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No. 9

BANGKOK SEWERAGE SYSTEM PROJECT
IN
KINGDOM OF THAILAND

MASTER PLAN REPORT
VOLUME IV
APPENDICES

AUGUST 2524 (1981)

JAPAN INTERNATIONAL COOPERATION AGENCY

BANGKOK SEWERAGE SYSTEM PROJECT
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MASTER PLAN REPORT

Guide to the Reports

The Reports consist of the following,

VOLUME I	:	EXECUTIVE SUMMARY
VOLUME II	:	MAIN REPORT
VOLUME III	:	DRAWINGS
VOLUME IV	:	APPENDICES

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ZONING

(1) Appropriate Scale of Sewerage Zone

As one of the fundamental data to determine a scale of sewerage zone which is covered by a single treatment facilities, following cost study was carried out.

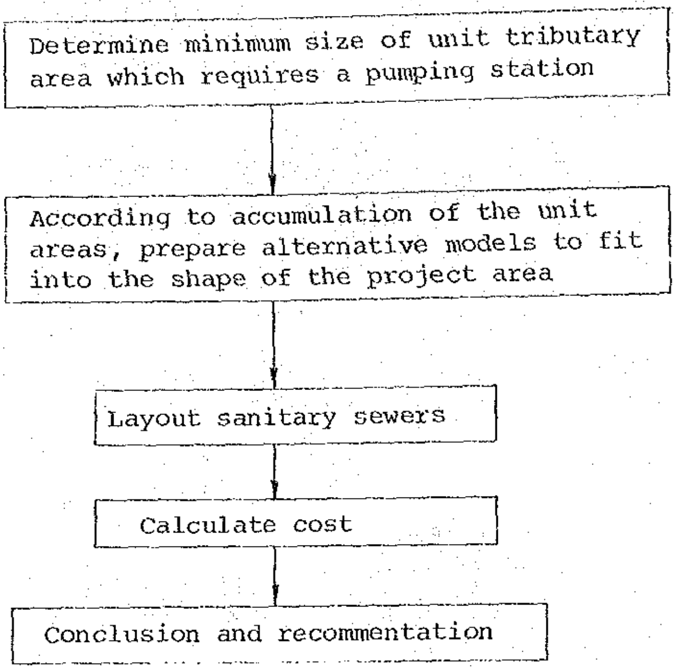
(a) Study Model

Before study, a separate sewerage system model illustrated in Figure A.1 was prepared on the assumption of followings:

<u>Assumptions</u>

1. Ground surface is uniformly flat,
2. No construction cost increase by river crossing is considered,
3. Population density is uniformly 150 persons/ha,
4. Per capita average wastewater flow is 300 l/day,
5. Length of lateral sewer is 200 m/ha,
6. Average slopes of submain sewers are 0.002 for less than 800 mm, 0.0008 for 900 to 1,500 mm and 0.0006 for more than 1,500 mm in diameter,
7. Pumping station is required when sewer depth becomes 6 m,
8. Treatment process is conventional activated sludge and aerated lagoon, and
9. Each zone has a treatment facilities.

The model was prepared according to the following steps:



Because average submain sewer slope is assumed at 0.002, total sewer length of 3,000 m will make sewer depth 6 m and will require a pumping station. Thus, a mimimum served area (unit tributary area for this study) which requires a pumping station will be 1.5 km square (225 ha).

Accumulation unit areas stated above, the study separate sewerage system model was made in shape of 18 km square (32,400 ha) which has 144 units.

(b) Cost study

Figure A.1 illustrates the plan of main sewer in case of that a single treatment facilities covers entire study area. On the basis of this plan the costs of several alternatives, changing zone scale, were obtained as shown in Tables A.1 and A.2 and Figure A.4.

All unit cost used in this appendix are shown in Appendix E of this report, and land acquisition cost is assumed at 3,000 baht per 4 square meters. Annual cost is calculated by means of sinking fund method at 8 percent interest, 50 years useful life of civil structures and 15 years useful life of machinery.

1) Result of cost study (refer to Tables A.1 & A.2 and Figure A.4)

<u>Alternative 1: Conventional activated sludge process</u>

i. Although the land acquisition cost is the lowest, because the construction cost of main sewers to convey wastewater to the treatment facilities located far from central area is singnificant, the Case H is under the greatest disadvantages.

ii. The Case A has the greatest advantage in the sewer construction cost, however, the land acquisition cost and the construction cost of treatment facilities are the highest.

iii. From Case C to Case F, no significant difference is found in the total costs.

iv. In case of served area of more than 10,000 ha, although the land acquisition cost is on the decrease as area scale is larger, the main sewer construction costs become higher.

<u>Alternative 2: Aerated lagoon method</u>

i. No advantage by centralizing is found.

ii. Therefore, if treatment facilities site is available, the smaller zone, the better.

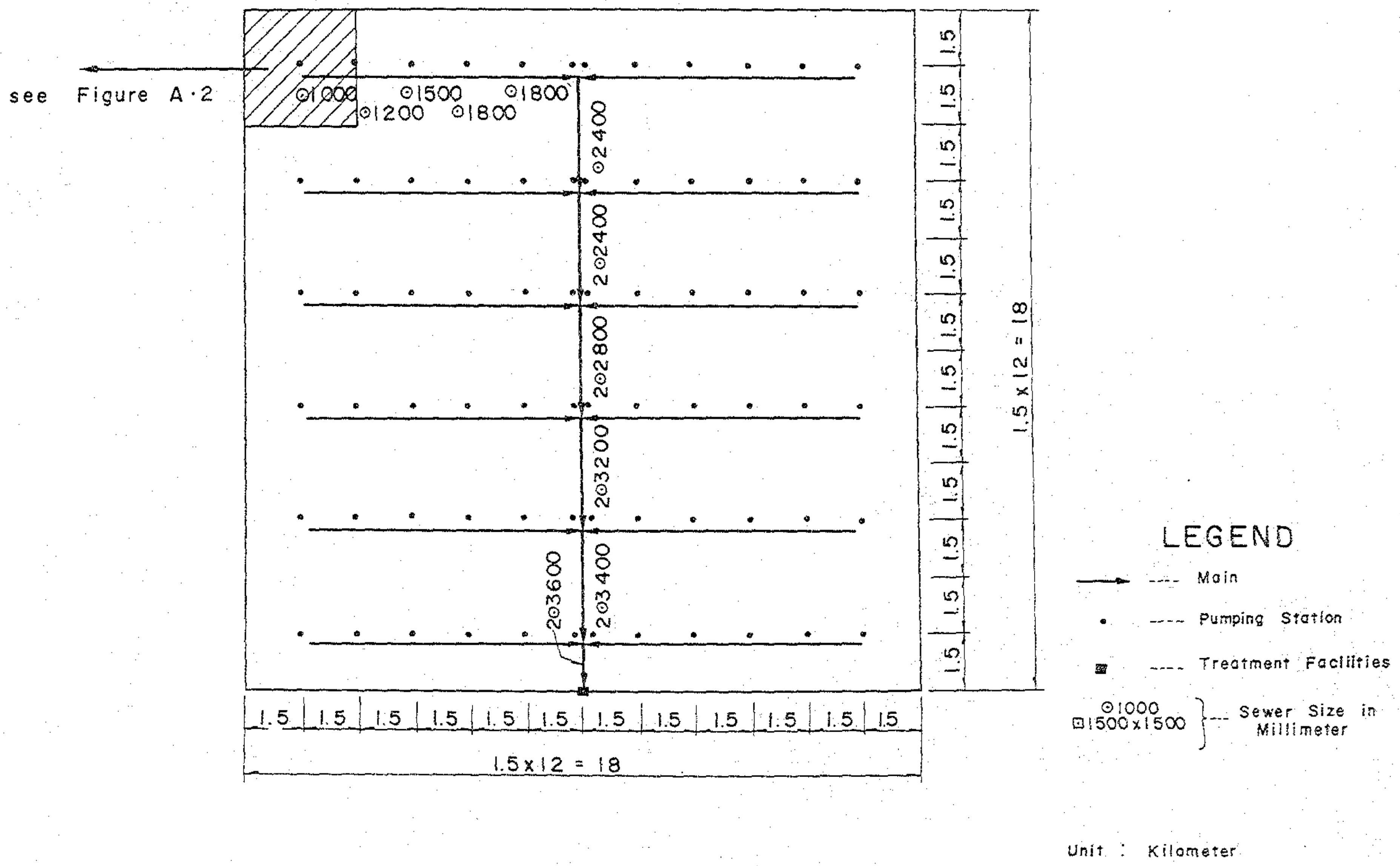


Figure A·1 Separate Sewerage System Model

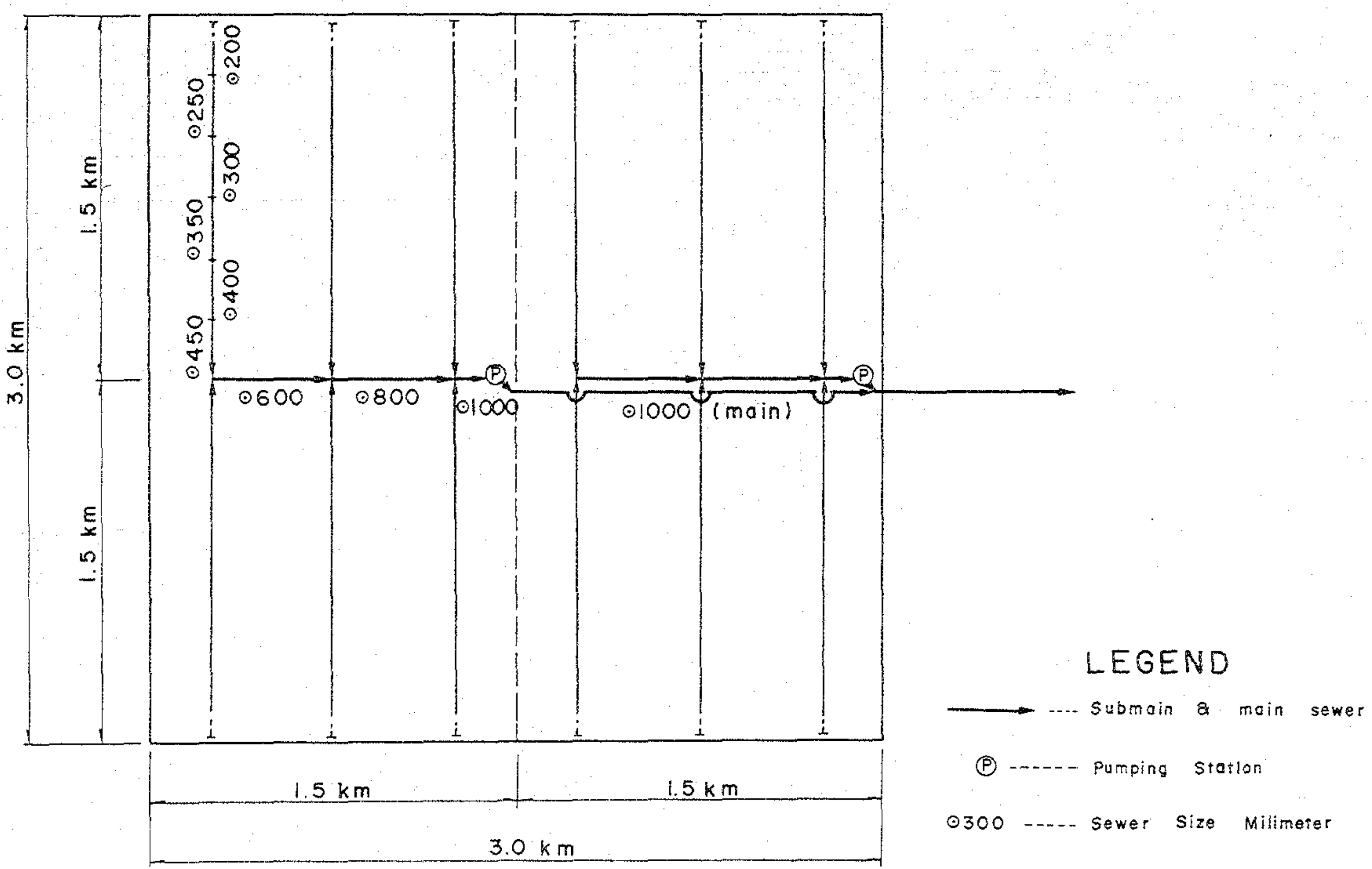


Figure A·2 Submain Sewer Layout

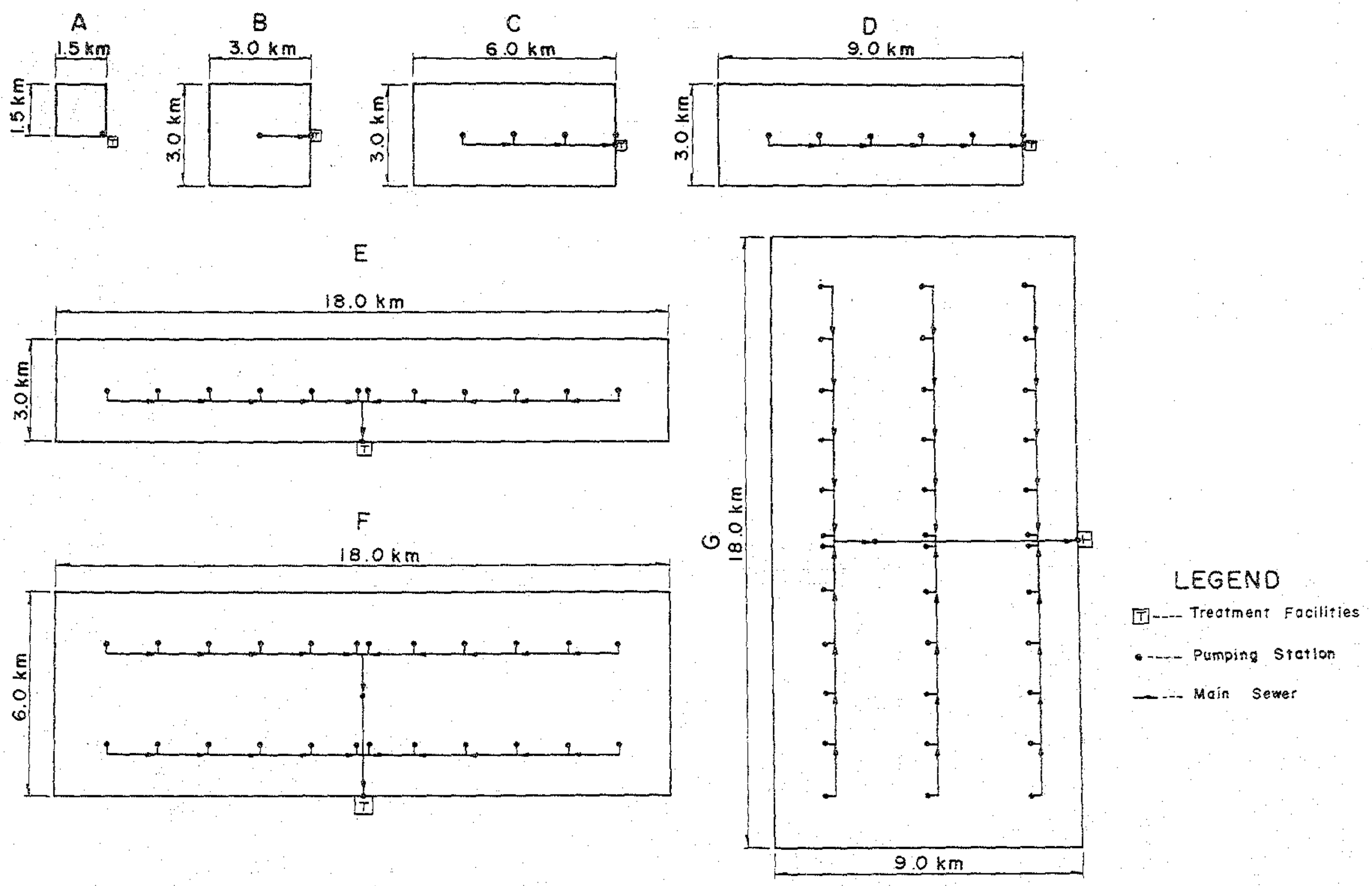


Figure A·3 Alternative Zone

Table A.1 Total Construction Cost at the End of 2523 (1980) Price Level

Unit: 1,000 Baht

Case	Sewer Construction		Pumping Station		Treatment Facility		Total	
	Branch & Lateral	Main	Construction	Land Acquisition	Construction	Land Acquisition	Construction	Land Acquisition
A 144 zones (225 ha each)	7,128,000	1,882,800	792,000	31,300	11,664,000 (2,055,800)	1,728,000 (7,763,800)	21,466,800 (11,858,600)	1,759,300 (7,795,100)
							23,226,100 (19,653,700)	
B 36 zones (900 ha each)	7,128,000	2,602,800	1,119,600	34,000	8,164,800 (1,807,900)	1,202,800 (7,381,100)	19,015,200 (12,658,300)	1,236,800 (7,415,100)
							20,252,000 (20,073,400)	
C 18 zones (1,800 ha each)	7,128,000	3,852,900	1,011,600	34,700	6,925,500 (1,589,200)	1,038,800 (6,998,400)	18,918,000 (13,581,700)	1,073,500 (7,033,100)
							19,991,500 (20,614,800)	
D 12 zones (2,700 ha each)	7,128,000	5,104,800	915,600	31,300	6,269,400 (1,458,000)	984,100 (6,670,300)	19,417,800 (14,606,400)	1,015,400 (6,701,600)
							20,433,200 (21,308,000)	
E 6 zones (5,400 ha each)	7,128,000	5,779,800	801,600	27,300	5,103,000 (1,297,600)	874,800 (6,451,600)	18,812,400 (15,007,000)	902,100 (6,478,900)
							19,714,500 (21,485,900)	
F 3 zones (10,800 ha each)	7,128,000	6,454,800	819,600	28,200	4,374,000 (1,122,700)	765,400 (6,123,600)	18,776,400 (15,525,100)	793,600 (6,151,800)
							19,570,000 (21,676,900)	
G 2 zones (16,200 ha each)	7,128,000	7,681,800	765,600	25,900	3,936,600 (1,057,100)	761,200 (5,904,900)	19,512,000 (16,632,500)	787,100 (5,930,800)
							20,299,100 (22,563,300)	
H 1 zone (32,400 ha)	7,128,000	9,589,700	747,600	25,200	3,353,400 (911,200)	656,100 (5,576,800)	20,818,700 (18,376,500)	681,300 (5,602,100)
							21,500,000 (23,978,500)	

Note: Figures in ( ) are for aerated lagoon process.

