CHAPTER 3 GROUNDWATER QUALITY

3.1 Water Quality of Existing Wells

The water quality of at least 10 existing wells in the target communes was investigated by field measurement and laboratory analysis. The latter involved a total of 213 samples; water samples were also taken during the pumping tests in the test wells.

The water quality of the shallow wells in the target communes differ by region. In terms of electric conductivity and main dissolved ions, Thai Nguyen, some parts of Ha Noi, the hilly area of Ninh Binh, and the north of Thanh Hoa have relatively good water quality. However, the opposite was observed in Yen Thang Commune in Ninh Binh, 4 communes in Ha Tinh, and from the center to the south of Thanh Hoa due to high TDS (total dissolved solids) levels. The pH value is especially low, between 4.5 and 5.5, in the area of Thai Nguyen characterized by red soil formed from weathered sandstone and shale in the basement rock. Even in the other areas groundwater in sandstone and shale tends to be acidic, whereas groundwater in the basement limestone is from neutral to slightly alkaline. Coliform bacteria were also detected in most dug well water, making the water undrinkable unless treatment is carried out.

The iron concentration is low in Thai Nguyen, but high in some parts of Ha Noi and Ninh Binh. Half of the surveyed existing wells in Thanh Hoa and Ha Tinh were detected with iron concentration exceeding the Vietnam drinking water standard of 0.5 mg/ℓ with 20 to 30 % having over 2 mg/ℓ. There are no problems regarding manganese concentrations in Thai Nguyen and Ninh Binh, except that most wells in the former have levels below the standard (0.1 mg/ℓ), and wells in 3 places in Yen Thang Commune in the latter have high levels. However, in Ha Noi, Thanh Hoa and Ha Tinh, manganese in many existing wells exceeded the standard value, especially in Ha Tinh where more than half of the wells contained levels above the standard.

In Thanh Hoa, wells in Nong Cong Town showed chloride ion levels exceeding the standard value (500 mg/ℓ). All tested wells in Thai Nguyen, Ha Noi and Ninh Binh had sulfate ion levels lower than the standard value (400 mg/ℓ). Some wells in Thanh Hoa and Ha Tinh had levels exceeding the standard. For sodium, wells in some parts of Ha Noi, Van Thang and Nong Cong Town in Thanh Hoa, and Bui Xa and Trung Le Communes in Ha Tinh were detected with levels exceeding the standard value of 200 mg/ℓ.

Ammonium, fluoride, and arsenic levels in groundwater did not exceed their established standard values.

3.2 Water Quality in Test Wells

Fourteen samples were taken from the test wells (excluding JICA-1 in Dong Bam, Thai Nguyen Province) dug for this project for the laboratory analysis of water quality. Only four of these samples complied with the Vietnam drinking water standard (2 in Thai Nguyen, 1 in Ninh Binh, and 1 in Thanh Hoa).

The pH value was lower than the standard value in Quang Son in Ninh Binh, and Trung Le in Ha Tinh. Samples in Yen Thang in Ninh Binh, Thieu Do in Thanh Hoa, and Duc Yen in Ha Tinh exceeded the standard TDS value (1,000 mg/ℓ). Manganese and iron levels in Hoa Thuong in Thai Nguyen, Quang Son and Yen Thang in Ninh Binh, Van Thang and Thieu Hung in Thanh Hoa, and Duc Yen and Trung Le in Ha Tinh exceeded the standard value. Iron levels in Vinh Thanh in Thanh Hoa also exceeded the standard value. Chloride ion and sodium levels in Yen Thang in Ninh Binh and Duc Yen in Ha Tinh exceeded the standard value. Wells in Van Thang Commune in Thanh Hoa also had sodium levels above the standard value. No test well was found to have ammonium ions, sulfate ions, fluoride and arsenic levels above their established standard values.

3.3 Water Quality Analysis in Ha Noi

Water quality in the groundwater observation wells in Ha Noi was surveyed twice a year (wet and dry seasons) from 1988 to 1997 by the Department of Geology and Minerals (DGM) of the Ministry of Industry of Vietnam (1998). JICA (1997) also gathered the results of the water quality analysis carried out on the production wells in the well field of the Ha Noi Business Campany from 1990 to 1995.

