(c) Recovery Test

A recovery test usually gives a good result because water level measurements could be made without being affected by pump vibrations and variations in the pumping rate. If a well is pumped for a given period of time t as a continuous pumping test and then shut down, water levels in the well were measured at the following time-steps:

0 to 10 minutes	: every 1 minute
10 to 25 minutes	: every 3 minutes
25 to 60 minutes	: every 5 minutes
60 to 120 minutes	: every 10 minutes
120 to 180 minutes	: every 15 minutes
180 to 300 minutes	: every 30 minutes
300 to 1,440 minutes	: every 60 minutes

A plot of residual drawdown versus logarithm of time ratio t/t', where t is the time since pumping started and t' is the since pumping stopped, yields a straight line.

The method of solution employed in this study was the least- squwere regression analysis and the fitting of a straight line through the reliable test data in a semilogarithmic diagram. If the well loss is significouldt in one well, rapid recovery data in the early stage should be eliminated from the computation. Transmissivity value is calculated from the straight line, and the storage coefficient couldnot be obtained directly from the recovery method.

(2) Results of Pumping Test Analyses

The results of pumping tests were summarized in Table 1.2.1, and all plots were given in the APPENDICES. The results for every site were described as follows:

(a) Site-A

Pumping tests were performed in seven (7) observation wells. Pumping tests could not be done in A-1 well (depth: 574m) because water recovery is very slow after the well development.

Well efficiencies of A-3 (depth: 360m) and A-8 (depth: 48m) wells were more than 90%, whereas the well efficiencies of the other observation wells vary from 71% to 84%.

Continuous pumping tests were carried out at pumping rates of 360m^3/d for A-2 well, 1,008m^3/d for both A-3 and A-4 wells, and 1,020m^3/d for A-8 well.

A-2 well (depth: 437m)

The measured drawdown fluctuated during the continuous pumping test because the pumping rate is slightly changed. But the recovery plot shows a good straight line. Therefore, the representative transmissivity of $26.1m^2/d$ from the recovery test is employed.

The storage coefficients vary depending on the selection of the reliable data from the plots. Considering a representative transmissivity and the results of curve-matching and straight line fitting, a storage coefficient of $1.34x10^{-11}$ from Theis method using corrected drawdown (by Correction 1) is used as the representative value.

A-3 well (depth: 360m)

This well had the highest well efficiency among the seven wells in Site-B; the aquifer parameters were therefore computed only from the measured drawdown. The transmissivities obtained using the three methods presented above range from $63.7m^2/d$ to $68.7m^2/d$. The representative transmissivity is $65.9m^2/d$, which is the logarithmic average of the three transmissivity values.

Storage coefficients from both Theis and Cooper-Jacob methods were in good agreement. Hence the representative storage coefficient is $1.38x10^{-03}$ which is the logarithmic average of the two storage coefficients.

A-4 well (depth: 302m)

Transmissivities computed by both Theis and Cooper-Jacob methods using corrected drawdown (by Correction 1) were in good agreement with the transmissivity obtained using the recovery test method. Therefore the representative transmissivity is $230.5m^2/d$ which is the logarithmic average of the three transmissivity values.

Representative storage coefficient is $1.51x10^{-13}$ which is the logarithmic average of the storage coefficient values obtained by employing Theis and Cooper-Jacob methods. These methods use the corrected drawdown (by Correction 1).

A-8 well (depth: 48m)

Because of high well efficiency, aquifer parameters were computed using the measured drawdown. Transmissivities computed using the three methods range from $865.2m^2/d$ to $942.4m^2/d$; the representative transmissivity is $903.6m^2/d$ which is the logarithmic average of the three values.

Representative storage coefficient of $3.38x10^{-12}$ is also the logarithmic average of the storage coefficients obtained using Theis and Cooper-Jacob methods.

(b) Site-B

Pumping tests were performed in five (5) observation wells. Deeper observation wells had low well efficiencies: B-1 well (depth: 272m) at 20.0% and B-2 well (depth: 192m) at 47.2%. Well efficiencies of B-3 well (depth: 153m) and B-4 well (depth: 94m) were more than 90%. The well efficiency of B-5 well (depth: 47m) is 76.0%.

Before conducting the continuous pumping tests, static water levels were measured in each well. The deepest static water level is measured in B-1 well at 35.050m below ground surface (BGS). The static water levels in B-2 well at 31.200m BGS and in B-3 well at 31.845m BGS were almost the same. The static water level in B-4 well is 24.980m BGS, and that in B-5 well is 6.600m BGS.

Specific capacities were computed using the final drawdown of the continuous pumping tests. B-3 well had the highest specific capacity at 152.0m^2/d. Specific capacity of B-4 well is 40.2m^2/d, and that of B-5 well is 41.0m^2/d. Compwered with these wells, B-1 and B-2 wells had lower specific capacities at 5.5m^2/d and 7.5m^2/d respectively.

The aquifer parameters of each well were given below.

B-1 well (depth: 272m)

Transmissivity of B-1 well is computed as 9.4m^2/d by both Theis type-curve matching method and Cooper-Jacob method using measured drawdown. Using drawdown corrected by Correction 1, higher transmissivities were computed: 11.6m^2/d by Theis method and 15.8m^2/d by Cooper-Jacob method. Using drawdown corrected by Correction 2, transmissivity computed by the Cooper-Jacob method is the highest at 24.0m^2/d. Transmissivity could not be computed by Theis method using drawdown corrected by Correction 2. Transmissivity from the recovery test is 159.2m^2/d. Considering the significouldt well loss and large variation of transmissivities computed using different drawdowns, the representative transmissivity for B-1 well could be the one obtained from the recovery test, which is 159.2m^2/d.

Representative storage coefficient might be 1.40×10^{-05} which is computed from both Theis and Cooper-Jacob methods using drawdown corrected by Correction 1.

B-2 well (depth: 192m)

Transmissivity obtained from the recovery test method, which is 112.9m^2/d, is about 10 times higher than that obtained from Theis method using measured drawdown. Transmissivity computed from Cooper-Jacob method using corrected drawdown by Correction 2, which is 105.6m^2/d, is almost the same as that of the recovery test method. Thus the logarithmic average of the two transmissivities, which is 109.2m^2/d, is employed as the representative transmissivity for B-2 well.

Representative storage coefficient obtained from the Cooper-Jacob method using corrected drawdown by Correction 2 is 8.13×10^{-10}.

B-3 well (depth: 153m)

This well had the highest well efficiency among the five observation wells at Site-B so that the aquifer parameters were computed using only the measured drawdown. Transmissivities computed by Theis and Cooper-Jacob methods were 1329.6 m^2/d and 1162.5m^2/d, respectively. Recovery test is not reliable in this case because water level had fluctuated in the latter half of the test period which might be caused by nearby pumping wells. Representative transmissivity is thus computed as 1,243.2m^2/d which is the logarithmic average of the two transmissivities (by Theis and Cooper-Jacob methods).

Storage coefficients, 7.18×10^{-43} and 5.19×10^{-54}, computed by Theis and Cooper-Jacob methods were very small; representative storage coefficients is 1.93×10^{-48} which is the logarithmic average of these two small values.

B-4 well (depth: 94m)

This well's appwerent well efficiency is computed as 114.3%; hence, the aquifer parameters were computed only from the measured drawdown. Transmissivities computed from the three methods were almost the same, ranging from 61.3m^2/d to 70.4m^2/d. Representative transmissivity is 66.3m^2/d which is the logarithmic average of the three transmissivities.

The respective storage coefficients from Theis and Cooper-Jacob methods were 1.69×10^{-05} and 7.51×10^{-06}. Representative storage coefficient is 1.13×10^{-05} which is the logarithmic average of the two values.

B-5 well (depth: 47m)

Aquifer parameters were computed using both the measured and corrected drawdowns. Transmissivity from the recovery test method is not reliable because the water level had fluctuated during the test period. The representative transmissivity is 232.5m^2/d which is the logarithmic average of the transmissivities obtained from Theis and Cooper-Jacob methods using corrected drawdown by Correction 2.

Representative storage coefficient is 2.46×10^{-14} which is the logarithmic average of the storage coefficients obtained from Theis and Cooper-Jacob methods using corrected drawdown by Correction 2.

(c) **Site-C**

C-1 well (depth: 320m)

This well had poor well efficiency (only 36.8%). Transmissivities were computed by Theis, Cooper-Jacob and recovery test methods. Transmissivity from the recovery test method, which is 148.9m^2/d, is not reliable since the straight line portion of the semilogarithmic plot is short. Transmissivities obtained from Theis method using measured and corrected drawdowns were smaller than those obtained using the Cooper-Jacob method. This is because the Cooper-Jacob method takes strictly the plotted straight line portion. Thus, the representative transmissivity is 63.8m^2/d which is the logarithmic average of the computed transmissivities by the Cooper-Jacob method using drawdowns corrected by Corrections 1 and 2.

Representative storage coefficient, which is the logarithmic average of the computed storage coefficients by the Cooper-Jacob method using the above said corrected drawdowns, is 4.45×10^{-9}.

1.2.3 Water Quality

Water samples were collected from the 18 monitoring wells constructed by the JICA Study Team. Samples were taken during the continuous pumping test. Temperature, electric conductivity, and pH values were measured at the time of sampling. Samples were transported to the laboratory and analyzed for the following chemical parameters.

pH, Electric Conductivity, Calcium Ion (Ca^{2+}), Magnesium Ion (Mg^{2+}), Sodium Ion (Na^+), Potassium Ion (K^+), Manganese Ion (Mn^{2+}), Ammonium Ion (NH_4^+), Bicarbonate Ion (HCO_3^-), Sulfate Ion (SO_4^{2-}), Iron Ion (Fe^{2+}), Chloride Ion (Cl^-), Bromide Ion (Br^-), Iodide Ion (I^-), Nitrate Ion (NO_3^-), Nitrite Ion (NO_2^-)

Chemical analyses for seven wells had been completed, and the results were given in Table 1.2.2.

1.2.4 Installation of Monitoring Equipment

(1) Construction of Monitoring Wells

Three sites were selected for the construction of the 18 monitoring wells, namely:

Site-A: Rom Klao Village of NHA, Lat Krabang
Site-B: AIT Campus, Pathum Thani
Site-C: Ron Riang Wat Klong Kru, Samut Sakhon

The locations of these sites were shown in Figure 1.1.1.

In Site-A, eight (8) monitoring wells were constructed (see Figure 1.2.4). The well depths range from 48m to 574m. The well screen position is determined from the results of lithologic observation of the core boring and resistivity logging conducted at A-1 well (depth: 574m). The effective length of screen is 7.25m for A-2 well, A-3 well, A-4 well, A-5 well, and A-6 well; for A-7 well and A-8 well, it is 5m. The specifications of each monitoring well were given in Table 1.2.3.

In Site-B, five (5) monitoring wells were constructed (see Figure 1.2.5). The well depths range from 47m to 272m. The well screen position is determined from the results of lithologic observation of the core boring and resistivity logging conducted at B-1 well (depth: 272m). The effective length of screen is 7.25m for B-1 well and 5.00m for the other wells. The specifications of each monitoring well were given in Table 1.2.3.

In Site-C, five (5) monitoring wells were constructed (see Figure 1.2.6). The well depths range from 78m to 320m. The well screen position is determined from the results of lithologic observation of the core boring and resistivity logging conducted at C-1 well (depth: 320m). The effective length of screen is 7.25m for C-1 well and 5.00m for the other wells. The specifications of each monitoring well were given in Table 1.2.3.

After drilling each well, well casings and screens were installed. The diameter of casing pipes is 7" and that of screens 8". The bottom plug, sliding unit, cement basket, cement ejector, and centralizers for casing pipes were installed along with the casing pipes and screens. Cement grouting were carried out above the cement basket. The space between casing pipes and drilled hole is filled up by gravel packing.

Well development is carried out by using the water jetting and air jetting methods. The water jetting method is used to clean the screen portion, and then the air jetting method is used until water from the well becomes clean.

After the completion of well development, pumping tests were performed at each well and water samples were collected for chemical analyses.

Lastly, the observation pipes (4" in diameter) for measuring land subsidence were installed along with the centralizers. The standard drawing is given in the Appendices.

(2) Installation of Monitoring Equipment

The monitoring wells will be used to measure groundwater level as well as land subsidence. The monitoring equipment described below were installed in each monitoring well. The schematic diagrams of the monitoring system were given in the Appendices.

Equipment for Monitoring Land Subsidence

The set of land subsidence equipment consists of sensor and monitor. The land subsidence sensor is installed at each monitoring well and consists of the sensor itself, dial gauge, bracket, and detection plate. For each monitoring well, two concrete footings were constructed and an I-beam is placed on top of the footings. The sensor is fixed at the observation pipes and measures the relative displacement between the observation pipes and the I-beam.

The land subsidence monitor consists of a digital panel meter, D.C. power supply, uninterruptive power supply, operation unit, recorder, and data logger. A 16-channel monitor is installed in Site-A and 10-channel monitors were installed in Site-B and Site-C. The monitor records the measured displacements from all sensor units. The data could be retrieved by an IC memory card, transferred to personal computers and analyzed.

Equipment for Monitoring Groundwater Level

The set of equipment for groundwater level monitoring consists also of sensor and monitor. The water level sensor was installed below the well's groundwater level. The range of measurements is 20m, so that the location of the installation should be cwerefully selected. The detected changes in water level were recorded by the water level monitor which works similarly as the land subsidence monitor.

(3) Construction of Observation Houses

Three (3) observation houses were constructed in Site-A and two (2) observation houses were constructed in Site-B and in Site-C. Drawings of the observation houses were also included in the Appendices.

(4) Installation of Benchmarks

Two (2) types of benchmark were constructed in each site: one is the surface benchmark and the other is the 1m-depth benchmark. Schematic diagrams of these benchmarks were given in the Appendices.

Two (2) benchmarks were also placed on the I-beam. Another three (3) benchmarks were fixed on top of the surface casing pipe, on top of the casing pipe and on the side of the observation pipe.

(5) Installation of Pore Water Pressure Meters

Five (5) pore water pressure meters were installed in the clayey beds in Site-A. Two (2) holes were drilled: one is 35m deep and the other is 15m deep. Two (2) pore water pressure meters were installed at 34-m and 25-m depths in the 35-m depth hole. In the 15-

m depth hole, three (3) pore water pressure meters were installed at 15-m, 10-m, and 5-m depths.

Two (2) holes were also drilled in Site-B and in Site-C for the installation of pore water pressure meters. Depths and diameters of the drilled holes were the same as those in Site-A.

1.2.5 Leveling

Leveling surveys were conducted from an existing benchmark to the monitoring station to determine the altitudes of the benchmarks constructed at the site as well as the top of pipe and I-beam of each monitoring well. The following existing benchmarks were selected as the reference benchmarks:

for Site-A: DMR 36 benchmark
for Site-B: CI 25-1 benchmark
for Site-C: DMR 5 benchmark

Accuracy of the leveling survey was determined by the difference of the two single runs, which should be less than 2.5mm S, where S is the distance of a single run in km.

