ROAD INUNDATION

1. Introduction

Bangkok was originated on low, marshy delta of Chao Phraya River. It used to sit on the land which rises above sea level slightly higher than other part of the low and marshy delta along the River.

When the population and the urban area were still small, the damage of floods was not so serious as it is today because the ground level of the urban area in those days was higher than the water level of the adjacent river and the canals. As the urban area expanded and developed into the lower marshy land according to the increase of the population, the flood problem become worse.

From 1900 to 1980, the urban area of Bangkok Metropolis increased as shown below:

Year	Area	Growth Index	ACGR (%)
1900	13 km^2	100	-
1936	43 km^2	330	3.4 (1900/1936)
1953	66 km^2	510	2.6 (1936/1953)
1971	183 km^2	1400	5.8 (1953/1971)
1980	345 km^2	2700	7.3 (1971/1980)
			4.2 (1900/1980)

It can be said that the problem of the inundation of roads in Bangkok began as canal transportation started being taken over by land transportation.

2. Causes and Analyses of Road Inundations in Bangkok

The phenomena inundation has been a continuous fight between man and nature for water.

The submergence of roads in Bangkok can be attributed to the causes which can be categorized into three types : natural causes, man-originated causes, and the insufficient capacity of flood control facilities.

(1) Natural causes

Natural causes are as follows:
- High intensity of the rainfall in Bangkok (Mean max. daily rainfall : 150 mm),
- Low altitude of roads (MSL+1.60 - 0.60m, as shown in Figure 1),
- Large volume of water discharge of Chao Phraya River ($4712m^3$/sec. at Nakhon Sawan in 1961, as seen in Table 1),
- High tide level (2.22m of highest high water level at Fort Phrachul in 1970),
- Large inflow of water into the urban area from the northern and the eastern sides ($76m^3$/sec. during Oct. to Nov. 1983).

(2) Man-originated causes

Man-originated causes which worsen the flood damages are as the followings:
- Land subsidence of the urban area,
- Increase in the peak discharge of Chao Phraya River,
- Decrease in the capacities of water ponding, retarding, and drainage in the urban area.

The following is the brief explanation of the effect of these man-made phenomena on the flood of roads.

1) Land subsidence

According to the survey done by AIT, the ground surface at Pathumwan and Bang Na have been subsiding by 4cm/year and 7cm/year respectively due to pumping up of ground water. Total subsidence between 1977 and 2000 at Pathumwan and at Bang Na are is estimated to be 1m and 1.4m, respectively (see Figure 2).

2) Increase of the peak discharge of Chao Phraya River

The construction of two huge dams, Bhumibol and Sirikit with the capacity of 8,000 millions m^3 for each one is supposed to have decreased flood discharge by 500 m^3/sec.

On the contrary, the flood discharge in Bangkok area has been increased by enclosing Bueng Boraped with railway and highway embankments which used to function as a retarding basin. Construction of continuous dykes from

Table A.4.1 ANNUAL MAXIMUM FLOOD DISCHARGE RECORDS OF CHAO PHRAYA RIVER

(Unit: m^3/s)

Year	Nakhon Sawan		Chai Nat		Remarks
1957	2,592	10 Oct.	2,670	12 Oct.	
1958	2,066	30 Sep.	2,295	30 Sep.	
1959	4,509	08 Oct.	4,325	09 Oct.	
1960	2,567	20 Oct.	2.095	13 Oct.	
1961	4,712	13 Oct.	3,985	15 Oct.	
1962	3,812	17 Oct.	3,609	15 Oct.	
1963	2,946	12 Oct.	2,628	11 Oct.	
1964	3,825	11 Oct.	3,475	18 Oct.	Construction of Bhumibol Dam
1965	1,537	02 Oct.	1,071	03 Oct.	
1966	2,930	24 Sep.	2,349	25 Sep.	
1967	2,768	08 Sep.	1,985	07 Oct.	
1968	1,263	21 Sep.	588	13 May	
1969	2,827	28 Sep.	2,047	06 Oct.	
1970	4,420	30 Sep.	4,049	07 Oct.	
1971	2,370	09 Oct.	1,560	13 Oct.	
1972	1,310	08 Oct.	1,129	09 Oct.	Construction of Sirikit Dam
1973	2,600	05 Oct.	1,910	07 Oct.	
1974	1,930	09 Nov.	2,089	19 Oct.	
1975	4,355	17 Oct.	3,977	22 Oct.	
1976	2,605	10 Oct.	1,798	10 Oct.	
1977	1,976	27 Sep.	1,372	27 Sep.	
1978	3,540	07 Oct.	3,741	11 Oct.	
1979	1,390	02 Oct.	1,158	02 Oct.	
1980	4,320	09 Oct.	3,795	10 Oct.	

Chainat to Ayutthaya also eliminated the deversoir.

By comparing all the factors for increasing and decreasing flood flow, it is apparent that the increasing portion is larger than the decreasing one (see Figure 3).

3) Decrease of the capacities of ponding, retardation and drainage

As the urban area expands to low marshy land, the ponding capacity becomes smaller and the retardation capacity of the area decrease due to the loss of the marsh and permeable ground surface as well as replacement of canals by roads. The drainage capacity of the area also becomes smaller because of the filling of canals and by enclosing of marsh lands.

(3) Insufficient capacity of the flood control facilities

There are two kinds of facilities to prevent floods on the roads. One of them is the facilities to prevent floods in the district and to protect the roads indirectly. The other is the facilities to directly protect the roads from floods.

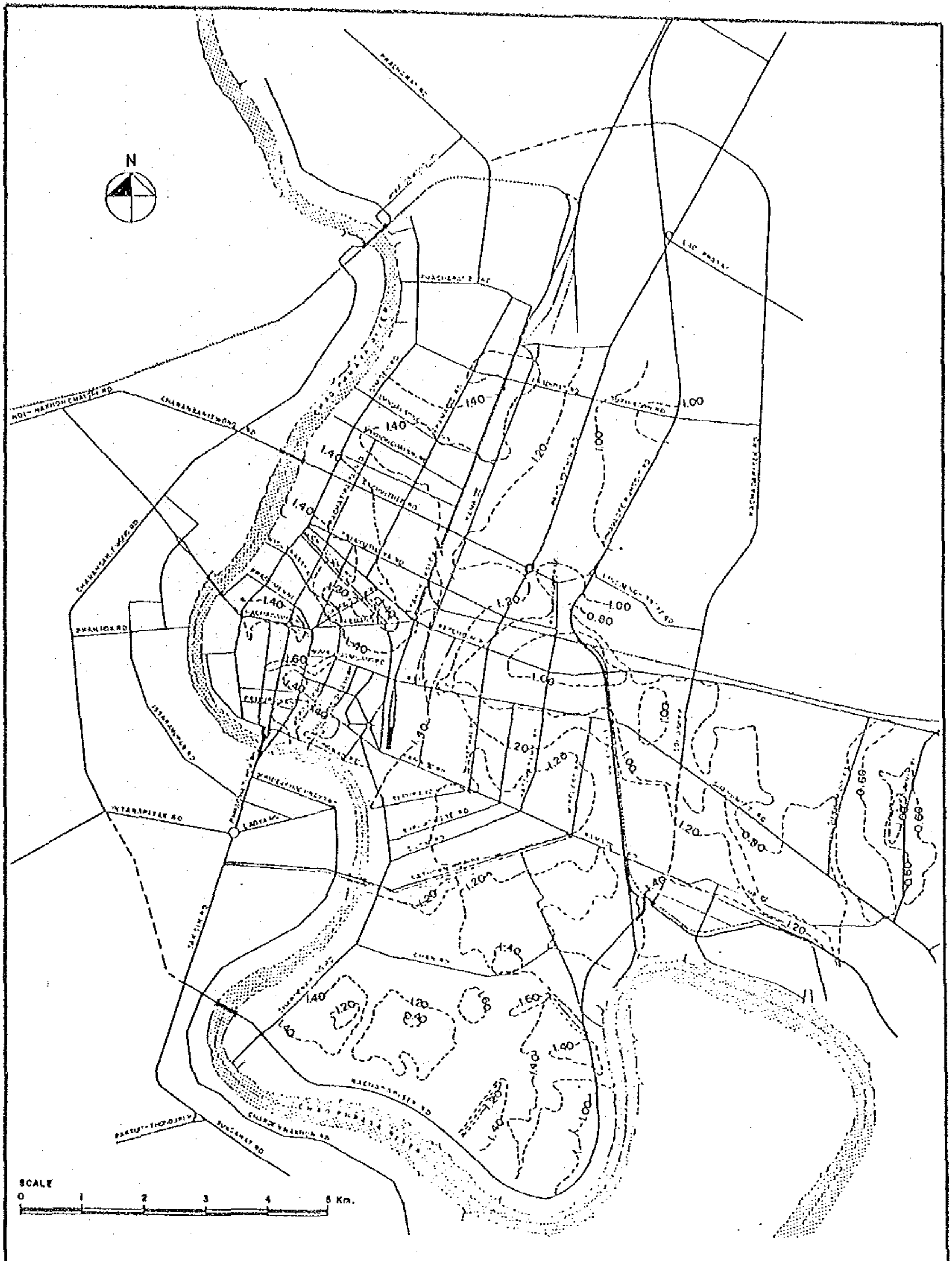
Indirect facilities are dykes and water gates to intercept the inflow of water into the area, and ponds, klongs and pumping stations to drain water. In 1983, there were no facilities to intercept the inflow from the north and the east into Bangkok where the Green Belt has been constructed. The lowest point of the crown of the dyke on Chao Phraya River was MSL+1.30 m at the crossing point of the railway and Klong Khud. Before the flood in 1983 the pumping capacity was 104 m^3/sec in the City Core and the Eastern Suburban Drainage Area and the total length of the klongs was 300 km. There was no pumping station in Thonburi Drainage Area.

