	1200	59
1954	34	111	51	107	259	433	61	-	-	-	-	-	1076	61
1955	59	225	426	102	337	171	9	-	-	-	32	48	1409	58
1956	86	220	169	400	313	240	56	-	-	-	15	36	1535	77
1957	56	225	131	95	204	201	29	-	-	9	3	20	1023	41
1958	39	81	175	128	296	343	33	-	-	-	44	3	1052	52
1959	69	134	159	290	276	422	33	-	-	-	7	37	1427	80
1960	-	183	73	161	151	427	105	6	-	-	-	-	1106	44
1961	16	163	251	114	346	595	109	-	-	-	-	6	1600	42
1962	89	181	219	234	311	341	60	-	-	-	-	100	1535	76
1963	27	112	78	206	148	151	36	54	-	-	-	18	980	61
1964	60	235	137	103	134	476	119	29	-	-	9	33	1435	75
1965	105	303	275	313	159	141	69	-	-	-	10	103	1478	68
1966	45	502	268	194	642	252	46	1	1	-	-	-	1951	76
1967	113	341	103	220	117	307	6	14	-	-	102	30	1353	71
1968	40	228	209	139	128	306	40	-	-	99	-	67	1255	77
1969	103	102	280	314	141	324	62	9	-	-	-	-	1335	73
1970	61	224	223	317	375	305	17	-	-	-	15	9	1546	93
1971	66	126	222	356	210	132	100	6	40	-	18	30	1356	101
Total	2386	7030	6056	6139	7436	9347	2383	274	120	201	446	868	42836	1839
Mean	74.56	221.25	189.25	193.41	233.94	292.09	74.47	8.56	3.75	6.28	13.94	27.13	1338.63	57.47

* - Data were supplied by Mr. Prasert Milintrangkul, Engineer, the Royal Irrigation Department, Bangkok, Thailand.

TABLE 6.* MONTHLY PRECIPITATION AT HUEY SI THON PROJECT IN MM.

	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Total	No. of Rainy Days
1957	53.9	208.6	135.8	207.2	175.3	243.8	51.1	17.1	-	8.5	10.1	33.5	1145.3	62
1958	69.2	206.1	191.5	188.7	274.4	289.3	66.9	-	-	-	27.2	13.2	1326.5	65
1959	88.5	194.8	178.5	188.2	236.1	507.5	8.0	1.5	-	-	-	56.8	1459.9	76
1960	-	226.7	140.8	226.5	283.7	294.4	96.1	-	-	-	-	53.4	1321.6	70
1961	168.6	317.6	282.6	118.6	237.1	616.3	149.1	5.3	-	0.3	-	20.4	1915.9	74
1962	123.0	251.3	263.2	216.7	322.4	402.1	63.9	0.3	-	-	4.2	83.8	1730.9	93
1963	31.2	77.5	166.8	290.1	278.9	176.9	68.2	41.3	-	-	-	40.0	1170.9	92
1964	83.4	272.6	65.4	100.5	195.5	489.0	118.3	27.2	-	-	6.3	41.8	1400.0	89
1965	123.3	362.9	255.5	374.1	163.0	170.8	29.4	0.2	-	-	22.2	115.8	1617.2	93
1966	65.6	410.4	169.8	174.6	637.9	211.5	26.4	-	7.6	-	1.1	9.5	1714.4	82
1967	120.2	152.7	102.4	130.6	126.7	360.0	6.2	15.2	-	-	69.2	10.3	1093.5	91
1968	35.5	103.9	208.1	113.1	187.2	283.3	53.3	-	-	68.7	-	59.8	1112.9	100
1969	56.7	156.6	264.6	252.6	145.7	403.0	32.7	20.4	-	-	-	6.2	1338.5	82
1970	76.7	155.2	172.8	364.1	347.9	244.1	16.8	-	1.7	-	4.8	4.3	1388.4	94
1971	34.7	164.4	176.2	371.7	205.5	256.0	117.4	4.9	28.8	-	11.6	30.4	1401.6	96
1972	61.9	64.7	473.8	391.7	200.0	118.5	107.4	3.1	5.5	-	-	3.0	1429.6	99
1973	76.2	176.5	178.0	243.1	286.8	216.3	5.7	-	-	26.6	0.5	23.5	1233.2	106
Total	1268.6	3502.5	3425.8	3952.1	4304.1	5282.8	1017.3	136.5	43.6	104.1	157.2	605.7	23800.3	1464
Mean	74.62	206.03	201.52	232.48	253.18	310.75	59.84	8.03	2.56	6.12	9.25	35.63	1400.02	86.12

* - Data were supplied by Mr. Prasert Milintrangkul, Engineer, the Royal Irrigation Department, Bangkok, Thailand.

The average monthly rainfall at the city of Kalasin and Huey Si Thon can be separated into periods of rainfall as shown in the Tables below. However, it must be stressed that the monthly rainfalls are variable from one year to another.

TABLE 7. AVERAGE RAINFALL DURING THE PERIODS AT THE CITY OF KALASIN

Periods	Rainfall in mm.	% of Annual
During Monsoon season (May-Nov)	1212.97	90.61
During Summer (Feb-Apr)	115.63	8.64
During May to October	1204.41	89.97
During November to April	134.22	10.03
During May to September	1129.94	84.41
During May to June	410.50	30.67
During July to September	719.44	53.74

TABLE 8. AVERAGE RAINFALL DURING THE PERIODS AT HUEY SI THON

Periods	Rainfall in mm.	% of Annual
During Monsoon season (May-Nov)	1271.83	90.84
During Summer (Feb-Apr)	119.50	8.54
During May to October	1263.80	90.27
During November to April	136.21	9.73
During May to September	1203.96	86.00
During May to June	407.55	29.11
During July to September	796.41	56.89

2. Number of Rainy days

A rainy day can be defined as a day in which rainfall occurred (or even the threat of rainfall), but for purposes of this study, a rainy day means a day in which measurable rainfall occurs. Tables 9 and 10 show the number of rainy days that have occurred at the city of Kalasin and Huey Si Thon dam. Rainfall irregularity is observed by examining the number of rainy days during the year 1941. There were 20 rainy days during the period April to September at the city of Kalasin with a total rainfall of 1225 mm. In 1945, on the other hand, there were 70 rainy days (occuring almost every month in the year) with a total of only 1115 mm. It should be emphasized that the number of rainy days in a year, especially during the cropping period will affect the cultivation, the water management and the size of a reservoir, because during a no rainfall period, the reservoir has to discharge its storage for irrigating the farms.

3. Temperature

The course of prevailing winds also influences the temperature. Table 11 presents the air temperatures which were recorded at Huey Si Thon from the year 1969 to 1974.

TABLE 9. NUMBER OF RAINY DAYS, AMPHUR MUANG - KALASIN PROVINCE

	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Total
1939	3	7	2	7	6	14	3	-	-	-	2	3	47
1940	-	3	3	5	13	5	-	-	-	-	-	-	29
1941	5	3	4	1	2	5	-	-	-	-	-	-	20
1942	4	6	6	1	-	5	-	-	-	-	-	-	22
1943	4	7	4	5	7	7	-	-	-	-	-	-	34
1944	4	5	8	4	11	9	8	1	-	-	1	-	51
1945	1	7	17	3	17	16	1	2	2	-	2	2	70
1946	3	12	4	2	9	8	1	-	-	2	-	1	42
1947	7	9	4	12	9	11	-	-	-	-	-	3	55
1948	5	9	11	5	4	14	3	5	-	-	-	-	56
1949	---------- Lack of data ----------												--
1950	6	-	-	-	6	8	6	-	-	-	-	5	31
1951	5	5	-	10	3	4	8	1	-	-	-	-	36
1952	-	5	8	4	11	4	5	-	-	1	3	-	41
1953	4	10	11	11	6	13	3	-	-	1	-	-	59
1954	2	9	9	8	10	20	3	-	-	-	-	-	61
1955	2	7	10	5	12	14	1	-	-	-	3	4	58
1956	6	11	10	17	18	7	3	-	-	-	1	4	77
1957	4	7	6	5	5	8	1	-	-	1	1	2	40
1958	2	6	7	9	11	11	2	-	-	-	3	1	52
1959	3	10	8	18	16	20	2	-	-	-	1	2	80
1960	-	6	3	6	10	14	4	1	-	-	-	-	44
1961	2	8	11	6	12	15	7	-	-	-	-	1	62
1962	7	10	10	11	14	15	5	-	-	-	-	4	76
1963	3	7	5	12	13	11	5	4	-	-	-	1	61
1964	5	17	8	5	14	14	9	1	-	-	1	1	75
1965	5	11	14	10	10	10	4	-	-	-	1	3	68
1966	3	15	8	10	20	12	6	1	1	-	-	-	76
1967	7	9	6	10	11	18	2	2	-	-	3	3	71
1968	6	12	14	11	7	15	5	-	-	4	-	3	77
1969	3	6	14	14	13	14	8	1	-	-	-	-	73
1970	4	14	20	15	19	16	3	-	-	-	1	1	93
1971	7	11	14	15	21	17	8	1	4	-	2	1	101
Mean	3.81	8.25	8.09	8.03	10.63	11.69	3.63	0.63	0.22	0.28	0.78	1.41	57.45

TABLE 10. NUMBER OF RAINY DAYS, HUEY SI THON PROJECT - KALASIN PROVINCE

	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	Mean
Apr	4	3	5	-	3	4	6	6	6	3	8	7	5	7	7	9	5	10	5.44
May	10	8	8	11	8	9	10	21	12	19	12	13	9	13	9	10	17	13	11.78
June	8	9	8	9	12	10	10	6	14	10	12	15	14	16	16	18	17	14	12.11
July	10	3	16	11	5	17	15	7	13	13	12	14	12	14	13	16	18	16	12.78
Aug	11	13	14	16	12	20	21	19	17	20	16	15	15	19	22	18	19	20	17.06
Sept	10	12	20	17	20	18	15	15	13	11	22	19	17	18	14	18	21	21	16.72
Oct	2	5	1	5	10	8	8	10	7	2	2	6	7	3	7	6	3	9	5.61
Nov	1	-	1	-	1	1	5	2	1	-	1	-	1	-	1	1	-	--Incomplete data--	0.94
Dec	-	-	-	-	-	-	-	-	-	2	-	-	-	2	4	2	-		0.59
Jan	1	-	-	-	1	-	-	-	-	-	-	7	-	-	-	-	2		0.65
Feb	2	3	-	-	-	1	-	1	3	1	3	-	-	1	2	-	1		1.06
Mar	3	4	3	1	2	5	2	2	7	1	3	4	2	1	1	1	3		2.65
Total	62	65	76	70	74	93	92	89	93	82	91	100	82	94	96	99	99	106	87.39

TABLE 11.⊕ AIR TEMPERATURE AT HUEY SI THON

	Mean air temperature in °C						
	1969	1970	1971	1972	1973	1974	Mean
January	-	21.5	20.0	22.8	23.1	21.9	21.9
February	-	24.6	22.4	25.3	26.1	22.7	24.2
March	-	27.4	26.3	25.5	27.8	25.3	26.5
April	26.4	28.6	27.9	29.2	27.9	-	28.0
May	27.7	26.1	30.3	28.8	28.3	-	28.2
June	27.7	23.1	30.0	27.9	28.3	-	27.4
July	26.5	24.1	29.1	26.3	26.9	-	26.6
August	25.9	25.1	26.9	24.5	26.2	-	25.7
September	26.3	28.1	27.5	24.4	27.3	-	26.7
October	25.0	25.7	27.1	23.2	26.3	-	25.5
November	22.6	24.1	26.0	21.1	-	-	23.5
December	23.3	23.5	23.4	17.7	-	-	22.0
	Yearly mean Temperature						25.5

⊕ - Data were supplied by Mr. Nukul Tongthawee, Chief Engineer Region 5, R.I.D.

4. Humidity

Details of humidity observations in the area are unfortunately scanty. The following relative humidity data are at Khon Kaen which is about 70 kilometers west of Kalasin and at Roi Et which is about 45 kilometers northeast of Kalasin.

TABLE 12.[8] MEAN RELATIVE HUMIDITIES FOR 1948-1965 AT KHON KAEN

Month	Relative Humidity in percent		
	Mean Max.	Mean Min.	Mean
January	88.3	46.1	63.2
February	86.2	45.7	62.5
March	84.0	44.4	60.8
April	83.6	46.7	62.8
May	88.4	57.5	72.0
June	88.8	63.0	74.8
July	90.6	65.7	77.6
August	91.9	67.6	79.6
September	93.0	69.8	81.3
October	91.1	63.7	76.5
November	89.0	54.4	70.6
December	89.4	49.2	66.3
Monthly Mean	88.7	56.2	70.7

Highest humidity of record 100% in May, July, August.

Lowest humidity of record 12.0% in March.

TABLE 13.[13] 1951-1961 MEAN MONTHLY RELATIVE HUMIDITY

(in percentage)

Month	Mean Monthly Relative Humidity	
	Khon Kaen	Roi Et
January	64.0	63.0
February	63.0	62.0
March	62.0	60.0
April	64.0	63.0
May	72.0	72.0
June	76.0	76.0
July	78.0	76.0
August	80.0	80.0
September	82.0	82.0
October	77.0	76.0
November	71.0	70.0
December	66.0	65.0
Monthly Mean	71.3	70.4

The following Table contains relative humidity data taken at Roi Et during the period 1943-1955.

TABLE 14.(2) 1943-1955 RELATIVE HUMIDITY AT ROI ET

Month	Average	Mean Max.	Mean Min.	Absolute Max.	Absolute Min.
January	61.3	88.5	45.3	100.0	25.0
February	60.9	87.1	44.3	100.0	27.0
March	60.0	83.9	44.7	100.0	25.0
April	64.3	85.5	49.4	99.0	29.0
May	73.0	90.4	59.1	99.0	33.0
June	75.9	90.5	64.9	99.0	40.0
July	74.3	91.2	64.2	100.0	43.0
August	79.0	92.1	67.8	100.0	48.0
September	80.8	93.2	69.7	100.0	42.0
October	73.2	89.7	61.3	100.0	35.0
November	63.7	90.3	54.3	100.0	35.0
December	62.7	89.3	49.6	100.0	29.0
Mean	69.1	89.3	56.2	100.0	25.0

The humidities at Khon Kaen and Roi Et indicate small differences; consequently, the humidity at an area located between the two cities can be utilized by either one of them as representative. For this study, the relative humidity at Khon Kaen is used to represent the humidity at the study area, because the mean humidity was taken from a longer record.

5. Evaporation

Evaporation observations at the project site have been recorded by a U.S. Weather Bureau class "A" pan from 1969 until the present. Table 15 is the monthly evaporation from a class "A" pan at the project area, Huey Si Thon, from April of 1969 to March of 1974.

When comparing the mean monthly evaporation at Huey Si Thon with the average monthly evaporation from a class "A" pan at Khon Kaen and Roi Et as shown in Table 16, these mean monthly evaporations are deemed reasonable.

TABLE 15.⊕ 1969-1974 MONTHLY EVAPORATION AT HUEY SI THON PROJECT

Months	Evaporation in mm.						
	1969	1970	1971	1972	1973	1974	Mean
Apr	174.43	185.38	181.90	187.44	168.30	-	155.32
May	175.51	202.05	223.32	169.62	185.02	-	191.10
June	113.46	151.39	169.88	151.41	172.42	-	151.71
July	156.51	134.66	169.04	180.53	172.24	-	162.60
Aug	141.12	173.92	137.84	150.20	138.74	-	148.36
Sept	122.21	154.28	149.02	142.13	166.15	-	146.74
Oct	163.36	159.27	149.95	151.26	151.19	-	155.01
Nov	163.45	150.90	155.94	161.26	-	-	157.89
Dec	173.59	144.32	144.30	172.84	-	-	158.76
Jan	-	163.40	172.24	147.68	155.55	137.72	155.32
Feb	-	158.34	147.62	132.68	142.17	141.38	144.44
Mar	-	197.16	194.08	136.52	159.32	157.09	168.83
Total	1383.64	1902.54	1970.11	1895.57	1923.73	(1908.00)	1919.75
Monthly Mean	153.74	158.55	164.18	157.96	160.31	159.03	160.00

⊕ Data were supplied by Mr. Nukul Tongthawee, Chief Engineer, Region 5, R.I.D.

\- No record or incompleted record

( ) Adjusted figure

TABLE 16[13] 1961-1969 AVERAGE MONTHLY EVAPORATION

U.S.W.B. CLASS "A" PAN

Monthly	Average Evaporation in mm.	
	Khon Kaen	Roi Et
January	174.0	154.0
February	180.0	154.0
March	228.0	188.0
April	229.0	185.0
May	206.0	164.0
June	179.0	150.0
July	174.0	151.0
August	162.0	132.0
September	146.0	116.0
October	171.0	151.0
November	176.0	162.0
December	177.0	151.0
Total	2,202.0	1,848.0
Monthly Mean	183.5	154.0

Chapter III

HYDROLOGY OF THE STUDY PROJECT

All small reservoirs in the Northeast region have been constructed and controlled by the Royal Irrigation Department (R.I.D.). In planning the construction of Huey Si Thon Dam, R.I.D. made a hydrological study indicating following information.

TABLE 17.[2] THE HYDROLOGY PROPERTIES OF THE HUEY SI THON DAM

Items	Quantity	Unit
Catchment basin	81.5	sq.km.
Mean annual rainfall	1,361	mm.
Storage capacity	5,870,500	m^3
Useful capacity	5,580,750	m^3
Dead storage	289,750	m^3
Maximum surface of lake	2,820,500	m^2
Total annual inflow	27,300,000	m^3
Run-off coefficient	24.6	%
Annual evaporation	1,380	mm.
Daily seepage	3	mm.

Work on the construction of the dam which formed the reservoir on the Huey Si Thon Tank was finished in 1958. Figure 3 presents diagrams of the water surface area and storage volume of the reservoir.

Since reservoir water management must take into consideration the risk of uncertainty of hydrologic events that occur year to year, an analysis of the local hydrology is necessary.

Precipitation

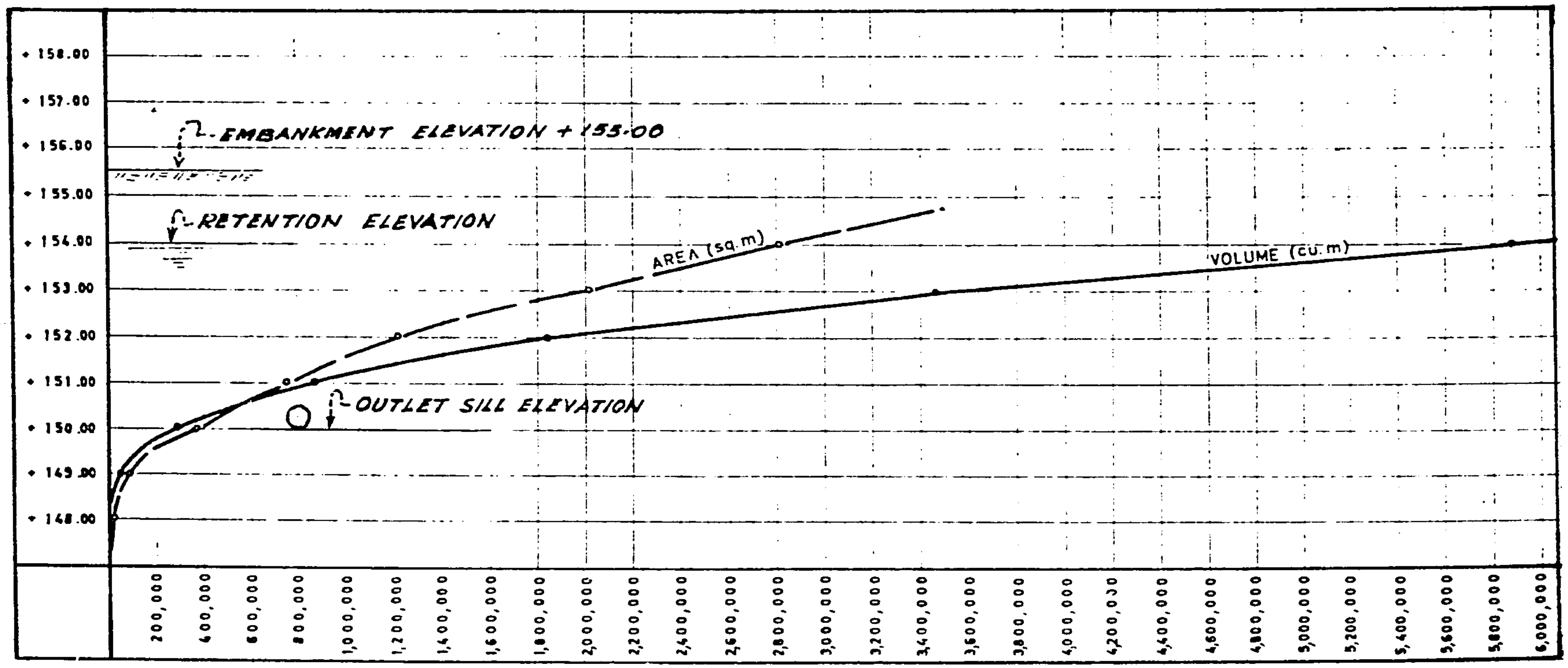
Rainfall plays an important role in irrigation project of this kind because rainfall is the source of water supply. Analysis of eighteen years of rainfall records at the project results in an average annual rainfall of about 1400 mm. and a breakdown into monthly rainfall as shown in Table 18.

TABLE 18. MEAN MONTHLY RAINFALL AT THE HUEY SI THON DAM SITE (unit in mm.)

Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
6.12	9.25	35.63	75.46	209.81	197.30	231.22	267.92	304.67	68.82	8.03	2.56

The mean yearly rainfall at the city of Kalasin (7 km. from the dam site) during 32 years (1939-1971) is 1338 mm. The mean monthly rainfall is shown in Table 19.

RESERVOIR AREA AND STORAGE VOLUMES: HUEY SI THON TANK **FIGURE 3**



NOTE THE ELEVATION IS THE ASSUMMED ELEVATION, IT WILL BE SUBTRACTED BY 3.27 M. FOR M.S.L.

(AFTER R.I.D.)

TABLE 19. MEAN MONTHLY RAINFALL AT THE CITY OF KALASIN

(unit in mm.)

Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
6.28	13.94	27.13	74.56	221.25	189.25	193.41	233.94	292.09	74.47	8.56	3.75

Records show that rainfall at the city of Kalasin is lower than at the dam site. The minimum rainfall at the dam site was 1093 mm. with 91 rainy days, while the minimum rainfall at Kalasin was 760 mm. with only 22 rainy days. As a consequence of this fact, it may be conservative to take the 32 years of record at Kalasin to be the basis of the study. Figure 4 depicts the mean rainfall diagram at the city of Kalasin and the Huey Si Thon Dam site.

Runoff

As noted earlier, reservoir storage is supplied by rainfall-runoff. In determining the available water supply for the reservoir, it is necessary to know the runoff. Prediction of seasonal runoff from the rainfall is very useful in developing reservoir operation strategies. The rainfall-runoff is affected by many factors, such as moisture deficiency of the basin, topological features of the watershed and the rainfall characteristics (for instance, depth, areal distribution, antecedent period and duration). In the tropical monsoon area where climate is reliable and consistent, soil moisture conditions,

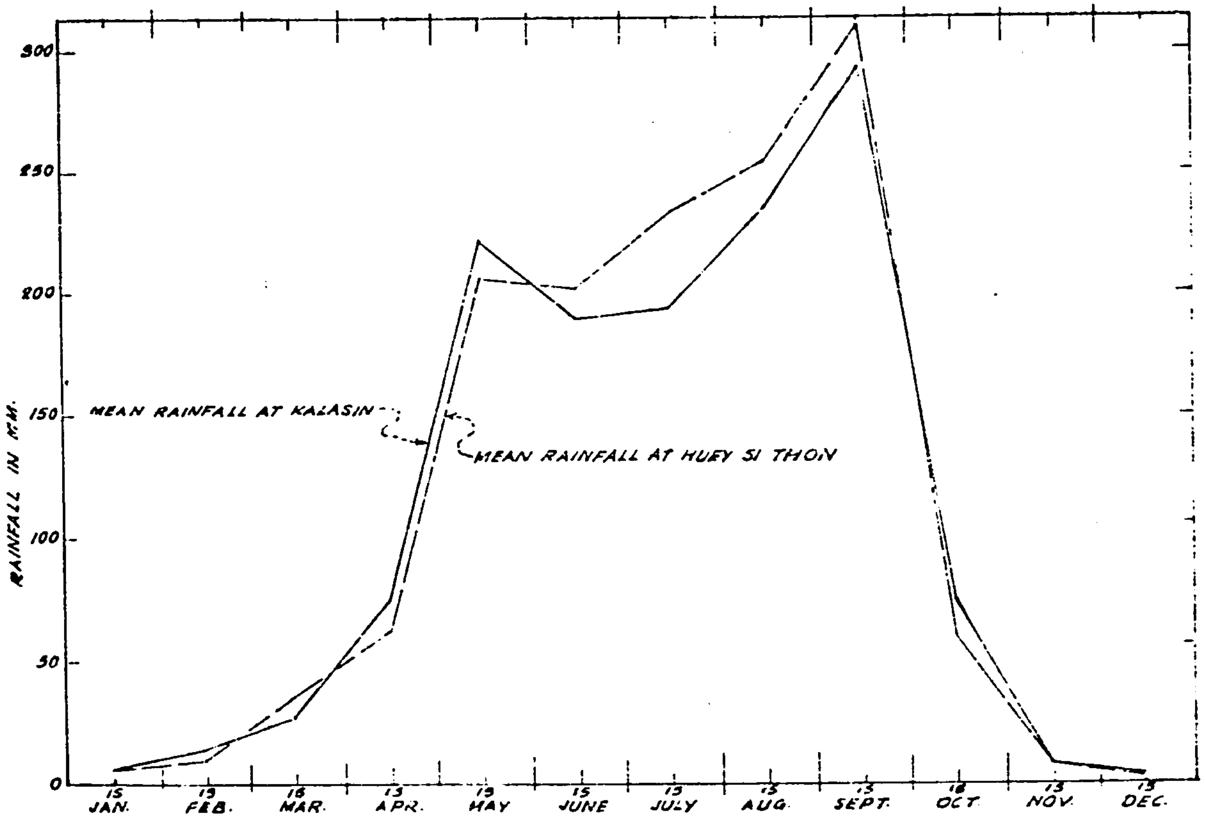


FIGURE 4 MEAN MONTHLY RAINFALL

in terms of season, are found to be an adequate index of the moisture deficiency. The effectiveness of rainfall in producing runoff depends upon the time of year it occurs.[3]

For the purposes of this study, it is assumed that the station rainfall is the equivalent uniform depth of rainfall over both the watershed and the service area of the reservoir. Since its watershed is only 81.5 km^2 and the irrigable area is 1200 ha,[2] this assumption should not be too unrealistic.

