(5) With respect to the effect of removal of pathogens, the Facultative and Maturation Ponds exhibit very high removal efficiencies, an important advantage from a public health viewpoint, though the algal growth contribute to increase in effluent BOD load.

5. Potential Ponds for Klong Water Purification

5.1 Location of Potential Ponds

Eight (8) potential pond sites, locations of which are given in Fig. D.20, were identified in the Study Area. The sites are shown in Fig. D.21.

The name, area, storage capacity, land ownership of the ponds and the klong waters that could be diverted are given below.

Name of Pond	Area (ha)	Storage Capacity (m^3)	Target Klong (Name)	Ownership
(1) Paholyothin Cargo Station	10	220,000	K. Premprachakon	Government
(2) Makkasan	16	310,000	K. Sam Sen	Government
(3) Tobacco Factory	20	680,000	(Sewage Line)	Government
(4) Huai Khwang	6	570,000	K. Lad Phrao	Private
(5) Rama IX Pond	20	300,000	K. Lad Phrao	Government
(6) Klong Chan	6	250,000	K. Tanang	Government
(7) Klong Kum	2.5	30,000	K. Bang Toei	Government
(8) Rama IX Park	10	90,000	K. Nung Bon	Government
Total	90.5	2,450,000		

5.2 Classification of Potential Ponds

The above eight (8) potential ponds are classified as follows, based on their depth, pollution levels in the respective klongs, and the existing utilization of the ponds.

(1) Pond Depth

1) Shallow Pond (Less than 4 m deep)
   - Paholyothin Cargo Station
   - Makkasan
   - Tobacco Factory
   - Rama IX Pond
   - Klong Kum
   - Rama IX Park

2) Deep Pond (More than 4 m deep)
   - Huai Khwang
   - Klong Chan

(2) Present State of Pollution of Target Klongs

1) Highly Polluted Klongs (Potential Pond)
   - K. Sam Sen (Makkasan)
   - Sewage Line (Tobacco Factory)
   - K. Lad Phrao (Huai Khwang)
   - K. Lad Phrao (Rama IX Pond)

2) Moderately Polluted Klongs
   - K. Premprachakon (Paholyothin Cargo Station)
   - K. Tanang (Klong Chan)
   - K. Toei (Klong Kum)
   - K. Nung Bon (Rama IX Park)

(3) Utilization of Pond

1) Recreation Site or Park
   - Tobacco Factory
   - Klong Kum
   - Rama IX Park

2) Flood Retention
   - Makkasan
   - Rama IX Pond
   - Klong Kum
   - Rama IX Park

3) No Specific Utilization at Present
   - Paholyothin Cargo Station : Small scale cultivation
   - Huai Khwang : Fishing by neighborhood
   - Klong Chan : NHA, North side is planned to be reclaimed for housing project.

5.3 Proposed Treatment Process for Klong Water Purification

(1) Proposed Treatment Process

The study was done using a treatment configuration consisting of the Aerated Lagoon, the Facultative Pond and the Maturation Pond.

Careful analysis of the results of these experiments and study of other related technical references were also made.

In conclusion, a treatment configuration consisting of Aerated Lagoon only is proposed as the treatment process for klong water quality improvement. The reasons for this are as follows:

- This study, "Purification of Klong Water in Bangkok" is essentially a stop-gap measure and treatment of klong water is only to supplement the dilution method.

- Therefore, the target of the klong water purification is firstly to improve the color and odor in the water, and secondly to reduce the BOD and COD concentration. Any significant removal of pathogenic organisms is considered to be a necessity.

- Rapid removal of the organic matter is expected in the Aerated Lagoon. This process is advantageous in view of the reduction of the required pond volume/the detention time, which will, in turn, minimize the requirement of land area.

(2) Ponds as Aerated Lagoons

Judging from the condition, location and shape of the ponds and the present state of pollution in the target klongs, out of the eight (8) potential ponds, the Makkasan Pond and the Rama IX Pond, could be used as Aerated Lagoons for the klong water quality improvement.

The target klongs that could be treated by the above two ponds are K. Sam Sen and K. Lad Phrao, the flow rates of which are $4\ m^3/s$ and $7\ m^3/s$ under the condition of dilution water introduction, respectively, and the average BOD concentration of both the klongs is about 15 mg/l. Under these conditions, the effect of aerated lagoon treatment is estimated.

About 85% of the water flow of K. Sam Sen and about 50% of the water flow of K. Lad Phrao can be treated by the respective Aerated Lagoons of Makkasan Pond and Rama IX Pond. As mentioned previously, 50% of the influent BOD load is considered to be removed with one day detention time. Therefore, the quantity of BOD reduction in each pond will be as follows.

Makkasan Pond : 3.4 m^3/s x 15 mg/l x 50% = 2,200 kg/Day
Rama IX Pond : 3.5 m^3/s x 15 mg/l x 50% = 2,270 kg/Day

Total existing pollution load generation in the Study Area is 61,900 kg/day as BOD.

Reduction of pollution load in these ponds with respect to total polution load is about 7%.

Hence by utilizing these ponds as Aerated Lagoons 7% of the pollution load of the Study Area can be removed.

The electricity consumed per cubic meter of treated water is calculated from data obtained in the operation of the experimental pond.

<u>(11 Kw x 2</u> <u>18.5 Kw)</u> x 24 Hrs. ÷ 28,800 m^3 = 0.03 Kwh/m^3
(Aerator) (pump)

Taking into account the BOD removal efficiency and the electricity consumption, it can be seen that Aerated Lagoon is very suitable in the water quality improvement of the klongs.

Table D.1 Advantages and Disadvantages of Various Biological Treatment Methods

Criteria	A.S.P.	T.F.	O.D.	A.L.	W.S.P.-1	W.S.P.-2
BOD Removal	**	**	***	***	***	***
FC Removal	*	*	**	***	***	***
SS Removal	***	***	***	**	**	**
Virus Removal	**	*	**	***	***	***
Ancillary Use Possibilities	*	*	*	***	***	***
Simple and Cheap Construction	*	*	**	**	***	***
Simple Operation	*	**	**	**	***	***
Land Requirement	***	***	***	**	**	*
Maintenance Costs	*	**	*	**	***	***
Minimization of Sludge for Removal	a/ **	a/ **	*	**	***	***
Evaluation Points	17	18	20	24	28	27

Note: A.S.P. : Activated Sludge Process
T.F. : Trickling Filter Process
O.D. : Oxidation ditch Process
A.L. : Aerated Lagoon System
W.S.P.-1 : Waste Stabilization Pond System with Anaerobic Units
W.S.P.-2 : Waste Stabilization Pond System without Anaerobic Units

a/ : Assumes provision of sludge digesters
*** : good
** : fair
* : poor

Ref. Notes on the Design and Operation of Waste Stabilization Ponds in Warm Climates of Developing Countries
J. P. Arthur, World Bank Technical Paper No. 7

Table D.2 Experimental Conditions

Item		Case-1 (Case-1-1 ~ Case-1-3)	Case-2	Case-3 (Case-3-1 ~ Case-3-2)	Case-4
Influent Flow Rate (m^3 /day)		28,800	9,600	28,800	57,600
Pump Operation	(Units x Hrs.)	1 x 24	1 x 8	1 x 24	2 x 24
Aerator	(Units x Hrs.)	3 x 24	3 x 24	2 x 24	2 x 24
Detention Time	A.L (Hrs.)	16	48	16	8
	F.P (Days)	1.7	5.1	1.7	0.9
	M.P (")	1.6	4.8	1.6	0.8
	Total (")	4	12	4	2

Note: A.L : Aerated Lagoon
F.P : Facultative/Maturation Pond
M.P : Maturation Pond

Note: In case-2 pump operation was only for 8 hours per day, from 6:00 am ~ 4:00 pm.

Table D.3 Water Quality Parameter

Parameter	Point ①	Point ②	Point ③	Point ④	Point ⑤	Remark
Color/Odor	*	*	*	*	*	On-Site
Water Temp.	*	*	*	*	*	"
PH	*	*	*	*	*	"
DO	*	*	*	*	*	"
BOD Total	*	*	*	*	*	Lab.
Soluble	*	*	*	*	*	"
COD Total	*	*	*	*	*	"
Soluble	*	*	*	*	*	"
SS	*	*	*	*	*	"
VS/VSS	*	*				"
NH_4-N	*	*	*	*	*	"
NO_2-N	*	*	*	*	*	"
NO_3-N	*	*	*	*	*	"
T-P	*	*	*	*	*	"
Coliform Count	*	*		*	*	"
Chlorophyll-a				*	*	"

* indicates analysis of the respective parameter at the point concerned.

Table D.4 Water Quality in Wastewater Source

Parameter	February Range	February Ave.	March Range	March Ave.	April Range	April Ave.	May Range	May Ave.	June Range	June Ave.	July Range	July Ave.	August Range	August Ave.
Color (Odor)	Black (Offensive)		Black (Offensive)		-		-		-		Grey (strong)~ Black (offensive)		Grey-Brown (faint) Grey (strong)	
Air Temp. (°C)	24.4~29.3	27.2	24.5~34.5	29.2	32.3~35.0	33.5	28.2~34.0	30.8	28.0~34.5	31.4	28.1~33.4	30.4	26.0~30.9	28.9
Water Temp.(°C)	27.3~29.1	28.0	26.1~29.6	28.3	30.5~31.6	31.0	29.5~31.4	30.4	28.1~30.6	29.5	28.7~30.2	29.6	28.1~30.1	29.2
pH/a	7.0~7.0	7.0	7.0~7.0	7.0	-	-	7.3~7.5	7.4	7.2~7.4	7.3	7.0~7.5	7.1	7.0~7.2	7.0
DO (mg/l)	0.0~0.7	0.0	0.0~1.0	0.0	0.2~0.9	0.8	0.2~0.5	0.4	0.3~0.6	0.4	0.0~0.7	0.1	0.1~0.8	0.4
T-BOD (")	13~34	21	8.0~28	19	9.5~28	20	8.5~20	15	10~24	18	8.4~22	13	6.0~22	14
S-BOD (")	3.0~12	8.7	5.4~12	7.6	3.7~9.6	6.5	4.2~8.3	6.2	3.0~12	7.9	2.3~9.2	5.6	2.6~11	5.7
T-COD (")	24~67	48	19~69	45	40~60	48	28~60	43	31~58	43	24~46	37	28~48	40
S-COD (")	15~41	25	17~58	30	28~34	31	18~40	28	22~39	32	16~36	27	22~35	27
SS (")	17~39	24	18~100	37	29~49	35	19~56	34	21~55	29	21~51	32	31~61	46
VS/b (")	200~339	286	249~1,000	390	12~20	16	4.4~19	10	0.4~15	6.7	2.8~16	8.7	8~18	12
NH_4-N (")	0.3~9.1	2.5	0.3~0.6	0.5	0.1~3.1	1.0	0.2~0.7	0.4	0.1~0.3	0.2	0.0~0.5	0.2	0.3~0.5	0.4
NO_2-N (")	0.01~0.01	0.01	0.01~0.15	0.02	0.00~0.01	0.01	0.00~0.01	0.01	0.00~0.01	0.00	0.00~0.01	0.01	0.00~0.00	0.00
NO_3-N (")	-	-	0.01~0.24	0.07	0.00~0.06	0.03	0.00~0.02	0.00	0.00~0.00	0.00	0.00~0.00	0.00	0.00~0.00	0.00
T-P (")	0.9~1.3	1.0	0.7~1.3	1.0	-	-	-	-	-	-	-	-	-	-
Coliform Count (col/ml)	2,000 ~28,000	12,000	2,100 ~35,000	13,000	-	-	-	-	-	-	1,700 ~4,000	3,100	3,100 ~5,900	4,800

Note: /a: pH is measured by pH meter during Apr. - Jun.
/b: VSS is analyzed from April.

Table D.5 Average Water Quality in Case-1-1 (Phase 1)

Term 13. Feb. ~ 17. Feb. '89
Average Air Temp. 26.5°C

Parameter		Point ①	Point ②	Point ③	Point ④	Point ⑤	Remark
Color (Odour)		Black (Offensive)	Gray-Green (Non)	Green (Non)	Green (Non)	Green (Non)	On-Site
Temperature		27.5	27.7	27.8	28.0	28.1	°C "
pH		7.0	7.0	7.2	7.6	7.7	"
DO		0.4	5.4	5.3	4.8	7.4	mg/l "
BOD	Total	17	7.6	16	23	19	"
	Soluble	9.2	4.9	3.7	5.8	4.2	"
COD	Total	43	33	35	43	49	"
	Soluble	29	32	28	26	24	"
SS		22	9	15	30	37	"
VS		275	258	-	-	-	"
NH_4-N		1.6	1.3	1.2	0.3	0.0	"
NO_2-N		-	-	-	-	-	"
NO_3-N		-	-	-	-	-	"
T-P		1.0	1.0	1.0	0.9	0.9	"
Coliform Count		8.9 x E5	1.1 x E5	-	9.7 x E3	7.3 x E3	col/100 ml
Chlorophyll-a		-	-	-	0.059	0.080	μg/l

Table D.6 Average Water Quality in Case-1-2 (Phase 2)

Term 13. Mar. ~ 17. Mar. '89
Average Air Temp. 29.2°C

Parameter		Point ①	Point ②	Point ③	Point ④	Point ⑤	Remark
Color (Odour)		Black (Offensive)	Brown (Non)	Brown (Non)	Green (Non)	Green (Non)	On-Site
Temperature		28.7	28.7	29.0	29.1	28.9	°C "
pH		7.0	7.0	7.1	8.0	8.2	"
DO		0.1	4.4	3.6	7.9	7.9	mg/l "
BOD	Total	20	8.1	6.4	13	18	"
	Soluble	6.8	5.9	3.4	3.6	5.6	"
COD	Total	50	29	25	35	34	"
	Soluble	31	21	21	27	18	"
SS		32	17	14	34	40	"
VS		309	277	-	-	-	"
NH_4-N		0.4	0.2	0.2	0.1	0.0	"
NO_2-N		0.01	0.03	0.02	0.20	0.23	"
NO_3-N		0.01	0.07	0.13	0.12	0.13	"
T-P		0.8	1.1	1.1	1.1	0.9	"
Coliform Count		7.9 x E5	3.5 x E4	-	6.9 x E3	5.2 x E2	col/100 ml
Chlorophyll-a		-	-	-	-	-	µg/l

Table D.7 Average Water Quality in Case-1-3 (Phase 3)

Term 29, Mar. ~ 1, Jun. '89
Average Air Temp. 32.4°C

Parameter		Point ①	Point ②	Point ③	Point ④	Point ⑤	Remark
Color (Odour)		Black (Offensive)	Brown (Non)	Brown (Non)	Green (Non)	Green (Non)	On-Site
Temperature		30.3	30.1	30.6	30.8	30.7	°C "
pH		7.4	7.9	8.0	8.6	8.5	"
DO		0.5	5.4	5.7	11	9.5	mg/l "
BOD	Total	17	9.2	8.8	11	12	"
	Soluble	6.9	2.6	2.2	2.8	3.3	"
COD	Total	46	30	31	38	39	"
	Soluble	29	21	20	23	20	"
SS		38	74	60	58	51	"
VS		11	9.6	-	-	-	"
NH_4-N		0.7	0.2	0.2	0.1	0.1	"
NO_2-N		0.02	0.19	0.20	0.26	0.29	"
NO_3-N		0.03	0.07	0.08	0.11	0.16	"
T-P		0.8	1.1	1.0	1.0	0.8	"
Coliform Count		1.0 x E4	2.7 x E2	-	8.2 x E2	4.4 x E2	col/100 ml
Chlorophyll-a		-	-	-	-	-	μg/l

Table D.8 Removal Efficiencies in Each Ponds in Case-1-1 to Case-1-3 (Phase 1 - Phase 3)

(1) Case-1-1 (13, Feb. - 17, Feb.) - Phase 1

Parameter		Aerated Lagoon	Open Channel	Facultative Pond	Maturation Pond
BOD	Total	55%	6%	- %	- %
	Soluble	47	60	37	54
COD	Total	23	19	0	-
	Soluble	-	3	10	17
SS		59	32	-	-
NH_4-N		19	25	81	100
T-P		0	0	10	10
Coliform		87.6	-	98.9	99.2

(2) Case-1-2 (13, Mar. - 17, Mar.) - Phase 2

Parameter		Aerated Lagoon	Open Channel	Facultative Pond	Maturation Pond
BOD	Total	60%	68%	35%	10%
	Soluble	13	50	47	18
COD	Total	42	50	30	32
	Soluble	32	32	13	42
SS		47	56	-	-
NH_4-N		50	50	75	100
T-P		-	-	-	-
Coliform		95.6	-	99.1	99.9

(3) Case-1-3 (29, Mar. - 1, Jun.) - Phase 3

Parameter		Aerated Lagoon	Open Channel	Facultative Pond	Maturation Pond
BOD	Total	46%	48%	35%	29%
	Soluble	46	68	59	52
COD	Total	35	33	17	15
	Soluble	28	31	21	31
SS		-	-	-	-
NH_4-N		71	71	86	86
T-P		-	-	-	0
Coliform		97.3	-	91.8	95.6

Table D.9 Average Water Quality in Case-2

Term 27. Feb. ~ 10. Mar. '89
Average Air Temp. 26.9°C

Parameter		Point ①	Point ②	Point ③	Point ④	Point ⑤	Remark
Color (Odour)		Black (Offensive)	Brown (Non)	Brown (Non)	Green (Non)	Green (Non)	On-Site
Temperature		27.9	27.7	28.1	28.4	28.6	°C "
pH		7.0	7.0	7.2	7.9	8.1	"
DO		0.0	6.7	7.7	5.4	8.7	mg/l "
BOD	Total	22	13	15	17	10	"
	Soluble	8.5	3.7	2.9	3.2	2.9	"
COD	Total	44	23	30	33	37	"
	Soluble	29	14	13	7.9	9.0	"
SS		35	27	41	40	41	"
VS		367	390	-	-	-	"
NH_4-N		0.5	0.2	0.2	0.1	0.0	"
NO_2-N		0.01	0.19	0.26	0.26	0.25	"
NO_3-N		0.01	0.11	0.11	0.12	0.13	"
T-P		1.2	1.2	1.1	1.1	1.0	"
Coliform Count		1.7 x E6	2.6 x E4	-	8.3 x E3	6.6 x E2	col/100 ml
Chlorophyll-a		-	-	-	-	-	μg/l

Table D.10 Removal Efficiencies in Each Pond in Case-2
(27, Feb. - 10, Mar.)

Parameter		Aerated Lagoon	Open Channel	Facultative Pond	Maturation Pond
BOD	Total	41%	32%	23%	55%
	Soluble	56	66	62	66
COD	Total	48	32	25	16
	Soluble	52	55	73	69
SS		23	-	-	-
NH_4-N		60	60	80	100
T-P		0	8	8	17
Coliform		98.5	-	99.5	99.9

Table D.11 Average Water Quality in Case-3-1 (Phase 1) - Dry Season

Term 7, Jun. ~ 29, Jun. '89

Average Air Temp. 31.0°C

Parameter		Point ①	Point ②	Point ③	Point ④	Point ⑤	Remark
Color (Odour)		Black (Offensive)	Brown (Non)	Brown (Non)	Green (Non)	Green (Non)	On-Site
Temperature		29.4	29.3	30.0	30.0	29.8	°C "
pH		7.3	7.7	7.7	8.1	8.1	"
DO		0.4	4.6	5.3	8.4	8.3	mg/l "
BOD	Total	18	6.7	6.3	12	14	"
	Soluble	7.4	3.9	2.4	2.6	3.8	"
COD	Total	42	34	36	38	36	"
	Soluble	30	25	24	23	21	"
SS		33	45	48	44	36	"
VS		7.3	9.5	-	-	-	"
NH_4-N		0.2	0.3	0.4	0.3	0.1	"
NO_2-N		0.00	0.03	0.04	0.14	0.02	"
NO_3-N		0.00	0.04	0.03	0.06	0.14	"
T-P		-	-	-	-	-	"
Coliform Count		1.3 x E4	1.0 x E2	-	2.8 x E1	3.8 x E1	col/100 ml
Chlorophyll-a		-	-	-	-	-	μg/l

Table D.12 Average Water Quality in Case-3-2 (Phase 2) Rainy Season

Term 5. Jul. ~ 31. Jul. '89

Average Air Temp. 30.4°C

Parameter		Point ①	Point ②	Point ③	Point ④	Point ⑤	Remark
Color (Odour)		Gray/Black (Fairly)	Brown (Non)	Brown(Non)	Green (Non)	Green (Non)	On-Site
Temperature		29.6	29.5	29.9	30.3	29.9	°C "
pH		7.1	7.2	7.4	7.8	8.0	"
DO		0.1	4.5	4.4	5.2	6.2	mg/l "
BOD	Total	13	7.9	6.3	7.6	19	"
	Soluble	5.6	3.0	2.7	3.0	3.8	"
COD	Total	37	36	33	31	31	"
	Soluble	27	26	22	18	22	"
SS		32	48	32	30	32	"
VS		8.7	6.3	-	-	-	"
NH_4-N		0.2	0.5	0.5	0.4	0.3	"
NO_2-N		0.01	0.04	0.04	0.11	0.20	"
NO_3-N		0.00	0.04	0.05	0.05	0.19	"
T-P		-	-	-	-	-	"
Coliform Count		3.1 x E5	2.7 x E5	-	1.6 x E4	3.7 x E2	col/100 ml
Chlorophyll-a		-	-	-	0.027	0.034	μg/l

Table D.13 Removal Efficiencies in Each Pond in Case-3-1 and Case-3-2

(1) Case-3-1 (7, June. - 29, Jun.) - Dry Season

Parameter		Aerated Lagoon	Open Channel	Facultative Pond	Maturation Pond
BOD	Total	63%	65%	33%	22%
	Soluble	47	68	65%	49
COD	Total	19	14	10	14
	Soluble	17	20	23	30
SS		-	-	-	-
NH_4-N		-	-	-	50
T-P		-	-	-	-
Coliform		99.2	-	99.8	99.7

(2) Case-3-2 (5, Jul. - 31, Jul.) - Rainy Season

Parameter		Aerated Lagoon	Open Channel	Facultative Pond	Maturation Pond
BOD	Total	39%	52%	42%	- %
	Soluble	46	52	46	32
COD	Total	3	11	16	16
	Soluble	4	19	33	19
SS		-	0	6	0
NH_4-N		-	-	-	-
T-P		-	-	-	-
Coliform		13.0	-	94.8	99.9

Table D.14 Average Water Quality in Case-4

Term 3. Aug. ~ 17. Aug. '89

Average Air Temp. 28.9°C

Parameter		Point ①	Point ②	Point ③	Point ④	Point ⑤	Remark
Color (Odour)		Gray (Faint)	Brown (Non)	Brown (Non)	Green (Non)	Green (Non)	On-Site
Temperature		29.2	29.3	29.5	29.6	29.5	°C "
pH		7.0	7.1	7.3	7.7	7.7	"
DO		0.4	3.4	3.3	3.4	4.2	mg/l "
BOD	Total	14	8.6	7.5	7.8	9.0	"
	Soluble	5.7	2.7	3.1	2.1	1.8	"
COD	Total	40	33	28	29	25	"
	Soluble	27	21	19	19	21	"
SS		46	45	32	37	43	"
VS		12	10	-	-	-	"
NH_4-N		0.4	0.4	0.5	0.5	0.5	"
NO_2-N		0.00	0.01	0.01	0.02	0.02	"
NO_3-N		0.00	0.01	0.02	0.03	0.03	"
T-P		-	-	-	-	-	"
Coliform Count		4.8 x E5	1.2 x E4	-	3.7 x E3	1.3 x E3	col/100 ml
Chlorophyll-a		-	-	-	0.009	0.014	μg/l

Table D.15 Removal Efficiencies in Each Pond in Case-4
(3, Aug. - 17, Aug.)

