4-1-3 Present Utilization of Groundwater :

This section deals with the present utilization of ground water and the variability of the groundwater level in the study area. In generally, the use of groundwater in the proposed study areas is small amount. At present groundwater is used for human use in Bang Yai, Nong Khaem, Nong Chok, Min Buri, Lat Krabang, Bang Phli and Bang Bo, and groundwater is drawn for industrial use in Bang Chan and in the industrial area between Bang Phli and Bang Bo. However, the groundwater level has been gradually drawn down from year to year in the area adjacent to Bangkok.

(1) Right Bank of the Chao Phraya River :

1) Sai Noi :

At present no use is made of groundwater in this district. There was a time when groundwater was drawn from a deep well for a water supply to the community for about 7 years, but the deep well was abandoned about 10 years ago. The pumpage was 20 to 30 CMD. The well was abandoned due to increased turbidity and saline water. No groundwater has been withdrawn ever since in this district.

2) Bang Bua Thong:

There is a water supply system which supplies the community with 2,000 CMD of surface water, but there is no deep well. As the water of the Klongs utilizing water source at present, has become poor quality in recent years, there appears to be a plan to tap groundwater. At present no use is made of groundwater in this district, the groundwater level seems to be 10 to 15 m below ground surface. Assuming the groundwater level was about 5 m in 1958-1959, declining of the groundwater level has become 5 to 10 m up to now.

3) Bang Yai :

Use is made of groundwater drawn from a deep well which reaches a depth of 162 m and the well is said to have a high yield and to produce good water. The present pumpage is about 800 CMD. The present groundwater level and its change in this district appears to be about the same as in Bang Bua Thong.

4) Nong Khaem :

One deep well is used as a water supply. It is 80 m deep with a bore of 250 mm. The pumpage is about 450 CMD. The water is not good as it contains chloride ions in a concentration of 250 to 300 ppm, and iron ions in a concentration of 2 to 3 ppm. The well casing has gone up above ground surface about 5 cm due to ground subsidence.

Besides the deep well, the Navy is using one well and three private wells are operating, but the water drawn from all these wells is also not good as it contains chloride ions in a concentration of 500 ppm or more. There has been little change in the groundwater level, and the groundwater is now presumed to be at a level of 5 m or so below ground surface.

(2) Left Bang of the Chao Phraya River :

1) Nong Chok :

There are four deep wells in this district. They are 150 m deep with a bore of 50 mm, and water is raised by air lift pumps. Their pumpage is about 430 CMD. The groundwater level in this district is not clear, but is preseumed to be at a depth of 5 to 8 m below ground surface.

2) Min Buri :

Two deep wells are existing and both of them are 200 mm in bore and 160 m in depth. The total capacity of the two wells is 3,700 CMD. The well casing has gone up above ground surface about 30 to 40 cm due to ground subsidence.

In addition, there are two deep wells which belong to the Bang Chan Industrial Estate and produce water. They are 300 mm in bore and 200 m in depth and their average pumpage is placed at 2,000 CMD or so. The groundwater level is now at a depth of about 20 m below ground surface and is said to have been declining at a rate of about 1 m per year.

3) Lat Krabang :

Three deep wells are existing in this district, and an institute of technology owns another two wells. Their pumpage is about 3,000 CMD. The well casing has gone up above ground surface about 10 cm due to ground subsidence.

4) Bang Phli :

A deep well with a 150 mm bore and 134 m depth is operated as a water supply in this district, and its pumpage is 720 CMD. The groundwater level in this district is now estimated to be at a depth of about 22 m below ground surface.

5) Bang Bo :

Two deep wells each with a 150 mm bore and 160 m depth are operated as a water supply in this district and their pumpage is 780 CMD.

The factories built along the national highway own their deep well, as shown in Table 4-5, and the pumpage of their wells is estimated to be 600 CMD.

As beeing mentioned above, at present no more than 9,900 CMD of groundwater is drawn for domestic use and no more than 2,600 CMD for industrial use in the proposed study area. This amount of water accounts for only about 1 % of the total pumpage of 936,755 CMD* in the low central plain. The decline of the groundwater level in the area adjacent to Bangkok is therefore not attributable to pumping of groundwater in that area but seems ascribable to over-pumping in metropolitan Bangkok.

* Report on Groundwater Monitoring Well Construction and Future Program, Table 2-4.

Table 4-5 PRIVATE WELL AT BANG BO

NAME OF COMPANY	WELL		QUANTITY OF YIELD
	DIAMETER OF WELL	DEPTH OF WELL	
THAI ACRYRIC CO. LTD.	150 mm	160 m	50 m^3/day
	150 mm	130 m	
SIAM KIKI CO. LTD.	150 mm	132 m	250 m^3/day
BANGKOK FEED MILL CO.LTD.	150 mm	118 m	200 m^3/day
THAI SWEDISH ASSY.	100 mm	135 m	80 m^3/day

4-1-4 Coefficients of Aquifers :

To obtain accurate coefficients of the aquifer it is necessary to install a main test well and an observation well to analyze the results of the yield test. In the 8 Amphoes, there are only production wells and no coefficients of the aquifer have been obtained by the yield test.

On the other hand, coefficients of the aquifer have been obtained at some locations in central Bangkok. Table 4-6 shows the values given by Charoen Piancharoen et al. (1976)*, and Vachi Ramnarong (1976)**, who performed detailed tests in the Bangkok aquifer and Nakohn Luang aquifer, and which indicates T = 250,000 gpd/ft and $S = 2.2 \times 10^{-3}$ as coefficients of transmissibility and storage of the Nakhon Luang aquifer.

* Charoen Piancharoen and Charoen Chuamthaisong, 1976
Groundwater of Bangkok Metropolis, Thailand, P. 13, Table 1

** Vachi Ramnarong, 1976
Pumping Test for Nakhon Luang and Bangkok Aquifers, P. 38

In the district where the coefficients of the aquifer have not been obtained by yield tests, the specific capacity (See Fig. 4-21) of wells can be determined from the data on the production wells. The specific capacity of a single well (having a bore of 250 mm) was determined from the coefficient of transmissibility which was in turn determined in a test well bored in Bangkok. The two values were plotted against each other to establish the relationship between them, as shown in Fig. 4-20.

The coefficients of the aquifer in the 8 Amphoes of the separate system were determined according to the flow chart shown in Fig. 4-22. In brief the specific capacity of the well is determined by consulting the data of the existing wells, and the transmissibility of aquifer perculiar to each Amphoe is determined from the relationship between the transmissibility and specific capacity.

On other hand, the average coefficient of transmissibility of the Nakhon Luang aquifers (in central Bangkok) is determined by calculation. The average coefficient of transmissibility is multiplied by the thickness of each aquifer to obtain an approximate value of transmissibility. The value of transmissibility thus obtained is adjusted to a reasonable value through comparison with the value determined from the specific capacity. (See Table 4-7)

In the determination of the coefficient of storage, the specific capacity is first obtained from the relationship between the observed value of coefficient of transmissibility and the assumed value of coefficient of storage. When a true specific capacity was obtained by changing the assumed value of coefficient of storage, the value of coefficient of storage assumed in that calculation is adopted. (See Table 4-8)

Table 4-6 COEFFICIENT OF AQUIFER

Aquifer	Location of tested well	Coefficient of Transmissibility (m^2/hr)	Permeability (m/hr)	Coefficient of storage
Nakhon Luang	Wat Phai Ngoen	65	2.21	1.00×10^{-4}
	Lum Phini Park	100	3.40	2.00×10^{-4}
	Pak Kret	110	2.55	-
	Bang Bua	125	3.45	2.2×10^{-3}
	Dept. of Mineral Re-sources	50	2.65	2.60×10^{-4}

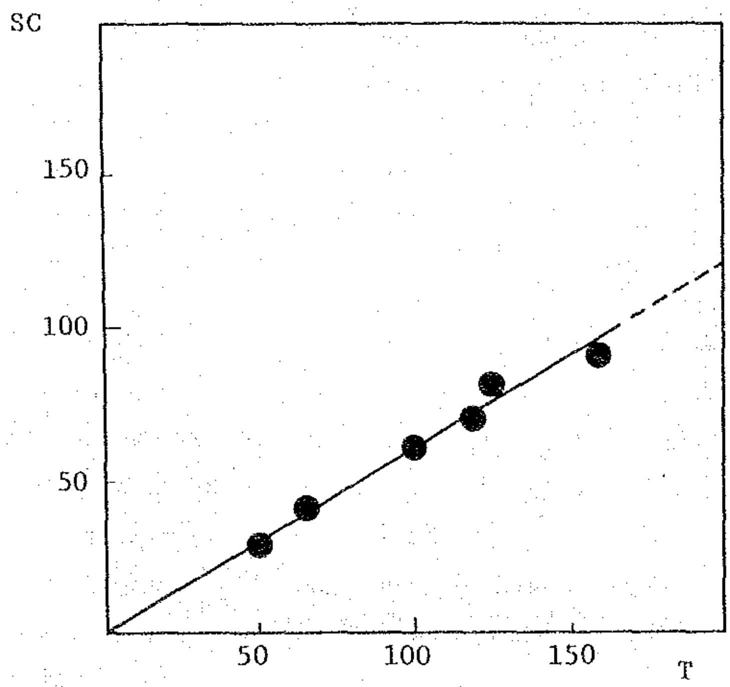


Fig. 4-20 RELATION OF TRANSMISSIBILITY AND SPECIFIC CAPACITY (See Table 4-6)

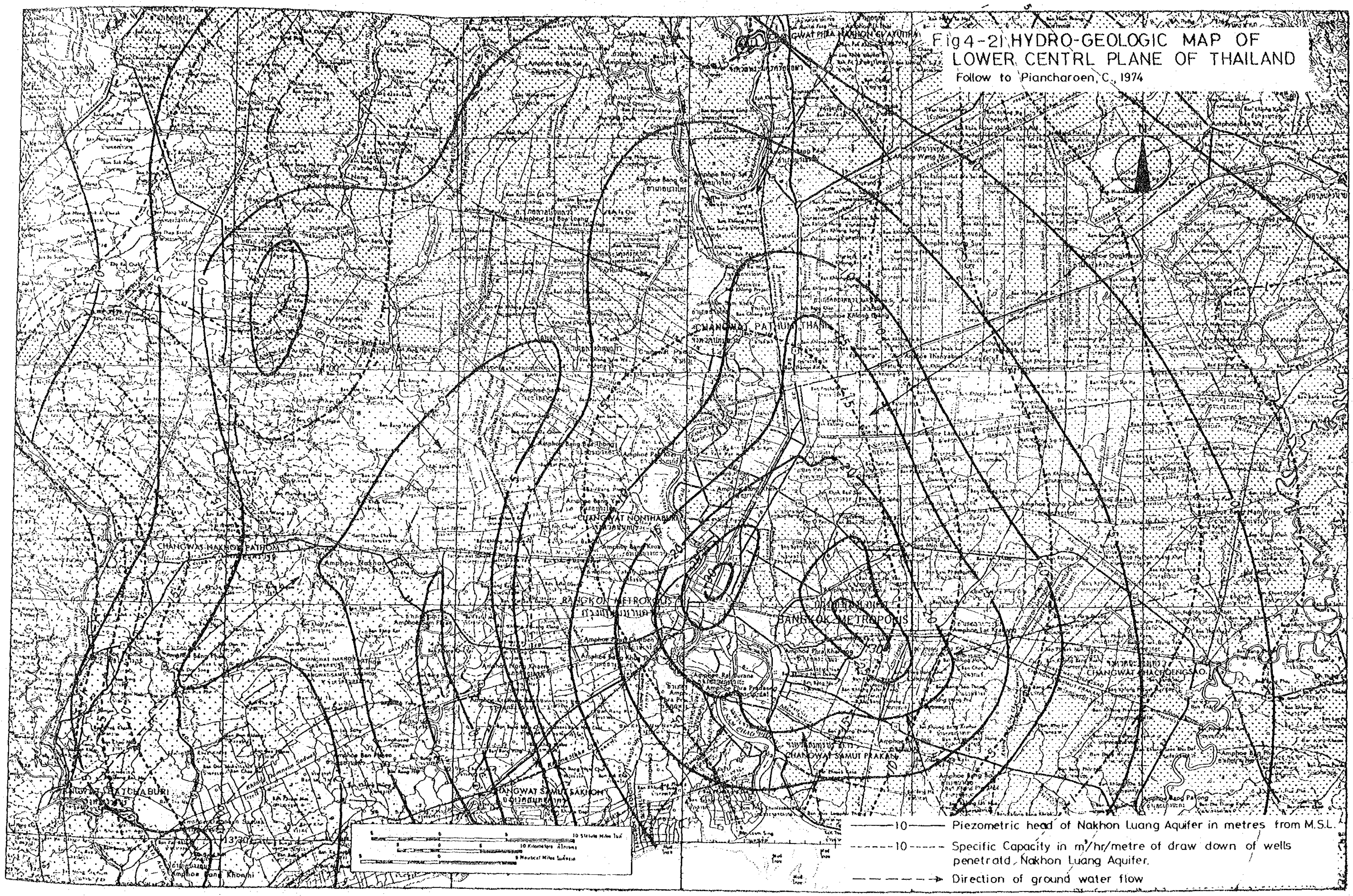


Fig 4-21 HYDRO-GEOLOGIC MAP OF LOWER CENTRL PLANE OF THAILAND
Follow to Piancharoen, C., 1974
——10—— Piezometric head of Nakhon Luang Aquifer in metres from M.S.L.
------10----- Specific Capacity in m³/hr/metre of draw down of wells penetratd, Nakhon Luang Aquifer.
- - - - - - → Direction of ground water flow
CHANGWAT PATHUM THANI
CHANGWAT NONTHABURI
CHANGWAT NAKHON PATHOM
BANGKOK METROPOLIS
CHANGWAT SAMUT PRAKAN
CHANGWAT SAMUT SAKHON
CHANGWAT CHACHOENGSAO
CHANGWAT RATCHABURI

Fig. 4-22 COEFFICIENT OF TRANSMISSIBILITY AND STORAGE

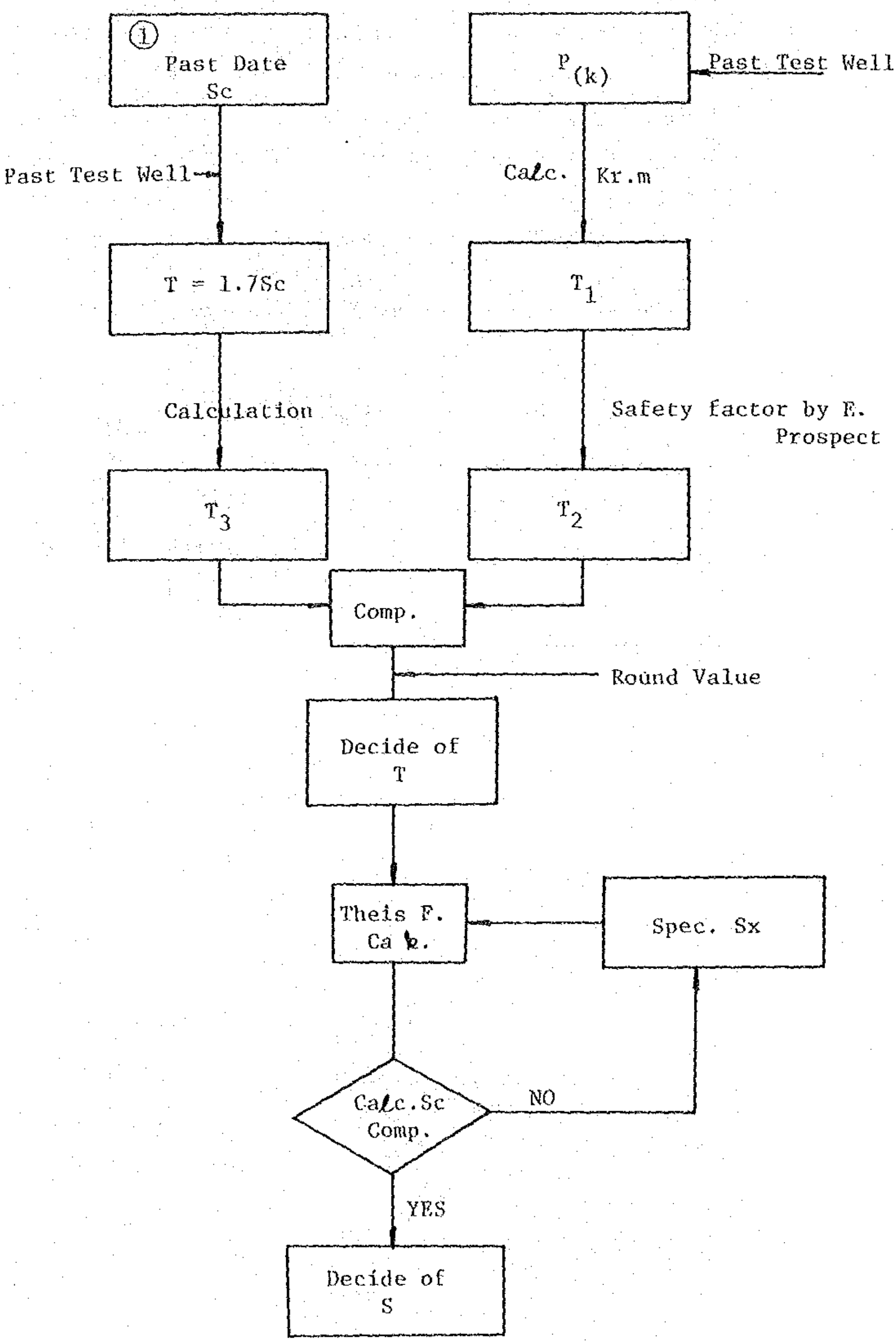


Table 4-7 FINAL VALUE OF TRANSMISSIBILITY

Sai Noi	20 $m^3/hr/m$
Bang Bua Thong	20 "
Bang Yai	20 "
Nong Chok	10 "
Min Buri	20 "
Lat Krabang	15 "
Bang Phli	15 "
Bang Bo	15 "

Table 4-8 COEFFICIENT OF STORAGE

$T = 10\ m^3/hr/m$	$S = 1 \times 10^{-3}$
$T = 15\ m^3/hr/m$	$S = 5 \times 10^{-4}$
$T = 20\ m^3/hr/m$	$S = 1 \times 10^{-4}$

4-1-5 Quality of Groundwater :

The location of 18 sampling wells and analysis results of them collected during the survey are shown in Fig. 4-23 and Table 4-9. The groundwater in the area adjacent to Bangkok is said to have been becoming saline water in recent years. Since the plan to use groundwater as a source of potable water may be influenced by the salinification of groundwater, the quality of groundwater was examined from a geochemical point of view and the mechanism of salinification was investigated on the bais of analysis results of the 18 water samples.

