estate and large factory are determined individually at their respective locations.

Location, wastewater discharge and pollution load generation of each housing estate and large factory are given in Data Book.

The regional distributions of total wastewater discharge in 1986 and 2000 are shown in Fig. C.10. The regional distribution of total pollution load generation in 1986 and 2000 are shown in Fig. C.11.

## 5. Pollution Load Runoff

### 5.1 Pollution Load Runoff Coefficient

The pollution load runoff coefficient is defined as the ratio of the pollution load entering the klongs to the pollution load generated at the sources.

The JICA Study Team made pollution load runoff observations at seven (7) sites for a continuous 24 hour period. The observation sites were selected from various land use pattern areas.

Suriwong Rd, Krung Kasem Rd, and Sukhumvit Rd Soi 40 were selected as representative residential and commercial areas. As the representative high density residential area, Pathumwan was selected.

Siam Jasco, Wipawadi Rangsit 1 and Wipawadi Rangsit 2 were selected as the representative low density residential areas.

Observation dates of pollution load runoff survey are shown in Table C.18.

The outline of the observation sites are listed in Table C.19. The locations of the sites are shown in Fig. C.12. The pollution load runoff coefficients determined are shown in Tables C.20 and C.21, respectively for BOD and SS.

## 5.2 Pollution Load Runoff in the Study Area

The pollution load runoff coefficient in the Study Area was determined based on the following consideration: The weighted average hourly pollution load runoff coefficient at each survey site that was obtained from the field surveys was used as the pollution load runoff coefficient of the area.

For the evaluation of the pollution load runoff coefficient, the following parameters must be taken into consideration:

(a) Discharge: In general, when discharge becomes large, velocity becomes high. As a result, sedimentation of pollutant decreases and the pollution load runoff coefficient tends to increase.

(b) Catchment area: If a catchment area is large, it requires longer time to wash down the pollutant and the pollution load runoff coefficient tends to decrease

(c) Urban development: If sewerage and drainage ditches are improved, the sewage runoff and drainage become easier. Thus, the pollution load runoff coefficient tends to increase

Considering the above-mentioned characteristics, the pollution load run-off coefficient of an area is estimated with respect to the specific discharge of the area ($m^3/day/km^2$).

Since the specific discharge of an area consists of sewage and rainfall, it was considered that the difference in the pollution load runoff coefficient during dry and rainy seasons will be reflected by the difference in specific discharge.

As for urbanization, a well developed area produces a large amount of sewage and drainage. Since such an area has a well developed drainage pipe system, it can be considered that the area's pollution load runoff coefficient is high.

Based on the above considerations, the relationship between the specific discharge and BOD runoff coefficient was obtained as follows (see Fig. C.13).

$$y = 1.625x + 37.6 \qquad (\gamma = 0.734)$$

where, y: runoff coefficient
x: specific discharge
γ: correlation coefficient

The BOD run-off coefficients for the Study are assumed to be constant average values based on the range of specific discharge, as an approximation to the above formula, and is illustrated in Fig. C.13.

| Specific Discharge ($10^3$ $m^3/day/km^2$) | BOD Runoff Coefficient (%) |
|---|---|
| 0 - 10 | 50 |
| 10 - 20 | 60 |
| 20 - 30 | 80 |
| >30 | 90 |

The runoff coefficient of SS was also determined as shown in Fig. C.13.

Table C.1 Population Growth in BMA and Whole Thailand

| Year | Population in BMA | Population in Whole Country |
|---|---|---|
| 1978 | 4,870,509 | 10,121,921 |
| 1979 | 4,999,515 | 10,388,095 |
| 1980 | 5,153,903 | 10,585,050 |
| 1981 | 5,331,402 | 10,856,057 |
| 1982 | 5,468,286 | 11,122,666 |
| 1983 | 5,018,327 | 10,797,324 |
| 1984 | 5,174,682 | 11,067,125 |
| 1985 | 5,363,378 | 11,423,946 |
| 1986 | 5,468,915 | 11,670,900 |

Source : National Statistical Office.

Table C.2 Current Population and Population Density in Each District of the Study Area

| District Name | Population (1986 Year) | Area ($km^2$) | Population Density (person/ha) |
|---|---|---|---|
| Phra Nakhon | 111,875 | 5.54 | 202 |
| Pom Prab Sattru Pai | 87,955 | 1.93 | 455 |
| Sampan Thawong | 51,121 | 1.42 | 360 |
| Pathumwan | 143,199 | 8.37 | 171 |
| Phya Thai | 359,604 | 21.11 | 170 |
| Huai Khwang | 255,774 | 9.50 | 269 |
| Phra Khanong | 629,386 | 143.56 | 44 |
| Bang Kapi | 409,785 | 158.78 | 26 |
| Bang Khen | 548,078 | 169.31 | 36 |
| Bang Rak | 90,672 | 5.54 | 164 |
| Dusit | 562,990 | 22.21 | 253 |
| Yan Nawa | 415,703 | 36.91 | 133 |
| Total | 3,666,142 | 584.18 | 63 |

Ref: Bangkok 1986
Statistical Profile of the Bangkok Metropolitan Administration
Department of Policy and Planning

Table C.3 Land Use in 1980

Unit: $km^2$

| Land Use Classification | City Core Area | Eastern Suburbans | Total |
|---|---|---|---|
| Residential | 37 | 97 | 134 |
| Commercial | 10 | 6 | 16 |
| Industrial | 3 | 3 | 6 |
| Institution | 15 | 22 | 37 |
| Park, Sport, Ground, etc. | 5 | 6 | 11 |
| Agricultural and Open Space | 27 | 149 | 176 |
| Total | 97 | 283 | 380 |

Ref: (1) Flood Protection/Drainage Project in Eastern Suburban Bangkok
JAPAN INTERNATIONAL COOPERATION AGENCY
(2) Bangkok Flood Control and Drainage Project (City Core)
NEDECO

Table C.4 Present and Future District Population in the Study Area

| | Present Population (1986) | Future Population (2000) |
|---|---|---|
| Phra Nakhon | 111,875 | 112,000 |
| Pom Prab Sattru Pai | 87,955 | 88,000 |
| Sampanthawong | 51,121 | 51,000 |
| Pathumwan | 143,199 | 143,000 |
| Phya Thai | 359,604 | 360,000 |
| Huai Khwang | 255,774 | 359,000 |
| Phra Khanong | 629,386 | 840,000 |
| Bang Kapi | 409,785 | 710,000 |
| Bang Khen | 548,078 | 809,000 |
| Bang Rak | 90,672 | 91,000 |
| Dusit | 562,990 | 772,000 |
| Yan Nawa | 415,703 | 416,000 |
| Total | 3,666,142 | 4,751,000 |

Table C.5 Future Land Use (2000)

| Land Use Classification | City Core Area ($km^2$) | Eastern Suburbs Area ($km^2$) | Total Area ($km^2$) |
|---|---|---|---|
| Residential | 37 | 185 | 222 |
| Commercial | 10 | 14 | 24 |
| Industrial | 3 | 3 | 6 |
| Institutional | 15 | - | 15 |
| Park, Sport Ground etc. | 5 | 14 | 19 |
| Agricultural & Open Space | 27 | 67 | 94 |
| Total | 97 | 283 | 380 |

Table C.6 Existing Water Supply by MWA (1986)

| Service Area | Supply Connection | Supply Population | Daily Water Supply ($m^3/d$) 1) | | | | Per Capita Water Supply (lcd) 1) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Residential | Government | Comm-Ent. | Total | Residential | Government | Comm-Ent. | Total |
| Nonthaburi | 66,613 | 339,726 | 79,018 | 155 | 22,485 | 101,658 | 233 | 0.5 | 66 | 330 |
| Bang Khen | 47,322 | 241,342 | 57,557 | 8 | 17,451 | 75,016 | 238 | - | 72 | 310 |
| Phya Thai | 56,188 | 398,934 | 93,816 | 497 | 42,784 | 137,097 | 235 | 1.2 | 107 | 343 |
| Thung Mahamek | 35,071 | 206,919 | 50,498 | 119 | 37,502 | 88,119 | 244 | 0.6 | 181 | 426 |
| Man Sri | 37,976 | 265,832 | 74,048 | 30 | 129,183 | 203,261 | 279 | 0.1 | 486 | 765 |
| Phra Khanong | 39,936 | 207,667 | 77,868 | 109 | 46,708 | 124,685 | 375 | 0.5 | 225 | 601 |
| Samut Prakarn | 36,891 | 177,077 | 50,082 | 87 | 18,221 | 68,390 | 283 | 0.5 | 103 | 387 |
| Total | 319,997 | 1,837,497 | 482,887 | 1,005 | 314,334 | 798,226 | 263 | 0.5 | 171 | 435 |

1) Include Unaccounted Water

Table C.7 Existing Unit Water Consumption (1986)

(Unit: lcd)

| Service Area | Residential | Government | Commercial & Enterprise | Total |
|---|---|---|---|---|
| Nonthaburi | 137 | 0.3 | 39 | 176 |
| Bang Khen | 140 | - | 42 | 182 |
| Phya Thai | 139 | 0.7 | 63 | 203 |
| Thung Mahamek | 144 | 0.4 | 107 | 251 |
| Man Sri | 165 | - | 287 | 452 |
| Phra Khanong | 221 | 0.3 | 133 | 354 |
| Samut Prakarn | 167 | 0.3 | 61 | 228 |

Table C.8 Served Population Ratio of Water Supply System

| Service Area | a. Served Population | b. Total Population | Service Ratio (a/b) |
|---|---|---|---|
| Thung Mahamek | 206,919 | 415,703 | 50% |
| Man Sri<br>Phya Thai | 664,765 | 1,559,550 | 43% |
| Bang Khen<br>Phra Khanong | 449,009 | 1,299,026 | 35% |
| Total | 1,320,693 | 3,274,279 | 40% |

Table C.9 Existing Unit Water Consumption of Total Water Sources

(Unit: lcd)

| District | Category | Water Supply | | Groundwater | | Water Supply + Groundwater |
|---|---|---|---|---|---|---|
| | | (lcd) | Ratio[1)] | (lcd) | Ratio[1)] | |
| Dusit<br>Phra Nakhon<br>Pom Prab Sattru Pai<br>Sampanthawong<br>Pathumwan<br>Bang Rak | Residen. | 165 | (43%) | 152 | (57%) | 158 |
| | Commer. | 287 | | 264 | | 274 |
| | Total | 452 | | 416 | | 432 |
| Phya Thai<br>Huai Khwang | Residen. | 139 | (43%) | 128 | (57%) | 133 |
| | Commer. | 64 | | 59 | | 61 |
| | Total | 203 | | 187 | | 194 |
| Phra Khanong | Residen. | 221 | (35%) | 203 | (65%) | 209 |
| | Commer. | 133 | | 122 | | 126 |
| | Total | 354 | | 325 | | 335 |
| Bang Kapi<br>Bang Khen | Residen. | 140 | (35%) | 129 | (65%) | 133 |
| | Commer. | 42 | | 39 | | 40 |
| | Total | 182 | | 169 | | 173 |
| Yan Nawa | Residen. | 144 | (50%) | 132 | (50%) | 138 |
| | Commer. | 107 | | 98 | | 103 |
| | Total | 251 | | 230 | | 241 |

1) Ratio of served population

Residen.: Residential
Comemr.: Government + Commercial/Enterprise

Table C.10 Present and Future Unit Water Consumption

Unit: lcd

| Districts | Category | Present | Future |
|---|---|---|---|
| Dusit<br>Phra Nakhon<br>Pom Prab Sattru Pai<br>Sampanthawong<br>Pathumwan<br>Bang Rak | Residen. | 158 | 215 |
| | Commer. | 274 | 297 |
| | Total | 432 | 512 |
| Phya Thai<br>Huai Khwang | Residen. | 133 | 215 |
| | Commer. | 61 | 146 |
| | Total | 194 | 361 |
| Phra Khanong | Residen. | 209 | 21 |
| | Commer. | 126 | 146 |
| | Total | 335 | 367 |
| Bang Kapi<br>Bang Khen | Residen. | 133 | 215 |
| | Commer. | 40 | 146 |
| | Total | 173 | 361 |
| Yan Nawa | Residen. | 138 | 215 |
| | Commer. | 103 | 146 |
| | Total | 241 | 361 |

Residen.: Residential
Commer.: Government+Commercial/Enterprise

Table C.11 Present and Future Water Consumption in the Study Area

(Unit: $m^3$ /day)

| District | Present (Year 1986) | | | | | | Future (Year 2000) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Population | Residential | | Commercial & Others | | Total | Popula-tion | Residential | | Commercial & Others | | Total |
| | | lcd | Consump-tion | lcd | Consump-tion | | | lcd | Consump-tion | lcd | Consump-tion | |
| Phra Nakhon | 111,875 | 158 | 17,676 | 274 | 30,654 | 48,330 | 112,000 | 215 | 24,080 | 297 | 33,264 | 57,344 |
| Pom Prab Sattru Pai | 87,955 | 158 | 13,897 | 274 | 24,100 | 37,997 | 88,000 | 215 | 18,920 | 297 | 26,136 | 45,056 |
| Sampanthawong | 51,121 | 158 | 8,077 | 274 | 14,007 | 22,084 | 51,000 | 215 | 10,965 | 297 | 15,147 | 26,112 |
| Pathumwan | 143,199 | 158 | 22,625 | 274 | 39,237 | 61,862 | 143,000 | 215 | 30,745 | 297 | 42,471 | 73,216 |
| Phya Thai | 359,604 | 133 | 47,827 | 61 | 21,936 | 69,763 | 360,000 | 215 | 77,400 | 146 | 52,560 | 129,960 |
| Huai Khwang | 255,774 | 133 | 34,018 | 61 | 15,602 | 49,620 | 359,000 | 215 | 77,185 | 146 | 52,414 | 129,599 |
| Phra Khanong | 629,386 | 209 | 131,542 | 126 | 79,303 | 210,845 | 840,000 | 221 | 185,640 | 146 | 122,640 | 308,280 |
| Bang Kapi | 409,785 | 133 | 54,501 | 40 | 16,391 | 70,892 | 710,000 | 215 | 152,650 | 146 | 103,660 | 256,310 |
| Bang Khen | 548,078 | 133 | 72,894 | 40 | 21,923 | 94,817 | 809,000 | 215 | 173,935 | 146 | 118,114 | 292,049 |
| Bang Rak | 90,672 | 158 | 14,326 | 274 | 24,844 | 39,170 | 91,000 | 215 | 19,565 | 297 | 27,027 | 46,592 |
| Dusit | 562,990 | 158 | 88,952 | 274 | 154,259 | 243,211 | 772,000 | 215 | 165,980 | 297 | 229,284 | 395,264 |
| Yan Nawa | 415,703 | 138 | 57,367 | 103 | 42,817 | 100,184 | 416,000 | 215 | 89,440 | 146 | 60,736 | 150,176 |
| Total | 3,666,142 | 154 | 563,702 | 132 | 485,073 | 1,048,775 | 4,751,000 | 216 | 1,026,505 | 186 | 883,453 | 1,909,958 |

