KINGDOM OF THAILAND
MINISTRY OF AGRICULTURE AND COOPERATIVES
ROYAL IRRIGATION DEPARTMENT

FEASIBILITY STUDY ON THE UPPER PASAK MEDIUM SCALE IRRIGATION PROJECT

VOLUME 2.2
ANNEX

VI. OPTIMIZATION OF PROJECT SCALE
VII. DAM AND RESERVOIR
VIII. IRRIGATION AND DRAINAGE
IX. ORGANIZATION AND MANAGEMENT
X. CONSTRUCTION PLAN AND COST ESTIMATE
XI. PROJECT EVALUATION

MARCH 1983

JAPAN INTERNATIONAL
COOPERATION AGENCY

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OPTIMIZATION OF PROJECT SCALE

1. GENERAL

To clarify optimum scale of exploitation of water resources and irrigable area, water balance study is made for various alternative plans on the basis of monthly runoff for long range from 1964 to 1980 and irrigation water demand estimated on cropping pattern, cropping intensity and irrigable area. The study procedures are as mentioned below.

2. PREPARATION OF ALTERNATIVE PLAN

Basic concepts for water resources and irrigation development are established as below mentioned, to select alternative plans;

(1) The maximum development of endowed water resources would be oriented as far as the topographic and geologic conditions are allowable,

(2) To exploited water resources would be consumed at the existing paddy fields extending the vicinity of the exploited sites of water resources, and

(3) The low cropping intensity would be proposed so as to delineate an extended irrigable area, in due consideration of the socio-economic impacts of the project.

Four alternative plans for each sub-project are selected as tabulated below, based on the concepts mentioned above.

Sub-Project	Alternative-1		Alternative-2		Alternative-3		Alternative-4	
	V (MCM)	I (%)	V (MCM)	I (%)	V (MCM)	I (%)	V (MCM)	I (%)
Huai Saduang Yai	21.0	135	21.0	150	27.0	135	27.0	150
Huai Khon Kaen	23.4	135	23.4	150	30.0	135	30.0	150
Huai Yai	6.4	135	6.4	150	13.3	135	13.3	150
Khlong Chaliang Lab	1.5	135	1.5	150	6.7	135	6.7	150

Note: V : Reservoir Capacity
I : Cropping Intensity

3. WATER BALANCE

To make water balance in each alternative reservoir, some assumptions are made as mentioned below.

(1) The Huai Saduang Yai reservoir serves irrigation water for the existing Pasak Left Bank irrigation project and the Sri Chan irrigation project under construction, because no land resources suitable for irrigated agriculture extend in the lower basin of Huai Saduang Yai. The reservoir firstly supplies irrigation water for the whole Sri Chan service area and then, serves for the Pasak Left Bank service area within its capacity. In case that the Saduang Yai reservoir is incapable of irrigating the whole Pasak Left Bank service area, the Khon Kaen reservoir irrigates the remaining area which is not served by the Saduang Yai reservoir. In intake efficiency of 80% are assumed at the Sri Chan and Pasak Left Bank weir.

(2) The Khon Kaen reservoir supplies municipal water throughout the year for the Lom Sak and/or the Phetchabun, in addition to irrigation water for the Khon Kaen service area. About 4,000 m^3/day are assumed for the municipal water supply, including conveyance losses from the reservoir to the intake site for municipal water.

(3) Riparian inhabitants in the downstream are subsisting depending their potable and domestic water on the relevant tributaries. Even after the reservoir is created, some amount of water must be continuously released to downstream throughout the year for the subsistance of the inhabitants. The released amount would be determined in proportion to the drainage area at dam site. Thus, the released amount of 1.0 l/s is assumed per km^2 of drainage area.

(4) Storage capacity in the reservoir would be monthly minor-adjusted by balancing the evaporation and rainfall on the reservoir surface.

(5) Spill-out is divided into two categories one is the direct spill-out which is defined as the spilling capacity during minor-adjusted by the evaporation and rainfall on the reservoir surface, and the other is the spill-out after regulated which is defined as the further spilled capacity after balancing inflow (supply) and outflow (demand).

(6) Reservoir capacity and service area would be determined through the water balance on the conditions that reservoir is completed depleted three times at least for recent 17 years, or in other words, drought damages recurs by about 5-years. The in-balance between supply and demand would be adjusted by changing service area.

(7) Water balance would be made on the estimated runoff data from 1964 to 1980, because the runoff of each tributary is estimated based on the runoff records at the Kaen Sida station which has been operated since 1964.

The results of the water balance calculation for the alternative plans of each sub-project are as illustrated in FIG. VI-1 through VI-4 and the calculation sheets are compiled in the Data Book. The reservoir capacity, cropping intensity, and service area fully balanced by the reservoir operation are as summarized below.

Sub-Project	Alternative-1			Alternative-2		
	V MCM	I %	A ha	V MCM	I %	A ha
Huai Saduang Yai	21.0	135	4,700	21.0	150	3,500
Huai Khon Kaen	23.4	135	4,300	23.4	150	3,300
Huai Yai	6.4	135	1,200	6.4	150	900
Khlong Chaliang Lab	1.5	135	130	1.5	150	60

Sub-Project	Alternative-3			Alternative-4		
	V MCM	I %	A ha	V MCM	I %	A ha
Huai Saduang Yai	27.0	135	5,400	27.0	150	4,200
Huai Khon Kaen	30.0	135	5,100	30.0	150	4,100
Huai Yai	13.3	135	1,800	13.3	150	1,500
Khlong Chaliang Lab	6.7	135	1,200	6.7	150	900

Note: V : Reservoir Capacity
I : Cropping Intensity
A : Service Area

4. ECONOMIC EVALUATION OF ALTERNATIVE PLAN

4.1 Assumption and Estimate

(1) Per-hectare net incremental value is assumed as given below based on the results of the agro-economic study.

Service Area	Crop Intensity 135% US$	(Baht)	Crop Intensity 150% US$	(Baht)
Huai Saduang Yai	1,084	(24,932)	1,707	(39,261)
Huai Khon Kaen	1,393	(32,039)	1,853	(42,619)
Yuai Yai	1,423	(32,729)	1,799	(41,377)
Khlong Chaliang Lab	1,338	(30,774)	1,714)	(39,422)

(2) Economic benefit or net incremental value for each alternative plan at full development stage is estimated based on the service area determined through the water balance study and per-hectare net incremental value. In addition, the water value derived from the water release for downstream use and municipal use is counted in the study. The total benefit thus estimated is as summarized below.

(Unit: 10^3 ฿)

Sub-Project	Alternative-1	Alternative-2	Alternative-3	Alternative-4
Huai Saduang Yai	122,733	144,347	139,381	171,024
Huai Khon Kaen	186,833	190,858	211,544	224,033
Huai Yai	49,815	48,124	68,762	72,261
Khlong Chaliang Lab	15,360	13,805	47,058	45,954

(3) Embankment volume-unit cost curve is developed based on the cost estimate prepared in the pre-feasibility study. The typical unit costs including appurtenant structures are assumed as given below.

Embankment Volume (MCM)	Unit Cost (฿/m^3)
0.50	330
1.00	225
1.50	197
2.00	194
2.50	192
3.00	190

The economic dam construction cost for each alternative plan is estimated, as given below, on the basis of the anticipated embank-ment volume and the assumed unit cost.

(Unit: 10^3 ฿)

Dam	Alternative-1 & -2	Alternative-3 & -4
Huai Saduang Yai	220,500	255,000
Huai Khon Kaen	521,400	680,400
Huai Yai	168,300	221,100
Khlong Chaliang Lab	93,600	225,000

Per-hectare construction cost for irrigation development is roughly estimated as US$1,650 for the Khon Kaen sub-project area and US$930 for the Huai Yai sub-project area, and US$830 for the Khlong Chaliang Lab sub-project area. The per-hectare construction cost for irrigation development in the Sri Chan service area is assumed at US$2,500. The per-hectare sunk cost in the Pasak Left Bank service area is assessed to be US$790 in terms of present worth. Furthermore, the per-hectare irrigation improvement works are assumed to be US$640. Finally, the economic construction cost for irrigation development is estimated as follows, by sub-project and alternative plan.

(Unit: 10^3 ฿)

Sub-Project	Alternative-1	Alternative-2	Alternative-3	Alternative-4
Huai Saduang Yai	179,200	139,700	202,200	162,800
Huai Khon Kaen	156,600	112,600	190,500	146,500
Huai Yai	25,700	19,300	38,500	32,100
Khlong Chaliang Lab	2,500	1,100	22,900	17,200

The direct economic construction cost comprising the costs for dam construction and for irrigation development can be summed up as follows.

(Unit: 10^3 ฿)

Sub-Project	Alternative-1	Alternative-2	Alternative-3	Alternative-4
Huai Saduang Yai	399,700	360,200	457,200	417,800
Huai Khon Kaen	678,000	633,600	870,900	826,900
Huai Yai	194,000	187,600	259,600	253,200
Khlong Chaliang Lab	96,100	94,700	247,900	242,200

Engineering and administration cost is assumed at 20% of the direct economic construction cost. Physical contingencies are also conservatively assumed at 20% of the direct economic construction cost plus the engineering and administration cost. Finally, the project cost for each alternative plan is estimated by summing up the direct economic construction cost, the engineering and administration cost, and the physical contingencies, as given below.

(Unit: 10^3 ฿)

Sub-Project	Alternative-1	Alternative-2	Alternative-3	Alternative-4
Huai Saduang Yai	575,500	518,600	658,300	601,700
Huai Khon Kaen	976,300	912,400	1,254,100	1,190,800
Huai Yai	279,400	270,100	373,800	364,600
Khlong Chaliang Lab	138,400	136,300	357,000	348,700

(4) Per-hectare operation and maintenance cost is assumed to be ฿1,150 or US$50 equivalence.

(5) The four sub-projects are concurrently implemented by package. The Khon Kaen sub-project would be completed within six (6) years, and other three (3) remaining sub-projects would be completed within five (5) years.

(6) Build-up period of each sub-project is assumed to be five (5) years in due consideration of current agriculture in and around the service area.

4.2 Evaluation

On the basis of the assumption and estimate mentioned above, the economic benefit and cost flow are prepared for calculating their present worths. The evaluation for each alternative plan is made in terms of economic internal rate of return (IRR) and net present value (NPV). The result of evaluation can be summarized as given TABLE VI-1.

4.3 Selection of Definite Plan

(1) Selection Criteria

Strictly following the development concept established in the Pre-Feasibility study undertaken in 1981, selection criteria are prepared as given below.

Criteria-1 Economic internal rate of return for the eligible plan should be sustained greater than 10% at lowest.

Criteria-2 The alternative plan providing greater NPV would be more eligible for the definite plan in view of the contribution to the regional and farmers economy.

Criteria-3 Irrigation facilities should be designed with the maximum water requirement for major crop. Low cropping intensity should be oriented for the definite plan so that the maximum irrigation requirement occurs during cultivation period of rainy season paddy.

Criteria-4 The alternative plan providing the most sizable reservoir should be possibly selected for the definite plan as far as topographic condition is allowable, and stability of dam will be sustainable.

Criteria-5 MSIP should be socio-impacted. The alternative plan providing extended service area should be eligible for the definite plan.

(2) Assessment of Alternative Plan and Selected Plan

As given in TABLE VI-1, the Alternative-3 for each sub-project nearly meets all the criteria given above. The IRR and NPV of each Alternative-3 is not the highest among the alternative plans, but sufficient for sustaining the economic feasibility under packaged condition and having immediate impacts on the regional economy. Highly regarding the criteria-3, -4 and -5, each Alternative-3 would be eligible for the definite plan. The selected plan for each sub-project is summarized in Table below.

Sub-Project	Alternative	Reservoir Capacity (MCM)	Service Area (ha)	Cropping Intensity (%)
Huai Saduang Yai	3	27.00	5,400	135
Huai Khon Kaen	3	30.00	5,100	135
Huai Yai	3	13.25	1,800	135
Khlong Chaliang Lab	3	6.73	1,200	135
TOTAL		76.98	13,500	135

TABLE VI-1

ECONOMIC EVALUATION ON ALTERNATIVE PLANS

Sub-Projects	Economic Index	Alternative-1	Alternative-2	Alternative-3	Alternative-4
Huai Saduang Yai	IRR (%) NPV (10^6 ฿)	14.5 504.3	17.6 721.6	14.3 567.1	17.3 862.8
Huai Khon Kaen	IRR (%) NPV (10^6 ฿)	13.6 706.9	14.5 791.0	13.8 841.9	15.1 1,000.5
Huai Yai	IRR (%) NPV (10^6 ฿)	15.1 223.3	15.3 219.0	14.6 293.8	15.5 331.4
Khlong Chaliang Lab	IRR (%) NPV (10^6 ฿)	9.4 21.6	8.8 11.21	10.2 92.2	10.3 93.1
Overall case - I	(Alternative-3, 3, 3, 3),	13,500 ha			IRR = 13.6% NPV = 1,795 x 10^6 ฿
Overall case - II	(Alternative-4, 4, 4, 4),	10,700 ha			IRR = 15.2% NPV = 2,286 x 10^6 ฿
Overall case - III	(Alternative-4, 4, 3, 3),	11,300 ha			IRR = 14.9% NPV = 2,223 x 10^6 ฿

Note: 1. IRR ; Internal (economic) rate of return
2. NPV ; Net present value (Benefit - Cost) at the economic rate of 8%

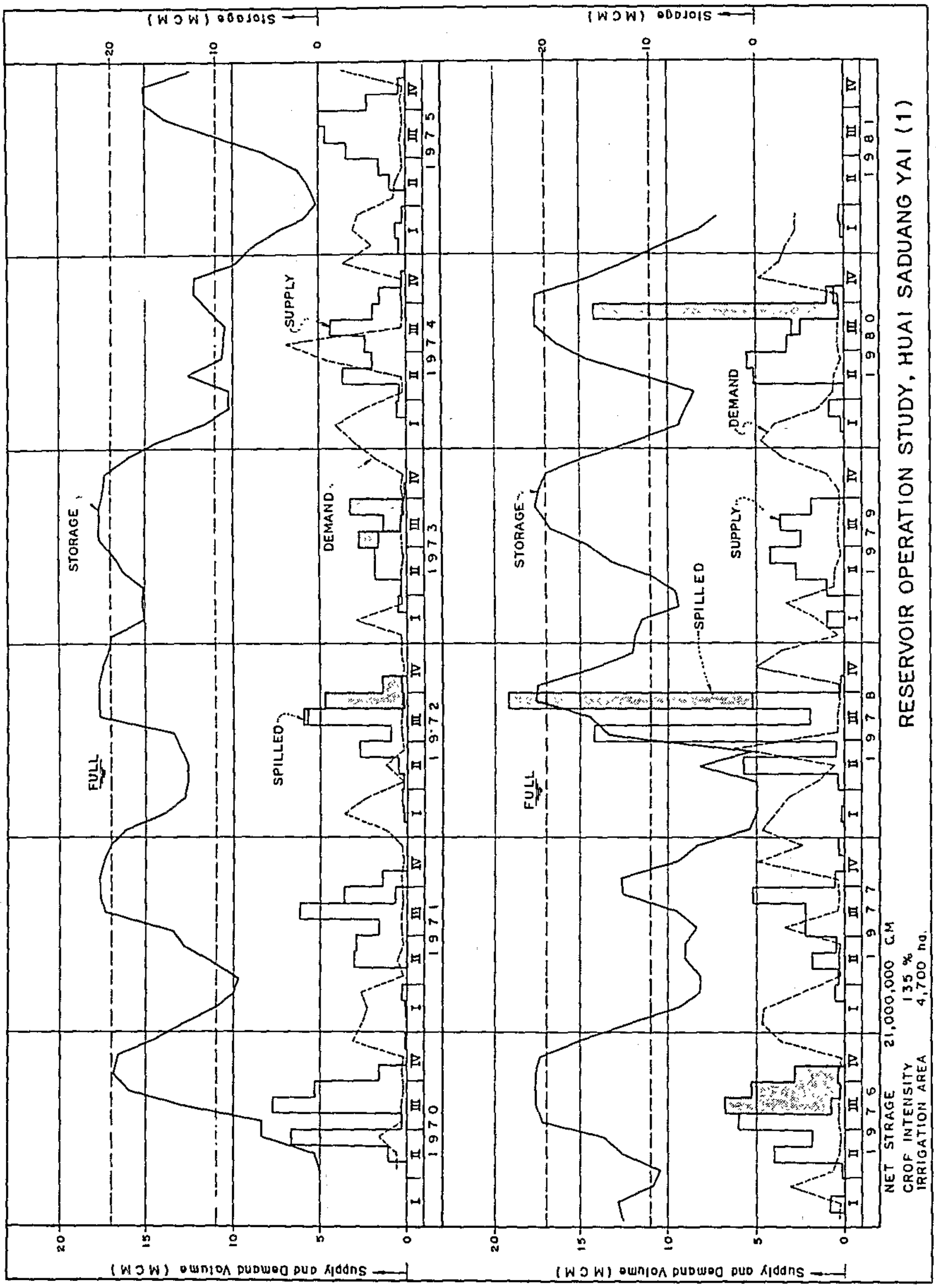
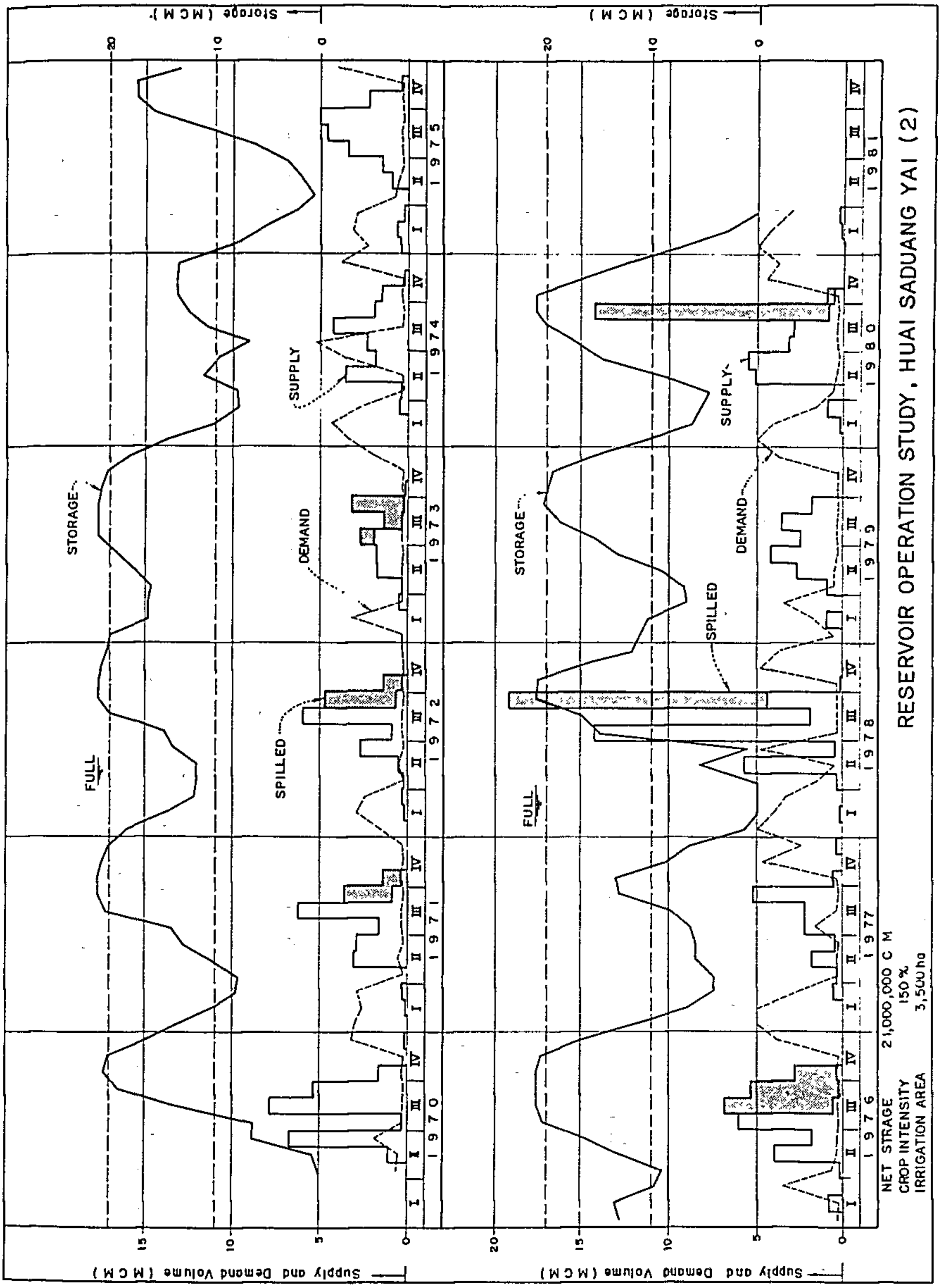
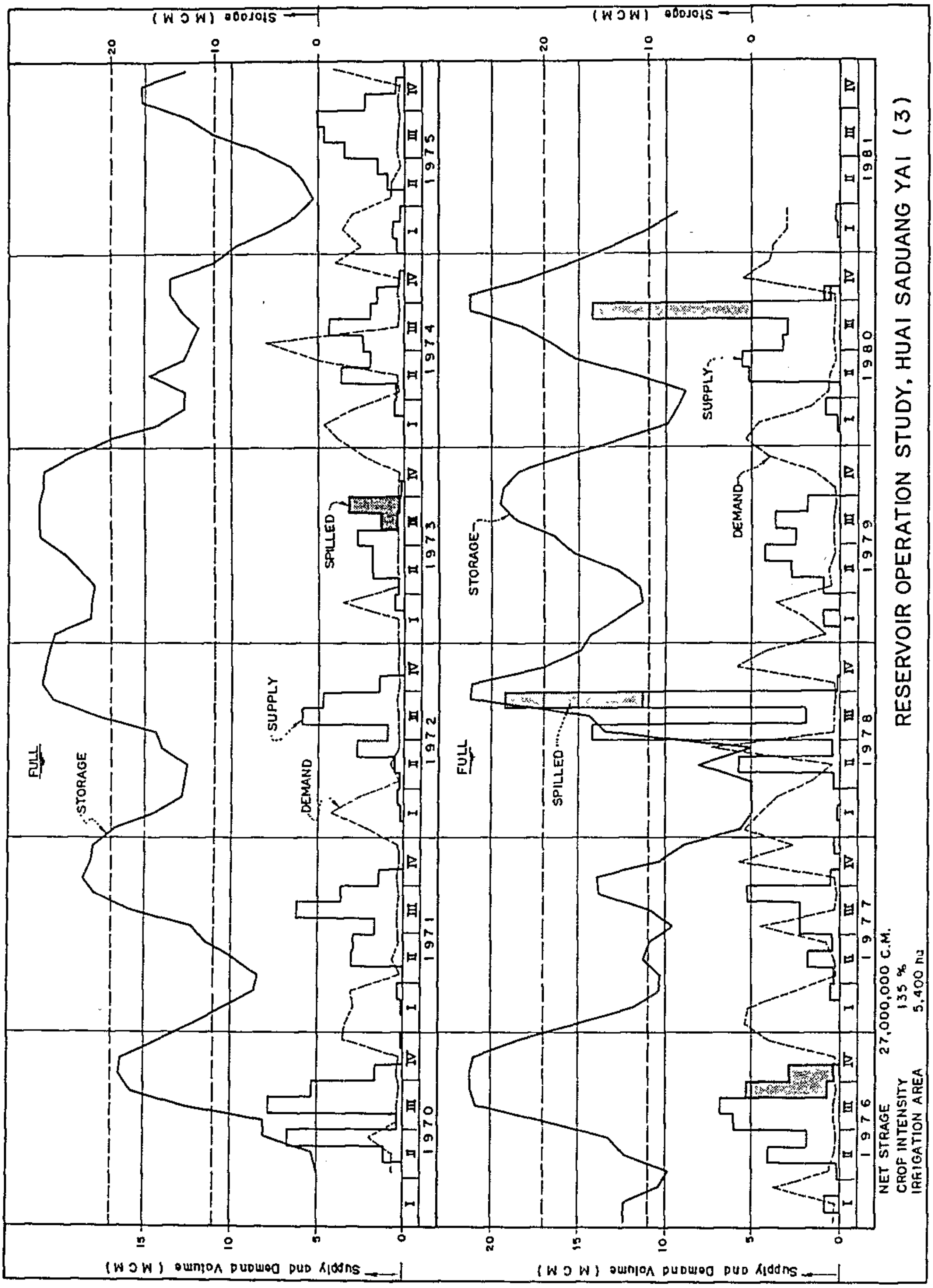
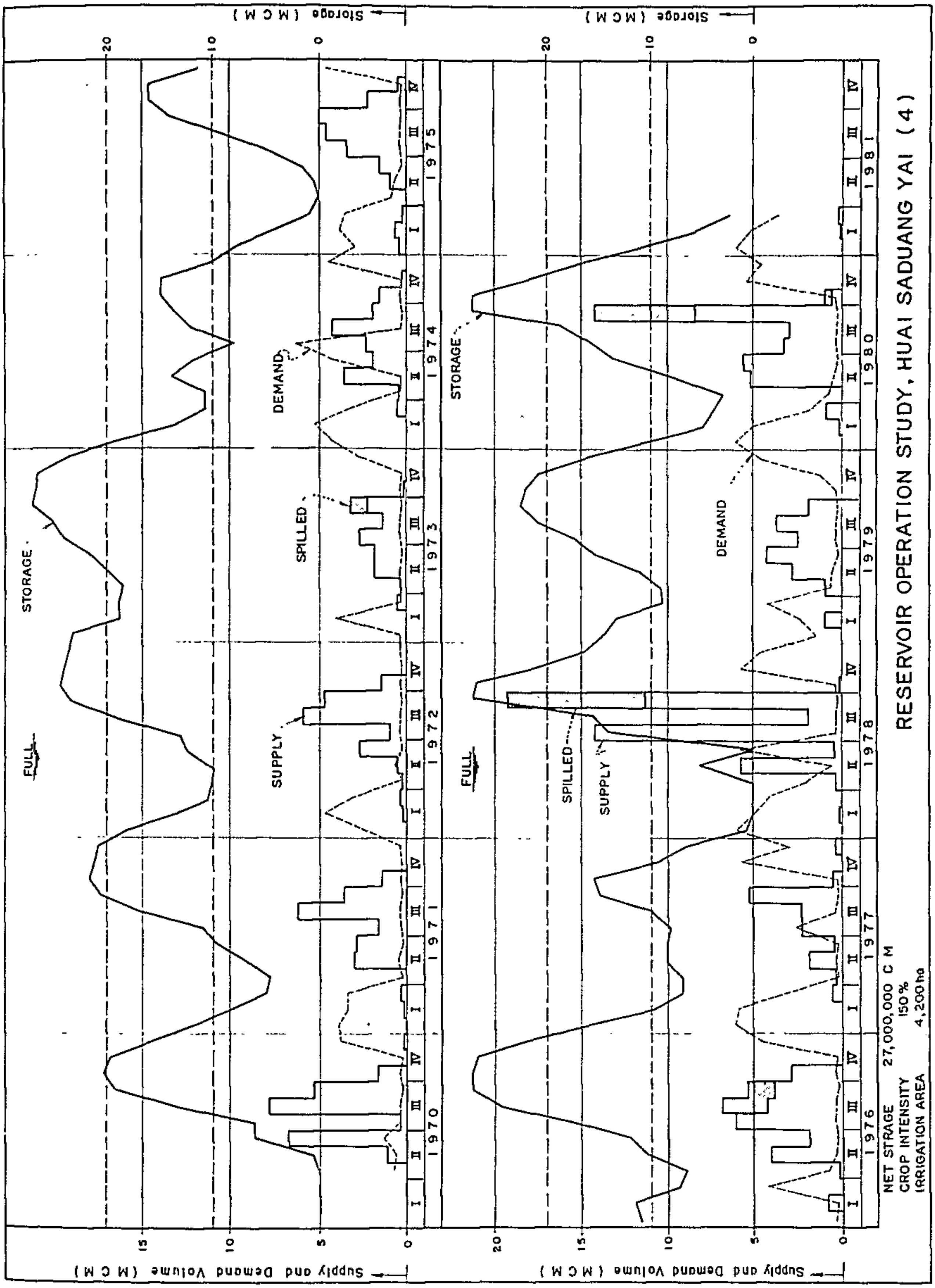

RESERVOIR OPERATION STUDY, HUAI SADUANG YAI (1)
Storage (M C M)
Supply and Demand Volume (M C M)
STORAGE
DEMAND
SUPPLY
SPILLED
FULL
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
NET STRAGE 21,000,000 C.M
CROF INTENSITY 135 %
IRRIGATION AREA 4,700 ha.