Direct facilities are special dykes for protection of roads, with a sufficient height above the grade of the road, street drains and the alignment of the road. If the capacity of road drainage is insufficient, inundation of the road is greatly influenced by the alignment of the road because surface water flows on the road surface. Many roads in Bangkok seem to have insufficient drain capacities.

3. Road Inundation Experience in Bangkok

(1) Flood in 1983

During the period from August to November,1983, Bangkok was attacked by



Source, Bkk Flood Control and Drainage Project
(City Core) June 1984

Figure 1 Contour Map of Ground Surface Elevation, Tear 1983

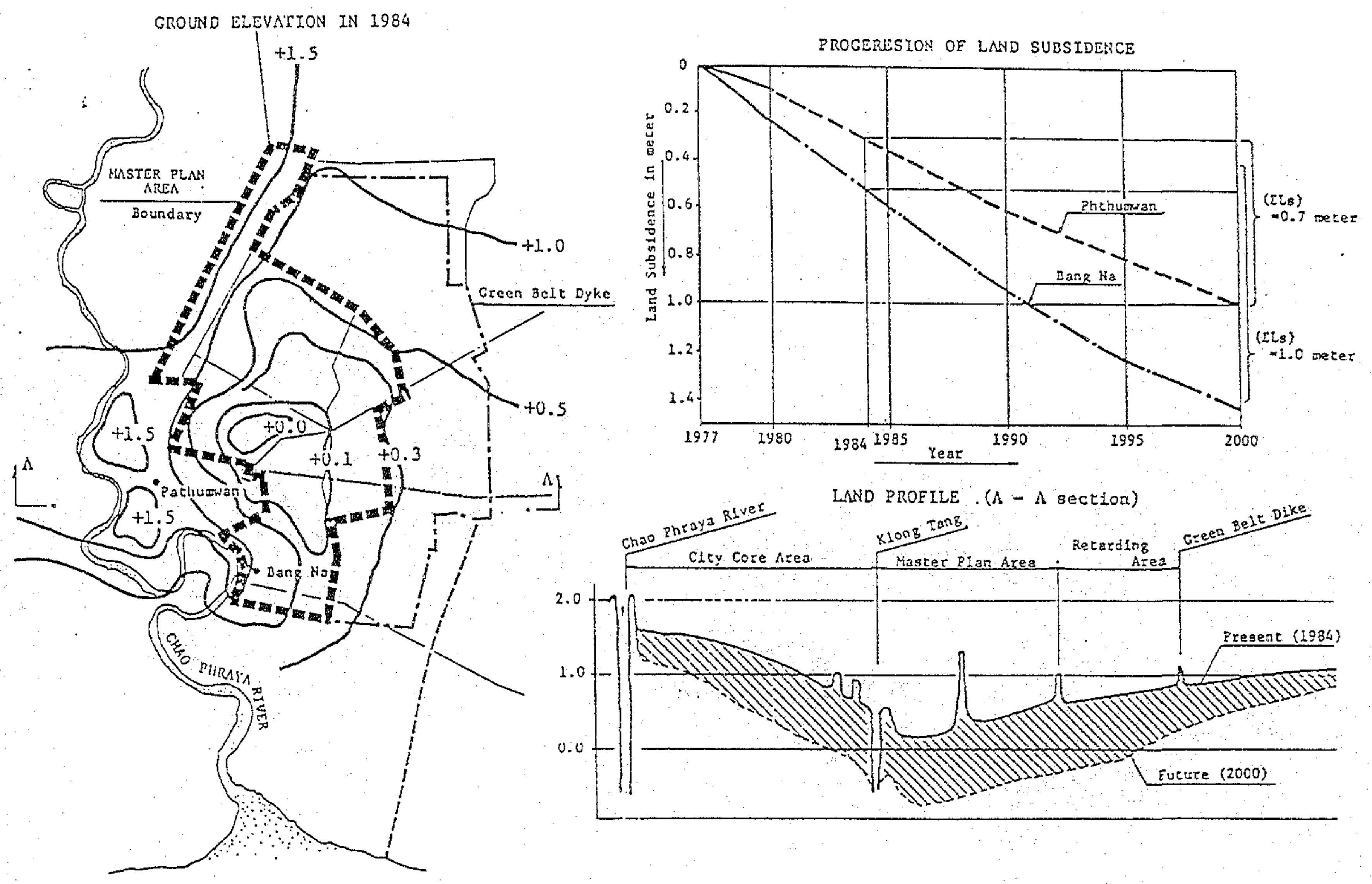
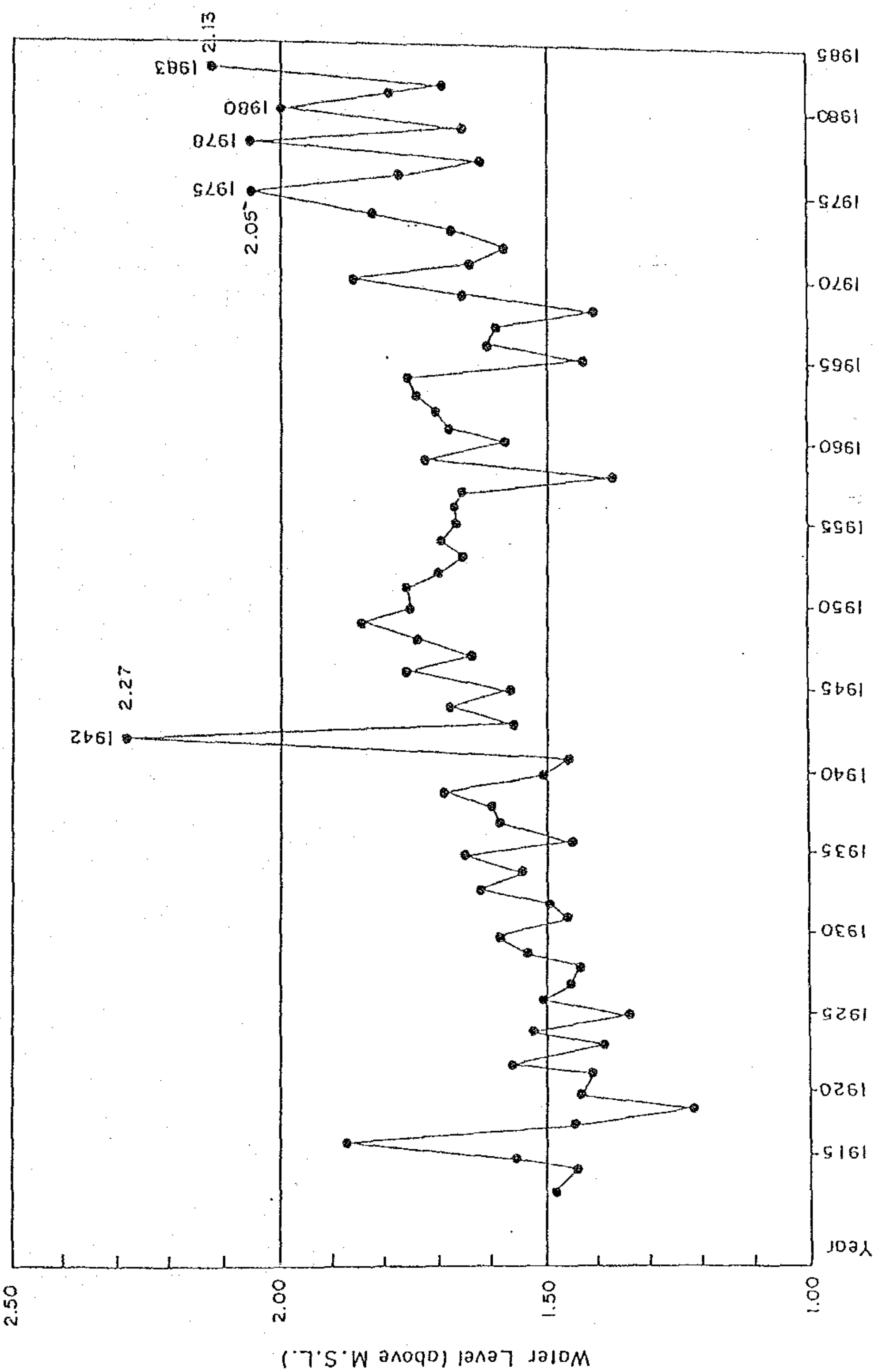


Figure 2 Progresstion of Land Subsidence



[Source; RID]

Note; 48 Kilometers from Mouth of River

Figure 3 Annual Highest Water Level at Memorial Bridge the largest flood since 1942. The most damaged districts were submerged for four months and the maximum flood depth was 110 cm on the eastern Sukhumvit Road. There were floods also in 1980 and 1982. Some district were submerged for two months in 1980, but the damage due to the flood in 1982 was not so large.

Mean monthly rainfalls from May to October in Bangkok are more than 150 mm. The peak discharge of Chao Phraya River usually occurs in August in the upper reaches around Chieng Mai, in September in the middle reaches around Nakon Sawan, and in October in the lower reaches around Bangkok.

High water level of the Gulf of Siam reaches to its highest level in November or December.

In 1983, although the monthly rainfalls from May through July were below the mean rainfall, there were a number of roads flooded as usual year (see Figures 4 - 6). The total rainfall from August to October, 1983 at Bangkok Station was 1,516 mm, twice as much as the average count. These heavy rainfalls were overlapped with the abnormally high water of Chao Phraya River and with the inflow of water at $76m^3$/sec from the northern and the eastern borders of Bangkok.