Table C.12 Unit Pollution Load in Previous Studies

| Agency | Year | Pollution Load (BOD·gcd) | Wastewater (lcd) | Remarks |
|---|---|---|---|---|
| JICA/1 | 1981 | 61 | 234 | Residential 48 gcd<br>Commercial 13 gcd |
| WHO | 1980 | 54 | - | |
| STRIT | 1980 | 20 | 138 | Science and Technical Research, Institute of Thailand |
| MR. THONGCHAI | 1979 | 35 | 390 | Mr. Thongchai Pansawad |
| AIT | 1978 | 45 | - | |
| NEB | 1987 | 48 | - | Sanitary Engineering Dept., Faculty of Engineering Chulalongkorn Univ. |

Source: National Seminar
Technology of Water & Wastewater, March 1988

Table C.13 Unit Pollution Load in Previous Studies (STRIT Study)

| Observation Site | Number of Household | Person per Household | Population | Flow | | $BOD_5$ | | $COD_{cr}$ | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | $m^3/d$ | lcd | mg/l | gcd | mg/l | gcd |
| Din Daeng 3-1 | 330 | 4.14 | 1,366 | 272.3 | 199.4 | 118.5 | 23.6 | 226.2 | 45.1 |
| Din Daeng 3-3 | 330 | 4.14 | 1,366 | 260.0 | 190.4 | 106.9 | 20.4 | 223.0 | 42.5 |
| Bang Buo | 1,214 | 3.95 | 4,796 | 476.5 | 99.4 | 184.7 | 18.4 | 310.9 | 30.9 |
| Bang Na | 1,654 | 3.12 | 5,167 | 602.0 | 116.5 | 152.8 | 17.8 | 235.1 | 27.4 |
| Bon Kai | 308 | 4.16 | 1,282 | 208.4 | 162.6 | 124.6 | 20.3 | 275.9 | 44.9 |
| Huai Khwang | 3,360 | 5.15 | 17,304 | 2698.4 | 155.9 | 114.3 | 17.8 | 222.6 | 34.7 |

Ref.: Thailand Institute of Science and Technical Research
"Project Study for Evaluation of Waste Water Treatment of the National Housing Authority"
Bangkok, 1980

Table C.14 Survey Results of Unit Pollution Load Generation from Resident

| Site | Date | Flow ($m^3$/d) | Quality (mg/l) | | | Pollution Load (kg/d) | | | Popula-tion | Per Capita Flow (lcd) | Per Capita Pollution Load (gcd) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | BOD | COD | SS | BOD | COD | SS | | | BOD | COD | SS |
| Din Daeng | Feb. 24-25 | 267 | 99 | 273 | 91 | 26.4 | 73.0 | 24.2 | 1320 | 202 | 20.0 | 55.3 | 18.3 |
| Din Daeng | Jul. 21-22 | 175 | 80 | 187 | 77 | 14.0 | 32.7 | 13.5 | 1320 | 133 | 10.6 | 24.8 | 10.2 |
| Din Daeng | Sep. 7-8 | 190 | 132 | 308 | 120 | 25.0 | 58.6 | 22.8 | 1320 | 144 | 18.9 | 44.4 | 17.3 |
| Bon Kai | Aug. 10-11 | 266 | 109 | 192 | 98 | 28.9 | 51.0 | 26.1 | 1900 | 140 | 15.2 | 26.8 | 13.7 |
| Bon Kai | Sep. 7-8 | 315 | 220 | 385 | 154 | 69.5 | 121.5 | 48.5 | 1900 | 165 | 36.6 | 63.9 | 25.5 |
| Total | - | 1213 | *128 | *269 | *108 | 163.8 | 336.8 | 135.1 | 7760 | *157 | *20.3 | *43.0 | *17.0 |

* Average

Table C.15 Survey Results of Unit Pollution Load Generation from Commercial Enterprise

| Name | Flow $m^3$/d | Water Quality (mg/l) | | | Pollution Load (kg/d) | | |
|---|---|---|---|---|---|---|---|
| | | BOD | COD | SS | BOD | COD | SS |
| Suriwong Rd. | 5108 | 74 | 137 | 30 | 375.6 | 698.0 | 153.4 |
| Silom Rd. | 15064 | 60 | 115 | 75 | 905.5 | 1725.3 | 1134.6 |
| Siam Square | - | 305 | 457 | 133 | - | - | - |
| Average | - | 146 | 236 | 79 | - | - | - |

Table C.16 Pollution Load of Commercial Wastewater

| Item | Wastewater (Ratio) | Quality (mg/l) | | |
|---|---|---|---|---|
| | | BOD | COD | SS |
| Restaurant | 31,000 $m^3$/d (33%) | 305 [2)] | 457 [2)] | 133 [2)] |
| Other [1)] | 63,000 $m^3$/d (67%) | 67 [3)] | 126 [3)] | 53 [3)] |
| Average | 94,000 $m^3$/d (100%) * | 145 | 235 | 80 |

1) Hotel, Theater, Market, Department Store, Office, Hospital, etc.
2) Quality of Wastewater: Siam Square
3) Quality of Wastewater: Average of Suriwong Rd. and Silom Rd.

* : Total

Table C.17 (1) Present and Future Estimated Unit Pollution Load Generation (BOD)

| Districts | Item | Present (1986 Year) | | | Future (2000 Year) | | | Remarks |
|---|---|---|---|---|---|---|---|---|
| | | Residen. | Commer. Gover. | Total | Residen. | Commer. Gover. | Total | |
| | Quality | 130 mg/l | 145 mg/l | - | 130 mg/l | 145 mg/l | - | |
| Dusit<br>Phra Nakhon<br>Pom Prab Sattru Pai<br>Sampanthawong<br>Pathmwan<br>Bang Rak | Discharge | 158 lcd | 274 lcd | 432 lcd | 215 lcd | 297 lcd | 512 lcd | |
| | Pollution Load | 20.5 gcd | 39.7 gcd | 60.2 gcd | 28.0 gcd | 43.1 gcd | 71.1 gcd | |
| Phya Thai<br>Huai Khwang | Discharge | 133 lcd | 61 lcd | 194 lcd | 215 lcd | 146 lcd | 361 lcd | |
| | Load | 17.3 gcd | 8.8 gcd | 26.1 gcd | 28.0 gcd | 21.2 gcd | 49.2 gcd | |
| Phra Khanong | Discharge | 209 lcd | 126 lcd | 335 lcd | 221 lcd | 146 lcd | 367 lcd | |
| | Load | 27.2 gcd | 18.3 gcd | 45.5 gcd | 28.7 gcd | 21.2 gcd | 49.9 gcd | |
| Bang Kapi<br>Bang Khen | Discharge | 133 lcd | 40 lcd | 173 lcd | 215 lcd | 146 lcd | 361 lcd | |
| | Load | 17.3 gcd | 5.8 gcd | 23.1 gcd | 28.0 gcd | 21.2 gcd | 49.2 gcd | |
| Yan Nawa | Discharge | 138 lcd | 103 lcd | 241 lcd | 215 lcd | 146 lcd | 361 lcd | |
| | Load | 17.9 gcd | 14.9 gcd | 32.8 gcd | 28.0 gcd | 21.2 gcd | 49.2 gcd | |

* Growth rate: Residen. = 0.6 g/year Total = 1.2 g/year

Table C.17 (2) Present and Future Estimated Unit Pollution Load Generation (COD)

| Districts | Item | Present (1986 Year) | | | Future (2000 Year) | | | Remarks |
|---|---|---|---|---|---|---|---|---|
| | | Residen. | Commer. Gover. | Total | Residen. | Commer. Gover. | Total | |
| | Quality | 270 mg/l | 235 mg/l | - | 270 mg/l | 235 mg/l | - | |
| Dusit<br>Phra Nakhon<br>Pom Prab Sattru Pai<br>Sampanthawong<br>Pathmwan<br>Bang Rak | Discharge | 158 lcd | 274 lcd | 432 lcd | 215 lcd | 297 lcd | 512 lcd | |
| | Pollution Load | 42.7 gcd | 64.4 gcd | 107.1 gcd | 58.1 gcd | 69.8 gcd | 127.9 gcd | |
| Phya Thai<br>Huai Khwang | Discharge | 133 lcd | 61 lcd | 194 lcd | 215 lcd | 146 lcd | 361 lcd | |
| | Load | 35.9 gcd | 14.3 gcd | 50.2 gcd | 58.1 gcd | 34.3 gcd | 92.4 gcd | |
| Phra Khanong | Discharge | 209 lcd | 126 lcd | 335 lcd | 221 lcd | 146 lcd | 367 lcd | |
| | Load | 56.4 gcd | 29.6 gcd | 86.0 gcd | 59.7 gcd | 34.3 gcd | 94.0 gcd | |
| Bang Kapi<br>Bang Khen | Discharge | 133 lcd | 40 lcd | 173 lcd | 215 lcd | 146 lcd | 361 lcd | |
| | Load | 35.9 gcd | 9.4 gcd | 45.3 gcd | 58.1 gcd | 34.3 gcd | 92.4 gcd | |
| Yan Nawa | Discharge | 138 lcd | 103 lcd | 241 lcd | 215 lcd | 146 lcd | 361 lcd | |
| | Load | 37.3 gcd | 24.2 gcd | 61.5 gcd | 58.1 gcd | 34.3 gcd | 92.4 gcd | |

* Growth rate: Residen. = 1.2 g/year Total = 2.1 g/year

Table C.17 (3) Present and Future Estimated Unit Pollution Load Generation (SS)

| Districts | Item | Present (1986 Year) | | | Future (2000 Year) | | | Remarks |
|---|---|---|---|---|---|---|---|---|
| | | Residen. | Commer. Gover. | Total | Residen. | Commer. Gover. | Total | |
| | Quality | 110 mg/l | 80 mg/l | - | 110 mg/l | 80 mg/l | - | |
| Dusit<br>Phra Nakhon<br>Pom Prab Sattru Pai<br>Sampanthawong<br>Pathmwan<br>Bang Rak | Discharge | 158 lcd | 274 lcd | 432 lcd | 215 lcd | 297 lcd | 512 lcd | |
| | Pollution Load | 17.4 gcd | 21.9 gcd | 39.3 gcd | 23.7 gcd | 23.8 gcd | 47.5 gcd | |
| Phya Thai<br>Huai Khwang | Discharge | 133 lcd | 61 lcd | 194 lcd | 215 lcd | 146 lcd | 361 lcd | |
| | Load | 14.6 gcd | 4.9 gcd | 19.5 gcd | 23.7 gcd | 11.7 gcd | 35.4 gcd | |
| Phra Khanong | Discharge | 209 lcd | 126 lcd | 335 lcd | 221 lcd | 146 lcd | 367 lcd | |
| | Load | 23.0 gcd | 10.1 gcd | 33.1 gcd | 24.3 gcd | 11.7 gcd | 36.0 gcd | |
| Bang Kapi<br>Bang Khen | Discharge | 133 lcd | 40 lcd | 173 lcd | 215 lcd | 146 lcd | 361 lcd | |
| | Load | 14.6 gcd | 3.2 gcd | 17.8 gcd | 23.7 gcd | 11.7 gcd | 35.4 gcd | |
| Yan Nawa | Discharge | 138 lcd | 103 lcd | 241 lcd | 215 lcd | 146 lcd | 361 lcd | |
| | Load | 15.2 gcd | 8.2 gcd | 23.4 gcd | 23.7 gcd | 11.7 gcd | 35.4 gcd | |

* Growth rate: Residen. = 0.5 g/year Total = 0.8 g/year

Table C.18 Observation Date of Pollution Load Run-off

| Land Use Pattern | Name | Observation Date |
|---|---|---|
| Commercial and Residential Area | Suriwong Rd. | Aug. 3-4, 1988<br>Aug. 10-11, 1988 |
| | Krung Kasem Rd. | Aug. 3-4, 1988<br>Aug. 17-18, 1988 |
| | Sukhumvit Rd. | Feb. 18-19, 1988<br>Jul. 21-22, 1988<br>Aug. 17-18, 1988 |
| High Density Residential Area | Pathumwan | Aug. 17-18, 1988 |
| Low Density Residential Area | Siam Jasco<br>Wipawadi Rangsit 1<br>Wipawadi Rangsit 2 | Aug. 10-11, 1988<br>Aug. 10-11, 1988<br>Aug. 10-11, 1988 |

Table C.19 Conditions of Survey Areas for Pollution Load Runoff

| | Population | Area $km^2$ | Population Density (Person/ha) | Conditions of Survey Areas |
|---|---|---|---|---|
| Suriwong Rd. | 2,773 | 0.090 | 308 | In Suriwong Rd., there are many large company offices, banks, hotels and stores. The survey area is located in the residential area behind the main streets. |
| Krung Kasem Rd. | 11,886 | 0.340 | 349 | Unlike Suriwong Rd. and Silom Rd. that have many large company offices, banks, hotels, and stores, there are many small and medium sized stores in the survey areas. These stores are located on the ground floors of buildings that have residential units above the second floor. |
| Sukhumvit Rd. Soi 40 | 66,000 | 6.150 | 107 | The survey area is a large area between Sukhumvit Street and the K. Saen Saep. The area facing the street is a commercial zone. The area behind the commercial zone is a high class residential area having many condominiums. |
| Pathumwan | 2,777 | 0.050 | 555 | Relatively low income families live in this area. About one half of the area is occupied by congested low houses and is heavily populated. |
| Siam Jasco | 9,072 | 0.220 | 412 | The roadsides in the survey area are occupied by open weather restaurants and stores. However, more than 90% of the area is residential. |
| Wipawadi Rangsit 1 | 2,943 | 1.140 | 25 | The area is located to the north of Bangkok City. It is a high class residential area that faces the highway connecting Bangkok City to the airport. Most of the houses face the paved roads that have nice side ditches. |
| Wipawadi Rangsit 2 | 4,577 | 0.560 | 82 | Pollution load in the area is discharged from a large complex of police flats and scattered houses. Except for the police flat area, the area is densely populated. The pollution load from the police flats flows into one spot of the upper part of the areas. |