Table 1.2.1 RESULTS OF PUMPING TESTS PERFORMED AT JICA MONITORING WELLS

WELL NAME	DEPTH (m)	SCREEN DEPTH (m)	SCREEN LENGTH (m)	RESULTS OF STEP-DRAWDOWN TEST			RESULTS OF CONTINUOUS PUMPING TEST AND RECOVERY TEST								
				AQUIFER LOSS COEFFICIENT (day/m2)	WELL LOSS COEFFICIENT (day2/m5)	AVERAGE WELL EFFICIENCY (%)	PUMPING RATE (m3/d)	STATIC WATER LEVEL (m)	MEASURED DRAWDOWN (m)	SPECIFIC CAPACITY (m2/d)	TRANSMISSIVITY (m2/d)			STORAGE COEFFICIENT	
											THEIS MEASURED <CORRECTED 1> (CORRECTED 2)	COOPER-JACOB MEASURED <CORRECTED 1> (CORRECTED 2)	RECOVERY MEASURED	THEIS MEASURED <CORRECTED 1> (CORRECTED 2)	COOPER-JACOB MEASURED <CORRECTED 1> (CORRECTED 2)
JICA A-1	574	549.190 - 557.495	7.25												
JICA A-2	437	426.190 - 436.495	7.25	4.15E-02	7.41E-05	70.720	360.0	20.292	34.341	10.4	29.3 <50.6> (69.5)	38.7 <67.0> (89.3)	26.1	7.73E-12 <1.34E-11> (1.93E-16)	5.49E-16 <9.43E-16> (1.37E-21)
JICA A-3	360	351.190 - 359.495	7.25	1.90E-02	1.50E-06	96.645	1008.0	20.725	20.723	48.6	63.7	65.5	66.7	1.71E-03	1.12E-03
JICA A-4	302	293.190 - 301.495	7.25	1.36E-02	8.26E-06	83.640	1008.0	24.893	19.400	52.0	157.5 <212.9> (263.6)	182.5 <246.5> (307.2)	233.3	1.96E-12 <2.66E-12> (8.38E-15)	8.32E-15 <8.55E-15> (7.62E-16)
JICA A-5	215	206.190 - 214.495	7.25	1.14E-01	1.34E-04	81.137									
JICA A-6	145	136.190 - 144.495	7.25												
JICA A-7	108	101.960 - 107.495	5.00	7.60E-02	9.99E-05	82.776									
JICA A-8	48	41.960 - 47.495	5.00	2.25E-03	2.29E-07	95.469	1020.0	17.580	3.490	292.3	942.4	905.0	865.2	1.63E-12	7.01E-12
JICA B-1	272	263.180 - 271.495	7.25	1.37E-02	5.15E-04	20.027	144.0	35.050	26.204	5.5	9.4 <57.0> (N.A.)	9.4 <56.9> (337.3)	159.2	2.32E-06 <1.40E-06> (N.A.)	2.32E-08 <1.40E-05> (8.01E-30)
JICA B-2	192	185.870 - 191.495	5.00	3.06E-02	3.43E-04	47.203	172.8	31.200	22.910	7.5	11.6 <36.2> (69.9)	15.8 <49.0> (105.6)	112.9	1.42E-05 <4.42E-05> (7.88E-11)	2.88E-06 <8.92E-06> (8.13E-16)
JICA B-3	153	146.960 - 152.495	5.00	6.48E-03	2.35E-07	98.133	1080.0	31.845	7.105	152.0	1329.6	1162.5	1800.6	7.16E-43	5.19E-54
JICA B-4	94	87.960 - 93.495	5.00	2.74E-02	(-5.85E-06)	(114.294)	1080.0	24.980	26.885	40.2	67.6	70.4	61.3	1.69E-05	7.51E-06
JICA B-5	47	40.960 - 46.495	5.00	1.33E-02	2.77E-05	78.024	336.0	6.600	8.195	41.0	111 <180.3> (226.0)	115.4 <189.9> (239.2)	482.0	1.31E-10 <2.12E-10> (7.96E-14)	3.49E-11 <3.83E-11> (7.61E-15)
JICA C-1	320	311.190 - 319.495	7.25	5.65E-02	1.07E-03	36.765	108.0	27.100	10.440	10.3	14.6 <43.1> (46.7)	20.4 <59.6> (66.2)	146.9	7.76E-05 <2.26E-04> (9.03E-07)	1.67E-07 <4.88E-07> (4.06E-11)
JICA C-2	212	205.970 - 211.500	5.00	5.78E-02	6.25E-04	55.203									
JICA C-3	140	133.960 - 139.495	5.00												
JICA C-4	105	98.960 - 104.495	5.00												
JICA C-5	78	71.960 - 77.495	5.00												

N.A. : Not applicable.

MEASURED : INTERPRETED USING MEASURED DATA
<CORRECTED 1> : INTERPRETED USING CORRECTED DATA COMPUTED FROM WELL EFFICIENCY AT THE PUMPING RATE.
(CORRECTED 2) : INTERPRETED USING CORRECTED DATA COMPUTED FROM WELL EFFICIENCY AT THE DRAWDOWN.

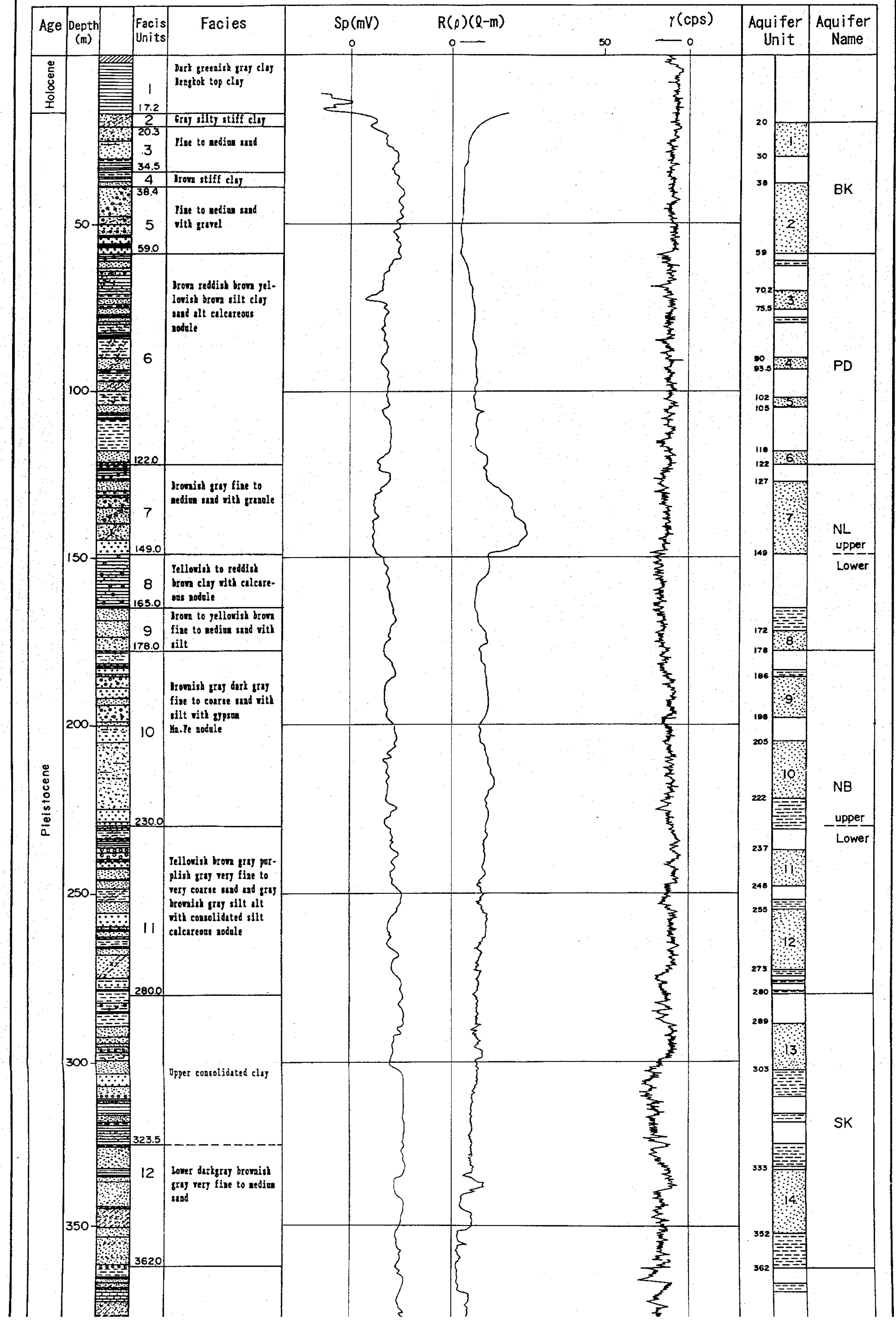
Table 1.2.2 CHEMICAL ANALYSES OF GROUNDWATER FROM MONITORING WELLS

Well No.	A-3	B-1	B-2	B-2	B-3	B-4	B-5	C-1	C-1
Well Depth (m)	215	272	192	192	153	94	47	320	320
Sampling Date	23-May-93	22-Feb-93	23-Mar-93	08-May-93	08-May-93	29-Apr-93	29-Apr-93	15-Mar-93	08-May-93
pH	8.13	7.88	7.71	7.60	7.64	7.59	6.35	7.50	7.34
Electric Conductivity (us/cm)	975	981	865	858	783	1450	21900	477	486
Calcium Ion (ppm)	6.34	24.13	27.13	26.1	30.5	71.2	76.5	40.21	45.0
Magnesium Ion (ppm)	0.31	4.43	5.49	6.06	21.38	15.06	122.6	14.18	15.19
Sodium Ion (ppm)	134.77	46.40	303.14	110.63	95.22	212.78	329.7	29.44	37.57
Potassium Ion (ppm)	1.32	2.77	2.08	1.86	1.47	2.41	45.19	17.69	7.03
Manganese Ion (ppm)	ND	0.02	<0.02	0.06	0.06	0.35	1.22	<0.02	0.06
Ammonium Ion (pmm)	ND	ND	ND	0.25	0.17	0.17	1.54	ND	0.08
Bicarbonate Ion (ppm)	222.0	90.30	179.3	201.3	206.20	195.4	242.2	146.4	151.28
Sulfate Ion (ppm)	34.5	36.05	70.70	60.14	46.21	162.3	1923.0	7.24	6.33
Iron Ion (ppm)	0.16	0.02	<0.02	0.17	0.07	0.13	6.6	ND	0.07
Chloride Ion (ppm)	69.5	203.0	80.7	78.3	34.2	210.4	7631.7	10.8	7.6
Bromide Ion (ppm)	<0.3	1.1	1.6	1.2	1.8	0.6	<0.3	1.6	1.3
Iodide Ion (ppm)	0.17	<0.2	<0.2	<0.2	<0.2	0.2	0.5	<0.2	<0.2
Nitrate Ion (ppm)	1.7	<1	<1	2.74	2.88	ND	7.73	<1	1.97
Nitrite Ion (ppm)	NIL	<6	<6	8.9	11.8	20.8	26.1	ND	<6

Table 1.2.3 SPECIFICATION OF JICA MONITORING WELLS

Site	Well No.	Planned Well Depth (m)	Actual Well Dept (m)	Depth Difference (Actual-Planned) (m)	Screen				Cementation Depth (m)
					5.50m (nos.)	2.75m (nos.)	Total Effective Length (m)	Screen Depth (m)	
A	JICA A-1	550	574	+24	1	1	16.50	555.800-574.000	471.60-531.60
	JICA A-2	450	437	-13	1	1	7.25	428.190-436.495	355.60-410.60
	JICA A-3	350	360	+10	1	1	7.25	351.190-359.495	274.40-324.40
	JICA A-4	300	302	+2	1	1	7.25	293.190-301.495	230.60-275.60
	JICA A-5	200	215	+15	1	1	7.25	206.190-214.495	148.60-188.60
	JICA A-6	150	145	-5	1	1	7.25	136.190-144.495	83.60-118.60
	JICA A-7	100	108	+8	1	-	5.00	101.960-107.495	54.30- 84.30
	JICA A-8	50	48	-2	1	-	5.00	41.960- 47.495	15.30- 30.30
Subtotal at Site-A		2,150	2,189	+39	8	6	62.75		
B	JICA B-1	300	272	-28	1	1	7.25	263.180-271.495	200.60-245.60
	JICA B-2	200	192	-8	1	-	5.00	185.970-191.495	128.20-168.20
	JICA B-3	150	153	+3	1	-	5.00	146.960-152.495	94.30-129.30
	JICA B-4	100	94	-6	1	-	5.00	87.960- 93.495	40.30- 70.30
	JICA B-5	50	47	-3	1	-	5.00	40.960- 46.495	9.30- 29.30
Subtotal at Site-B		800	758	-42	5	1	27.25		
C	JICA C-1	300	320	+20	1	1	7.25	311.190-319.495	248.60-293.60
	JICA C-2	200	212	+12	1	-	5.00	205.970-211.500	142.40-182.40
	JICA C-3	150	140	-10	1	-	5.00	133.960-139.495	81.30-116.30
	JICA C-4	100	105	+5	1	-	5.00	98.960-104.495	51.30- 81.30
	JICA C-5	50	78	+28	1	-	5.00	71.960- 77.495	34.30- 54.30
Subtotal at Site-C		800	855	+55	5	1	27.25		
Grand Total		3,750	3,802	+52	18	8	117.25		

JICA-A LOGGING



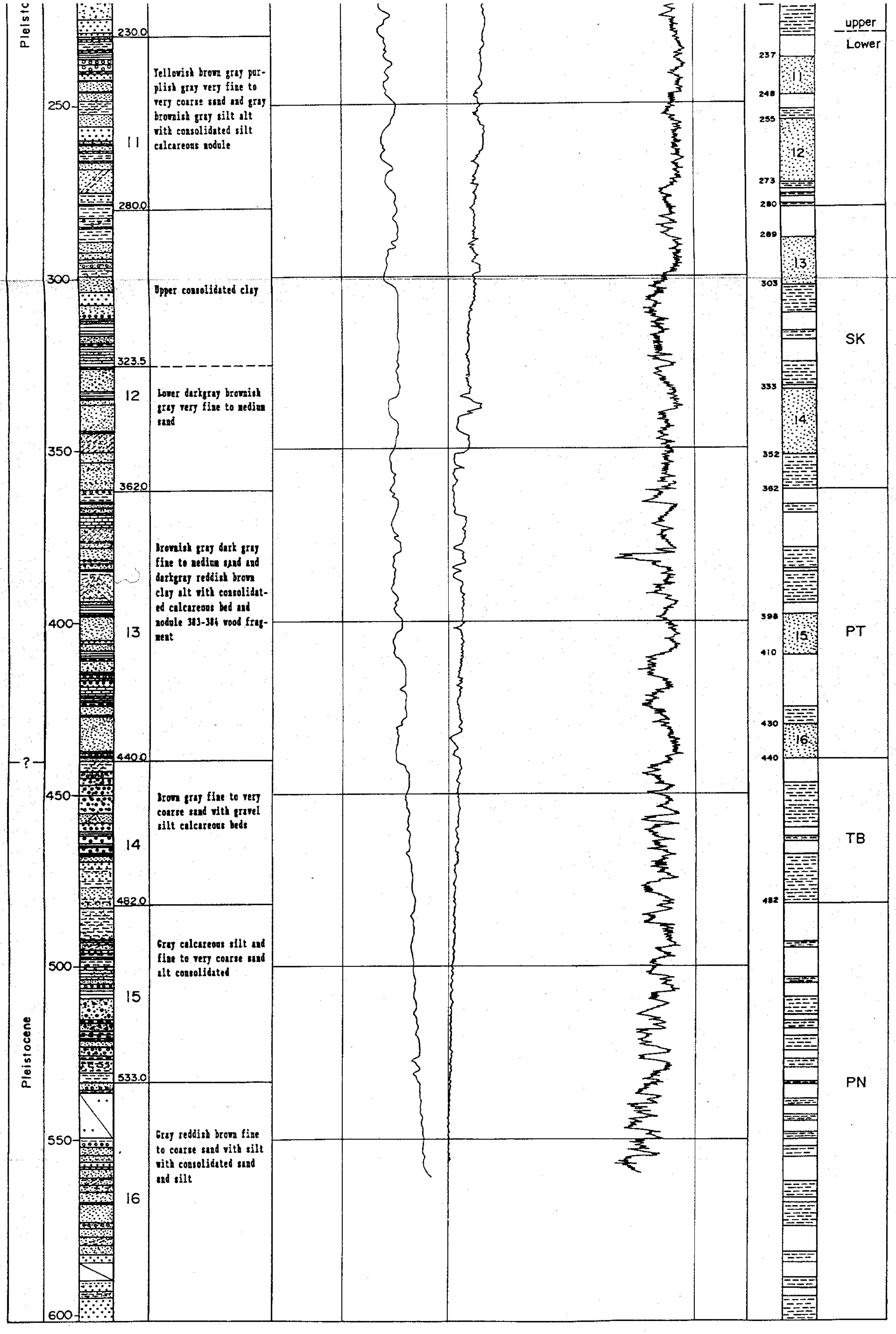


Figure 1.2.1	JICA - A Logging and Aquifer
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	KOKUSAI KOGYO CO., LTD.

