CHAPTER V

GROUNDWATER POTENTIAL ANALYSIS

All groundwater used in Bangkok Metropolis comes from wells that are screened in the water-bearing sediments of Quaternary Age. Water moves into and through the water-bearing sediments in an immense network of extremely small interconnecting voids which extend in all directions throughout the water-bearing rock unit (Ryling, 1960). Estimates of the total groundwater pumpage in the Bangkok Metropolitan area is approximately 1,100,000 cubic meters per day and most groundwater production is from the Phra Pradaeng, Nakhon Luang, and Nonthaburi aquifers (Metcalf & Eddy Inc, 1977).

This chapter discusses the water quality and some hydraulic characters of four aquifers (Bangkok, Phra Pradaeng, Nakhon Luang and Nonthaburi) that are described in Chapter 4.

5.1 Water quality. The chemical, physical and bacterial characteristics of groundwater determine its usefulness for municipal, commercial, industrial, agricultaral and domestic water supplies. For this study of groundwater quality is focussing upon the domestic water use. Interpretation of groundwater chemical composition commonly involves statistical analysis of the data and preparation of trilinear diagrams, maps or graphs (Walton, 1970), as follows :

a) Trilinear diagrams are very useful in bringing out the chemical relationships among groundwater in more definite terms (Walton, 1970). This diagram is more versatile than other plotting methods.

b) Maps show the aerial distribution of the concentration of irons or of chemical characteristics (total dissolved solids, total hardness). The map is used as indicators of chemical character of groundwater (Heath and Trainer, 1968).

c) The graphical presentation of chemical analyses proposed by Collins (1923) shows the relation of total concentration of the cations and anions expressed in equivalents per million to silica concentration expressed in parts per million.

Analyses of water quality in Bangkok Metropolitan area are expressed in the trilinear diagram and the contour map respectively.

5.1.1 Piper's trilinear diagram. The composition of groundwater can be represented conveniently by trilinear plotting (Hem, 1959), and in 1953 Piper further developed a form of the trilinear diagram (Figure 25). For the Piper trilinear diagram, a groundwater is treated substantially as though it contains three cation constituents (Mg, Na+K and Ca) and three anion constituents (Cl, SO_4, CO_3+HCO_3). Distinct groundwater quality types can be quickly discriminated by their plottings in certain subareas of the diamond shaped field (Piper, 1953), as indicated in Figure 25. The explanation is as follows :

<u>Area 1</u> : carbonate hardness exceeds 50 percent-that is, chemical properties of the groundwater are dominated by alkaline earth and weak acids. This area is called "Carbonate Hardness Facies" or "Hydrochemical Facies I" (Ca + Mg > 50 %, Cl + SO_4 < 50 %). Besides, the recharge areas are characterized by the presence of data points in this facies at the left hand vertex (Wu, 1979).

<u>Area 2</u> : carbonate alkali exceeds 50 percent-that is, chemical properties of the groundwater are dominated by alkali and weak acid. The groundwater plotted in this area are inordinately soft (Piper, 1953). This area is called "Carbonate Alkali Facies" or"Hydrochemical Facies II" (Ca + Mg < 50 %, Cl + SO_4 < 50 %) (Wu, 1979).

<u>Area 3</u> : noncarbonate hardness exceeds 50 percent-that is, chemical properties of the groundwater are dominated by alkaline-earth and strong acids. This area is called "Noncarbonate Hardness Facies" or "Hydrochemical Facies III" (Ca + Mg > 50 %, Cl + SO_4 > 50 %) (Wu, 1979).

<u>Area 4</u> : noncarbonate alkali exceeds 50 percent-that is, chemical properties of the groundwater are dominated by alkali and strong acids; ocean water and many brines plot in this area, near the right hand vertex (Piper, 1953). This area is called "Noncarbonate Alkali Facies" or "Hydrochemical Facies IV" (Ca + Mg < 50 %, Cl + SO_4 > 50 %) (Wu, 1979).

Hydrochemical facies of groundwater in Bangkok Metropolitan area are separately determined for each aquifer and presented in Figure 25 and 26.

A) Bangkok aquifer. This aquifer exhibits three hydrochemical facies (2, 3, 4) but hydrochemical facies 2 and 4 are the important facies (Figure 25-1). The hydrochemical facies map of Bangkok aquifer (Figure 26-1) shows that the water quality data are densely developed in the southern part of the study area indicating that Bangkok aquifer contains freshwater near the sea and saline water in inland areas (Metcalf & Eddy Inc, 1977). Besides, it shows that hydrochemical facies 2 is developed in the middle and eastern part of the area while hydrochemical facies 3 and 4 are developed in the western and southern part of the area. Therefore the salinity should be increasing westward of the Phra Pradaeng area. As a consequence, the groundwater of Bangkok aquifer in the study area becomes increasingly more saline in a westerly and northerly direction.

B) Phra Pradaeng aquifer. This aquifer exhibits three hydrochemical facies (2, 3, 4). The hydrochemical facies 2 appears to be more important than hydrochemical facies 4 and 3 respectively because of inordinately soft in quality (Piper, 1953; Figure 25-2). The hydrochemical facies map of Phra Pradaeng aquifer (Figure 26-2) shows that hydrochemical facies 2 and 4 are developed as the major facies and are distributed throughout the study area whereas the hydrochemical facies 3 is developed in only 2 areas, at Ban Chaeng Ron (1), Amphoe Rat Burana and Chulalongkorn Hospital, Amphoe Pathumwan. Besides, the hydrochemical facies 2 is developed in the middle and eastern part of the study area while the hydrochemical facies 4 is developed in the middle and western part of the study area. Or it can say that the hydrochemical facies 2 is developed on the east bank side of Chao Phraya River and hydrochemical facies 4 developed on the west bank side of the Chao Phraya River. Therefore, the salinity increases from the east bank side to the west bank side.

C) Nakhon Luang aquifer. This aquifer shows four hydrochemical facies (1, 2, 3 and 4). It is noted that the hydrochemical facies 2 is more important than 4, 3 and 1 respectively (Figure 25-3). The hydrochemical facies map of Nakhon Luang aquifer (Figure 26-3) shows that hydrochemical facies 2 and 4 are developed as the major facies and are distributed throughout the study area while hydrochemical facies 1 is developed only at Wat Bowon Niwet Wihan extending to Saphan Krung Thon in the north. The hydrochemical facies 3 is developed in 5 areas, at Ban Talat Khwan, Amphoe Muang Nonthaburi; Amphoe Phra Nakhon; Rong Rian Sutthi Wararam, Amphoe Yannawa; Ban Wat Ang Kaeo, Amphoe Phasi Charoen; Ban Khlong Phraya, Amphoe Phasi Charoen. The hydrochemical facies 2 is mainly developed in the middle and eastern parts of the study area, and also separately developed at Ban Bang Wa, Ban Tambun Bang Duan, Amphoe Phasi Charoen, whereas the hydrochemical facies 4 is developed in the middle and western part of the study area. Generally, the hydrochemical facies 2 is developed on the east bank side of Chao Phraya River and the hydrochemical facies 4 developed on the west bank side of Chao Phraya River. As a consequence, the salinity is high on the west bank side and low on the east bank side of Chao Praya River. The pattern is similar to Phra Pradaeng aquifer.

D) Nonthaburi aquifer. This aquifer also shows four hydrochemical facies (1, 2, 3 and 4). The hydrochemical facies 2 is more important than hydrochemical facies 4, 1 and 3 respectively (Figure 25-4). The hydrochemical facies map of Nonthaburi aquifer (Figure 26-4) shows that hydrochemical facies 2 and 3 are developed as the major facies and distributed throughout the study area while the hydrochemical facies 1 is developed in 2 areas, at Sathani Bang Son and Wat Bowon Niwet Wihan. The hydrochemical facies 4 is developed in 2 areas at an adjoining area of Amphoe Pak Kret and Amphoe Bang Bua Thong, and Chulalongkorn University in Amphoe Pathumwan. The hydrochemical facies 2 is developed in the middle and eastern part of the study area whereas the hydrochemical facies 3 is developed in the western and southwestern parts of the study area. Generally, the hydrochemical facies 3 is developed on the west bank side of Chao Phraya River. Therefore the salinity is accordingly high on the west bank side and relatively low on the east bank side of Chao Phraya River. The salinily pattern of Nonthaburi aquifer issimilar to Phra Pradaeng and Nakhon Luang aquifers.

According to Table 18, the hydrochemical facies 2 of all aquifers show a lower range of chemical quality as compared with the acceptable limits for potable water (W.H.O., 1963). Therefore, the area on

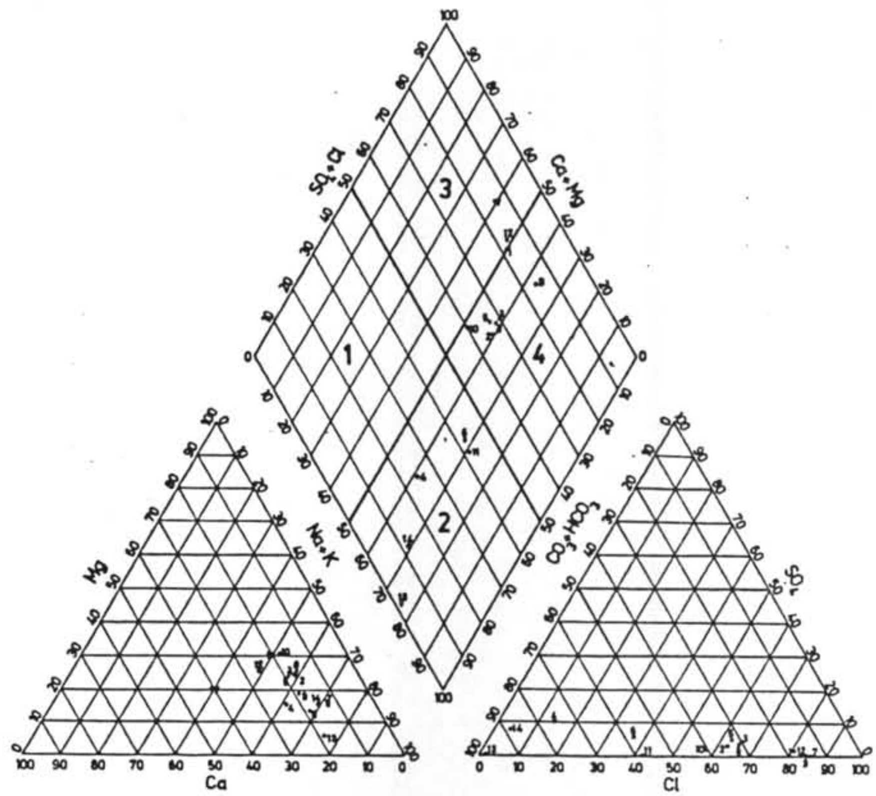

Figure 25-1 HYDROCHEMICAL FACIES OF GROUNDWATER IN BANGKOK AQUIFER
(1975 - 1978)