The area of submerged road extended to the maximum in November, and a number of roads were left continually submerged until December because of the high tide level (see Figures 7 - 11). The water depth on flooded road on 24th October, 1983 is shown as Figure 12. The higher water stage at Memorial Bridge on Chao Phraya River in 1983 was MSL+ 2.13m on 8th November which was 0.23m higher than the mean annual maximum water stage.

(2) Flood in May, 1986

1) Outlines

There was a localized torrential rain in Bangkok from the early morning to the evening of 9th in May of 1986. The amazing volume of daily rainfall at the Meteorological Department, soi 24 Sukhumvit Road, registered 248.6 mm on the 9th morning and 143.5 mm on the 10th morning, respectively. It had been the heaviest daily rainfall since 1937. The Meteorological Department announced that the probability of the daily rainfall intensity was once in 500 years or 1000 years. The rainfall distribution on the both days was shown as Figures 13 and 14.

On the early morning of the 9th, the flooded area begun to spread and soon

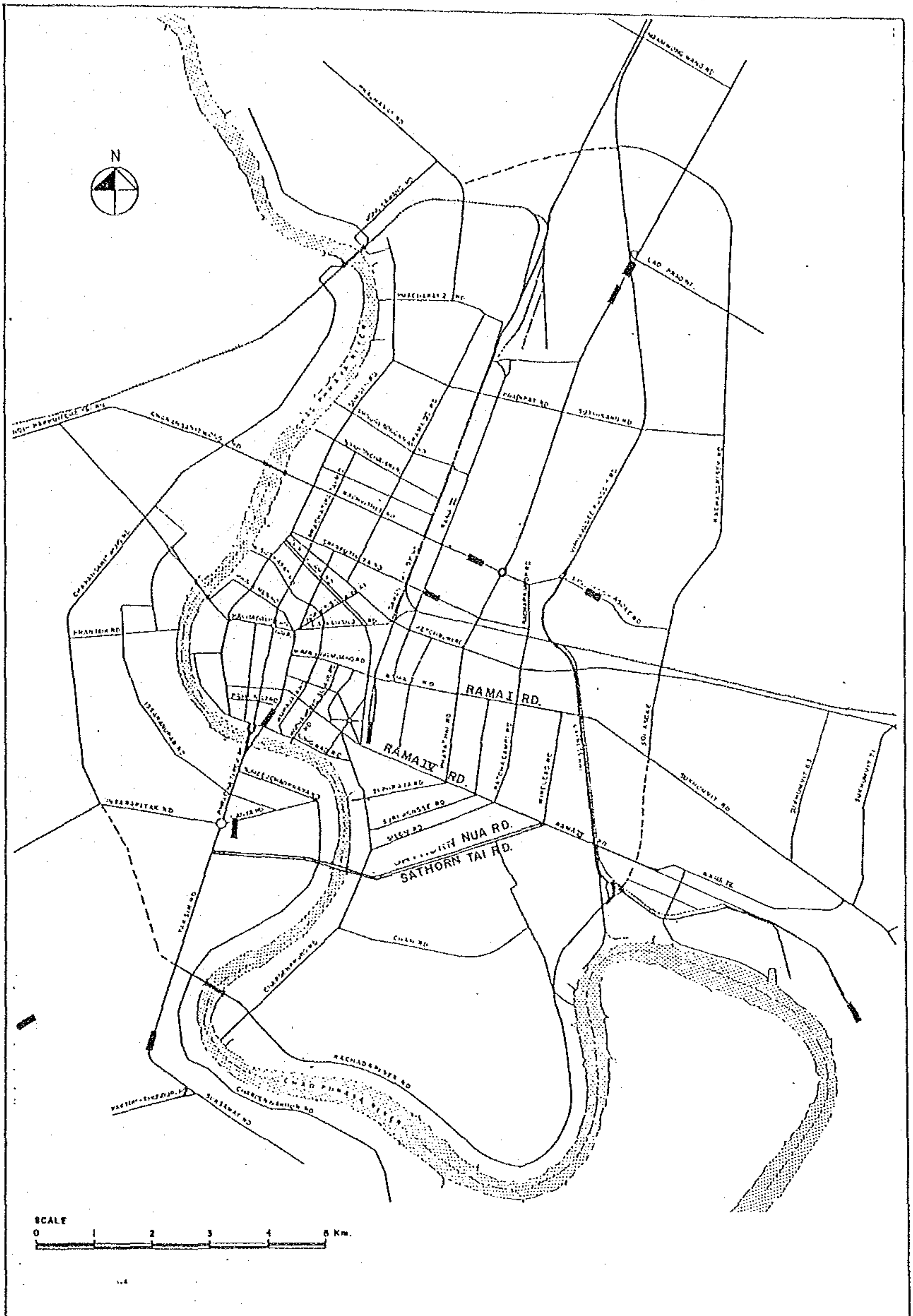


Figure 4 Record of Flooded Road (Period : May 1983)

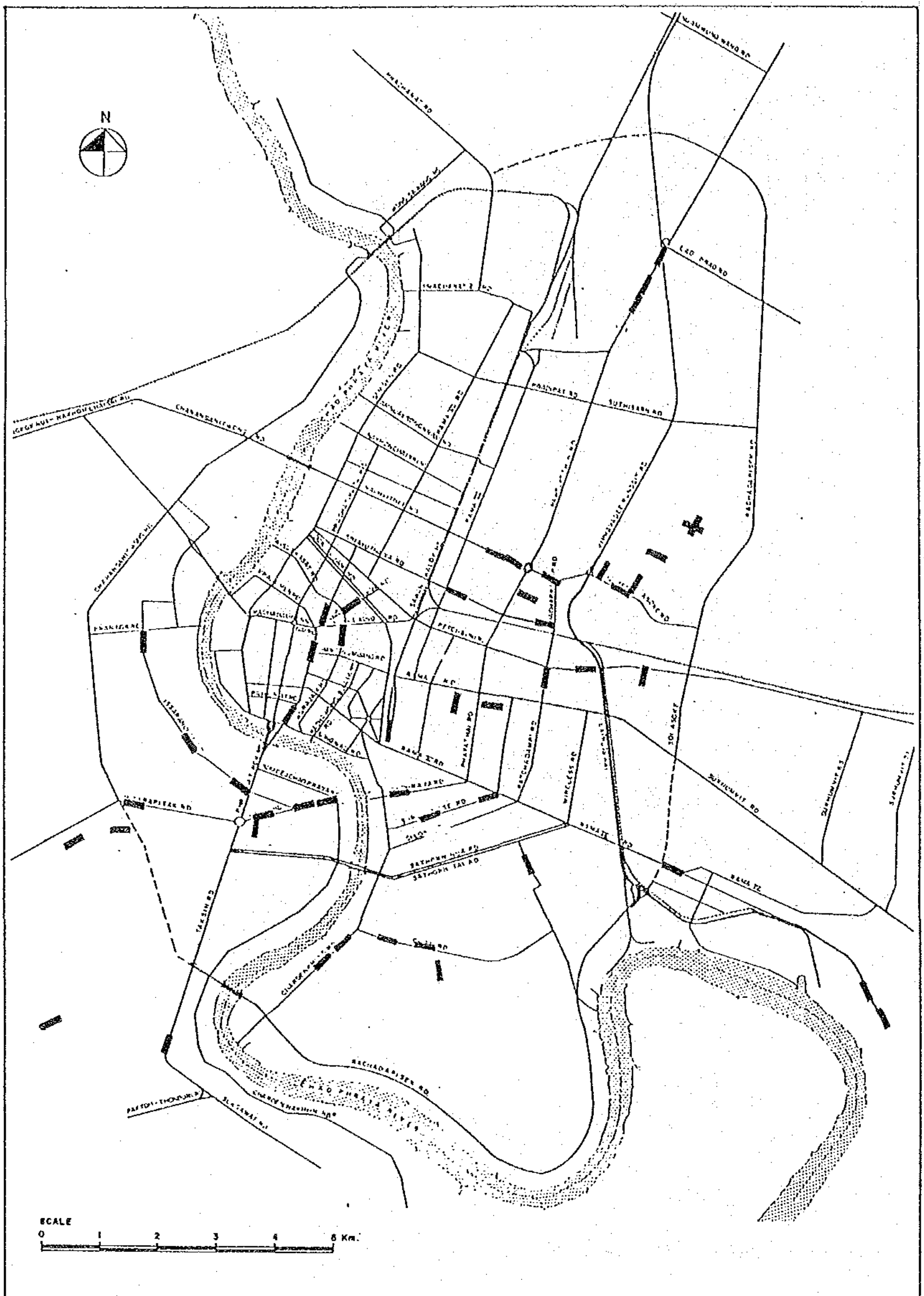


Figure 5. Record of Flooded Road (Period : June 1983)