Table C.20 BOD Run-off Coefficient

| Name | Date | Discharge $m^3/d$ | Average Quality mg/l | Run-off Load kg/d | Popula-tion | Per Capita Load Generation gcd | Generated Load kg/d | Run-off Coefficient % | Area $km^2$ | Population Density person/ha | Specific Discharge $10^3m^3/d/km^2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Suriwong Rd. | Aug. 3-4 | 4311 | 54 | 231.4 | 2773 | 60.2 | 166.9 | 139 | 0.090 | 308 | 47.9 |
| Suriwong Rd. | Aug.17-18 | 4251 | 54 | 230.9 | 2773 | 60.2 | 166.9 | 138 | 0.090 | 308 | 47.2 |
| Krung Kasem Rd. | Aug. 3-4 | 10710 | 65 | 694.3 | 11886 | 60.2 | 715.5 | 97 | 0.340 | 349 | 31.5 |
| Krung Kasem Rd. | Aug.17-18 | 7360 | 40 | 297.9 | 11886 | 60.2 | 715.5 | 42 | 0.340 | 349 | 21.6 |
| Sukhumvit soi 40 | Feb.18-19 | 33800 | 42 | 1419.3 | 66000 | 45.5 | 3003.0 | 47 | 6.150 | 107 | 5.5 |
| Sukhumvit soi 40 | Jul. 21-22 | 72538 | 19 | 1363.4 | 66000 | 45.5 | 3003.0 | 45 | 6.150 | 107 | 11.8 |
| Sukhumvit soi 40 | Aug.17-18 | 44278 | 49 | 2171.9 | 66000 | 45.5 | 3003.0 | 72 | 6.150 | 107 | 7.2 |
| Pathumwan | Aug.17-18 | 1757 | 45 | 78.6 | 2777 | 60.2 | 167.2 | 47 | 0.050 | 555 | 35.1 |
| JASCO | Aug.10-11 | 2399 | 43 | 102.7 | 9072 | 26.1 | 236.8 | 43 | 0.220 | 412 | 10.9 |
| Wipawadi Rangsit-1 | Aug.10-11 | 1542 | 32 | 48.7 | 2943 | 23.1 | 68.0 | 72 | 1.140 | 25 | 1.4 |
| Wipawadi Rangsit-2 | Aug.10-11 | 3600 | 29 | 103.0 | 4577 | 23.1 | 105.7 | 97 | 0.560 | 82 | 6.4 |

Table C.21 SS Run-off Coefficient

| Name | Date | Discharge $m^3/d$ | Average Quality mg/l | Run-off Load kg/d | Popula-tion | Per Capita Load Generation gcd | Generated Load kg/d | Run-off Coefficient % | Area $km^2$ | Population Density person/ha | Specific Discharge $10^3m^3/d/km^2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Suriwong Rd. | Aug. 3-4 | 4311 | 25 | 108.8 | 2773 | 39.3 | 109.0 | 100 | 0.090 | 308 | 47.9 |
| Suriwong Rd. | Aug.17-18 | 4251 | 123 | 524.1 | 2773 | 39.3 | 109.0 | 481 | 0.090 | 308 | 47.2 |
| Krung Kasem Rd. | Aug. 3-4 | 10710 | 46 | 490.0 | 11886 | 39.3 | 467.1 | 105 | 0.340 | 349 | 31.5 |
| Krung Kasem Rd. | Aug.17-18 | 7360 | 32 | 235.5 | 11886 | 39.3 | 467.1 | 50 | 0.340 | 349 | 21.6 |
| Sukhumvit soi 40 | Feb.18-19 | 33800 | 35 | 1198.6 | 66000 | 33.1 | 2184.6 | 55 | 6.150 | 107 | 5.5 |
| Sukhumvit soi 40 | Jul. 21-22 | 72538 | 39 | 2824.4 | 66000 | 33.1 | 2184.6 | 129 | 6.150 | 107 | 11.8 |
| Sukhumvit soi 40 | Aug.17-18 | 44278 | 90 | 3965.3 | 66000 | 33.1 | 2184.6 | 182 | 6.150 | 107 | 7.2 |
| Pathumwan | Aug.17-18 | 1757 | 64 | 111.6 | 2777 | 39.3 | 109.1 | 102 | 0.050 | 555 | 35.1 |
| JASCO | Aug.10-11 | 2399 | 13 | 30.2 | 9072 | 19.5 | 176.9 | 17 | 0.220 | 412 | 10.9 |
| Wipawadi Rangsit-1 | Aug.10-11 | 1542 | 21 | 32.9 | 2943 | 17.8 | 52.4 | 63 | 1.140 | 25 | 1.4 |
| Wipawadi Rangsit-2 | Aug.10-11 | 3600 | 12 | 43.5 | 4577 | 17.8 | 81.5 | 53 | 0.560 | 82 | 6.4 |

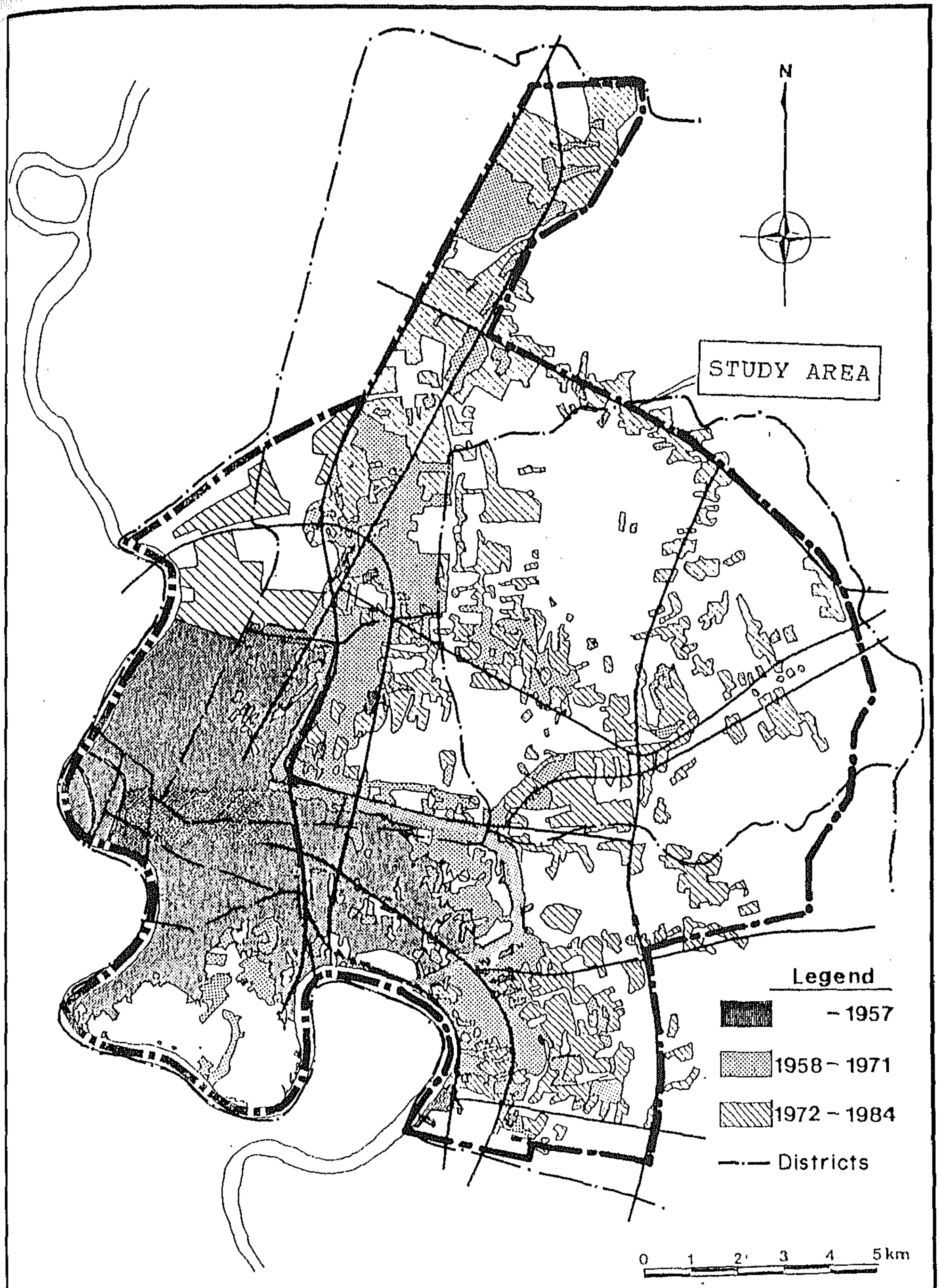


FIG. C.1 EXPANSION OF URBANIZED AREA IN THE STUDY AREA

THE FEASIBILITY STUDY ON PURIFICATION OF KLONG WATER IN BANGKOK

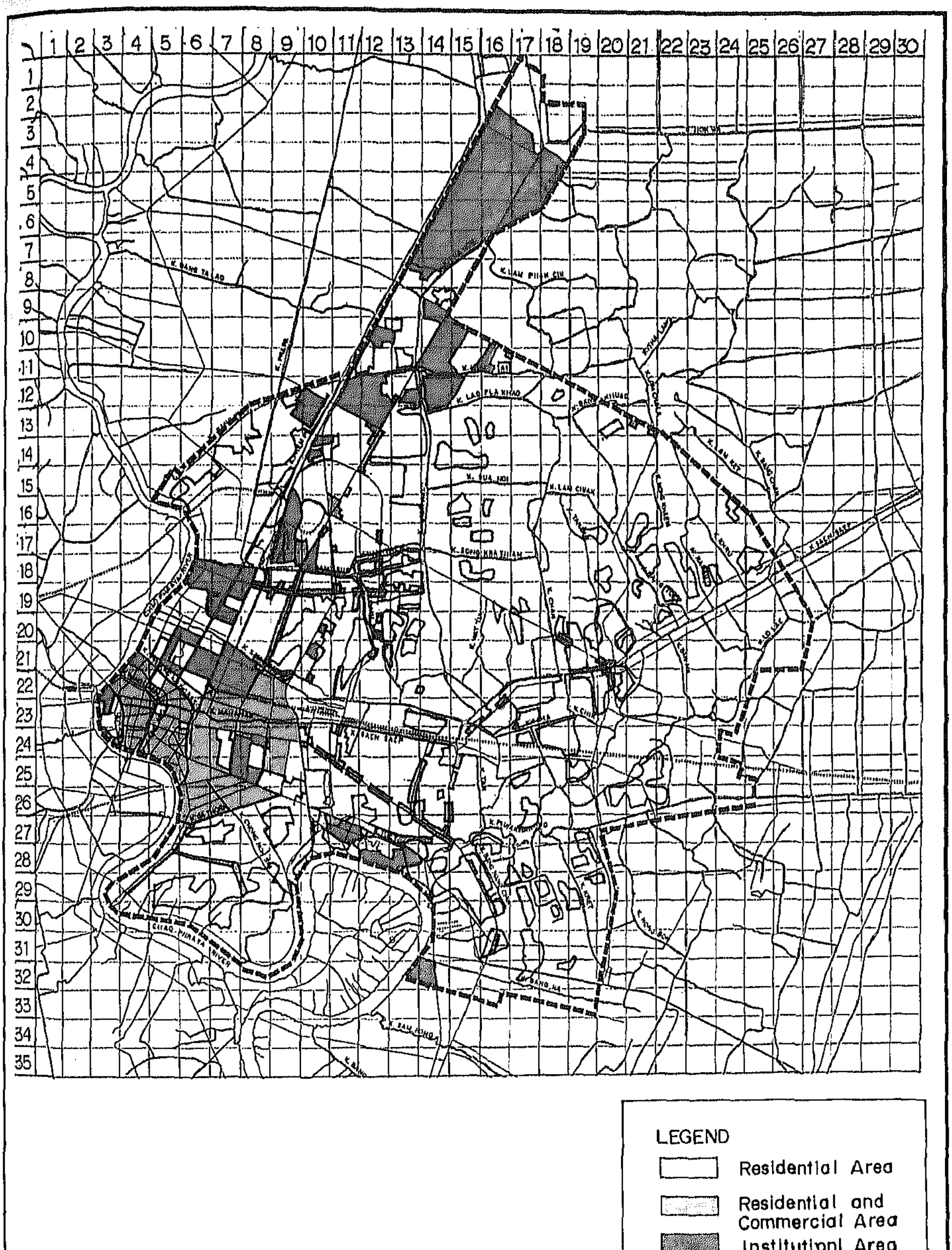


FIG. C.2 EXISTING LAND USE

**THE FEASIBILITY STUDY ON PURIFICATION OF KLONG WATER IN BANGKOK**

| Bangkok | Metropolis |
|---|---|
| 1980 | 5,070,000 |
| 1990 | 6,400,000 |
| 2000 | 7,700,000 |

| Urban | Core Area |
|---|---|
| 1980 | 390,000 |
| 1990 | 320,000 |
| 2000 | 270, 000 |

District Name

- ✱ Phra Nakhon
- ✱ Pom Prap Sattru Pai
- ✱ Sampan thawong

| Core | Fringe Area |
|---|---|
| 1980 | 2,580,000 |
| 1990 | 2,840,000 |
| 2000 | 3,070,000 |

District Name

- ✱ Pathumwan
- ✱ Bang Rak
- ✱ Yan Nawa
- ✱ Dusit
- ✱ Phya Thai
- Thonburi
- Klong San
- Bangkok Noi
- Bangkok Yai

Suburban Area

| Eastern | Suburban Area |
|---|---|
| 1980 | 1,160,000 |
| 1990 | 1,790,000 |
| 2000 | 2,500,000 |

District Name

- ✱ Huai Khwang
- ✱ Phra Khanong
- ✱ Bang Khen
- ✱ Bang Kapi

| Remaining | Area |
|---|---|
| 1980 | 940,000 |
| 1990 | 1,450,000 |
| 2000 | 1,860,000 |

District Name

- Phra Khanong
- Bang Khen
- Bang Kapi
- Min Buri
- Nong Chok
- Lad Krabang
- Rat Burana
- Bang Khun Thian
- Phasi Charoen
- Taling Chan
- Nong Khaem

Note : Districts marked by ✱ are included in the Study Area.

