Table IV-3 NUMBER OF FARM HOUSEHOLDS BY SIZE OF HOLDING (ESTIMATE)

Province & district	Number of Holding	Size of Holding (Rai) Under 2	2 ~ 5.9	6 ~ 14.9	15 ~ 24.9	25 ~ 39.9	40 ~ 59.9	60 ~ 99.9	100 ~ 139.9	140 and Over
Uthai Thani	(29,057)									
(1) Uthai Thani	3,255	13	146	342	641	1,110	656	277	49	21
(2) Thap Than	4,669	19	210	490	920	1,592	943	397	70	28
(3) Swang Arom	3,573	14	161	375	704	1,218	722	304	54	21
(4) Nong Khayyang	2,137	9	96	224	421	729	432	182	32	12
(5) Nong Chang	5,094	20	229	535	1,004	1,737	1,029	433	76	31
(6) Ban Rai	2,322	9	104	244	457	792	469	197	35	15
Nakhon Sawan	(90,598)									
Lat Yao	21,152	85	1,354	2,686	3,744	5,161	4,167	2,961	698	296
Khampheng Phet	(57,533)									
(1) Khanu Waralaksaburi	797	2	45	125	170	209	145	78	15	8
(2) Khong Khlung	144	-	8	22	31	38	26	14	3	2
Chai Nat	(36,018)									
Wat Sing	653	1	69	147	148	150	86	40	9	3
T o t a l	43,766 100.0%	172 0.4	2,422 5.5	5,190 11.9	8,240 18.8	12,736 29.1	8,657 19.8	4,883 11.1	1,041 2.4	437 1.0

Source: 1978 Agricultural Census Report. Office of Prime Minister
Population & Housing Census 1980. Office of Prime Minister

Table IV-4 AGRICULTURAL LAND IN STUDY AREA

Province & district	Total Area	Agricultural Land	% of Agricultural Land	Coverage in Study area	Agricultural Land in Study Area
	(Rai)	(Rai)	(%)	(%)	(Rai)
Uthai Thani					
(1) Uthai Thani	135,594	87,785	82.5	100	87,785
(2) Thap Than	202,188	140,603	76.4	100	140,603
(3) Swang Arom	213,125	120,291	39.8	100	120,291
(4) Nong Khayang	217,250	61,922	65.2	100	61,922
(5) Nong Chang	240,625	158,118	85.8	100	158,118
(6) Ban Rai	2,527,500	298,907	13.2	25	74,700
Nakhon Sawan					
Lat Yao	1,327,500	467,601	34.5	100	467,601
Kamphaeng Phet					
(1) Khanu Waralakusaburi	1,312,500	488,943	57.4	5	24,400
(2) Khlong Khlung	1,656,562	367,339	31.1	1	3,600
Chai Nat					
Wat Sing	389,238	204,027	52.5	25	20,400
T o t a l	8,222,082 (1,315,533 ha)	2,395,536 (383,285 ha)			1,159,420 (185,507 ha)

Table IV-5 PRESENT LAND USE IN STUDY AREA

Province & district	Paddy Field	Upland Field	Orchard	Forest & Pasture	All Others	Total
	Rai	Rai	Rai	Rai	Rai	Rai
Uthai Thani						
(1) Uthai Thani	76,372	3,716	4,798	1,946	953	87,735
(2) Thap Than	125,595	9,066	1,510	2,528	1,904	140,603
(3) Swang Arom	106,495	12,606	177	888	125	120,291
(4) Nong Khayang	59,855	419	454	725	469	61,922
(5) Nong Chang	129,904	20,514	2,421	3,285	1,994	158,118
(6) Ban Rai	23,190	37,440	1,880	11,000	1,190	74,700
Nakhon Sawan						
Lat Yao	311,810	127,748	4,642	21,169	2,232	467,601
Kamphaeng Phet						
(1) Khanu Waralakusaburi	13,260	10,250	300	400	190	24,400
(2) Khlong Khlung	2,890	600	30	60	20	3,600
Chai Nat						
Wat Sing	18,800	1,290	100	120	80	20,400
T o t a l	868,171 (138,907ha)	223,649 (35,783ha)	16,322 (2,611ha)	42,121 (6,739ha)	9,157 (1,465ha)	1,159,420 (185,507ha)

Table IV-6 PRESENT CROPPING INTENSITY

Province & district	Paddy Field			Upland Field		
	Total	Single Cropping	Double Cropping	Total	Single Cropping	Double Cropping
	Rai	Rai	Rai	Rai	Rai	Rai
Uthai Thani						
(1) Uthai Thani	76,372	70,941	5,431	3,716	1,675	2,041
(2) Thap Than	125,595	114,193	11,402	9,066	4,630	4,436
(3) Swang Arom	106,495	97,448	9,047	12,606	8,675	3,931
(4) Nong Khayang	59,855	56,784	3,071	419	207	212
(5) Nong Chang	129,904	111,539	18,365	20,514	12,080	8,434
(6) Ban Rai	23,109	11,800	11,390	37,440	18,880	18,560
Nakhon Sawan						
Lat Yao	311,810	230,827	80,983	127,748	81,800	45,948
Kamphaeng Phet						
(1) Khanu Waralakusaburi	13,260	8,070	5,190	10,250	5,900	4,350
(2) Khlong Khlung	2,890	2,360	530	600	360	240
Chai Nat						
Wat Sing	18,800	1,879	910	910	890	400
T o t a l	868,171 (138,907ha) 100%	721,852 (115,496ha) 83.1%	146,319 (23,411ha) 16.9%	223,649 (35,788ha) 100%	135,097 (21,615ha) 60.4%	88,552 (14,168ha) 39.6%

Table IV-7 CROP PRODUCTION STATISTICS (1978/79 - 1982/83) (1/2)

Major Rice

			1978/79	1979/80	1980/81	1981/82	1982/83
Uthai Thani	Planted area	1,000 rai	729	557	551	521	646
	Production	1,000 ton	162	152	158	171	114
	Yield	kg/rai	222	272	286	328	176
Nakhon Sawan	Planted area	1,000 rai	1,781	2,079	1,782	2,303	2,356
	Production	1,000 ton	562	511	529	732	623
	Yield	kg/rai	282	246	306	318	264
Khampheng Phet	Planted area	1,000 rai	890	897	980	1,010	959
	Production	1,000 ton	247	268	275	321	332
	Yield	kg/rai	275	299	281	318	346
Chai Nat	Planted area	1,000 rai	728	601	664	725	853
	Production	1,000 ton	301	310	308	287	295
	Yield	kg/rai	414	514	464	396	345

Second Rice

			1978/79	1979/80	1980/81	1981/82	1982/83
Uthai Thani	Planted area	1,000 rai	-	7	16	19	7
	Production	1,000 ton	-	4	10	12	4
	Yield	kg/rai	-	558	645	633	500
Nakhon Sawan	Planted area	1,000 rai	-	13	90	52	84
	Production	1,000 ton	-	8	56	33	51
	Yield	kg/rai	-	558	616	632	607
Kampheng Phet	Planted area	1,000 rai	-	26	17	22	26
	Production	1,000 ton	-	16	10	12	15
	Yield	kg/rai	-	607	600	573	580
Chai Nat	Planted area	1,000 rai	-	9	146	161	215
	Production	1,000 ton	-	6	94	107	121
	Yield	kg/rai	-	655	645	666	563

Table IV-7 CROP PRODUCTION STATISTICS (1978/79 - 1982/83) (2/2)

Mungbeans

			1978/79	1979/80	1980/81	1981/82	1982/83
Uthai Thani	Planted area	1,000 rai	17	15	21	34	-
	Production	1,000 ton	2	2	2	3	-
	Yield	kg/rai	119	100	107	96	-
Nakhon Sawan	Planted area	1,000 rai	288	294	346	323	339
	Production	1,000 ton	37	35	22	27	38
	Yield	kg/rai	129	119	64	85	111
Kampheng Phet	Planted area	1,000 rai	210	228	197	333	399
	Production	1,000 ton	16	19	3	4	3
	Yield	kg/rai	91	84	87	107	57
Chai Nat	Planted area	1,000 rai	9	6	2	10	15
	Production	1,000 ton	1	1	-	1	1
	Yield	kg/rai	106	100	71	100	76

Source: Agricultural Statistic of Thailand 1982/83, MOAC

Table IV-8 (1) STANDARD CULTIVATION METHOD OF IRRIGATED PADDY

Days	Management	Amount of Implementation
	(Preparation of Nursery)	
- 3	Seed selection	Salt solution for seed selection 10 liters of water + 2 kg of NaCl
- 3	Seed disinfection	Benlate-T/1 (200-400 times, 6-12 hours) or Homai (200-400 times, 6-12 hours)
- 2	Seed soaking	36 hours
- 2	Hastening of germination	24 hours
- 1	Application of fertilizer	Urea 100g, Triple Super Phosphate 50g per rai
0	Sowing	Acreage $100m^2$/rai, Seed $5kg/100m^2$
15	Control of disease and insect damage	Diazinon 30-50 cc in 1,000 liters of water 100 lit./$100m^2$ spraying, about 2 times
	Nursery Period: 20 - 25 days	
	(After transplanting)	
	(Preparation of Paddy Field)	
- 5	Basal manuring	Compound fertilizer 20 kg/rai
0	Transplanting	Spacing 20 x 25cm (20 hills per m^2) 3-4 seedling per hill, 25 days-aged seeding.
10	Weeding (1st)	Hand rotary weeding
13	Control of disease and insect damage (1st)	Diazinon 0.1 lit./rai, Kasumin 0.1 lit./rai
15	Application of fertilizer (Top dressing)	Urea 5 kg/rai
30	Weeding (2nd)	Hang rotary weeder
60	(Panicle initiation period)	
63	Application of fertilizer (2nd)	Urea 5 kg/rai
70	(Booting period)	
73	Control disease and insect damage (2nd)	Diazinon 0.6 lit./rai
80	(Heading period)	
105-110	Harvesting	Use of sickle

Note: /1; for paddy seeding diseases, rice blast, rice leaf spot, etc.

Table IV-8 (2) STANDARD CULTIVATION METHOD OF MUNGBEANS

Days	Management	Amount of Implementation
	(Preparation of field)	
0	Sowing	Seed 6 kg/rai Spacing 25 x 25 cm or row 50 cm and hole 20 cm with dig 4-5 seeds/per hole number of mungbeans 32,000 stem/rai
17	Application of fertilizer (1st)	Compound fertilizer 6 kg/rai
20	Intertillage and weeding	Hoe and hand
30	Control insect damage (1st)	Spraying of Sumithion 0.1 lit./rai
45	Application of fertilizer (2nd)	Compound fertilizer 4 kg/rai
47	Intertillage and weeding (2nd)	Hoe and hand
50	Control insect and disease damage (2nd)	Spraying of Sumithion 0.9 lit./rai and 0.8 lit./rai of fungicide
80	Harvesting Drying	By hand, about 2 times 2 - 3 times

Note: Recommendable high yield variety; U-Tong I

Table IV-9 ECONOMIC PRICE OF PADDY AND MUNGBEANS

I t e m	Paddy		Mung beans	
	₿/ton	Balance	₿/ton	Balance
FOB Bangkok	9,150 /1		12,300 /2	
Storage Loss	450	8,700	850	11,450
Warehouse Cost	60	8,640	60	11,390
Transportation Cost (Nakhon Sawan-Bangkok)	320	8,320	350	11,040
Milling Charge	200	8,120	1,530 /3	9,510
Ex-mill price of rice	8,120		-	
Price of Paddy at Mill	5,280		-	
Local Storage Loss	-		700	8,810
Local Transportation Cost	80	5,200	85	8,725
Farm-gate Price	5,200		8,725 ≑ 8,700	

/1 : Price in 1990 forecasted by IBRD, "Price Prospects for Major Primary Commodities", Dec. 1983.

/2 : Price in 1990 forcasted by using the export prices at Bangkok in the past and adjusted by using international market price index by IBRD, Dec. 1983.

/3 : Including cost of bags.

Table IV-10 CROP PRODUCTION COST UNDER "WITHOUT PROJECT" CONDITION

(UNIT: BAHT/HA)

Items	Unit Price (Economic)	Wet Season Paddy Rain-fed Quantity	Wet Season Paddy Rain-fed Value	Wet Season Paddy Semi-Irrigated Quantity	Wet Season Paddy Semi-Irrigated Value	Wet Season Paddy Irrigated Quantity	Wet Season Paddy Irrigated Value	Dry Season Paddy Quantity	Dry Season Paddy Value	Mungbeans Quantity	Mungbeans Value
Farm Input											
1. Seed - Local Variety (Paddy)	5.7/kg	35 kg	199.5	35 kg	199.5	18 kg	102.6	-		-	-
- High Yield Variety (Paddy)	6.3/kg	-	-	-	-	17 kg	107.1	35 kg	220.5	-	-
- Mungbeans	8.7/kg	-	-	-	-	-	-	-		40 kg	348.0
2. Fertilizer											
- Urea	8.8/kg	-	-	-	-	24 kg	211.2	60 kg	528.0	-	-
- Compound fertilizer	10.3/kg	-	-	48 kg	494.4	48 kg	494.4	100 kg	1,030.0	-	-
3. Agro-chemical											
- Insecticides	264/ℓ	-	-	-	-	0.21 ℓ	52.0	1 ℓ	264.0	-	-
- Fungicides	220/ℓ	-	-	-	-	-	-	0.4 ℓ	88.0	-	-
4. Land Preparation											
- Hand Tractor	84/day	6.25 day	525.0	6.25 day	525.0	6.25 day	525.0	6.25 day	525.0	6.25 day	525.0
5. Thresing-Machine	84/day	1.6 day	134.0	1.8 day	151.0	2.0 day	168.0	2.2 day	184.0	-	-
(A) Sub-Total			859		1,370		1,661		2,840		873
Labour Requirement											
1. Nursery Preparation	40/day	1.5 day	60.0	1.5 day	60.0	1.5 day	60.0	1.5 day	60.0	-	-
2. Land Preparation	40/day	6.25 day	250.0	6.25 day	250.0	6.25 day	250.0	6.25 day	250.0	6.25 day	250.0
3. Transplanting or Sowing	40/day	20.0 day	800.0	22.0 day	880.0	22.0 day	880.0	22.0 day	880.0	1.5 day	60.0
4. Weeding	40/day	-	-	-	-	2.0 day	80.0	2.0 day	80.0	-	-
5. Fertilizer Application	30/day	-	-	1.5 day	45.0	2.0 day	60.0	3.0 day	90.0	-	-
6. Chemical Application	40/day	-	-	-	-	1.0 day	40.0	1.5 day	60.0	-	-
7. Harvesting	40/day	18.0 day	720.0	20.0 day	800.0	21.0 day	880.0	22.0 day	880.0	1.5 day	600.0
8. Thresing, drying & winnowing	30/day	8.0 day	240.0	9.0 day	270.0	10.0 day	300.0	14.0 day	420.0	7 day	210.0
9. Water management	30/day	-	-	1.0 day	30.0	3.0 day	90.0	3.0 day	90.0	-	-
(B) Sub-Total		53.75 day	2,070	61.25 day	2,335	70.75 day	2,640	71.25 day	2,810	29.75 day	1,120
Miscellaneous Cost	8% of (A+B)		231		295		344		460		197
Grand-Total			3,160		4,000		4,645		6,110		2,190

Table IV-11 CROP PRODUCTION COST UNDER "WITH PROJECT" CONDITION

(UNIT: BAHT/HA)

Items	Unit Price (Economic)	Paddy Quantity	Paddy Value	Mungbeans Quantity	Mungbeans Value
Farm Input					
1. Seed - Local Variety (Paddy)	5.7/kg	18 kg	102.6	-	-
- High Yield Variety (Paddy)	6.3/kg	17 kg	107.1	-	-
- Mungbeans	8.7/kg	-	-	40 kg	348.0
2. Fertilizer					
- Urea	8.8/kg	60 kg	528.0		
- Compound fertilizer	10.3/kg	120 kg	1,236.0	62.5 kg	643.8
3. Agro-chemical					
- Insecticides	264/ℓ	1 ℓ	264.0	1.2 ℓ	316.8
- Fungicides	220/ℓ	0.5 ℓ	110.0	0.5 ℓ	110.0
4. Land Preparation					
- Hand Tractor	84/day	6.25 day	525.0	6.25 day	525.0
5. Thresing-Machine	84/day	3.0 day	252.0	-	-
(A) Sub-Total			3,125		1,944
Labour Requirement					
1. Nursery Preparation	40/day	1.5 day	60.0	-	
2. Land Preparation	40/day	6.25 day	250.0	6.25 day	250.0
3. Transplanting or Sowing	40/day	22.0 day	880.0	1.5 day	60.0
4. Weeding	40/day	2.0 day	80.0	6.25 day	250.0
5. Fertilizer Application	30/day	3.0 day	90.0	0.6 day	18.0
6. Chemical Application	40/day	2.0 day	80.0	1.5 day	60.0
7. Harresting	40/day	23.0 day	920.0	17.0 day	680.0
8. Threshing, drying & winnowing	30/day	15.0 day	450.0	9.0 day	270.0
9. Water management	30/day	3.0 day	90.0	1.0 day	30.0
(B) Sub-Total		77.75 day	2,900	43.1 day	1,618
Miscellaneous Cost	8% of (A+B)		485		358
Grand-Total			6,510		3,920

Table IV-12 FARM GATE PRICES OF MAJOR FARM INPUTS AND OUTPUTS

I t e m		Unit	Farm Gate price (1984)	Economic Price	Remarks
			Baht		
I. Farm Product					
Rice		Mt	3,200	5,200	
Mungbeans		Mt	7,200	8,700	
II. Farm Input					
Seed	L.V./1	kg	3.5	5.7	
	L.Y.V/2	kg	5.5	6.3	
	Mungbeans	kg	7.2	8.7	
Fertilizer	Urea	kg	6.0	8.8	
	Compound	kg	7.0	10.3	
Agro-Chemicals	Insecticides	ℓ	180	264	
	Fungicides	ℓ	150	220	
Land Preparation	Hand Tractor	day	120	84	Conversion Factor: 0.7
Threshing/ Winnowing	Machine	day	120	84	- do -
Labour	Light	day	30	30	
	Heavy	day	40	40	

Table IV-13 (1) GROSS AND NET CROP PRODUCTION VALUES UNDER "WITHOUT PROJECT" CONDITION (1/2)

(1) Existing Irrigation Areas

Project	Crops	Cultivated Area (ha)	Unit Yield (Ton/ha)	Total Production (ton)	Unit Price (฿/ton)	Gross Production Value (฿/Million)	Unit Production Cost (฿/ha)	Total Production Cost (฿/Million)	Net Production Cost (฿/Million)
1. Upper Mae Wong	Wet Season Paddy	36,800	2.2	80,120	5,200	416.6	4,410	162.3	254.3
	irrigated	23,600	2.5	59,000	5,200	306.8	4,640	109.5	197.3
	semi-irrigated	13,200	1.6	21,120	5,200	109.8	4,000	52.8	57.0
	rainfed	-	-	-	-	-	-	-	-
	Dry Season Paddy	510	3.7	1,890	5,200	9.9	6,110	3.1	6.8
	Mung Beans	1,530	0.6	920	8,700	8.0	2,190	3.4	4.6
	Total					434.5		168.8	265.7
2. Lower Mae Wong	Wet Season Paddy	36,800	2.2	80,120	5,200	416.6	4,410	162.3	254.3
	irrigated	23,600	2.5	59,000	5,200	306.8	4,640	109.5	197.3
	semi-irrigated	13,200	1.6	21,120	5,200	109.8	4,000	52.8	57.0
	rainfed	-	-	-	-	-	-	-	-
	Dry Season Paddy	510	3.7	1,890	5,200	9.9	6,110	3.1	6.8
	Mung Beans	1,530	0.6	920	8,700	8.0	2,190	3.4	4.6
	Total					434.5		168.8	265.7
3. Khlong Pho	Wet Season Paddy	10,600	2.4	24,970	5,200	129.9	4,540	48.1	81.8
	irrigated	8,900	2.5	22,250	5,200	115.8	4,640	41.3	74.5
	semi-irrigated	1,700	1.6	2,720	5,200	14.1	4,000	6.8	7.3
	rainfed	-	-	-	-	-	-	-	-
	Dry Season Paddy	190	3.7	700	5,200	3.6	6,100	1.1	2.5
	Mung Beans	570	0.6	340	8,700	3.0	2,190	1.2	1.8
	Total					136.5		50.4	86.1

Table IV-13 (1) GROSS AND NET CROP PRODUCTION VALUES UNDER "WITHOUT PROJECT" CONDITION (2/2)

(2) Potential Maximum Irrigation Areas

Project	Crops	Cultiated Area (ha)	Unit Yield (Ton/ha)	Total Production (ton)	Unit Price (฿/ton)	Gross Production Value (฿/Million)	Unit Production Cost (฿/ha)	Total Production Cost (฿/Million)	Net Production Cost (฿/Million)
1. Upper Mae Wong	Wet Season Paddy	47,800	2.0	93,320	5,200	485.2	4,120	197.1	288.1
	irrigated	23,600	2.5	59,000	5,200	306.8	4,640	109.5	197.3
	semi-irrigated	13,200	1.6	21,120	5,200	109.8	4,000	52.8	57.0
	Rainfed	11,000	1.2	13,200	5,200	68.6	3,160	34.8	33.8
	Dry Season Paddy	510	3.7	1,890	5,200	9.9	6,110	3.1	6.8
	Mung Beans	1,530	0.6	920	8,700	8.0	2,190	3.4	4.6
	Total					503.1		203.6	299.5
2. Lower Mae Wong	Wet Season Paddy	47,800	2.0	93,320	5,200	485.2	4,120	197.1	288.1
	irrigated	23,600	2.5	59,000	5,200	306.8	4,640	109.5	197.3
	semi-irrigated	13,200	1.6	21,120	5,200	109.8	4,000	52.8	57.0
	Rainfed	11,000	1.2	13,200	5,200	68.6	3,160	34.8	33.8
	Dry Season Paddy	510	3.7	1,890	5,200	9.9	6,110	3.1	6.8
	Mung Beans	1,530	0.6	920	8,700	8.0	2,190	3.4	4.6
	Total					503.1		203.6	299.5
3. Khlong Pho	Wet Season Paddy	17,900	1.9	33,730	5,200	175.4	3,980	71.2	104.2
	irrigated	8,900	2.5	22,250	5,200	115.8	4,640	41.3	74.5
	semi-irrigated	1,700	1.6	2,720	5,200	14.1	4,000	6.8	7.3
	rainfed	7,300	1.2	8,760	5,200	45.5	3,160	23.1	22.4
	Dry Season Paddy	190	3.7	700	5,200	3.6	6,110	1.1	2.5
	Mung Beans	570	0.6	340	8,700	3.0	2,190	1.2	1.8
	Total					182.0		73.5	108.5

Table IV-13 (2) GROSS AND NET CROP PRODUCTION VALUES UNDER "WITH PROJECT" CONDITION

(1) Existing Irrigation Areas

Project	Crops	Cultivated Area (ha)	Unit Yield (Ton/ha)	Total Production (ton)	Unit Price (₿/ton)	Gross Production Value (₿/Million)	Unit Production Cost (₿/ha)	Total Production Cost (₿/Million	Net Production Cost (₿/Million)
1. Upper Mae Wong	Paddy	36,800	4.25	156,400	5,200	813.3	6,510	239.6	573.7
	Mung Beans (30%)	11,040	1.20	13,250	8,700	115.3	3,920	43.3	72.0
	Total					928.6		282.9	645.7
2. Lower Mae Wong	Paddy	36,800	4.25	156,400	5,200	813.3	6,510	239.6	573.7
	Mung Beans (40%)	14,720	1.20	17,660	8,700	153.6	3,920	75.7	95.9
	Total					966.9		297.3	669.6
3. Khlong Pho	Paddy	10,600	4.25	45,050	5,200	234.3	6,510	69.0	165.3
	Mung Beans (90%)	9,540	1.20	11,450	8,700	99.6	3,920	37.4	62.2
	Total					333.9		106.4	227.5

(2) Potential Maximum Irrigation Areas

Project	Crops	Cultivated Area (ha)	Unit Yield (Ton/ha)	Total Production (ton)	Unit Price (₿/ton)	Gross Production Value (₿/Million)	Unit Production Cost (₿/ha)	Total Production Cost (₿/Million	Net Production Cost (₿/Million)
1. Upper Mae Wong	Paddy	47,800	4.25	203,150	5,200	1,056.4	6,510	311.2	745.2
	Mung Beans (5%)	2,390	1.20	2,870	8,700	25.0	3,920	9.4	15.6
	Total					1,081.4		320.6	760.8
2. Lower Mae Wong	Paddy	47,800	4.25	203,150	5,200	1,056.4	6,510	311.2	745.2
	Mung Beans (15%)	7,170	1.20	8,600	8,700	74.8	3,920	28.1	46.7
	Total					1,131.2		339.3	791.9
3. Khlong Pho	Paddy	17,900	4.25	76,080	5,200	395.6	6,510	116.5	279.1
	Mung Beans (40%)	7,160	1.20	8,590	8,700	74.7	3,920	28.1	46.6
	Total					470.3		144.6	325.7