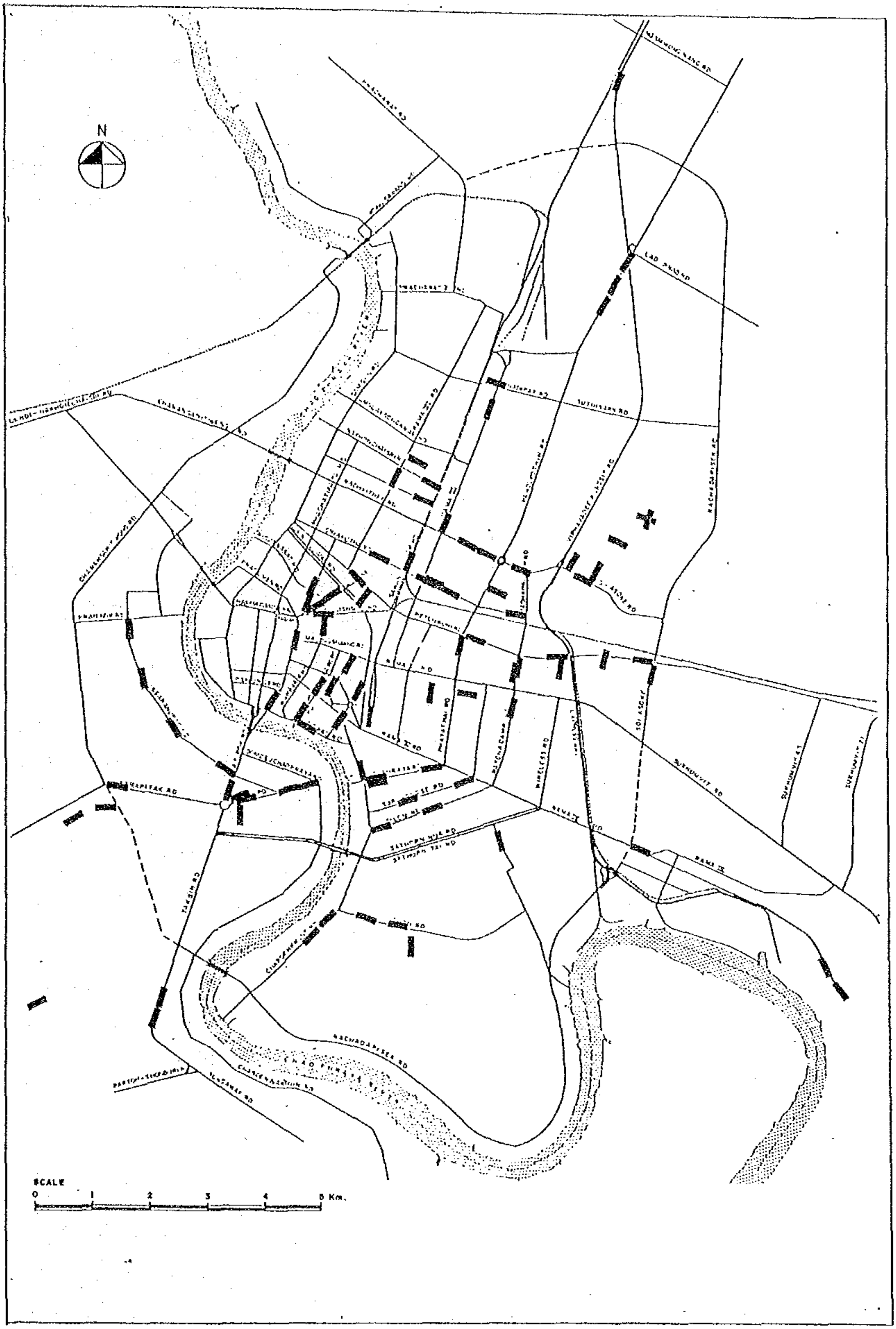


Figure 6 : Record of Flooded Road (Period : July 1983)

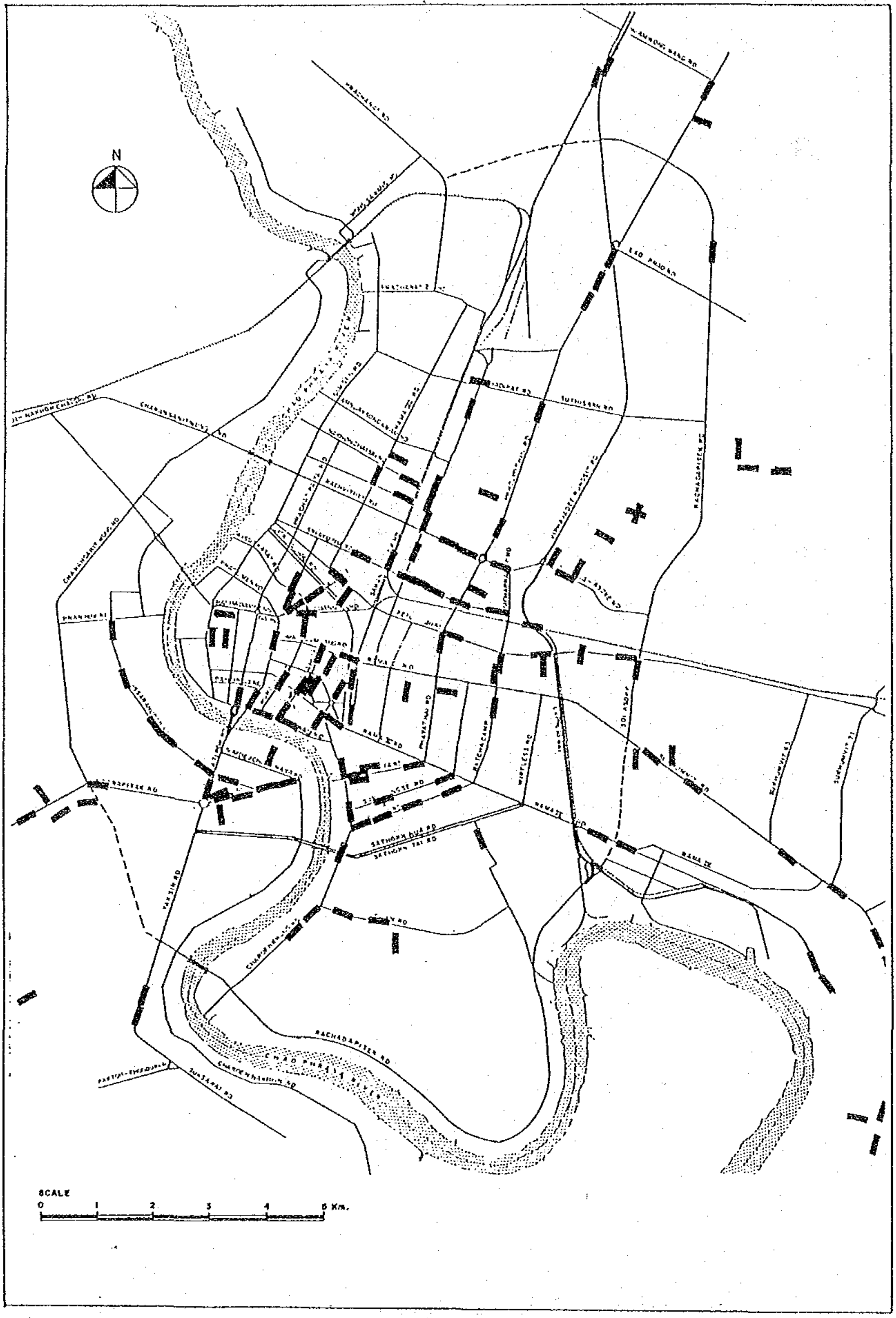


Figure 7 : Record of Flooded Road (Period : August 1983)

Figure 8. Record of Flooded Road (Period : September 1983)

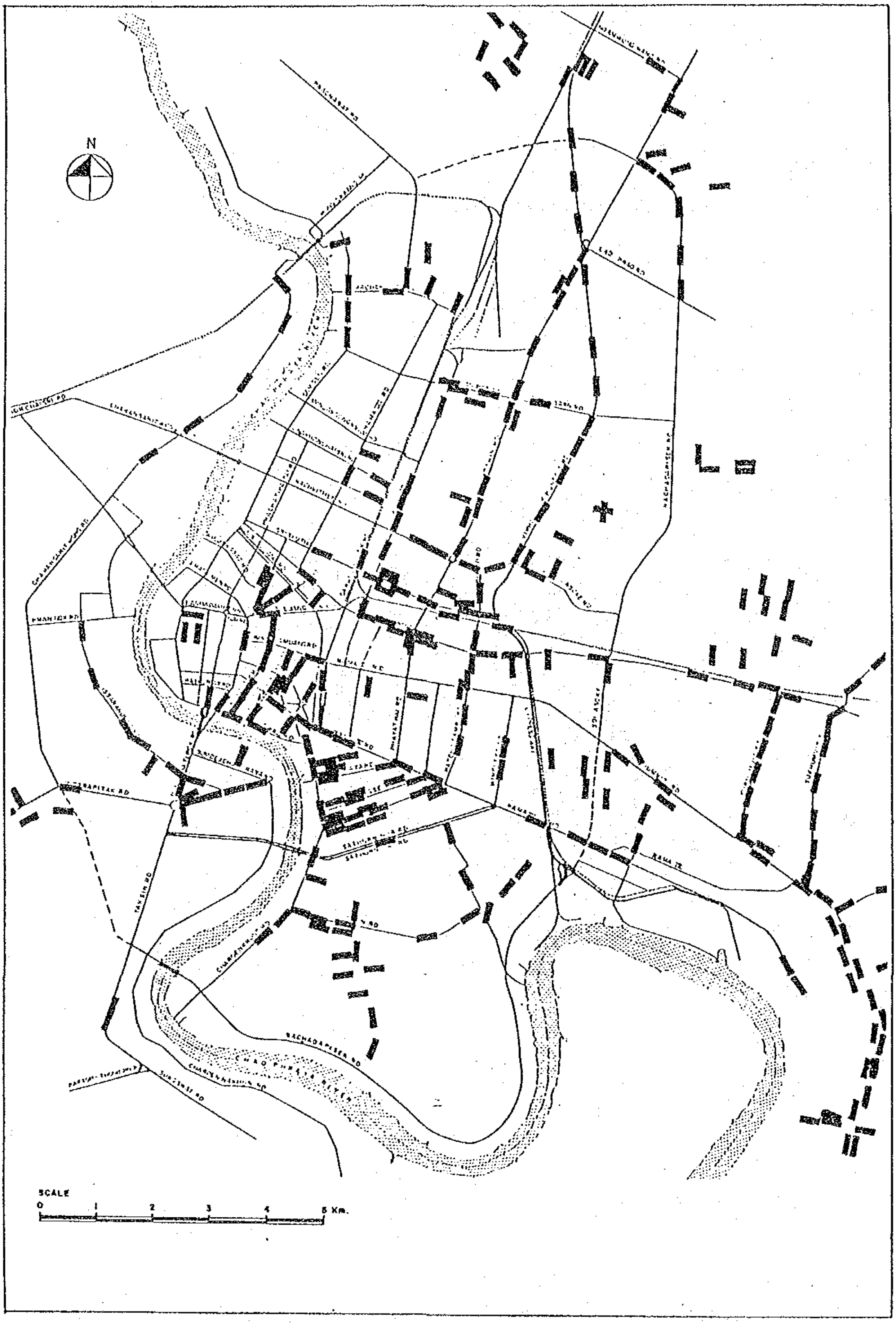


Figure 9 Record of Flooded Road (Period : October 1983)