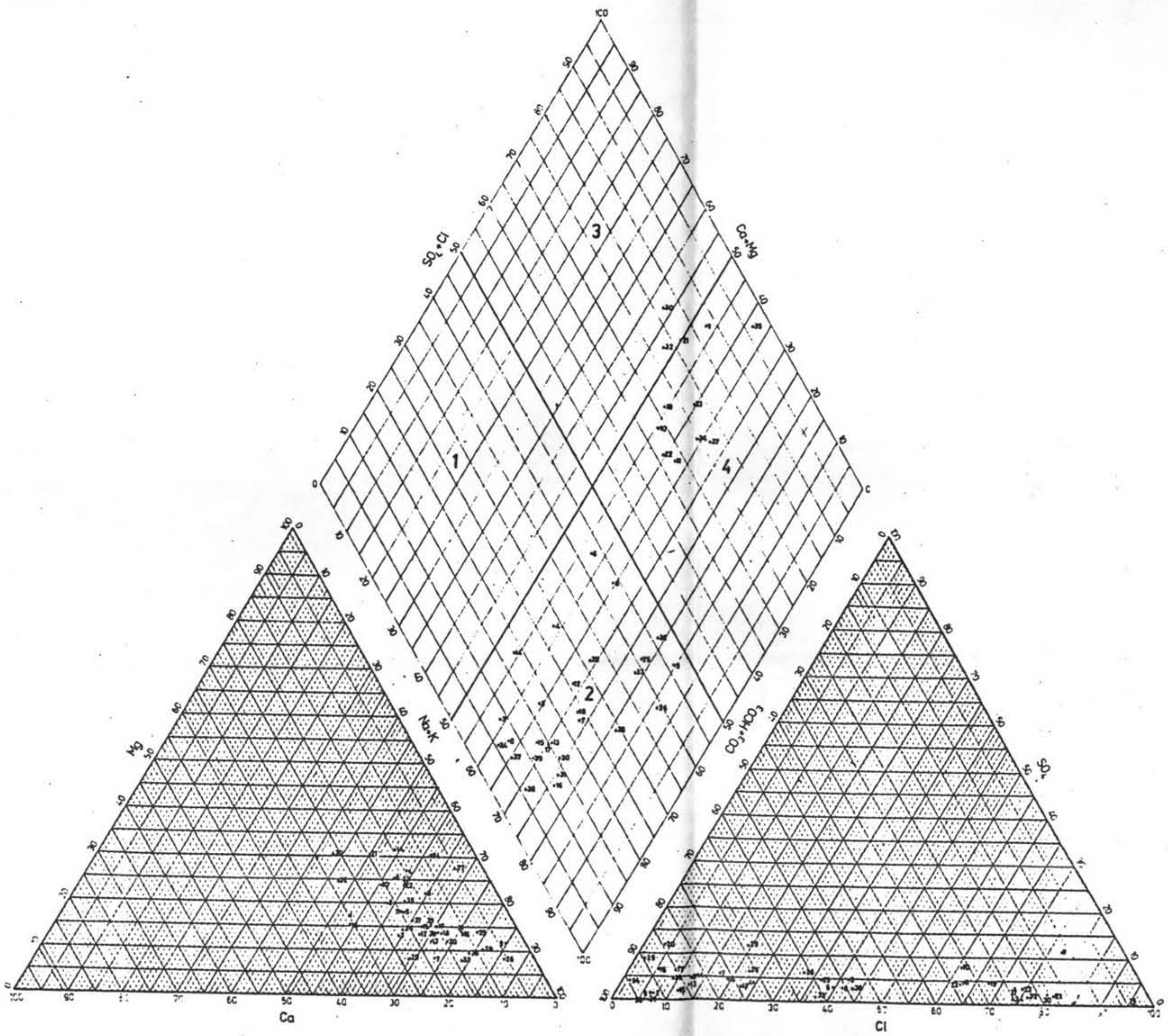

Figure 25-2 HYDROCHEMICAL FACIES OF GROUNDWATER IN PHRA PRADAENG AQUIFER
(1975 - 1978)

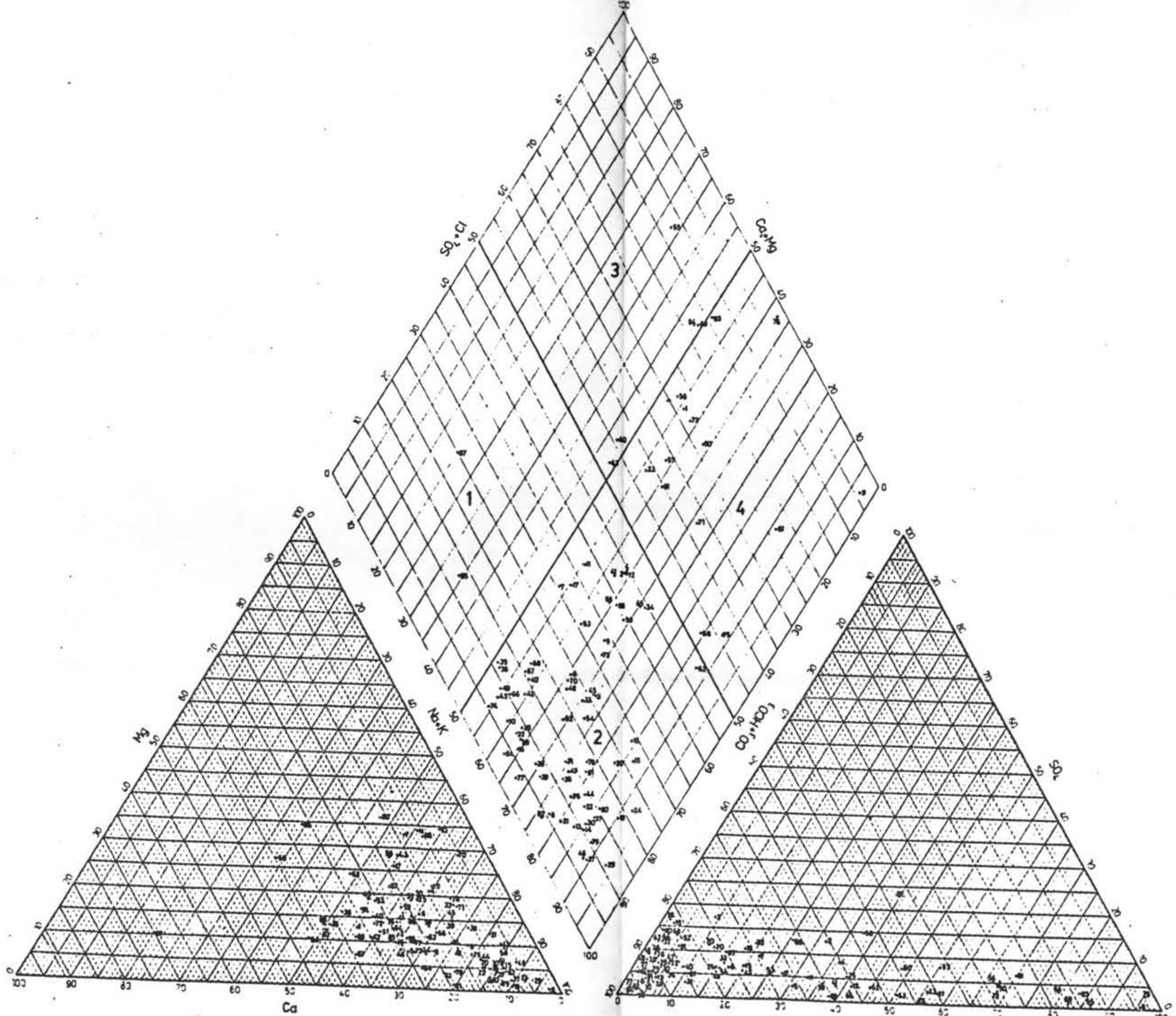

Figure 25-3 HYDROCHEMICAL FACIES OF GROUNDWATER IN NAKHON LUANG AQUIFER
[1975 - 1978]