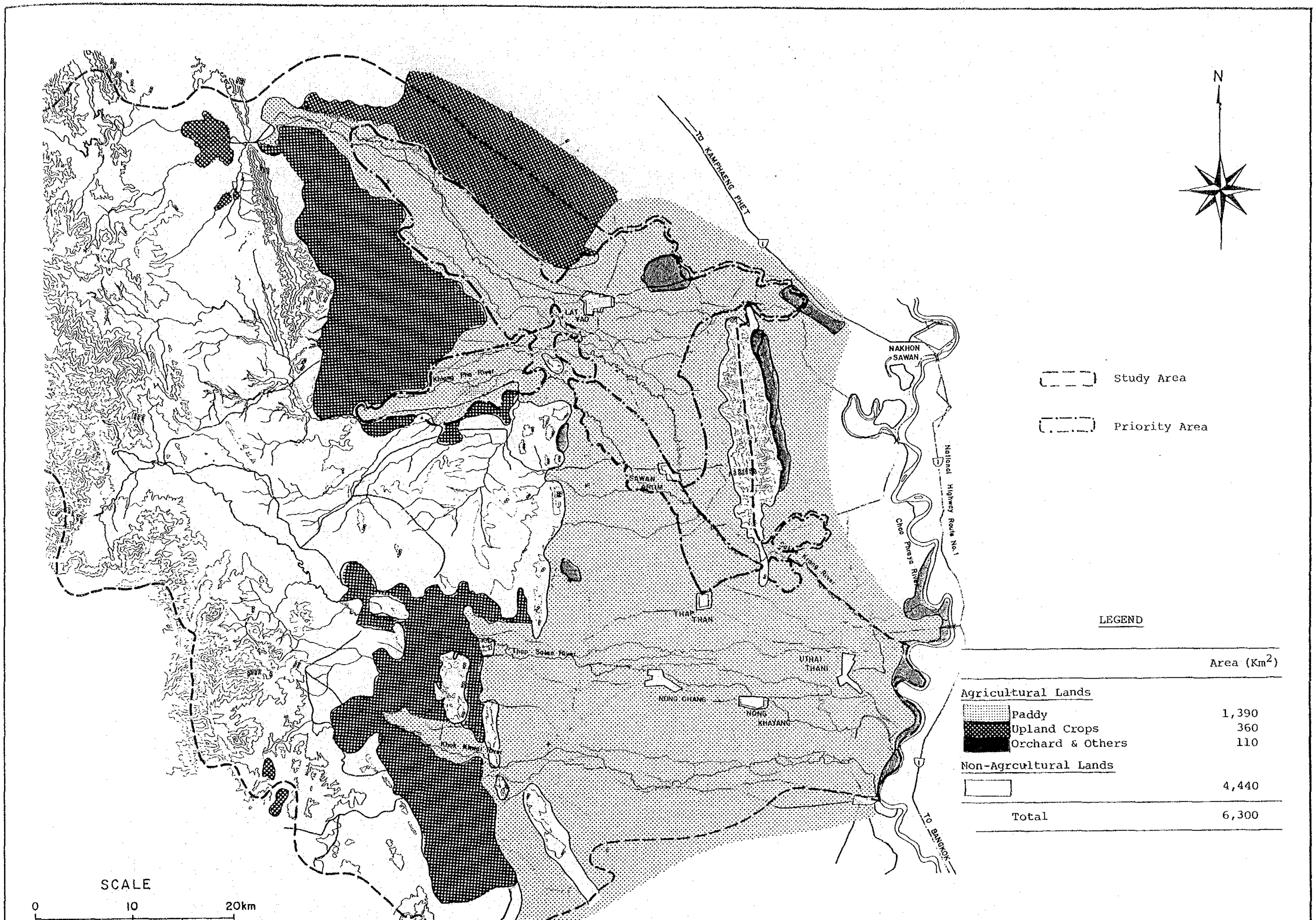


Fig. IV-1 Land Use Map

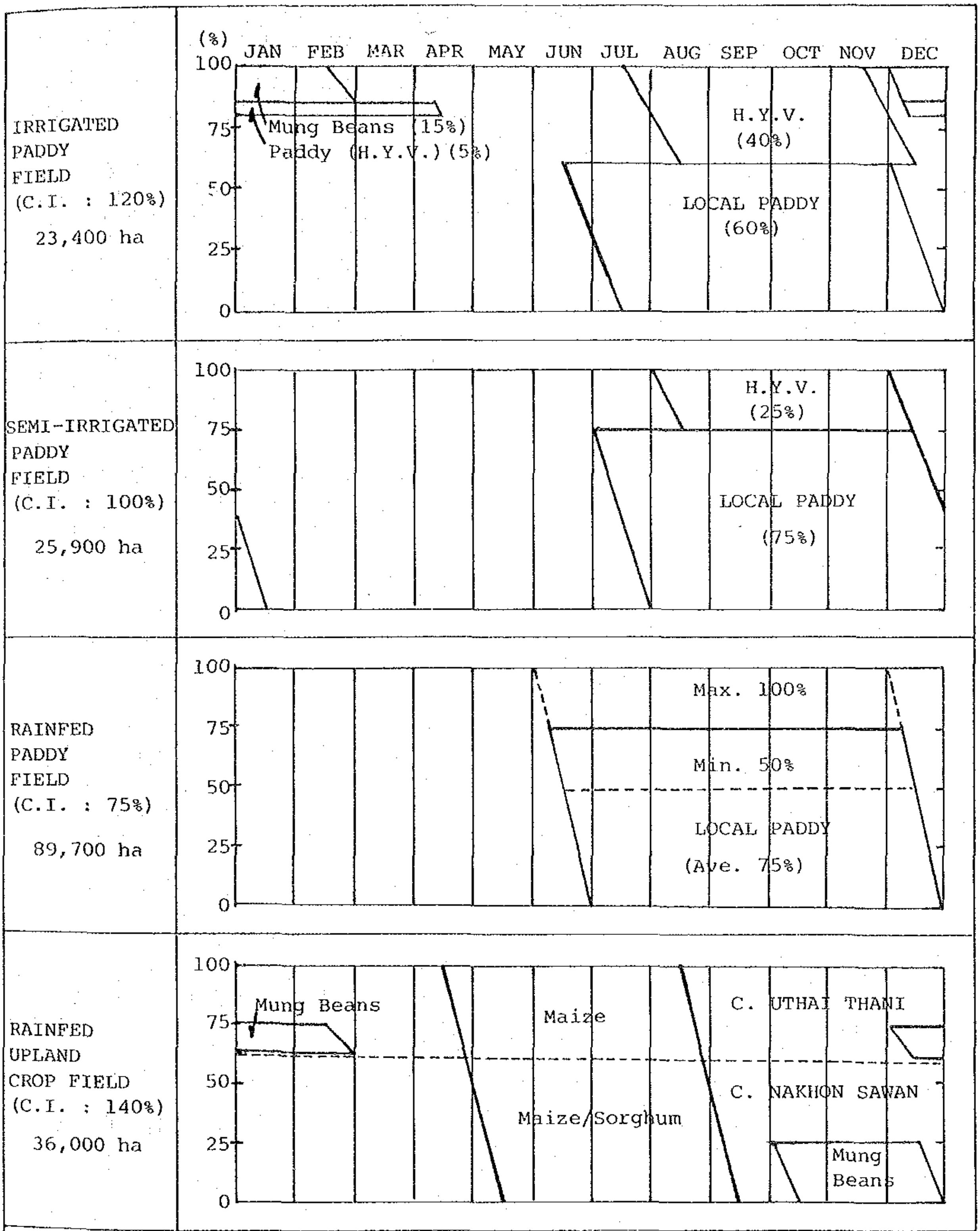


Fig. IV-2 Present Cropping Pattern

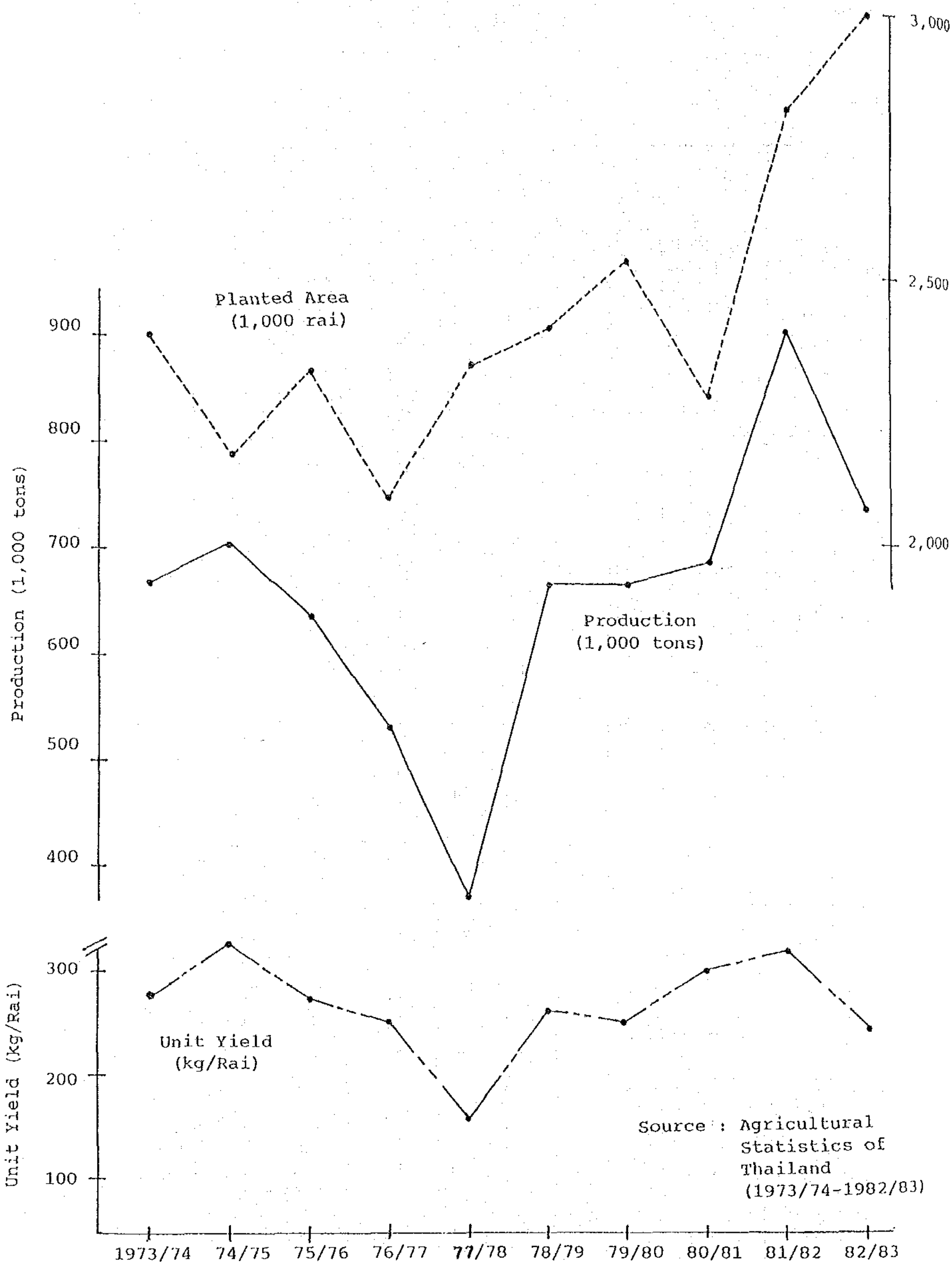
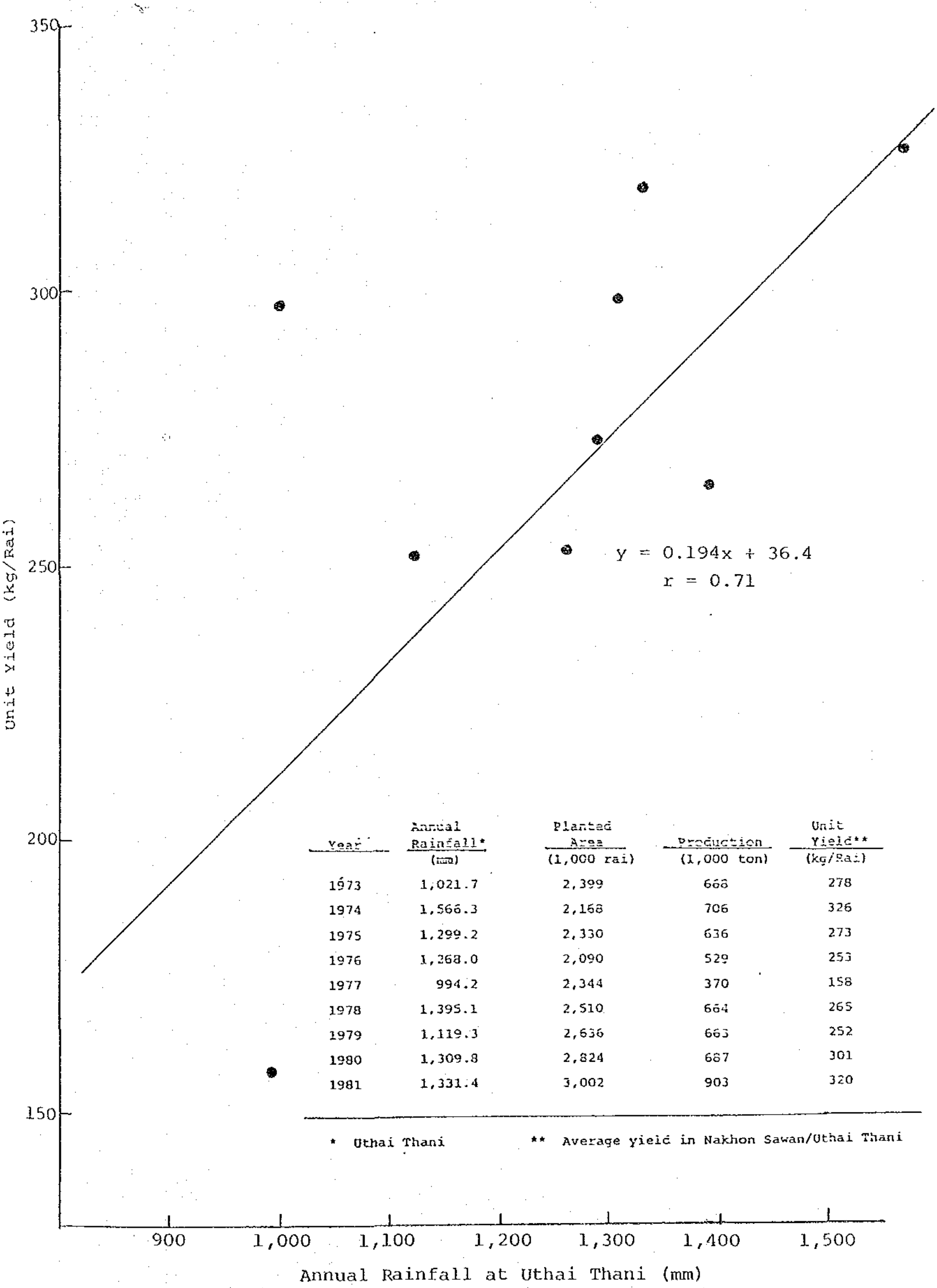


Fig. IV-3 Paddy Production in Uthai Thani and Nakhon Sawan (1973/74-1982/83)



Year	Annual Rainfall* (mm)	Planted Area (1,000 rai)	Production (1,000 ton)	Unit Yield** (kg/Rai)
1973	1,021.7	2,399	668	278
1974	1,566.3	2,168	706	326
1975	1,299.2	2,330	636	273
1976	1,268.0	2,090	529	253
1977	994.2	2,344	370	158
1978	1,395.1	2,510	664	265
1979	1,119.3	2,636	663	252
1980	1,309.8	2,824	687	301
1981	1,331.4	3,002	903	320

* Uthai Thani ** Average yield in Nakhon Sawan/Uthai Thani

Fig. IV-4 Paddy Yield and Annual Rainfall

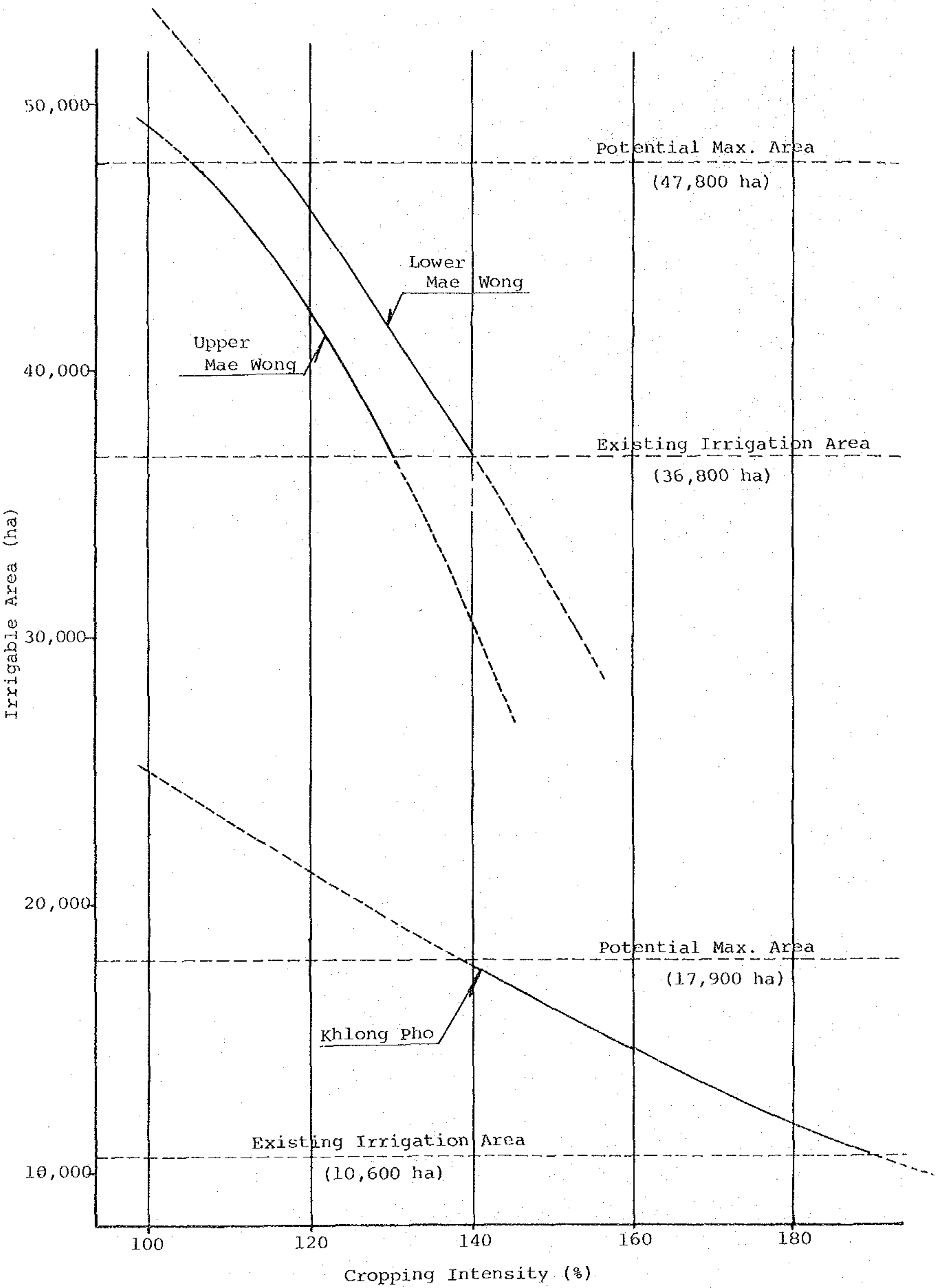


Fig. IV-5 Irrigable Area and Cropping Intensity

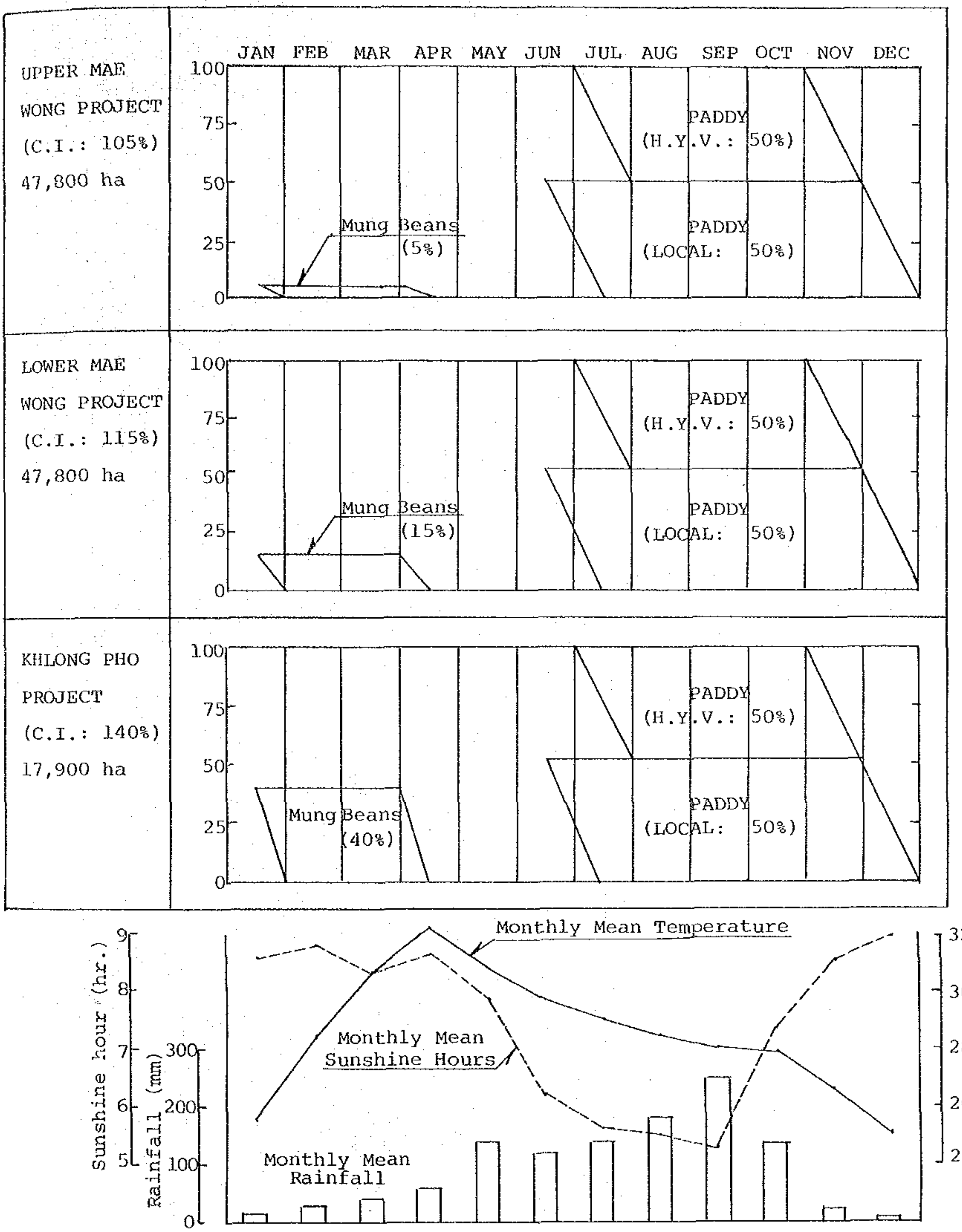


Fig. IV-6 Proposed Cropping Pattern

ANNEX V
WATER BALANCE STUDY

ANNEX-V

WATER BALANCE STUDY

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WATER BALANCE STUDY

1. INTRODUCTION

This report gives a summary of the water balance study done during the pre-feasibility study stage on the basis of the irrigation water requirements and river runnoff data.

The main purpose of this study is to calculate the following two cases of water balance over the Sakae Krang river basin.

(1) Present water balance study in the Sakae Krang basin. The main interest of this study is to check the present water use of existing irrigation areas and to reveal the areas actually irrigated in the existing irrigation service areas.

(2) Water balance study for with-project condition including reservoir operation study.

The main purpose of this study is to determine the possible development area of each proposed dam.

2. WATER BALANCE STUDY FOR PRESENT CONDITION

2.1 Procedures

2.1.1 Layout of irrigation water supply system

Figure V-1 shows a systematic layout of irrigation water supply system under the present condition. There are four main river system in the Sakae Krang river basin. They are:

(1) The Mae Wong river,

(2) The Khlong Pho river,

(3) The Thap Salao river, and

(4) The Khok Khwai river.

The Mae Wong river is called the Sakae Krang river after joining the Khlong Pho river and the Thap Salao river.

In the water balance calculation, the existing irrigation areas in the river basin are divided into 25 blocks as shown in Table V-1.

2.1.2 Definitions

(1) Simulation period and calculation interval

Calculation of water balance at each irrigation block is carried out for 28 years from 1954 to 1981 on the basis of runoff data estimated in the hydrologic studies. The calculation is carried out on 10 day-basis.

(2) Return flow

Generally, a part of water for irrigation returns to rivers and is reused for further downstream areas. According to the Chao Phraya - Meklong Basin Study, the return flow factor of 75% can be considered as effective return flow available for reuse. Rather conservative figure of 60% is used for the water balance study. The derivation of the effective return flow is given as follows:

Irrigation efficiency 45%

Effective return flow = (1 - 0.45) × Return Flow Factor
= (1 - 0.45) × 0.60
= 0.33 of diversion requirement

(3) Excess water of rainfall from paddy field

The rainfall in the paddy field is effectively used as a part of irrigation water. Non-effective rainfall (excess water of rainfall) is drained into the river together with the return flow of irrigation water. According to the results of calculation on irrigation water requirements, about 60 to 70% of rainfall are effectively used for irrigation. Consequently, the excess water of rainfall is assumed as follows:

Excess water of rainfall = 0.2 × Rainfall

(4) Water balance calculation

A basic balance at an irrigation block is simply expressed as follows:

If Runoff > Diversion Requirement
Surplus = Runoff - Diversion Requirement

If Runoff < Diversion Requirement
Deficit = Diversion Requirement - Runoff

where,
Runoff: Natural runoff at the diversion point to irrigation block including return flows and excess water of rainfall from upstream

Diversion requirement: Irrigation requirement at the diversion point to irrigation block.

A flow chart for the present water balance calculation is shown in Fig. V-2.

2.2 Basic Data

2.2.1 Runoff

Runoff data used for water balance calculation of each river basin are as follows:

(1) Mae Wong river basin: Observed runoff and runoff generated by the Tank Model method at CT5A

(2) Khlong Pho river basin: Observed runoff and runoff generated by the Tank Model method at CT7

(3) Thap Salao and Khok Khwai river basin: Observed runoff and runoff generated by the Tank Model method at CT9

2.2.2 Irrigation water demand

Irrigation water requirements are estimated in ANNEX - VII. (See Chapter 4). The irrigation water demand of each irrigation block is calculated multiplying the size of irrigation block by the unit irrigation water requirement.

2.2.3 Rainfall

The rainfall data at the Thap Than station (Code No. 69022) are used for calculation on the excess water of rainfall from paddy field.

2.3 Results of Water Balance Calculation

2.3.1 Verification of systematic diagram

There exist three gauging stations downstream of proposed dam sites in the river basin as shown below.

CT4 station: Mae Wong river (Observation Period: 1975 - 1982)

CT3 station: Thap Salao river (Observation Period: 1967 - 1971)

CT8 station: Sakae Krang river (Observation Period: 1975 - 1977)

CT4 station is selected to verify the results of the present water balance calculation, because it has long term and recent discharge records. Table V-2 shows the observed river discharge and simulated river discharge at CT4 station. Monthly mean river discharge calculated on the present systematic diagram is compared with the actual river discharge recorded at CT4 station as shown in Fig. V-3.

The calculated river discharge is satisfactorily similar to the recorded discharge.

2.3.2 Overall water balance in the Sakae Krang river basin

The results of overall water balance in each river basin are shown below.

Overall Water Balance

(Unit: MCM)

River Basin	Runoff	Re-used Water	Irrigation Water Demand	Deficit	Surplus	Water Discharged to Outside
Mae Wong	581	27	380	134	232	130
Khlong Pho	250	58	83	15	231	9
Thap Salao	318	50	251	123	156	84
Khok Khwai	253	27	118	37	199	0
Sakae Krang	1,570	174	851	309	1,066	136

Note: 1. Table shows the overall water balance of each river basin at the confluence of the Sakae Krang river and the Chao Phraya river.

2. Re-used water = Irrigation Water Demand - Deficit + Surplus + Water discharged to outside - Runoff

3. All show the average figures for 28 years period from 1954 to 1981.

In the above table, the runoff includes the excess water of rainfall from the paddy field. Except for the Mae Wong river basin, the water discharged to the outside of basin can be used within the Sakae Krang river basin. The deficit ratios of irrigation water are 35% of the Mae Wong river basin, 18% of the Khlong Pho river basin, 49% of the Thap Salao river basin, 31% of the Khok Khwai river basin and 36% of the overall Sakae Krang river basin, respectively. It can be said that the Thap Salao river basin faces much water shortage compared with the other river basins. In the Khlong Pho river basin, the return flow is effectively used for irrigation, about 70% of irrigation water demand.

2.3.3 Actually irrigated areas

The areas actually irrigated were estimated based on the ratio of deficit versus irrigation water demand in each irrigation block. Table V-3 shows the estimated areas actually irrigated based on the results of present water balance calculation. The irrigation ratio of each river basin is 65% of the Mak Wong river basin, 82% of the Khlong Pho river basin, 51% of the Thap Salao river basin, 69% of the Khok Khwai river basin and 64% of the overall Sakae Krang river basin, respectively.

3. WATER BALANCE STUDY FOR WITH-PROJECT CONDITION

3.1 Procedures

3.1.1 Layout of irrigation water supply system

The systematic layout of irrigation water supply system for each river basin under the with-project condition is shown in Figure SV-4 to V-7. The irrigation water for the Wang Rom Klao, an existing medium scale irrigation project, which is located on the Sakae Krang river, has been planned to supply mainly from the Khlong Pho river. Accordingly, the Wang Rom Klao Project is included in the Khlong Pho river basin.

3.1.2 Calculation step

The water balance calculations for the with-project condition are divided into following two steps.

Step 1: The water balance of irrigation area is calculated in accordance with the same procedures as the water balance calculation for the present condition. Through this calculation, required water amount for irrigation to be released from the proposed storage dam is estimated.

Step 2: The reservoir operation is carried out to determine the possible irrigable areas and reservoir capacity of the proposed dams by trial and error method based on the released water amount for irrigation estimated through Step 1 and given reservoir capacity.

In calculations of reservoir operation, a balance of inflow and outflow of a reservoir to be created at a proposed dam site is calculated for 28 years period on the basis of the runoff data from 1954 to 1981. The balance of a certain 10-day period of calculation is given as follows.

$$Se = Sb + I - Or - E - Os$$

where, Se: Reservoir storage of the end of the period

Sb: Reservoir storage at the beginning of the period

I: Inflow to the reservoir during the period

Or: Outflow from the reservoir during the period, this is equal to the release water for irrigation estimated through the water balance calculation downstream of the proposed dam in Step 1.

E: Evaporation from the reservoir surface during the period

Os: Spillout discharge during the period, if any. Because the storage at the end of the period is limited to the storage at the full supply water level in the maximum, the excess water is defined as spillout discharge.

A flow chart of reservoir operation is shown in Fig. V-8.

3.1.3 Definitions

(1) Simulation period and calculation interval

Water balance and reservoir operation calculations are carried out for 28 years period from 1954 to 1981 on the basis of runoff data and irrigation water demand. The calculations are made on 10 day-basis.

(2) Return flow

The derivation of effective return flow is given as follows:

Irrigation efficiency 55%
Effective return flow = (1 - 0.55) × Return Flow Factor
= (1 - 0.55) × 0.60
= 0.27 of diversion requirement

(3) Excess water of rainfall from paddy field

Excess water of rainfall = 0.2 × Rainfall

(4) Determination of possible irrigable area

Possible irrigable area is determined through the reservoir operation calculation in Step 2 on conditions that reservoir is completely depleted five times at least for the 28 years period, or in other word, drought damage recurs by 5 years return.

3.2 Basic Data

3.2.1 Runoff

Runoff data used for the water balance study of with-project condition are the same ones for the present water balance study.

3.2.2 Irrigation water demand

Irrigation water requirements for with-project condition estimated in ANNEX - VII are used for calculations.

3.2.3 Rainfall

The rainfall data at the Thap Than station (Code No. 69022) are used for calculation on the excess water of rainfall from paddy field.

3.2.4 Evaporation

Evaporation from reservoir surface in the reservoir operation calculation is based on the evaporation data at Nakhon Sawan. The evaporation loss from reservoir surface is assumed to be the estimated evaporation depth shown in Table V-4 multiplied by the reservoir surface.

3.3 Alternative Plan for Development

3.3.1 Development plan for selection of high priority projects

To select the high priority projects out of the projects identified through the overall river basin development study, water balance for the with-project condition is made based on the following condition:

(1) The water resources endowed in the sub-river basins would be developed by constructing storage dams to the maximum extent.

(2) To evaluate all identified projects at the same level, irrigation development scale would be determined under the supplemental irrigation for the wet season paddy (cropping intensity of 100%).

3.3.2 Alternative plan for high priority projects

The following alternative development plans for high priority projects were made for optimization of development scale and consequently selection of first priority project among high priority projects.

(1) Alternative development plan for optimization of dam scale

Alternative D-1 : supplemental irrigation to the existing irrigation area for wet season paddy

Alternative D-2 : supplemental irrigation to the possible maximum irrigable area in each river basin for wet season paddy

Alternative D-3 : supplemental irrigation to the possible maximum irrigable area in each basin for wet season paddy and dry season crop

(2) Alternative development plan for optimization of irrigable area and cropping intensity

Alternative I-1 : supplemental irrigation to the existing irrigation area

Alternative I-2 : supplemental irrigation to the possible maximum irrigable area in each river basin

3.4 Results of Water Balance Study

3.4.1 Water balance study results for selection of high priority projects

(1) Water balance study results

Based on the systematic diagram shown in Fig. V-4 to Fig. V-7, the water balance and reservoir operation calculations for each sub-river basin are made. The results are shown in Table V-5. The storage changes of the Lower Mae Wong Dam, the Upper Mae Wong Dam and the Khlong Pho Dam are representatively shown in Figures V-9 to V-11. From Table V-5, the relationship curve between required effective reservoir capacity and possible irrigable area is made as shown in Fig. V-12. The figure shows that even further increase of reservoir capacity, no more increase of possible irrigable area can be expected. Subsequently, assumptions applied for determination of possible maximum reservoir capacity described in ANNEX - VI are approved within certain accuracy.

From the results shown in Table V-5, the possible irrigable area of each proposed dam with possible maximum reservoir capacity is summarized in Table V-6.