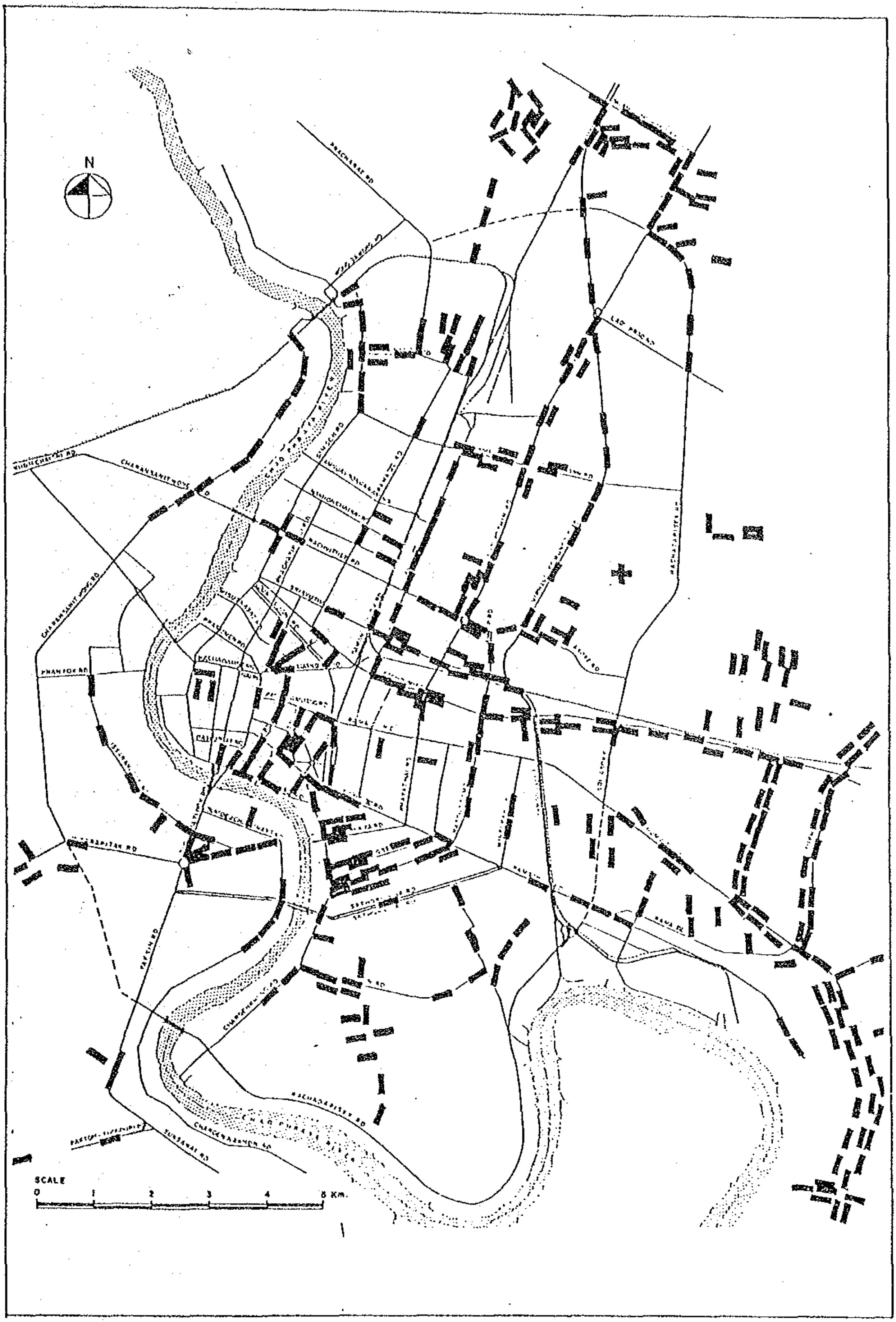


Figure 10 Record of Flooded Road (Period : November 1983)

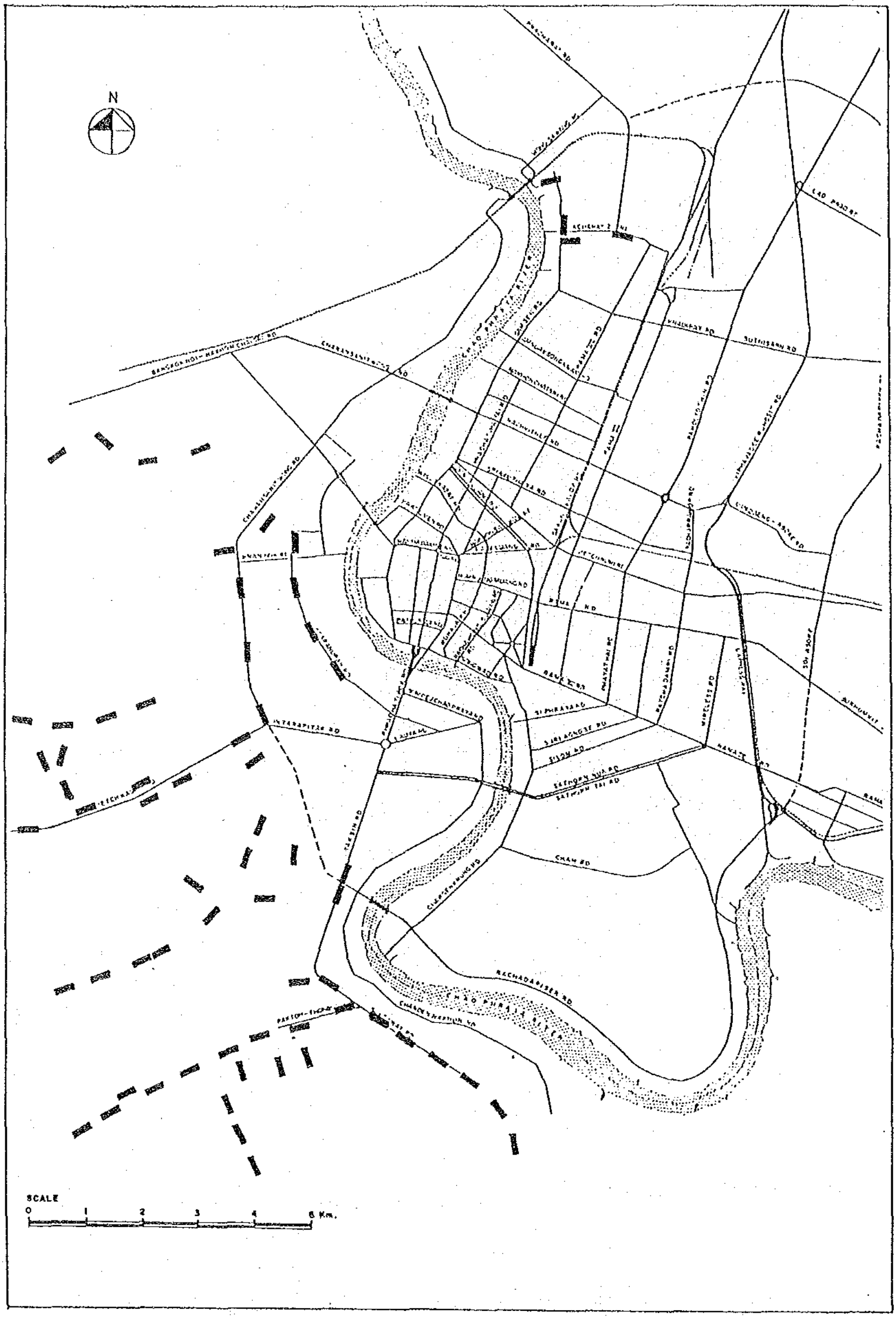


Figure 11 Record of Flooded Road (Period : December 1983)