For estimating runoff of this reservoir, the R.I.D. has used a runoff coefficient value of 24.6%. Italconsult[2] has presented a chart (Figure 5) to estimate the runoff coefficient by breaking down the annual rainfall into monthly rainfall. The report recommended the watershed of the reservoir be on the line for type C soils. However, for an annual runoff, these two methods obtain similar results. A comparison of both methods in estimating the runoff for 1942 at the city of Kalasin, which is the driest year on record, is shown in Tables 20 and 21.

COEFFICIENT OF RUNOFF
(AFTER ITAI CONSULT)

FIGURE 5

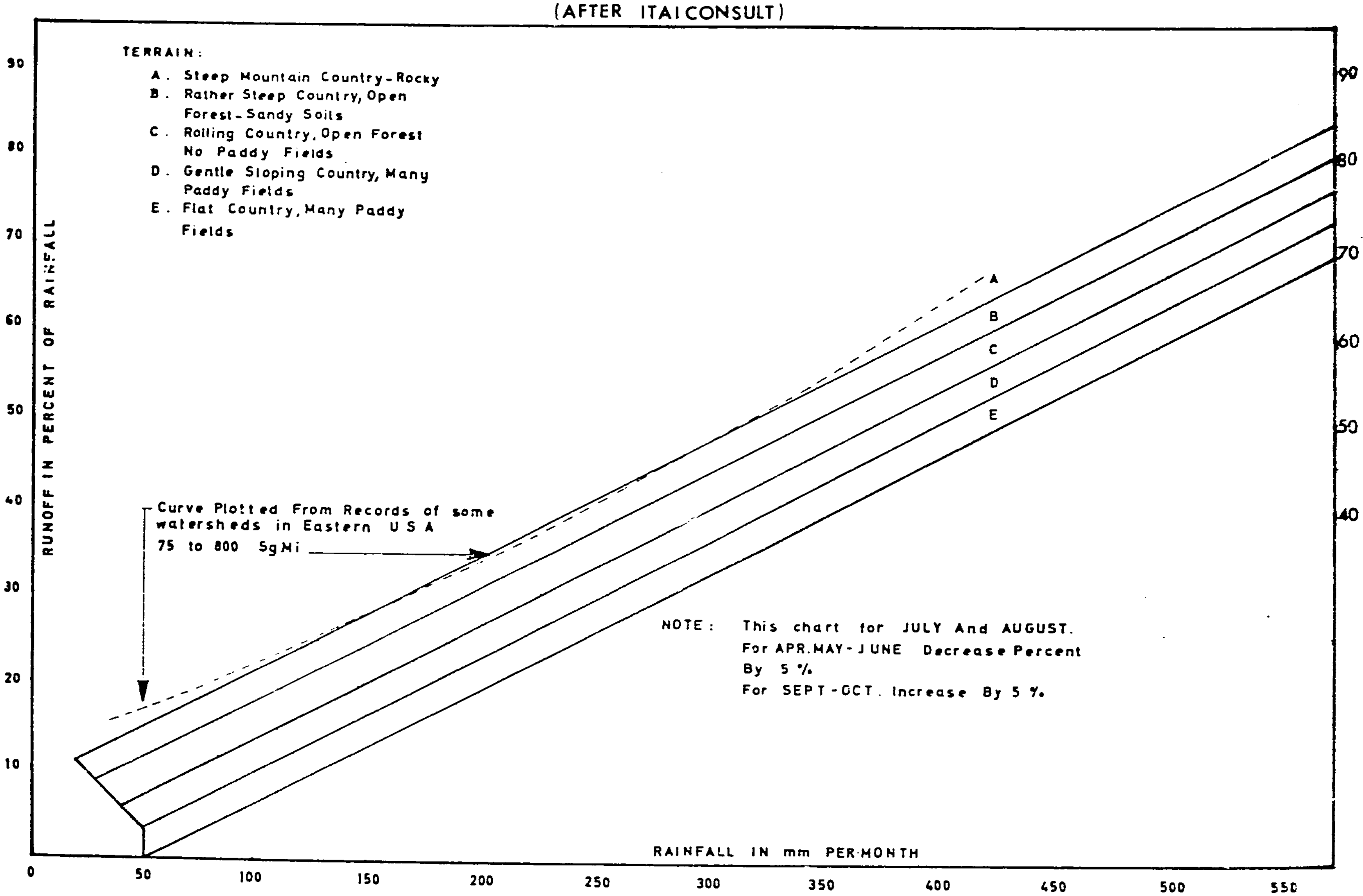


TABLE 20. ESTIMATE RUNOFF BY R.I.D. METHOD

Months	Rainfall (mm.)	Runoff coef. (%)	Quantity of Water (1000 m^3)	
			Monthly	Accumulated Total
April	85	24.6	1,704	1,704
May	185	24.6	3,709	5,413
June	213	24.6	4,270	9,683
July	52	24.6	1,043	10,726
August	-	-	-	10,726
September	225	24.6	4,511	15,237
October	-	-	-	15,237

TABLE 21. ESTIMATE RUNOFF BY ITALCONSULT METHOD

Months	Rainfall (mm.)	Runoff coef. (%)	Quantity of Water (1000 m^3)	
			Monthly	Accumulated Total
April	85	10.45	724	724
May	185	22.85	3,445	4,169
June	213	26.60	4,618	8,787
July	52	7	297	9,084
August	-	-	-	9,084
September	225	31.50	5,776	14,860
October	-	-	-	14,860

Another method for estimating rainfall-runoff from rainfall data has been developed by Kanchanalak[13] for the Lam Pao Irrigation Project. Since this project is only 17 km. from Huey Si Thon, the method will be evaluated and compared to the previous two methods. The following are the series of effective rainfall functions to be correlated with seasonal runoff over the area.

$$P_e^{May} = 0.5P_{16-30}^{Apr} + 1.0P_{1-15}^{May} + 0.5P_{16-31}^{May}$$

$$P_e^{Jun} = 0.5P_{16-31}^{May} + 0.95P_{1-15}^{Jun} + 0.4P_{16-30}^{Jun}$$

$$P_e^{Jul} = 0.05P_{1-15}^{Jun} + 0.6P_{16-30}^{Jun} + 0.9P_{1-15}^{Jul} + 0.4P_{16-31}^{Jul}$$

$$P_e^{Aug} = 0.1P_{1-15}^{Jul} + 0.6P_{16-31}^{Jul} + 0.9P_{1-15}^{Aug} + 0.15P_{16-31}^{Aug}$$

$$P_e^{Sep} = 0.1P_{1-15}^{Aug} + 0.8P_{16-31}^{Aug} + 0.75P_{1-15}^{Sep} + 0.20P_{16-30}^{Sep}$$

$$P_e^{Oct} = 0.05P_{16-31}^{Aug} + 0.25P_{1-15}^{Sep} + 0.8P_{16-30}^{Sep} + 0.9P_{1-15}^{Oct} + 0.3P_{16-31}^{Oct}$$

$$P_e^{Nov} = 0.1P_{1-15}^{Oct} + 0.7P_{16-31}^{Oct} + 1.0P_{1-30}^{Nov}$$

where P_e is an effective basin rainfall in mm.

P is the rainfall occuring at different periods of the month in mm.

When substituting the rainfall data of the year 1942 in the above equations, the results are as shown in the Table 22.

TABLE 22. ESTIMATE RUNOFF BY KANCHANALAK METHOD

Months	Effective basin rainfall (mm.)		Quantity of Water (1000 m^3)	
			Monthly	Accumulated Total
April	$P_e = 0$		0	0
May	$P_e = 0.5 \times 84.5 + 1.0 \times 179.6 + 0.5 \times 5.4$	= 224.55	18,300	18,300
June	$P_e = 0.5 \times 5.4 + 0.95 \times 142.2 + 0.4 \times 71.0$	= 166.19	13,544	31,845
July	$P_e = 0.05 \times 142.2 + 0.6 \times 71.0 + 0.9 \times 0 + 0.4 \times 52.0$	= 70.51	5,746	37,591
August	$P_e = 0.1 \times 0 + 0.6 \times 52.0 + 0.9 \times 0 + 0.15 \times 0$	= 31.20	2,543	40,134
September	$P_e = 0.1 \times 0 + 0.8 \times 0 + 0.75 \times 118.5 + 0.20 \times 106.8$	= 110.24	8,984	49,118
October	$P_e = 0.05 \times 0 + 0.25 \times 118.5 + 0.8 \times 106.8 + 0.9 \times 0 + 0.3 \times 0$	= 115.07	9,378	58,496
November	$P_e = 0.1 \times 0 + 0.7 \times 0 + 1.0 \times 0$	= 0	0	58,496

* – This compares with 15,237,000 m^3 by R.I.D. method and 14,860,000 m^3 by Italconsult.

Obviously, this method cannot work for a reservoir with a small watershed because the drainage area of the basin under which these equations were developed is 3,818 km^2. The typical characteristics of the larger watershed are different from the small watershed, especially when the station rainfall represents the equivalent uniform depth over the area.

Hence, this study will use the Italconsult method to estimate the monthly runoff and periodical runoffs during the year. The annual runoff will be estimated by the runoff coefficient that has been given by R.I.D.

Reservoir Losses

1. Reservoir Evaporation Losses

The evaporation observations from a class "A" pan at Huey Si Thon Project are shown in the following Tables.

TABLE 23. MEAN DAILY EVAPORATION-UNIT IN MM.

Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
5.0	5.14	5.45	6.0	6.16	5.07	5.26	4.77	4.90	5.0	5.23	5.10

TABLE 24. MEAN MONTHLY EVAPORATION-UNIT IN MM.

Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
155	144	169	180	191	152	163	148	147	155	157	158

The mean daily evaporation for the whole year is about 5.26 mm. and the total annual pan evaporation is 1919 mm.

TABLE 25. MEAN DAILY TEMPERATURES - UNIT IN DEGREE CELSIUS

Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
21.9	24.2	26.5	28.0	28.2	27.4	26.6	25.7	26.7	25.5	23.5	22.0

The average temperature for the whole year is 25.5°C.

The Huey Si Thon Project is located on latitude 16° - 26'N and longitude 103° - 31'E. The average monthly total shortwave solar radiation is shown in Table 26.

TABLE 26.[12] SHORTWAVE SOLAR RADIATION AT THE HUEY SI THON (R_e) UNIT IN LANGLEY (g-cal/cm^2/day)

Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
380	414	450	480	489	426	440	425	387	398	428	418

Unfortunately, the humidity, sunshine duration and wind velocity observations are not recorded at the project. For purposes of estimating the reservoir evaporation losses, these data will be assumed to be the same as the record data at Khon Kaen. The locations of both places are about the same latitude, Khon Kaen is on latitude 16° - 21'N and 102° - 51'E.[12] The comparison of humidities at Khon Kaen and Roi Et shows almost no difference. All of these data from Khon Kaen are shown in the following Tables.

TABLE 27.[12] THE AVERAGE MONTHLY RELATIVE HUMIDITIES AT KHON KAEN UNIT IN PERCENTAGE

Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
63.2	62.5	60.8	62.8	72.0	74.8	77.6	79.6	81.3	76.5	70.6	66.3

TABLE 28. *THE AVERAGE PAN WIND MOVEMENT AT THE NORTHEAST AGRICULTURAL CENTER, KHON KAEN - UNIT M/SEC.

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Mean
1972	1.90	2.24	2.17	1.71	2.61	2.13	3.16	2.45	1.87	1.61	1.67	1.52	2.20
1973	1.45	1.46	1.52	2.73	1.61	1.80	1.65	1.55	1.40	1.87	2.53	-	1.78
Ave.	1.68	1.84	1.85	2.22	2.11	1.97	2.41	2.00	1.64	1.74	2.10	1.52	1.99

The average wind velocity at pan location for the whole year is 2.0 m/sec.

Note * The data were taken from the data sheets recorded at the Northeast Agricultural Center which is about 13 km. south from Khon Kaen. The wind movement was measured at 1.5 ft. above ground surface.

TABLE 29.[12] SUNSHINE DURATION AT KHON KAEN - DAILY AVERAGE MONTHLY MEASUREMENTS - BY CAMBELL STOKES INSTRUMENT (n), UNIT - HOURS/DAY

Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
9.5	8.8	8.1	8.4	7.6	6.1	6.1	5.6	5.3	7.9	8.5	9.2

TABLE 30.[12] POSSIBLE SUNSHINE HOURS AT NAKHON RATCHASIMA (D) UNIT - HOURS/DAY

Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
11.3	11.7	12.1	12.4	12.8	13.1	13.0	12.6	12.2	11.8	11.4	11.2

TABLE 31. RATIO OF ACTUAL TO POSSIBLE SUNSHINE ($^n/D$)

Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
0.84	0.75	0.67	0.68	0.59	0.47	0.47	0.44	0.43	0.67	0.75	0.82

The above possible sunshine hours are obtained from the daily average monthly daylight hours between sun rise and sunset.[12] The data of Khon Kaen are not available. However, Nakhon Ratchasima is located at about latitude 14° - 58'N, 102° - 07'E, less than 2° south of Khon Kaen. It should not cause a significant difference in the possible sunshine hours between Nakhon Ratchasima and Khon Kaen.

Review of the literature indicates that a class "A" pan evaporation correlates to the reservoir evaporation. It can set up as the following formula.

$$\text{Lake Evaporation} = C_{pan} \times \text{Pan Evaporation}^{(14)}$$

Generally, the average pan coefficient for a class "A" tank is 0.70. However, the actual values of this coefficient vary from place to place and during the year because of greatly different heat storage capacities of the tank and the lake.[14] By using the average pan coefficient 0.70 of the class "A" pan, the estimated evaporation losses of the Huey Si Thon reservoir are obtained as presented Tables 32 and 33.

TABLE 32. THE ESTIMATED MONTHLY RESERVOIR EVAPORATION IN MM.

Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Mean
109	101	118	126	134	106	114	104	103	109	110	111	112

TABLE 33. THE ESTIMATED DAILY RESERVOIR EVAPORATION IN MM.

Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Mean
3.50	3.60	3.82	4.20	4.31	3.55	3.68	3.34	3.43	3.50	3.66	3.57	3.68

Total annual evaporation = 1345 mm.

The above results using the pan evaporation formula and a pan coefficient of .7 are a very rough approximation of values for reservoir evaporation losses. On the other hand, a formula based on energy budget concept such as Penman's empirical formula should give a far better approximation of the reservoir evaporation losses provided all the required data are determined correctly. But, the accuracy of the evaporation values will depend upon how accurately the various components of the empirical formula have been observed and determined.

However, in this study, values of the reservoir evaporation losses will be calculated by both methods, then compared, and the most reasonable values chosen for the analysis.

The reservoir evaporation losses can be estimated by Penman's empirical formula.[15]

$$E_o = \frac{\Delta H + \gamma E_a}{\Delta + \gamma}$$

where E_o = the daily reservoir evaporation in mm.

H = net radiation

E_a = parameters including wind velocity and the saturation deficit

γ = psychrometric constant = 0.49 mm. Hg/°C

Δ = the slope of the saturation vapor pressure curve at air temperature

The nomogram (Figure 6) for determining evaporation E_o from a free water surface according to the above formula of Penman can be used. The computation is based on the following data.[15]

t = mean daily temperature °C

$^n/D$ = ratio of actual to possible daily of sunshine

h = relative humidity of air (daily average)

U_2 = average daily wind velocity at 2 m. (6.56 ft.) in m/sec.

$$= U_{ob} \left[\frac{Z_2}{Z_{ob}} \right]^{1/7} \quad (14)$$

$$= U_{ob} \left[\frac{6.56}{1.50} \right]^{1/7}$$

$$= 1.23 U_{ob}$$

U_{ob} = wind velocity at the anemometer level (1.5 ft. above ground surface)

Z_2 = the elevation where the determining wind velocity is desired (2m. or 6.56 ft. above ground surface)

Z_{ob} = the elevation of the observation (1.5 ft.)

R_A = mean extra-terrestrial radiation expressed in equivalent of mm/day evaporation (g-cal/cm^2/day)

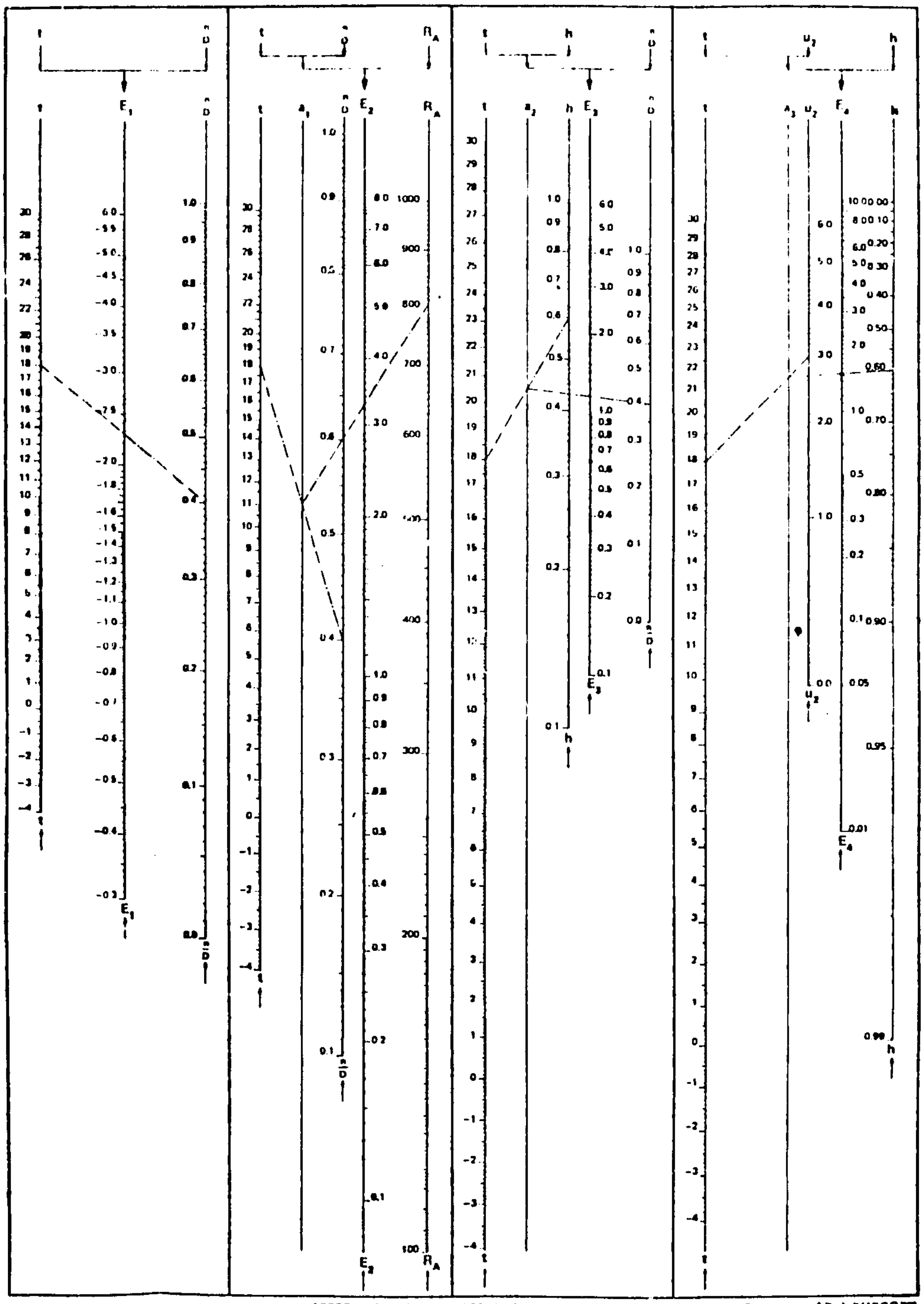
For the Huey Si Thon Dam site at latitude 16° - 26'N, the values of R_A (extra-terrestrial radiation) are given in Table 34.

TABLE 34.[16] MEAN EXTRA-TERRESTRIAL RADIATION AT THE HUEY SI THON DAM SITE - UNIT IN g-cal/cm^2/day

Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
669	825	831	907	893	921	891	875	862	762	703	640

NOMOGRAM FOR DETERMINING EVAPORATION E_0 FROM A FREE WATER SURFACE ACCORDING TO THE FORMULA OF PENMAN

$$E_0 = \frac{\Delta H + \gamma E_a}{\Delta + \gamma} = E_1(t, \tfrac{n}{D}) + E_2(t, R_A, \tfrac{n}{D}) + E_3(t, \tfrac{n}{D}, h) + E_4(t, u_2, h)$$



EXAMPLE

$t = 18°C$

$\frac{n}{D} = 0.4$

$R_A = 800$ g cal/cm²/day

$h = 0.8$

$u_2 = 3.0$ m/sec.

ACCORDING TO THE NOMOGRAM, THE FOLLOWING VALUES ARE FOUND FOR E_1, E_2, E_3 AND E_4:

$E_1 = -2.28$ mm/day
$E_2 = +3.30$ "
$E_3 = +1.12$ "
$E_4 = +1.52$ "

SO THAT $E_0 = +3.66$ mm/day

By courtesy of P. J. RIJKOORT, Royal Meteorological Institute, Netherlands

FIGURE 6. (AFTER E. M. WILSON)

Generally, R_c/R_A will correlate to $^n/D$ in the form $\frac{R_c}{R_A} = a + b\frac{n}{N}$. (17)

The values of "a" and "b" will not be evaluated in this study. Obviously, the results are still in error. The reasons are: the data are taken from different sources, some are observed in a short period and the correct values of "a" and "b" should be tested with the observed data for a reasonable period. But for purposes of this study, the reservoir evaporation losses will be approximated by using the nomogram shown in Figure 6. The reservoir evaporation losses of the Huey Si Thon estimated by Penman's formula are shown in Tables 35 and 36.

TABLE 35. ESTIMATED DAILY RESERVOIR EVAPORATION LOSSES BY PENMAN'S FORMULA

Data	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Units
t	21.9	24.2	26.5	28.0	28.2	27.4	26.6	25.7	26.7	25.5	23.5	22.0	°C
$^n/D$	0.84	0.75	0.67	0.68	0.59	0.47	0.47	0.44	0.43	0.67	0.75	0.82	-
h	63.2	62.5	60.8	62.8	72.0	74.8	77.6	79.6	81.3	76.5	70.6	66.3	%
U_2	2.07	2.27	2.28	2.74	2.61	2.43	2.98	2.47	2.02	2.15	2.59	1.88	m/sec
R_A	669	825	831	907	893	921	891	875	862	762	703	640	g-cal/ cm^2/day
E_o	3.96	5.11	5.23	6.15	5.50	4.83	4.69	4.22	4.10	4.40	4.14	3.56	mm.

TABLE 36. ESTIMATED MONTHLY RESERVOIR EVAPORATION LOSSES BY PENMAN'S FORMULA

Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Mean
123	143	162	185	171	145	145	131	123	136	124	110	144

Total annual reservoir evaporation by Penman's formula is 1588 mm. Comparison of the annual reservoir evaporation to the average annual pan evaporation results in the following.

Given annual evaporation 1380 mm. $= \frac{1380}{1919} = 0.72$

0.70 pan coefficient : evaporation 1340 mm. $= \frac{1340}{1919} = 0.70$

Evaporation from Penman's formula 1580 mm. $= \frac{1580}{1919} = 0.83$

Estimating evaporation using Penman's formula may result in values that are too high. In April, the estimated reservoir evaporation exceeds the pan evaporation observed data. Of the data used in determining the reservoir evaporation, some were recorded in a short period and some are taken from other places. So the percentage of correctness has to be reduced. However, it will be a guide for selecting a reasonable value for the pan coefficient of the study area. The correlation value of the pan coefficient for this reservoir should not be given a constant value of 0.7 because its actual value varies from place to place and it ranges from 0.60 for arid areas to 0.80 for humid climates.[18] In fact, the previous selection of a pan coefficient of 0.70 may be too low for this reservoir, because the observed evaporation was recorded at a project area near the reservoir while the humidity was not observed. It is known that the pan evaporation may be affected by the humidity from the reservoir, and this may decrease the pan evaporation. Hence, a reasonable estimate of the pan coefficient for this reservoir based on the foregoing analysis should be 0.75. It is greater than the given value, but it will be the safety factor for determining the volume of water in the reservoir for the purpose of water management. Tables 37 and 38 show the new values of the reservoir evaporation losses that will be used for this study.