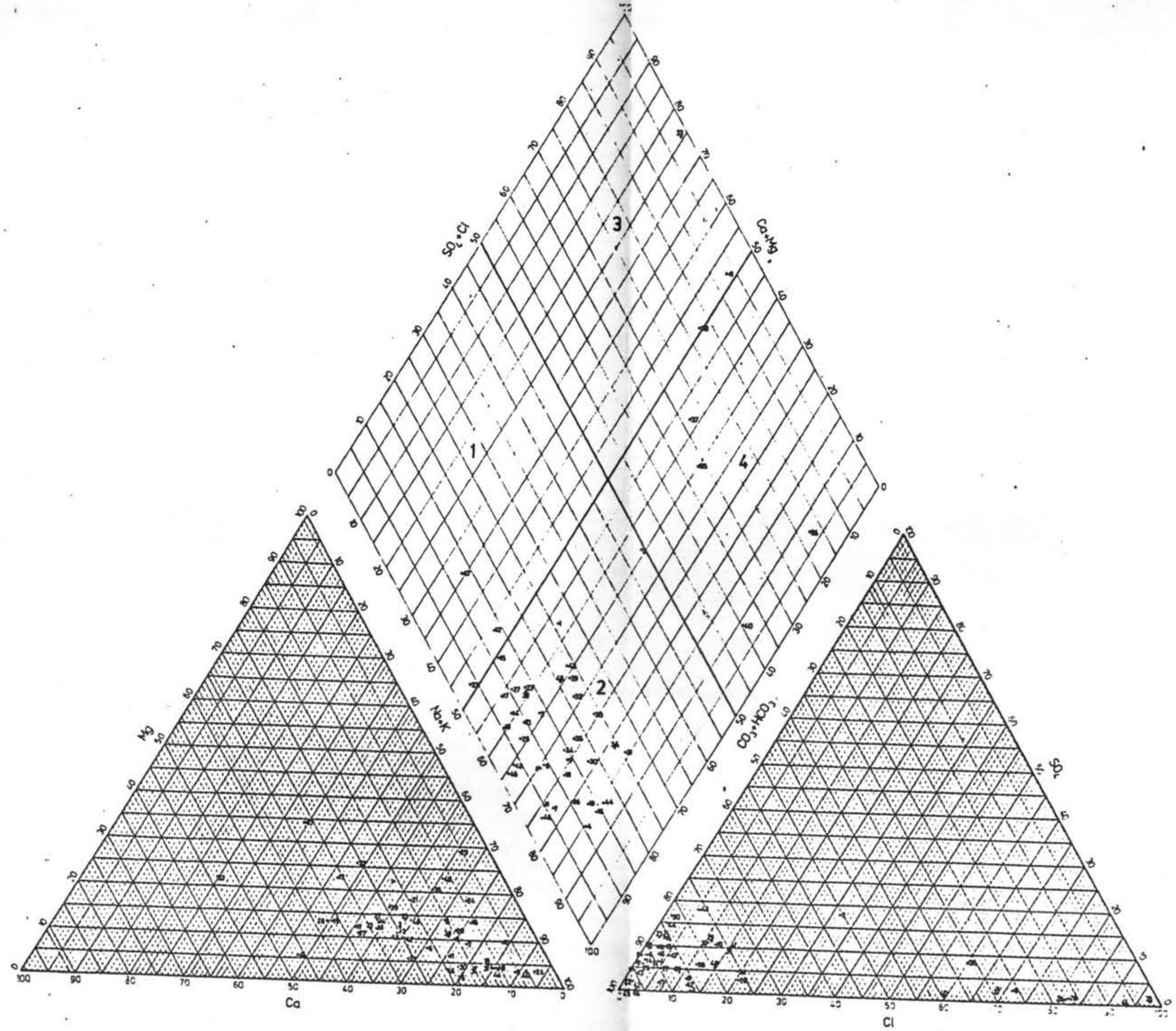

Figure 25-4 HYDROCHEMICAL FACIES OF GROUNDWATER IN NONTHABURI AQUIFER [1975-1978]