Ref. : Report of Flood Protection / Drainage in Eastern Suburban Bangkok, JICA

FIG. C.3 PROJECTED POPULATION OF URBAN CORE, CORE FRINGE AND SUBURBAN AREAS

THE FEASIBILITY STUDY ON PURIFICATION OF KLONG WATER IN BANGKOK



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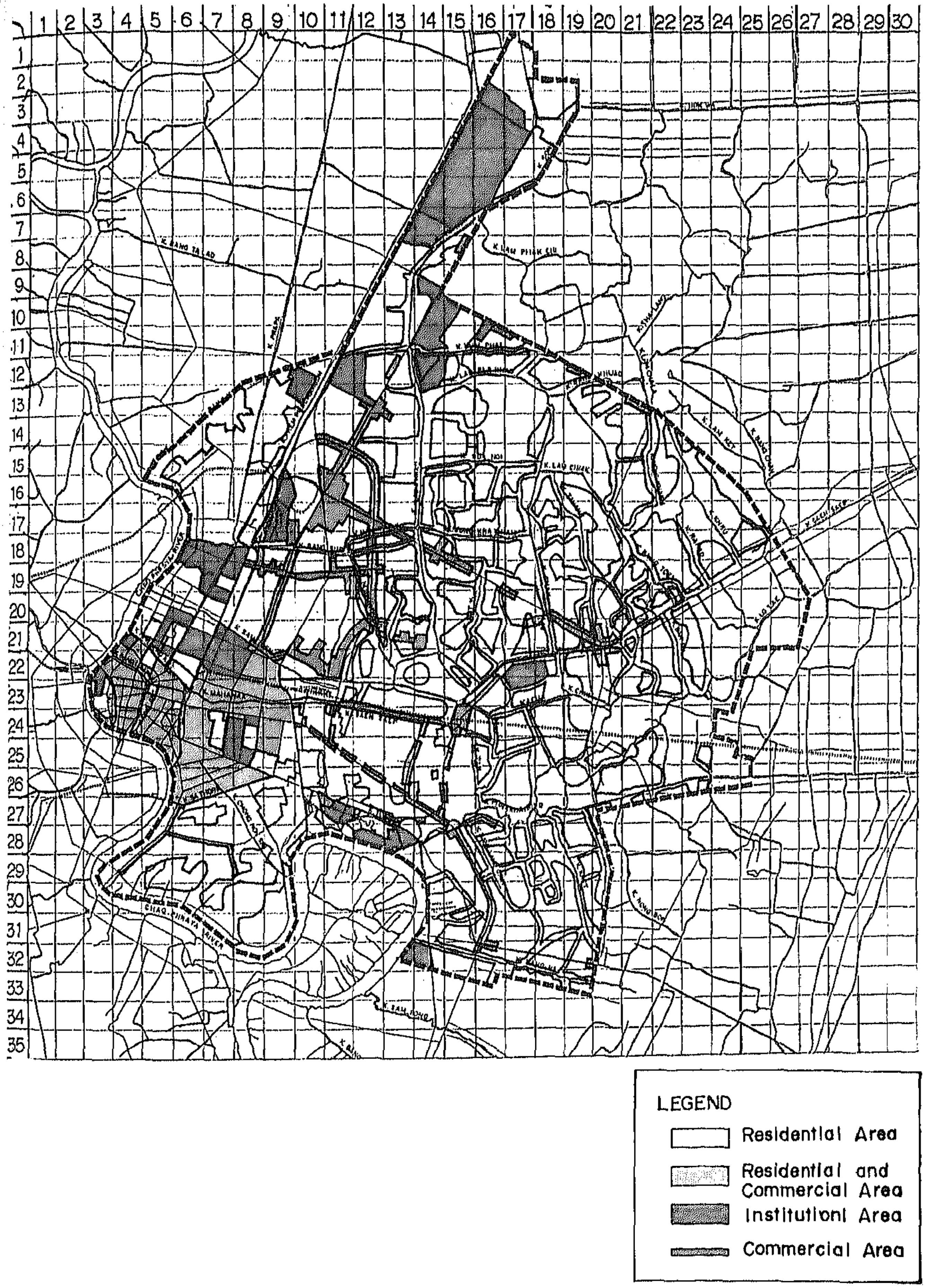
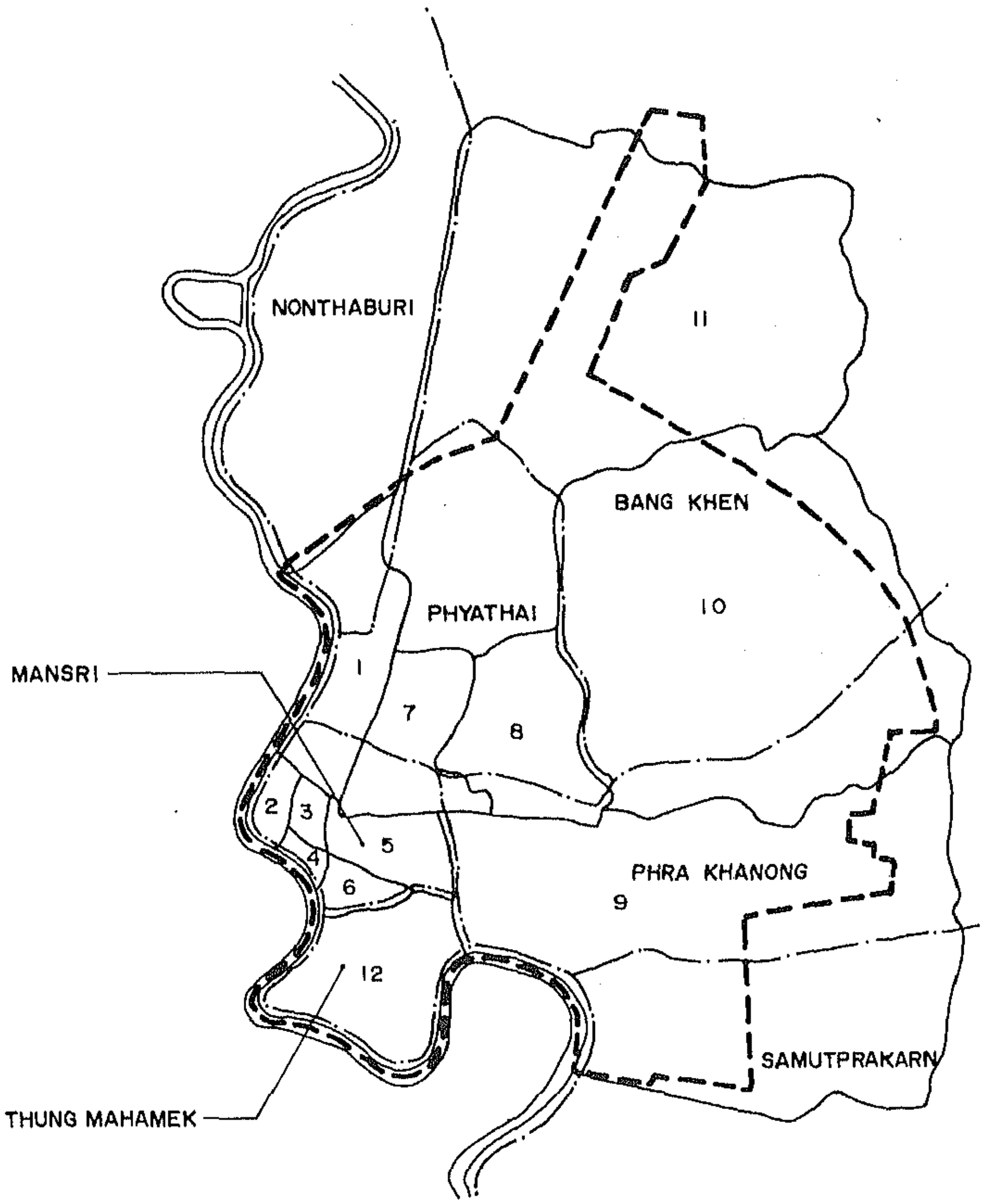



FIG. C.4 FUTURE LAND USE

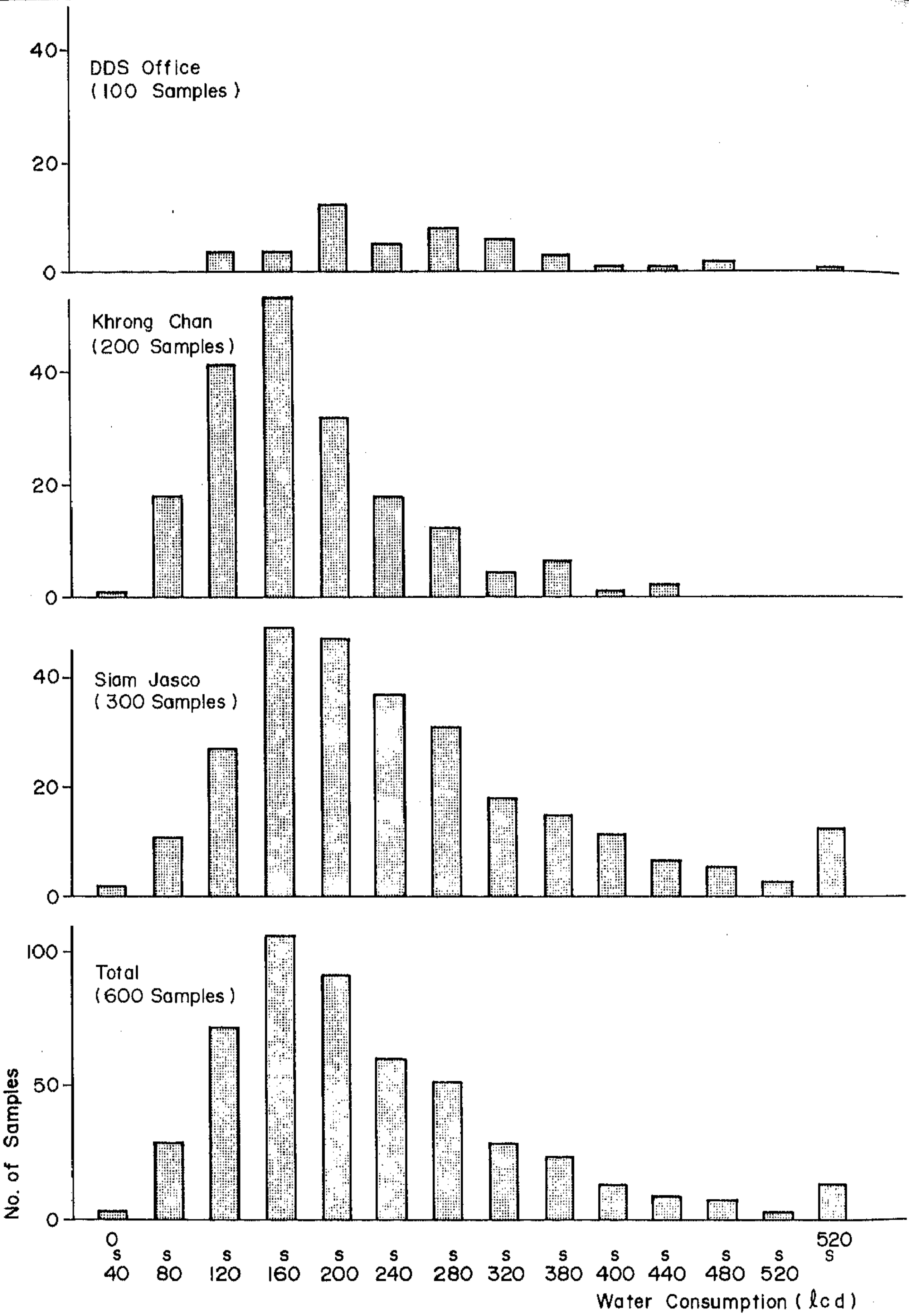
**THE FEASIBILITY STUDY ON PURIFICATION OF KLONG WATER IN BANGKOK**




| No. | Districts |
|---|---|
| 1 | Dusit |
| 2 | Phra Nakhon |
| 3 | Pom Prab Sattru Pai |
| 4 | SamPanthawong |
| 5 | Pathumwan |
| 6 | Bang Rak |
| 7 | Phya Thai |
| 8 | Huai Khwang |
| 9 | Phra Khanong |
| 10 | Bang Kapi |
| 11 | Bang Khen |
| 12 | Yan Nawa |