TABLE 37. THE MEAN DAILY RESERVOIR EVAPORATION LOSSES - UNIT IN MM.

Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Mean
3.74	3.86	4.10	4.50	4.61	3.80	3.94	3.58	3.67	3.74	3.93	3.84	3.94

TABLE 38. THE MEAN MONTHLY RESERVOIR EVAPORATION LOSSES - UNIT IN MM.

Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Mean
116	108	127	135	143	114	122	111	110	116	118	119	120

Total annual evaporation is 1439 mm.

2. Reservoir Seepage Losses

The reservoir seepage losses are hard to determine.[19] Hence, the given value of the daily seepage losses of 3 mm. will be used. This is the value used in the initial study for the reservoir.

3. Total Reservoir Losses

The main purpose of this reservoir is for irrigation. A small amount of the reservoir volume is used for domestic consumption, but it will be neglected. Two factors that affect the reservoir storage are evaporation and seepage losses. For the purpose of this study, the total reservoir losses are the summation of these two losses. The total reservoir losses are shown in Tables 39 and 40.

TABLE 39. MEAN DAILY RESERVOIR LOSSES - UNIT IN MM.

Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Mean
6.74	6.86	7.10	7.50	7.61	6.80	6.94	6.58	6.67	6.74	6.93	6.84	6.94

TABLE 40. MEAN MONTHLY RESERVOIR LOSSES - UNIT IN MM.

Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Mean
209	192	220	225	236	204	215	204	200	209	208	212	211

Total annual reservoir losses is 2534 mm. (2.534 m.)

Figure 7 depicts a diagram of the reservoir losses.

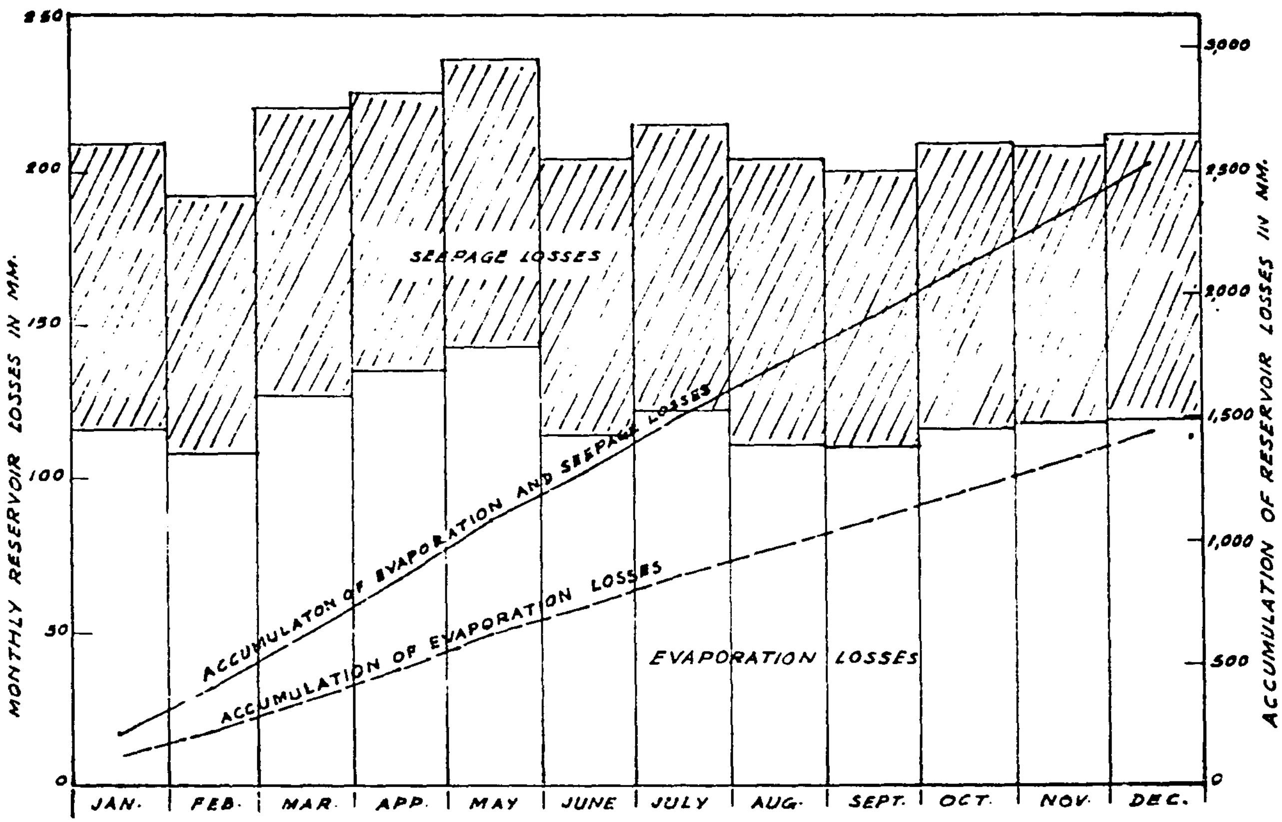


FIGURE 7: **RESERVOIR LOSSES**

Rainfall Frequency Study

Rainfall is extremely crucial to the operation of this type of reservoir as previously mentioned. Water management of these reservoirs has to consider the variability of local occurrences of rainfall since their catchments and capacities are small. This is especially true where the reservoir capacities can irrigate only one of two crop-periods during the year depending on the occurrence of rainfall. Hence, a study of the statistical distribution of past rainfall records can serve as a yardstick for predicting future events.[20]

Chow has stated that, "The great need for information relating to hydrologic frequencies is apparent in various economic studies and in efficient designs of coffer-dams, waterway opening in bridges, highway and railway culverts, urban storm sewers, farm terraces, airfield drainage, stream-control works, hydroelectric power installations, water-supply facilities and many other hydraulic structures and projects which are designed in consideration of the frequency of certain hydrologic events."

For this study, the methods of rainfall frequency analysis will follow those developed by Chow.[21] The rainfall data of both stations (Kalasin and Huey Si Thon) has been analyzed and plotted in the probability graphs shown in Figures 8, 9 and 10. They show that the reliable rainfall period should be during May to September and the rainfall during November to February should be deemed as a no rainfall period, because the probability of rainfall during these months is almost zero. The probability of rainfall at Kalasin and the Huey Si Thon can be analyzed monthly as shown in Tables 41 and 42.

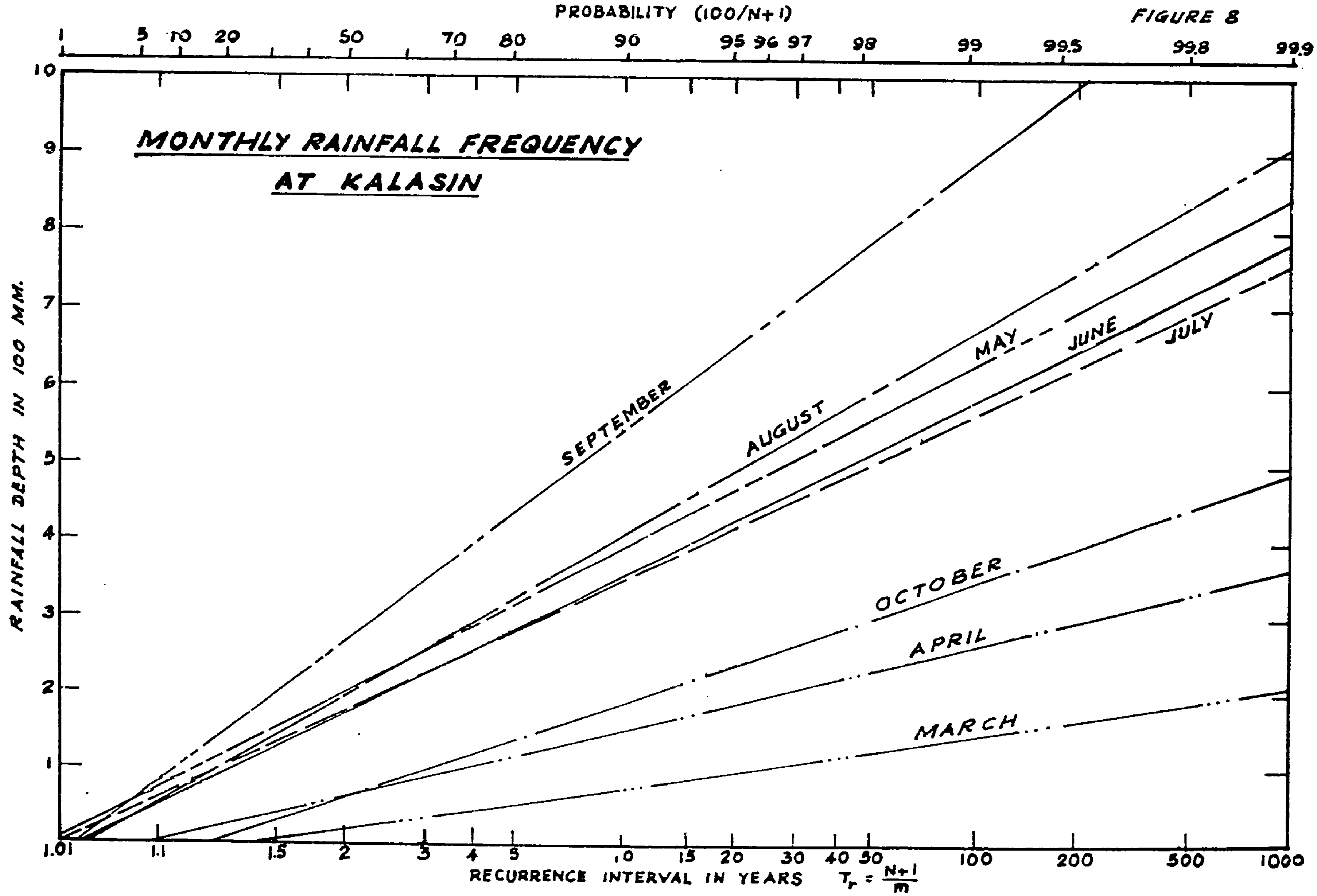
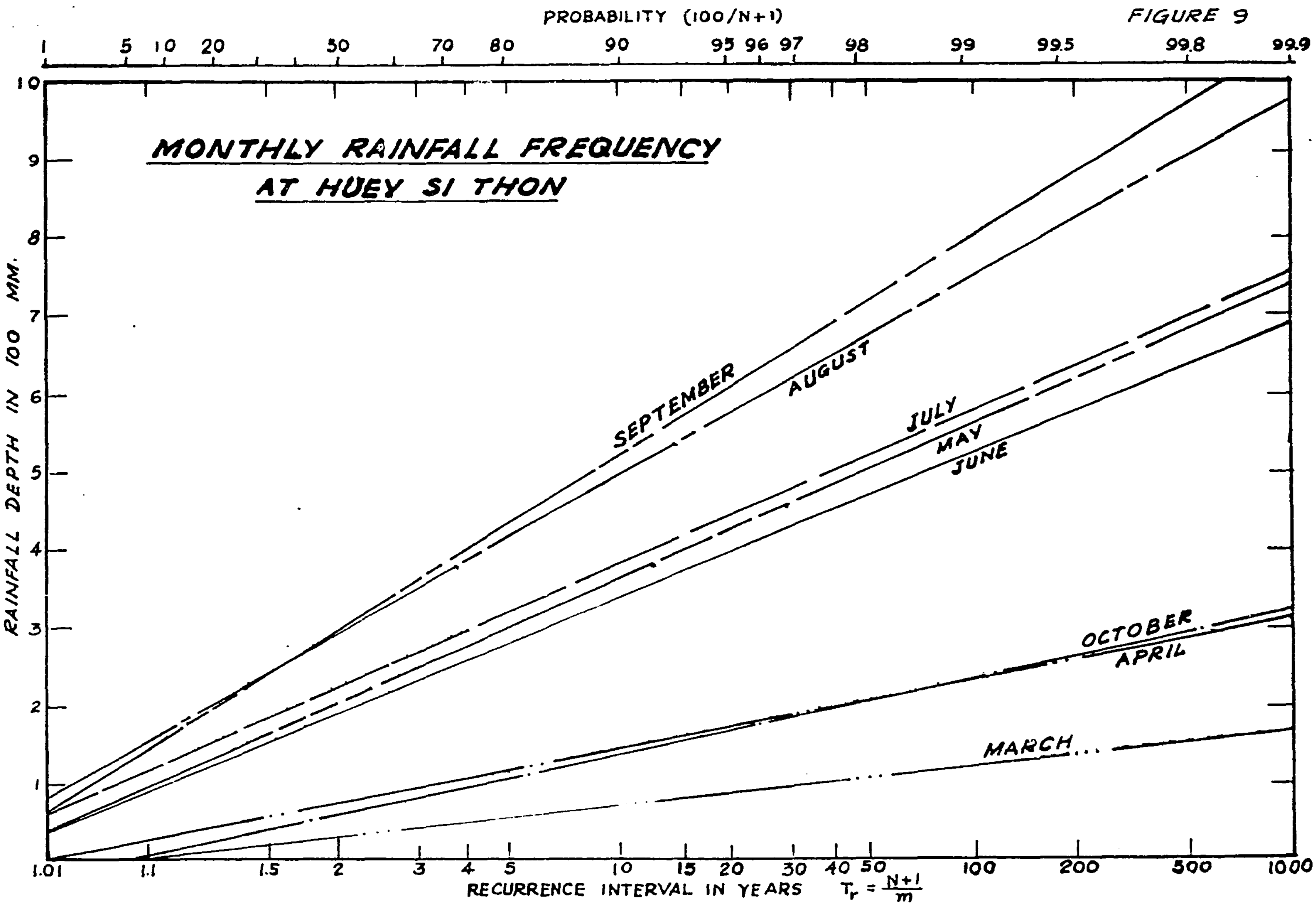

MONTHLY RAINFALL FREQUENCY
AT KALASIN
PROBABILITY (100/N+1)
1 5 10 20 50 70 80 90 95 96 97 98 99 99.5 99.8 99.9
RAINFALL DEPTH IN 100 MM.
10 9 8 7 6 5 4 3 2 1
SEPTEMBER
AUGUST
MAY
JUNE
JULY
OCTOBER
APRIL
MARCH
1.01 1.1 1.5 2 3 4 5 10 15 20 30 40 50 100 200 500 1000
RECURRENCE INTERVAL IN YEARS $T_r = \frac{N+1}{m}$

FIGURE 8

FIGURE 9



PROBABILITY (100/N+1)
1 5 10 20 50 70 80 90 95 96 97 98 99 99.5 99.8 99.9
MONTHLY RAINFALL FREQUENCY
AT HÜEY SI THON
RAINFALL DEPTH IN 100 MM.
1 2 3 4 5 6 7 8 9 10
SEPTEMBER
AUGUST
JULY
MAY
JUNE
OCTOBER
APRIL
MARCH
1.01 1.1 1.5 2 3 4 5 10 15 20 30 40 50 100 200 500 1000
RECURRENCE INTERVAL IN YEARS $T_r = \frac{N+1}{m}$

FIGURE 10

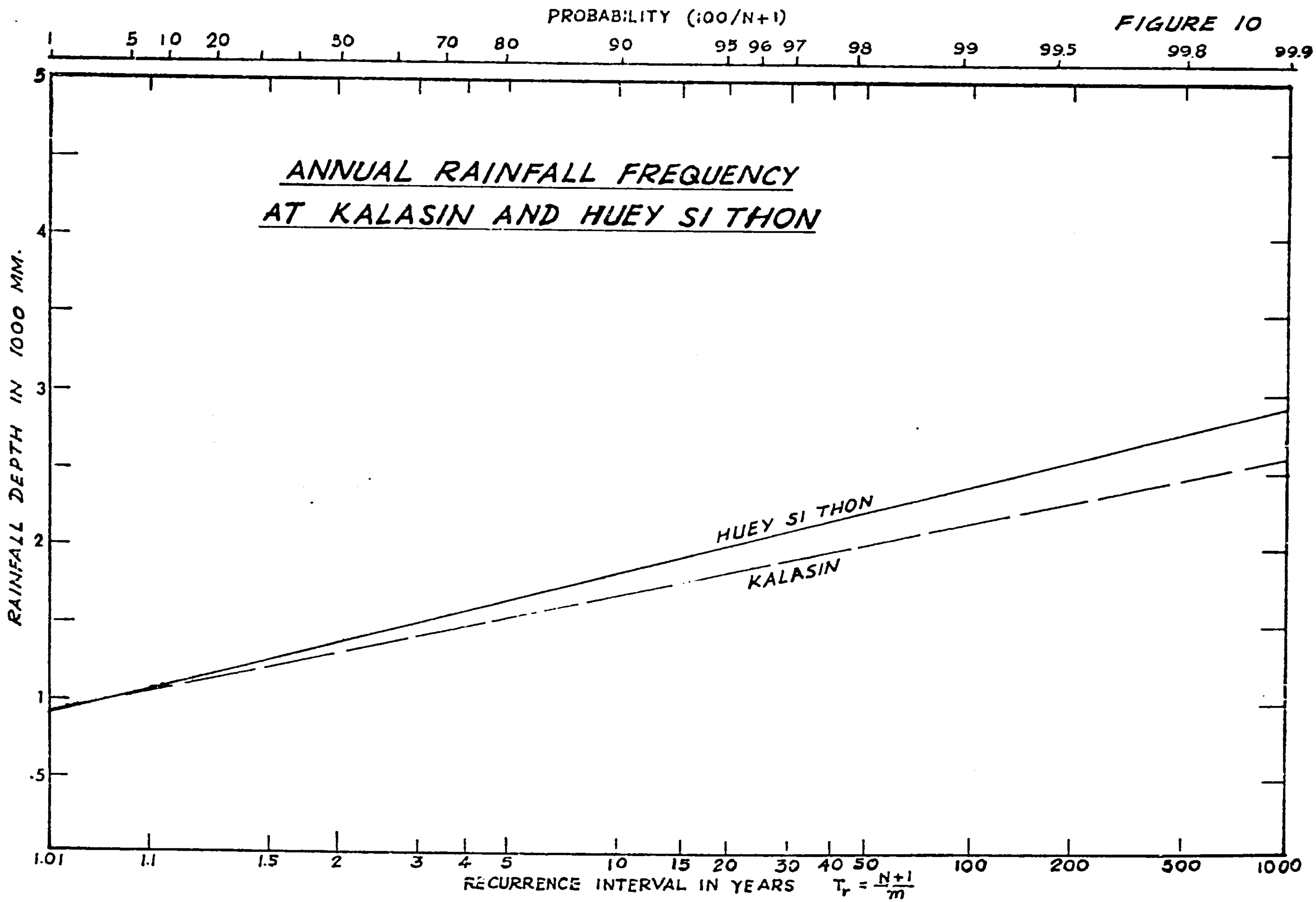

ANNUAL RAINFALL FREQUENCY
AT KALASIN AND HUEY SI THON
PROBABILITY (100/N+1)
1 5 10 20 30 70 80 90 95 96 97 98 99 99.5 99.8 99.9
RAINFALL DEPTH IN 1000 MM.
5 4 3 2 1 .5
HUEY SI THON
KALASIN
1.01 1.1 1.5 2 3 4 5 10 15 20 30 40 50 100 200 500 1000
RECURRENCE INTERVAL IN YEARS $T_r = \frac{N+1}{m}$

TABLE 41. THE PROBABILITY THAT RAINFALL WILL EXCEED 100 MM. (MONTHLY) AT THE CITY OF KALASIN - UNIT IN PERCENTAGE

Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
0	0	5	30	85	78	80	88	90	36	0	0

TABLE 42. THE PROBABILITY THAT RAINFALL WILL EXCEED 100 MM. (MONTHLY) AT THE HUEY SI THON DAM SITE - UNIT IN PERCENTAGE

Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
0	0	2.4	28	91	89	95	98	97	20	0	0

Hence, reservoir water actually depends on the rainfall during May to September. When the minimum annual rainfall in the year 1942 (760 mm.) is compared to the rainfall frequency curve, the probability of rainfall similar to that year will occur less than 1.01% of the time. If it is assumed that the runoff coefficient is 24.6%, the existing reservoir will require a rainfall in the watershed of only 294 mm. in order to fill it, which is less than the amount of rainfall in some months of the past rainfall records. This figure does not include evaporation and seepage losses.

Conclusions can be drawn that generally, the annual runoff of this reservoir exceeds 15 million m^3 and the reservoir capacity is about 25% of the annual runoff from the average annual rainfall, and this reservoir should be replenished to full capacity every year.

Ground Water

Another element in the hydrology of an area is the behavior of the ground water. Quality of the ground water and level of the water table are important in determining the irrigation requirements.[22] In 1962, Italconsult[2] made the following conclusions with respect to ground water.

"1. the general level of the ground waters closely follows the topography of the area.

2. the maximum level reached by the water at the end of the rainy season (September-October) is in very nearly every case equal to or above the level of the surrounding land, even in the case of the highest ground.

3. the minimum level at the end of dry season (March-April) is 1.50 - 3.00 m. below the maximum.

4. during the dry season the water-table level is at least 1.50 m. below ground, even on the lowest-lying land.

5. the greatest drops in level are to be found from October to December, and greatest rise from August to September, with ranges of 1.00 - 1.30 m. in any one month."

At the present time, the ground water levels of 26 grid-observed wells in the area are still being recorded. Data on ground water for the year 1973 indicated a situation almost identical to the past records with one exception, the minimum level at the end of dry season seemed to be rising up within the ranges of 0.60 - 2.00 m. Quality of ground water will not be harmful to the crops if proper drainage systems are established to maintain the water table at a desirable level below the root zone.

Chapter IV

WATER DEMAND

Thailand is a humid country. Availability of water resources is not as critical as in arid countries. Normally, the amount of rainfall during the rainy season is enough to supply water for agriculture, but the irregular distribution of rainfall poses a risk to agriculture. Crops cannot be grown during the dry season (due to a lack of water), while the climate and soils of Thailand are suitable to grow crops year-round. For these reasons, irrigation projects are necessary for Thailand.

At the present time, irrigation technology in Thailand is not as well developed as it could be. Few irrigation projects supply water for growing crops in the dry season as well as the rainy season. If irrigation is to occur year-round, many factors of crop production, such as marketing, price, water, capital, education etc., must be carefully evaluated. However, the necessity for increasing production per unit of land and water will increase in the near future due to the population growth. The irrigation projects in Thailand will have to supply water for growing crops during all seasons of the year as much as possible. So, a study to improve the irrigation water management for existing projects and to provide for planning of new projects is necessary.

The water requirement of crops is an important factor related to the management and design of irrigation projects. In determining the water use of crops for a humid country such as Thailand, McGuinness and Bordne[23] have mentioned that, "accurate estimates of water use in humid areas are necessary to estimate the occurrence of droughts and water shortages. The significance of water shortages relative to supplies is less in humid areas because of the infrequency of such shortages."

The water requirement of a crop is that amount of water the crop needs for transpiration, including the evaporation losses, during the growing period. There has been much research on the evapotranspiration of crops. Researchers have developed many empirical formulas to determine the evapotranspiration, but no formula is widely accepted as being suitable for Thailand. Engineering Consultant Inc., Bangkok, in the report of land classification for Lam Pao Irrigation Project,[8] discussed the Thornwaite method of estimating potential evapotranspiration (an empirical method developed on the basis of humid conditions), and used the Thornwaite and Blaney-Criddle methods to estimate the evapotranspiration of crops for that report. The U.S.B.R.[12] made a comparison of three methods, Haise-Jensen, Blaney-Criddle and Hargreave, G. H., in estimating evapotranspiration for the feasibility report of Nam Mun Project, Northeast Thailand, and recommended that the Haise-Jensen method gave the results closest to long term averages of measured crop consumptive use.

Schulz[24] suggested some empirical equations that might realistically represent tropical conditions. However, Thailand needs research for basic field data for water management. No attempt will be made to estimate evapotranspiration of crops from empirical formulas or will any experimental data be taken.

Evapotranspiration Experiments

At the present time, there are few research reports on evapotranspiration of crops in Thailand. The Royal Irrigation Department has been doing research in this field since 1964,[8] but the experiments were concentrated on the evapotranspiration of rice. Data for the other crops is not available. Fortunately, there were three experiments dealing with the evapotranspiration of soybean, mungbean and sweet corn at the Food and Agricultural Organization (FAO) Agriculture Experimental Station in the Huey Si Thon Project. Table 43 is the potential evapotranspiration of crops that have been observed at the experimental stations in Thailand.

Figures 11 and 12 depict the graph of daily consumptive use of rice in the dry and wet seasons respectively, which were prepared by the Royal Irrigation Department.

Cropping Selection and Cropping Schedule

Climatic conditions are not a significant factor in selecting the cropping pattern for irrigated areas in Thailand. This is due to the favorable climatic conditions in the potential irrigated areas for year-round crop production. Production can only occur, however, if irrigation water is available from October through May. A supplemental irrigation supply assists in optimizing crop production from June to September (the wet season). Summaries of climatological data were shown in Chapter 2.

Selection of a cropping pattern for this study will be made by giving the traditional agricultural practices the highest priority; then suitable crops for the area[9] and suitable cropping times will be selected on a consumptive use basis which can maximize use of existing reservoir storage capacity.