Fig 4-23 LOCATION MAP OF SAMPLING WELLS

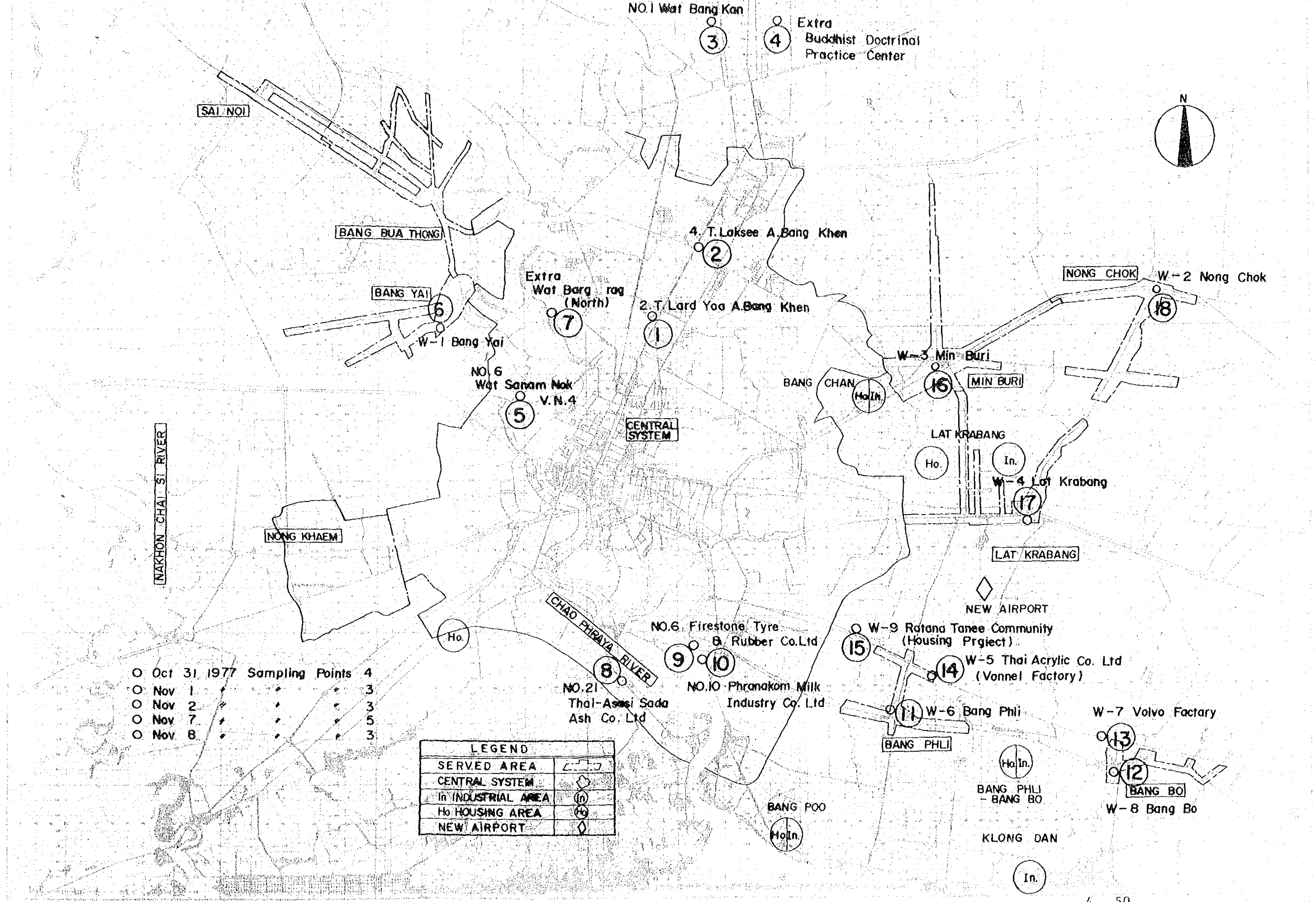


Table 4-9 RESULTS OF CHEMICAL TEST (1)

No. / Item	1 Bang Khen	2 Bang Khen	3 Klong Luang	4 Klong Luang	5 Bang Kruai	6 Bang Yai	7 Muang, Nonthaburi
	NON-aqf	NON-aqf	NAK-aqf	NAK-aqf	NAK-aqf	NON aqf	NON-aqf
Color	nil	nil	nil	nil	nil	nil	nil
Odor	nil	nil	nil	nil	nil	nil	nil
Turbidity	0.29	24.0	0.25	2.7	0.9	7.2	3.5
pH	7.4	6.95	7.42	7.5	7.32	7.10	6.95
Methyl Orange Alkalinity	324	258	386	358	294	250	280
Phenolphthalein Alkalinity	nil	nil	nil	nil	nil	nil	nil
Total Solids	400	2,650	480	500	372	366	335
Dissolved Solids	290	1,450	370	380	300	285	265
Total Hardness	70	1,150	108	82	106	146	124
Carbonate Hardness	70	258	108	82	106	146	124
Non-Carbonate Hardness	nil	892	nil	nil	nil	nil	nil
Cℓ	3	740	6	13	22.0	40.0	9
SO_4	85.2	493.3	76.7	102.2	147.5	144.7	153.2
NO_2	0.0042	0.0040	0.0060	0.0060	trace	trace	trace
NO_3	nil	nil	nil	nil	nil	nil	nil
Ca	20.0	312.0	28.8	20.8	27.2	39.2	23.2
PO_4	0.18	0.40	0.05	0.03	0.10	0.08	0.04
Fe	nil	1.90	nil	0.21	2.92	0.65	0.31
Mn	trace	2,414	trace	nil	0.151	0.302	0.244
Mg	4.80	88.80	8.64	7.20	9.21	11.52	15.84
Free Carbon Dioxide	40.0	81.0	25.0	21.0	30.0	72.0	44.0
Na	148.0	1,725.0	155.0	175.0	157.0	140.0	122.0
K	8.0	21.0	7.0	5.0	8.0	9.0	8.0
E.C.	710	3,370	864	897	750.0	730	650

NOTE : NON-aqf : Nonthaburi Aquifer
NAK-aqf : Nakhon Luang Aquifer
PRA-aqf : Phra Pradaeng Aquifer
BKK-aqf : Bangkok Aquifer

RESULTS OF CHEMICAL TEST (2)

Item \ No.	8 Tai-Asahi Soda	9 Firestone Type	10 Phranakorn Milk Industry	11 Bang Phli	12 Bang Bo	13 Bang Bo	14 Bang Phli
	BKK-aqf	PRA-aqf	PRA-aqf	PRA-aqf	NAK-aqf	PRA-aqf	NAK-aqf
Color	nil	nil	nil	nil	nil	nil	nil
Odor	nil	nil	nil	nil	muddy	nil	nil
Turbidity	7.0	4.4	8.3	0.33	1.0	0.27	0.18
pH	7.82	7.8	7.61	7.49	7.45	7.50	7.50
Methyl Orange Alkalinity	226	300	292	332	302	350	302
Phenolphthalein Alkalinity	nil	nil	nil	nil	nil	nil	nil
Total Solids	1,065	460	410	605	882	510	500
Dissolved Solids	890	380	355	510	770	440	390
Total Hardness	348	116	94	166	224	74	102
Carbonate Hardness	226	116	94	166	224	74	102
Non-Carbonate Hardness	122	nil	nil	nil	nil	nil	nil
Cℓ	415	65	54	128	310	57	46
SO_4	73.8	62.5	59.6	71.0	105.1	68.0	102.2
NO_2	0.02	0.0064	0.0024	trace	0.0034	0.0012	trace
NO_3	-	-	-	-	-	-	-
Ca	52.0	24.0	21.6	50.4	62.2	24.0	31.2
PO_4	0.02	0.10	0.01	0.03	0.02	0.01	0.01
Fe	1.37	0.36	0.90	nil	nil	nil	nil
Mn	0.444	0.198	0.160	0.151	0.01	nil	0.066
Mg	52.32	13.44	9.60	9.60	18.24	3.36	5.76
Free Carbon Dioxide	60.0	24.0	42.0	32.0	13.0	18.0	27.0
Na	435.0	196.0	186.0	290.0	430.0	260.0	215.0
K	19.0	7.0	9.0	8.0	9.0	6.0	4.0
E.C.	2,020.0	905.0	825.0	1,225.0	1,920.0	1,045.0	950.0

NOTE : NON-aqf : Nonthaburi Aquifer
NAK-aqf : Nakhon Luang Aquifer
PRA-aqf : Phra Pradaeng Aquifer
BKK-aqf : Bangkok Aquifer

RESULTS OF CHEMICAL TEST (3)

Item \ No.	15 Ratana Tanee Community Housing Project	16 Min Buri	17 Lat Krabang	18 Non Chok	WHO Standard
	PRA-aqf	NAK-aqf	NAK-aqf	PRA-aqf	
Color	nil	nil	nil	nil	-
Odor	nil	nil	nil	nil	-
Turbidity	0.15	0.26	0.18	0.57	-
pH	7.40	7.82	7.7	7.90	7.0 - 8.5
Methyl Orange Alkalinity	424	360	376	276	-
Phenolphthalein Alkalinity	nil	nil	nil	nil	-
Total Solids	724	510	485	850	100 - 500 ppm
Dissolved Solids	655	390	390	710	-
Total Hardness	180	94	80	34	-
Carbonate Hardness	180	94	80	34	-
Non-Carbonate Hardness	nil	nil	nil	nil	-
Cℓ	234	24	14	160	200 ppm
SO_4	54.0	93.7	102.2	130.6	200 ppm
NO_2	0.0066	-	-	-	
NO_3	-	-	-	-	40 ppm
Ca	54.6	29.6	24.8	12.0	75 ppm
PO_4	0.02	0.01	0.01	nil	-
Fe	nil	nil	nil	0.17	0.3 ppm
Mn	0.188	0.151	trace	nil	0.1 ppm
Mg	12.48	4.80	4.32	3.36	50 ppm
Free Carbon Dioxide	35.0	26.0	18.0	22.0	-
Na	340.0	155	140	285	-
K	12.0	4.0	4.0	3.0	-
E.C.	1,545.0	1,000.0	810.0	1,685.0	-

NOTE : NON-aqf : Nonthaburi Aquifer
NAK-aqf : Nakhon Luang Aquifer
PRA-aqf : Phra Pradaeng Aquifer
BKK-aqf : Bangkok Aquifer

(1) Discussion on Salinification of Groundwater :

1) Classification of Groundwater :

Pure water is a compound of hydrogen and oxygen, but water in such a pure form does not exist in the natural world. Substance floating in the air gets dissolved in rain, and surface water contains a large variety of substance on the ground surface. Groundwater is recharged in the aquifer, as surface water containing such impurities returns to the aquifer. Furthermore, surface water collects many other impurities as it flows through the aerated zone and aquifer before it reaches the surface of groundwater.

When the assumption is made that the cations of the main constituents (e.g., Na, Ca, Mg and K) of impurities dissolved in groundwater are in chemical equilibrium with the anions (e.g., SO_4, $C\ell$, HCO_3 and CO_3), groundwater can be classified into four types as follows:

i) $Ca(HCO_3)_2$ type.

ii) $NaHCO_3$ type

iii) $CaSO_4$ or $CaC\ell_2$ type

iv) Na_2SO_4 or $NaC\ell$ type

i) and ii) Groups of Groundwater :

Fresh water is generally of the $Ca(HCO_3)_2$ type, but groundwater may be either of the $Ca(HCO_3)_2$ type or of the $NaHCO_3$ type. Groundwater of type i) is generally at a shallow depth, while type ii) is at a deep depth. When the mechanism of recharge and flow of groundwater is considered, the following three stages can be considered to explain the process in which the composition of dissolved substance changes as surface water transforms itself into unconfined groundwater to confined groundwater.

① Oxidation → Reduction

② Rendering

③ Ion exchange

In the stage of ① the dissolved oxygen is consumed in the decomposition of organic matter which takes place as ground flows in the aquifer. As the confined groundwater does not come into contact with air, it is exposed to a reducing atmosphere. As a result, chemical components undergo the following changes:

a. Dissolved oxygen decreases.

b. Fe^{2+} increases.

c. SO_4^{2-} decreases.

d. As a result of nitrogen fixation by micro-organisms, NO_3^-, which has increased in the presence of a lot of dissolved oxygen, is reduced to NH_4 through the following process:

$$NO_3^- \rightarrow NO_2^- \rightarrow NH_2OH \rightarrow NH_4$$

e. As a result of anaerobic methane fermentation, dissolved methane is produced.

In the stage of ② the following changes take place as groundwater comes into contact with the aquifer and aquiclude:

a. All kinds of cations increase.

b. HCO_3^- increases; that is, [HCO_3/all anions] increase, while[$C\ell^{-1}$/all anions] decrease.

Stage ③ represents a chemical process in which ions attached to the molecular structure of an insoluble substance exchange with ions present in a surrounding solution. The ion exchangers undergo exchange with positively charged ions (cations), and ion exchange of this type is called *cation exchange or base exchange*. For example, equilibrium represented by the following equation is attained when the ion exchanger adsorbing Na^+ is exchanging ions with water containing Ca^{2+}.

$$2NaX + Ca^{2+} \rightleftarrows CaX_2 + 2Na^+$$

where, X stands for the ion exchanger.

This reaction explains the phenomenon of groundwater softening.

If water containing Na^+ in an unusually high concentration like seawater intrudes into the aquifer filled with fresh water, the reaction indicated above proceeds from right to left so that Ca^{2+} increases.

iii) Group of Groundwater :

The groundwater of this group contains mainly compounds of Ca, Mg, SO_4 and Cℓ. This groundwater occurs as permanent hardness is imparted to groundwater. Acidic waste water in the mine and volcanic water are generally of this type and fossil water may also belong to this group.

iv) Group of Groundwater :

The water of this group is seawater or the like. The groundwater in the alluvial or diluvial layer is contaminated with the seawater remaining in the soil in the littoral area. Contamination of groundwater, seawater in the littoral area may also occur as a result of a change in the hydraulic condition. Such contaminated water belongs to the NaCl type in most instances.

The classification of groundwater has been briefly discussed. Now brief mention will be made of saline water.

Saline water is classified according to the total solid content as shown in Table 4-10.

Saline water can occur underground in the following conditions:

① Saline water gathered during the formation of the layer remains trapped in it.

② Salts are leached out of soil of the layer itself or the neighboring layer into the groundwater.

③ The layer is exposed to seawater or other source of salt after formation of the layer.

Table 4-10 RELATION OF SALINE WATER AND TOTAL SOLID

	Total Solid	Electrical Conductivity
Fresh Water	< 100 ppm	1,400 μʊ/cm
Low Saline Water	100 - 1,000	1,000 - 4,000
Middle "	1,000 - 10,000	4,000 - 14,000
High "	10,000 - 17,000	14,000 - 50,000
Sea Water	> 17,000	> 50,000

2) Discussion on Salinification

i) General

① The total concentration of dissolved ions in the 18 samples of groundwater was compared by measuring their electric conductivity.

When the electric conductivity of ground water was compared among the samples, using the value of 1,400 μ℧/cm obtained with low saline water as the reference level, five samples were exceeding the reference level, as shown following (Refer to Table 4-10).

No. 2	3,370 μ℧/cm
No. 8	2,020 μ℧/cm
No. 12	1,920 μ℧/cm
No. 15	1,545 μ℧/cm
No. 18	1,685 μ℧/cm

Other samples showed electric conductivity which value was lower than 1,400μ /cm. Needless to say, the five samples showed a high value of total solid content, furnishing evidence to indicate high electric conductivity. (Refer to Table 4-12).

② When the salinity range of $0.5 < C\ell/HCO_3 + CO_3 < 1.3$ (Refer to Table 4-11) obtained with ground water slightly contaminated with seawater was taken as the reference, four samples fell within this range (Refer to Table 4-13), as follows:

Table 4-11 DEGREE OF SALINE WATER

	Degree of Saline Water
$0.5 > C\ell/CO_3 + HCO_3$	Not Contaminated with Saline Water
0.5 < " < 1.3	Low degree Saline Water
1.3 < " < 2.8	Midium degree Saline Water
2.8 < " < 6.6	High degree Saline Water
6.6 < " < 15.5	Heavy degree Saline Water
15.5 < " < 200±	Sea Water

Table 4-12 SUMMARY OF WATER QUALITY

Item / No.	District	Aquifer	Pumping Capacity	Electrical Conductivity	Turbidity	Total-Solids	Dissolved Solids
1	Bang Khen	NON-aqf	33.3 [m^3/h]	710 [$\mu\upsilon$/cm]	0.29 [ppm]	400 [ppm]	290 [ppm]
2	Bang Khen	NON-aqf	20	3,370	24.0	2,650	1,450
3	Klong Luang	NAK-aqf	0.4	864	0.25	480	370
4	Klong Luang	NAK-aqf	12.4	897	2.7	500	380
5	Bang Kruai	NAK-aqf	5	750	0.9	372	300
6	Bang Yai	NON-aqf	20	730	7.2	366	285
7	Muang Nonthaburi	NON-aqf	354	650	3.5	335	265
8	Tai-Asahi Soda Ash Co. Ltd.	BKK-aqf	55 - 60	2,020	7.0	1,065	890
9	Firestone Type & Rubber Co. Ltd.	PRA-aqf	81.9	905	4.4	460	380
10	Phranakorn Milk Industry Co. Ltd.	PRA-aqf	41.7	825	8.3	410	355
11	Bang Phli	PRA-aqf	-	1,225	0.33	605	510
12	Bang Bo	NAK-aqf	-	1,920	1.0	882	770
13	Bang Bo	PRA-aqf	-	1,045	0.27	510	440
14	Bang Phli	NAK-aqf	-	950	0.18	500	390
15	Ratana Tanee Community Housing Project	PRA-aqf	-	1,545	0.15	742	655
16	Min Buri	NAK-aqf	-	1,000	0.26	510	390
17	Lat Krabang	NAK-aqf	-	810	0.18	485	390
18	Nong Chok	PRA-aqf	-	1,685	0.57	850	710

Table 4-13 COMPARISON OF ION CONTENT

[meq]

Aquifer	No.	Cℓ [meq]	Cℓ/HCO_3 + CO_3	SO_4/Total Anion
Bangkok	8	11.69	0.89	0.06
Phra Pradaeng	9	1.83	0.23	0.12
	10	1.52	0.20	0.12
	11	3.61	0.33	0.09
	12	8.73	0.69	0.09
	13	1.61	0.16	0.11
	14	1.30	0.16	0.19
	15	6.59	0.59	0.06
	18	4.51	0.74	0.20
Nakhon Luang	3	0.17	0.02	0.18
	4	0.37	0.05	0.23
	5	0.62	0.11	0.34
	16	0.68	0.11	0.22
	17	0.39	0.07	0.27
Nonthaburi	1	0.08	0.01	0.22
	2	20.85	0.30	0.09
	6	1.13	0.22	0.33
	7	0.25	0.06	0.40

③ The key diagram of the 18 water samples was drawn. As a result, the 18 water samples could be classed into two groups as follows. (Refer to Fig. 4-24):

a. $NaHCO_3$ Type;

Nos. 1, 2, 3, 4, 5, 6, 7, 9, 10, 11, 12, 13, 14, 15, 16, 17

b. Na_2SO_4 or $NaC\ell$ Type;

Nos. 8, 18

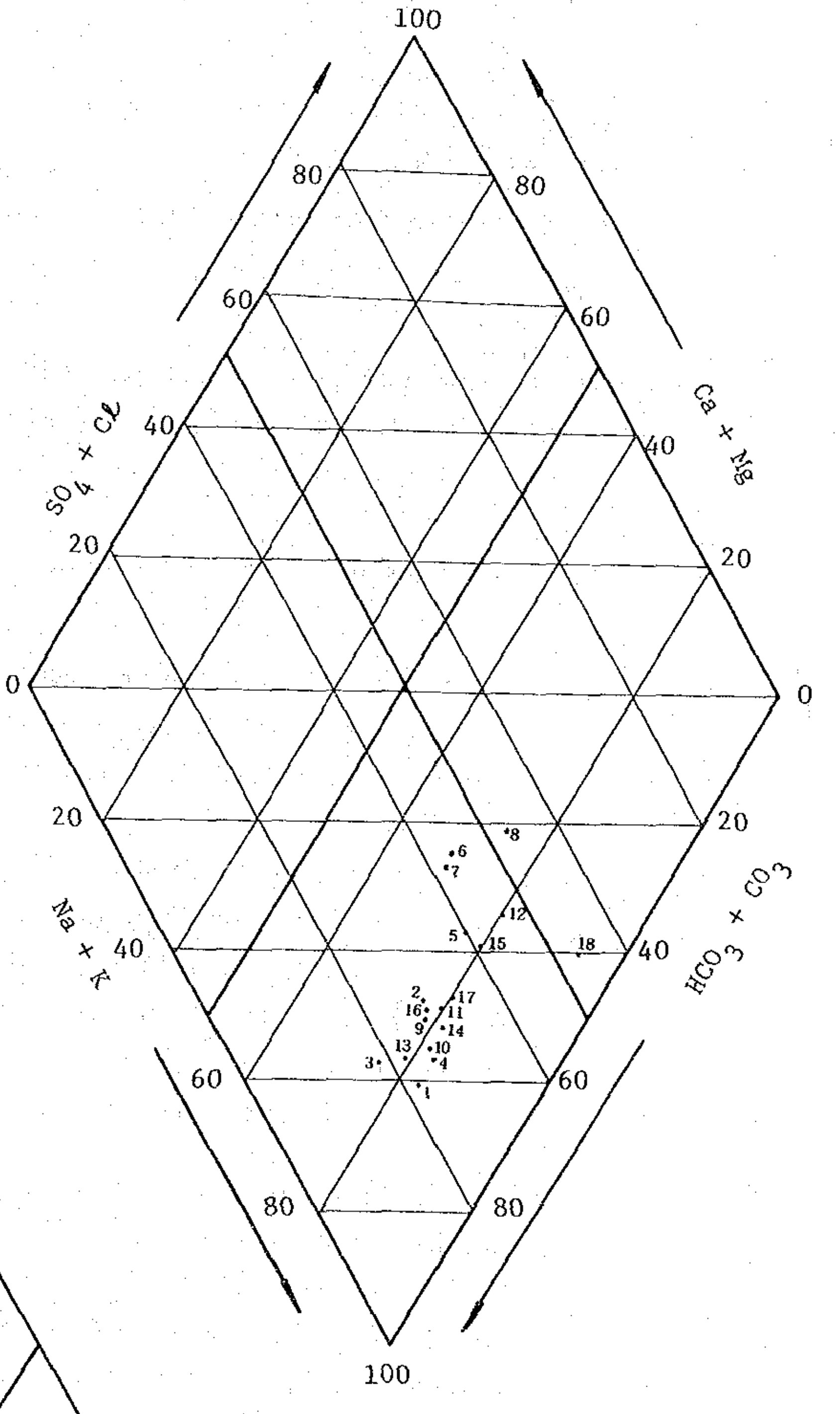
The inference may be made from the above results that No. 8 and No. 18 water samples are seawater or the like, while other water samples are confined as fresh water. As is clear from the key diagram in Fig. 4-24, however, Nos. 5, 6, 7, 8, 12, 15 and 18 water samples seem intermediates between seawater and fresh water.