FIG. C.5 MWA SERVICE AREA

THE FEASIBILITY STUDY ON PURIFICATION OF KLONG WATER IN BANGKOK




| FIG. C.6 | RESULTS OF SAMPLING SURVEY ON UNIT WATER CONSUMPTION |
|---|---|

**THE FEASIBILITY STUDY ON PURIFICATION OF KLONG WATER IN BANGKOK**

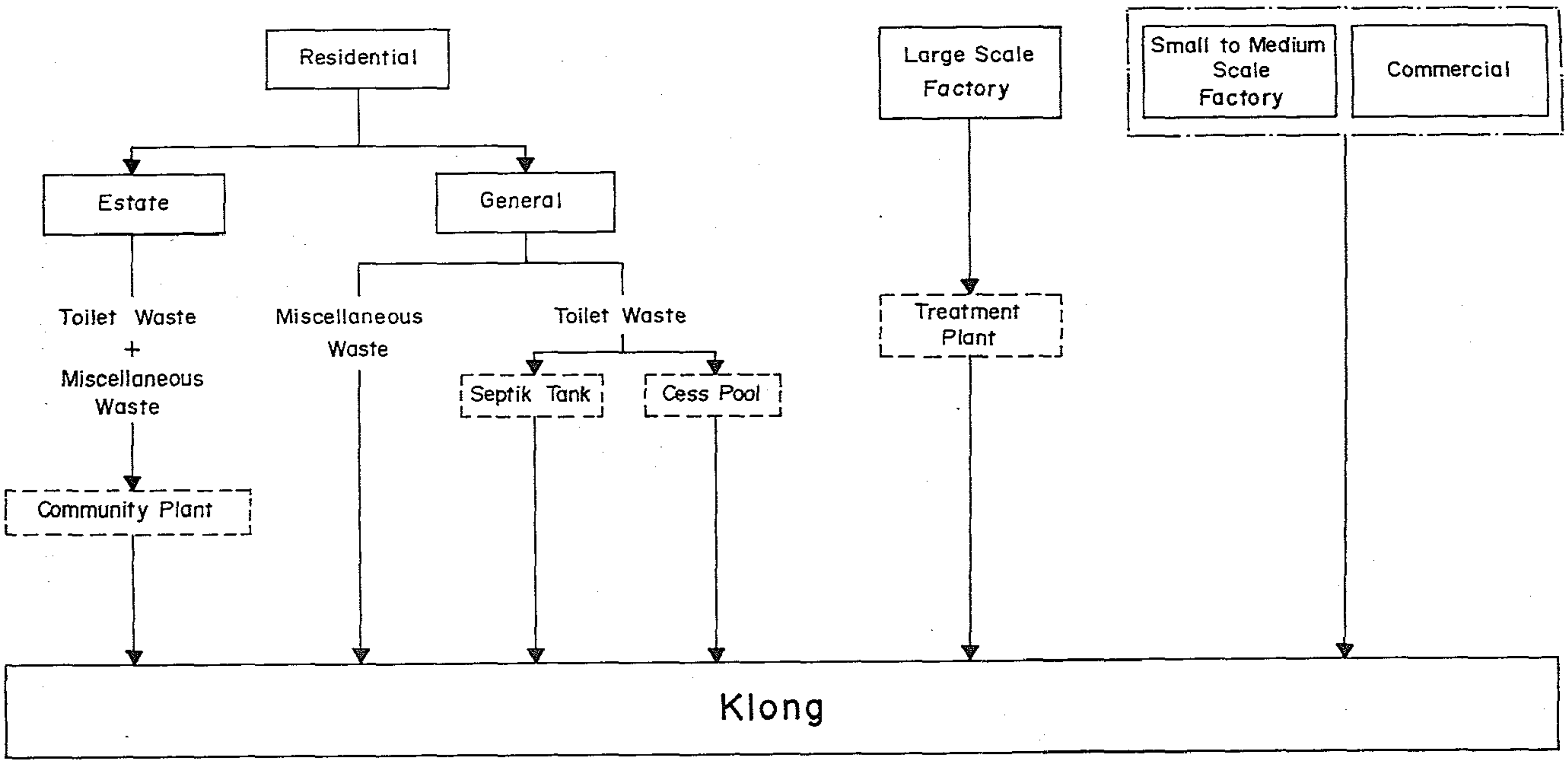



FIG. C.7 CONCEPT OF POLLUTION LOAD GENERATION

THE FEASIBILITY STUDY ON PURIFICATION OF KLONG WATER IN BANGKOK

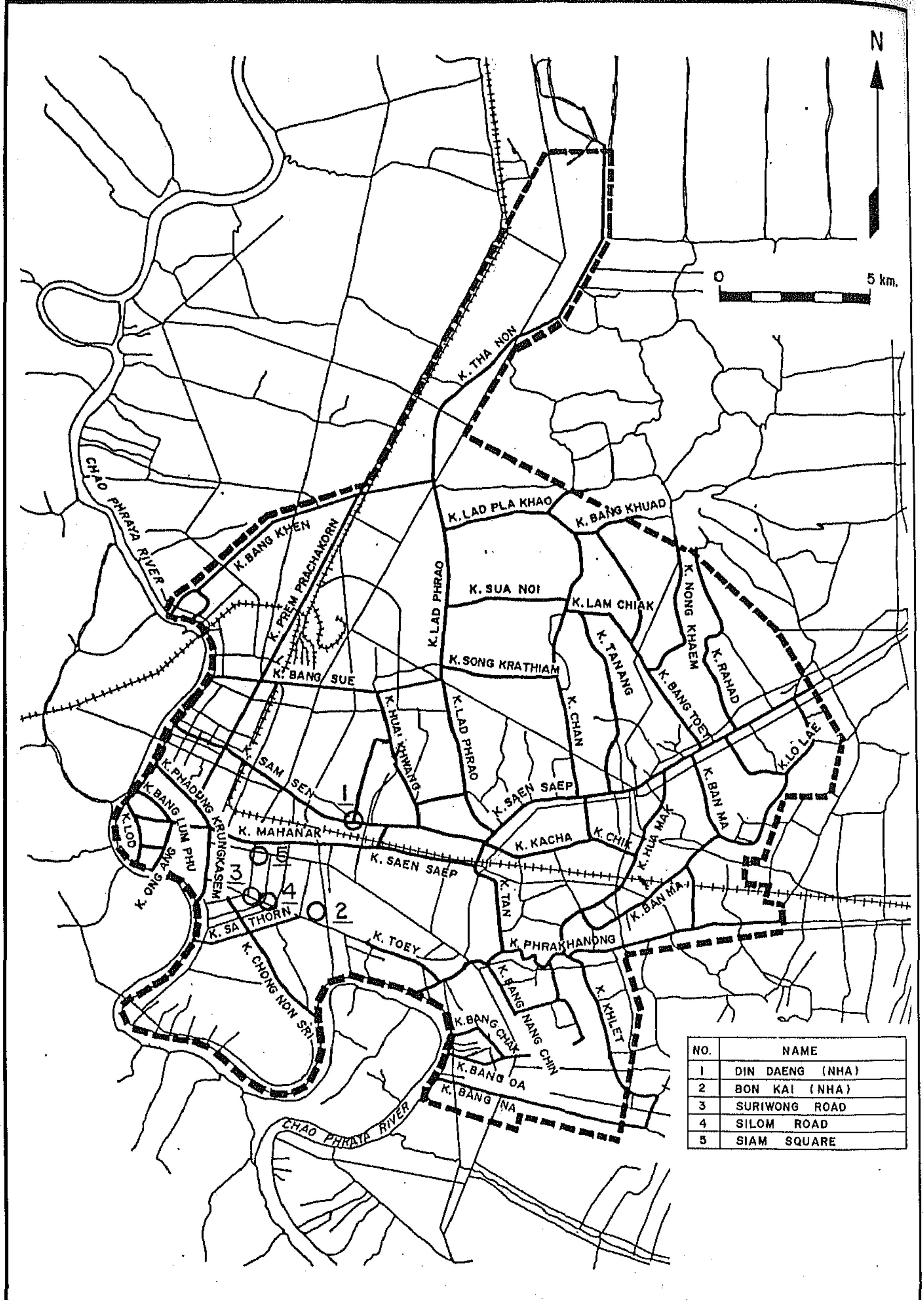



**FIG. C.8** LOCATION OF UNIT POLLUTION LOAD GENERATION SURVEY

**THE FEASIBILITY STUDY ON PURIFICATION OF KLONG WATER IN BANGKOK**



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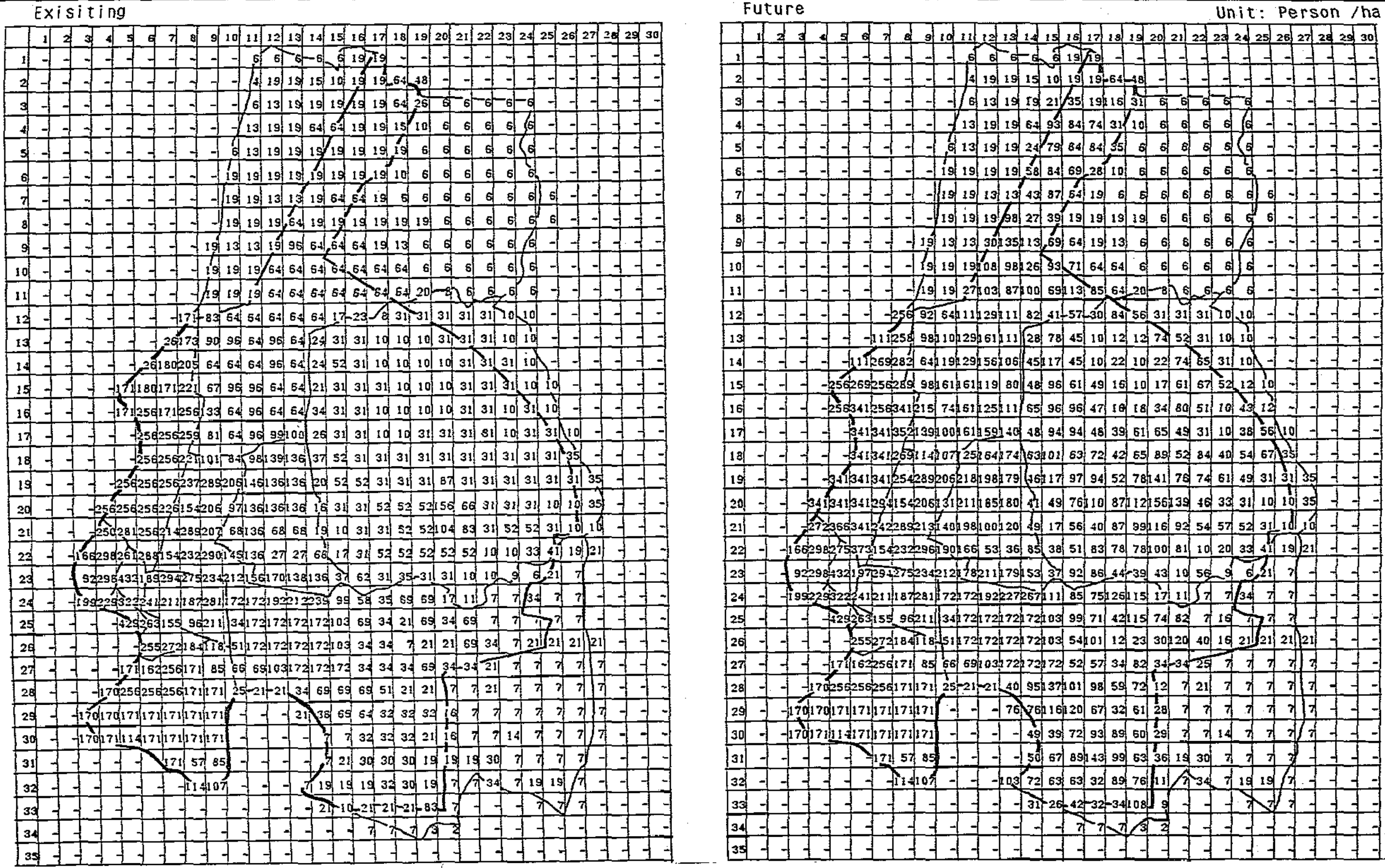
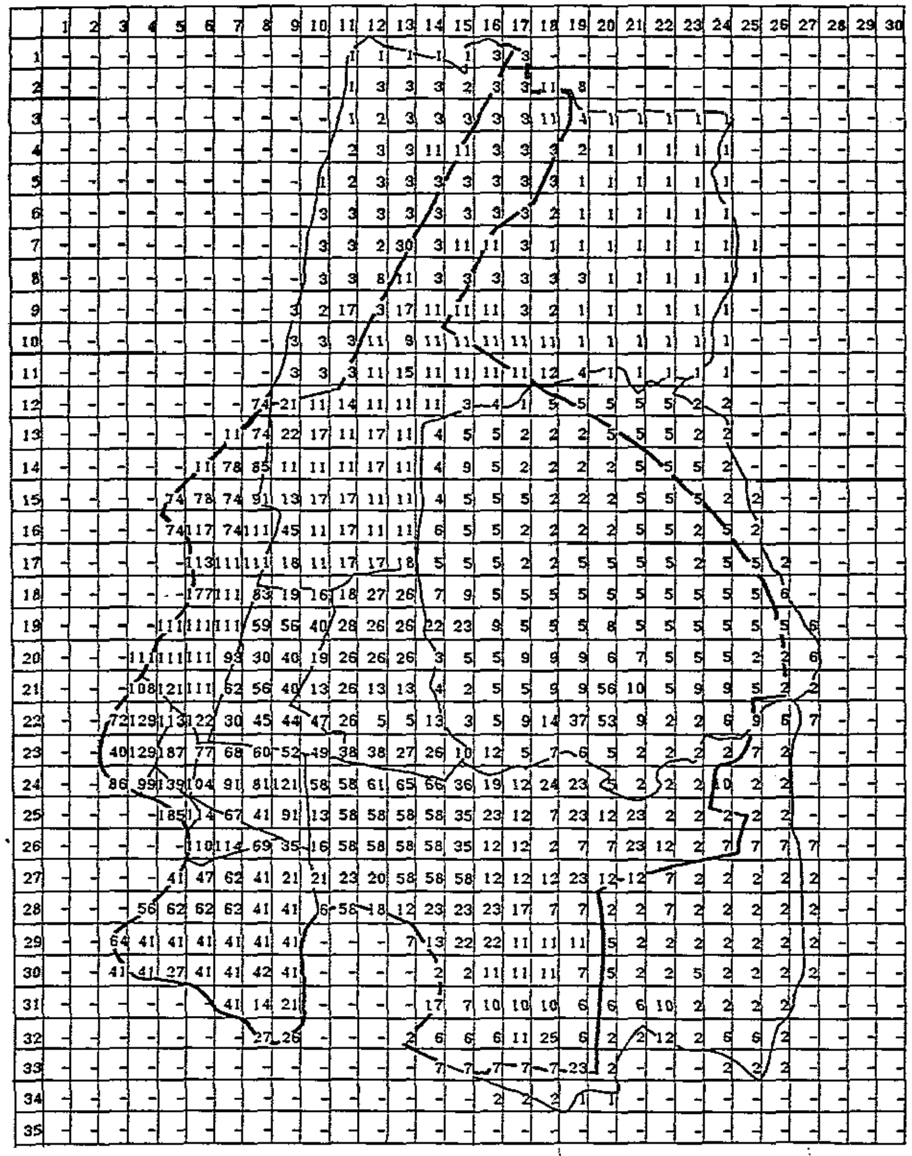