(2) Selection of high priority projects

Referring the preliminary design of dam and reservoir, the major dimensions of possible projects such as watershed, reservoir, dam, irrigable area and reservoir capacity are determined on a preliminary basis and are shown in Table V-7. For selection of high priority projects, preliminary evaluation is made on the possible projects by using several indicators like reservoir performance, incremental irrigable area and dam construction cost which are calculated on the basis of the said major dimensions. The indicators used for evaluation are summarized below:

Items		Mae Wong Upper	Mae Wong Lower	Phlong Pho	Huai Rang	Khun Kaew Upper	Khun Kaew Lower
1. Reservoir Performance							
Irr. Area/Eff. Storage	ha/MCM	213	153	260	111	342	292
Embk. Vol/Eff. Storage	10^3m^3/MCM	14.8	1.1	7.7	46.1	34.7	40.4
2. Irrigation							
Irrigation area	10^3 ha	49.0	53.5	25.0	2.0	13.0	14.9
Incremental Irrigation Area	10^3 ha	25.4	29.9	18.0	-	4.7	6.6
Irr. Area/Eff. Storage	ha/MCM	110	85	187	-	124	129
3. Dam Construction Cost							
Direct Const. Cost	M฿	1,148	620	567	195	403	545
Const/Eff. Storage	M฿/MCM	4.9	1.8	5.9	10.8	10.6	10.7
Cost/Embk. Vol.	฿/m^3	326	1,140	497	235	305	265
Construction Period	Yr	5	5	5	4.5	5	5
4. Resettlement							
House	No	40	520	365	218	30	105
Land	km^2	19.5	68.0	32.0	2.2	2.2	7.3
Compensation	@0.2 M฿/House, @0.6 M฿/km^2 M฿	19.7	144.8	92.2	44.9	7.3	25.4

The proposed projects are obviously classified into two groups such as large and medium scale projects according to their development scales of irrigation areas. Large scale irrigation development will be attained by projects of Upper Mae Wong, Lower Mae Wong and Khlong Pho, having total irrigation area in wet season from 25,000 ha to 53,500 ha and incremental irrigation area of more than 10,000 ha. Comparison of two groups are expressed as follows.

	Upper Mae Wong Lower Mae Wong Khlong Pho	Huai Rang Upper Khun Kaew Lower Khun Kaew
Embk. Vol./Eff. Storage	Small	Large
Irrigation area	Large	Small
Incremental Irr. area	Large	Small
Dam Cost/Eff. Storage	Small	Large

Based on the evaluation on these four components, it is concluded that the high priority projects are selected to be the Upper Mae Wong, Lower Mae Wong and Khlong Pho projects. Among these three projects, merits and demerits are counted as follows:

(a) Upper Mae Wong Project

(Merit)

- Higher effective use of reservoir storage
  Irrigation Area/Effective Storage = 213 ha/MCM
- Small problem expected for resettlement
- Higher potentiality of hydro-power generation
- Large irrigation area
- Good foundation and materials available for dam

(Demerit)

- Large construction cost for dam

(b) Lower Mae Wong Project

(Merit)

- Small construction cost for dam
- Large irrigation area

(Demerit)

- Resettlement problem
- Low efficiency in use of reservoir storage
  Irrigation Area/Effective Storage = 153 ha/MCM

(c) Khlong Pho Project

(Merit)

- Smaller construction cost for dam
- Higher effective use of reservoir storage
  Irrigation Area/Effective Storage = 260 ha/MCM

(Demerit)

- Resettlement problem
- Unsuitable geological structure (loose sand layer) for dam foundation
- Poor materials for embankment.

(3) Consideration on the Upper Khun Kaew project

Based on the engineering evaluation on the scale of irrigation development and the dam construction cost efficiency on the exploitation of water resources, the said three projects are selected to be high priority projects. However, it is necessary to emphasize the expected difficulties involved in the resettlement programme which will deal with political, social and economical aspects to be duly settled.

Among six proposed projects, the Upper Mae Wong and Upper Khun Kaew projects have less number of household in the submerged area. It is foreseen from the study that the Upper Khun Kaew project will not gain higher economical performance in the project evaluation. But, the total investment amount is the smallest among them except for the Huai Rang project.

Resettlement problems will be less, and geological formation is suitable for dam construction. Considering these merits, it is necessary to keep attention on the Upper Khun Kaew project.

3.4.2 Water balance study results for high priority projects

The results of the water balance study for each alternative plan are shown as follows.

Dam	Alternative plan	Reservoir Capacity (MCM)	Possible Irrigable Area			Cropping intensity (%)
			Existing (ha)	Potential (ha)	Total (ha)	
Upper Mae Wong	D-1	115	36,800	-	36,800	100
	D-2	205	36,800	11,000	47,800	100
	D-3	230	36,800	11,000	47,800	105
	I-1	230	36,800	-	36,800	130
	I-2	230	36,800	11,000	47,800	105
Lower Mae Wong	D-1	115	36,800	-	36,800	100
	D-2	235	36,800	11,000	47,800	100
	D-3	350	36,800	11,000	47,800	115
	I-1	350	36,800	-	36,800	140
	I-2	350	36,800	11,000	47,800	115
Khlong Pho	D-1	25	10,600	-	10,600	100
	D-2	45	10,600	7,300	17,900	100
	D-3	96	10,600	7,300	17,900	140
	I-1	96	10,600	-	10,600	190
	I-2	96	10,600	7,300	17,900	140

Note: Cropping Pattern = Paddy + Mung Bean

The storage changes of Alternative I-2, for each dam are shown in Fig. V-13 to Fig. V-15. From the above results, the relationship between possible irrigable area and cropping intensity is worked out as shown in Fig. V-16.

Table V-1 IRRIGATION BLOCK FOR PRESENT WATER BALANCE

River Basin	Block	Service Area (rai)	Remark
	MW1	105,000	
	MW2	10,000	
	MW3	3,000	
Mae Wong	MW4	3,000	
	MW5	73,000	sub-total
	MW6	10,000	230,000 rai
	MW7	26,000	(36,800 ha)
	KP1	4,000	
Khlong Pho	KP2	20,800	sub-total
	KP3	17,500	53,800 rai
	KP4	11,500	(8,600 ha)
	TS1	7,500	
	TS2	10,000	
	TS3	21,500	
Thap Salao	TS4	88,000	
	TS5	7,500	
	TS6	12,500	sub-total
	TS7	11,000	162,000 rai
	TS8	4,000	(25,920 ha)
	KK1	6,000	
	KK2	21,700	
Khok Khwai	KK3	11,850	sub-total
	KK4	10,000	76,050 rai
	KK5	26,500	(12,170 ha)
Sakae Krang	SK1	12,500	(2,000 ha)

Table V-2 RIVER DISCHARGE AT CT4 STATION

Observed River Discharge at CT4 Station

(Unit: MCM)

Year	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	Total
1975	14.0	12.3	16.9	70.7	103.2	51.2	11.1	6.6	2.7	0.8	0.7	13.8	304.0
1976	2.9	1.4	7.9	99.2	105.3	88.6	11.1	5.6	1.9	1.9	2.1	2.9	330.8
1977	0.5	0.0	0.2	18.3	17.3	6.1	1.6	0.7	0.0	0.0	0.1	8.9	53.9
1978	3.3	30.4	25.7	76.7	119.1	18.3	6.8	1.7	0.1	0.1	-	-	-
1979	-	-	-	-	-	-	-	-	-	-	0.4	37.2	-
1980	86.9	26.8	30.6	81.7	134.7	30.9	8.0	2.5	0.1	0.2	0.4	7.6	410.4
1981	8.0	6.1	20.3	36.3	63.6	164.5	32.8	10.0	1.6	0.6	1.7	5.4	350.9
Mean	19.3	12.8	16.9	63.8	90.5	59.9	11.9	4.5	1.1	0.6	0.9	12.6	294.8

Simulated River Discharge at CT4 Station

(Unit: MCM)

Year	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	Total
1975	28.7	4.0	4.9	71.4	117.4	57.3	21.4	2.0	1.1	4.3	3.8	21.8	338.1
1976	6.4	1.8	17.0	88.1	81.0	101.2	9.7	1.0	0.4	0.3	3.9	6.6	317.4
1977	2.7	1.4	4.5	21.4	5.2	1.6	1.3	0.3	0.7	0.3	3.7	13.0	55.9
1978	8.6	25.9	6.8	91.6	143.2	3.7	7.3	0.8	0.6	0.2	3.1	7.3	298.9
1979	34.7	2.6	3.8	110.1	25.6	1.5	1.4	0.4	0.3	0.5	2.3	88.2	271.4
1980	36.2	6.9	9.8	87.1	230.4	20.2	7.7	0.9	1.2	0.9	7.5	18.9	427.6
1981	28.5	6.1	8.4	51.9	75.9	64.3	25.9	1.1	0.6	0.4	3.0	11.5	277.6
Mean	20.8	7.0	7.9	74.5	96.9	35.7	10.7	0.9	0.7	1.0	3.9	23.9	283.8

Table V-3 ACTUALLY IRRIGATED AREA

River Basin	Block	Irrigation Service Area (rai)	Actually Irrigated Area (rai)
Mae Wong	MW1	105,000	75,600
	MW2	10,000	5,200
	MW3	3,000	2,700
	MW4	3,000	1,300
	MW5	73,000	43,000
	MW6	10,000	9,700
	MW7	26,000	10,100
	Sub-total	230,000 (36,800 ha)	147,600 (23,600 ha)
Khlong Pho	KP1	4,000	3,800
	KP2	20,800	17,000
	KP3	17,500	13,800
	KP4	11,500	9,200
	Sub-total	53,800 (8,600 ha)	43,800 (7,000 ha)
Thap Salao	TS1	7,500	7,200
	TS2	10,000	8,300
	TS3	21,500	12,400
	TS4	88,000	33,400
	TS5	7,500	6,500
	TS6	12,500	5,700
	TS7	11,000	5,300
	TS8	4,000	3,600
	Sub-total	162,000 (25,920 ha)	82,400 (13,100 ha)
Khok Khwai	KK1	6,000	5,300
	KK2	21,700	17,100
	KK3	11,850	5,500
	KK4	10,000	8,100
	KK5	26,500	16,100
	Sub-total	76,050 (12,170 ha)	52,100 (8,300 ha)
Sakae Krang	SK1	12,500 (2,000 ha)	12,000 (1,900 ha)
	Total	534,350 (85,500 ha)	337,900 (54,000 ha)

Table V-4 ESTIMATED EVAPORATION DEPTH

NUMBER OF RAINLESS DAY AT CT-5A

(Unit: day)

Year	A	M	J	J	A	S	O	N	D	J	F	M
1970	24	14	6	9	6	10	20	25	25	31	26	29
1971	24	13	21	18	16	11	17	28	31	31	29	31
1972	26	20	18	31	25	14	20	23	28	31	28	24
1973	29	8	12	18	15	13	20	26	31	30	27	22
1974	19	20	23	15	18	11	15	26	31	20	27	25
1975	28	15	23	19	16	14	13	25	30	31	28	28
1976	26	15	20	19	11	11	17	24	31	31	28	29
1977	23	20	24	22	20	11	21	30	30	31	24	31
1978	29	19	21	8	13	10	19	30	31	30	27	31
1979	28	23	17	21	22	11	27	30	31	31	28	29
1980	27	22	12	10	17	4	19	30	31	31	28	28
1981	26	23	13	15	10	12	17	25	-	-	-	-
1982	30	22	23	19	17	9	17	25	31	30	28	29
Average	26.1	18.0	17.9	17.2	15.9	10.9	18.6	26.7	30.1	29.8	27.3	28.0
Ratio	0.87	0.58	0.60	0.56	0.51	0.36	0.60	0.89	0.97	0.96	0.97	0.90

EVAPORATION DEPTH

(Unit: mm)

	J	F	M	A	M	J	J	A	S	O	N	D
Ep	4.9	6.2	7.5	8.7	7.1	6.1	5.6	4.9	4.3	4.5	4.4	4.5
Ed	3.06	3.91	4.39	4.92	2.68	2.38	2.04	1.62	1.01	1.76	2.55	2.84

Note: Ep = Mean monthly evaporation at Nakhon Sawan

Ed = Estimated evaporation depth

= Ep x Ratio of Rainless Day x 0.65

Table V-5 WATER BALANCE STUDY RESULTS FOR SELECTION OF HIGH PRIORITY PROJECT

Dam	Inflow (MCM)	Reservoir Capacity (MCM)	Irrigable Area (ha)	Release for Irrigation (MCM)	Evaporation (MCM)	Spill-out (MCM)	Deficit (MCM)
Lower Mae Wong	298	115	36,800	154	26	119	7.0
	298	205	44,800	186	34	75	5.0
	298	235	47,800	206	35	57	6.2
	298	350	53,500	246	37	16	13.3
Upper Mae Wong	196	115	36,800	105	9	82	4.0
	196	175	44,800	132	11	53	5.3
	196	205	47,800	148	11	37	7.8
	196	230	49,000	154	12	30	7.9
Khlong Pho	87	25	10,600	8	19	60	1.5
	87	45	17,900	27	21	39	2.2
	87	82	24,000	40	26	22	2.5
	87	96	25,000	43	25	19	3.4
Thap Salao	124	160	23,500	14	13	2	11.6
Huai Rang	18	18	2,000	105	1	5	0.7
Lower Khun Kaew	51	25	10,270	16	5	30	1.1
	51	51	14,910	33	6	12	4.5
Upper Khun Kaew	38	20	10,270	15	1	21	1.7
	38	38	13,000	24	2	12	3.2

Note: Cropping Intensity = 100 %

Table V-6 ESTIMATED POSSIBLE IRRIGABLE AREA

River Basin	Dam	(1) Reservoir Capacity (MCM)	(2) Irrigable Area (ha)	(1)/(2)
Mae Wong	Lower Mae Wong	350	53,500	6,540
	Upper Mae Wong	230	49,000	4,690
Khlong Pho	Khlong Pho	96	25,000	3,840
Thap Salao	Thap Salao	160	23,500	6,800
	Huai Rang	18	2,000	9,000
Khok Khwai	Lower Khun Kaew	51	14,910	3,420
	Upper Khun Kaew	38	13,000	2,920

Table V-7 SUMMARY OF PROJECT DIMENSION FOR SELECTION OF HIGH PRIORITY PROJECTS

Item		Mae Wong River		Khlong	Thap Salao River		Khok Khwai River	
		Upper	Lower	Pho	Thap Salao	Huai Rang	Upper Khun Kaew	Lower Khun Kaew
1. Watershed								
Drainage Area	km^2	612	930	394	534	76	162	219
Ave. Ann, Inflow	MCM	193	294	80	125	18	38	51
Ave. Ann. Rainfall	mm	1,293	1,293	1,284	1,347	1,347	1,347	1,347
2. Reservoir								
Effective Storage	MCM	230	350	96	160	18	38	51
Dead Storage	MCM	20	30	14	8	3	6	8
Total Storage	MCM	250	380	110	168	21	44	59
Reservoir Area								
Full Storage	km^2	17.0	54.0	30.0	18.2	2.0	2.0	6.7
High Water	km^2	19.5	68.0	32.0	20.3	2.2	2.2	7.3
3. Dam								
Type		RF	ZEF	EF	EF	ZEF	RF	EF
Height	m	62.0	38.1	20.9	28.2	30.5	49.5	32.0
Crest Length	m	780	240	1,555	4,270	1,470	570	2,500
Embankment	MCM	3.40	0.38	0.74	5.1	0.83	1.32	2.06
Design Flood	cum/s	1,770	2,600	1,190	952	260	530	690
4. Irrigation Area								
Existing Area	ha	36,800	36,800	10,600 3/	25,900	25,900	10,300	10,300
Irrigated Area 1/	ha	23,600	23,600	7,000	13,100	13,100	8,300	8,300
Irrigated Area 2/	ha	49,000	53,500	25,000	23,500	2,000	13,000	14,900
5. Reservoir Operation (Annual Mean)								
Evapo. Loss	MCM/yr	12	37	25	13	1	2	6
Spillout	MCM/yr	30	16	19	2	5	12	12

1/ Estimated from water balance for the present condition.
2/ Estimated from water balance for with-project condition of wet season paddy.
3/ Include the Wang Rom Klao fo 2,000 ha.

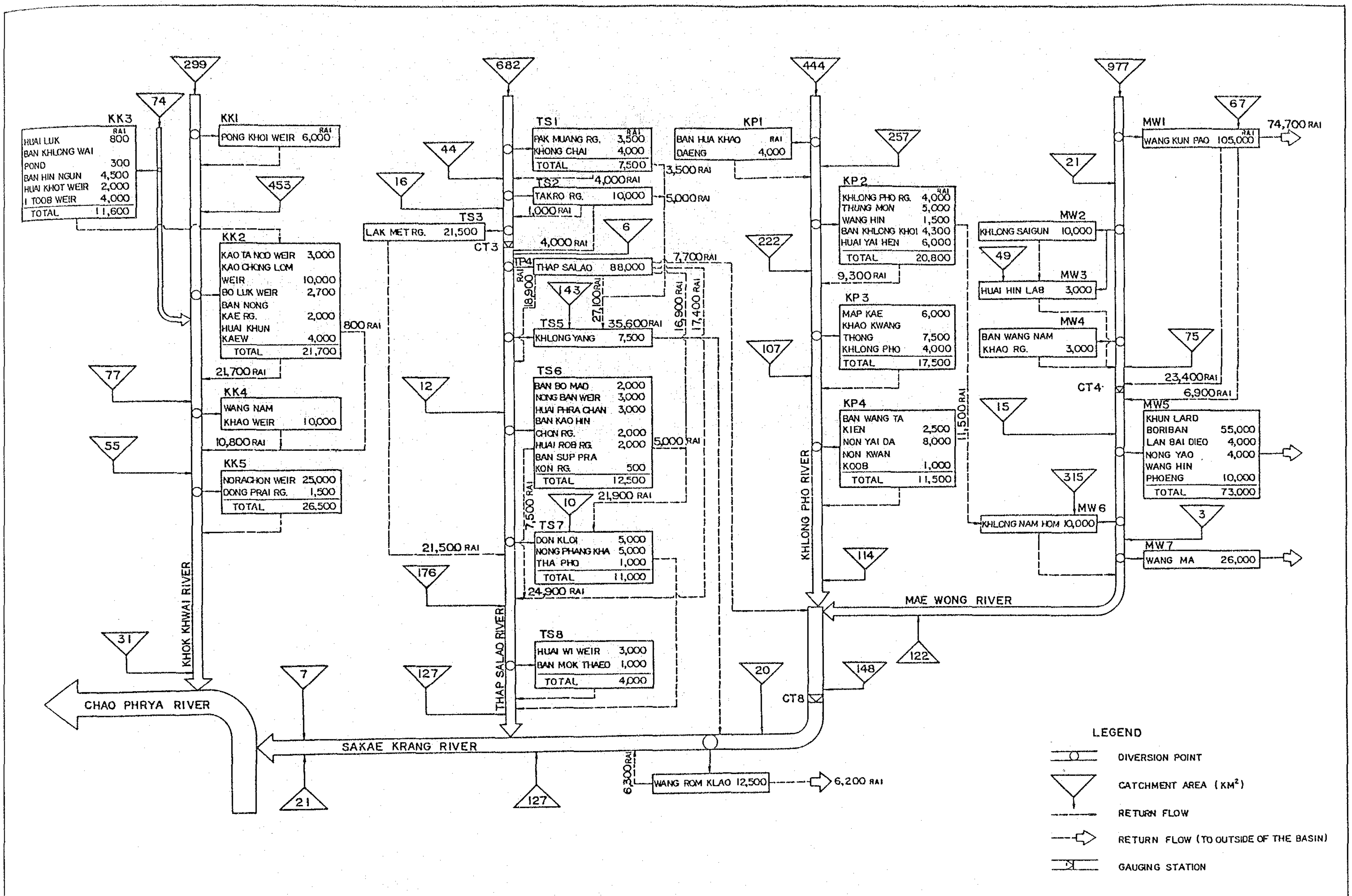


Fig. V-1 Systematic Diagram of Sakae Krang River Basin for Water Balance Study under Present Condition

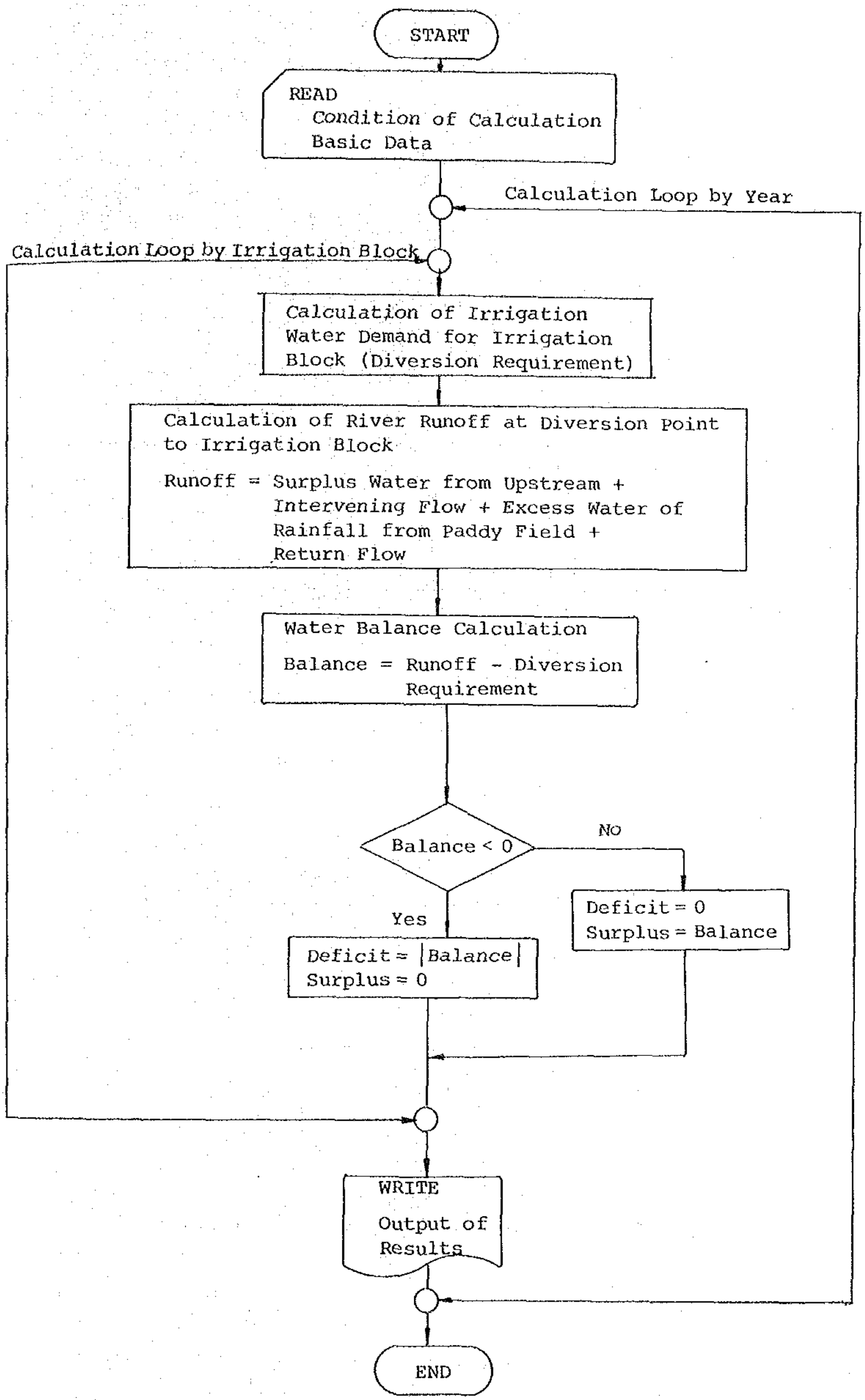


Fig. V-2 Flow Chart of Water Balance Calculation

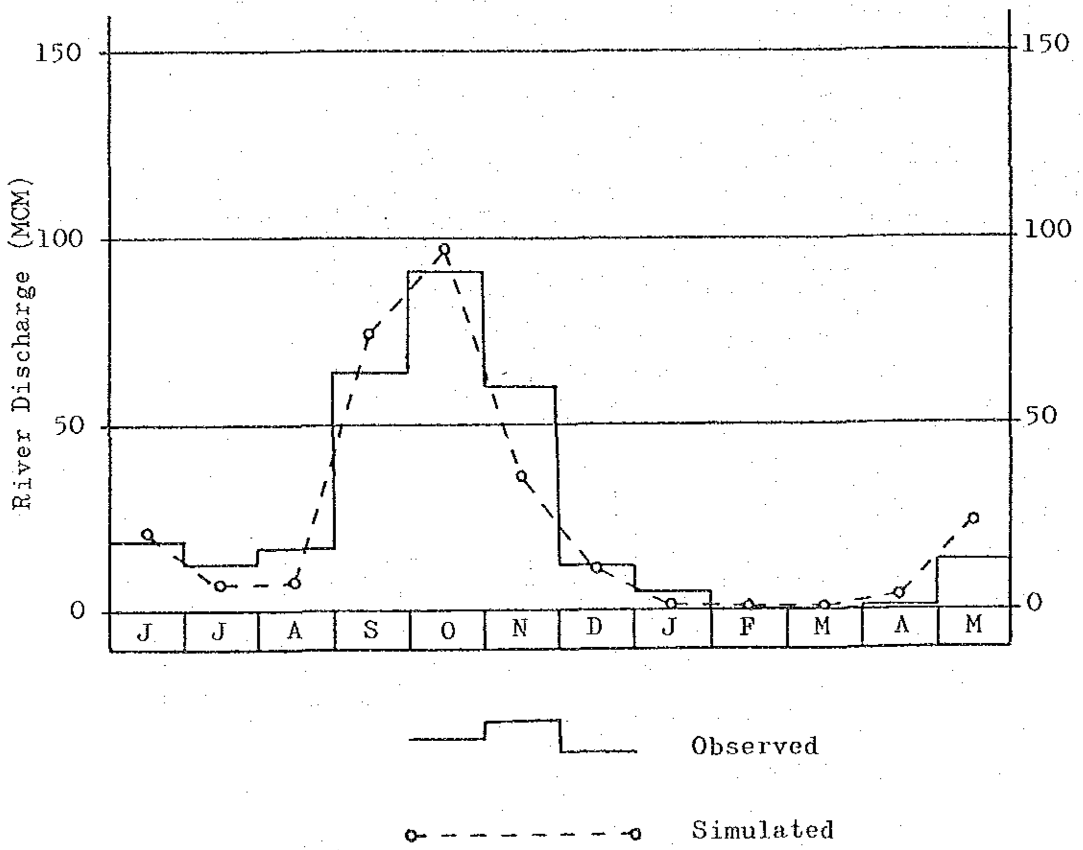


Fig.V-3 Monthly Mean River Discharge at CT 4 Station

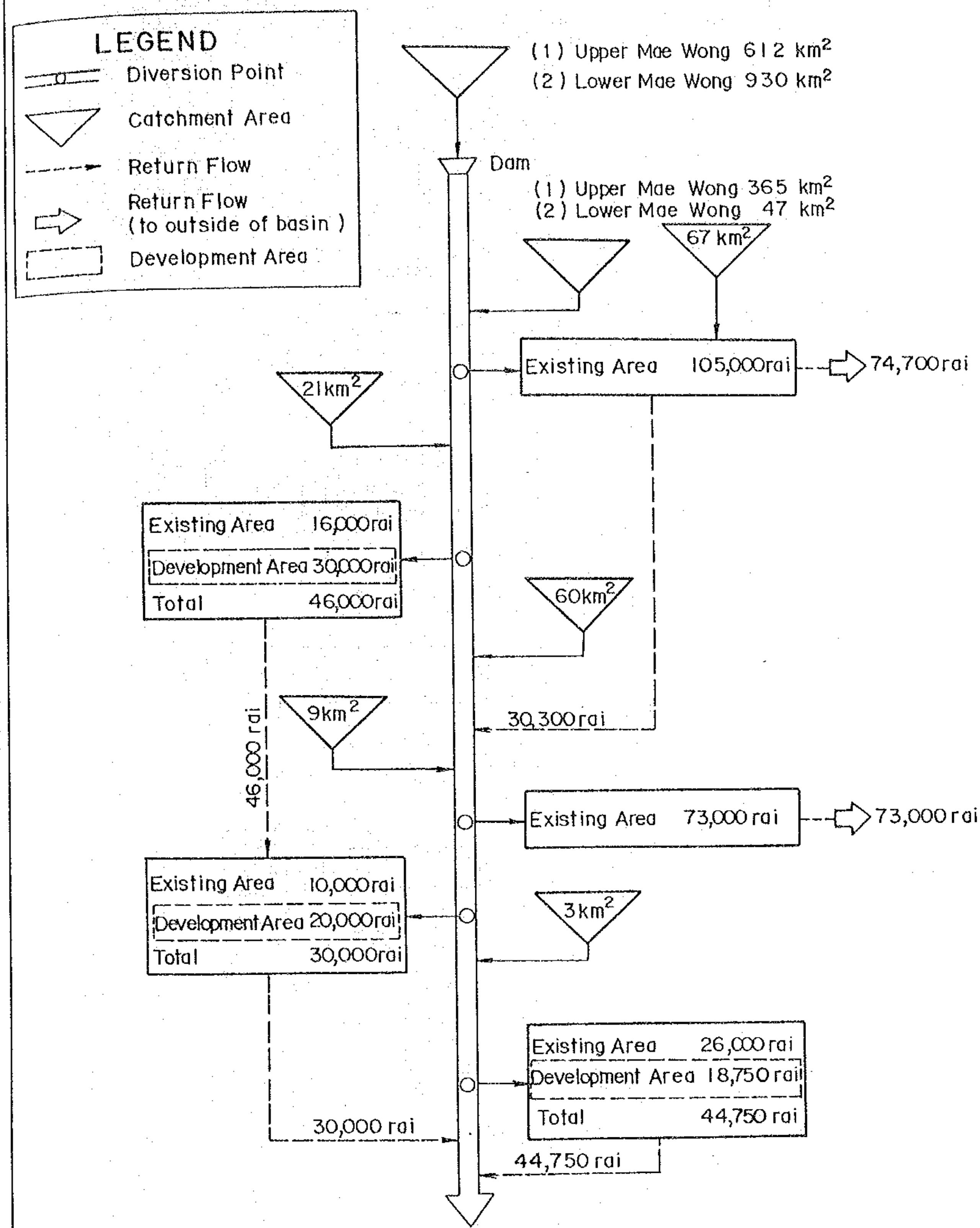


Fig. V-4 Systematic Diagram of Mae Wong River Basin for Water Balance Study under With-Project Condition