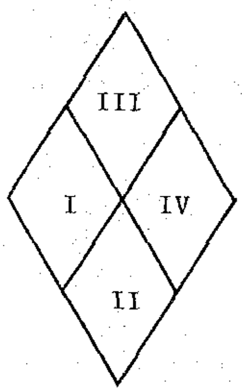
Be that as it may, the 18 water samples belong to the $NaHCO_3$ type or Na_2SO_4 or $NaC\ell$ type. It is obvious that Na ions are present in these water samples in greater more abundance than other cations.

Judging from ① the value of electric conductivity, ② the tendency toward salinification, and ③ the key diagram, Nos. 8, 12, 15 and 18 water samples seem to indicate a problem of salinification.

The ions contained in the 18 samples will be discussed with a view to clarifying the cause of salinification. For purposes of comparison, No. 2 sample, which showed an unusually high value of electric conductivity, will be discussed likewise.

Fig. 4-24 KEY - DIAGRAM





I : $Ca\ (HCO_3)_2$ Type

II : $NaHCO_3$ Type

III : $CaSO_4$ or $CaC\ell_2$ Type

IV : Na_2SO_4 or $NaC\ell$ Type

ii) Causes of Salinification:

Groundwater can be salinified for reasons as follows:

① Contamination of groundwater with fossil seawater.

② Salinification of groundwater resulting from the intrusion of seawater into the aquifer.

③ Salinification of groundwater resulting from the leaching of salts out of the soil of the layer.

① Contamination of groundwater with fossil seawater:

The salinification of groundwater cannot be discussed in detail on the basis of the existing data alone. However, in general, fossil seawater contains chloride ions in the highest concentration of all anions and contains SO_4 in a low concentration as it is in a reducing atmosphere. The $SO_4/C\ell$ ratio is said to be almost zero, while the corresponding value of seawater is on the order of 0.14 approximately.

The $SO_4/C\ell$ ratio of the 18 water samples ranged from 0.13 to 22.25. The samples which showed a tendency toward salinification showed the following $SO_4/C\ell$ ratios (Refer to Table 4-14).

No. 2	0.40
No. 8	0.13
No. 12	0.25

No. 15	0.17
No. 18	0.60

In the case of these water samples, it is difficult to assign fossil seawater as the cause of salinification.

Table 4-14 ION COMPOSITION

[meq]

Item / No.	Na	K	Ca	Mg	Cℓ	SO_4	HCO_3+CO_3
1	6.43	0.20	1.00	0.40	0.08	1.78	6.17
2	75.0	0.54	15.57	7.31	20.85	8.40	69.17
3	6.74	0.18	1.40	0.71	0.17	1.60	7.26
4	7.60	0.13	1.04	0.59	0.37	2.13	6.86
5	6.83	0.20	1.36	0.75	0.62	3.07	5.45
6	6.09	0.23	1.96	0.95	1.13	3.01	5.09
7	5.30	0.20	1.16	1.30	0.25	3.19	4.52
8	18.91	0.49	2.59	4.31	11.69	1.54	13.07
9	8.52	0.18	1.20	1.11	1.83	1.30	7.88
10	8.09	0.23	1.08	0.79	1.52	1.24	7.43
11	12.61	0.20	2.51	0.79	3.61	1.48	11.02
12	18.70	0.23	3.10	1.50	8.73	2.19	12.61
13	11.30	0.15	1.20	0.28	1.61	1.42	9.90
14	9.35	0.10	1.56	0.47	1.30	2.13	8.05
15	14.78	0.31	2.72	1.03	6.59	1.13	11.12
16	6.74	0.10	1.48	0.40	0.68	1.95	6.09
17	6.09	0.10	1.24	0.36	0.39	2.13	5.27
18	12.39	0.08	0.60	0.28	4.51	2.72	6.12

② Salinification Due to Intrusion of Seawater:

Groundwater can be salinified by seawater in one of two ways: 1) seawater can intrude into the layer, or 2) seawater can intrudes the aquifer through the ion exchangers contained in the aquiclude and other layer of soil.

a. Direct Intrusion of Seawater:

Assuming that the aquifer had been directly intruded by seawater, the concentrations of specific cations were plotted against the concentration of chloride ions, as shown in Figs. 4-25 through 4-28. No. 8, 12, and 15 water samples showed $SO_4/C\ell$ ratios that were suggestive of the direct intrusion of seawater, but the concentrations of cations did not show correlation with the direct intrusion of seawater; and, the concentrations of cations were generally higher.

As for Nos. 2, 8, 12, 15 and 18 water samples, which indicated a tendency toward salinification, the concentration of $C\ell$ ions was too low for the amount of Na ions, except for No. 8 water sample; assuming salinification was to be explained by the direct intrusion of seawater.

No.	Na (meq)	$C\ell$ (meq)
No. 2	75.0	20.85
No. 8	18.91	11.69
No. 12	18.70	8.73
No. 15	14.78	6.59
No. 18	12.39	4.51

The tendency toward salinification in these samples other than No. 8 cannot therefore be explained by the direct intrusion of seawater into the aquifer.

b. Intrusion of Seawater through Ion Exchangers:

Assuming that the aquifer had been intruded by seawater through ion exchangers like clay and minerals, the concentrations of specific cations were plotted against the concentration of chloride ions, as shown in Figs. 4-29 through 4-31.

When seawater intrudes the aquifer through ion exchangers, the following reaction must take place, for seawater contains Na ions in a high concentration:

$$2Na^{+} \longrightarrow Ca^{2+}$$

If the assumption held true, there should be an increase in Ca ions. The fact was, however, that none of the 18 water samples showed an increase in Ca ions. The data shown in Fig's. 4-28 through 4-31 therefore preclude the possibility of intrusion of seawater into the aquifer through ion exchangers.