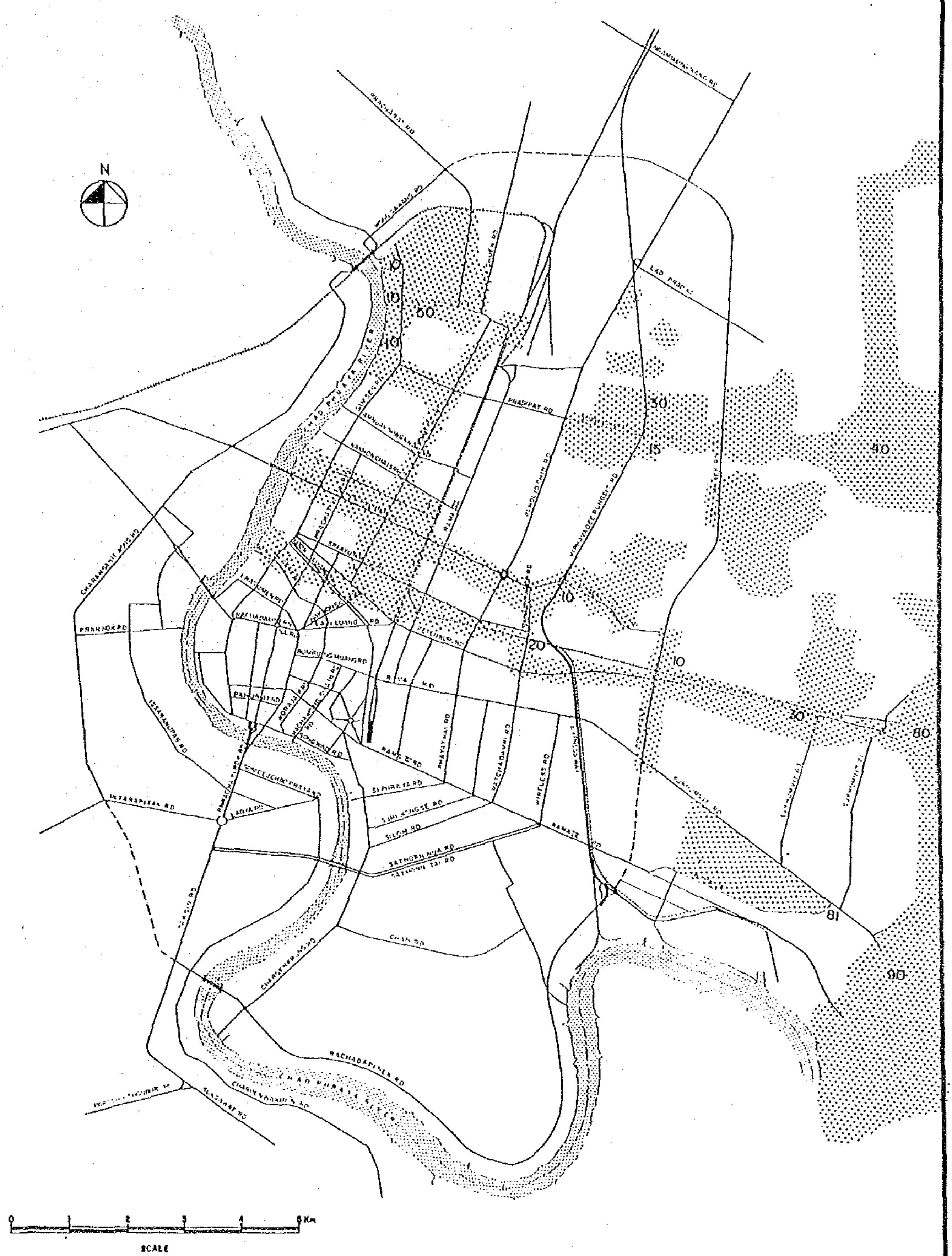


Figure 12 Water Depth on Flooded Road on 24th October 1983

reached at the largest extent which was as much scale as that of 1983. Bangkok City seemed to be submerged in whole area.

By the midnight of 10th May, an enormous amount of flooded water was drained out in such a short period in most part of the city by the operation of the drainage system in the Metropolis of which capacity had been remarkably improved by implementation of the Urgent Flood Protection Measures proposed by the Committee of Flood Protection and Solution in Bangkok and Vicinity since the flood of 1983.

The most damaged roads were under water from 9th to 11th May (see Figure 15). It was one of the severest trouble during the flood that the urban transportation system was almost paralyzed. Especially, a lot of cars left submerged on the main roads made its trouble worse. The situation of the most damaged roads were a bit different from that of 1983 according to the cause and the drainage capacity.

There had been the flood for 47 hours in Bangkok. But if most of the pumps in the city, especially the pumps at Phra Kanong, and most of the gates along the Chao Phraya River had been working more efficiently, the flooded water could have been far less and discharged into the river far earlier.

2) Assessement of the capacity of the pumping station at Phrakanong

It rained heavily for 13 hours, one o'clock to 14 o'clock of the 9th May (see Table 2). The total rainfall for the 13 hours is 342.3 mm as much as 94 percent of the daily rainfall of that day.

The DDS judged that the flood would be cleared to the normal condition at 24 o'clock of 10th. It means that it would take 47 hours to drain out the flood water of which most part was by above intensive 13 hours. Calculating with the Table 3, the mean working efficiency of the pumps at the Prakanong station for the 47 hours is 16.3/35.

By estimation, if all the pumps at the Phrakanong station had worked, it would have taken 22 hours to drain out the total rainfall in the basin and the maximum depth of the flood would have been about 70% of what it was at 9 o'clock on the morning of 9th.

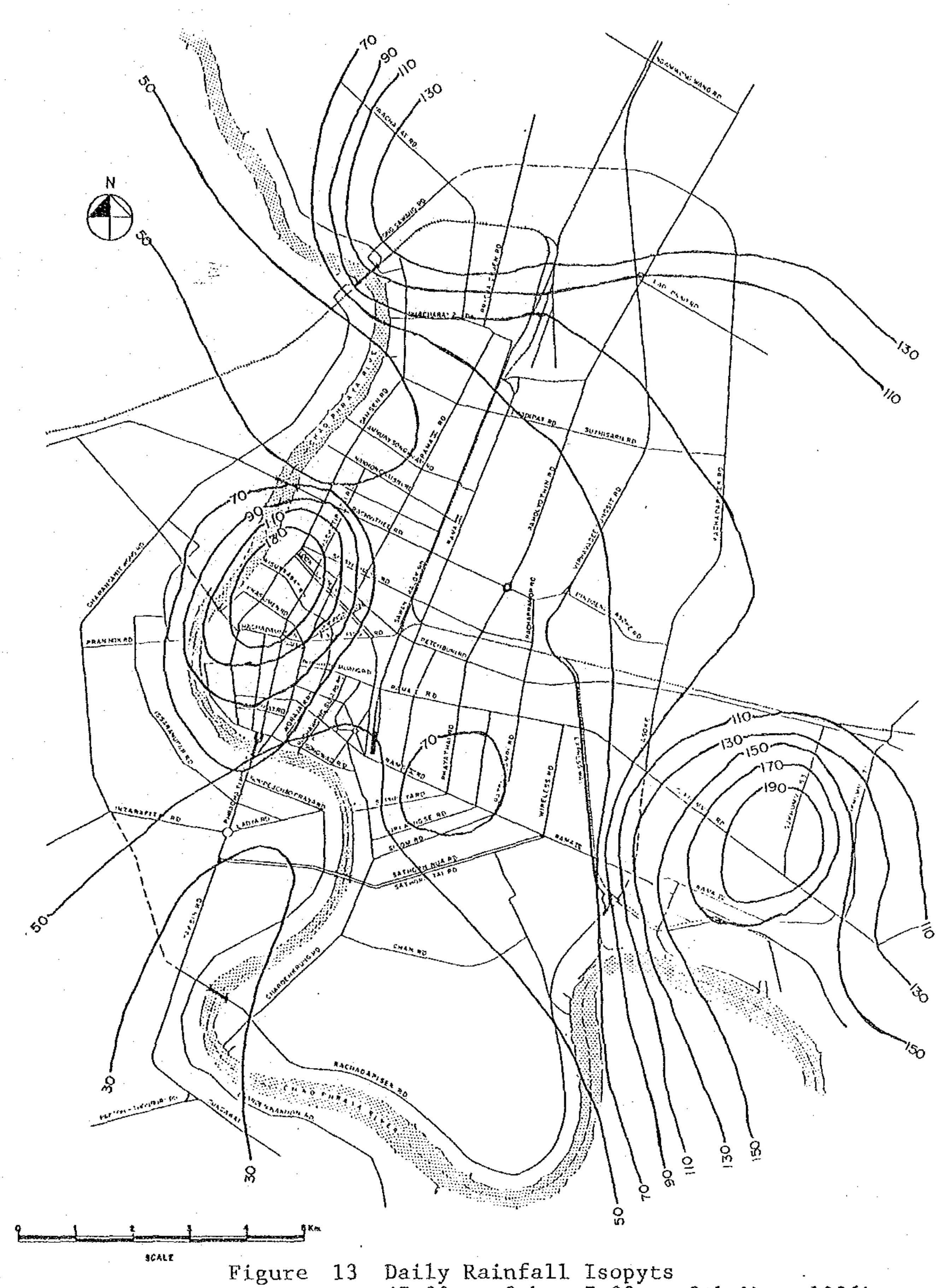


Figure 13 Daily Rainfall Isopyts
(7:00a.m 8th - 7:00a.m 9th May, 1986)