Table A.2 Total Annual Cost at the End of 2523 (1980) Price Level

Unit: Million Baht/Year

Case	Depreciation	Interest	Operation & Maintenance	Total
A	377,740 (63,384)	1,858,088 (1,572,296)	509,730 (400,380)	2,705,558 (2,036,060)
B	253,281 (67,044)	1,620,160 (1,605,872)	501,680 (406,910)	2,375,121 (2,079,826)
C	220,775 (63,685)	1,599,320 (1,649,184)	486,410 (406,220)	2,306,505 (2,119,089)
D	203,846 (61,943)	1,634,656 (1,704,640)	465,840 (400,230)	2,304,342 (2,166,813)
E	172,141 (58,388)	1,577,160 (1,718,872)	453,490 (387,880)	2,202,791 (2,165,140)
F	154,489 (57,151)	1,565,600 (1,734,152)	456,770 (405,740)	2,176,859 (2,197,043)
G	144,078 (57,209)	1,623,928 (1,805,064)	436,020 (392,280)	2,204,026 (2,254,553)
H	131,708 (57,880)	1,720,000 (1,918,280)	449,890 (406,150)	2,301,598 (2,382,310)

Note: Interest is assumed at 8 percent, and useful lives are assumed at 15 years for machinery and at 50 years for others.
Figures in ( ) are for aerated lagoon process.

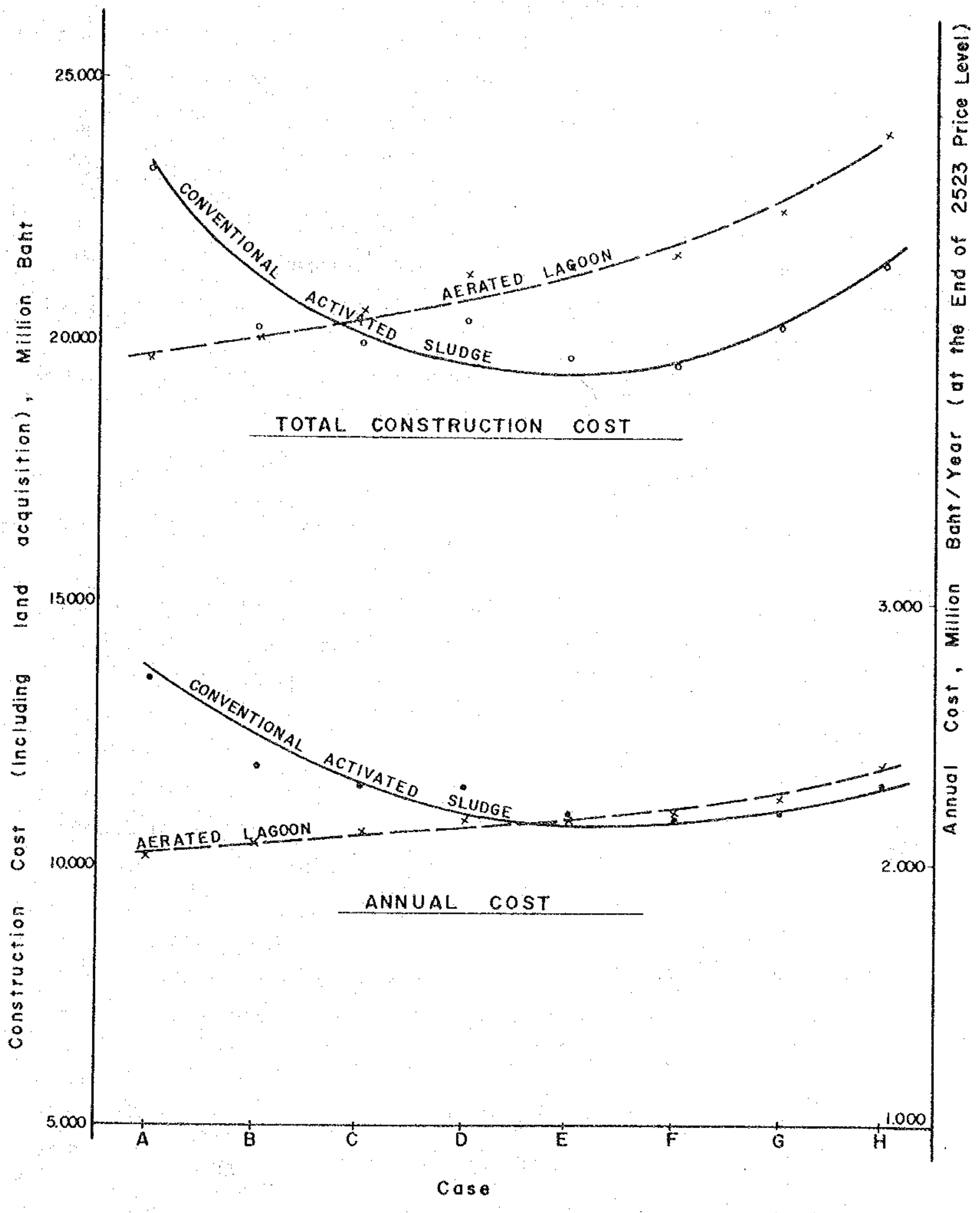


Figure A·4 Result of Cost Study

2) Conclusion and Recommendation

In this study, no river, no canal and no railway crossings which usually require additional construction costs were considered. If these additional costs are taken into account, the system which has long conveyers will have significant disadvantage.

Where conventional activated sludge method for wastewater treatment is adopted, the appropriate scale of sewerage zone with a treatment facility is recommended as some of 3,000 to 10,000 ha.

However, if aerated lagoon process is adopted, centralized system has no advantage.

(2) Zoning for Central Area

The principal idea is that the entire Master Plan Area should be divided into two regions which are densely populated urbanized area of about 9,500 hectares (includes 1st priority area of flood protection, hereinafter called central area) and remained area.

In the central area, available site areas for treatment facilities are limited in these spots of 20 hectares in Makkasan, 25 hectares in Tobacco-monopoly and 50 hectares in Klong Chong Nonsi as shown in Figure A.5.

This alternative study was carried out to select the suitable sewerage system and to utilize limited land spaces effectively for the central area which would have the highest priority for sewerage implementation.

(a) Dividing into Zone

The central area is divided into 4 zones (see Figure A.5) according to characteristics and topographical conditions. Conditions of each zone are as follows.

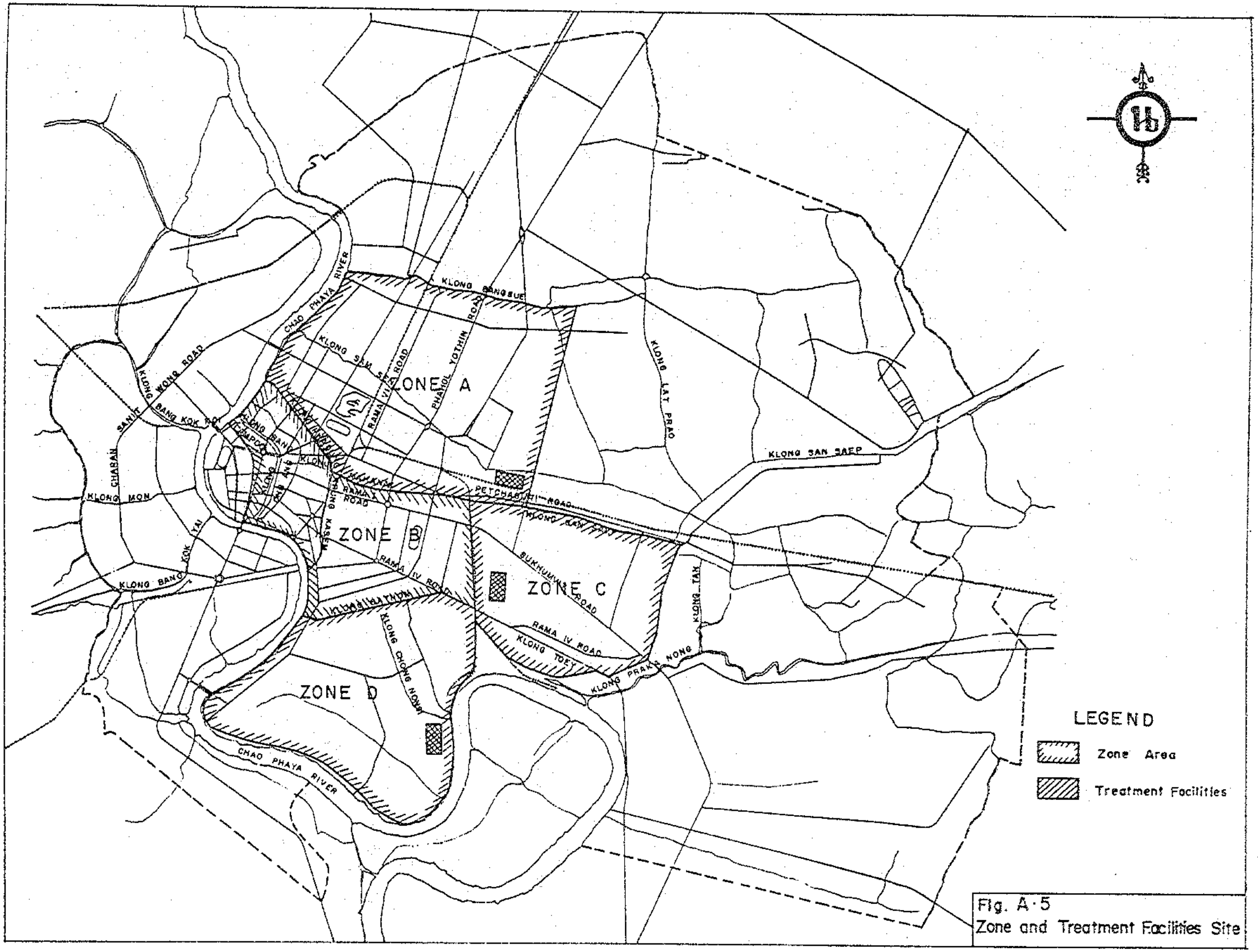


Fig. A·5
Zone and Treatment Facilities Site

Zone A ....The area consists of mainly the public, green and institutional area of 3,400 hectares. The present population density is about 230 persons per hectare. Estimated population of this zone in the year 2543 (2000) is 1,019,000 persons.

Zone B ....This area is the most densely populated urbanized area of 1,800 hectares and consists of mainly the commercial, institutional and residential area. This area is the center of commercial in Bangkok. The present population density is about 350 persons per hectare. Estimated population of this zone in the year 2543 (2000) is 692,000 persons.

Zone C ....This area consists of mainly the residential area of 1,800 hectares which was developed recently. The present population density is about 90 persons per hectare. Estimated population of this zone in the 2543 (2000) is 132,000 persons.

Zone D ....This area is neighbouring the south of Zone B and developed recently for the commercial and residential area of 2,500 hectares. The present population density is about 150 persons per hectare. Estimated population of this zone in the year 2543 (2000) is 500,000 persons.

(b) Wastewater Flow in Each Zone

Table A.3 shows estimated wastewater flow generated from zones in terms of daily average flow basis for the year 2543 (2000).

Table A.3 Wastewater Flow

Name of Zone	Area (ha)	Population in 2543 (2000)	Wastewater Flow* (m^3/day)
Zone A	3,400	1,019,000	275,000
Zone B	1,800	692,000	315,000
Zone C	1,800	132,000	60,000
Zone D	2,500	500,000	119,000
Total	9,500	2,343,000	769,000

Note: * includes domestic, commercial wastewater and infiltration flow.

(c) Treatment Capacity by Available Land for Treatment Facilities

In the central area, available lands for treatment facilities are (1) the pond of Makkasan, (2) the pond of Tobacco-Monopoly and (3) the mouth of Klong Chong Nonsi.

Conditions of each land is tabulated in Table A.4.

Table A.4 Conditions of Available Treatment Facilities Site

Location	Available Area (ha)	Present Situation	Land Owner	Receiving Water
The pond of Makkasan	20	pond	Royal Railway	Klong Sam Sen
The pond of	25	pond	Tobacco-Monopoly	Klong Toey
The mouth of Klong Chong Nonsi	50	Fruit Garden	BMA--5 ha Private--45 ha	Chao Phya River

In each available land for treatment facilities, the maximum treatment capacity by conventional activated sludge process is 270,000 m^3/day in 20 ha, 360,000 m^3/day in 25 ha and 880,000 m^3/day in 50 ha.

(d) Alternative Zoning

From above mentioned location of zone and treatment capacity by available land for treatment facilities, following alternatives were considered (see Figure A.6).

Alternative (1) ..... The central area is divided into
3 zones: Zone A, Zone (B+C), Zone D

(2) ..... The central area is divided into
3 zones: Zone A, Zone (B+D), Zone C

(3) ..... The central area is divided into
3 zones: Zone A, Zone B, Zone (C+D)

(4) ..... The central area is one zone
: Zone (A+B+C+D)

(e) Sewerage Facilities

Sewerage facilities for each alternative are summarized in Table A.5.

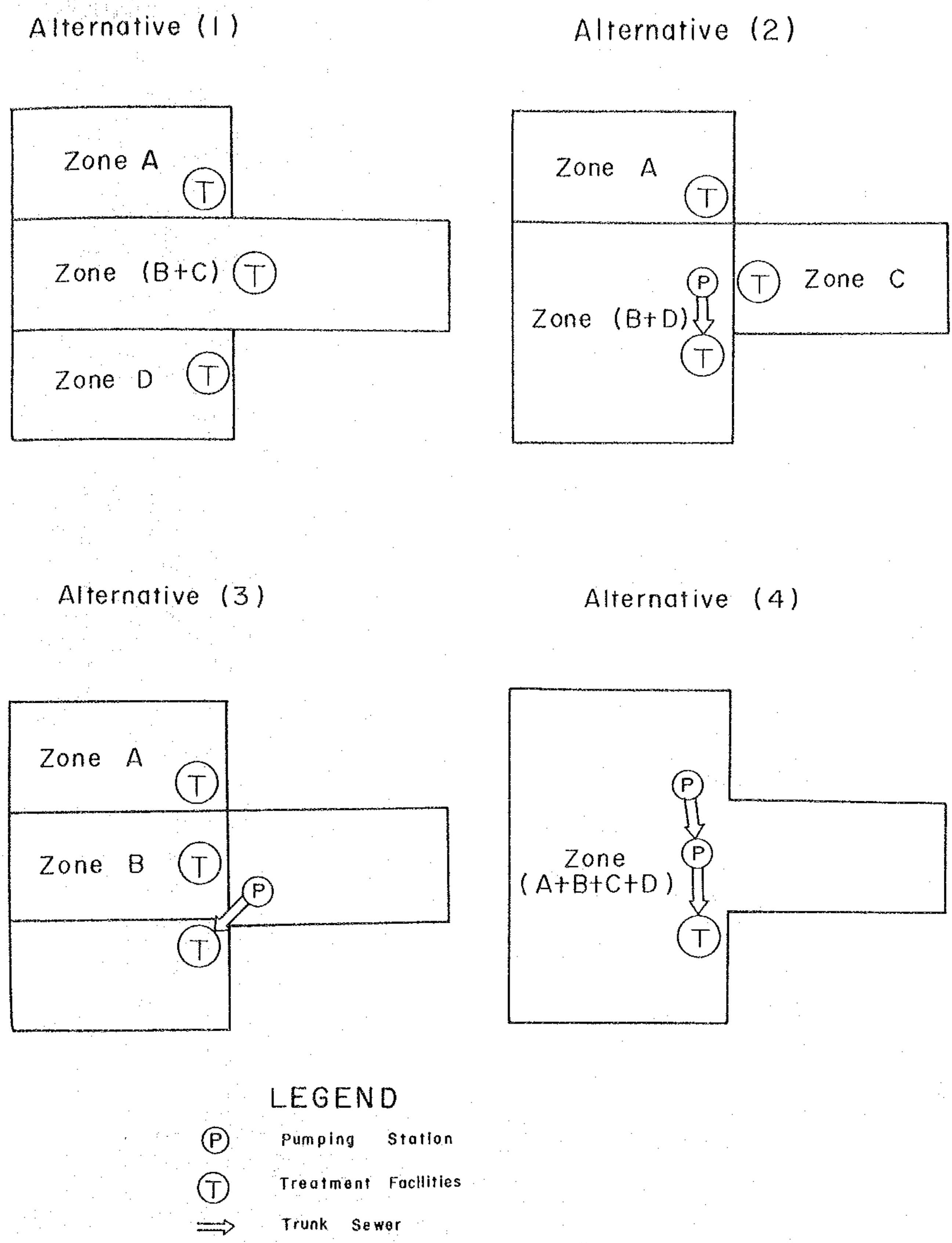


Figure A·6 Alternatives for Zoning

Table A.5 Sewerage Facilities

Alternative	Area (ha)	Population (in 2543)	Trunk Sewer Length (km)	Pumping Station		Treatment Facilities		Location of Treatment Facilities
				Peak Flow (m^3/sec)	Required Land Area (m^2)	Average Daily Flow (m^3/day)	Required Land Area (ha)	
Alternative (1)								
Zone A	3,400	1,019,000				275,000	20	Makkasan
Zone (B+C)	3,600	824,000				375,000	25	Tobacco-Monopoly
Zone D	2,500	500,000				119,000	11	K.Chong Nonsi
Alternative (2)								
Zone A	3,400	1,019,000				275,000	20	Makkasan
Zone (B+D)	4,300	1,192,000	4(Ø2,600mm)	6.2	1,500	434,000	29	K.Chong Nonsi
Zone C	1,800	132,000				60,000	6	Tobacco-Monopoly
Alternative (3)								
Zone A	3,400	1,019,000				275,000	20	Makkasan
Zone B	1,800	692,000				315,000	23	Tobacco-Monopoly
Zone (C+D)	4,300	632,000	5(Ø2,100mm)	1.4	1,000	179,000	15	K.Chong Nonsi
Alternative (4)								
Zone (A+B+C+D)	9,500	2,343,000	4(Ø2,700mm) 5(Ø3,900mm)	5.4 12.8	1,400 1,900	769,000	45	K.Chong Nonsi