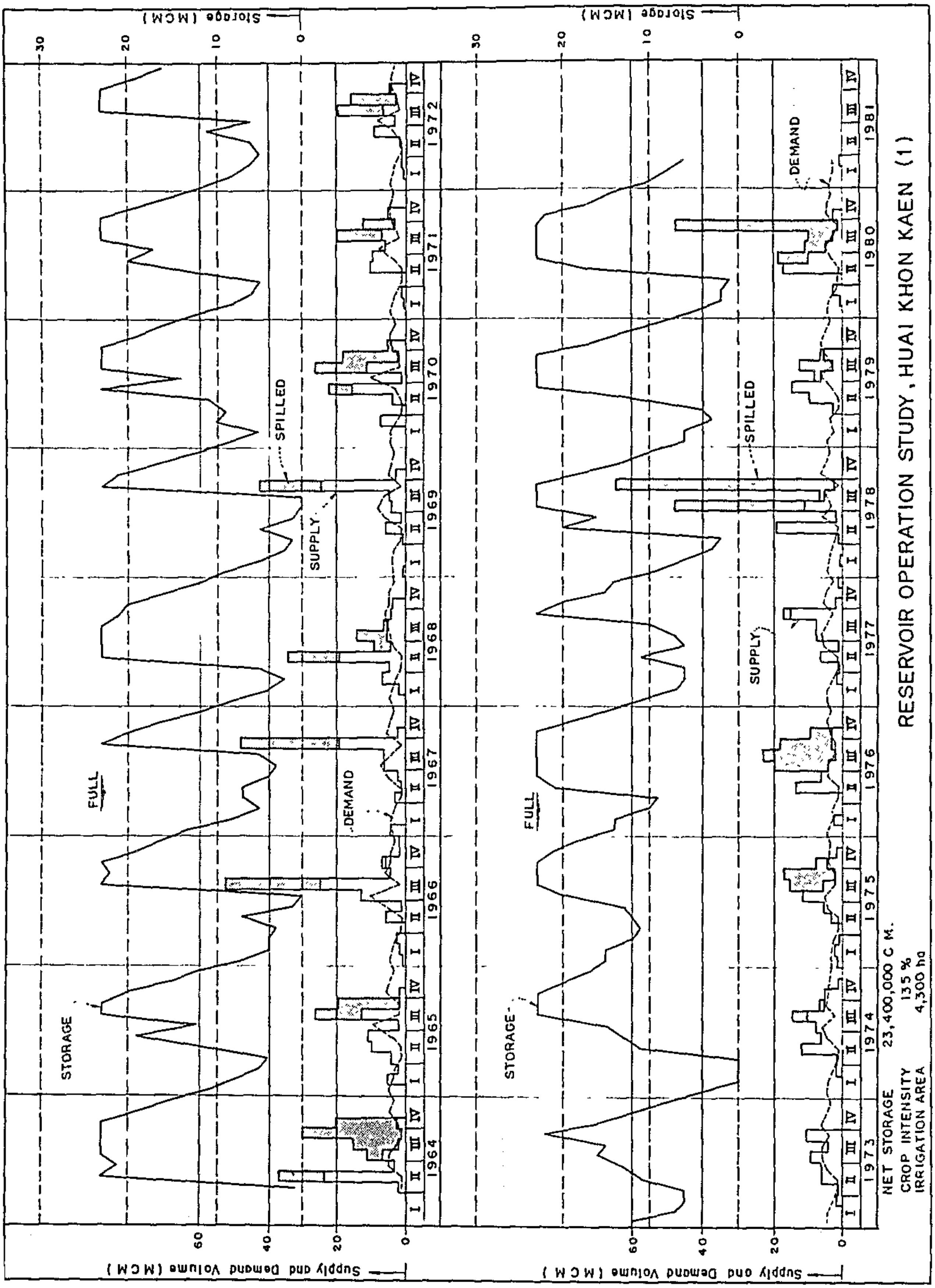
FIG. VI-1
(2)

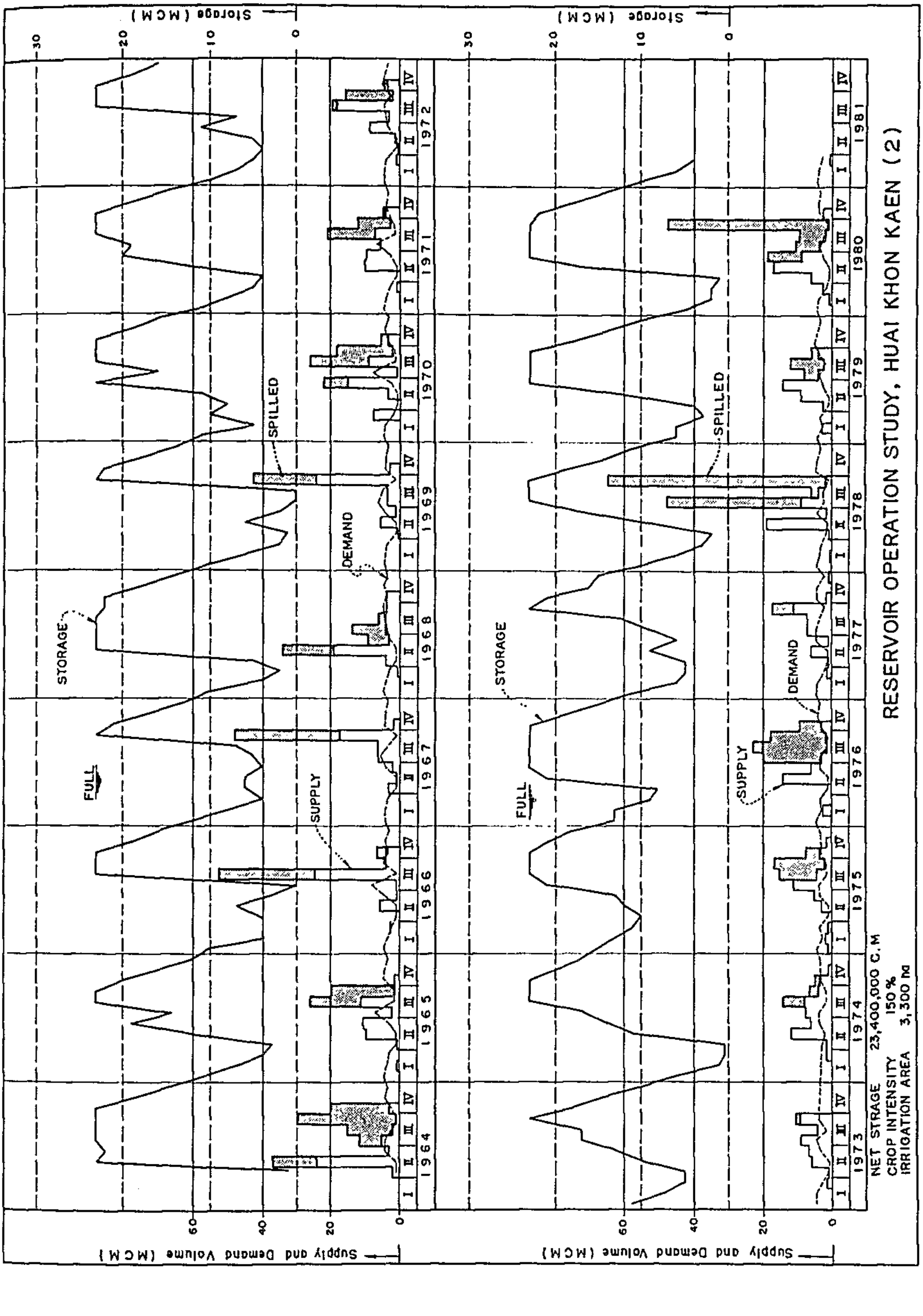

RESERVOIR OPERATION STUDY, HUAI SADUANG YAI (2)
Storage (M C M)
Supply and Demand Volume (M C M)
STORAGE
SUPPLY
DEMAND
SPILLED
FULL
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
NET STRAGE 21,000,000 C M
CROP INTENSITY 150%
IRRIGATION AREA 3,500 ha

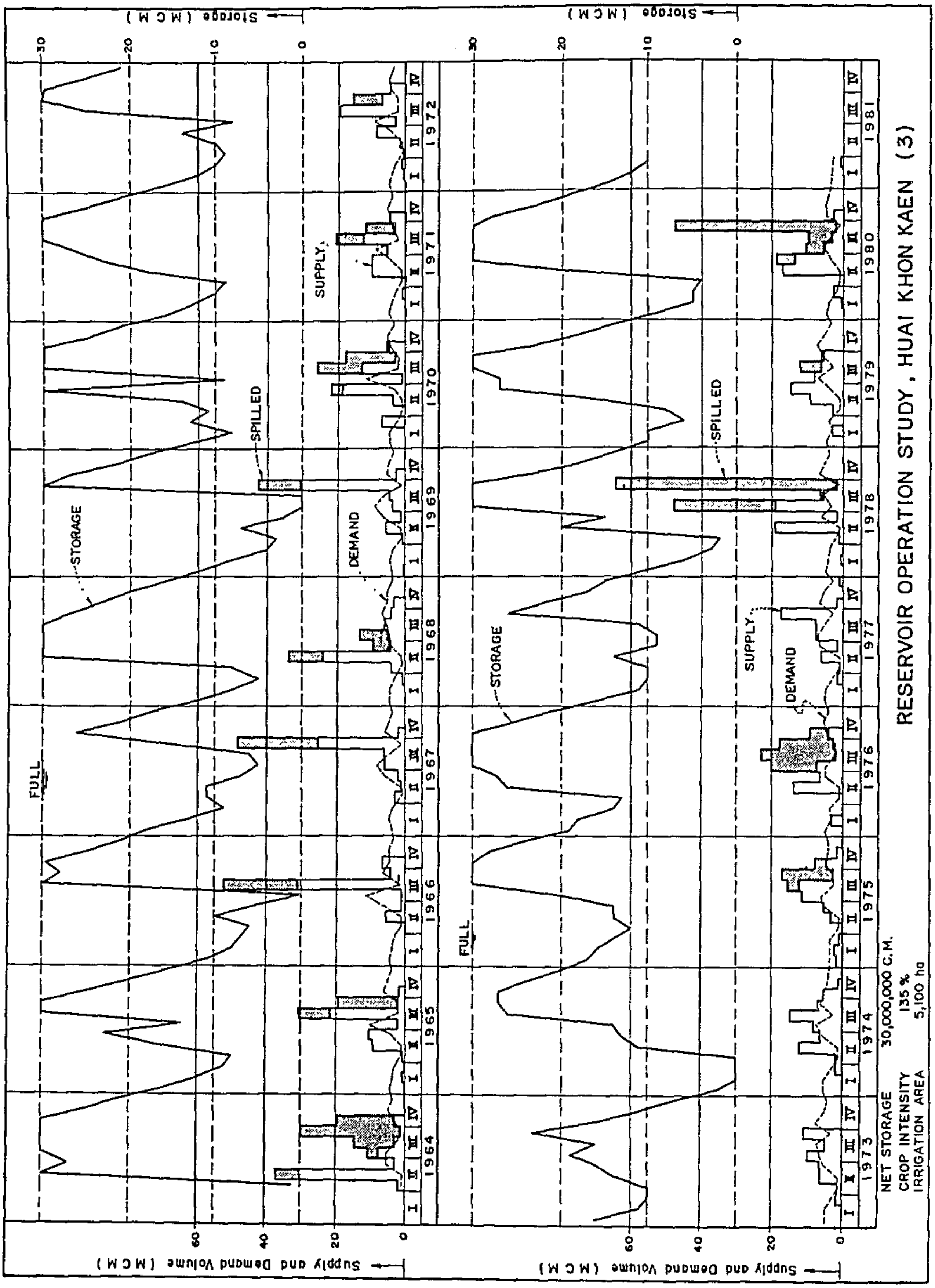


RESERVOIR OPERATION STUDY, HUAI SADUANG YAI (3)

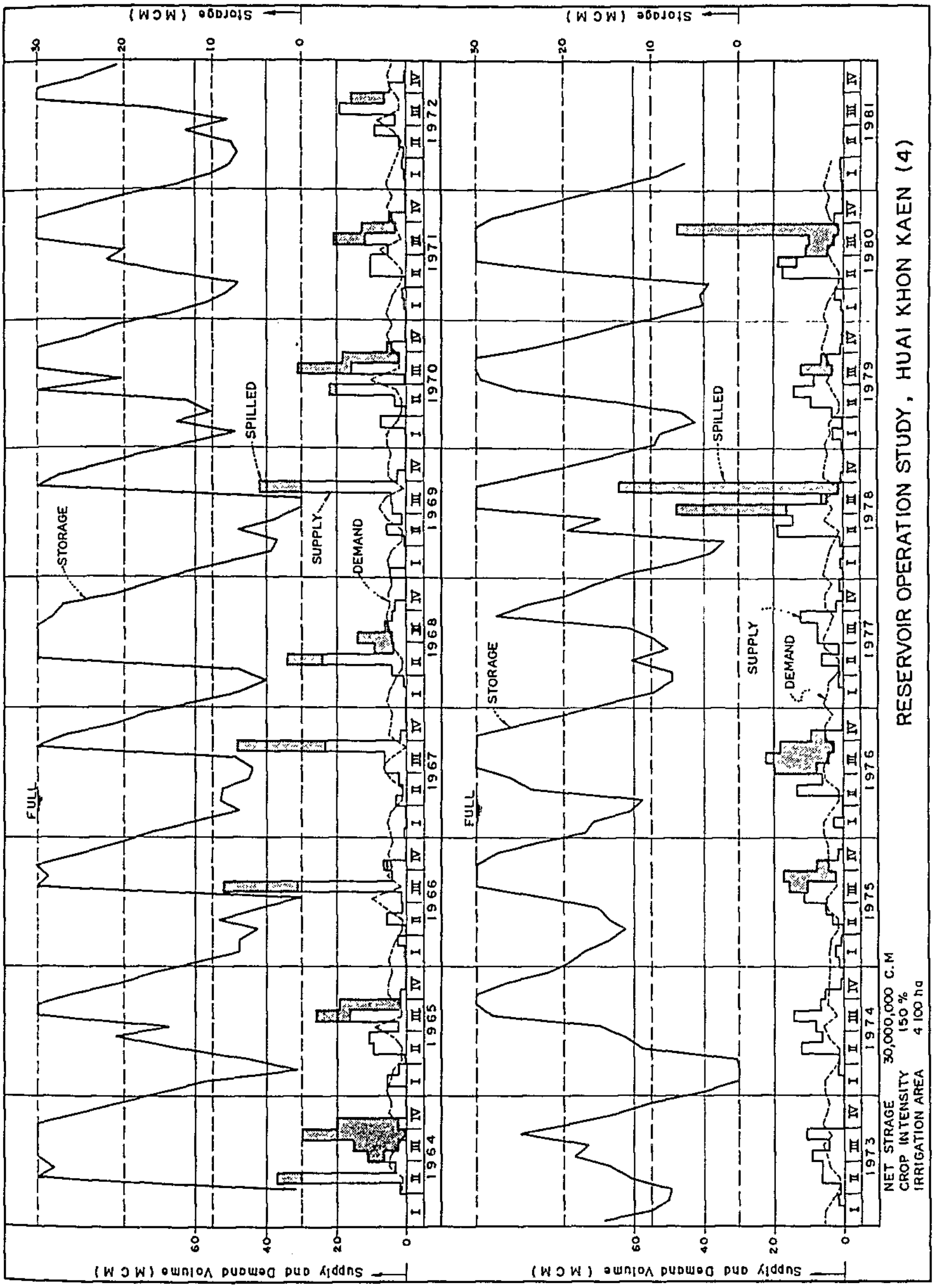

RESERVOIR OPERATION STUDY, HUAI SADUANG YAI (4)
NET STRAGE 27,000,000 C M
CROP INTENSITY 150%
IRRIGATION AREA 4,200 ha
Supply and Demand Volume (M C M)
Storage (M C M)
STORAGE
DEMAND
SUPPLY
SPILLED
FULL
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981

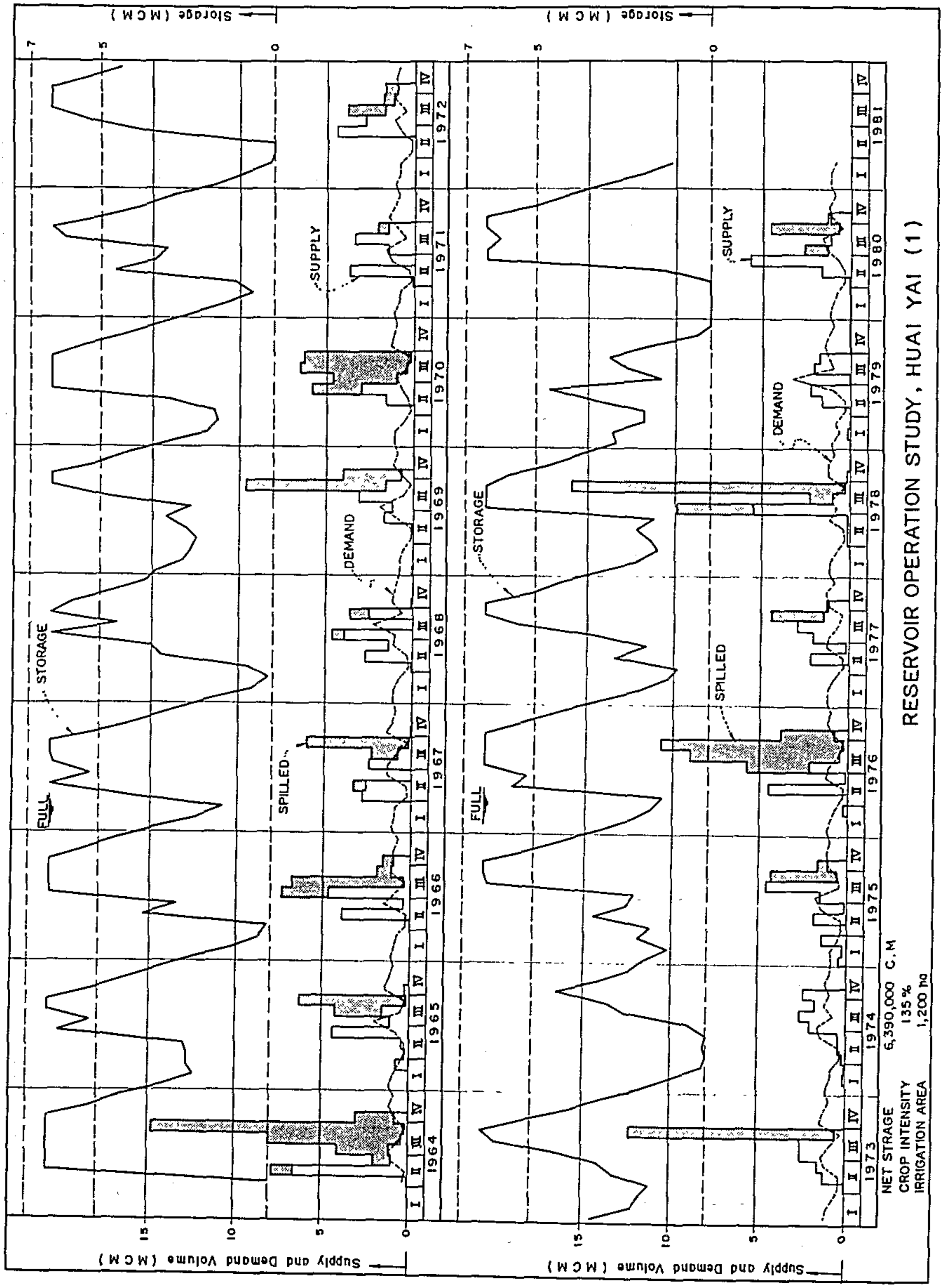

RESERVOIR OPERATION STUDY, HUAI KHON KAEN (1)
NET STORAGE 23,400,000 C M.
CROP INTENSITY 135 %
IRRIGATION AREA 4,300 ha
Storage (M C M)
Supply and Demand Volume (M C M)
STORAGE
FULL
DEMAND
SUPPLY
SPILLED
1964
1965
1966
1967
1968
1969
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981

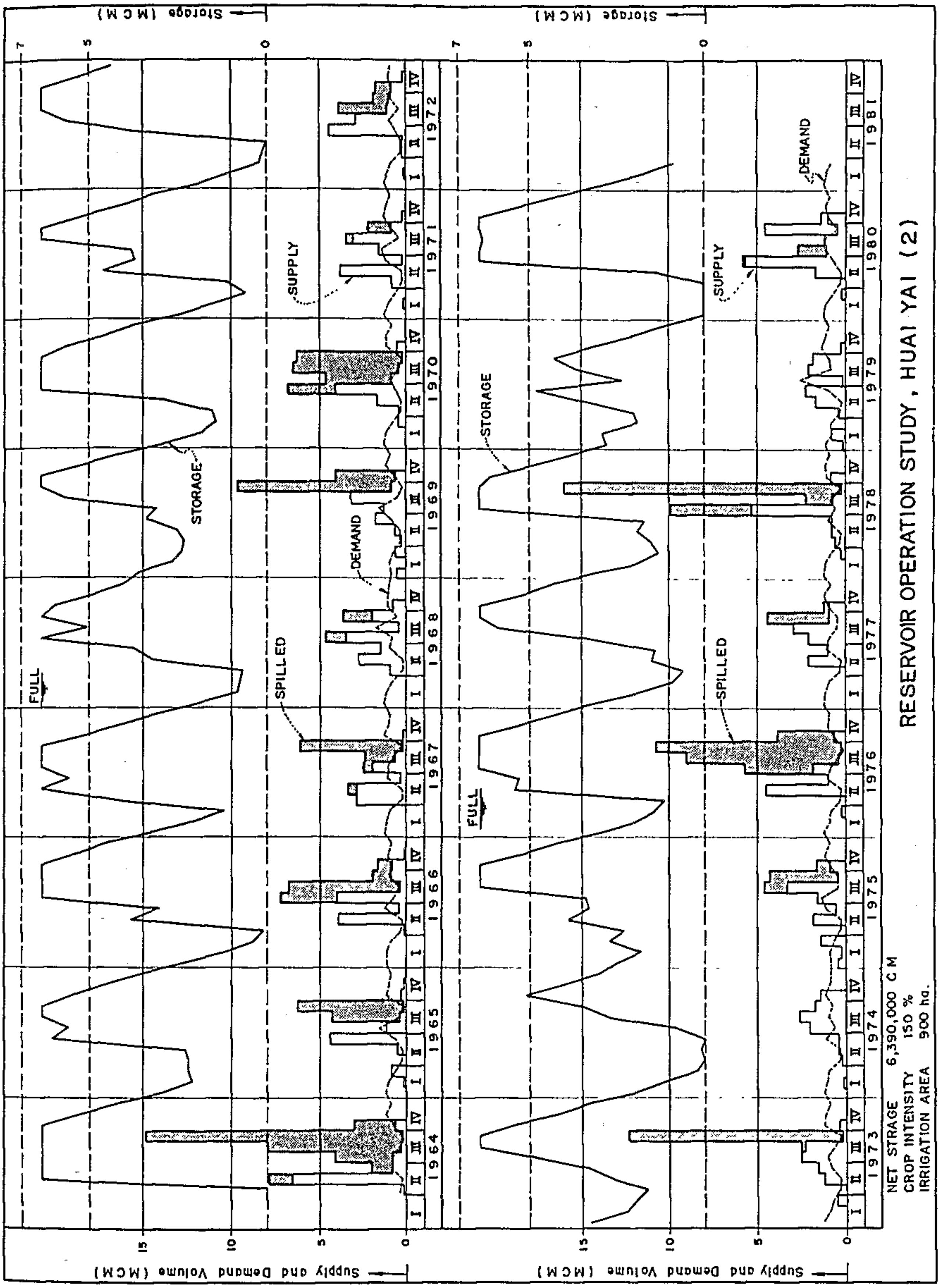

RESERVOIR OPERATION STUDY, HUAI KHON KAEN (2)
Storage (MCM)
Supply and Demand Volume (MCM)
STORAGE
SUPPLY
DEMAND
SPILLED
FULL
NET STRAGE 23,400,000 C.M
CROP INTENSITY 150 %
IRRIGATION AREA 3,300 ha
1964
1965
1966
1967
1968
1969
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981