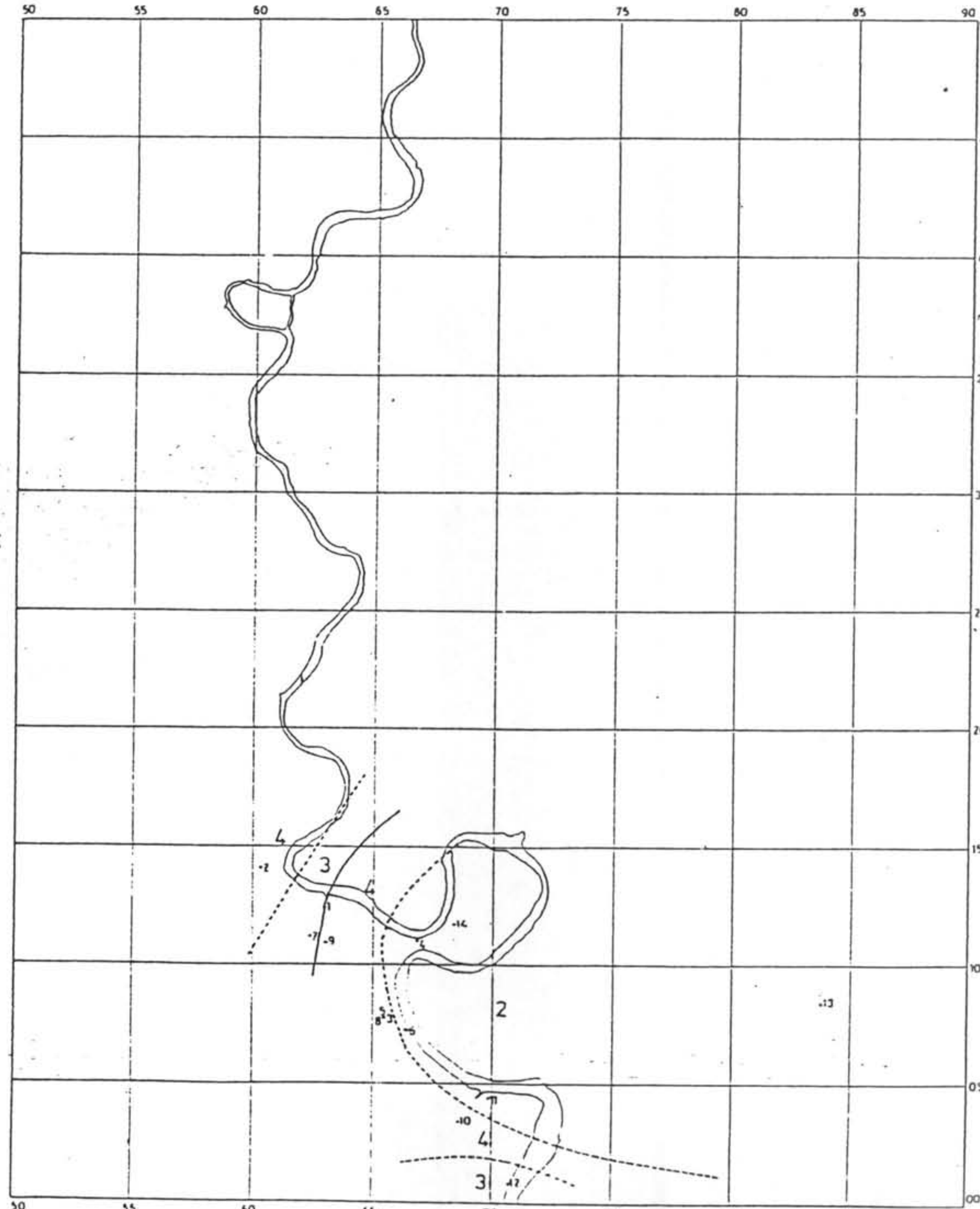

Figure 26-1 HYDROCHEMICAL FACIES MAP OF BANGKOK AQUIFER

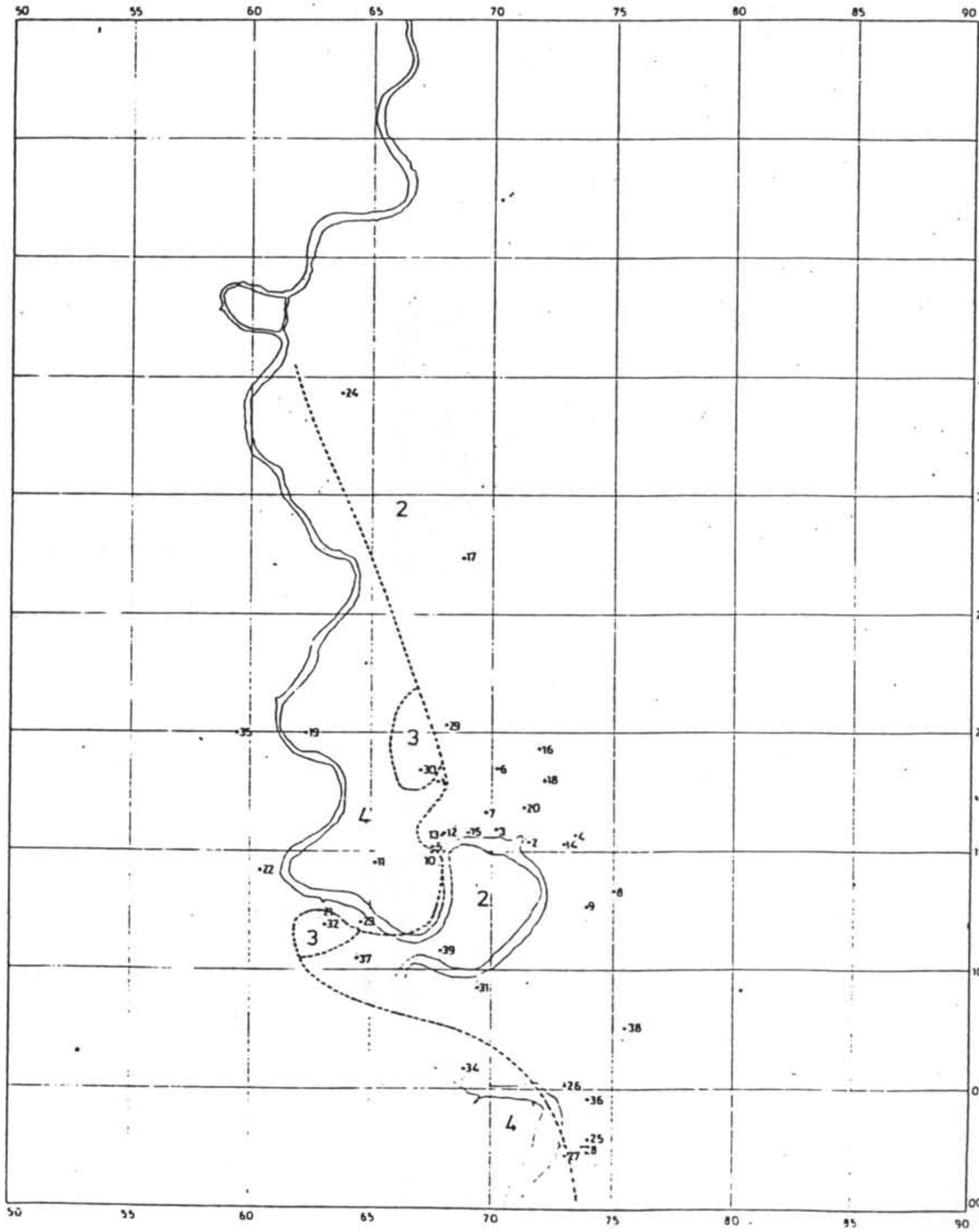

Figure 26-2 HYDROCHEMICAL FACIES MAP OF PHRA PRADAENG AQUIFER

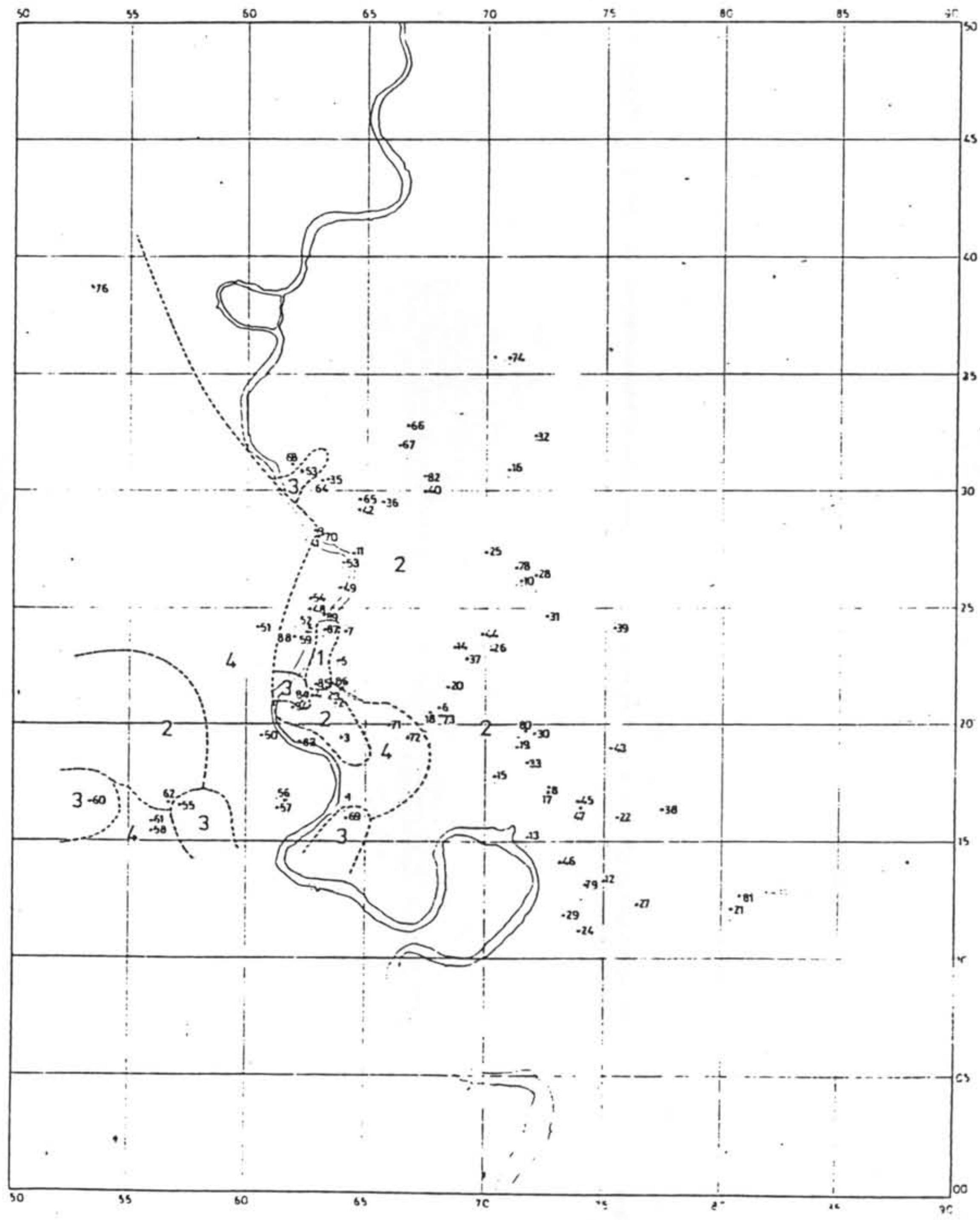

Figure 26-3 HYDROCHEMICAL FACIES MAP OF NAKHON LUANG AQUIFER

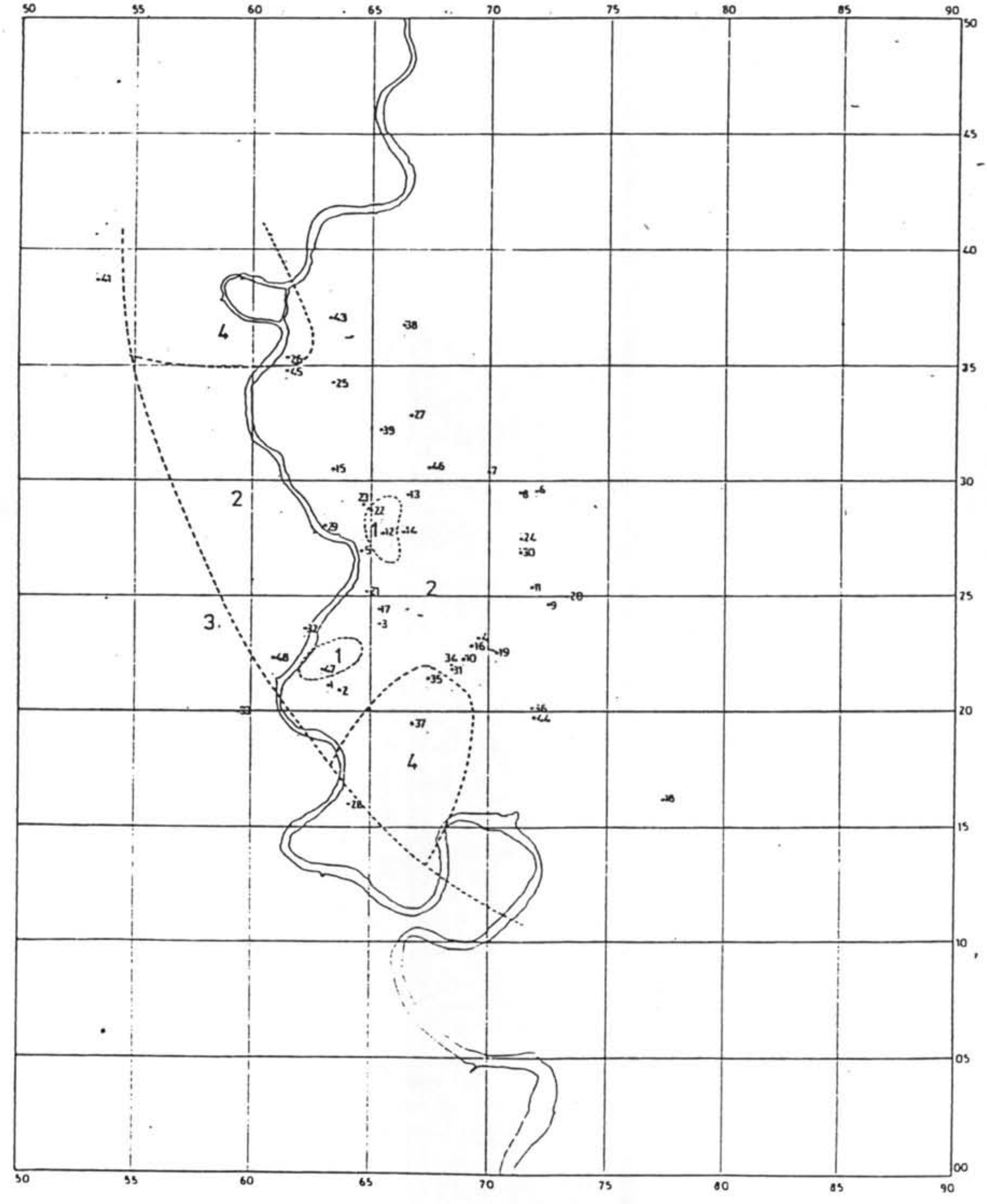

Figure 26-4 HYDROCHEMICAL FACIES MAP OF NONTHABURI AQUIFER

Table 18-1 Ranges of chemical quality of water in Bangkok Aquifer (1975-1978)

Hydrochemical Facies		pH	Concentration in mg/l: Total Alkalinity	Total Hardness	Total Dis-solved Solids	Cl	SO_4 as $NaSO_4$	Free Ammonia as N	NO_3 as N	NO_2 as N	Fe	Mn	Ca	Mg	F
Acceptable Limits for Potable Water 1/					1500	600	400		10		1.0	0.5	200	150	1.0
BANGKOK AQUIFER															
1 Ca + Mg > 50% Cl + SO_4 < 50%	min.														
	max.														
2 Ca + Mg < 50% Cl + SO_4 < 50%	min.	6.94	189	88	240	5	0		0	0	0.13	0	19.2	5.28	
	max.	8.21	348	144	529	137	41.2		0.63	0.002	0.9	0.25	28	21.12	
3 Ca + Mg > 50% Cl + SO_4 > 50%	min.	7.05	186	536	1250	600	0				1.35	0	84.8	90	
	max.	7.2	274	1160	2000	1160	31.24				4.8	0.48	315.2	75.44	
4 Ca + Mg < 50% Cl + SO_4 > 50%	min.	6.9	180	277	642	242	0				0	0	43.2	39.15	
	max.	7.2	244	536	1300	700	43				3.25	0.546	88	77.28	

1/ World Health Organization, International, 1963.