According to the data of the DGM (1998), iron levels in the latter half of 1997 (rainy season) was estimated at 3~10 mg/ℓ in the eastern part of Ha Noi City, and 10~30 mg/ℓ in the target communes of Xuan Dinh and Dong Ngac. However, it is thought that these data are the results of the analysis of stagnant water in the monitoring wells, which might be different from the water quality of actually pumped water.

According to JICA (1997), the iron levels in the Mai Dich well field (17 source wells) 4 km southwest of Xuan Dinh, ranged from a maximum of 3.3 mg/ℓ, an average of 0.7 mg/ℓ, and a minimum of 0.0 mg/ℓ. In the Ngoc Ha well field (11 source wells) 2 km south of Xuan Dinh, the levels ranged from a maximum of 4.7 mg/ℓ, an average of 1.6 mg/ℓ, and a minimum of 0.1 mg/ℓ. Iron levels were also observed to hit a maximum of 11.6 mg/ℓ and a minimum of 0.3 mg/ℓ, averaging 3.7 mg/ℓ, in the Yen Phu well field located between the West Lake (Ho Tay) and the Red River, in the northeast of Ha Noi. In the Ngo Si Lien well field (14 source wells) in central Ha Noi, the level was 16.7 mg/ℓ at the most, 3.1 mg/ℓ on average and 0.4 mg/ℓ at the least. It was high in the Ha Dinh well field (9 source wells) located 8 km south of Xuan Dinh, reaching a maximum of 19.7 mg/ℓ, a minimum of 6.7 mg/ℓ, and averaging 11.4 mg/ℓ. These data were obtained in Second Aquifer which is the main aquifer in Ha Noi, but it was estimated from these data that the iron concentration in the target communes also exceeded the standard value of 0.5 mg/ℓ.

Manganese levels in the Ngoc Ha well field, which is closest to the target communes, exceeded the standard value of 0.1 mg/ℓ at a maximum of 2.4 mg/ℓ, an average of 1.1 mg/ℓ, and a minimum of 0.0 mg/ℓ; the average value exceeds the standard value. As the average value in other well fields also exceeded the standard value, it is possible that manganese levels in the target communes exceed the standard value

A high concentration of ammonium ions was also measured in the Ngoc Ha well field, Yen Phu well field, and Ha Dinh well field as shown in the table below.

Ammonium Ion Levels

unit: mg/ℓ

Well Field	Maximum Level	Minimum Level	Average	Standard Value
Ngoc Ha	30.0	0.0	0.7	3.0
Yen Phu	20.0	0.0	2.8	3.0
Ha Dinh	20.0	4.0	12.8	3.0

It is, therefore, possible that the ammonium ion levels in the target communes exceed the standard value of 3.0 mg/ℓ. However, in view of the well depths, there is also a probability that some of the contaminated water from the surface flows into the wells due to problems in well structure, etc. According to JICA (1997), the design value for ammonium level in well water used as water source for the Ha Noi Water Supply Systems is set at 1.2 mg/ℓ.

Table 3.1 Results of Laboratory Chemical Analysis of Groundwater Samples Taken from JICA Test Wells