TABLE 43. POTENTIAL EVAPOTRANSPIRATION OF CROPS IN THAILAND

Experimental Stations	Crops	Season	Observed Date	Mean H %	Mean T °C	E_p mm.	Procedure of Experiments
Sam Chook - R.I.D. (The central plain)	180-day Rice[8]	Wet	June 25, 1964 to Dec. 11, 1964	76	28	885	Tanks (continuous Irr.)
	120-day Rice[8]	Dry	Feb. 20, 1965 to June 8, 1965	59	30	695	Tanks (continuous Irr.)
	150-day Rice[11]	Dry	Feb. 10, 1970 to June 10, 1970	81	30	736	Tanks (continuous Irr.)
	180-day Rice[11]	Wet	June 22, 1970 to Dec. 28, 1970	91	28	817	Tanks (continuous Irr.)
	120-day Rice[11]	Wet	July 21, 1970 to Oct. 25, 1970	92	29	513	Field Plot (continuous Irr.)
	120-day Rice[25]	Dry	Feb. 22, 1971 to June 5, 1971	85	30	669	Tanks (continuous Irr.)
Tayang[26] - R.I.D. (The Southern part of Central region)	120-day Rice	Dry	Feb. 13, 1970 to May 20, 1970	68	27	718	Tanks (continuous Irr.)
	120-day Rice	Wet	July 18, 1970 to Nov. 3, 1970	78	27	738	Tanks (continuous Irr.)
Cha-Am[27] - R.I.D. (The Southern part of Central region)	120-day Rice	Dry	Feb. 12, 1971 to June 8, 1971	70	27	821	Tanks (continuous Irr.)
	120-day Rice	Wet	July 19, 1971 to Nov. 8, 1971	87	27	639	Tanks (continuous Irr.)

(continued)

TABLE 43. POTENTIAL EVAPOTRANSPIRATION OF CROPS IN THAILAND

(continued)

Experimental Stations	Crops	Season	Observed Date	Mean H %	Mean T °C	E_p mm.	Procedure of Experiments
Huey Ban Yang[28] - R.I.D. (The Northeast)	120-day Rice	Dry	Jan. 30, 1971 to June 10, 1971	-	28	933	Tanks (continuous Irr.)
	120-day Rice	Wet	July 10, 1971 to Nov. 3, 1971	-	27	637	Tanks (continuous Irr.)
Kalasin[29] - F.A.O. (The Northeast)	Mungbean	Wet	June 16, 1973 to Sept 2, 1973	-	-	241	Lysimeter
	Soy bean	Dry	Dec. 26, 1973 to Apr. 22, 1974	-	24	628	Lysimeter
	Sweet corn	Wet	Apr. 25, 1974 to July 3, 1974	-	28	337	Lysimeter

H = relative humidity

T = temperature

E_p = potential evapotranspiration

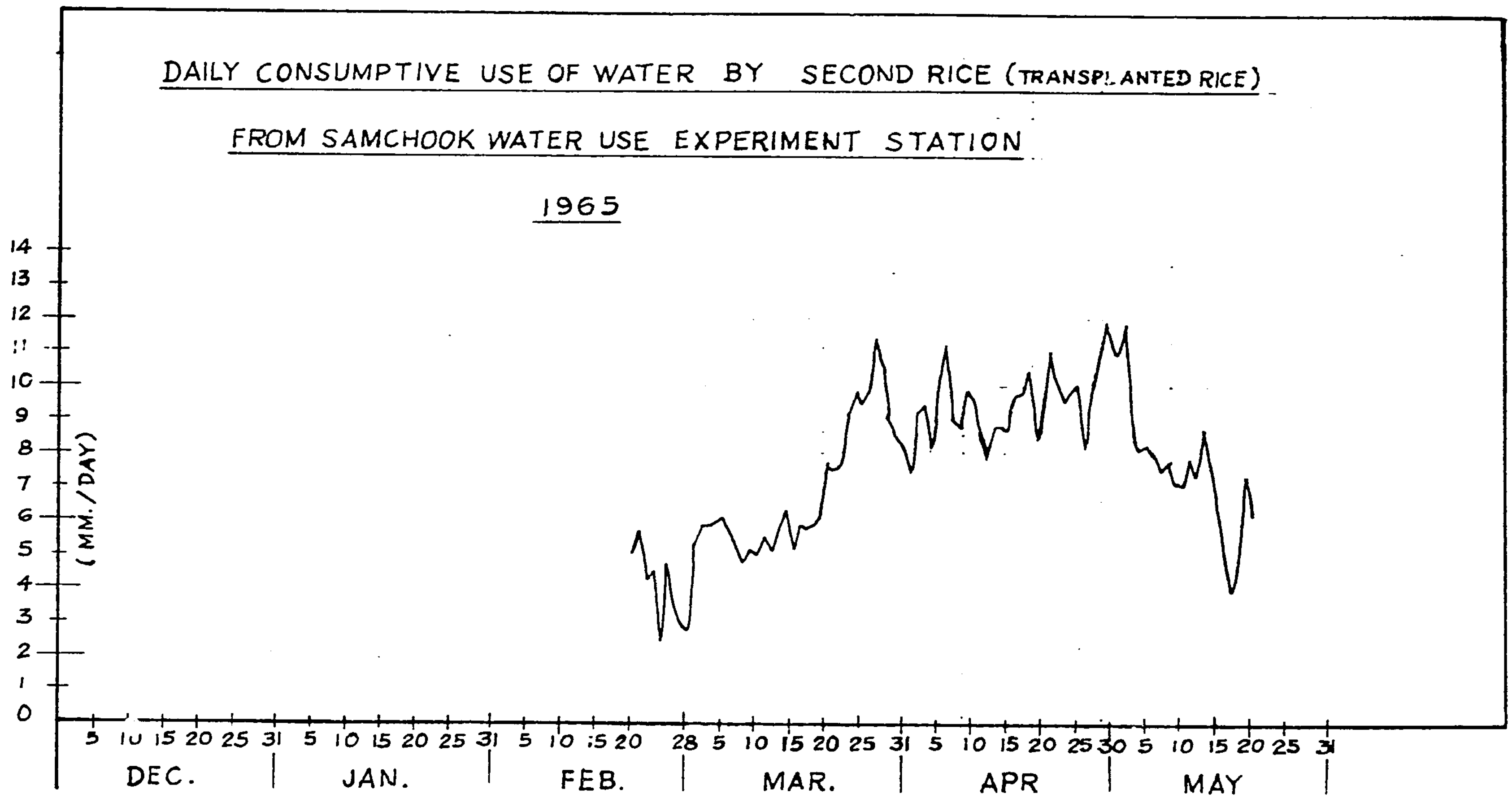
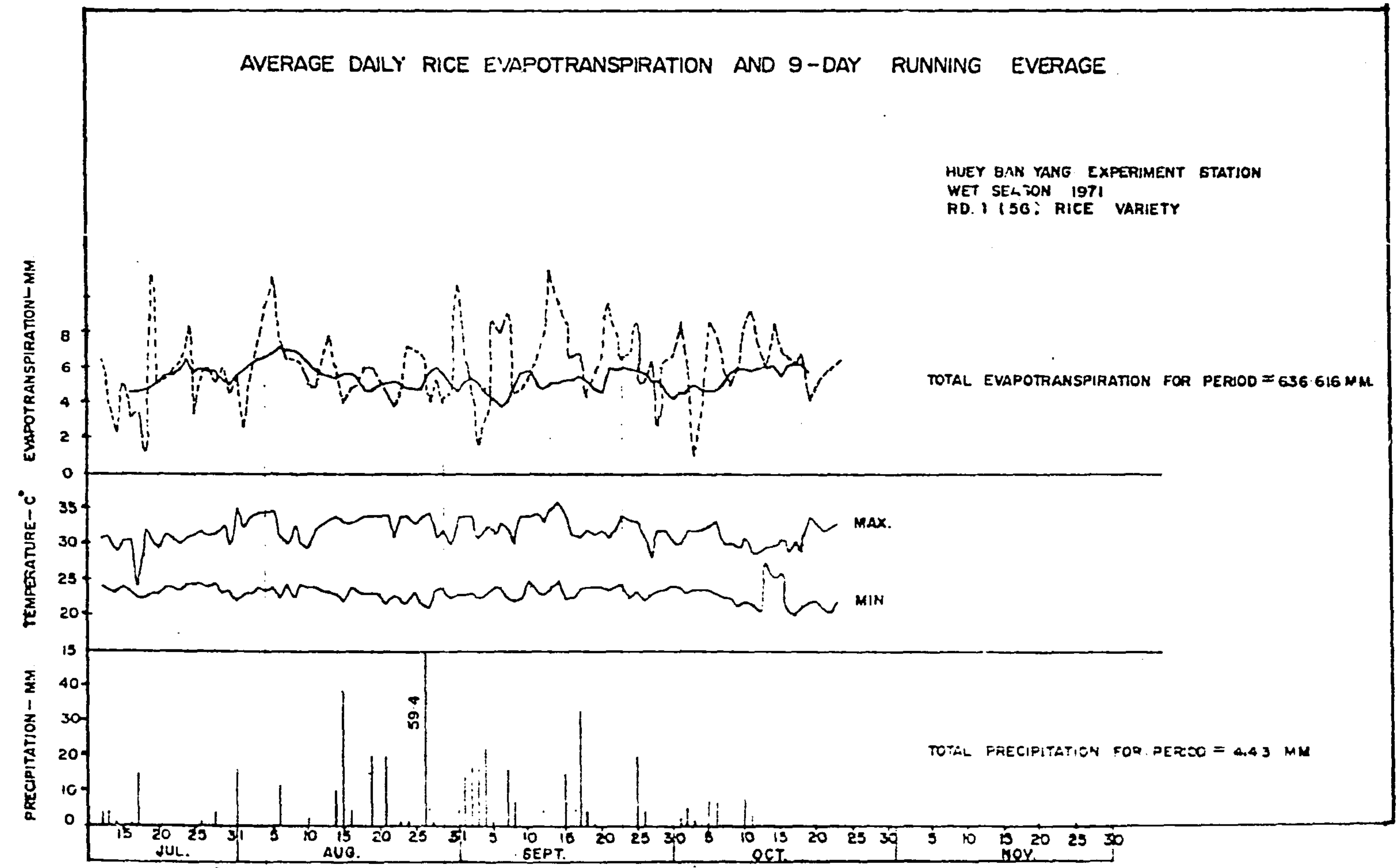


FIGURE 11. (AFTER R.I.D.)

IRRIGATION AGRONOMY SECTION
OPERATION AND MAINTENANCE DIV.
R.I.D.

FIGURE 12


AVERAGE DAILY RICE EVAPOTRANSPIRATION AND 9-DAY RUNNING EVERAGE
HUEY BAN YANG EXPERIMENT STATION
WET SEASON 1971
RD. 1 (5G) RICE VARIETY
TOTAL EVAPOTRANSPIRATION FOR PERIOD = 636.616 MM.
TOTAL PRECIPITATION FOR PERIOD = 4.43 MM
EVAPOTRANSPIRATION – MM
TEMPERATURE – C°
MAX.
MIN
PRECIPITATION – MM
59.4
JUL.
AUG.
SEPT.
OCT.
NOV.

If the wet-season crops are defined to be the crops that are grown during the periods of the southwest monsoon season (May to October) and the dry-season crops are the crops that are grown during the period of the northeast monsoon season (November to April), the crops that are suitable for cropping during the wet-season of the Northeast region will consist of soy beans, cotton, sweet corn, mungbean, gasava, jute, kenaf, peanuts, rice, sorghum and corn (maize) and the dry-season crops will be soy bean, sweet corn, mungbean, and peanuts (Figure 2).

1. Wet-season crops

Since rice is currently widely grown and is a basic staple of the people, its continued utilization as a crop must be considered. Therefore, the water requirements of rice must normally be satisfied first with other crops being considered with the remaining water. The following discussion spells out the water demand of rice.

According to the duration of maturity, rice in Thailand normally can be divided into 3 varieties; an early maturity, a medium maturity and a late maturity. The duration of an early maturity variety is about 120 days from a seedling to ripening date, and for purposes of this study it will be called a 120-day rice. The duration of a medium maturity variety takes about 150 days from a seedling to ripening date; consequently, it will be called a 150-day rice. The duration of a late maturity variety takes about 180 days or longer; therefore, it will be called a 180-day rice. The yield of each variety will not be significantly different if fertilizer and water are managed carefully.[10] But the difference of their duration and potential evapotranspiration as shown in Table 43 is meaningful to the irrigation water.

The major management aspects of growing rice involve the timing of growing seasons and the rainfall duration so that enough water can be obtained for the rice fields. Because rice has a high consumptive use, it needs some water for seedling nursery and land preparation. Past rainfall records at Kalasin and Huey Si Thon show that the high intensity rainfall period will occur during May to September, then it will decrease in October. Therefore, the suitable time for growing the 120-day rice should start on July 1, and end in October. The reasons for selecting this period are; first, it can minimize the reservoir water for seedling and land preparation because rainfall during May and June will moisten the soil; second, the highest intensity rainfall is usually in September which is the peak consumptive use-period of the 120-day rice; and third, the harvesting period will be in the dry season. So, the 120-day rice should be the most economical (from strictly a water use standpoint) type for the irrigation project being considered, and it will be selected to be the wet-season crop of the studied project.

2. The dry-season cropping

Suppose rice harvesting is finished at the end of October. The dry-season cropping period begins in early November and lasts to the end of June. There are 7 months (210 days) for dry-season cropping excluding one month for the transition cropping period. Table 44 lists crops recommended by Food and Agricultural Organization (FAO) Agricultural Experimental Station for the study area.[9]

TABLE 44.[9] RECOMMENDED CROPS IN THE KALASIN AREA

Type of Crops	Suitable cropping time	Duration Dates (days)
Groundnuts (peanuts)	Dry or rainy seasons	95 - 115
Mungbean	Dry or rainy seasons	70 - 85
Cotton	Dry or rainy seasons	110 - 130
Sorghum	Dry or rainy seasons	200 - 220
Jute (for fibers)	Dry or rainy seasons	110 - 120
Jute (for seeds)	Dry or rainy seasons	150
Sweet potatoes	All the year round	120
Cucumbers	All the year round	70 - 130
Soy bean	Dry or rainy seasons	105 - 120
Sweet corn	Dry or rainy seasons	75

There were many other recommended crops in the report[9], but the time duration to maturity was not shown and the success of soy beans for the reservoir service area is still being researched.

The procedure for selecting crops needs to consider other factors besides the time duration to maturity and water requirement for crops in order to maximize the benefit of the project and the farmers. However, for purposes of this study, these two will be stressed, and rice will not be considered for growing during the dry-season because its high water demand is not suitable for the small reservoir, and the rate of return between rice production and field crops does not differ significantly. Soy beans, mungbeans and sweet corn are chosen to be the dry-season crops for purposes of the study because their consumptive uses are known.

The duration to maturity of soy beans, mungbeans, and sweet corn shows that two consecutive cultivations can be done successfully during the dry season if irrigation water is available. The suitable time for growing the first dry-season crops should start in early November following the rice because the soil still contains available moisture.

<u>Land Use</u>

For the purpose of this study, the 1200 hectares of irrigable area in the project are deemed to be well developed for the irrigation purposes. The distribution and drainage systems are completed. The soil type is assumed to be homogeneous in the area. Further, it is assumed that during each growing period, the land is used to serve one crop and 100 percent of the land is used for growing rice during the rainy season. The percentage of land for the dry-season crops will depend on the remaining reservoir storage after the wet-season crops. The dry-season crops can be grown in the paddy fields.

Effective Rainfall

For a tropical country such as Thailand, effective rainfall is a factor involving the water management of irrigation projects. Engineering Consultant Inc.[8] has defined effective rainfall as follows:

"A small amount of rain falling on bare dry soil moistens the soil to only a very shallow depth. This moisture is soon lost in evaporation, thus it is ineffective in supplying moisture for agricultural purposes. Larger amounts of rain, of course, moisten the dry soil to deeper depths and much of this moisture remains effective for rather long periods of time.

The proportion of rain that can be effectively used by a crop over a period of time is dependent on the amounts, timing and intensities of rainfall, infiltration, permeability and runoff characteristics of soils; available water-holding capacity of the soil; effective rooting depth of crop plants; and the amount of evapotranspiration from the crop. Paddy rice, because of the water basin checks that are part of the rice cultural practice, ordinarily can make more use of rain water than upland-type crops. For this reason, and because other factors differ significantly, effective rainfall for rice is considered separately from that for upland-type crops."

There are three methods for estimating effective rainfall in Thailand at the present time. Each method was developed by experienced engineers. There is no research in this field in the service or a nearby location

1. The Royal Irrigation Department method[30]

The Hydrology Section of the Royal Irrigation Department made an analysis of effective rainfall for a rice crop on a daily rainfall basis and developed this into percentages of effective rainfall. These percentages on a monthly basis are shown in Table 45.

TABLE 45. PERCENTAGES OF EFFECTIVE RAINFALL TO TOTAL MONTHLY RAINFALL

Months	% effective rainfall	Months	% effective rainfall
April	75	October	65
May	75	November	80
June	75	December	90
July	75	January	90
August	75	February	90
September	75	March	90

2. The E.C.I. method[8]

Engineering Consultant, Inc., (E.C.I.) Bangkok has developed a graph, shown in Figure 13, to estimate effective rainfall on the paddy rice for the Lam Pao Irrigation Project which is about 17 km. from the study area.

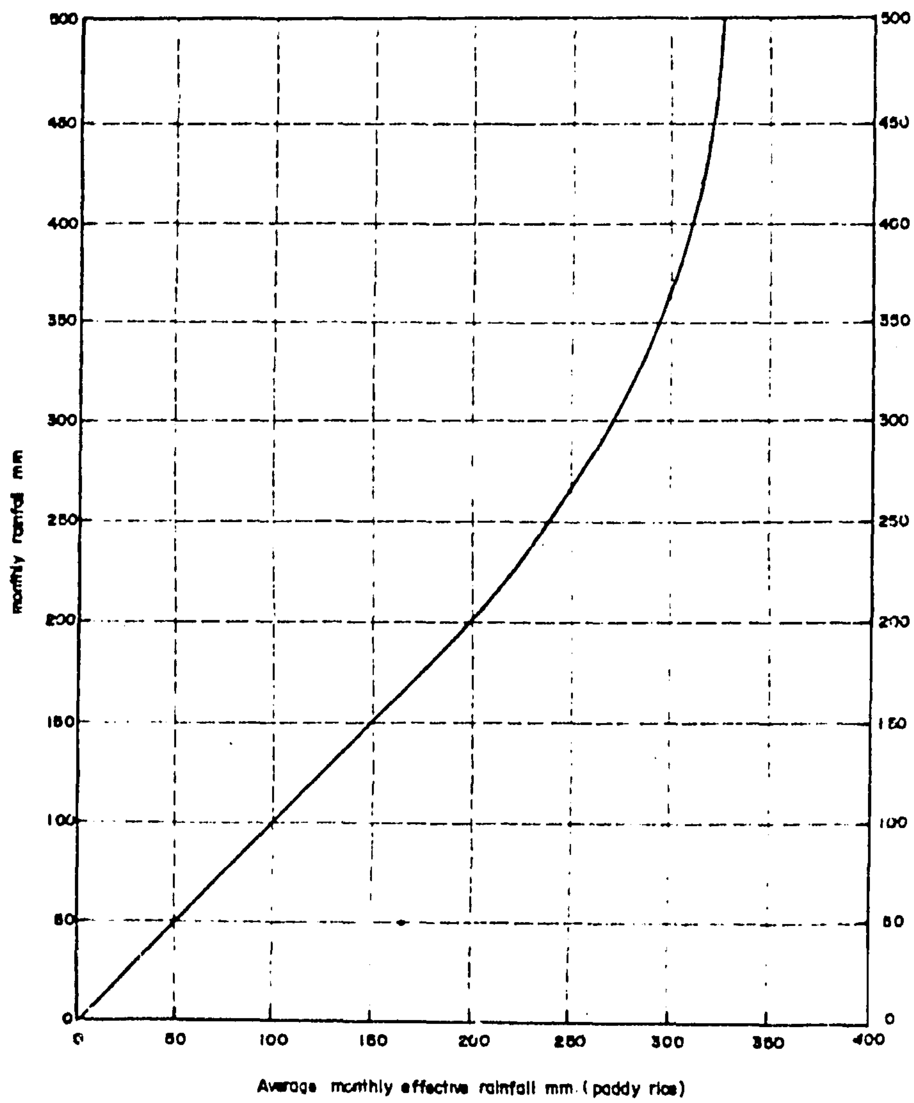


FIGURE 13. AVERAGE MONTHLY EFFECTIVE RAINFALL AS RELATED TO MONTHLY RAINFALL FOR PADDY RICE (AFTER E.C.I.)

The effective rainfall obtained from E.C.I. method will be different from R.I.D. method (see the comparison in Table 46).

3. The Me Kong method (12)

The U.S.B.R. has used the precedure of Dr. Peter Kung in estimating the effective rainfall for a rice paddy in the feasibility report on the Nam Mun Irrigation Project in the Northeast under the following criteria.

"1. Use daily measured rainfall in mm. for each month of reliable record.

2. Rice paddy average daily consumptive use and deep percolation loss in 6.0 mm./day.

3. The normal water layer depth in the rice paddy in a 50 hectare rotation service unit is 90 mm. with a range of 30 to 150 mm.

4. Single day rainfall is an individual day with recorded rainfall and is isolated by three consecutive days from another day which has recorded rainfall greater than 5.0 mm.

a) Rainfall less than 5.0 mm. is not considered to be effective since irrigation water deliveries would continue as scheduled.

b) Rainfall amounts of more than 5.0 mm. but less than 66 mm. are considered effective. The balance is assumed average paddy surface runoff.

5. Continuous rainy period in a given month is a group of individual days between terminating days which

have recorded rainfall greater than 5.0 mm. The continuous rainy period is isolated by three consecutive days from another individual day which has recorded rainfall greater than 5.0 mm. The sum of the recorded rainfall during the continuous rainy period is considered to be 100 percent effective if it is less than 60 mm. plus 6.0 mm. times the number of days in the period; the excess is assumed to be average paddy overflow and lost in the form of surface waste."

4. Comparison of estimated effective rainfall by three methods

The comparison of effective rainfall estimating by the three different methods for the rainfall record at Kalasin in 1942 is shown in Table 46.

Effective rainfall in 1942 at Kalasin as estimated by the E.C.I. method is very similar to that estimated by the Me Kong method. In this study, the E.C.I. method will be used to estimate effective rainfall at the Huey Si Thon Project, because it can be used easily and rapidly. However, accurate effective rainfall of a project should be determined from research at that project, since the U.S.B.R.[12] cited that "there are no universal criteria for estimating the effective rainfall which can be applied to all conditions. It is difficult to estimate growing period effective rainfall for the varying conditions of soils, crops, topography and climate." To improve efficiency of water management, research on effective rainfall in a project is necessary for a rainy country such as Thailand.

TABLE 46. ESTIMATED EFFECTIVE RAINFALL AT KALASIN IN THE YEAR 1942 - UNIT IN MM.

Months	R.I.D. Method	E.C.I. Method	Me Kong Method
April	63.38	84.5	84.5
May	138.75	185.0	171.0
June	159.90	210.0	210.70
July	39.00	52.0	52.0
August	-	-	-
September	168.98	220.0	215.8
October	-	-	-
November	-	-	-
December	-	-	-
January	-	-	-
February	-	-	-
March	-	-	-

Field Application Efficiency

Field application efficiency is a factor that affects reservoir discharge and, consequently, reservoir capacity. For a reasonably accurate estimate of field application efficiency, the following factors of the project must be considered.(31)

- intake characteristics of soils
- topography
- climate
- net depth of irrigation
- irrigation method
- adequacy of system design and installation
- skill of the irrigator
- tailwater recovery systems

If the existing field application efficiency of the studied project is broken down and estimated on a growing season basis, (the field application efficiency for the wet-season cropping and for the dry-season cropping), it will be easy to estimate the respective efficiencies.

1. Field application efficiency for wet-season cropping

The field application efficiency of the project will be high in the wet-season due to high rainfall intensity in the region. The efficiency may be decreased in a drought year. In Table 47, efficiencies are estimated on the various factors listed above. Before the results of this report are used in an application, these estimates should be verified.

TABLE 47. FIELD APPLICATION EFFICIENCY OF THE HUEY SI THON PROJECT FOR WET-SEASON CROPPING

Factors of the project	unit of percentage
intake characteristics of soils	90
topography (mild slope)	70
climate (rainy season)	90
net depth of irrigation (high level of groundwater)	90
irrigation method (small check system)	70
adequacy of system design and installation	70
skill of the irrigator (no water charge)	50
average field application efficiency	75 (approx.)

2. Field application efficiency for dry-season cropping

Field application efficiency for dry-season cropping will be low, due to the dry soil needing much more water for evaporation and percolation losses. The estimating efficiencies for dry-season cropping are shown in Table 48. Total application efficiency for the dry-season in this project will be about 55%. This estimating efficiency will be used for purposes of the study; however, as before, these estimates should be verified before any operational plans are based on this report.

TABLE 48. FIELD APPLICATION EFFICIENCY OF THE HUEY SI THON PROJECT FOR DRY-SEASON CROPPING

Factors of the project	unit of percentage
intake characteristics of soils (loamy sand)	50
topography (mild slope)	70
climate (hot and dry)	50
net depth of irrigation (about 12")[32]	30
irrigation method (small checks)	70
adequacy of system design and installation	70
skill of the irrigator (no water charge)	50
average field application efficiency	55 (approx.)

Conveyance Losses

Conveyance losses are the second factor that affects reservoir diversion. The delivery systems of this project are concrete lined canals. Consequently, conveyance losses in these systems are assumed to be small; however, farm distribution systems are earth ditches which result in large losses of water. It is estimated that total conveyance losses are 10 percent of the total water requirement on the fields. This estimate should be verified before any operational plans are developed based on this report.