JICA - B LOGGING

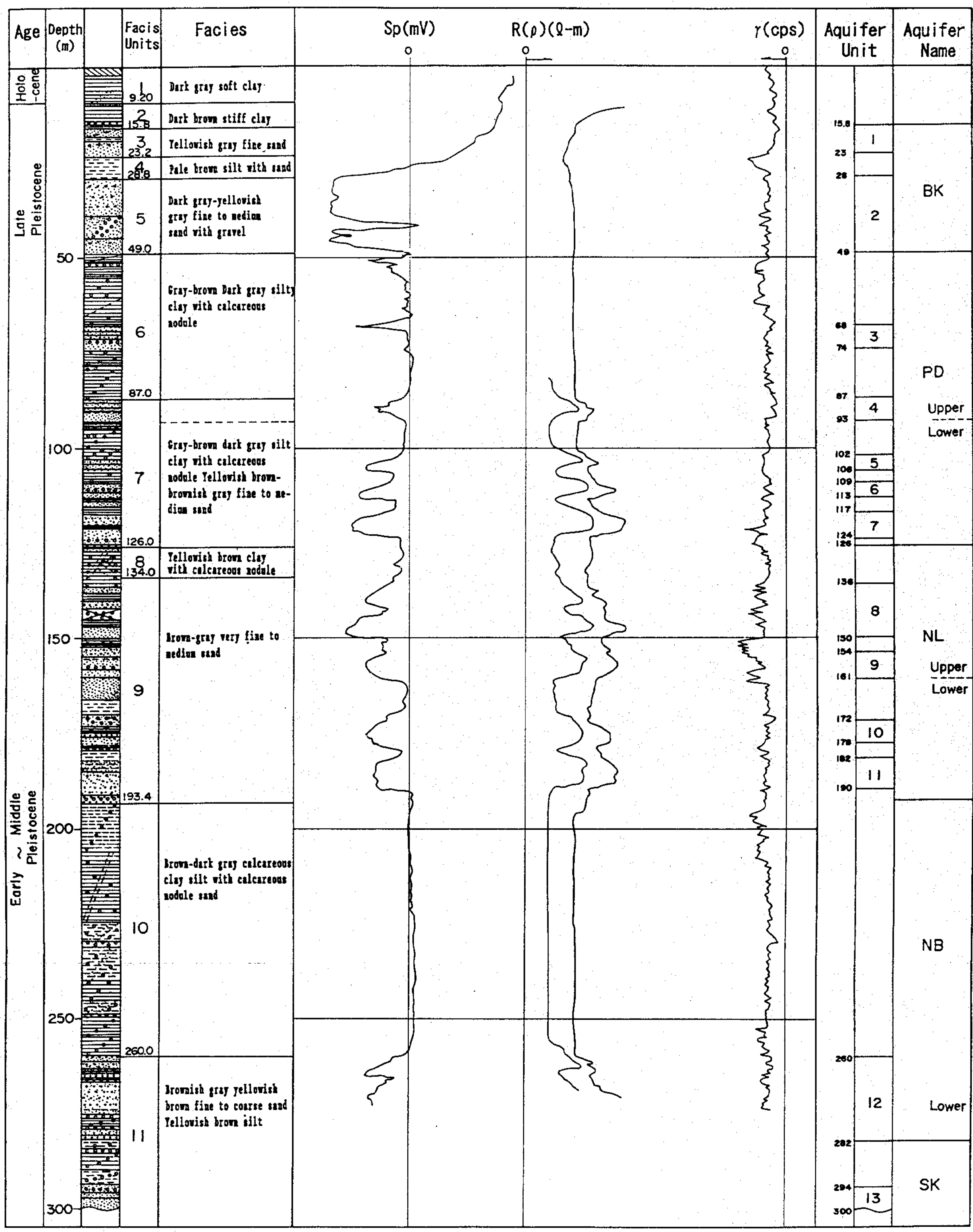


Figure 1.2.2	JICA - B Logging and Aquifer
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	KOKUSAI KOGYO CO., LTD.

JICA - C LOGGING

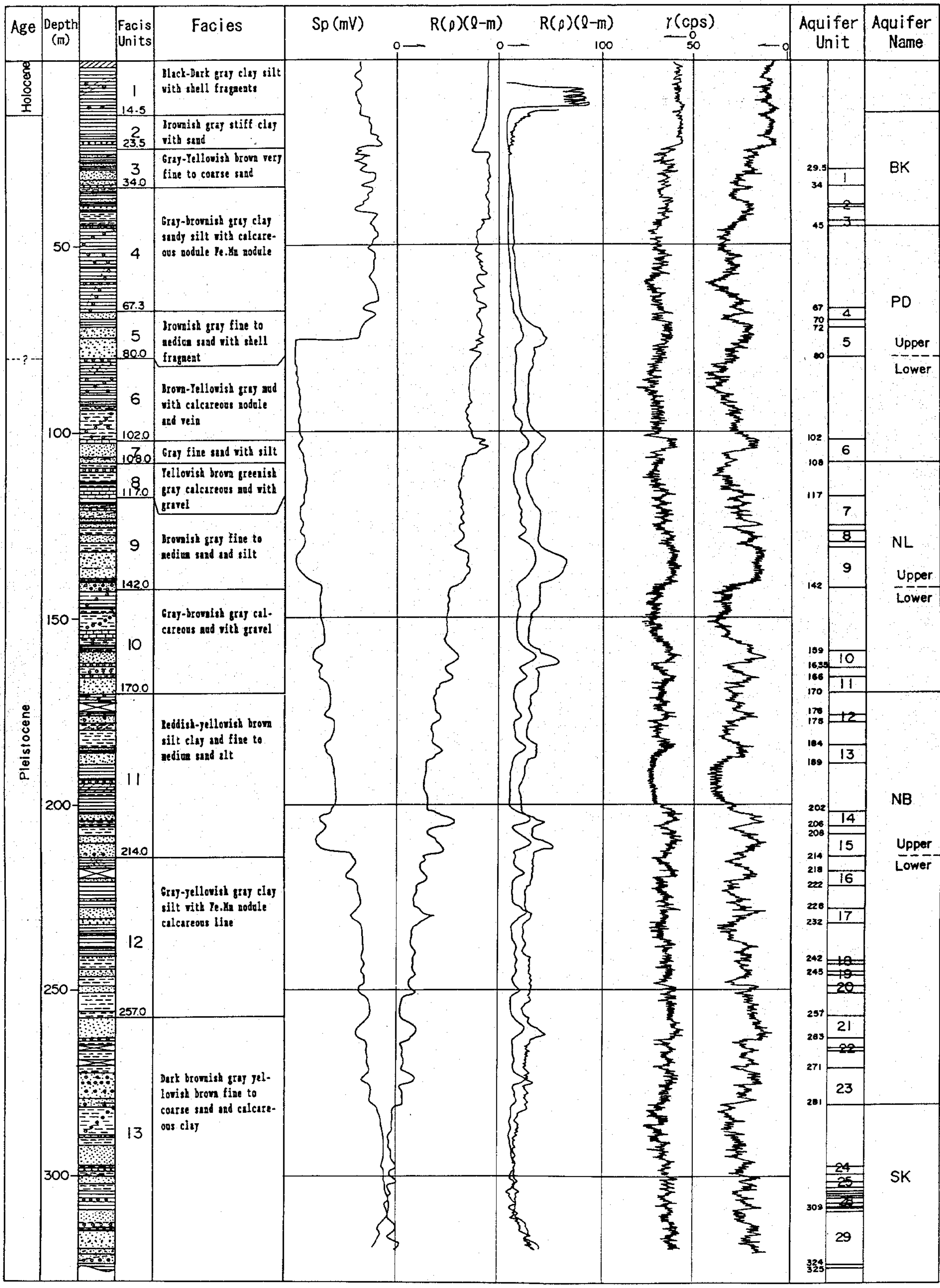


Figure 1.2.3 JICA - C Logging and Aquifer

THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA) | KOKUSAI KOGYO CO., LTD.

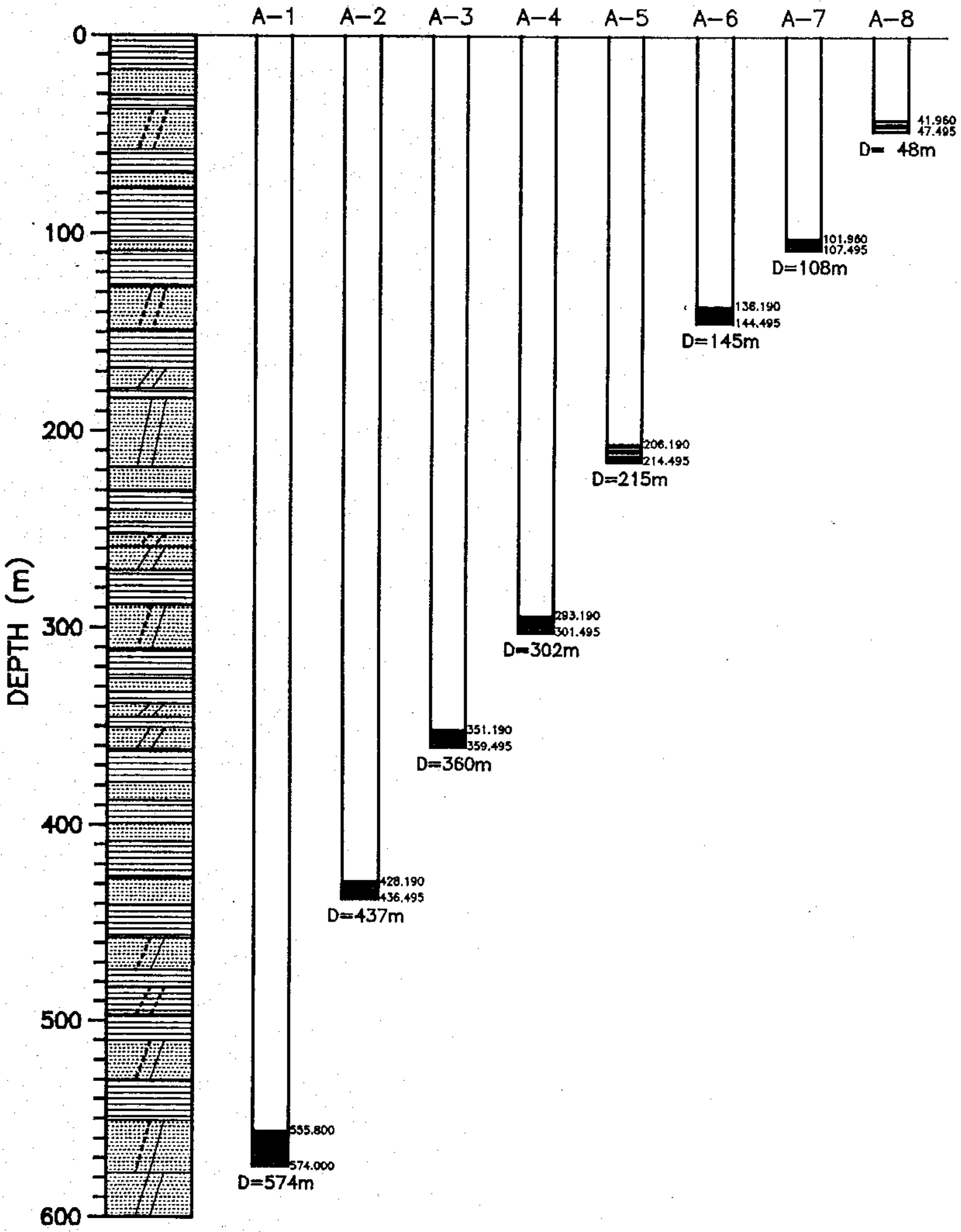


Figure 1.2.4	**SCHEMATIC DIAGRAM OF MONITORING WELLS AT SITE - A**
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	KOKUSAI KOGYO CO., LTD.

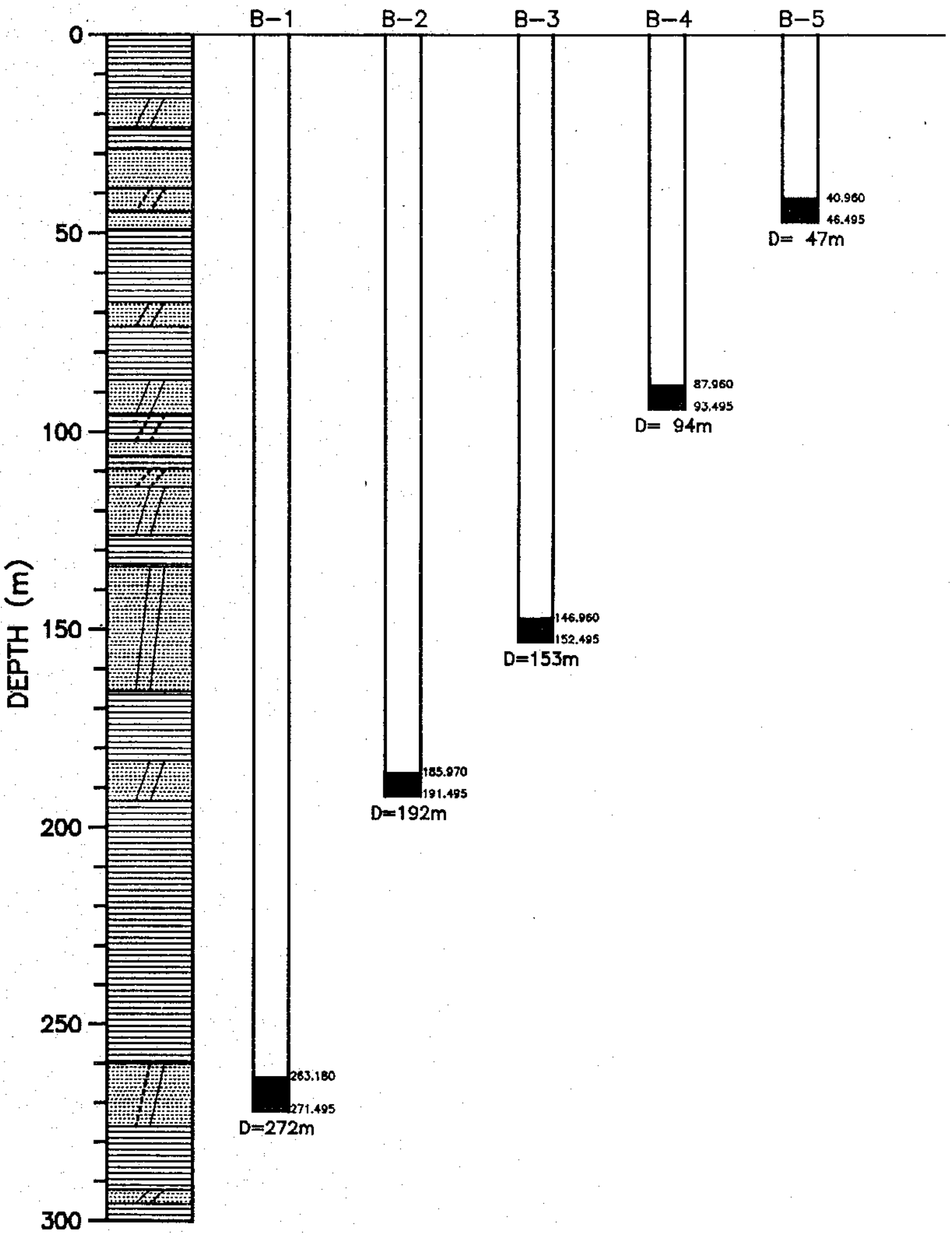


Figure 1.2.5	SCHEMATIC DIAGRAM OF MONITORING WELLS AT SITE - B
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	KOKUSAI KOGYO CO., LTD.