Test Well No.	Commune	Geology	pH	Temp.	EC	Hardness	TDS	Redox potential	DO	Nitrate (NO_3^-)	Nitrite (NO_2^-)	Ammonium (NH_4^+)	Manganese (Mn^{2+})	Sulfate (SO_4^{2-})	Iron (Σ Fe)	Chloride (Cl^-)	Bicarbonate (HCO_3^-)	Calcium (Ca^{2+})	Magnesium (Mg^{2+})	Sodium (Na^+)	Potassium (K^+)	Fluoride (F)	Arsenic (As)
WHO Guideline Values for Drinking Water							1000			50.000		1.500	0.100	250.00	0.300	250.00				200.00		1.500	10.00
Vietnamese Drinking and Domestic Water Quality Standard for Ground Water (Rural Supply)			6.5~8.5				1000			10.000	0.000	3.000	0.100	400.00	0.500	500.00				200.00		1.500	50.00
				(° C)	(mS/m)	(meq/l)	(mg/l)	(mV)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(μg/l)
JICA-1	Dong Bam	Quaternary/ Limestone	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
JICA-2	Hoa Thuong	Quaternary/ Limestone/ Sandstone	7.22	25.4	48.8	5.440	466	140	5.88	1.120	0.080	0.195	[illegible]	40.22	[illegible]	17.75	295.20	83.20	15.61	12.20	2.52	0.058	1.89
JICA-3	Nam Tien	Quaternary/ Sandstone/ Siltstone	8.50	25.9	15.8	1.300	145	148	6.15	0.405	0.014	0.058	0.032	20.68	0.045	12.88	90.80	22.20	3.60	18.40	3.07	0.052	2.03
JICA-4	Thinh Duc	Quaternaly/ Claystone	7.51	25.1	16.8	1.436	160	165	6.12	0.680	0.030	0.112	0.084	11.40	0.052	7.12	122.20	19.20	5.76	20.92	1.26	0.049	1.74
JICA-5	Quang Son	Quaternary/ Limestone	[illegible]	24.1	4.1	3.790	408	285	6.15	0.694	0.025	0.178	[illegible]	23.69	0.420	19.20	238.50	48.00	15.60	18.30	11.70	0.055	1.66
JICA-6	Yen Thang	Quaternary/ Limestone	7.05	23.6	295.0	31.000	[illegible]	208	5.95	0.412	0.015	0.088	[illegible]	80.10	[illegible]	[illegible]	260.60	275.50	210.50	[illegible]	78.60	0.053	1.68
JICA-7	Dong Phong	Top Soil/ Limestone	7.82	25	40.5	3.980	402	204	6.18	0.750	0.042	0.172	0.026	26.12	0.048	26.63	207.40	51.20	17.28	17.90	1.51	0.060	1.96
JICA-8	Van Thang	Quaternary/ Sandstone	6.75	23.8	72.5	7.120	782	148	5.75	0.305	0.022	0.088	[illegible]	48.20	[illegible]	412.80	486.50	110.50	18.20	[illegible]	10.90	0.060	1.69
JICA-9	Thieu Hung	Quaternary/ Sandstone	6.80	23.8	64.0	3.170	628	198	6.15	0.341	0.100	0.073	[illegible]	24.20	[illegible]	93.43	156.50	46.50	10.40	62.10	1.70	0.043	1.80
JICA-10	Dinh Tuong	Quaternary/ Sandstone	7.50	26.3	41.6	3.108	409	206	6.02	0.321	0.024	0.068	0.026	8.40	0.048	19.53	222.80	50.80	6.90	25.88	3.92	0.052	1.74
JICA-11	Vinh Thanh	Quaternary/ Limestone	7.78	25.4	38.5	2.410	382	235	6.05	0.250	<0.010	0.078	0.076	3.42	[illegible]	14.22	183.40	40.20	4.80	21.78	1.68	0.059	1.62
JICA-12	Duc Yen	Quaternary/ Neogene clay	6.80	24.1	183.5	7.380	[illegible]	195	6.10	0.238	0.009	0.064	[illegible]	116.52	[illegible]	[illegible]	40.50	64.20	50.20	[illegible]	44.60	0.049	2.02
JICA-13	Trung Le	Quaternary/ Neogene clay	[illegible]	25.8	517.5	12.620	[illegible]	158	5.81	0.425	0.026	0.081	[illegible]	36.78	[illegible]	[illegible]	27.40	90.80	82.20	[illegible]	36.80	0.084	1.89
JICA-14	Thieu Do	Quaternary/ Limestone	7.65	26.5	110.2	2.297	[illegible]	195	6.10	0.412	0.019	0.057	0.088	25.56	0.084	92.30	345.80	26.05	12.08	118.40	51.26	0.052	1.86
JICA-15	Trung Le	Quaternary/ Neogene clay	[illegible]	26.1	216.5	3.000	[illegible]	174	5.90	0.329	0.018	0.071	0.024	105.21	0.043	[illegible]	29.40	22.60	22.80	[illegible]	11.32	0.056	1.76

(dark shading) More than WHO GuidelineValue (light shading) More than Vietnamese Guideline Value

Table 3.1 Results of Laboratory Chemical Analysis of Groundwater Samples Taken from JICA Test Wells