Parameter		Aerated Lagoon	Open Channel	Facultative Pond	Maturation Pond
BOD	Total	39%	46%	44%	36%
	Soluble	53	46	63	68
COD	Total	18	30	28	38
	Soluble	22	30	30	22
SS		2	30	20	7
NH_4-N		0	-	-	-
T-P		-	-	-	-
Coliform		97.5	-	99.2	99.7

Table D.16 Results of Heavy Metal Analysis

Unit: mg/l

Parameter	Cd	Cr	Pb	Hg
Influent	0.001	0.043	0.02	ND
Aerated Lagoon	0.002	0.150	0.43	ND
Facultative Pond	ND	0.021	0.15	ND
Maturation Pond	ND	0.007	0.10	ND

FIG. D.1 LOCATION OF THE RAMA IX POND

THE FEASIBILITY STUDY ON PURIFICATION OF KLONG WATER IN BANGKOK

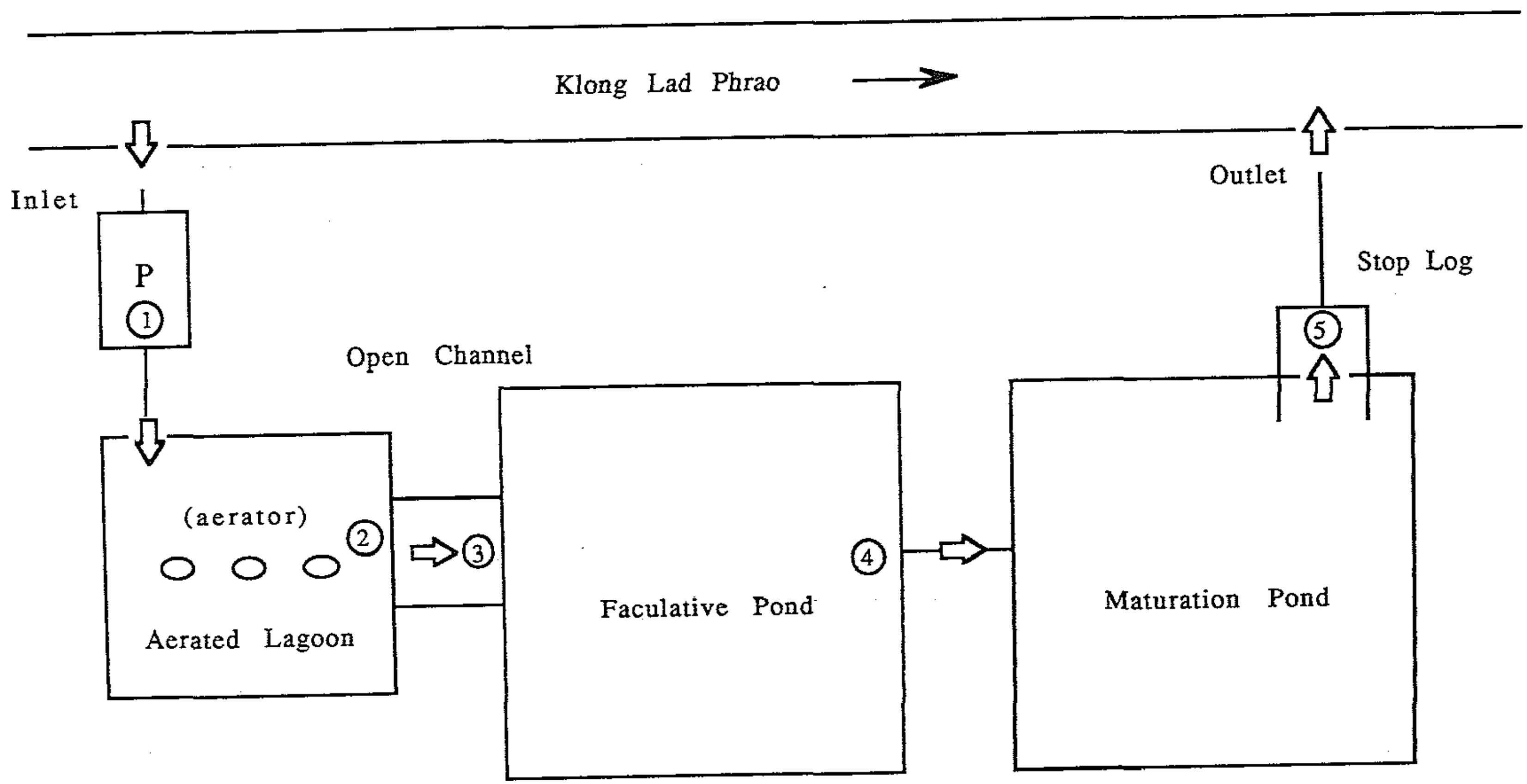


FIG. D . 2 LAYOUT OF THE RAMA IX POND AND LOCATION OF SAMPLING POINTS

THE FEASIBILITY STUDY ON PURIFICATION OF KLONG WATER IN BANGKOK

JICA 2532B.E. 1989A.D.

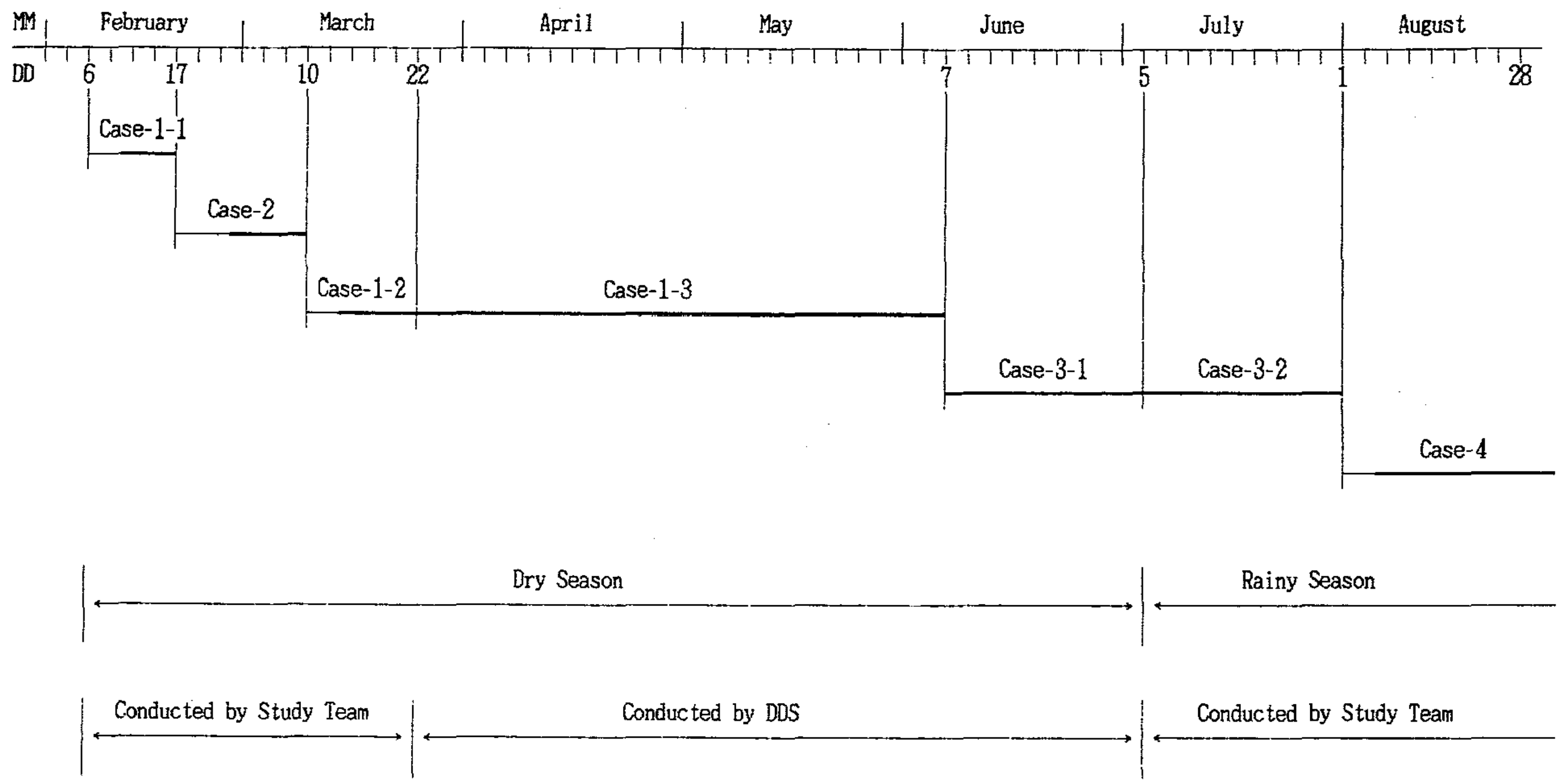


FIG. D . 3 SCHEDULE OF EXPERIMENTAL WORK AT RAMA IX POND

THE FEASIBILITY STUDY ON PURIFICATION OF KLONG WATER IN BANGKOK

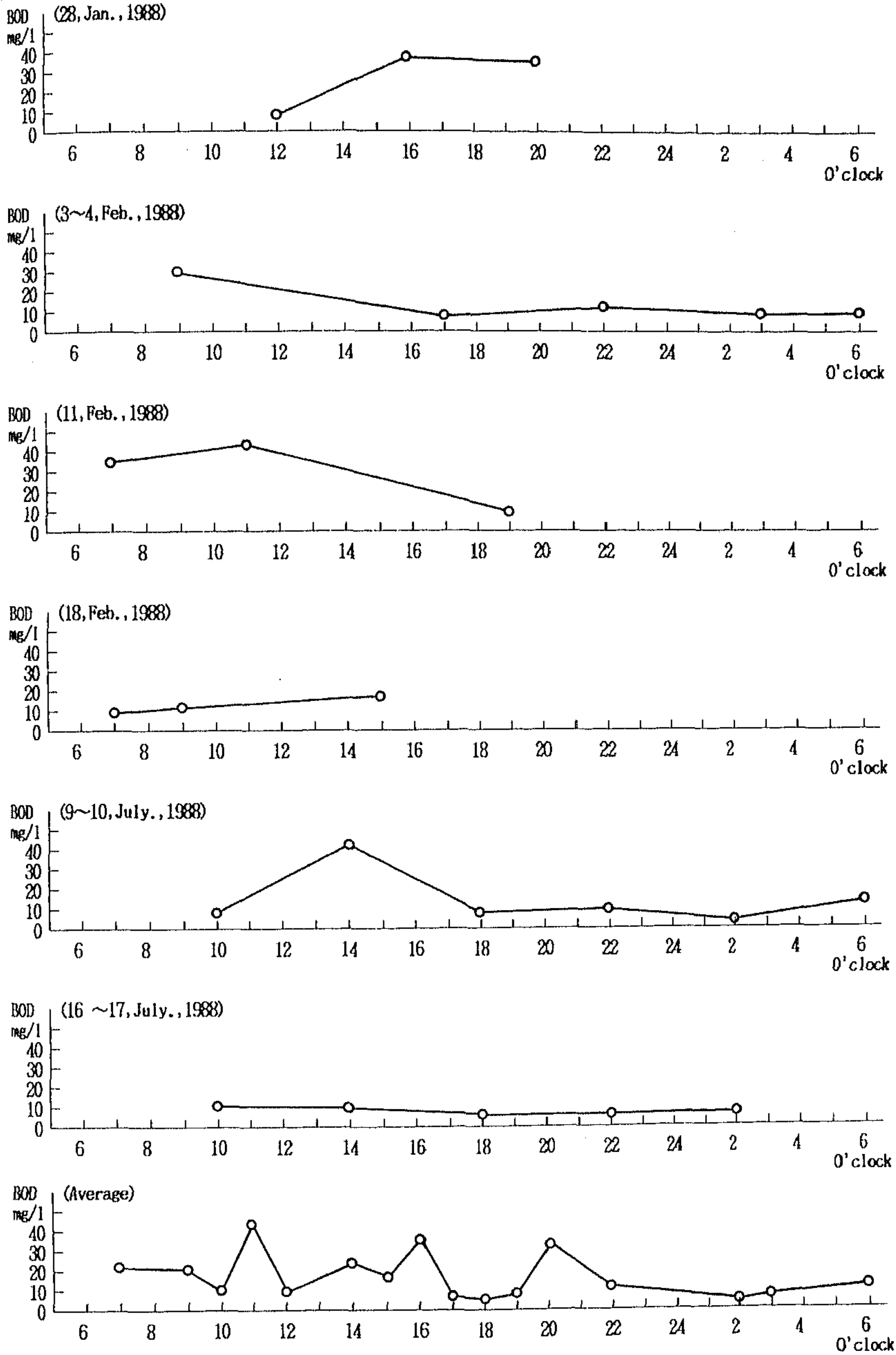


FIG. D.4 HOURLY VARIATION OF BOD IN K. LAD PHRAO (AT ST. 10)

THE FEASIBILITY STUDY ON PURIFICATION OF KLONG WATER IN BANGKOK

JICA 2532B.E. 1989A.D.

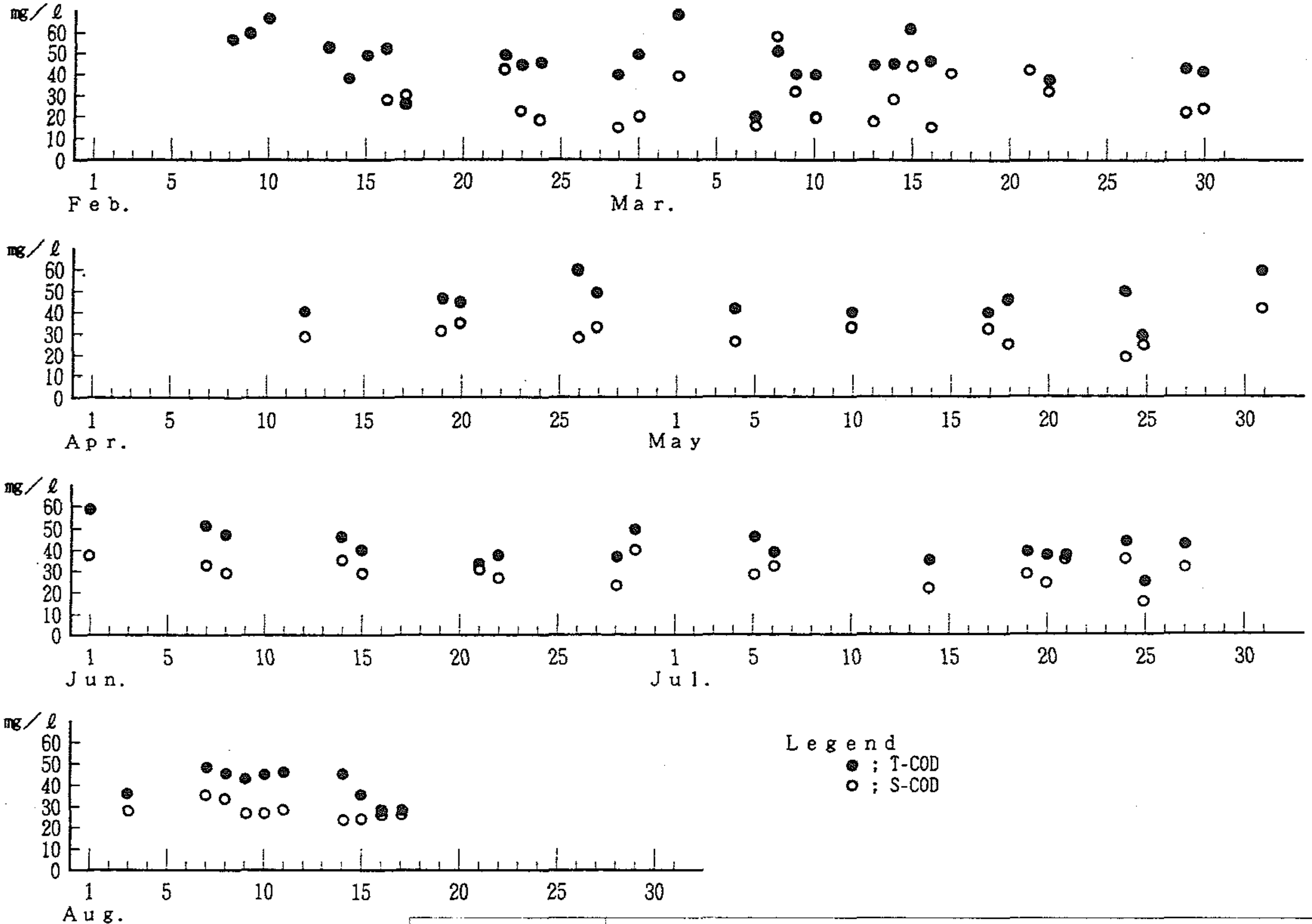


FIG. D.5 (1) THE VARIATION IN WASTEWATER INFLUENT

THE FEASIBILITY STUDY ON PURIFICATION OF KLONG WATER IN BANGKOK

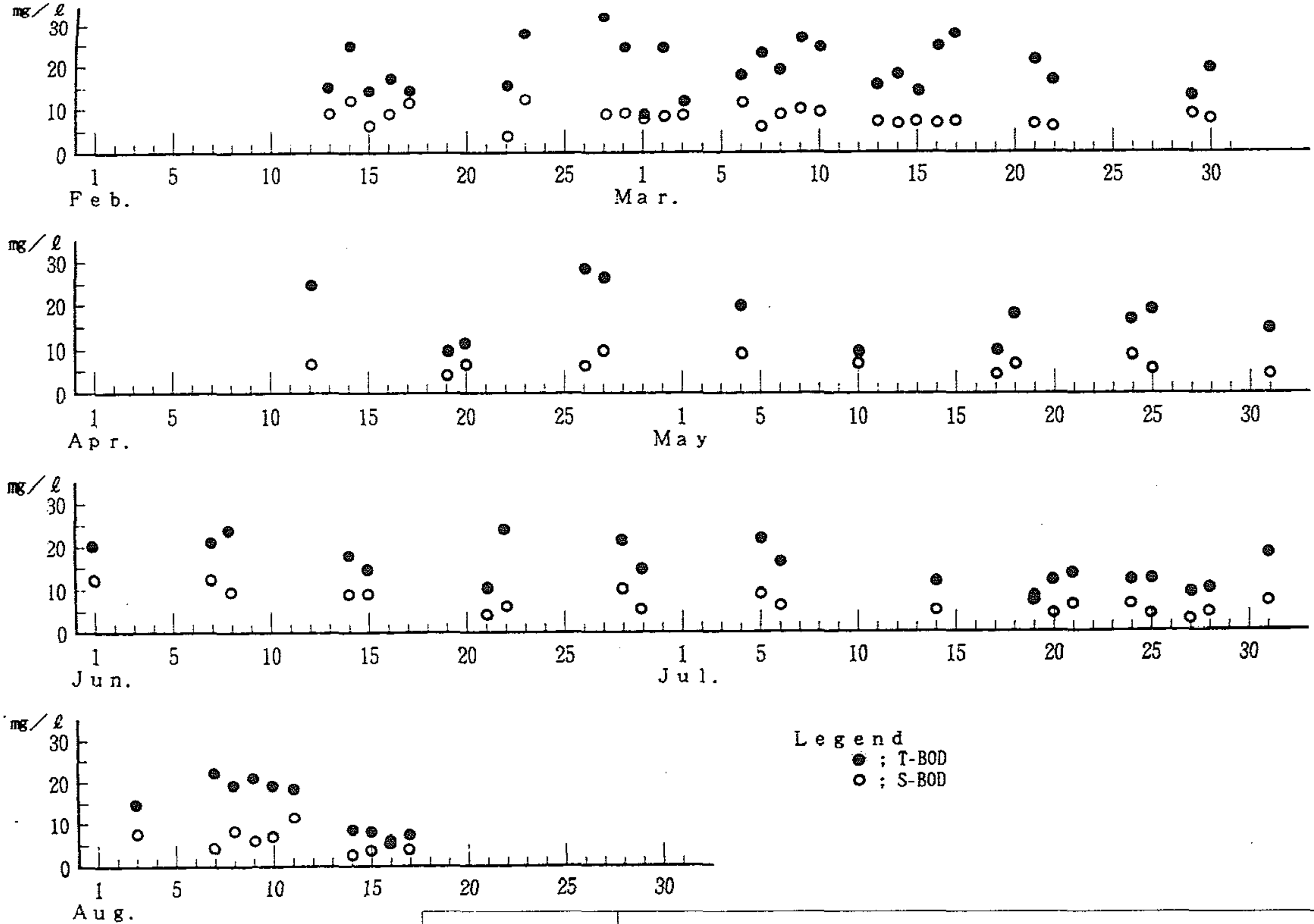
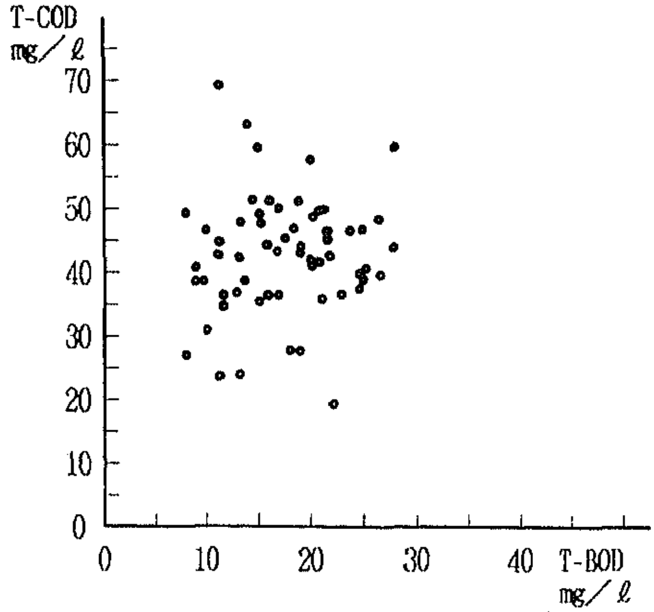