Note: i) Treatment process is Conventional Activated Sludge Process.

(f) Construction Cost

Table A.6 shows construction cost with land acquisition cost of alternatives.

Table A.6 Construction Cost at the End of 2523 (1980) Price Level

Unit: 1,000 baht

Alternative	Sewer	Pumping Station		Treatment Facilities		Total
		Land	Facilities	Land	Facilities	
Alternative (1)						
Zone A				50,000	911,000	
Zone (B+C)				187,500	1,149,700	
Zone D				33,000	488,200	
Total				270,500	2,548,900	2,819,400
Alternative (2)						
Zone A				50,000	911,000	
Zone (B+D)	292,000	1,130	50,700	87,000	1,282,500	
Zone C				45,000	294,100	
Total	292,000	1,130	50,700	182,000	2,487,600	3,013,430
Alternative (3)						
Zone A				50,000	911,000	
Zone B				172,500	1,008,800	
Zone (C+D)	305,000	750	19,300	45,000	661,500	
Total	305,000	750	19,300	267,500	2,581,300	3,173,800
Alternative (4)						
Zone (A+B+C+D)	904,000	1,780	127,500	135,000	1,969,900	3,138,180

Note: i) Treatment process is Conventional Activated Sludge Process.

(g) Operation and Maintenance Cost

Annual operation and maintenance costs are tabulated in Table A.7.

Table A.7 Annual Operation and Maintenance Cost at the End of 2523 (1980) Price Level

Unit: 1,000 baht/year

Alternative	Sewer	Pumping Station	Treatment Facilities	Total
Alternative (1)				
Zone A			60,800	
Zone (B+C)			81,500	
Zone D			28,200	
Total			170,500	170,500
Alternative (2)				
Zone A			60,800	
Zone (B+D)	40	9,300	93,500	
Zone C			15,100	
Total	40	9,300	169,400	178,740
Alternative (3)				
Zone A			60,800	
Zone B			69,200	
Zone (C+D)	50	1,500	41,000	
Total	50	1,500	171,000	172,550
Alternative (4)				
Zone (A+B+C+D)	90	30,200	161,100	191,390

(h) Total Cost

Assuming useful life of all sewerage facilities is 30 years, total cost of four alternatives are obtained as shown in Table A.8.

Table A.8 Total Cost at the End of 2523 (1980) Price Level

Unit: 1,000 baht

Alternative	Construction Cost	Operation & Maintaince Cost	Total
Alternative (1)	2,819,400	5,115,000	7,934,400
Alternative (2)	3,013,430	5,362,200	8,375,630
Alternative (3)	3,173,850	5,176,500	8,350,350
Alternative (4)	3,138,180	5,741,700	8,879,880

(i) Result of Cost Analysis

Alternative (1) is the most economical of four alternatives in construction cost and total cost with 30 years operation and maintenance cost.

(j) Minimum Requirement

As previously mentioned the central area for which alternative zoning study is performed, is already urbanized portion and furnished with underground conduits for both storm-water and sullage. Although it is unsatisfactory in slope, the drainage system is presently functioning in removing wastewater from living environment to the nearest klong or the Chao Phya River through pumping station. If the inadequate slope and other defects are permitted temporarily of as an interim measure, the existing piping system could be incorporated as the part of the collection and conveyance system of sewerage, and it is possible for sewerage system to fulfil, even partly, its objective i.e. to prevent wastewater from being discharged to receiving water body without treatment.

With the construction of a treatment facilities and the addition of some supplemental facilities to the existing drainage system, if it is possible to alleviate present water pollution problems namely caused by effluents from two pumping stations, Rama IV and Padung Krung Kasem, it is worth while to do and could be considered as minimum requirement or very initial step in the context of multi-stage program, and it could be done with minimum segment of necessary total cost for the improvement of the area.

From the stand point mentioned above, the alternatives under discussion are compared, too. Of four alternatives, alternatives (1) and (4) are selected for comparison, because they are considered to be more preferable due to their less project cost than other two.

It is assumed, for the purpose of comparative study, that zone B would be more vulnerable to be claimed as main cause of water pollution in the klongs and the Chao Phya River, because of its high population density and active land use as well as being tributary of klongs located in the central core portion of the city, and the existing major pumping stations, Rama IV and Padung Krung Kasem.

Therefore, the collection and treatment of wastewater generated in Zone B with maximum use of existing drainage facilities, is assumed as the minimum requirement. To accomplish the objective, the required costs under alternatives (1) and (4) are estimated for economic comparison.

The minimum required sewerage facilities are composed of a treatment facility, a pumping station and main and intercepting sewers.

Branch and lateral sewers and a part of intercepting sewers comprise of existing drains. (see Figure A.7)

The minimum required sewerage facilities and construction cost are tabulated in Tables A.9 and A.10.

Table A.9 Sewerage Facilities

Alternative	Sewer		Pumping Station		Treatment Facilities	
	Main (km)	Interceptor (km)	Land Area (m^2)	Flow (m^3/sec)	Land Area (ha)	Flow (m^3/day)
Alternative(1)	10.0	1.0	1,300	2.7	25.0	315,000
Alternative(4)	10.0	2.0	1.300	2.7	45.0	315,000

Table A.10 Construction Cost at the End of 2523 (1980) Price Level

Unit: 1,000 baht

Alternative	Sewer		Pumping Station		Treatment Facilities		Total
	Main	Interceptor	Land	Facilities	Land	Facilities	
Alternative(1)	134,500	87,300	3,250	29,700	187,500	1,008,800	1,451,050
Alternative(4)	134,500	280,000	3,250	29,700	135,000	1,008,800	1,591,250

Through the comparative study it is understood that alternative (1) is preferable due to its less construction cost. It is also considered that the alternative (1) has advantageous potentiality which could reduce the cost of the land for the treatment facilities, because the land belongs to the government sector enterprise to which the government could impose political option. Further, depend on available magnitude of fund, the collection of wastewater generated in the area enclosed by the Klong Padung Krung Kasem might not be intended for the time being, and if it is the case, the alternative (1) could be performed with the cost far less than that mentioned in Table A.10. The alternative is realizable one which could be implemented in stepwise.

On the basis of understanding above mentioned the alternative (1) is selected to be recommendable.

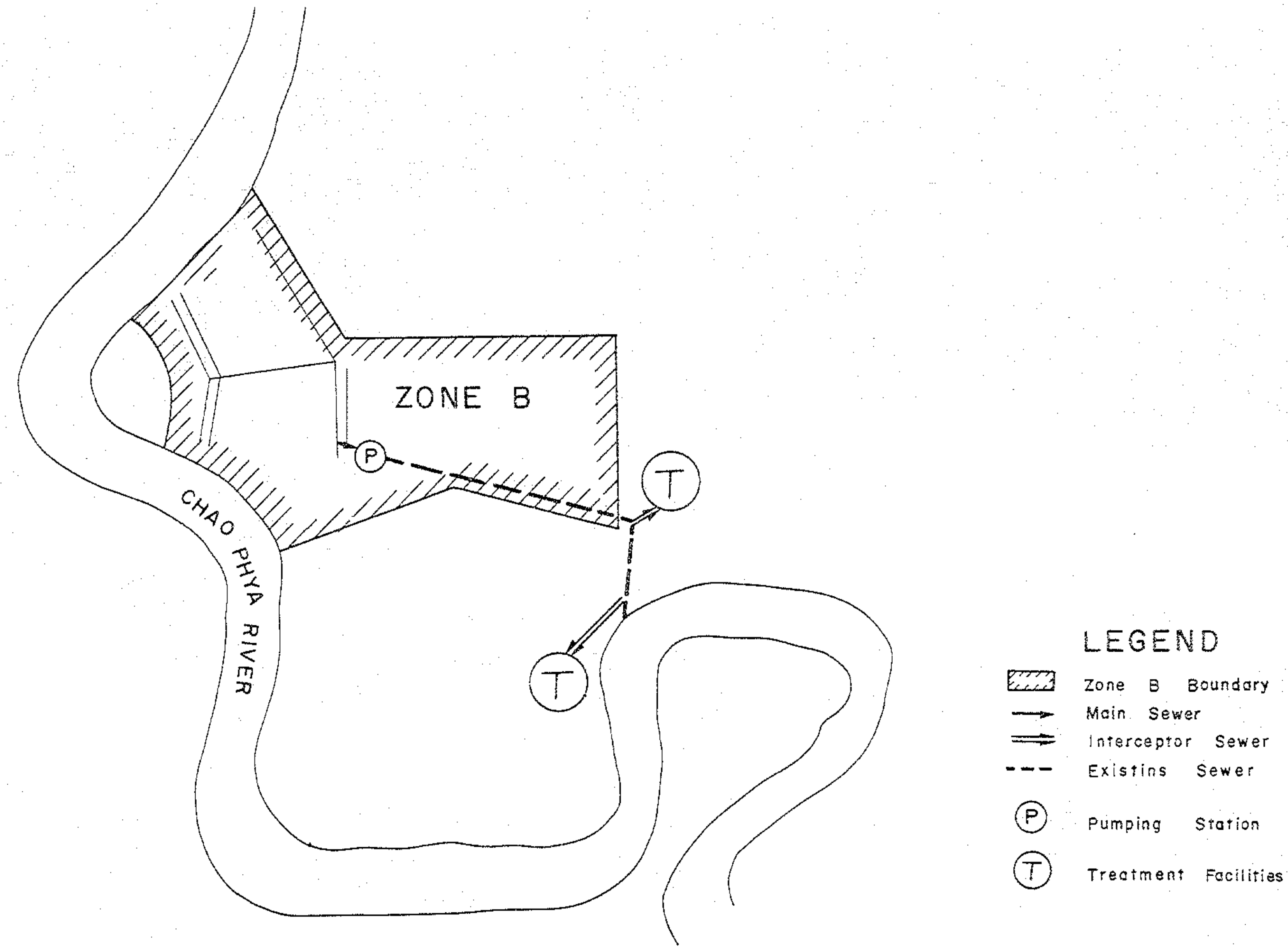


Figure A·7 Layout for Comparative Study

APPENDIX B

COMBINED WASTEWATER OVERFLOWS

APPENDIX B

COMBINED WASTEWATER OVERFLOWS

1. General

Because it may be necessary to use combined sewerage system in some of the areas which have existing drains, where adoption of such system is both economically and physically feasible, the effect of combined wastewater overflows on water courses of the Study Area was studied. Rainfall data for the past ten years were tabulated according to average accumulation and number of events. An analysis was then made by the method of C.K. Chen and W.W. Saxton[1/] for estimating sanitary wastewater to be discharged into the water courses. The overflow sanitary wastewater at different intercepting capacities, 1, 2, 3, 4, 5 and 6 times the dry weather flow (DWF) were estimated and compared with each other as to effects on receiving waters.

2. Analysis of Rainfall and Runoff

(a) Method and Analysis

In order to develop a relationship between the percentage runoff and rainfall for each rainstorm, the rainfall records for the last ten years were collected and tabulated by average rainfall accumulation and number of events as given in Table B.1. The relationship between rainfall and volume of runoff may be expressed by runoff coefficient or rate of discharge. The former may be used to estimate the peak runoff while the latter indicates the ratio of rainfall to discharge that is generally obtained from long-time observation. The relationship between rainfall on the impervious portions of areas and the corresponding total volume of runoff was studied for several cities in the United States by C.K. Chen and W.W. Saxton, as shown in Figure B.1. The regression line of runoff, R, versus rainfall, I, can be expressed as:

1/ C.K. Chen and W.W. Saxton, "Combined Waste-Water Overflows" Journal WPCF, Vol. 45, No. 3, March 1973, PP 434 - 448.

$$R = a\ (I - b) \quad (1)$$

This same method has been applied for this study, hence for a given rainfall pattern and percentage runoff, it is possible to develop a rational method for predicting the performance of a combined sewer overflow by means of a simple synthetic hydrograph.

An explanatory sketch of a synthetic hydrograph for a single combined overflow structure serving a given sanitary and storm drainage area is given in Figure B.2. The following equations have been established from the geometric configuration of the synthetic hydrograph:

$$t_0 = t \left[1 - \frac{Q_d}{Q_p} (n-1) \right] \quad (2)$$

and

$$V_0 = 0.5\ t_0 Q_p \left[1 - \frac{Q_d}{Q_p} (n-1) \right] \quad (3)$$

where
- Q_p = peak discharge of runoff, m^3/hr (equal to 2V/t)
- V = runoff, m^3
- t = runoff duration, min.
- Q_d = average dry weather flow, m^3/hr
- n = intercepting factor
- t_0 = overflow duration, hr, and
- V_0 = volume of overflow, m^3

(b) Application of the Method

For applying this method to analysis of the overflows from combind sewers in Bangkok, it would be desirable to conduct a flow measuring program to establish the rainfall-runoff relationship, as shown in Figure B.2. However, in the absence of local data, the percentage runoff was assumed at 80 percent with 0.75 mm for surface wetting. Then equation (1) may expressed in the form:

$$R = 0.80\ (I - 0.75) \qquad (4)$$

For application of this method the following input data were assumed:

1. Study area : 1,800 ha
2. Wastewater flow : 100 m^3/day/ha
3. Assumptions
   . Rain will fall uniformly over the area.
   . Wastewater discharge will be same throughout the year.
   . Total impervious area will be 70 percent of the entire study area.