Test Well No.	Commune	Geology	pH	Temp.	EC	Hardness	TDS	Redox potential	DO	Nitrate (NO_3^-)	Nitrite (NO_2^-)	Ammonium (NH_4^+)	Manganese (Mn^{2+})	Sulfate (SO_4^{2-})	Iron (Σ Fe)	Chloride (Cl^-)	Bicarbonate (HCO_3^-)	Calcium (Ca^{2+})	Magnesium (Mg^{2+})	Sodium (Na^+)	Potassium (K^+)	Fluoride (F)	Arsenic (As)
WHO Guideline Values for Drinking Water							1000			50.000		1.500	0.100	250.00	0.300	250.00				200.00		1.500	10.00
Vietnamese Drinking and Domestic Water Quality Standard for Ground Water (Rural Supply)			6.5~8.5				1000			10.000	0.000	3.000	0.100	400.00	0.500	500.00				200.00		1.500	50.00
				(° C)	(mS/m)	(meq/l)	(mg/l)	(mV)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(μg/l)
JICA-1	Dong Bam	Quaternary/ Limestone	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
JICA-2	Hoa Truong	Quaternary/ Limestone/ Sandstone	7.22	25.4	46.8	5.440	466	140	5.88	1.120	0.080	0.195	0.392	40.22	5.150	17.75	295.20	83.20	15.61	12.20	2.52	0.058	1.89
JICA-3	Nam Tien	Quaternary/ Sandstone/ Siltstone	6.50	25.9	15.8	1.300	145	146	6.15	0.405	0.014	0.058	0.032	20.66	0.045	12.88	90.80	22.20	3.60	18.40	3.07	0.052	2.03
JICA-4	Thinh Duc	Quaternaly/ Claystone	7.51	25.1	16.8	1.436	160	165	6.12	0.680	0.030	0.112	0.084	11.40	0.052	7.12	122.20	19.20	5.76	20.92	1.26	0.049	1.74
JICA-5	Quang Son	Quaternary/ Limestone	6.25	24.1	4.1	3.790	408	265	6.15	0.694	0.025	0.178	0.250	23.69	0.420	19.20	238.50	48.80	15.60	16.30	11.70	0.055	1.66
JICA-6	Yen Thang	Quaternary/ Limestone	7.05	23.6	295.0	31.000	2372	208	5.95	0.412	0.015	0.088	0.420	80.10	1.800	2343.00	260.60	275.50	210.50	802.60	78.60	0.053	1.68
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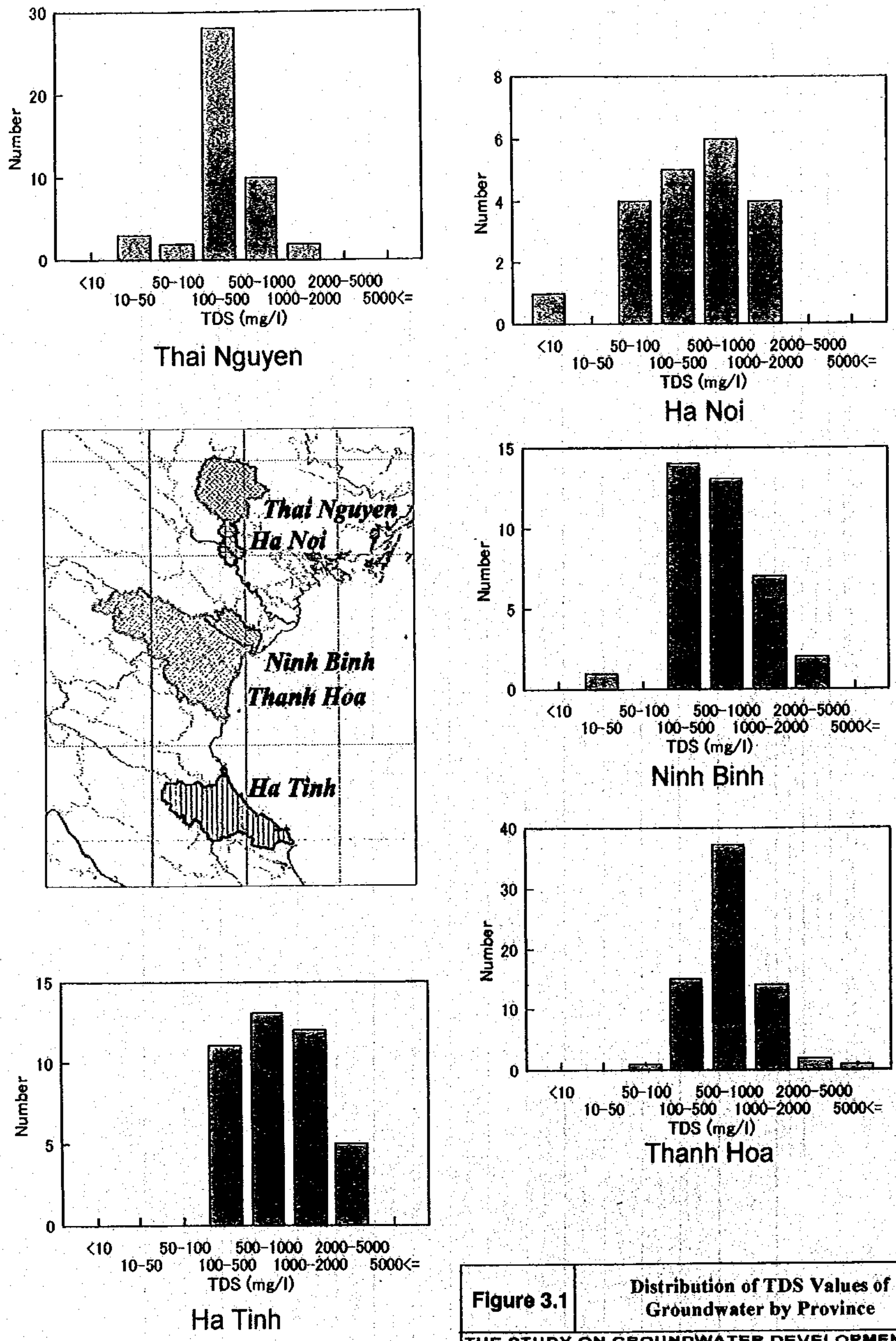
(shaded) More than WHO Guideline Value (box) More than Vietnamese Guideline Value