FIG. C.9 REGIONAL DISTRIBUTION OF EXISTING AND FUTURE POPULATION DENSITY

THE FEASIBILITY STUDY ON PURIFICATION OF KLONG WATER IN BANGKOK

(Exisiting)



(Future) UNIT : *100 m³ / d - Km²

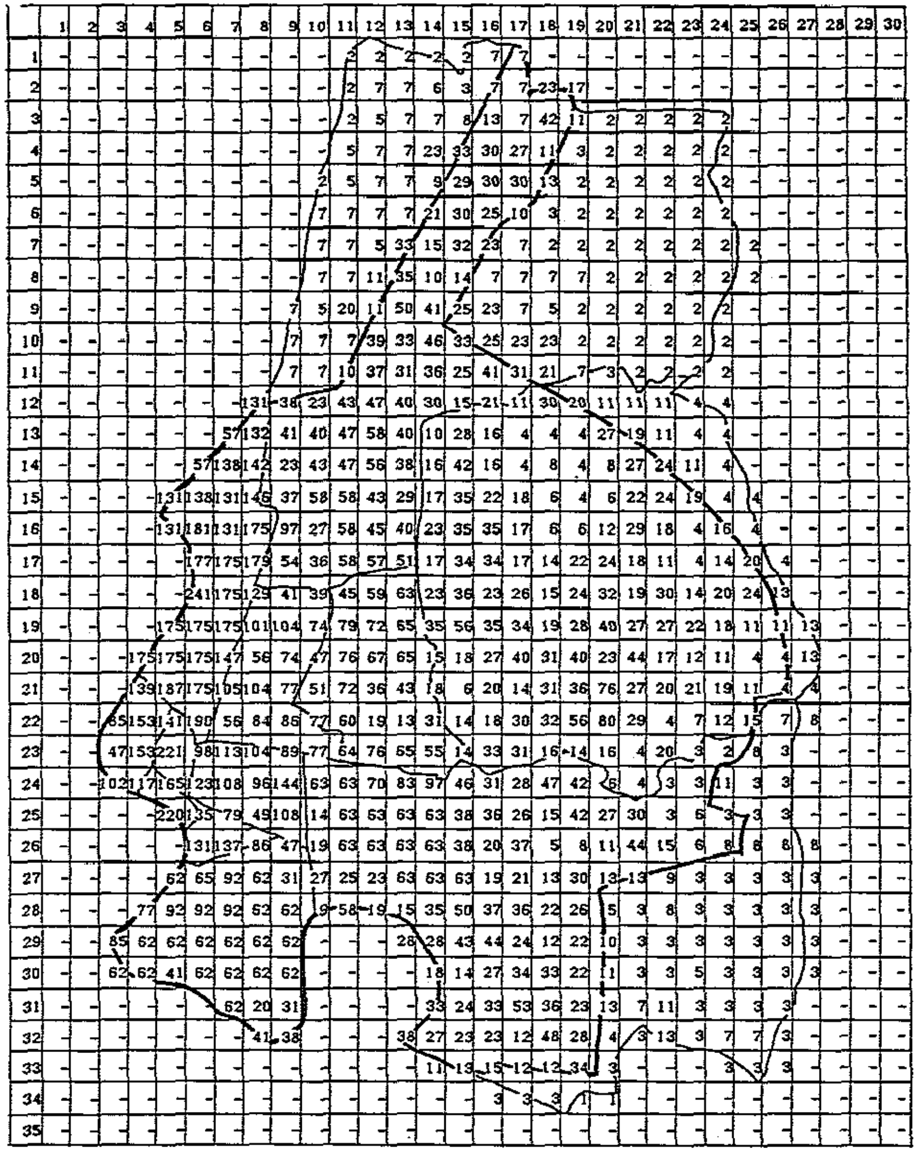
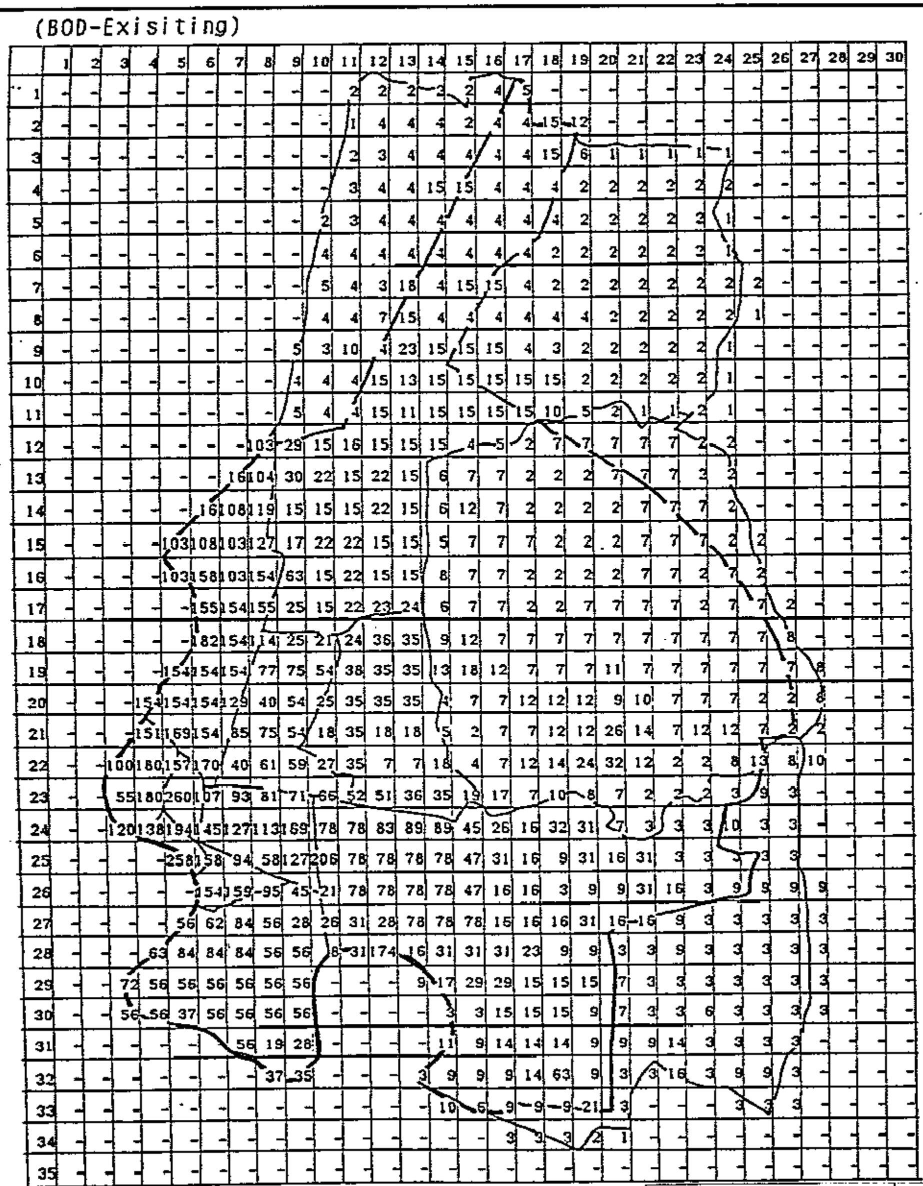


**FIG. C.10** REGIONAL DISTRIBUTION OF EXISTING AND FUTURE WASTEWATER DISCHARGE

**THE FEASIBILITY STUDY ON PURIFICATION OF KLONG WATER IN BANGKOK**



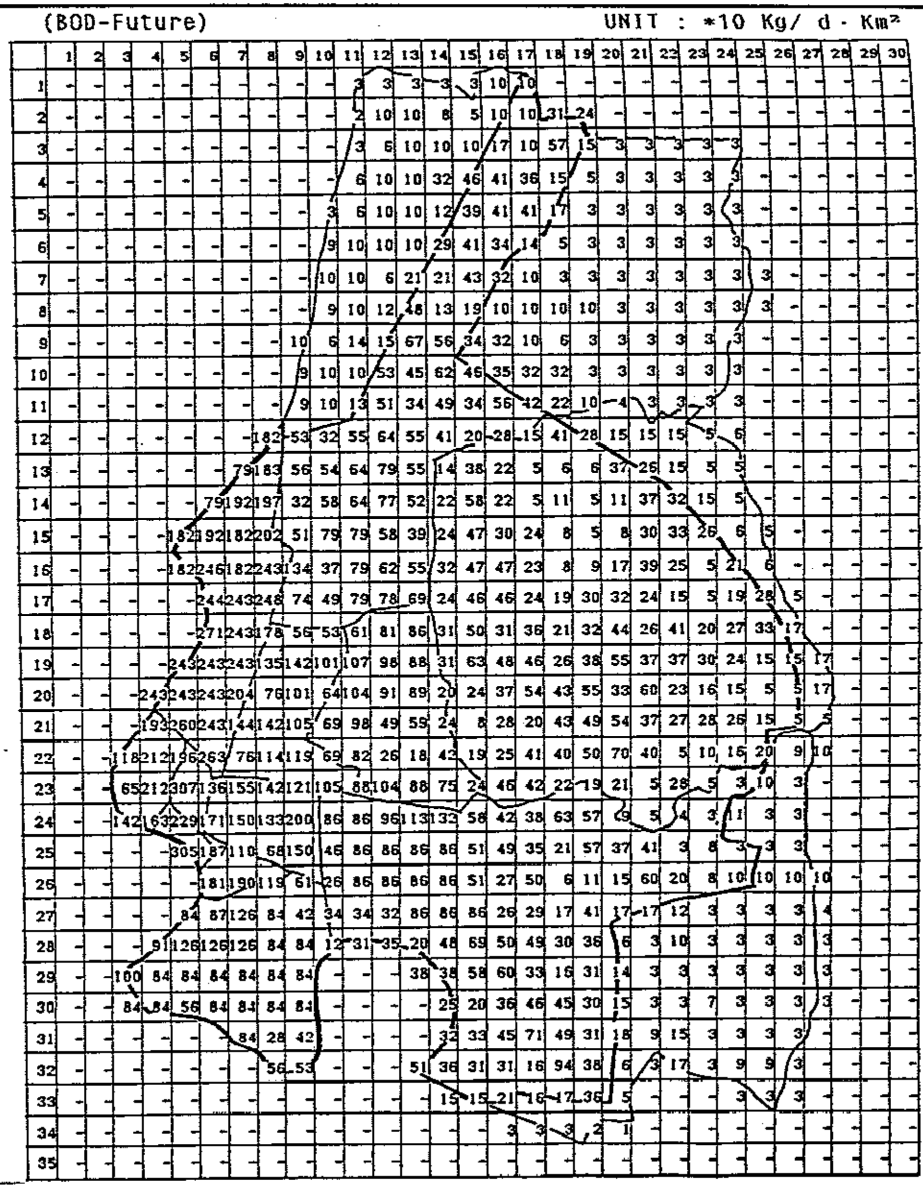
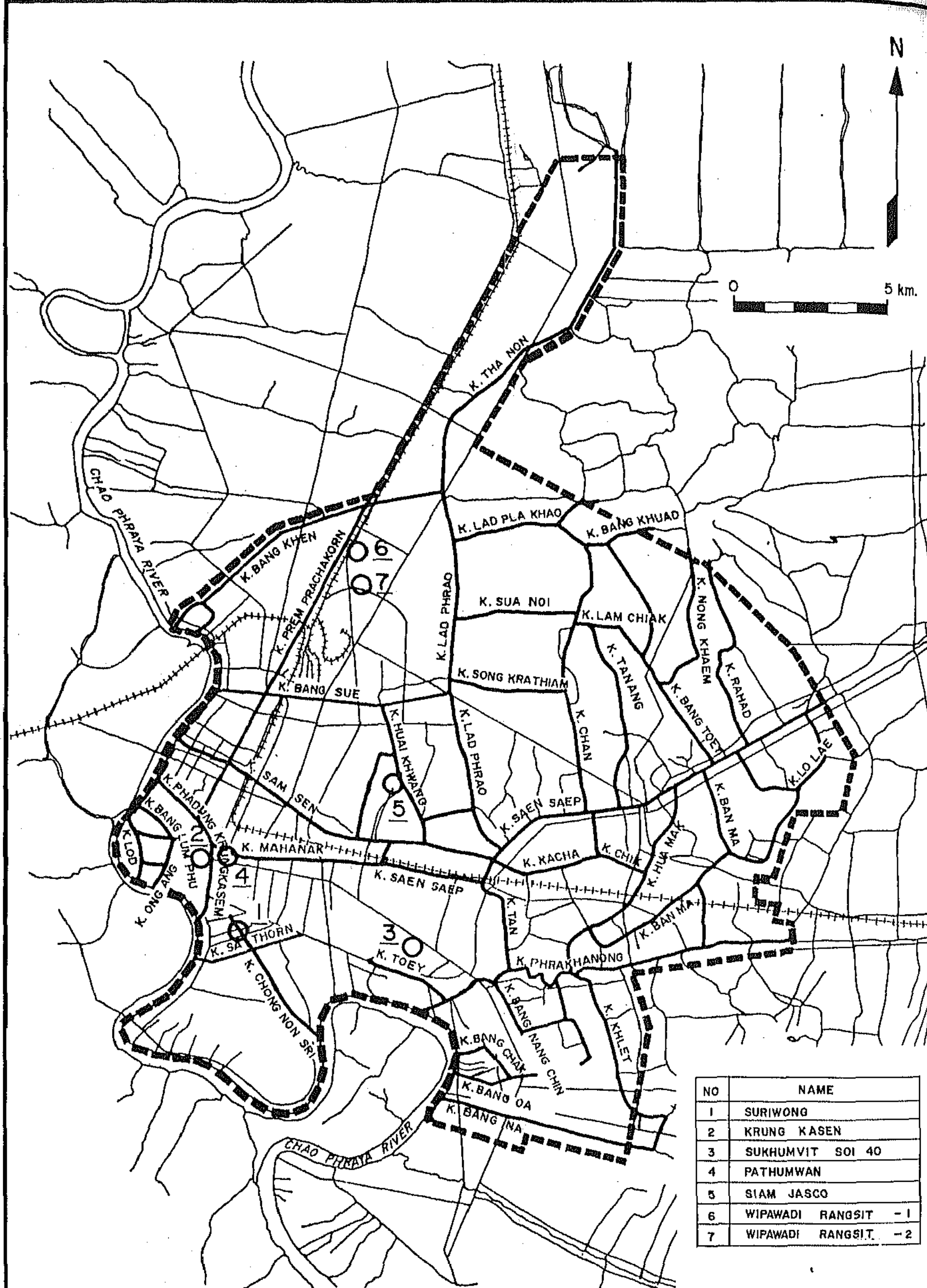