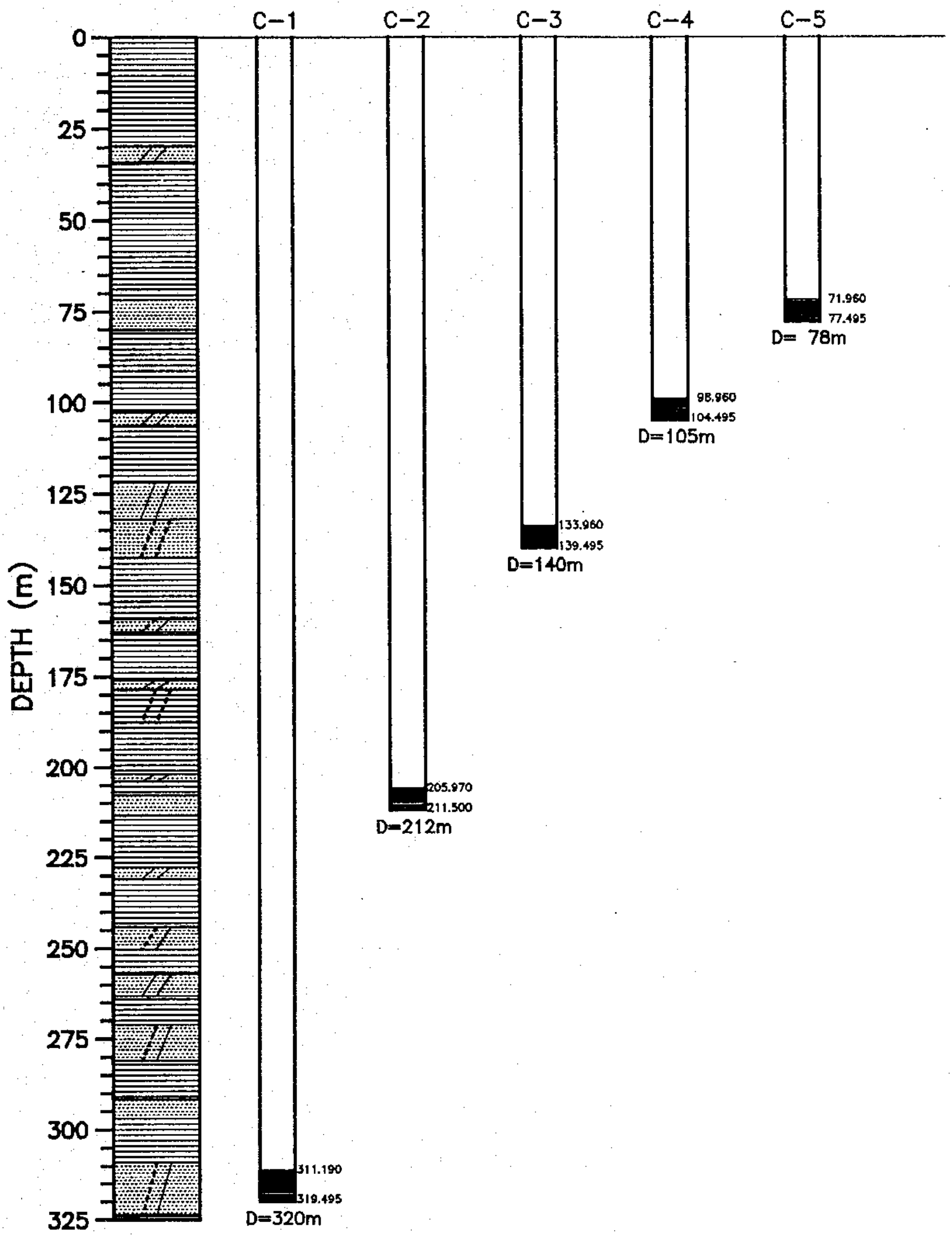


Figure 1.2.6	SCHEMATIC DIAGRAM OF MONITORING WELLS AT SITE - C
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	KOKUSAI KOGYO CO., LTD.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 2 DATABASE SYSTEM

2.1 Background

Effective use of large data sets will require a more sophisticated approach. A database system offers such an approach. It provides storage and access capabilities for large amounts of data. Proper use of a database system eliminates the need for maintaining several highly redundant input data files. Users want to employ the same data for many types of analyses and application programs. Storing the data in a database system with adequate access capabilities allows the data to be reused without extensive reformatting. The typical program user requires comparisons of the results of several similar analyses. Storing results using a database system simplifies comparative reporting.

In groundwater basin management, a database system is needed to utilize and analyze large volume of data and information collected during monitoring. It is particularly needed to manage the data on land subsidence, groundwater levels, benchmark elevations, groundwater withdrawals, and water quality. Sometimes it is used to prepare a geological columnar section to understand the structure of a groundwater basin. It also provides the necessary information to decide on schemes tq regulate groundwater use. More than anything else, the database system is roled to accummulate data for a long period of time and enable the users to evaluate them comprehensively from the historical viewpoint.

The **groundwater database system** established in the Department of Mineral Resources (DMR) by the JICA Study Team aims to support the management of groundwater and land subsidence in the Bangkok Metropolitan Area and its vicinity. The system was designed to facilitate the storage and retrieval and the preparation of tables and reports related to well information, land subsidence data, meteorological data, groundwater level data, hydrological station data as well as related literature through the use of computers.

The system is composed of six main databases:

1.	Well Inventory	- contains the location of wells and well data
2.	Meteorology	- contains the meteorological station data and data being observed
3.	Hydrology	- contains the hydrological station data and data being observed
4.	Groundwater Monitoring	- contains the groundwater level and water quality data
5.	Land Subsidence	- contains the benchmark data and land subsidence and pore water pressure data
6.	Literature Records	- contains the library of related literatures on groundwater management

The groundwater database system is flowcharted in Figure 2.1.1.

2.2 Hardware Requirements

The system runs on 80386 processors but a faster computer would be preferable. It should have the following configuration:

1. Minimum memory size of 4 megabytes (MB) but 8 MB is ideal.
2. Hard disk space of 100 MB
3. Laser printer and a dot Matrix printer
4. Mouse
5. Color monitor

2.3 Software Requirements

1. FOXPRO 2.5
2. SPSS 4.0
3. DOS 5.0 or higher
4. Cache software

The FOXPRO database software is the main database software used for the creation and management of the database system. A program written in FOXPRO was prepared to facilitate data entry and editing, with validation on the integrity of the data incorporated in the program. Several reports can be generated from the database and using standard FOXPRO commands that were incorporated in the database program, the user is able to learn easily the use of the program.

The SPSS statistical software was used in generating some statistical reports such as distribution of wells by Changwat, aquifer, type of users, and agency responsible, and estimation of daily groundwater pumpage for preparing the historical yearly tabulation of groundwater pumpage. The groundwater pumpage is also distributed by Changwat, Agency, Aquifer, Amphoe and *x* and *y* coordinates.

2.4 Databases

2.4.1 Well Inventory Database

The well inventory database stores data of DMR-registered private wells, non-DMR-registered public wells which were constructed or managed by DMR, PWD, MWA, PWA, DOH, ARD and IEAT, and groundwater monitoring wells operated by DMR and constructed by the JICA Study Team. Abandoned and inactive wells are also stored in the database.

Well inventory are stored in seven related data files:

1.	\GWS\WINV\WELL.DBF	- well location and basic data
2.	\GWS\WINV\WSCRN.DBF	- well screen data
3.	\GWS\WINV\WSTR.DBF	- well strata log record
4.	\GWS\WINV\WCAS.DBF	- well casing schedule
5.	\GWS\WINV\WSEAL.DBF	- annular seal data
6.	\GWS\WINV\WQUAL.DBF	- physical and chemical quality contents
7.	\GWS\WINV\TQUAL.DBF	- toxic elements data

Monthly discharge data of public wells are stored in \GWS\NDMR\DISC.DBF. These are used for the computation of historical groundwater pumpage. For wells which do not have actual groundwater pumpage, groundwater pumpage is estimated using the well yield data obtained during pumping test and the number of hours of operation per day.

Twelve separate screens are used for data entry and editing:

1. Well Location
2. Permits
3. Well Design
4. Strata Log
5. Well Casing
6. Well Screens
7. Annular Seal
8. Sand Collector
9. Well Development
10. Water Quality (Physical)
11. Water Quality (Chemical)
12. Toxic/Trace Elements

Several database files are used in validating data entries:

\GWS\DBFS\CHANGWAT.DBF	- Changwat names and codes (01-Bangkok, 02-Nonthaburi, 03-Pathum Thani, 04-Samut Prakan, 05-Samut Sakhon, 06-Phra Nakhon Si Ayutthaya, 07-Nakhon Pathom, 08-Chachoengsao)
\GWS\DBFS\AMPHOE.DBF	- Amphoe names and codes
\GWS\DBFS\TAMBON.DBF	- Tambon names and codes
\GWS\DBFS\TYPE.DBF	- Well type codes (public, private, observation)
\GWS\DBFS\STATUS.DBF	- Well status codes (1-Active, 2-Inactive, 3-Abandoned, 4-Others)
\GWS\DBFS\PURPOSE.DBF	- Well use codes (11-Domestic, 21- Institutional, 31- Commercial, 41...63-numerous Industrial categories)
\GWS\DBFS\CASING.DBF	- Casing types and codes (1-ASTM A-53, 2-ASTM A-120, 7-Thermoplastics, etc.)
\GWS\DBFS\DEVELOP.DBF	- Well development codes (1-Overpumping, 2-Backwashing, 3-Mechanical Surging, 4-Air Development by Surging and Pumping, 5-Others)
\GWS\DBFS\CHMETHOD.DBF	- Sampling method codes (1-Bailer, 2-Air-lift Samplers, 3-Submersible Pump, 4-Suction-lift Pump, 5-Gas-operated Pump, 6-Hand Pump)
\GWS\DBFS\AQUIFER.DBF	- Aquifer codes (BK-Bangkok, PD-Phra Pradaeng, NL-Nakhon Luang, NB-Nonthaburi, SK-Sam Khok, PT-Phaya Thai, TB-Thon Buri, PN-Pak Nam)
\GWS\DBFS\FLOW.DBF	- Method of flow measuremenent codes (1-Flowmeter, 2-Orifice, 3-Weir, 4-Flume, 5-Container, 6-Others)
\GWS\DBFS\AGENCY.DBF	- Agency codes (1-DMR, 2-PWD, 3-MWA, 4-PWA, 5-DOH, 6-ARD, 7-IEAT, 8-Others)
\GWS\DBFS\PUMPTEST.DBF	- Test pumping codes (1-Step Drawdown, 2-Constant rate, 3-Others)
\GWS\DBFS\SCRNTYPE.DBF	- Screen type codes (1-Slotted Perforation, 2-Continuous-slot, 3-Wedge Wire Wound, 4-Louvered and Bridge Slot)
\GWS\DBFS\SEALTYPE.DBF	- Annular seal type codes (1-Backfill, 2-Cement, 3-Cement & Sand, 4-Cement with Clay, 5-Clay, 6-Sandy Clay, 7-Sand, 8-Gravel)
\GWS\DBFS\PUMPTYPE.DBF	- Pump type codes (1-Air Compressor, 2-Air Lift Pump, 3-Hand Pump, 5-Submersible, 6-Turbine, etc)
\GWS\DBFS\ODOR.DBF	- Well odor codes (1-Odorless, 2-Slightly Smelly, 3-Strong Smell)
\GWS\DBFS\LITHO.DBF	- Lithological codes of strata encountered (C-Clay, S-Sand, B-Pebble, TS-Top Soil, etc.)
\GWS\DBFS\GRAIN.DBF	- Soil grain size codes (VF-Very Fine, F-Fine, M-Medium)
\GWS\DBFS\COLOR.DBF	- Soil color codes (B-Brown, K-Black, N-Green, P-Pink, R-Red, V-Violet, W-White, C-Cream, etc.)

Profiles of the above mentioned data files are shown in Tables 2.4.1-1 to 2.4.1-9.

2.4.2 Meteorology Database

The meteorology database contains data on meteorological stations including the monthly and annual records of rainfall, temperature (mean, minimum, and maximum), evaporation, humidity, wind velocity, sunshine duration, and solar radiation measured from these stations. There are 11 data files comprising this database containing the following:

1.	\GWS\WMET\MSTATION.DBF	- Meteorological station data
2.	\GWS\WMET\RAIN_M.DBF	- Monthly rainfall data
3.	\GWS\WMET\RAIN_DAY.DBF	- Monthly number of rainfall days
4.	\GWS\WMET\TMEAN_M.DBF	- Monthly mean temperature
5.	\GWS\WMET\TMIN_M.DBF	- Monthly minimum temperature
6.	\GWS\WMET\TMAX_M.DBF	- Monthly maximum temperature
7.	\GWS\WMET\EVAP_M.DBF	- Monthly evaporation data
8.	\GWS\WMET\HUMID_M.DBF	- Monthly humidity data
9.	\GWS\WMET\SUN_M.DBF	- Monthly sunshine duration
10.	\GWS\WMET\SOLAR_M.DBF	- Monthly solar radiation
11.	\GWS\WMET\WIND_M.DBF	- Monthly wind velocity

2.4.3 Hydrology Database

The hydrology database provides information about the hydrological gaging stations as well as the monthly and annual observations on the river discharge and gage height measured from the said stations. The database comprises five data files with the following data items:

1.	\GWS\WHLOG\HSTATION.DBF	- Hydrological station information
2.	\GWS\WHLOG\RDIS_M.DBF	- Monthly river discharge
3.	\GWS\WHLOG\RDIS_D.DBF	- Daily river discharge
4.	\GWS\WHLOG\MGAGE.DBF	- Monthly gage height
5.	\GWS\WHLOG\GAGE_D.DBF	- Daily gage height

2.4.4 Groundwater Monitoring Database

The groundwater monitoring database contains data on the groundwater monitoring stations operated by DMR as well as the monthly observations of the groundwater level measured from these stations. It also gives data on the quality of groundwater sampled periodically from these stations. The database comprises four data files with the following data items:

1.	\GWS\WHGEO\HGEO.DBF	- Groundwater monitoring station data
2.	\GWS\WHGEO\GWL.DBF	- Groundwater level observation
3.	\GWS\WHGEO\GWQUAL.DBF	- Groundwater quality measurement
4.	\GWS\DBFS\WIONS.DBF	- Names and codes of water quality parameters

2.4.5 Land Subsidence Database

The land subsidence database contains data on the land subsidence monitoring stations operated by NEB, and the DMR, BMA, NEB and RTSD benchmarks. Collected soil layer compression data and land subsidence data from benchmark levelling are entered in the database. The database is composed of four related data files containing the following data items:

1.	\GWS\WLAND\BENCHMRK.DBF	- Benchmark data
2.	\GWS\WLAND\COMPRESS.DBF	- Soil layer compression data
3.	\GWS\WLAND\POREPRES.DBF	- Pore water pressure data
4.	\GWS\WLAND\BMELEV.DBF	- Benchmark elevation data

2.4.6 Literature Records Database

The literature records database provides a library of related literatures relevant to the land subsidence and groundwater management study. The database is composed of two related data files containing the following data items:

1.	\GWS\WLITR\LITR.DBF	- Title, author(s), subject and abstract
2.	\GWS\WLITR\SUBJ.DBF	- Subject codes

2.5 Manual

The JICA Study Team has prepared for GWS users a separate GROUNDWATER DATABASE SYSTEM MANUAL which describes in detail the different procedures in the use or operation of the system.