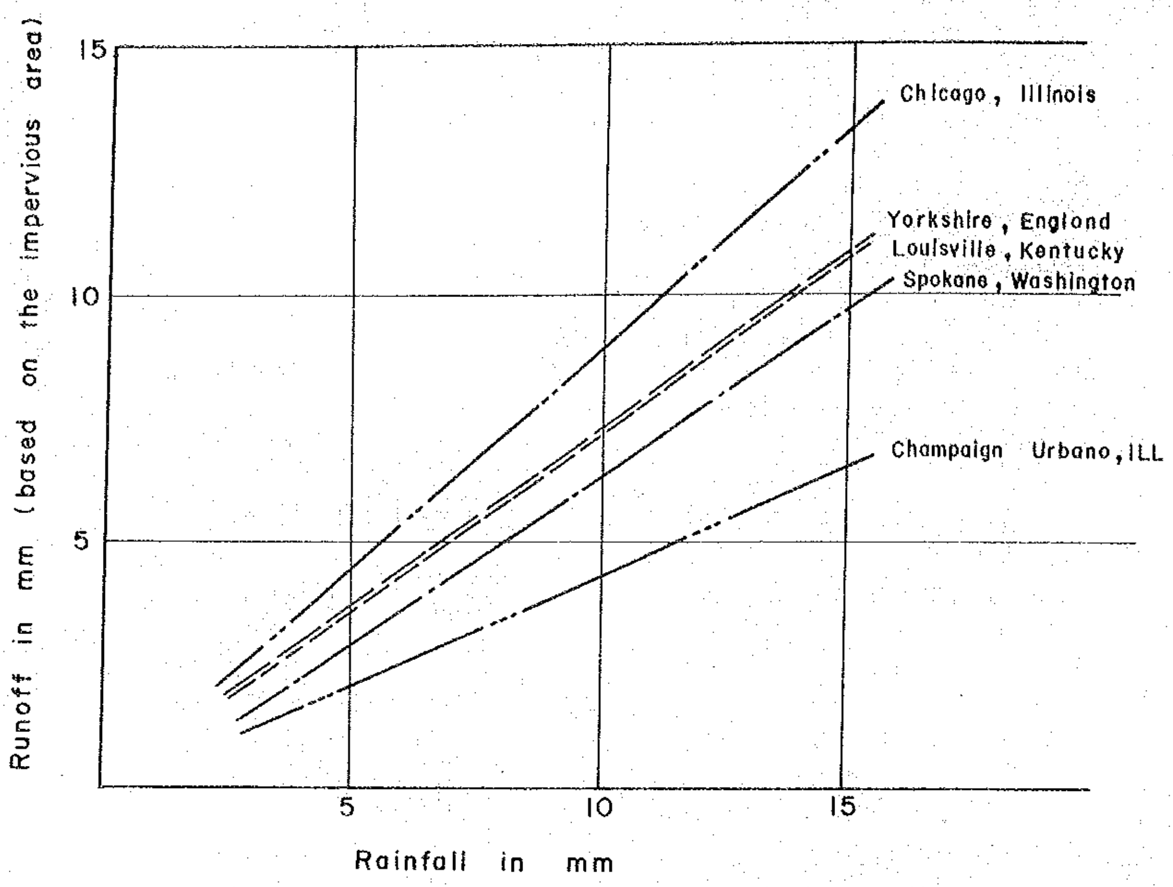


Figure B·1 Comparison of Rainfall-Runoff Relationship for Various Cities

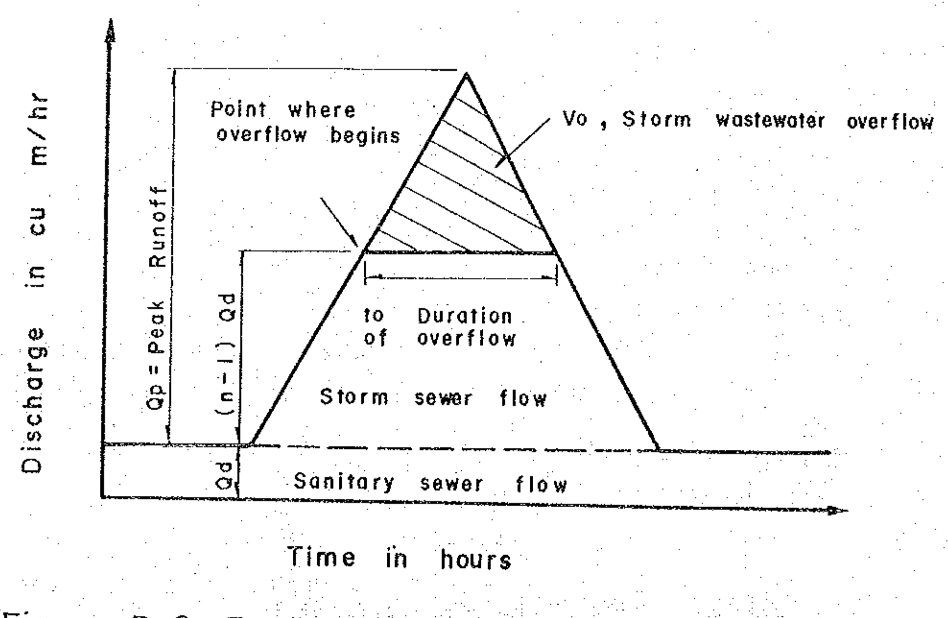


Figure B·2 Explanatory Sketch of Synthetic Hydrograph for Combined Sewer Flows

Table B.1 Analysis of Overflows with Intercepting Capacity Twice Dry Weather Flow

(n=2)

	(1) Average Rainfall (mm)	(2) Number of Event	(3) Average Rainfall/ Event (hr)	(4) Total Rainfall Duration (hr) (2)x(3)	(5) Total Rainfall (mm) (2)x(1)	(6) Surface Runoff/ Event (m^3) 5.6[(1)-0.75]	(7) Total Surface Runoff (m^3) (2)x(6)	(8) Sanitary Flow/ Event (m^3) 4.17x(3)	(9) Total Flow/ Event (m^3) (6)+(8)	(10) Waste-water in Flow (8)/(9)	(11) Qp, Peak Runoff/Event (m^3/hr) 2x(6)/(3)	(12) Qd/Qp 4.17/(11)	(13) $1-\frac{Qd}{Qp}(n-1)$ 1-(12) x(n-1)	(14) to, Duration of Over-flow/Event (3)x(13)(hr)	(15) Total Duration of Overflow/Event (hr) (2)x(14)	(16) Vo Volume of Overflow/ Event (m^3) 1/2(11)(13)(14)	(17) Total Volume of Overflow/Yr (m^3) (2)x(16)	(18) Sanitary Waste-water Lost/ Yr (10).(17)
0	0.35	41.2	1.35	55.8	14.4	0	0	5.6	5.6	1.000	0	-	-	0	0	0	0	0
1	1.35	26.4	2.00	52.8	35.6	3.4	89.8	8.3	11.7	0.709	3.40	1.226	0	0	0	0	0	0
2	2.45	10.8	2.54	27.4	26.5	9.5	102.6	10.6	20.1	0.527	7.48	0.557	0.443	1.13	12.20	1.9	20.5	10.8
3	3.45	8.3	2.54	21.1	28.6	15.1	125.3	10.6	25.7	0.412	11.89	0.351	0.649	1.65	13.7	6.4	53.1	21.9
4	4.45	7.4	2.49	18.4	32.9	20.7	153.2	10.4	31.1	0.334	16.63	0.251	0.749	1.87	13.84	11.6	85.8	28.7
5	5.45	6.3	3.05	19.2	34.3	26.3	165.7	12.7	39.0	0.326	17.25	0.242	0.758	2.31	14.55	15.1	95.1	31.0
6	6.45	3.7	3.19	11.8	23.9	31.9	118.0	13.3	45.2	0.294	20.00	0.209	0.791	2.52	9.32	19.9	73.6	21.6
7	7.45	4.0	2.53	10.1	29.8	37.5	150.0	10.6	48.1	0.220	29.64	0.141	0.859	2.17	8.68	27.6	110.4	24.3
8	8.45	3.6	3.56	12.8	30.4	43.1	155.2	14.8	57.9	0.256	24.21	0.172	0.828	2.95	10.62	29.6	106.6	27.3
9	9.45	2.8	3.71	10.4	26.5	48.7	136.4	15.5	64.2	0.241	26.25	0.159	0.841	3.12	8.74	34.4	96.3	23.2
10	10.95	5.5	3.60	19.8	60.2	57.1	314.1	15.0	72.1	0.208	31.72	0.131	0.869	3.13	17.22	43.1	237.1	49.3
11	12.95	4.6	3.80	17.5	59.6	68.3	314.2	15.8	84.1	0.188	35.95	0.116	0.884	3.36	15.46	53.4	245.6	46.2
12	14.95	4.0	3.63	14.5	59.8	79.5	318.0	15.1	94.6	0.160	43.80	0.095	0.905	3.29	13.16	65.2	260.8	41.7
13	16.95	2.7	4.04	10.9	45.8	90.7	244.9	16.8	107.5	0.156	44.90	0.093	0.907	3.66	9.88	74.5	201.2	31.4
14	18.95	1.7	3.88	6.6	32.2	101.9	173.2	16.2	118.1	0.137	52.53	0.079	0.921	3.57	6.07	86.4	146.9	20.1
15	20.95	1.7	3.35	5.7	35.6	113.1	192.3	14.0	127.1	0.110	67.52	0.062	0.938	3.14	5.34	99.4	169.0	18.6
16	22.95	2.4	4.04	9.7	55.1	124.3	298.3	16.8	141.1	0.119	61.53	0.068	0.932	3.77	9.05	108.1	259.4	30.9
17	24.95	1.8	4.11	7.4	44.9	135.5	243.9	17.1	152.6	0.112	65.94	0.063	0.937	3.85	6.93	118.9	214.0	24.0
18	26.95	1.3	4.85	6.3	35.0	146.7	190.7	20.2	166.9	0.121	60.49	0.069	0.931	4.52	5.86	127.3	165.5	20.0
19	28.95	1.8	3.78	6.8	52.1	157.9	284.2	15.8	173.7	0.091	83.55	0.050	0.950	3.59	6.46	142.5	256.5	23.3
20	32.45	3.1	4.00	12.4	100.6	177.5	550.3	16.7	194.2	0.086	88.75	0.047	0.953	3.81	11.81	161.1	499.4	42.9
21	37.45	2.1	3.43	7.2	78.7	205.5	431.6	14.3	219.8	0.065	119.83	0.035	0.965	3.31	6.95	191.4	401.9	26.1
22	42.45	1.3	5.23	6.8	55.2	233.5	303.6	21.8	255.3	0.085	89.29	0.047	0.953	4.98	6.47	211.9	275.5	23.4
23	47.45	1.5	4.87	7.3	71.2	261.5	392.3	20.3	281.8	0.072	107.39	0.039	0.961	4.68	7.02	241.5	362.3	26.1
24	54.95	1.4	4.64	6.5	76.9	303.5	424.9	19.3	322.8	0.060	130.82	0.032	0.968	4.49	6.29	284.3	398.0	23.9
25	64.95	0.9	4.22	3.8	58.5	359.5	323.6	17.6	377.1	0.047	170.38	0.024	0.976	4.12	3.71	342.6	308.3	14.5
26	74.95	0.4	8.25	3.3	30.0	415.5	166.2	34.4	449.9	0.076	100.73	0.041	0.959	7.91	3.16	382.1	152.8	11.6
27	84.95	0.6	4.33	2.6	51.0	471.5	282.9	18.1	489.6	0.037	217.78	0.019	0.981	4.25	2.55	454.0	272.4	10.1
28	94.95	0.1	2.00	0.2	9.5	527.5	52.8	8.3	535.8	0.015	527.50	0.008	0.992	1.98	0.20	518.0	51.8	0.8
29	109.95	0.1	5.00	0.5	11.0	611.5	61.2	20.9	632.4	0.033	244.60	0.017	0.983	4.92	0.49	591.5	59.2	2.0
30	159.95	0.2	24.00	4.8	34.0	947.5	189.5	100.1	1,047.6	0.096	78.96	0.053	0.947	22.73	4.55	849.8	170.0	16.3
Total																	5,749.0	692.0

Note: Average D.W.F. = 100 m^3/day   Served Area = 1 ha

(c) Results of Computations

The results of computations are summarized in Tables B.2 and B.3 and Figures B.3 and B.4, from which the following observations are made:

i. The ratio of wastewater lost will decrease according to the increment of intercepting capacity.

ii. With an intercepting capacity 1 x D.W.F., about 2.7 percent of sanitary wastewater and with a capacity 6 x D.W.F. about 0.7 percent of sanitary wastewater will be lost through combined overflows. The difference in the percentage of sanitary wastewater lost between 1 x D.W.F. and 6 x D.W.F. is only 2.0 percent.

iii. It is not possible to eliminate all or even most of the wastewater overflow even if an interceptor capacity much greater than 6 x D.W.F. is provided.

(d) Proposed Interceptor Capacity

The percentage of sanitary wastewater volume to storm runoff is quite low because of the high rainfall intensity in the area, thus, sanitary wastewater is generally diluted at a high rate. Under this condition, there would be little advantage to increasing the interceptor capacity to reduce the extent of sanitary wastewater overflow.

It is therefore recommended that the intercepting capacity for combined sewers in most cases be one times the peak dry-weather wastewater flow rate.

Table B.2 Relationship of Sanitary Wastewater Loss to Intercepting Capacity

Intercepting Capacity (times average D.W.F.)	(A) Sanitary Wastewater Lost (1,000 m^3/Year)	(B) Sanitary Wastewater Lost Ratio (percent of total D.W.F.)	(C) Reduction of Overflow Wastewater (percent)	Remarks
1	1,798.7	2.7	0	
2	1,245.6	1.9	30.8	D.W.F. = 100 m^3/ha
3	941.4	1.4	47.7	
4	729.9	1.1	59.4	Area = 1,800 ha
5	575.3	0.9	68.0	
6	465.5	0.7	74.1	

$$(C) = 1 - \frac{(A)}{1,798.7}$$

Table B.3 Relationship of Volume of Overflows to Intercepting Capacity

Intercepting Capacity (times average D.W.F.)	(D) Volume of Overflows ($1,000\ m^3$/Year)	(E) Reduction of Overflow Volume (percent)	Remarks
1	12,508.0	0	
2	10,348.2	17.3	
3	8,737.9	30.1	
4	7,436.5	40.5	
5	6,358.3	49.2	
6	5,492.9	56.1	

$$(E) = 1 - \frac{(D)}{12,508.0}$$

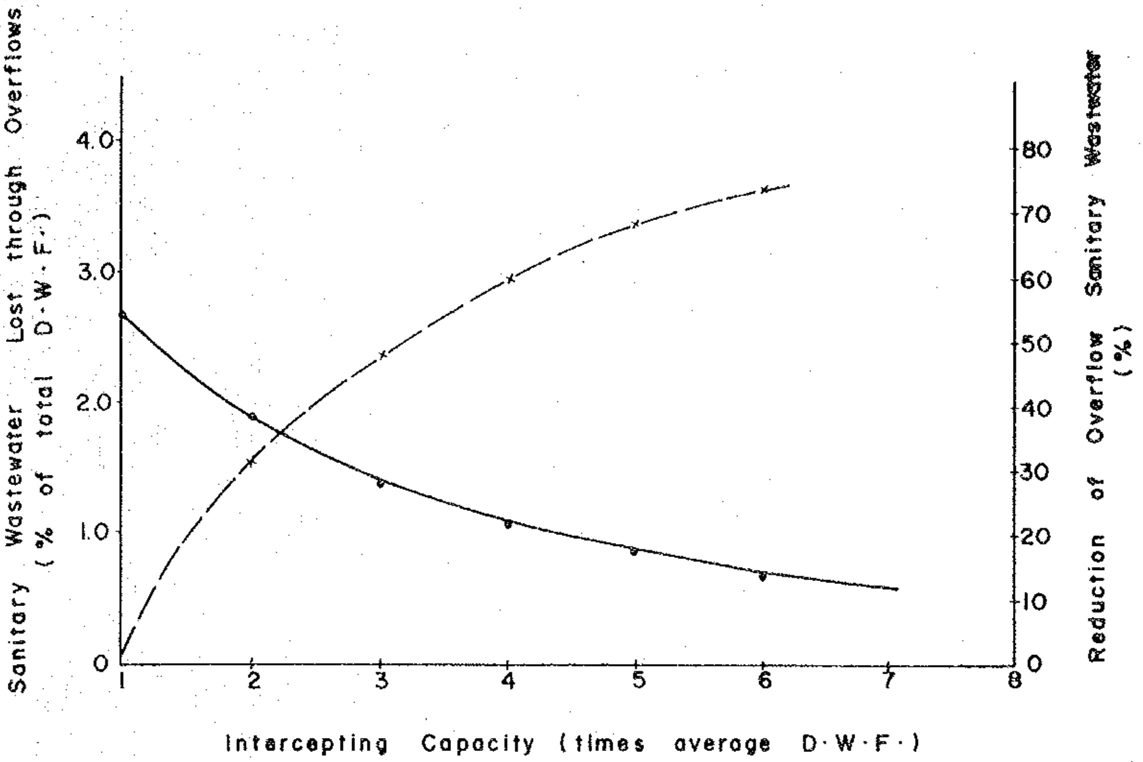


Figure B·3 Relationship of Sanitary Wastewater Loss to Intercepting Capacity

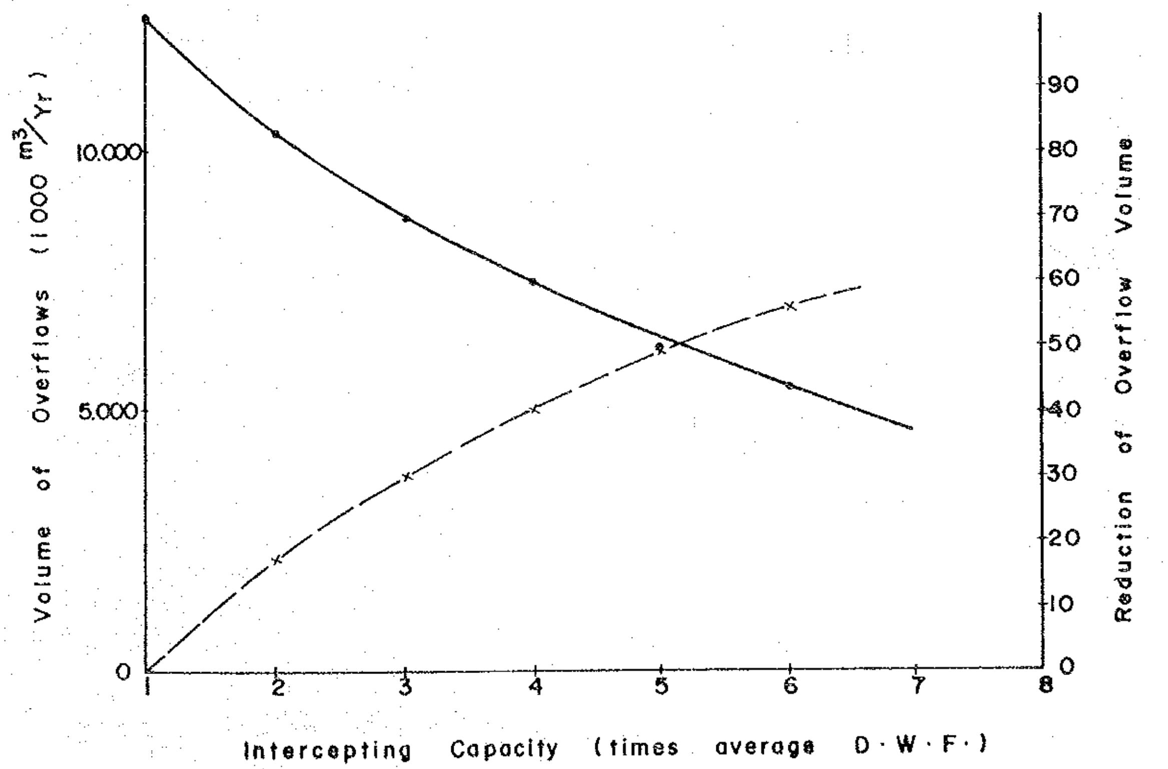


Figure B·4 Relationship of Volume of Overflows to Intercepting Capacity

APPENDIX C

COMPARATIVE STUDY ON COMBINED VS. SEPARATE SEWERAGE SYSTEM

APPENDIX C

COMPARATIVE STUDY ON COMBINED VS. SEPARATE SEWERAGE SYSTEM

(1) Model Study

There may be some difference between construction cost of combined sewerage system and that of separate sewerage system. In this section, taking the existing conditions such as distribution of klongs and location of the river into account, as typical urbanized area in the central area, a model layout illustrated in Figure C.1 was prepared.