**FIG. C. 11** REGIONAL DISTRIBUTION OF EXISTING AND FUTUER POLLUTION LOAD GENERATION (BOD)

## THE FEASIBILITY STUDY ON PURIFICATION OF KLONG WATER IN BANGKOK




| NO | NAME |
|---|---|
| 1 | SURIWONG |
| 2 | KRUNG KASEN |
| 3 | SUKHUMVIT SOI 40 |
| 4 | PATHUMWAN |
| 5 | SIAM JASCO |
| 6 | WIPAWADI RANGSIT -1 |
| 7 | WIPAWADI RANGSIT -2 |

FIG. C.12 LOCATION OF POLLUTION LOAD RUN-OFF OBSERVATION

THE FEASIBILITY STUDY ON PURIFICATION OF KLONG WATER IN BANGKOK



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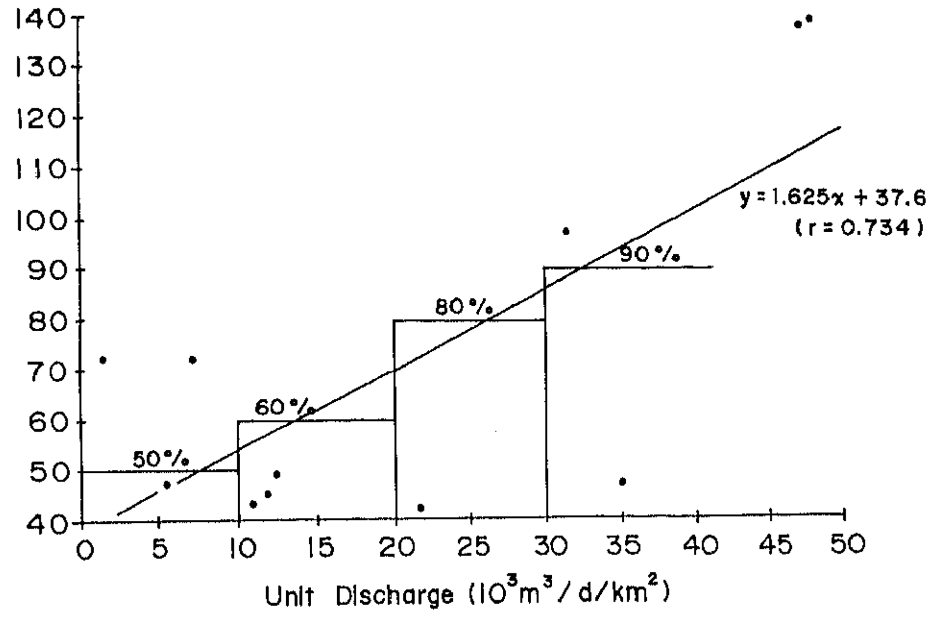
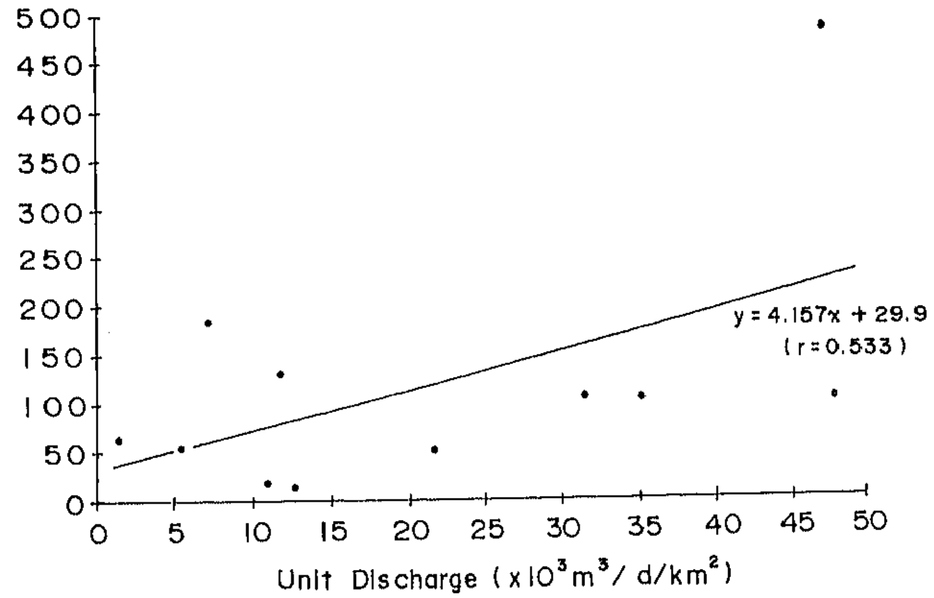



Correlation Between Run - off Coefficient of BOD and Specific Discharge




Correlation Between Run - off Coefficient of SS and Specific Discharge

| FIG. C.13 | CORRELATION BETWEEN RUN-OFF COEFFICIENT AND UNIT DISCHARGE |
|---|---|

**THE FEASIBILITY STUDY ON PURIFICATION OF KLONG WATER IN BANGKOK**



JICA 2532B.E. 1989A.D.

# APPENDIX D.

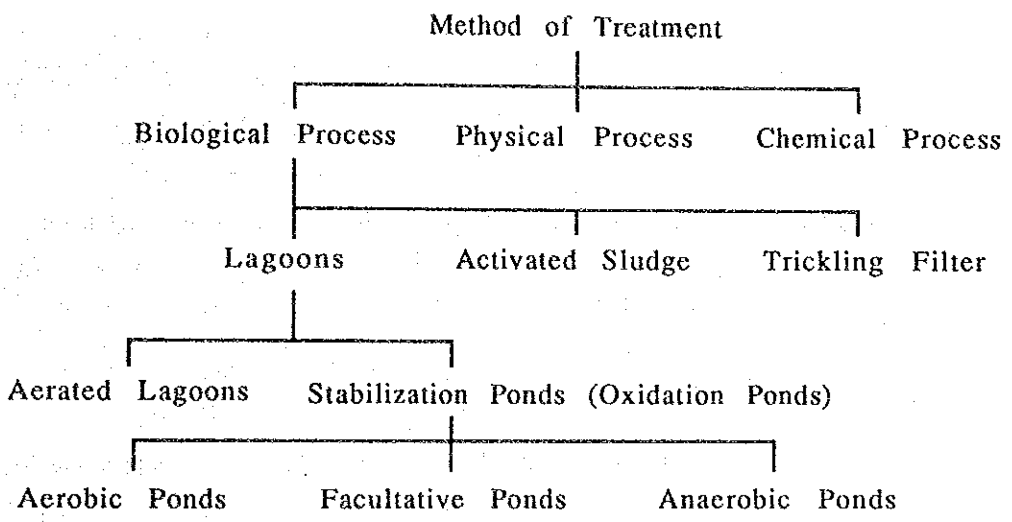
# AERATED LAGOON TREATMENT

# APPENDIX D. AERATED LAGOON TREATMENT

## 1. Wastewater Treatment Alternatives

### 1.1 Comparison of Treatment Methods

There are many treatment methods available for wastewater treatment, consisting of physical, chemical and biological processes as shown in the following flow chart.




The choice of the best method of treatment will depend on the following considerations:

(1) The required treatment level
(2) Economic considerations
(3) Local and environmental conditions

An important characteristics peculiar to the klong wastewater is that, it is of large quantity with relatively low concentration of BOD, in comparison to conventional sewered domestic wastewater.

Also the treatment method shall be low in cost and simple to operate and maintain, from the view point of large quantity of wastewater as well.

To treat the klong water directly, it is necessary to obtain the land for treatment facilities near the klongs. In Bangkok city, there exists many ponds in the vicinity of klongs and consequently, lagoon systems appears to be the obvious means of simple treatment.

Table D.1 gives a comparison of various options of biological treatment systems, their advantages and disadvantages.

## 1.2 Selection of Treatment Method

The characteristic features of aerated lagoon system is that it is a biological treatment process utilizing aerobic microbial oxidation with no sludge recycle, hence the hydraulic and solids retention times being the same. As a result, the main disadvantage of this process in the high capacity requirement and in turn large area of land. However, it is simple and can achieve a high treatment efficiency with relatively low construction and operation and maintenance cost (Refer to Table D.1).

By assuming evaluation points, to qualitatively compare the alternative treatment methods of Table D.1, as shown below, aerated lagoon and waste stabilization system (with/without anaerobic unit) gain the highest rankings.

| | | |
|---|---|---|
| * (poor) | : | 1 point |
| ** (fair) | : | 2 points |
| *** (good) | : | 3 points |

In this study, as existing ponds should be utilized for klong water treatment, the available pond capacity would limit the lagoon treatment options. As such it is decided to experimentally evaluate a combined lagoon system, which will while optimising land requirement would also achieve high treatment efficiency, including removal of pathogens in final maturation pond.

Aerated Lagoon → Facultative Pond → Maturation Pond

## 2. Experimental Plan

### 2.1 General

Rama IX pond was used in this Study to investigate the feasibility of klong water treatment by lagoon methods as a low cost option and to collect the necessary basic data for the klong water purification plan. Location of the Rama IX Pond is shown in Fig.D.1.

Experiments were performed during both dry and rainy seasons, as these two seasons represent very different hydraulic conditions in the kolngs. During each season, a number of alternatives with various pond detention times were studied to understand the effects of different detention times on treatment dfficiencies and hence the water quality improvement of the klongs.

### 2.2 Overview of the Plan

The processes used in this study are as shown below.

Aerated lagoon → Facultative Pond → Maturation Pond

The klong water is treated in each pond, which have different biological and ecological conditions.

In the Aerated Lagoon, as will be described later, 3 floating type aerators will be used. Under normal operation, aerobic conditions will prevail, and pollutants in the water, especially organic matter as BOD or COD, will be biodegraded by aerobic microorganisms biologically utilizing oxygen.

The Facultative Pond receives the effluent from the Aerated Lagoon. The upper layer of the Facultative Pond is aerobic, where the wastewater undergo aerobic treatment, while the lower layer is anaerobic, where the wastewater will undergo anaerobic treatment. Symbiosis between algae and bacteria, and the resultant photosynthetic oxygen is a prime source of day time DO for microbial oxidation.

The Maturation Pond is the last stage in the treatment scheme and acts to polish the treated water, including the removal of pathogenic organisms which is in effect equivalent to disinfection.

## 2.3 Overview of Treatment Facilities

The pond used for the experiments is the Rama IX Pond, which draws polluted water from Klong Lad Phrao and discharges the treated water into the same klong, as shown in Fig. D.2.

The important characteristic features/specification of all facilities and equipment are as shown below.

| | | |
|---|---|---|
| (1) | Inlet Facility ................ | Pump 20 $m^3$/min. x 2 units |
| (2) | Aerator .......................... | Floating type 11 Kw x 3 units |
| (3) | Aerated Lagoon ........... | Capacity 19,200 $m^3$ (Depth 3 m, Surface Area 6,400 $m^2$) |
| (4) | Open Channel .............. | Length 120 m, Depth 3 m |
| (5) | Facultative Pond .......... | Capacity 49,700 $m^3$ (Depth 2.5 m, Surface Area 19,900 $m^2$) |
| (6) | Maturation Pond ......... | Capacity 45,900 $m^3$ (Depth 2.5 m, Surface Area 18,400 $m^2$) |
| (7) | Outlet Facility ............... | Stop Log Width 2 m |

## 2.4 Experimental Method

### (1) Experimental Conditions

As it will be difficult to obtain new land for lagoons to be used for klong water quality improvement, it is decided, in principle, that only the existing ponds could be used.

The hydraulic conditions and water quality of these klongs and the ponds of their vicinity vary according to their locality.

In this experiment using Rama IX Pond, several cases, obtained by varying detention time, were studied. These cases of experiment are described in Table D.2. Accordingly, four (4) number of cases with varying detention times of aerated lagoon, facultative pond and maturation pond were investigated (Case 1 ~ Case 4). Of these Case-1 and Case-3 consisted respectively of three (3), Case 1-1 ~ Case 1-3, and two (2), Case 3-1 ~ Case 3-2, experimental phases, whereas Case 2 and Case 4 consisted of one single phase for each.

(2) Experimental Schedule

The experimental work was conducted from the beginning of February to the middle of August. The schedule of the experimental work is shown in Fig. D.3.

(3) Water Quality Analysis

1) Sampling Points

To evaluate the effectiveness of the lagoon treatment, mass balance analysis was performed across all three (3) ponds. For this purpose, water sampling and the subsequent analysis of water quality parameters were carried from samples taken at the following locations (Refer to Fig. D.2):

Point ① Inlet of the Aerated Lagoon
Point ② Outlet of the Aerated Lagoon
Point ③ Outlet of the Open Channel (Inlet of Facultative Pond)
Point ④ Outlet of the Facultative Pond
Point ⑤ Outlet of the Maturation Pond

As the Open Channel connecting the Aerated Lagoon and the Facultative Pond is rather long (120 m), and considerable sedimentation occurs in this section, and it is likely that this would affect the water quality. Therefore sampling was conducted at the outlet of the Open Channel as well to evaluate its influence, and to be representative location of facultative pond inlet.