Table 18-2 Ranges of chemical quality of water in Phra Pradaeng Aquifer (1975-1978)

Hydrochemical Facies		pH	Total Alkalinity	Total Hardness	Total Dis-solved Solids	Cl	SO_4 as $NaSO_4$	Free Ammonia as N	NO_3 as N	NO_2 as N	Fe	Mn	Ca	Mg	F
			Concentration in mg/l												
Acceptable Limits for Potable Water 1/					1500	600	400		10		1.0	0.5	200	150	1.0
PHRA PRADAENG AQUIFER															
1 Ca + Mg > 50% Cl + SO_4 < 50%	min.														
	max.														
2 Ca + Mg < 50% Cl + SO_4 < 50%	min.	6.7	200	79	215	5	0	0.3	0	0	0	0	11.04	6.72	0
	max.	8.05	338	280	570	160	68.16	1.65	1.58	0.058	1.31	0.49	39.2	44.64	0.65
3 Ca + Mg > 50% Cl + SO_4 > 50%	min.	7.05	165	364	1016	387	13.8	0			0	0	81.36	43.74	0
	max.	7.7	198	606	1250	600	35.5	1.26			3.22	1.487	112.8	77.8	0.265
4 Ca + Mg < 50% Cl + SO_4 > 50%	min.	6.81	166	258	610	300	0		0		0	0	16.32	28	0
	max.	7.8	232	1700	4400	2840	49.7		0.27		3.92	0.624	303.6	204.1	0.3

1/ World Health Organization, International, 1963.

Table 18-3 Ranges of chemical quality of water in Nakhon Luang Aquifer (1975-1978)

Hydrochemical Facies		pH	Concentration in mg/l: Total Alkalinity	Total Hardness	Total Dis-solved Solids	Cl	SO_4 as $NaSO_4$	Free Ammonia as N	NO_3 as N	NO_2 as N	Fe	Mn	Ca	Mg	F
Acceptable Limits for Potable Water[1/]					1500	600	400		10		1.0	0.5	200	150	1.0
NAKHON LUANG AQUIFER															
1 Ca + Mg > 50% Cl + SO_4 < 50%	min.	7.61	76	78	94	5.1	14.2				0.06	0.207	23.2	2.4	
	max.	7.78	166	122	260	10	18.5				2.99	0.48	27.2	15.36	
2 Ca + Mg < 50% Cl + SO_4 < 50%	min.	6.6	162	40	249	2	0	0	0	0	0	0	7.2	0.96	0
	max.	8.05	392	280	1200	681	93.72	1.04	0.31	0.027	0.86	0.81	48	44.64	0.363
3 Ca + Mg > 50% Cl + SO_4 > 50%	min.	6.82	190	274	500	188	15.6	0			0.39	0.058	38.4	29.3	0
	max.	7.2	256	990	1400	900	68.16	0.916			1.56	1.38	236	96	0.335
4 Ca + Mg < 50% Cl + SO_4 > 50%	min.	6.5	150	104	440	172	0	0	0		0	0	16.8	11.04	0
	max.	7.8	308	4980	14400	8850	229	0.98	0.625		20.6	1.102	1256	442	0.335

1/ World Health Organization, International, 1963.

Table 18-4 Ranges of chemical quality of water in Nonthaburi Aquifer (1975-1978)

Hydrochemical Facies		pH	Concentration in mg/l												
			Total Alkalinity	Total Hardness	Total Dis-solved Solids	Cl	SO_4 as $NaSO_4$	Free Ammonia as N	NO_3 as N	NO_2 as N	Fe	Mn	Ca	Mg	F
Acceptable Limits for Potable Water 1/					1500	600	400		10		1.0	0.5	200	150	1.0
NONTHABURI AQUIFER															
1 Ca + Mg > 50% Cl + SO_4 < 50%	min.	7.05	166	122	235	5.1	4.2	0.714	0.011	0	0.335	0	23	9.6	0.3
	max.	7.78	252	144	260	16	18.5	0.804	0.37	0.003	2.97	0.076	41.6	15.36	0.335
2 Ca + Mg < 50% Cl + SO_4 < 50%	min.	6.75	214	56	249	1	0	0	0	0	0	0	8.8	2.4	0
	max.	8.5	378	640	1020	515	93.72	0.884	0.475	0.19	0.85	0.472	44	24	0.47
3 Ca + Mg > 50% Cl + SO_4 > 50%	min.	6.82	98	592	1400	672	0	0.04			1.56		174.6	36	0.2
	max.	7.9	198	4500	6600	4100	56.8	0.42			2		1280	312	0.398
4 Ca + Mg < 50% Cl + SO_4 > 50%	min.	6.82	220	270	710	336	18.48				0.32	0.377	24.8	12	
	max.	7.21	266	540	1700	885	93.7				0.77	0.848	86.4	39.84	

1/ World Health Organization, International, 1963.

the east bank side of Chao Phraya River has a high potential of good water quality for domestic use whereas on the west bank side of Chao Phraya River are generally not favourable. The hydrochemical facies 1, which indicates the additional rechange, is changing downgradient to either hydrochemical facies 2 or 3, and finally to hydrochemical facies 4 at saline water encroachment area (Piper, 1953 and Wu, 1979). Therefore, Nonthaburi aquifer has a better water quality than the other three aquifers because its major hydrochemical facies considering from the characteristics of the hydrochemical facies (Figure 26). However, throughout the study area Phra Pradaeng, Nakhon Luang and Nonthaburi aquifers have a better water quality than Bangkok aquifer. This is due to the fact that acceptable limits for domestic uses of groundwater in Bangkok aquifer is developed only in the southern part of the study area whereas the water quality other aquifers are found throughout the east bank side of Chao Phraya River (Figure 26).

Besides, fresh groundwater is expected to originate almost exclusively from recharge outside of the study area. This is concluded from the absence of the hydrochemical facies 1 near the left hand vertex of dimond-shaped field in Bangkok and Phra Pradaeng aquifers. The presence of the hydrochemical facies 1 of Nakorn Luang and Nonthaburi aquifers might indicate the vertical seepace from upper aquifers. Correspondence with the studies of Band and Duangkhae (1971) and Metcalf & Eddy Inc. (1977), recharge from precipitation or stream flow infiltration in Bangkok Metropolitan area is estimated to be negligible because of the widespread occurrence of the impervious Bangkok Clay which caps the aquifer system.

5.1.2 Maps. The analytical data of groundwater from numerous water wells undoubtedly reveal the variation of water composition in the aquifer concerned. Subsequent evaluation and correlation of this information coupled with the aquifer characteristics lead to the groundwater potential of the area. Aerial variation in water quality of each aquifer is best accomplish through preparation of map (Walton, 1970).

The water quality of four aquifers in Table 18 are graphically presented in terms of maps showing the distribution patterns of important parameters (Figure 27-30). In this study, an attempt has been made to consider only the concentration of chloride, total dissolved solid, total hardness and iron. This is due to the fact that these four parameters have a tendency to be concentrated higher than the acceptable limits for potable water (W.H.O., 1963).

A) Chloride. The two principle types of groundwater are freshwater having a chloride content of less than 100 ppm. and saline water in which chloride content exceeds 2,000 ppm. Groundwater at the interface between the fresh and saline water occurs within a zone of mixing in which chloride concentration ranges between 100 to over 2,000 ppm. (Metcalf & Eddy Inc., 1977). Generally, all aquifers on the east bank side of Chao Phraya River yield fresh water whereas saline water is found in many places on the west bank side. Besides, the interface between the fresh and saline water is reported in many places particularly on the west bank side. The distribution patterns of chloride content in water of each aquifer are shown in Figure 27. The characteristics of chloride distribution patterns within each aquifer are as follows.

a) Bangkok aquifer. The chloride concentration varies within the range of 5 to 1,160 ppm.. The distribution of chloride increases toward the southern and western part of the study area (Figure 27-1). The over acceptable limit for potable water (> 600 ppm.) are found only on the west bank side of Chao Phraya River.

b) Phra Pradaeng aquifer. The chloride concentration varies within the range of 5 to 2,840 ppm. with a tendency to be increased in the distribution toward the northwest and southwest directions (Figure 27-2). The over acceptable limits for potable water (> 600 ppm.) are located in two zones on the west bank side of Chao Phraya River. These two zones are however entirely separated by the fresh water zone.

c) Nakhon Luang aquifer. The chloride concentration varies within the range of 2 to 8,850 ppm. with a tendency to be concentrated less than 100 ppm. on the east bank side of Chao Phraya River. The concentration appears to increase westwardly. The over acceptable limits for potable water (> 600 ppm.) are mainly developed on the west bank side of the upper parts of the study area and as two separates small zone on both side of the river bank in the lower part of the area (Figure 24-3)

d) Nonthaburi aquifer. The chloride concentration varies within the range of 1 to 1,400 ppm. with a tendency to be increase westardly and southwestardly. The chloride content less than 100 ppm. appears as a zone on the east bank side whereas the over acceptable limits for potable water are mainly developed on the west bank side (Figure 27-4).

The cause of saline water on the west bank side of Chao Phraya River is nebulous and poorly defined due to the limitation of data. However, the study of Metcalf & Eddy Inc. (1977) indicated that this saline water occured as the main body that occupy an area located approximately between the Chao Phraya River and Samut Sakhon and extending north to Amphoe Lat Lum Kaeo or over 50 kilometers inland from the Gulf of Thailand. And it is believed to be connate water which occurs in less permeable sediments incompletely flushed by freshwater.

The cause of saline water might also be from the salt water encroachment from the Upper Gulf of Thailand. If this is a case there should be a continuous increasing chloride content patterns toward the north through time. Consistent monitoring program on groundwater quality throughout the area is considered to be essential in drawing such a conclusion. However, this is beyond the scope of the present investigation.