Using this model cost comparison for following 4 alternatives were conducted.

Alternative 1

Separate system. There are existing public drains, and all of them are fully applied as separate storm sewers.

Alternative 2

Separate system. There is no existing public drain.

Alternative 3

Combined system. There are existing public drains, and all of them are fully applied as combined sewers.

Alternative 4

Combined system. There is no existing public sewer.

Alternatives mentioned above were selected on condition that all klongs are useful as the main drains.

Construction costs were calculated on the following conditions.

1. Average per capita wastewater flow is 300 l/day.
2. Population density is 250 persons/ha.
3. Length of lateral sewer is 200 m/ha.
4. Intercepting capacity of combined system is 1 or 3 times to peak flow.
5. As approximately the same size and type of wastewater treatment will be required, for either the flow from a separate system or for the dry-weather flow from a combined system, the basis wastewater treatment facilities are not considered in the comparative cost studies.

Result of cost comparision (refer to Tables C.1 and C.2)

The cost estimates indicate that the combined system would be more expensive than the separate system. (compare Alt. 2 & 4) However, the most costless case is that, existing public drains are useful as combined sewers and construction required is interceptor only (Alt. 3). This alternative is followed by Alternative 1 which has the existing public sewer converted to storm sewers and construction of sewerage facilities are required.

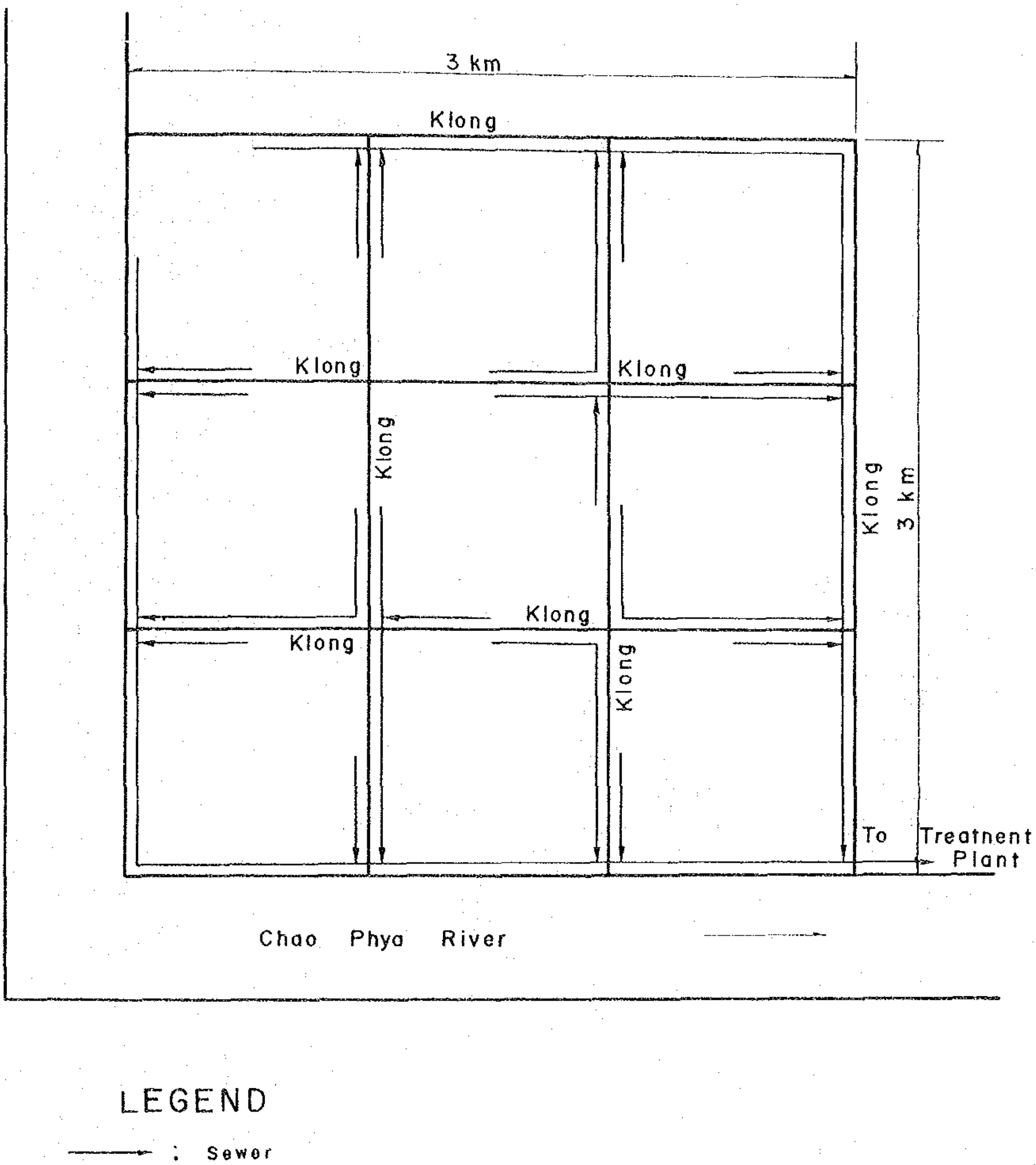


Figure C-1 Study Model Layout

Table C.1 Construction Cost

(1,000 baht)

Alternative	Separate Sewerage System				Combined Sewerage System			Total
	Wastewater Pipe	Wastewater Pumping Station	Stormwater Pipe	Storm-water Pumping Station	Sewer	Interceptor	Pumping Station	
1	270,300	32,511	-	-	-	-	-	302,811
2	270,300	32,511	1,392,552	-	-	-	-	1,695,363
3	-	-	-	-	-	154,680 (373,000)	36,348 (70,162)	191,028 (443,162)
4	-	-	-	-	1,547,280 (1,547,280)	154,680 (373,000)	36,348 (70,162)	1,738,308 (1,990,442)

Note: Figures in ( ) are in case of intercepting capacity of 3 times to peak flow.

Table C.2 Cost (Capital) Comparison of
4 Alternatives

Alternative	Description	(Million Baht)
1.	Separate system. Drainage System is completed.	Wastewater pipes 270; Pumping stations 33
2.	Separate system. No existing sewer.	Wastewater pipes 270; Pumping stations 33; Storm-water pipes 1,393
3.	Combined system. Drains are completed.	Interceptors 155; Pumping stations 36
4.	Combined system. No existing sewer.	Interceptors 155; Pumping stations 36; Combined sewers 1,547

(2) Comparative Study by CDM

This section is quoted from the Master Plan prepared by CDM.

There are several general types of urban development in Bangkok and Thonburi. Typical areas were selected, each representative of varying types of development. Alternate schemes for combined and for separate wastewater sewerage and storm-water systems were then studied for each typical area. The location of these typical areas is indicated on Figure C.2 and described as follows:

1. Construction Area - area bounded by the Chao Phya River and Klong Padung Krung Kasem
2. Sathorn Triangle Area - area southwest of Rama IV Road and north of Sathorn Road
3. Rathum Wan Area - area bounded by Rama IV Road, Ploenchit Road, Klong Padung Krung Kasem and the Railroad to the Port
4. Bonkai Urban Redevelopment Project - area covering 137 rai (53 acres) fronting on Rama IV Road, between the Railroad and Soi Plukjit
5. Bang Kapi Area - area bounded by the Railroad, Soi 71 and by a line slightly north of Sukhumvit Road
6. Thonburi Area - central Thonburi, consisting of a portion of Amphurs Klong Sarn and Thonburi

The detailed studies of separate and combined systems, in the six typical areas listed above, used the estimated total capital cost of each type of system for the purpose of comparison. These cost comparisons indicated only one area (Area No. 2) in which the combined system was less expensive than the separate system.

The estimated total capital cost of each type of system, for each of the six typical areas, is summarized in Table C.3.

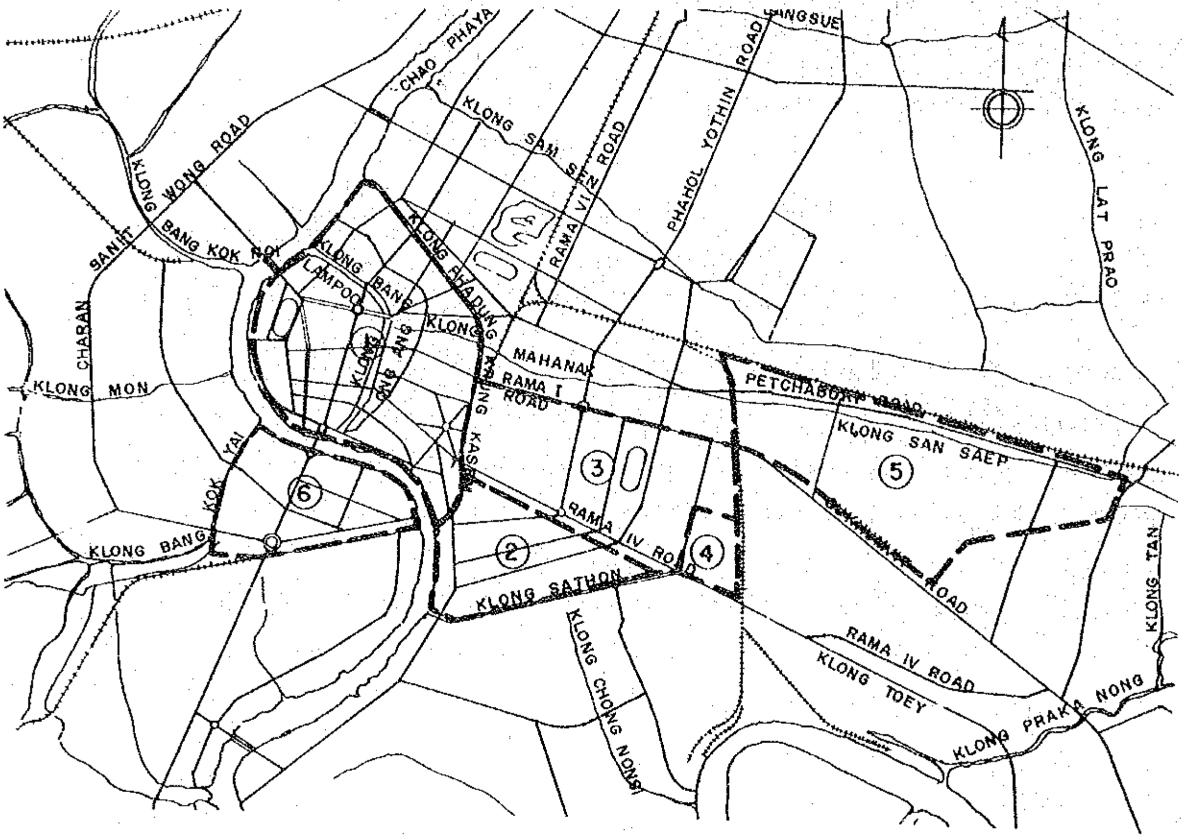
Table C.3 Summary of Cost Comparison of Combined System vs. Separate System

Area	Estimated Capital Cost, Baht		Combined System Cost As a Percentage of Separate System Costs
	Separate System	Combined System	
1. Construction	464,000,000	532,500,000	115%
2. Sathorn Triangle	229,500,000	184,900,000	81
3. Pathum Wan	306,500,000	498,000,000	163
4. Bonkai	4,500,000	9,400,000	210
5. Bang Kapi	242,800,000	312,000,000	129
6. Thonburi	126,600,000	168,300,000	132
Total	1,373,900,000	1,705,100,000	124%

The total estimated capital cost of the combined systems is about 24 percent greater than the cost of the separate systems. This represents a cost differential of approximately 330 million baht. The total land area of the study areas is about 33 square kilometers which represents nine percent of the Master Plan Area. The reason for the economic advantage in favor of separate systems in the comparative study comes about as a result of using the existing klongs for major drainage conduits as a part of the separate drainage system. With the combined system this is not possible and large enclosed conduits would have to be constructed.

AREA DESIGNATIONS

① CONSTRUCTION AREA
② SATHORN TRIANGLE AREA
③ PATHUM WAN AREA
④ BONKAI URBAN REDEVELOPMENT PROJECT
⑤ BANG KAPI AREA
⑥ THONBURI AREA



LEGEND

— — — TYPICAL AREA BOUNDARY
① STUDY AREA

Figure C·2 Typical Study Areas for Combined Systems

APPENDIX D

SITE REQUIREMENT FOR SEWERAGE FACILITIES

APPENDIX D

SITE REQUIREMENT FOR SEWERAGE FACILITIES

1. Site Area for Pumping Station

In developing equation for land area required for pumping station, six stations with different capacities (peak flow) of 0.1 m^3/sec, 0.4 m^3/sec and 0.8 m^3/sec for smaller pumping stations, and 1 m^3/sec, 2 m^3/sec and 4 m^3/sec for larger pumping stations were designed, and following results were obtained.

Site Area Required for Pumping Stations

Peak Flow (m^3/sec)	0.1	0.4	0.8	1.0	2.0	4.0
Area (m^2)	220	295	530	900	1,089	1,369

The relationship between peak flow and site area is illustrated in Figure D.1. The equation can be expressed as follows:

$$Sp = 511.7 \times Q_p^{0.394} \qquad Q_p < 1.0$$

$$Sp = 889.2 \times Q_p^{0.301} \qquad 1.0 \leqq Q_p$$

Where Sp : Site area, m^2

Q_p : Peak flow, m^3/sec

2. Site Area for Treatment Facilities

On the basis of wastewater treatment facility layout plan of three different capacities of 50,000 m^3/day, 100,000 m^3/day, and 500,000 m^3/day for five different treatment processes, site area required is obtained as shown in Table D.1 and Figure 11.7 of Volume II.