FIG. D.5(2) THE VARIATION IN WASTEWATER INFLUENT

THE FEASIBILITY STUDY ON PURIFICATION OF KLONG WATER IN BANGKOK

(1) T-BOD — T-COD



(2) S-BOD — S-COD

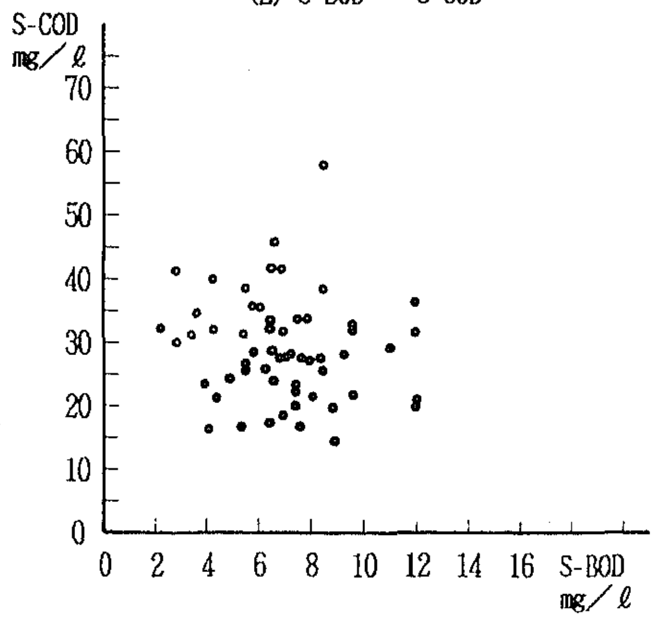


FIG. D.6	CORRELATION BETWEEN BOD AND COD IN INFLUENT WATER

THE FEASIBILITY STUDY ON PURIFICATION OF KLONG WATER IN BANGKOK

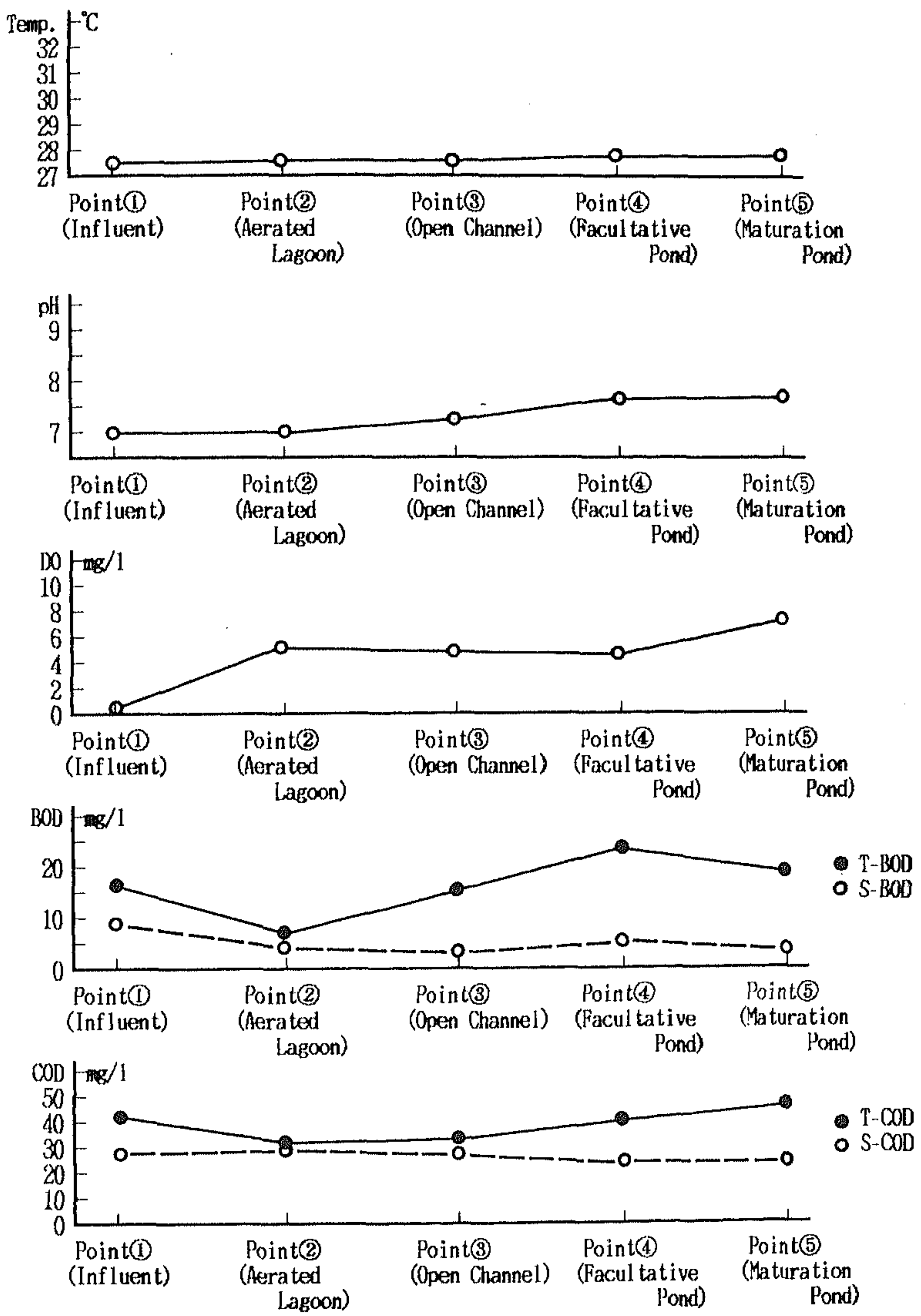


FIG. D.7(1) LONGITUDINAL VARIATION OF WATER QUALITY IN CASE 1-1

THE FEASIBILITY STUDY ON PURIFICATION OF KLONG WATER IN BANGKOK

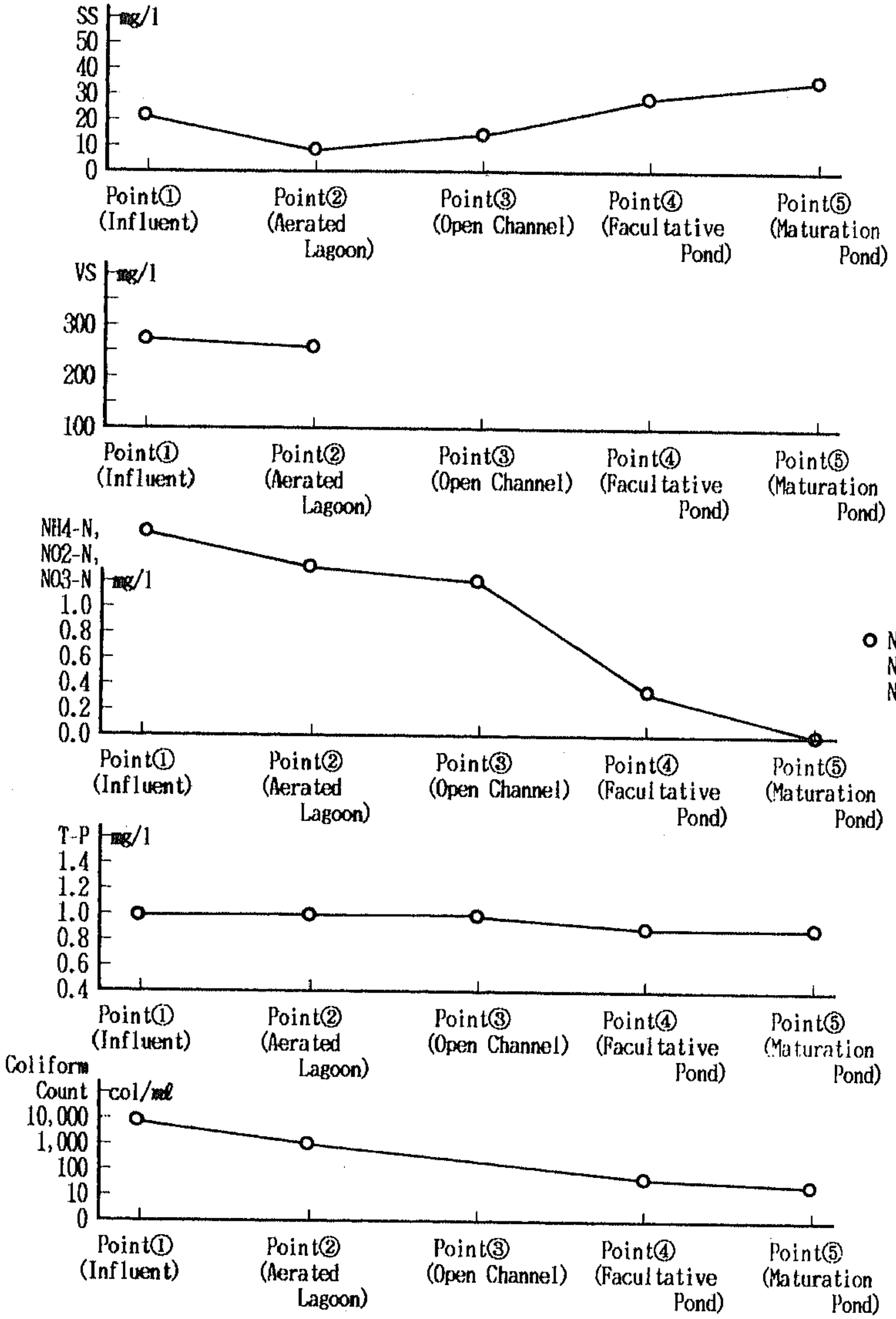


FIG. D.7(2) LONGITUDINAL VARIATION OF WATER QUALITY IN CASE 1-1

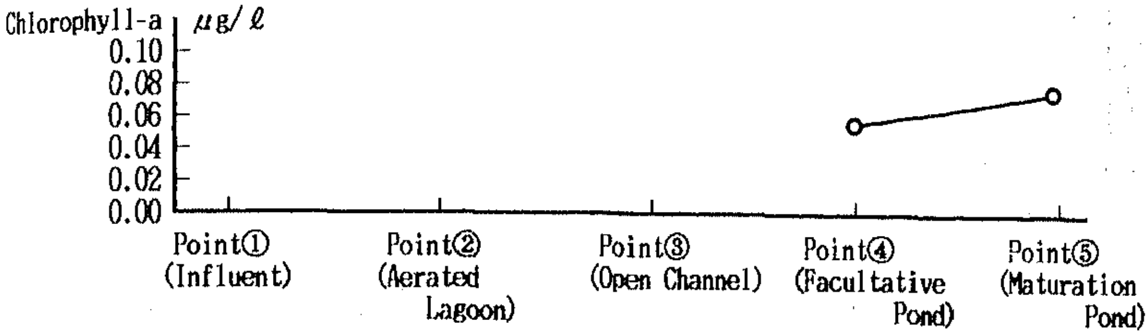


FIG. D.7(3)	LONGITUDINAL VARIATION OF WATER QUALITY IN CASE 1-1

THE FEASIBILITY STUDY ON PURIFICATION OF KLONG WATER IN BANGKOK

JICA 2532B.E. 1989A.D.

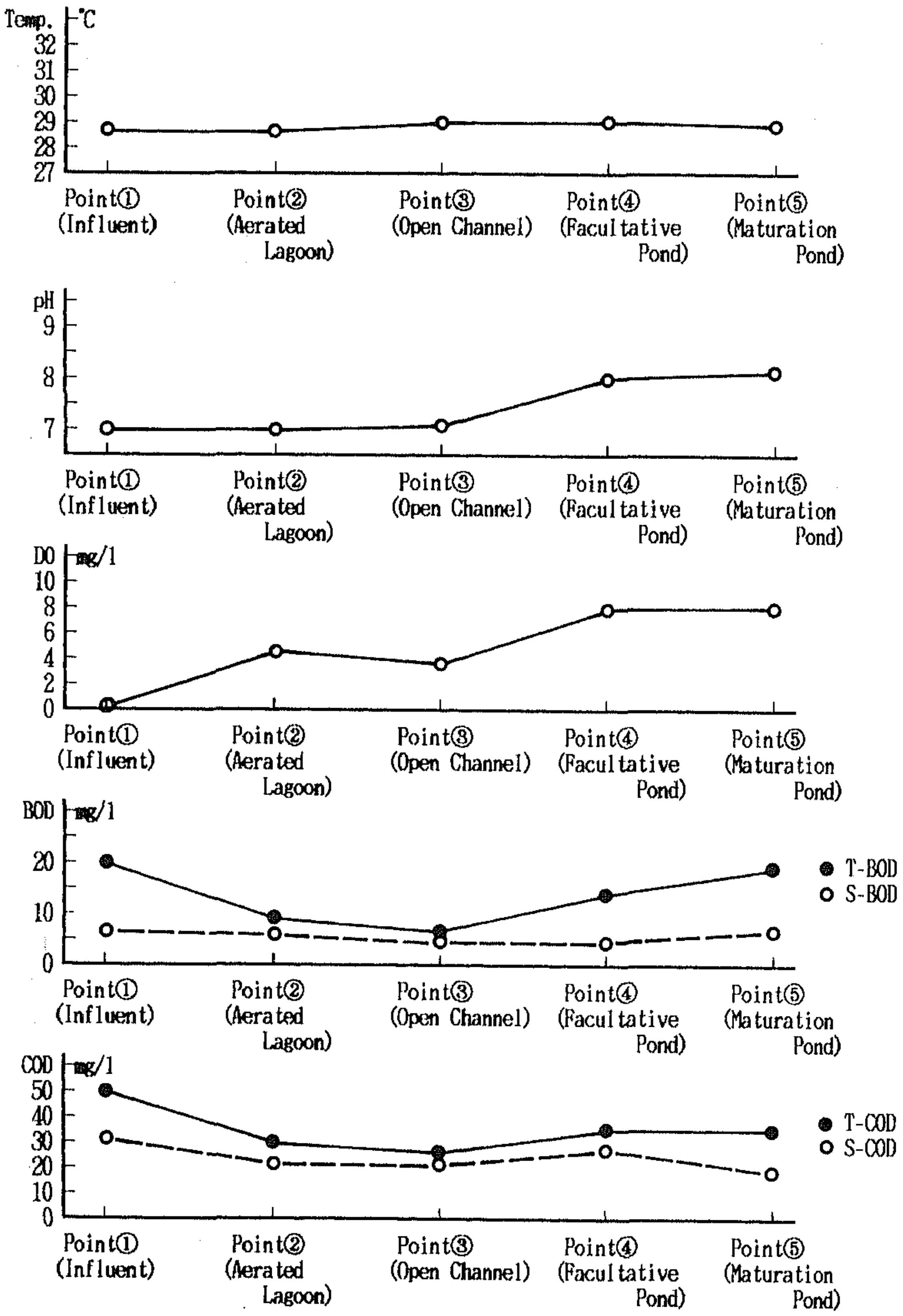


FIG. D.8 (1) LONGITUDINAL VARIATION OF WATER QUALITY IN CASE 1-2

THE FEASIBILITY STUDY ON PURIFICATION OF KLONG WATER IN BANGKOK

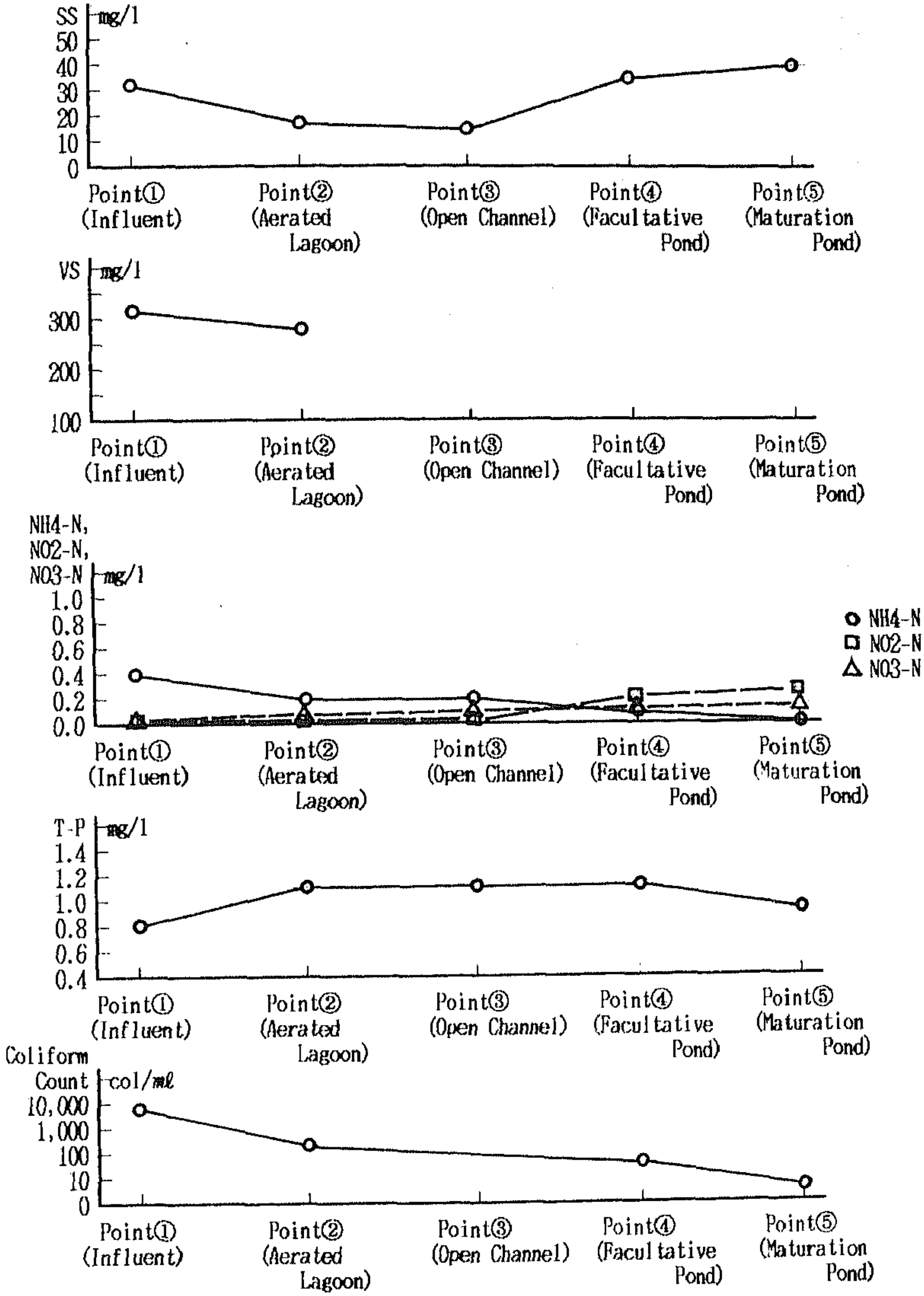


FIG. D.8(2) LONGITUDINAL VARIATION OF WATER QUALITY IN CASE 1-2

THE FEASIBILITY STUDY ON PURIFICATION OF KLONG WATER IN BANGKOK

JICA 2532B.E. 1989A.D.

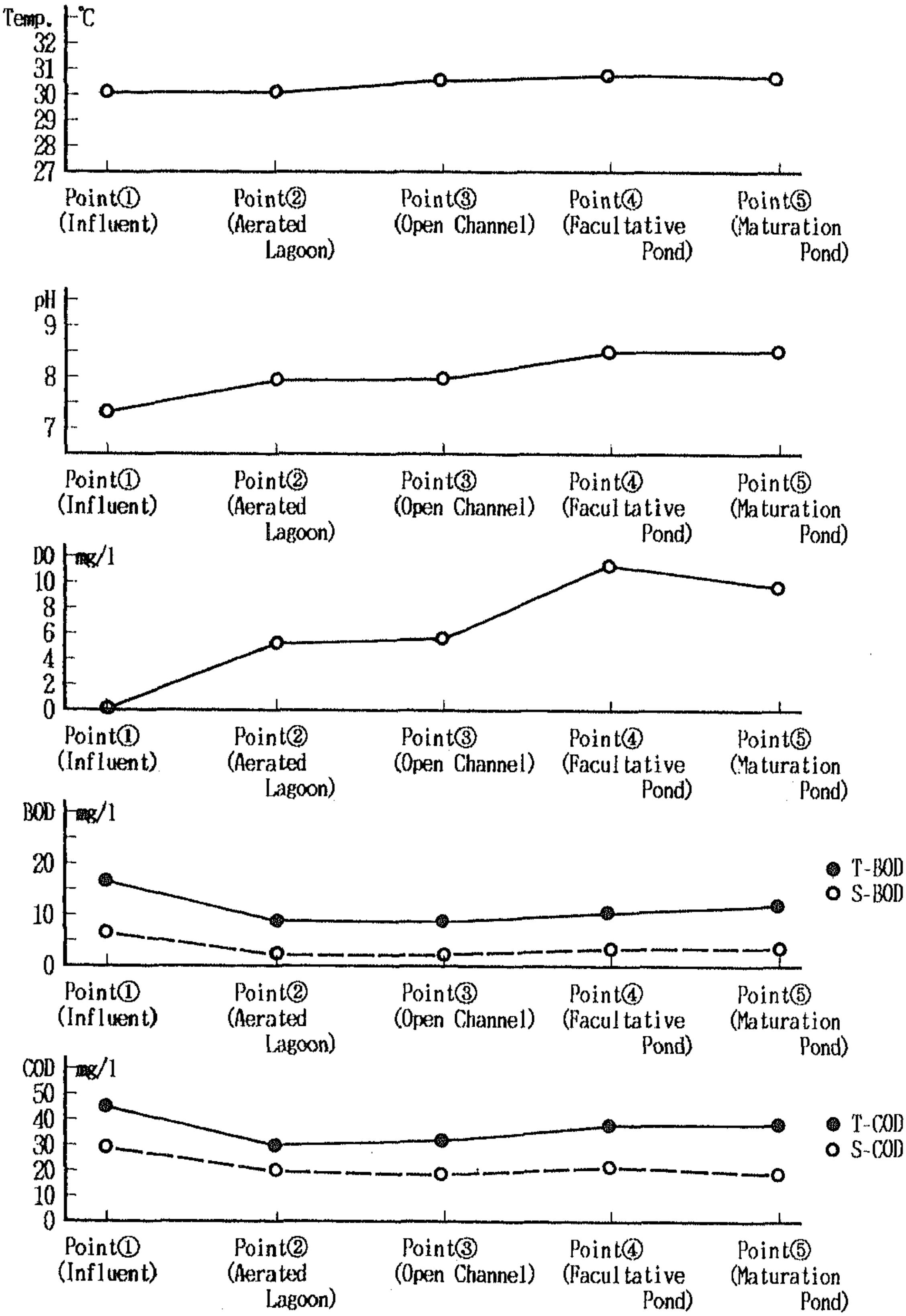


FIG. D.9 (1) LONGITUDINAL VARIATION OF WATER QUALITY IN CASE 1-3

THE FEASIBILITY STUDY ON PURIFICATION OF KLONG WATER IN BANGKOK

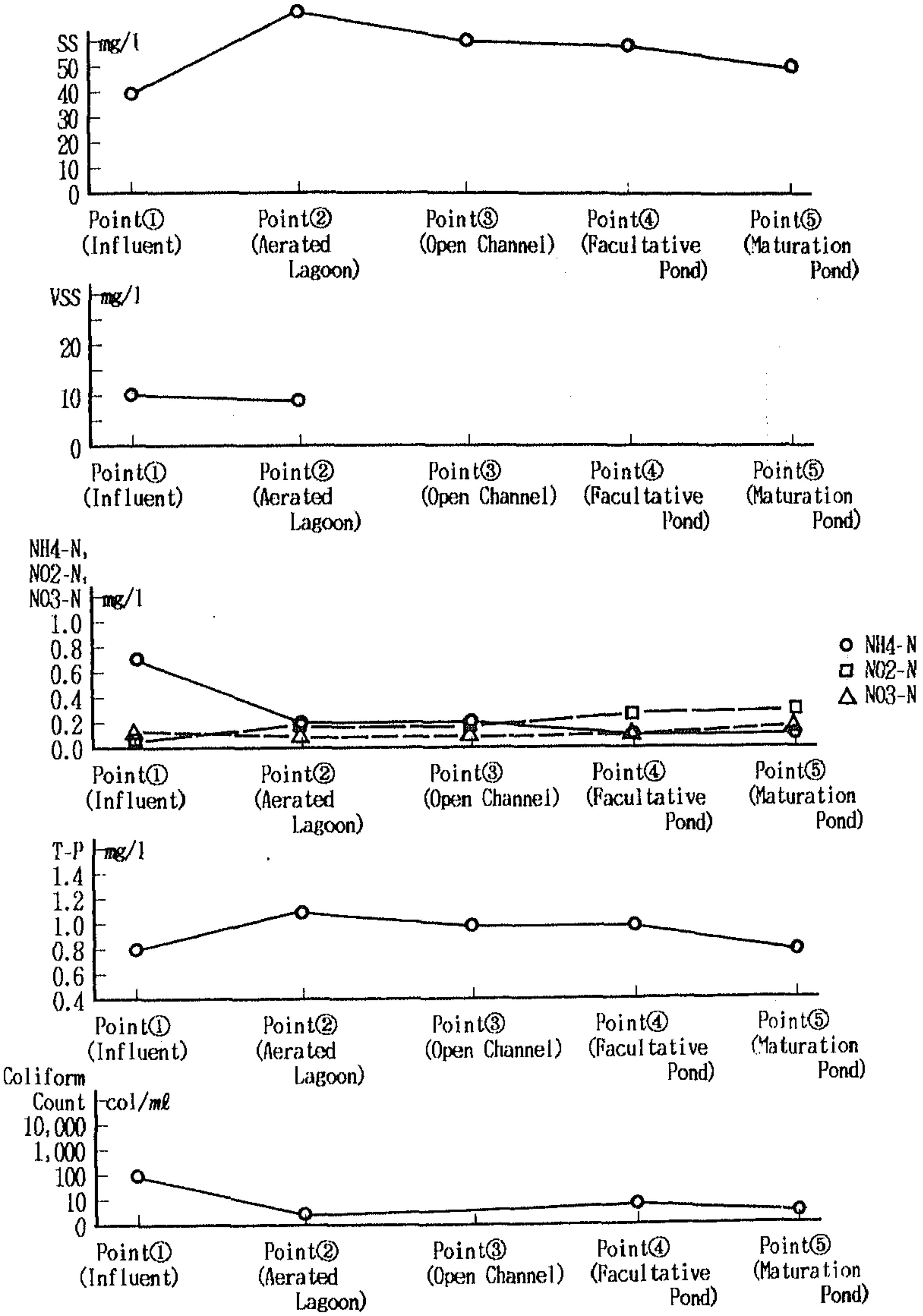
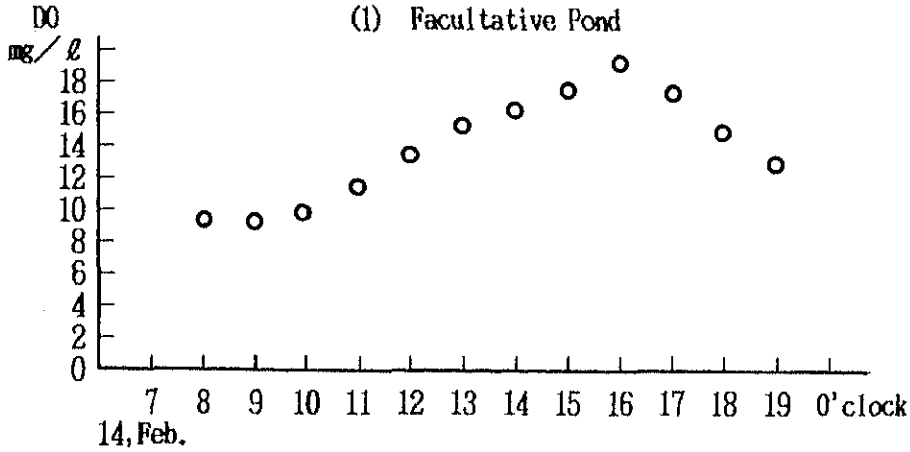