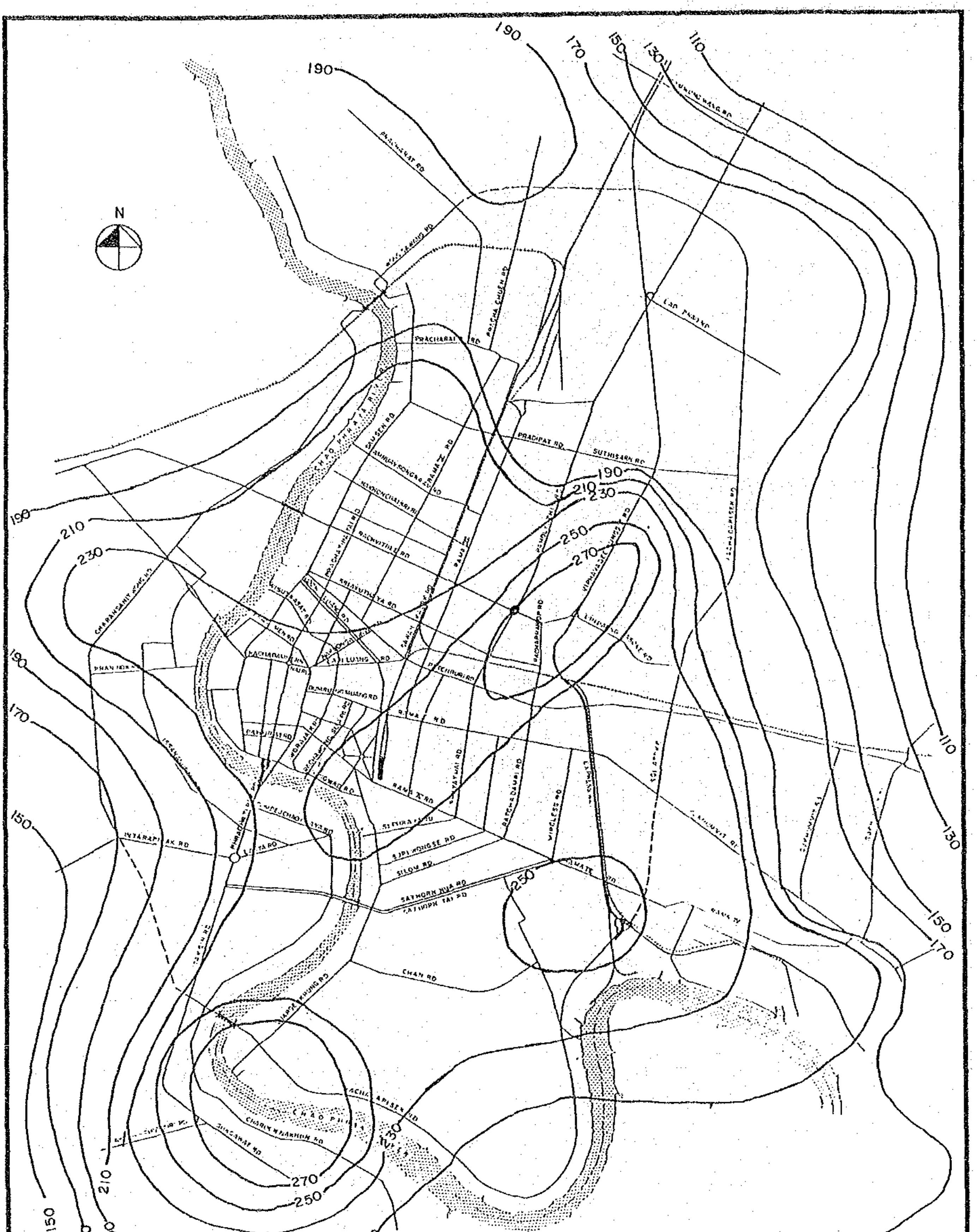


Figure. 14 Daily Rainfall Isopyts (7:00a.m 9th - 7:00a.m 10th May, 1986)

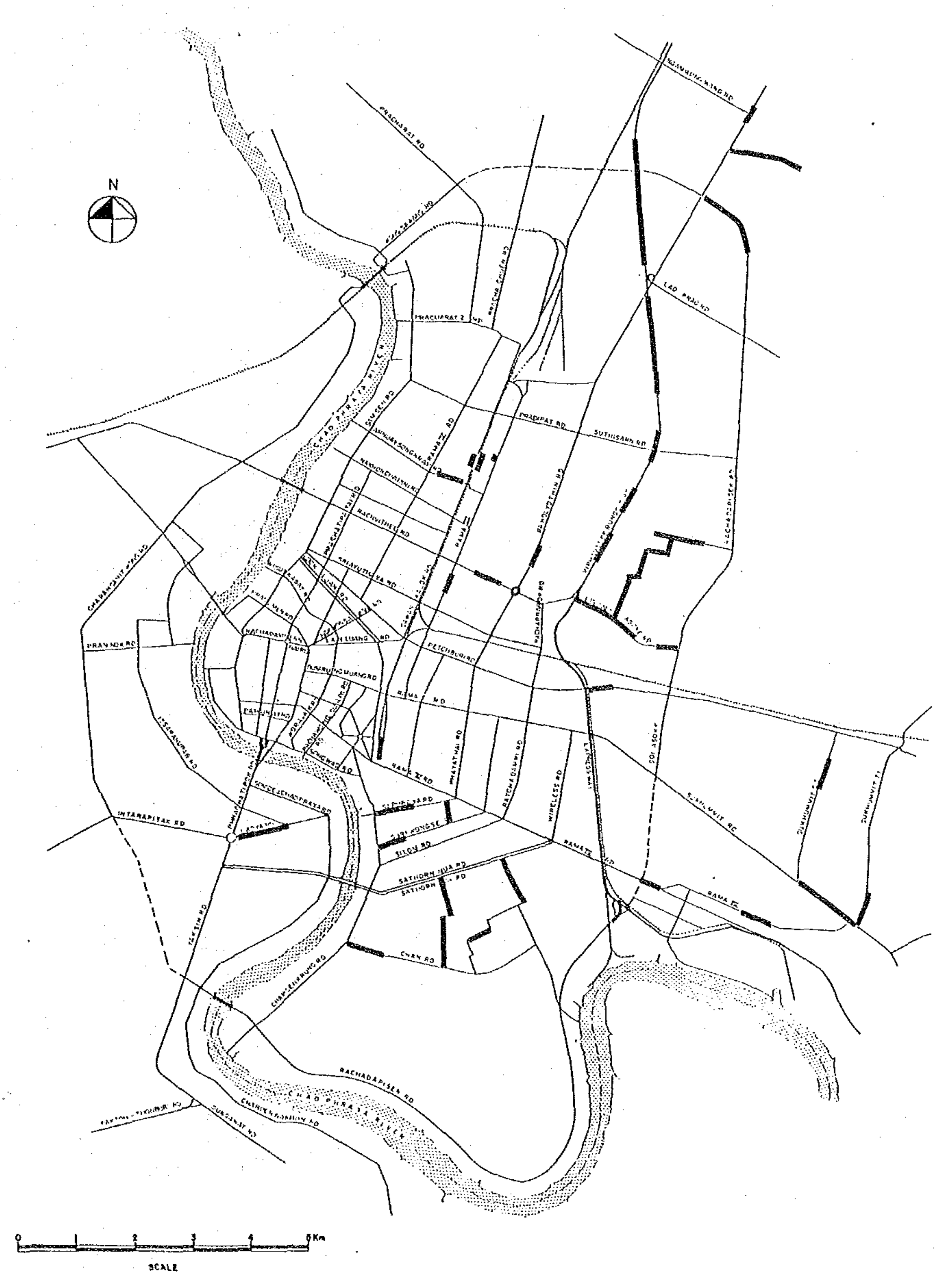


Figure 15 Most Damaged Roads
(Submerged: 9th - 11th May, 1986)

Table 2 Rainfall Record at the Meteorology Department on 8th, 9th and 10th May, 1986

Time	Date		
	8th	9th	10th
0 - 1	-	4.0	0.1
1 - 2	-	23.6	R
2 - 3	-	52.3	R
3 - 4	-	22.4	R
4 - 5	-	40.5	R
5 - 6	R	45.0	0.2
6 - 7	0.3	32.0	0.3
7 - 8	-	38.2	1.6
8 - 9	0.2	2.5	0.1
9 - 10	1.7	6.9	0.1
10 - 11	1.5	9.4	0.7
11 - 12	10.0	21.1	0.5
12 - 13	0.3	18.5	0.1
13 - 14	0.2	29.9	-
14 - 15	0.8	5.1	-
15 - 16	1.1	2.6	-
16 - 17	1.3	0.4	-
17 - 18	0.1	2.2	-
18 - 19	1.8	1.0	-
19 - 20	1.0	-	-
20 - 21	2.6	-	-
21 - 22	2.2	-	-
22 - 23	7.5	R	-
23 - 24	5.3	0.1	-
Total	29.1	362.7	3.7

Even if all the pumps at Phrakanong had worked normally, it would have been impossible for the road to be open for vehicle traffic for at least 11 hours on 9th May which would be half of the time of actually interrupted transportation because it would have been is very difficult to drive under the rainfall more than 10 mm/hour.

Judging from the record of the Phrakanong pumping station, if the normal conditions returned at noon of the 11th and all the pumps had worked, it would have taken 30.5 hours to drain out the water and the maximum depth of the flood would have been 80% as deep as it was.

Table 3 Operation Record of Pumps at the Pumping Stations

Date	Time	Bang Khen	Bang Sue	Krung Kasem	Rama IV	Phra Kanong	Bang Or
		Capacity					
		3m³/s x7	3m³/s x12	5m³/s x5	5.7m³/s x4	3m³/s x35	3m3/s x6
May 8th	12:00	0	6	4	1	0	0
	18:00	0	5	4	1	10	0
	20:00	0	5	4	1	10	0
	22:00	0	5	4	2	10	0
	24:00	0	6	4	2	10	1
May 9th	02:00	0	6	4	2	10	1
	04:00	0	6	4	3	10	2
	06:00	0	10	4	3	19	4
	08:00	0	10	4	3	20	5
	10:00	0	12	4	3	20	4
	12:00	0	12	4	3	0	1
	14:00	0	12	2	3	0	2
	16:00	4	12	4	3	23	4
	18:00	5	12	4	3	23	4
	20:00	5	12	4	3	20	4
	22:00	5	12	4	3	16	3
	24:00	5	12	4	3	16	3
May 10th	02:00	5	2	4	3	15	2
	04:00	5	2	4	3	15	1
	06:00	5	3	4	3	15	2
	08:00	5	12	4	3	14	1
	10:00	5	12	4	3	14	1
	12:00	5	12	4	3	0	2
	14:00	3	10	4	3	0	0
	16:00	3	11	4	3	19	0
	18:00	5	11	4	3	32	1
	20:00	5	10	4	3	29	0
	22:00	5	11	4	3	29	2
	24:00	3	11	4	3	29	2
May 11th	02:00	5	11	4	3	28	1
	04:00	5	11	4	3	27	1
	06:00	5	11	4	3	31	1
	08:00	5	11	4	3	33	0
	10:00	5	11	4	3	33	0
	12:00	6	11	4	3	0	0

Estimation (case of the flood for 47 hours):

Total Rainfall for 13 hours = 13R = 47(16.3/35)P
P = 0.594 R

Appropriate period to drain out = 13R/P = 13R/0.594R = 21.9 = 22 hours

Rainfall from 2 o'clock to 8 o'clock on 9th which means one hour time lag of runoff = (254/342.3)x13R = 9.65R

Depth at 9 o'clock on the morning of 9th as it was
H (9 o'clock)p = 10-20 = 9.65R-P(10/35+10/35+19/35+19/35+20/35+20/35+20/35)
= 9.65R-0.594xRx(118/35)
= 7.65R

if all the pumps worked
H(9 o'clock)p = 35 = 9.65R-7P
= 9.65R-7x0.594R
= 5.49R

H(9 o'clock)p = 35 / H(9 o'clock)p = 10-20
= 0.717

R : mean hourly rainfall for the 13 hours in the Phrakanong basin,
P : total capacity of the pumps at the Phrakanong station per hour.