Fig. 4-25 RELATION OF SO_4 AND $C\ell$

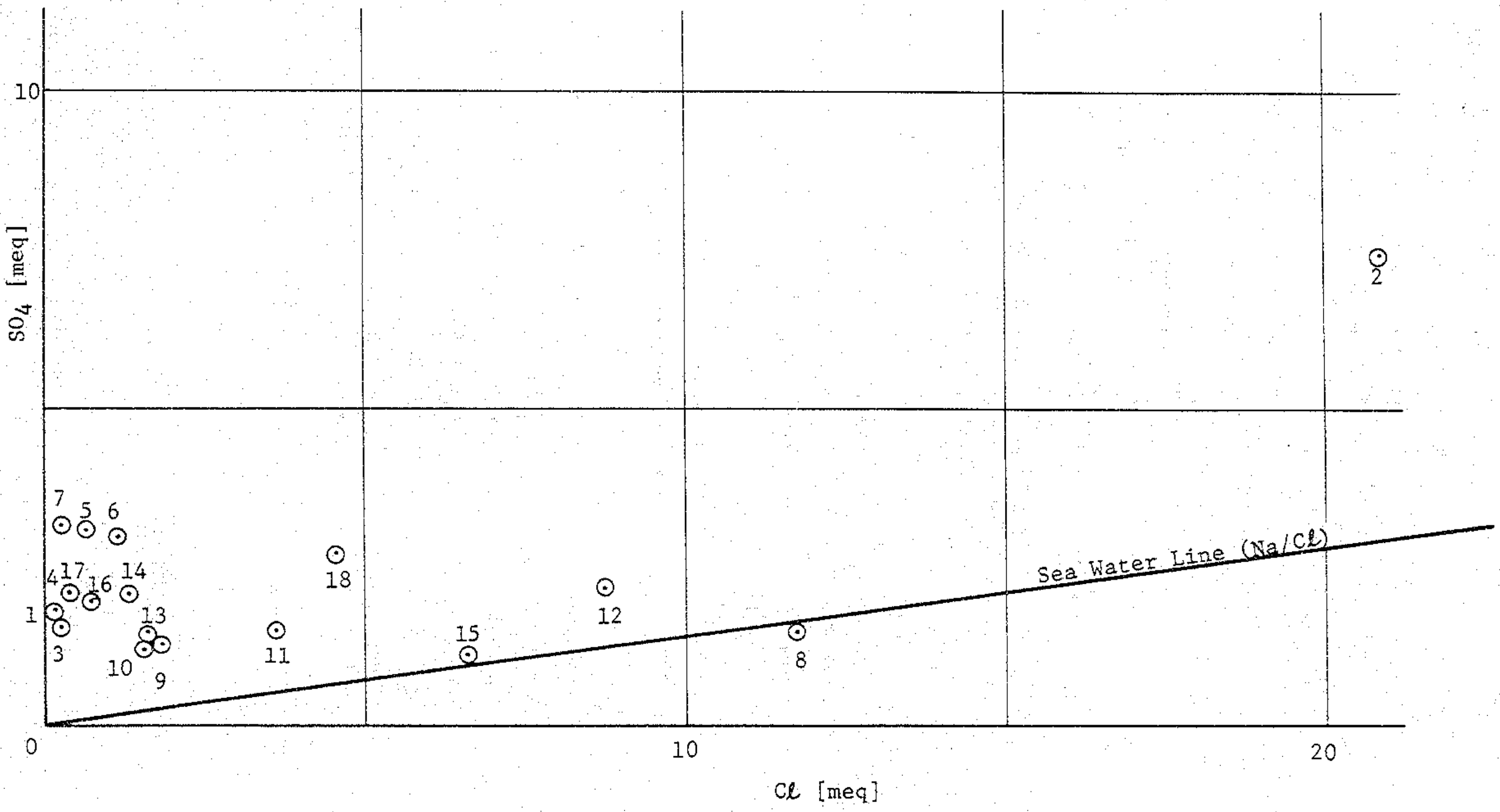


Fig. 4-26 RELATION OF Na AND Cℓ

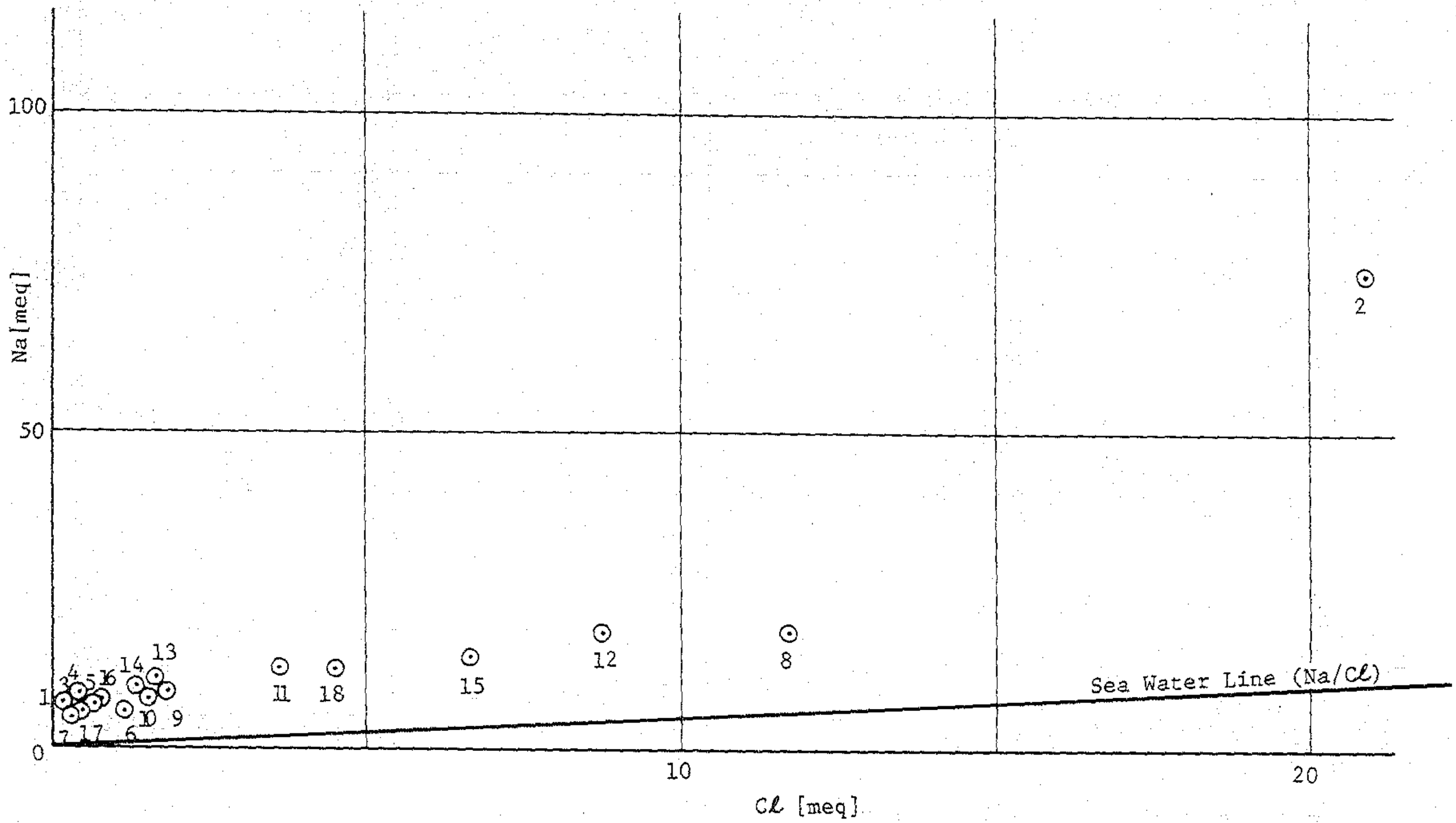


Fig. 4-27 RELATION OF Ca AND Cℓ

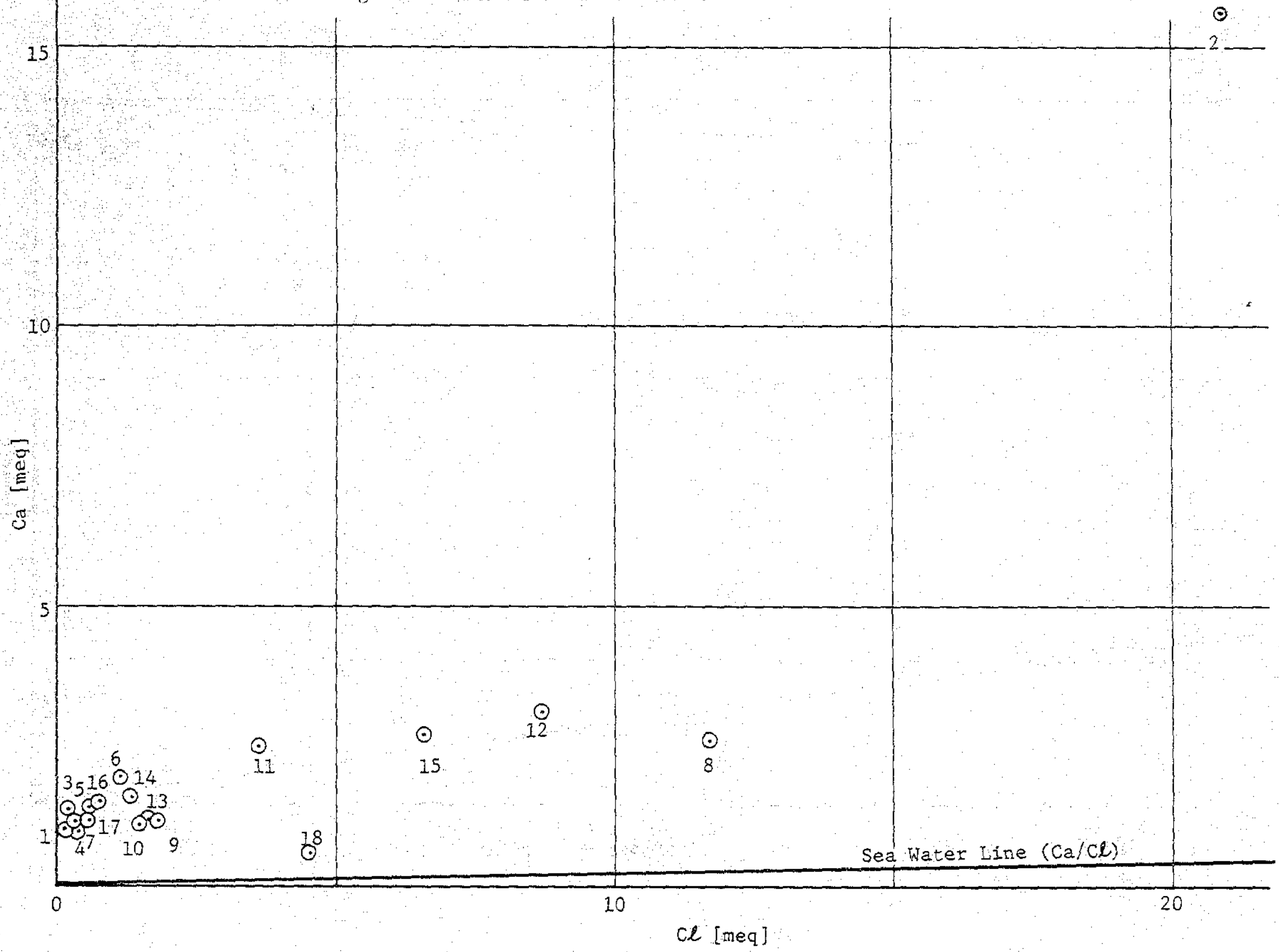


Fig. 4-28 RELATION OF Mg and Cℓ

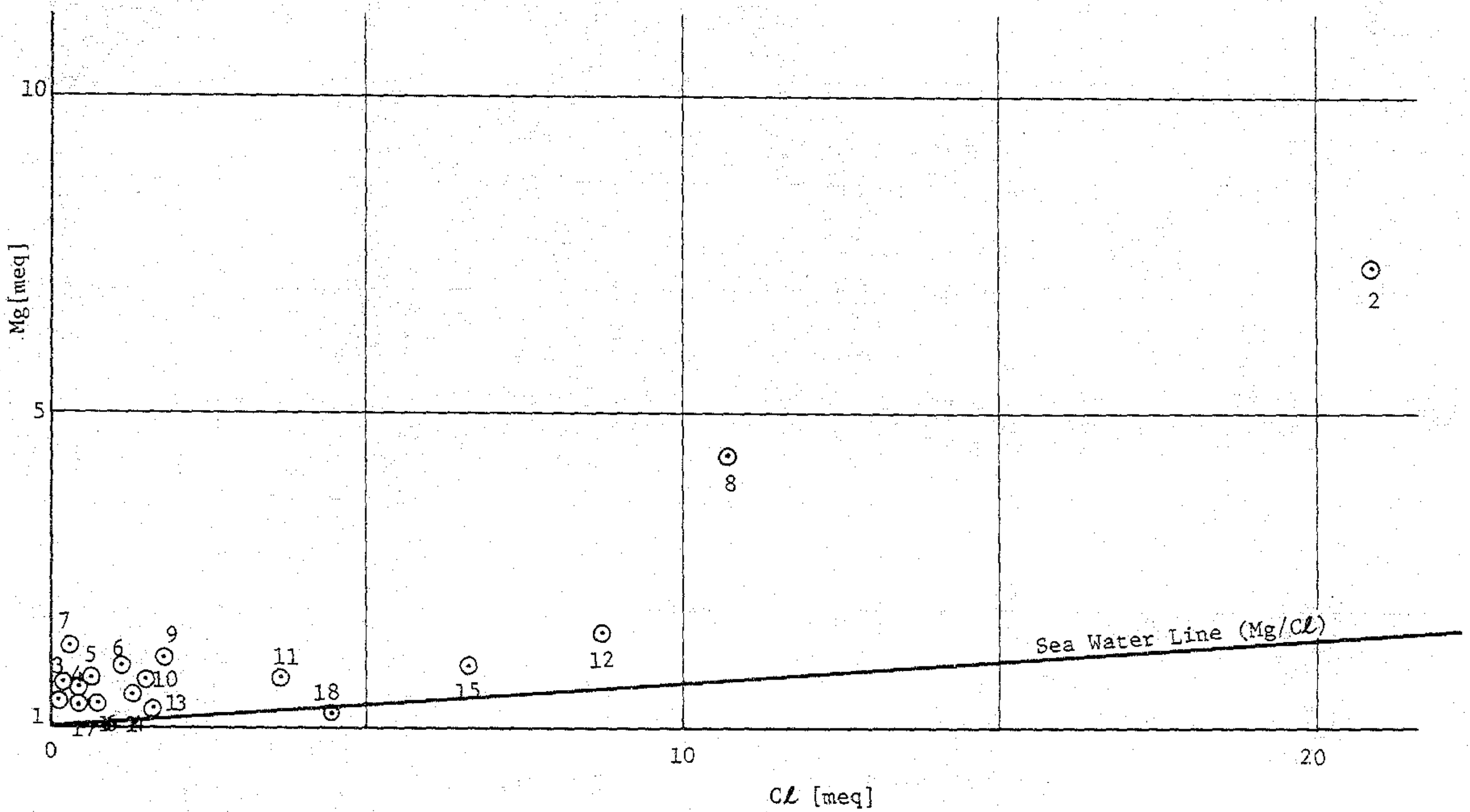


Fig. 4-29 RELATION OF Na/Cℓ AND Cℓ

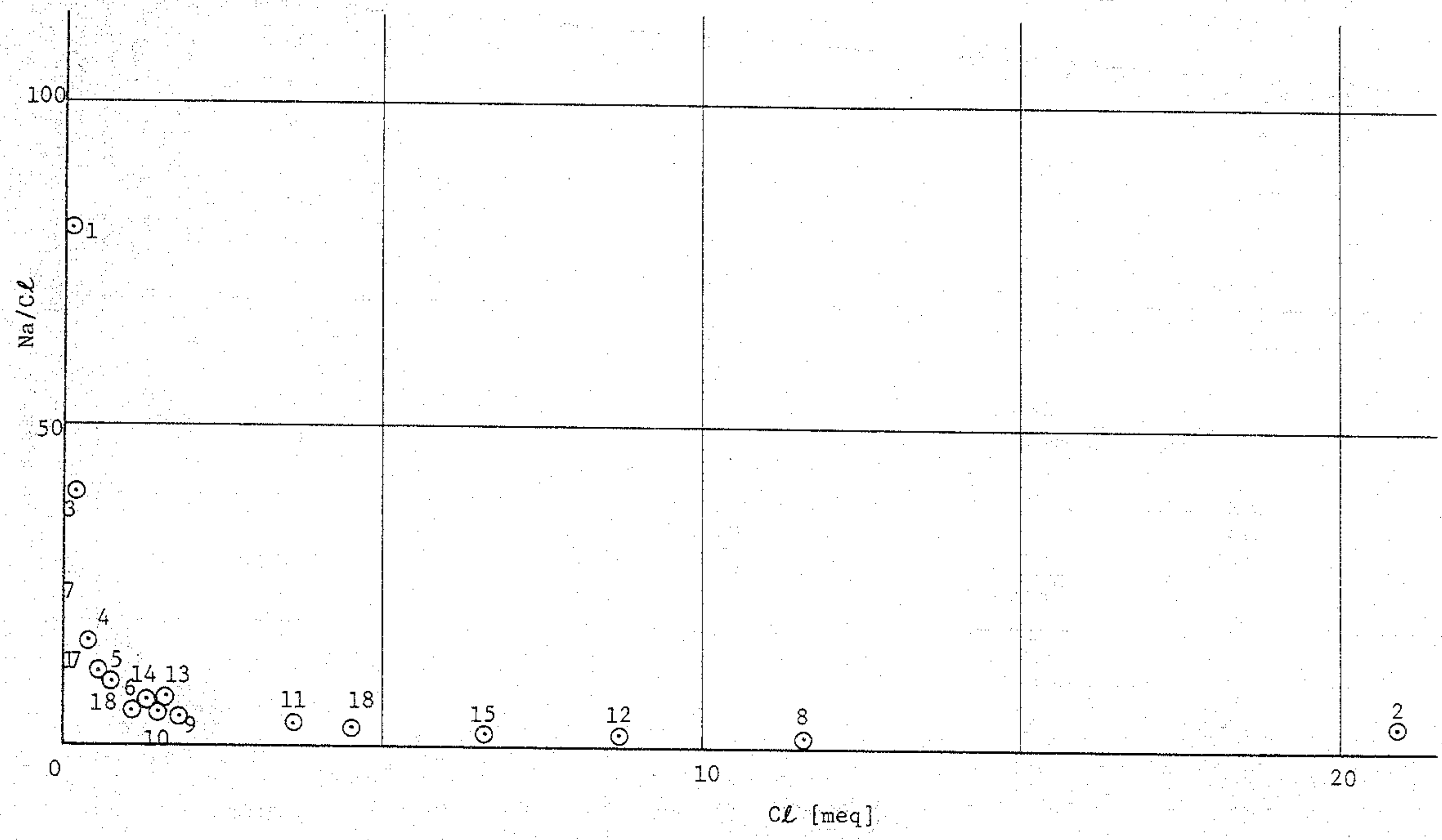


Fig. 4-30 RELATION OF Ca/Cℓ AND Cℓ

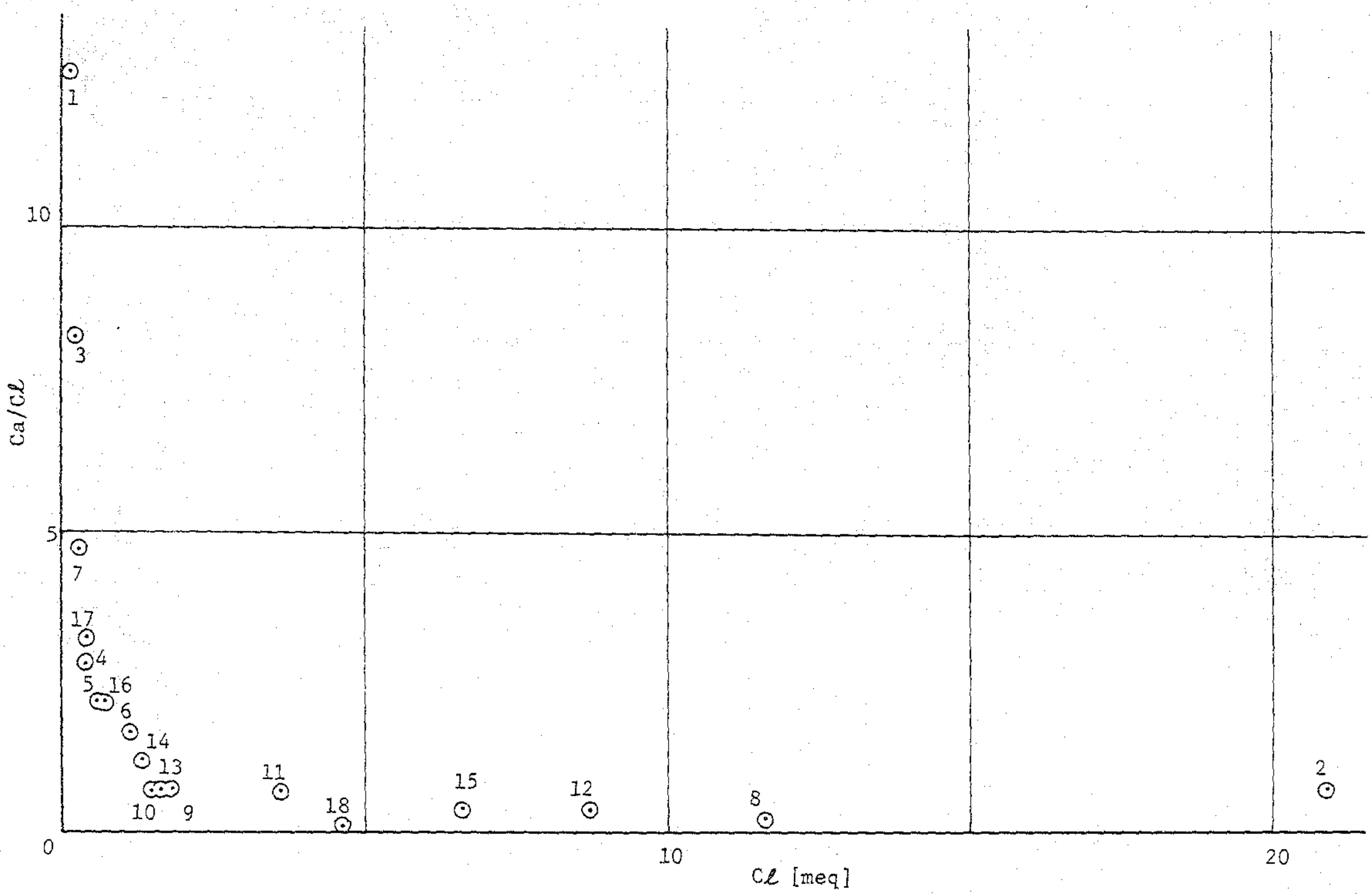
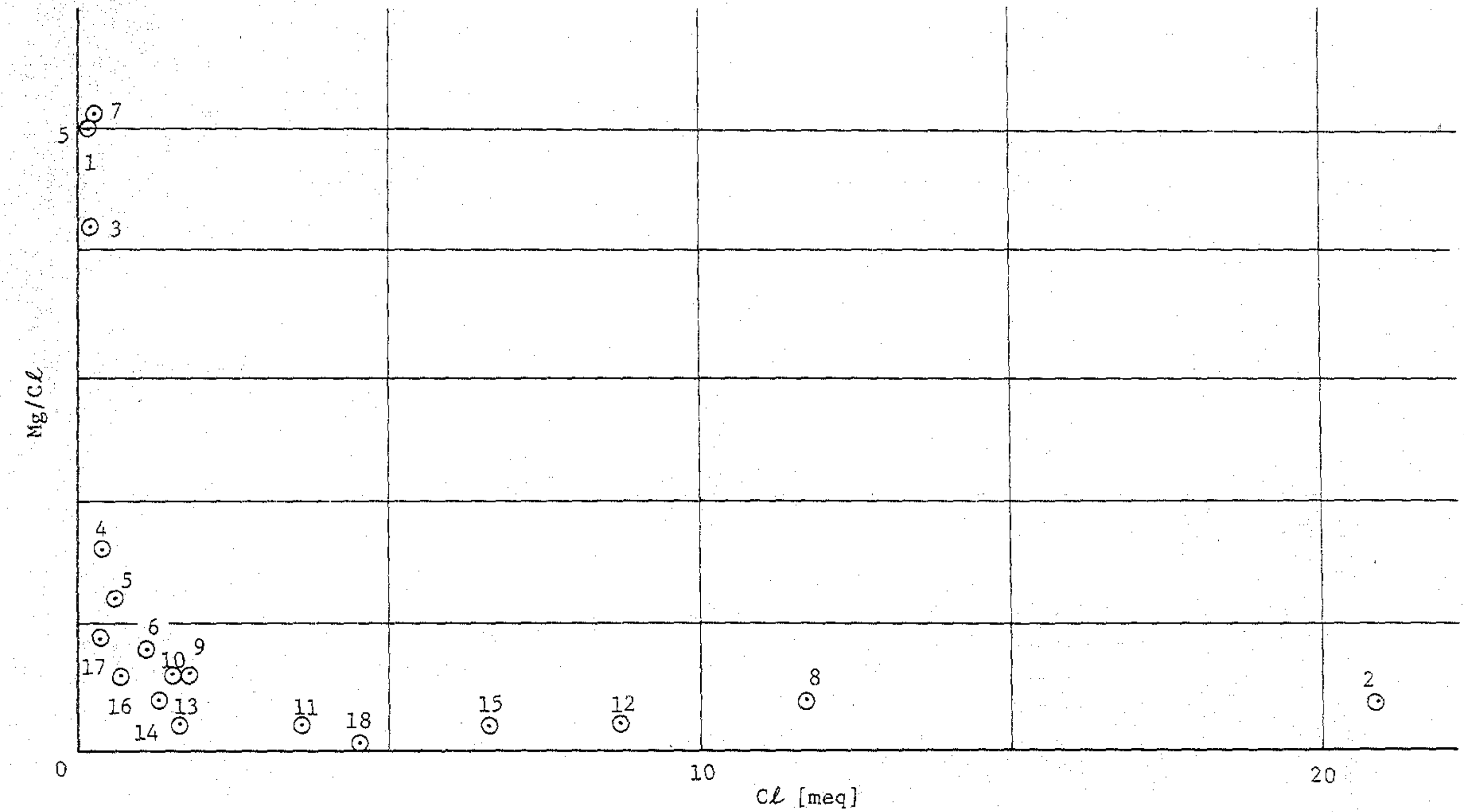


Fig. 4-31 RELATION OF Mg/Cℓ AND Cℓ



③ Salinification Due to Leaching of Salts:

Na ion was the chief cation and HCO_3 ion was the chief anion in the 18 water samples, and HCO_3 ion accounted for 50 % or more of all anions in 16 water samples, excluding No. 8 and 18. This condition can be considered to indicate softened groundwater.

The increase in Na ions was plotted against a unit increase in HCO_3 ions relative to the concentration of $C\ell$ ions in the 18 water samples, as shown in Fig.4-32 All the samples, including Nos. 2, 8, 12, 15 and 18 which showed a tendency toward salinification, were distributed along a straight line expressed by the equation $Na/C\ell = HCO_3 + CO_3/C\ell$. This phenomenon is indicative that if one HCO_3 ion is leached out of the layer into the groundwater, one Na ion is leached out into the groundwater. It may therefore be inferred from this fact that the groundwater in the area adjacent to Bangkok belongs to the $NaHCO_3$ type whose recharge is limited.

No. 2, 8, 12, 15 and 18 water samples, which showed a tendency toward salinification were indicative of a close relationship between salinification and increased ions, especially Na ion, but the $C\ell/Na$ ratio of these samples, except for No. 8, was smaller than that of seawater.

The probable cause of salinification is therefore the leaching of salts and $C\ell$ ions out of the soil of the aquifer.

In other words, the mechanism of salinification of the aquifers in the area adjacent to Bangkok can be explained more or less as follows:

During the accumulation of ion exchangers like clay they came into contact with seawater and ions are exchanged as follows:

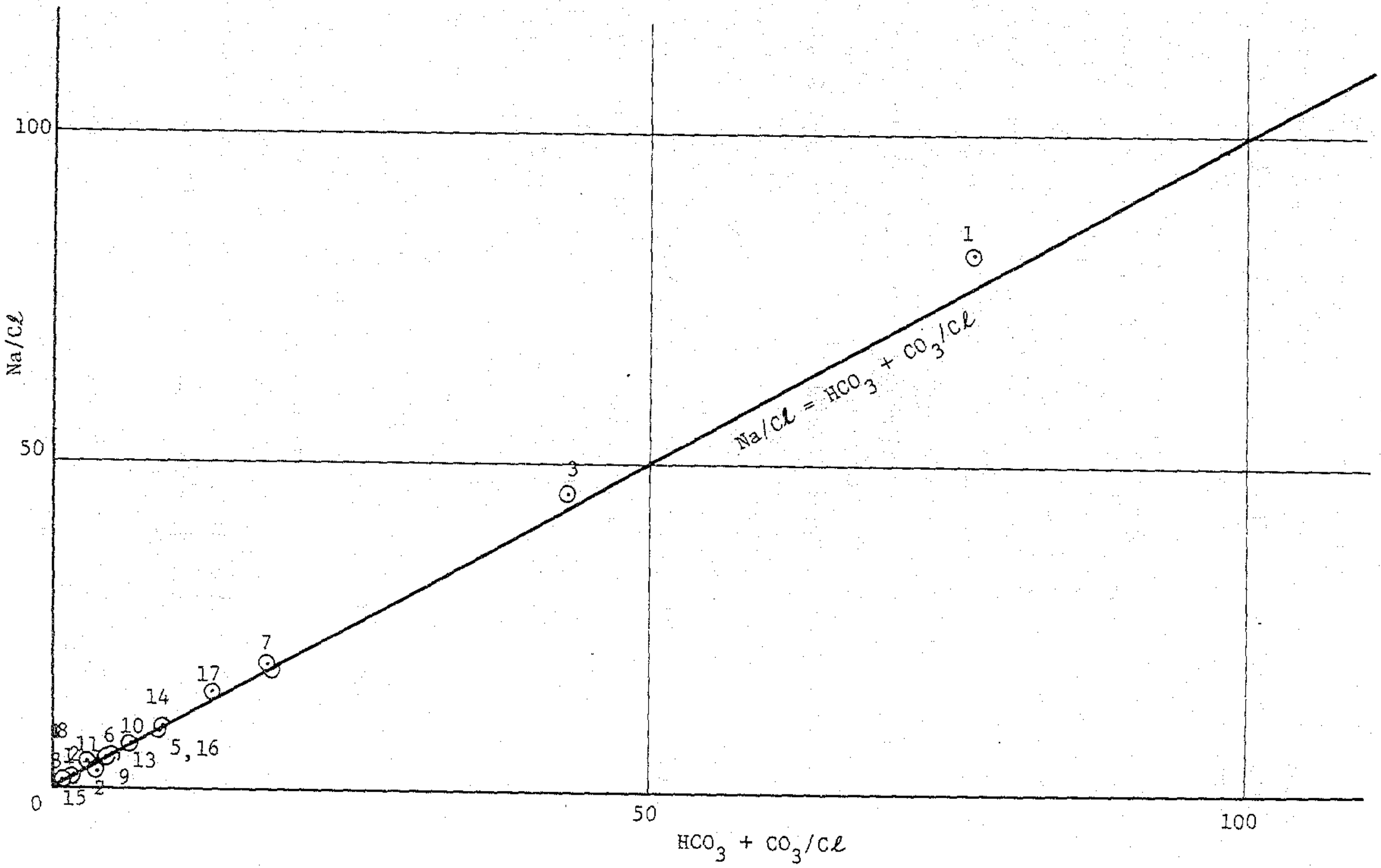
$$2Na^{+} + CaX \longrightarrow 2NaX + Ca^{2+}$$

The ion exchangers rich in Na ions like clay were accumulated, and at the same time the clay adsorbed $C\ell$ ions of seawater.

The groundwater of the area adjacent to Bangkok belongs to the $NaHCO_3$ type which contains Na and HCO_3 ions in a normal condition. When a physical force is exerted on the aquifer as in overpumping, Na ions abundantly present in the ion exchangers like clay and $C\ell$ ions adsorbed by the layer are leached out into the groundwater . In sum, the groundwater in the area adjacent to Bangkok belongs to the $NaHCO_3$ type whose recharge is limited. When the aquifer is subject to a physical force as in overpumping, $C\ell$ ions adsorbed by the layer are leached out into the groundwater, resulting in salinification.

The salinification of No. 8 water sample may be ascribable to the intrusion of seawater into the aquifer for several reasons: the water sample contains $C\ell$ ions in a higher concentration than Nos. 2, 12, 15 and 18 water samples; the $SO_4/C\ell$ ratio of this sample is similar to that of seawater; and the water sample was taken from the Bangkok aquifer located near the coast line.