FIG. D.9 (2) LONGITUDINAL VARIATION OF WATER QUALITY IN CASE 1-3

THE FEASIBILITY STUDY ON PURIFICATION OF KLONG WATER IN BANGKOK



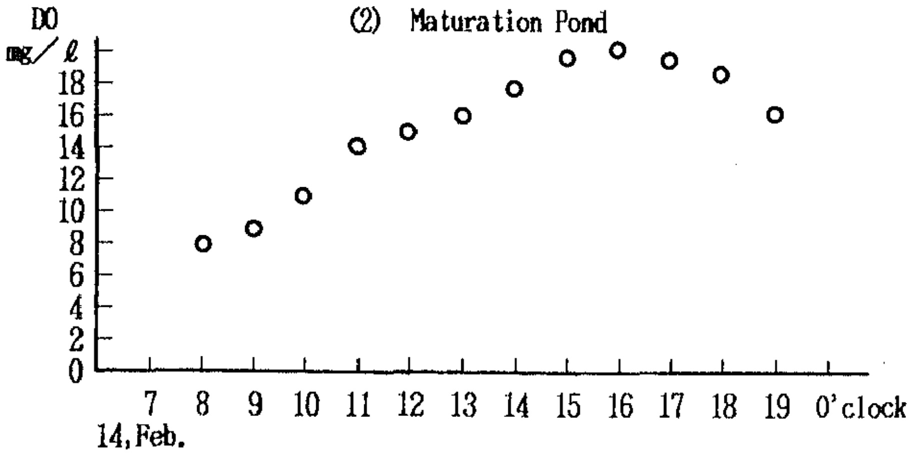


FIG. D.10	DO PROFILE OF FACULTATIVE AND MATURATION PONDS

THE FEASIBILITY STUDY ON PURIFICATION OF KLONG WATER IN BANGKOK

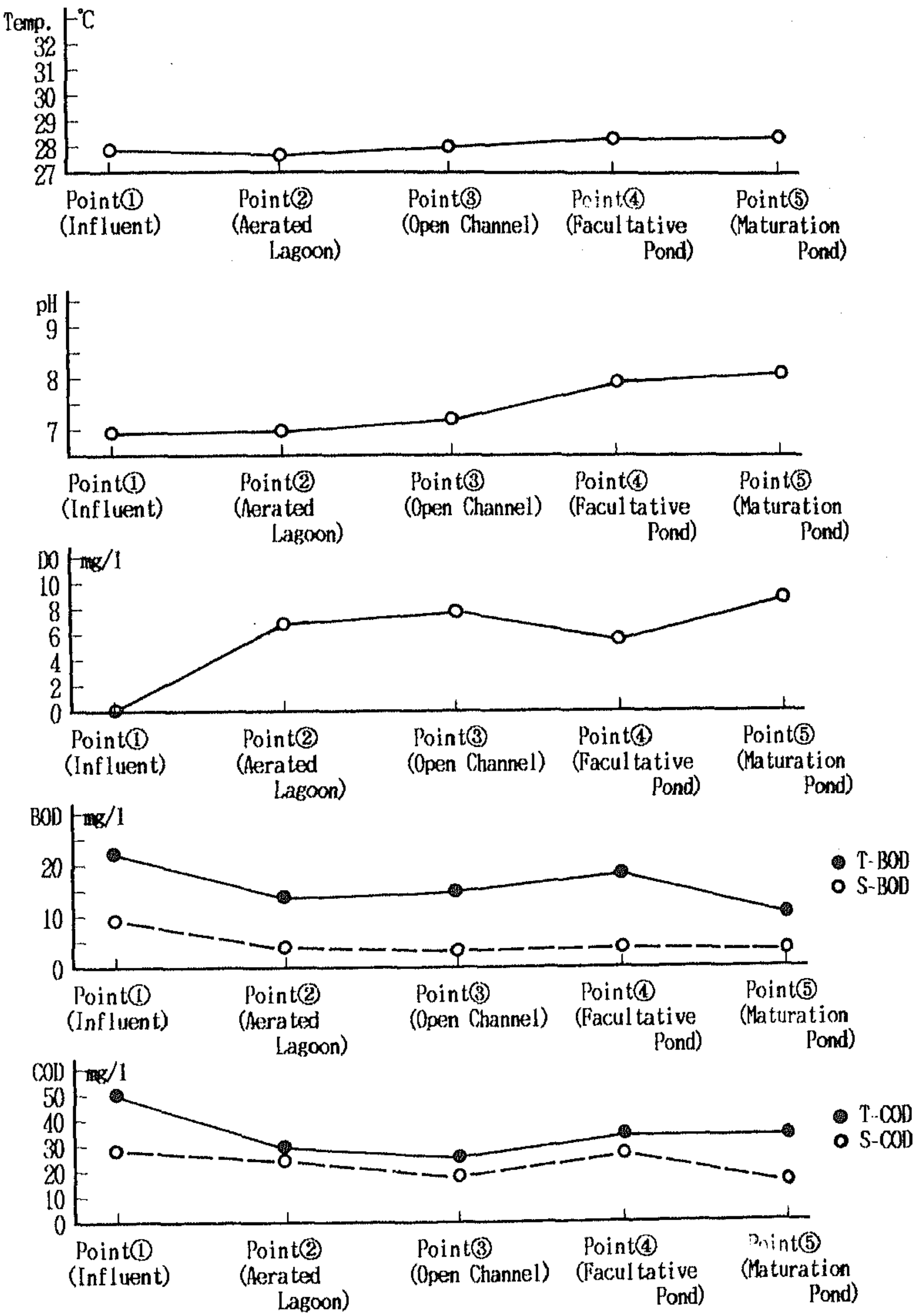


FIG. D.11(1) LONGITUDINAL VARIATION OF WATER QUALITY IN CASE 2

THE FEASIBILITY STUDY ON PURIFICATION OF KLONG WATER IN BANGKOK

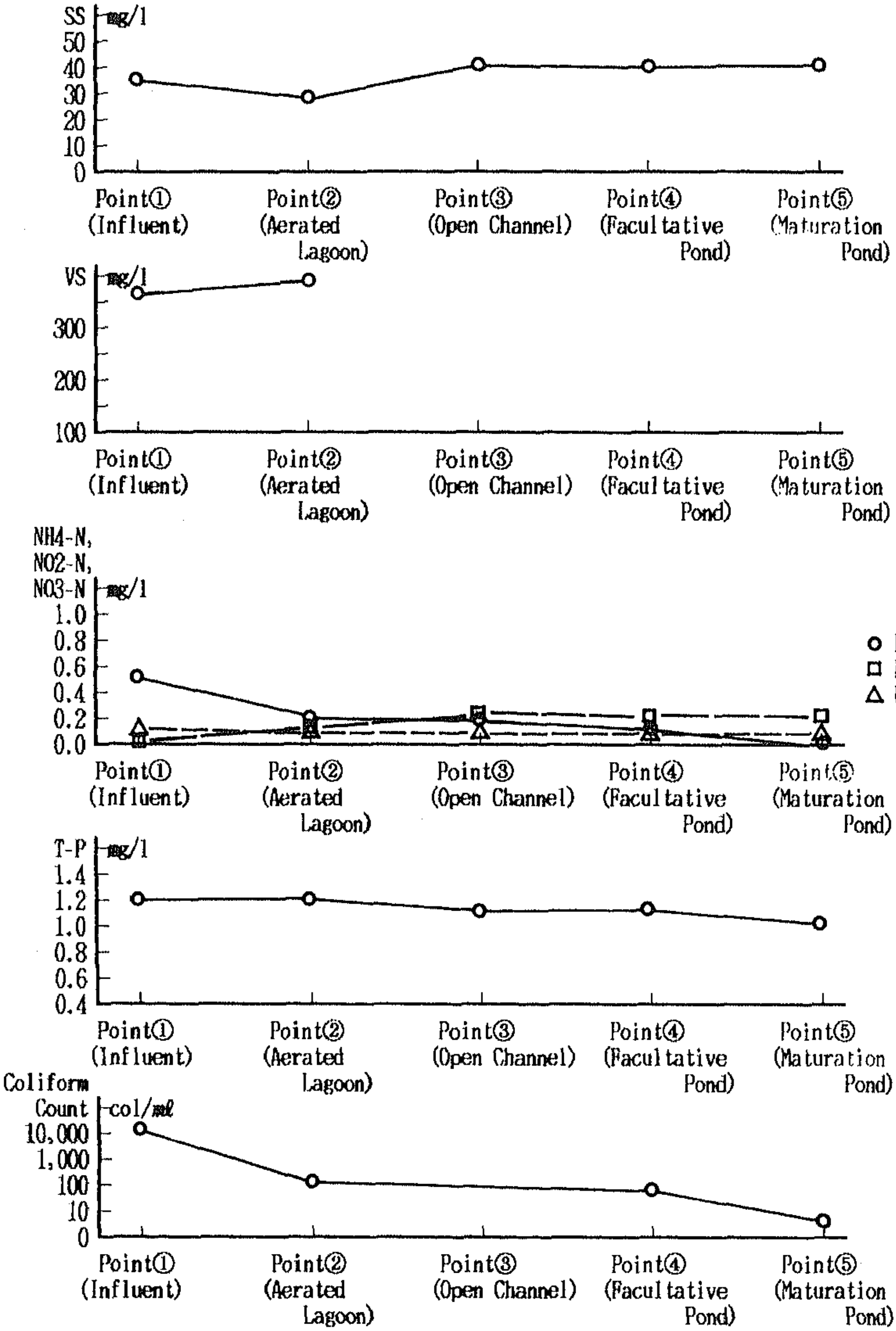


FIG. D.11(2)	LONGITUDINAL VARIATION OF WATER QUALITY IN CASE 2

THE FEASIBILITY STUDY ON PURIFICATION OF KLONG WATER IN BANGKOK

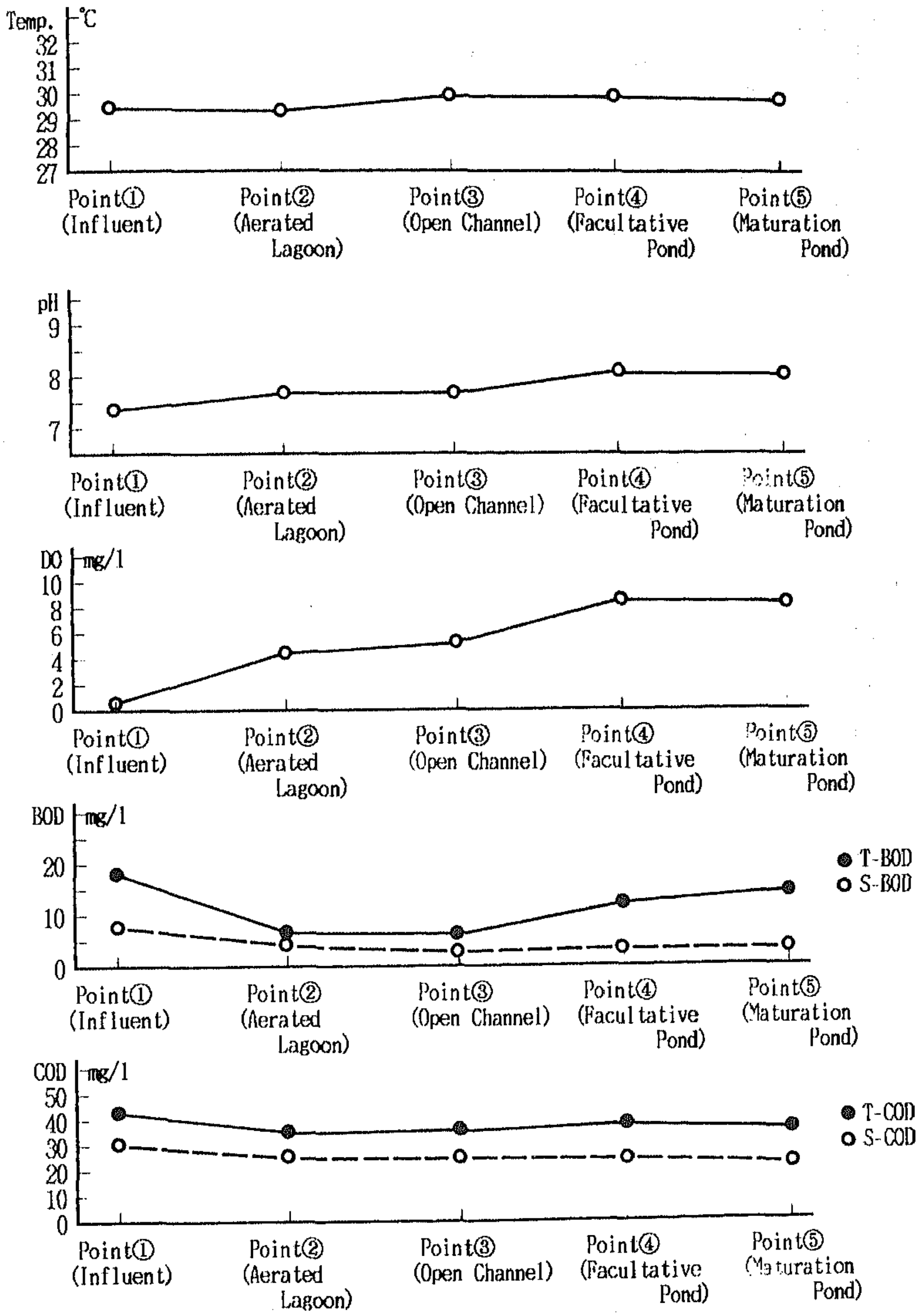


FIG. D.12(1)	LONGITUDINAL VARIATION OF WATER QUALITY IN CASE 3-1

THE FEASIBILITY STUDY ON PURIFICATION OF KLONG WATER IN BANGKOK

JICA 2532B.E. 1989A.D.

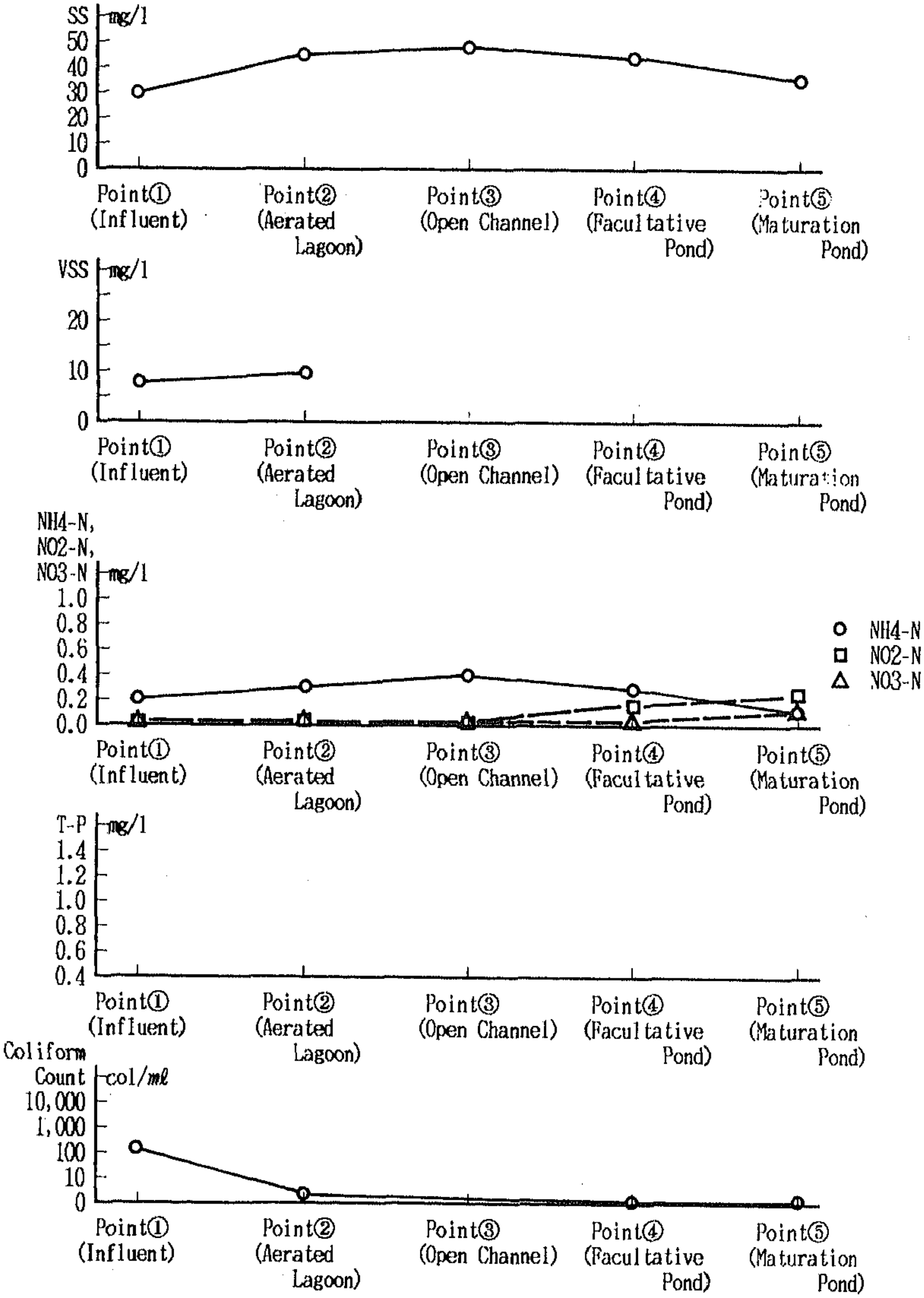


FIG. D.12 (2)	LONGITUDINAL VARIATION OF WATER QUALITY IN CASE 3-1

THE FEASIBILITY STUDY ON PURIFICATION OF KLONG WATER IN BANGKOK

JICA 2532B.E. 1989A.D.