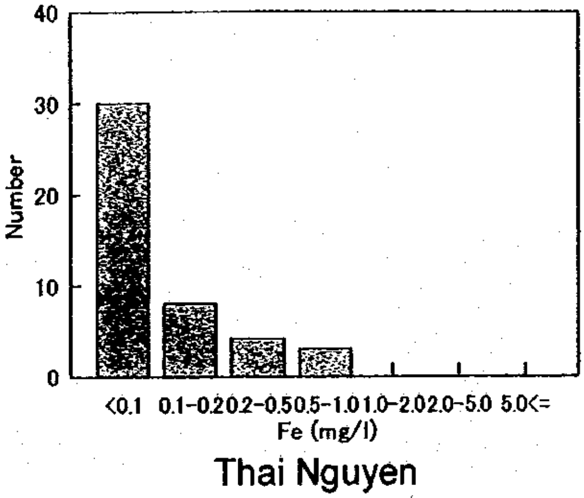


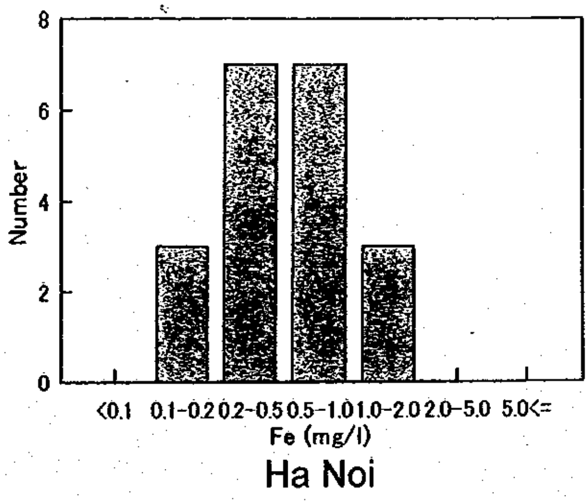
(Groundwater samples were collected from existing wells.)