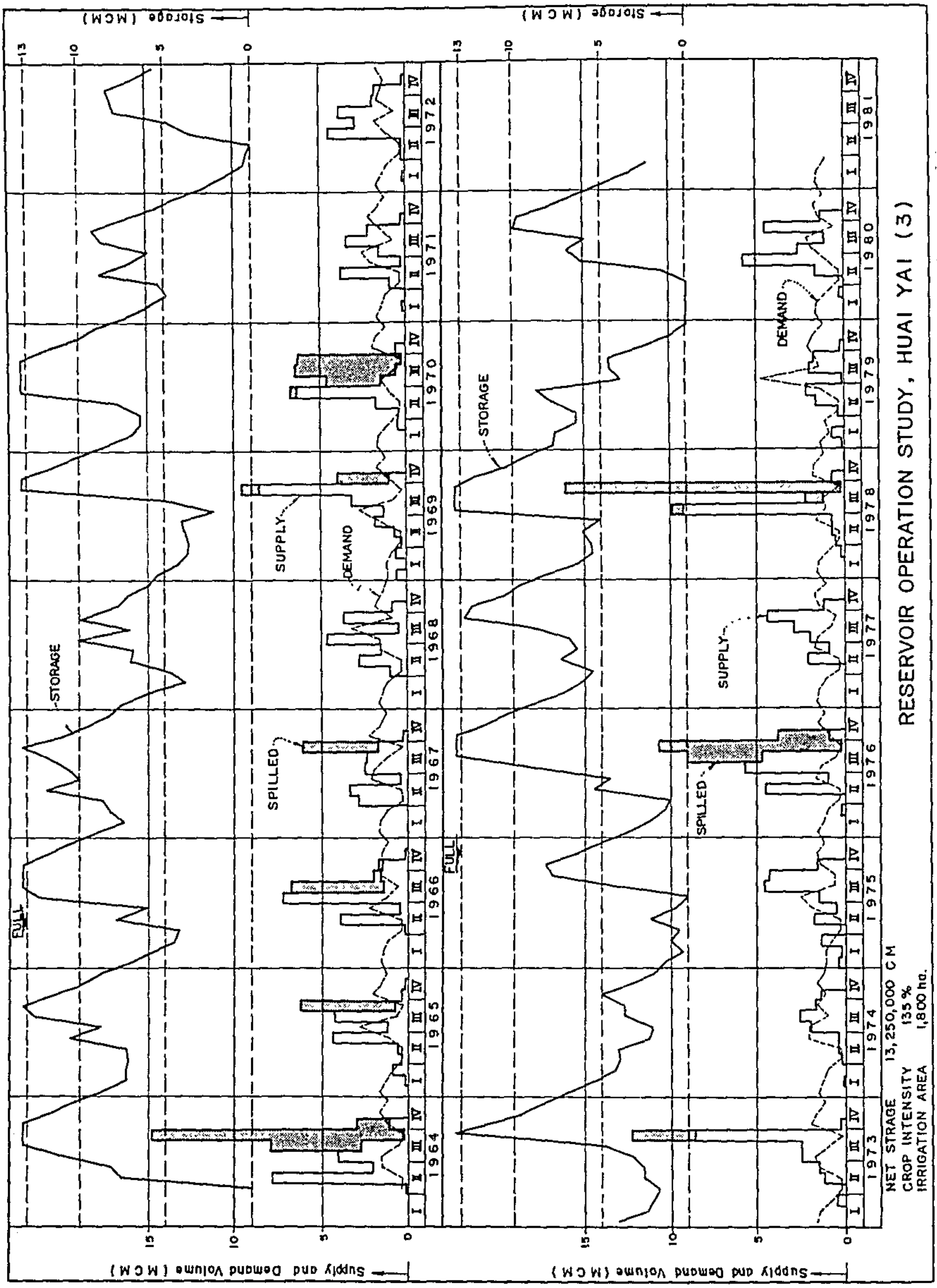


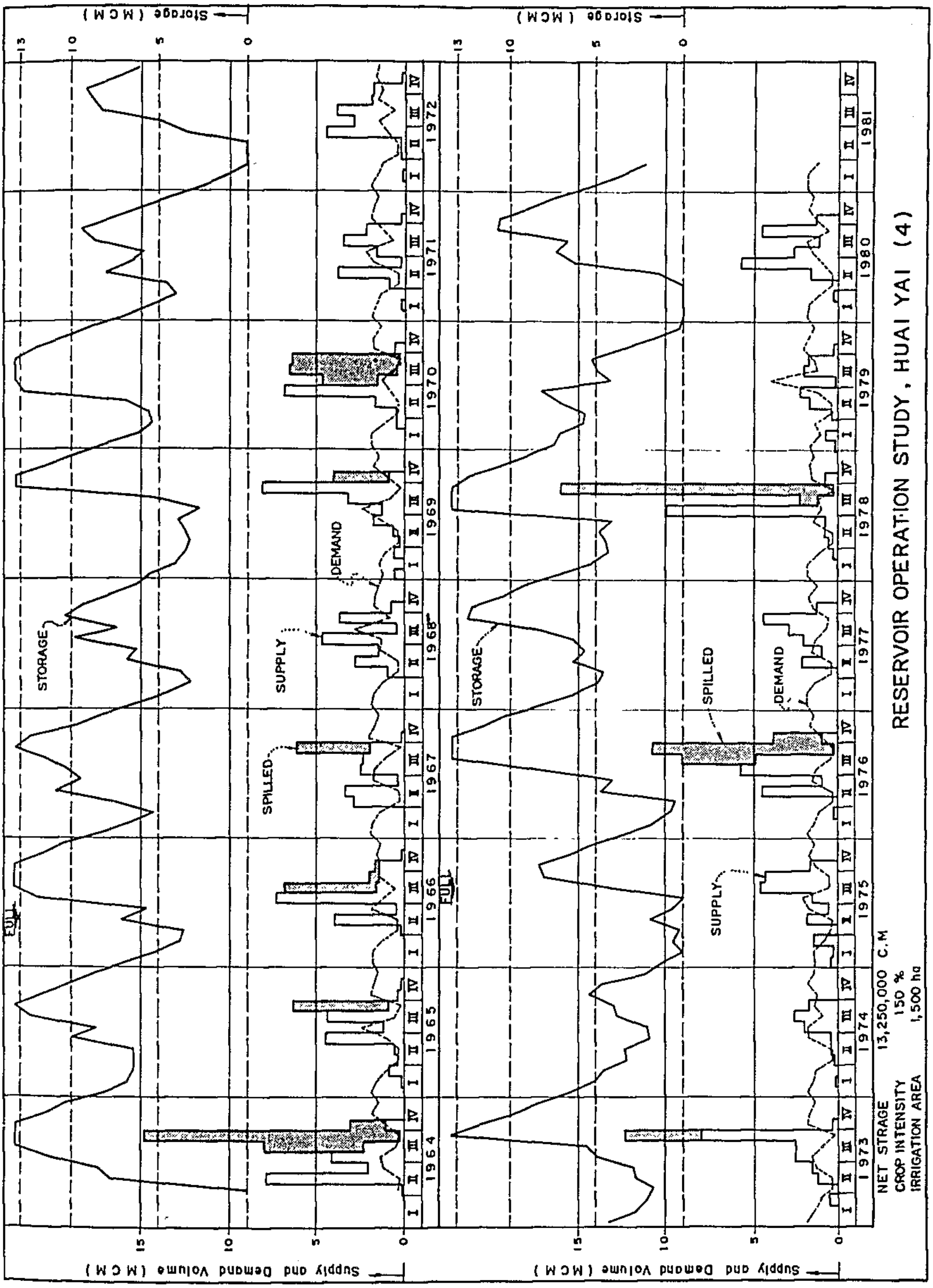
RESERVOIR OPERATION STUDY, HUAI KHON KAEN (3)


RESERVOIR OPERATION STUDY, HUAI KHON KAEN (4)
Storage (M C M)
Supply and Demand Volume (M C M)
STORAGE
SUPPLY
DEMAND
SPILLED
FULL
1964
1965
1966
1967
1968
1969
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
NET STRAGE 30,000,000 C.M
CROP INTENSITY 150 %
IRRIGATION AREA 4 100 ha


RESERVOIR OPERATION STUDY, HUAI YAI (1)
Storage (M C M)
Supply and Demand Volume (M C M)
STORAGE
SUPPLY
DEMAND
SPILLED
FULL
NET STRAGE 6,390,000 C.M
CROP INTENSITY 135%
IRRIGATION AREA 1,200 ha
1964
1965
1966
1967
1968
1969
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981


RESERVOIR OPERATION STUDY, HUAI YAI (2)
NET STRAGE 6,390,000 C M
CROP INTENSITY 150 %
IRRIGATION AREA 900 ha.
Storage (M C M)
Supply and Demand Volume (M C M)
STORAGE
SUPPLY
DEMAND
SPILLED
FULL


RESERVOIR OPERATION STUDY, HUAI YAI (3)
NET STRAGE 13,250,000 CM
CROP INTENSITY 135%
IRRIGATION AREA 1,800 ha.
Storage (MCM)
Supply and Demand Volume (MCM)
FULL
STORAGE
SUPPLY
DEMAND
SPILLED
1964
1965
1966
1967
1968
1969
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981



RESERVOIR OPERATION STUDY, HUAI YAI (4)

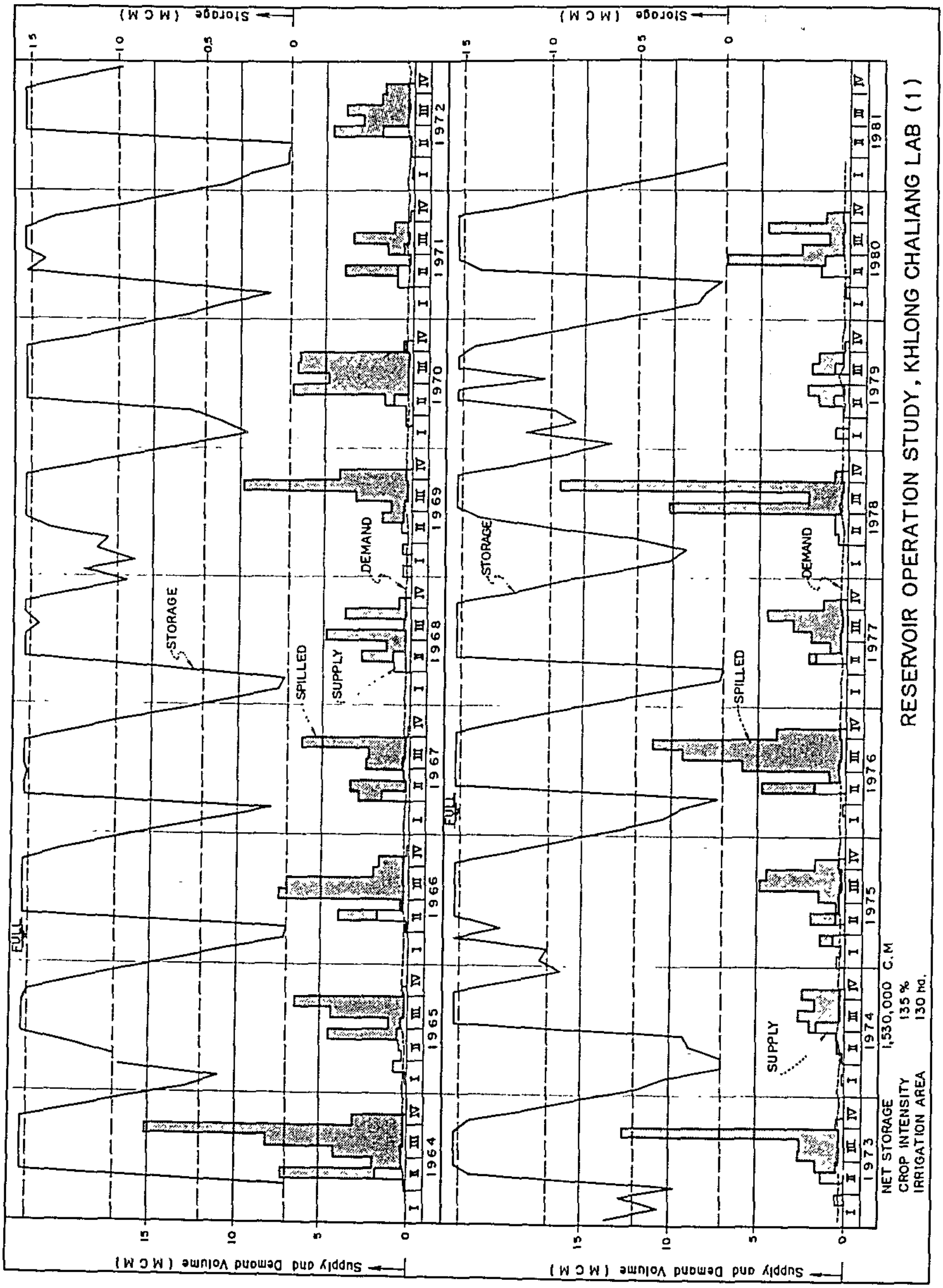
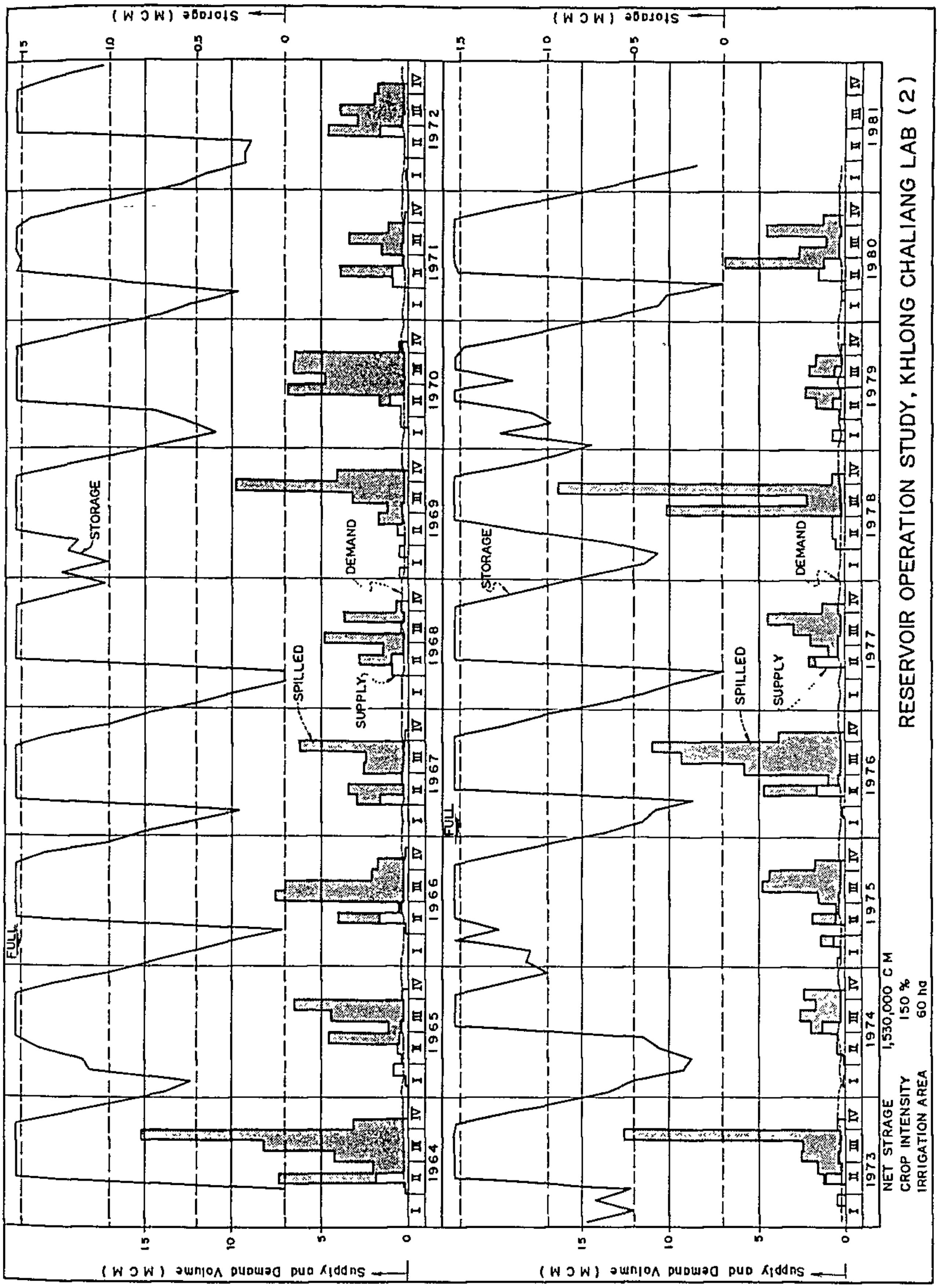

RESERVOIR OPERATION STUDY, KHLONG CHALIANG LAB (1)
Storage (M C M)
Supply and Demand Volume (M C M)
FULL
STORAGE
SPILLED
SUPPLY
DEMAND
NET STORAGE 1,530,000 C.M
CROP INTENSITY 135 %
IRRIGATION AREA 130 ha.
1964
1965
1966
1967
1968
1969
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981

FIG. VI-4
(2)



RESERVOIR OPERATION STUDY, KHLONG CHALIANG LAB (2)
Storage (M C M)
Supply and Demand Volume (M C M)
STORAGE
DEMAND
SUPPLY
SPILLED
FULL
NET STRAGE 1,530,000 C M
CROP INTENSITY 150 %
IRRIGATION AREA 60 ha
1964
1965
1966
1967
1968
1969
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981

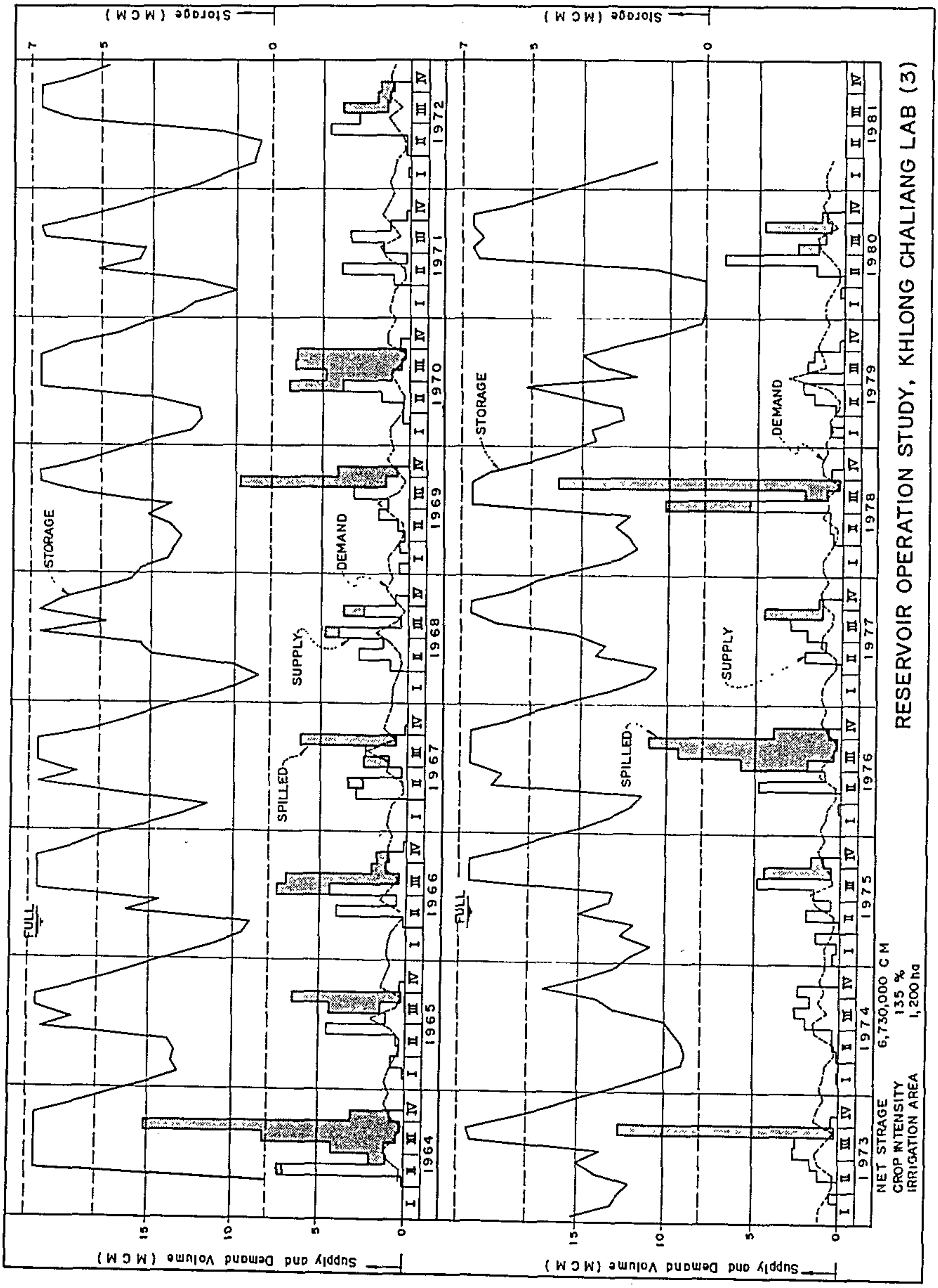
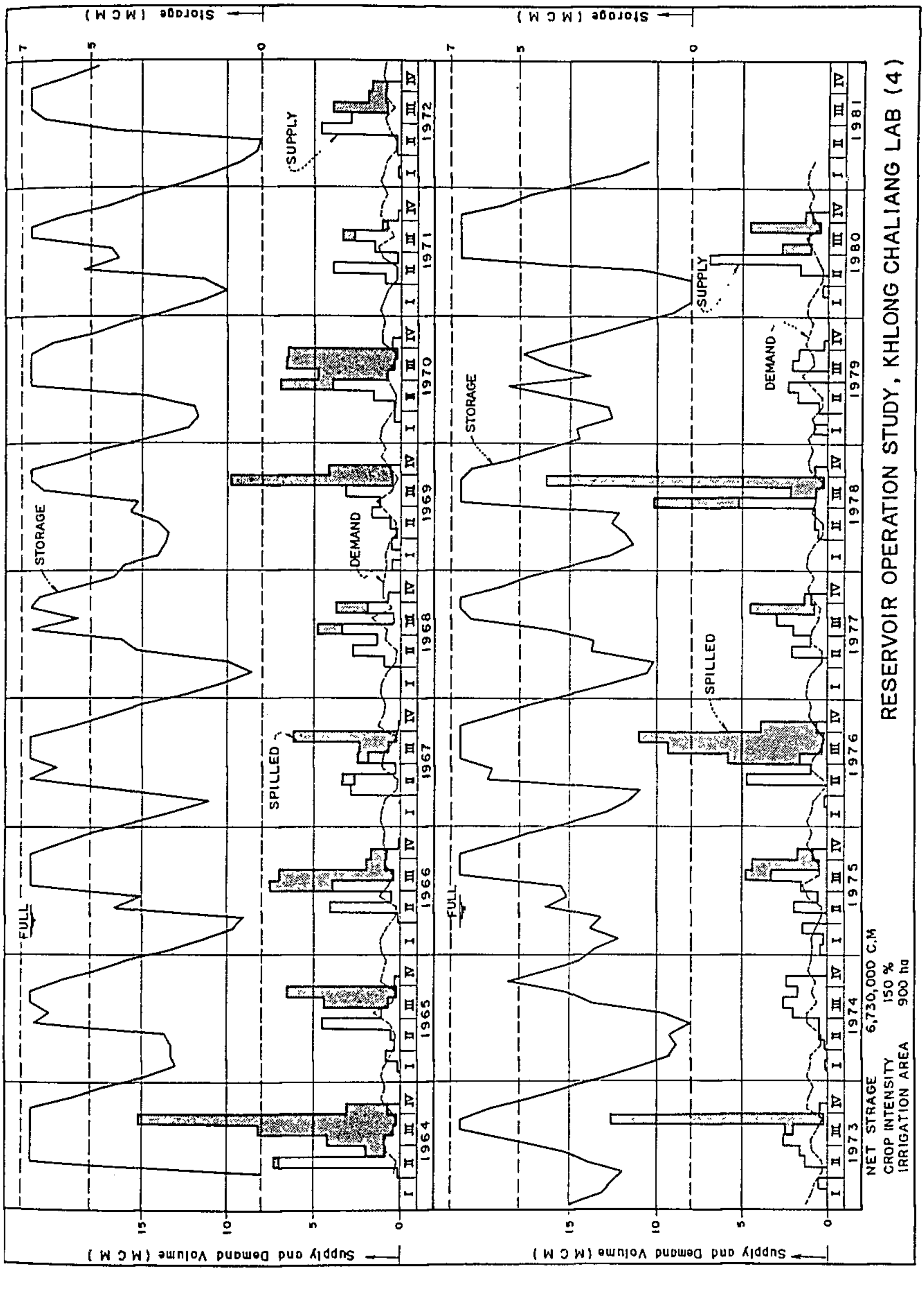

RESERVOIR OPERATION STUDY, KHLONG CHALIANG LAB (3)
Storage (M C M)
Supply and Demand Volume (M C M)
FULL
STORAGE
DEMAND
SUPPLY
SPILLED
1964
1965
1966
1967
1968
1969
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
NET STRAGE 6,730,000 C M
CROP INTENSITY 135 %
IRRIGATION AREA 1,200 ha

FIG. VI-4
(4)


RESERVOIR OPERATION STUDY, KHLONG CHALIANG LAB (4)
Storage (M C M)
Supply and Demand Volume (M C M)
FULL
STORAGE
DEMAND
SUPPLY
SPILLED
1964
1965
1966
1967
1968
1969
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
NET STRAGE 6,730,000 C.M
CROP INTENSITY 150 %
IRRIGATION AREA 900 ha

ANNEX VII
DAM AND RESERVOIR

ANNEX - VII

DAM AND RESERVOIR

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DAM AND RESERVOIR

1. DAM ENGINEERING

1.1 Dam Site

Four dam sites was initially reconnoitered by RID engineers, and the topographic survey and the geological investigation at the sites were subsequently undertaken by RID. Among four dam sites reconnoitered by RID, the Huai Yai dam site was shifted to about 500 m upstream from the original site at the pre-feasibility study stage in 1981, in due consideration of topographic and geologic conditions, and reservoir planning. To exploit the water resources endowed in each watershed to the maximum extent, each dam site was selected in the proximity of the debouchment to alluvial fan, so far as the topographic and geologic conditions are allowable.