2) Sampling Frequency and Time

As the minimum detention time used in this study, even in the Aerated Lagoon, is at least 8 hours, the daily variation in the influent water quality could possibly be averaged. Hence it was decided that frequency of sampling and analysis should, in principle, be done only once a day. Also the water quality observation in klongs was carried out between January and July in 1988. Fig. D.4 shows the hourly variation of BOD observed in Klong Lad Phrao near the inlet of the Aerated Lagoon. From Fig. D.4, it can be seen that the BOD value around 10 a.m. is quite representative to the average for the whole day. Hence, 10 a.m. was selected as the daily sampling time.

3) Water Quality Parameter

To get a comprehensive understanding for the specific features of each pond, treatment conditions, etc., the water quality parameters, given in Table D.3, were analyzed.

## 3. Results of Water Quality Observations

### 3.1 Water Quality of Wastewater Source

The wastewater in this study is from Klong Lad Phrao. DDS has maintained records of water quality in klongs in Bangkok city for many years. Judging from the data of the 6 year period, 1981 - 1986, the average BOD value in Klong Lad Phrao is approximately 14 mg/l. Other klongs in the study area have BOD values ranging from 5 - 54 mg/l. Therefore, the average BOD of Klong Lad Phrao falls under lower range in comparison to other klongs.

However, Klong Lad Phrao is black in color, very malodorous, and compared to its water quality measurements, it presents an image of being highly polluted based on observation (visual, smell).

The results of the water quality of wastewater source at the inlet of aerated lagoon are given in Table D.4, and the variation of BOD and COD are given in Fig. D.5.

As shown in Table D.4, the influent DO is practically 0 mg/l, total BOD (henceforth referred to as T-BOD) and soluble BOD (S-BOD) are approximately 20 mg/l and 8 mg/l, respectively. T-COD and S-COD (T and S as in the case of BOD) are approximately 45 mg/l and 30 mg/l, respectively.

In the rainy season, rainwater flows into klongs and dilutes the pollutant concentration of klongs. As Table D.4 indicates, during rainy season the black color of the klong water turned to gray or brown color, and the value of BOD and COD concentration and Coliform count decreased slightly compared to that of dry season.

The BOD load of influent to the Aerated Lagoon in Case-1 is

$$28{,}800\ m^3/d \times 20\ mg/l \div 19{,}200\ m^3 = 0.03\ kg/d/m^3$$

This is extremely low, about one-tenth that in conventional activated sludge systems.

In the Aerated Lagoon, as already emphasized there is no recycling of settled sludge, and the effect of BOD loading on the process was also investigated in this study.

Fig. D.5 shows the variation of influent BOD (T-BOD and S-BOD) and COD (T-COD and S-COD). Although neither of these values have good correlation, the value of T-COD is approximately three (3) times that of T-BOD and the value S-COD is four (4) times that of S-BOD, in general.

## 3.2 Experimental Results of All Cases

The experiments were conducted as per the experimental schedule shown in Fig. D.3 from February 6 to August 28 of 1989. The daily experimental data obtained are given in Data Book.

(1) Case-1

All three (3) phases of the experiments were conducted during dry season.

The experimental results obtained have been averaged over the whole experimental period for each sampling point and are organized as given in Table D.5 to Table D.7, for all 3 phases. The corresponding longitudinal variation of the measured water quality parameters from influent (Point ①) to effluent (Point ⑤) of the whole system is shown in Fig. D.7 to Fig. D.9.

Table D.8 shows the pollutant removal efficiencies in each pond for the three (3) phases (Case-1-1, Case-1-2 and Case-1-3) under similar experimental conditions.

The removal efficiencies in Case-1-1 (Phase 1) differ markedly from those observed in other two (2) cases, especially, BOD and COD removal efficiencies.

This may be attributed to the fact that at the start of Case-1-1, the Rama IX Pond, which was previously filled with rainwater, was gradually replaced by polluted influent water from Klong Lad Phrao, and consequently, the microbial phase in the Facultative and Maturation ponds was not, as yet, fully developed and acclimated. In other words, steady state condition was not reached.

Considering the results of Case-1-2 and Case-1-3, which were performed in about one (1) month and two (2) months, respectively, after the start of the pond operation, it can firstly be seen that the DO of the effluent from the Aerated Lagoon increased up to 58% and 72% of the saturation DO value of 7.6 mg/l and 7.5 mg/l, respectively, based on the respective temperatures of the lagoon mixed liquor (Refer to Table D.6 and Table D.7).

The average removal efficiency of T-BOD for Case 1-2 and Case 1-3 in the Aerated Lagoon is approximately 50%, while that of S-BOD is 30%. The average T-COD and S-COD removal efficiencies for the same phases are 40% and 30%, respectively (Refer to Table D.8).

The $NH_4$-N and coliform count reduction is not very significant. Due to the short detention and no sludge recycling, the VS content in the Aerated Lagoon did not increase sufficiently. High water temperature and the DO concentration in the Aerated Lagoon resulted in significant reduction of organic matter represented as BOD.

Further, in the Aerated Lagoon, there is considerable reduction in the color and odor, with the black color being replaced by a brown color and odor becoming almost undetectable.

Because the Open Channel connecting the Aerated Lagoon and the Facultative Pond is about 120 m long, it is possible that sedimentation could occur in this channel. But as can be seen from Table D.6 and Table D.7 sedimentation is not very significant. As there is an increase in pH value, rather than sedimentation, the Open Channel appear to act rather as a portion of the Facultative Pond.

In the Facultative and Maturation Ponds, good $NH_4$-N and coliform reductions were observed. However, the effluent BOD, COD and other parameters from these ponds were higher than that of effluent from the Aerated Lagoon. This seemingly reverse phenomenon can be attributed to the fact that the BOD of the source is 17 mg/l, which is relatively low, and algal growth and the resultant carbon fixing which results from treatment in ponds, increases the value of BOD in these ponds.

The diurnal variation of DO profiles in facultative and maturation ponds were determined on 14 February 1989 at 1 hour interval, and are shown in Fig. D.10. The temperature is around 29 - 30°C, at which the DO saturation concentration is about 7.6 mg/l. The DO profile indicates approximately three (3) times this value at its maximum, which occurred around 4:00 p.m., is the typical profile around which time the maximum super saturated DO levels occur due to (day time) photosynthetic activity in oxidation ponds.

The chlorophyll-a concentration, however, was 0.06 - 0.08 μg/l in the Facultative and Maturation Ponds. Compared to values reported in literature, this concentration is very low, which is attributable to the low influent concentration of wastewater and the respective nutrients (N, P).

(2) Case-2

The experiments were conducted during dry season (Refer to Fig. D.3).

The experimental results obtained have been averaged over the whole experimental period for each sampling point and are organized as given in Table D.9. Fig. D.11 shows the corresponding longitudinal variation of all the measured water quality parameters from influent (Point ①) to effluent (Point ⑤) of the whole system.

In Case-2, the detention time in the Aerated Lagoon was 32 hours. Consequently, the influent pollutant load was approximately half of that in Case-1 (Refer to Table D.2).

Compared to Case-1, the DO concentration in the Aerated Lagoon was about 30% higher and was 86% of its saturation level of 7.8 mg/l at the water temperature of 27.7°C.

The removal efficiencies of BOD, COD and other parameters given in Table D.10 were generally higher than those observed in Case-

1 (Refer to Table D.8). This is attributed to the fact that the detention time was twice that in Case-1.

Similar to that observed in Case-1, there was significant improvement in color and odor level in the Aerated Lagoon. Furthermore, in the Maturation Pond, the $NH_4$-N concentration and coliform count reduced, with the former dropping to insignificant level, and the latter dropping to about one-thousandth of its level in the Aerated Lagoon.

It therefore appears that the Maturation Pond with at least five (5) days detention time serves well in producing a good quality polished effluent.

(3) Case-3

The experiments of Case-3 were started from June 7, 1989 (Refer to Fig. D.3). In this case, one (1) aerator was stopped, as the DO concentration in the Aerated Lagoon was too high in Case-1 and Case-2, where three (3) aerators were operated for 24 hours.

Case-3 was divided into two (2) phases. Case-3-1 (Phase 1) was conducted in the dry season, whereas Case-3-2 (Phase 2) was conducted in the rainy season.

The experimental results obtained have been averaged over the whole experimental period for each sampling point and are organized as given in Table D.11 and Table D.12, respectively for Case 3-1 and Case 3-2. Fig. D.12 and Fig. D.13 show the corresponding longitudinal variation of all the measured water quality parameters from influent (Point ①) to effluent (Point ⑤) of the whole system, respectively for Case 3-1 and Case 3-2.

Reducing the magnitude of aeration in the Aerated Lagoon resulted in a drop in the DO value to about 80% of the value when all three (3) aerators were operated, corresponding to 59% of the saturation DO value of 7.6 mg/l at the average water temperature of 29.4°C.

Based on the BOD and COD removal efficiencies shown in Table D.13, it is evident that the overall removal efficiencies of Case-3-1 and Case-3-2 are almost equivalent. The BOD removal efficiency was, similar to that observed in Case-1 or Case-2, approximately from 50% to 60% through the Aerated Lagoon and the Open Channel, in spite of the decrease in the DO concentration.

However, compared to the results obtained in Case-1 or Case-2, the COD removal in the Aerated Lagoon was slightly low, and in the Facultative and Maturation Pond, and also no significant reduction in $NH_4$-N was observed in the ponds.

The Chlorophyll-a concentration observed in Case-3-2 during rainy season decreased to approximately half of that observed in Case-1 during dry season. This may be attributed to the fact that the influent load was less than that in the dry season and that, the algal photosynthesis decreased in the rainy season.

The latter is in part due to decrease in depth of penetration of solar radiation into the pond by the high turbidity of the incoming rainwater runoff and in part due to reduced solar radiation by cloudiness and an overall decrease in day time, typical to rainy seasons.

(4) Case-4

The experiment in Case-4 was carried out by operating two (2) pumps in addition to the two (2) aerators as per Case-3.

The experimental results obtained have been averaged over the whole experimental period for each sampling point and are organized as given in Table D.14. Fig. D.14 shows the corresponding longitudinal variation of all the measured water quality parameters from influent (Point ①) to effluent (Point ⑥) of the whole system.

By means of operating the two (2) pumps, the detention time in the Aerated Lagoon was reduced to 8 hours and the BOD loading to the Aerated Lagoon was increased to more than twice that in any other cases, Case 1 and Case 3. The DO concentration profile observed in the Aerated Lagoon decreased to 75% of that observed in Case-3.

The removal efficiencies of the water quality parameters, BOD and COD, are shown in Table D.15, which are nearly equal to those observed in Case-3. Although the T-COD removal efficiency was less than 20% in the Aerated Lagoon, it appears to increase in the following ponds in contrast to the results in the other cases.

Due to the reduced detention time, the Chlorophyll-a concentration also dropped to approximately one-third the level observed in Case-3.

(5) Correlation of Removal Efficiency

Fig. D.15 shows the correlation between the removal efficiencies of T-BOD and T-COD and the detention time in the Aerated Lagoon for all 4 cases. In this figure, the value of each removal efficiency was averaged over for all phases of Case 1 and Case 3 where the same operational conditions prevailed. As such, each case is represented only by a single point.

While T-BOD removal efficiency remained practically unchanged over all the detention times studied, the T-COD removal is related to the detention time and/or the magnitude of aeration. Therefore, from the point of view of COD removal, it seems about one day detention time of Aerated Lagoon is required for the satisfactory treatment of klong water.

Fig. D.16 shows the correlation between the BOD removal efficiency and the influent BOD loading with respect to both the T-BOD and S-BOD for all cases of experiments. The similar removal efficiencies, but with respect to both the T-COD and S-COD are shown in Fig. D.17.

No discernable relationship or trend between removal efficiency and BOD loading (for both the T-BOD and S-BOD) is observed in the range of BOD loading used in the experiments (Refer to Fig. D.16). However a general trend of decrease in efficiency of COD removal, with increasing COD loading (for both the T-COD and S-COD), from Case 2 to Case 4, is discernable (Refer to Fig. D.17)

In all cases, the DO level, which is almost zero in the influent klong water, increased in the effluent of Aerated Lagoon. T-BOD and S-BOD removal efficiencies observed in the Aerated Lagoon as a function of effluent DO is shown in Fig. D.18. Fig. D.19 shows similar results of COD removal efficiencies. Though no discernable relationship between removal efficiency and DO is observed in case of BOD removal (both T-BOD and S-BOD), an increasing trend in removal efficiency with increasing DO is discernable in case of COD removal. with respect to both the T - COD and S - COD.

(6) Supplemental Observation of Heavy Metals

Heavy metal concentrations were also observed as a supplement to the general water quality parameters, and the results are shown in Table D.16.

The heavy metal levels in Table D.16 are within the allowable limits set in the river water quality standards of Japan. But, since some heavy metals get adsorbed to the settled sludge in the lagoons and ponds and accumulate in benthic deposits, further consideration may be required into this matter.

## 4. Conclusion

The experimental study in the Rama IX Pond for the klong water quality improvement project had been carried out from the beginning of February to the end of August in 1989 with the cooperation of DDS.

The purpose of this study is to get basic data for the Aerated Lagoon process. Based on the results, it is to be decided whether the Aerated Lagoon process should be used as a supplementary method for klong water treatment.

The results of all cases were discussed in the foregone sections, and based on these, the following conclusions were made.

(1) From the experimental results obtained using the lagoon system it is clear that the variation in detention time and magnitude of aeration of the Aerated Lagoon, did not exert any significant influence on the overall treatment efficiency. This may be attributed to low pollution load of influent wastewater and the effects of algal growth in facultative and maturation ponds.

(2) A very significant improvement in color and odor is attained in the three (3) ponds. Black color in klong water changed to brown color in the Aerated Lagoon and to green color in the Facultative and Maturation Ponds, respectively. Odor was almost undetectable in any ponds.

(3) The Aerated Lagoon is effective with respect to BOD and COD removals. The removal efficiencies of T-BOD and T-COD in the Aerated Lagoon are approximately 50% and 30%, respectively, when the detention time is almost one (1) day under aerobic conditions.

(4) Algal growth in facultative and maturation ponds affect the overall removal efficiencies of T-BOD and T-COD. However, if some method of algal harvesting at the outlet of the Maturation Pond can be considered, it can be inferred that these removal efficiencies be increased.