The present study inclines to believe that the chloride content in the groundwater is probably due to the connate water contamination. This is reasoning from the geographic location of the high chloride

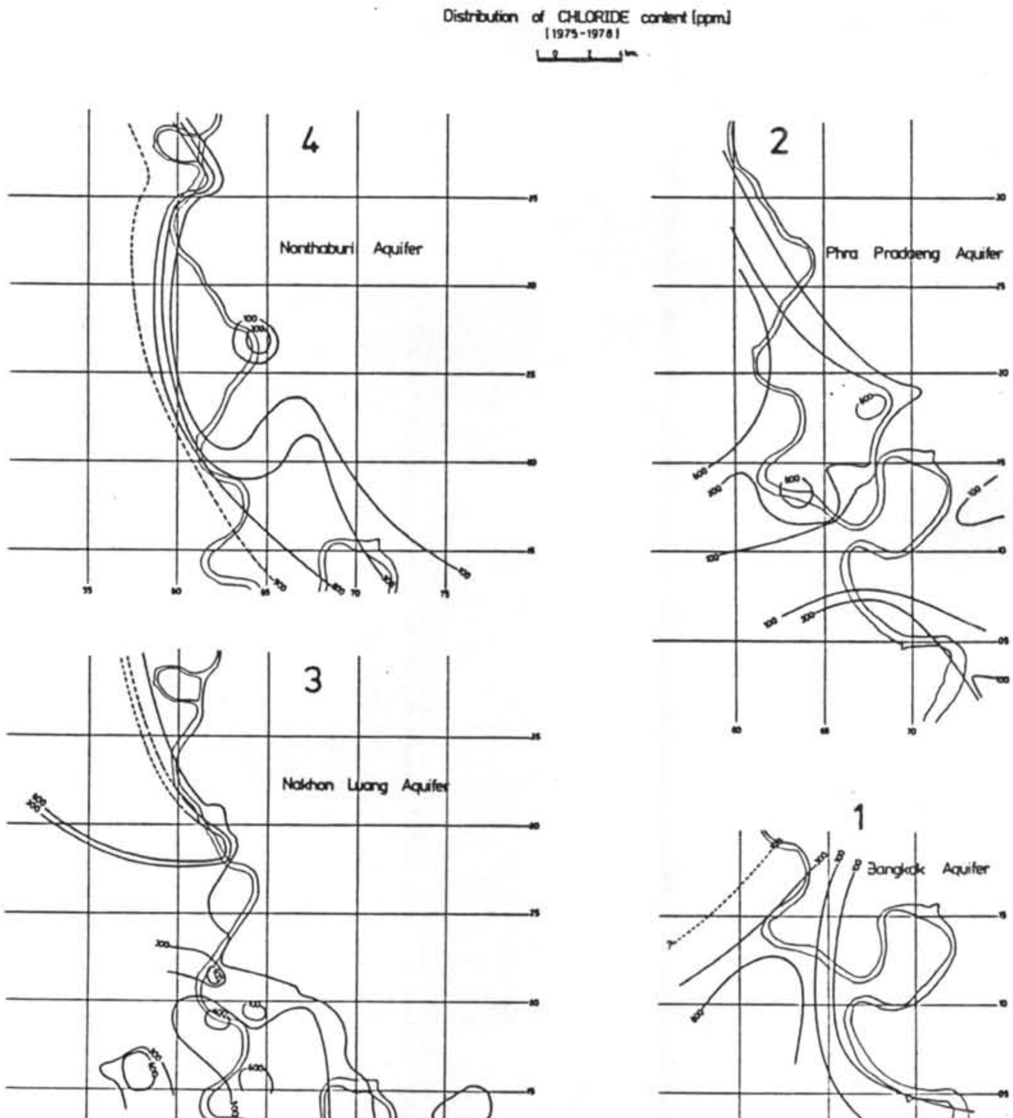

Figure 27 Distribution Patterns of Chloride in the Groundwater of Four Aquifers, Bangkok Metropolis.

content zone which is not covering or overlapping the maximum groundwater utilized zones. The salt water encroachment zones which have been reported elsewhere all occur in the groundwater over utilized zones.

B) Total dissolved solids. Generally areas of excessive quantities of total dissolved solids (> 1,500 ppm.) conformed with the areas of excessive quantities of chloride (> 600 ppm.) in all aquifer (Figure 28). These areas are found in groundwater along the saline-freshwater interface (Metcalf & Eddy Inc., 1977). The distribution of total dissolved solids within each aquifer are shown in Figure 28.

a) Bangkok aquifer. The range of the total dissolved solids is from 240 to 2,000 ppm. The distribution of total dissolved solids is increasing in the southwest direction toward the over acceptable limits for potable water (> 1,500 ppm.) (Figure 28-1).

b) Phra Pradaeng aquifer. The ranges of the total dissolved solids is from 215 to 4,400 ppm. The distribution of total dissolved solids is increasing westwardly. The over acceptable limits for potable water (> 1,500 ppm.) are developed on the west bank side of Chao Phraya River (Figure 28-2).

c) Nakhon Luang aquifer. The range of the total dissolved solids is from 94 to 14,400 ppm. Generally, the distribution of total dissolved solids is increasing in the northwest direction (Figure 28-3). The area where total dissolved solids are over acceptable limits for potable water (> 1,500 ppm.) appear to develop on the west bank side of

Chao Phraya River.

d) Nonthaburi aquifer. The range of the total dissolved solids is from 235 to 6,600 ppm. The distribution is increasing in westwardly and southwestwardly. Over acceptable limits for potable water (> 1,500 ppm.) are developed on the west bank side of Chao Phraya River (Figure 28-4).

C) Total Hardness. The studies of total hardness concentration and the distribution patterns of total hardness of each aquifer have been extensively carried out. The purpose of these studies are primarily concerning with the determination of acceptable limits for potable water using the standard proposed by Sawyer (1969). The distribution patterns of total hardness in part per million (ppm.) are summarized and presented in Figure 29.

Table 19 : Standard Water Hardness (Sawyer, 1969)

Total Hardness (ppm.)	Degree of Hardness
0 - 75	soft
75 - 200	moderately hard
200 - 300	hard
> 300	very hard

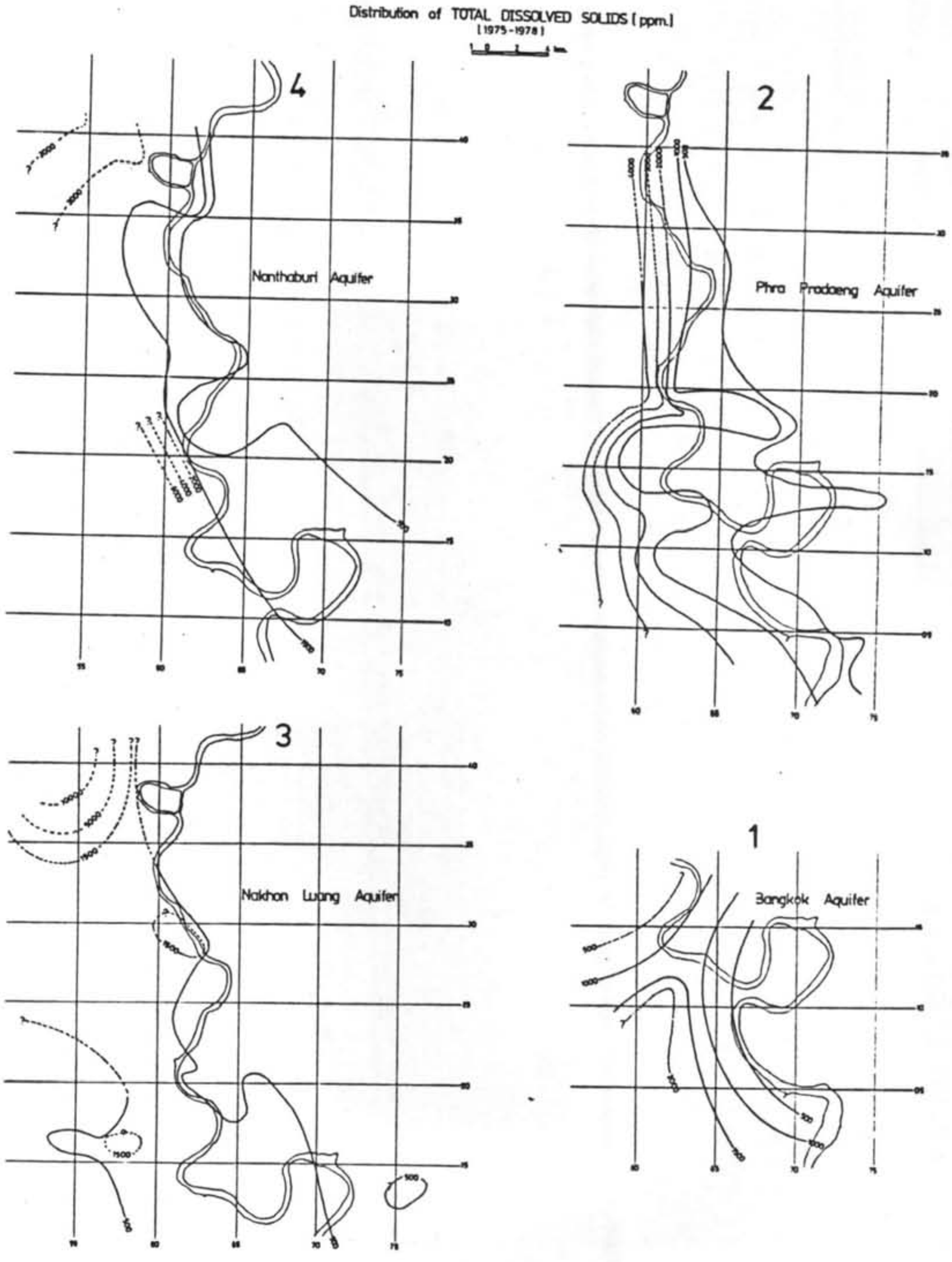

Figure 28 Distribution Patterns of Total Dissolved Solids in the Groundwater of Four Aquifers, Bangkok Metropolis.

a) Bangkok aquifer. The total hardness concentration varies with in the range of 86 to 1,160 ppm.. The distribution pattern of total hardness appears to increase from below 75 ppm. in the eastern part westwardly to the value of approximately 300 ppm. in the central part of the study area. However, in the western part of the study area there is a trend of decreasing in total hardness from approximately 300 ppm. to less than 200 ppm. in the northwest direction. The over all degree of hardness of groundwater in Bangkok aquifer is consider to be moderately hard to very hard (Figure 29-1).