1.1.1 Huai Saduang Yai

The proposed site for the Huai Saduang Yai dam is located at about 17 km northeastward from the Lom Sak Municipality approximately 16°53'37" north in latitude and 101°21'53" east in longitude. The gorge at the proposed site is relatively symmetric, having a steep slope of about 25° at its right abutment and 20° at its left abutment. Thus, the proposed site is blessed with the most favourable topographic condition for constructing fill dam. To make the storage capacity as large as possible, the dam embankment would be made as high as possible nearly to the top of both abutment. The small saddle behind the left abutment would be used for the disposition of emergency spillway. The lowest altitude of riverbed at the dam axis is about 164.0 m above MSL.

1.1.2 Huai Khon Kaen

The proposed site for the Huai Khon Kaen dam is located at about 1.5 km eastward from the Wang Khon Du village, the Lom Sak district, approximately 16°49'31" north in latitude and 101°22'11" east in longitude. The site comprises a gorge and two saddles separated by two gentle humps. The topography at the site is blessed with much favourable condition for constructing fill dam lower than the top of humps. In case a dam is proposed higher than the top of humps, special consideration should be paid to unequal consolidation of embankment. The existing channel gut meanders toward the vicinity of the left abutment; the lowest altitude of channel gut is about 171 m above MSL.

The altitude of the left and the right saddles is surveyed to be about 183.0 m above MSL., respectively; the altitude of the left and the right hump is surveyed to be about 212 m and 214 m above MSL.

1.1.3 Huai Yai

(1) Alternative Study of the Dam Axis

The site for the Huai Yai dam newly proposed at pre-feasibility study is located at about 25 km upstream from the confluence of the mainstem of the Pasak river and the Huai Yai river. To select an optimum dam axis, two alternative axes of main dam are studied at the proposed dam site, comparing the embankment volume of main dam and disposition of the spillway and outlet works for the respective dam axes. Their two alternative axes are illustrated in Fig. VII-1. As for saddle dam and spillway, the same types are installed for the alternative dams. General features of two alternative dams are tabulated as follows. Breakdown of the work volume is given in Table VII-1.

Item	Downstream Dam Axis		Upstream Dam Axis
Dam Height	38.00 m		38.65 m
Crest Length	791.00 m		617.00 m
Full Water Level	EL 216.50 m		EL 217.15 m
Dam Crest Elevation	EL 220.00 m		EL 220.65 m
Storage Capacity	14,000,000 m^3		14,000,000 m^3
Main Dam			
Embankment Volume	851,280 m^3		882,980 m^3
Excavation Volume	99,000 m^3		80,800 m^3
Spillway	————	Same	————
Outlet Conduit	200 m		380 m

Judging from the above table, the embankment value at the downstream axis is slightly less than that at the upstream dam axis. As for the dam foundation, geological investigation has been fully executed along the downstream dam axis and it is clarified that the foundation thereabout is sufficiently stable to support earth embankment. While, along the upstream dam axis, no geological investigation has been done so far. Furthermore, the downstream axis is topographically much favourable for disposition of outlet work. Based on the above three seasons, the downstream axis is picked out for the definite axis of the Huai Yai dam even though the axis is convex toward the downstream. The work quantity at the downstream axis is estimated as given in Table VII-2.

(2) Damsite

The dam site is located at approximately 16°28'57" north in latitude and 101°19'09" east in longitude. The dam site shapes the narrowest gorge at the debouchment of the Huai Yai valley and topographically much favourable for fill dam construction. The left bank abutment is steeply slanting with a slope of about 25°; the right bank abutment is relatively gentle with a slope of 15°. Behind the right bank abutment, there extends a shallow saddle which must be embanked. The altitude of the top of the left and right abutment of gorge is surveyed to be about 235 m and 215 m above MSL, respectively. The channel gut sharply meanders near the site and is close to the left bank abutment at the site: the lowest altitude at the channel gut is surveyed to be about 186 m above MSL at the site. The altitude of the saddle extending behind the right bank abutment is about 208 m above MSL.

1.1.4 Khlong Chaliang Lab

The proposed site for the Khlong Chaliang Lab dam is located at about 12 km due eastward from the Phetchabun Municipality, approximately 16°24'35" north in latitude and 101°17'24" east in longitude. The gorge at the site is narrow and V-shaped. The riverbed at the site is about 20 m wide and the lowest altitude of the channel gut is surveyed to be about 180 m above MSL. The left bank abutment is rather steeply slanting with a slope of about 30°; the right bank abutment is also steep with a slope of about 25°. The left bank abutment has a sufficient altitude for embankment; the right bank abutment is relatively as low as 200 m above MSL and an undulating low ridge stretches from the right bank abutment. The gorge is rather unfavourable for creating a large capacity of reservoir. To sharply increase the storage capacity of reservoir, the undulating long ridge has to be embanked.

1.2 Foundation and Construction Materials

1.2.1 Foundation

Essential requirements of foundation for fill dam are that it provides stable support for embankment under all conditions of saturation and loading, and that it provides sufficient resistance to seepage to prevent excessive loss of water.

As clarified in geologic and soil mechanic studies, the foundation at each dam site comprising interbedded sandstone and shale is sufficiently stable to support embankment. The base rock at each site is partly weathered and cracked, and indicates relatively high Luzéon value. But the high permeability of the foundation would be readily improvable by grouting. The drilled cores at each site evidence there exists no geological faults and/or fractured strata.

1.2.2 Construction Materials

(1) Embankment Materials

Qualitative and quantitative studies on embankment materials are dealt in ANNEX - II. Basically, all the embankment materials for each dam would be borrowed in and around the reservoir site. According to the results of in-situ visible study and the laboratory test on the sample obtained in the test pits, the borrowing plan of the embankment materials is proposed as hereinafter.

Core Materials:

According to the results of laboratory tests undertaken by RID, the core materials obtainable from the borrow area for the Khlong Chaliang Lab dam are naturally better-graded and readily embankable without any processing. While, the core materials obtainable from the borrow area for the Huai Saduang Yai, the Huai Khon Kaen, and the Huai Yai dam are fine-graded, slightly lacking in coarse materials. In order to propose the optimum plan for construction plan, further materials investigation is essential for the said three dams.

From economically conservative side, it is provisionally proposed at this moment that some amount of coarse materials should be so blended as to avoid crack in core zone after embankment and to increase workability and shearing stress of core materials. However, further investigation for core materials should be necessarily made in and around the said dam sites in the next study stage before determining a definite plan for collecting core materials.

Materials for Shell Zone:

Coarse materials for shell zone are sporadically scattered in and around reservoir site. To produce a large amount of the coarse materials in the vicinity of embankment site, deep excavation is essential until sub-surface layer or weathered rock; better-graded coarse materials are deposited deeper than about 3 m below ground surface. Otherwise, the coarse materials have to be collected and hauled for a few kilometer away from the embankment site. To utilize various kinds of coarse material obtainable in and around reservoir sites, the shell zone would be embanked as random fill.

(2) Concrete Aggregates and Filter and Riprap Materials

Concrete aggregates, filter and riprap materials would be purchased from the quarry sites developed by private sector, taking into account the total requirement at each dam site. The aggregates and riprap materials for the Huai Saduang Yai and the Huai Khon Kaen dam would be purchased at the Silalat crushing plant which is located at the half way from the Phetchabun to the Lom Sak along the National

Highway Route-21, and the plant is about 30 km remote away from both dam sites; those for the Huai Yai and the Khlong Chaliang Lab dam would be purchased at the Saluong crushing plant which is located at about 30 km southward from the Huai Yai site along the provincial road (Route 2271). The rock materials excavated at the sites of the service and emergency spillways would be used for riprapping so far as possible.

1.3 Selection of Type of Dam

The more common type for medium scaled dam is classified into earthfill, rockfill and concrete gravity. Among them, the concrete gravity dam would be left out of consideration in view of topography, foundation and project economy. The rockfill type offers relatively less embankment than the earthfill type. Actually however, the rockfill type is unfavourable in view of availability of rock materials, since it is clarified through material survey that no quarry site for the rockfill dam can be exploitable within the economic hauling distance.

After all, the earthfill type is the most eligible for each dam site, because the construction of earthfill dam involves utilization of material in the natural state requiring the minimum of processing. Moreover, the foundation requirements for earthfill dam are less stringent than for the other types. According to the outcomes of material survey, the top soil scattered around the embankment site are fine-grained, such as silty sand, clayey sand, sandy clay and silty clay. These materials are relatively suitable for impervious core. Coarse materials essential for shell zone are also obtainable within the economic hauling distance. In view of the proposed embankment height and the materials available in and around the site, zoned type of earthfill dam, which is more stable than homogenious type, would be proposed at each dam site.

1.4 Preliminary Design

1.4.1 Embankments

(1) Fundamental Consideration

The zoned type fill dam, selected in the preceding section, is so laid out that impervious core zone is arranged at central part of dam section and its upstream and downstream sides are covered with impervious and pervious shell zones. The impervious core zone mainly serves for water tightness, while the shell zone serves for stability of dam. The embankment materials for both zones should be basically obtained in and around dam site without any processing. The materials excavated at the sites of various appurtenant structures should be also fully used for the embankment of both zones.

Selection of the zoned type enables construction of high fill dam, because the zoned type dissipates pore pressure, makes phreatic line lower, and strengthens shearing stress of embankment. According to the outcomes of detailed field inspection, the construction of the zoned type fill dam seems to be technically feasible in view of availability of embankment materials. Design values on stability analysis are assumed as follows, based on soil test and referred to the design data of dams recently constructed.

Seismic Intensity:

Seismic intensity of 0.05 is assumed for stability analysis of dam on reference to that for the Srinagrind dam.

Physical and Mechanical Values of Embankment Materials:

Physical and mechanical values for core materials are estimated on the basis of the results of laboratory test. The values for random materials are assumed referring to design values for the dams recently constructed. The design values applied for the stability analysis in this study are as tabulated below:

- For core materials

Design Value \ Name of Dam		1. Huai Saduang Yai 2. Huai Khon Kaen 3. Huai Yai	1. Khlong Chaliang Lab
Coefficient of permeability	(k)	$5x10^{-6}$ cm/sec	$5x10^{-6}$ cm/sec
Wet unit density	(Vt)	1.9 t/m^3	1.8 t/m^3
Saturated unit density	(Vsat)	2.1 t/m^3	2.0 t/m^3
Submerged unit density	(Vsub)	1.1 t/m^3	1.0 t/m^3
U-U test			
Cohesion	(c)	0.25 kg/cm^2	0.25 kg/cm^2
Internal friction angle	(ø)	15°	15°
C-U test			
Cohesion	(c)	0.15 kg/cm^2	0.15 kg/cm^2
Internal friction angle	(ø)	30°	30°

- For random materials

Wet unit density		2.1 t/m^3
Saturated unit density		2.2 t/m^3
Submerged unit density		1.2 t/m^3
U-U test	cohesion (c)	1.0 t/m^2
	internal friction angle (ø)	25°
C-U test	cohesion (c)	1.0 t/m^2
	internal friction angle (ø)	30°

(2) Pore Water Pressure

Pore water pressure directly affects stability of fill dam and it is generally assumed to normally act on sliding plane. In the analysis, the pore pressure would be considered as given below:

(a) During construction and immediately after construction

Pore pressure in impervious zone is estimated by the Hilf's equation based on Load-Void ratio curve developed through the laboratory test as given below:

$$U = 0.60 \text{ kg/cm}^2 \quad (0 < \sigma < 6.0 \text{ kg/cm}^2)$$

$$U = 0.8\sigma - 1.2 \quad (\sigma \geqq 6.0 \text{ kg/cm}^2)$$

where, U: Pore water pressure (kg/cm^2)
σ: Total stress (kg/cm^2)

(b) Pore pressure caused by seepage through dam embankment at full water level

In this case, pore pressure is obtainable from flow net developed by the Casagrande's method. Dead weight of impervious materials embanked below phreatic line is deemed to be fully saturated.

(c) Residual pore pressure at rapid drawdown of water level

Total pore pressure in the core materials remains even after rapid drawdown of water level in reservoir. Dead weight of impervious materials below phreatic line is also deemed to be fully saturated.

(3) Seepage through Embankment

The phreatic line is drawn by the Casagrande's graphical method as line in Fig. VII-2.

Amount of percolation through embankments is estimated by equations as shown below:

$$Q = k \cdot y_o \cdot L \quad (m^3/sec)$$

$$k = \sqrt{kh \cdot kv} \quad (m/sec)$$

$$y_o = \sqrt{h^2 + d^2} - d \quad (m)$$

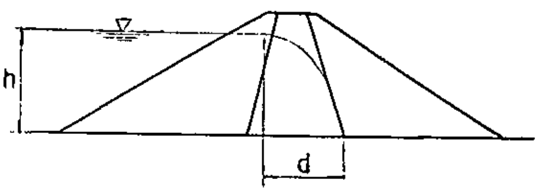
where, Q : Amount of percolation

k : Coefficient of permeability modified

kh : Horizontal coefficient of permeability

kv : Vertical coefficient of permeability

h,d: Distance shown below



L : Longitudinal length of embankments effected percolation

The amount of percolation is roughly estimated based on the above equation as given below:

Name of Dam	Seepage Amount	
	ℓ/sec	m^3/day
Huai Saduang Yai	0.59	50.9
Huai Khon Kaen	1.06	91.6
Huai Yai	0.52	44.9
Khlong Chaliang Lab	0.71	61.7

(4) Extra-Banking

Earthfill dam gradually settles down after terminating embankment works. Some extra banking would be previously made for the settlement of embankment, on the basis of the following equation and the data of the compaction test.

$$H = \frac{1}{2E} WH^2A$$

$$E = \frac{Pm}{S}$$

where, H : Extra banking (m)
E : Deformation coefficient (referred to ANNEX - II)
W : Unit weight of embankment (1.9 t/m)
Hd: Dam height (m)
A : Coefficient of settlement 0.35
Pm: Maximum load
S : Total settlement amount

The extra-banking for each dam is estimated as given below.

	Hd (m)	E (t/m)	H (m)	Extra-Banking (m)
Huai Saduang Yai	38.0	550	0.87	1.00
Huai Khon Kaen	57.0	1,100	0.98	1.00
Huai Yai	38.0	960	0.50	0.60
Khlong Chaliang Lab	35.3	740	0.53	0.60

(5) Stability Analysis of Dam

Stability analysis of each dam is made under following condition based on the design values derived from the laboratory test made by RID.

(a) Reservoir is filled up with storage water. The water level of reservoir is kept at normal full water level. The phreatic line in the embankment of dam is also kept steady (high water level state),

(b) Immediately after completion of embankment works, there occurs residual construction pore water pressure (post-construction state), and

(c) At rapid drawdown of water level, there also occurs residual pore water pressure (rapid drawdown state).

The equation for Swedish slip circle method is generally expressed as,

$$n = \frac{\sum\{C\ell + (N - U - N_e)\tan\phi\}}{\sum(T + T_e)}$$

where, n : Factor of safety

N : Normal force acting on slip circle of each slice

T : Tangential force acting on slip circle of each slice

U : Pore pressure acting on slip circle of each slice

N_e: Normal force of earthquake load acting on slip circle of each slice

T_e: Tangential force of earthquake load acting on slip circle of each slice

ϕ : Angle of internal friction of materials on slip circle of each slice

C : Cohesion of materials on slip circle of each slice

ℓ : Arc length of slip circle of each slice

The factor of stability against sliding estimated on the above equation should be sustained to be greater than 1.20 at least in any cases. The factors for various slip circle arches are obtainable by computer as illustrated in Fig. VII-2, and those for the critical slip circles for respective dams are as tabulated below:

Safety Factor on Stability of Dam

Case	Portion	Dam: Huai Saduang Yai	Dam: Huai Khon Kaen	Dam: Huai Yai	Dam: Khlong Chaliang Lab
A	Upstream slope	1.678	1.628	1.697	1.728
	Downstream slope	1.567	1.521	1.568	1.580
B	Upstream slope	1.526	1.481	1.549	1.572
	Downstream slope	1.301	1.251	1.568	1.308
C	Upstream slope	1.447	1.350	1.420	1.428
	Downstream slope	-	-	-	-

As summarized in the above table, the minimum factor of stability for each dam is greater than 1.20. Thus, it is clarified that the embankment of each proposed dam is fully stable from soil-mechanic view point.

1.4.2 Embankment Details

(1) Crest Design

The crest width of each dam is determined as given below in due consideration of available embankment materials, height of dam, possible roadway requirement, practicability of construction works, and provision of safe percolation gradient through embankment at full water level of reservoir. The roadway requirement and practicability of construction would be highly regarded in determining the crest width of each dam. Empirical formula derived from the above concepts would be applied for estimating the crest width.

$$B_1 = 3.6H^{1/3} - 3.0$$

$$B_2 = 0.6 + 1.1\sqrt{H}$$

where, B_1, B_2: Crest width (m)

H : Dam height (m)

The crest widths estimated on the above formula are averaged and rounded up as follows:

Dam	H (m)	B_1 (m)	B_2 (m)	B (m)
Huai Saduang Yai	38.0	9.1	7.4	8.0
Huai Khon Kaen	57.0	10.9	8.9	10.0
Huai Yai	38.0	9.1	7.4	8.0
Khlong Chaliang Lab	35.3	8.8	7.1	8.0

According to the above estimate, the Huai Khon Kaen dam is provided with the crest width of 10 m and the remaining dams are provided with the crest width of 8 m.

The surface drainage of the dam crest would be provided by sloping the crest 3% towards the upstream slope. A surfacing by gravels would be made for the crest for protection against damages caused by wave splash, rainfall runoff, wind, and traffic wear. The gravels of 50 cm thick would be spread over the crest.

(2) Freeboard

Normal freeboard is defined as a vertical distance between the crest of dam and the full water level, while the minimum freeboard is also defined as a vertical distance between crest of dam and the maximum reservoir water level caused by design flood and wave action. On reference to a criterion on freeboard recommended by USBR, the normal and minimum freeboards are estimated as mentioned hereinafter.

The maximum probable wind velocity in and around each dam site is estimated to be 50 miles per hour or 22.2 m/s based on the records in the Phetchabun Meteorological Station. While, the fetch of each reservoir at full water level is,

Reservoir	Fetch
Huai Saduang Yai	3.0 km
Huai Khon Kaen	2.3 km
Huai Yai	1.5 km
Khlong Chaliang Lab	1.5 km

Based on the USBR criterion, the freeboard for each dam is computed as given below:

Dam	Standard Estimate			
	Fetch (km)	Wave Height (m)	Normal Freeboard (m)	Minimum Freeboard (m)
Huai Saduang Yai	3.0	0.91	1.7	1.4
Huai Khon Kaen	2.3	0.88	1.6	1.3
Huai Yai	1.5	0.79	1.6	1.3
Khlong Chaliang Lab	1.5	0.79	1.6	1.3

Freeboard must be sufficient to prevent overtopping of embankment by abnormal and severe flooding and wave action of rare occurence.

Accounting some allowance for the extraordinary situation, the freeboard for each dam is conservatively determined as follows:

Dam	Normal Freeboard (m)	Minimum Freeboard (m)
Huai Saduang Yai	3.5	1.5
Huai Khon Kaen	4.5	1.5
Huai Yai	3.5	1.5
Khlong Chaliang Lab	3.5	1.5

(3) Upstream Slope and its Protection

To determine the upstream slope of each dam, special consideration would be given to available embankment materials, foundation condition, and dam height. The upstream slope usually varies from 1 : 2.0 to 1 : 4.0. A storage dam, subject to rapid drawdown of the reservoir, should have an upstream zone with permeability sufficient to dissipate pore water pressures exerted outwardly in the stream part of dam. The embankment materials for random zone available around each dam site are rather fine and contain less coarse materials. Therefore, a gentle slope of 1 : 3.0, vertical to horizontal, would be provided for the upstream slope of each dam against rapid drawdown.

The upstream slope of earthfill dam must be protected against destructive wave action. The slope protection would extend from the crest of the dam to the lowest water level. Usual types of surface protection for the upstream slope are made with rock riprap, either dry-dumped or hand-placed, and concrete pavement. Among the types mentioned above, the concrete pavement is left out of consideration due to high construction cost, and consolidation and settlement of the embankment materials behind the slope protection. In due consideration of quality of rock materials and construction cost, the hand-placed riprap is selected for the upstream slope protection for each dam. All the rock materials for riprapping should be hard, dense, and durable, and should be able to resist long exposure to weathering. The materials would be hauled from the quarry site where a large amount of hard limestone suitable for riprapping is readily available at any time.

Thickness of riprap must be sufficient to accommodate the weight and size of stone necessary to resist wave action. The thickness and gradation of riprap are decided as follows based on the criteria offered by USBR.

Thickness	Max. Size	40 to 50% greater than	50 to 60% from - to	0 to 10% less than
1.0 m	1.2 ton	0.56 ton	0.035 - 0.56 ton	0.035 ton

A graded gravel layer of 50 cm would be provided underneath the riprap in order to prevent the compacted materials from washing out through voids in the riprap by wave action.

(4) Downstream Slope and its Protection

In view of nature of embankment materials available for random zone, the proposed zone typed earthfill dam is substantially similar to homogeneous type. A slope of 1 to 2.5, which is rather gentle for downstream slope, would be conservatively provided for each dam.

This type of dam must be modified to provide for the inclusion of internal drainage facilities. A vertical filter of 2.0 m thick would be aligned between the core zone and the downstream shell zone to lower the phreatic line and to stabilize the downstream portion of dam. Furthermore, to smoothly drain the seepaged water in the filter, a horizontal drain of 2.0 m thick extends from the foot of vertical filter to the downstream toe of embankment where a rockfill toe would be placed to quickly drain the seepaged water through the drain.

To prevent the embankment from erosion caused by wind and/or rainfall runoff, a sod-facing would be proposed on the downstream slope. Drainage berms of 2.0-m width would be provided at every 10 m vertical on the downstream slope. Besides, to eliminate unsightly gullings and boggy areas which are likely to cause at the contact of the toe of embankment with earth abutment and valley floor, gutters would be placed along the said contact: the gutters would be composed of dry-rock.

1.4.3 Appurtenant Structures

(1) Spillways

All the proposed dams are provided with two kinds of spillway, i.e. service spillway and emergency spillway. The service spillway functions for relatively low magnitude of flood; it is designed with a flood of 100-year recurrence. The emergency spillway has a supplemental function for the service spillway in case of extraordinary flood of 500-year recurrence.

The selection of spillway is vitally influenced by the condition of site for spillway. Prior to the selection of the type of spillway, the following items would be highly regarded:

- Steepness of terrain,
- Amount of excavation,
- Availability of excavated materials for embankments,
- Lining requirement, and
- Bearing capacity of foundation, etc.

Generally, side channel, chute, and glory hole spillways are eligible for filldam. The glory hole spillway seems to be economically and technically disadvantageous at each proposed site, because no diversion tunnel is excavated and available for discharging floods, and the reservoir is relatively deep. Thus, the side channel and chute spillways are eligible for each proposed site.

Service spillway must be designed to safely pass exceeding floods which are likely to occur frequently. A comparative study between the side channel and the chute type is made prior to determining the type of spillway. As the results, the side channel spillway is selected for the service spillway at each dam site.

In each dam site, there extends saddle or depression along the rim of reservoir which leads into natural waterway and is much favourable for constructing chute spillway. Therefore, chute type spillway would be proposed for the emergency spillway of each dam.

(a) Service spillway

Ungated side-channel type is selected for the service spillway. The spillway is composed of side channel, transition, chute, and energy dissipator.