Fig. 4-32 RELATION OF Na/Cℓ AND $HCO_3 + CO_3/Cℓ$



(2) Other Water Quality

Of the 18 water samples discussed above, Nos.6, 11, 12, 13, 14, 16, and 18 were taken from the proposed served area of the separate system. They would pose problems, as shown in Table 4-15, when used as drinkable water.

No. 6 water sample was taken from the existing well in Bang Yai and the well is assumed to continue in use as a water source for the separate system. No. 16 water sample was taken from the existing well in Min Buri which drews water from the Nakhon Luang aquifer which is planned to be tapped for the separate system. Nos.11, 12, 13, 14 and 18 of the samples shown in Table 4-15, were taken from the existing wells in the proposed served area of the separate system, but these wells draw water from the aquifers which are not planned to be tapped for the separate system. They will therefore be left out of consideration.

The quality of Nos.6 and 16 water samples will now be briefly discussed.

1) No. 6 Water Sample (Sampled in Bang Yai):

This water sample contains Fe ion in a concentration of 0.65 ppm, and Mn ion in a concentration of 0.302 ppm. The values of these are exceeding by accepted standards for drinking water.

The values of dissolved solids and methyl orange alkalinity are also high so that the presence of abundant HCO_3^- is suggested.

As it appears that Fe and Mn can be removed by a simple procedure like aeration or Chlorination, these minerals do not pose a serious problem when water is taken from this source for domestic use.

2) No. 16 Water Sample (Sampled in Min Buri):

The total solid content of this water sample is somewhat high (510 ppm), but its turbidity is as low as 0.26 ppm. The water from this source can be safely used as drinking water.

The quality of water samples was evaluated in relation to the drinking water standards on the basis of very limited data. The existing data on the Nakhon Luang and Nonthaburi aquifers which are planned to be tapped to supply the 8 Amphoes covered by the separate system are very scarce.

As the two aquifers are planned to be tapped as a long-term water source supplying the 8 Amphoes, it is recommended that the changes in the quality of water be determined at certain period of time in the stage of detail design of the separate system and that water treatment or any other necessary measures be planned according to the results of additional survey.

Table 4-15 SUMMARY OF POOR WATER QUALITY

No.	District	Aquifer	Depth	Poor Item
6	Bang Yai	NON-aqf	170	Turbidity, Fe, Mn
11	Bang Phli	PRA-aqf	134	Total-Solids
12	Bang Bo	NAK-aqf	160	Odor, Total-Solids, $C\ell$
13	Bang Bo	PRA-aqf	135	Total-Solids
14	Bang Phli	NAK-aqf	160	Total-Solids
16	Min Buri	NAK-aqf	160	Total-Solids
18	Nong Chok	PRA-aqf	72	Total-Solids

NOTE : NON-aqf : Nonthaburi Aquifer
NAK-aqf : Nakhon Luang Aquifer
PRA-aqf : Phra pradaeng Aquifer

4-1-6 Recharge to Aquifers

The soil profile of the metropolitan Bangkok area and its vicinity shows that there is a layer of considerable continuity, or the so-called Bangkok clay layer near the ground surface which seems to interfere with the permeation of surface water into the five aquifers underlying this clay layer.

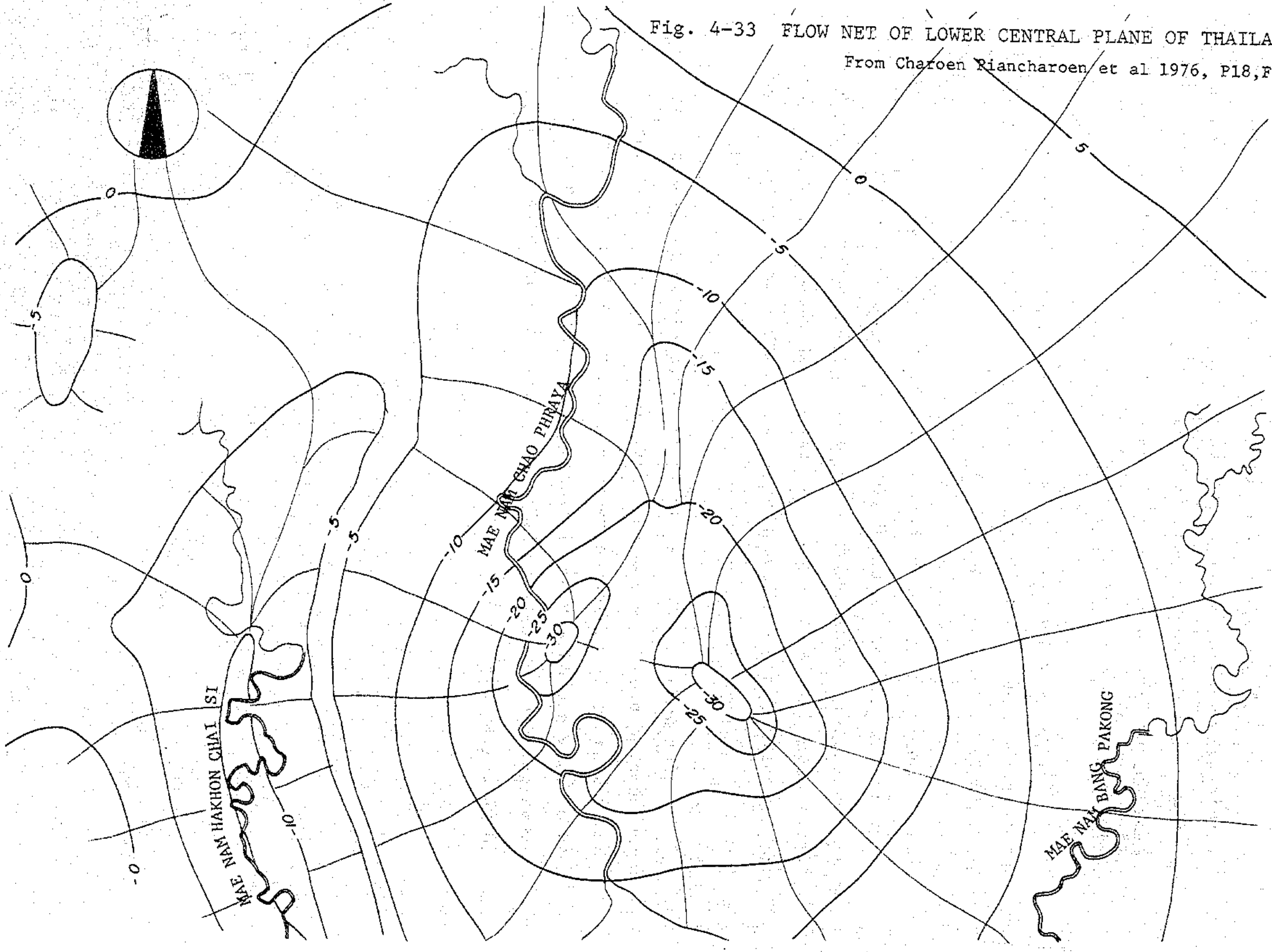
It is very important to the utilization of groundwater whether the aquifer is recharged or not or how much surface water is returned to the aquifer.

The aquifers are recharged in more than one way. In one case flow in the aquifer varies with the head consumed on the slope of the hydraulic gradient according to the law of Darcy, and in the other case where the head of the lower aquifer is lower than the upper aquifer, water flows through an impermeable layer in the form of a leak.

The heads of five aquifers in metropolitan Bangkok and its surrounding area have lowered considerably due to overpumping in Bangkok since 1958, and there is a drawdown reaching a depth of 30 m below ground surface. As a result, many flow lines of groundwater converge into central Bangkok from the surrounding area of metropolitan Bangkok (See Fig. 4-33).

Fig. 4-33 FLOW NET OF LOWER CENTRAL PLANE OF THAILAND

From Charoen Piancharoen et al 1976, P18, Fig.4



It seems quite possible that the aquifers are recharged, but the fact is that the drawdown has been widening from year to year. This fact indicates that the recharge is small as compared with the total pumpage so that the groundwater stored in the aquifers is consumed.

It is extremely difficult to say whether the aquifers can be recharged in the form of water leaks. It may be safe to say that vertical leakage of water does not occur in these aquifers, as there exists an extensive, thick and continuous impermeable layer. However, vertical leakage is theoretically possible in this case where the heads of the aquifers are consumed in large measure. Assuming that a pressure head difference is 30 m, vertical leakage at a rate of about 200 CMD/km^2 can occur through the impermeable layer having a coefficient of permiability of 5×10^{-9} m/sec even if there exists a semi-confined layer 50 m thick.

It is said that it can be known from the type of groundwater whether or not the aquifer is markedly recharged. When a key diagram was drawn by consulting the existing data (Table 4-16) collected in the first field survey, $Ca(HCO_3)_2$ type groundwater of an adequate recharge was noted in part of the area (Fig's. 4-34 and 4-35).

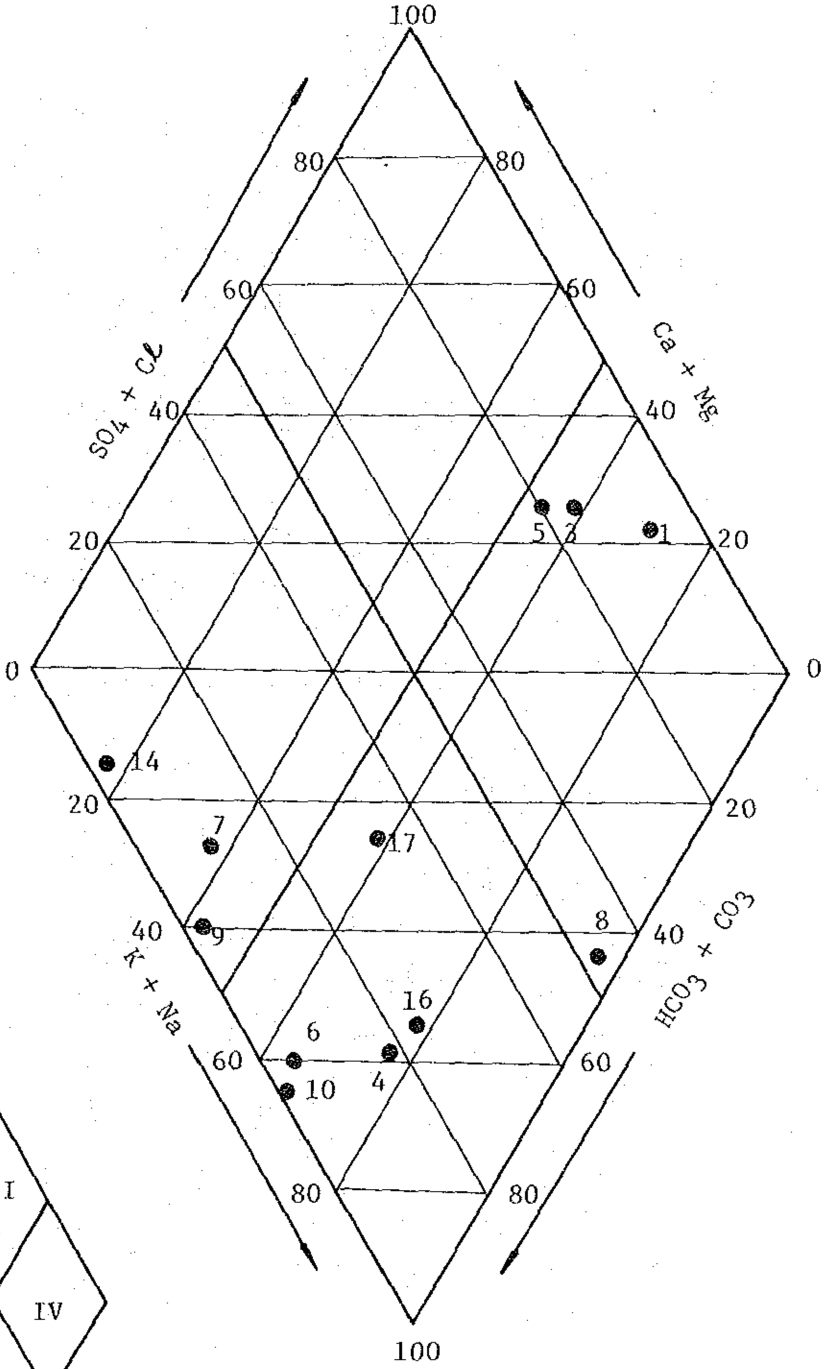
In the second field survey, however, it was revealed that all water samples belonged to the $NaHCO_3$ type of stagnant groundwater or the Na_2SO_4 or NaCl type contaminated with saline water. In this stage, this essentially precludes the possibility of recharge to the aquifer.

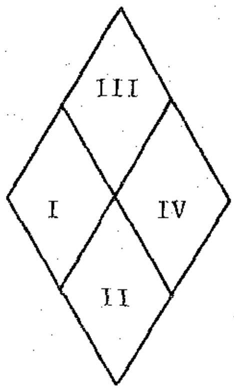
Charoen, et al, postulated in 1976 that about 6 % or 4,212 million cubic meters of annual precipitation in the low central plain was recharged to the aquifers. Nobody else has estimated the recharge in concrete terms to date. The argument as to the location of the recharge area should cover the area outside the low central plain, and the recharge area required to return as much as 4,212 million cubic meters of surface water to the aquifers is placed at 54,000 km^2. (Refer to Table 4-17). However, it is not pertinent to discuss this question in this report.

Table 4-16 CHEMICAL ANALYSES OF GROUND WATER FROM SELECTED WELLS IN BANGKOK

AQUIFER		Location Code	Depth (meters)	pH	Ca	Mg	Mn	K	Fe (Total)	Mn (Total)	Cℓ	CO_2	CO_3	NO_3	F	HCO_3	SO_4	Total Solids	Hardness as $CaCO_3$
BANGKOK	1	707473	47	7.3	308	193	1610	29	-	113	3075	28	0	0.0	0.1	350	366		1560
PHRA PRADAENG	2	670169	120	7.5	19	7.1	-	-	0.10	0.00	14	3.0	0	0.2	0.1	60	1.4	121	76
	3	698992	106	7.5	142	51	338	1.2	4.4	0.63	773	13	0	1.4	0.0	253	5.0	-	567
	4	661092	88	9.0	12	8.8	90	6.5	0.08	0.00	33	0.5	16	0.0	0.1	227	0.4	-	66
NAKHON LUANG	5	658145	152	7.2	72	75	248	7.0	0.16	1.00	578	27	0	1.1	0.00	270	2.8	-	490
	6	649326	198	8.4	15	11	66	4.7	0.12	0.00	2.8	1.6	6	0.0	0.00	251	5.2	-	82
	7	671206	158	8.3	25	73	98	0.0	0.28	0.00	17	3	0	0.0	0.1	341	4.0	-	94
NONTHABURI	8	629369	149	7.3	2.4	1.9	251	2.3	0.16	0.00	198	24	0	0.0	0.1	304	1.6	-	16
	9	639280	176	7.4	38	14	47	5.5	0.26	0.00	1.6	19	0	0.0	0.2	307	2.8	-	152
	10	722293	198	7.2	28	9.8	93	3.1	0.00	-	0.0	38	0	0.4	0.1	376	1.2	383	110
SAM KHOK	11	659426	268	7.7	27	7.0	-	-	0.06	0.00	8.8	14	1	0.4	0.1	449	0.0	463	97
	12	545385	274	8.2	-	-	-	-	2.1	-	5.8	-	-	0.004	-	-	-	404	106
PHYATHAI	13	545385	335	8.0	-	-	-	-	1.0	-	90	-	-	0.006	-	-	-	476	128
THONBURI	14	475147	487	7.7	46	27	16	9.8	0.16	0.00	4.0	7.9	2	0.0	0.8	248	1.2	-	226
	15	545385	457	8.0	-	-	-	-	2.1	-	580	-	-	0.0	0.5	258	54	-	120
PAKNAM	16	560158	640	7.4	16	19	175	16	20	0.80	78	27	12	0.0	1.2	423	6.4	-	118
	17	699054	560	7.4	32	9.8	76	5.5	0.36	0.00	33	16	0	0.0	0.5	258	54	-	120

Fig. 4-34 KEY-DIAGRAM ANALYSIS OF GROUND WATER FROM EACH AQUIFERS





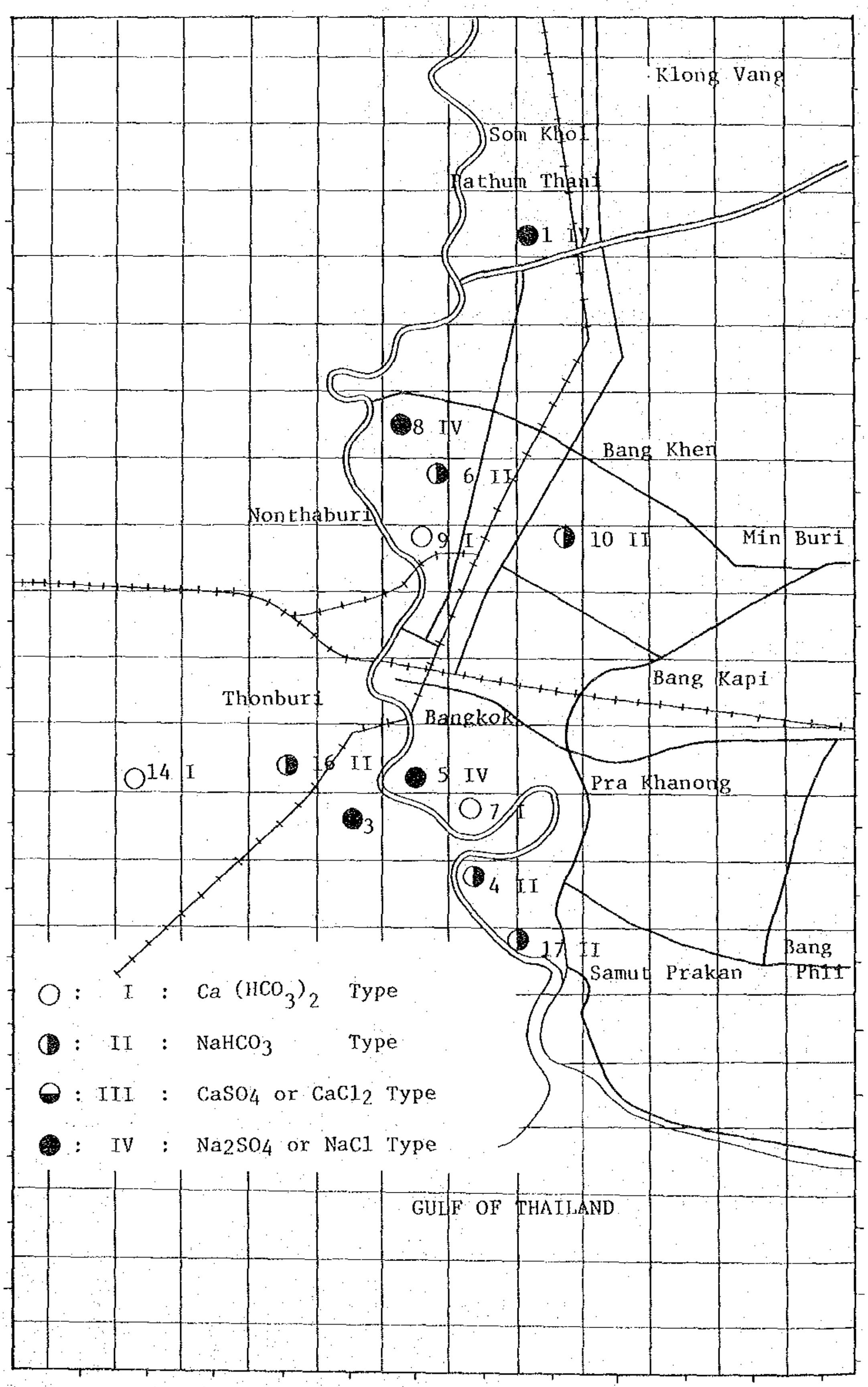
I: $Ca(HCO_3)_2$ Type

II: $NaHCO_3$ Type

III: $CaSO_4$ or $CaC\ell_2$ Type

IV: Na_2SO_4 or $NaC\ell$ Type

Fig. 4-35 DISTRIBUTION OF GROUND WATER QUALITY WITH KEY-DIAGRAM ANALYSIS



In planning a water supply project, it is necessary to adopt a safe yield. In such a case as described above, the optimum pumpage should be determined through mathematical simulation of data on the groundwater level variability so as to avoid ground subsidence due to the lowering of the groundwater level or the contamination of groundwater with saline water. In the present feasibility study, however, an attempt to meet this requirement had to be given up for required data obtained by the pumping test with observation wells.