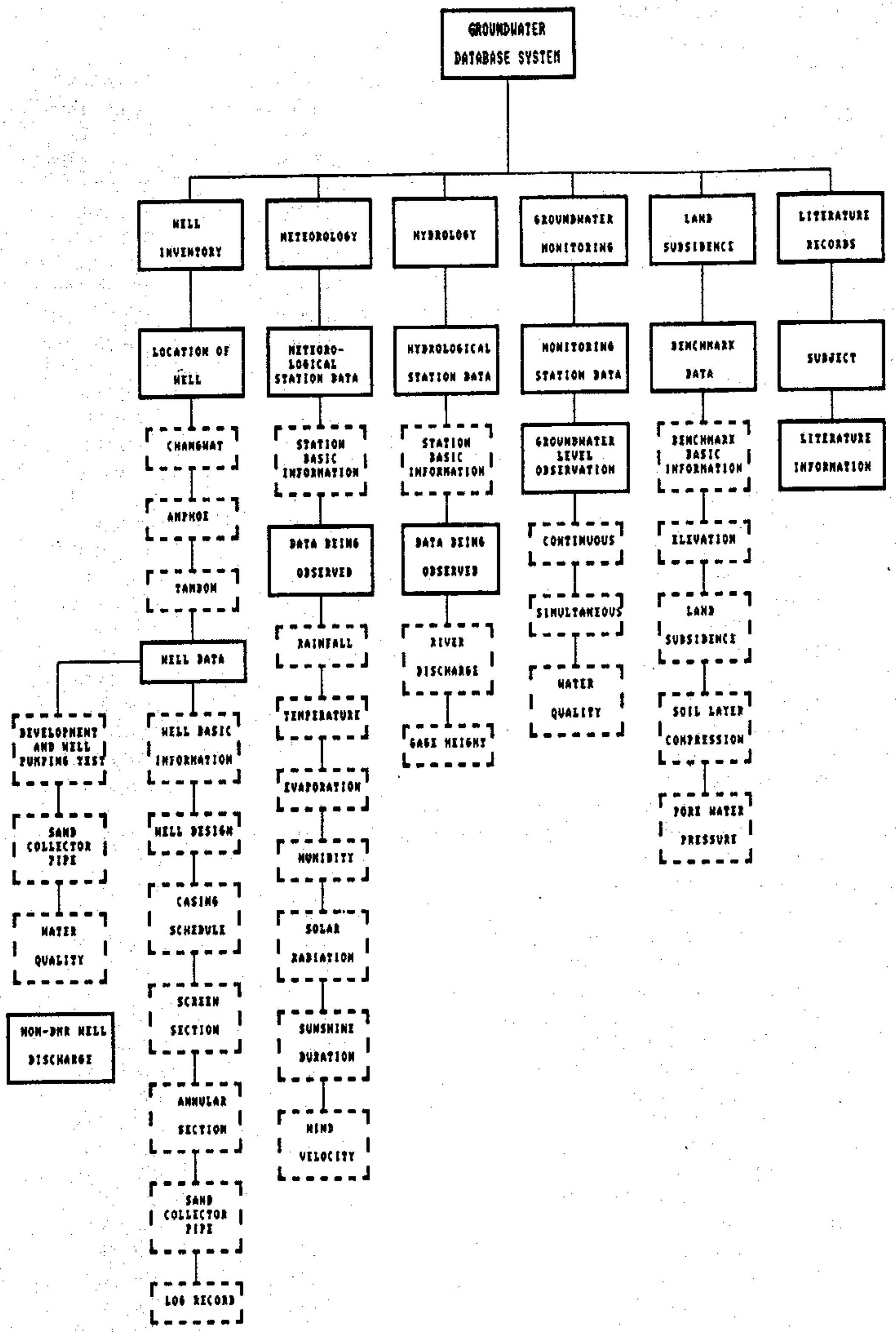


Figure 2.1.1	FLOWCHART OF THE GROUNDWATER DATABASE SYSTEM
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	KOKUSAI KOGYO CO., LTD.

TABLE 2.4.1-1 DATA PROFILE
\GWS\WINV\WELL.DBF

	DATA	NO. OF WELLS WITH DATA	DATABASE FIELD NAME
1	WELL CODE	13,944	W_CODE
2	CHANGWAT CODE	13,944	W_CHANGWAT
3	AMPHOE CODE	13,944	W_AMPHOE
4	TAMBON CODE	13,944	W_TAMBON
5	WELL TYPE	13,944	W_TYPE
6	WELL NAME	12,923	W_NAME
7	WELL STATUS	13,938	W_STATUS
8	AQUIFER	12,842	AQUI_NAME
9	SOURCE OF DATA	13,944	DAT_SOURCE
10	DRILLER CODES		DRILL_CODE
11	DRILLER	4,522	DRILLER
12	WELL NEW NUMBER	13,686	NEW_NO
13	WELL OLD NUMBER	2,641	OLD_NO
14	WELL ADDRESS	13,944	W_ADDR1
15	WELL ADDRESS	10,191	W_ADDR2
16	WELL OWNER	13,610	OWNER
17	ADDRESS OF THE OWNER	12,121	OW_ADDR1
18	ADDRESS OF THE OWNER	8,545	OW_ADDR2
19	GROUND ELEVATION	13,074	ELEVATION
20	MAP SHEET NUMBER	12,889	MAP_NO
21	LATITUDE (DEGREES)		LAT_DEGR
22	LATITUDE (MINUTES)		LAT_MIN
23	LATITUDE (SECONDS)		LAT_SEC
24	LONGITUDE (DEGREES)		LONG_DEGR
25	LONGITUDE (MINUTES)		LONG_MIN
26	LONGITUDE (SECONDS)		LONG_SEC
27	UNIVERSAL TRANSVERSE MERCATOR (UTM) EAST	13,845	UTM_E
28	UNIVERSAL TRANSVERSE MERCATOR (UTM) NORTH	13,845	UTM_N
29	GRID ZONE DESIGNATION	13,877	GZD
30	BASE MAP X-COORDINATE	13,865	X
31	BASE MAP Y-COORDINATE	13,877	Y
32	DATE DRILLING STARTED (MONTH)	6,212	START_MM
33	DATE DRILLING STARTED (DAY)	6,097	START_DD
34	DATE DRILLING STARTED (YEAR)	6,846	START_YY
35	DATE DRILLING COMPLETED (MONTH)	7,707	COMP_MM
36	DATE DRILLING COMPLETED (DAY)	7,123	COMP_DD
37	DATE DRILLING COMPLETED (YEAR)	8,664	COMP_YY
38	DRILLING PERMIT NUMBER	4,605	DRILL_NO
39	DATE ISSUED (MONTH)	4,524	ISSUE_MM
40	DATE ISSUED (DAY)	4,496	ISSUE_DD
41	DATE ISSUED (YEAR)	4,527	ISSUE_YY
42	GROUNDWATER USE PERMIT NO.	10,907	GWUSE_NO
43	PURPOSE OF USE	13,686	GW_USE
44	VOLUME PERMITTED	11,286	VOL_PER
45	ACTUAL VOLUME USE	135	VOL_ACT
46	DATE PERMIT ISSUED (MONTH)	11,096	PISSUE_MM
47	DATE PERMIT ISSUED (DAY)	11,096	PISSUE_DD
48	DATE PERMIT ISSUED (YEAR)	11,096	PISSUE_YY
49	DATE OF EXPIRATION (MONTH)	11,094	EXPIRE_MM
50	DATE OF EXPIRATION (DAY)	11,094	EXPIRE_DD
51	DATE OF EXPIRATION (YEAR)	11,096	EXPIRE_YY
52	DATE OF EXTENSION (MONTH)	930	EXTEND_MM
53	DATE OF EXTENSION (DAY)	930	EXTEND_DD
54	DATE OF EXTENSION (YEAR)	930	EXTEND_YY
55	METER INSTALLED		METER

TABLE 2.4.1-1 CONTINUATION
\GWS\WINV\WELL.DBF

DATA	NO. OF WELLS WITH DATA	DATABASE FIELD NAME
56 . METER SIZE		M_SIZE
57 . NO. OF HOURS OF OPERATION PER DAY	2,196	HRS_DAY
58 . NO. OF DAYS OF OPERATION PER WEEK	26	DAYS_WK
59 . NO. OF WEEKS OF OPERATION PER YEAR	26	WKS_YR
60 . TOTAL DRILLING DEPTH	9,248	D_DEPTH
61 . TOTAL WELL DEPTH	10,048	W_DEPTH
62 . DIAMETER OF CASING AT TOP	10,470	DIA_TOP
63 . DIAMETER OF CASING AT BOTTOM	10,044	DIA_BOTTOM
64 . DIAMETER OF RISER/SUCTION PIPE	11,072	DIA_RISER
65 . TYPE OF PUMP	12,036	PTYPE
66 . BRAND OF PUMP	117	PBRAND
67 . PUMP HP RATING	4,115	P_HP
68 . RATED PUMP CAPACITY	97	P_RC
69 . TOTAL DYNAMIC HEAD	35	P_TDH
70 . PUMP SETTING	11,078	P_SET
71 . BRAND OF MOTOR	26	MBRAND
72 . MOTOR HP RATING	26	M_HP
73 . TYPE OF CASING	5,178	C_TYPE
74 . TOTAL LENGTH OF CASING	9,719	C_LENGTH
75 . TOTAL LENGTH OF SCREENS	9,617	S_LENGTH
76 . SIZE OF GRAVEL		GR_SIZE
77 . GRAVEL DEPTH FROM	4,374	GRDEPTH_FR
78 . GRAVEL DEPTH TO	4,389	GRDEPTH_TO
79 . PIPE LENGTH	548	PIPE_LEN
80 . PIPE DIAMETER	546	PIPE_DIA
81 . PIPE DEPTH FROM	546	PDEPTH_FR
82 . PIPE DEPTH TO	545	PDEPTH_TO
83 . ELECTRIC LOGGING, RESISTIVITY LOG		ER_LOG
84 . SPONTANEOUS POTENTIAL (SP) LOG		SP_LOG
85 . RADIATION LOGGING, GAMMA RAY LOG	1	GR_LOG
86 . WELL DEVELOPMENT METHOD	4,612	W_DEV
87 . WELL DEVELOPMENT DATE STARTED (MONTH)	4,467	WDSTART_MM
88 . WELL DEVELOPMENT DATE STARTED (DAY)	4,466	WDSTART_DD
89 . WELL DEVELOPMENT DATE STARTED (YEAR)	4,466	WDSTART_YY
90 . WELL DEVELOPMENT DATE COMPLETED (MONTH)	4,450	WDCOMP_MM
91 . WELL DEVELOPMENT DATE COMPLETED (DAY)	4,449	WDCOMP_DD
92 . WELL DEVELOPMENT DATE COMPLETED (YEAR)	4,450	WDCOMP_YY
93 . WELL DEVELOPMENT DURATION	4,476	WDURATION
94 . WELL DISCHARGE	4,256	DISCHARGE
95 . DATE PUMPING TEST CONDUCTED (MONTH)	4,413	PTEST_MM
96 . DATE PUMPING TEST CONDUCTED (DAY)	4,413	PTEST_DD
97 . DATE PUMPING TEST CONDUCTED (YEAR)	4,408	PTEST_YY
98 . TYPE OF TEST PUMP	5,107	PMPTYPE
99 . PUMP CAPACITY	25	PUMPCPCT
100 . TEST PUMP SETTING	5,021	PUMPSET
101 . STATIC WATER LEVEL	9,779	SWL
102 . DRAWDOWN	9,352	DRAWDOWN
103 . YIELD	9,895	YLD
104 . SPECIFIC CAPACITY	5,185	SPCF_CPCTY
105 . METHOD OF FLOW MEASUREMENT	4,313	FLOW
106 . PUMPING DURATION	4,429	DURATION
107 . TYPE OF PUMPING TEST	4,563	PTEST_TYPE
108 . TRANSMISSIVITY	7	TRANSMISS
109 . STORAGE COEFFICIENT	1	ST_COEFF
110 . CHECK	5	CHECK

TABLE 2.4.1-2 DATA PROFILE
\GWS\WINV\WCAS.DBF

DATA	NO. OF WELLS WITH DATA	DATABASE FIELD NAME
1 . WELL CODE	9,750	W_CODE
2 . CASING NO.	9,750	CINT_NO
3 . DIAMETER	9,733	C_DIA
4 . DEPTH FROM	9,750	CDEPTH_FR
5 . DEPTH TO	9,750	CDEPTH_TO

TABLE 2.4.1-3 DATA PROFILE
\GWS\WINV\WSCRN.DBF

DATA	NO. OF WELLS WITH DATA	DATABASE FIELD NAME
1 . WELL CODE	10,366	W_CODE
2 . SCREEN INTERVAL NO.	10,366	SINT_NO
3 . TYPE	9,629	S_TYPE
4 . SCREEN DIAMETER	10,333	S_DIA
5 . SCREEN NUMBER	767	S_NUMBER
6 . SIZE OF OPENING	3,786	S_OPEN
7 . DEPTH OF INTERVAL FROM	10,366	SDEPTH_FR
8 . DEPTH OF INTERVAL TO	10,366	SDEPTH_TO

TABLE 2.4.1-4 DATA PROFILE
\GWS\WINV\WSTR.DBF

DATA	NO. OF WELLS WITH DATA	DATABASE FIELD NAME
1 . WELL CODE	67,452	W_CODE
2 . STRATA NUMBER	67,452	STR_NO
3 . DEPTH FROM	67,452	DEPTH_FR
4 . DEPTH TO	67,452	DEPTH_TO
5 . TYPE OF SOIL	67,381	TYPE
6 . GRAIN SIZE	18,560	GRAIN
7 . COLOR	34,567	COLOR

TABLE 2.4.1-5 DATA PROFILE
\GWS\WINV\WSEAL.DBF

DATA	NO. OF WELLS WITH DATA	DATABASE FIELD NAME
1 . WELL CODE	6,836	W_CODE
2 . ANNULAR SEAL SECTION NO.	6,836	SLINT_NO
3 . TYPE OF MATERIAL	6,733	SLTYPE
4 . DEPTH FROM	6,836	SLDEPTH_FR
5 . DEPTH TO	6,836	SLDEPTH_TO

TABLE 2.4.1-6 DATA PROFILE
\GWS\WINV\WQUAL.DBF

	DATA	NO. OF WELLS WITH DATA	DATABASE FIELD NAME
1	. WELL CODE	6,993	W_CODE
2	. SAMPLING METHOD		METHOD
3	. DATE OF SAMPLING (MONTH)	184	SAMPLE_MM
4	. DATE OF SAMPLING (DAY)	184	SAMPLE_DD
5	. DATE OF SAMPLING (YEAR)	185	SAMPLE_YY
6	. DATE OF ANALYSIS (MONTH)	5,681	ANAL_MM
7	. DATE OF ANALYSIS (DAY)	5,680	ANAL_DD
8	. DATE OF ANALYSIS (YEAR)	5,699	ANAL_YY
9	. PH	5,818	PH
10	. SPECIFIC CONDUCTIVITY	1,987	SPCOND
11	. TURBIDITY	5,175	TURBIDITY
12	. COLOR	4,465	COLOR
13	. ODOR	18	ODOR
14	. TEMPERATURE	30	TEMP
15	. ALKALINITY	54	ALKALINITY
16	. ACIDITY	10	ACIDITY
17	. RESIDUAL CHLORINE	16	RCHLORINE
18	. CALCIUM	1,767	CALCIUM
19	. MAGNESIUM	1,758	MAGNESIUM
20	. SODIUM	1,592	SODIUM
21	. POTASSIUM	1,545	POTASSIUM
22	. DISSOLVED IRON	94	DIS_IRON
23	. TOTAL IRON	6,625	TOT_IRON
24	. MANGANESE	5,259	MANGANESE
25	. COPPER	4,599	COPPER
26	. ZINC	4,666	ZINC
27	. CHLORIDE	6,850	CHLORIDE
28	. SULPHATE	5,010	SULPHATE
29	. CARBONATE	1,619	CARBONATE
30	. BICARBONATE	1,598	HCO_3
31	. CARBON DIOXIDE	1,610	CO_2
32	. NITRITE	1,737	NITRITE
33	. NITRATE	5,008	NITRATE
34	. FLOURIDE	5,259	FLOURIDE
35	. TOTAL SOLIDS	5,631	TSOLIDS
36	. TOTAL HARDNESS	6,590	THARDNESS
37	. NON CARBONATE HARDNESS	4,799	NON_HARD

TABLE 2.4.1-7 DATA PROFILE
\GWS\DBFS\CHANGWAT.DBF

DATA	NO. OF WELLS WITH DATA	DATABASE FIELD NAME
1 . CHANGWAT CODE	8	CHANG_CODE
2 . CHANGWAT NAME	8	CHANG_NAME
3 . CODE NAME	8	CODE_NAME

TABLE 2.4.1-8 DATA PROFILE
\GWS\DBFS\AMPHOE.DBF

DATA	NO. OF WELLS WITH DATA	DATABASE FIELD NAME
1 . CHANGWAT CODE	91	CHANG_CODE
2 . AMPHOE CODE	91	AMPHO_CODE
3 . AMPHOE NAME	91	AMPHO_NAME
4 . CODE NAME	91	CODE_NAME

TABLE 2.4.1-9 DATA PROFILE
\GWS\DBFS\TAMBON.DBF

DATA	NO. OF WELLS WITH DATA	DATABASE FIELD NAME
1 . CHANGWAT CODE	752	CHANG_CODE
2 . AMPHOE CODE	752	AMPHO_CODE
3 . TAMBON CODE	752	TAMBO_CODE
4 . TAMBON NAME	752	TAMBO_NAME
5 . CODE NAME	752	CODE_NAME

CONTENTS

LIST OF FIGURES

CHAPTER 3 REVIEW ON ARTIFICIAL RECHARGE

3.1 Recharge Methods

Artificial recharge may be defined as augmenting the natural movement of surface water into underground formations by some method of construction, by spreading of water, or by artificially changing the natural conditions (Todd,1980).