The service spillway for each dam would be aligned close to the top of left or right abutment at each dam site, contemplating the topographic and geologic conditions at abutment and meandering existing river channel. Flooding water spilled over the weir would be released into the existing river channel of each tributary through the chute and the energy dissipator. The design discharge and alignment of each service spillway are as summarized below:

Dam	Design Discharge (m^3/s)	Alignment
Huai Saduang Yai	445.7	Right Abutment
Huai Khon Kaen	821.1	Left Abutment
Huai Yai	289.5	Left Abutment
Khlong Chaliang Lab	248.0	Left Abutment

To find out the optimum crest length of overflow weir of each service spillway, flood routing in each reservoir is graphically made, and the results are as given below by altering the crest length of overflow weir.

Huai Saduang Yai

Inflow Peak Discharge	Crest Length of Spillway	Outflow Peak Discharge	Overflow Water Level	Depth
445.7 m^3/sec	100 m	386 m^3/sec	EL 197.14	1.64 m
	105 m	391 m^3/sec	EL 197.10	1.60 m
	110 m	402 m^3/sec	EL 197.08	1.58 m
	120 m	406 m^3/sec	EL 197.00	1.50 m

Huai Khon Kaen

Inflow Peak Discharge	Crest Length of Spillway	Outflow Peak Discharge	Overflow Water Level	Depth
821.1 m^3/sec	100 m	789 m^3/sec	EL 219.15	2.65 m
	110 m	800 m^3/sec	EL 219.00	2.50 m
	120 m	811 m^3/sec	EL 218.88	2.38 m

Huai Yai

Inflow Peak Discharge	Crest Length of Spillway	Outflow Peak Discharge	Overflow Water Level	Depth
289.5 m^3/sec	60 m	255.6 m^3/sec	EL 218.25	1.75 m
	65 m	265.0 m^3/sec	EL 218.20	1.70 m
	70 m	266.0 m^3/sec	EL 218.12	1.62 m

On reference to the result of flood routing summarized above and the topographic condition at the site selected for each service spillway, the crest length of overflow weir is determined respectively as given below:

Dam	Crest Length (m)
Huai Saduang Yai	105
Huai Khon Kaen	110
Huai Yai	65

Width, depth, and sill of side channel, transition, chute, and energy dissipator for each spillway are determined as given below, based on a flood of 500-year recurrence. Hydraulic calculation in side channel is made by the wellknown Hind's formula.

Huai Saduang Yai

Structure of Spillway	Width of Channel (m)	Depth of Channel (m)	Sill of Channel EL (m) above MSL
Side Channel	6.0 - 10.0	7.2 - 14.2	192.00 - 185.00
Transition	12.0	14.2 - 8.0	185.00 - 184.85
Chute	12.0 - 18.0	5.0 - 12.50	184.85 - 160.00
Energy Dissipator	18.0	12.50	160.00

Huai Khon Kaen

Structure of Spillway	Width of Channel (m)	Depth of Channel (m)	Sill of Channel EL (m) above MSL
Side Channel	10 - 20	8.6 - 15.1	212.60 - 206.10
Transition	25	15.1 - 8.0	206.10 - 205.91
Chute	25	5.0 - 16.0	205.91 - 165.00
Energy Dissipator	25	16.0	165.00

Huai Yai

Structure of Spillway	Width of Channel (m)	Depth of Channel (m)	Sill of Channel EL (m) above MSL
Side Channel	6.0 - 8.0	6.8 - 16.80	213.40 - 208.40
Transition	10.0	11.8 - 7.00	208.40 - 208.01
Chute	10.0	4.0 - 14.0	208.01 - 180.00
Energy Dissipator	10.0	14.0	180.00

The service spillway for the Khlong Chaliang Lab would be jointly constructed with the emergency spillway due to the topographic constraints. No flood retention is expected at all in the Khlong Chaliang Lab reservoir, since the ratio of pool area to drainage area is extremely low.

Hence, the inflow peak discharge is applied for determining the hydraulic dimension of the spillway for the Khlong Chaliang Lab. From the topographic constraints, the crest length of overflow weir is limited to be 70.0 m. The surcharge head caused by the inflow flood of 100 year return period is estimated as,

$$Q = CBH^{3/2}$$

where, Q: Design discharge, 244.2 m^3/sec (see ANNEX - I)

C: Coefficient of overflow, 1.84

B: Crest length of weir, 70.0 m

H: Surcharge head

$$H = (Q/C \cdot B)^{2/3}$$

$$= (244.2/1.84 \times 70.0)^{2/3}$$

$$\fallingdotseq 1.55 \text{ m}$$

Hydraulic calculation on side-channel, transition, chute, and energy dissipator are made for the Khlong Chaliang Lab spillway as well as the other spillways to determine the hydraulic dimension of the spillway. The main features of channel can be summarized as follows:

<u>Khlong Chaliang Lab</u>

Structure of Spillway	Width of Channel (m)	Depth of Channel (m)	Sill of Channel EL (m) above MSL
Side Channel	6.0 - 8.0	6.5 - 11.5	203.70 - 198.70
Transition	10.0	11.5 - 7.0	198.70 - 198.57
Chute	10.0	5.0 - 14.0	198.57 - 174.00
Energy Dissipator	10.0	14.0	174.00

(b) Emergency spillway

The emergency spillway supplements the service spillway to spill out excess flood in the reservoir during such a extraordinary flood as 500-year recurrence. Each spillway would be aligned on the topographic saddle extending behind the left or right abutment, excepting the spillway for the Khlong Chaliang Lab. As before mentioned, the emergency spillway for the Khlong Chaliang Lab would be jointly proposed with the service spillway which is aligned close to the abutment.

The design discharge and alignment for each emergency plus service spillway are as summarized below:

Dam	Design Discharge (m^3/s)*	Alignment of Spillway
Huai Saduang Yai	577.3	Left Bank Saddle
Huai Khon Kaen	1,069.9	Right Bank Saddle
Huai Yai	367.6	Right Bank Saddle
Khlong Chaliang Lab	310.1	Left Bank Abutment

* This discharge is split out by both service and emergency spillways.

Ungated overflow type would be proposed for all the emergency spillway excepting the spillway for the Khlong Chaliang Lab. This type of the emergency spillway is composed of overflow weir and guide channel as required. Flooding water spilled over the weir rushes into natural glens and is finally released into existing river channel thereabout through the guide channel.

The crest length of emergency spillway is determined by the following formula:

$$Q = CB_1h_1^{3/2} + CB_2h_2^{3/2}$$

where, Q : Design discharge

C : Coefficient of overflow; 1.84

B_1: Crest length of service spillway

h_1: Overflow depth at service spillway

B_2: Crest length of emergency spillway

h_2: Overflow depth at emergency spillway

In the light of the allowable surcharge head which must be kept 1.5 m lower than the crest elevation, the overflow depth for each service spillway is estimated. Then, the crest elevation for the emergency spillway is assumed to get the overflow depth for each emergency spillway. The outspilled discharge from both service and emergency spillways would be iterated by altering the crest length of emergency spillway until the spilled discharge meets the extraordinary design discharge of 500-year recurrence. The outcomes of calculation can be summarized in the table below:

Dam	Design Discharge Q (m^3/s)	B_1 (m)	h_1 (m)	Q_1 (m^3/s)	B_2 (m)	h_2	Q_2	Total Spilled Discharge $Q_1 + Q_2$
Huai Saduang Yai	577.3	105.0	2.0	546.5	70.0	0.4	32.5	579.0
Huai Khon Kaen	1,069.9	110.0	2.95	1,025.5	80.0	0.45	44.4	1,069.9
Huai Yai	367.6	65.0	2.0	338.3	100.0	0.3	30.2	368.5
Khlong Chaliang Lab	310.1	70.0	1.8	311.0	-	-	-	311.0

Based on the above calculation, the crest length for each emergency spillway is determined as,

Dam	Crest Length (m)
Huai Saduang Yai	70.0
Huai Khon Kaen	80.0
Huai Yai	100.0
Khlong Chaliang Lab	70.0 (same to the crest length of service spillway)

Flood retention in the reservoir is disregarded in the above calculation in due consideration of critical condition under the extraordinary food.

(c) Reservoir flood routing

Accumulation of storage in a reservoir depends on the difference between the rates of inflow and outflow. For an interval of time Δt, this relationship can be expressed by the equation below:

$$\Delta S = Q_i \Delta t - Q_o \Delta t \quad \text{or} \quad \frac{\Delta S}{\Delta t} = Q_i - Q_o$$

where, ΔS: Storage accumulated during Δt

Q_i: Average rate of inflow during Δt

Q_o: Average rate of outflow during Δt

The Ekdahl method is applied for solving the continuous equation above. The calculation is made by computer as compiled in the Data Book. The outcomes can be summarized as given below.

		Design Flood	Extra-ordinary Flood	P.M.F.
Huai Saduang Yai	Regulated Discharge (m^3/s)	49.5	46.2	32.7
(Dam Crest: EL.199.00)	Max. Water Level (EL. m)	197.12	197.41	198.09
(FWL : EL.195.50)	Surcharge	1.62	1.91	2.59
	Freeboard (m)	1.88	1.59	0.91
Huai Khon Kaen	Regulated Discharge (m^3/s)	14.3	11.3	17.6
(Dam Crest: EL.221.00)	Max. Water Level (EL. m)	219.01	219.43	220.73
(FWL : EL.216.50)	Surcharge	2.51	2.93	4.23
	Freeboard (m)	1.99	1.57	0.27
Huai Yai	Regulated Discharge (m^3/s)	35.27	28.18	12.69
(Dam Crest: EL.220.00)	Max. Water Level (EL. m)	218.16	218.46	219.40
(FWL : EL.216.50)	Surcharge	1.66	1.96	2.90
	Freeboard (m)	1.84	1.54	0.60
Khlong Chaliang Lab	Regulated Discharge (m^3/s)	12.15	14.89	12.14
(Dam Crest: EL.210.00)	Max. Water Level (EL. m)	207.99	208.25	209.77
(FWL : EL.206.50)	Surcharge	1.49	1.75	3.27
	Freeboard (m)	2.01	1.75	0.23

As shown in the table above, each reservoir retains relatively small amount of flooding water and has less function of flood mitigation. The surcharge in each reservoir caused by the retention of flooding water is limited within the provided freeboard even under the probable maximum flood (P.M.F.).

(2) Outlet Works

The outlet works comprise intake tower, outlet conduit and access bridge. The water offtaken at the intake tower is dissipated its energy at the bottom of intake tower and then free-flows through outlet conduit. The area of regulating gate is determined by the following orifice formula:

$$Q = C \cdot A \cdot \sqrt{2gh} \quad \text{or} \quad A = Q/C \cdot \sqrt{2gh}$$

where, Q: Design discharge
C: Coefficient 0.62
g: Acceleration of gravity 9.8 m/sec^2
h: Half distance between gates

The calculation can be as summarized in the below table:

Dam	Design * Discharge (Q) (m^3/sec)	Coeffi-cient (c)	Hydraulic Head (h) (m)	Area of Gate (a) (m2)	Side of Square Gate (a) (m)
Huai Saduang Yai	5.496	0.62	2.25	1.325	1.2
Huai Khon Kaen	5.468	0.62	2.50	1.260	1.2
Huai Yai	1.875	0.62	2.25	0.460	0.7
Khlong Chaliang Lab	1.277	0.62	2.00	0.330	0.6

* See ANNEX - VIII

Each intake tower is of reinforced concrete and equipped with four or five regulating gates, respectively. The sill elevation of each gate at each intake tower is proposed as given below:

Dam	Regulating Gate				
	No. 1	No. 2	No. 3	No. 4	No. 5
Huai Saduang Yai	EL.191.00	EL.186.50	EL.182.00	EL.174.50	-
Huai Khon Kaen	EL.211.50	EL.206.50	EL.201.50	EL.196.50	EL.187.50
Huai Yai	EL.212.00	EL.207.50	EL.203.00	EL.197.00	-
Khlong Chaliang Lab	EL.202.50	EL.198.50	EL.194.50	EL.189.00	-

The section of outlet conduit would be initially constructed for the channel diversion during embankment work and then, is given a function of outlet conduit at the later stage of construction works.

The size of each conduit is mainly determined based on the construction plan for embankment and hydrological condition during construction period, disregarding the offtake discharge of each outlet work. The diameter of conduit is conservatively determined to be 2.0 m for each conduit in view of river diversion works. The steep longitudinal slope of 1 : 200 is given for each conduit to get a drainage capacity as large as possible, within the limits of permissible velocity for reinforced concrete channel.

While, the capacity of conduit is also examined in view of the conveyance of the offtake discharge for outlet work. Among the four outlet work, the maximum offtake discharge of 5.496 m^3/s is proposed for the Huai Saduang Yai outlet work. The examination is made by the following formula, based on the hydraulic condition at the Huai Saduang Yai outlet work.

$$Q = \alpha \beta^{\frac{2}{3}} \cdot I^{\frac{1}{2}} \cdot r^{\frac{8}{3}} \cdot \frac{1}{n}$$

where, Q : Design discharge; 5.496 m^3/sec

$\alpha\beta^{\frac{2}{3}}$: Coefficient according to the ratio of radius to water depth

I : Longitudinal slope of conduit; 1/200

r : Radius of conduit

n : Coefficient of roughness; 0.015

$$5.496 = \alpha\beta^{\frac{2}{3}} \left(\frac{1}{200}\right)^{\frac{1}{2}} \times 1.0^{\frac{8}{3}} \times \frac{1}{0.015}$$

$$\alpha\beta^{\frac{2}{3}} = 1.166$$

From a nomograph for hydraulic depth and coefficient $\alpha\beta^{\frac{2}{3}}$, the depth is estimated to be about 1.2 m which is less than 2.0 m, the proposed diameter of conduit. The conduit intitially constructed for diversion conduit is, therefore, safety appropriate for the outlet work.

A bridge access to intake tower would be spanned between the dam crest or abutment and the tower for each outlet work to operate regulator equipped with. The bridge is composed of steel girders. The span would be limited within 35 m. The abutments and piers are of reinforced concrete. The main features of outlet works can be summarized as below:

Dam	Intake Tower		Outlet Conduit		Bridge	
	Size (mm)	Height (m)	Diameter (mm)	Length (m)	Length (m)	Bridge (nos)
Huai Saduang Yai	4,000 x 4,000	29.0	2,000	145	59	2
Huai Khon Kaen	4,000 x 4,000	37.0	2,000	200	105	3
Huai Yai	4,000 x 4,000	37.5	2,000	140	105	3
Khlong Chaliang Lab	4,000 x 4,000	25.5	2,000	160	62	2

1.4.4 Foundation Treatment

(1) Excavation of Foundation

In advance of embankment work, stripping would be made all over the embankment site to completely eliminate organic materials in the top soil and to obtain a stable support. The shell zone would be embanked directly on the soil layer after stripping. But in order to create impervious zone, a key trench would be excavated at the site of impervious zone after the stripping with a cut slope of 1 to 1.0 on both side down to the depth in which grouting is workable. Thus, fluvial deposits and highly weathered rocks and argillized strata would be clearly eliminated at the trench site.

(2) Grouting

Curtain grouting works would be made directly from the bottom of key trench. The grouting would be made to the following extent.

i) The grouting would be made deeper than existing aquifer.

ii) The grouting would be made so that the permeability at foundation will be decreased by 1 to 5 Lugéon value.

The grouting holes would be arranged three meter meshes at the longitudinal three rows. The effects after grouting would be confirmed by the Lugéon value to be measured at permeability test holes. In case the permeability stipulated above is not attainable, supplemental groutings would be further carried out. The grouting length for each dam site is mentioned in Section 1.5 hereof (WORK QUANTITY). Immediately after completing the required grouting, the trench would be filled by impervious materials for water barrier.

1.5 Work Quantity

On the basis of the preliminary design, the drawing for each dam are prepared as attached to the report. The quantity takings are made, as summarized in Table VII-2 on the drawings for the cost estimate.

2. RESERVOIR PLAN

2.1 Selected Reservoir Site

General rules for choice of reservoir sites are:

i) A suitable dam site must exist since the dam cost is a vital factor in selection of a site,

ii) The cost of real estate in the site must not be excessive,

iii) The site to be selected has an adequate capacity for the maximum exploitation of water resources

iv) A deep reservoir is preferable to a shallow one because of low land acquisition cost, less evaporation, and less weed growth.

Among the four items above, the item i) and iii) are highly regarded so as to exploit the endowed water resources to the maximum extent. It is virtually impossible to locate a reservoir site having completely ideal characteristics. The selected sites are, however, the most favourable for storage of water under the given conditions.

All the proposed reservoir sites are topographically gentle and rolling, and enclosed by low hilly ranges. Each valley to be pooled by constructing dam is rather narrow and shallow. The pocket for each reservoir is not so favourable for storing water. The storage ratio or storage capacity by embankment volume is estimated for each reservoir and summarized in the following table, together with impounded area at full water level.

Reservoir	Storage Capacity (MCM)	Embankment Volume (MCM)	Storage Ratio	Impounded Area (km^2)
Huai Saduang Yai	27.00	1.09	24.77	2.08
Huai Khon Kaen	30.00	3.41	8.80	1.60
Huai Yai	13.25	0.84	15.77	1.09
Khlong Chaliang Lab	6.73	0.84	8.01	0.65

Among the selected reservoir sites, the Huai Saduang Yai reservoir site shows the highest storage ratio and economically the most favourable for storing water.

2.2 Physical Characteristics

2.2.1 Elevation-Storage and Elevation-Area Curves

The elevation-volume and -area curves for each reservoir are developed by planimeter on the basis of topographic maps of 1/4,000 scale. The occupied by upstream embankment is eliminated out of storage area to get more detailed storage capacity. The elevation-storage and -area curves are given in Fig. VII-3.

2.2.2 Pool Level

The normal pool level or the full water level for each reservoir is determined based on the result of reservoir operation study which is undertaken in the course of the alternative study on the optimum project scale (ANNEX - VI). While, the minimum pool level or the dead water level is determined on the basis of the deposited sediments in the reservoir (the sedimentation is mentioned in Section 2.4) and the elevation-volume curve, aforementioned. The maximum water level is defined as the water level which is the surcharge head caused by the extraordinary flood of 500-year recurrence plus the normal pool level. These pool levels can be summarized as follows:

Reservoir	Minimum Pool Level	Normal Pool Level	Maximum Pool Level	Effective Storage Depth (m)
Huai Saduang Yai	EL.174.50	EL.195.50	EL.197.50	21.00
Huai Khon Kaen	EL.187.50	EL.216.50	EL.219.50	29.00
Huai Yai	EL.197.00	EL.216.50	EL.218.50	19.50
Khlong Chaliang Lab	EL.189.00	EL.206.50	EL.208.30	17.50

2.2.3 Useful and Dead Storage Capacity

The dead storage capacity is equivalent to the deposited sediment volume mentioned in Section 2.4. The useful storage capacity is estimated by deducting the dead storage capacity from the full storage capacity.

Each useful and dead storage capacities can be summarized as follows:

Reservoir	Full Storage Capacity (m^3)	Dead Storage Capacity (m^3)	Useful Storage Capacity (m^3)
Huai Saduang Yai	27,960,000	960,000	27,000,000
Huai Khon Kaen	33,220,000	3,220,000	30,000,000
Huai Yai	14,000,000	750,000	13,250,000
Khlong Chaliang Lab	7,500,000	770,000	6,730,000

2.2.4 Surcharge Storage

The surcharge storage is estimated as a retained flood in the reservoir during extraordinary flood of 500-year recurrence. The retained flooding capacity is estimated based on the capacity of the service and emergency spillways. The estimated surcharge for each reservoir is as given in the table below:

Reservoir	Overflow Depth at Emergency Spillway (m)	Overflow Depth at Service Spillway (m)	Surcharge Storage (m^3)
Huai Saduang Yai	0.4	2.0	4,700,000
Huai Khon Kaen	0.5	3.0	5,000,000
Huai Yai	0.3	2.0	2,100,000
Khlong Chalinag Lab	-	1.8	1,100,000

2.3 Reservoir Yield

Reservoir yield is defined as the amount of water which can be annually supplied from the reservoir. The yield is mainly dependent on inflow and varies from year to year. The firm yield must be the maximum quantity of water which can be highly guaranteed during a critical dry period.

The irrigation system would be proposed so as to tolerate 20 % of the period with yield below the normal design value. Thus, the drought year of 5-year recurrence would be selected for the estimate of the firm reservoir yield. As the result of reservoir operation study in 1977, which is equivalent to the drought year of 5-year recurrence, the firm yield of each reservoir is estimated as tabulated below. The annual usable index or the annual yield-reservoir capacity ratio is also estimated as given in the table below:

Reservoir	Useful Capacity (MCM)	Reservoir Yield (MCM)	Usable Index
Huai Saduang Yai	27.000	28.113	1.041
Huai Khon Kaen	30.000	49.766	1.659
Huai yai	13.250	13.534	1.021
Khlong Chaliang Lab	6.730	9.872	1.467

2.4 Reservoir Sediment

In planning and creating a reservoir, storage space for deposited sediment must be provided for each reservoir in order that reservoir useful storage is safely used thoughout life of reservoir. The suspended sediment of the Upper Pasak river has been recorded at Kaen Sida station since 1964. The annual suspended sediment records during 1964 to 1975 are as tabulated in the upper part of Table VII-3 in relation to the annual flow. In the vicinity of the study river basins, there are also a number of station recording the suspended sediment load. The lower part of Table VII-3 summarizes those suspended sediment records. The suspended sediment yield in the surrounding watersheds widely ranges from 26.4 to 163.4 tons/km^2/year averaging about 95 tons/km^2/year. While, the total sediment transport would be empirically estimated by adding about 20 % to the suspended transport to allow for the bed-load contribution; thus total sediment transport is estimated to be about 115 tons/km^2/year based on the averaged suspended sediment yield. Assuming that the specific dry weights of sediment samples is 1.1 tons/m^3, the capacity of total sediment transport is estimated to be about 105 m^3/km^2/year. The trap efficiency of each proposed reservoir can be assumed to be 95 %, accounting for the capacity-annual inflow ratio of the proposed reservoir. Thus, the total deposited sediment can be estimated to be about 100 m^3/km^2/year.

The useful life of each proposed reservoir would be assumed to be 100 years which are equivalent to double of the economic life of each subproject contemplated in this study. The total traped and deposited sediments in each reservoir are estimated as follows:

Reservoir	Sediment Yield ($m^3/km^2/year$)	Useful Reservoir Life (year)	Drainage Area (km^2)	Reservoir Sediment (10^3m^3)	Sediment Capacity Ratio (%)
Huai Saduang Yai	100	100	96	960	3.6
Huai Khon Kaen	100	100	322	3,220	10.7
Huai Yai	100	100	75	750	5.7
Khlong Chalinag Lab	100	100	77	770	11.4

2.5 Reservoir Leakage

The geological structure of the area to be impounded by each dam consists of interbedded sandstone and shale belonging to the so-called Nan Duk formation. The overall geological structure of each reservoir site is dominated by a north to south folding axis. No tectonic lines or no noticeable geological fault is found in each reservoir site through the geological field inspection. Furthermore, it is clarified that there exists no fractured rock, no permeable volcanic materials and no cavernous limestone which surely cause serious leakage. Therefore, no special treatment for the reservoir leakage would be proposed in this project.

2.6 Reservoir Operation

2.6.1 General

To clarify the efficient use of the installed capacity of reservoir, the operation study is made for 17 years from 1964 to 1980 in accordance with the presumed operation rules as described below.

Storage capacity in the reservoir would be adjusted by evaporation and precipitation in the pool site. Natural inflow would be balanced with total demand to clarify surplus or deficit of water resources in the current month. The surplus water would be stored for the subsequent month. In case of the deficit of water resources, the storage water in the reservoir would be released to meet the deficit. Total amount of water exceeding the full storage capacity of reservoir would be unavailingly outspilled.

Since the exploited water in the Huai Saduang Yai reservoir would be used as the supplementary supply for the Sri Chan Irrigation Project area and the Pasak Left Bank Irrigation Project area, the Huai Saduang Yai reservoir would be operated accounting for non-regulated runoff in the mainstream of the Pasak river. Special operation rules are set forth for the Huai Saduang Yai reservoir as mentioned below.

The initial operation conditions for the Huai Saduang Yai reservoir are same as those for the other reservoirs. Where the runoff in the Pasak river exceeds irrigation demand for the service areas of 33,750 rai (5,400 ha), no storage water in the Huai Saduang Yai reservoir would be released. In case of the deficit of irrigation water for the service areas, the storage water in the reservoir would be supplied to meet the deficit. As regards the balance of supply and demand, and spilling out of reservoir, the same rules for other three reservoirs would be also applied for the Huai Saduang Yai reservoir.

2.6.2 Supply and Demand

(1) Supply

The monthly runoff of the tributary is produced by multiplying monthly rainfall by the runoff coefficient which is read on the line C in the estimated chart of runoff coefficient authorized in RID. The estimated runoffs in respective tributaries for 17 years from 1964 to 1980 are shown in ANNEX - I, and these values are used for the supply data of operation study.

(2) Demand

The demand of water resources comprises irrigation requirement, municipal water and downstream release flow.

i) Irrigation Requirement

The irrigation requirement is calculated on the basis of meteorological data, recommendable cropping pattern and proposed crop intensity. As discussed in ANNEX-VI, the crop intensity of 135 % is applied for the Lom Sak area and the Phetchabun area, respectively. The estimated irrigation requirement is as given in ANNEX - VIII.

ii) Municipal Water Requirement

The municipal water of 4,000 m^3/day, including conveyance losses of 20 % would be daily supplied for the Lom Sak and/or Phetchabun municipality throughout year from the Huai Khon Kaen reservoir.

iii) Downstream Release Requirement

The downstream release flow of 1.0 ℓ/sec/km^2 of watershed would be released to downstream throughout year in due consideration of riparian right of downstream population.