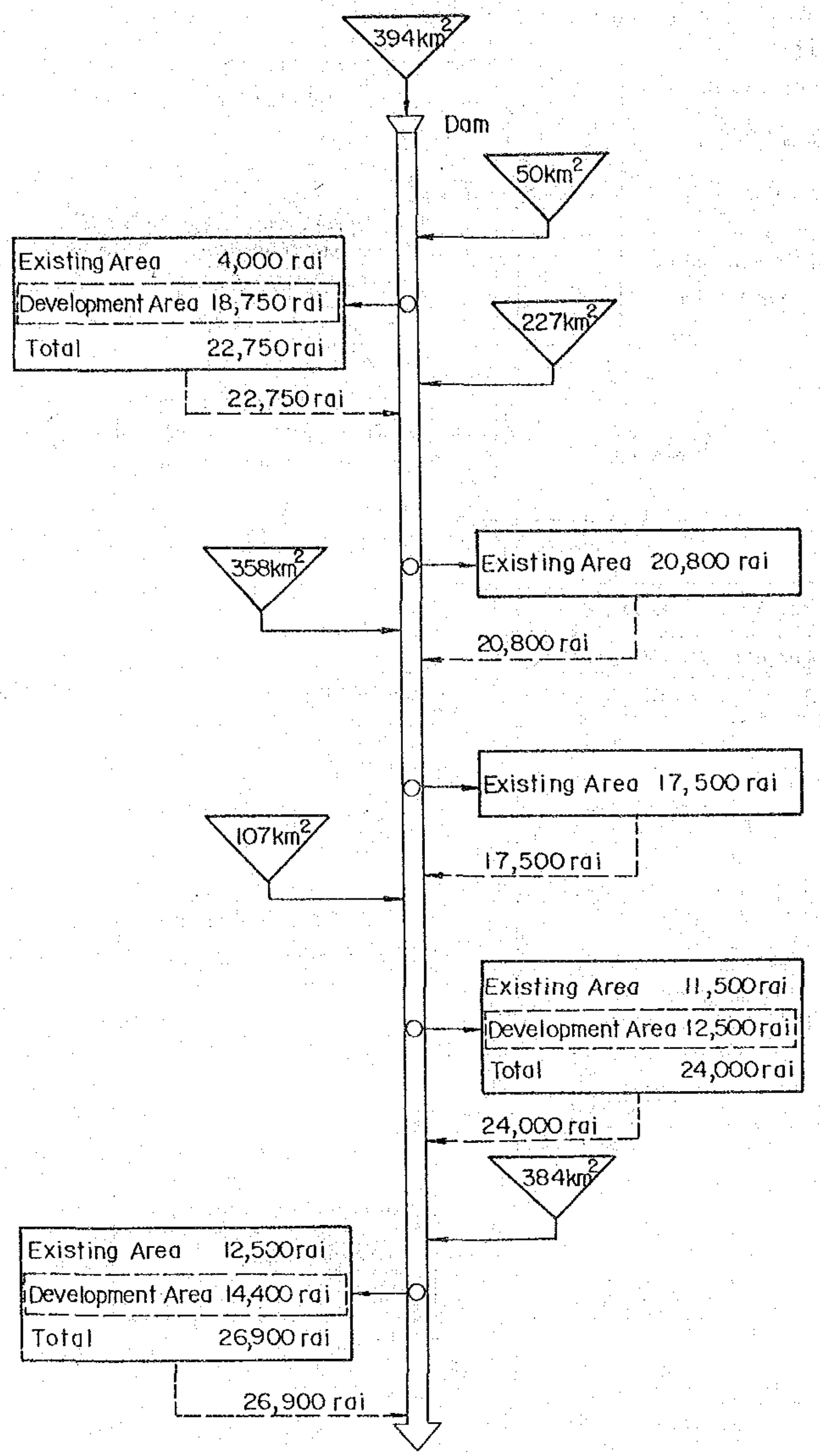


Fig. V-5 Systematic Diagram of Khlong Pho River Basin for Water Balance Study under With-Project Condition

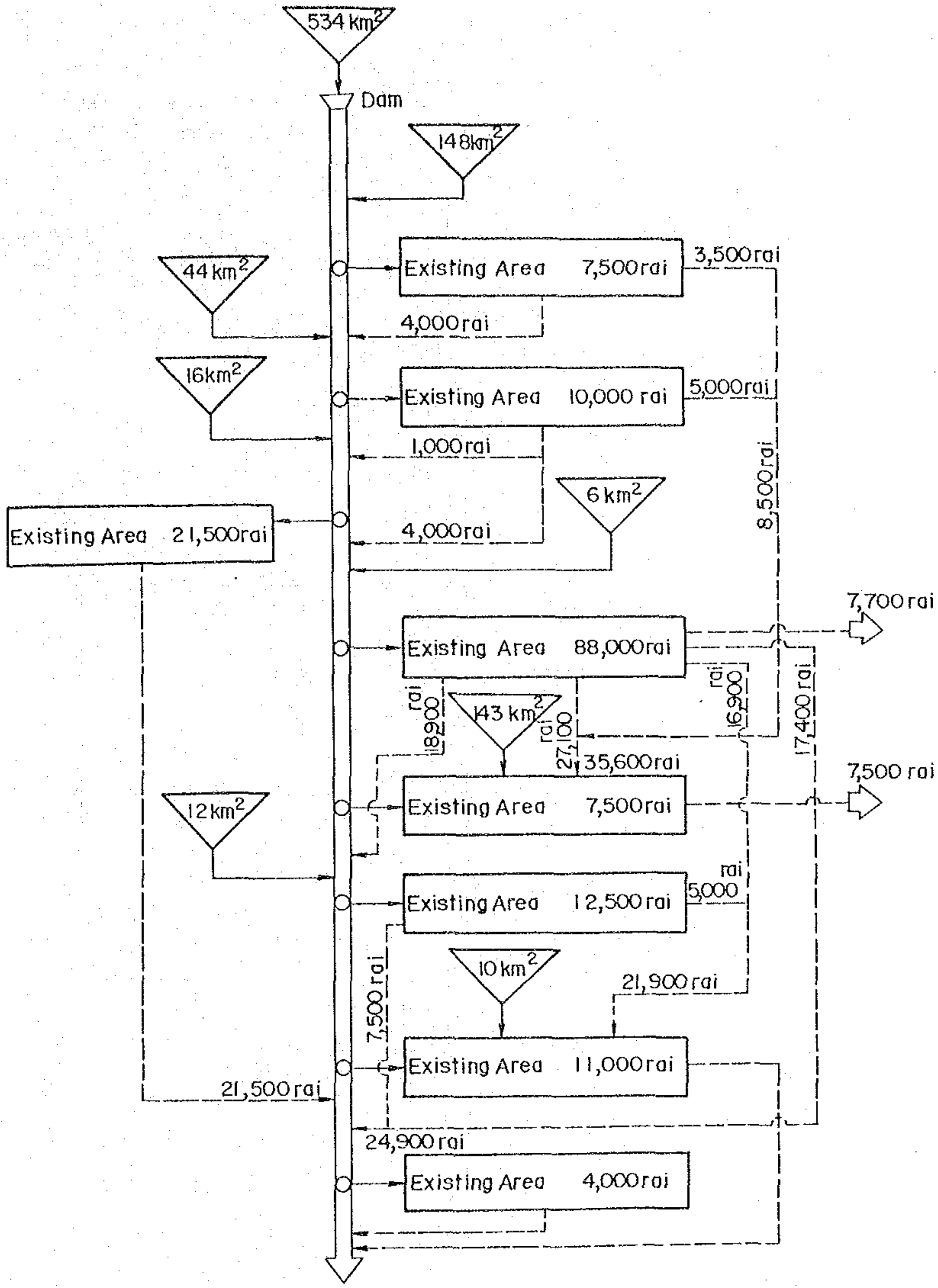


Fig. V-6 Systematic Diagram of Thap Salao River Basin for Water Balance Study under With-Project Condition

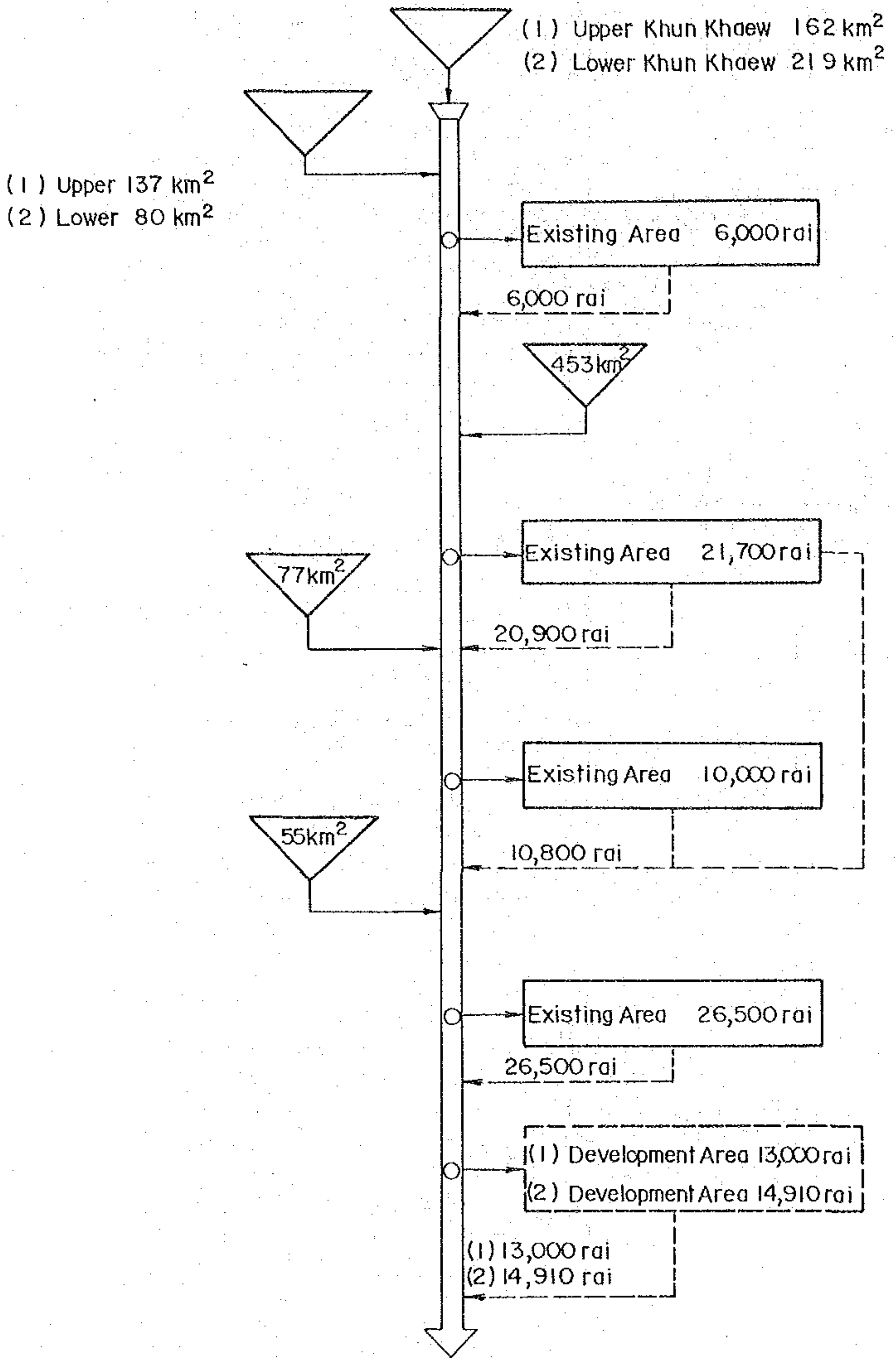


Fig. V-7 Systematic Diagram of Khok Khwai River Basin for Water Balance Study under With-Project Condition

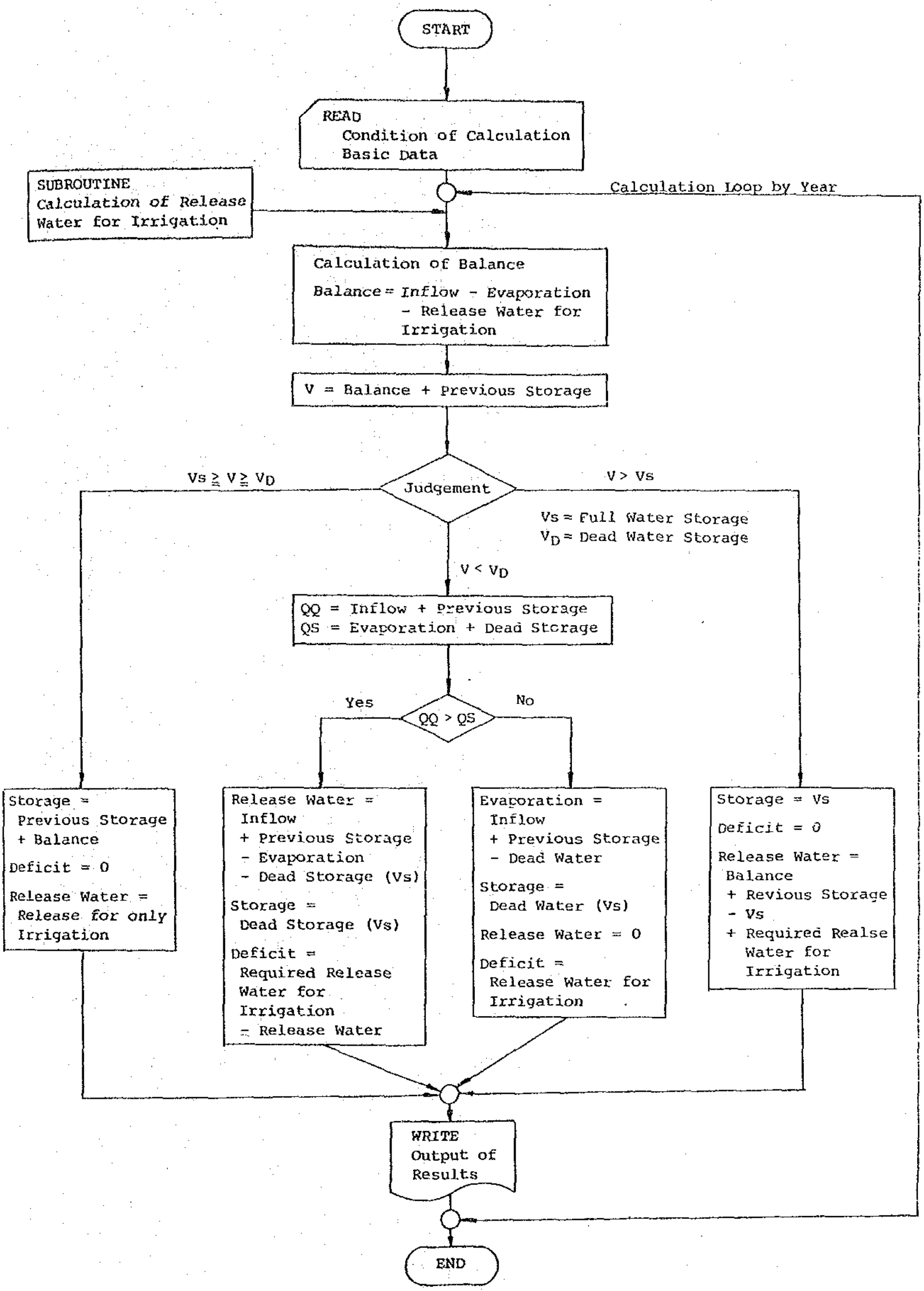


Fig. V-8 Flow Chart of Reservoir Operation

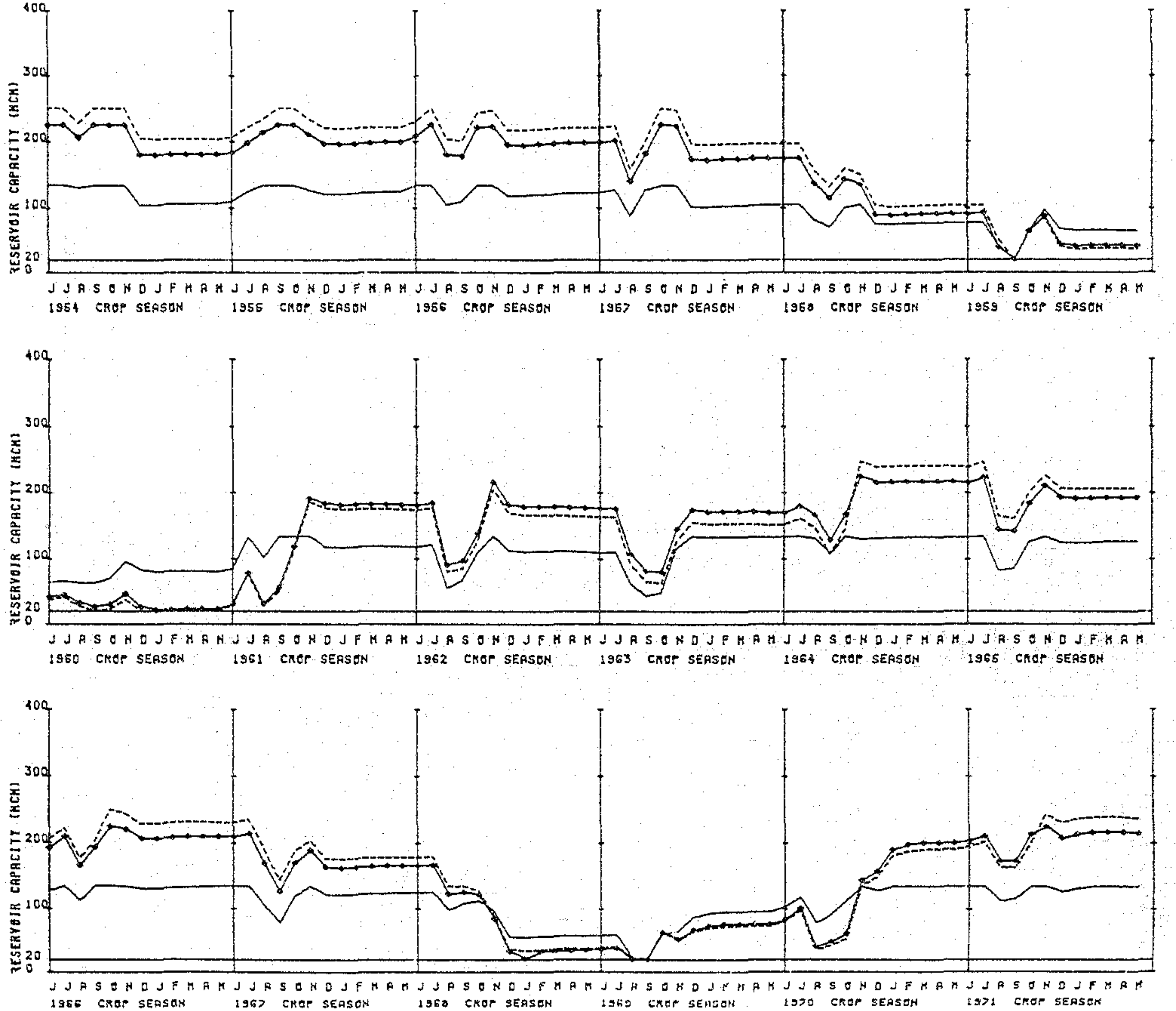
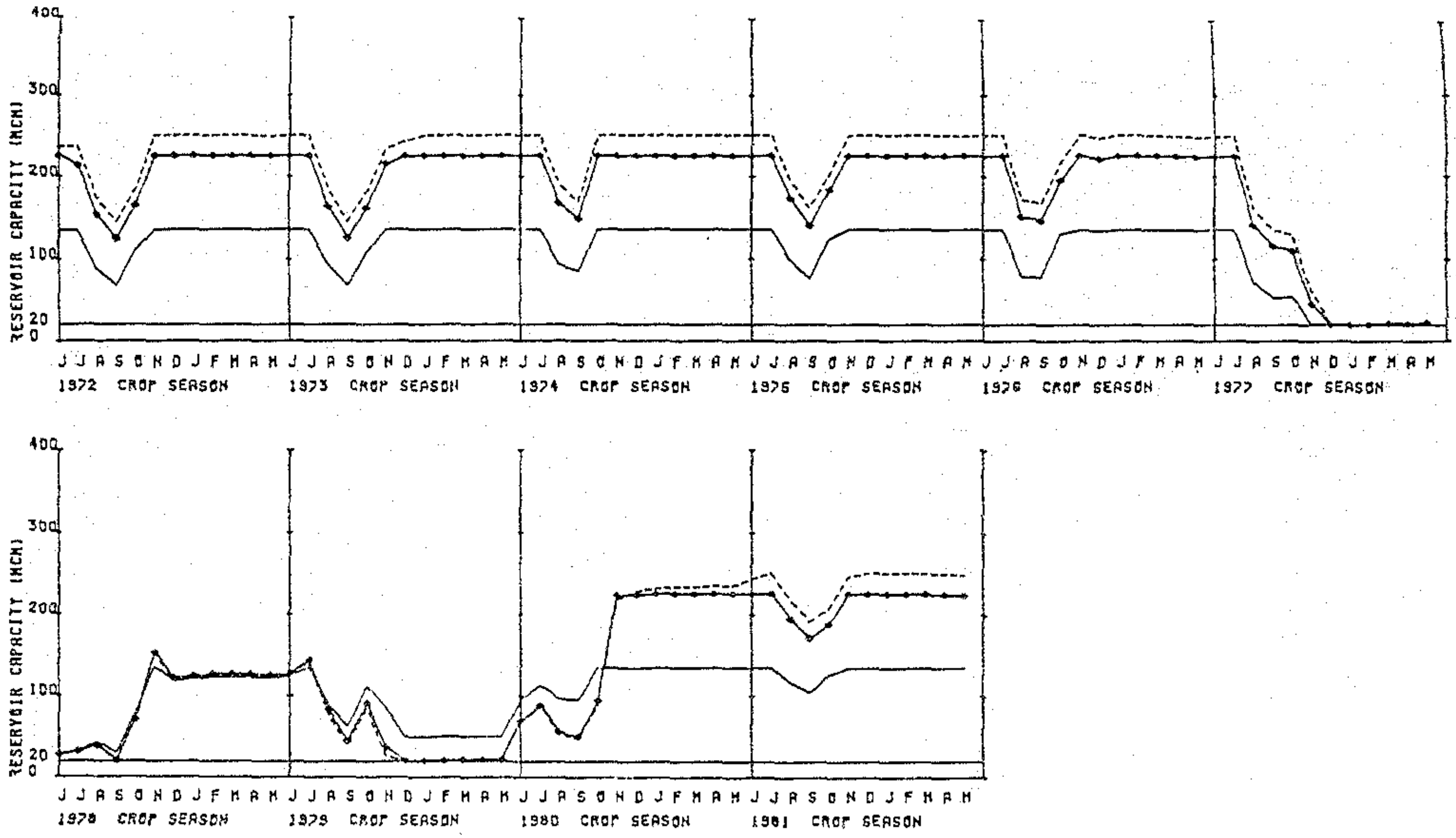


Fig. V-9 Storage Charges of Upper Mae Wong Dam (1/2)



LEGEND

———————	Storage Capacity: 135 MCM, Irrigable Area: 36,800 ha
•———————•	Storage Capacity: 225 MCM, Irrigable Area: 47,800 ha
- - - - - - -	Storage Capacity: 250 MCM, Irrigable Area: 49,000 ha

Fig. V-9 Storage Charges of Upper Mae Wong Dam (2/2)

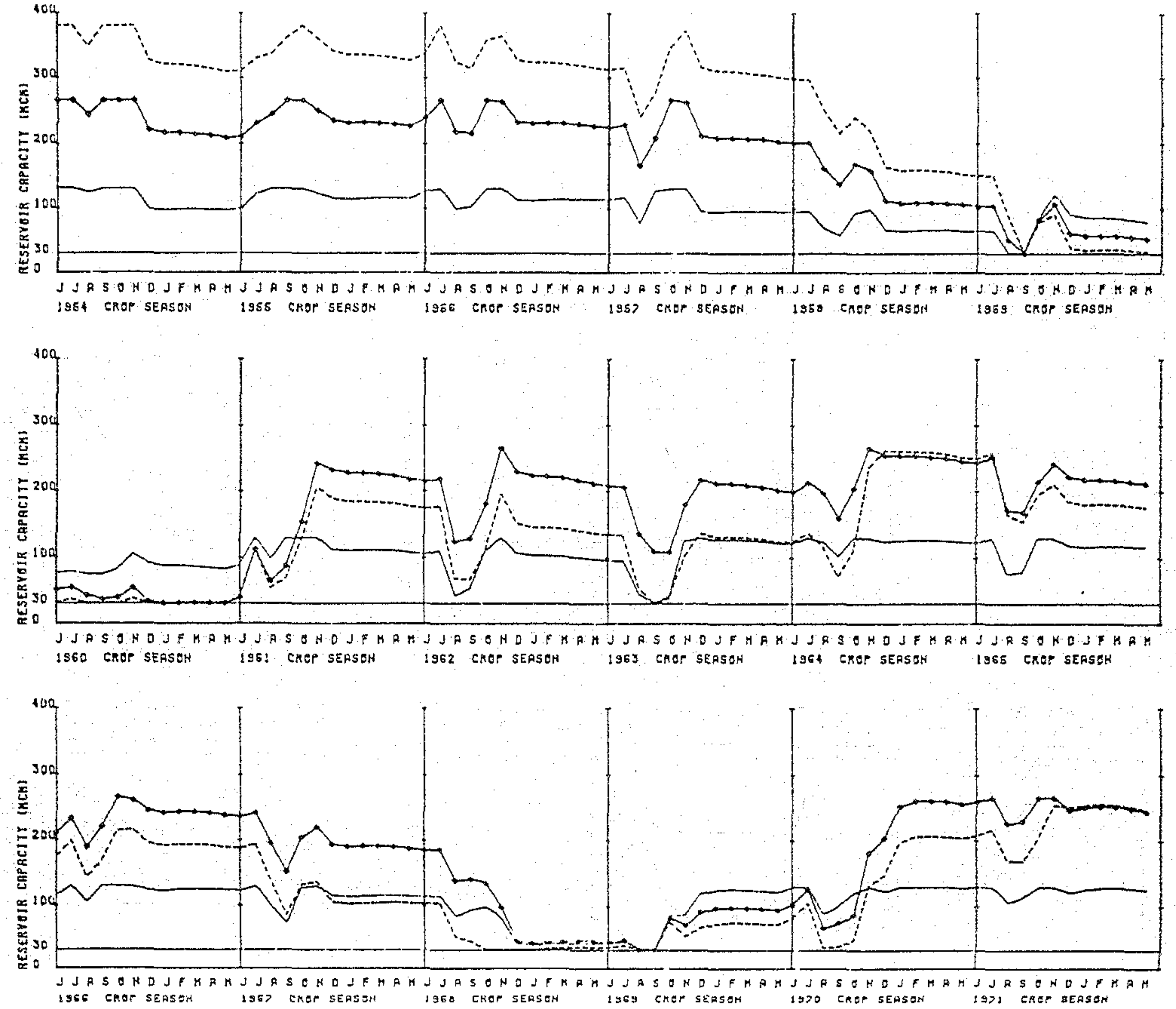
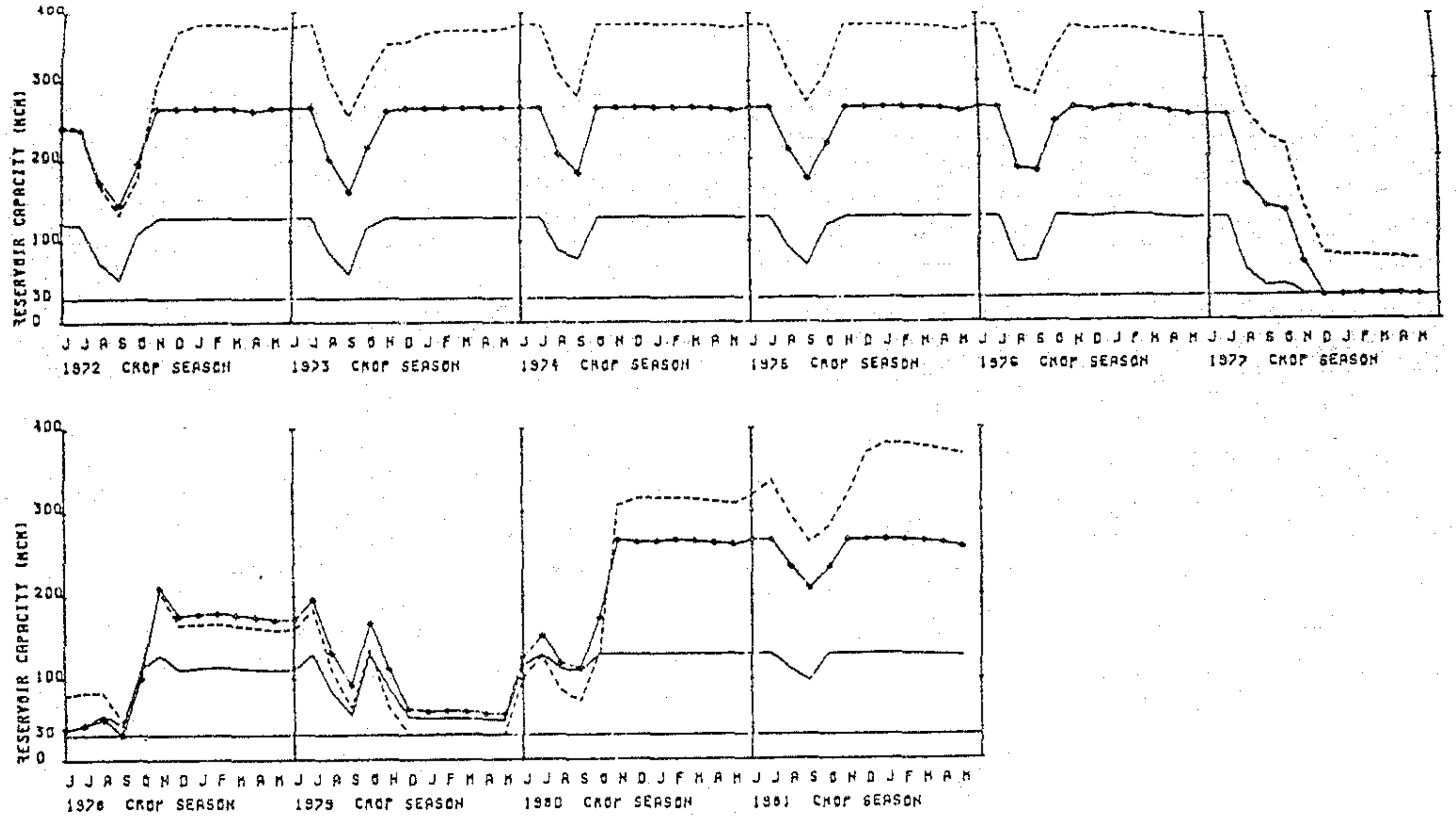