b) Phra Pradaeng aquifer. The total hardness of groundwater in this aquifer varies from 79 to 1,700 ppm.. In the half eastern part of the study area the total hardness concentration appears to be relatively low arround 75 ppm.. However to what the north-south trend in the central part of the study area, the total hardness concentration drastically increases to 300 ppm.. The concentration of total hardness pattern is then progressively decreasing westwardly to the value of approximately 200 ppm. (Figure 29-2). It is interesting to note that the Chao Phraya River course appears to be the boundary between the zones of lower and higher total hardness.

c) Nakhon Luang aquifer. The total hardness concentration falls within the ranges of 40 to 4,980 ppm.. The zone of high total hardness concentration is mainly distributed in the western bank of Chao Phraya River and in the southwest part of the study area with the value between 200-300 ppm.. In contrast, the distribution pattern of total hardness concentration on the eastern bank of Chao Phraya River is generally low value (approximately 75 ppm.) and uniform. The degree of hardness of groundwater in this aquifer is distinctively different on both side of the river banks, that is soft and moderately hard on the eastern bank and hard to very hard on the western bank (Figure 29-3).

d) Nonthaburi aquifer. The distribution pattern of total hardness is more or less similar to that of Phra Pradaeng aquifer. That is the zone of a relatively low total hardness (approximately 75 ppm.) appears on the eastern part of Chao Phraya River course and the zone of maximum total hardness appears as a distinctively narrow belt almost parallel to the river course. On the western part of the study area the distribution pattern is rather uniform with the total hardness concentration varies around 300 ppm. (Figure 29-4). It is therefore concluded that the degree of hardness of groundwater in this aquifer on the eastern bank of Chao Phraya River is soft to moderately hard whereas that of on the western bank is very hard (Figure 29-4).

D) Total Iron. Generally, the presence of total iron concentration appears to be related to the chloride content in the groundwater. That is where the chloride content is less than 100 ppm. the total iron concentration will be relatively low (Less than 1 ppm.). The findings of the present study reveal that the relatively high chloride content zone of all aquifers is present on the western bank of the river course. Therefore the saline-fresh water interface must be accordingly present in the zone on the western bank of the river course (Metcalf & Eddy Inc, 1977). As a consequence, the area of over acceptable limits for potable

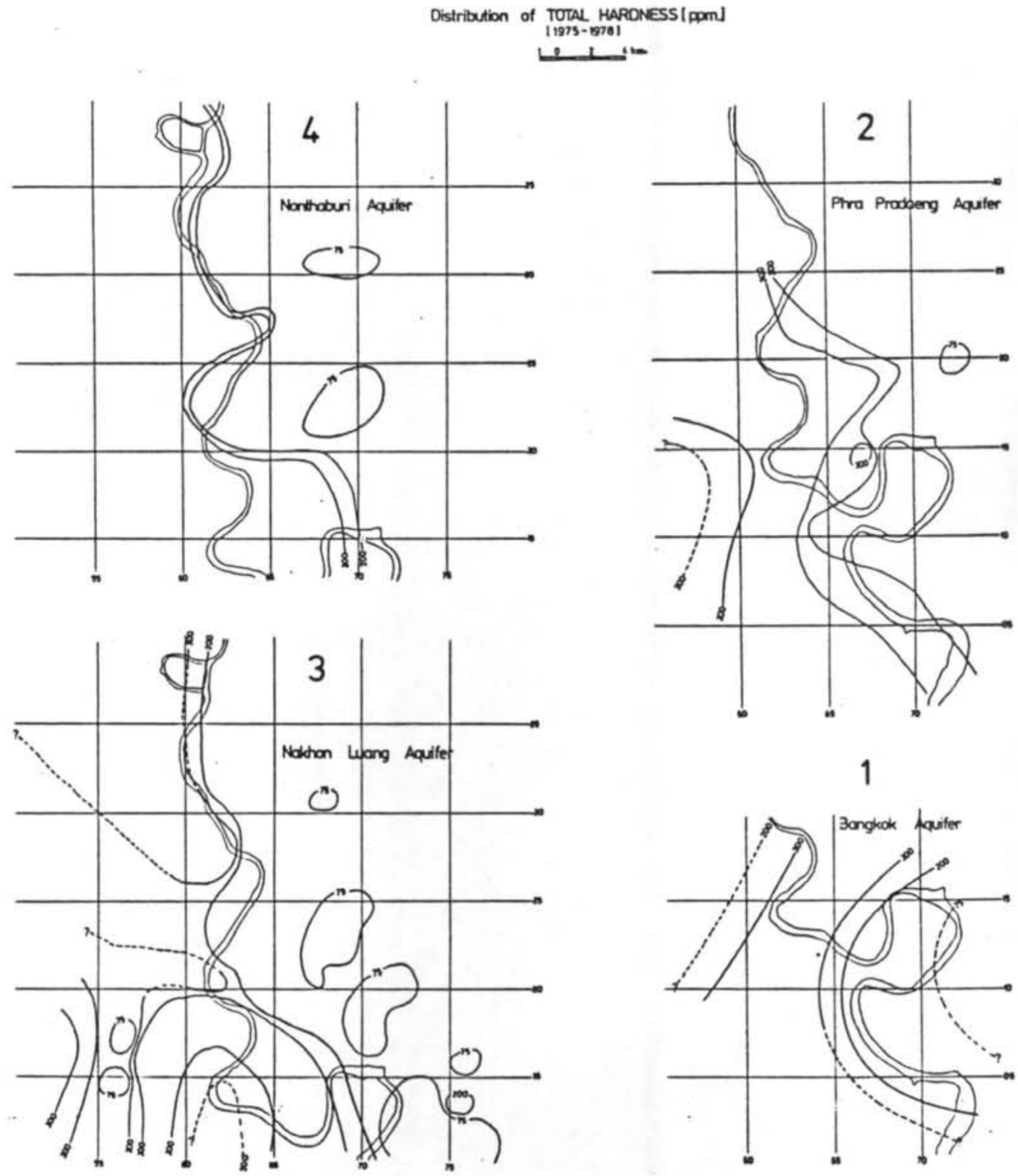

Figure 29 Distribution Patterns of Total Hardness in the Groundwater of Four Aquifers, Bangkok Metropolis.

water with regard to total iron concentration (> 1 ppm.) is likely to be found on the western bank of the river course. Detailed distribution patterns of total iron concentration in groundwater of each aquifer are as follows (Figure 30).

a) Bangkok aquifer. The total iron concentration in the groundwater of this aquifer varies from 0 to 4.8 ppm.. The zone of maximum total iron concentration, the over acceptable zone, extends more or less in the north-northeast and south-southwest direction. Beyond this zone on both side the total iron concentration is progressively decreased to the value of approximately less than 1 ppm. (Figure 30-1)

b) Phra Pradaeng aquifer. The total iron concentration in the groundwater of this aquifer varies from 0 to 3.92 ppm.. The zones of relatively high total iron concentration (> 3 ppm.) appear mainly on the western bank of the river course and on the south most of the study area right over the river course. These zones are also the over acceptable zone for potable water. Besides, there is a small over acceptable zone isolately present in the eastern bank of the river course near the central part of the study area (Figure 30-2).

c) Nakhon Luang aquifer. Generally the total iron concentration falls within the range of 0 to 4.8 ppm.. There are 6 small zones of relatively high total iron concentration or over acceptable zones sporadically distributed throughout the study area particularly on the western bank of river course. It is interesting to note that this aquifer contains higher volume of good quality groundwater with regard to the total iron concentration as compared with the other previously mention ones (Figure 30-3).

d) <u>Nonthaburi aquifer</u>. The total iron concentration varies within the range of 0 to 2.97 ppm. with limited numer of over acceptable zones. Totally there are only 3 small total iron concentration zones (> 1 ppm.) distributed more or less along the river course in an isolated manner (Figure 30-4). Considering the groundwater quality with regard to total iron concentration, this aquifer has a higher potable water potential compare with the other three.

In conclusion, it is apparent that the groundwater quality of four aquifers in the study area with regard to four important chemical constituents, namely, Chloride, Total dissloved solids, Total hardness and Total iron, has a tendency to be more suitable for potable use on the eastern bank of the river course as compared with that of on the western bank. The findings of present investigation on many aspects are similar to that of Metcalf & Eddy Inc., (1977). The zone of fresh-saline groundwater interface must have been present in an area of the western bank of the river course as concluded from the distribution patterns of four major chemical constituents of the water and from the hydrochemical facies previously described (Table 20).