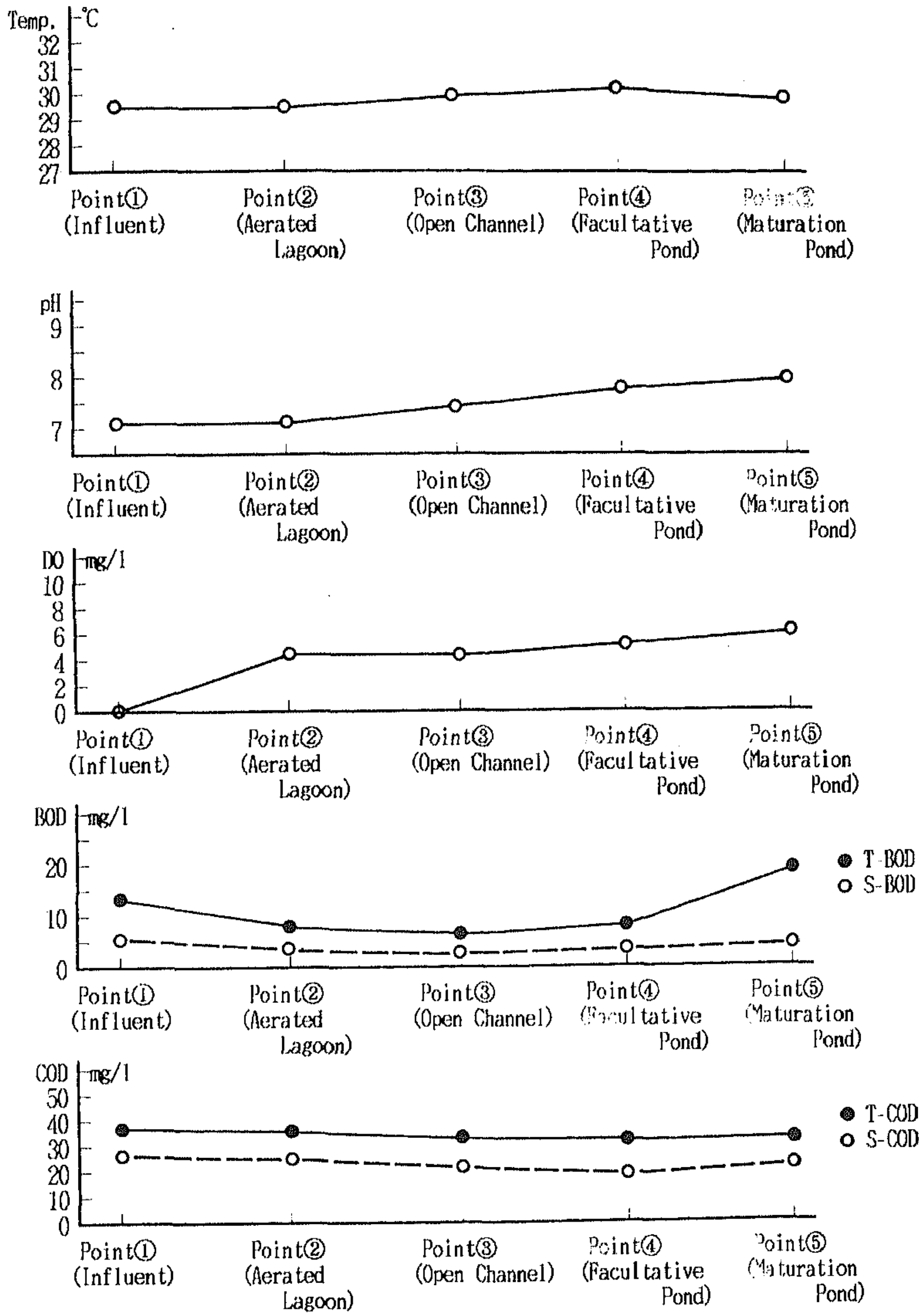


FIG. D.13 (1) LONGITUDINAL VARIATION OF WATER QUALITY IN CASE 3-2

THE FEASIBILITY STUDY ON PURIFICATION OF KLONG WATER IN BANGKOK

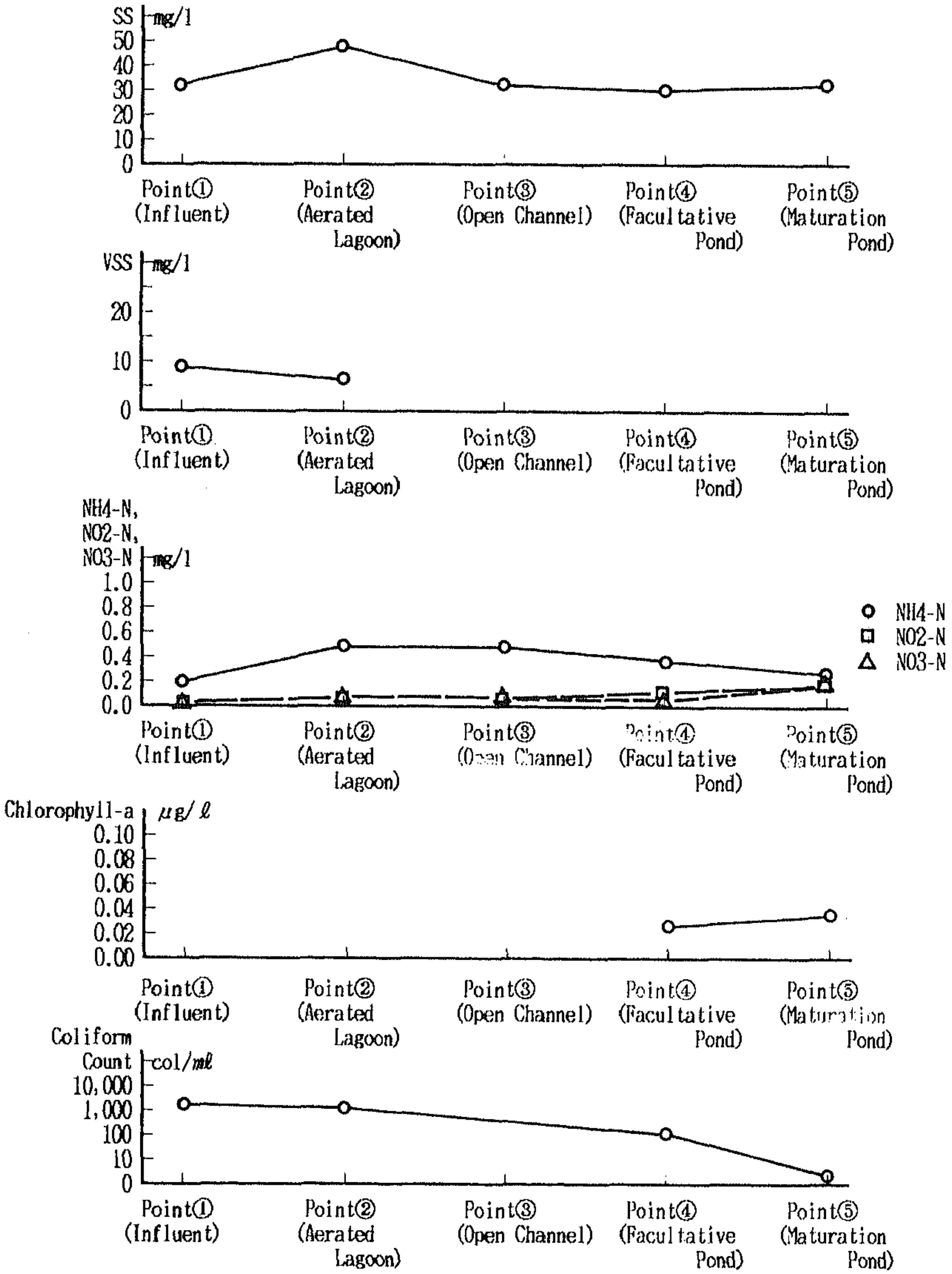


FIG. D.13 (2) LONGITUDINAL VARIATION OF WATER·QUALITY IN CASE 3-2

THE FEASIBILITY STUDY ON PURIFICATION OF KLONG WATER IN BANGKOK

JICA 2532B.E. 1989A.D.

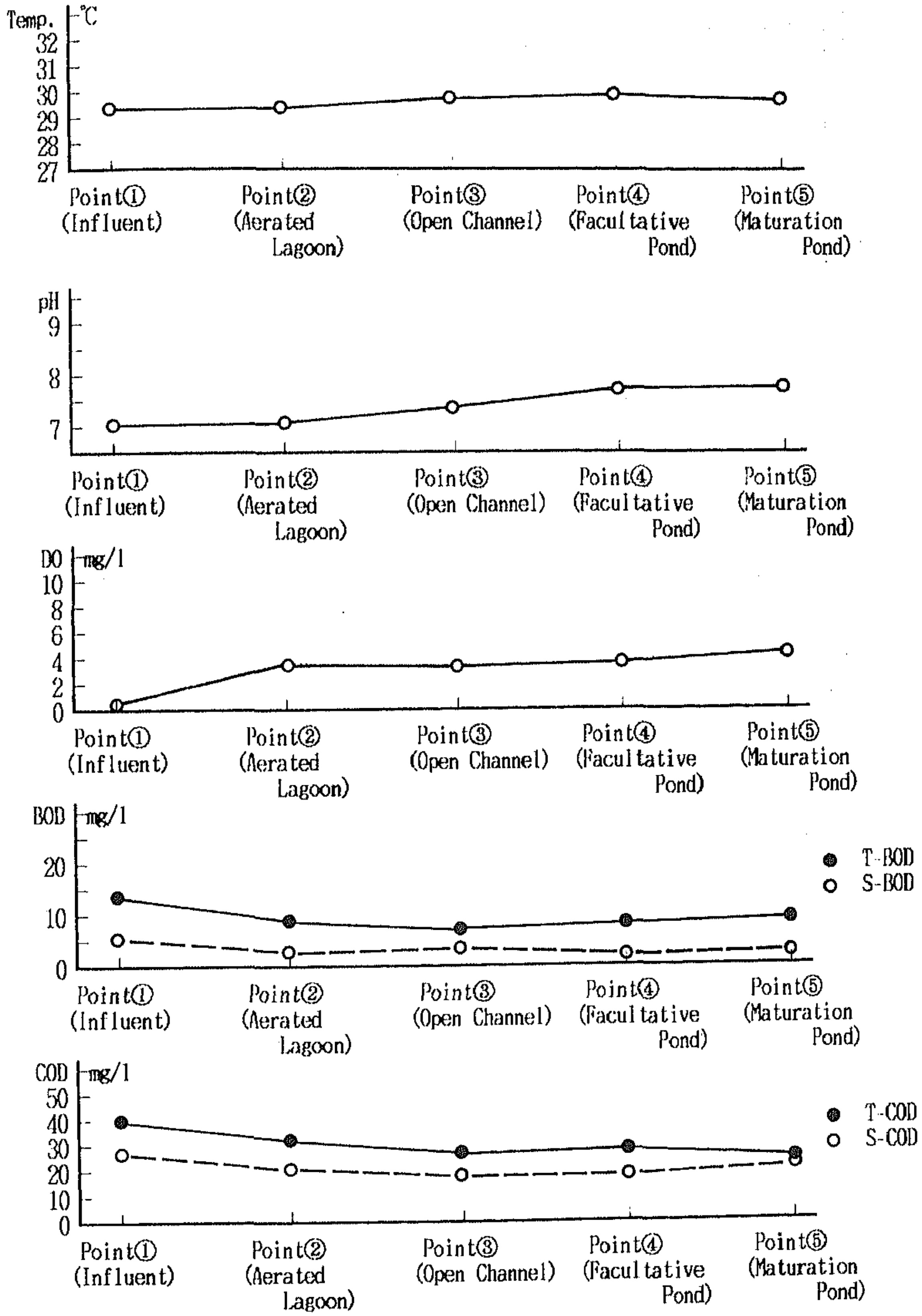


FIG. D.14 (1)	LONGITUDINAL VARIATION OF WATER QUALITY IN CASE 4

THE FEASIBILITY STUDY ON PURIFICATION OF KLONG WATER IN BANGKOK

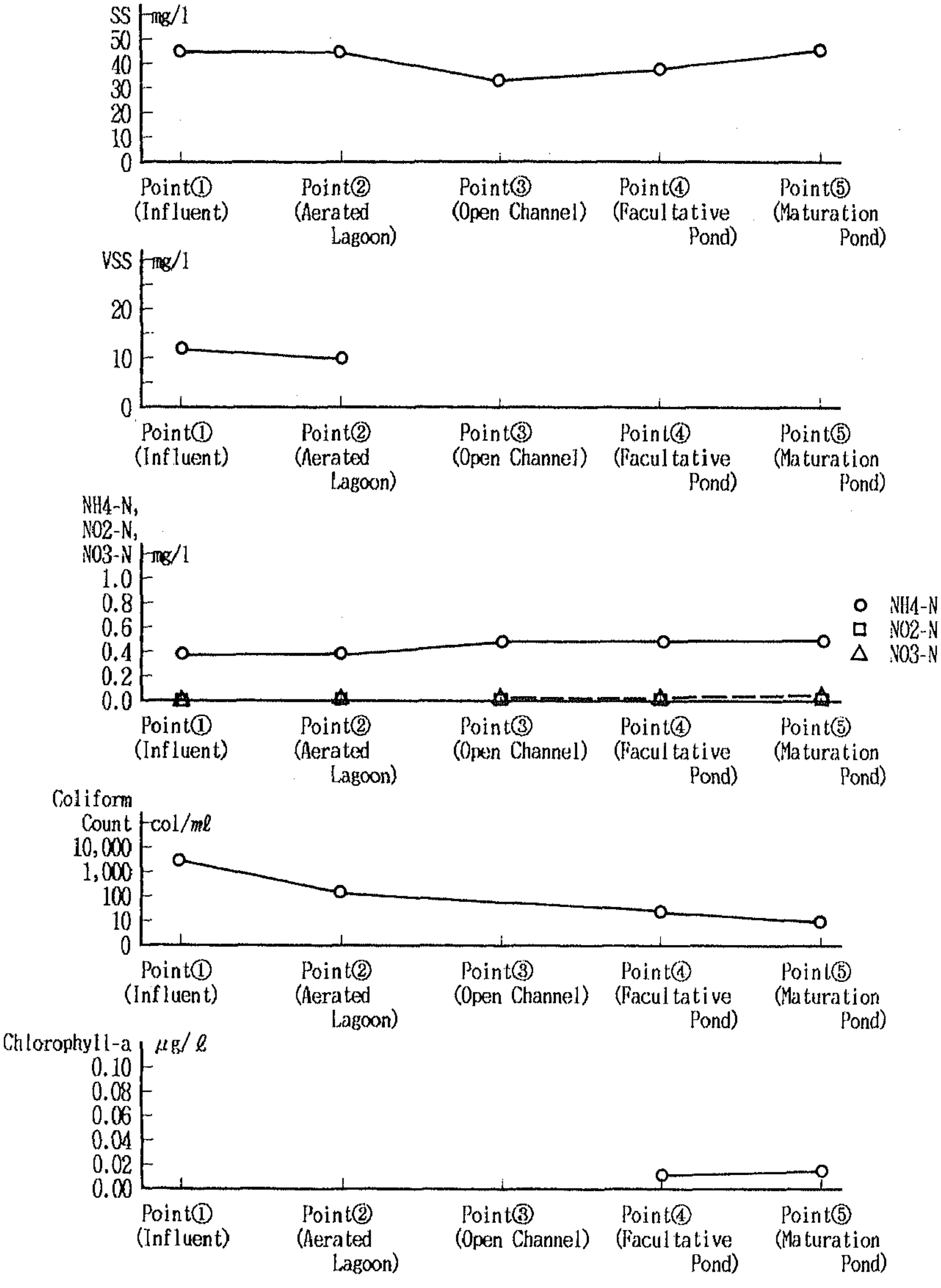


FIG. D.14 (2) LONGITUDINAL VARIATION OF WATER QUALITY IN CASE 4

THE FEASIBILITY STUDY ON PURIFICATION OF KLONG WATER IN BANGKOK

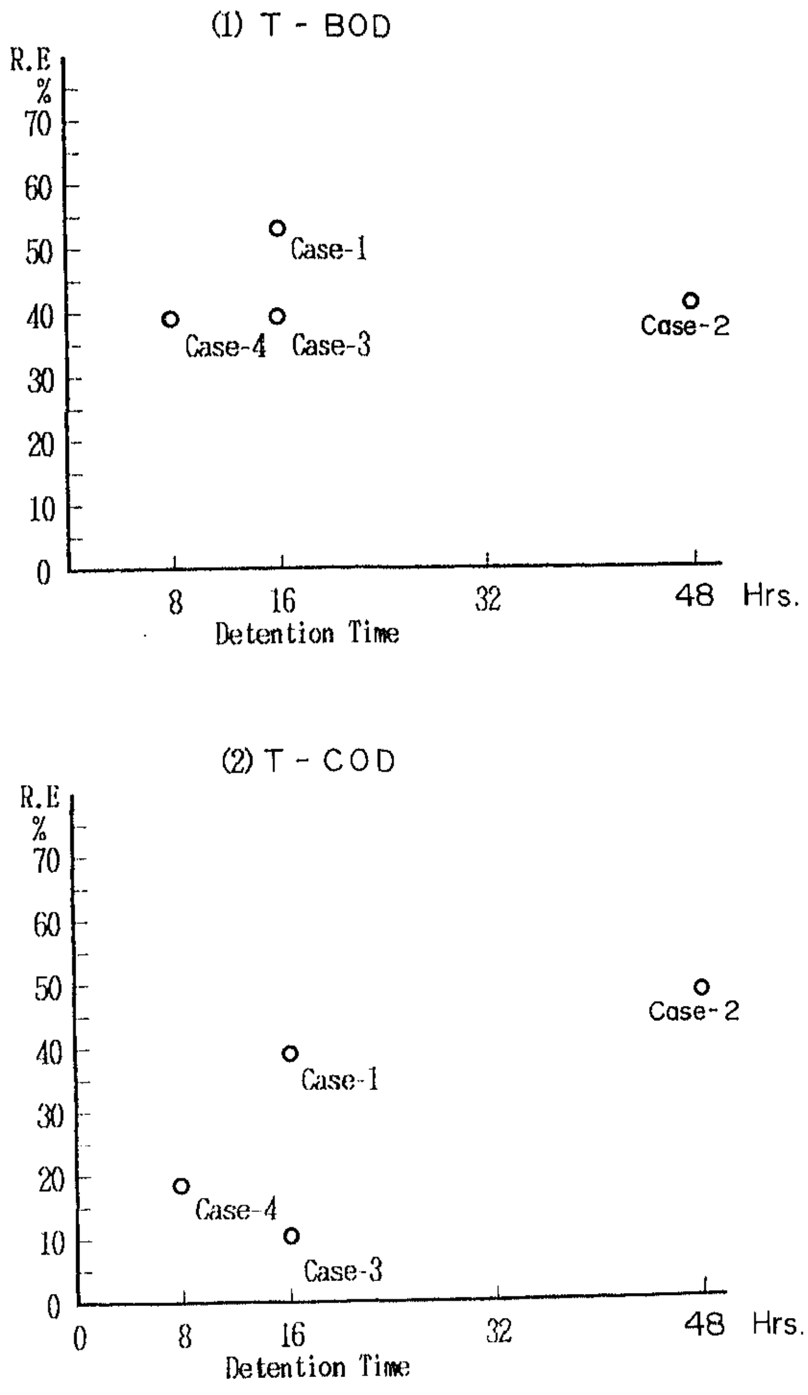
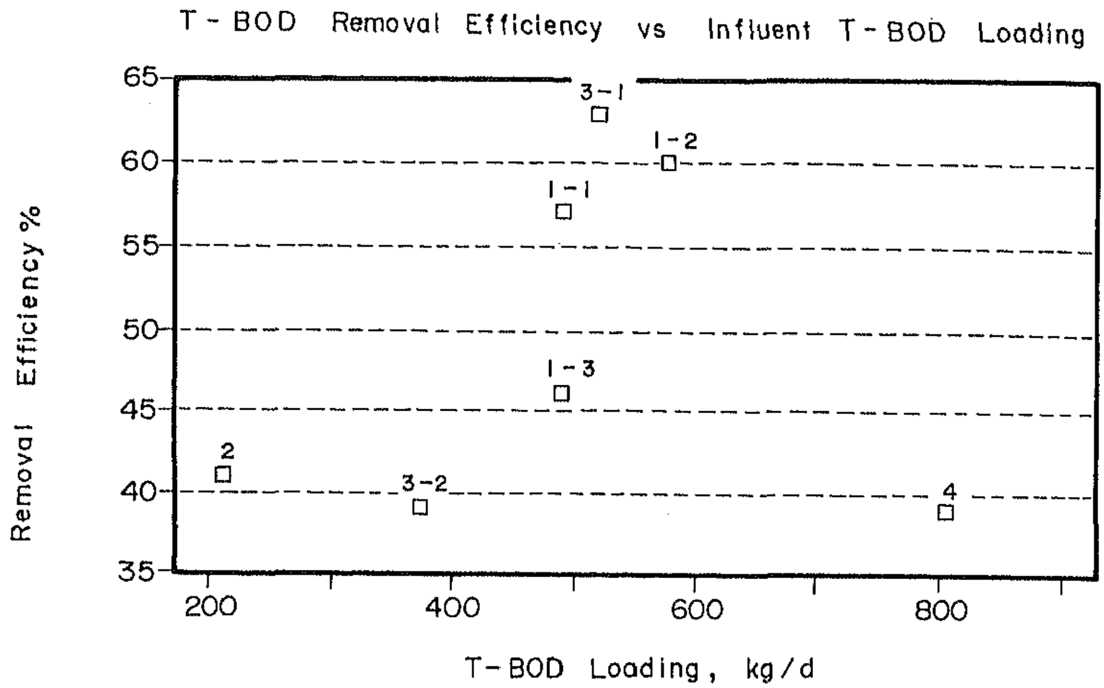


FIG. D.15	CORRELATION BETWEEN REMOVAL EFFICIENCY AND DETENTION TIME

THE FEASIBILITY STUDY ON PURIFICATION OF KLONG WATER IN BANGKOK



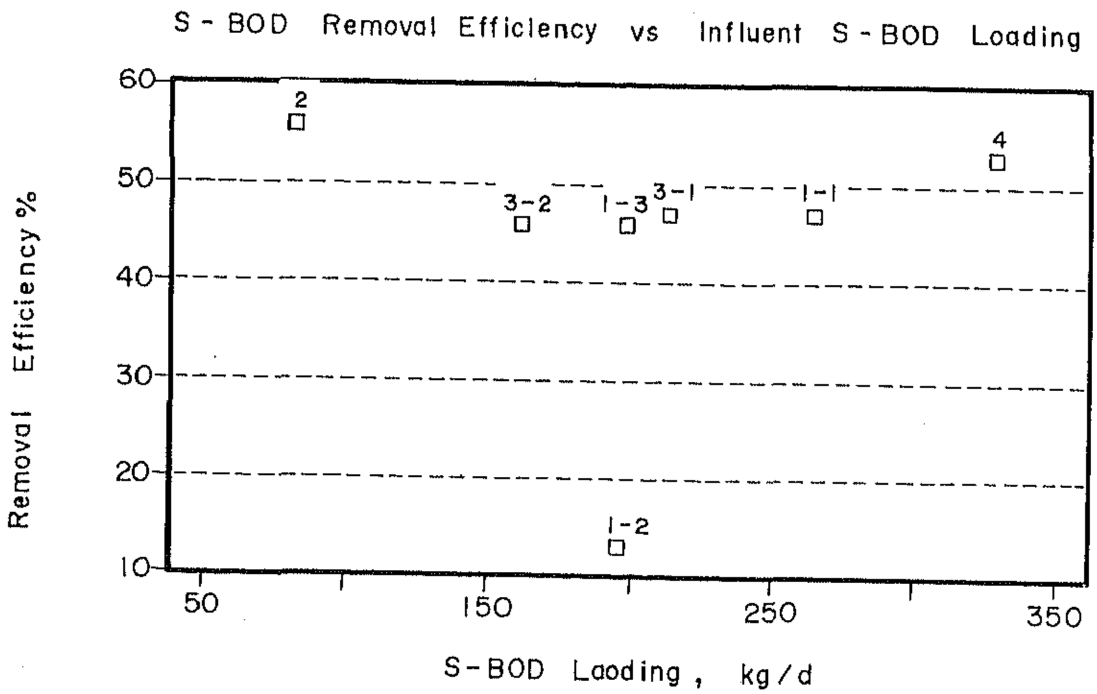
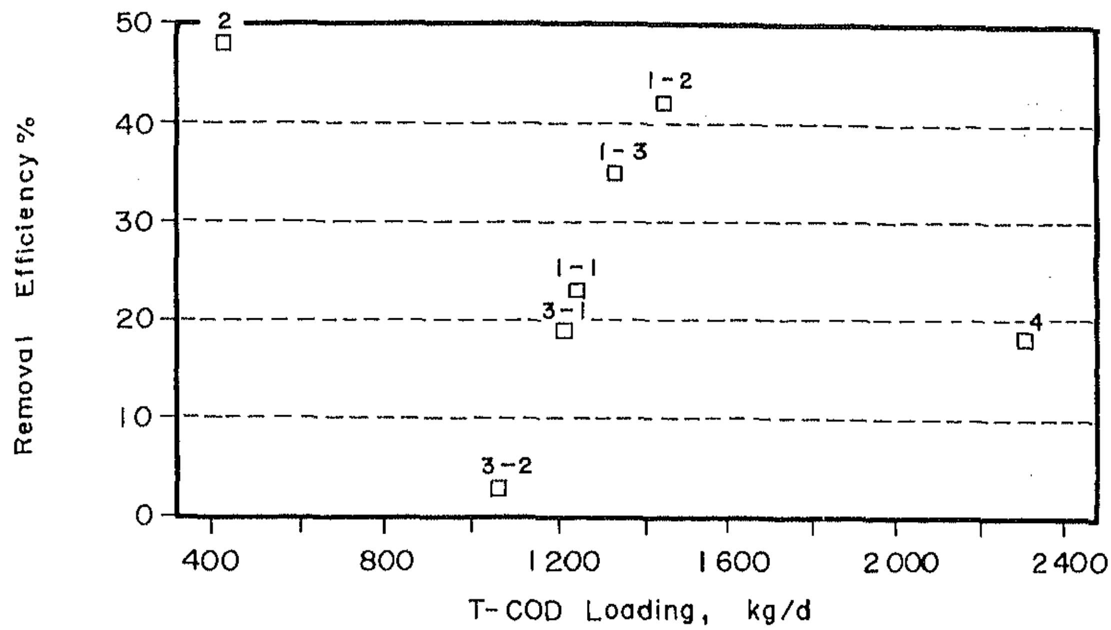