Fig. V-10 Storage Charges of Lower Mae Wong Dam (1/2)



LEGEND

————————	Storage Capacity: 130 MCM, Irrigable Area: 36,800 ha
•———————•	Storage Capacity: 265 MCM, Irrigable Area: 47,800 ha
- - - - - - - -	Storage Capacity: 380 MCM, Irrigable Area: 53,500 ha

Fig. V-10 Storage Charges of Lower Mae Wong Dam (2/2)

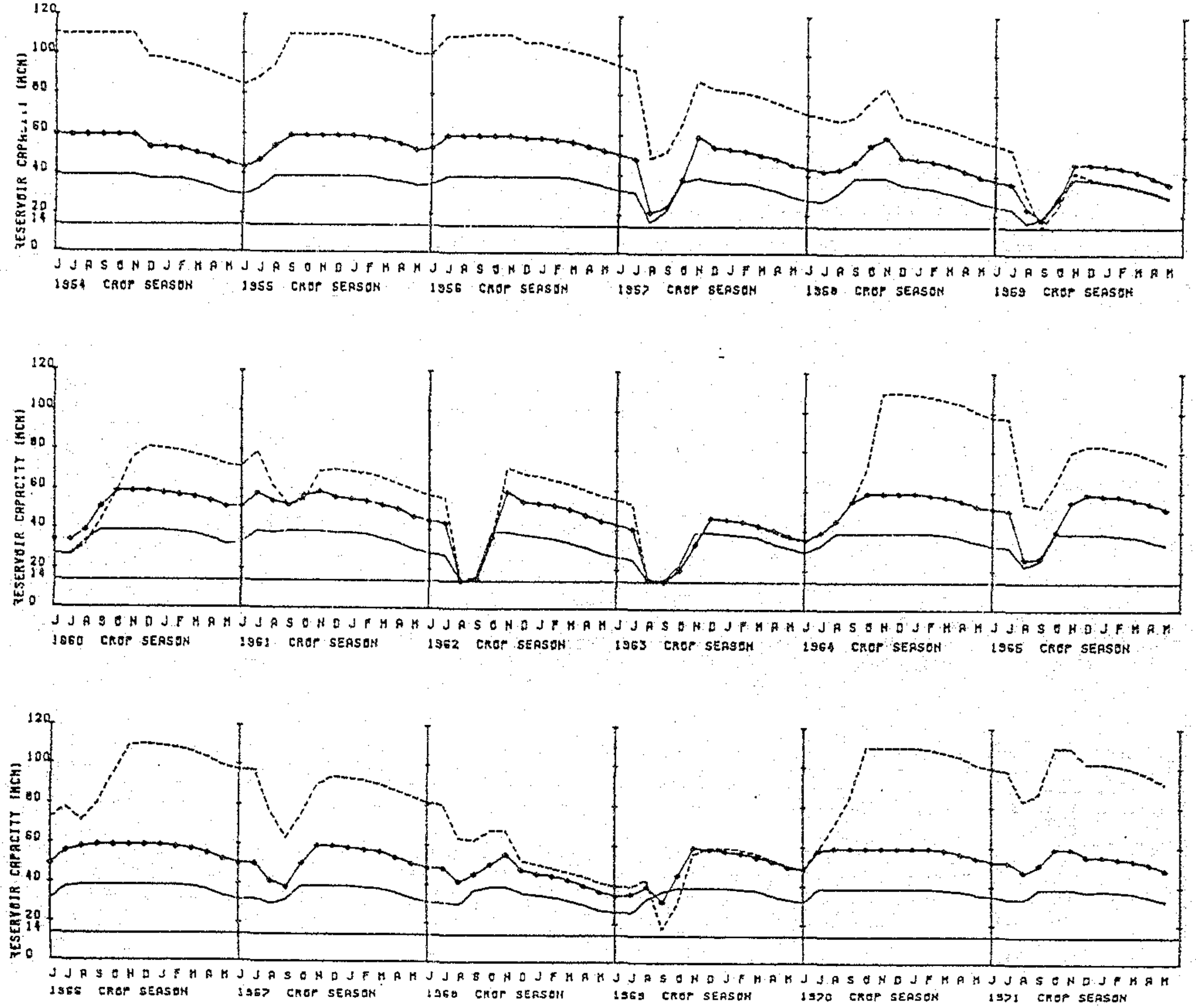
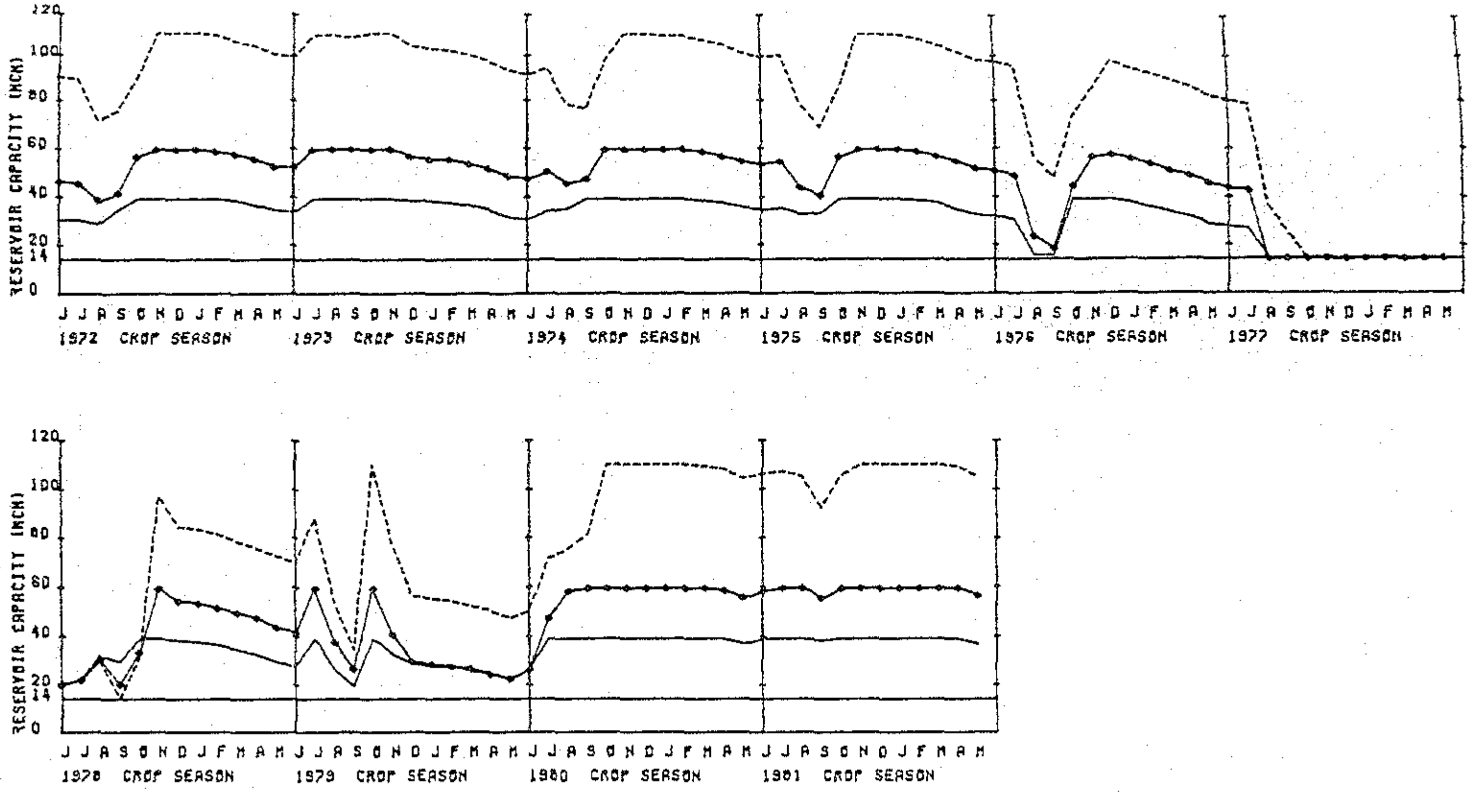


Fig. V-11 Storage Charges of Khlong Pho Dam (1/2)



LEGEND

——————— Storage Capacity: 39 MCM, Irrigable Area: 10,600 ha

●———————● Storage Capacity: 59 MCM, Irrigable Area: 17,900 ha

- - - - - - - Storage Capacity: 110 MCM, Irrigable Area: 25,000 ha

Fig. V-11 Storage Charges of Khlong Pho Dam (2/2)

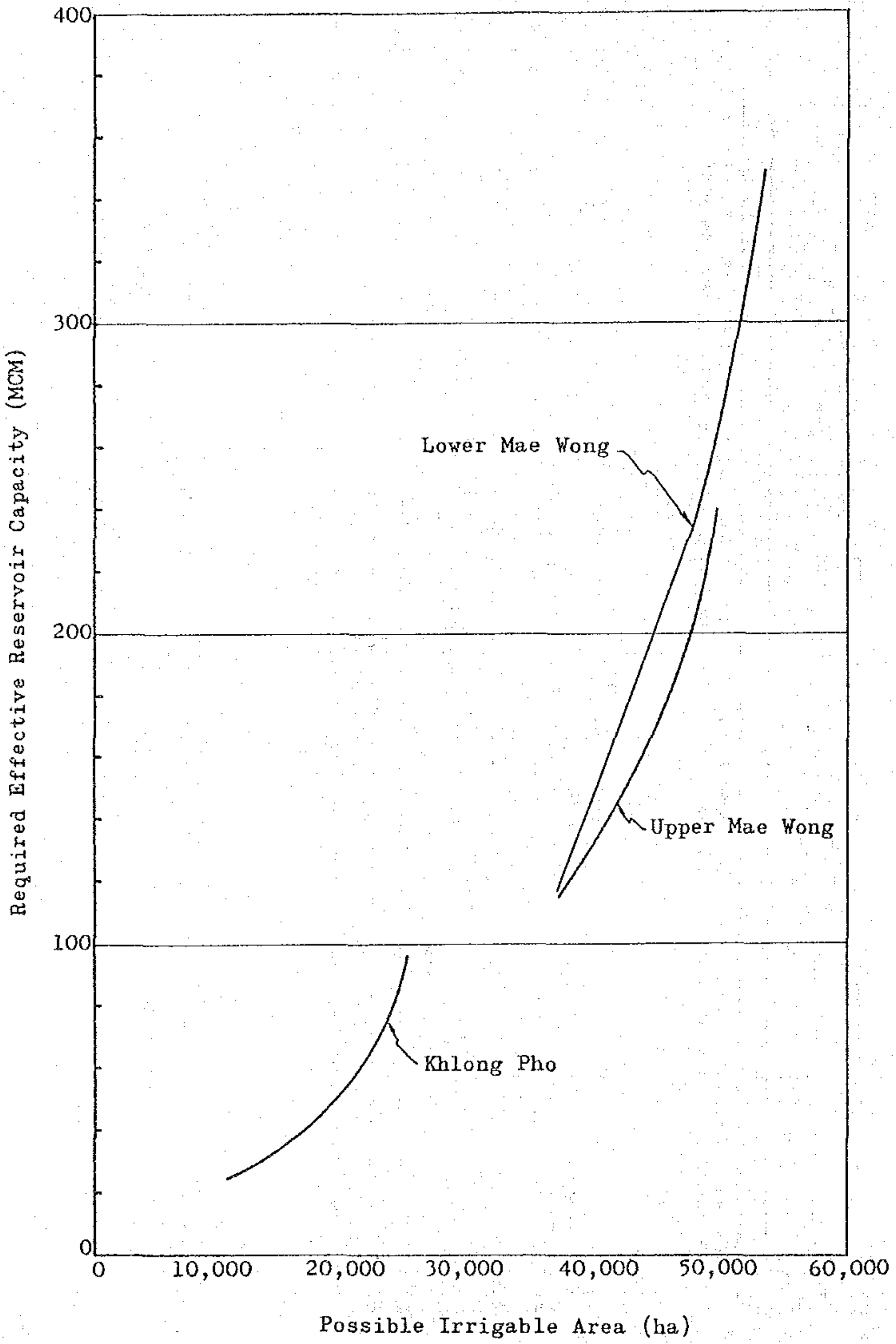


Fig.V-12 Relationship between Possible Irrigable Area and Required Effective Reservoir Capacity

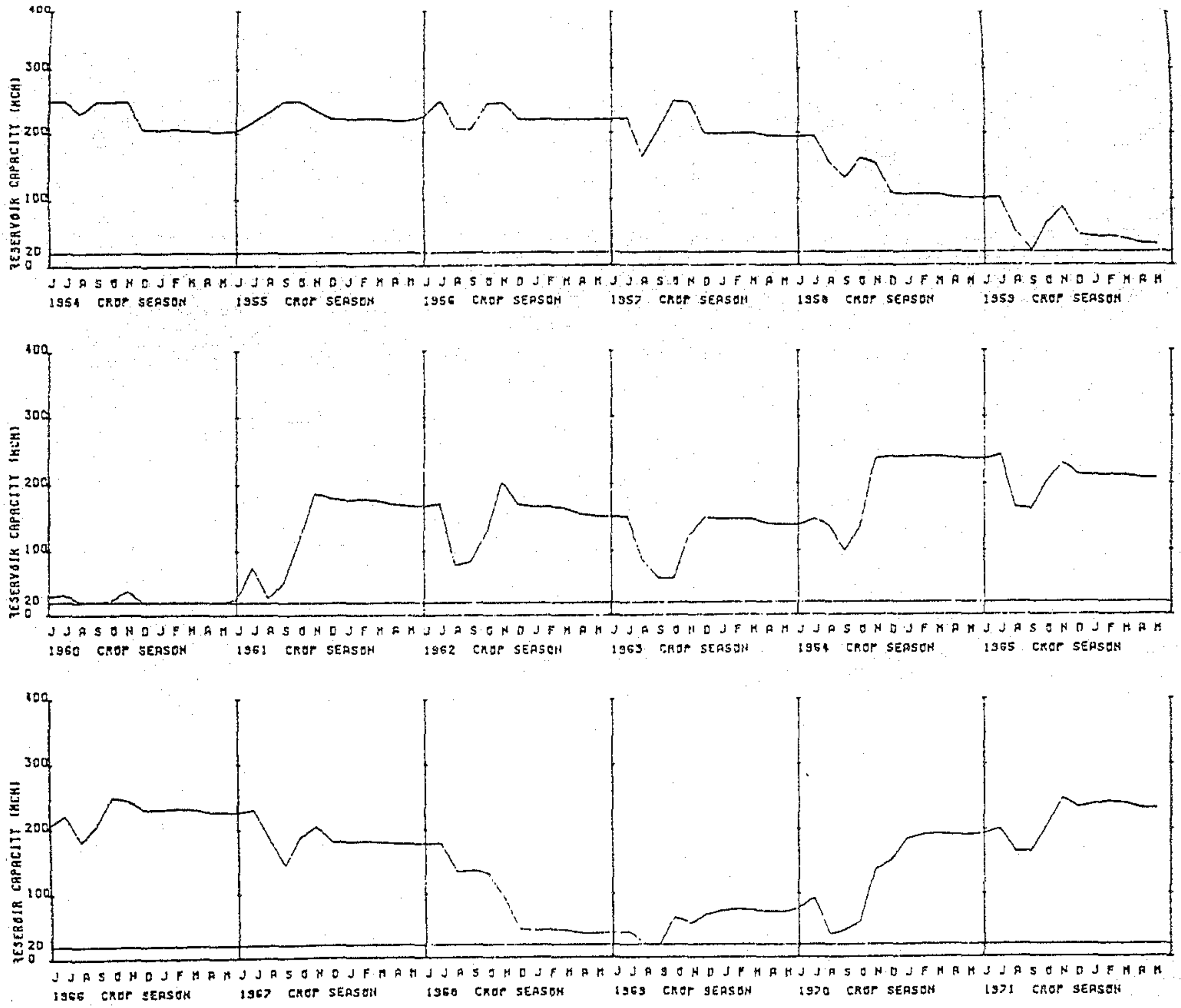


Fig. V-13 Storage Changes of Upper Mae Wong Dam for Alternative I-2 (1/2)

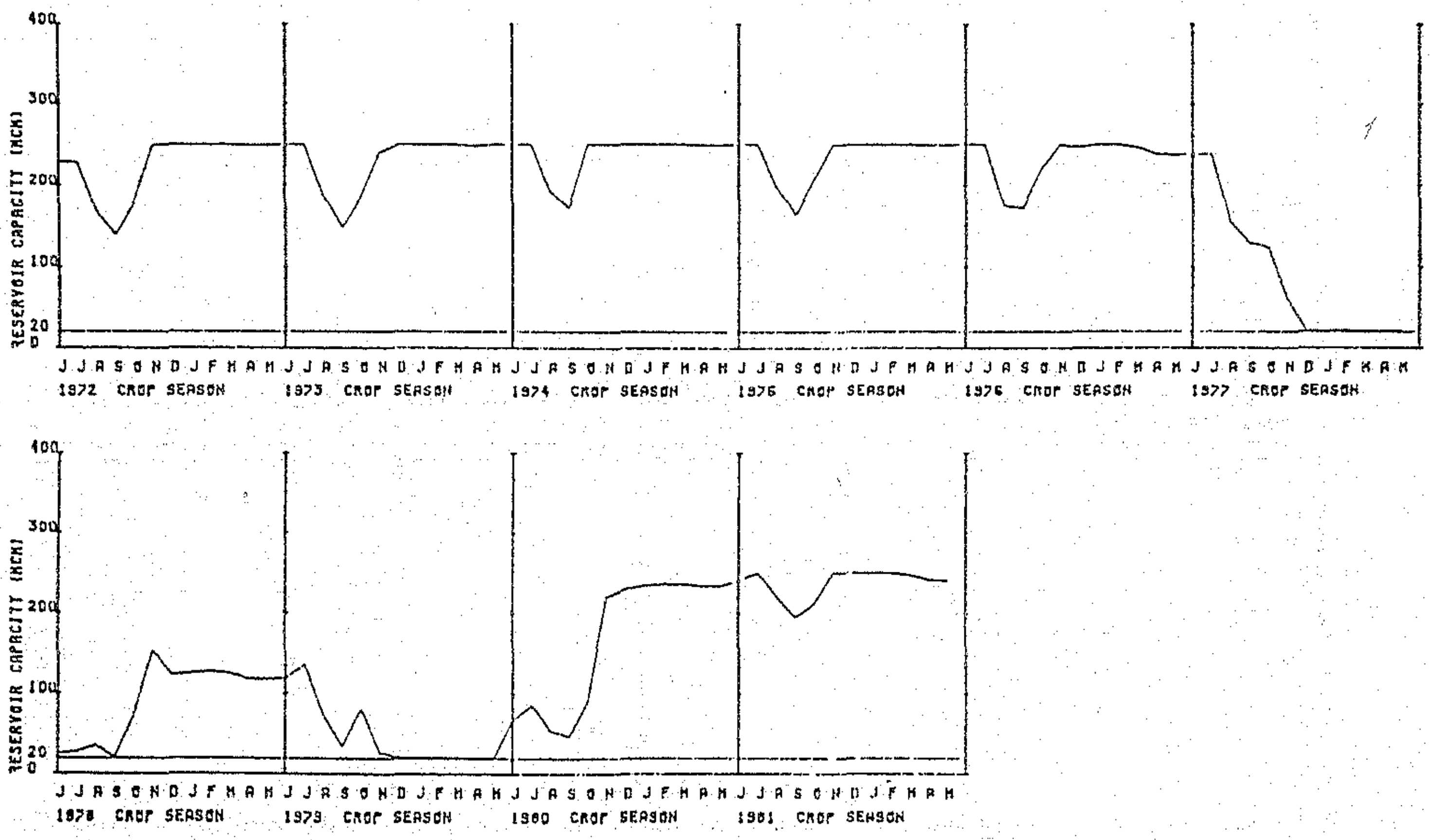


Fig. V-13 Storage Changes of Upper Mae Wong Dam for Alternative I-2 (2/2)

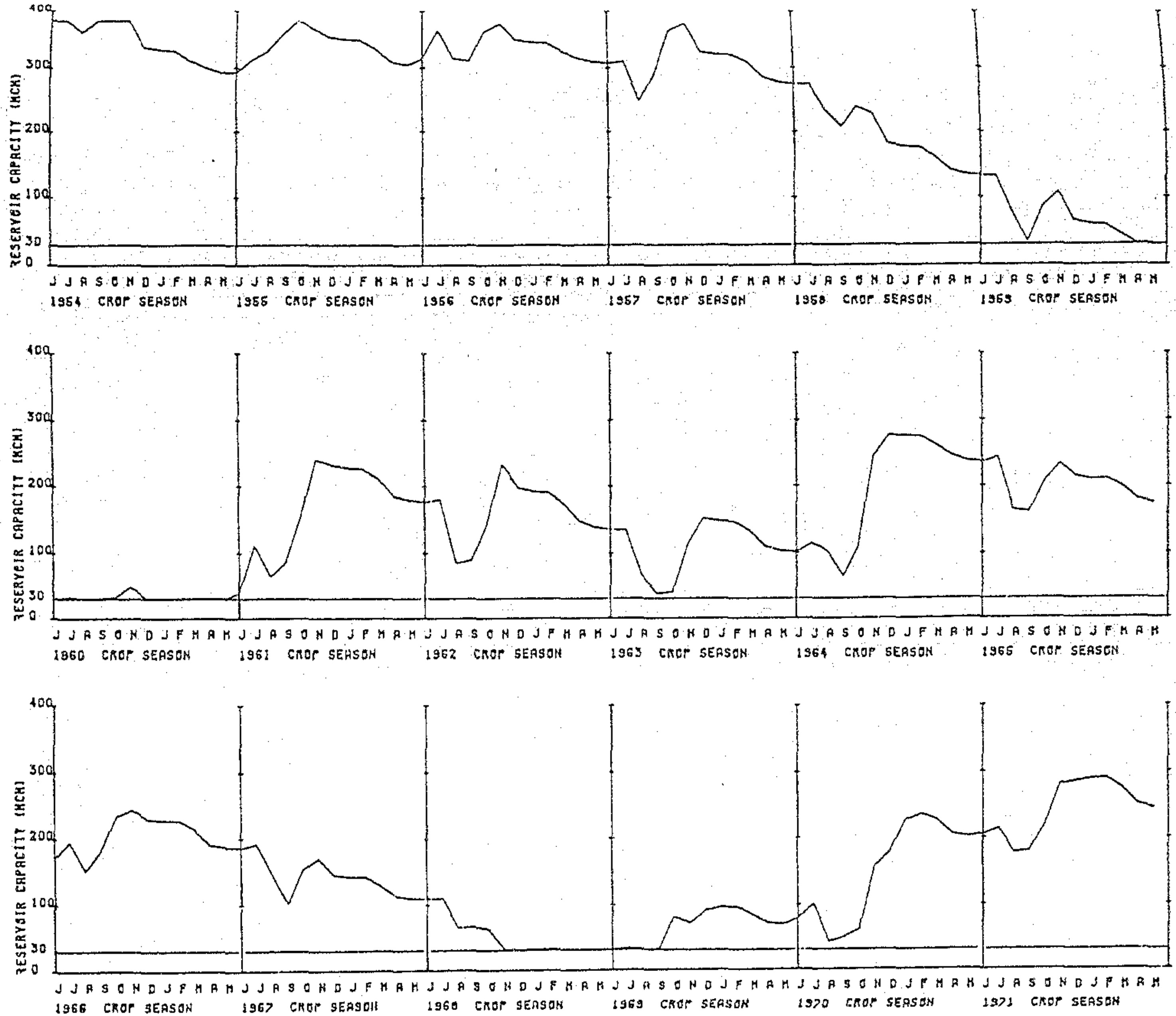


Fig. V-14 Storage Changes of Lower Mae Wong Dam for Alternative I-2 (1/2)

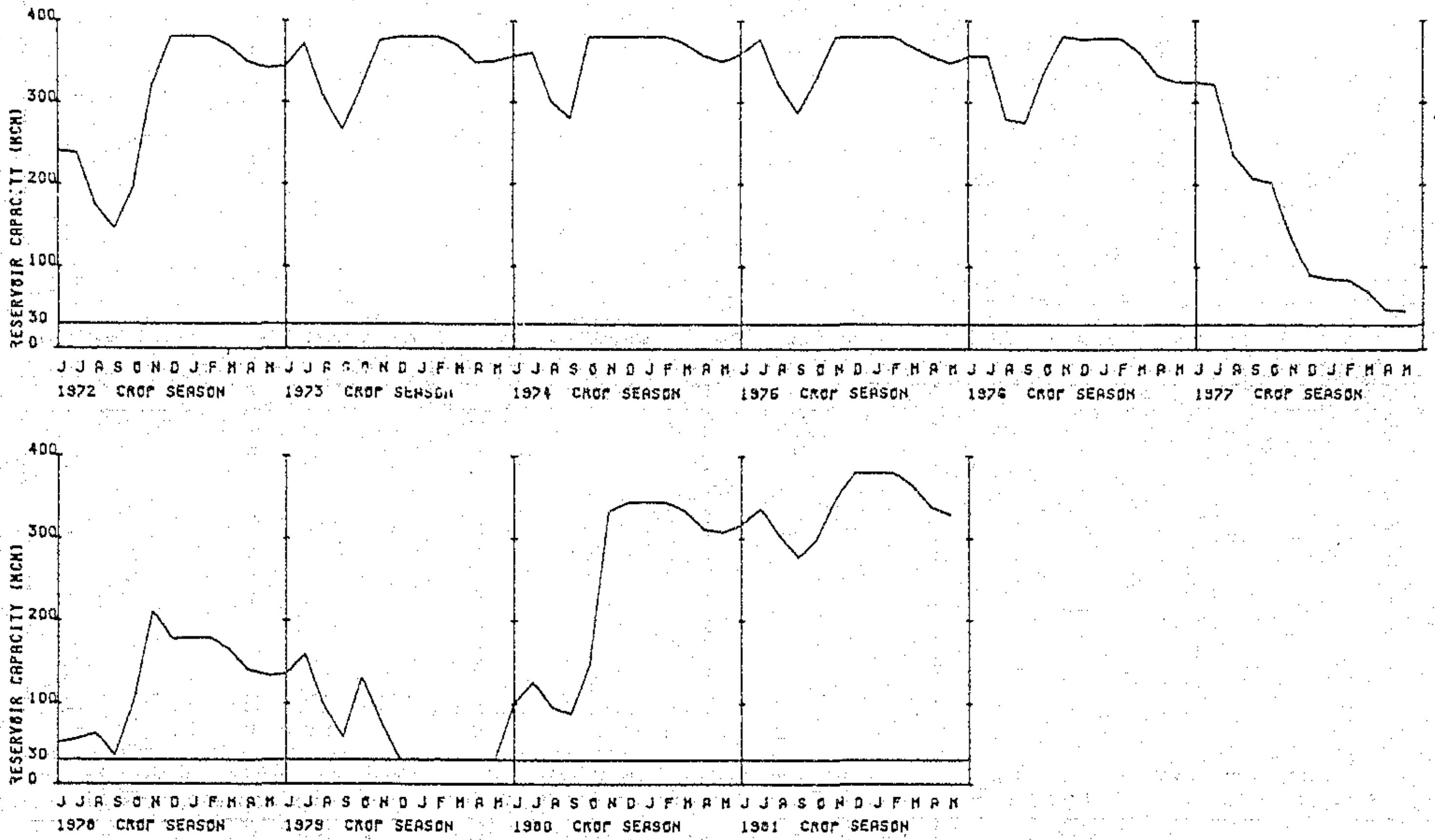


Fig. V-14 Storage Changes of Lower Mae Wong Dam for Alternative I-2 (2/2)