The problem of salt water encroachment in the study area can be identified from the 250 ppm. isochlor in a continuous time frame

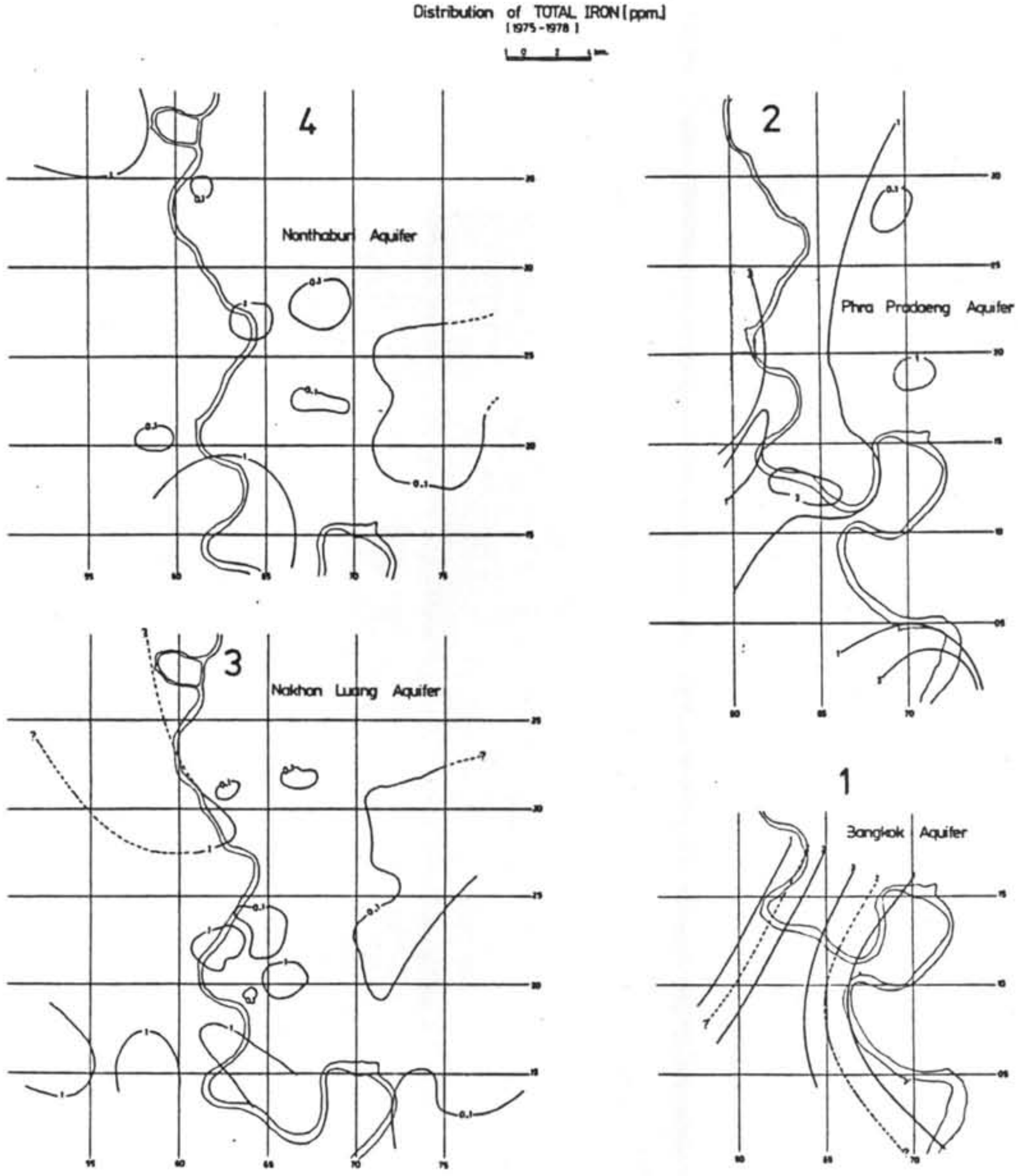

Figure 30 Distribution Patterns of Total Iron in the Groundwater of Four Aquifers, Bangkok Metropolis.

Table 20 : Relationships between Hydrochemical facies and Distribution of some components.

Aquifer	Hydro-chemical facies	Distribution of components							
		Tot. diss. solid		Total Hardness		Chloride		Total Iron	
		Range of conc. (ppm.)	Distri-bution	Range of conc. (ppm.)	Distri-bution	Range of conc. (ppm.	Distri-bution	Range of conc. (ppm.)	Distri-bution
Bangkok (water quality data available only in the southern part of the study area)	2 & 4	240-2,000	South & West (increase)	88-1,160	North & West (increase)	5-1,160	South & West (increase)	0-4.8	Northwest (increase)
Phra Pradaeng (data available in middle to southern part of study area)	2	215-4,400	West (increase)	79-1,700	South & West (increase)	5-2,840	Northeast & Southwest (increase)	0-3.92	West & South (increase)
Nakhon Luang (data available in middle to northern part of study area)	2	94-14,400	Northwest (increase)	40-4,980	West (increase)	2-8,850	West (increase)	0-4.8	West (increase)
Nonthaburi (data available in middle to northern part of study area)	2	235-6,600	West (increase)	56-4,500	West (increase)	1-4,100	West & Southwest (increase)	0-2.97	West (increase)

(Metcalf & Eddy Inc., 1977). The distribution patterns of chloride content in the groundwater of four aquifers in the present study against the study of Metcalf & Eddy Inc.(1977) concretely proved that the problem of salt water encroachment in Bangkok Metropolis area has increased in magnitude and intensity. There appears to be a tendency of salt water encroachment moving eastwardly across the Chao Phraya River course in all aquifers. The areas which have reasonably suffered from this problem includes Amphoe Phra Pradaeng, Amphoe Yannawa, Amphoe Bang Rak, Amphoe Samphanthawong and Amphoe Pathumwan (Figure 27).

5.2) Hydraulic characters. The present investigation is concerned with the analysis of preexisting data regarding the water level, yield, drawdown, specific capacity, transmissibility and storage coefficient (Tables 21 and 22). In order to avoid any confusion which might caused by the terminology employ in this study, the following definitions are used

Water Level is the imaginary surface to which water rises in wells tapping artesian aquifers or called the piezometric level because all aquifers in the study area are confined aquifers. This parameters measured from land surface to piezometric surface.

Yield is the amount of water that can be taken continuously from a aquifer per unit time.

Drawdown is the lowering of the water table or piezometric surface caused by pumping (Walton, 1970).

Specific Capacity is the ability of well in each aquifer for discharge and expressed as rate of yield per unit of drawdown (Walton, 1970).

The coefficient of storage is the volume of water, it releases from or takes into storage per unit surface area of the aquifer, per unit change in the component of head normal to that surface (Ryling, 1960).

The coefficient of transmissibility is the capacity of an aquifer to transmit water through its entire thickness.

Basically, the four hydraulic character data, namely water level, yield, drawdown and specific capacity are summarized and tabulated in Table 21. However these only represent part of aquifer properties which can be used as a guidance to indicate that there is a substantial declination for every aquifer. The average water level of these four aquifers has declined from about 22.45 meters below the ground surface in 1975 to as much as 32.98 meters in 1978. Therefore the rate of declination is between 2.0 to 4.5 meters per year during this period when compared with the pumpage which has steadily increase from about 725,000 cubic meters per day in 1975 to about 1,100,000 cubic meters per day in 1978. Evidences from other studies regarding this matter are Ramnarong (1975) which reports the decline of water level at the rate of 1 to 2 and 2 to 4 meters per year in heavily pumped areas for Phra Pradaeng and Nonthaburi aquifers respectively, and Piancharoen (1976) reports the decline of up to 3 to 4 meters annually for Phra Pradaeng, Nakhon Luang and Nonthaburi aquifers including 1 meter per year for Bangkok aquifer. Undoubtedly, this decline is caused by the over pumpage of groundwater.

Table 21 : Some hydraulic characteristics of aquifers (1975-1978)

(MWWA)

Hydraulic character / Aquifer	Water level (m) average				Yield (m^3/h) average				Drawdown (m) average				Specific capacity ($m^3/h/m$) average			
	1975	1976	1977	1978	1975	1976	1977	1978	1975	1976	1977	1978	1975	1976	1977	1978
Bangkok	21.25	23.3	25.3	-	57.5	175.0	241.0	-	7.4	6.55	8.5	-	7.77	26.72	28.35	-
Phra Pradaeng	21.02	23.8	26.6	30.2	59.25	157.5	216.5	300.0	6.83	6.9	9.24	12.43	8.67	22.83	23.43	24.14
Nakhon Luang	22.7	24.33	29.72	33.7	120.5	237.19	269.54	300.0	8.94	11.02	12.94	14.24	13.48	21.52	20.83	21.07
Nonthaburi	24.85	26.74	31.76	35.04	68.0	295.88	279.29	301.91	5.65	20.60	15.5	20.18	12.04	14.36	18.02	14.96
Average	22.45	24.54	28.35	32.98	76.31	216.39	251.58	300.64	7.21	11.27	11.55	15.62	10.58	19.20	21.78	19.25

Table 22 : Hydraulic Aquifer Coefficients
(Metcalf & Eddy Inc., 1977)

Aquifer	Transmissibility m^2/d	Permeability m/d	Storage Coefficient	Location
Bangkok Upper (30 m zone)	500 1/			**Rat Burana Area**
Bangkok Lower (50 m zone)	3100 - 4160		7×10^{-3} to 5.9×10^{-3}	Well D-205
	3840	82	1×10^{-4}	Bang Pun
	900 - 1200			Well 506
	620 1/			Rat Burana Area
Phra Pradaeng (100 m zone)	1750 - 3000	58 - 88	1×10^{-4}	Bangkok Area
	960 - 3100			Bangkok Area
	2640	90		Pom Phra Chun Navy Base
	1680	57		Amphoe Phra Pradaeng
	2880	57	1×10^{-4}	Wat Phai Ngoen
	2484		2×10^{-4}	Well PB - 151
	2981		1×10^{-4}	Wat Pai Ngern
	2900 - 4100			Well 504
Nakhon Luang (150 m zone)	1600 - 2750	52 - 82	1 to 2×10^{-4}	**Bangkok Area**
	960 - 3100			Bangkok Area
	1560	53	1×10^{-4}	Wat Phai Ngoen
	2400	82	2×10^{-4}	Lumphini Park
	2640	61		Pak Kret
	3000	83	2.2×10^{-3}	Bang Bua
	1200	64	2.6×10^{-4}	Dept.of Mineral Resources
	1615			Well 89/1

1/ Average values

The ability of an aquifer to yield water to wells is dependent upon two important hydraulic properties. These particular characteristics pertain to the ability of the water-bearing formation to store and transmit water (Ryling, 1960). Early study by Metcalf and Eddy Inc. (1977) has summarized the hydraulic aquifer coefficients (Table 22). It is suspected that within the study area, the capacity for an aquifer to transmit water will vary considerable depending on the aquifer's thickness and sediment make up (Plate 4 and Appendix 2-C). Generally, the highest well yields are available from the Phra Pradaeng, Nakhon Luang and Nonthaburi aquifers principally (Table 21) because of their greater depth and greater water column available for a well to draw on. However, the data on geological logs suggest that there is a progressive decrease in the transmissibility of these four aquifer westwardly and eastwardly of the study area. As a result, wells located in these parts will generally yield lesser quantities of water (Metcalf and Eddy Inc., 1977).