5. Urgent Flood Protection Measures

As the 1983 flood was so severe that the Prime Minister ordered the setting up of a Committee of Flood Protection and Solution in Bangkok and the Vicinity in October, 1983. The Committee proposed an urgent programme at a budget of 1,021 million Baht.

The objectives of the urgent measures are as follows:

1) To prevent inflow from the eastern and northern areas (Part of the Green Belt Project)
2) To prevent inflow from the Chao Phraya River (10 tide gates)
3) To increased drainage capacity (dredging of may klongs and constructing pumping stations totalling 354 m^3/s).

Following by execution of the above mentioned urgent measures in 1984, additional urgent measures (1985/1 plan) which consist of 17 projects at a budjet of 505 million Baht, were planned by the Committee.

Most of the 17 projects were in the City Core Districts, the Eastern Suburb Districts, and the Nontaburi Province. In the Thonburi area, there was only one project with a budget of 8 million Baht to construct a pumping station and a control gate at klong Samrae. The existing flood protection and drainage facility in Bangkok is shown as Figure 16.

One of the most effective measures to prevent the inflow of flood into the urban area from the north and the eastern sides was the construction of the Green Belt of 76 km from Rangsit to Bangphlee. And the other one was the installation of enormous pumping capacity in the City Core and the Eastern Suburb District. The total capacity of the primary pumps in both the district on the 9th May, 1986 was 358m^3/sec which is 3.5 times as much capacity as that of 1983. It was by this pumping capacity that a huge amount of water in the city was discharged out in such a short period in May, 1986.

The implemented urgent measures could change long-period and large-area flooding to short duration and small-area flooding for design rainfall. The constructed embankment and the control gates to prevent inflow from the outer area can reduce the maximum flood depth by about half of that in 1983 to 40cm - 70cm and that flood duration in total will be shortened by one third. The pumps to drain out the inner water can much reduce flooding, and the significant effect is on the flood duration which is reduced to a few days.

BMA has been exerting to allocate large portion of the budget for the Drainage System since 1983. To compare with the Japanese National Budget in 1986 the flood mitigation investment is 837 billion yen but its portion to the total budget is only 1.5% which is far less than that of BMA.

6. Flood Mitigation Plans and Projects

As early as in the 1960s, various plans for flood protection in Bangkok were studied/proposed, and a master plan on flood protection/drainage in the Bangkok metropolis (370 km^2) was prepared in 1986 by a engineering consultant firm, Camp Dresser & McKee (CDM plan). In the master plan a polder system was proposed.

CDM plan had long served as the measures for flood protection and drainage system in Bangkok, however, only some facilities were constructed due to financial constraint. In view of increased flood damage during the 1970s, the following plans and projects have been/are being studied or executed in order to alleviate flood damage in and around Bangkok.

- City Core Project (NEDECO, BMA)
- Eastern Suburban Project (JICA, BMA)
- Green Belt Project (including Channel Improvement Project)
- Samut Prakan Project (TISTR, Samut Prakan Province)
- Flood By-Pass (East Bank) Project (AIT, NESDB)

Since the 1983 flood, the Department of Drainage and Sewerage (DDS) of BMA and the Royal Irrigation Department (RID) have been working hard to improve the drainage capacity, especially in the City Core Districts and the Eastern Suburb Districts (see Figure 16). Their implementation schedules are as the Table 4.

The main hydrological design criteria in both plans are as follows:

1) Crest elevation of the flood protection barriers along the Chao Phraya River was determined based on once in 100 years return period water levels.
2) The drainage system was designed for 3 hours areal rainfall with a return period of 2 years in the City Core Districts and for 24 hours areal rainfall with a return period of 2 years or 24 hours areal rainfall with a return period of 5 years due to the importance of the trunk drainage facilities in the Eastern Suburban Districts, respectively.

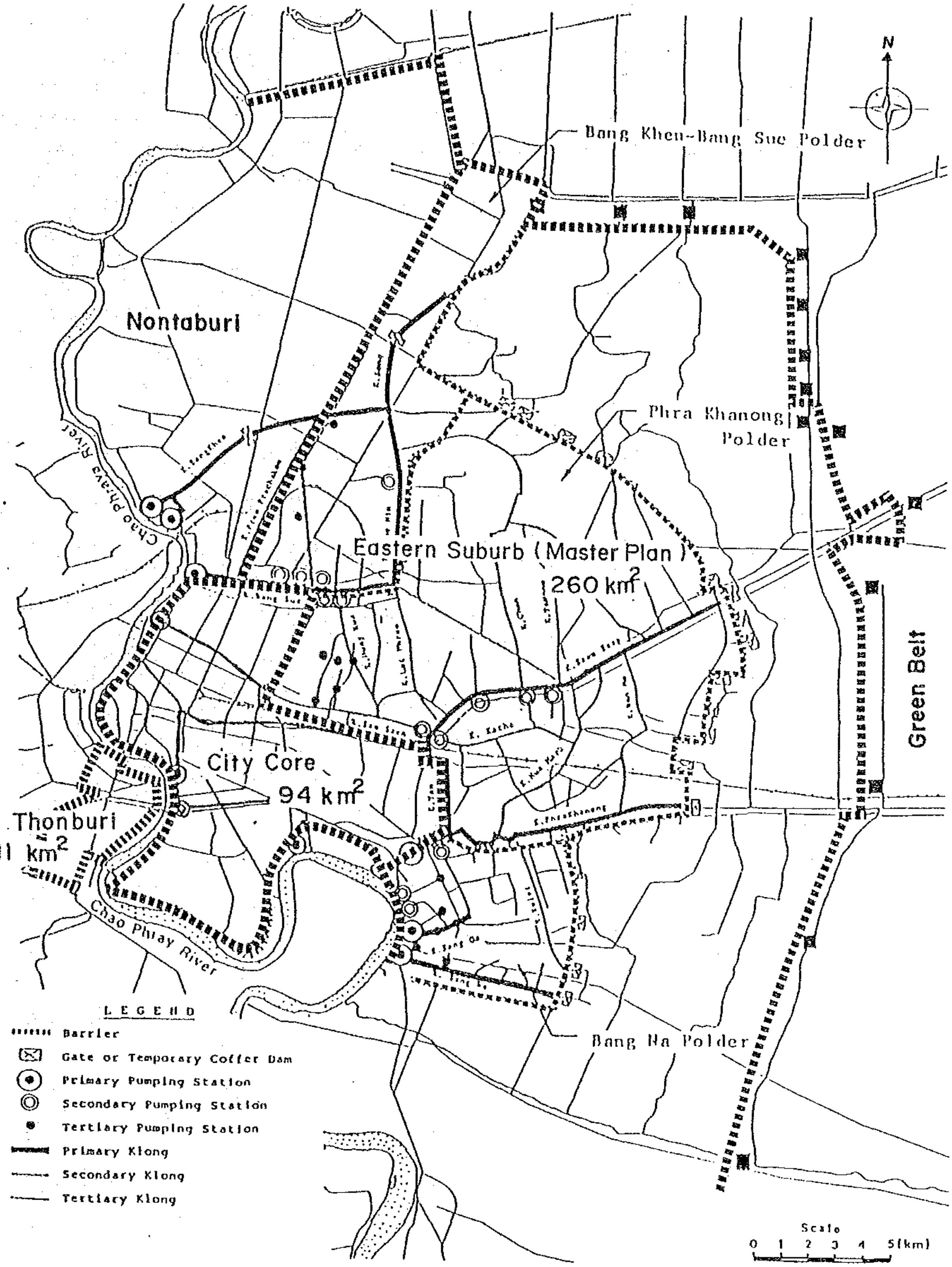


Figure 16 Existing Flood Protection/Drainage Facility

In the Thonburi Districts with an area of 11 Km^2, neither master plan nor feasibility study on flood protection has been made, but the construction works have been proceeding on a rough plan. The polder dyke of 16.7 km is being formed to lift the existing roads. The first two pumping stations were completed late in June, 1986. Their total capacity is $8m^3$/sec. In near future, the capacity in the Districts will be expanded to $20m^3$/sec.

Table 4 Implementation Schedule

Item	City Core	Eastern Suburban
Date of Completion of Report	November, 1984	May, 1985
Catchment Area	94 Km^2	260 km^2
Implementing Period	1985-1993	1987-2000
Embankment along the River side	32.9 km	6.2 km
Cost (million Baht at 1984 prices)	3,400	6,280
Pumping Station with Gate	10 stations ($141m^3$/sec)	10 stations ($218m^3$/sec)
Gate	25 places	55 places
Klong	111.3 km	133.0 km
Main Pipe	10 km	110 km
Others	-	-

JICA