FIG. D.16	CORRELATION BETWEEN BOD REMOVAL EFFICIENCY AND INFLUENT BOD LOADING

THE FEASIBILITY STUDY ON PURIFICATION OF KLONG WATER IN BANGKOK

T - COD Removal Efficiency vs Influent T - COD Loading



S - COD Removal Efficiency vs Influent S - COD Loading

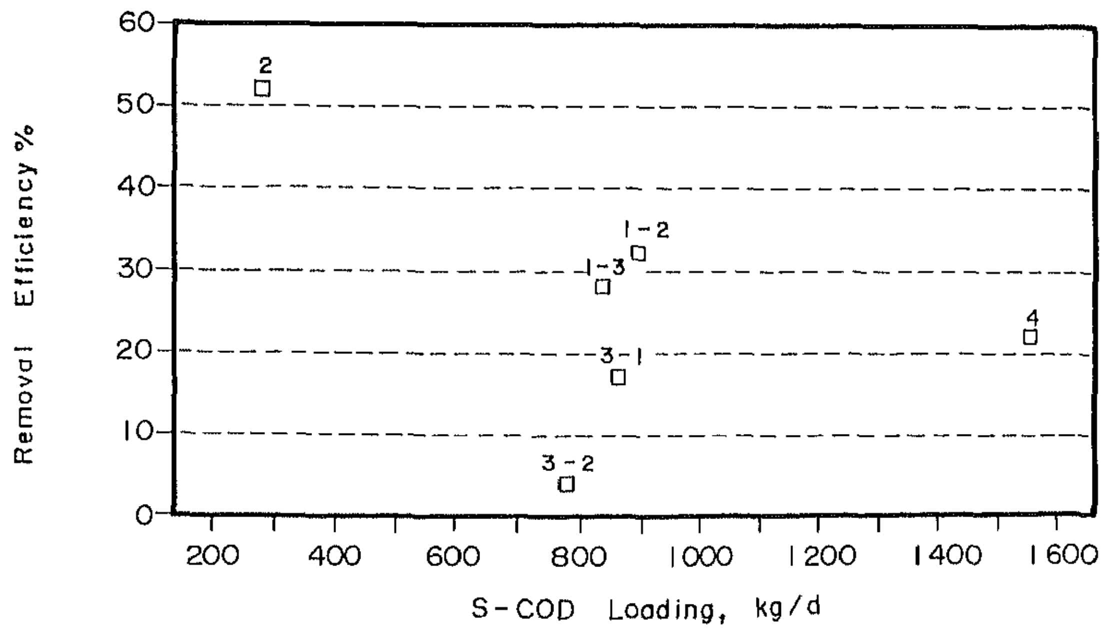
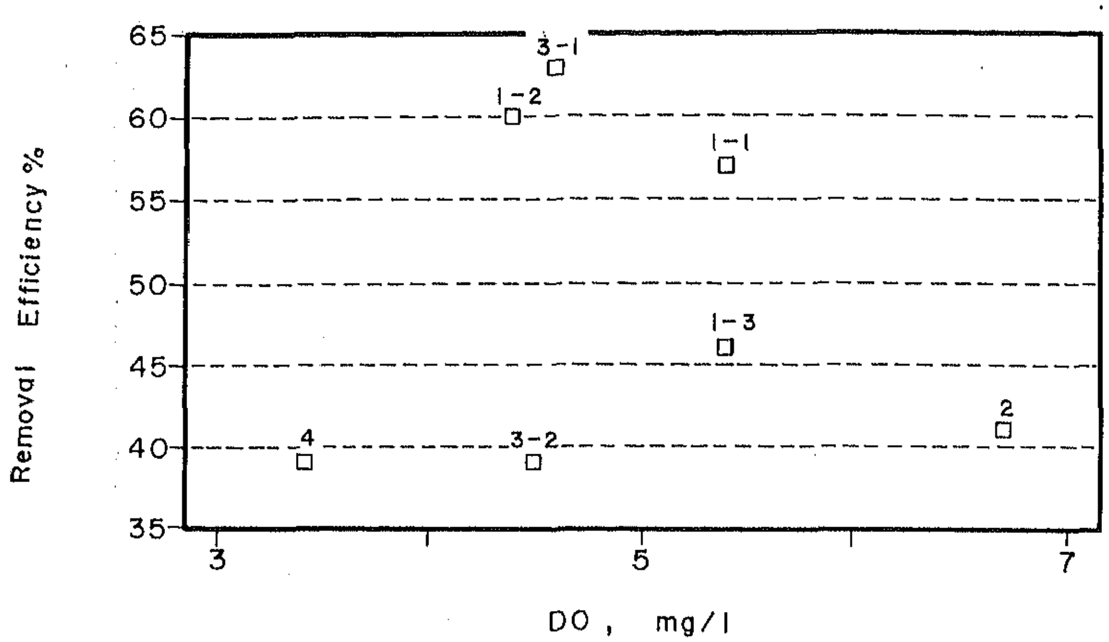


FIG. D. 17	CORRELATION BETWEEN COD REMOVAL EFFICIENCY AND INFLUENT COD LOADING

THE FEASIBILITY STUDY ON PURIFICATION OF KLONG WATER IN BANGKOK

T - BOD Removal Effluent vs DO in Aerated Lagoon.



S - BOD Removal Effluent vs DO in Aerated Lagoon.

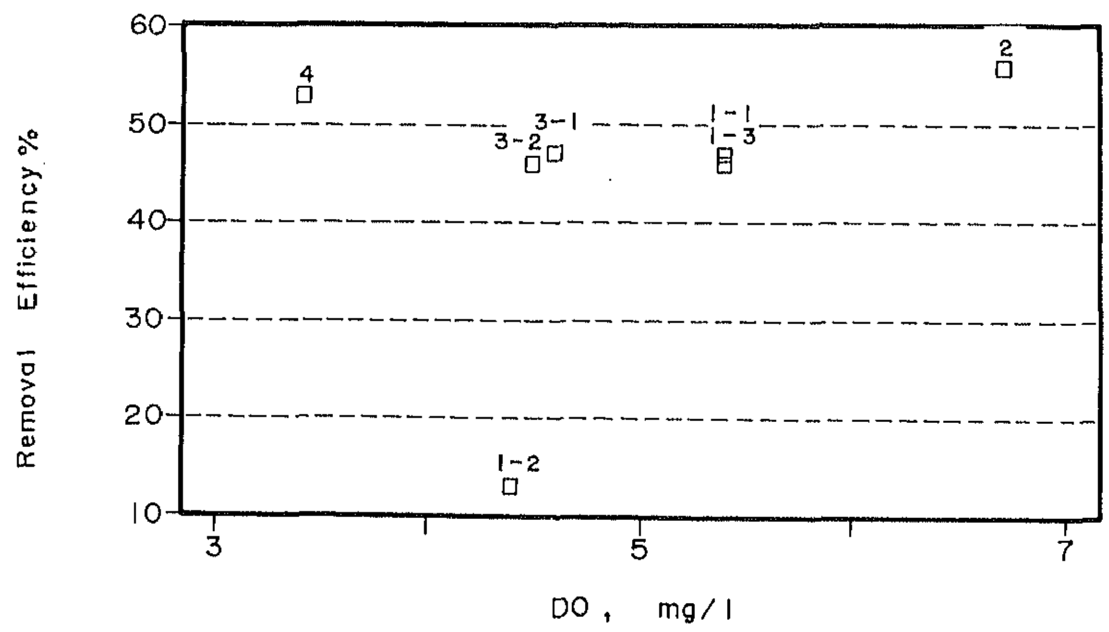
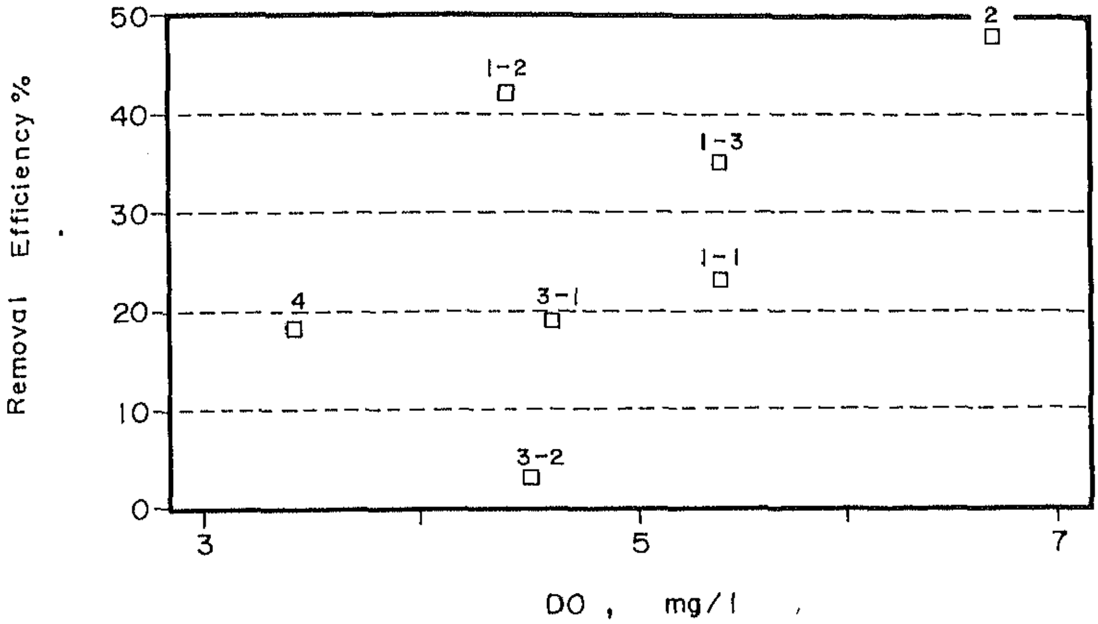


FIG. D.18	CORRELATION BETWEEN BOD REMOVAL EFFICIENCIES AND DO IN AERATED LAGOON EFFLUENT

THE FEASIBILITY STUDY ON PURIFICATION OF KLONG WATER IN BANGKOK

T- COD Removal Effluent vs DO in Aerated Lagoon.



S- COD Removal Effluent vs DO in Aerated Lagoon.

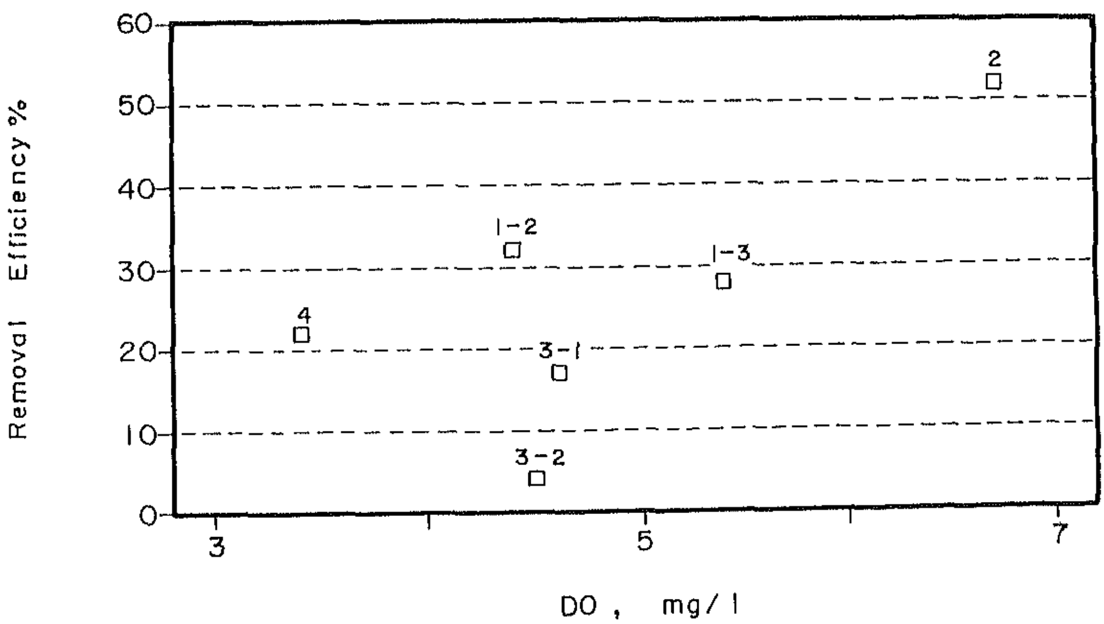


FIG. D. 19	CORRELATION BETWEEN COD REMOVAL EFFICIENCIES AND DO IN AERATED LAGOON EFFLUENT

THE FEASIBILITY STUDY ON PURIFICATION OF KLONG WATER IN BANGKOK

Potential Pond

Name of Pond	Area (ha)	Stor. Cap. (m³)	Diversion from	Ownership	Remarks
1. Paholyothin Cargo Station	10	220,000	K. Premprachakorn K. Bang Sui	Government	Dredging, low loading
2. Makkasan	16	310,000	K. Sam Sen	Government	Squatters
3. Tobacco Factory	20	680,000	Sewage Line	Government	Low loading, recreation site
4. Hual Khwang	6	570,000	K. Lad Phrao	Private	Fishery
5. Rama IX Pond	6.5	150,000	K. Lad Phrao	Government	Excavation, flood regulation
6. K. Chan	6	250,000	K. Tanang	Government	Low loading
7. K. Kum	2.5	30,000	K. Bang Toel	Government	Low loading, Park flood regulation
8. Rama IX Park	10	90,000	K. Nong Bon	Government	Low loading, Park flood regulation
Total	77.0	2,300,000			

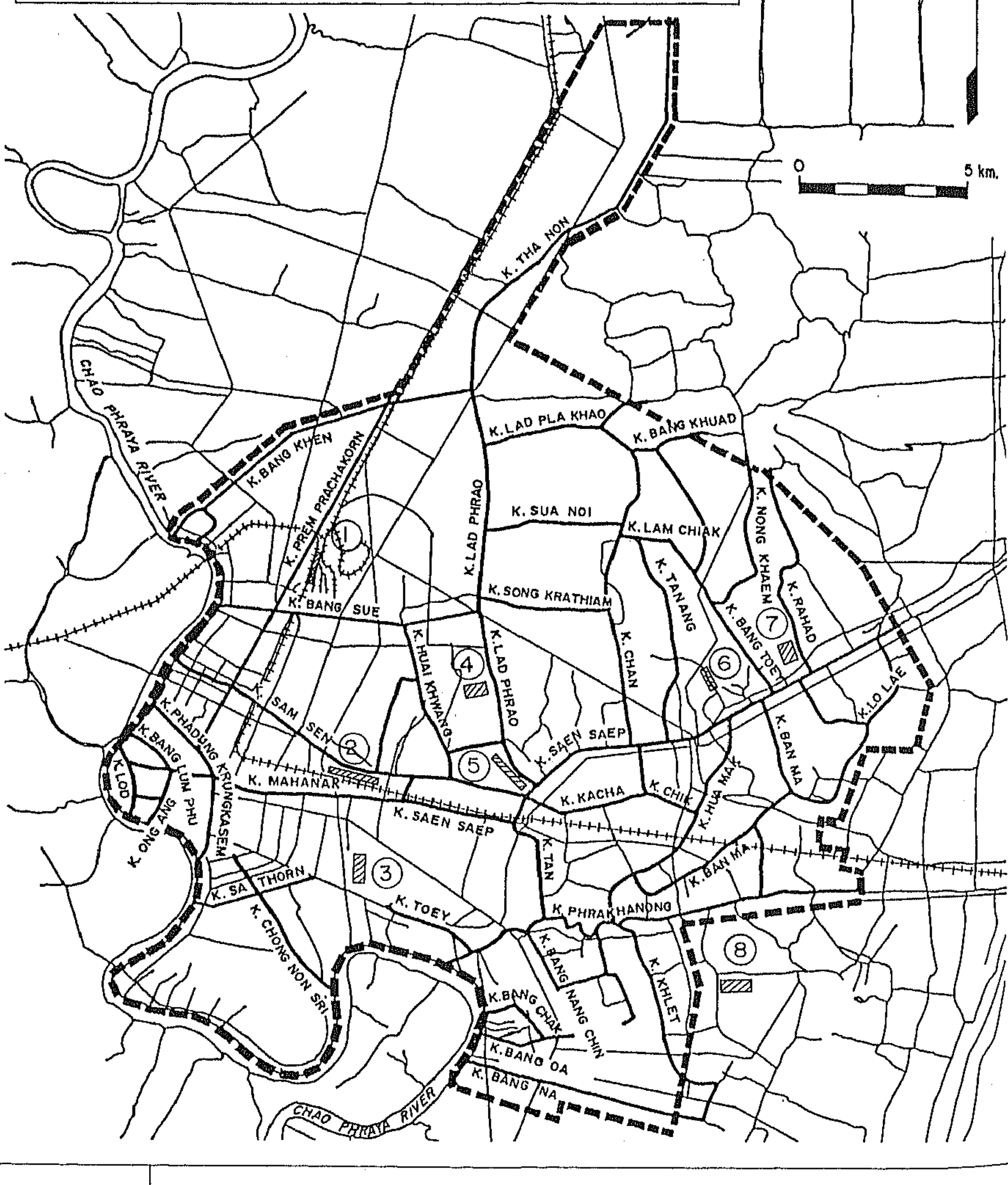


FIG. D.20	LOCATION OF POTENTIAL POND

THE STUDY ON URBAN DRAINAGE AND WASTE WATER DISPOSAL PROJECT IN THE CITY OF JAKARTA

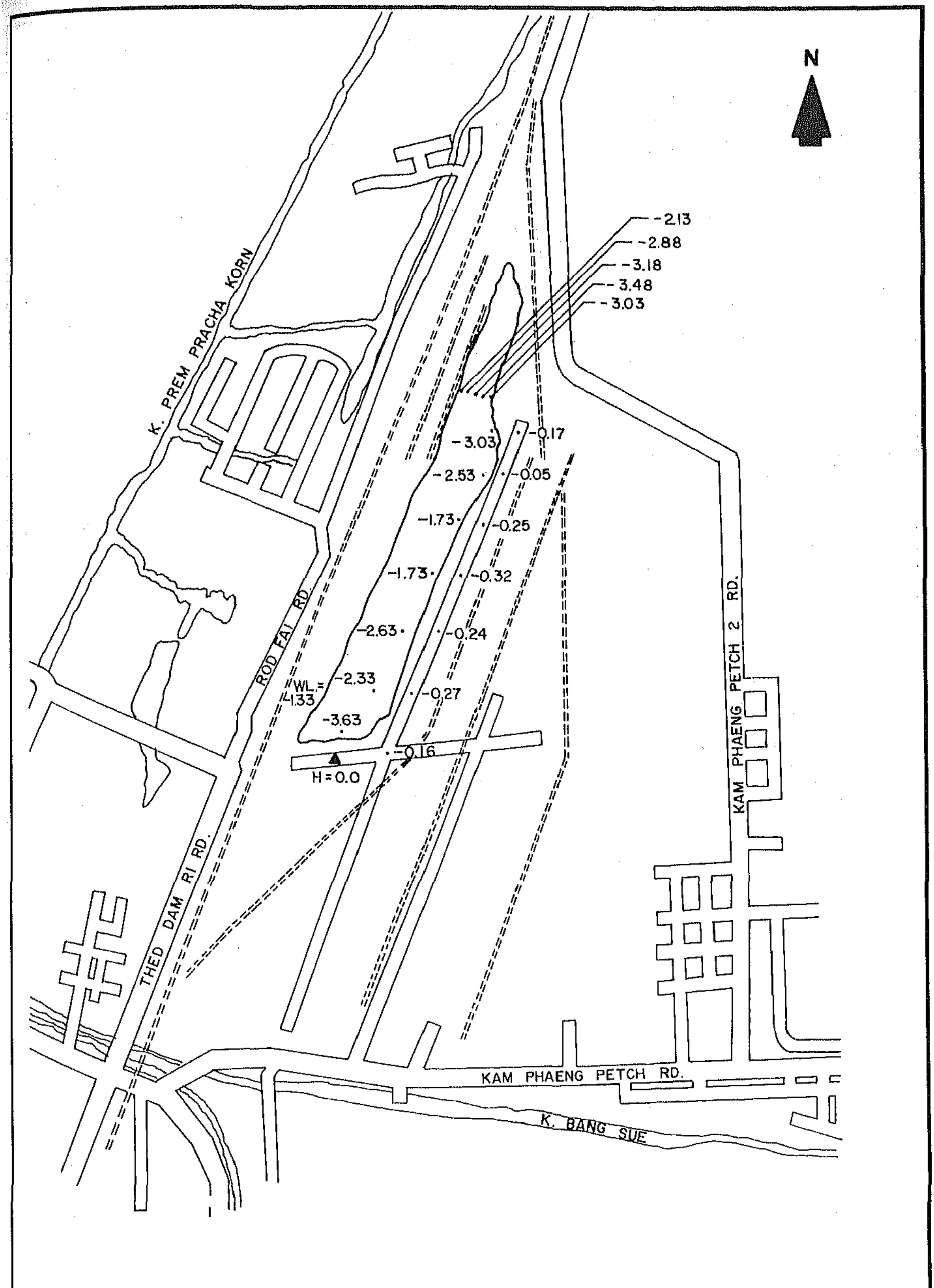


FIG. D.21(1) POTENTIAL POND (PAHOLYOTHIN CARGO STATION)

THE FEASIBILITY STUDY ON PURIFICATION OF KLONG WATER IN BANGKOK

JICA 2532B.E. 1989A.D.