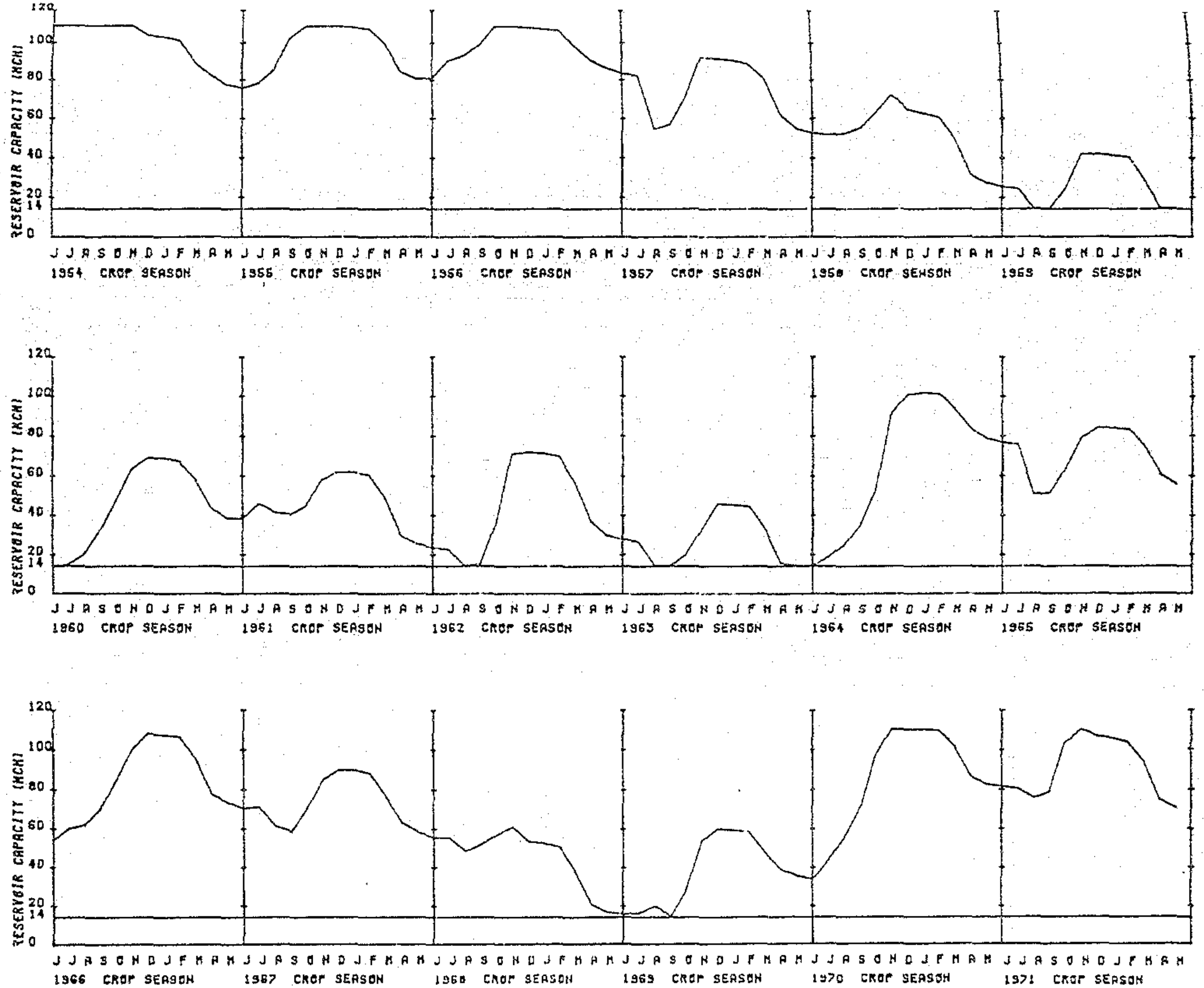


Fig. V-15 Storage Change of Khlong Pho Dam for Alternative I-2 (1/2)

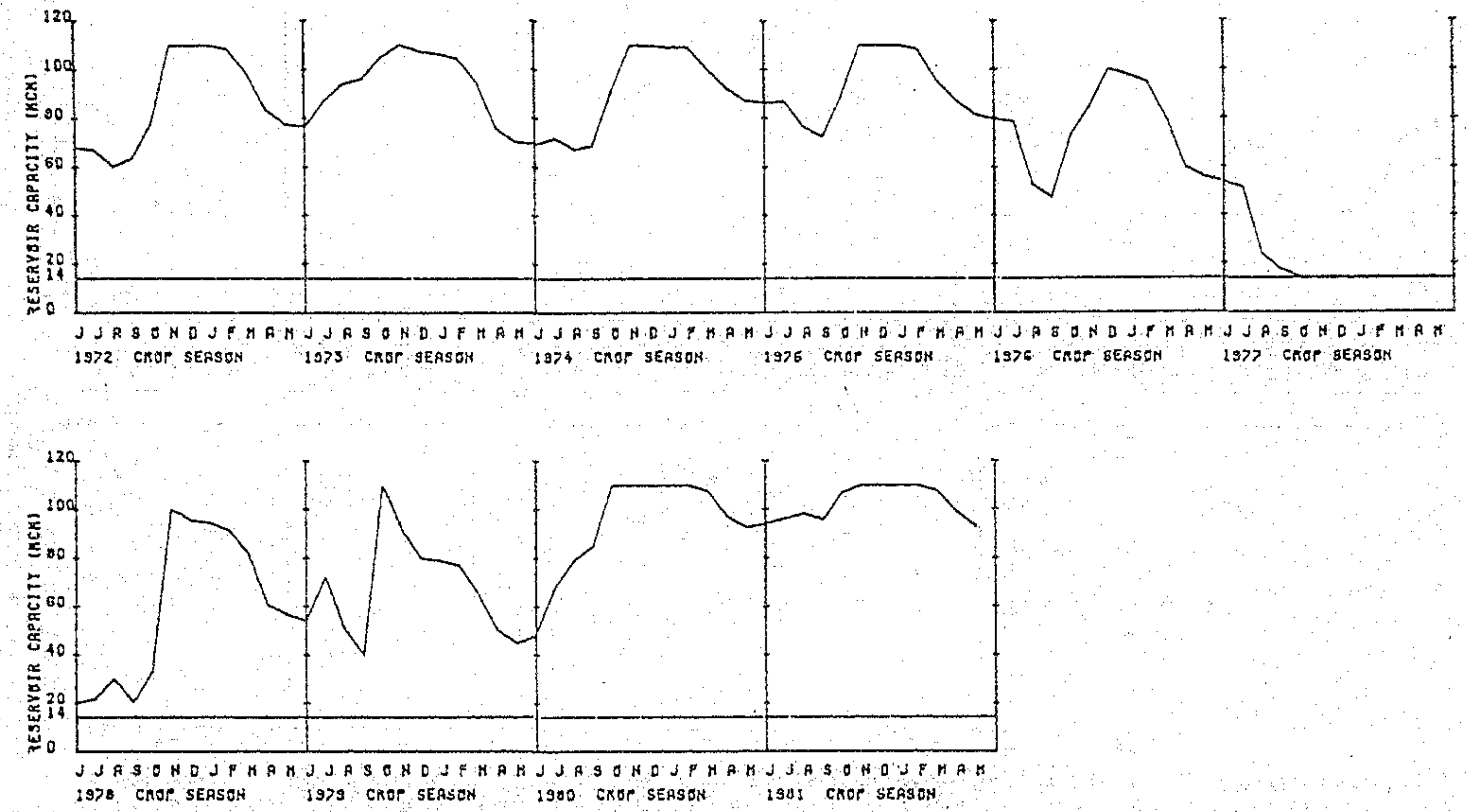
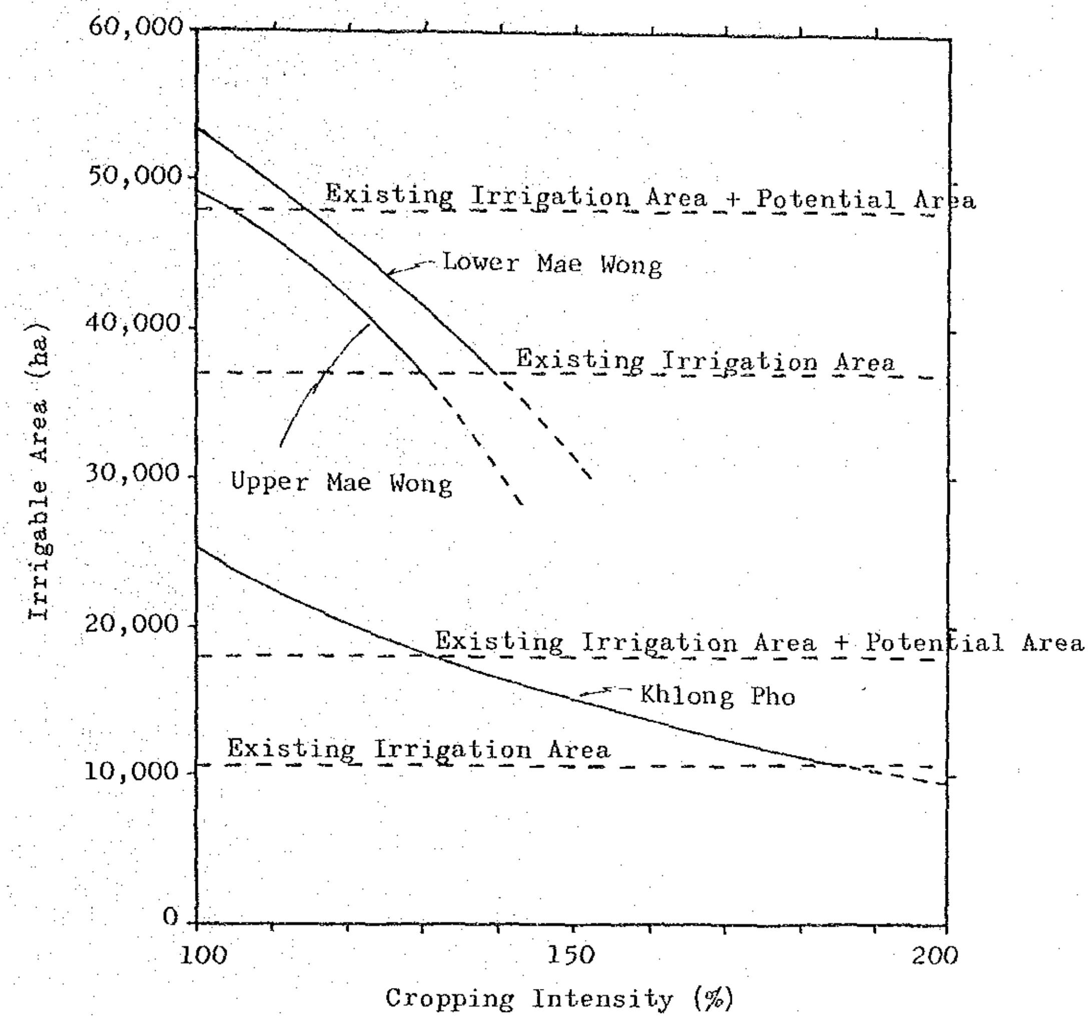


Fig. V-15 Storage Changes of Khlong Pho Dam for Alternative I-2 (2/2)



Note

Cropping Pattern: Paddy + Mung Bean

Overall Irrigation Efficiency: 55 %

Reservoir Capacity:	Lower Mae Wong	350 MCM
	Upper Mae Wong	230 MCM
	Khlong Pho	96 MCM

Fig. V-16 Relationship between Irrigable Area and Cropping Intensity

ANNEX VI
DAM AND RESERVOIR

ANNEX - VI

DAM AND RESERVOIR

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DAM AND RESERVOIR

1. INTRODUCTION

1.1 General Condition

Following the results of the Part-A study undertaken in 1984, three dam and reservoir sites were selected as high priority projects, namely, the Upper Mae Wong dam, the Lower Mae Wong dam and the Khlong Pho dam. Required effective storage capacities of these reservoirs and their drainage areas are as follows:

	Effective Storage (MCM)	Drainage Area (km^2)
Upper Mae Wong	230	612
Lower Mae Wong	350	930
Khlong Pho	96	394

The lower Mae Wong dam and the Khlong Pho dam are located within the range of the Khao Chonkan mountains. The Upper Mae Wong dam is located at about 17 km upstream of the Lower Mae Wong dam site, where the mountain ranges of the Mt. Khao Mokochun meet with the flood plain. Geologically foundations at these dam sites are formed mainly by the Palaeozoic metamorphic complexes and Mosozoic sandstones, shales, minor and volcanic conglomerates.

The design of these dams were conducted at the pre-feasibility level which aimed to define the major dimensions of dam body and related structures. Most of design values on the earth fill materials and foundation conditions are based on the estimates obtained from the site investigation. Bore hole drilling data are available only for the Khlong Pho dam. Topographical maps applied in the study are 1/50,000 scale for the Upper Mae Wong and the Khlong Pho dams and 1/10,000 scale for the Lower Mae Wong dam.

1.2 Basic Design Criteria Applied for the Study

1.2.1 Seismic force

Seismic force is one of the major components in the design of large dam. Data on the distribution of epicenter locations and their magnitudes are available for the period from 1912 to 1981 in the Studies and Research Div. of the Meteological Department and they are shown in

Fig. VI-1. The most of epicenters are located along the Indian ocean plate which has arciform extending from Indonesia to Burma. Reliable epicenters of greater magnitude are not recorded within Thailand.

(1) Seismic acceleration force distribution

Along the epicenter arciform belt, the maximum magnitude of M = 8 was recorded at two points but eastern area of arciform belt has relatively minor magnitude epicenters. Drawing the envelope line along the eastern edge of the recorded epicenter locations and assuming M = 7 magnitude on the envelope with depth of 40 km from the ground surface, the seismic acceleration force (gal) distribution was estimated. The results are shown in Fig. VI-2. In the calculation of relation between distance from the epicenter and seismic force (gal), the following formulae were adopted.

(a) Seed (1968)

$$\log Gmax = 2.04 + 0.35M = 1.6 \log L$$

(b) Okamoto (1979)

$$\log \left(\frac{Gmax}{1,000}\right) = \frac{L+50}{100} (-4.93 + 0.89M - 0.043M^2)$$

where M : magnitude

Gmax : maximum accelaration (gal)

L : distance from epicenter (km)

(2) Design seismic force

Proposed dam sites are located about 300 km away from the M = 7 line and the estimated seismic acceleration is less than 5 gal. Considering that the proposed dam sites are located near to the epicenter zone, it was assumed that the magnitude of M = 8 occurs at the edge of epicenter zone. Then, the acceleration force is estimated to be 10 gal. For design of the proposed dam, safety factor should be taken into consideration for different geological conditions. The design seismic force Kh is then determined at 0.03 which is derived by 10gal x 3/980, taking safety factor at 3.

1.2.2 Basic design criteria

(1) Safety factor

Safety factor for slope stability of dam body is taken at 1.2.

(2) Dam dimension for fill dam

(a) Core crest elevation

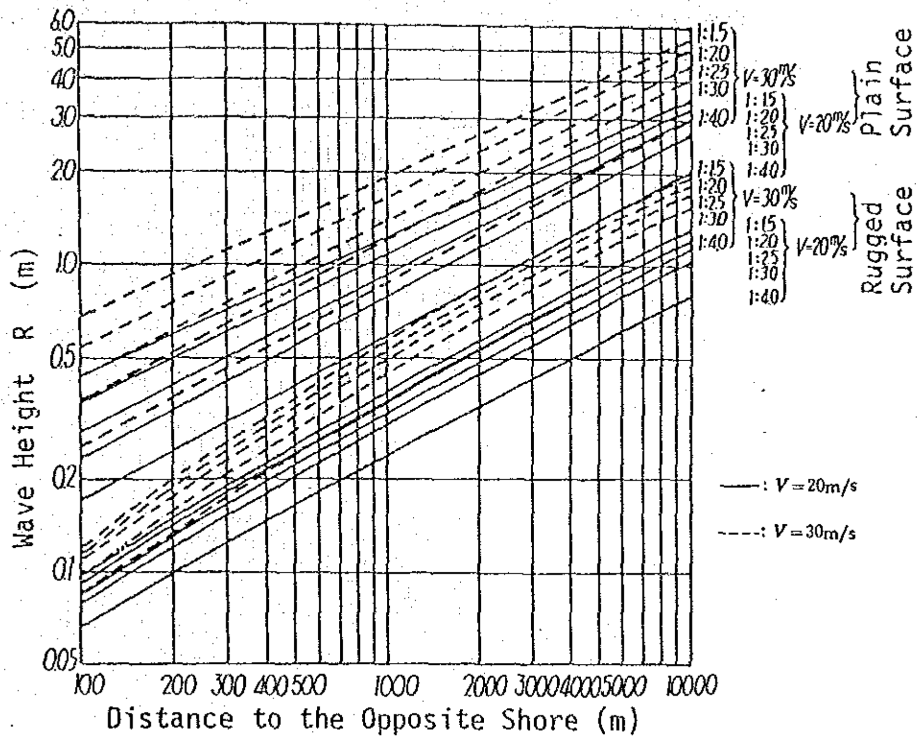
Core crest elevation = H.W.L. + Hf

$$Hf = R + 1.0 > 2.0$$

where, H.W.L. : flood water level

R : wave creep height to the slope

For estimation of R, the following figure is applied taking a wind speed of 30 m/sec.



(b) Dam crest width

Dam crest is often used as a part of local road and the crest width is determined as follows, taking a minimum width of 8 m.

$B = 3.6 \sqrt[3]{H} - 3.0$ *for earthfill dam*

$B = 0.05H + 6.0$ *for rockfill dam*

H : dam height (m)

(3) Sediment inflow to the reservoir

According to the sediment gradation analysis based on the data at CT-5A shown in Annex I, the average sediment inflow becomes about 0.8 m^3/km^2/year of bed load and 71.3 m^3/km^2/year of suspended load. These values are considered too low. In the design of the

Huai Thap Salao dam, total sediment inflow to the reservoir is estimated at 340 $m^3/km^2/year$.

Considering the difference of forest cover on the watershed and of geological conditions, the design values for sediment inflow on the Mae Wong and the Khlong Pho rivers are determined as follows:

Unit sediment inflow

Mae Wong river	300 $m^3/km^2/year$
Khlong Pho river	350 $m^3/km^2/year$

The dead storage capacity in the reservoir is estimated using the following equation:

100 years x (Unit sediment inflow) x (Drainage area)

2. UPPER MAE WONG DAM

2.1 General

The Upper Mae Wong dam site is located at about 17 km upsteam of the Lower Mae Wong dam, where the mountain ranges of the Mt. Khao Mokochun meet with the flood plain. Valley shape is relatively wide, about 400 m to 800 m but foundation rocks are hard, exposed on the surface and bearable for all types of high dam. As it is reported in Annex II, the elasticity modulus of foundation rocks is estimated at a range of 50,000 kg/cm^2 to 100,000 kg/cm^2. The reservoir area is covered by thick forest, and numbers of households within the expected submerged area will be 40 according to the official data. The resettlement is considered to be a minor compornent for the project implementation.

The reservoir storage volume and area versus elevation curve is made from the topographical map of 1/50,000 scale and is shown Fig. VI-3. The effective storage required from the water balance study is 230 MCM at full water level of EL. 216 m and dam height is expected to be about 62 m.

2.2 Preliminary Design of Dam

2.2.1 Dam type

Selection of dam type is made based on the studies laying stress on the available materials near the dam site, foundation conditions and economical construction cost. In case of the Upper Mae Wong dam, the foundation rocks are considered to be suitable for all types of dam. Valley shape is wide with a river bed width of about 400 m and a valley width of about 800 m. A concrete dam is considered to be disadvantageous because of wide valley shape which will require obviously higher construction cost for concrete dam type.

As the height of dam is expected to be more than 60 m, the embankment materials, in case of earthfill type, should have large shearing strength against shear failure and should be uniform in quality. Large volume of such embankment materials is not obtainable near the proposed dam site. Rock materials with sufficient strength for high dam embankment are abundant around the dam site and excavated materials from the service spillway can be diverted to the embankment. Rockfill type is preferable in all aspects such as material availability, suitability for high dam and economical construction. Rockfill dam with center-core is then selected for the Upper Mae Wong dam.

2.2.2 Design of dam

(1) Dimension

Freeboard

The freeboard is designed at 2.5 m taking design factors as follows:

Distance to the opposite shore	:	F = 5 km
Maximum wind velocity	:	V = 30 m/sec
Embankment slope	:	1 : 1.5
Slope surface	:	rugged surface
Wave creep height	:	R = 1.5 m

Hf = 1.5 + 1.0 = 2.5 m

Crest of core zone

H.W.L. + Hf = EL. 219 + 2.5 = EL. 221.5 m

H.W.L. : high water level

Dam crest

EL. 221.5 + Crest road 0.5 m = EL. 222 m

Crest width

$B = 6 + 0.05 H = 9.1$ m $H = 62$ m

$B = 3.6 \times \sqrt[3]{H} - 3 = 11.2$ m

Taking average value, crest width is designed at 10 m.

(2) Materials for embankment

Core zone : Borrow area is selected at downstream of dam axis, where talus deposit and deep weathered granite are found.
Among excavated materials from service spillway, talus deposit and deep weathered materials can be used for core zone.

Rock zone : Borrow area for rock material is selected at left side of the river about 1.5 km upstream from the dam axis.

Transition zone: Most of excavated materials from the service spillway are utilized for transition zone. Small grade of blasted rocks from the rock borrow area are also used for this zone.

Filter zone : River sand is applied.

Rock materials obtained from the diversion tunnel will be used for pavement of construction road.

(3) Design values of embankment materials

Based on the site investigations, the design values of embankment materials are assumed as follows.

Zone	Gs	γd	e	γw	γsat	φ	c	k
	t/m^3	t/m^3		t/m^3	t/m^3		t/m^2	cm/sec
Filter	2.65	1.70	0.559	1.80	2.06	30°	0	$k > 1x10^{-3}$
Core	2.67	1.70	0.571	1.95	2.05	25°	2.5	$k < 1x10^{-5}$
Transition	2.65	-	0.325	2.00	2.25	37°	0	$k > 5x10^{-4}$
Rock	2.65	-	0.325	2.00	2.25	42°	0	-

where, Gs : unit weight
γd : dry density
e : void ratio
γw : wet density
γsat : saturated density
φ : internal friction angle
c : cohesion
k : permeability coefficient

(4) Typical cross section

The layout plan and typical cross sections of dam are shown in Fig. IV-4, VI-5 and VI-6. The safety factor for the dam slope stability is calculated by a slip circle method applying the above design values.

Condition	Safety Factor
1. Upstream slope (S = 1:1.70)	
a. Immediately after the construction (with earthquake pore pressure 50% remain)	Fs = 1.82
b. Full storage level with earthquake (seismic force kh = 0.03)	Fs = 1.56
c. Sudden drop of water level (core & transition, pressure 100% remain)	Fs = 1.44
d. Sudden drop of water and earthquake	Fs = 1.33
e. Surface slip	Fs = 1.357
2. Downstream slope (S = 1:1.60)	
a. Surface slip	Fs = 1.348

(5) Foundation treatment

The lowest excavation line for core zone is determined at EL. 160 m. As the dam foundation is formed by hard rocks, the principal purpose of foundation treatment is to decrease the seepage through dam foundation. Cement groutings are adopted for this purpose and they are composed of blanket grout, curtain grout and supplemental curtain grout.

Blanket grout with short depth would be made for the all foundation area of core zone. It is designed to improve the loosened rock foundation zone near the ground surface due to excavation by means of filling up the open cracks in the rock with cement milk. Main curtain grout is designed at the centre of core basement and would have deep grouting length to stop seepage through foundation. Supplemental grout would have medium length locating both sides of main curtain grout lines and is designed to increase the efficiency of main curtain grout. These grout lines are designed as follows:

<u>Main curtain grout</u>

$$d = h/3 + c$$

where, h : depth from full water level to foundation level

c : Simond's coefficient, assumed at 15

d : maximum grout depth

d = 56/3 + 15 = 34 m

number of grout lines	:	3 lines
line space	:	3 m
grout hole space	:	3.5 m

Supplemental grout

grout depth	:	1/3 of curtain grout, minimum 5.0 m
number of grout lines	:	1 line each at outside of curtain grout
line space	:	3 m
grout hole space	:	3.5 m

Blanket grout

grout depth	:	3 m
number of grout lines	:	2 lines each outside of supplemental grout
line space	:	3 m
grout hole space	:	3.5 m

(6) Service spillway

The location of service spillway is selected at the right side of the dam considering mainly topographic and geological conditions. At the dam site, the river course changes from the left side to the right side, so if the spillway is located at the right side of dam, a connecting canal from the spillway to the river is not necessary. Excavated materials are expected to be hard rocks of granite and they can be used for the embankment of transition zone. Dimensions of the spillway are designed as follows;

Design flood	:	1,770 m^3/sec
Spillway type	:	side spillway combined with chute and hydraulic jump stilling pool.
Flood overflow depth	:	3.0 m
Spillway crest length	:	165 m
Spillway channel		
total length	:	525 m
width	:	25 m
depth	:	22 m

(7) Diversion tunnel and intake structure

Based on the same reasons for selection of the service spillway location, the diversion tunnel is to be located at the right side bank to minimize the tunnel length. The construction period of the dam is estimated at about 5 years. Since the dam foundation is wide having about 300 m to 400 m in width, excavation of foundation and embankment of dam can partly be progressed prior to the completion of diversion tunnel, by use of the open channel to be excavated at the right side of valley for diversion of the river flow. After completing the diversion tunnel, the river flow will be diverted through tunnel and the open channel will be closed for embankment of dam. The diversion tunnel would be utilized only for 2 to 3 years. Considering these conditions, the design discharge for diversion tunnel is determined at 700 m^3/sec equivalent to the flood with 5-year return period. Intake facilities are designed so as to utilize the diversion tunnel. Designed dimensions are as follows;

Diversion tunnel

design discharge	:	700 m^3/sec
tunnel diameter	:	9 m
tunnel length	:	190 m

Intake structure

type	:	drop inlet
intake discharge (max.)	:	35 m^3/sec

3. LOWER MAE WONG DAM

3.1 General

The Lower Mae Wong dam site is located at about 3 km upstream of gaging station CT-5A, where the Mae Wong river runs through the narrow valley of the Khao Chonkan mountians. The valley shape is steep and river width is narrow having about 60 m, which is considered to be fairly suitable for dam site. The reservoir area was formerly beautiful forest reserve but the villagers have treaspassed and settled down in the reserved area. The upstream of the proposed dam site has been turned into the farmland. Thus, the reservoir area becomes vast flat farmland and it gives great potentials for reservoir storage but the resettlement of people and their properties to be submerged under the reservoir will be the difficult problem for the implementation of the dam construction. According to the official data, the number of household within the reservoir are is reported to be 520. Careful considerations and deliberate studies are required for the preparation of resettlement program.

Based on the 1/10,000 scale topographic map, the reservoir storage volume and area versus elevation curve is prepared and shown in Fig. VI-7. Drainage area at dam site is 612 km . Required effective storage volume based on the water balance studies is 350 MCM. Full water storage level is at EL. 136 m. Dam height becomes at 38.1 m.

3.2 Preliminary Design of Dam

3.2.1 Dam type

Taking into account the valley shape at dam site and the large scale of design flood for spillway, a concrete dam type seems to be most preferable. However, existence of the fault running from north to south is indicated in the geological map at about 400 m upstream of porposed dam axis. This fault could not be confirmed by the site investigation because of thick alluvial deposits and vegetable covers. Foundation rocks of sandstone and shale at the dam site are condsidered to be disturbed considerably by this fault.

As far as evaluating from the surface investigation at site, elasticity modulus of the foundation rocks are estimated at about 3,000 kg/cm^2 to 5,000 kg/cm^2 for weathered shale. Weathering of rocks are considered to be also proceeded for wide range. Evaluating from these conditions, construction of a concrete dam with height of more than 25 m may be difficult. Embankment materials obtainable in and around the dam site, are mostly talus deposit and weathered sandstone and shale. Hard rocks will be obtained from deep excavation but limited in quantity.

From the above, the earthfill dam type with a center core zone is selected for the Lower Mae Wong Dam.

3.2.2 Design of dam

(1) Dimension

Freeboard

Distance to the opposite shore	:	F = 7.0 km
Maximum wind velocity	:	V = 30 m/sec
Embankment slope	:	1 : 2.5
Slope surface	:	rugged surface
Wave creep height	:	R = 1.6 m

Hf = 1.6 + 1.0 = 2.6 m

Crest of core zone

H.W.L. + Hf = EL. 140 + 2.6 = EL. 142.6 m

Dam crest

EL. 142.6 + 0.5 m (crest road) = EL. 143.1 m

Crest width

$B = 6\text{ m} + 0.05 \times 38.1\text{ m} = 7.9\text{ m} < 8.0\text{ m}$

$B = 3.6 \times \sqrt[3]{38.1} - 3 = 9.1\text{ m}$

Crest width is determined at 9.0 m

(2) Materials for embankment

Four zones are considered from the availability of materials for embankment.

Core zone : Core material borrow area is selected at left side of downstream where the talus deposit and weathered shale are found in a shape of terrace.

Semi-pervious zone : Greater part of excavated materials from spillway is considered to be weathered shale and sandstone, and can be utilized for semi-pervious zone.

Random zone : Among excavated materials, deeply weathered rocks will be utilized for this zone.

Rock zone : Hard rock materials will be obtained from spillway excavation and tunnel excavation. Quantity may be small but they are to be used for rock zone which is necessary to keep the slope stability at upstream.

Filter zone : River sand is applied.

(3) Design values of embankment materials

Based on the site investigations, the design values of embankment materials are assumed as follows;

Zone	Gs	γd	e	γw	γsat	φ	c	k
	t/m^3	t/m^3		t/m^3	$5/m^3$		t/m^2	cm/sec
Filter	2.65	1.70	0.559	1.80	2.06	30°	0	$k > 1x10^{-3}$
Core	2.70	1.55	0.74	1.90	1.98	20°	3.5	$k > 1x10^{-5}$
Semi pervious	2.65	1.75	0.514	2.00	2.09	35°	1.0	$k = 1x10^{-4}$
Random	2.65	1.75	0.154	2.00	2.09	35°	-	-
Rock	2.65	-	0.325	2.00	2.25	40°	–	–

where, Gs : unit weight
γd : dry density
e : void ratio
γw : wet density
γsat : saturated density
φ : internal friction angle
c : cohesion
k : permeability coefficient

(4) Typical cross section

The layout plan and typical cross sections of dam are shown in Fig. VI-8, VI-9 and VI-10. The safety factor for the dam slope stability is calculated by a slip circle method.

Condition	Safety Factor
1. Upstream slope (S = 1:2.5)	
a. Immediately after the construction with earthquake, (pore pressure 50% for core and 30% for semi-pervious)	Fs = 1.47
b. Sudden drop of water level and earthquake (pore pressure 100% remain except rock zone)	Fs = 1.39
2. Downstream slope (S = 1:2.5)	
a. Immediately after the construction with earthquake	Fs = 1.33

(5) Foundation treatment

The lowest excavation line for core zone is determined at EL. 105 m and the dam height becomes 38.1 m. Cement groutings are adopted for the foundation treatment. As the foundation is considered to be soft rocks formation, the spaces for the grout line and grout hole are selected narrower than those in the case of the Upper Mae Wong dam.