Table 4-17 ESTIMATED GROUND WATER SAFE YIELD

Ground Water Basin	Effective area(km^2)	Average annual rainfalls(mm)	% of rainfalls reaching ground water reservoir	Recharging water (safe yield) (millions m^3)
Northern Highland and Upper Central Plain	99,000	1,200	8.75	10,395
Lower Central Plain	54,000	1,300	6.00	4,212
Khorat Plateau	180,000	1,200	5.00	10,800
Mae Klong Basin	30,000	1,300	8.75	3,412
Gulf Coastal Plain	10,000	1,800	8.75	1,575

THAILAND COUNTRY REPORT, UNITED NATIONS WATER CONFERENCE, ESCAP REGIONAL PREPARATORY MEETING, 1976, Table IV-1

As a conclusion of the overall study of the metropolitan Bangkok area and its vicinity, two forms of recharge were postulated: the groundwater stored in the surrounding area of the low central plain flows into the aquifers of central Bangkok resulting from declining of the groundwater level; and leaks through the semi-confined layer under reduced pressure.

In the light of this way of looking at the recharge of the aquifer, there are two criteria for determination of a safe yield:

1) Pumpage which does not give rise to the salinification of groundwater.

2) Pumpage which does not cause ground subsidence which might result from the leakage of water through the semi-confined layer.

Groundwater can be salinified by the direct intrusion of seawater into the aquifer and/or by the leakage of saline water contained in the upper layer into the aquifer under reduced pressure.

In the case of Bangkok, not so much the direct intrusion of seawater into the aquifer as the leakage of saline water into the aquifer seems responsible for the salinification of groundwater, as discussed in Sec. 4-1-5. The recharge of aquifers in the area surrounding Bangkok may be expressed by the following equation.

$$\frac{\partial}{\partial x}\left(Tx\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(Ty\frac{\partial h}{\partial y}\right)=S\frac{\partial h}{\partial t}+W(x,y,t)$$

where:

h = groundwater level

Tx, Ty = coefficients of transmissibility in X and y directions

S = coefficient of storage

W(x,y,t)= pumpage

The left term indicates the amount of water which flows to the aquifer in proportion to the head consumed. If W(x,y,t) is larger than the recharge, $S.\frac{\partial h}{\partial t}$ becomes a negative value so that the groundwater level falls from year to year. As the pressure of the aquifer becomes reduced, salinification of groundwater and ground subsidence ensues. When the left and right terms equal, the groundwater level remains unchanged; that is, recharge and pumpage are in equilibrium.

If the pumpage for the separate system is equal to or lower than the amount of water which flows in proportion to the head consumed, groundwater can be stably drawn from this water source far into the future. To obtain evidence to support this postulation, an attempt was made to calculate the flow of groundwater by using the groundwater level of the Nakhon Luang aquifer in 1973.

The aquifers to be tapped for the separate system are the Nakhon Luang and Nonthaburi aquifers. Judging from the fact that the confined aquifer in Bangkok showed a similar fall of head, the assumption was made that the Nakhon Luang and Nonthaburi aquifers had the same hydraulic gradient and a combined coefficient of transmissibility of 40 $m^3/hr/m^2$. As a result, the recharge of the aquifer in Bangkok can be placed at about 86,000 CMD. (Hydraulic Gradient : $i = 1/1,200 \sim 1/3,000$, Flow Width Groundwater : L=166,000m)

The recharge to the multiple well system in the 8 Amphoes on the left bank of the Chao Phraya river can be placed at 43,000 CMD. On the other hand, Sai Noi on the right bank must be considered separately from other districts, as it belongs to the groundwater valley formed by the Nakhon Cha Si river. Assuming that the coefficient of transmissibility of the Nonthaburi aquifer is 20 $m^3/hr/m^2$, the recharge by the flow net can be estimated at about 1,700 CMD for Sai Noi and at about 9,600 CMD for Bang Bua Thong and Bang Yai. The planned pumpage for the entire area on the left bank is 31,800 CMD, whereas the planned pumpage for the right bank is 1,500 CMD in Sai Noi and 9,600 CMD in Bang Yai and Ban Bua Thong.

When the multiple well system of each Amphoe comes into operation, a drawdown cone is naturally formed around the multiple well system. The natural drawdown due to formation of a cone affect in the influence circle of the multiple well system is placed at about 2 m or less in Bang Yai and Bang Bua Thong, about 7 m in Nong Chok, about 8 m in Min Buri and Lat Krabang, and at nearly zero in Bang Phli, Bang Bo and Sai Noi.

The above predictions are based on only the pumpage planned for each Amphoe in the separate system. In other words, the influence of the lowering groundwater level in metropolitan Bangkok must also be taken into account.

In Min Buri the groundwater level is at a depth of about 20 m below ground surface. According to the information obtained from the Banchan industrial well, the groundwater level has been declining about 1 m per each year in this district. If the groundwater level continues to decline at this rate until 2000, it will be at a depth of 40 m or more in that year so that this district will face as much a serious problem as metropolitan Bangkok does now. If some administrative measures are taken to restrict the pumpage of groundwater in Bangkok at a tolerable level, the separate system will find itself in a more favorable position to tap groundwater.

4-2 Surface Water

4-2-1 General:

As being indicated in Fig. 4-36, it would be said that these Klongs and Rivers seem to be feasible enough as water source which will be able to supply water to the served area.

In general, the quantity and quality of such water must be most important factors as far as the water supply undertakings are concerned. In this respect, the Japanese Survey Team had collected many data in relating with a possibility of these sources to be used. The summary of data collected is as follows.

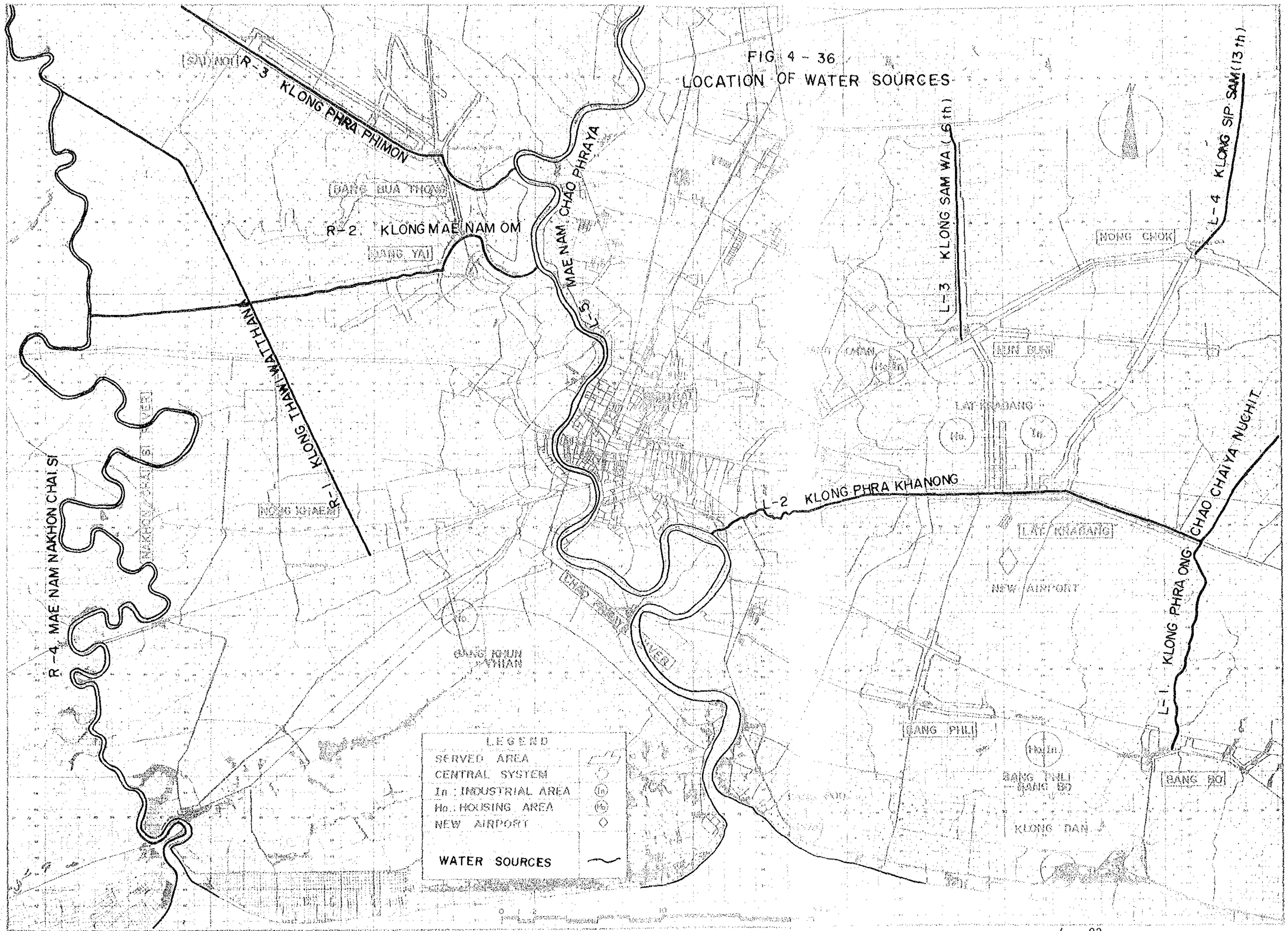


FIG 4 - 36
LOCATION OF WATER SOURCES
R-3 KLONG PHRA PHIMON
R-2 KLONG MAE NAM OM
R-1 KLONG THAWI WATTHANA
R-4 MAE NAM NAKHON CHAI SI
L-5 MAE NAM CHAO PHRAYA
L-3 KLONG SAM WA (6th)
L-4 KLONG SIP SAM (13th)
L-2 KLONG PHRA KHANONG
L-1 KLONG PHRA ONG CHAO CHAIYA NUCHIT
BANG BUA THONG
BANG YAI
NONG KHAEM
NONG CHOK
MIN BURI
LAT KRABANG
NEW AIRPORT
BANG KHUN THIAN
BANG PHLI
BANG BO
KLONG DAN
LEGEND
SERVED AREA
CENTRAL SYSTEM
In : INDUSTRIAL AREA
Ho.: HOUSING AREA
NEW AIRPORT
WATER SOURCES

4-2-2 Right Bank of Chao Phraya River

(1) Klong Water:

1) Klong Thawi Watthana (R-1) :

The Klong Thawi Watthana had ever been recommended as a water source for the Amphoe Nong Khaem in the comparative studies carried out at 1973 by the former Japanese Survey Team. However, in that occasion, it had been mentioned that the domestic sewage and/or industrial wastes from dwellings and/or factories along the Klong would be one of the reasons of water pollution in these surface water.

Judging from the data investigated by the Japanese Survey Team, it had been also suggested that the five (5) days BOD of Klong will be an index of water pollution, in consequence of Table 4-18 as a result of quantitative analysis.

In general speaking, it is unlikely to take a surface water from Klongs in which the five (5) days BOD is recorded more than four(4) ppm, which is considered to indicate the maximum tolerant level of pollution.

In addition to the fact abovementioned, the previous value of five (5) days BOD was only 1.6 ppm in 1972, which means that the pollution has increased rapidly at rate of 0.8 ppm per year, in the result of three(3) times as much as previous value. On the other hand, from the viewpoint of quantity of the Klong, some restriction for water consumption must be made to correspond with the water demand for Nong Khaem Area, because of shortage in dry season.

As being studied above, it is obliged to deem that the Klong Thawi Watthana is not suitable for the water sources, taking water quality and quantity into consideration.

Table 4-18 WATER QUALITY OF KLONG THAWI WATTHANA

Item / Point	DO (ppm)	BOD-5 (ppm)	Remarks
Amphoe Taling Chun	1.5	4.3	Near Railway Bridge
Amphoe Phasi Charom	2.8	5.2	In front of Wat Saladaeng
Amphoe Phasi Charoen	1.6	4.5	Near Petch Kasem Bridge

2) Klong Mae Nam Om (R-2) :

It is well-known that the Klong Mae Nam Om is one of the tributaries of Chao Phraya River. Thus, it is seemed that the capacity of this Klong is good enough for water source. Furthermore, there is no water gate and other facilities to control the flow of tributary, so that the quality of its water must be nearly same as that of Chao Phraya River.

According to the description concerning to serious pollution in the water of Klong Thawi Watthana, the Klong Mae Nam Om will be considered available for a water source of right bank of Separate System, if the Authority would agree to give up using the Klong Thawi Watthana as a water source. Meantime, water pollution analysis shall also be involved in the water quality survey of Chao Phraya River in any case.

3) Klong Phra Phimon (R-3) :

The Klong Phra Phimon might be considered as a water source for Sai Noi District where is located far from other sanitary districts, because this Klong is now flowing through the center of Sai Noi as being shown in Fig. 4-36. However, unfortunately, water of this Klong is also remarkably polluted and quantity of water is not enough. Therefore, the Klong Phra Phimon shall be abandoned from the selection of water source.

(2) River Water :

1) Nakhon Chai Si River (R-4):

Judging from additional investigation for surface water, the River Nakhon Chai Si will be situated as water source for right bank of Chao Phraya River, although the Klong Mae Nam Om is seemed to be a feasible water source, because of adjacent location to several Amphoe such as Sai Noi and Bang Bua Thong.

In respect to total amount of raw water at right bank as 62,000 CMD(0.72 cu.m./sec.) in target year of AD 2000, it is clear that the flow of Nakhon Chai Si River is good enough to cover such demand, because it has been informed from Royal Irrigation Department that the total discharge of the River is approximately 50 cu.m./sec. in dry season, among which 30 cu.m./sec. shall be kept to prevent an intrusion of sea water into upstream, and consequently 20 cu.m./sec. would be available to be used for water supply system.

If it is possible to compare two figures abovementioned, it seems to be good balance because 20 cu.m./sec. is obviously enough to cover the water demand of 0.72 cu.m./sec.

On the other hand, the Nakhon Chai Si River has an important problem, that is, the intrusion of salt water into the river. In general practice, the concentration of saline in water is expressed by the concentration of chlorine ions. The former is called salinity and the latter chlorinity.

According to the 14th edition of the "Standard Method" the relationship between salinity and chlorinity can be expressed by the formula which has been learned by experience.

Salinity o/oo = 0.03 + 1.805 (chlorinity)

where, the symbol o/oo indicates parts per thousand. Relatively scarce is the data concerning the intrusion of salt water into the Nakhon Chai Si River, but use has been made of such scarce data to the full extent in order to make the following recommendations concerning the location of the water intake.

① Data No. 1 (Sampling year, 1977)

Fig. 4-37 represents the latest data that was obtained by the first reconnaissance (June - March, 1977). It can be known from this figure that all data indicate nearly the same degree of salinity where is 30 km upstream from the mouth of the river.

Chlorinity (or the amount of chloride ions) is used here as an index of saline to evaluate data No.1, and it is assumed that the upper limit of chlorinity for potable water is 200 ppm.

Substituting C = 200 ppm = 0.2 o/oo for S of the above formula, it is obtained as follows:

S o/oo = 0.03 + 1.805 C o/oo.

Therefore,

S = 0.391 o/oo = 391 ppm

This is shown as the acceptable limit by a broken line in Fig. 4-37.

The distance of the sampling points where 391 ppm of salinity (200 ppm of chlorinity) was recorded is shown below for all the data taken.

Sampling Date	Distance from the Mouth of the River
1. Feb. 1977	22 km
3. "	23 km
5. "	31 km
7. "	33 km
9. "	32 km
13. "	30 km

The distances of these sampling points suggest that water will be taken from the Nakhon Chai Si River at a point 30 km or more apart from the mouth of the river.

② Data No. 2 (Sampling year, 1968 - 1970)

Fig. 4-38 represents the measurements of salinity that were taken of the Nakhon Chai Si River between 1968 and 1970.

Among the data taken from March to May 1970, those indicating a salinity of 391 ppm (chlorinity of 200 ppm) or less were appeared at a distance of 60 km or more from the mouth of the river.

As far as these data goes, it may be said that water would be safe to drink, if it is taken near the Po Kaw Bridge which is a point of intersection of the Nakhon Chai Si River and the Phet Kasem Road.

However, the data taken in May 1968 shows that salinity near the Po Kaw Bridge was in the neighborhood of 16,000 ppm and that chlorinity was as high as 8,850 ppm.

This data makes no mention of the time that sampling water was taken, but if sampling was performed a greater number of times upstream of the bridge, a estimated line as shown in the figure could be obtained.

The point that corresponds to the acceptable limit of 200 ppm for chlorinity (391 ppm for salinity) on this estimated line suggests that the safe intake would be somewhere between the points of 70 and 80 km from the mouth of the river.

③ Data No. 3 (Sampling year, 1973 - 1976)

Table 4-20 shows the data of chlorine of the Nakhon Chai Si River that was obtained between 1973 and 1976 and Fig. 4-39 is a graphical representation of the data.

As shown in Fig. 4-39 this data differs from data No.1 and No.2 in that the saline level of water is expressed by the concentration of chloride ions, in data No. 3.

Data No. 3 bears a close resemblance to data No.1. In other words, the curve of data No.3 about overlaps that of data No.1, if the curve of data No.1 is moved about 20 km upstream on the graph.

This fact suggests that both data is rather reliable and that the intrusion of sea water into the Nakhon Chai Si River is represented by this curve.

As has already been mentioned, however, the intake points suggested by data No.1 would be at a point 30 km upstream from the mouth of the river, whereas data No.3 suggests that the intake points be located 20 km more upstream.

As differences among the data of three sampling values are so wide that it is extremely difficult to determine the correlation among these.

For the present stage, therefore, it is considered that data No.2 should be adopted for an extra margin of safety. In other words, there seems little or no danger so long as water is taken at a point about 80 km upstream.

However, the analysis of water quality at the proposed intake site should be continued for at least one year, if the Nakhon Chai Si River is to be recommended as the water source.

For information, the results of analysis of water samples collected during the last reconnaissance are presented Table 4-19.

Table 4-19 CHLORINITY OF NAKHON CHAI SI RIVER
(Sampling Date 9, Mar.)