2.6.3 Operation Study

The operation study on the respective proposed reservoir is made by use of the estimated supply and demand according to the operation rules above-mentioned. The calculation is illustrated in Fig. VII-1. The outcomes of the study show that all of the proposed reservoirs are efficiently operated even in the 20% recurrence of droughty year.

WORK QUANTITY OF ALTERNATIVE MAIN DAM
(Huai Yai Dam)

Work Item		Downstream Dam Axis	Upstream Dam Axis
1. Excavation			
Normal Soil	(m^3)	96,798	78,881
Weathered Rock	(m^3)	2,203	1,907
Total		99,001	80,788
2. Embankment			
Core Zone	(m^3)	152,292	134,852
Shell Zone	(m^3)	619,956	677,164
Rip-rap	(m^3)	31,407	28,153
Filter (side of core)	(m^3)	22,430	20,292
Filter (lower part of rip-rap)	(m^3)	15,936	14,321
Sand and Gravel	(m^3)	4,400	4,100
Rock for Down Toe	(m^3)	1,700	1,630
Gravel Pavement	(m^3)	3,164	2,468
Total		851,285	882,980
3. Sodding	(m^2)	30,662	31,046

WORK QUANTITY OF DAMS

Description		Huai Saduang Yai	Huai Khon Kaen	Huai Yai	Khlong Chaliang Lab
		Name of Dam			
I. Dam					
1. Excavation					
Normal Soil	(m^3)	101,100	283,600	96,800	138,800
Weathered Rock	(m^3)	1,800	4,500	2,200	3,000
Total	(m^3)	102,900	288,100	99,000	141,800
2. Embankment					
Core Zone	(m^3)	179,200	544,200	152,300	158,800
Shell Zone	(m^3)	821,200	2,833,000	619,900	628,800
Rip-rap	(m^3)	29,300	86,700	31,400	53,400
Filter	(m^3)	23,000	61,500	22,400	30,300
Filter (under Rip-rap)	(m^3)	14,700	43,400	15,700	26,700
Drain	(m^3)	4,200	9,500	4,400	4,100
Toe Drain (rock)	(m^3)	2,400	7,800	1,700	2,000
Pavement with gravel	(m^3)	1,900	4,800	3,200	5,100
Total	(m^3)	1,075,900	3,590,900	851,000	909,200
3. Sodding	(m^2)	30,800	79,300	28,700	46,900
4. Curtain grouting	(m)	12,500	18,500	15,000	10,000
II. Spillway					
1. Excavation					
Normal Soil	(m^3)	44,800	107,500	72,900	15,000
Weathered Rock	(m^3)	84,800	170,500	10,700	20,100
Rock	(m^3)	87,600	168,700	126,100	15,400
Total	(m^3)	217,200	446,700	209,700	54,000

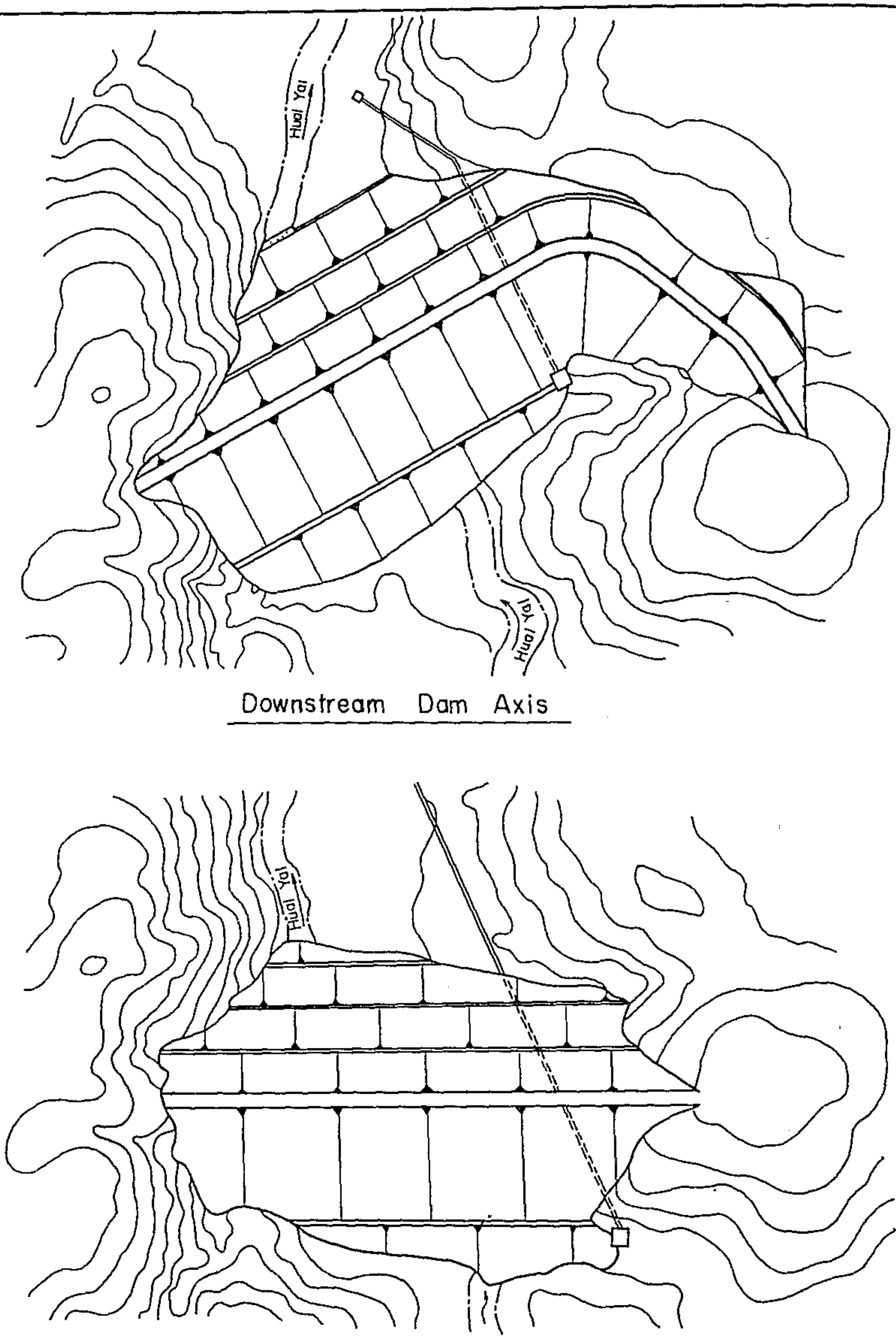
Description		Name of Dam			
		Huai Saduang Yai	Huai Khon Kaen	Huai Yai	Khlong Chaliang Lab
2. Concrete					
Plain Concrete	(m^3)	3,700	5,600	3,600	,100
Reinforced Concrete	(m^3)	5,500	13,600	6,100	10,100
Total	(m^3)	9,200	19,200	9,700	10,200
3. Back Fill	(m^3)	7,200	38,000	16,600	37,800
III. Emergency Spillway					
1. Normal Soil	(m^3)	5,200	1,400	1,900	Combined
Weathered Rock	(m^3)	7,800	2,000	2,900	with II
Rock	(m^3)	13,000	3,400	4,900	Spillway
Total	(m^3)	26,000	6,800	9,700	
2. Length of Guide Channel	(m)	380	500	1,200	
IV. Outlet Structure					
1. Intake Tower					
Height	(m)	29.0	37.0	27.5	25.5
Excavation	(m^3)	3,600	3,800	2,100	2,100
Reinforced Concrete	(m^3)	710	740	640	620
2. Outlet Works					
Length	(m)	145	200	140	160
Excavation	(m^3)	4,900	8,700	3,600	3,600
Plain Concrete	(m^3)	1,450	2,000	1,400	1,600
3. Access Bridge					
Length	(m)	59	105	105	62
Pier	(No)	1	2	2	1
H. type Steel Weight	(t)	11.0	20.0	20.0	11.6

RECORD OF ANNUAL SUSPENDED SEDIMENT OF PASAK RIVER AT KAENG SIDA

Year	Annual Discharge (mcm)	Annual Suspended Sediment (tons)
1964	246	57,980
1965	263	93,700
1966	239	58,500
1967	119	43,300
1968	137	52,000
1969	204	107,000
1970	267	52,300
1971	185	14,500
1972	149	30,400
1973	117	124,000
1974	104	27,300
1975	237	76,000
Average	189	61,415
Suspended Sediment Yield (tons/km²/year) 74.2		

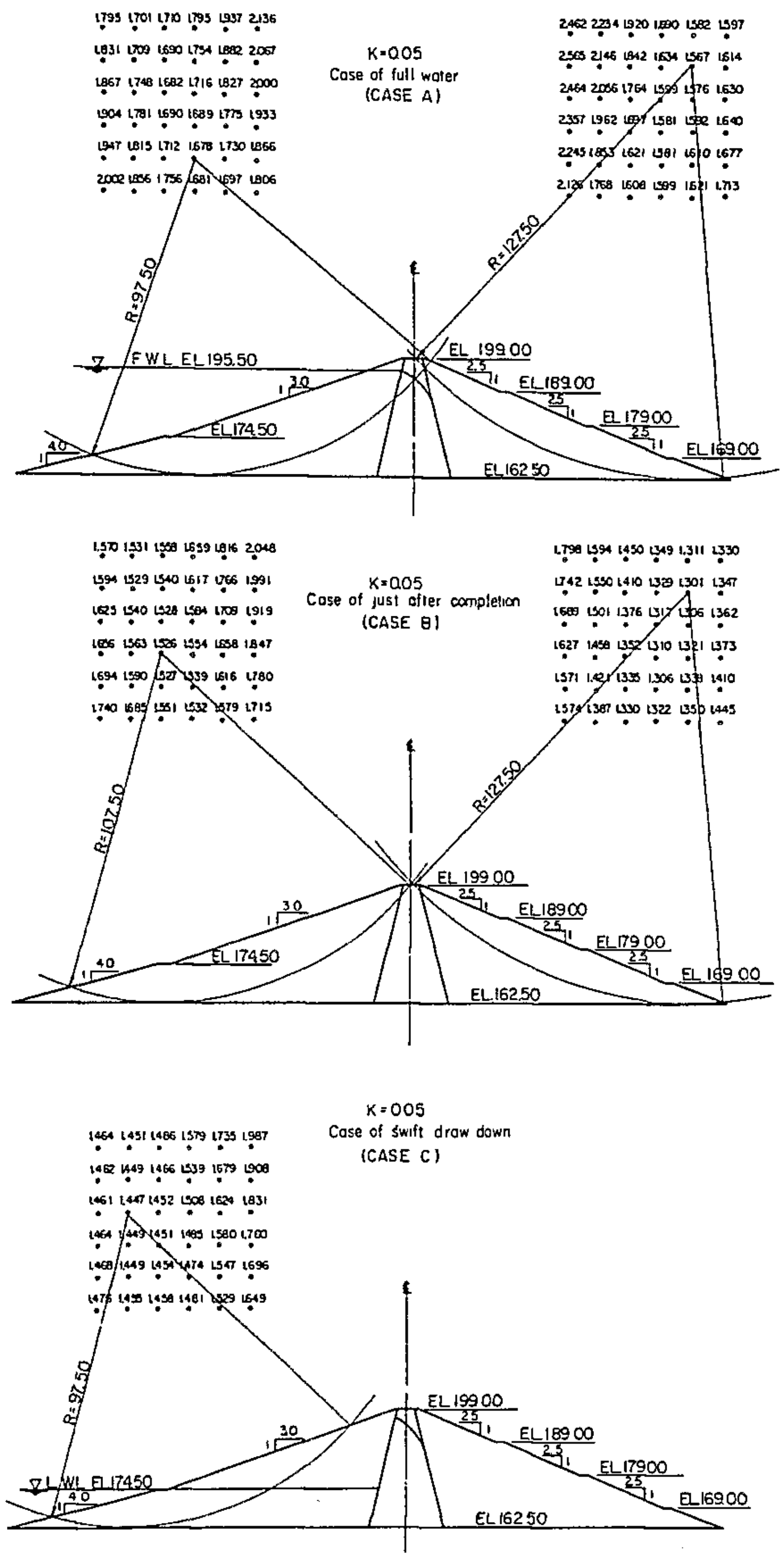
SUSPENDED SEDIMENT RECORD OF ADJACENT WATERSHED AREA

River/Gaging Station	Period of Record	Ave. Annual Suspended Sed. (tons)	Drainage Area (km²)	Suspended Sed. Yield (tons/km²/year)
Nam Lai/Dam site	1965-1966	9,473	206	36.4
Nam Man/Dan Sai	1967-1973	27,808	404	69.4
Nam Khek/Ban Khek Yai	1972-1973	26,013	993	26.4
Nam Loei/Wang Saphung	1967-1971, 1973	202,574	1,240	163.4
Kwae Noi/Kaeng Bua Kham	1969-1973	247,625	3,320	74.6
Nam Huang/Ban Pak Huai	1967-1973	389,990	4,090	95.4

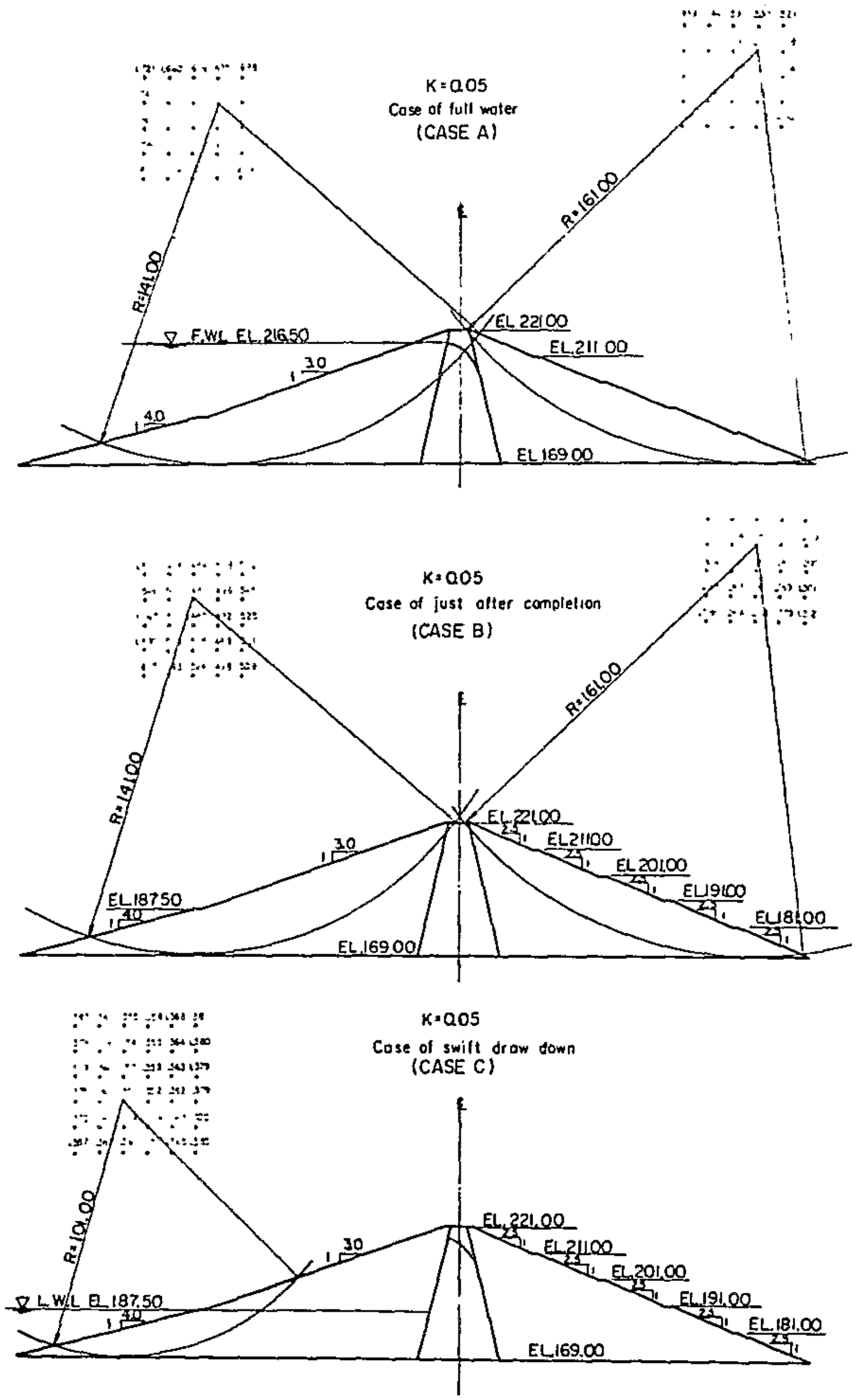


ALTERNATIVE DAM AXIS OF HUAI YAI DAM

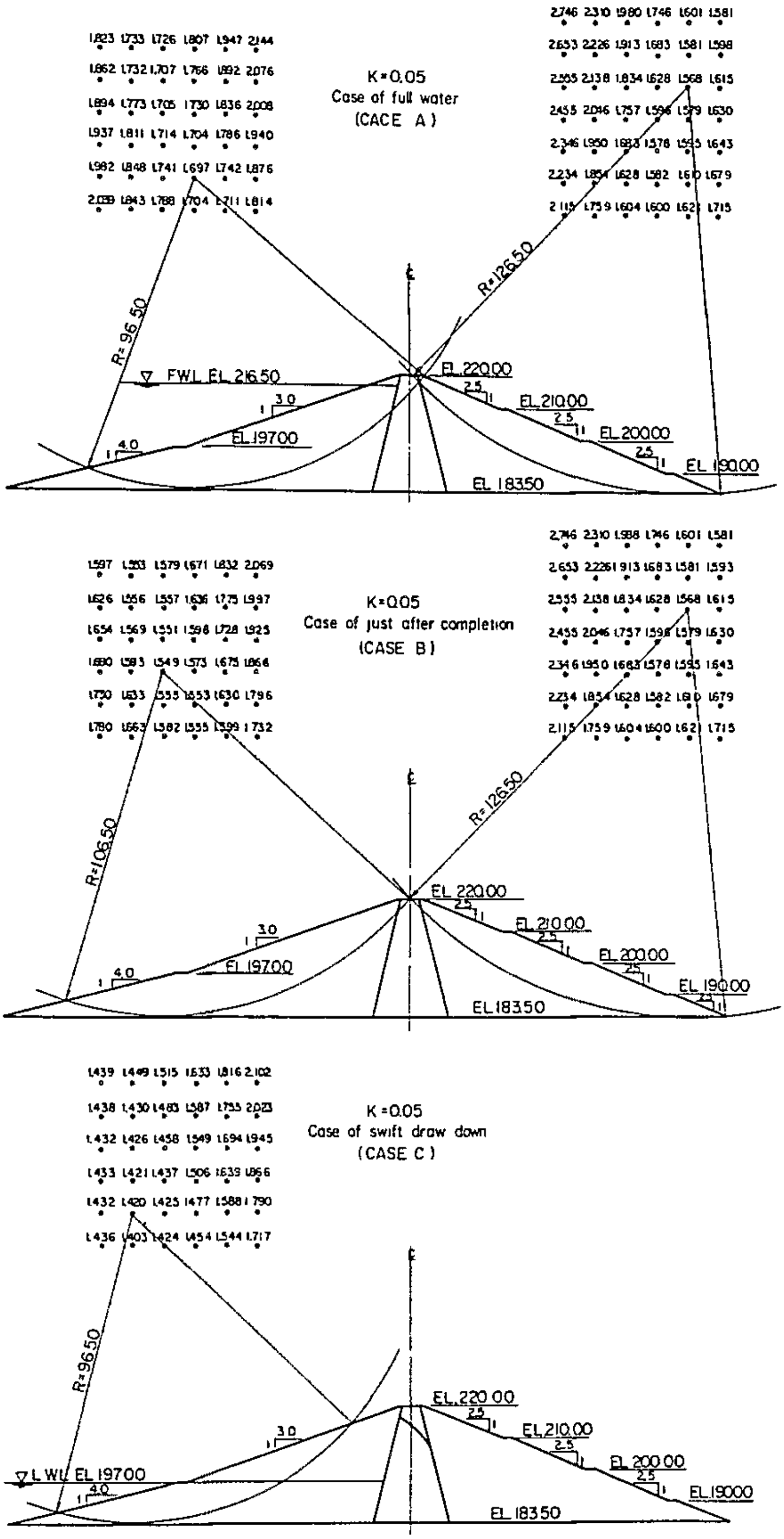
FIG. VII-2
(1)



STABILITY ANALYSIS BY SWEDISH SLIP CIRCLE METHOD
(1) HUAI SADUANG YAI

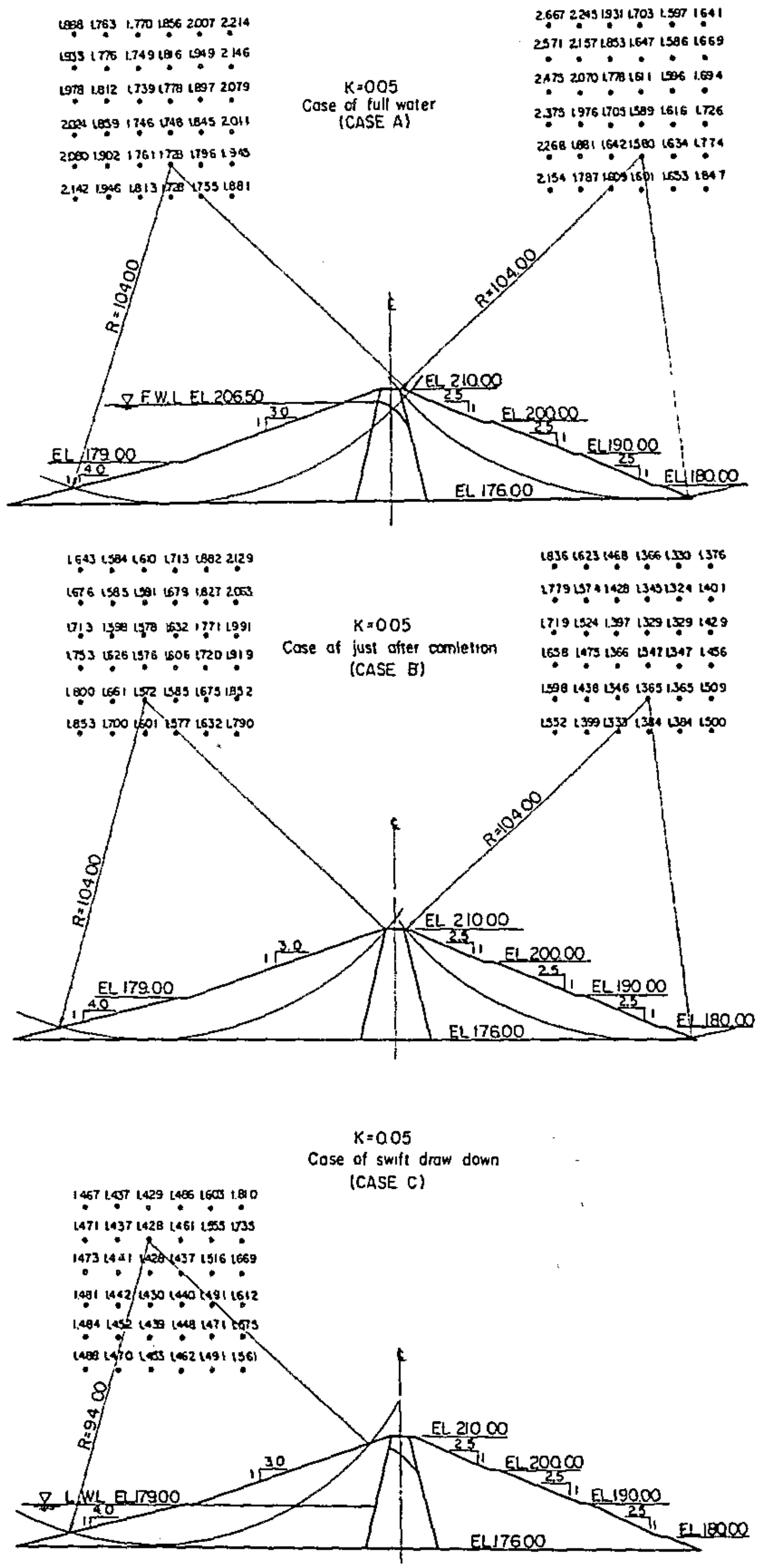


STABILITY ANALYSIS BY SWEDISH SLIP CIRCLE METHOD
(2) HUAI KHON KAEN

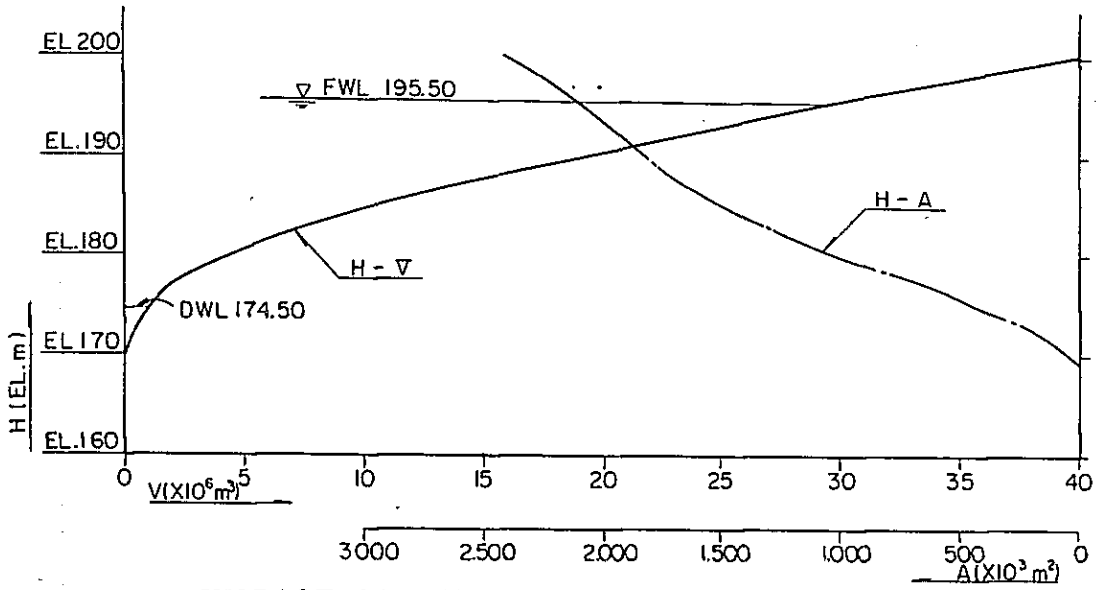


STABILITY ANALYSIS BY SWEDISH SLIP CIRCLE METHOD
(3) HUAI YAI

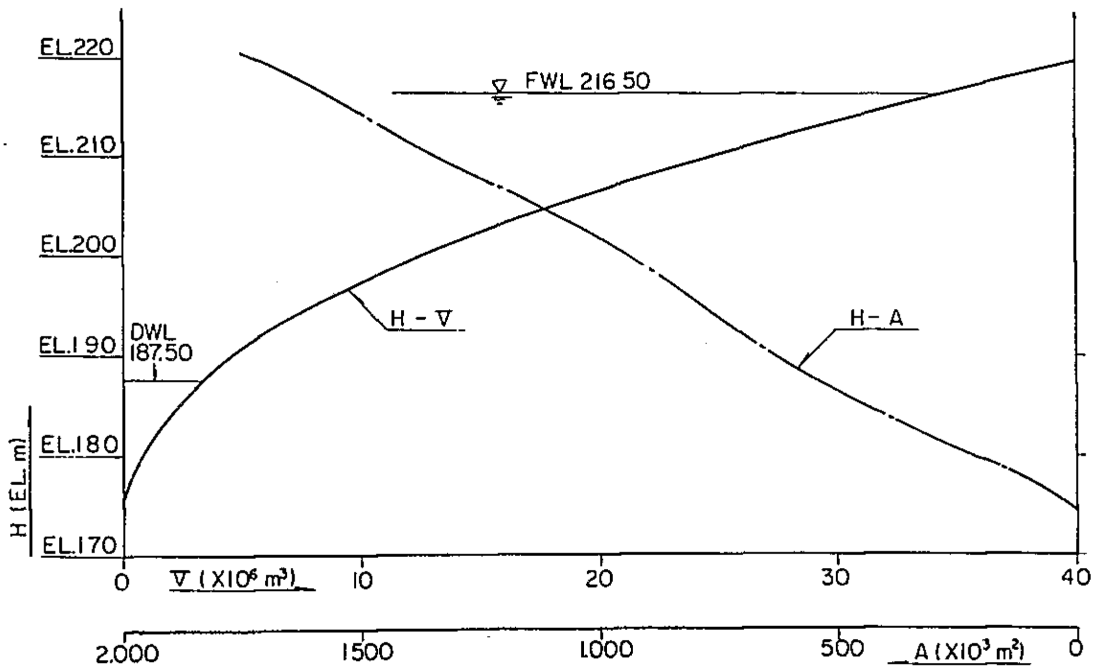
FIG. VII-2 (4)