Operational Losses

Sometimes, the irrigation structures in the delivery systems and farm distribution systems might be leaking due to low levels of management. Also, farmers are offered irrigation water free of charge, thus removing any incentive to increase the level of management. These factors tend to cause high operational losses. For this study, suppose the operational losses are about 15 percent of the total water requirement at the diversion. On a carefully managed project, these losses can usually be held below 10 percent of the diversion.(31) Again, this value should be verified before results of the report are used.

Minimum Water Requirements for the Main Crop (Rice)

Rice is the main crop of the project for this study because it is desired by the people at the present time as previously mentioned. In growing rice, a certain amount of water is required for seedling nursery and land preparation. This amount of water, including the reservoir losses, should be the minimum reservoir storage at the beginning of the rice growing period, since a rainfall deficiency during the seedling nursery and land preparation period can occur. Past rainfall record shows that during this period in July, about 20-30 days, rainfall should occur, but to be on the safe side in estimating the minimum water storage in the reservoir, no occurrence of rainfall is assumed. Therefore, water for the seedling nursery and land preparation is supplied by the reservoir.

1. Water requirements for rice seedling nursery

No experimental work is reported on water used by rice seedling nurseries, but general estimates are given in a report issued by the Royal Irrigation Department.(33) Quoting from the report, "It is estimated that 150 mm. to 200 mm. of water is enough for nursery preparation and 250 mm. to 400 mm. for nursery irrigation making a total of 400 mm. to 600 mm. The irrigation period may extend to 30-40 days in most of the South-East Asian Countries. Generally, the seedlings from one hectare of nursery are sufficient to plant about 15 hectares."

In order to understand the water requirements for a rice seedling nursery, the following quote from E.C.I.[(8)] is given.

"The soil of a seedling nursery is not puddled, but it is maintained in a wet or near-wet condition by frequent irrigation. Downward movement of water below the shallow rooting zone is therefore appreciable, about on the order of 35 or 45% of the irrigation water applied for finer-textured soils and likely about 45 or 55% for coarser-textured soils. Water losses other than downward movement below the root zone are expected to be small, ----------

Evapotranspiration is high from the seedling crop because of seedling density and wet or near-wet soil at the surface; it is likely close to the potential evapotranspiration rate, ET_p, for the period ----

The water requirements for the rice seedling nursery crop are small relative to the total water requirements for the corresponding transplanted rice crop. Even so, the nursery water requirements are of essential importance and are a part of the water requirements for the rice crop."

Current practice has each farmer developing his own seedling nursery; consequently, the nurseries are scattered over the project area. If the nurseries are maintained this way, large conveyance losses will be required for a relatively small portion of the rice cultivation process. It would be much more efficient if one large nursery were developed near the reservoir site.

Estimated water requirements for seedling nursery are based on the above one-nursery concept.

- the period of seedling nursery to transplant = 1 month
- the area for seedling nursery is 10 percent of the total area = 120 hec.
- the water requirements for seedling nursery = 400 mm.
- the conveyance losses is 50 percent of the field water requirement = 200 mm.

$$\text{The total water demand} = 120 \times (100)^2 \times \frac{600}{1000}$$

$$= 720{,}000\ m^3$$

2. Water requirements for land preparation, paddy rice

The water requirements for land preparation will depend greatly on the initial moisture in the soils and/or the occurrence of rainfall and its intensity during this period. However, the water requirements in this study will be based on the assumption of no rainfall during this period. The water requirement for land preparation will be estimated for two situations; the extreme situation and the general situation.

2.1 The extreme situation

The water requirements for land preparation in the extreme situation will be determined using the same basis that E.C.I. has used to estimate the water requirements for land preparation of paddy rice for the Lam Pao Irrigation Project.(8) "The basis for estimating water needed for land preparation and establishment of the transplant rice crop can best be given by an extreme example.

The assumption for this example are:

1. The soil is fine-textured; it is air dry in the upper part, and vertical cracks penetrate to 20 or 30 cm. from the surface. All water supplied is by gravity surface flow.

2. The soil available moisture capacity (AM) averages 0.22 cm/cm; the degree of dryness to 40 cm. (0.4 m.) is such that 5/3 times AM would be required to bring the soil to field capacity to this depth (moist basis).

3. Because the soil is dry and cracked, it is expected that an irrigation amount sufficient to bring the soil to field capacity to an average depth of 40 cm. is necessary and unavoidable, even this depth of moistening is considerably more than needed for tillage. Even though irrigation for shallower depth could be accomplished, water from following irrigations would most likely distribute itself such that field moisture capacity is reached to an average depth of at least 40 cm.

4. The saturated hydraulic conductivity of the subsurface below 30 cm. is very slow (0.01 to 0.10 cm./hr.).

Field preparation and paddy establishment irrigation sequences are:

1. Irrigation of dry soil to moisten for plowing. The soil is too dry and hard for effective tillage otherwise. The plowing is done after time for moisture distribution and some drying near the surface (several days). It is assumed that 20 mm. of water is lost from the soil by evaporation during this time and up to the time of the second irrigation. Even though the soil is fine-textured, relatively high rates of water application per field unit are required for this first irrigation in order to get water across the dry, cracked soil without serious unevenness of irrigation resulting in excessive water use, since initial intake rates are very high. Field-unit rates are on the order of 10 or 12 LSR. (Liters per Second per Rai [0.16 hectare]).
2. Irrigation for puddling and transplanting. In addition to water for puddling, water is added equivalent to that for bringing standing water above the puddled surface to 5 cm. (50 mm.) depth. During the puddling and transplant time it is assumed that 50 mm. of water is lost by evaporation and percolation.
3. Irrigation after transplanting to replace water lost and to bring paddy water level to 5 cm. depth.

Calculations are:

1. 0.4 m. x 0.22 AM x 5/3 x 1000 = 147 mm.

   for first irrigation to bring to field capacity

   to depth of 40 cm.

2. a) Loss of water from first irrigation due to

      evaporation from soil = 20 mm.

   b) 0.2 m. x 2 x 0.22 AM x 1000 = 88 mm.

      to bring soil to puddled surface state.

   c) Additional water equivalent to standing water

      5 cm. above puddled surface = 50 mm.

   d) 20 + 88 + 50 = 158 mm. total for second

      irrigation for puddling and preparation for

      transplants.

3. a) Loss of water from second irrigation = 50 mm.

   b) Water to bring standing water to depth of 5 cm.

      in paddy = 50 mm. total for third irrigation

      to establish paddy.

4. 147 + 158 + 50 = 355 mm. total water required for

   land preparation and paddy establishment for extreme

   situation. This does not include chak (distribution

   system) water conveyance losses or other losses in

   field application."

The estimated amount of water for land preparation in the extreme case is:

$$\text{The field requirements} = \frac{355}{1000} \times 1200 \times (100)^2$$

$$= 4{,}260{,}000 \text{ m}^3$$

Conveyance losses 10 percent of field requirements

= 426,000 m^3

Total water requirements for land preparation

= 4,686,000 m^3

The required reservoir storage for the extreme case, excluding the reservoir losses, is the amount of water required for seedling nursery plus that required for land preparation. This amount is equal to 5,406,000 m^3, which is close to the useful reservoir capacity (5,580,750 m^3).

To determine the total required amount of water, reservoir losses must be added to the amount of water used for the seedling nursery, land preparation and the transplant period (the month of July). The volume of evaporation losses can be estimated by multiplying the monthly evaporation losses by two-thirds of the maximum area of the reservoir.(19) For all analyses in this study, the volume of the reservoir losses (evaporation and seepage losses) will be estimated by this same procedure. In July, estimated reservoir losses are equal to 404,000 m^3. So, in the extreme case, the total minimum required storage, including the reservoir losses, requires that the reservoir storage volumes at the end of June be 5,810,000 m^3, which exceeds the existing reservoir useful storage.

2.2 The general situation

According to past rainfall records, rainfall in 1951 was a problem due to a deficiency in the early stages of rice production (there was only 121 mm. of rainfall in May and no rainfall in June). This then will be the second case for estimating the water requirements for land preparation. The probability that rainfall in May is less than 120 mm. is only about 25%. When there is rain in May, it will be reasonable to reduce the degree or dryness to a depth of 20 cm. (0.20 m.) at the beginning of rice production (the first of July). The calculations are the same as in the previous extreme situation. After performing the calculations, the total water required for land preparation and paddy establishment in this general case is 237 mm. The reservoir storage water requirements, excluding the amounts for seedling nursery and reservoir losses, are 3,128,000 m^3. The total required reservoir storage, including amounts for seedling nursery and reservoir losses, will be 4,252,000 m^3.

3. Water requirements for cropping

After rice has been transplanted, water requirements of the initial, wet cropping period are evapotranspiration and percolation losses. It is assumed that evapotranspiration of the 120-day rice at the studied project is 637 mm. This estimate was taken from experimental data of the Huey Ban Yang Experimental station (see Table 43), because the Huey Ban Yang Experimental station and the studied project are in the Northeast region and the period of the experiment was during July to October, which is the same period of the cropping schedule of the project. The average daily evapotranspiration of the 120-day rice at the Huey Ban Yang Experimental station is 6.13 mm. during the transplanted to drainage period of 104 days.[28]

The percolation losses in the rice paddy are assumed to be 3 mm. per day which is equal to the seepage losses of the reservoir.

So, the total field water requirements for rice establishment (wet period cropping) will be 9.13 mm. daily. Figure 14 depicts the water requirement at the reservoir in m^3 per square meter of paddy field obtained from the following equation.

$$\frac{\text{Reservoir of volume}}{\text{square meter of paddy field}} = \frac{(E_T + P - R_F)}{0.75 \times .90 \times .85}$$

$$= 1.74\ (E_T + P - R_F)$$

where E_T = the total evapotranspiration of rice during the cropping period (637 mm.)

P = the total percolation losses in the rice paddy during the cropping period. For this study, $P = 3 \times 104 = 312$ mm.

R_F = the amount of rainfall during the cropping period

0.10 = the conveyance losses

0.15 = the operational losses

0.75 = the field application efficiency for the wet-season cropping

For this project the required reservoir volume per square meter of the paddy field will be expressed by the formula shown below.

$$\frac{\text{Reservoir volume}}{\text{square meter of paddy field}} = 1654.03 - 1.74\ R_F$$

Water Requirements for the dry-season crops

For estimating water requirements of the dry-season crops, it is assumed that no rainfall occurs during this period and the first cropping is cultivated in November following the rice crop while the soil moisture is available for plant use. The second cropping is

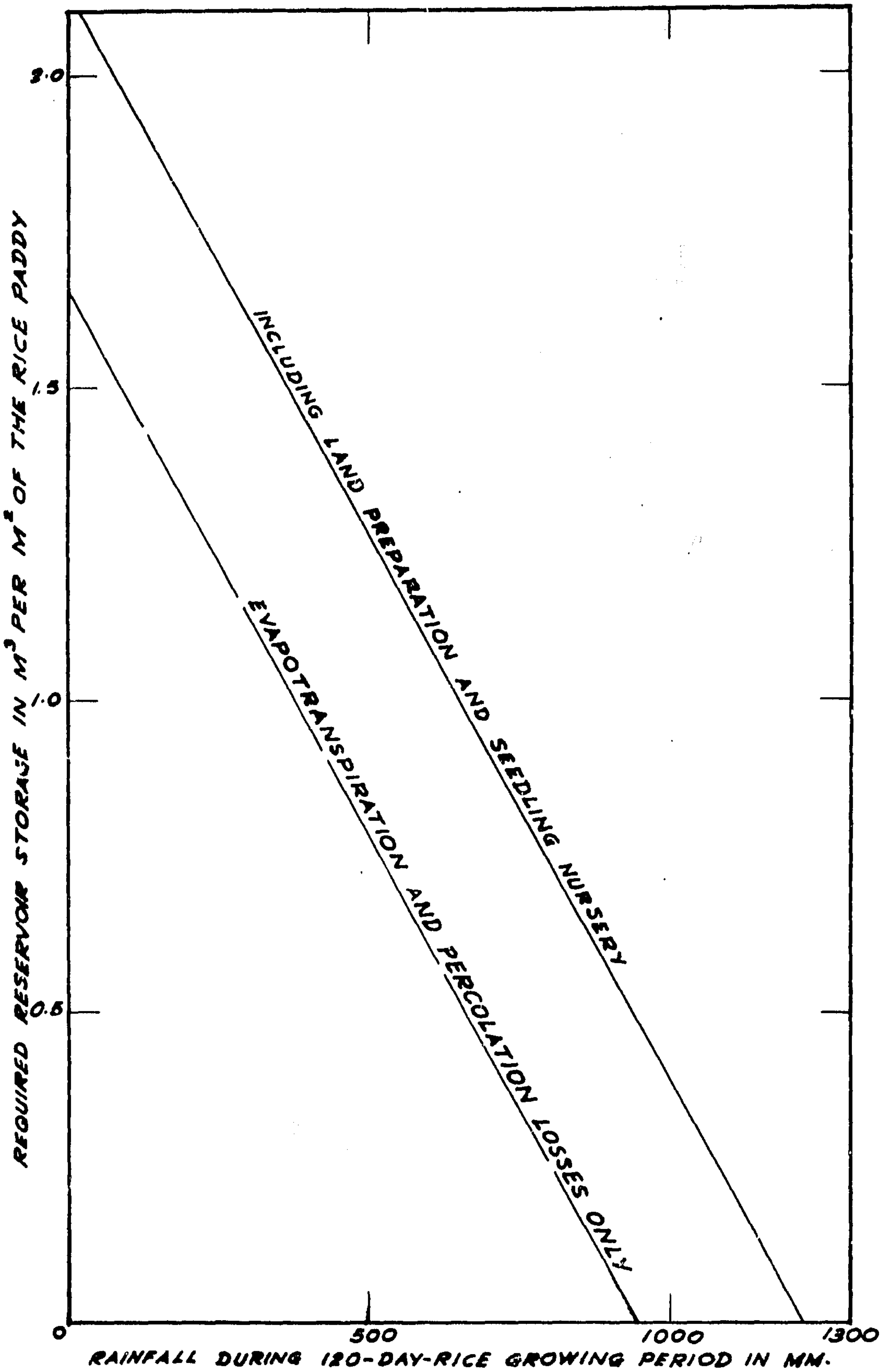


FIGURE 14: **RESERVOIR STORAGE FOR RICE CROPPING**

consecutive to the first cropping. The field water requirements of the dry-season crops will be the summation of their evapotranspiration and the amount of water for seedling. For this study, suppose that the amount of water for seedling of the dry-season crops is 100 mm. So, the total field water requirements of soy beans, mungbeans and sweet corn will be 728 mm., 341 mm. and 437 mm., respectively. Since, application efficiency for dry-season cropping is 55 percent, the water demand at the reservoir can be determined. Figure 15 depicts the water demand at the reservoir for the dry-season crops with different field water requirements and cropping area.

Since, rainfall may occur during dry-season cropping in some years, the irrigation water needed to supply the dry-season crops will be reduced proportionally to amount of effective rainfall. The amount of water which will be diverted from the reservoir, can be expressed by the following formula.

$$\frac{\text{Diversion volumes}}{\text{1 square meter of cropping area}} = \frac{(E_T + P - R_F)}{0.55 \times 0.90 \times 0.85}$$

where E_T = evapotranspiration of crops in mm.

P = percolation losses, for this study, P is assumed to be zero

R_F = effective rainfall during the cropping period in mm.

0.10 = conveyance losses

0.15 = operational losses

0.55 = field application efficiency for dry-season cropping

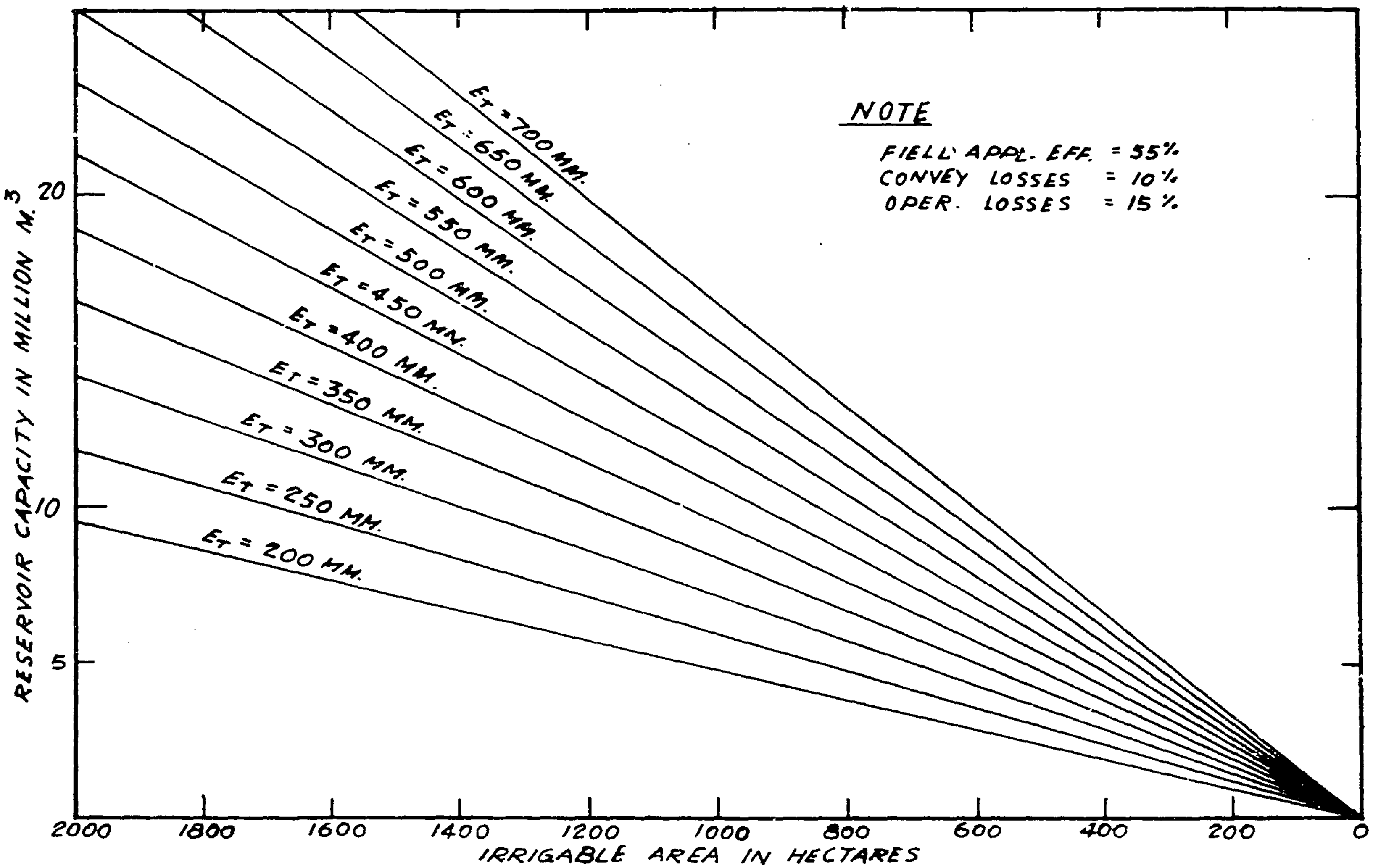
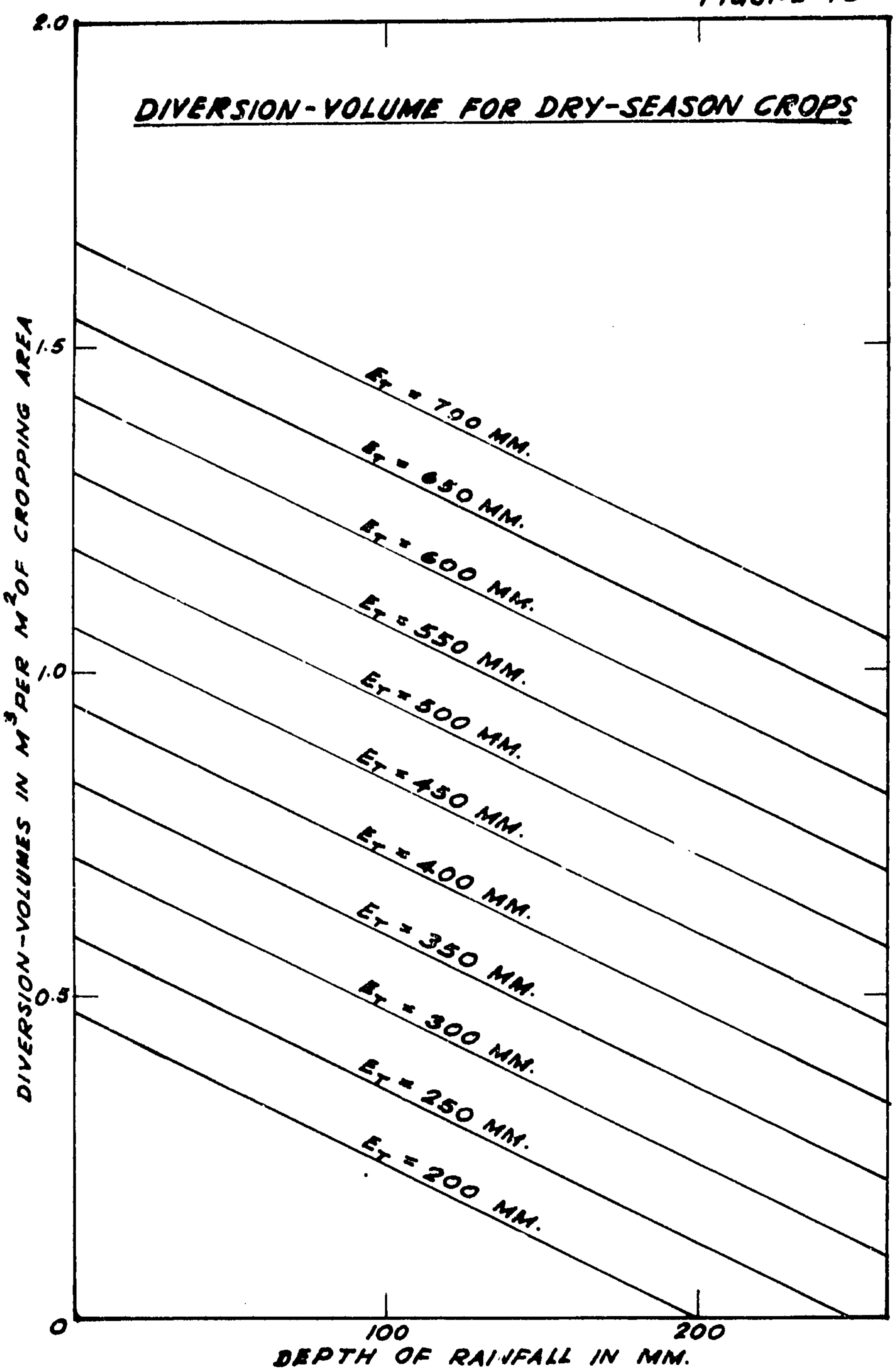


FIGURE 15: RESERVOIR STORAGE FOR DRY-SEASON CROPS

so that: $$\frac{\text{Diversion volumes}}{\text{1 square meter of cropping area}} = 2.38\ (E_T - R_F)$$

Figure 16 depicts the diagram of diversion volumes per square meter of the dry-season cropping area at different levels rainfall and evapotranspiration.

FIGURE 16


DIVERSION-VOLUME FOR DRY-SEASON CROPS
2.0
1.5
1.0
0.5
0
100
200
DEPTH OF RAINFALL IN MM.
DIVERSION-VOLUMES IN M³ PER M² OF CROPPING AREA
E_T = 700 MM.
E_T = 650 MM.
E_T = 600 MM.
E_T = 550 MM.
E_T = 500 MM.
E_T = 450 MM.
E_T = 400 MM.
E_T = 350 MM.
E_T = 300 MM.
E_T = 250 MM.
E_T = 200 MM.

Chapter V

THE RESERVOIR OPERATION AND ANALYSIS

The study of water demand in the previous chapter shows that the reservoir capacity is too small to irrigate the main crop (rice) for the whole service area of the project in the extreme case that was assumed. However, the past rainfall records at the project and Kalasin illustrate that the extreme case rarely occurs. For the average situation, which assumes at least 120 mm. of rainfall in May, the reservoir can operate the whole project area for rice. Suppose there is no rainfall during November to April and the reservoir is at full capacity at the end of October. The estimated amount of reservoir losses from November to June is 2,381,000 m^3, and the runoff from 120 mm. of rainfall in May is 1,500,000 m^3. Then, there will be 4,700,000 m^3 of water in the reservoir at the end of June if the reservoir is not used for dry season cropping. This exceeds the water demands for seedling nursery and land preparation. Since this type of the reservoir depends on rainfall, a more realistic procedure for its operation would be to take advantage of the rainfall, and, consequently, operate with less risk and more efficiency.

Rainfall Analysis

The rainfall record at Kalasin indicated only one year in 32 years of records in which there was no rainfall from May to July (1950). There was no rainfall in June only 2 years (1950 and 1951). Minimum rainfall of the other years was 81 mm., 51 mm., and 47 mm. in May, June and July, respectively. The minimum rainfall during May to July was 269 mm. and 121 mm. during May to June, while the average rainfall is 221 mm. in May, 189 mm. in June and 193 mm. in July. The rainfall data at Huey Si Thon shows that the minimum rainfall was 77 mm., 65 mm. and 100 mm. in May, June and July, respectively, and there is no record of rainfall not occurring during these months.