(ppm)

Sampling Point	Nakhon Chai Si River		
	Surface	Middle	Bottom
1	10.0	9.0	8.0
2	13.0	11.0	11.0
3	13.0	15.0	14.0
4	14.0	17.0	16.0
5	19.0	18.0	17.0
6	144.0	–	–

Table 4-20 CHLORINITY OF NAKHON CHAI SI RIVER
- Data No. 3 (1973 - 1976)

Date of Analysis	Tidal Condition	Result of Analysis(Chlorine, mg/ℓ)				Remarks
		1	2	3	4	
1973, 1 Aug.	-	-	34	14	17	
14 Nov.	-	-	23	12	11	
1975, 5 Mar.	-	-	350	16	16	
8 Apr.	-	5,000	41	16	*72	
12 May.	Low	200	33	23	14	
14 May.	High	200	65	18	-	
18 Jun.	Low	1,775	34	25	17	
18 Jun.	High	3,575	40	*26	18	
14 Jul.	Low	1,315	46	23	14	
15 Jul.	High	2,525	45	19	10	
5 Nov.	-	30	11	8	7	
25 Dec.	-	-	-	-	-	
1976, 17 Jun.	-	3,850	19	15	14	
27 Feb.	Low	6,450	115	25	18	
23 Mar.	Low	6,875	1,500	12	8	
23 Mar.	High	*10,500	*2,850	14	7	
14 Jun.	-	370	31	24	18	
15 Jul.	Low	78	23	26	25	
15 Jul.	High	1,800	33	24	22	
Mean	-	2,969.5	294.1	18.9	18.1	

* Maximum Value

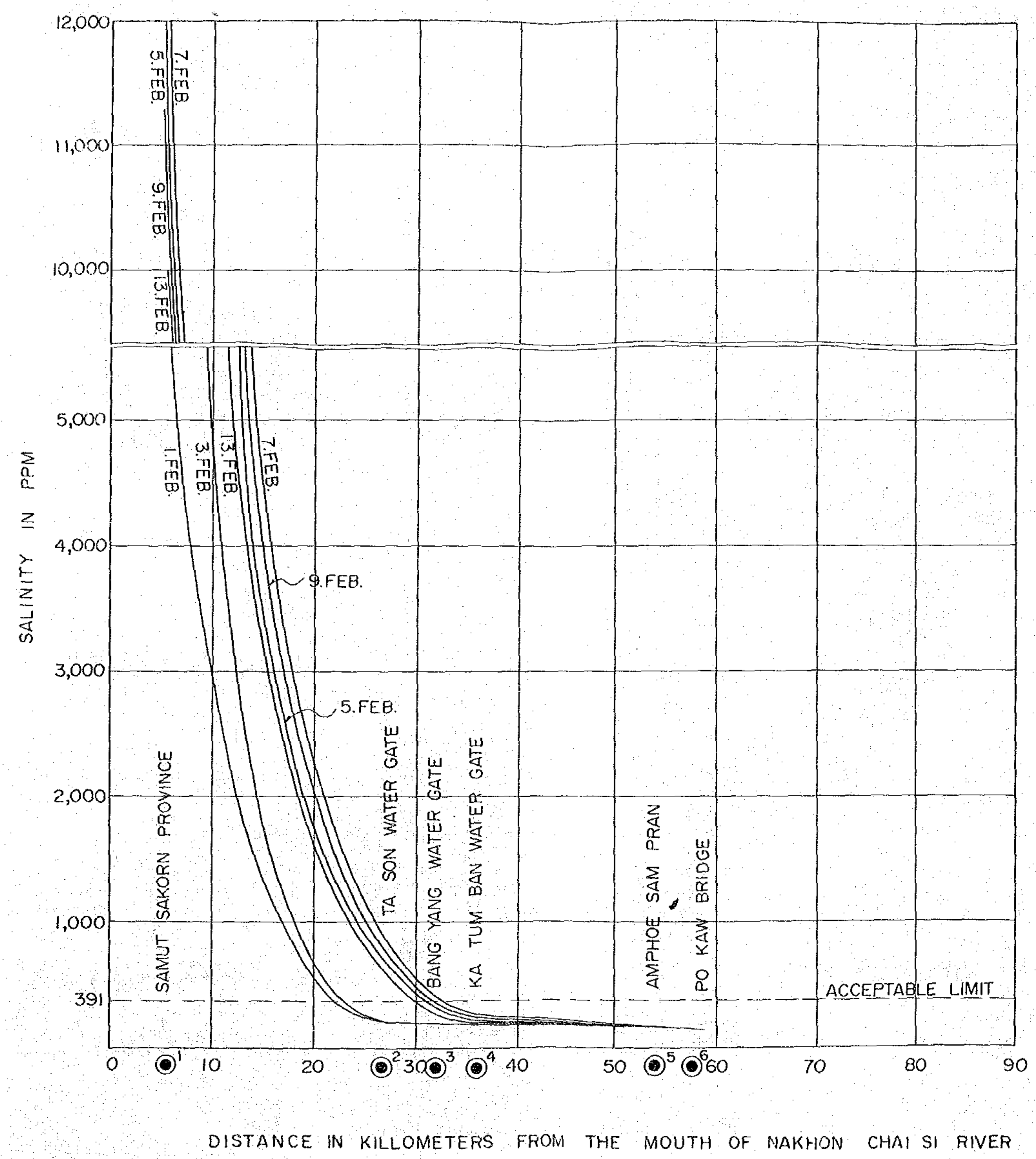
1 Samut Sakorn Province

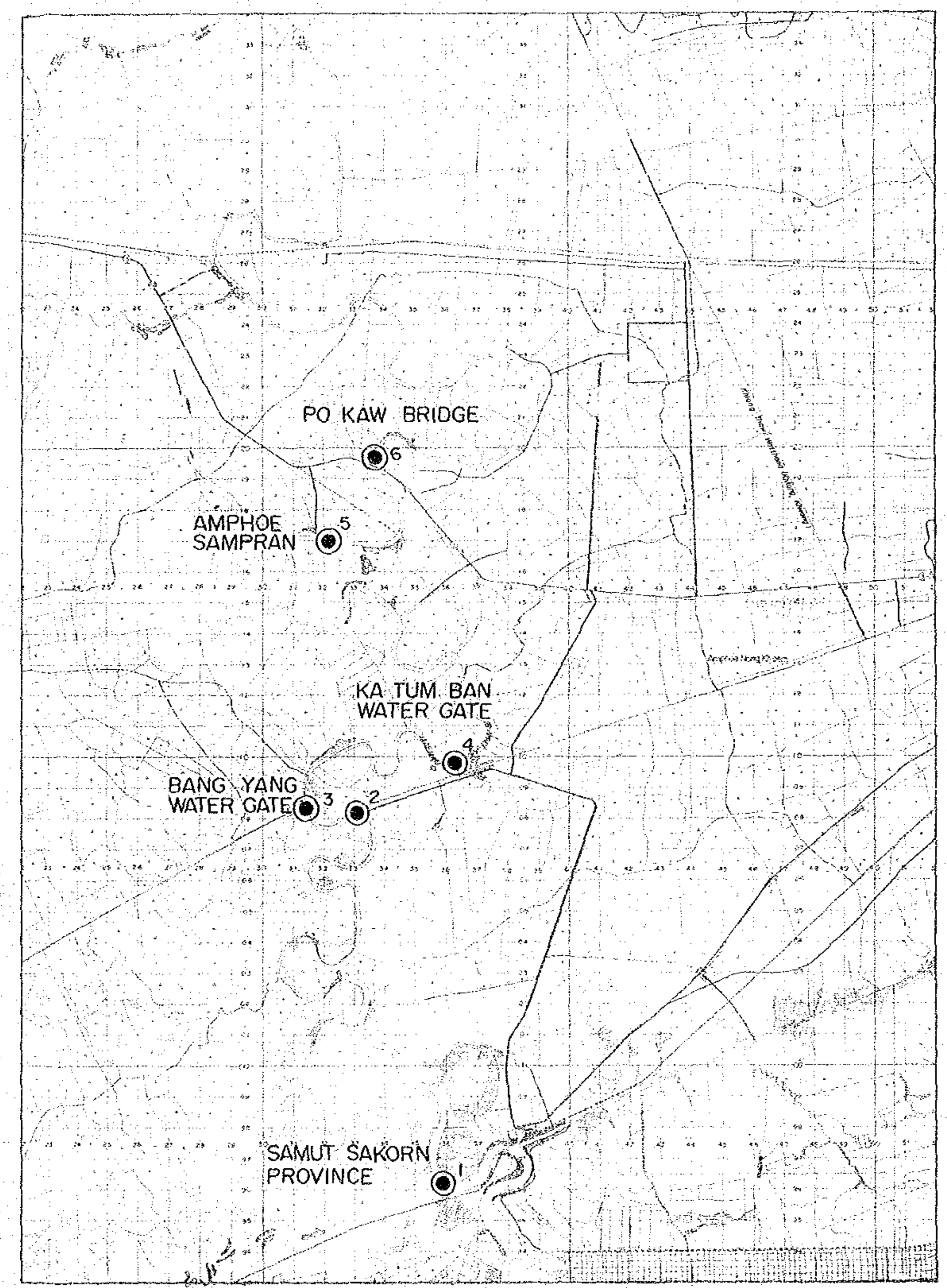
2 Amphoe Katum Ban

3 Amphoe Sam Pran

4 Amphoe Nakhon Chai Si

Fig. 4-37 SALINITY OF NAKHON CHAI SI RIVER — DATA NO.1 (MAR.1977) —





SAMPLING LOCATION

Fig. 4 -38 SALINITY OF NAKHON CHAI SI RIVER —DATA NO.2 (MAY.1968~MAY.1970)—

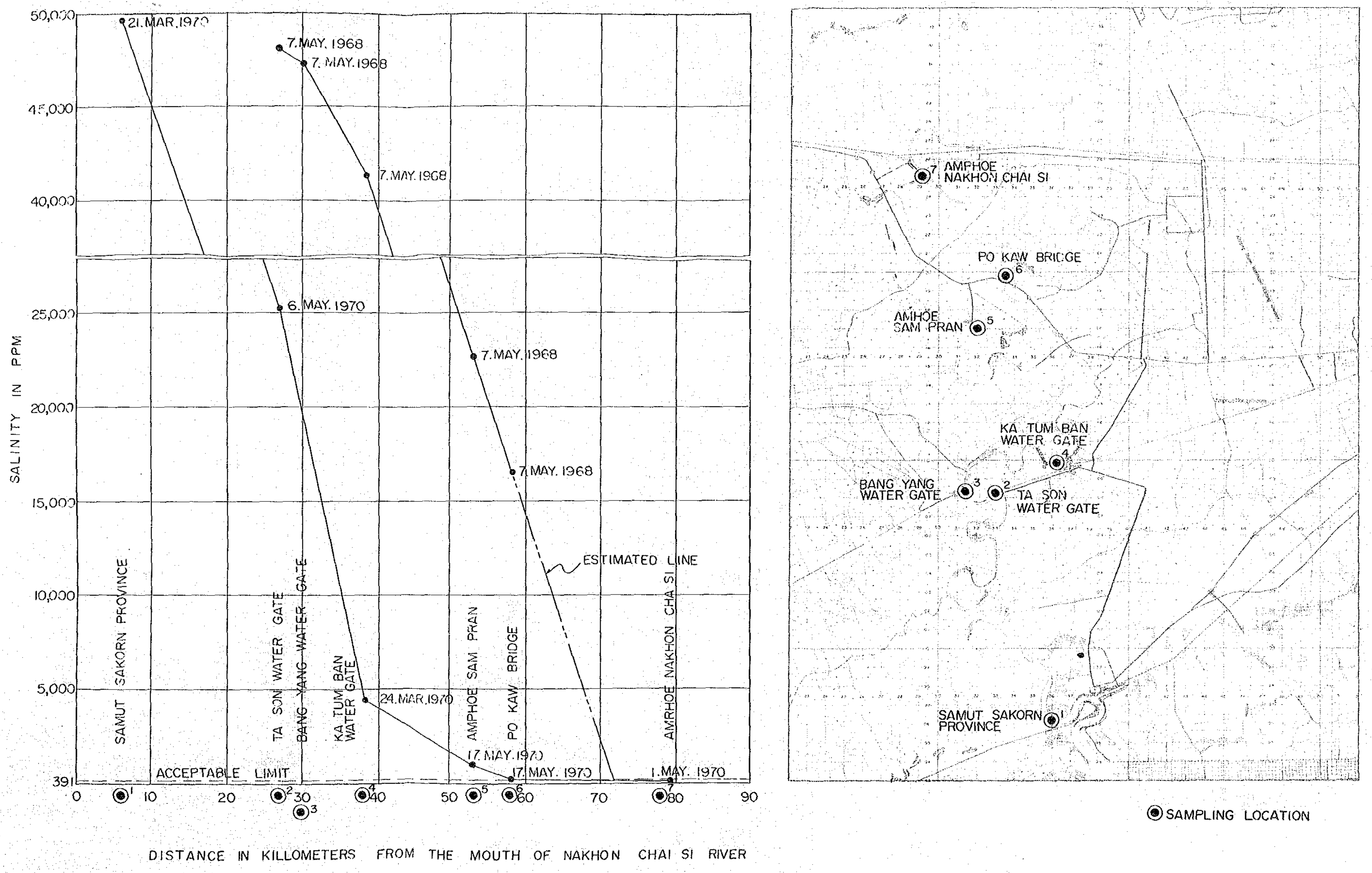
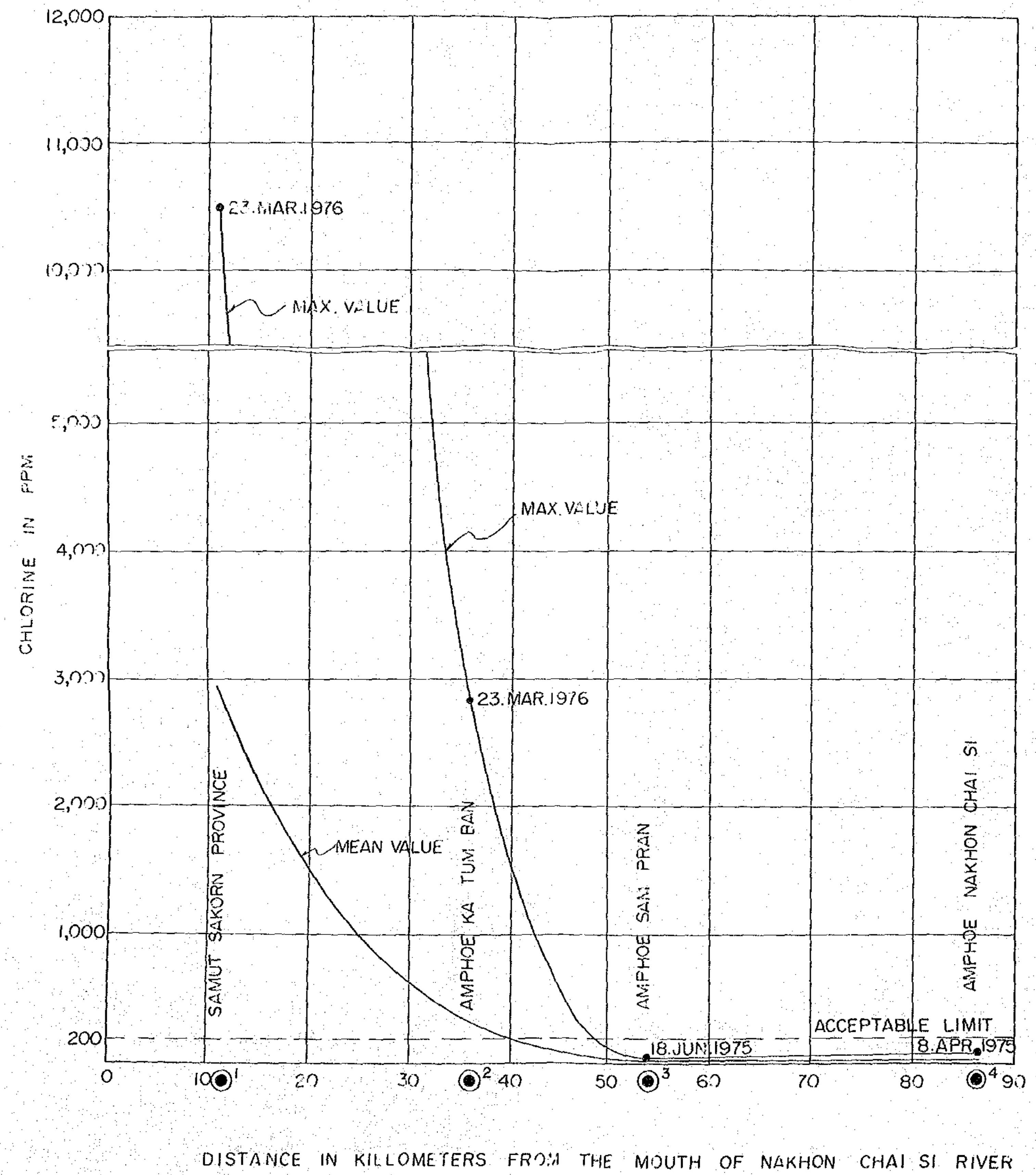
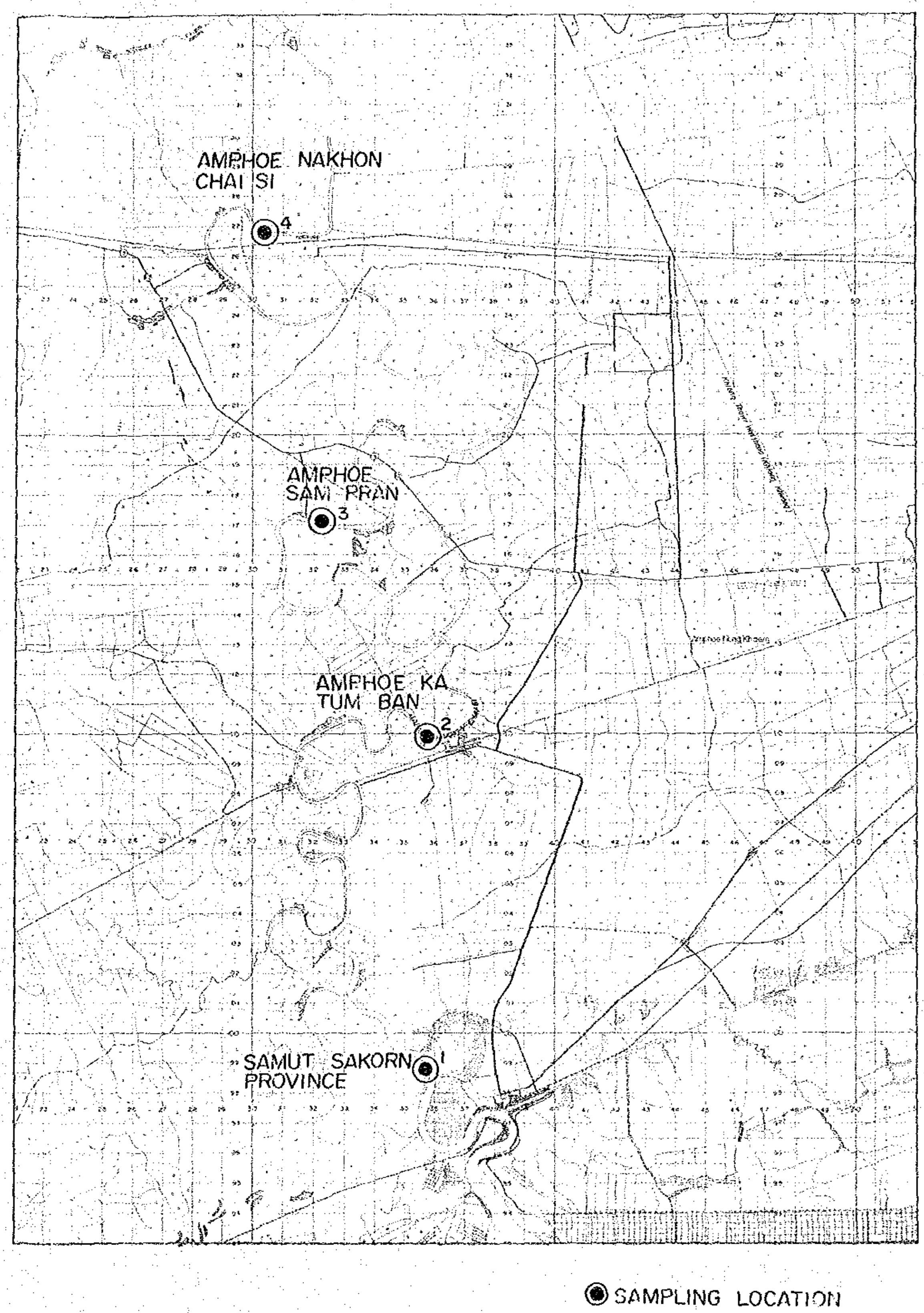


Fig 4-39 CHLOLINE OF NAKHON CHAI SI RIVER —DATA NO.3 (AUG.1973~JUL.1976)—





4-2-3 Left Bank of Chao Phraya River

(1) Klong Water:

1) Klong Phra Ong Chao Chaiya Nuchit (L-1):

As being indicated in Fig. 4-36, the Klong Phra Ong Chao Chaiya Nuchit looks like a reasonable source to serve water to Amphoe Bang Bo and Bang Phli, taking its situation into consideration. Judging from appearance of the Klong water, it is clear to meet with standard of drinking water.

At present amount of 4,800 CMD water has been taken from this Klong as a water source of Chachoeng Sao Water Works Undertaking which belongs to Public Works Department, and another 4,800 CMD water is now planning to supply to a extension work of the Undertaking in near future.