Table D.1 Site Area Required for Treatment Processes

(ha)

Treatment Process	Flow Rate (m^3/day)		
	50,000	100,000	500,000
Stabilization Pond	60.72	114.54	545.10
Aerated Lagoon	26.04	47.74	226.92
Oxidation Ditch	9.45	16.20	59.40
Conventional Activated Sludge	5.58	8.68	32.86
Modified Aeration	4.59	7.14	26.08

From this table, equations are developed as follows:

(a) Stabilization pond process

$$S = 0.00193\ Q^{0.956}$$

(b) Aerated lagoon

$$S = 0.00092\ Q^{0.945}$$

(c) Oxidation ditch

$$S = 0.00163\ Q^{0.800}$$

(d) Conventional activated sludge

$$S = 0.00116\ Q^{0.780}$$

(e) Modified aeration

$$S = 0.00115\ Q^{0.763}$$

where S : Site area required, ha

Q : Daily average flow, m^3/day

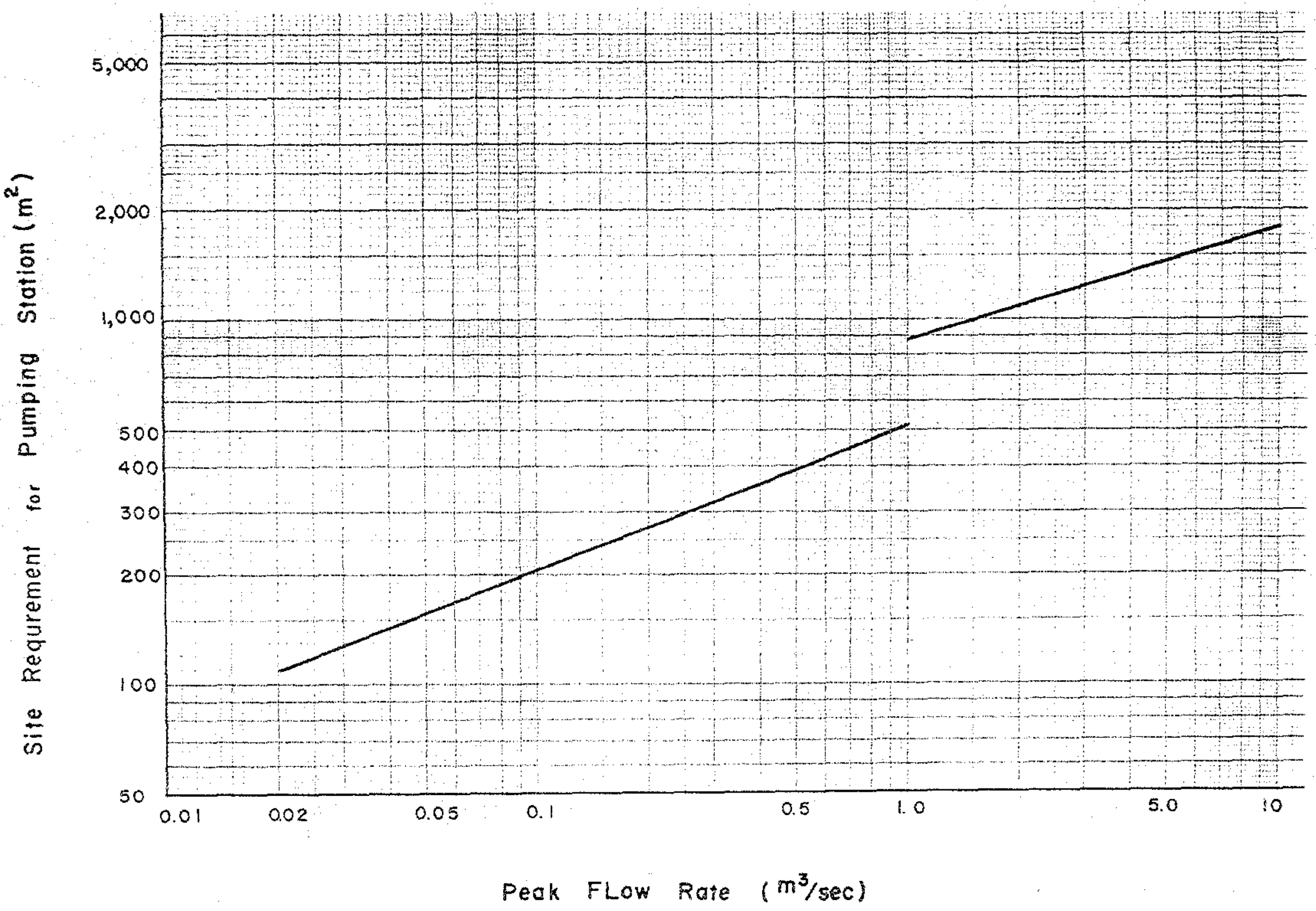


Figure D-1 Site Requirement for Pumping Stations

APPENDIX E

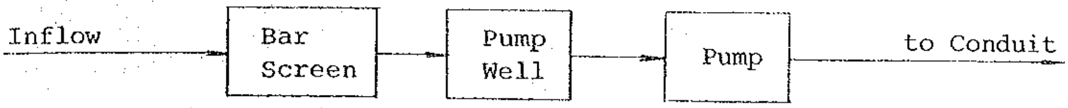
COST FUNCTION

APPENDIX E

COST FUNCTION

1. Cost Function for Pumping Stations

In developing cost function for pumping stations, cost estimates were made for six cases of different capacity, namely, 0.1 m^3/sec, 0.4 m^3/sec, 0.8 m^3/sec, 1.0 m^3/sec, 2.0 m^3/sec and 4.0 m^3/sec and additional three different cases of inflowing depths of conduits, namely, 6 m, 8 m and 10 m. Flow sheet for the station is as follows:



Cost estimates for civil and building works are based on preliminary drawings as shown in figures, Chapter 9 of Volume II. Cost Estimates for mechanical and electrical equipment installation are based on quotations obtained from various manufacturers in Japan, including allowance for freight, transportation and installation. Construction cost for each case includes civil and building works, pipings, mechanical and electrical equipment and other appurtenances and summarized in Tables E.1 and E.2.

As illustrated in Figure 14.3, Chapter 14 of Volume II, the cost can be expressed in an exponential function such as;

$$Cp = aQ^b$$

where Cp : Construction cost, 1,000 baht

Q : Peak flow rate, m^3/sec

a,b : Constant

The constant "a" and "b" are obtained by the least square method for three different depths, and these cost functions can be expressed as follows:

$$Cp = 10{,}467\ Q^{0.6367} \quad (D = 6\ m,\ Q < 1.0)$$
$$Cp = 12{,}296\ Q^{0.6122} \quad (D = 8\ m,\ Q < 1.0)$$
$$Cp = 13{,}827\ Q^{0.5697} \quad (D = 10\ m,\ Q < 1.0)$$
$$Cp = 15{,}039\ Q^{0.6388} \quad (D = 6\ m,\ Q \geqq 1.0)$$
$$Cp = 15{,}487\ Q^{0.6498} \quad (D = 8\ m,\ Q \geqq 1.0)$$
$$Cp = 16{,}020\ Q^{0.6587} \quad (D = 10\ m,\ Q \geqq 1.0)$$

where D : Earth covering of inflow sewer.

Table E.1 Construction Costs of Small Pumping Station with Varying Pump Capacity at the End of 2523 (1980) Price Level

(1) 6 m depth

1,000 Baht

Capacity (m^3/sec)	Civil & Building Works	Mechanical & Electrical Works	Total
0.1	1,761	677	2,438
0.4	2,644	3,041	5,685
0.8	4,553	4,693	9,246

(2) 8 m depth

1,000 Baht

Capacity (m^3/sec)	Civil & Building Works	Mechanical & Electrical Works	Total
0.1	2,286	738	3,024
0.4	3,440	3,433	6,873
0.8	5,839	5,036	10,875

(3) 10 m depth

1,000 Baht

Capacity (m^3/sec)	Civil & Building Works	Mechanical & Electrical Works	Total
0.1	2,896	880	3,776
0.4	4,253	3,619	7,872
0.8	7,210	5,307	12,517

Table E.2 Construction Costs of Circular Pumping Stations with Varying Pump Capacity at the End of 2523 (1980) Price Level

(1) 6 m depth

1,000 Baht

Capacity (m^3/sec)	Civil & Building Works	Mechanical & Electrical Works	Total
1.0	4,530	10,304	14,834
2.0	7,664	16,405	24,069
4.0	12,316	23,645	35,961

(2) 8 m depth

1,000 Baht

Capacity (m^3/sec)	Civil & Building Works	Mechanical & Electrical Works	Total
1.0	4,923	10,328	15,251
2.0	8,241	16,816	25,057
4.0	13,030	24,513	37,543

(3) 10 m depth

1,000 Baht

Capacity (m^3/sec)	Civil & Building Works	Mechanical & Electrical Works	Total
1.0	5,326	10,425	15,751
2.0	8,831	17,329	26,160
4.0	13,773	25,481	39,254

2. Cost Functions for Treatment Facilities

A relation is found between varying treatment capacities and construction costs in a form of function for five conceivable treatment processes in the Study Area, namely, stabilization pond, aerated lagoon, oxidation ditch, conventional activated sludge, and modified aeration. The costs were estimated by designing the facilities for these treatment processes with treatment capacity of 50,000 m^3/day, 100,000 m^3/day and 500,000 m^3/day.

2.1 Stabilization Pond Process

Using the design criteria set out in Chapter 11 of Volume II the sizes of treatment facilities and schematic layout were prepared together with estimates of quantities as follows:

- (i) Stabilization ponds have 1.5 m liquid depth with one to one side slope and stone-pitched;
- (ii) For ease of operation, maintenance, and control the maximum surface area of ponds are limited to about 4 ha with a length to breadth ratio of about 1 to 1.5 or 2;
- (iii) Pond is lined with 0.3 m layer of impervious clay material;
- (iv) Top of embankment is 4 m width to permit access of maintenance vehicles;
- (v) Pond area is enclosed with a suitable fence to preclude livestock and to discourage trespassing;
- (vi) Treatment facility site is surrounded by not less than 10 m wide trip of land.

A typical layout plan of stabilization pond is shown in Figure 11.2 Chapter 11 of Volume II. The construction costs of civil works were estimated on the basis of material costs and unit cost for construction at the end of 2523 (1980) price level. Table E.3 shows estimated construction costs.

Table E.3 Construction Costs for Stabilization Pond Process with Varying Treatment Capacity at the End of 2523 (1980) Price Level

(1,000 Baht)

Item	Daily Flow (m^3/day)		
	50,000	100,000	500,000
Civil & Building Works			
Embankments	26,788	36,811	112,664
Inlet & Outlet	2,679	3,681	11,266
Selected Soil Filling	15,190	30,803	153,093
Turfing	468	540	1,277
Fencing	1,910	2,198	5,146
Sedimentation Cell	449	770	2,777
Office & Store	1,260	1,980	3,960
Total	48,744	76,783	290,183

The cost for stabilization pond process can be expressed in an exponential function as follows:

$Cs = aQ^b$

where Cs : Construction cost; 1,000 baht

Q : Daily flow, m^3/day

a,b : Constant

The figures of "a" and "b" are obtained by the least square method as 9.751 and 0.784 respectively. Hence, the cost function can be expressed as:

$Cs = 9.751\ Q^{0.784}$

2.2 Aerated Lagoon Process

Based on the design criteria in Chapter 11 of Volume II and reasonable design conditions as described hereafter, schematic layout was worked out for estimating construction costs.

(i) Liquid depth of aerated lagoon is 3 m with one to one side slope, and the wall has 0.3 m stone pitched thickness to protect it from scouring by surface aerators;

(ii) For ease of operation, maintenance, and control, the maximum surface area of ponds is limited to about 4 ha with a length to breadth ratio of about 1 to 1.5 or 2;

(iii) Pond is lined with 0.3 m layer of impervious clay material;

(iv) Top of embankment is 4 m width to permit access of maintenance vehicles;

(v) Pond area is enclosed with a suitable fence to preclude livestock and to discourage trespassing;

(vi) Treatment facility site is surrounded by not less than 10 m wide strip of land;

A typical layout plan of aerated lagoon is given in Figure 11.3 Chapter 11 of Volume II. Table E.4 shows estimated construction costs. The construction costs of civil works include for ponds, sedimentation cell, inlet and outlet works, fencing, turfing, and embankments. The costs for mechanical and electrical works include installation costs of aerator and control panels, and allowances; freight and transportation.

Table E.4 Construction Costs for Aerated Lagoon Process with Varying Treatment Capacity at the End of 2523 (1980) Price Level

(1,000 Baht)

Item	Daily Flow (m^3/day)		
	50,000	100,000	500,000
Civil & Building Works			
Embankments	20,060	27,974	87,288
Inlet & Outlet	2,006	2,797	8,729
Excavation	2,190	4,277	21,578
Selecting Soil Filling	8,350	16,626	83,248
Turfing	312	406	1,258
Fencing	1,248	1,661	3,245
Sedimentation Cell	449	770	2,777
Office & Store	1,800	2,880	5,400
Sub-total	36,415	57,391	213,523
Mechanical & Electrical Works			
Aerators	10,816	14,847	66,818
Control Panel	5,884	9,133	25,381
Motors	360	721	3,244
Sub-total	17,060	24,701	95,443
Total	53,475	82,092	308,966

The cost for aerated lagoon process can be expressed in an exponential function as follows:

$$C_A = 11.980\ Q^{0.773}$$

where C_A : Construction cost, 1,000 baht

Q : Daily flow, m^3/day

2.3 Oxidation Ditch Process

Using the design criteria in Chapter 11 of Volume II reasonable design conditions as described hereunder, schematic layout was prepared together with estimates of quantities.

(i) Liquid depth of Oxidation ditch is 1.5 m with 1 to 1 side slope, and the wall has 0.3 m stone pitched thickness to protect it from scouring by mechanical brush aerators;

(ii) For ease operation, maintenance and control, the maximum width of ditch is limited to 7 m;

(iii) Ditch is lined with 0.3 m layer of impervious clay material;

(iv) Top of embankment is 3 m width;

(v) Shape of sedimentation basin is circular type and its maximum diameter is 20 m;

(vi) Ditch area is enclosed with a suitable fence to preclude livestock and to discourage trespassing;

(vii) Treatment facility site is surrounded by not less than 10 m wide strip of land.

The estimated costs are shown in Table E.5.

Table E.5 Construction Costs for Oxidation Ditch Process with Varying Treatment Capacity at the End of 2523(1980) Price Level

(1,000 Baht)

Item	Daily Flow (m^3/day)		
	50,000	100,000	500,000
Civil & Building Works			
Embankments	8,879	17,759	75,120
Selected Soil Filling	210	419	2,096
Excavation	163	329	1,633
Sedimentation Tanks	14,884	29,768	148,841
Chlorination Tank	625	625	625
Drying Bed	3,229	6,459	32,294
Sedimentation Cell	449	770	2,777
Fencing	720	1,142	2,016
Turfing	389	745	2,374
Office & Store	1,800	2,880	5,400
Sub-total	31,348	60,896	273,176
Mechanical & Electrical Works			
Rotors	25,920	46,656	207,360
Clarifiers	28,800	51,840	230,400
Pumps	960	1,728	7,680
Electric Equipment	2,400	4,320	19,200
Pipes	840	1,512	6,720
Sub-total	58,920	106,056	471,360
Total	90,268	166,952	744,536

The cost for oxidation ditch process can be expressed in an exponential function as follows:

$$Co = 4.318\ Q^{0.919}$$

where Co : Construction cost, 1,000 baht

Q : Daily flow, m^3/day

2.4 Conventional Activated Sludge Process

Based on the design criteria and reasonable design conditions, schematic layout was worked out for estimating construction costs.

Table E.6 Construction Costs for Conventional Activated Sludge Process with Varying Treatment Capacity at the End of 2523 (1980) Price Level

(1,000 Baht)

Item	Daily Flow (m^3/day)		
	50,000	100,000	500,000
Civil & Building Works			
Primary Sedimentation Tanks	10,328	18,900	77,625
Aeration Tanks	27,346	51,192	220,320
Final Sedimentation Tanks	12,442	22,680	90,720
Chlorination Tanks	2,268	3,645	10,530
Thickening Tanks	2,387	4,142	14,742
Digestion Tanks	14,251	29,344	120,042
Drying Beds	1,281	2,561	12,807
Operating Building	1,800	3,600	4,500
Compressor Building	8,100	12,150	31,590
Landscape and Other	12,772	22,864	33,505
Sub-total	92,975	171,078	616,381
Mechanical & Electrical Works			
Primary Sedimentation Tanks	25,619	45,348	171,573
Aeration Tanks	14,479	17,136	80,631
Final Sedimentation Tanks	26,850	48,620	192,814
Chlorination Tanks	5,722	7,630	15,371
Thickening Tanks	4,264	6,732	18,850
Digestion Tanks	17,675	23,178	58,373
Compressor Building	19,775	29,284	74,052
Electric Equipment	28,475	56,100	117,810
Sub-total	142,859	234,028	729,474
Total	235,834	405,106	1,345,855

The cost for conventional activated sludge process can be expressed in an exponential function as follows:

$$Cc = 67.634\ Q^{0.755}$$

where Cc : Construction cost, 1,000 baht

Q : Daily flow, m^3/day

2.5 Modified Aeration Process

Based on the design criteria and reasonable design conditions, schematic layout was worked out for estimating construction costs which are shown in Table E.7.