Grout line space : 2.0 m

Grout hole space : 2.5 m

Main curtain grout

Three numbers of main curtain grout lines are designed.
The maximum grout depth is determined as follows;

$d = h/3 + c$

$h = EL.\ 136\ m - EL.\ 105\ m = 31\ m$

$c = 15$

$d = 31/3 + 15 = 26\ m$

Supplemental grout

grout depth : 1/2 of curtain grout depth

nujber of grout line : 1 line each at outside of curtain

Blanket grout

grout depth : 5 m

number of grout line : 2 lines each at outside of supplemental grout

(6) Service spillway

Considering the topographic condition and utility of excavated materials for embankment, the location of service spillway is selected at right side abutment. The design flood of spillway is 2,600 m^3/sec which will make the scale of spillway structure excessively large compared with the size of dam body. In this study, a comparative study was made for two spillways plan consisting of a service spillway and a emergency spillway. However, this plan could not be adopted because there is no suitable site for a emergency spillway. Designed dimensions of spillway are as follows;

Design flood	:	2,600 m^3/sec
Spillway type	:	side spillway combined with chute and stilling pool
Flood overflow depth	:	4.0 m
Spillway crest length	:	155 m
Spillway channel		
total length	:	465 m
width	:	30 m
depth	:	23 m

(7) Diversion tunnel and intake structure

In case of the Lower Mae Wong dam, the valley shape is narrow so that all construction works should be commenced after completion of diversion tunnel for diversion of river flow. The design discharge for diversion tunnel is determined at 1,240 m^3/sec equivalent to the flood with 10-year return period. With this design flood, two diversion tunnels are necessary to keep the tunnel diameter not excessively large. The tunnel is designed at both sides of the river. Tunnel alignment is determined to keep sufficient distance from the spillway and dam foundation. Designed dimensions are as follows;

Diversion tunnel

design discharge	:	1,240 m^3/sec
for single tunnel	:	620 m^3/sec
tunnel diameter	:	8.5 m
tunnel length		
right side tunnel	:	565 m
left side tunnel	:	266 m

Intake structure

type	:	drop inlet
intake discharge (max.)	:	36 m^3/sec

4. KHLONG PHO DAM

4.1 General

The Kholong Pho river originates from the southern edge of the Khao Mokochun mountain ranges and most of the drainage areas are gently undulating alluvial plain having river gradient of more than 1/250. Exploitation of large reservoir with a high dam is considered to be difficult because the valley shape is shallow and wide, watershed area is relatively thin and geological condition is not suitable for large dam.

The proposed dam site is located at the southern tip of the Khao Chonkan mountain ranges, where the river runs through the high terrace of the plain. The valley width is about 1,500 m and the maximum dam height from the river bed will not exceed 20m. The drainage area at dam site is 394 km^2.

The reservoir area has been developed for agriculture and number of household within the reservoir area is reported to be 365 according to the official data. The resettlement program becomes one of the major components for this project implementation. The reservoir storage volume and area versus elevation curve is made from the topographical map of 1/50,000 scale and is shown in Fig. VI-11. Effective storage capacity is 96 MCM according to the water balance study. The full water level is EL. 100 m.

4.2 Preliminary Design of Dam

4.2.1 Dam type

The foundation at the dam site is composed of loose diluvial sand, and available materials for embankment are sand and sandy silt. Construction of a concrete dam will not be possible as the foundation sandy layers have not enough shearing strength for the load of a concrete dam. Rock materials are not obtainable around the dam, and therefor the earthfill type dam is preferable.

Core materials will be obtained at around the foot hills located about 5 km away from the dam site. In order to utilize the sandy silt materials obtainable abundantly from the dam site, the inclined core type is selected. Since the sandy silt material decreases its shearing strength under the condition of saturation, this material is designed to be embanked at downstream zone behind the core zone. Zoning of dam consists of inclined core zone, sandy silt zone and filter zone in between them, taking account of the dam scale with height of about 21 m.

4.2.2 Design of dam

(1) Dimension

Freeboard

Distance to the opposite shore	:	F = 5 km
Maximum wind velocity	:	V = 30 m/sec
Embankment slope	:	1 : 2.5
Wave creep height	:	R = 1.4 m

Crest of core zone

H.W.L. + Hf = EL. 102.0 + 2.4 = EL. 104.4

Dam crest

EL. 104.4 + 0.5 = EL. 104.9

Crest width

$B = 6 + 0.05H = 7.1$ m, $H = 21$ m

$B = 3.6 \times \sqrt[3]{H} - 3 = 6.8$ m

Taking minimum core crest width, it is designed at 8 m.

(2) Design value of embankment materials

Zone	Gs	γd	e	γw	γsat	φ	c	k
	t/m^3	t/m^3		t/m^3	t/m^3		t/m^2	cm/sec
Foundation	2.65	1.55	0.71	1.96	1.96	28°	-	$k = 1 \times 10^{-4}$
Core	2.70	1.55	0.74	1.90	1.98	20°	3.5	$k < 1 \times 10^{-5}$
Random	2.65	1.45	0.828	1.80	1.90	20°	1.0	$k = 1 \times 10^{-4}$

where, Gs : unit weight
γd : dry density
e : void ratio
γw : wet density
γsat : saturated density
φ : internal friction angle
c : cohesion
k : permeability coefficient

(3) Typical cross section

The layout plan and typical sections of dam are shown Fig. VI-12, VI-13 and VI-14. The safety factor for the slope stability is calculated by a slip circle method.

(a) Upstream slope

As shown in the typical cross section of dam, the inclined core zone is extended to the holizontal blanket zone at EL. 95 m having a berm width of 15 m.

Case	B = 8 m	B = 15 m	B = 20 m
1. Immediately after the construction and earthquake	Fs = 1.27	Fs = 1.67	Fs = 2.29
2. Sudden drop of water level and earthquake	Fs = 1.07	Fs = 1.33	Fs = 1.77

where, B : Bearm width at EL. 95 m
Fs : Safety factor

In case of immediately after the construction, it is assumed that 30 % pore pressure remains in all zones including foundation zone. In case of sudden drop of water level, it is assumed that 100 % pore pressure remains for all zones within the seepage line.

(b) Downstream slope

Slope stability is calculated with slopes of 1:2.0 and 1:2.5, and berm widths of 3.0 m at EL. 98 m and 10.0 m at EL. 92 m.

In case of immediately after the construction, with 30 % pore pressure remaining, safety factor is given at 1.34.

(4) Foundation treatment

As it is discussed in the Annex II, the eroded valley is buried in the foundation near the boring hole DH-6 near the right side of river. Loose diluvial sands are deposited in this valley. At both sides abutments, diluvial deposit is shallow but consolidated well, and weathered foundation rocks of sand-stone or mud-stone may be found. In the river bed or buried valley, the foundation rock may be found in the deep distance. The foundation exacavation line is determined following the buried valley shape.

Datum of foundation excavation is at EL. 84 m and the dam height becomes 20.9 m.

Cement grouting is planned for both abutments as their foundations are considered to be consolidated. These grouts are composed of 3 lines of main curtain grout, 2 lines of supplemental grout and 2 lines of blanket grout having line space at 2 m and grout hole spacd at 2.5 m.

In roder to treat the loose diluvial deposit in the buried valley portion, chemical grouting is preferred. Considering that the permeability of foundation is estimated at about 1×10^{-4} cm/sec, is determined at 1.0 m and grout hole space at 1.5 m for chemical groutings.

(5) Service spillway

The location of spillway is selected at the right side abutment where N values are reported to be more than 50. The designed spillway dimensions are as follows;

Design flood	:	1,190 m^3/sec
Spillway type	:	side spillway
Flood overflow depth	:	2.0 m
Spillway crest length	:	200 m
Spillway channel		
total length	:	850 m
width	:	30 m
depth	:	13.4 m

(6) Diversion tunnel and intake

In case of the Khlong Pho dam, the dam site valley is about 1,500 m wide and dam height is only 20.9 m. Since the width of river is very narrow, only about 30 m, river diversion is not necessary except for the last enclosure of the dam site. Selecting the construction period for enclosing embankment during dry season, river diversion will be required for only small dry season flow.

The maximum intake discharge for irrigation is estimated at 10.0 m^3/sec. Therefore, the river diversion would be made through the intake tunnel which is located at the right side.

Intake tunnel

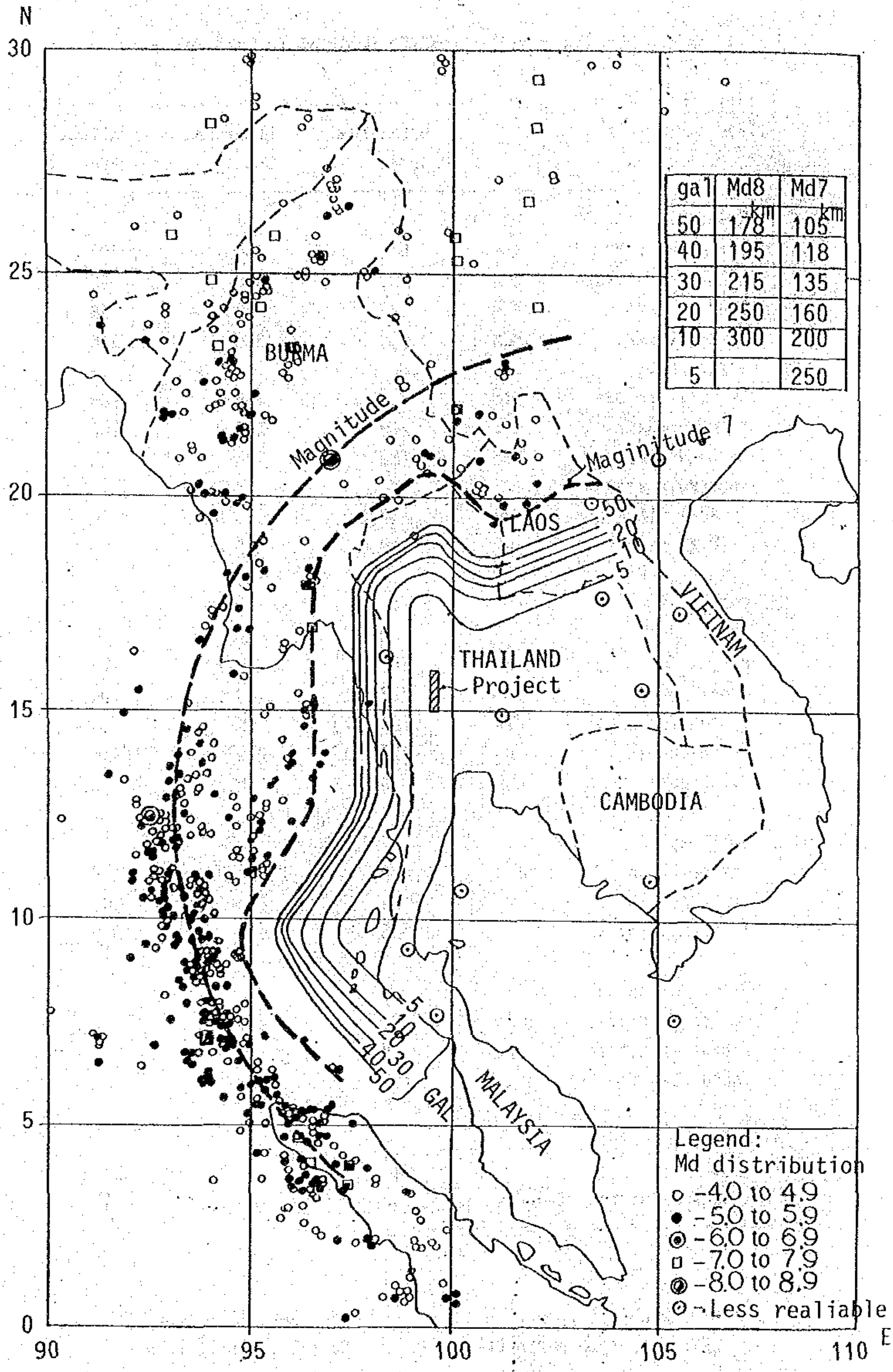
diameter	:	1.8 m
intake discharge	:	10.0 m^3/sec
length	:	300 m
intake type	:	drop inlet

Table VI-1 SUMMARY OF RESERVOIR AND DAM

Item		Upper Mae Wong	Lower Mae Wong	Khlong Pho
1. Reservoir				
Catchment area	km²	612	930	394
Effective storage	MCM	230	350	96
Dead storage	MCM	20	30	14
Total storage	MCM	250	380	110
Water level				
Full storage	Elm	216	136	100
High water	Elm	219	140	102
Dead storage	Elm	189	124	95
Reservoir area				
Full storage	km²	17.0	54.0	30.0
High water	km²	19.5	68.0	36.0
2. Dam				
Type		RF	ZEF	EF
Height	m	62.0	38.1	20.9
Crest level	Elm	222	143.1	104.9
Foundation level	Elm	160	105	84
Crest length	m	775	225	1,555
Embankment	MCM	3.40	0.38	0.74
3. Spillway				
Design flood	m³/s	1,770	2,600	1,190
Crest length	m	165	155	200
Total Length	m	525	465	850
4. Diversion tunnel				
Design discharge	m³/s	700	1,240	10
Tunnel diameter	m	9.0	8.5	1.8
Tunnel length	m	190	831 *	300
5. Intake structure				
Type		DI	DI	DI
Intake discharge	m³/s	35.0	36.0	10

RF : Rockfill type
ZEF: Zone type earthfill
EF : Earthfill type
DI : Drop Inlet type

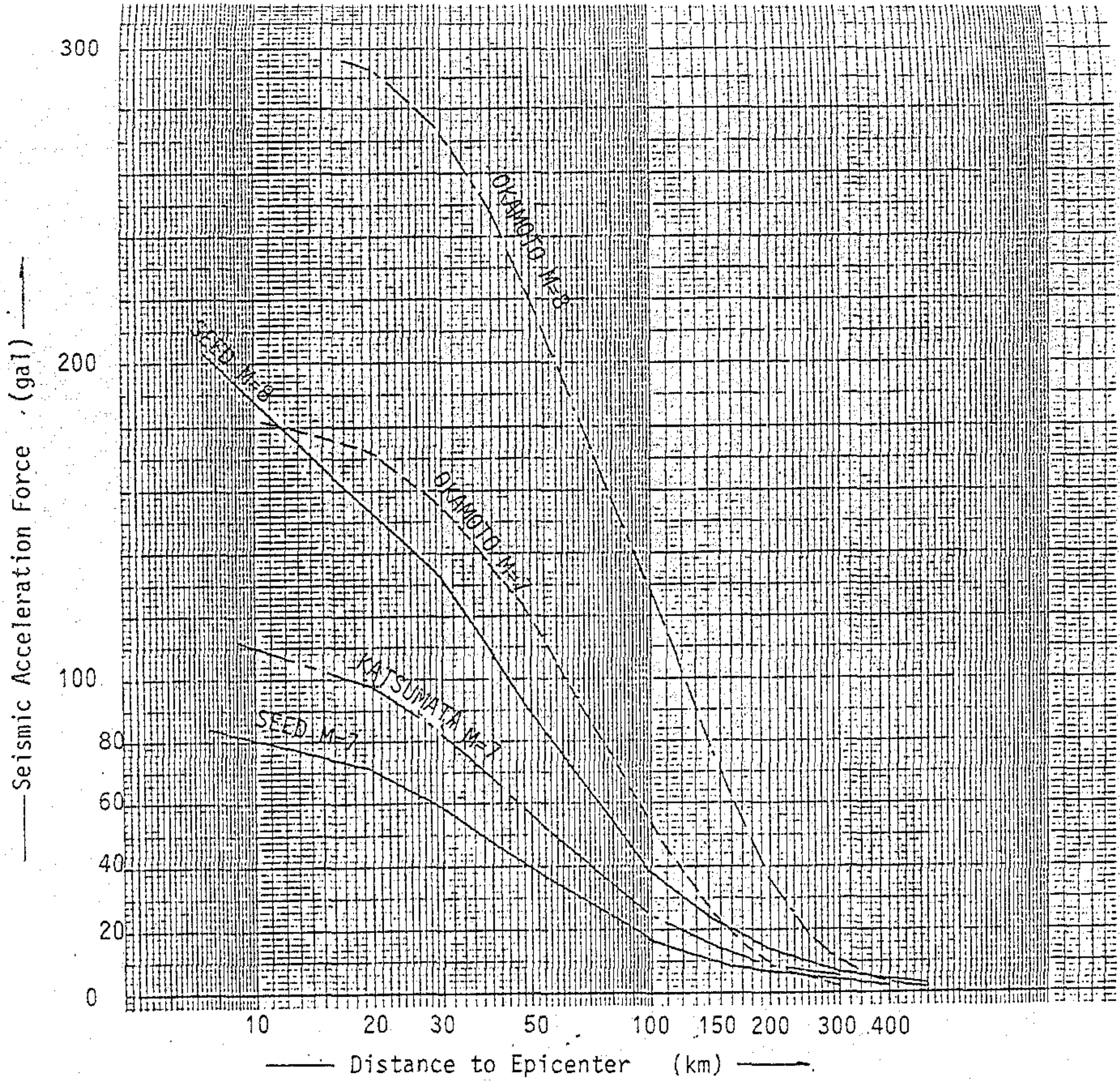
* : Right side tunnel 565 m
Left side tunnel 266 m



Ref. : Studies and Research Div.
Meteorological Department.

Data : 1900 - 1981

Fig. VI-1 Seismic Force Distribution



Note : Epicenter depth is 40 km from ground surface

Fig. VI-2 Relation Between Seismic Acceleration Force And Distance to Epicenter

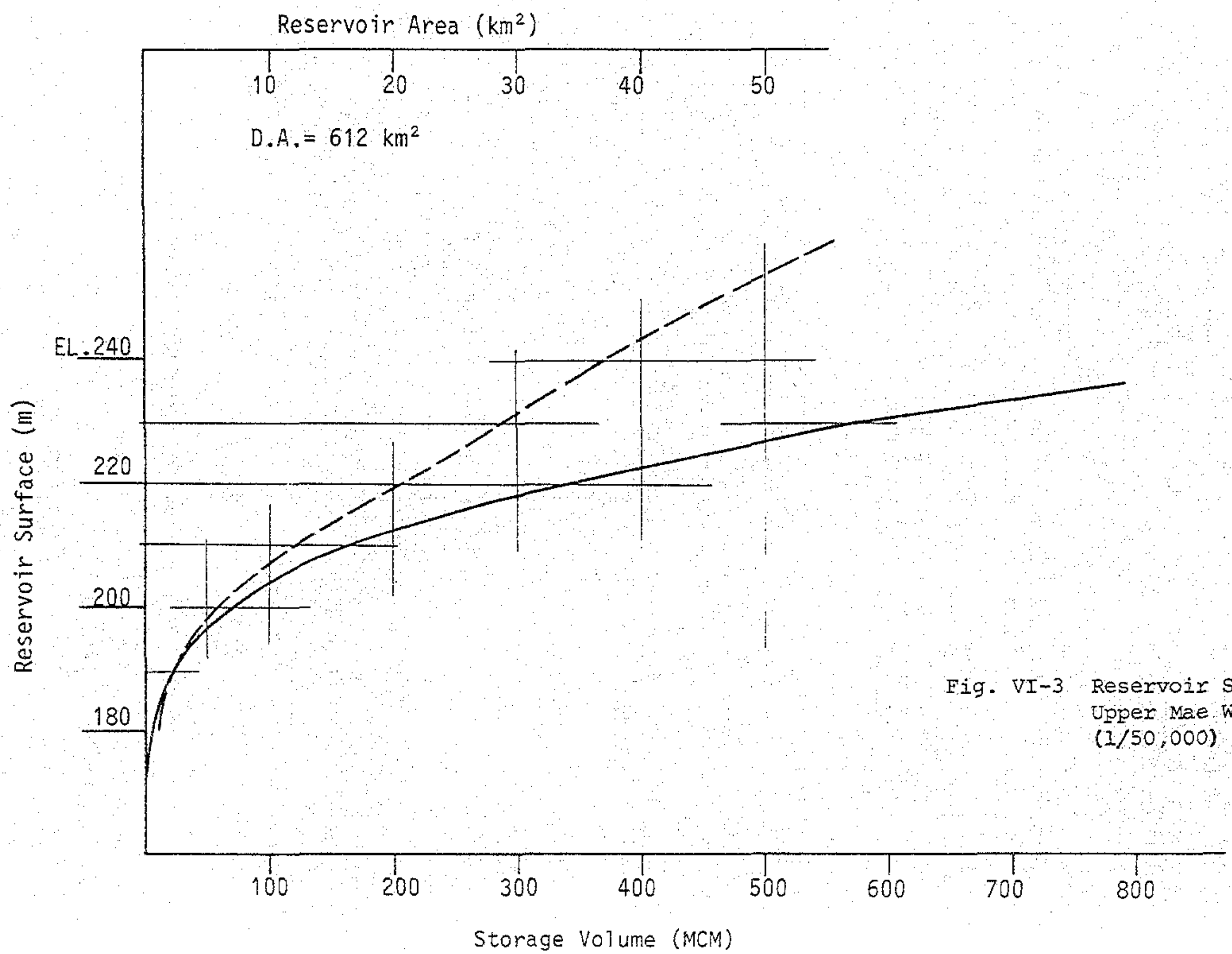


Fig. VI-3 Reservoir Storage Curve
Upper Mae Wong Dam
(1/50,000)

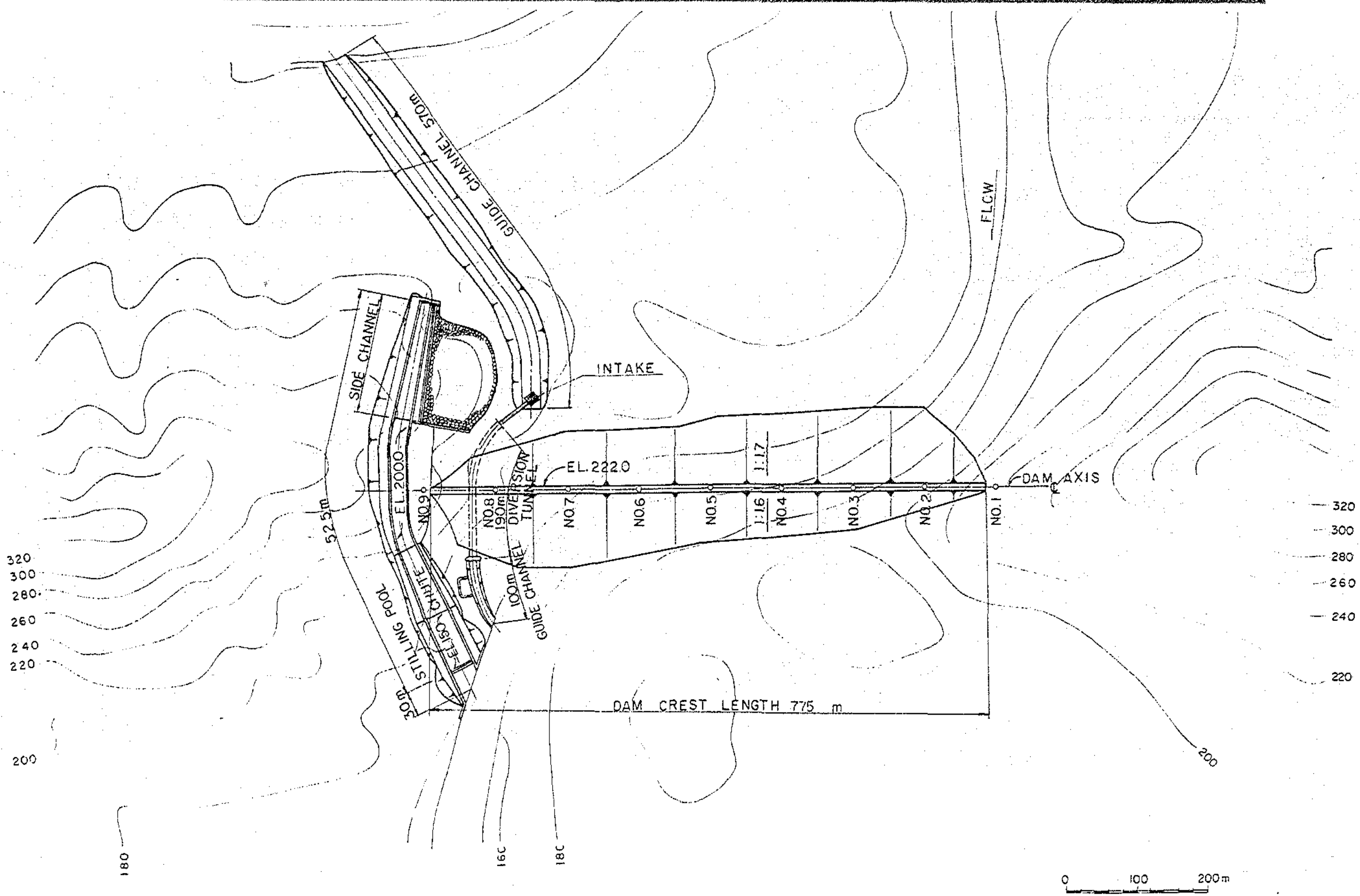


Fig. VI-4 Plan of Upper Mae Wong Dam

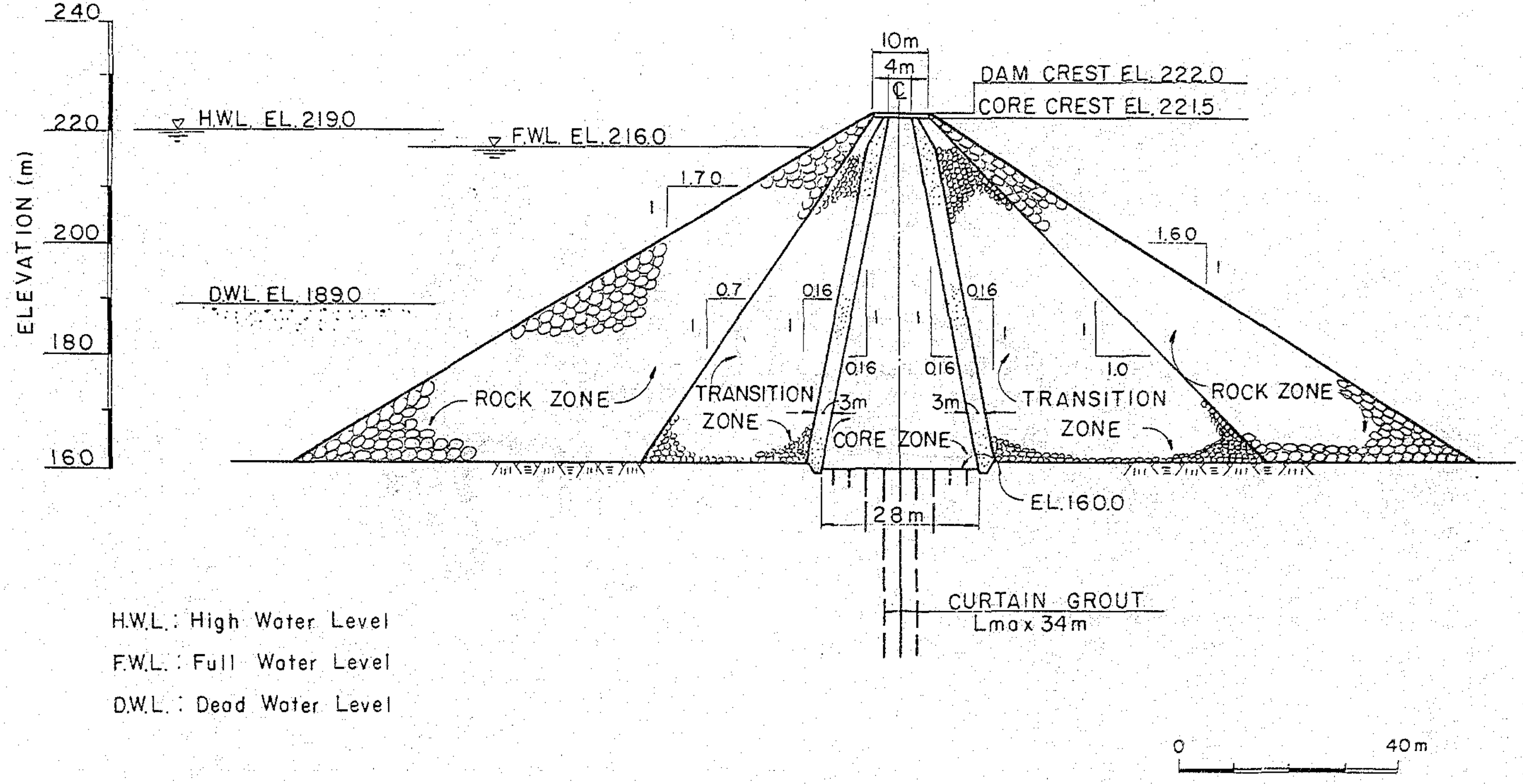
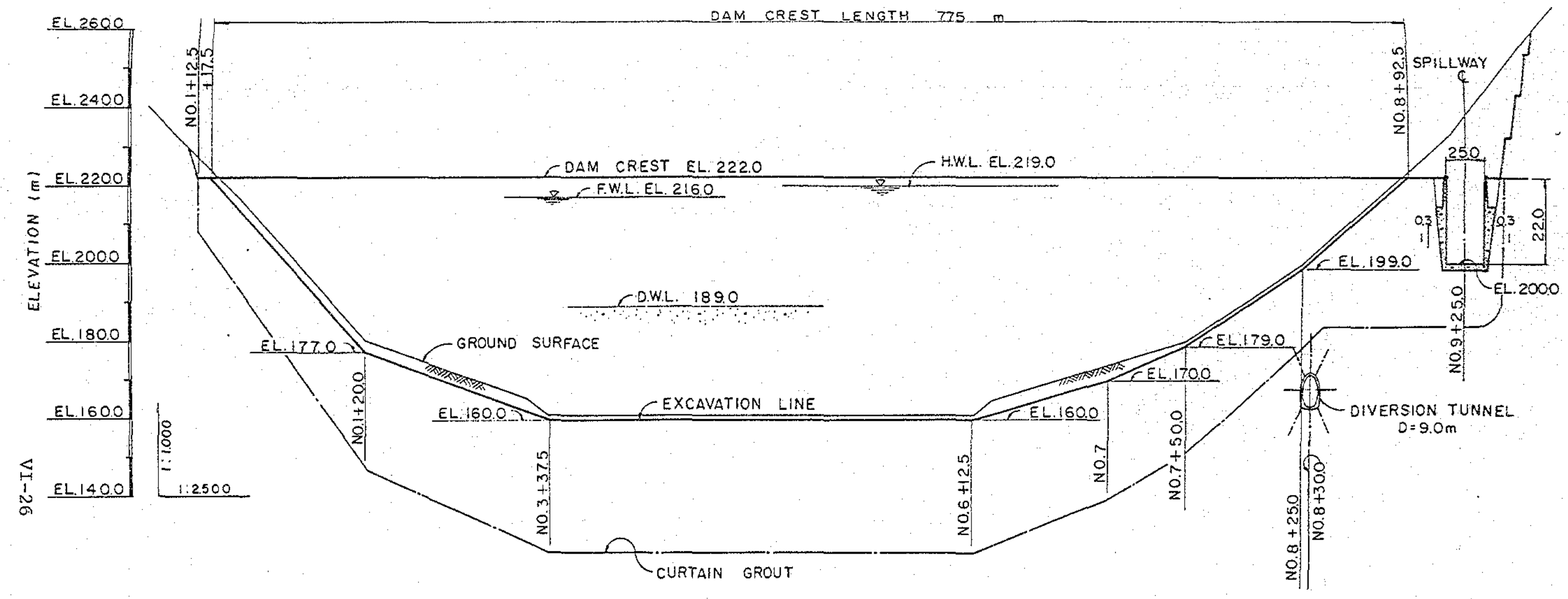