A variety of methods have been developed to recharge groundwater artificially. The most widely practiced method is water spreading. Another method is by using recharge well.

3.1.1 Spreading Methods

Water spreading was originally developed in Europe in the 19th century. Its main purpose then was to treat surface water. Rivers were ponded, and water percolated through the river bed deposits or sand dune in order to take clean water for domestic water supply. The method of artificial recharge was later introduced in the USA where it made rapid progress.

Water spreading methods may be classified into basin, stream channel, ditch and furrow, flooding and irrigation. Pit method may also be considered as a water spreading method.

(1) Basin method

Streamflow is diverted into the basins formed by constructing dikes or levees or by excavation. Water infiltrates into the shallow aquifers through the bottom of the basins.

(2) Stream channel method

The method includes stream channel improvements by widening, leveling, scarifying, or ditching to increase the time and area of infiltration through the streambed. In addition, low check dams and dikes are often constructed across the channel for the enhancement of the infiltration.

(3) Ditch and furrow method

Shallow, flat bottomed and closely spaced ditches or furrows are constructed in a series in order to obtain maximum water-contact area. Stream water is diverted to the highest beginning of the ditch and flow through ditches up to the lower end.

(4) Flooding method

Water is released at intervals over the upper end of the flooding area. A thin sheet of water over the land may be formed and water infiltrates into the ground without disturbing the surface soil. In order to control the water, embankments or ditches are constructed to surround the flooding area.

(5) Irrigation method

Water is spread in the irrigated land during dry or non-irrigating seasons. Not only from the crop land, water is recharged continuously by seepage from the canals. However, this method may cause some leaching action by the percolating water.

(6) Pit method

A pit is excavated in order to recharge directly into the aquifers. Use of abandoned excavations, such as gravel pits, is the most economical. However, frequent occurrence of siltation is a problem which is also common with other spreading methods.

3.1.2 Recharge Well Method

A recharge well admits water from the surface to aquifers. Its flow is the reverse of a pumping well. This method was firstly developed in large scale in Long Island, New York in 1933. The artificial recharge scheme aimed at preventing the lowering of groundwater level and the salt water intrusion in the west of New York. In the 1950's, the method was adopted in the west coast of the USA where land subsidence problem took place. Since then, the method has been widely applied not only in the USA but also in many European countries, Russia, Israel, China, Japan, etc.

In Japan, the first attempt of using recharge well was made in 1951 at the river side of Mukogawa, Hyogo Prefecture. The depth and diameter of the well were 70m and 50cm respectively. However, this attempt failed due to clogging since water was not treated before being recharged. Since that time, many experimental recharge wells were constructed in many places in order to investigate the control of land subsidence. However, only a few wells were successful because of clogging.

In contrast to those in Japan, recharge wells were constructed in large scale and worked successfully in other countries such as the USA, Israel, etc. For example, more than 1,000 recharge wells are being operated to control seawater intrusion in Long Island, New York. About 189,000m^3/day of pumped groundwater is returned to its original aquifers after using for air conditioning and industrial cooling. Pumped water flows through the system without aeration and returns to the aquifers.

A variety of artificial recharge methods is employed in Long Island and has played a significant role in the area.

3.2 Previous Studies Thailand

3.2.1 Injection Well in Pathum Thani

In 1972 and 1973, the DMR conducted an experimental artificial recharge test at the Thai-German Agricultural Training Center, Bangpoon, Pathum Thani Province (Ramnarong,1975). The site was located close to the Bang Luang Rak canal, a tributary of the Chao Phraya River.

The depth of the injection well was 212 feet. The well was cased with 12-inch steel pipe from the surface to 118 feet depth. A 10-inch perforated casing was continued down to a depth of 193 feet. The well tapped the Bangkok Aquifer. Six (6) observation wells were constructed to measure water level changes: four wells tapped the Bangkok aquifer, one well had its screen positioned in the Phra Pradaeng Aquifer, and the screen of the last well was placed in the Nakhon Luang aquifer.

Injection test was conducted seven (7) times: twice by a free-flow method and five times by a pressure method. The free-flow method was successful when operated with clear fresh water obtained from one of the observation wells. The rate was 75 gpm ($408m^3$/day), and water was injected for a period of 10 hours. But the free-flow method was unsuccessful when untreated canal water was injected even at a rate of 600 gpm ($3,272m^3$/day).

The pressure method was conducted at different rates and pressures. The total amount of water injected during the pressure tests was 12,392,200 gallons ($46,940m^3$/day), and the maximum rate of injection was 1,056 gpm ($5,755m^3$/day). But this was terminated because of upward leakage through the Bangkok Clay that overlies the aquifer. The longest injection was conducted for a period of 192 hours at a rate of 882 gpm ($4,809m^3$/day). But this rate decreased gradually to 774 gpm ($4,218m^3$/day) at the end of the test.

The well was redeveloped by pumping at the end of each test for a period of at least 24 hours. At the end of the last test, the specific capacity decreased from the original 79.8 gpm/ft ($1,427m^2$/day) to 29.72 gpm/ft (532 m^2/day).

Results of the recharge experiments were analyzed, and the following conclusions were derived:

1. The disposal of floodwater into the Bangkok Aquifer was achieved at an injection rate of more than 880 gpm or $200m^3$/hour. Ideally, floodwater should be treated.

2. A reduction of injection rate occurs due to clogging. Clogging was mainly caused by an accumulation of colloidal particles dissolved from clayey lenses in the aquifer and was strongly dependent upon the turbidity of the injected water.

3. Redevelopment by pumping after injection or intermittent pumping during injection operation are important to eliminate clogging.

4. Compaction of the gravel pack due to redevelopment and injection could cause a reduction of the specific capacity.

3.2.2 Ban Rong Kong Kao Recharge Project

Since 1987, PWD has been carrying out an experimental recharge project at Bang Rong Kong Kao, Tambon Buak Kang, Amphoe San Kampang, Changwat Chiang Mai. The objectives of the project are:

1. To find the right method to improve the groundwater situation and apply it to solve similar problems in other areas.

2. To solve the water supply problems in the villages; and

3. To store rainwater underground in order to mitigate flood and use it in the dry season.

Many farmers of the villages in Amphoe San Kampang, Chiang Mai are drilling wells in order to use groundwater for domestic and agricultural purposes. The depth of these wells is about 20m to 25m and the diameter is about 2 to 3 inches. Because of excessive pumping, groundwater head has declined annually since 1984 particularly in the southern part of the San Kampang. Compared with that of 1980, the 1987 groundwater level has declined more than 3m. This has resulted in the shortage of water supply because existing village wells have insufficient capacity to pump up water from lower groundwater levels.

Rong Kong Kao village was chosen as an experimental recharge site for the project that has started in 1987. A hydrogeologic study, which includes geophysical survey, drilling of a recharge well and observation wells, water level measurements and analysis of water quality, was conducted.

Two different recharge facilities were constructed: one is a surface water recharge system, and the other is a rainwater recharge system.

(1) Surface Water Recharge System

A 2m by 4m rectangular trench with a depth of 1.2m was dug and filled with gravel and sand filter. A 4-inch screen PVC pipe was buried in the trench. It was connected to a recharge well drilled next to the trench. As the trench was dug in a low ground, runoff naturally flows into and floods it in the rainy season. Water percolates through the filter down to the screen and enters into the recharge well.

(2) Rainwater Recharge System

Rainwater from roofs is gathered and stored in a tank. Overflow from this tank goes into a filter tank connected to the recharge well.

First test facility was constructed at Wat Rong Kong Kao. It consisted of a recharge well (depth: 23m) and two observation wells (depths: 22.5m and 22m). Rainwater was recharged to the well.

As of 1990, twenty (20) surface water recharge systems and seventy-four (74) rainwater recharge systems were constructed in Rong Kong Kao and in two other villages. Water from existing and newly constructed wells were also diverted to the recharge wells. About 366,280m^3 of water were recharged from the surface water systems and 19,870m^3 from rainwater systems in a 4-year period. However, no clear effect of recharge was indicated by the piezometric levels observed since 1987.

Groundwater samples were collected and analyzed before and after recharge. However, no significant change in water quality was detected.

3.3 Case Studies in Japan

(1) Shiroishi Plain (after Uno,K. and Sayama,M., 1969)

The Shiroishi plain, a reclaimed land, is situated in the northern part of the Ariakekai Bay in Kyushu district. The plain is underlain by unconsolidated deposits of clay, sand and gravel of Holocene to Pleistocene age which form a multiple confined aquifer system.

Test injection well was bored by a percussion rig. The specification of well and aquifer coefficients were as follows:

Well depth	165 m.
Well diameter	150 mm.(Depth between 0 m. -31.5 m)
	75 mm.(Depth between 31.5 m.- 165 m)
Screen	opening diameter 4 mm, opening intervals 25 mm to 30 mm, open area 5%, total screen length - 67.5 m , aquifers consist of Pleistocene sand and gravel
Transmissivity :	259 m^2/day
Coefficient of storage	4×10^{-3}

Pressure injection method with a pressure rate of 0.4 kg/cm^2 was employed for the four recharge tests in 1964.

First continuous injection for 5 days
Second injection for 15 days (continuous injection during -10 hours a day)
Third injection for 9 days (continuous injection during -10 hours a day)
Fourth for 4 days (continuous injection during 10 hours a day)

After each injection test, a step-drawdown test was conducted.

The fresh water for injection was taken from an existing deep well located 2,150 m from the test well and was introduced through open channel and stored in a tank. The results of the four injection tests were shown in Figure 3.3.1.

The injection yields reduced as time passed. The injection well was redeveloped by pumping immediately after an injection test stopped. It was effective to recover injection yield to its initial value. However, it gradually reduced as the injection tests go on.

The initial water recovered at each re-development was turbid with light black color, which mainly consisted of the fragments of organic matter and some species of algae. This organic matter probably orginated from the decomposed algae, which clogged of well screen and finally reduced the injection rate. Suspended particles of silt were removed, but the injected water was still turbid because of algae growth in the open channel.

Piezometric levels rose more than 1 meter in the vicinity of the injection well. The area of water level rise extended elliptically in an area of about 1.5 x 0.6 km . Although the water levels rose, there was no increase of groundwater storage because the rise was just an elastic response of the confined aquifer.

(2) Hiratsuka City (after Shibasaki, T., Tanaka, M.and Sugiyama,A., 1974)

Hiratsuka City is located in the alluvial plain at the downstream of the Sakawa river which flows in the west of Kanto district, central Japan. The plain is underlain by unconsolidated deposits clay, sand and gravel of Holocene to Pleistocene age and forms multiple aquifer system.

Test injection well was bored by a percussion rig. The specification of well was as follows:

Well depth	: 80 m.
Well diameter	: 300 mm.
Screen length	: 20 m.
Aquifer installed screen	: the third aquifer consists of Pleistocene sediment

A free-flow method was used for the test. The clear fresh water was pumped from an existing well and directly injected to the test well through pipeline without aeration. A submersible pump was installed in the test well for re-development and pumping test (Figure 3.3.2).

Specific capacity generally increases during the pumping test. This indicates the effect of surging action by pumping. However, this effect is reduced during three or four days injection.

Specific capacity reduced sharply during the injection tests. In proportion to the rise of groundwater level, its value decreased at every injection test. The specific capacity computed from the pumping test was 0.4 m^3/min/m on the average. After injection, the specific capacity reduced sharply to 0.1 m^3/mim/m on the average, one fourth of the value obtained from the pumping test.

Analysis of well efficiency was also conducted. The total well loss was calculated by the following Rorabaugh's formula:

$$SW = BQ + CQ^n$$

where, SW: total well loss (total drawdown of groundwater level); BQ: aquifer loss; CQ^n : well loss; Q: extraction or injection rate; B: coefficient of aquifer loss; and C: coefficient of well loss.

Jacob proposed that the value of N=2 was suitable to the present conditions. Therefore, the Rorabough's formula can be expressed as:

$$SW = BQ + CQ^2$$

In this test operation , the coefficients of both aquifer loss and well loss were calculated by the following Jacob's formula.

$$SW/Q = B + CQ$$

Figure 3.3.4 shows the well loss at 1 m^3/min of pumping and injection yield. The total well loss (SW) is shown in the left side of the well column while the values of the right side are the well loss (above) and aquifer loss (below). The total well losses in the pumping process show smaller values than those in the injection process. The well losses in the early and later stage of pumping process are nearly the same. Generally, the well loss in the later stage of pumping is smaller than early stage value. This indicates that the pumping yield increases in the later stage because of continuous pumping.

The total well loss in the early stage of injection process is almost the same as in the pumping process, but in the later stage, it becomes five to seven times of the early stage value. Re-development by pumping before injection could be effective, but the well efficiency keeps on decreasing sharply as the injection continues for a long time.

The result of the study suggests that the physical process undergone by the confined aquifer system between pumping and injection through well is virtually irreversible.

3.4 Issues on Artificial Recharge

3.4.1 Recharge Well Method

The main technical issue regarding the application of the recharge well method is the clogging of well screens. Clogging may be caused by the following:

- movement of particles
- oxide adhesion to particles
- growth of bacteria
- chemical reactions between chemical constituents contained in the normal groundwater and recharged water
- binding of dissolved air
- oxidation and corrosion of the casing

Suspended materials in the recharged water can be removed but the dissolved air can not be. In the case of injecting warm water into relatively cold groundwater, an air barrier is formed in the surroundings of the well. Growth of bacteria and adhesion of their remains also clog well screens. However, clogging may be minimized if water is recharged without aeration. Therefore, supply-recharge well facility is often constructed in order to return groundwater directly to the original aquifers without aeration after using for industrial cooling and air conditioning.

In the USA, disposal wells were widely employed to place industrial waste water underground in aquifers. Such disposal wells have sometimes caused upward flow of harmful substances, collapse of wells and occurrence of earthquake in some places. Such disposal wells have been criticized from a health standpoint because of the potential for pollutants to be released directly into a clean aquifer.

Actually, groundwater have been contaminated in many places, although the contamination is not caused by disposal wells alone. Therefore, the Comprehensive Environmental Response, Compensation, and Liability Act of 1983 (CERCLA) was established and clean-up programs at waste (disposal) sites have been required since the 1980's in the USA.

Disposal well is an example of the recharge well method but it may deliberately contaminate groundwater and may not give any significant contribution to recharge of groundwater. Therefore, its use is not recommended.

At present, the Groundwater Act of Thailand B.E.2520 requires application for a permit to dispose (waste) water into the wells in the Groundwater Area.

3.4.2 Spreading Method

The main cause of clogging in the spreading method is silt accumulation. It is further agravated by sunlight activation of microbial growths that clog the soil pores. Growing vegetation on the spreading area and algal growths in water also cause clogging. However, compared to that of recharge well method, clogging is easier and less costly to remove if maintained periodically. Therefore, the spreading method is recommended if harmful substances can be prevented from entering the recharge basin.

In some areas in Japan, some facilities composed of permeable pavements and infiltration boxes were constructed recently so that rainwater can infiltrate underground. Originally, the method is applied for flood mitigation and at the same time for recharge of aquifers. In addition to the said facilities, a subsurface infiltration dam is now under construction as a pilot project for the purpose of flood mitigation and groundwater recharge. The dam is being constructed on a permeable ground located in an urban river basin so that storm runoff can be stored and eventually infiltrate underground. The concept is basically the same as that of the spreading method that is being practiced in many countries.