In addition to the fact abovementioned, it has been also planned that amount of 5,000 CMD water will be taken from this Klong to Bang Prakong Water Works Undertaking which also belongs to PWD.

From these standpoints, it seems to be somewhat difficult to designate the Klong water as a source for the Amphoe such as Bang Bo, Bang Phli, Klong Dan and Bang Poo.

2) Klong Phra Khanong (L-2):

Under previous survey made in 1972, the Klong Phra Khanong had been recommended as a water source to Amphoe Lat Krabang, subject to an periodic elimination of water pollution. As the fact, five (5) days BOD test had shown the value of 2 ppm which reaches almost to a saturation of pollution. To compare with the water in Klong Thawi Watthana which had shown 1.6 ppm, this Klong had been somewhat doubtful to be a water source.

Apart from the previous study made in 1972, additional survey was done in this field study. However, unfortunately, the Klong and its surroundings have not been improved during past five (5) year in term of water quality preservation.

3) Klong Sam Wa (L-3) and Klong Sip Sam (L-4) :

These two Klongs are situated in the Amphoe Town of Min Buri and Nong Chok. Since these two Klongs have a vast water-shed area surrounded by Khao Yai mountain range situating at northern part of Thailand, the discharge of these two Klongs are recorded that the discharge of Klong Sip Sam is 20 cu.m./sec. in flood season and 5 cu.m./sec. even in dry season.

On the other hand, the total water demand in left bank of Chao Phraya River is 193,150 CMD in the target year of AD 2000, in comparison with the quantity of Klong Sip Sam as 432,000 CMD (5 cu.m./sec. as mentioned before). Therefore, it is possible to designate Klong Sip Sam as a water source for all of planned sanitary district in left bank.

The contamination of water with organic matter gives rise to public discussion from time to time in Klong, but exceptionally does not pose any problem to the two Klongs at present.

As will be discussed in the following, the Klong is a recommendable water source.

The last survey which did not make it a chief main to investigate into the pollution of water did not give a good deal of information on this problem. In this study, therefore, the information obtained from the last water source survey and BOD test will be used to consider the relationship between the quality of water and BOD load and so as to make a projection into the future.

As shown in Fig. 4-36 the sampling point (L-3) of the Klong Sam Wa is at about 3 km north of the Min Buri district office. In the estimation of the pollution of water it is assumed from the field survey that the Klong is lined with dwelling houses at spacings of 50 m on both sides for about 1 km upstream of this sampling point and at spacings of 100 m beyond 1 km and that the river flows at a velocity of 2.5 km/day.

It is also assumed that the unit of BOD load is 13 g per cap. per day for human waste, the total BOD load is 26 g per cap. per day and the population is 6 persons per household.

The pollution of the water of the Klong will now be estimated on the above assumptions. When the reaches of the Klong are divided into zone A and an infinite zone at the above sampling point according to the density of dwelling houses, the BOD load can be computed as follows.

i) Zone A

$$\text{BOD Load} = \frac{10{,}000\ \text{m}}{50\ \text{m/house}} \times 6\ \text{persons/house} \times 2\ \text{sides} \times 26\text{g/cap./day} = 62{,}400\ \text{g/day}$$

The BOD load per division 2.5 km distance will, therefore, be -

$$62{,}400\ \text{g/day} \div \left(\frac{10\ \text{km}}{2.5\ \text{km}}\right) = 15{,}600\ \text{g/day}.$$

ii) Infinite Zone

The BOD load per division in the infinite zone can be calculated to be -

$$\text{BOD Load per Division} = \frac{2{,}500\ \text{m}}{100\ \text{m/house}} \times 6\ \text{persons/house} \times 2\ \text{sides} \times 26\ \text{g/cap./day} = 7{,}800\ \text{g/day}$$

The decrease in BOD (or BOD load) can generally be expressed by the following equation.

$$L = Lo \cdot 10^{-Ki \cdot t}$$

where,

L = BOD after T days (or BOD load in g/day)

Lo = BOD when t = 0 day (or BOD load in g/day)

Ki = Constant of deoxygenation

The value of constant of deoxygenation should be experimentally determined, but its average is placed at 0.1 at 20°C in general use.

The value of Ki at a water temperature of 28°C can therefore be computed as follows.

$$\begin{aligned} Ki\text{-}T &= K_{20}(1.047^{T-20}) \\ &= 0.1 \cdot (1.047^{28-20}) \\ &= 0.14 \end{aligned}$$

The BOD of the Nth division includes the accumulation of organic matter produced in its upstream divisions, and an equal load is assumed to occur in each division (2.5 km long).

Therefore, the equation $L = Lo \cdot 10^{-Ki \cdot t}$ can be rewritten to read

$$Ln = Lo(10^{-Ki \cdot t} + 10^{-2Ki \cdot t} + \ldots\ldots 10^{-(n-1)Ki \cdot t} + \ldots 10^{-n\ Ki \cdot t})$$

where,

- Ln = BOD load of the Nth division, g/day
- Lo = 15,600 g/day in zone A
- = 7,800 g/day in the infinite zone
- Ki = k_{i-T} = 0.14
- t = time that organic matter is carried from the point of occurrence to the sampling point
- n = number of divisions counted down the river

The total BOD load of zone A up to the sampling point can, therefore, be computed as follows.

$$L_{n-1} = 15,600 \times (10^{-0.14} + 10^{-0.14 \times 2} + 10^{-0.14 \times 3} + 10^{-0.14 \times 4})$$
$$= 15,600 \times (0.724 + 0.525 + 0.380 + 0.275)$$
$$= 29,700 \text{ g/day}$$

The total BOD load of the infinite zone up to the sampling point can be computed likewise to be as follows.

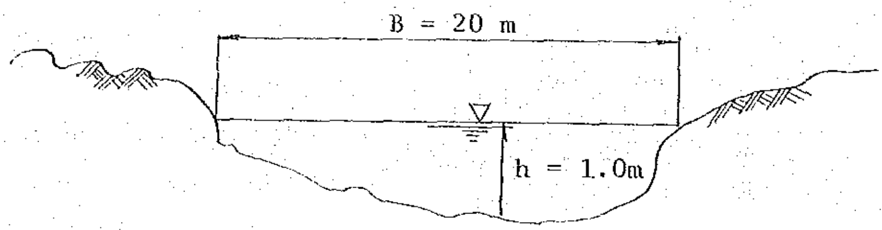
$$L_{n-2} = 7,800\ (10^{-0.14 \times 5} + 10^{-0.14 \times 6} + \ldots 10^{-0.14 \times \infty}$$
$$= 7,800 \times (0.200 + 0.145 + 0.105 + 0.076 + 0.055 + 0.040 + 0.029 + 0.021 \ldots\ldots) = 5,600 \text{ g/day}$$

The total BOD load at the sampling point will, therefore, be as follows.

$$\Sigma Ln = L_{n-1} + L_{n-2} = 29,700 + 5,600 = 35,300 \text{ g/day}$$

The cross section of the river at the sampling point is assumed to be about as shown below, and the water is assumed to flow at a velocity of 2.5 km/day. The water flow rate of the river can, therefore, be computed to be -

$$Q = AV = 16\ m^2 \times 2,500\ m/day = 40,000\ m^3/day$$



$$A = 20\ m \times 1.0\ m \times 0.8 = 16\ m^2$$

The BOD at the sampling point will be -

$$BOD = \frac{\Sigma Ln}{Q} = \frac{35,300\ g/day}{40,000\ m^3/day} = 0.88\ g/m^3 \fallingdotseq 0.9\ ppm$$

The estimation can be considered to be reasonable, as compared with the observed value of 0.8 ppm and suggests that the assumptions, reflect the actual condition of the river.

It can be inferred from the above calculation that Ln does not infinitely increase when n is infinite and that the BOD at the sampling point does not exceed 1 ppm at present.

When limit value of BOD of the water source is assumed to be 4 ppm, as suggested by experience in Japan, the BOD load per division of the Klong will not be allowed to exceed about 61,000 g/day, when it is considered as potable water source.

$$4(ppm) = \frac{B(g/d)}{Q(m/d)} \cdot (10^{-Ki \cdot t} + 10^{-2Ki \cdot t} \ldots\ldots\ldots + 10^{-nKi \cdot t})$$

$$4 = \frac{B}{40,000} \cdot (10^{-0.14} + 10^{-2x0.14} + 10^{-nx0.14})$$

$$B = 61,000\ g/day$$

In other words, the utilization of the Klong as a source of potable water should be given up when the BOD load along the Klong Sam Wa has increased to 61,000 g/day.

Assuming that the unit of BOD load is 26 g per cap. per day and the life-condition of the community people remains unchanged, the BOD load of the Klong will reach its limit when the population producing 61,000 g/day of waste increases by about four times.

$$\frac{61,000 \text{ g/day}}{15,600 \text{ g/day}} \div 4$$

As has been discussed, the observed and assumed values of BOD of the Klong Sam Wa are as low as 0.8 ppm and 0.9 ppm at present, and indicate that it seems to serve enough as a source of potable water.

However, the population will grow and the life-condition of inhabitants will change according to development. As a result, the unit of BOD load will be increased rapidly. Since rapid water pollution is expected, it is most desirable that effective measures for waste disposal must be established at an early date in line with the prevalence of the water supply system in order to preserve water of a good quality and to maintain hygienic conditions.

The necessity of an investigation and a study to verify the assumed values of BOD and the estimated water pollution is keenly felt.

(2) River Water :

1) Chao Phraya River (L-5) :

Chao Phraya River will have a significant possibility as the water source for the Separate System when wells and Klong water become useless.

According to recent investigation by RID for the discharge of Chao Phraya River, total amount of discharge is 85 cu.m./sec. at the lower stream of this river, among which 60 cu.m./sec. is to be used for intrusion prevention from sea water and another 25 cu.m./sec. (2,160,000 CMD) is available for use of Central System.

On the other hand, future raw water demand of Central System is as followings.

Judging from the Table 4-21, it will become necessary to undertake some special program for water reconnaissance throughout Thailand in order to supply enough and safe drinking water to Central System as soon as possible.

Table 4-21 DEMAND ESTIMATES OF RAW WATER FOR WATER SUPPLY IN BANGKOK METROPOLITAN AREAS

Year	Raw Water Required			
	Surface Water (CMD)	Ground Water (CMD)	Total (CMD)	Percentage of Ground Water (%)
1977	950,000	312,000	1,262,000	24.72
1979	1,800,000	532,000	2,332,000	22.81
1981	2,300,000	448,000	2,748,000	16.30
1985	3,600,000	294,000	3,894,000	7.55
1990	4,700,000	–	4,700,000	–
1995	6,000,000	–	6,000,000	–
2000	6,000,000	–	6,000,000	–

4-2-4 Water Sampling:

Sampling for water quality analysis for the surface water has been conducted as follows;

1) Analysis for intrusion of Chao Phraya River and Nakhon Chai Si River.

2) Analysis for water quality of Klong water. After the water quality analysis, reasonable recommendation of water sources was made for the Separate System. The location of water sampling points is shown Fig. 4-40 and results of water quality analysis is shown Table 4-22,and 4-23.

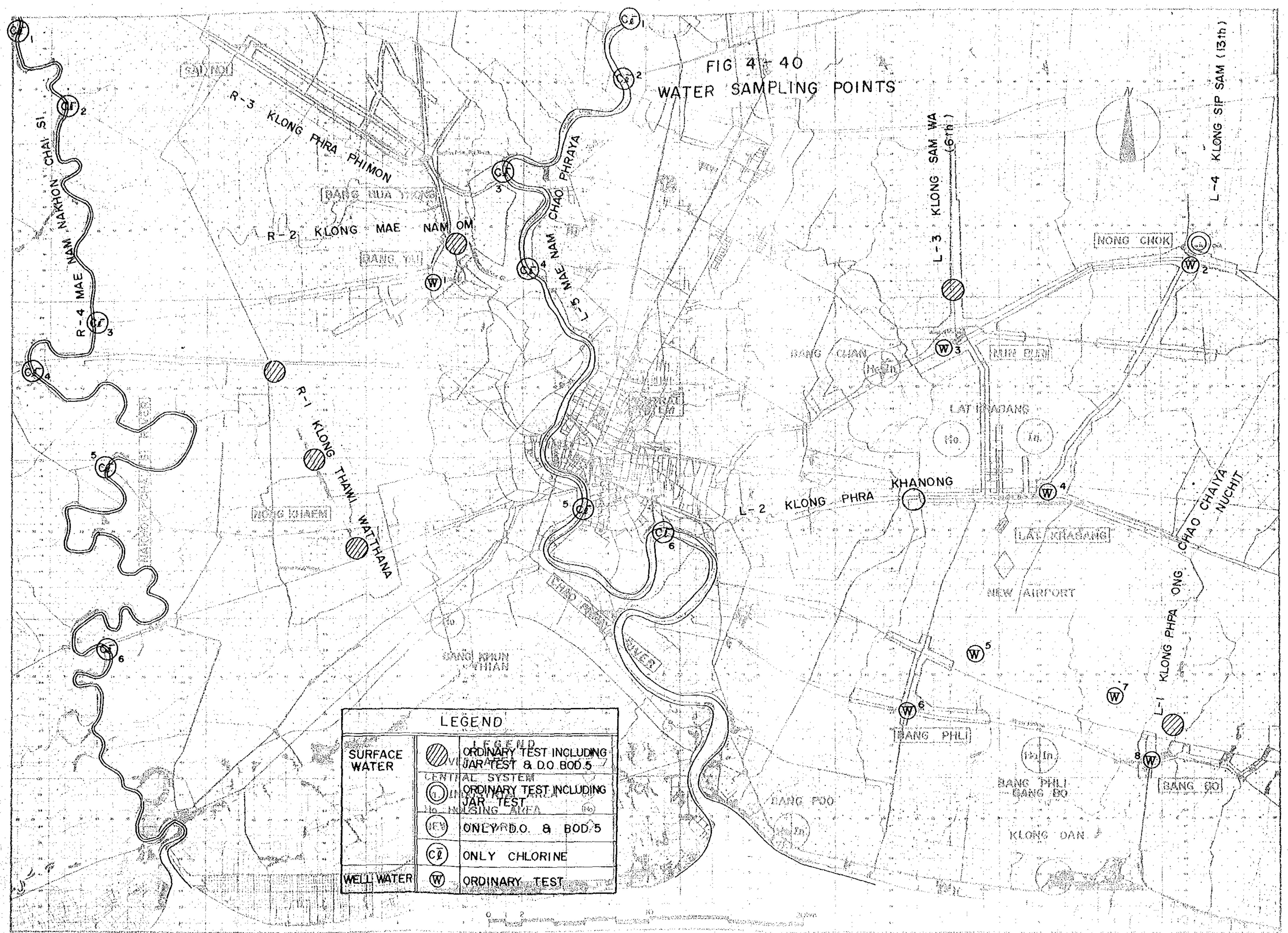


FIG 4-40
WATER SAMPLING POINTS

Table 4-22 RESULT OF WATER QUALITY ANALYSIS

Klong

Chemical Analysis	R-1-1	R-1-2	R-1-3	R-2	L-1	L-2	L-3	L-4
Color	nil	nil	nil	nil	nil		nil	nil
Odor	"	"	"	"	"		"	"
Turbidity	125	170	80	22.0	88		73	75
pH	7.10	7.22	7.46	7.4	7.3		7.2	7.65
Methyl Orange Alkalinity	110	112	136	92	134		82	88
Phenolphthalein Alkalinity	nil	nil	nil	nil	nil		nil	nil
Total Solids	574	954	436	152	642		303	415
Dissolved Solids	206	230	250	100	310		120	90
Suspended Solids (by M.F.)	-	-	-	-	262		154	295
Total Hardness as Calcium Carbonate	140	152	144	94	152		106	88
Carbonate Hardness "	110	112	136	92	134		82	88
Non-Carbonate Hardness "	30	40	8	2	18		24	nil
Chloride as Chlorine	25	40	66	8	92		10	8
Sulphate as Sodium Sulphate	42.6	-	-	6.4	59.6		52.5	22.7
Oxygen Consumed 37°C. 3 hours	5.782	7.036	6.554	1.620	6.112		2.222	0.889
Ammonia free as Nitrogen	0.700	0.564	1.056	0.336	-		0.496	0.404
Ammonia-albuminoid as Nitrogen	1.092	1.348	1.124	0.408	-		0.604	0.804
Total Organic N. as Nitrogen	-	-	-	-	-		-	-
Nitrate as Nitrogen	0.625	0.385	0.025	0.250	0.175		0.115	nil
Nitrite as Nitrogen	0.0530	0.0374	0.0194	0.002	0.0218		0.0176	0.0046
Calcium	-	-	-	-	-		-	-
O-Phosphate	0.14	0.07	0.23	0.13	-		-	-
Iron	4.0	7.8	2.0	0.52	3.7		1.63	1.77
Fluoride as Fluorine	-	-	-	0.39	-		-	-
Manganese	0.207	0.450	0.070	nil	0.263		nil	nil
Magnesium	-	-	-	-	-		-	-
Free Carbon Dioxide	11	14	14	6.0	-		-	-
D.O.	1.5	2.8	1.6	4.7	0.5	0.1	2.6	-
B.O.D.	4.3	5.2	4.5	1.3	2.2	4.2	0.8	-
Bacteria 37°C-24 hrs.(Number/ml)	11,000	18,000	35,000	16,500	18,000		24,000	13,000
Coliform Bacteria (")	115,000	135,000	144,000	23,000	47,000		261,000	162,000
Faecal Coliform (Number/100 ml)	55,000	60,000	81,000	5,000	2,000		66,000	14,000

Note : R-1-1, Klong Thawi Watthana — L-1, Klong Phra Ong Chao Chaiya Nuchit

R-1-2, " " " — L-2, Klong Phra Khanong

R-1-3, " " " — L-3, Klong Sam Wa

R-2, Klong Mae Nam Om — L-4, Klong Sip Sam

Table 4-23 Water Quality of Well Water

Item \ Place	W-1 Bang Yai	W-2 Nong Chok	W-3 Min Buri	W-4 Lat Krabang	W-5 Bang Phli 1	W-6 Bang Phli 2	W-7 Bang Bo 1	W-8 Bang Bo 2
Color	nil	nil	nil	nil	nil	nil	nil	nil
Odor	"	"	"	"	"	"	"	"
Turbidity	3.6	0.5	2.3	1.2	14.0	2.8	1.3	3.4
pH	7.1	7.98	7.55	7.5	7.6	7.5	7.92	7.7
Methyl Orange Alkalinity	256	430	368	386	292	340	328	282
Phenolphthalein Alkalinity	nil	14	8	4	nil	nil	8	nil
Total Solids	364	926	500	534	507	654	567	740
Dissolved Solids	330	730	390	400	375	510	430	595
Suspended Solids	-	-	-	-	-	-	-	-
Total Hardness as Calcium Carbonate	166	120	96	86	136	172	76	148
Carbonate Hardness	166	120	96	86	136	172	76	148
Non-Carbonate Hardness	nil	nil	nil	nil	nil	nil	nil	nil
Chloride as Chlorine	40	126	18	13	43	118	48	166
Sulphate as Sodium Sulphate	9.7	73.8	58.2	48.2	61.1	75	12.8	110
Oxygen Consumed 37°C. 3 hours	-	-	-	-	-	-	-	-
Ammonia-free as Nitrogen	-	-	-	-	-	-	-	-
Ammonia-albuminoid as Nitrogen	-	-	-	-	-	-	-	-
Total Organic N. as Nitrogen	-	-	-	-	-	-	-	-
Nitrate as Nitrogen	-	nil	nil	nil	nil	nil	nil	trace
Nitrite as Nitrogen	-	trace	trace	trace	trace	0.0026	trace	0.0036
Calcium	-	-	-	-	-	-	-	-
O-Phosphate	0.03	-	-	-	-	-	-	-
Iron	0.40	nil	nil	nil	2.4	nil	nil	nil
Fluoride as Fluorine	0.39	-	-	-	-	-	-	-
Manganese	0.31	trace	trace	trace	trace	nil	nil	nil
Magnesium	-	-	-	-	-	-	-	-
Free Carbon Dioxide	56.0	28.0	34.0	36.0	28.0	22.0	16.0	42.0
MPN per 100 ml	0	0	0	0	0	38	0	38
24 hr. Total Plate Count at 37°C	0				2	49	14	11