When the data is analyzed for the periods of May to June and May to July, it indicates that the probability of rainfall at Kalasin during the period of May to June being less than or equal to 200 mm. is only about 5% and about 1% for the Huey Si Thon project (Figure 17). The probability of Kalasin and Huey Si Thon having zero rainfall during May to July is less than 1% (Figure 18). So, it is not economical to build the reservoir to store water for land preparation and seedling nursery in the extreme case.

During the rice cropping period, July to October, the reliable rainfall should be considered during the period July to September because rice needs more water for evapotranspiration at this period. Also, evapotranspiration will be decreasing to zero as the rice ripens. Figures 19, 20 and 21 depict the histograms of rainfall distribution during July to September at Kalasin and the Huey Si Thon project.

Another important characteristic of rainfall that has to be considered in water management for this reservoir is the short drought periods during the rainy season. A drought period is defined as a time during which no effective rainfall occurs. If a short drought occurs during the rice growing period, reservoir storage is involved. Reservoir storage should have sufficient water to supplement the rainfall for a reasonable period of drought. The Hydrology Section[3] commented about the series of short droughts in the Northeast of Thailand, "rainfall is not a

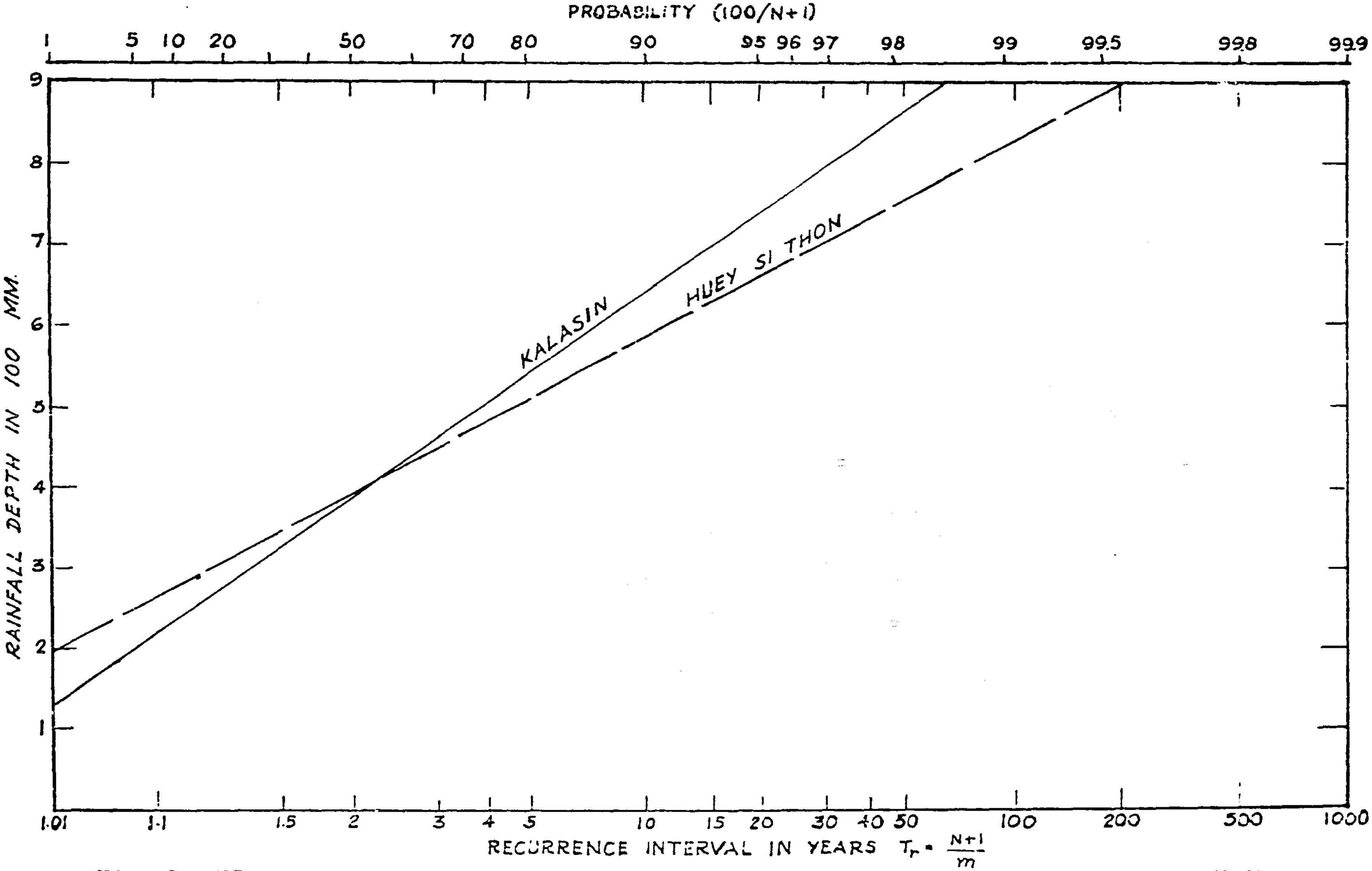


FIGURE 17: PROBABILITY OF RAINFALL DURING PERIOD MAY TO JUNE

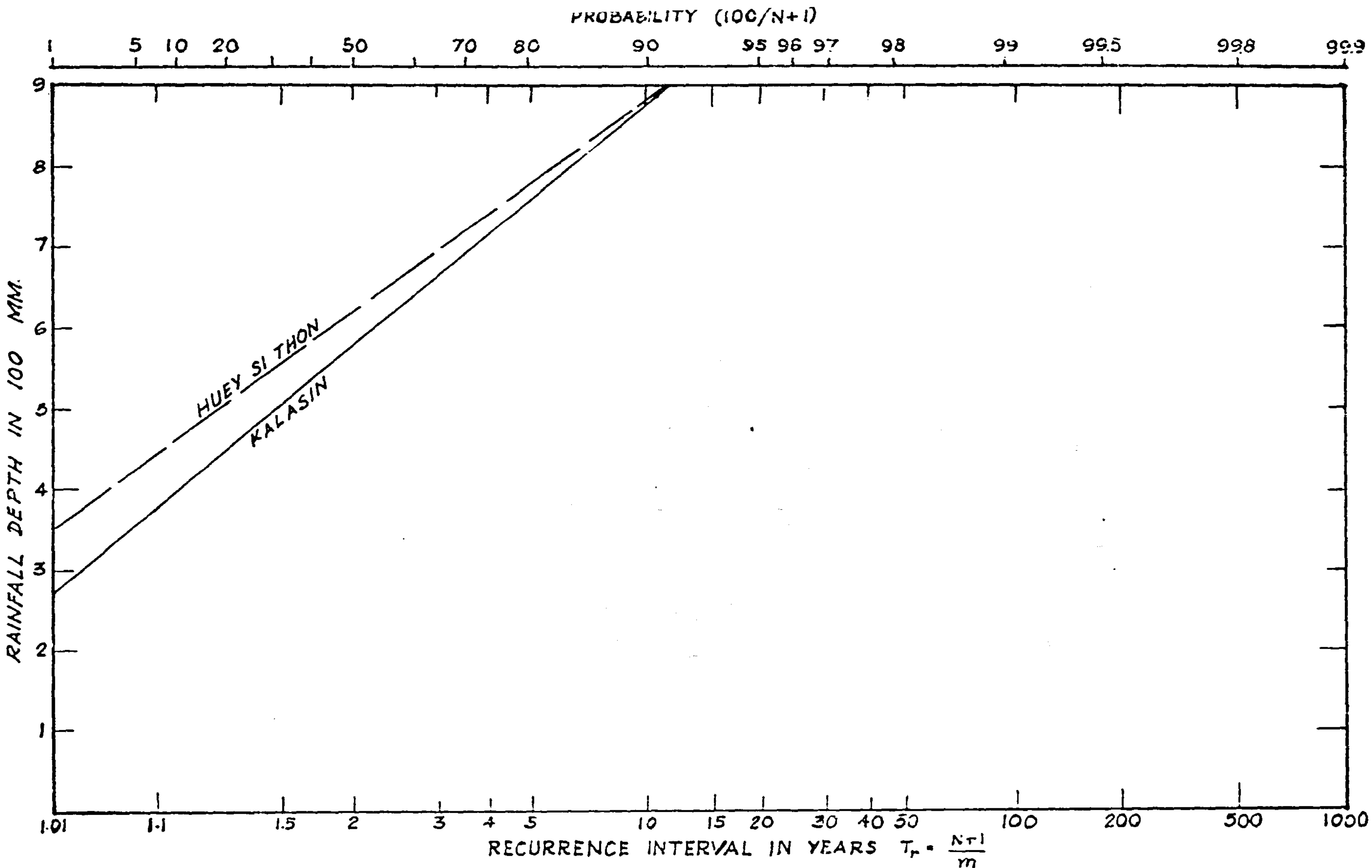


FIGURE 18: PROBABILITY OF RAINFALL DURING PERIOD MAY TO JULY

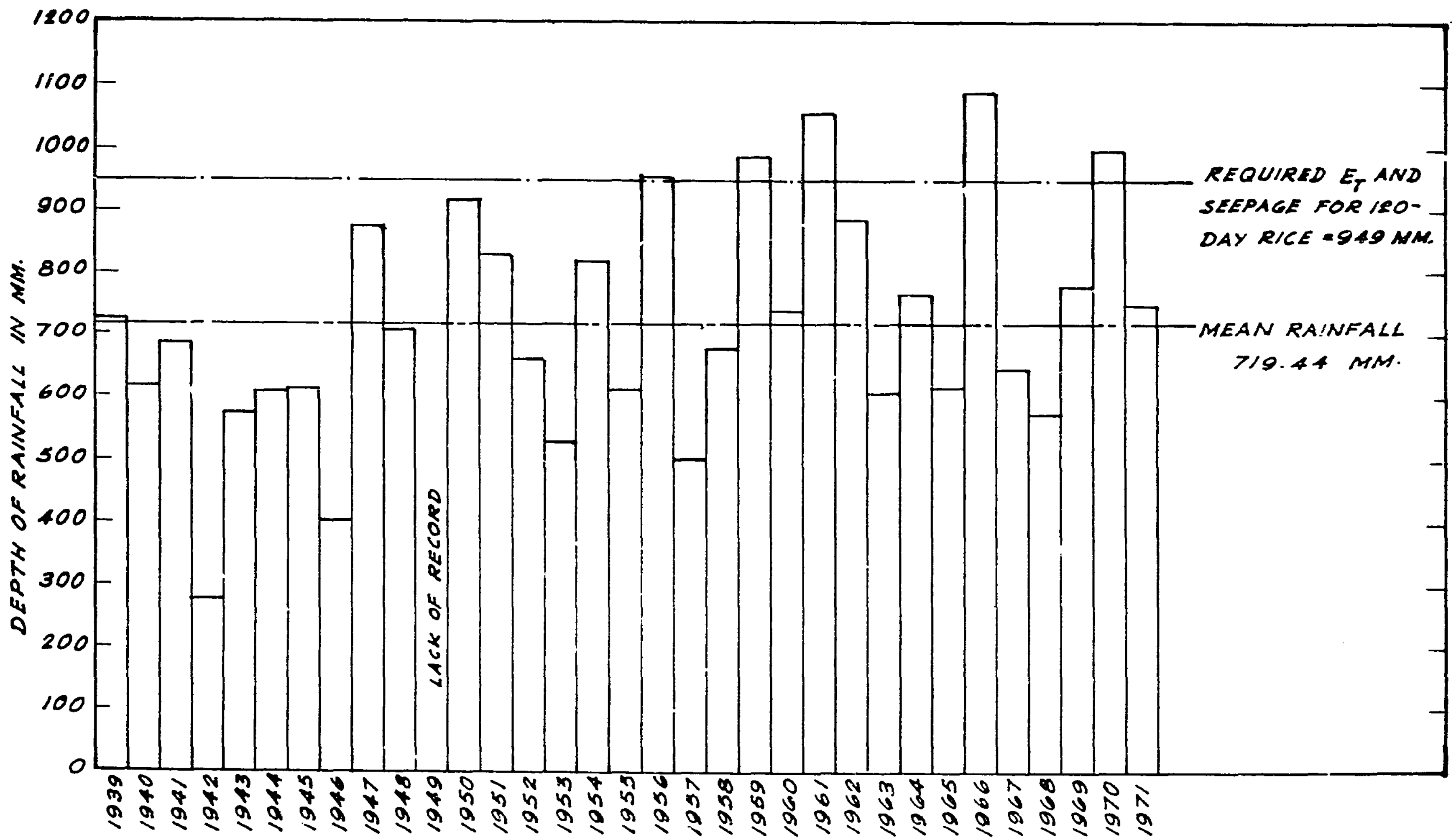


FIGURE 19 : RAINFALL DURING JULY TO SEPTEMBER AT KALASIN

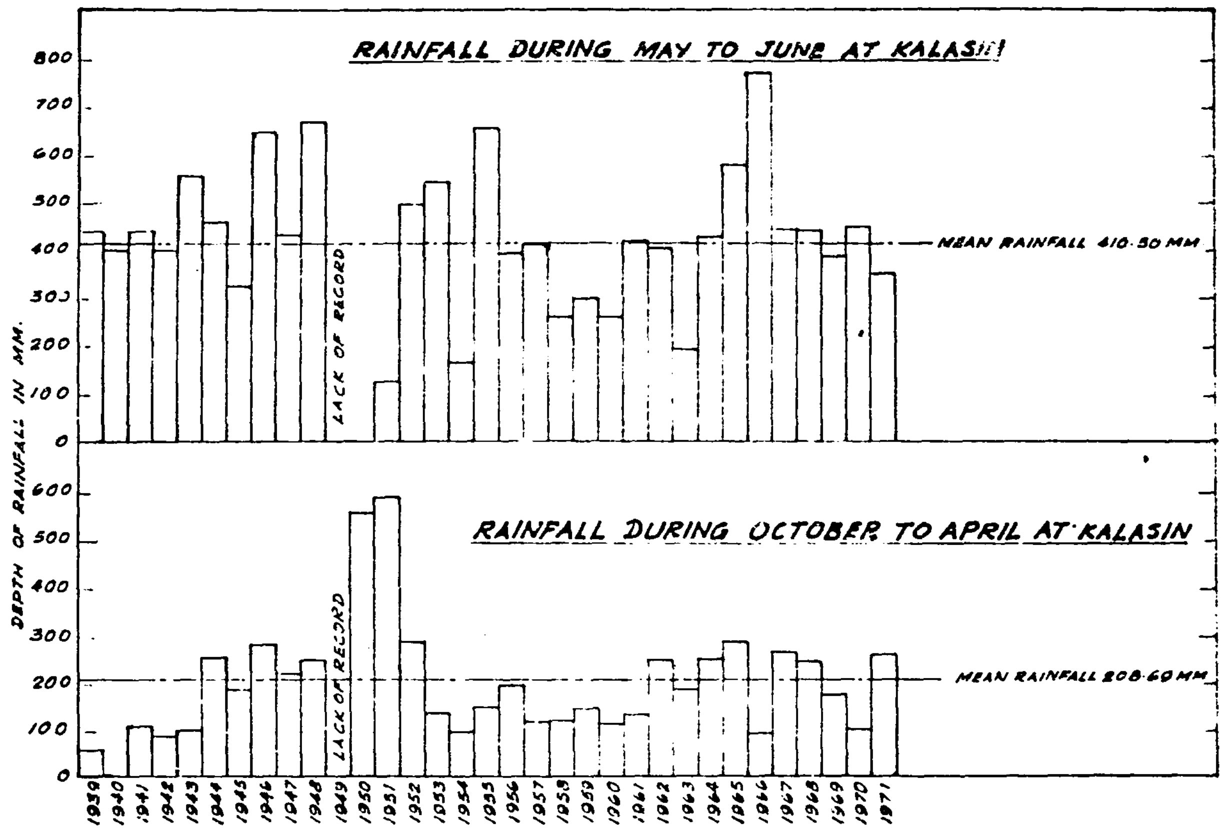

RAINFALL DURING MAY TO JUNE AT KALASIN
RAINFALL DURING OCTOBER TO APRIL AT KALASIN
DEPTH OF RAINFALL IN MM.
MEAN RAINFALL 410.50 MM
MEAN RAINFALL 208.60 MM
LACK OF RECORD
LACK OF RECORD
0
100
200
300
400
500
600
700
800
1939
1940
1941
1942
1943
1944
1945
1946
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FIGURE 20

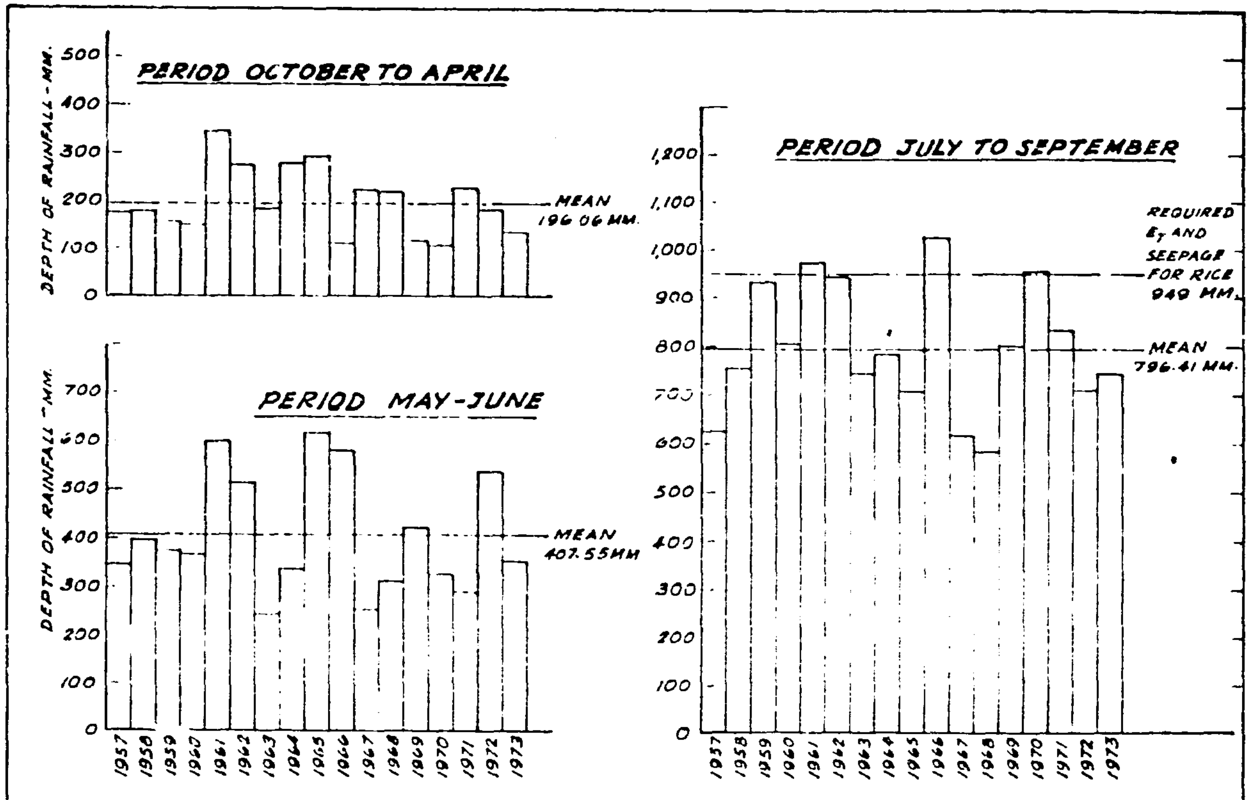

FIGURE 21 PEPIODICAL RAINFALL AT HUEY SI THON

fully dependable source of water supply during the beginning and the ending of the rainy season. The period of short drought might be as much as 3 to 5 weeks occurring with moderate frequency. This of course affects the growth and yields of crops adversely, since the period without rainfall in excess of 2 weeks are stated to be damaging. The measures of utilizing the available water resources have, therefore, to be planned." Figures 22 and 23 show the maximum annual drought periods which have occurred during the rainy season at Kalasin and Huey Si Thon, respectively.

Runoff Analysis

Rainfall-runoff is the source of water supply for this type of reservoir. If the rainfall-runoff amounts available to the reservoir are determined monthly and periodically, water management of the reservoir is rather straightforward. Tables 49 and 50 are the estimated monthly and periodical runoff volumes calculated from the monthly rainfall of May and June at Kalasin and Huey Si Thon (Figure 5). They show that this reservoir needs rainfall during May and June totaling about 300 mm. in order to obtain enough runoff to replenish it to capacity. Only five years in 32 years of the rainfall records at Kalasin has the runoff been less than 4 million m^3. This corresponds to two years in 18 at Huey Si Thon. For these two months, the records at Huey Si Thon indicate that the reservoir will obtain a runoff of more than 3 million m^3 every year. The probabilities of rainfall during the period May to June being less than or equal to 300 mm. at Kalasin and Huey Si Thon (Figure 17) are 25% and 19%, respectively.

Water Balance Study

A water balance study is another way to facilitate water management of the reservoir, and to analyze suitable capacities of the

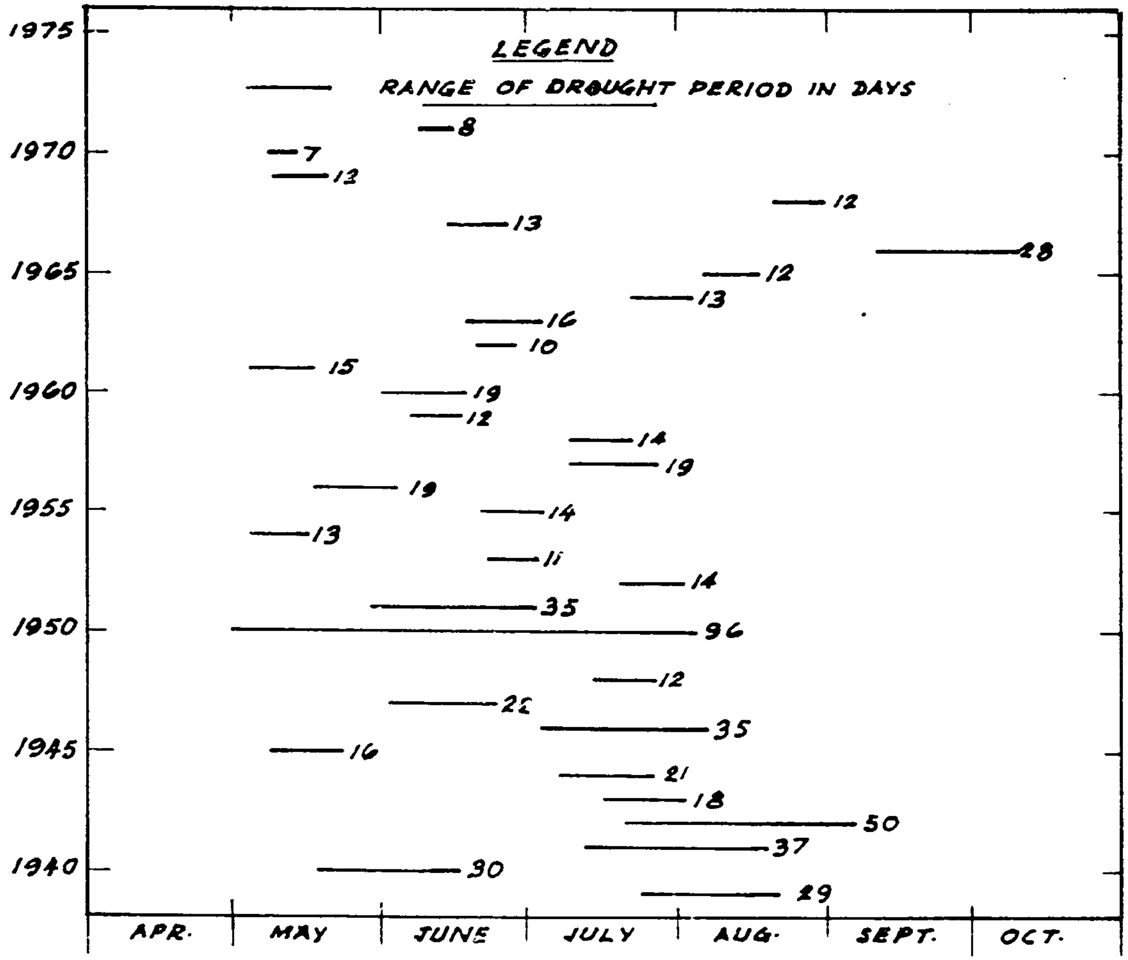

FIGURE 22: MAX. DROUGHT PERIOD DURING RAINY SEASON (MAY TO SEPT.) AT KALASIN

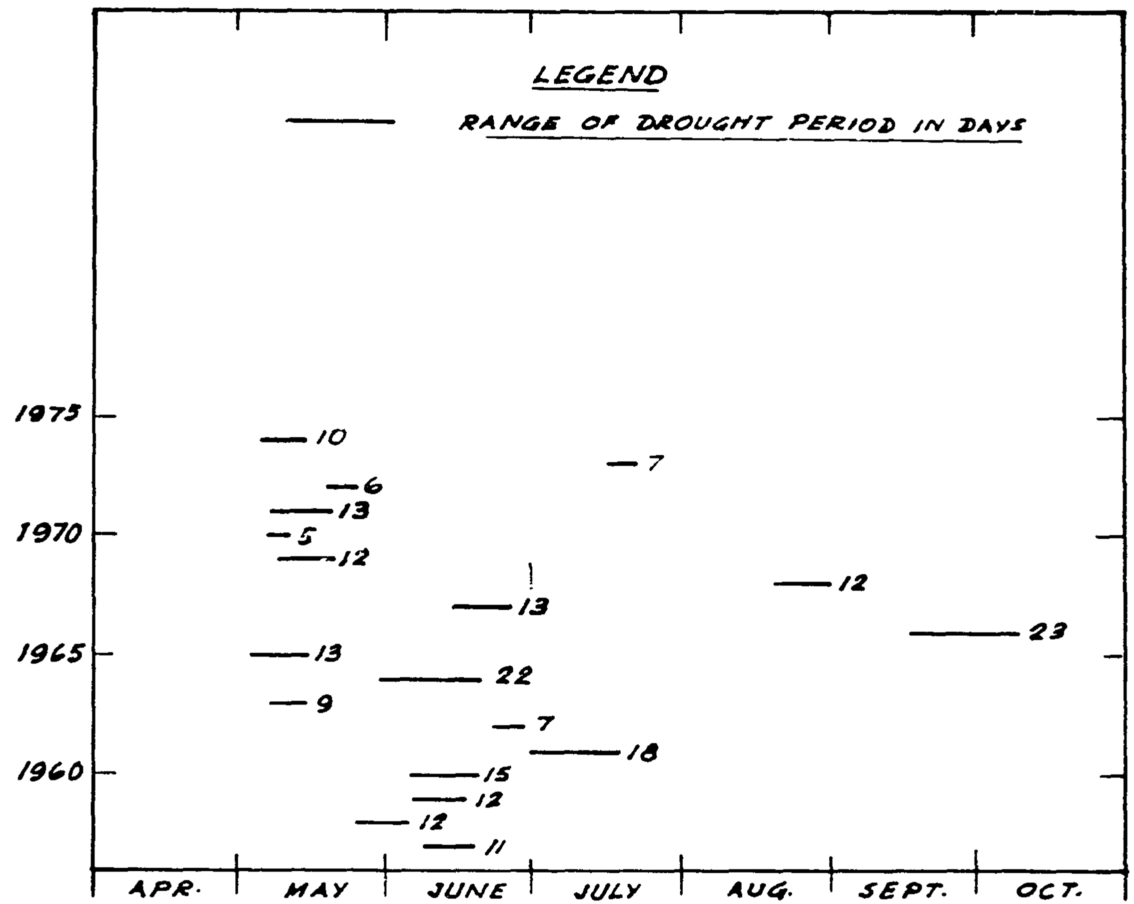

FIGURE 23: MAX. DROUGHT PERIOD DURING RAINY SEASON (MAY-SEPT) AT HUEY SI THON DAM SITE

TABLE 49. ESTIMATED MONTHLY AND PERIODICAL RUNOFF COMPUTED FROM THE MONTHLY RAINFALL OF MAY AND JUNE AT KALASIN (FROM FIGURE 5)