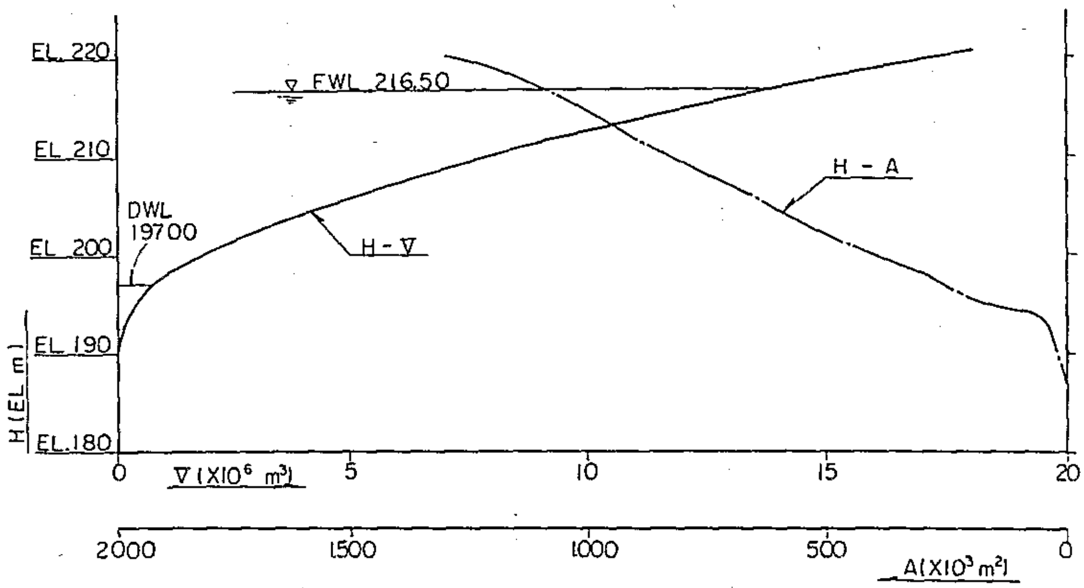
STABILITY ANALYSIS BY SWEDISH SLIP CIRCLE METHOD
(4) KHLONG CHALIANG LAB



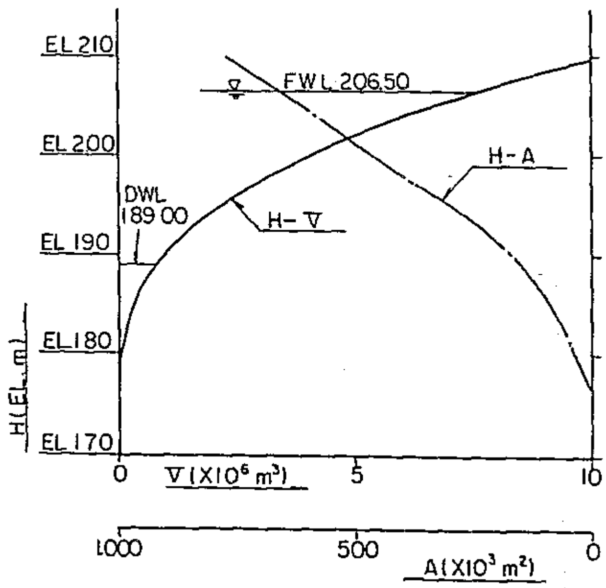
STORAGE CAPACITY AND INUNDATED AREA
(1) HUAI SADUANG YAI



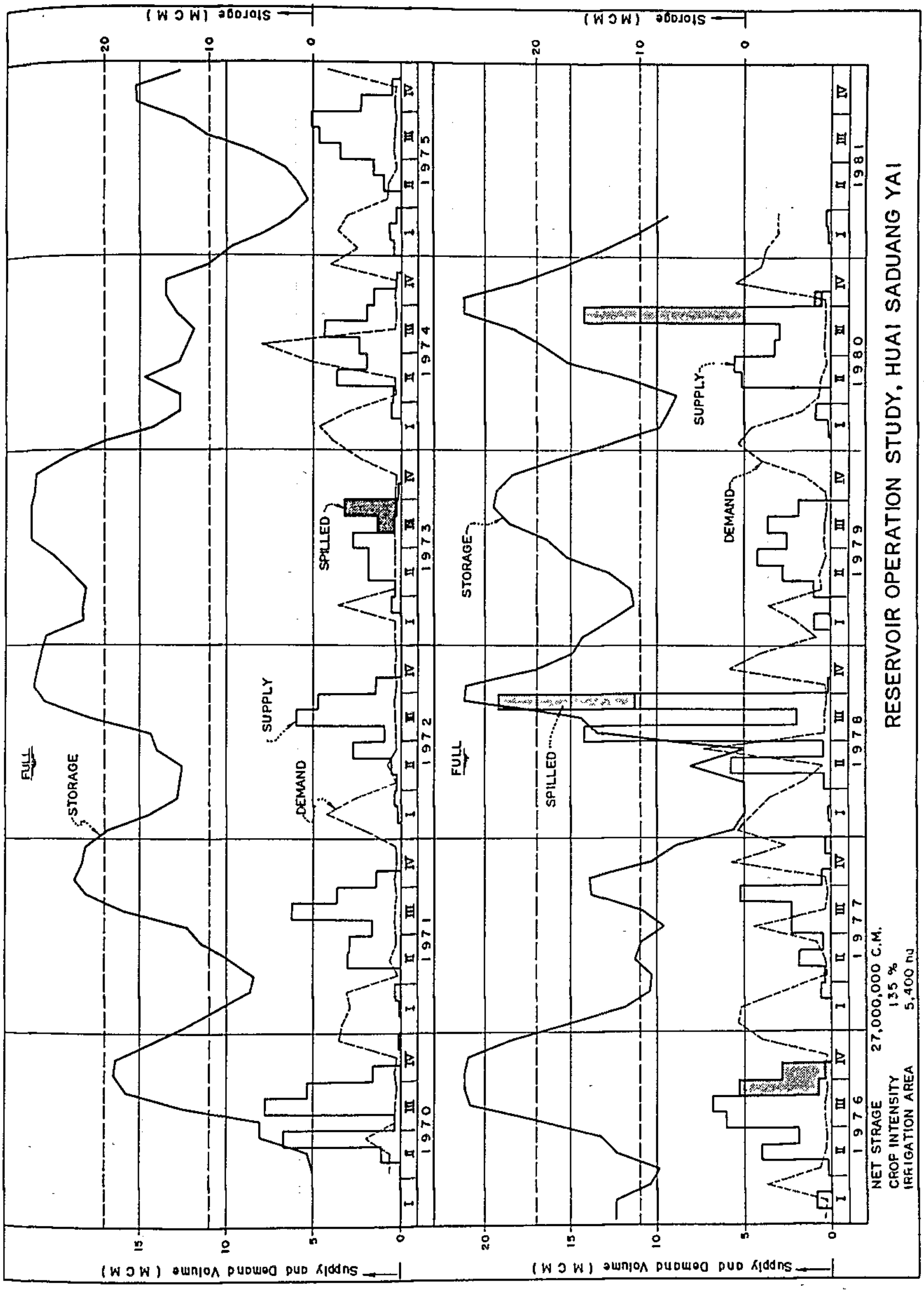
STORAGE CAPACITY AND INUNDATED AREA
(2) HUAI KHON KAEN

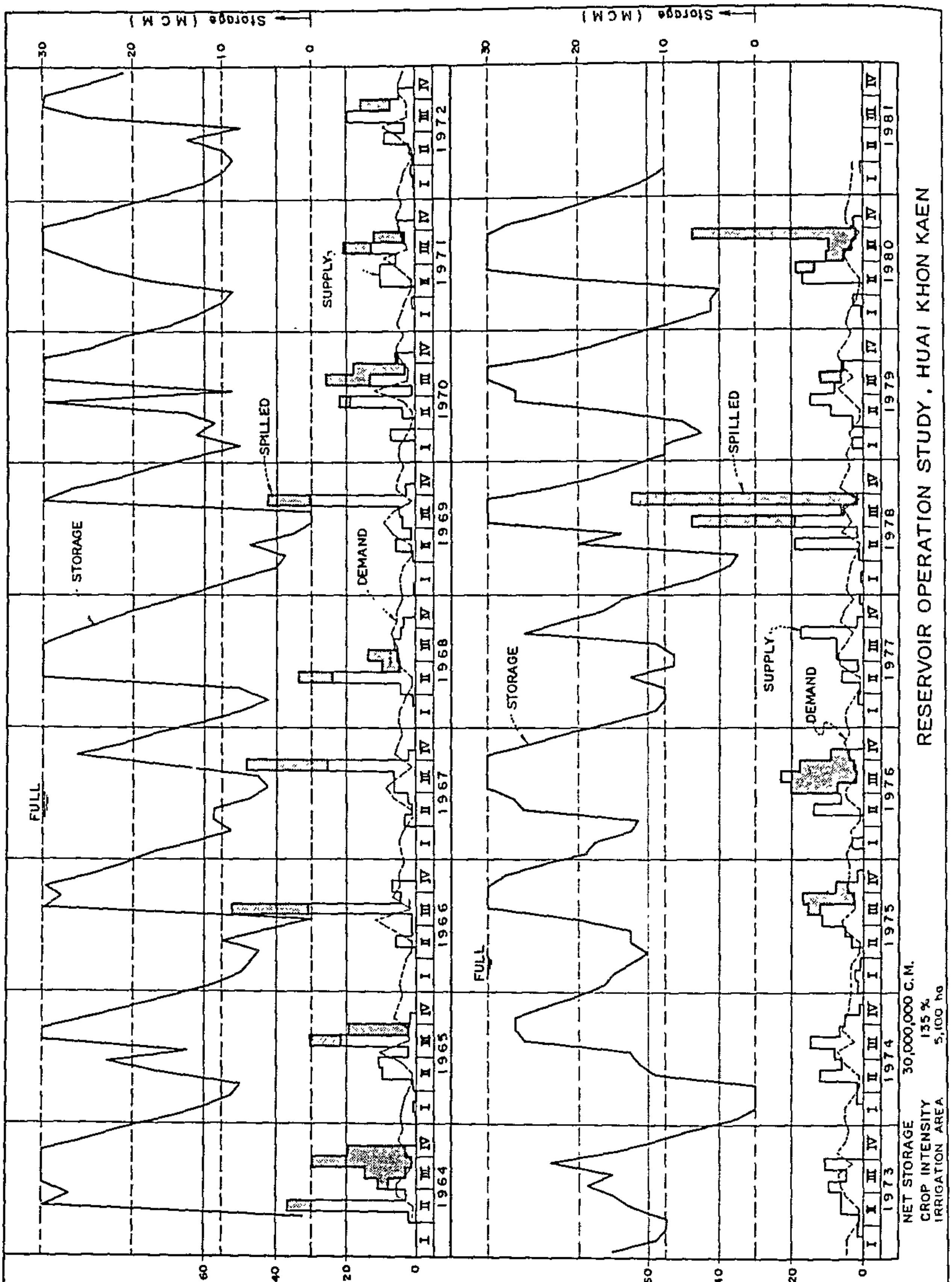


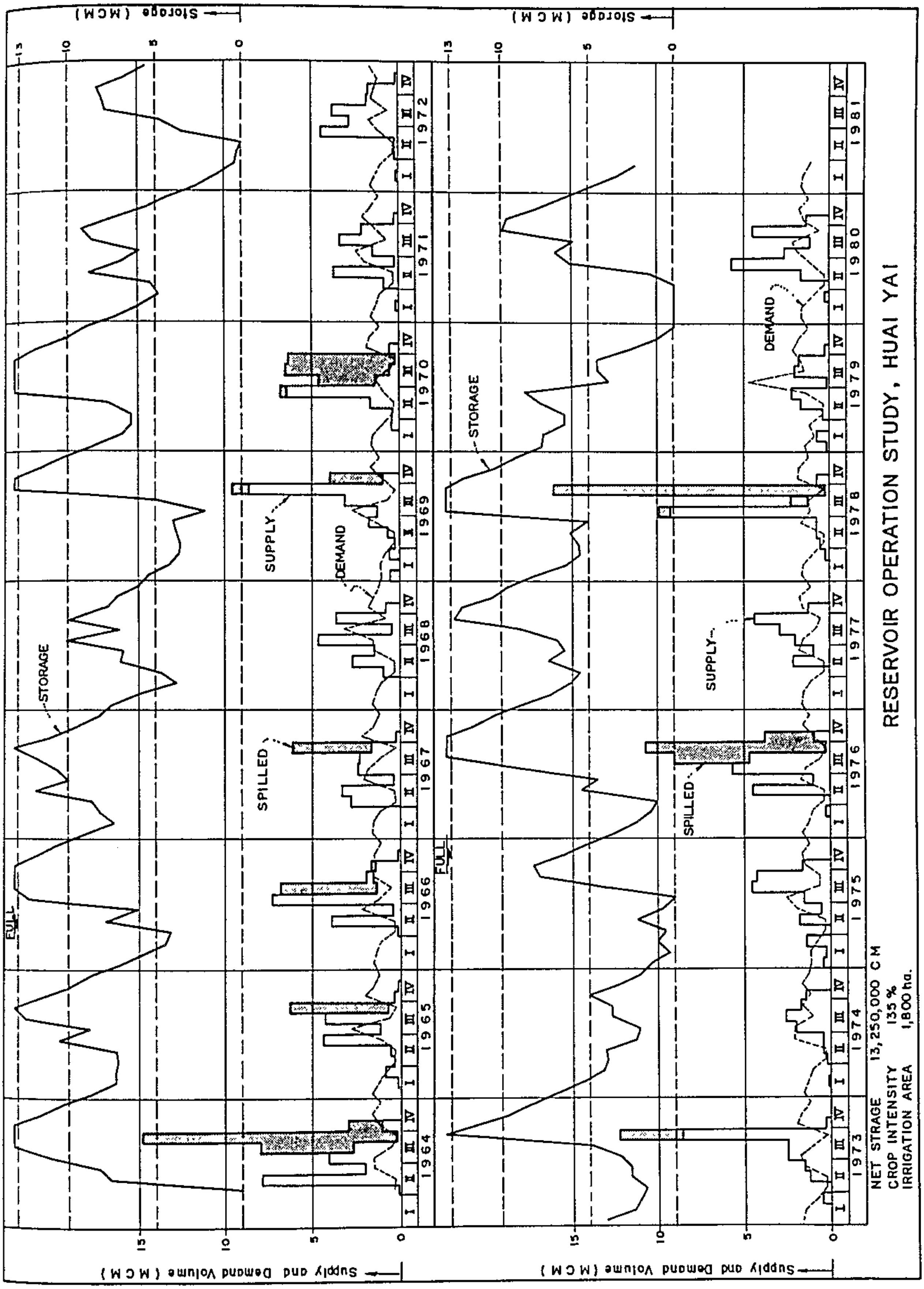
STORAGE CAPACITY AND INUNDATED AREA
(3) HUAI YAI

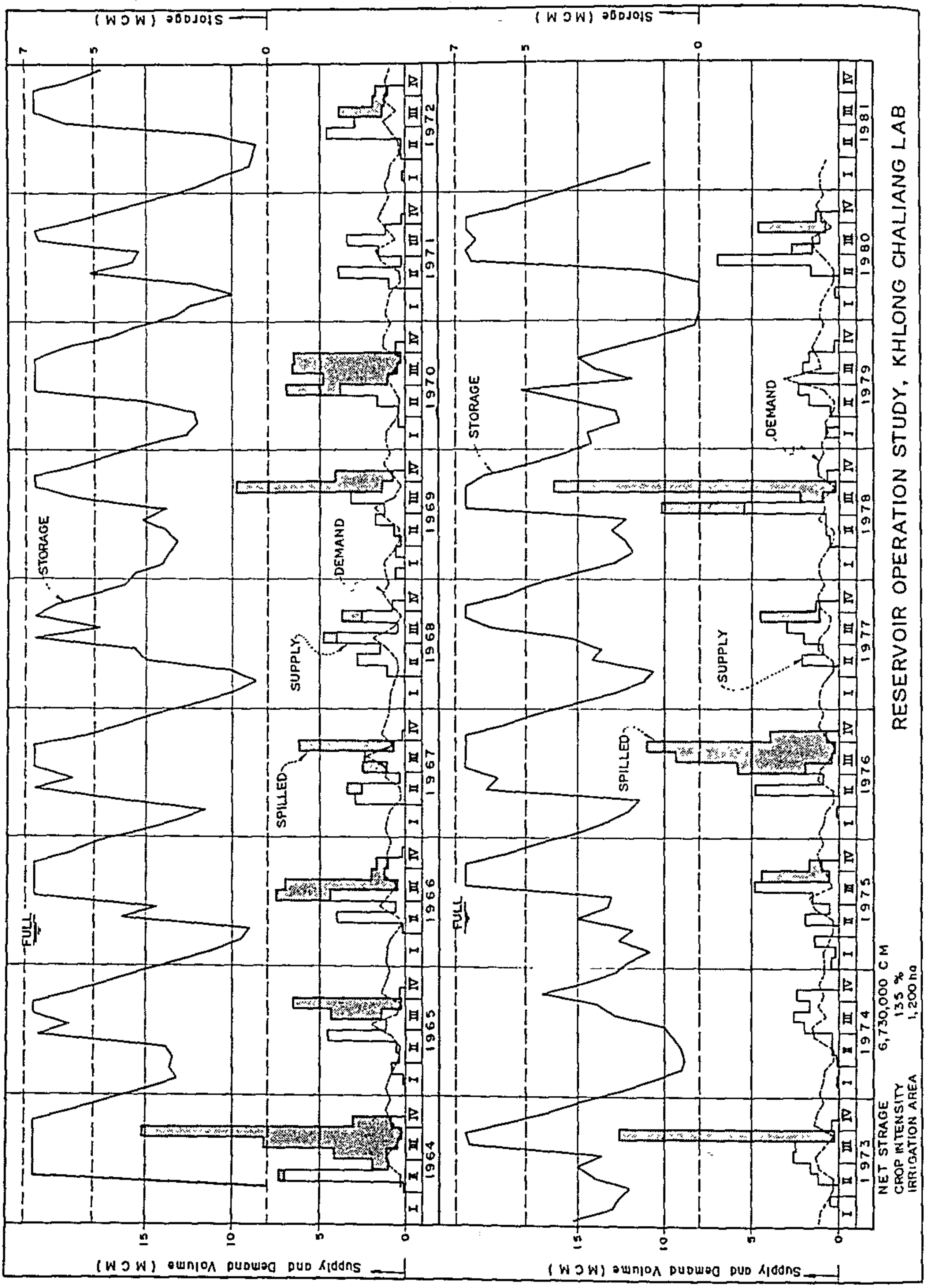


STORAGE CAPACITY AND INUNDATED AREA
(4) KHLONG CHALIAND LAB


RESERVOIR OPERATION STUDY, HUAI SADUANG YAI
NET STRAGE 27,000,000 C.M.
CROP INTENSITY 135 %
IRRIGATION AREA 5,400 ha
Storage (M C M)
Supply and Demand Volume (M C M)
STORAGE
SUPPLY
DEMAND
SPILLED
FULL
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981


RESERVOIR OPERATION STUDY, HUAI KHON KAEN
NET STORAGE 30,000,000 C.M.
CROP INTENSITY 135 %
IRRIGATION AREA 5,100 ha
Storage (M C M)
Supply and Demand Volume (M C M)
FULL
STORAGE
SPILLED
SUPPLY
DEMAND
1964
1965
1966
1967
1968
1969
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981


RESERVOIR OPERATION STUDY, HUAI YAI
NET STRAGE 13,250,000 C M
CROP INTENSITY 135 %
IRRIGATION AREA 1,800 ha.
Storage (M C M)
Supply and Demand Volume (M C M)
STORAGE
SUPPLY
DEMAND
SPILLED
FULL



RESERVOIR OPERATION STUDY, KHLONG CHALIANG LAB

ANNEX VIII
IRRIGATION AND DRAINAGE

ANNEX - VIII

IRRIGATION AND DRAINAGE

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IRRIGATION AND DRAINAGE

1. EXISTING IRRIGATION AND DRAINAGE CONDITIONS IN AND AROUND THE PROJECT AREA

1.1 Existing Irrigation Projects around the Project Area

1.1.1 General

The first activity for the irrigation development taken by RID in and around the project area is the construction of irrigation facilities in the Pasak Left Bank Project Area with a net irrigation area of 31,460 rai. The construction was started in 1953 and completed after spending 16 years. Following the completion of this project, RID took up the Huai Pa Daeng Project having dual purposes of irrigation water supply to 13,560 rai and municipal water supply of 1.5 MCM per annum. Its construction was initiated in 1969 and completed in 1978. Other major activities of RID in this area are the construction of Wang Bon and Huai Saen Nga diversion weirs. The commanding areas of these weirs are 2,000 rai and 2,500 rai respectively. These weirs were completed in 1979 and 1982 respectively after spending one year. RID has just started the construction of the Sri Chan diversion weir which commands 6,000 rai of irrigation area. The locations of these projects are shown in Fig. VIII.1.

Other than the above-mentioned irrigation facilities, there are village-level irrigation facilities constructed by villagers themselves, depending their water sources on small tributaries of the Pasak river. Most of these systems serve only for supplementary irrigation in the rainy season.

The main features and operation and maintenance condtions in the above-mentioned RID projects are briefed below.

1.1.2 Pasak Left Bank Irrigation Project

The project area of 31,460 rai is located immediately east of Lom Sak and slenderly extends along the left bank of the Pasak river. The major facilities of the project comprise a 100-m long diversion weir constructed across the Pasak river, 24.5-km long main canal and 34.4-km long lateral canals. The capacity of main canal at its head is 5.4 m^3/sec. Almost all the canal reaches are still unlined. The farm ditches have been constructed by farmers themselves in about 50 % of the area, and the remaining areas are irrigated by plot-by-plot system.

The canal system can supply water to all the area in the rainy season, but in the dry season the water supply is limited to only 5,000 rai (16 % of the total area) due to the depleted flow of the Pasak river. According to the operation records at the diversion weir, about 24 MCM of irrigation water were released to the area in the drought year of 20 % recurrence.

Operation and maintenance works are carried out by RID for the main and lateral canals. The annual budget allotted for these works is about 2,440,000 Baht (฿78/rai) for this year.

Ten water users' groups have been established so far on the lateral canal basis, but overall organization of water users' groups; water users' association, has not been established yet in this project area. The irrigation schedule is prepared every year by the water master and water management section of the Phetchabun Irrigation Office, and irrigation water is released to the fields according to the schedule. No water charge is collected from the farmers.