Table E.7 Construction Costs for Modified Aeration Process with Varying Treatment Capacity at the End of 2523 (1980) Price Level

(1,000 Baht)

Item	Daily Flow (m^3/day)		
	50,000	100,000	500,000
Civil & Building Works			
Primary Sedimentation Tanks	10,328	18,900	77,625
Aeration Tanks	9,115	17,064	73,440
Final Sedimentation	12,442	22,680	90,720
Chlorination Tanks	2,268	3,645	10,530
Digestion Tanks	14,251	29,344	120,042
Drying Beds	1,281	2,561	12,807
Operating Building	1,800	3,600	4,500
Compressor Building	4,050	6,075	15,792
Landscape and Other	870	1,589	5,321
Sub-total	56,405	105,458	410,777
Mechanical & Electrical Works			
Primary Sedimentation Tanks	25,619	45,348	171,573
Aeration Tanks	4,826	5,712	26,877
Final Sedimentation Tanks	26,850	48,620	192,814
Chlorination Tanks	5,722	7,630	15,371
Digestion Tanks	17,675	23,178	58,373
Compressor Building	6,592	9,795	24,684
Electric Equipment	20,196	56,100	117,810
Sub-total	107,480	196,383	607,502
Total	163,885	301,841	1,018,279

The cost for modified aeration process can be expressed in an exponential function as follows:

$$C_M = 33.861\ Q^{0.787}$$

where C_M : Construction cost, 1,000 baht

Q : Daily flow, m^3/day

3. Function of Operation and Maintenance Cost

3.1 Pumping Stations

In developing the cost function, followings are assumed in advance;

(i) Daily average number of operator is one person per station,

(ii) Electricity is assumed at 1.5 baht/kWh, and annual salary of operator is assumed at 40,000 baht and

(iii) Cost of repairs and replacement of parts are estimated at one percent of capital cost of civil works and two percent of mechanical and electrical works.

The operation and maintenance costs by capacity were estimated as shown in Table E.8.

Table E.8 Annual Operation and Maintenance Costs for Pumping Stations by Capacity

(1,000 Baht)

Peak Flow (m^3/sec) / Item	0.1	0.4	0.8	1	2	4
. Salary	20	20	20	20	20	20
. Electricity	44 (1)	207 (2)	720 (3)	710 (4)	2,168 (5)	4,599 (6)
. Repairs & Replacement of parts	38 (7)	103 (8)	159 (9)	256 (10)	419 (11)	621 (12)
Total	102	330	899	986	2,607	5,240

Note: (1) $(0.1m^3/s \div \overset{*}{4.5} x86,400s/day) \div (3m^3/min x60min/h) x365day/yr x7.5kW$ $x1.5baht/kWh$ = 43,800 baht/yr

(2) $(0.4m^3/s \div \overset{*}{3.0} x86,400s/day) \div (8m^3/min x60min/h) x365day/yr x21kW$ $x1.5baht/kWh$ = 206,956 baht/yr

(3) $(0.8m^3/s \div \overset{*}{2.7} x86,400s/day) \div (12m^3/min x60min/h) x365day/yr x37kW$ $x1.5baht/kWh$ = 720,267 baht/yr

(4) $(1.0m^3/s \div \overset{*}{2.5} x86,400s/day) \div (20m^3/min x60min/h) x365day/yr x45kW$ $x1.5baht/kWh$ = 709,560 baht/yr

(5) $(2.0m^2/s \div \overset{*}{2.0} x86,400s/day) \div (40m^3/min x60min/h) x365day/yr x110kW$ $x1.5baht/kWh$ = 2,168,100 baht/yr

(6) $(4.0m^3/s \div \overset{*}{1.8} x86,400s/day) \div (80m^3/min x60min/h) x365day/yr x210kW$ $x1.5baht/kWh$ = 4,599,000 baht/yr

where: * is ratio of peak flow to average daily flow.

(7) 2,286,000 x 0.01 + 738,000 x 0.02 = 37,620 baht

(8) 3,440,000 x 0.01 + 3,433,000 x 0.02 = 103,060 baht

(9) 5,839,000 x 0.01 + 5,036,000 x 0.02 = 159,110 baht

(10) 4,923,000 x 0.01 +10,328,000 x 0.02 =255,790 baht

(11) 8,241,000 x 0.01 +16,816,000 x 0.02 =418,730 baht

(12) 13,030,000 x 0.01 + 24,513,000 x 0.02 =620,560 baht

The cost can be expressed in an exponential function such as:

$$C_{MP} = 1,002.096\ Q^{1.018}$$

where C_{MP} : Annual operation and maintenance cost, 1,000 baht

Q : Peak flow rate, m^3/sec, $Q < 1.0$

$$C_{MP} = 1,032.102\ Q^{1.205}$$

where $Q \geq 1.0$

3.2 Treatment Facilities

Cost functions for five different treatment processes were developed based on the some assumptions which are described in Chapter 11 of Volume II. Table E.9 shows annual operation and maintenance costs for each treatment process.

Table E.9 Annual Operation and Maintenance Cost for Treatment Facilities at the End of 2523 (1980) Price Level

(1,000 Baht)

Treatment Process	Daily Flow (m^3/day)		
	50,000	100,000	500,000
(i) Stabilization Pond			
. Salary	120	200	400
. Repair & Replacement of Parts	487 (1)	768 (2)	2,902 (3)
Total	607	968	3,302

Note: (1) 48,744,000 x 0.01= 487,440 baht (refer to Table E.3)
(2) 76,783,000 x 0.01 = 767,830 baht
(3) 290,183,000 x 0.01 = 2,901,830 baht

(1,000 Baht)

Treatment Process	Daily Flow (m^3/day)		
	50,000	100,000	500,000
(ii) Aerated Lagoon			
. Salary	120	200	400
. Electricity	7,884 (1)	15,768 (2)	70,956 (3)
. Repair & Replacement of Parts	705 (4)	1,068 (5)	4,044 (6)
Total	8,709	17,036	75,400

Note:
(1) 15kWx40unitsx24h/dx365d/yrx1.5baht/kWh = 7,884,000 baht/yr
(2) 30kWx40unitsx24h/dx365d/yrx1.5baht/kWh = 15,768,000 baht/yr
(3) 30kWx180unitsx24h/dx365d/yrx1.5baht/kWh = 70,956,000 baht/yr
(4) 36,415,000 x 0.01 + 17,060,000 x 0.02 = 705,350 baht (refer to Table E.4)
(5) 57,391,000 x 0.01 + 24,701,000 x 0.02 = 1,067,930 baht
(6) 213,523,000 x 0.01 +95,443,000 x 0.02 = 4,044,090 baht

Treatment Process	50,000	100,000	500,000
(iii) Oxidation Ditch			
. Salary	320	400	600
. Electricity	11,116 (1)	22,233 (2)	111,164 (3)
. Repair & Replacement of Parts	1,492 (4)	2,730 (5)	12,159 (6)
. Chemicals	1,460 (7)	2,920 (8)	14,600 (9)
. Sludge Disposal	684 (10)	1,369 (11)	6,844 (12)
Total	15,072	29,652	145,367

Note:
(1) (30kWx24units+0.75kWx8units+15kWx8units)x24h/dx365d/yr x1.5baht/kWh = 11,116,440 baht/yr
(2) (1) x 2 = 22,232,880 baht/yr
(3) (1) x 10 = 111,164,400 baht/yr
(4) 31,348,000 x 0.01 + 58,920,000 x 0.02 = 1,491,880 baht (refer to Table E.5)
(5) 60,896,000 x 0.01 + 106,056,000 x 0.02 = 2,730,080 baht
(6) 273,176,000 x 0.01 + 471,360,000 x 0.02 = 12,158,960 baht
(7) 1.0 t/d x 365 d/yr x 4,000 baht/t = 1,460,000 baht/yr
(8) (7) x 2 = 2,920,000 baht/yr
(9) (7) x 10 = 14,600,000 baht/yr
(10) 18.75 t/d x 365 d/yr x 100 baht = 684,375 baht/yr
(11) (10) x 2 = 1,368,750 baht/yr
(12) (10) x 10 = 6,843,750 baht/yr

(1,000 Baht)

Treatment Process	Daily Flow (m^3/day) 50,000	100,000	500,000
(iv) Conventional Activated Sludge			
. Salary	800	1,200	2,000
. Electricity	4,845 (1)	9,691 (2)	48,454 (3)
. Repair & Replacement of Parts	3,787 (4)	6,391 (5)	20,753 (6)
. Chemicals	1,460	2,920	14,600
. Sludge Disposal	548 (7)	1,095 (8)	5,475 (9)
Total	11,440	21,297	91,282

Note: (1) [7,000kWh/d(Compressor)+360kWh/d(Pumps)+990kWh/d (Gas holder) +500kWh/d(Other)]x365d/yrx1.5baht/kWh = 4,845,375 baht/yr

(2) [14,000kWh/d(Compressor)+720kWh/d(Pumps)+1,980kWh/d (Gas holder) +1,000kWh/d]x365d/yrx1.5Baht/kWh = 9,690,750 baht/yr

(3) [70,000kWh/d(Compressor)+3,600kWh/d(Pumps)+9,900 (Gas holder) +5,000kWh/d(Other)]x365d/yrx1.5baht/kWh = 48,453,750 baht/yr

(4) 92,975,000 x 0.01 + 142,859,000 x 0.02 = 3,786,930 baht (refer to Table E.6)

(5) 171,078,000 x 0.01 + 234,028,000 x 0.02 = 6,391,340 baht

(6) 616,381,000 x 0.01 + 729,474,000 x 0.02 = 20,753,290 baht

(7) 15 t/d x 365 d/yr x 100 baht/t = 547,500 baht/yr

(8) (7) x 2

(9) (7) x 10

(v) Modified Aeration			
. Salary	720	1,080	1,800
. Electricity	3,526 (1)	7,052 (2)	35,259 (3)
. Repair & Replacement of Parts	2,714 (4)	4,982 (5)	16,258 (6)
. Chemicals	1,460	2,920	14,600
. Sludge Disposal	475 (7)	949 (8)	4,745 (9)
Total	8,895	16,983	72,662

Note: (1) [4,740kWh/d(Compressor)+210kWh/d(Pumps)+990kWh/d (Gas holder) +500kWh/d(Other)]x365d/yrx1.5baht/kWh = 3,525,900 baht/yr

(2) [9,480kWh/d(Compressor)+420kWh/d(Pumps)+1,980kWh/d (Gas holder) +1,000kWh/d(Other)]x365d/yrx1.5baht/kWh = 7,051,800 baht/yr

(3) [47,400kWh/d(Compressor)+2,100kWh/d(Pumps)+9,900kWh/d (Gas holder) +5,000kWh/d(Other)]x365d/yrx1.5Baht/kWh = 35,259,000 Baht/yr

(4) 56,405,000 x 0.01 + 107,480,000 x 0.02 = 2,713,650 baht

(5) 105,458,000 x 0.01 + 196,383,000 x 0.02 = 4,982,240 baht

(6) 410,777,000 x 0.01 + 607,502,000 x 0.02 = 16,257,810 baht

(7) 13 t/d x 365 d/yr x 100 baht/t = 474,500 baht/yr

(8) (7) x 2

(9) (8) x 10

These costs for five treatment processes can be expressed in exponential functions as follows:

(i) Stabilization pond

$$C_{MS} = 0.198\ Q^{0.740}$$

(ii) Aerated lagoon

$$C_{MA} = 0.355\ Q^{0.935}$$

(iii) Oxidation ditch

$$C_{MO} = 0.354\ Q^{0.985}$$

(iv) Conventional activated sludge

$$C_{MC} = 0.657\ Q^{0.902}$$

(v) Modified aeration

$$C_{MM} = 0.471\ Q^{0.911}$$

where C : Annual operation and maintenance cost, 1,000 baht

Q : Daily flow, m^3/day

4. Land Cost

An official land cost at the end of 2523 (1980) price level in the Study Area is shown in Table E.10, which is obtained from the Department of Land, MOI.

Table E.10 List of Official Land Price at the End of 2523 (1980) Price Level

District/Town	Item	Area	Unit Price Baht/4 m^2
1. PHANAKORN			
1.1 Chanasongkarm Town	1	Area within a 40 meters wide along the Jakkra Pong and Phasumain road	45,000
	2	Area in Item 1 and an opposit of the road side	12,000
	3	Area beyond 40 meters and within 80 meters from the edge of Jakkra Pong and Phasumain road	6,500
	4	Area within a 40 meters wide along the Joa Fa and Phaaretit road	20,000
	5	Area in Item 4 and an opposit of the road side	7,500
	6	Area beyond 40 meters and within 80 meters from the edge of Joa Fa and Phaaretit road	6,000
	7	Area within a 20 meters wide along the public and private road	
		7.1 Road width 4 meters and more	12,000
		7.2 Road width less than 4 meters	7,000
	8	Area which is not identified in the above items	5,000
1.2 Wat Sam Phya Town	1	Area within a 40 meters wide along the Visutikrasat and Takasem road	40,000
	2	Area in Item 1 and an opposit of the road side	12,000
	3	Area beyond 40 meters and within 80 meters from the edge of Visutikrasat and Takasem road	6,500

- to be continued -

District/Town	Item	Area	Unit Price Baht/4 m^2
	4	Area within a 40 meters wide along the Prayap, Samphaya and Lum Pum road	10,000
	5	Area in Item 4 and an opposit of the road side	6,500
	6	Area beyond 40 meters and within 80 meters from the edge of Praya, Samphaya and Lum Pew road	6,000
	7	Area within a 20 meters wide along the public and private road	
		7.1 Road width 4 meters and more	12,000
		7.2 Road width less than 4 meters	7,000
	8	Area which is not identified in the above items	5,000
2. YAN NAWA			
Chongnonsi Town	1	Area within a 40 meters wide along the Cher Puang road	10,000
	2	Area in Item 1 and an opposit of the road side	1,600
	3	Area beyond 40 meters and within 80 meters from the edge of the Cher Puang road	800
	4	Area within a 40 meter wide along the King, Satuphadit, Jan, Yenarekat, and Nang Lin Jee road	10,000
	5	Area in Item 4 and an opposit of the road side	1,400
	6	Area beyond 40 meters and within 80 meters from the edge of King, Satuphadit, Jan, Yenarekat, and Nang Lin Jee road	800
	7	Area with a 20 meters wide along the public and private road	
		7.1 Road width 4 meters and more	1,400
		7.2 Road width less than 4 meters	1,200

- to be continued -

District/Town	Item	Area	Unit Price Baht/4 m^2
	8	Area within a 20 meters wide along the Ring road and Chao Phya river	1,200
	9	Area which is not identified in the above items	800
3. DUSIT Bang Sua Town	1	Area within a 20 meters wide along the public and private road 1.1 Road width 4 meters and more 1.2 Road width less than 4 meters	2,000 2,000 1,800
	2	Area in the Bang Sua Town and car can not go inside	1,200
4. HUAY KWANG Huay Kwang Town	1	Area within a 20 meters wide along the public road 1.1 Road width 4 meters and more 1.2 Road width less than 4 meters	 2,000 1,800
	2	Area in the Huay Kwang Town and car can not go inside.	1,000
5. BANG KAEN Lad Yoa Town	1	Area within a 40 meters wide along the Lad Plao road	8,000
	2	Area in Item 1 and an opposit of the the road side	2,500
	3	Area beyond 40 meters and within 80 meters from the edge of Lad Plao road	1,500
	4	Area within a 40 meters wide along the public and private road	2,500
	5	Area which is not identified in the above items	600
6. BANG KAPI 6.1 Sam Sen Nok Fung Nova Town	1	Area within a 40 meters wide along Lad Phao road	8,000

- to be continued -

District/Town	Item	Area	Unit Price Baht/4 m^2
	2	Area in Item 1 and an opposit of the road side	2,000
	3	Area beyond 40 meters and within 80 meters from the edge of Lad Phao road	1,200
	4	Area within a 20 meters wide along the public and private road	
		4.1 Road width 4 meters and more	3,000
		4.2 Road width less than 4 meters	1,800
	5	Area which is not identified in the above items	600
6.2 Sam Sen Nok Town	1	Area within a 40 meters wide along Lad Phao road	8,000
	2	Area in Item 1 and an opposit of the road side	2,000
	3	Area beyond 40 meters and within 80 meters from the edge of Lad Phao road	1,200
	4	Area within a 40 meters wide along the Sudthisarnvinijchai and Ring road	4,000
	5	Area within a 40 meters wide along the Phachasajkum Pen road	3,000
	6	Area within a 20 meters wide along the public and private road	
		6.1 Road width 4 meters and more	2,000
		6.2 Road width less than 4 meters	1,800
	7	Area which is not identified in the above items	600
7. PHA KANONG			
7.1 Klong Tauy Town	1	Area within a 40 meters wide along the Sukumvit road	14,000
	2	Area in Item 1 and an opposit of the road side	4,000

- to be continued -

District/Town	Item	Area	Unit Price Baht/4 m^2
	3	Area beyond 40 meters and within 80 meters from the edge of Sukumvit road	1,600
	4	Area within a 40 meters wide along the Rama IV, Suntorn Kosa, Asnasong, and Asoke road	8,000
	5	Area in Item 4 and an opposit of the road side	3,000
	6	Area beyond 40 meters and within 80 meters from the edge of IV, Suntorn Kosa, Asnasong, and Asoke road	1,400
	7	Area within a 20 meters wide along the public and private road	4,000
	8	Area which is not identified in the above items	1,400
7.2 Klong Ton Town	1	Area within a 40 meters wide along the Sukumvit road	14,000
	2	Area in Item 1 and an opposit of the road side	4,000
	3	Area beyond 40 meters and within 80 meters from the edge of Sukumvit road	1,600
	4	Area within a 40 meters wide along the Akkamai and Rama IV road	10,000
	5	Area in Item 4 and an opposit of the road side	3,000
	6	Area beyon 40 meters and within 80 meters from the edge of Akkamai and Rama IV road	1,400
	7	Area within a 40 meters wide along the Pattanakarn road	6,000