Year	May			June			Total May-June	
	Rain-fall (mm.)	Runoff Coeff. (%)	Runoff Vol. (1000 m^3)	Rain-fall (mm.)	Runoff Coeff. (%)	Runoff Vol. (1000 m^3)	Rain-fall (mm.)	Runoff Vol. (1000 m^3)
1939	411	50.35	16,865	26	0	0	437	16,865
1940	302	38.00	9,353	94	11.40	873	396	10,226
1941	325	40.85	10,820	112	14.25	1,301	437	12,121
1942	185	21.85	3,294	213	26.60	4,618	398	7,912
1943	289	36.10	8,503	265	34.20	7,386	554	15,889
1944	162	19.95	2,634	293	37.05	8,847	455	11,481
1945	119	15.20	1,474	202	25.65	4,223	321	5,697
1946	519	66.50	28,129	125	16.15	1,645	644	29,774
1947	306	38.00	9,477	123	16.15	1,619	429	11,096
1948	266	34.20	7,414	400	50.35	16,414	666	23,828
1949	Lack of data							
1950	0	0	0	0	0	0	0	0
1951	121	15.20	1,499	0	0	0	121	1,499
1952	169	20.90	2,879	324	40.85	10,787	493	13,666
1953	160	19.95	2,601	380	47.50	14,711	540	17,312
1954	111	14.25	1,289	51	7.60	316	162	1,605
1955	225	28.50	5,226	426	62.70	21,769	651	26,995
1956	220	27.55	4,940	169	20.90	2,879	389	7,818
1957	225	28.50	5,226	181	21.85	3,223	406	8,449
1958	81	10.45	690	175	20.90	2,981	256	3,671
1959	134	17.10	1,867	159	19.95	2,585	293	4,453
1960	184	21.85	3,277	73	9.50	565	256	3,842
1961	163	19.95	2,650	251	31.35	6,413	414	9,063
1962	181	21.85	3,223	219	27.55	4,917	400	8,140
1963	112	14.25	1,301	78	10.45	664	190	1,965
1964	285	36.10	8,385	137	17.10	1,909	422	10,294
1965	303	38.00	9,384	275	35.15	7,878	578	17,262
1966	502	63.65	26,041	268	34.20	7,470	770	33,511
1967	341	42.75	11,881	103	12.35	1,037	440	12,918
1968	228	29.45	5,472	209	26.60	4,531	437	10,003
1969	102	12.35	1,027	280	36.10	8,238	382	9,265
1970	224	28.50	5,203	223	28.50	5,180	447	10,383
1971	126	16.15	1,658	222	28.50	5,157	348	6,815

TABLE 50. ESTIMATED MONTHLY AND PERIODICAL RUNOFF COMPUTED FROM THE MONTHLY RAINFALL OF MAY AND JUNE AT HUEY SI THON (FROM FIGURE 5)

Year	May			June			Total May-June	
	Rain-fall (mm.)	Runoff Coeff. (%)	Runoff Vol. (1000 m^3)	Rain-fall (mm.)	Runoff Coeff. (%)	Runoff Vol. (1000 m^3)	Rain-fall (mm.)	Runoff Vol. (1000 m^3)
1957	208.6	26.60	4,522	135.8	17.10	1,893	344.4	6,415
1958	206.1	26.60	4,468	191.5	24.70	3,855	397.6	8,323
1959	194.8	24.70	3,921	178.5	21.85	3,179	373.3	7,100
1960	226.5	28.50	5,261	140.8	17.10	1,962	367.5	7,223
1961	317.6	39.90	10,328	282.6	36.10	8,314	600.2	18,642
1962	251.3	31.35	6,421	263.2	34.20	7,336	514.5	13,757
1963	77.5	10.45	660	166.8	20.90	2,841	244.3	3,501
1964	272.6	35.15	7,809	65.4	8.55	456	338.0	8,265
1965	362.9	45.60	13,487	255.5	31.35	6,528	618.4	20,015
1966	410.4	50.35	16,841	169.8	20.90	2,892	580.2	19,733
1967	152.7	19.00	2,364	102.4	12.35	1,031	255.1	3,395
1968	103.9	12.35	1,046	208.1	26.60	4,511	312.0	5,557
1969	156.6	19.00	2,425	264.6	34.20	7,375	421.2	9,800
1970	155.2	19.00	2,403	172.8	20.90	2,943	328.0	5,346
1971	164.4	19.95	2,673	176.2	20.90	3,001	340.6	5,674
1972	64.7	8.55	451	473.8	59.85	23,111	538.5	23,562
1973	176.5	21.85	3,143	178.0	21.85	3,170	354.5	6,313

reservoir for given irrigable areas. For this study, some water short years will be selected to estimate the amount of rainfall needed during the wet-season cropping and how much will be left for the dry-season cropping. The annual rainfall of 1942 and 1963 at Kalasin are selected for the study for the following reasons: first, the annual rainfalls were less than 1000 mm.; second, their rainfall distributions are contrasting. For 1942, rainfall distribution was concentrated during April to July, while the rainfall of 1963 was concentrated during the growing period. This affects the ability of the reservoir to hold the runoff during the pre-growing season.

According to past rainfall statistics at Kalasin and Huey Si Thon, reservoir inflow is usually obtained from the rainfall runoff during the period April to October. This is the southwest monsoon season. The amount of the reservoir inflow is reduced by reservoir losses before diverting to the fields. So, the water balance formula can be set up as following.

Reservoir Inflow = Required outflow

$$\sum_{Apr}^{Oct} (R_{OF} - L_R) = (E_T + L_P + W_{LP} - R_F) \times A \times \frac{1}{0.75 \times 0.90 \times 0.85}$$

where R_{OF} = monthly runoff in m^3

L_R = monthly reservoir losses in m^3

E_T = evapotranspiration of rice in mm.

L_P = percolation losses in the fields during cropping period in mm.

W_{LP} = the amount of water for land preparation and seedling nursery in mm.

R_F = amount of rainfall during the cropping period (July to September)

A = irrigable area in hectare

0.10 = conveyance losses

0.15 = operation losses

0.75 = field application efficiency

For this study:

E_T = 637 mm. = 0.637 m.

L_P = 312 mm. = 0.312 m.

W_{LP} = 237 + 40 = 277 mm. = 0.277 m. for general case

A = $1200 \times (100)^2 = 1200 \times 10^4$ m^3

Therefore

$$\sum_{Apr}^{Oct} (R_{OF} - L_R) = 20915\ (1226 - R_F)$$

Tables 51 and 52 show the water balance for rainfall for 1942 and 1963 assuming rice is growing during the wet season and that the reservoir is at dead storage on the first of April.

TABLE 51. WATER BALANCE FOR WET-SEASON CROPPING AND RAINFALL IN 1942

ASSUMPTION: THE RESERVOIR IS AT DEAD STORAGE ON APRIL 1.

Months	Rain-fall (mm.)	Reservoir inflow - 1000 m^3				Required outflow 1000 m^3
		Begin-ning Volume	Runoff Volume	Reservoir Losses	Vol. at the end of the month	
Apr	85	0	724	423	301	
May	185	301	3,294	444	3,151	20915 x
June	213	3,151	4,618	384	7,385	(1226 - 277)
July	52	7,385	297	404	7,278	= 19,848
Aug	-	7,278	0	383	6,895	
Sept	225	6,895	5,776	376	12,295	
Oct	-	12,295	0	393	11,902	
Total	760	-	14,709	2,807	11,902	19,848

TABLE 52. WATER BALANCE FOR WET-SEASON CROPPING AND RAINFALL IN 1963

ASSUMPTION: THE RESERVOIR IS AT DEAD STORAGE ON APRIL 1.

Months	Rain-fall (mm.)	Reservoir inflow - 1000 m^3				Required outflow 1000 m^3
		Begin-ning Volume	Runoff Volume	Reservoir Losses	Vol. at the end of the month	
Apr	27	0	0	290*	-290*	
May	112	-290	1,301	444	567	20915 x
June	78	567	664	384	847	(1226 - 605)
July	306	847	9,976	404	10,419	= 12,988
Aug	148	10,419	2,412	383	12,448	
Sept	151	12,448	2,584	376	14,656	
Oct	86	14,656	810	393	15,073	
Total	908	-	17,747	2,674	15,073	12,988

* - the dead storage volume

In 1942, the reservoir inflow was not enough to irrigate the entire irrigable area of the project. The total volume of inflow would only irrigate 744 hectares of paddy rice. Although the total reservoir inflow at the end of June is 7.385 million m^3, it still cannot irrigate 1200 hectares of paddy rice because the drought period occurs during July and August.

For 1963, the reservoir inflow at the end of June is less than 1 million m^3 which is not enough for seedling nursery and land preparation. In this case, the cropping schedule should be delayed until the land is moistened by rainfall. At the end of the wet-season cropping period, 2.085 million m^3 will be left in the reservoir to irrigate the dry-season crops. Figure 15 can be used to select the crops and estimate the land available for dry-season cropping.

Reservoir Operating Schedule and Guides

Rutter and Engstrom[19] state that, "Schedule and guides for reservoir operation should be developed in preliminary form in the operation planning stage and used to determine in advance the most effective use of reservoir storage. Later refinements are usually necessary, based on further study and on actual operating experience. Schedules may vary from rigid or fixed rules to be followed during floods by nontechnical operators at dams to general seasonal guides and long-range plans for the storage and release of water for conservation purposes. They may be in the form of graphs, tabulations or narrative or a combination of the three."

Rainfall has a great influence on this type of reservoir. The previous sections have indicated its occurrence and characteristics that affect the water management of the reservoir. The following guides and operating schedule for this reservoir can be set up to minimize the risk in operation and maximize reservoir utilization.

1. Reservoir operation for wet-season cropping

Operation for wet-season cropping using 120-day rice should start on the first of July since the reservoir will be filled with needed runoff due to rainfall during May and June. This will ensure enough water for supplementation during any rainfall shortage in July or August. This also reduces the amount of water required for land preparation and seedling nursery because the soil is saturated with the rains of May and June. In the extreme situation, no rainfall occurs from May to July, such as in 1950, or the amount of rainfall during May and June is not sufficient to moisten the soil (or fill the reservoir) in 1963. In these two cases, the reservoir cannot be operated on the planned irrigation schedule. In such situations, it would be reasonable to wait until sufficient rain has fallen for effective tillage before beginning land preparation for a wet-season rice crop. At the end of dry-season cropping or in early March, the reservoir should be shut down in order to collect the runoff which will be used for the wet-season cropping, since the southwest monsoon is beginning.

During the wet period of the rice crop, reservoir storage should be maintained at full level. This will help prevent a series of drought periods that might occur during the growing season from reducing yields. The capacity of this reservoir can supplement water which may be missing due to a drought for about one month (30 days). Past records show that a drought longer than this is possible during the cropping season; however, it does not occur often. The excess runoff should be diverted continuously to the rice paddy.

The above reservoir operation strategy will reduce the risk of a crop failure for farmers in growing rice, their main crop during the rainy season. The extreme situation occurs in some years and the cropping schedule must be shifted. If it goes beyond the middle of August there may be a reduction in the yield of rice. However, the probability that the cropping schedule must be moved to August, as it was in 1950, is less than 1 percent. It is better to get a reduced yield than to get nothing during this highly irregular situation.

2. Reservoir operation for dry-season cropping

Usually, the dry-season cropping should begin in November following the rice crop while moisture still remains in the soil. This causes a reduction in the water required for seedling. At the end of the wet-season cropping, the reservoir will often be full, because it collects the rainfall of September. Past rainfall records show that it did not only rain in September of every year but its intensity was also the highest. The probability of no rainfall in this month is less than 2 percent for Kalasin and less than 1 percent for Huey Si Thon (Figures 8 and 9). So, this reservoir can service the dry-season cropping.

All the reservoir storage following the wet-season crop should be used for dry-season cropping, otherwise it will be lost by evaporation and seepage, etc. Reservoir losses are significant when compared with the reservoir capacity. However, the actual estimated amount of water for dry-season cropping should be reduced by the expected reservoir losses during the cropping period. Then, Figure 15 can be used to estimate the land that the reservoir can service. If the reservoir is full and the crop is mungbeans (with its potential evapotranspiration, including seedling, of 341 mm., a duration to maturity of 79 days, and the cropping beginning in November) the reservoir will have enough water to irrigated approximately 650 hectares of mungbeans.

Current Reservoir Operation

At the present time, a formal operating schedule for this reservoir for wet-season cropping has not been established. The water demand of rice is influenced by possible occurrences of rainfall during the rainy season. Past records of the reservoir water level show that during the rainy season, reservoir water is diverted continuously. For dry-season cropping, reservoir operation is concentrated on the demonstration farms with an area of about 300 hectares, 130 farms[34] or 25 percent of the project area. There are many kinds of dry-season crops grown during November to May, such as peanuts, sweet-potatoes, sweet-corn, cow-peas and cucumber. The irrigation schedule is set up weekly to rotate over the 7 zones of the demonstration farm.[35] The record amount of water diverted from the reservoir during the dry season occurred from November 1972 to May 1973 and totaled 1,652,205 m^3.

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(35) Data are supported by Mr. Nukul Tongthawee, Chief Engineer, Region 5, The Royal Irrigation Department.

Table 53 shows the record of water discharged from the reservoir and measured with a Parshall flume in the main canal during November 1972 to July 1973. The amount of water discharged during November to May was used to irrigate the dry-season crops and from June to July, it was diverted to irrigate rice.

TABLE 53.[36] THE RECORD OF WATER DISCHARGED FROM THE RESERVOIR

Months	Year	The amount of diversion as measured in the main canal m^3	Estimated from the curve* m^3	Rainfall (mm.)
November	1972	113,958	380,000	31
December	1972	97,074	400,000	58
January	1973	259,545	620,000	-
February	1973	282,213	600,000	-
March	1973	312,597	450,000	-
April	1973	189,918	420,000	76.2
May	1973	396,900	400,000	176.5
June	1973	410,634	460,000	178
July	1973	384,120	**1,320,000	243.1

* - reservoir storage volume curve (Fig. 3)

** - the reservoir was increased by the rainfall

(36) Data are supported by Mr. Nukul Tongthawee, Chief Engineer, Region 5, The Royal Irrigation Department.

Comparison of Existing Reservoir Operation with the New Operation

Figure 24 shows the diagram of the reservoir elevation between the existing operation and the new operation from November 1972 to October 1974. It is assumed that the rainfall record at Huey Si Thon represents the rainfall over the catchment area and the volume of runoff, reservoir losses are estimated monthly. Reservoir operation under the new operation schedule is at dead storage on the first of May and the remaining water after wet-season cropping is used for dry-season cropping. The estimated reservoir elevations are shown in Tables 54 and 55.

TABLE 54. ESTIMATED RESERVOIR ELEVATION FOR THE YEAR 1973

Months	Rain-fall mm.	Runoff Vol. 1000 m^3	Reservoir Losses 1000 m^3	Irriga-tion 1000 m^3	Reservoir Inflow 1000 m^3	Total Storage 1000 m^3	Reservoir Elevation (m)
May	176.5	3,143	444	-	2,699	2,699	+152.5
June	178.0	3,170	384	-	2,786	5,485	+153.8
July	243.1	5,944	404	3,848	1,692	5,581	+154.0
Aug	286.8	8,857	384	-	8,473	5,581	+154.0
Sept	216.3	5,354	376	1,163	3,815	5,581	+154.0
Oct	5.7	-	393	-	-393	5,188	+153.7

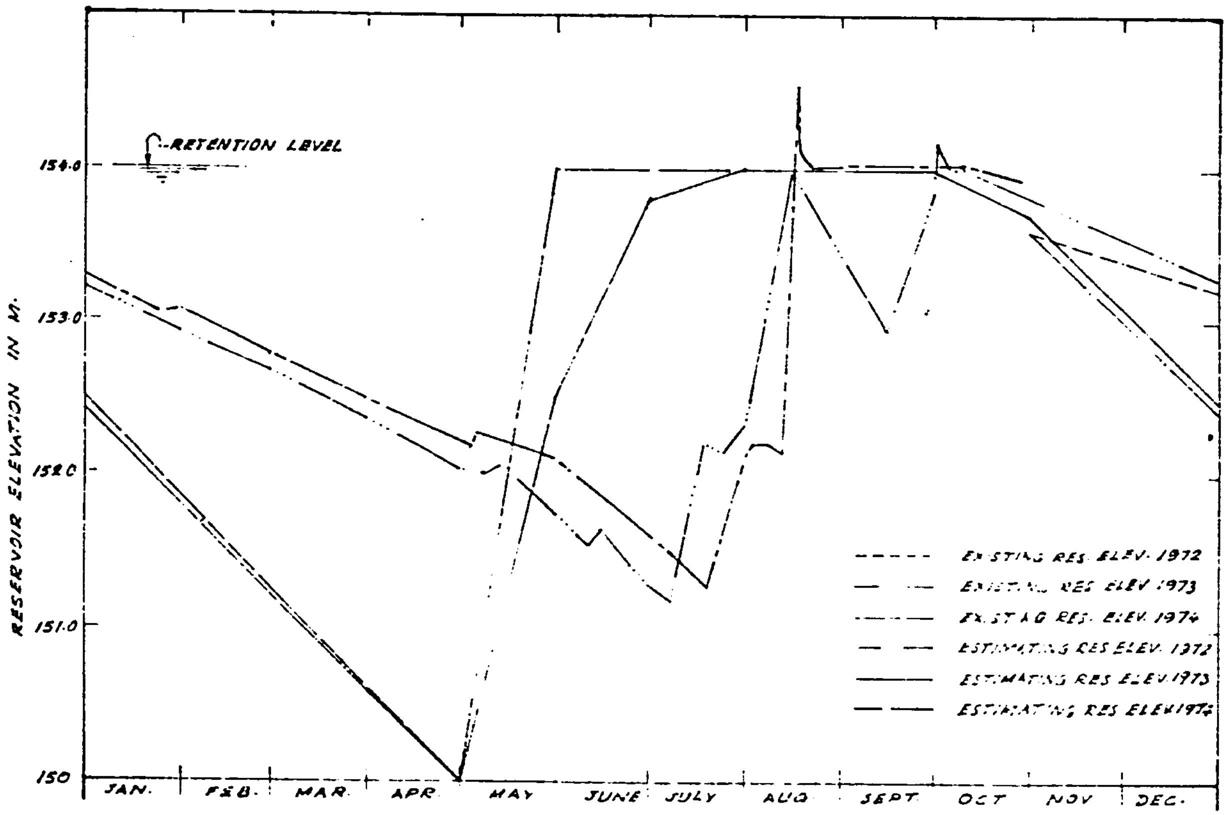


FIGURE 24: **COMPARISON OF RESERVOIR OPERATION**

TABLE 55. ESTIMATED RESERVOIR ELEVATION FOR THE YEAR 1974

Months	Rain-fall mm.	Runoff Vol. 1000 m^3	Reservoir Losses 1000 m^3	Irriga-tion 1000 m^3	Reservoir Inflow 1000 m^3	Total Storage 1000 m^3	Reservoir Elevation (m)
May	274.1	7,850	444	-	7,406	5,581	+154.0
June	125.6	1,650	384	-	1,266	5,581	+154.0
July	207.9	4,732	404	3,848	480	5,581	+154.0
Aug	518.4	28,707	384	-	28,323	5,581	+154.0
Sept	201.2	4,637	376	1,468	2,793	5,581	+154.0
Oct	113.7	1,483	393	-	1,090	5,581	+154.0

A Proposal to Develop Additional Water for the Reservoir

Rainfall is the source of water supply for this type of reservoir. The function of the reservoir is to store runoff from the watershed and regulate that runoff to irrigate the rice paddy and dry-season crops. For wet-season cropping, while there is rainfall, the reservoir water requirements of the crop will be decreased, but the reservoir inflow will be increased. When the reservoir is maintained at capacity, the excess runoff cannot be stored. If this excess runoff could be diverted from the reservoir and stored in the rice paddy, it could be considered a part of the irrigation water. As a result, this would reduce the reservoir capacity or increase the irrigable area for the wet-season cropping. However, the effective amount of runoff that can be diverted for storage in the rice paddies has limits. The amount depends on the distribution of rainfall, the depth of rainfall at each occurrence, the infiltration rate of soil and the growth period of crop. If runoff storage in the paddies exceeds the capacity of the paddy basin, flooding will result with the possibility of a crop disaster, if the diversion is followed by a heavy rainfall. If runoff storage in the paddies is small, maximum benefit from the water is not realized. The optimum diversion is difficult to determine without further research. For purposes of this study, it is assumed that the total amount of runoff which can be diverted and stored in rice paddies during the growing period will be 400 mm., because the dike of the rice paddy is generally about 400-500 mm. high. The water balance formula for this case is established as follows:

$$E_T + L_P + W_{LP} = R_F + R_{OF} + I$$

where E_T = evapotranspiration of crop in mm.

L_P = field percolation losses during the growing period in mm.

W_{LP} = field water requirement for land preparation and seedling nursery in mm.

R_F = total rainfall depth at fields during the cropping period in mm.

R_{OF} = total effective runoff from the watershed is diverted to store in the fields in mm.

$$R_{OF} = \frac{C(1 - L_c)(1 - L_o)R_w \times A_w \times A_{pf}}{A} \leq 400 \text{ mm.}$$

C = runoff coefficient of watershed in percentage

R_w = equivalent uniform depth of rainfall on the watershed in mm.

A_w = watershed area in m^2

A_{pf} = field application efficiency in percentage

L_c = conveyance losses in percentage

L_o = operational losses in percentage

A = total irrigable area for wet-season crops in m^2

I = required irrigation water on the field in mm.

Then, the required supplemental storage (S_R) for the events of the past rainfall records can be determined by the following formulas.

$$S_R = \frac{IA}{A_{pf} \times (1 - L_c)(1 - L_o) \times 1000}$$

$$I = E_T + L_P + W_{LP} - R_F - R_{OF}$$

For this study:

E_T = 637 mm.

L_P = 312 mm.

W_{LP} = 237 + 40 = 277 mm.

$E_T + L_P + W_{LP}$ = total water requirement for rice = 1226 mm.