Fig. VI-5 Typical Cross Section of Upper Mae Wong Dam



STATION NUMBER	DISTANCE	GROUND ELEVATION
+81.5	81.5	240.0
NO.1	100.0	
+31.0	131.0	220.0
+75.0	175.0	200.0
NO.2	200.0	189.0
+20.0	220.0	180.0
NO.3	300.0	168.0
+25.0	325.0	165.0
		161.0
NO.4	400.0	161.0
NO.5	500.0	161.0
NO.6	600.0	161.0
		161.0
+25.0	625.0	165.0
NO.7	700.0	174.0
+50.0	750.0	180.0
NO.8	800.0	194.0
+25.0	825.0	200.0
+75.0	875.0	220.0
NO.9	900.0	230.0
+25.0	925.0	240.0

Fig. VI-6 Longitudinal Section of Upper Mae Wong Dam

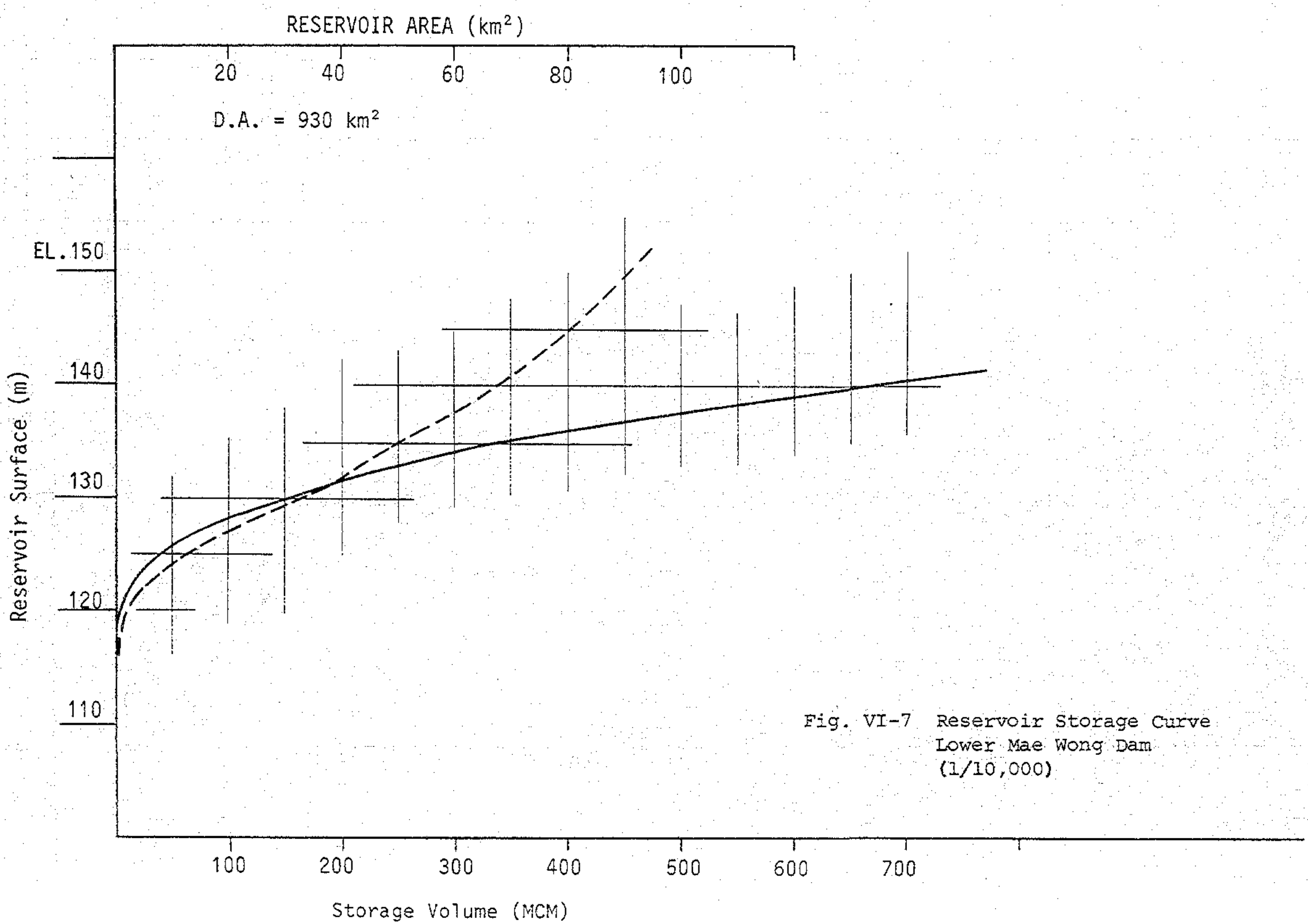


Fig. VI-7 Reservoir Storage Curve
Lower Mae Wong Dam
(1/10,000)

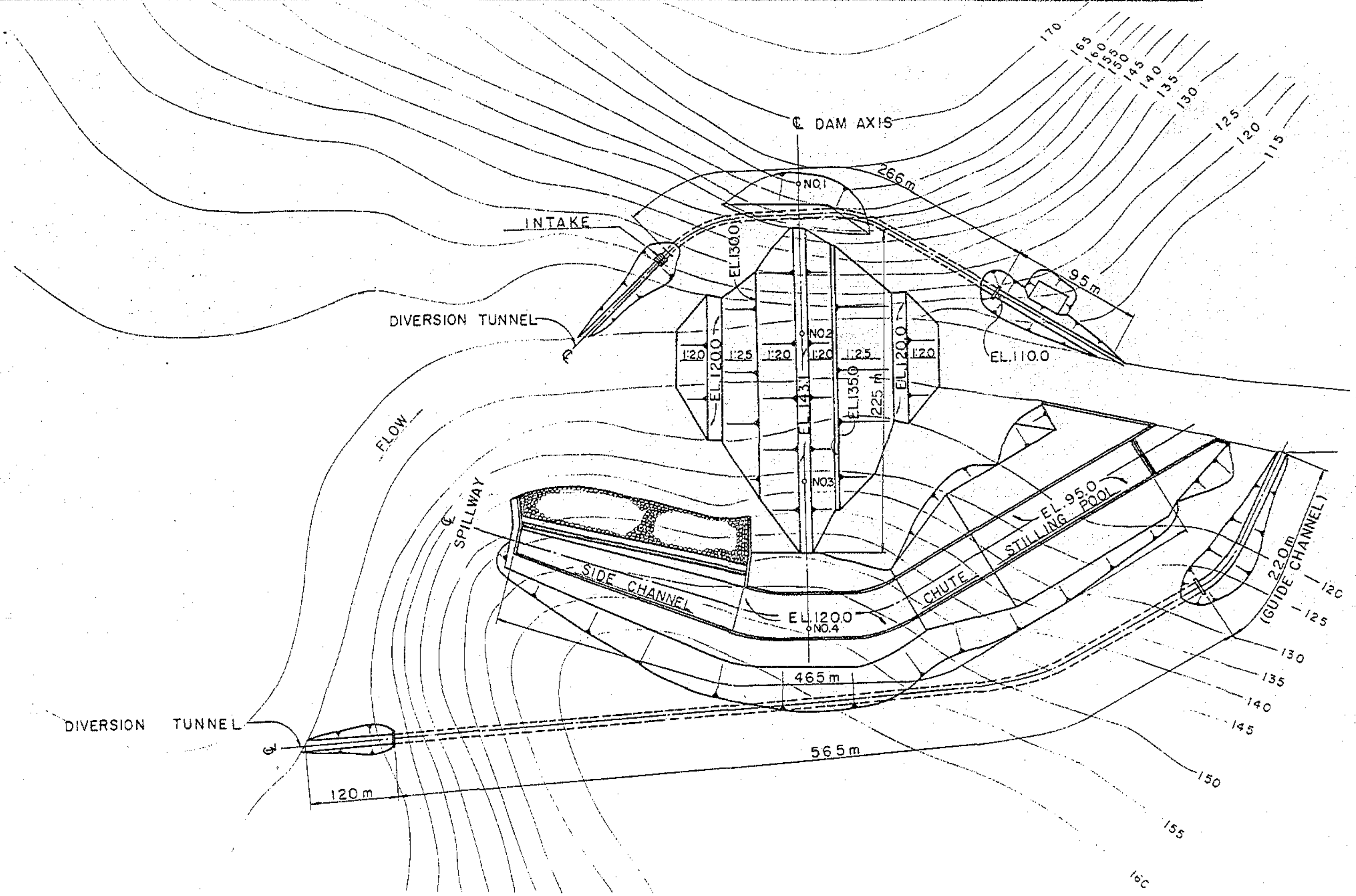


Fig. VI-8 Plan of Lower Mae Wong Dam

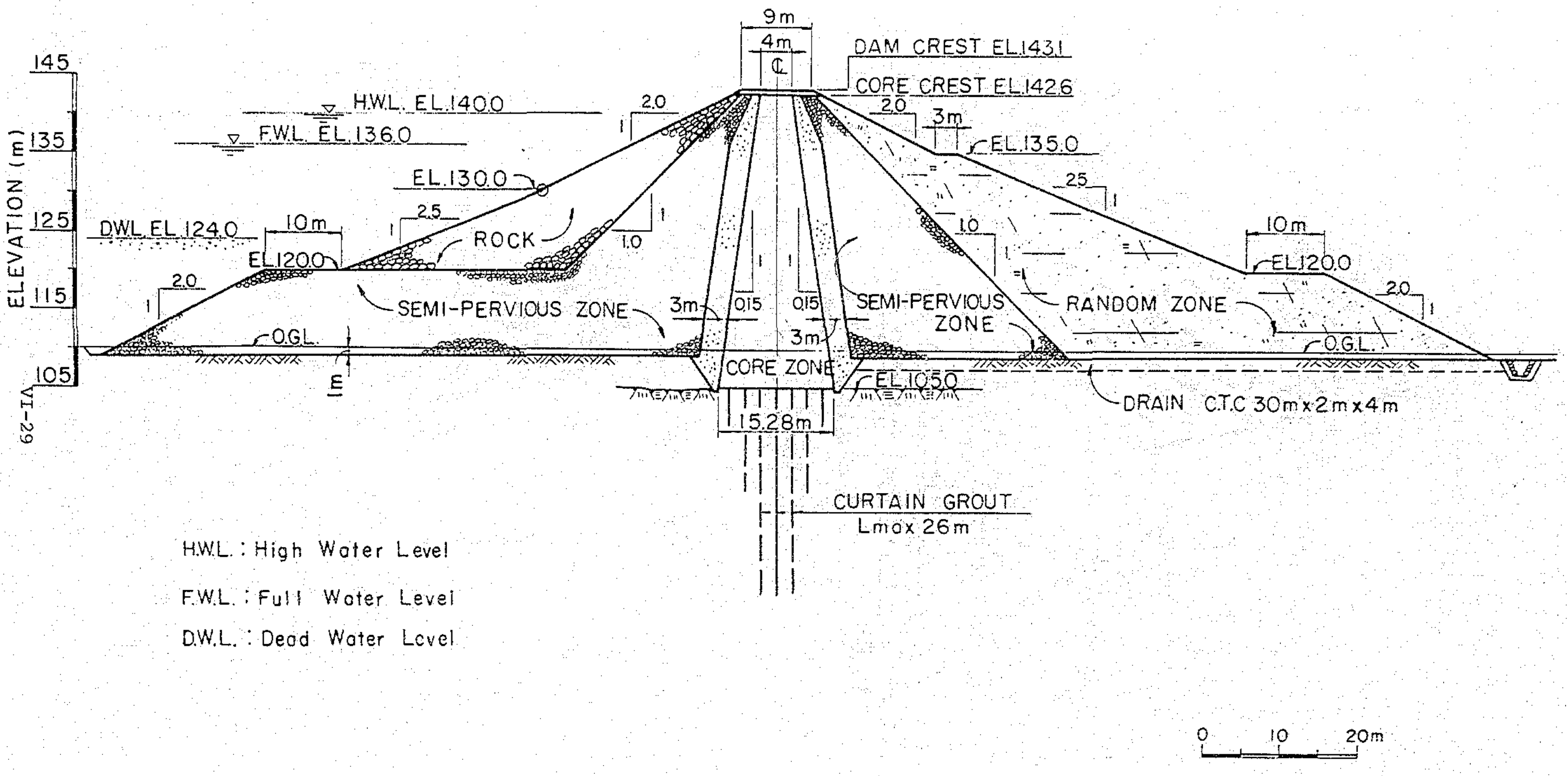
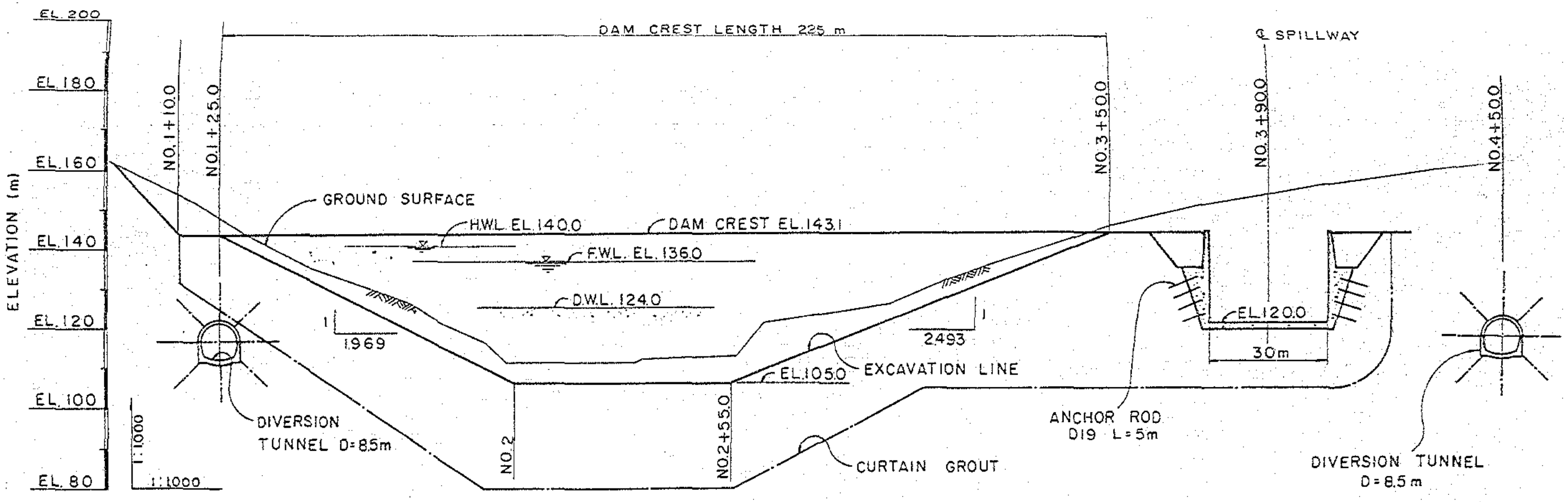


Fig. VI-9 Typical Cross Section of Lower Mae Wong Dam



STATION NUMBER	NO.1	+25.0	+74.0	+93.0	NO.2	+55.0	+63.0	+95.0	NO.3	+50.0	+90.0
DISTANCE	100.0	125.0	174.0	193.0	200.0	255.0	263.0	295.0	300.0	350.0	390.0
GROUND ELEVATION	160.0	147.0	125.0	115.0	110.0	111.0	120.0	125.0	127.0	145.0	158.0

Fig. VI-10 Longitudinal Section of Lower Mae Wong Dam

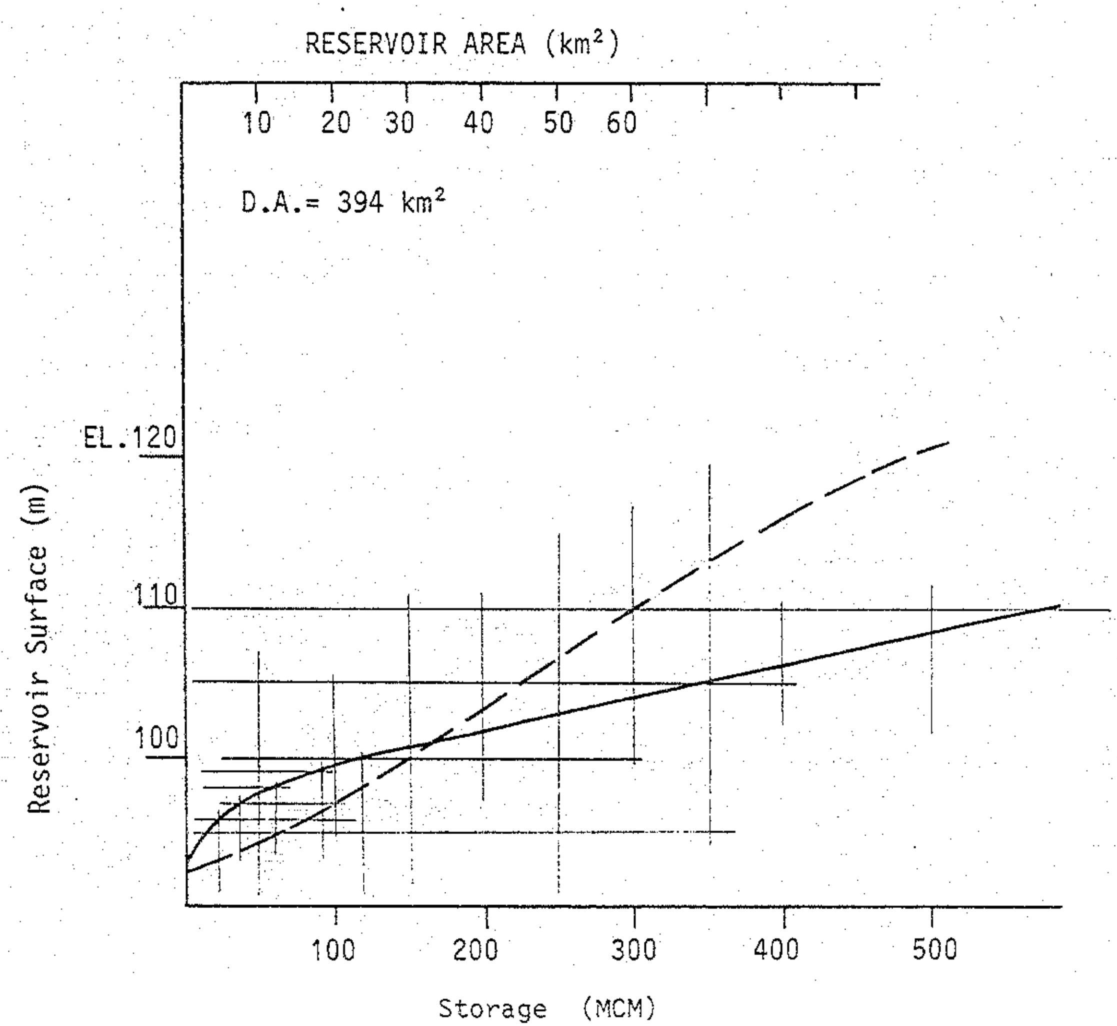


Fig. VI-11 Reservoir Storage Curve
Khlong Pho Dam
(1/50,000)

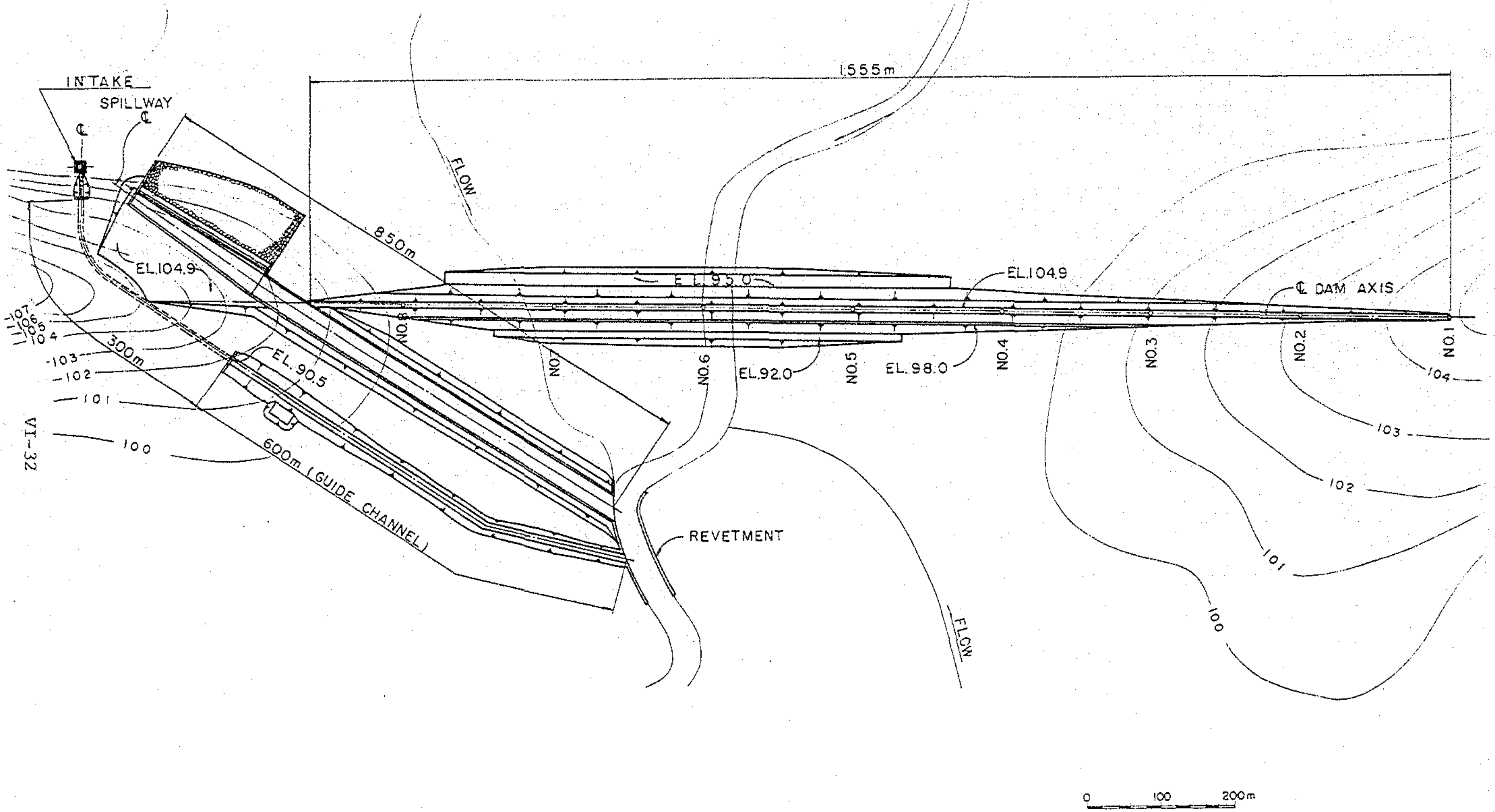


Fig. VI-12 Plan of Khlong Pho Dam

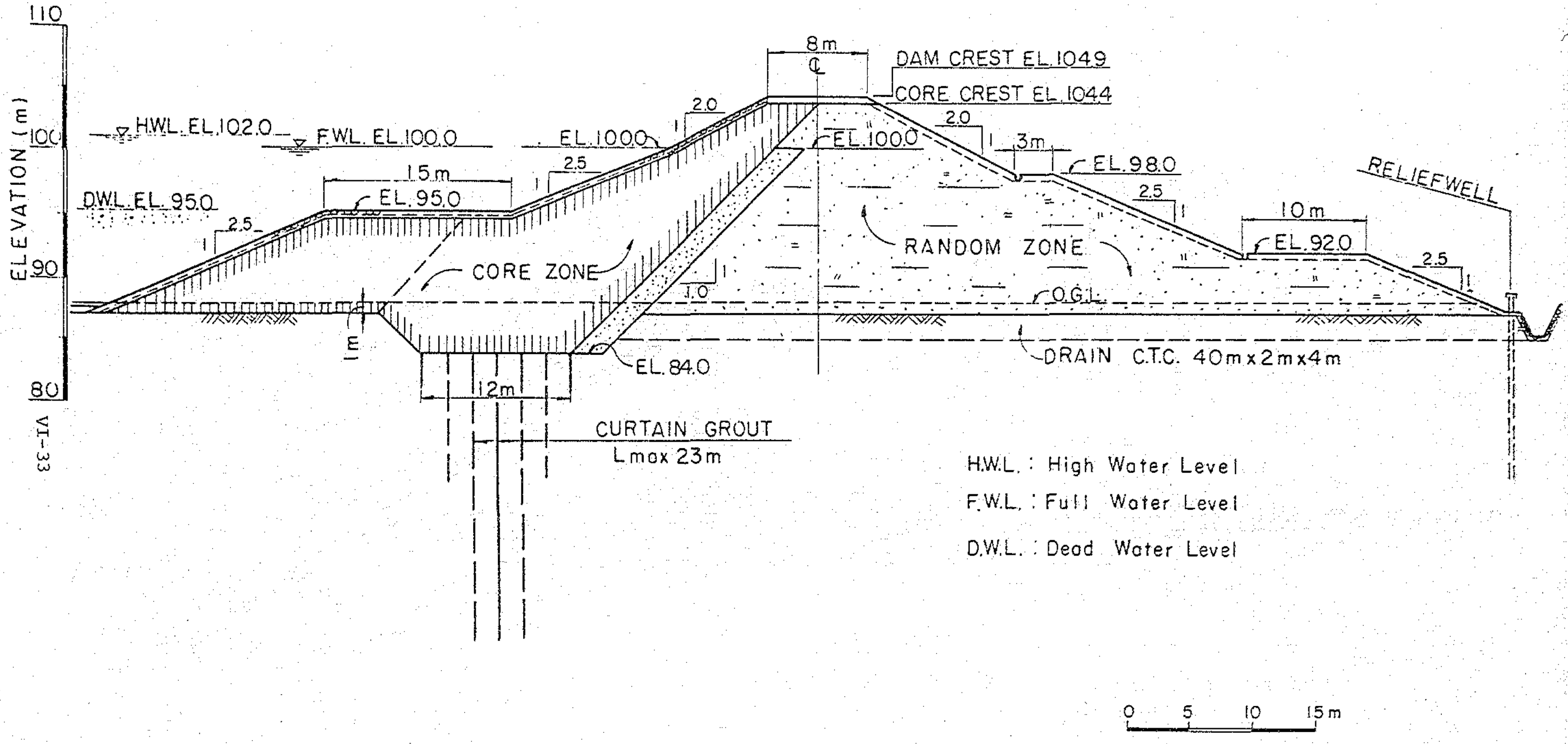
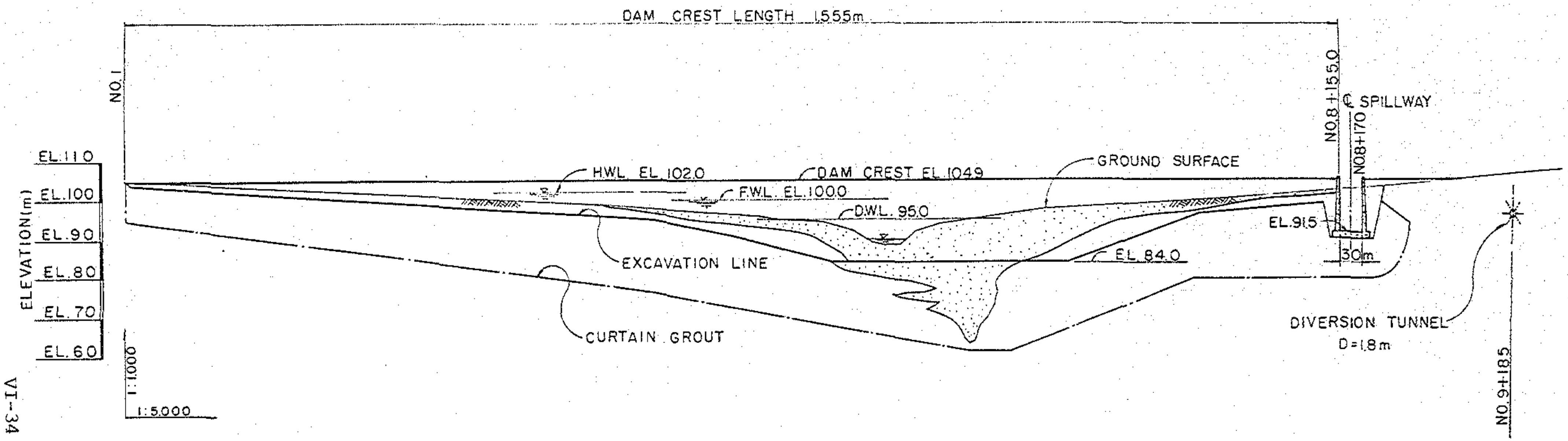


Fig. VI-13 Typical Cross Section of Khlong Pho Dam



STATION NUMBER	DISTANCE	GROUND ELEVATION
NO.1	0	104.9
NO.2	200.0	103.0
NO.3	400.0	101.0
NO.4	600.0	99.0
+70.0	670.0	98.0
NO.5	800.0	96.0
+105.0	905.0	93.0
NO.6	1000.0	89.0
NO.7	1200.0	98.0
+10.0	1210.0	98.0
+175.0	1375.0	100.0
NO.8	1400.0	100.0
+155	1555.0	102.5
+170	1570.0	103.0

Fig. VI-14 Longitudinal Section of Khlong Pho Dam