There is no drainage facility in the project area except some cross drains. Along the left bank of the Pasak river, the flood protection dike has been constructed for about 2 km from Ban Tah Kok to Ban Tah Kok Pho, but its strength is not enough against the flood from the Pasak river.

1.1.3 Huai Pa Daeng Irrigation Project

The project area is located immediately west of the Phetchabun municipality. For the irrigation of 13,560 rai and municipal water supply to Phetchabun, an earthfill dam with a length of 1,360 m and a height of 32 m was constructed on the Huai Pa Daeng; about 15 km upstream from the confluence with the Pasak river. Its reservoir capacity is 18.7 MCM in net. Two main canals with a total length of 14.7 km and four lateral canals with a total length of 20.9 km were also constructed in the project area. Except 372 m of upper reaches of the main canals, all reaches of the canals are still unlined. The total capacities of the main canals are 0.501 m^3/sec for LMC and 0.524 m^3/sec for RMC at their heads. The farm ditches have been constructed by farmers themselves for 4,700 rai, and the remaining areas are irrigated by plot-by-plot system.

The intake structure at the dam is opened for only 4 months from mid-July to mid-November for the rainy season paddy cultivation, and in the dry season the intake structure is opened only for the municipal water supply.

Operation and maintenance works for the dam and main and lateral canals are done by RID Phetchabun Irrigation Office, for which about 1,070,000 Baht (฿79/rai) are allotted to this office in this year.

In this area six water users' groups have been established so far, but the project-base water users' association has not been organized yet. For this project also, the irrigation schedule is prepared by the Phetchabun Irrigation Office,and irrigation water is released accordingly. No water charge is collected from the farmers.

There is no flood problem in this area due to its high topography. Any drainage facilities, except some cross drains have not been constructed in the area.

1.1.4 Sri Chan Irrigation Project

The project area of 6,000 rai is located 10 km northeast of the Lom Sak municipality. The area extends north to south along the right bank of the Pasak river. A timber-made intake weir was initially constructed by farmers themselves in 1940. Since then, the weir has been washed away by floods many times. Around 9 km of main canal and 16 km of lateral canals have also been constructed by farmers themselves. Recently RID provided 8 pump units to the farmers for irrigation use and further has taken up the construction of 70-m long diversion weir in April 1982, which is scheduled to be completed in January 1984.

Operation and maintenance works are made by farmers themselves at their own cost, except the operation and repair costs of pump units which are paid by RID.

Six water users' groups have been established so far on the farmers' own initiative. Irrigation water is distributed to farms according to the irrigation schedule which is established every year through the discussion among the members of water users' group.

There is no serious drainage problem in this area,because dual-purpose canals; irrigation and drainage, have been networked over the area.

1.1.5 Wang Bon Irrigation Project

The project area extends over 2,000 rai bounded by National Highway No. 12 in north and the Chun river in south. For the irrigation of this area, the farmer had constructed a timber-made diversion weir on the Chun river, but this weir was washed away in 1975. At the request from the farmers, RID took up the construction of a diversion weir under SSIP program in 1977 and completed the work in 1978. Around 4-km long irrigation canals have been constructed by farmers themselves. Due to less intensity of farm ditch, the irrigation is mainly practiced by applying plot-by-plot system. The head regulator at the diversion weir is opened for only 5 months from July to November for the cultivation of rainy season paddy.

Operation and maintenance works for the canal system are usually done by farmers at their own cost, but large damages on the diversion weir is repaired by RID. Actually RID has repaired the downstream protection work of the diversion weir this year, spending 500,000 Baht.

Three water users' groups have been established on the farmers' own initiative. The irrigation schedule is prepared through the discussion among the members of the water users' group, and irrigation water is distributed to the farms accordingly.

There is no serious drainage problem in this area, because there exists dual-purpose canal system.

1.1.6 Huai Saen Nga Irrigation Project

The project area of 2,500 rai extends over both banks of the Huai Saen Nga which joins with the Pasak river near Ban Rai, 15-km downstream from Lom Sak. This area has been irrigated by about 4-km long canal system constructed by farmers themselves. At the request from the farmers, RID has constructed a 24-m long weir in 1982 under SSIP program.

The operation and maintenance works for the canal system and water management in the area are done in the same manner as those of the Sri Chan and the Wang Bon Irrigation Projects.

There is no serious drainage problem in this area also, because of its high topography and the existence of dual-purpose canal system.

1.2 Existing Irrigation and Drainage Conditions in the Project Area

1.2.1 Huai Khon Kaen Service Area

This service area is located about 9-km east of the Lom Sak municipality. The area is bounded by the hill skirts in north and east, by the Khlong Daeng in south and by the main canal of the Pasak Left Bank Irrigation Project in west, and extends for 30 km from north to south with an average width of 2 km. The general topography of the area is characterized by the flat alluvial plains and the undulating peneplains. The ground elevations of irrigation area range from EL 170 m to EL 130 m.

In this area, there exist four timber-made weirs on the Huai Khon Kaen and about 40 km of irrigation canals (Fig. VIII.2). All these irrigation facilities have been constructed by farmers on their own initiative, but these are temporary ones and require re-construction or repair every year. The cost for re-construction and repair is prepared by farmers themselves.

In every weir-service area, they have a water users' group. The irrigation rotation among the service area is decided by the chief of village based on the irrigation schedule prepared through discussion among the farmers, and the irrigation rotation in each service area is decided by chief of the water users' group who is elected by the group members in every 3-4 years.

The drainage conditions in the area except some portions are generally good because of its topography and the existence of dual-purpose canals for irrigation and drainage. Some portions particularly along the main canal of the Pasak Left Bank Project, however, suffers from inundation problem. The inundation is observed 2-3 times a year in the past 10 years on an average, and its depth is 0.3 - 0.5 m for 2-3 days. This mal-drainage condition is mainly caused by the main canal of the Pasak Left Bank Project.

1.2.2 Huai Yai Service Area

The service area extends for 15 km along both banks of the Huai Yai, having 2 km of width. The area has a gentle topography sloping down westward from EL 180 m to EL 120 m, and most of the area is covered by paddy fields.

In the area, there are five intake weirs and two diversion structures on the Huai Yai, most of which are of concrete and masonry (Fig. VIII.3). These structures were constructed by the district office concerned and well maintained. In addition, there exist about 15 km of irrigation canals constructed by farmers themselves. Tubewell irrigation is also practiced using hand pumps in a limited area. The repair and maintenance works are fully vested in the farmers. The existing canal operation and water management systems are similar to those of the Huai Khon Kaen service area.

Due to existence of natural creek (Lum Pasak Mol) which connect the Pasak river, the lower part of the area; for around 2 km from the Pasak river, is attacked by floods carried by the creek for 2 times a year on an average. The flood usually stays there for about 2-3 weeks and its inundation depth is 0.3 - 0.7 m. In the other area, the drainage conditions are fairly good.

1.2.3 Khlong Chaliang Lab Service Area

The service area extends along both banks of the Khlong Chaliang Lab for about 10 km in length and 2 km in width. The area is gently sloped westward. Ground elevations in the area range from EL 175 m to EL 120 m.

In the area there exist six intake weirs on the Khlong Chaliang Lab, most of which are of concrete and masonry (Fig. VIII.4). These structures were constructed by the district office concerned and well maintained. The farmers have constructed about 10 km of irrigation canals. Tubewell irrigation systems with hand pumps are also provided by farmers themselves in very limited area. The operation and maintenance of the canal system and water management are totally done by farmers themselves in almost the same manner as mentioned for the Huai Khon Kaen service area.

There is no drainage problem in this area because of its high topography and the existence of the dual-purpose canals for irrigation and drainage.

2. SELECTION OF THE PROJECT AREA

2.1 General

To select the project area, various data on complex natural resources and interrelated land data have been collected and analized from many-sided view points. Systematic appraisal for land, soils, topography and so on has been conducted as an integrated study with economics, engineering and other fields in selection of relative degree of land suitability. Lands selected as irrigable area should be suitable for sustained crop production under the irrigation and drainage improvements. In the irrigable area specified above, following criteria are laid down to delineate the project area.

Criteria 1 : Project area should be delineated in the vicinity of the exploited site of water resources.

Criteria 2 : To quickly reap the project return and to save investment, project area should be delineated in the existing paddy field in principle.

Criteria 3 : In case availability of water resources and land suitability allow, project area should be extended over existing upland area.

2.2 Factors to be Considered in Selecting the Area

2.2.1 Land, Soil and Topography

Land classification survey related to the soil, topography and drainage characteristics has revealed the grade of irrigation suitability. Typical soil characteristics involved are texture, structure, depth, stoniness, horizon arrangement and layering, EC, pH, infiltration rate, moisture characteristics and so on.

Micro and macro topographic conditions are evaluated with respect to degree and direction of slope, land capability and land development, based on the topographic maps (1/10,000 and 1/50,000) and results of canal route surveys. Irrigability in relation to location and topography is the main point in this context.

2.2.2 Water Resources and Water Demands

The water resources of four sub-projects depend on four tributaries of the Pasak river, i.e. Huai Saduang Yai, Huai Khon Kaen, Huai Yai and Khlong Chaliang Lab. The water resources endowed in each tributary would be exploited by construction of the storage dam. The annual runoff at the proposed dam sites are limited as compared with the water demands in their respective irrigable areas.

Water demands comprise irrigation water demand, release for downstream use and municipal water supply. Water demands of each sub-project to be counted are as follows:

- Huai Saduang Yai : Supplementary water supply to the Pasak river for the irrigation of existing Sri Chan and Pasak Left Bank service areas and release for downstream use,
- Huai Khon Kaen : Irrigation water demands in the Huai Khon Kaen sub-project area and a part of the Pasak Left Bank service area, release for downstream use including municipal water supply for the Lom Sak municipality,
- Huai Yai : Irrigation water demands in the Huai Yai sub-project area and release for downstream use,
- Khlong Chaliang Lab : Irrigation water demands in the Khlong Chaliang Lab sub-project area and release for downstream use.

In order to use the limited water resources for the agricultural development to the maximum extent, comparative studies are made for the various combinations of reservoir capacity, cropping intensity and irrigation area as shown below (ANNEX - VI):

Sub-Project	Alt.-1	Alt.-2	Alt.-3	Alt.-4
(1) Huai Saduang Yai				
- Reservoir capacity (MCM)	21.00	21.00	27.00	27.00
- Cropping intensity (%)	135	150	135	150
- Irrigation area (rai)	29,380	21,880	33,750	26,250
(2) Huai Khon Kaen				
- Reservoir capacity (MCM)	23.40	23.40	30.00	30.00
- Cropping intensity (%)	135	150	135	150
- Irrigation area (rai)	26,880	20,630	31,880	25,630
(3) Huai Yai				
- Reservoir capacity (MCM)	6.39	6.39	13.25	13.25
- Cropping intensity (%)	135	150	135	150
- Irrigation area (rai)	7,500	5,630	11,250	9,380
(4) Khlong Chailang Lab				
- Reservoir capacity (MCM)	1.53	1.53	6.73	6.73
- Cropping intensity (%)	135	150	135	150
- Irrigation area (rai)	810	380	7,500	5,630

2.2.3 Government's Development Policy

In the delineation of irrigation area, the most important factor to be considered is the Government's development policy, which comprises followings:

- to maximize the irrigation area to serve beneficial farmers as many as possible;
- to maximize the effective storage of reservoir to utilize limited water resources effectively; and
- to establish the project within a economical and financial range.

2.3 Area to be Developed Under the Project

The land suitability classification is made on the basis of erodability of lands, cultivable depth of soil, topography, flooding condition, drainability and degree of soil acidity (ANNEX - III). Following the results on the land suitability classification, the cultivable area for paddy in each sub-project area is selected by eliminating the non-suitable lands (land class Group U3 and 6) as follows:

(unit : Rai)

Land Class Group	Sri Chan	Pasak Left Bank	Huai Khon Kaen	Huai Yai	Khlong Chaliang Lab
R1	3,500	22,930	13,850	7,250	5,370
R2	4,030	10,700	-	-	-
R3	460	4,640	7,870	2,650	2,750
U2/R2	-	1,920	11,670	3,320	840
Total	7,990	40,190	33,390	13,220	8,960

Further taking into account the results of water balance study, the irrigation areas of the respective sub-projects are delineated as follows (DWG. NOS. 305, 406 and 506):

Sub-Project Area	Gross Irrigable Area (Rai)	Net Irrigable Area* (Rai)
(1) Huai Saduang Yai	37,500	33,750
(Sri Chan Service Area)	(6,670)	(6,000)
(Pasak Left Bank Service Area)	(30,830)	(27,750)
(2) Huai Khon Kaen	35,420	31,880
(Pasak Left Bank Service Area)	(4,100)	(3,690)
(Huai Khon Kaen Service Area)	(31,320)	(28,190)
(3) Huai Yai	12,500	11,250
(4) Khlong Chaliang Lab	8,330	7,500
Total	93,750	84,380

Note* : conversion factor of 0.9

3. IRRIGATION AND DRAINAGE PLANS

3.1 Irrigation Water Requirements

3.1.1 General

In planning of irrigation project, a full knowledge of irrigation water requirements of crops from time of seeding until harvest is needed. It is also necessary to know the total amount of water required in each season to produce optimum yields for the climate and soils involved.

Peak water requirement by a crop must be known in order to determine the capacity of irrigation system. It is also important to check when the peak use period for the proposed cropping pattern combined with diversified crops occurs.

3.1.2 Consumptive Use of Water

The consumptive use of water is the sum of the volume of water used by vegetative growth in a given area, i.e. the transpiration for building of plant tissue and that evaporated from adjacent soil or intercepted precipitation on the area in any specified time. In case of rice cultivation where a water level is maintained above the ground surface, evaporation from the water surface will be substituted for evaporation from soil surface. Then, the consumptive use of water can be calcualted by the following formula.

$$Cu = Kc \times ETp$$

where

Cu : Consumptive use of water

Kc : Crop coefficient

ETp : Potential evapotranspiration

(1) Potential evapotranspiration (ETp)

Potential evapotranspiration is defined as the rate of evapotranspiration from an extensive water surface covered by green grass of uniform height, completely shading the ground.

In the selection of formula among the various empirical and theoretical formulas, Penman method and Radiation method are chosen, considering the latitudinal and altitudinal location of the study area and availability of meteorological data. The potential evapotranspirations derived from two methods are compared with the values directly converted from the evaporation records observed at Phetchabun meteorological station, and these values show the similarity each other. Then, the average values drived from both Penman and Radiation methods are applied for the calculation of consumptive use of water.

The applied value for each month is as shown below:

(unit : mm)

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
121	115	116	168	152	108	99	87	87	124	126	121	(1,469)

(2) Crop coefficients (Kc)

Crop coefficients are employed to relate the potential evapotranspiration to the consumptive use of water. Values of crop coefficients vary with the crop characteristics, time of planting and/or sowing and climatic conditions.

Applied crop coefficients are as shown below, which are the actually measured results by Irrigated Agriculture Section, RID.

Crops	Month				
	1st	2nd	3rd	4th	5th
Paddy					
Improved Local Variety	0.9	1.15	1.30	1.0	
High Yield Variety	0.9	1.15	1.30	(1.0)	
Upland Crops					
Tobacco	0.4	0.7	1.0	1.0	1.0
Beans	0.3	0.4	1.0	0.8	

3.1.3 Irrigation Water Requirements for Water Balance Study

The irrigation water requirements to be used for the water balance studies for the four sub-projects are calculated on the monthly basis for the past 17 years (1964-1980) using the following formula:

Paddy

$$Wd = Wf \times \frac{100}{E}$$

$$Wf = Cu + Lp + Wn + Wp - Re$$

Upland Crops

$$Wd = Wf \times \frac{100}{E}$$

$$Wf = Cu + Wi - Re$$

where,

Wd : diversion water requirement,

Wf : farm water requirement,

E : irrigation efficiency,

Cu : consumptive use of water,

Lp : percolation loss (for paddy field only),

Wn : nursery water requirement (for paddy field only),

Wp : paddling water requirement (for paddy field only),

Wi : pre-irrigation requirement (for upland crops only),

Re : effective rainfall

(1) Percolation loss (Lp)

The percolation loss of 1.0 mm/day is incorporated in the calculation of the irrigation water requirement for paddy, which is based on the actual field measurements at the representative site in the course of the study and the data measured in other several projects in Thailand.

(2) Effective rainfall (Re)

The effective rainfall is estimated using the "Effective Rainfall Chart" authorized by RID (Fig. VIII.5), and rainfall records at Lom Sak at Phetchabun meteorological stations.

The estimated effective rainfalls in Lom Sak area and Phetchabun area are shown in Data Book.

(3) Nursery water requirement (Wn)

The nursery water requirement is calculated using the following formula:

$$Wn = Wfn + Wpn$$

$$Wfn = 1.5.n.d - Re1$$

$$Wpn = Pw - Re2$$

where,

Wfn : water requirement in nursery period

Wpn : puddling water requirement in nursery bed d : potential evapotranspiration + percolation loss

Rel : effective rainfall in nursery period

Pw : puddling water for nursery bed (150 mm)

Re2 : effective rainfall during the period of nursery bed preparation

In the calculation of nursery water requirement, the area required for the nursery bed is assumed to be 6/100 of main field and nursery period to be 25 days for high yield variety of paddy and 30 days for improved local variety of paddy respectively.

(4) Puddling water requirement (Wp)

The quantity of water required for puddling is theoretically calculated for the soil depth to be puddled and porosity, which vary relatively from place to place. In this study, the following formula and assumptions are adopted for the approximation:

(a) Formula

$$Wp = Ds + Ws + Lf - Re$$

where,

Ds : required water depth above soil surface after puddling

Ws : difference in soil moisture contents before and after puddling

Lf : field loss including percolation, evaporation and application losses

Re : effective rainfall

(b) Assumption

i) Water depth above soil after puddling is 30 mm.
ii) Polosity is 50 % in surface soil of 20 cm.
iii) Vapor phase in soils after puddling is 5 %.
iv) Soil moisture before irrigation is 20 % in volume.
v) Field losses consist of:

- percolation loss : 20 mm
- evaporation : 30 mm
- application losses : 20 %

(c) Calculated results

$$Wp = 150 - Re \text{ (mm)}$$

(5) Pre-irrigation (If)

The pre-irrigation water required for the cultivation of upland crops is estimated at 40 mm, referring to the other similar projects in Thailand.

(6) Irrigation efficiency (E)

The irrigation efficiency is usually defined as follows:

$$E = \frac{Ea}{100} \times \frac{Eco}{100} \times 100$$

where,

Ea : water application efficiencies

Eco : canal conveyance and operation efficiencies

The water application efficiencies for paddy and upland crops are assumed as 70 % and 60 % respectively in due consideration of soil characteristics, topography, climate, irrigation practices and experiences in the project area.

The canal conveyance and operation efficiencies depend on the condition of irrigation system and operation skill of the irrigation facilities. Taking into account the size of the project and the technical level of water management in the project areas, the canal conveyance and operation efficiencies are assumed as 80 % of net irrigation water requirements.

The combined irrigation efficiency is obtained as follows, based on the above assumptions:

Crop	Ea (%)	Eco (%)	E (%)
Paddy	70	80	56
Upland Crops	60	80	48

(7) Calculated results

Following the above-mentioned calculation procedure, the unit water requirement (m^3/month/ha) are calculated for two cropping patterns; 135 % and 150 % cropping intencities, in both Lom Sak and Phetchabun areas as shown in Table VIII.1. The water requirements calculated for the Lom Sak area will be used for the water balance study for the Huai Saduang Yai and the Huai Khon Kaen sub-projects, and those calculated for the Phetchabun area will be used for the water balance study for the Huai Yai and Khlong Chaliang Lab sub-projects.

3.1.4 Unit Design Irrigation Water Requirement

According to the calculation results of the water requirements for water balance study, the peak irrigation water requirements concentrate in July in most years. Therefore, the unit design irrigation water requirements in July are calculated on the 10-day basis through the same procedures as that of the previous section. In the calculation, the 10-day effective rainfall with 5-year return period of non-excess probability are estimated using 17-year rainfall records observed at Lom Sak and Phetchabun stations. The estimated results are as shown below:

(unit : mm)

Area	1st 10-day	2nd 10-day	3rd 10-day
Lom Sak Area	8.9	12.4	23.6
Phetchabun Area	3.8	15.0	27.5

Based on the above effective rainfall, the unit irrigation requirements are calculated for the respective crops. Using the unit irrigation requirements thus calculated and taking into account the cropping intensities of the respective crops, the unit irrigation water requirements for the respective cropping patterns are calculated and summed up in Table VIII.2. According to the calculation, the peak unit irrigation water requirements for respective 10-day periods are summarized as follows:

(unit : ℓ/sec/ha)

Area	1st 10-day	2nd 10-day	3rd 10-day
Lom Sak Area	0.8	0.9	0.8
Phetchabun Area	0.9	0.8	0.8

These calculation results show the peak unit irrigation water requirement of 0.9 ℓ/sec/ha for both areas, but the unit design irrigation water requirements are determined to be 1.0 ℓ/sec/ha for both areas taking an allowance of 10 % for possible increase of crop intensity in future.

3.1.5 Design Diversion Requirements

The design diversion requirements are defined as the peak diversion discharge, which are obtained by multiplying the unit design water requirement by irrigation area. The design diversion requirements thus calculated for the respective sub-project areas are as shown below:

Sub-project	Irrigation Area	Design Division Requirement
Huai Saduang Yai	5,400 ha	5.4 m^3/sec
Huai Khon Kaen	5,100 ha	5.1 m^3/sec
Huai Yai	1,800 ha	1.8 m^3/sec
Khlong Chaliang Lab	1,200 ha	1.2 m^3/sec

In case of the Huai Khon Kaen sub-project area, it is required to add 46 ℓ/sec of municipal water requirement to the above requirement.

3.2 Drainage Water Requirements

3.2.1 Standard for Drainage Plan

The project areas extend over the alluvial fans of the tributaries and the low-lying of the Pasak river. The latter portion suffers from mal-drainage in the rainy season. If the lands are not drained well within a feasible range, the productivity will not go up even after the provision of well-designed irrigation facilities.

From the past experiments and observations in Japan /1 on the relation between the yield reduction rate of paddy and depth and duration of submergence at different growing stages of paddy, the following considerations could be made:

(a) The submergence at the growing stage of young panicle formation gives the serious damage to the yield of paddy, on the contrary, damage due to submergence at the stage of maturing is insignificant.

(b) The duration of submergence within 1 to 3 days is not significant, but damage of paddy remarkably increases due to submergence beyond 3 days.

(c) When a part of leaves still remains above water surface, the damage to paddy is decreased as compared with that when leaves are completely submerged.

While, the midest rainy season in the project area occurs in the period between August and October. The growing stage of paddy between middle stage of tillering and beginning stage of panicle formation would correspond to the midest rainy season.

/1 These are presented in "Hand Book on Yield Reduction Rates of Summer Crop due to Various Causes" published by the Ministry of Agriculture, Forestry and Fisheries of Japan in 1975.

Taking into account the above considerations, the following design standard would be applied for making the future drainage plan in the project.

(1) The allowable depth of submergence in the paddy fields should be 30 cm, and duration of submergence should not exceed 3 days.

(2) The submergence more than 30 cm in depth should not last more than 24 hours.

3.2.2 Drainage Requirement

In general, the criteria for the calculation of unit drainage requirement defines the rainfall intensity with certain probability and a drain period necessary for removal of excess water to an allowable extant.

In this study, the drainage requirements are estimated on the basis of following assumptions and procedures:

(1) The daily rainfall data at Lom Sak and Phetchabun (1964-1980) are used for this study.

(2) Design rainfalls at Lom Sak and Phetchabun are respectively estimated to be 154.2 mm and 155.4 mm of 3 days consecutive rainfall with a 10-year return period.

(3) Based on the average rainfall distribution pattern, the distribution percentage of the design daily rainfall is estimated as follows:

Distribution Percentage

Day	Lom Sak Area	Phetchabun Area
1st day	21 %	29 %
2nd day	41 %	38 %
3rd day	38 %	33 %

(4) Relationship between rainfall and runoff distribution is assumed as follows:

Relationship between Cumulative Rainfall and Total Runoff

Cumulative Rainfall (mm)	Runoff Coefficient (f)
less than 10	0
10 - 30	0.1
30 - 50	0.3
50 - 100	0.5
100 - 300	0.8

Relationship between Rainfall and Runoff Distribution (%)

Rainfall (mm)	1st day	2nd day	3rd day	4th day
less than 30	100	-	-	-
30 - 50	70	30	-	-
50 - 100	60	30	10	-
more than 100	50	30	15	5

(5) Based on the above assumptions, the drainage requirements are estimated as follows:

Design Rainfall (mm)	Cumulative Rainfall (mm)	f	Runoff (mm)				
			1st day	2nd day	3rd day	4th day	5th day
1. Lom Sak Area							
32.4	32.4	0.3	6.8	2.9	-	-	-
63.2	95.6	0.5	-	19.0	9.5	3.2	-
58.6	154.2	0.8	-	-	28.1	14.1	4.7
Total			6.8	21.9	37.6	17.3	4.7
Unit Drainage Req. (ℓ/sec/ha)			0.79	2.53	4.35	2.00	0.54
2. Phetchabun Area							
45.1	45.1	0.3	9.5	4.1	-	-	-
59.1	104.2	0.8	-	28.4	14.2	4.7	-
51.3	155.5	0.8	-	-	24.6	12.3	4.1
Total			9.5	32.5	38.8	17.0	4.1
Unit Drainage Req. (ℓ/sec/ha)			1.10	3.76	4.49	1.97	0.47

From the above calculation, the design drainage requirements are determined to be 4.5 ℓ/sec/ha for Lom Sak area and Phetchabun area which is defined as the peak requirement in the above calculation.