R_F = total rainfall depth during July to September

C = 0.246

R_w = R_F

A_w = $81.5 \times 10^6 \ m^2$

A_{pf} = 0.75

L_c = 0.10

L_o = 0.15

A_F = $1200 \times (100)^2$

$$R_{OF} = \frac{0.246 \times 0.90 \times 0.85 \times R_F \times 81.5 \times 10^6 \times 0.75}{1200 \times (100)^2} = 0.96 \ R_F$$

$$I = (1226 - R_F - 0.96 \ R_F)$$

$$= 1226 - 1.96 \ R_F \quad \text{for} \quad R_{OF} \leq 400 \text{ mm.}$$

$$= 826 - R_F \quad \text{for} \quad R_{OF} \geq 400 \text{ mm.}$$

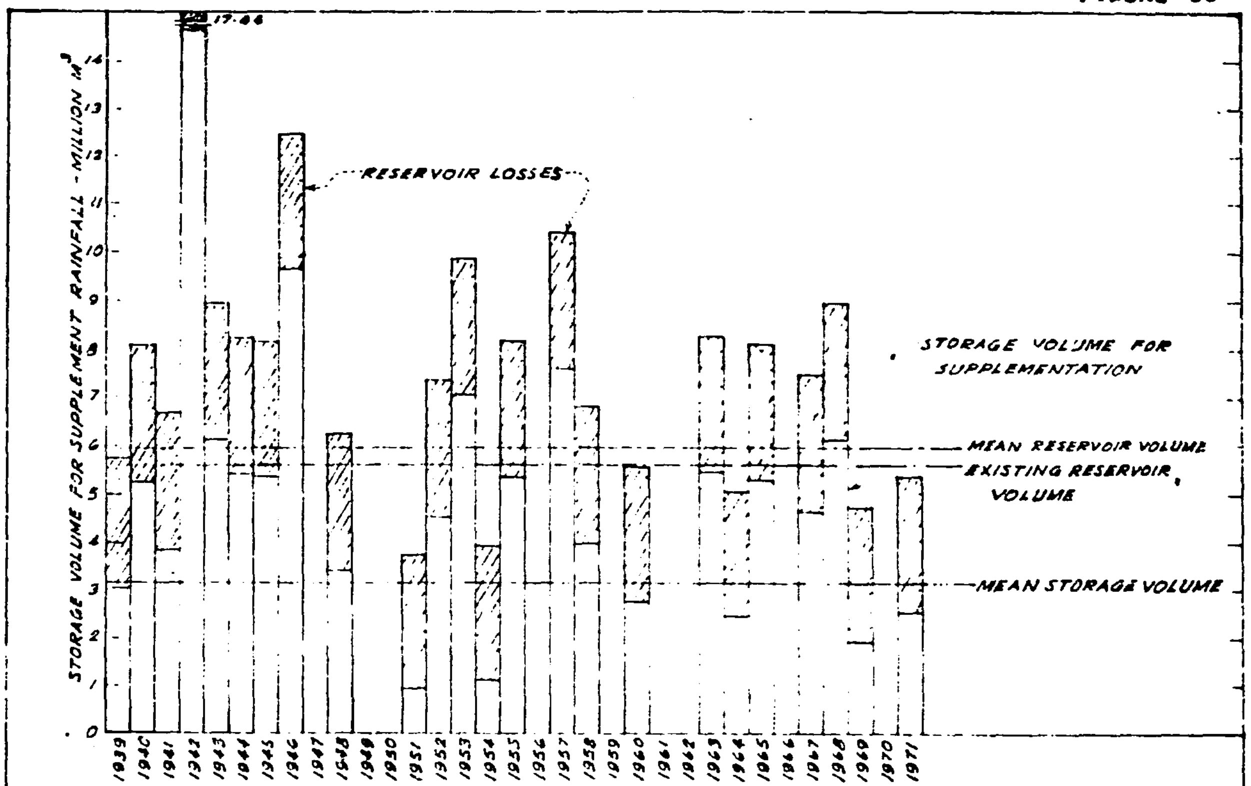
$$S_R = 20915 \ (1226 - 1.96 \ R_F) \quad \text{for} \quad R_{OF} \leq 400 \text{ mm.}$$

$$= 20915 \ (826 - R_F) \quad \text{for} \quad R_{OF} \geq 400 \text{ mm.}$$

Figures 25 and 26 show the diagrams of the yearly required reservoir storage volumes including the reservoir losses during the rice cropping period for the rainfall period of July to September at Kalasin and Huey Si Thon.

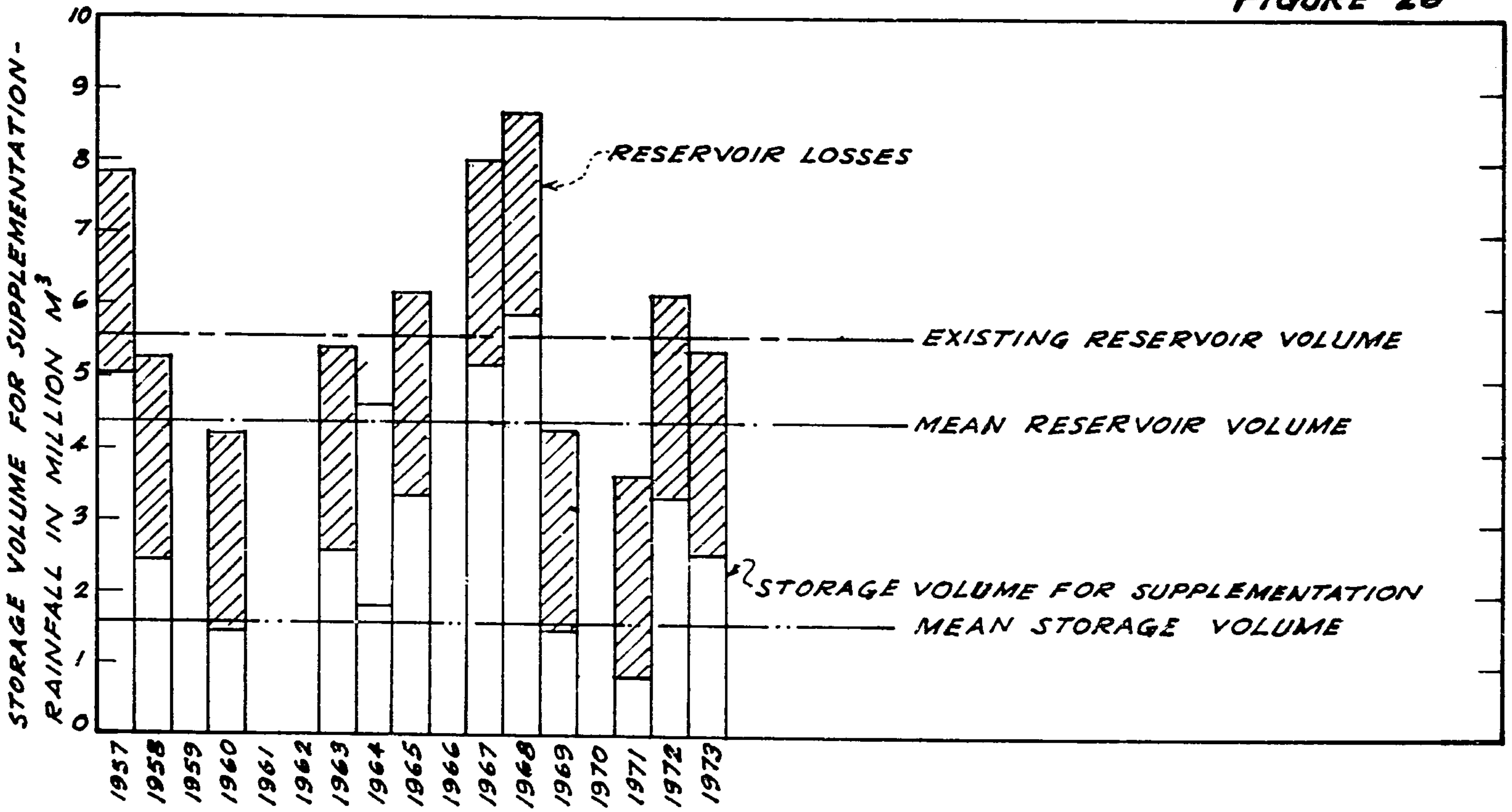
The past rainfall records indicate that the mean rainfalls during July to September at Kalasin and at the Huey Si Thon are 719 mm. and 976 mm., respectively. On the safe side, the mean rainfall at

FIGURE 25



REQUIRED STORAGE VOLUMES FOR SUPPLEMENTATION RAINFALL IN GROWING RICE DURING JULY TO OCT. AT KALASIN

FIGURE 26



REQUIRED STORAGE VOLUME FOR SUPPLEMENTATION RAINFALL IN GROWING RICE DURING JULY TO OCT. AT HUEY SI THON

Kalasin will be used to estimate the required reservoir storage for 1200 hectares of 120-day rice cropping. Figure 27 indicates that the required reservoir capapcity is smaller than the existing reservoir. Figure 28 shows the significance of the runoff that can be stored in the rice paddy to the irrigable area of the project. If 400 mm. of runoff can be stored in the rice paddy, the existing reservoir capacity can be used to expand the irrigable area from 1200 hectares to 2200 hectares of 120-day rice, an increase of 83 percent.

The reservoir storage for rice cropping shown in Figure 27 was determined using the following formulas:

$$S_R = 20915\ (1226 - 1.96\ R_F) \text{ for } R_{OF} \leq 400 \text{ mm.}$$

and

$$S_R = 20915\ (826 - R_F) \text{ for } R_{OF} \geq 400 \text{ mm.}$$

The runoff that can be stored in the rice paddy depends on the amount of rainfall in the watershed; however, for purposes of this analysis, the amount stored is assumed not to exceed 400 mm. If runoff from the watershed is greater than 400 mm, the second equation stated above is used to determine the supplemental storage achieved. By assuming that the wet season (April to October) seepage and evaporation losses of the reservoir are 2,800,000 m^3, then the storage curve in Figure 27 is obtained.

The reservoir storage for rice cropping shown in Figure 28 was determined by the following procedures:

$$R_{OF} = \frac{0.246\ R_F \times 81.5 \times 10^6 \times 0.75 \times 0.90 \times 0.85}{A_F \times (100)^2}$$

where A_F = irrigable area in hectares.

Therefore,

$$R_{OF} = \frac{1150.31\ R_F}{A_F} \quad .$$

The irrigation water required on the field in mm is,

$$I = E_T + L_P + W_{LP} - R_F - R_{OF} \quad .$$

Using the previous results, this reduces to,

$$I = 1226 - R_F - R_{OF} \quad \text{for} \quad R_{OF} \leq 400 \text{ mm.}$$

$$= 1226 - R_F - \frac{1150.31\ R_F}{A_F} \quad .$$

This can now be substituted into the equation for S_R as follows:

$$S_R = \frac{I\ A_F}{(1 - LC)(1 - LO)\ A_{pf} \times 1000}$$

$$= \frac{\left(1226 - R_F - \frac{1150.31\ R_F}{A_F}\right) A_F}{0.90 \times 0.85 \times 0.75 \times 1000}$$

$$= 0.001743\ A_F \left(1226 - R_F - \frac{1150.31\ R_F}{A_F}\right)$$

$$= 2.137\ A_F - 0.001743\ R_F A_F - 2.004898\ R_F \quad .$$

This equation holds for levels of water stored in the paddy of less than 400 mm. When the runoff exceeds this 400 mm. value, $I = 826 - R_F$. In this case,

$$S_R = \frac{I\ A_F}{0.90 \times 0.85 \times 0.75 \times 1000}$$

$$= 0.001743\ (826 - R_F)\ A_F \quad \text{for} \quad R_{OF} \geq 400 \text{ mm.}$$

$$= 1.440\ A_F - 0.01743\ R_F A_F \quad .$$

Figure 28 is computed using the above results.

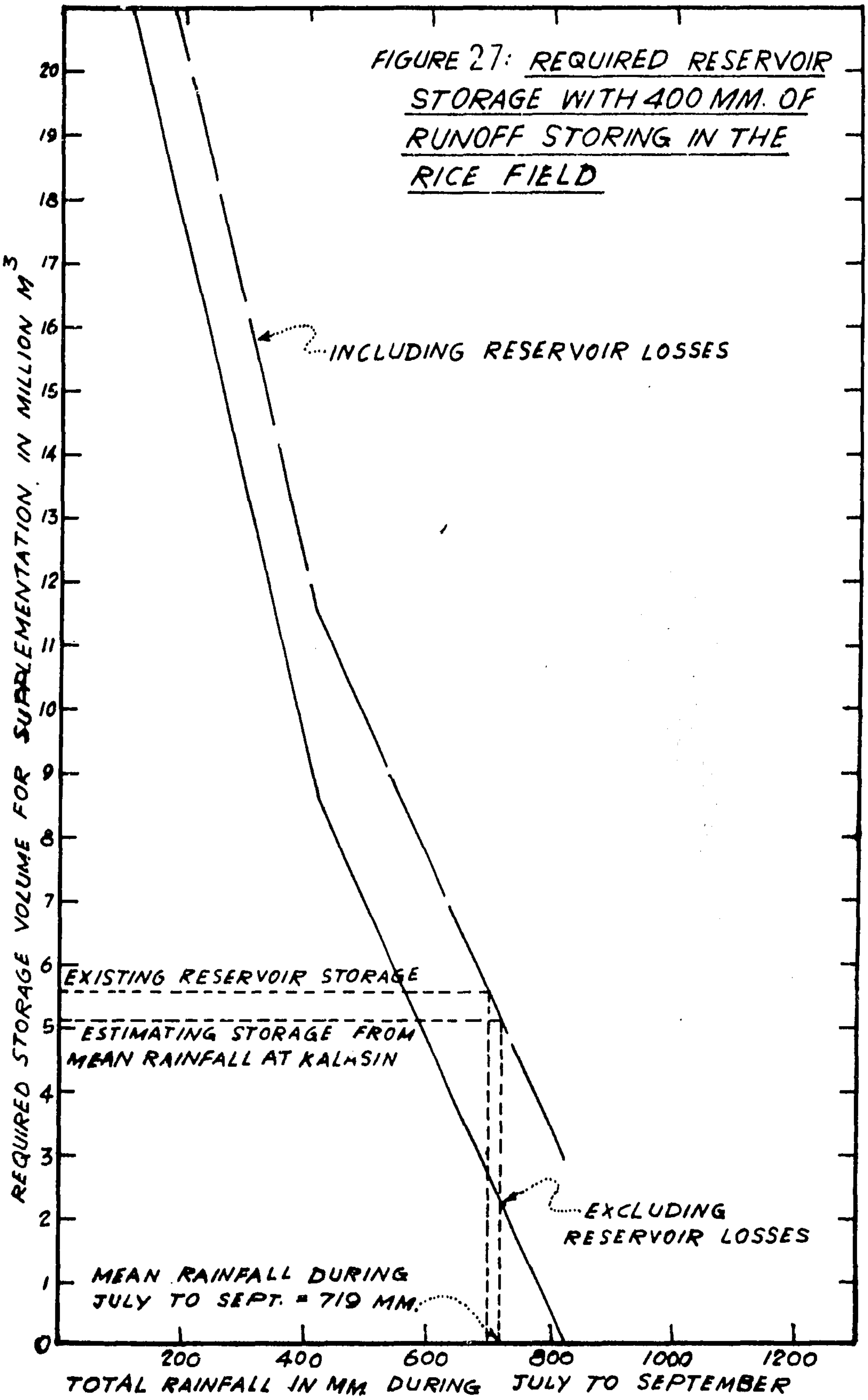


FIGURE 27: REQUIRED RESERVOIR STORAGE WITH 400 MM. OF RUNOFF STORING IN THE RICE FIELD
INCLUDING RESERVOIR LOSSES
EXISTING RESERVOIR STORAGE
ESTIMATING STORAGE FROM MEAN RAINFALL AT KALASIN
EXCLUDING RESERVOIR LOSSES
MEAN RAINFALL DURING JULY TO SEPT. = 719 MM.
REQUIRED STORAGE VOLUME FOR SUPPLEMENTATION IN MILLION M^3
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
200
400
600
800
1000
1200
TOTAL RAINFALL IN MM DURING JULY TO SEPTEMBER

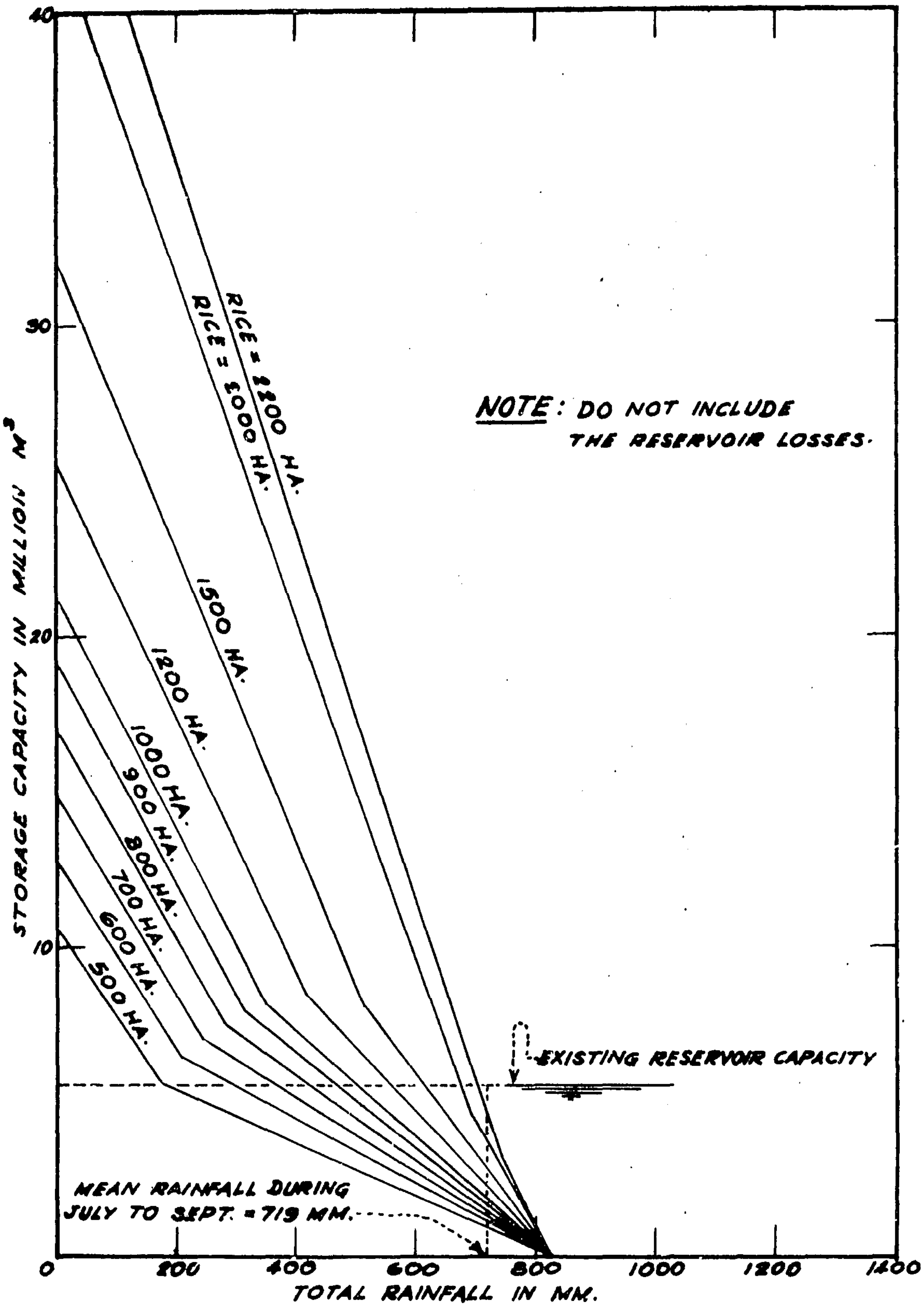


FIGURE 28: REQUIRED STORAGE PER AREA OF RICE INCLUDING RUNOFF 400 MM. IN THE FIELD

Chapter VI

SUMMARY AND CONCLUSIONS

The study has evaluated in detail the design and operation of a small irrigation water reservoir in Thailand. Reservoirs of the type analyzed here are common in Thailand; consequently, the analysis used should be generally applicable to other locations in the Northeast region.

Several conclusions can be drawn from the study. These conclusions are listed and discussed in terms of the alternatives available for improving existing design techniques and/or operation procedures.

Hydrologic Conclusion

The existing Huey Si Thon reservoir is not capable of retaining more than 35 percent of the mean annual runoff from the months July to September (see Figure 29). Thus, it can be concluded that the reservoir is not able to retain much of the excess water generated during the wet season.

Also, the current reservoir has the ability to irrigate more land if the operation is closely tied to the ability of the rice fields to "store" water. During the wet season, runoff can be directed to the rice paddies as it occurs, thus keeping the reservoir full at all times. The existing practice of using reservoir water for rice growing requires a rainfall of 1000 mm. By storing 400 mm. of runoff in the paddies (the amount of water that may be directed to the rice paddies as it occurs), rice cropping will require a rainfall of only 600 mm. Consequently, the reservoir will be able to supply water to more land if better use is made of the ability of the rice paddies to store water.

The major problem of this proposal is to determine exactly how much runoff the paddies will be able to "store". It depends on the distribution and amount of rainfall at any one time, infiltration rate of soils, and the particular growth period of the rice. For example, if runoff were stored in a rice paddy and this was followed by a high intensity rainfall, the crops may be destroyed if the excess is not removed. Storing only a small amount of runoff does not permit efficient use of the runoff if a dry spell follows. In this case, reservoir water must be used.

Research is needed to permit better management of runoff storage and use of reservoir water. Through better coordination, the land area served by the reservoir could be expanded.

Reservoir Capacity Conclusion

There are many factors that should be considered in determining the "optimum" size of a reservoir as that studied herein.

First, the relationship between the rainfall to be expected and the water requirement of the wet-season crops must be established. If the water requirements exceed the expected rainfall, storage is diverted. The total water requirement will be a function of the total hectares of rice planted. Figure 29 illustrates the reservoir volumes needed for various size plantings. Looking at the mean rainfall and the existing size of the reservoir, 700 hectare of rice can be safely produced. Increasing the capacity to 9 million m^3 will permit 1200 hectares of rice to be grown.

Second, the variability of rainfall (and thus risk of dry spells) during the wet-season cropping will affect the amount of water needed to be held in reserve for such situations. Once this risk is defined, the capacity needed is a function of the rice variety selected.

A third factor stems from the ability of the runoff to fill the reservoir. Again, referring to Figure 29, it can be seen that a reservoir of 16 million m^3 could be filled during an average year. This fact indicates that for humid countries such as Thailand with the high runoff coefficients, the annual runoff will not be a restriction.

A fourth factor involves the ability to predict the amount of runoff that occurs before the rainy season starts. The runoff that occurs during this time is used to prepare the land and seedling nursery. If there is not enough for total preparation, some land will have to be planted later (a shift in the growing season that will utilize the first part of the rainy season's water for preparation). In estimating the water which will be available for initial crop preparation, the reservoir losses must be taken into consideration, along with the fact that July has had some two to three week dry spells. Providing sufficient water for this eventuality may greatly reduce the amount of land prepared early. An entire month of dry weather in July has been recorded; however, it is an extreme case with a low probability of occurring. This risk may be acceptable.

A fifth factor dealing with reservoir capacity involves the dry-season crops which follow the wet-season cropping. If the reservoir is expanded to reduce risk of wet-season crop failure, and the water is not needed; then the dry-season cropping area can be increased to match the available water.

Considering all of these factors, the optimum reservoir capacity is more than now exists. The optimum reservoir capacity should satisfy the above conditions. Based on average rainfall during July to September at Huey Si Thon, the existing reservoir capacity should supply an irrigable area of only 700 hectares, or for the existing irrigable area, the reservoir capacity should be increased to 9 million m^3. If this is the case, the reservoir would be able to prevent the short drought periods of up to 50 days and the dry-season cropping area could be increased to 1100 hectares of mungbean (E_T = 241 mm.) or 850 hectares of sweet corn (E_T + 337 mm.). It is assumed that 100 mm. is needed to establish each of the crops. Thus, when entering the E_T value in Figure 29, each of the above values must be increased by 100. Also remember that reservoir capacities expressed in Figure 29 are at the beginning of the dry season. To get estimates of the dry-season area which can be served, reservoir evaporation and seepage losses must be taken into consideration.

Reservoir Operation Conclusion

In assuming the reservoir will supply water for land preparation and the seedling nurseries, the rainfall of May and June will greatly affect its operation. The probability of rainfall for May and June being below 300 mm. is 25% for Kalasin and 19% for Huey Si Thon; consequently, assuming an average of 300 mm., the runoff yield is approximately 4.50 million m^3. This volume of water is sufficient for initial cropping preparation, but is not sufficient if a dry period requiring irrigation occurs in July.

Even though the existing reservoir may be full at the beginning of cropping preparation, only 5.20 million m^3 remain after reservoir losses of July. This leaves only 438 mm. (assuming 700 hectares are cropped), or 265 mm. for 1200 hectares, for potential droughts. The existing reservoir capacity can prevent a short drought period of only one month for 1200 hectares of rice, which often occurs in the rainy season. The reservoir operation for wet-season cropping should begin to retain the runoff in March since it is the beginning of the southwest monsoon. After the end of wet-season cropping, the remaining reservoir storage should be used for the dry-season cropping, otherwise it will be lost by the reservoir losses. The reservoir losses are significant for this reservoir.

Limitations of Results

Throughout this study estimates have been made on the conservative side. This fact may prevent the reservoir service area and its people from realizing maximum return on the available water. However, by being conservative, it is felt that the results represent a less risky operational plan than if less conservative estimates had been made. The guarantee of a crop, with less than optimum yields, is considered to be more acceptable than a risk of maybe no crop, as one attempts to squeeze maximum yields from the area. The question becomes: Is the additional yield worth the risk when an average yield is not totally consumed locally?

Estimates of field application efficiency, conveyance losses and operational losses had to be made in order to complete the study. These estimates are weak factors in the analysis and should definitely be determined before any attempt is made to apply the results of this report. Research on these factors is needed in order to improve water management of the small reservoir in Northeast Thailand.

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