3.4.3 Possibility of Artificial Recharge in Bangkok

According to a preliminary study conducted by AIT (1981), the pit method was recommended as the most suitable technique of artificial recharge in the Bangkok area. Since the first aquifer is overlain by impermeable Bangkok Clay, the spreading method is not suitable. The recharge pits have to be drilled up to the top of the Bangkok Aquifer. Required depth of the pit is more than 25m and the diameter is 10m. If recharge to more deeper aquifers, such as Phra Pradaeng, Nakhon Luang and Nonthaburi, is considered, injection wells are needed.

A theoretical estimation gave a flow rate through the pit in the order of 5,000 to 20,000 m^3/day. AIT's study indicated three locations, namely, the north, the northeast and the center of Bangkok, as the recharge sites considering the head difference between the surface and groundwater levels. Recharge water may possibly be taken from the Chao Phraya River and has to be treated because of its high turbidity. The study also suggested that a pilot recharge test is necessary to assess the potential of the recharge scheme in Bangkok.

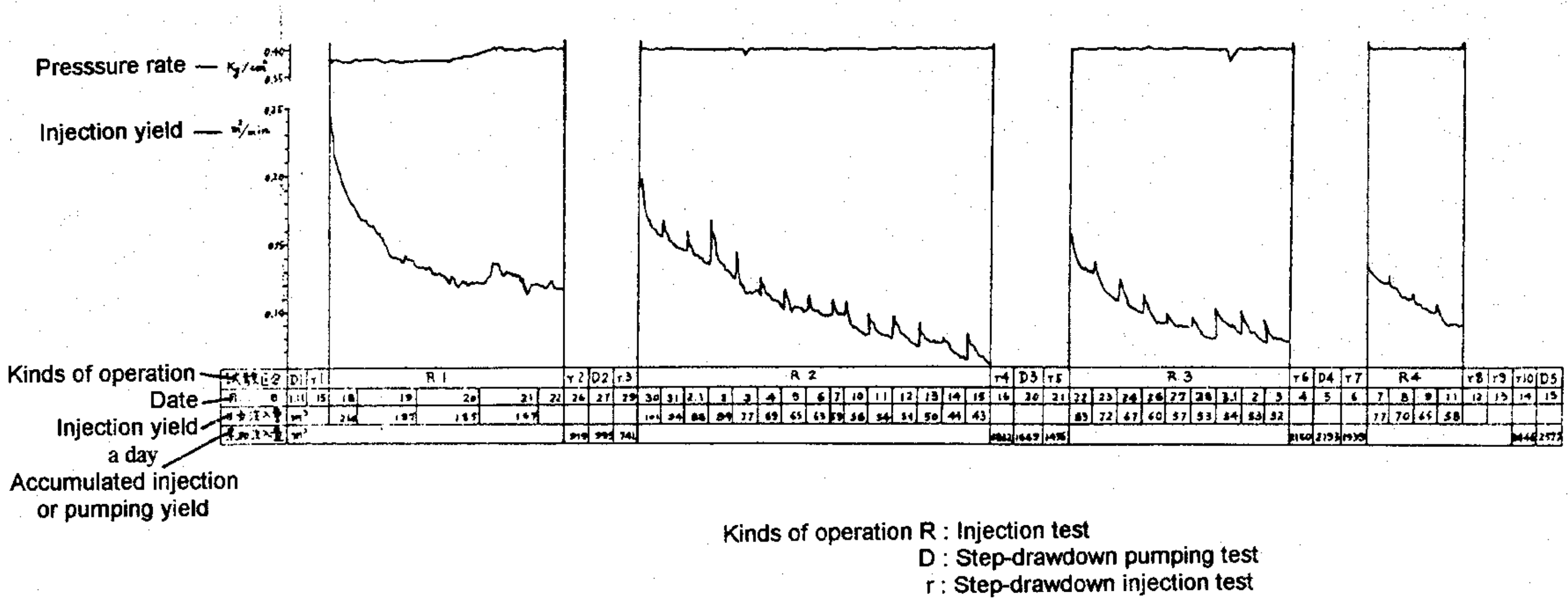
In addition to the above, Sverdrup & Parcer (1989) also recommended the following action plans in their report entitled "Managing Consulting Services for Flood Control of Bangkok and Vicinity" for BMA:

1) Control groundwater usage.
2) Prevention of illegal use of groundwater
3) Artificial recharge
4) Refinement of mathematical model
5) Monitoring of subsidence and piezometric levels

Sverdrup & Parcer strongly recommended the recharge program to the second, third and fourth aquifers, which are the main sources of groundwater extraction in the Bangkok area. However, they confirm that major problems of artificial recharge through well should be considered. One problem is the rapid reduction of injection rate which is caused by partial clogging of aquifer.

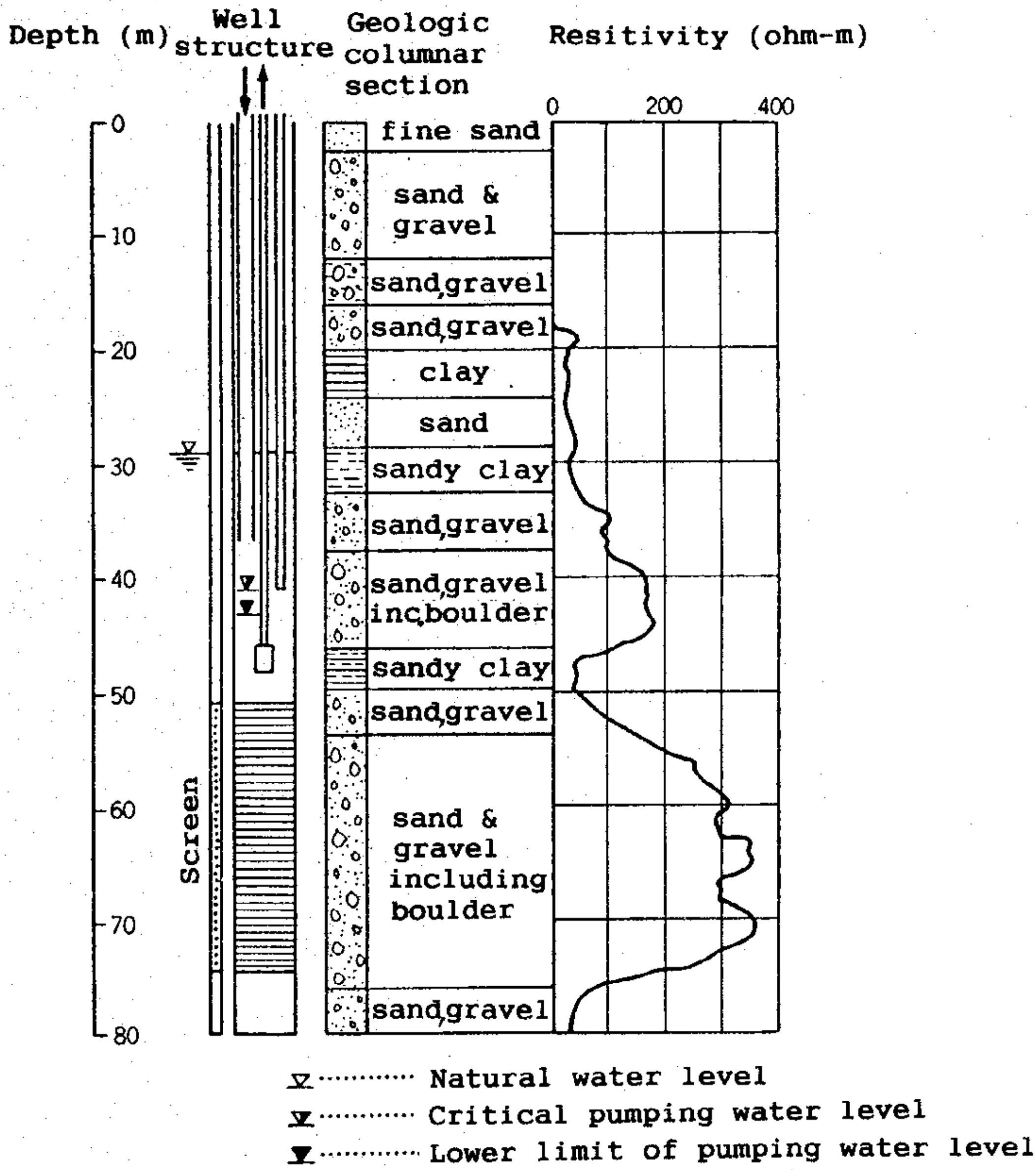
Meanwhile, the well clogging would likely occur due to the release of dissolved air and accumulation of fine particles of clay or organic matters such as bacteria or algae. The irreversible physical condition between pumping and injecting processes would be an essential problem of artificial recharge.

As pointed out by many researchers, the recharge scheme must first be assessed not only from the technical aspect but also from the economical and legal points of view. Technical issues include the hydrogeologic conditions and the recharge techniques. The economical and legal aspects may be studied and discussed, incorporating the optimal use of the basin wide water resources. Since a recharge project will entail huge capital outlay when implemented in a large scale, the economic, institutional and legal considerations will be important as well as the technical aspects.



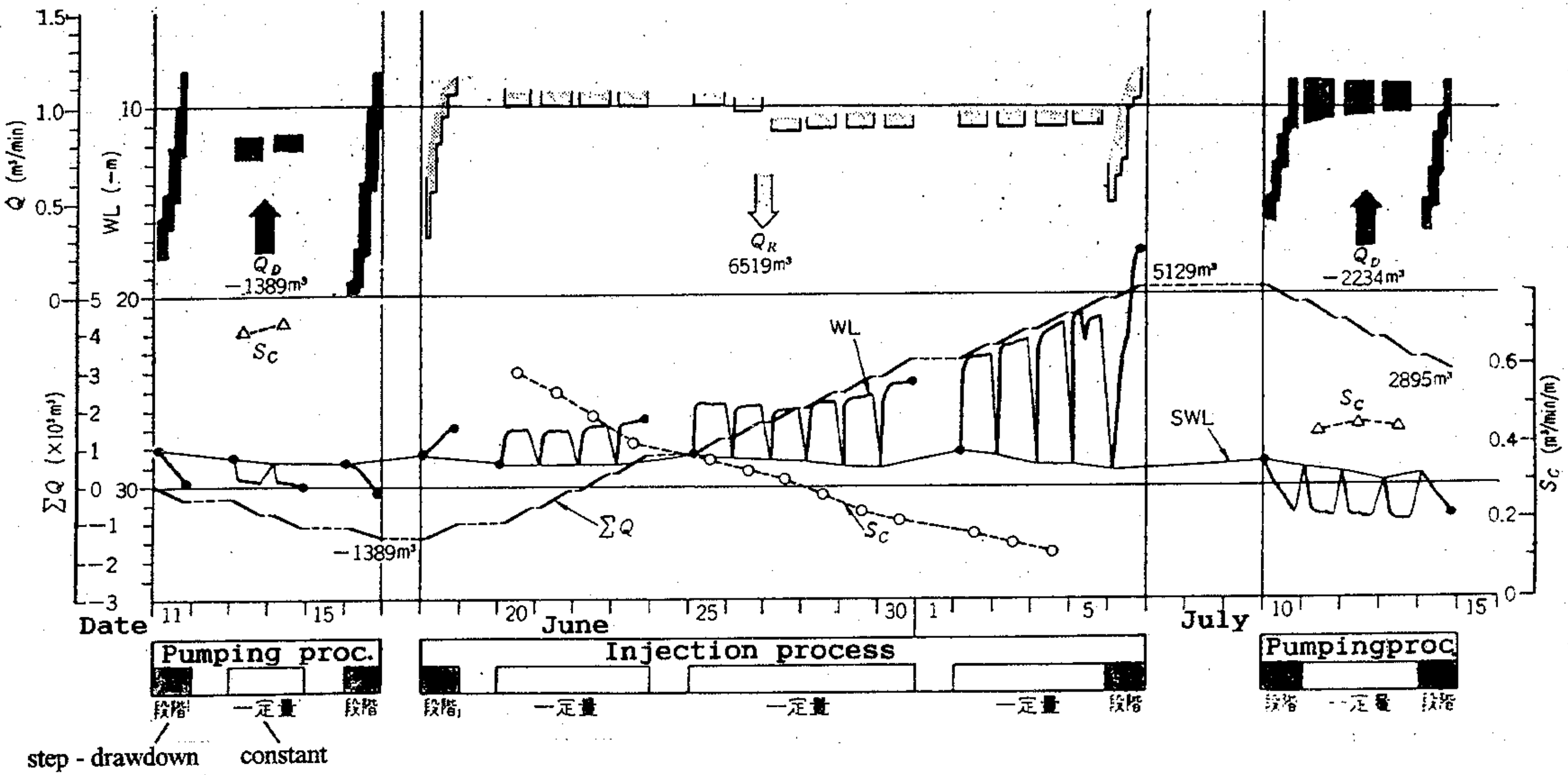
(after Uno and Sayama, 1969)

Figure 3.3.1	VARIATION OF THE INJECTION YIELDS AT THE TEST WELL IN SHIROISHI PLAIN, JAPAN
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	KOKUSAI KOGYO CO., LTD.



(after Shibasaki, et. al., 1974)

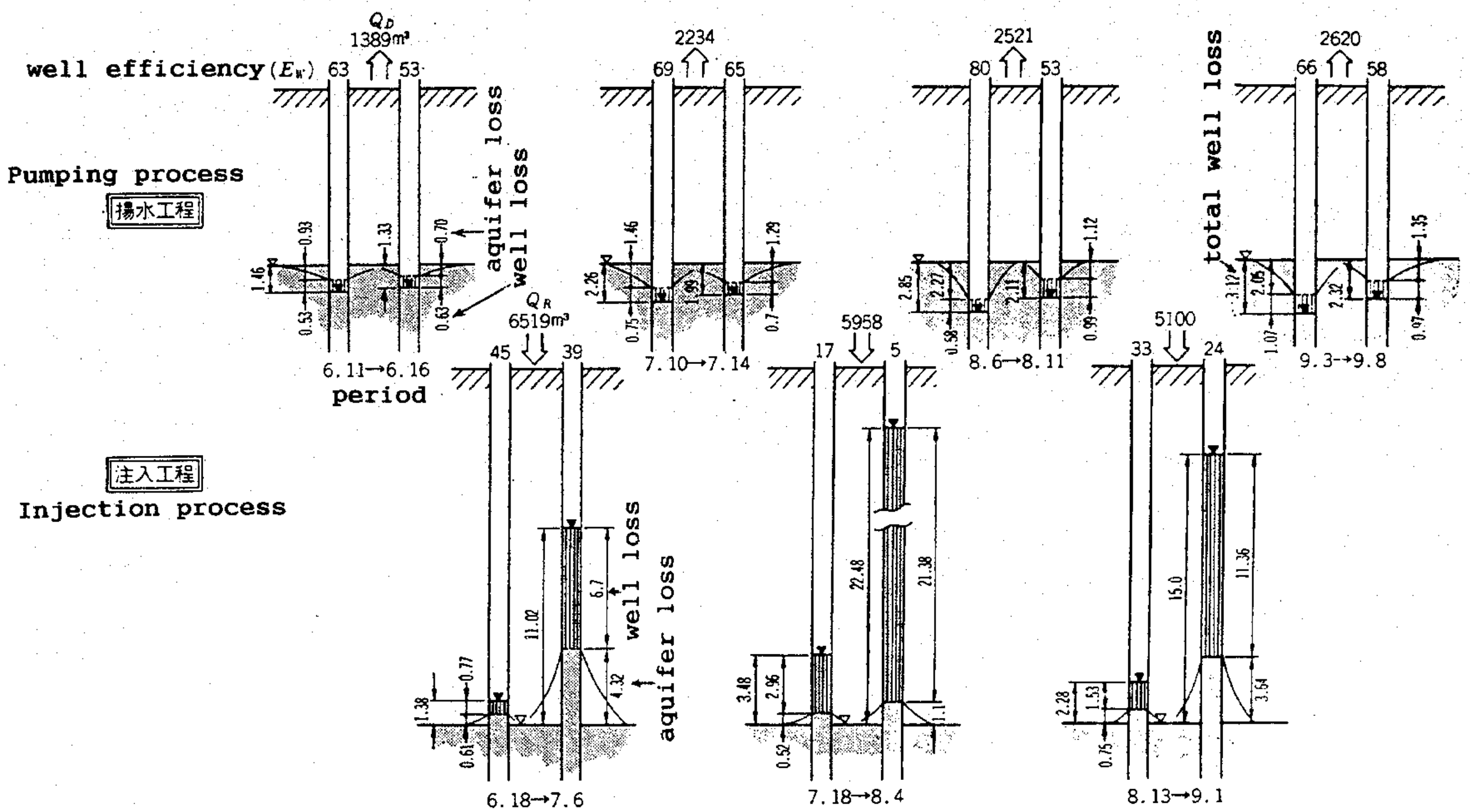
Figure 3.3.2	GEOLOGIC COLUMNAR SECTION AND STRUCTURE OF THE TEST INJECTION WELL IN HIRATSUKA CITY, JAPAN
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	KOKUSAI KOGYO CO., LTD.