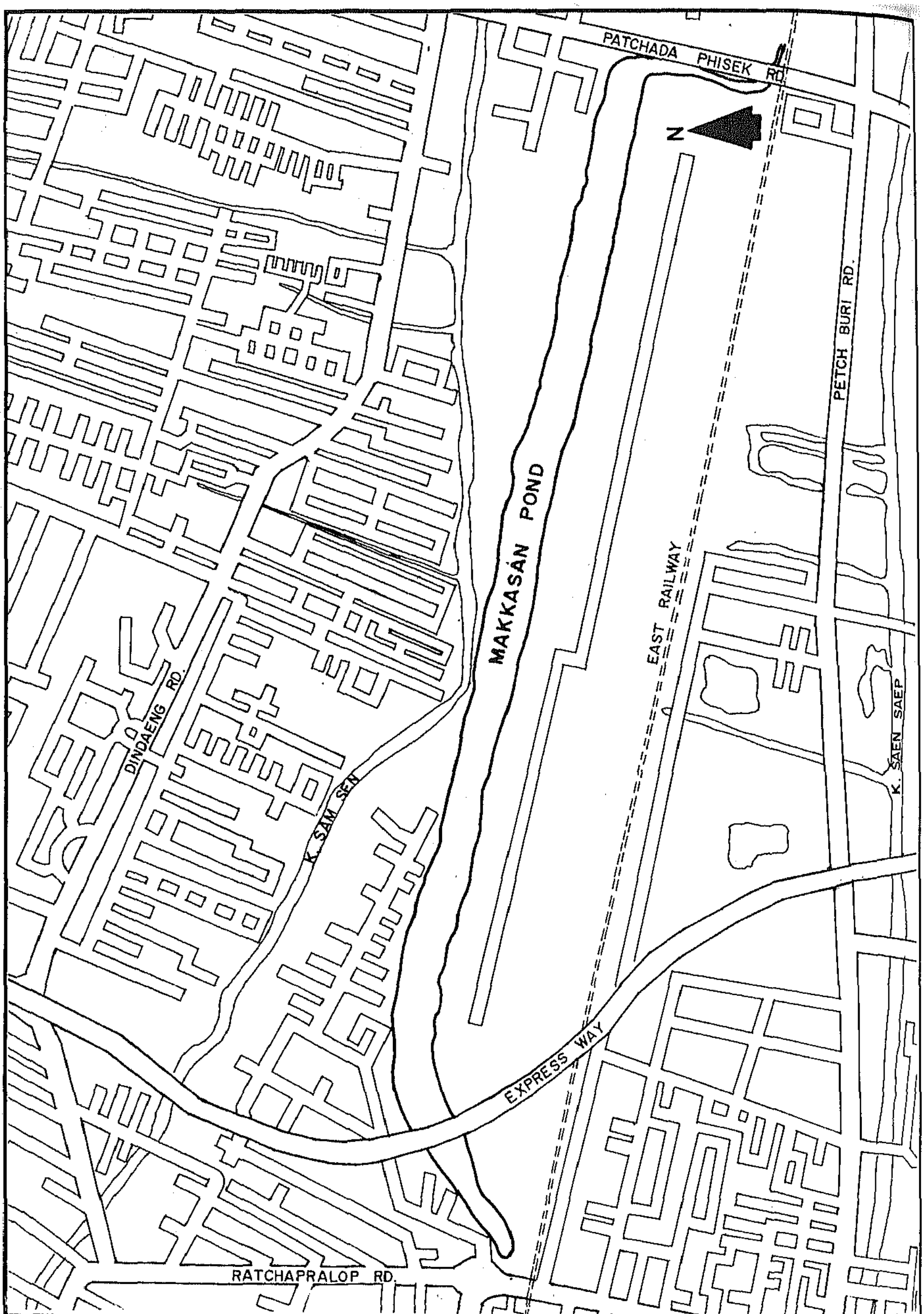


FIG. D.21(2) POTENTIAL POND (MAKKASAN)

THE FEASIBILITY STUDY ON PURIFICATION OF KLONG WATER IN BANGKOK

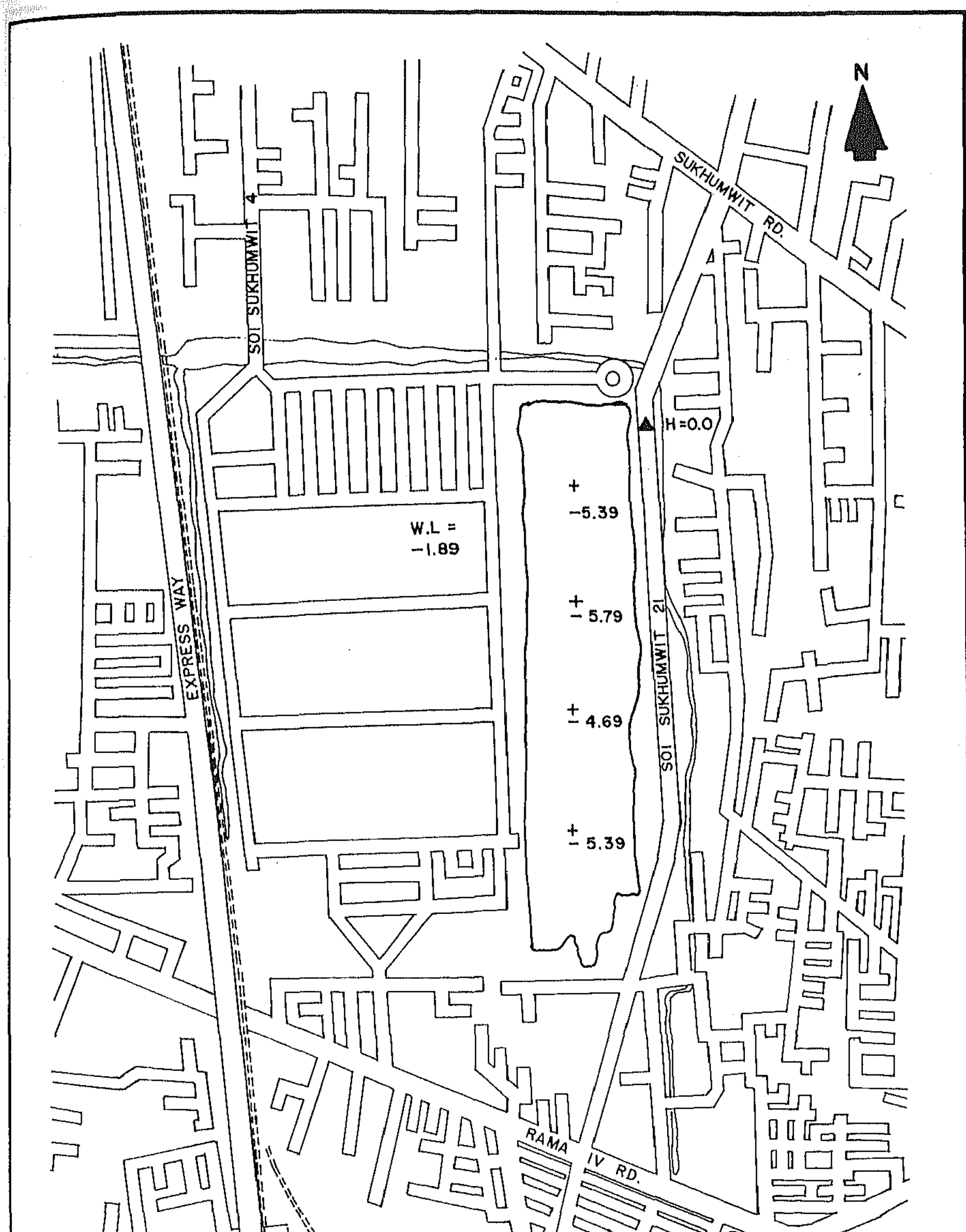


FIG. D.21(3) POTENTIAL POND (TOBACCO FACTORY)

THE FEASIBILITY STUDY ON PURIFICATION OF KLONG WATER IN BANGKOK

JICA 2532B.E. 1989A.D.

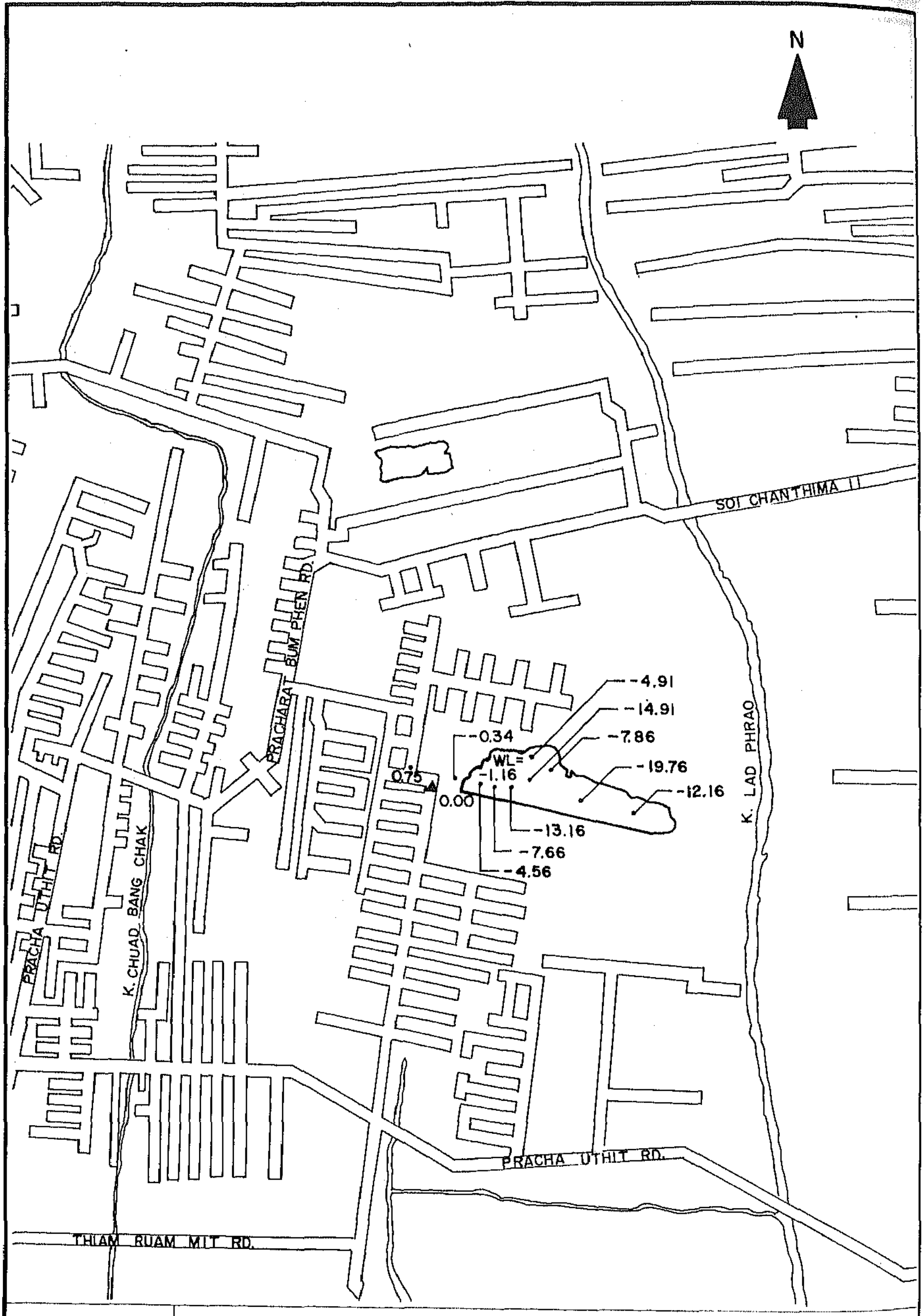


FIG. D.21(4) POTENTIAL POND (HUAI KHWANG)

THE FEASIBILITY STUDY ON PURIFICATION OF KLONG WATER IN BANGKOK

JICA 2532B.E. 1989A.D.

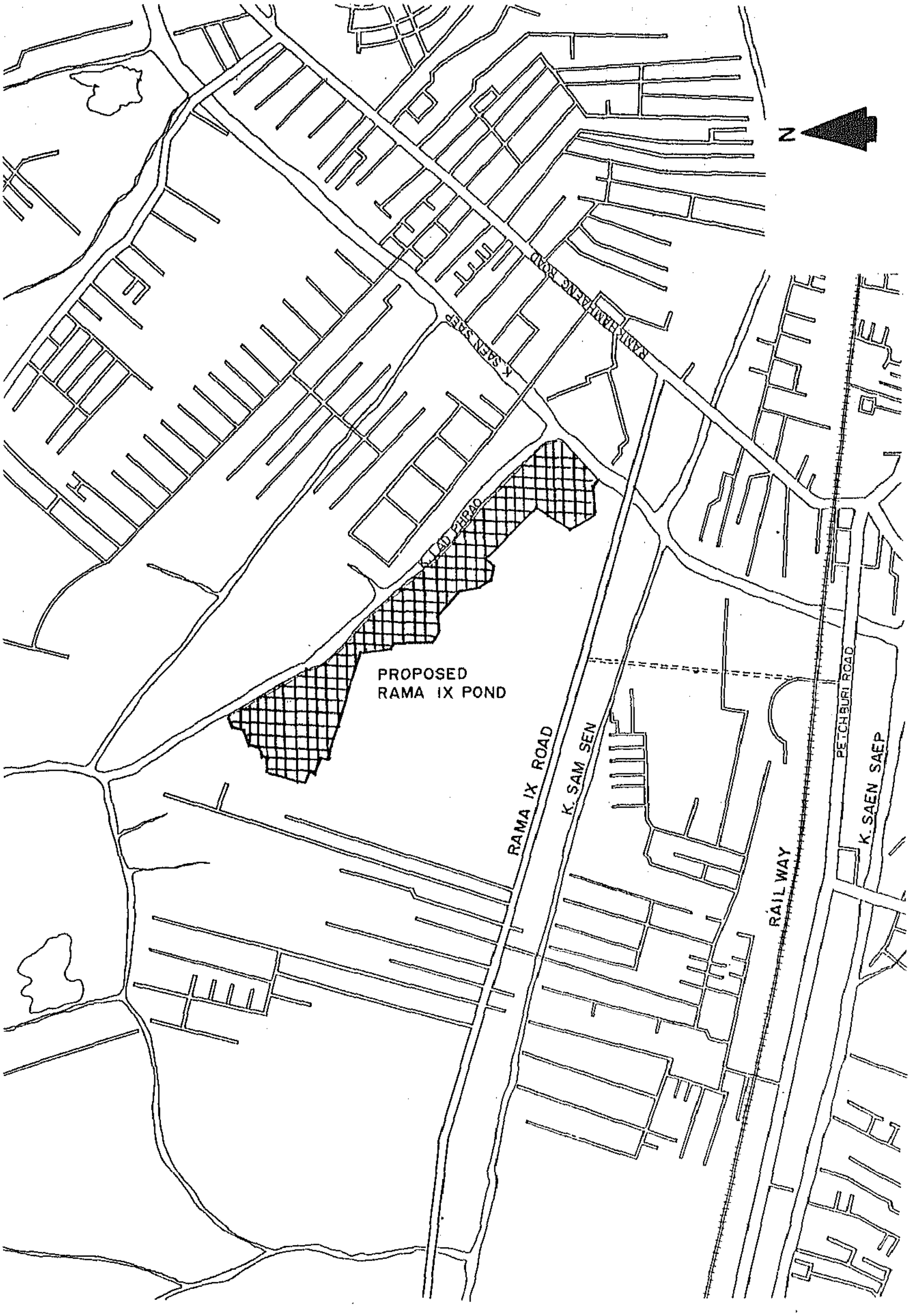


FIG. D. 2 1 (5) POTENTIAL POND (RAMA IX)

THE FEASIBILITY STUDY ON PURIFICATION OF KLONG WATER IN BANGKOK

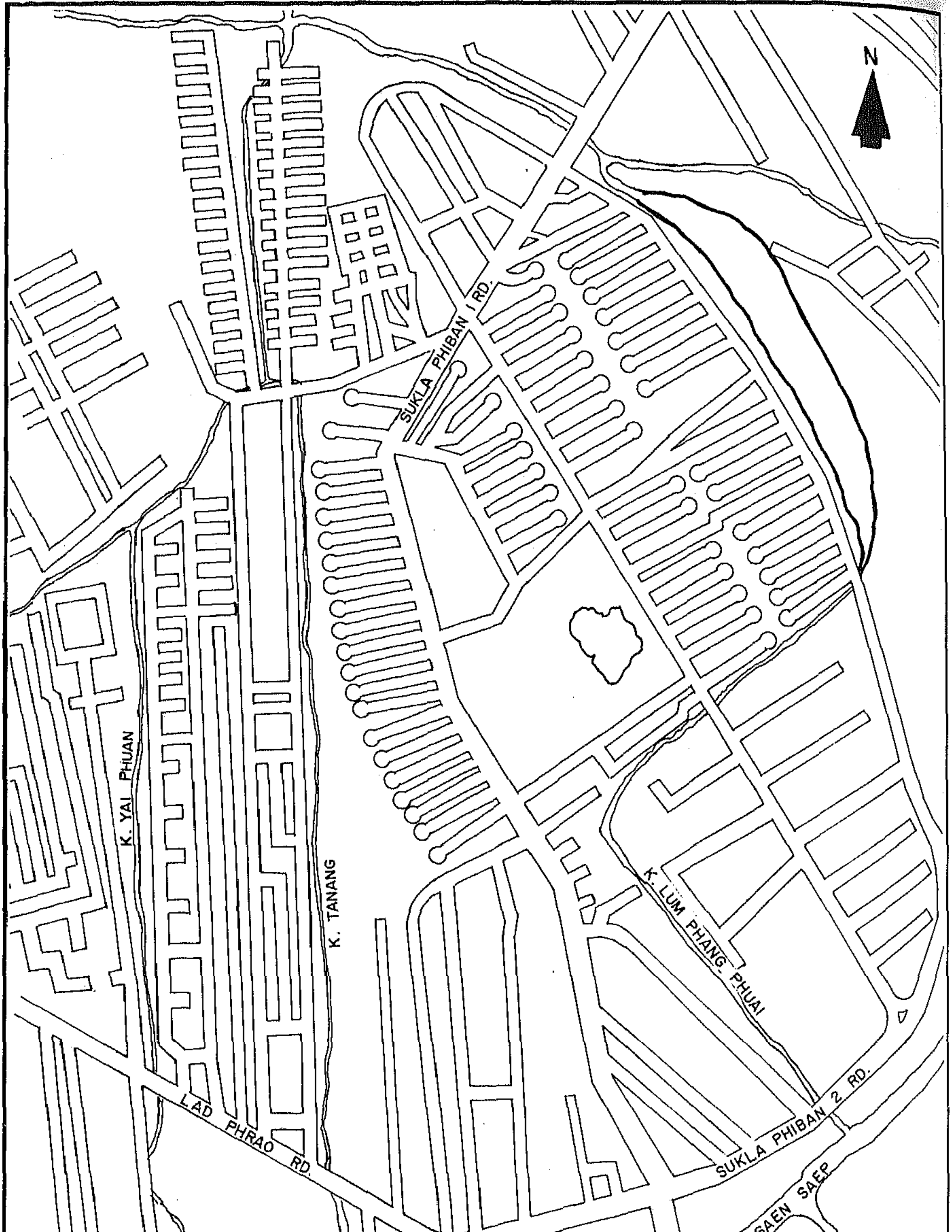


FIG. D. 21 (6) POTENTIAL POND (KLONG CHAN)

THE FEASIBILITY STUDY ON PURIFICATION OF KLONG WATER IN BANGKOK

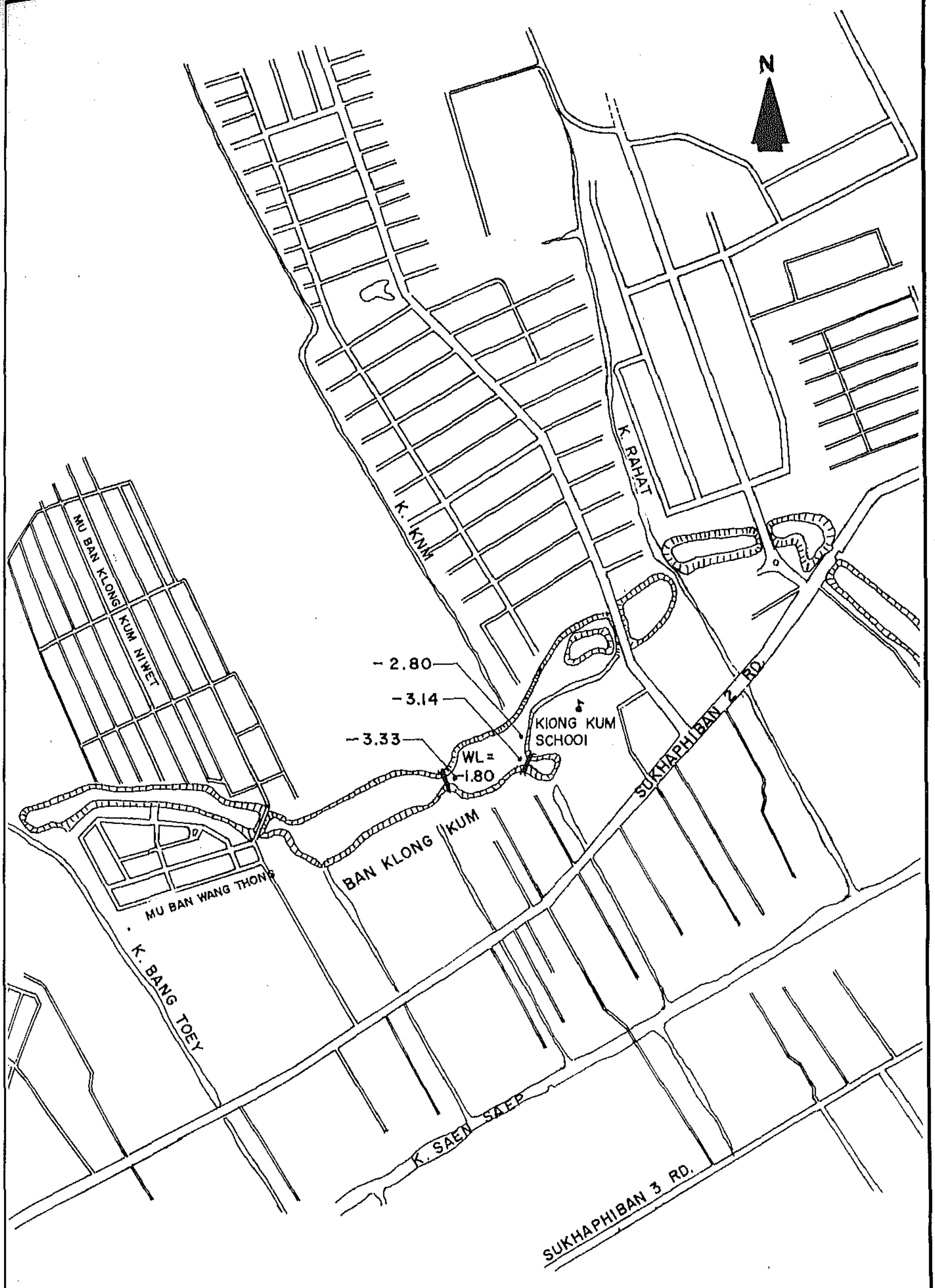


FIG. D. 21 (7) POTENTIAL POND (KLONG KUM)

THE FEASIBILITY STUDY ON PURIFICATION OF KLONG WATER IN BANGKOK

JICA 2532 B.E. 1989 A.D.

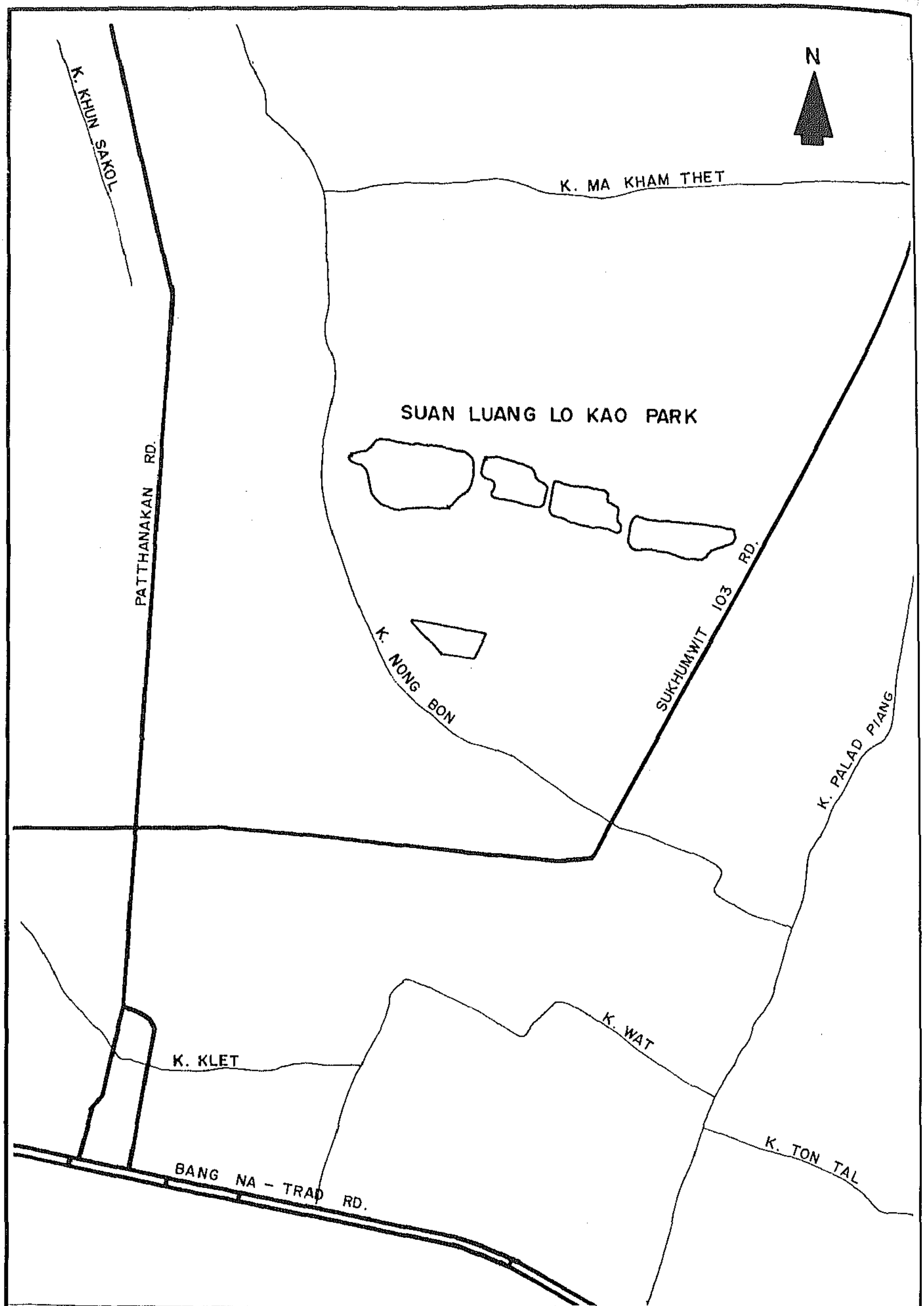


FIG. D. 21 (8) POTENTIAL POND (RAMA IX PARK)

THE FEASIBILITY STUDY ON PURIFICATION OF KLONG WATER IN BANGKOK

APPENDIX E.