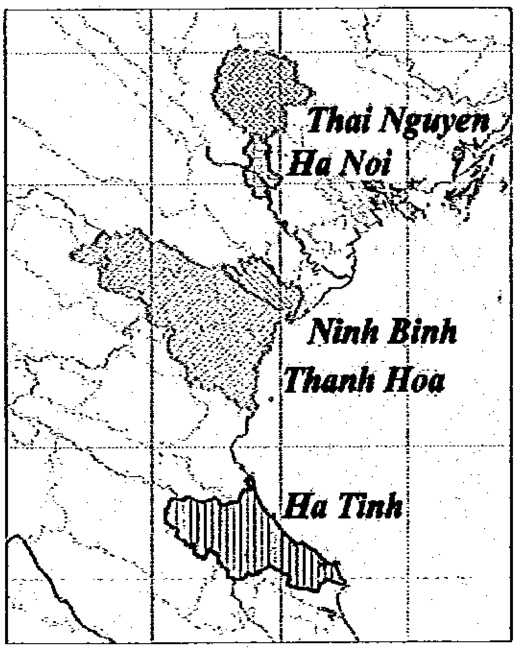
Figure 3.1 Distribution of TDS Values of Groundwater by Province

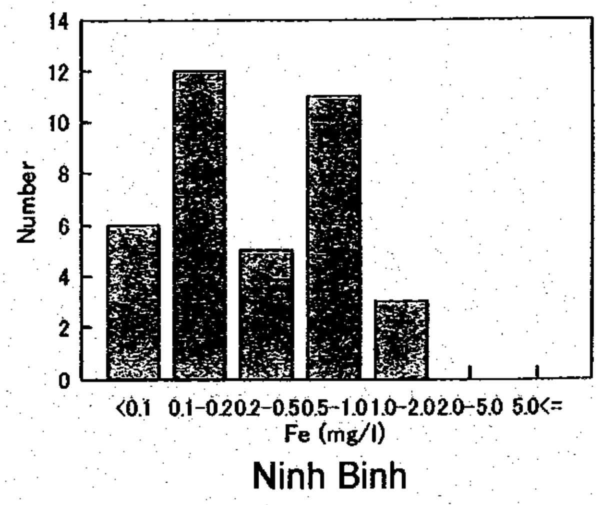
THE STUDY ON GROUNDWATER DEVELOPMENT IN THE RURAL PROVINCES OF NORTHERN PART IN THE SOCIALIST REPUBLIC OF VIETNAM

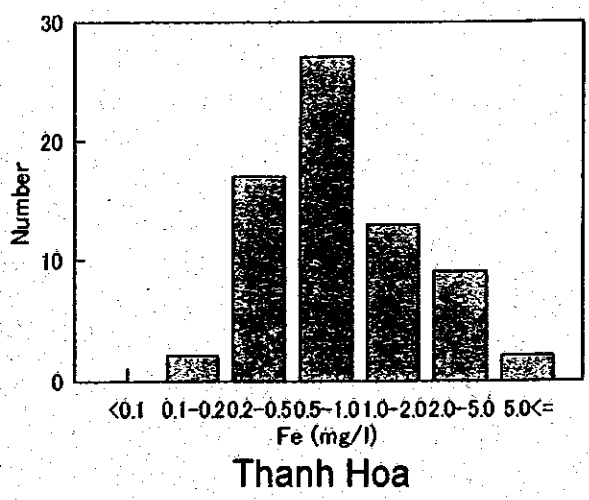
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

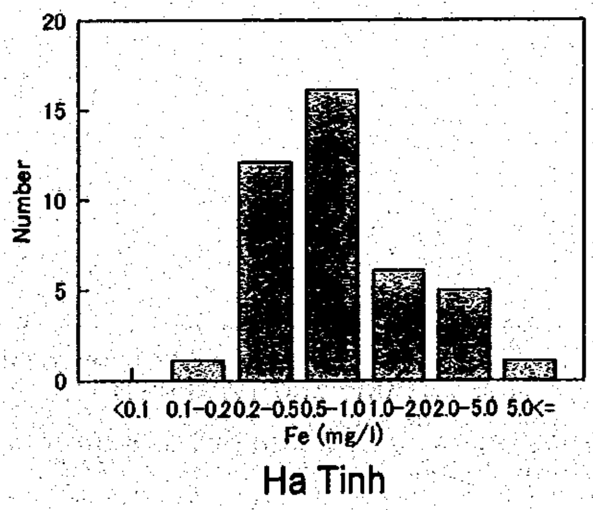












(Groundwater samples were collected from existing wells.)