Q_D : Sum of pumped capacity (m^3)
Q_R : Sum of injected capacity (m^3)
S_C : Specific capacity in pumping and injecting ($m^3/min/m$)
WL : Pumping or injecting water level (-m)
SWL : Static water level (-m)
Q : Pumping or injecting rate ($m^3/min/m$)
ΣQ : Sum of pumped and injected capacity (m^3)

(after Shibasaki, et. al., 1974)

Figure 3.3.3	FIRST INTERMITTENT PUMPING AND INJECTION TEST
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	KOKUSAI KOGYO CO., LTD.



Value of well loss and aquifer loss was calculated as that of both pumping and injection yields at 1 m^3/min.

(after Shibasaki, et. al., 1974)

Figure 3.3.4	VARIATION OF WELL LOSS AND AQUIFER LOSS
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	KOKUSAI KOGYO CO., LTD.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 4 URBAN DEVELOPMENT PLAN

4.1 Introduction

This Chapter provides the background information on the socio-economic and urban development plans to be used for the study on the management of ground water and land subsidence in the Bangkok metropolitan Area and its vicinity.

The reference data are based on the review of existing data, field investigation and observation carried out in different sectors during the second stage of the study.

4.2 Background of The Study Area

4.2.1 Study Area

Bangkok Metropolis, located on the lowflat plain along the Chao Phraya River, was established in 1782 as the new capital of Thailand by King Rama I, the First Monarch of the Chakri Dynasty, as a natural defense from the enemy. Since its establishment, attempts have been made to promote Bangkok Metropolis, which covered only 4.14 square kilometers at that time, as the center of commerce and trade and government administration. Up until now, Bangkok Metropolis is the growth pole of the Central Region, with a total area of 1,568.74 square kilometers.

The Metropolitan Area and its vicinity lie on the southern part of the lower central plain characterized by high temperature and humidity. The climate is predominantly monsoonal with three main seasons: rainy (May-October), cool (November-January) and hot (February-April).

The Metropolitan area is characterized by rapid urbanization leading to serious problems in water supply, sewerage, transportation, housing, garbage disposal and other related issues.

4.2.2 Study Area Coverage

The coverage of the research comprises the entire Bangkok Metropolis and its vicinity as shown in Figure 4.2.1, and covers the following eight (8) provinces, namely: Bangkok, Nonthaburi, Samut Prakarn, Pathum Thani and parts of Chachoengsao, Samut Sakhon, Nakhon Pathom, Phra Nakhon Si Ayutthaya. The study area covers approximately 6360 km^2.

(1) Data Collection

The data and study reports collected by the Study Team constitute the primary basis of the study.

Subsequently, with regard to the socio-economic and urban development plan, the Study Team contacted, individually or as groups, officials/representatives of different organizations/agencies for data collection and discussions.

* National Statistical Office (NSO)
* Department of Local Administration (DLA)
* Bangkok Metropolitan Administration (BMA)

* Asian Institute of Technology (AIT)
* Industrial Estate Authority of Thailand (IEAT)
* Metropolitan Waterworks Authority (MWA)
* Department of Town and Country Planning (DTCP)
* Office of the National Economic and Social Development Board (ONASDB)
* Land Development Department (LDD)
* Provincial City Hall of: Samut Prakarn
  Samut Sakhon
  Pathom Thani
  Nakhon Pathom
  Ayutthaya
  Chachoengsao
  Nonthaburi

(2) Work Progress

The basic survey undertaken were:

a) Collection and arrangement of data and information related to the Study.

   Existing data and reports were collected from NSO, BMA, AIT, IEAT, MWA, DLA, DTCP, NESDB and other government agencies concerned.

b) Review of present socio-economic conditions and urban development.

c) Review of the organizational management system and legal aspects related to urban development

   Activities and achievements of government agencies regarding urban development in general for data collection and discussions.

d) Field reconnaissance
   Preparation of provisional land use map and profiles using collected data and field reconnaissance.

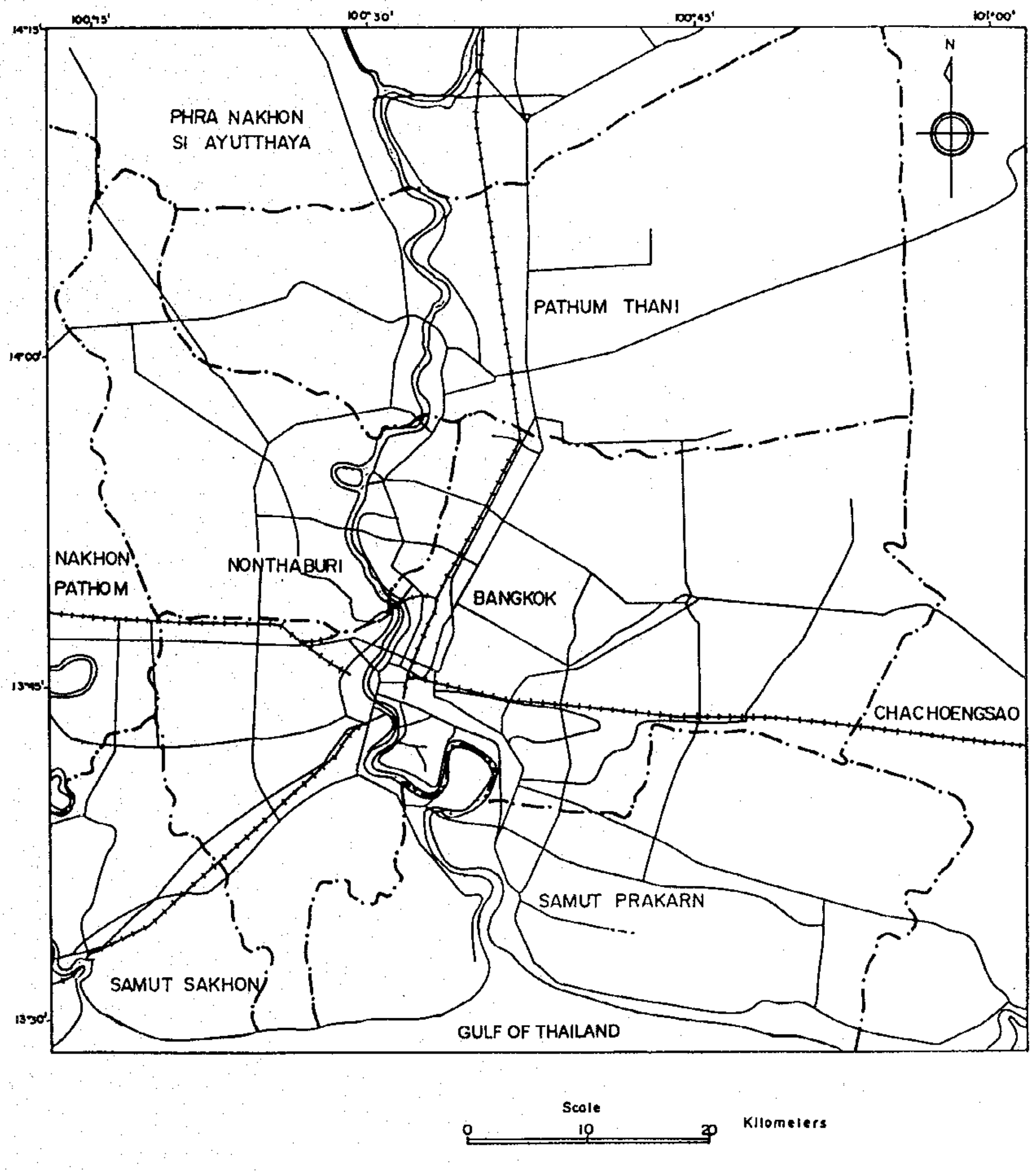


Figure 4.2.1	LOCATION MAP OF THE STUDY AREA
THE STUDY ON MANAGEMENT OF GROUNDWATER AND LAND SUBSIDENCE IN THE BANGKOK METROPOLITAN AREA AND ITS VICINITY	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	KOKUSAI KOGYO CO., LTD.

4. 3 Socio-economic Conditions

4.3.1 National Development Policy

(1) Economic Development in Thailand

Economic growth in Thailand over the past decade has been one of the highest and steadiest of the developing countries.

Between 1960 and 1980, the average rate of real GDP growth was above 7% annually. Breaking down the period from 1960 to 1985 into five-year intervals, the economic growth was lowest in the periods of the two oil shocks : 1970 - 75 and 1980 - 85. The impact of the oil shock was cushioned by a boom in commodity prices during the same period. This helped to increase farm income and reduced poverty in rural areas. However, after the second oil shock, all the main agricultural commodities of the Kingdom suffered from price reductions. While Thailand still maintained a satisfactory growth rate, the impact on agricultural income was severe. After 1986, the economy began a period of very rapid growth, and driven by an increase in the manufacture of exports, capital inflows, as well as tourism, growth in GDP reached 13.2% in 1988, falling to 10% in 1990. The growth in GDP during the last three years has been remarkable, averaging over 10 percent per annum (Table 4.3.1).

At the same time, Thailand has been experiencing a rapid transformation form an agrarian society to an increasingly industrialized one.

(2) Seventh National Economic and Social Development Plan (1992 - 1996)

The formulation of the Seventh Plan was intended to be a consensus-building exercise which relied on the cooperative effort of all sectors, not only including government agencies, state enterprises and universities but also the private sector and non-governmental organizations. With a broad-based participation, the substance of the Seventh Plan reflects a liberalization process in many aspects. It encourages the revision of existing legislation and the formulation of new laws and regulations for the conservation of natural resources and the protection of the environment.

The three main development objectives of the Seventh Plan were set out as follows:

a) Maintain economic growth rates at appropriate levels to ensure sustainability and stability.

b) Redistribute income and decentralize development to the regions and rural areas more widely.

c) Accelerate the development of human resources and upgrade quality of life, the environment and natural resources management.

Table 4.3.2 shows the major development targets of the Seventh Plan compared with results of the sixth Plan. According to the Seventh Plan, the economic growth during the period is expected to be 8.2% per year at constant prices distributed as follows: 3.4% for agricultural sector, 9.5% for industry, 8.9% for construction, and 8.1% for services and others.

The investment of the public sector, is expected to achieve a growth of 8.5% per annum compared with the 6.5% per annum for the Sixth Plan period. On the other hand, the Seventh Plan is designed to maintain low rates of 1.2% and 0.5% annum in population growth and unemployment, respectively.

The first three-year National Economic and Social Development Plans (1961 - 1976) emphasized economic growth as the primary objective in the country's development. Development activities are focused on the construction of infrastructure, such as roads and railways, to improve access to rural areas and allow the utilization of natural resources.

The Fifth Plan (1981 - 1986) introduced a more integrated approach to natural resources development in which planning strategies were coordinated with local socio-economic development, with the aim of increasing the efficiency of natural resources utilization.

The major targets of the Sixth Plan were to raise the country's level of development for future progress and prosperity, while working to solve problems accumulated from the past.

And, the commencement of the Seventh Plan is a promising move towards more sustainable development, keeping a balance between growth and income distribution, industrialization and protection of environmental quality, urbanization and support for the rural population.

4.3.2 Economic Structure

(1) General

During the Sixth Plan period (1986 - 1991), the Thai economic growth has skyrocketed with the gross domestic product (GDP) expanding at an average of 10.5% per year, twice the Plan target, representing the highest average growth rate of the past twenty five years. The economic structure has become more outward-oriented and internationalized, as indicated by the increase in the proportion of international trade to GDP from 60% in 1986 to 80% by 1991.

Key factors which have brought about the high growth rates include growth in exports, investment and tourism, all of which had grown considerably faster than the projected rates.

On the macroeconomic level, cautious fiscal and monetary policies, together with political stability were also instrumental in boosting business confidence, propelling Thai economy to grow and making Thailand the fastest-growing economy in the world during the past 5 years.

Although the high economic growth has had significant beneficial effects on the overall economy, the pattern of growth has led to several structural imbalances, which may become long-term development issues for the country, such as:

- Income disparities among households of different socio-economic status and between rural and urban areas: regional disparities have been on the rise as the Bangkok Metropolis and surrounding towns continue to play a dominant role and have rapid economic growth rates. In 1981, Bangkok contributed about 42% to GDP. By 1989, this share increased to 48%, while in most other regions, it had actually declined. For instance, the shares of the Northeast, North and South declined from 14.7% to 12.9%, 13.5% to 11.4% and 10% to 9%, respectively, during the same period.

- Infrastructure bottlenecks
  Virtually all types of basic infrastructure services were inadequate to meet the strong demands resulting from the rapidly growing economy. The policy to promote private sector provision of infrastructural services has not been implemented in an effective and timely manner, impeding both current and future development efforts.

(2) Gross National Product (GNP) and Gross Domestic Product (GDP)

In 1990, the GDP and GNP of Thailand amounted to about 2,051,208 million Baht and 2,030,064 million Baht at current market prices, respectively, and the per capita GNP was about 36,032 Baht (refer to Table 4.3.3). Of the GDP, the contribution of each economic sector in the same year was 26.10% for the manufacturing/industrial sector, 15.25% for the wholesale and retail trade, 13.58% for the services sector and 12.41% for the agricultural sector. The total amount of the above four sectors came to about 1,381,287 million Baht which corresponds to 67.34% of the GDP (refer to Table 4.3.4).

In recent years, Thailand's economy showed a high growth rate brought by the increased production of upland crops other than rice, the development of light manufacturing industries, growth of the export sector, investment etc. This means that from 1986 to 1990, the average annual growth rate of Thailand's economy was about 11.3% for GDP and GNP, and about 9.5% for per capita GNP (refer to Table 4.3.5 and Table 4.3.6).

Bangkok Metropolitan Area (BMA) and the Central Region, serve as the core of Thailand's economy and have accounted for a half of the country's GDP, i. e., for example in 1986, of the 557,960 million Baht, 509,033 million Baht and 48,927 million Baht were for BMA and the Central Region, respectively. The average annual growth rate from 1986 to 1988 of BMA and the Central Region was 18.5% (21.8% for BMA and 15.2% for the Central Region) which was more than the national average growth rate (17.3%) of GRP (refer to Table 4.3.7).

On the other hand, per capita GRP (Gross Regional Product) in 1986 was about 61,544 Baht for BMA and about 18,724 Baht for the Central Region, i. e., the value in BMA showed three times of the average value of the whole country, while the average annual growth for the 1986 - 1988 period indicated a rate of 18.9% for BMA and a rate of 14.2% for the Central Region compared with the 15.3% nationwide (refer to Table 4.3.8).

Table 4.3.9 and 4.3.10 indicate's the Gross Provincial Product (GPP) and the per capita GPP by province in the Study Area. GPP in the Study Area in 1988 amounted to about 785,886 million Baht which corresponded to 52.1% of GDP (1,506,977 million Baht) of the Kingdom. Of the GPP in the Study Area, the GPP of Bangkok City in the same year amounted to 609,924 million Baht which accounted for 77.6% of that in the Study Area or 40.5% of the Kingdom's GDP. The growth in GPP in the Study Area for the 1986-1988 period was 21.4% which was more than the average growth rate of the GDP in the whole country.

In the Study Area, the three provinces of Nonthaburi, Samut Prakarn and Samut Sakhon achieved a fairly high growth in GPP or 24.3%, 28.4% and 20.8% per annum, respectively, during the same period (refer Table 4.3.9).