DILUTION WATER INTRODUCTION

APPENDIX E. DILUTION WATER INTRODUCTION

1. Planning Policy and Criteria

1.1 Planning Policy

(1) Plans are to be prepared to abate the existing water pollution of the klongs.

(2) In this Study, the target water quality is set up with respect to klong stream BOD. The relationship between klong appearance and klong water quality expressed as BOD are as follows.

In APPENDIX B, existing klong appearance is classified into four (4) Ranks. Rank A is green or light brown color and no smell, Rank B is dark green or dark brown color and faint smell, Rank C is grey color and strong smell and Rank D is blackish color and offensive odor. Observed color and odor of klongs in the Study Area in both dry and raing seasons of 1988 are shown in Fig. E.1.

The average BOD of each of these classified appearances are as follows:

Average BOD Observed by DDS in1984 - 1986

Rank of Appearance	Dry Season	Rainy Season	Average
A	12.8	11.8	12.3
B	16.5	12.5	14.5
C	20.9	20.2	20.6
D	29.5	25.4	27.5

The average BOD of each classified rank of appearance are about 13 for Rank A, 15 for Rank B, 21 for Rank C and 28 for Rank D.

The following klongs are classified under Rank A and Rank B.

Rank A:

K. Bank Khen, K. Tha Non and the stretches of K. Prem Prachakorn, K. Saen Saep and K. Phra Khanong in the eastern suburban area in both dry and rainy seasons.

The parts of K. Bang Sue, Sam Sen, Phadung Krung Kasem, and Bang Lum Phu near the Chao Phraya River in dry season.

Rank B:

Some part of K. Lad Phrao and K. Saen Saep in dry season.

All the other klongs fall under Rank C or Rank D.

Based on the above considerations, the klong water quality of the Study Area is characterized as follows:

1) Color

Green or brown	:	BOD < 15 mg/l
Black or black-gray	:	BOD > 20 mg/l

2) Odor

No smell or faint smell	:	BOD < 15 mg/l
Strong smell or offensive odor	:	BOD > 20 mg/l

The JICA Study Team proposes to improve the klong water quality to at least to that of Rank B. Average BOD of klong water in Rank B is about 15 mg/l. Then the Study Team has set up the klong stream BOD of 15 mg/l as the minimum target water quality for simulation analyses of this Study.

(4) Target klongs are set for the highly polluted klongs (BOD more than 15 mg/l) which are located in the present highly urbanized areas (Refer to Fig. E.2 and APPENDIX C Fig. C.2).

The targeted major klongs for water quality improvement are:

- Klongs in Ratanakosin Area:
  K. Lod, K. Ong Ang, K. Wat Tep Tida
  K. Wat Rajabopit, K. Bang Lum Phu
  K. Mahanak, K. Phadung Krung Kasem
- K. Saen Saep
- K. Bang Sue
- K. Sam Sen
- K. Prem Prachakorn
- K. Huai Khwang
- K. Tan
- K. Phra Khanong
- K. Sathorn
- K. Chong Non Sri
- K. Toey

These targeted major klongs are shown in Fig. E.2.

(5) This dilution water introduction is only an intermediate and supplementary water pollution control measure. As such, large-scale structural measures will not be proposed. Conceivable simple structural measures are:

- Introduce dilution water from the Chao Phraya River and the outer areas of the polder by using the existing and planned flood control and drainage facilities (pumps and gates) .

- Increase the discharge capacity of the klongs by dredging to facilitate the dilution water introduction.

1.2 Planning Criteria for Introduction of Dilution Water

(1) Period of the Dilution Water Introduction

Period of the dilution water introduction from the Chao Phraya River is limited only for dry season (November-June). While in rainy season, the gates on the Chao Phraya River banks shall be closed and the klong water level is kept low to meet the incoming flood discharge. No dilution water introduction from the Chao Phraya River is expected.

(2) Available Water of the Chao Phraya River

The minimum seasonal discharge of the Chao Phraya River in the typical dry season (Jan. - April) during the period of 14 years at Bang Sai is 120 m^3/s. The existing water withdrawal in the reaches between Bang Sai and Study Area is 14.5 m^3/s.

The available discharge of the Chao Phraya River for the dilution of the klong water is estimated to be 70 ~ 80 m^3/s, taking into consideration the increasing water withdrawal from the Chao Phraya River in future.

(3) Available Water of the Eastern Outer Areas

In dry season, 10 m^3/s of surplus irrigation water is expected from the outer areas of the polder. While in rainy season, 35 m^3/s could be introduced.

(4) Water Level of Klong

Water level of the klongs shall be maintained below +0.77 m M.S.L. in dry season. While in rainy season, the maintenance water level shall be drawn down below -0.23 m M.S.L., in principle, as the flood mitigation measure.

(5) Water Stage of the Chao Phraya River

Water stage hydrograph of the Chao Phraya River in the Study Area varies with the river distance. Therefore, the design water stage hydrographs of the Chao Phraya River for the klong water purification plan are determined at the 13 existing gates and pump stations.

The updated water stage hydrograph records of February 3-4 and July 16-17, 1988 are adopted as the design water stage hydrographs for the dry season and rainy season respectively. This is because, their tidal ranges and patterns are similar to the design ones determined in APPENDIX A, (Section 3). The proposed design water stage hydrographs of the Chao Phraya River at the 13 existing gates and pump stations are shown in Fig. E.6 and Fig. E.7.

2. Preparation of Analysis Model

The sequence of the analyses is generalized in Fig. E.3.

2.1 Objective Klong

Objective klongs for the water quality simulation are shown in Fig. E.4.

2.2 Simulated Water Quality Parameter

The water quality parameter of BOD was simulated.

2.3 Applied Mathematical Model

2.3.1 Basic Flow and Diffusion Equations

The water flow and quality of the klongs vary every moment due to the tidal effects of the Chao Phraya River. The flow velocity and water quality of the klongs does not vary so much both vertically and laterally. In consideration of the above mentioned facts, a mathematical model consisting of one (1) dimensional unsteady flow equation and one (1) dimensional unsteady diffusion equation were applied.

The applied flow equation is shown below:

Kinetic Equation: $$\frac{\partial Q}{\partial t}+\frac{\partial}{\partial X}\left(\frac{Q}{A}\right)^2+gA\left(-i+\frac{\partial h}{\partial X}\right)+g\frac{n^2uQ}{R\ 4/3}=0$$

Continuity Equation: $$\frac{\partial A}{\partial t}+\frac{\partial Q}{\partial X}=q$$

where,
- t : time (s)
- X : distance in the direction of flow (m)
- u : velocity (m/s)
- Q : discharge (m^3/s)
- h : water depth (m)
- A : flow area (m^2)
- R : hydraulic depth (m)
- n : Manning's roughness coefficient ($m^{-1/3}\cdot s$)
- g : acceleration of gravity (m/s^2)
- i : river bed slope
- q : lateral inflow per unit area ($m^3/m^2\cdot s$)

The applied diffusion equation of pollution load is shown below:

$$\frac{\partial(AC)}{\partial t}=-\frac{\partial}{\partial X}(AUC)+\frac{\partial}{\partial X}\left(ADx\,\frac{\partial C}{\partial X}\right)-KAC+ALa$$

where,
- C : BOD content (mg/l)
- Dx : diffusion coefficient (m^2/s)
- K : purification coefficient (s^{-1})
- La : BOD load inflow ($g/m^2\cdot s$)
- X : distance in the direction of flow
- t : time (s)
- A : flow area (m^2)
- U : velocity (m/s)

2.3.2 Klong Network Model

The proposed klong network model is shown in Fig. E.5. The Study Area was divided into 128 subdivided drainage areas. The existing klong networks were divided into 128 stretches.

2.4 Calibration of Simulation Model

The proposed simulation model was calibrated by using the flow and water quality data observed during the period of February 3-4 (Dry Season), and July 16-17 (Rainy Season) 1988.

The reasons why the above two periods were selected are as follows:

1) The 24 hour continuous flow data and the water quality investigation results had been obtained.

2) The tidal range and pattern had a high occurrence probability (tidal range of approximately 1.5 m and the pattern of II, Refer to APPENDIX A).

3) The climate conditions during February 3-4 and July 16-17 were considered to be the representative dry and rainy seasons,

2.4.1 Conditions for the Calibration

(1) Cross Section Data

Each klong's cross section was determined based on the results of the past surveys and surveys conducted under this Study.

(2) Boundary Water Level

Water stages of the Chao Phraya River at the sites of the following gates were used as the boundary water levels for the calibration:

Gate Name	Point No. in Model
Bang Khen	50
Bang Sue	57
Sam Sen	63
Tavate	75
Bang Lum Phu	79
Phra Pinkao	85
Pak Klong Tarad	88
Ong Ang	83
Krung Kasem	78
Phra Khanong	14
Bang Na	118
Sathorn	124
Chong Non Sri	128

The original water stage records were used with some modifications. The used boundary water level in comparison to the observed water level is shown in Fig. E.6 (Dry Season), and in Fig. E.7 (Rainy Season).

(3) Inflow from the Outer Area

The inflow amounts from the northern and eastern suburban areas was decided principally based on the data obtained during the survey periods. For the calibration, 1.5 m^3/s and 28 m^3/s are adopted as the inflow from the outer area in dry and rainy seasons respectively.

(4) Operation of Gate and Pump

Inflow and outflow from and to the Chao Phraya River were calculated based on the operation conditions of the gates and pumps existing along the Chao Phraya River banks. The original operation records were used with some modifications. The used operation condition of the gates and pumps are shown in Fig. E.8 (dry season) and in Fig. E.9 (rainy season). It was observed in rainy season that two (2) gates at Phra Pinklao and Ong Ang in the Ratanakosin Area were kept slightly open resulting in exchange of water between Klong and Chao Phraya River.

(5) Wastewater Volume

Wastewater volume of each subdivided drainage area was estimated from the study results of APPENDIX C (details are shown in Data Book).

(6) Manning's Roughness Coefficient:

n = 0.03 was applied.

(7) Time Step (Δt)

The time step controls the stability and convergence of the calculation. It must satisfy the following relationship in general:

$$\Delta t \leq \frac{d \cdot \Delta Sm}{\sqrt{2g \cdot h}} \text{mini} \cong \Delta tcr$$

where, ΔSm : block length
h : water depth
g : acceleration of gravity (9.8 m/sec^2)
Δtcr : critical time step for stability (sec)
d : coefficient related to time integration method (d = 1.5)

The time step (Δt) was determined as 30 seconds by checking all blocks with the above equation.

2.4.2 Conditions for Water Quality Calibration

(1) Cross Section Data

Same as those used for flow calibration

(2) Flow Data

Flow calibration results were applied.

(3) Pollution Load Inflow

Pollution load inflow into each subdivided klong was estimated from the study results of APPENDIX C (details are shown in Data Book).

(4) Diffusion Coefficient (Dx)

Taking into account the flow velocity and the bank conditions of the klongs, the diffusion coefficient was decided upon as being 1 m^2/sec in Ratanakosin Area and 10^2 m^2/sec in other areas.

(5) Purification, Internal Production, Dissolution, and Sedimentation

Purification rate, internal production, and dissolution were decided upon based on the field measurement results (details are shown in Data Book). Since it was difficult to conduct the sedimentation field survey, sedimentation effect was calculated by using the formula shown below.

1) Purification Coefficient (K):
Assumed as 0.01 l/day

2) Production of BOD in Klong:
Assumed as nil

3) Dissolution of BOD from Sludge in Klong Bed:
Assumed as nil

4) Sedimentation of BOD:

Estimated by the following formula:

$$Ps = \alpha \cdot Ws \cdot C$$

where,
- Ps : sedimentation ($g/m^2/day$)
- α : settling ratio of BOD
- Ws : settling velocity (m/day)
- C : BOD content (mg/l)

Ps of 0.9 $g/m^2/day$ was obtained by assuming $\alpha = 0.3$, $Ws = 0.1$ m/day, and C = 30 mg/l.

(6) Boundary Water Quality

From the observed values, the following BOD values were applied:

Chao Phraya River:	3 mg/l
Inflow water from the eastern suburban areas:	5 mg/l

(7) Time Step (Δt)

Δt = 30 sec was applied.

2.5 Flow and Water Quality Calibration Results

Based on the above-mentioned conditions, discharge (Q), klong stage (Z), and BOD values at the observation stations in the main klongs were calculated. The calculated values were indicated in the time-variation graphs in comparison to the measured values (detailed time-variation graphs are shown in Data Book). The average of the measured BOD values was also compared with the average of the calculated BOD values.

The calculated and measured discharge, stage, and BOD values are shown in the following figures:

Dry Season:

Discharge	:	Fig. E.10 (1) thru E.10 (5)
Stage	:	Fig. E.11 (1) thru E.11 (5)
BOD	:	Fig. E.12 (1) thru E.12 (5)
Average BOD	:	Fig. E.13

Rainy Season:

Discharge	:	Fig. E.14 (1) thru E.14 (5)
Stage	:	Fig. E.15 (1) thru E.15 (5)
BOD	:	Fig. E.16 (1) thru E.16 (5)
Average BOD	:	Fig. E.17

2.5.1 Dry Season

The calculated discharge for Station 28 (K. Tan) varies from the actually measured one at the same station. The calculated value was strongly influenced by the flow conditions at Station 30 (K. Phra Khanong) which is located at downstream of Station 28. Judging from the area topography, the calculated discharge for Station 28 seems to be admissible. Thus, it can be considered that the discharge measurement at Station 28 was an error.

The calculated discharge values and their time variations for other stations are well in agreement with the measured values.

The calculated stages for all stations are well in agreement with the measured levels.

In the City Core Area (St. 17, 22, 23, 24), the hourly variation range of the calculated BOD is smaller than that of the measured one. However, both are well in agreement in terms of daily average.

2.5.2 Rainy Season

The calculated discharge and stage values are well in agreement with the measured values. Their time variation was well simulated.

3. Alternative Plans of Klong Water Purification

3.1 Proposed Alternative Plans

The following three (3) alternative plans are proposed for discussion.

(1) Plan A

Under the present condition, dilution water from the Chao Phraya River is introduced through the gates only at the high tide of the Chao Phraya River. The existing pumps on the Chao Phraya River banks function only for drainage of the inner water.

In this Study, the existing pump stations are proposed to be remodeled into reversible type so that the dilution water can be introduced also at the low tide of the Chao Phraya River. The proposed pump stations for reconstruction are Bang Sue, Sam Sen, Tavate and Sathorn. The remodelling into reversible type is performed by reconstruction of the existing gate structures for Bang Sue and Sam Sen. While, for Tavate and Sathorn, additional pumps for the withdrawal of dilution water are proposed. The proposed pump capacity for the introduction of dilution water is shown below.

Name of P.S.	Pump Capacity		
	Existing (Set) x (m^3/s)	Reversible (Set) x (m^3/s)	Additional (Set) x (m^3/s)
Bang Sue	17 x 3 = 51	4 x 3 = 12	-
Sam Sen	15 x 3 = 45	4 x 3 = 12	-
Tavate	5 x 1 = 5	-	2 x 3 = 6
Sathorn	2 x 3 = 6	-	2 x 3 = 6
Total	107	24	12

Location of the proposed pump station is shown in Fig. E.18.

(2) Plan B

A small-scale dredging of the klongs is considered along with Plan A to increase the capacity of dilution water introduction. The dredging is proposed for the klongs in Ratanakosin Area and Yannawa district. The proposed klong dredging is shown below.

Name of Klong	Dredging Plan			
	Length (m)	Width (m)	Volume (m^3)	Bed EL. (MSL, m)
Wat Tep Tida	745	7.0	4,000	-1.5
Wat Rajabopit	1,122	6.8	8,000	-1.5
Chong Non Sri	3,600	6.0 ~ 10.0	77,000	-1.5 ~ -2.0
Total	5,467		89,000	

Location of the proposed klong dredging is shown in Fig. E.18.

(3) Plan C

In order to increase the capacity of dilution water introduction more than Plan B, a large-scale reconstruction of pump stations and a large-scale dredging of the Klongs are proposed.
The proposed pump capacity for the introduction of dilution water and the proposed dredging are shown below.

Name of P.S	Pump Capacity		
	Existing (Set) x (m^3/sec)	Reversible (Set) x (m^3/sec)	Additional (Set) x (m^3/sec)
Bang Sue	17 x 3 = 51	7 x 3 = 21	-
Sam Sen	15 x 3 = 45	6 x 3 = 18	-
Tavate	5 x 1 = 5	-	3 x 3 = 9
Sathorn	2 x 3 = 6	-	2 x 3 = 6
	107	39	15

Name of Klong	Dredging Plan			
	Length (m)	Width (m)	Volume (m^3)	Bed EL. (MSL, m)
Wat Tep Tida	745	7.0	4,000	-1.5
Wat Rajabopit	1,122	6.8	8,000	-1.5
Chon Non Sri	3,600	6.0 ~ 10.0	77,000	-1.5 ~ -2.0
Bang Sue	8,011	20.0	194,000	-2.5
Sam Sen	6,834	10.0 ~ 15.0	100,000	-2.0
Huai Khwang	3,465	6.0	20,000	-1.4
Lad Phrao	7,100	35.0	271,000	-2.3
Tan	1,922	26.0	14,000	-2.8
Total	32,799		688,000	

Location of the proposed pump station and the proposed klong dredging are shown in Fig. E.18.

3.2 Optimum Suction Water Level of Drainage Pump

3.2.1 Dry Season

The introduced dilution water form the Chao Phraya River is drained again into the Chao Phraya River through Phra Khanong and Krung Kasem pump stations.

The maintenance water level of the klongs is restricted below +0.77 m M.S.L. If the klong water level at the introduction site of dilution water is assumed to be +0.77 m M.S.L., introducible dilution water quantity, the consequent water quality improvement and the required pump up water for dilution water introduction and the subsequent discharge vary corresponding to the suction water level of Phra Khanong and Krung Kasem pump stations.

The optimum suction water level of Phra Khanong and Krung Kasem pump stations for the three alternative plans were obtained through comparative studies of the klong water quality improvement and required pump up water volume for introduction and discharge of dilution water.

Suction Water Level (m : MSL)

	Phra Khanong P.S.	Krung Kasem P.S.
Plan A	0	+0.30
Plan B	0	+0.30
Plan C	-0.50	0

3.2.2 Rainy Season

The water level of the klongs shall be maintained below -0.23 m M.S.L. to carry incoming flood discharge. The suction water level of Phra Khanong and Krung Kasem pump stations shall be kept further lower than the above maintenance water level to obtain a sufficient hydraulic gradient in the klongs. In this Study, the suction water level of the two (2) pump stations is proposed to be -0.35 m M.S.L. in accordance with the existing pump operation mode.

3.3 Comparison of Alternative Plans

The three (3) alternative plans are compared in terms of effect on water quality improvement, construction cost and pump operation cost.

3.3.1 Simulated Water Quality

Water quality (BOD) of the target klongs was simulated for the three alternative plans by using the simulation model proposed in Section 2. The simulation was made under the following gate and pump operation rules.

(1) For Simulation of the Existing Conditions:

The updated gate and pump operation records of February 3-4 and July 16-17, 1988 are applied for the simulations of existing conditions during dry and rainy seasons (See Fig. E.8 and Fig. E.9).

(2) For Simulation of the Plan A, Plan B and Plan C

- In dry season, gates and pumps are operated to attain the maximum dilution effects, keeping the klong water level below the design maintenance level.

- In rainy season, all the gates are opened to drain inner water during the time when the water stage of the Chao Phraya River is lower than the klong water level and they are all closed during the remaining time.
  Drainage pumps are operated to keep the klong water level below the design maintenance level.

The simulated results are summarized in Fig. E.19 to Fig. E.26. These figures present the following water quality distribution as BOD.

- The distribution of daily maximum and daily average BOD (water quality), along the target klongs, in dry and rainy seasons under the existing conditions (without project).

- The simulated distribution of daily maximum and daily average BOD (water quality), along the target klongs, in dry and rainy seasons under the proposed alternative plans, Plan A, Plan B and Plan C (with dilution water introduction).

The distribution of daily average and daily maximum water quality as BOD during dry season in the target klongs under both the conditions, without project (existing condition) and the three (3) alternatives of dilution water introduction, Plan A, Plan B and Plan C, are summarized in Table E.1.

Similarly the distribution of the same water quality as BOD under both the conditions of without project and with dilution water introduction plan, but during rainy season, are summarized in Table E.2.

From the above simulation results, the following conclusions are drawn.

(1) Dry Season

The simulated water quality of the proposed plans is considerably better than that of the existing conditions in almost all the target klongs.

(2) Rainy Season

1) The simulated water quality of the proposed plans shows no significant difference from that of the existing conditions in the target klongs other than K. Sam Sen, K. Mahanak, K. Saen Saep and the klongs in the Ratanakosin area.

2) The simulated water quality of the proposed plans is somewhat better, compared to that of the existing conditions especially in K. Sam Sen, K. Mahanak and K. Saen Saep.

This is because:

- Under the existing conditions, the flow of water in the above klongs remains practically stationary due to the balanced pumping for drainage of the Krung Kasem and Phra Khanong pump stations.

- While, under the proposed plans, the water of the above klongs flow continuously westward to drain through the Sam Sen and Krung Kasem pump stations but not through the Phra Khanong pump station. The typical pump and gate operations during rainy season introduces water from the eastern outer areas into the klongs of Sam Sen, Mahanak and Saen Saep thereby diluting the klong water.

3) The simulated water quality of the proposed plans is worser than that of the existing conditions in the Ratanakosin Area. This aggravation of water quality is caused by:

- Under the existing conditions, there is some water leakage from the Chao Phra River, approximately 1.0 m^3/s, in

Ratanakosin Area and this leakage water dilutes the klong water.

- Under the Plan A, Plan B and Plan C, dilution water is not introduced at all into this area from the Chao Phraya River.

3.3.2 Construction and Operation & Maintenance Costs

The required total construction costs of Plan A, Plan B and Plan C are estimated as follows, and the cost break down is shown in Table E.3.

Construction Cost

(Unit: million Baht)

	Plan A	Plan B	Plan C
Pump Station	38.0	38.0	57.0
Dredging	-	8.5	74.4
Retaining Wall	-	-	949.0
Total	38.0	46.5	1,080.4

Pump Operation by the dry season rule is assumed for the period of eight (8) months (Nov. - June). No pump operation is assumed for water purification of the klongs with dilution water introduction during the period of four (4) months of the mid-rainy season (July. - Oct.) for all alternative plans, Plan A, Plan B and Plan C.

The required pump operation costs of Plan A, Plan B and Plan C are estimated, under the above mentioned conditions, as shown below. The respective cost break down is shown in Table E.4.

Pump Operation Cost

(Unit: thousand Baht/day)

	Plan A	Plan B	Plan C
For Introduction	45.6	51.8	60.2
For Discharge	86.4	93.3	182.4
Total	132.0	145.1	242.6