Figure 3.2 Distribution of Fe Concentration of Groundwater by Province

THE STUDY ON GROUNDWATER DEVELOPMENT IN THE RURAL PROVINCES OF NORTHERN PART IN THE SOCIALIST REPUBLIC OF VIETNAM

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

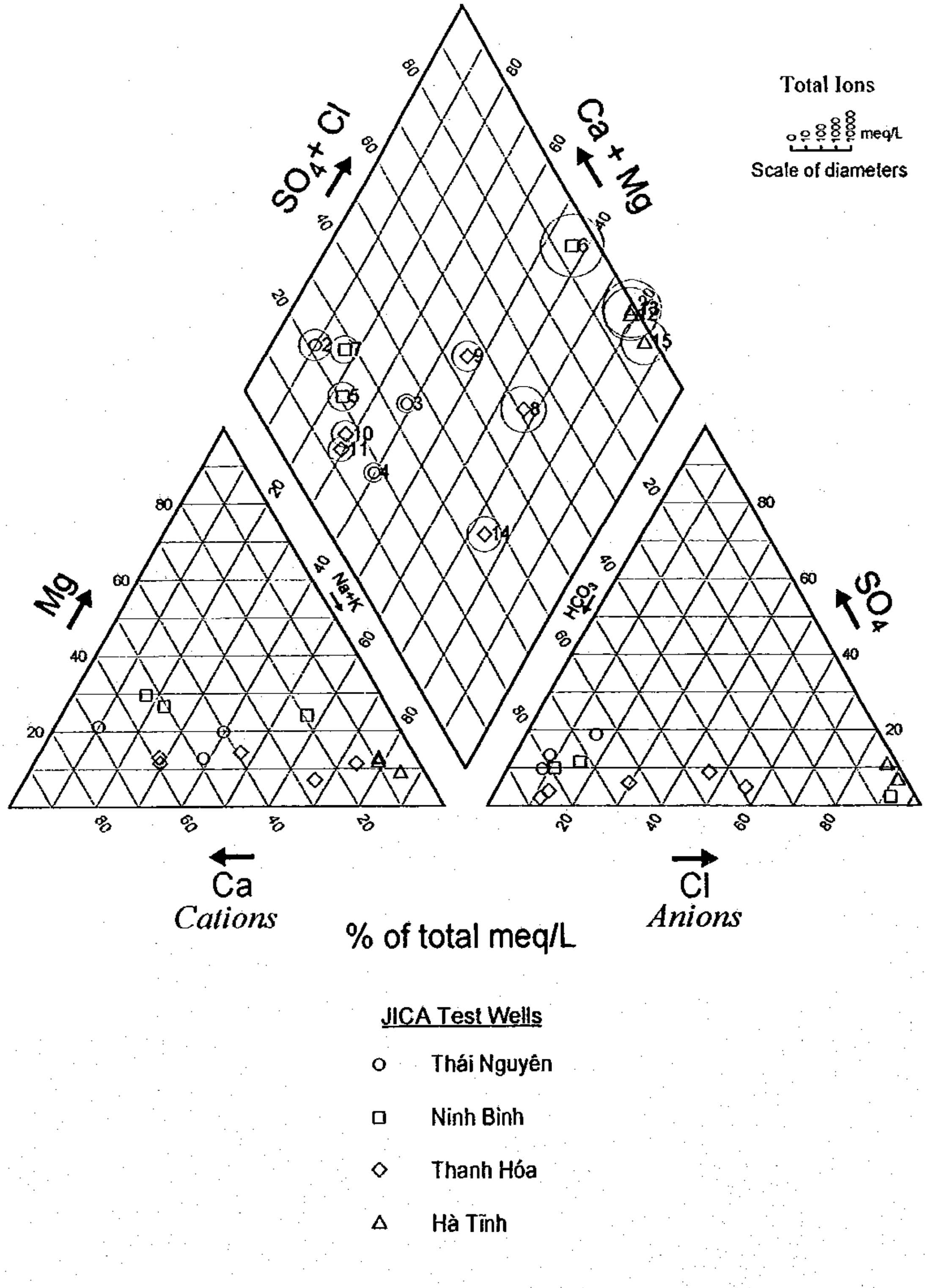