- to be continued -

District/Town	Item	Area	Unit Price Baht/4 m^2
	8	Area in Item 7 and an opposit of the road side	3,000
	9	Area beyond 40 meters and within 80 meters from the edge of Pattanakarn road	1,400
	10	Area within a 40 meters wide along the Phakanong-Klong Ton and Old Rail road	6,000
	11	Area in Item 10 and an opposit of the road side	3,000
	12	Area beyond 40 meters and within 80 meters from the edge of Phakanong-Klong Ton and Old Rail road	1,400
	13	Area within a 20 meters wide along the public and private road	4,000
	14	Area which is not identified in the above items	1,400
7.3 Phakanong Town	1	Area within a 40 meters wide along the Sukumvit road	14,000
	2	Area in Item 1 and on opposit of the road side	4,000
	3	Area beyond 40 meters and within 80 meters from the edge of Sukumvit road	1,600
	4	Area within a 40 meters wide along the Rama IV, Ekkamai, and Phakanong-Klong Ton road	8,000
	5	Area in Item 4 and an opposit of the road side	3,000
8. BANGKOK NOI	1	Area within a 20 meters wide along the Pha Pinkao and Arun Amarin road	10,000

- to be continued -

District/Town	Item	Area	Unit Price Baht/4 m^2
	2	Area beyond 20 meters and within 40 meters from the edge of Pha Pinkao and Arun Amarin road	8,000
	3	Area within a 20 meters wide along the Jarunsanitvong road	6,000
	4	Area beyond 20 meters and within 40 meters from the edge of Pha Pinkao, Arun Amarin, and Janun-sanitvong road	4,000
	5	Area beyond 40 meters and within 100 meters from the edge of Pha Pinkao, Arun Amarin, and Jarunsanitvong road	2,500
	6	Area within a 100meters wide along the Chao Phya river	2,000
	7	Area beyond 100 meters and within 200 meters from the edge of Pha Pinkao, Arun Amarin, and Jarunsanitvong road	1,500
	8	Area which is not identified in the above items	1,000
9. BANGKOK YAI			
9.1 Wat Tapra Town	1	Area within a 20meters wide along the Pechkasem and Jaransanitvong road	10,000
	2	Area beyond 20 meters and within 40 meters from the edge of Pechkasem and Jaransanitvong road	8,000
	3	Area beyond 40 meters and within 100 meters from the edge of Pechkasem and Jaransanitvong road	5,000
	4	Area along the Klong Bangkok Yai, Klong Morn, and Klong Bangkok Noi	1,200
	5	Area which is not identified in the above items	1,000

- to be continued -

District/Town	Item	Area	Unit Price Baht/4 m^2
9.2 Bang Yi Rua Town	1	Area within a 20 meters wide along the Phachati Pok, King Taksin Memoric, Pechakasem, Intra Pitak, and Terd Thai road	15,000
	2	Area beyond 20 meters and within 40 meters from the edge of Phachati Pok, King Taksin Memoric, Pechakasem, Intra Pitak, and Terd Thai road	10,000
	3	Area beyond 40 meters and within 60 meters from the edge of Phachati Pok, King Taksin Memoric, Pechakasem, Intra Pitak, and Terd Thai road	7,000
	4	Area beyond 60 meters and within 100 meters from the edge of Phachati Pok, King Taksin Memoric, Pechakasem, Intra, and Terd Thai road	4,000
	5	Area within a 20 meters wide along the Mea Kong Railway	3,500
	6	Area within a 50 meters wide along Klong Bangkok Yai	3,500
	7	Area which is not idenfitied in the above items	2,500
10. RAT BURANA			
10.1 Rat Burana Town	1	Area within a 20 meters wide along the Suksawat and Chareanakorn road	10,000
	2	Area beyond 20 meters and within 40 meters from the edge of Suksawat and Chareanakorn	5,000
	3	Area within a 40 meters wide along the Chao Phya river	7,000
	4	Area within a 20 meters wide along the Rat Burana road	2,000

- to be continued -

District/Town	Item	Area	Unit Price Baht/4 m^2
	5	Housing area in above items	400
	6	Area which is not identified in the above items	200
10.2 Bang Pra Kok	1	Area within a 20 meter wide along the Suksawat and Tonburi-Paktoa road	10,000
	2	Area beyond 20 meters and within 40 meters from the edge of the Suksawat and Tonburi-Paktoa road, and area within a 20 meter wide along the Chareannakorn and Rat Burana road	5,000
	3	Area within a 100 meters wide along the Chao Phya river	7,000
	4	Area beyond 20 meters and within 40 meters from the edge of Chareannakorn and Rat Burana road	3,000
	5	Area beyond 40 meters and within 100 meters from the edge of Chareannakorn and Rat Burana road	1,000
	6	Area which is not identified in the above items	400

APPENDIX F

COMPARATIVE STUDY ON WASTEWATER TREATMENT PROCESS

APPENDIX F
COMPARATIVE STUDY ON WASTEWATER TREATMENT PROCESS

The purpose of this study is to judge most suitable treatment process without particular reference to local requirement in the Study Area.

As described in Chapter 11 "Wastewater Treatment and Disposal", land requirement, capital construction costs, and operation and maintenance costs vary widely with the treatment process. In this chapter, stabilization pond process, aerated lagoon process, oxidation ditch, conventional activated sludge and modified aeration are selected and studied taking into account land acquisition costs, capital construction costs, and operation and maintenance costs.

A selection among five treatment process be based on a comparison of annual costs, i.e. interest of capital construction costs and land acquisition costs, depreciation, operation and maintenance costs. Cost estimates are prepared for each type works in units designed to treat from 10,000 to 1,000,000 m^3/day (daily average flow) on the assumptions of followings:

a) The expected BOD contents for influent and effluent flow are 200 mg/l and 20 - 60 mg/l respectively.

b) Land acquisition costs of treatment sites vary from 100 baht/m^2 to 1,000 baht/m^2 in the Study Area.

c) The weighted average useful lives for structures, machinery and electrical equipment are 50 years and 15 years respectively.

d) The available interest rate is 8 percent.

Then, estimated costs per wastewater flow are as follows:

Table F.1 Construction Costs at the End of 2523 (1980) Price Level

(Baht/m^3)

Treatment Process	Flow Rate (m^3/day)				
	10,000	50,000	100,000	500,000	1,000,000
(1) Stabilization Pond	1,334	942	811	573	493
(2) Aerated Lagoon	1,481	1,028	878	609	521
(3) Oxidation Ditch	2,048	1,797	1,699	1,492	1,410
(4) Conventional Activated	7,082	4,774	4,029	2,716	2,292
(5) Modified Aeration	4,761	3,379	2,915	2,069	1,785

Table F.2 Land Acquisition Cost at the End of 2523 (1980) Price Level

(Baht/m^3)

Treatment Process	Flow Rate (m^3/day)				
	10,000	50,000	100,000	500,000	1,000,000
(1) Stabilization Pond					
Unit Land Cost					
100 Baht/m^2	1,290	1,198	1,163	1,083	1,051
500 Baht/m^2	6,450	5,990	5,815	5,417	5,255
1,000 Baht/m^2	12,900	11,980	11,630	10,834	10,509
(2) Aerated Lagoon					
Unit Land Cost					
100 Baht/m^2	550	508	488	447	430
500 Baht/m^2	2,750	2,540	2,440	2,235	2,152
1,000 Baht/m^2	5,500	5,080	4,880	4,470	4,303
(3) Oxidation Ditch					
Unit Land Cost					
100 Baht/m^2	260	188	163	118	103
500 Baht/m^2	1,300	940	815	591	514
1,000 Baht/m^2	2,600	1,880	1,630	1,182	1,028
(4) Conventional Activated Sludge					
Unit Land Cost					
100 Baht/m^2	150	108	92	65	56
500 Baht/m^2	750	540	460	323	278
1,000 Baht/m^2	1,500	1,080	920	646	555
(5) Modified Aeration					
Unit Land Cost					
100 Baht/m^2	130	88	75	51	44
500 Baht/m^2	650	440	375	256	218
1,000 Baht/m^2	1,300	880	750	512	435

Table F.3 Annual Operation and Maintenance Cost at the End of 2523 (1980) Price Level

(Baht/m^3)

Treatment Process	Flow Rate (m^3/day)				
	10,000	50,000	100,000	500,000	1,000,000
(1) Stabilization Pond	18.1	11.9	9.9	6.5	5.5
(2) Aerated Lagoon	195.1	175.7	168.0	151.3	144.6
(3) Oxidation Ditch	308.3	301.0	297.9	290.7	287.7
(4) Conventional Activated Sludge	266.4	227.5	212.6	181.6	169.7
(5) Modified Aeration	207.5	179.8	169.1	146.5	137.7

Tables F.4 through F.6 and Figures 11.10 through 11.12 of Chapter 11 of Volume II show the total annual costs for five treatment processes at unit land cost of 100, 500 and 1,000 baht/m^2. These indicate that stabilization pond is more economical than the other processes of treatment at land value of about 100 baht/m^2. Further, at land value of about 500 baht/m^2 and wastewater flow of less than approximately 150,000 m^3/day, aerated lagoon is economical process. On the condition with land value of about 500 baht/m^2 and wastewater flow of 150,000 m^3/day and above, modified aeration is more economical, because of the lower land aquisition cost. On the condition with land value of about 1,000 baht/m^2, modified aeration is the most economical one.

In Tables F.4 through F.6, the sinking fund method is used to calculate annual depreciation charges. In the calculations, it is assumed that money is borrowed at 8 percent interest and that annual depreciation payment into the sinking fund will grow at the same 8 percent. Sinking found factor is expressed as follows:

$$S.F.F. = \frac{i}{(1 + i)^n - 1}$$

where i: annual interest rate

n: the number of years (useful life)

In the Tables, interest for land acquisition is annual interest to be paid for the capital used to acquire land.

Table F.4 Total Annual Cost at Land Value of 100 Baht/m^2 at the End of 2523 (1980) Price Level

(Baht/m^3)

Treatment Process	Flow Rate (m^3/day)				
	10,000	50,000	100,000	500,000	1,000,000
(1) Stabilization Pond					
a. Interest (8%)					
. Construction	106.7	75.4	64.9	45.8	39.4
. Land Acquisition	103.2	95.8	93.0	86.6	84.1
b. Depreciation (0.174%)	2.3	1.6	1.4	1.0	0.9
c. Operation and Maintenance	18.1	11.9	9.9	6.5	5.5
Total Annual Cost	230.3	184.7	169.2	139.9	129.9
(2) Aerated Lagoon					
a. Interest (8%)					
. Construction	118.5	82.2	70.2	48.7	41.7
. Land Acquisition	40.0	40.6	39.0	35.8	34.4
b. Depreciation (0.402%)	6.0	4.1	3.5	2.4	2.1
c. Operation and Maintenance	195.1	175.7	168.0	151.3	144.6
Total Annual Cost	363.6	302.6	280.7	238.2	222.8
(3) Oxidation Ditch					
a. Interest (8%)					
. Construction	163.9	143.8	135.9	119.4	112.8
. Land Acquisition	20.8	15.0	13.0	9.4	8.2
b. Depreciation (1.115%)	22.8	20.0	18.9	16.6	15.7
c. Operation and Maintenance	308.3	301.0	297.9	290.7	287.7
Total Annual Cost	515.8	479.8	465.7	436.1	424.4
(4) Conventional Activated Sludge					
a. Interest (8%)					
. Construction	566.6	381.9	322.3	217.3	183.4
. Land Acquisition	12.0	8.6	7.4	5.2	4.5
b. Depreciation (0.906%)	64.2	43.3	36.5	24.6	20.8
c. Operation and Maintenance	266.4	227.5	212.6	181.6	169.7
Total Annual Cost	909.2	661.3	578.8	428.7	378.4
(5) Modified Aeration					
a. Interest (8%)					
. Construction	380.9	270.3	233.2	165.5	142.8
. Land Acquisition	10.4	7.0	6.0	4.1	3.5
b. Depreciation (1.086%)	51.7	36.7	31.7	22.5	19.4
c. Operation and Maintenance	207.5	179.8	169.1	146.5	137.7
Total Annual Cost	650.5	493.8	440.0	338.6	303.4

Table F.5 Total Annual Cost at Land Value of 500 Baht/m^2 at the End of 2523 (1980) Price Level

(Baht/m^3)

Treatment Process	Flow Rate (m^3/day)				
	10,000	50,000	100,000	500,000	1,000,000
(1) Stabilization Pond					
a. Interest (8%)					
. Construction	106.7	75.4	64.9	45.8	39.4
. Land Acquisition	516.0	479.2	465.2	433.4	420.4
b. Depreciation (0.174%)	2.3	1.6	1.4	1.0	0.9
c. Operation and Maintenance	18.1	11.9	9.9	6.5	5.5
Total Annual Cost	643.1	568.1	541.4	486.7	466.2
(2) Aerated Lagoon					
a. Interest (8%)					
. Construction	118.5	82.2	70.2	48.7	41.7
. Land Acquisition	220.0	203.2	195.2	178.8	172.2
b. Depreciation (0.402%)	6.0	4.1	3.5	2.4	2.1
c. Operation and Maintenance	195.1	175.7	168.0	151.3	144.6
Total Annual Cost	539.6	465.2	436.9	381.2	360.6
(3) Oxidation Ditch					
a. Interest (8%)					
. Construction	163.9	143.8	135.9	119.4	112.8
. Land Acquisition	104.0	75.2	65.2	47.3	41.1
b. Depreciation (1.115%)	22.8	20.0	18.9	16.6	15.7
c. Operation and Maintenance	308.3	301.0	297.9	290.7	287.7
Total Annual Cost	599.0	540.0	517.9	474.0	457.3
(4) Conventional Activated Sludge					
a. Interest (8%)					
. Construction	566.6	381.9	322.3	217.3	183.4
. Land Acquisition	60.0	43.2	36.8	25.8	22.2
b. Depreciation (0.906%)	64.2	43.3	36.5	24.6	20.8
c. Operation and Maintenance	266.4	227.5	212.6	181.6	169.7
Total Annual Cost	957.2	695.9	608.2	449.3	396.1
(5) Modified Aeration					
a. Interest (8%)					
. Construction	380.9	270.3	233.2	165.5	142.8
. Land Acquisition	52.0	35.2	30.0	30.5	17.4
b. Depreciation (1.086%)	51.7	36.7	31.7	22.5	19.4
c. Operation and Maintenance	207.5	179.8	169.1	146.5	137.7
Total Annual Cost	692.1	522.0	464.0	355.0	317.3

Table F.6 Total Annual Cost at Land Value of 1,000 Baht/m^2 at the End of 2523 (1980) Price Level

(Baht/m^3)

Treatment Process	Flow Rate (m^3/day)				
	10,000	50,000	100,000	500,000	1,000,000
(1) Stabilization Pond					
a. Interest (8%)					
. Construction	106.7	75.4	64.9	45.8	39.4
. Land Acquisition	1,032.0	958.4	930.4	866.7	840.7
b. Depreciation (0.174%)	2.3	1.6	1.4	1.0	0.9
c. Operation and Maintenance	18.1	11.9	9.9	6.5	5.5
Total Annual Cost	1,159.1	1,047.3	1,006.6	920.0	866.5
(2) Aerated Lagoon					
a. Interest (8%)					
. Construction	118.5	82.2	70.2	48.7	41.7
. Land Acquisition	440.0	406.4	390.4	357.6	344.2
b. Depreciation (0.402%)	6.0	4.1	3.5	2.4	2.1
c. Operation and Maintenance	195.1	175.7	168.0	151.3	144.6
Total Annual Cost	759.6	668.4	632.1	560.0	532.6
(3) Oxidation Ditch					
a. Interest (8%)					
. Construction	163.9	143.8	135.9	119.4	112.8
. Land Acquisition	208.0	150.4	130.4	94.6	82.2
b. Depreciation (1.115%)	22.8	20.0	18.9	16.6	15.7
c. Operation and Maintenance	308.3	301.0	297.9	290.7	287.7
Total Annual Cost	703.0	615.2	583.1	521.3	498.4
(4) Conventional Activated Sludge					
a. Interest (8%)					
. Construction	566.6	381.9	322.3	217.3	183.4
. Land Acquisition	120.0	86.4	73.6	51.7	44.4
b. Depreciation (0.906%)	64.2	43.3	36.5	24.6	20.8
c. Operation and Maintenance	266.4	227.5	212.6	181.6	169.7
Total Annual Cost	1,017.2	739.1	645.0	475.2	418.3
(5) Modified Aeration					
a. Interest (8%)					
. Construction	380.9	270.3	233.2	165.5	142.8
. Land Acquisition	104.0	70.4	60.0	41.0	34.8
b. Depreciation (1.806%)	51.7	36.7	31.7	22.5	19.4
c. Operation and Maintenance	207.5	179.8	169.1	146.5	137.7
Total Annual Cost	744.1	557.2	494.0	375.5	334.7