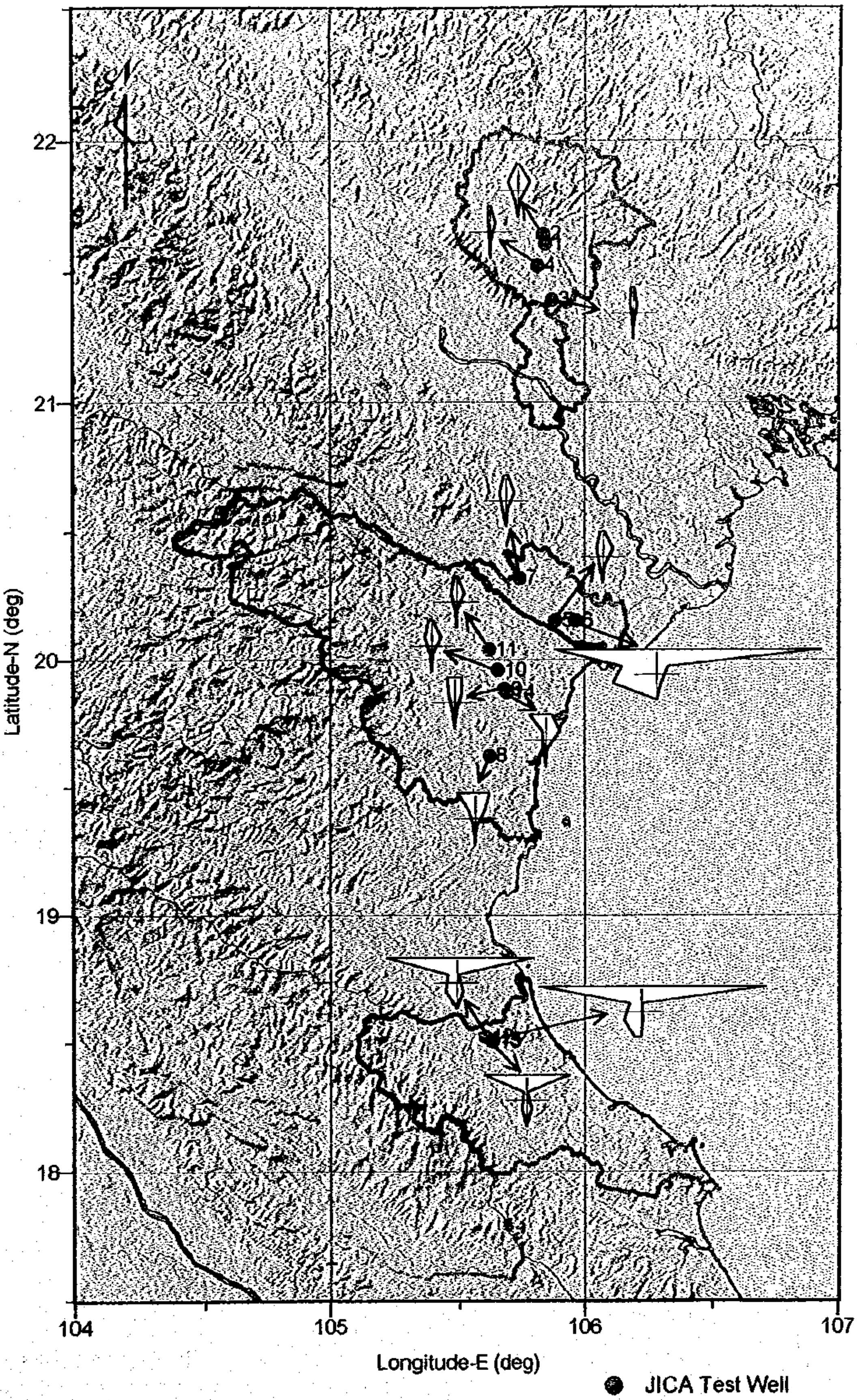


Figure 3.3	TRILINEAR DIAGRAM OF GROUNDWATER TAKEN FROM TEST WELLS

THE STUDY ON GROUNDWATER DEVELOPMENT IN THE RURAL PROVINCES OF NORTHERN PART IN THE SOCIALIST REPUBLIC OF VIETNAM

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)



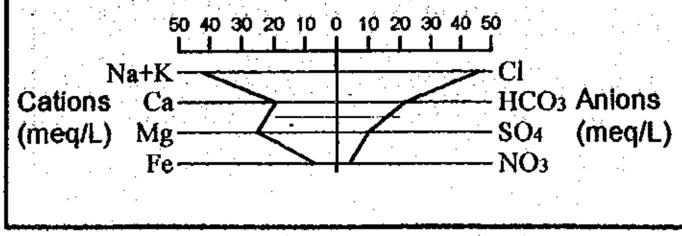
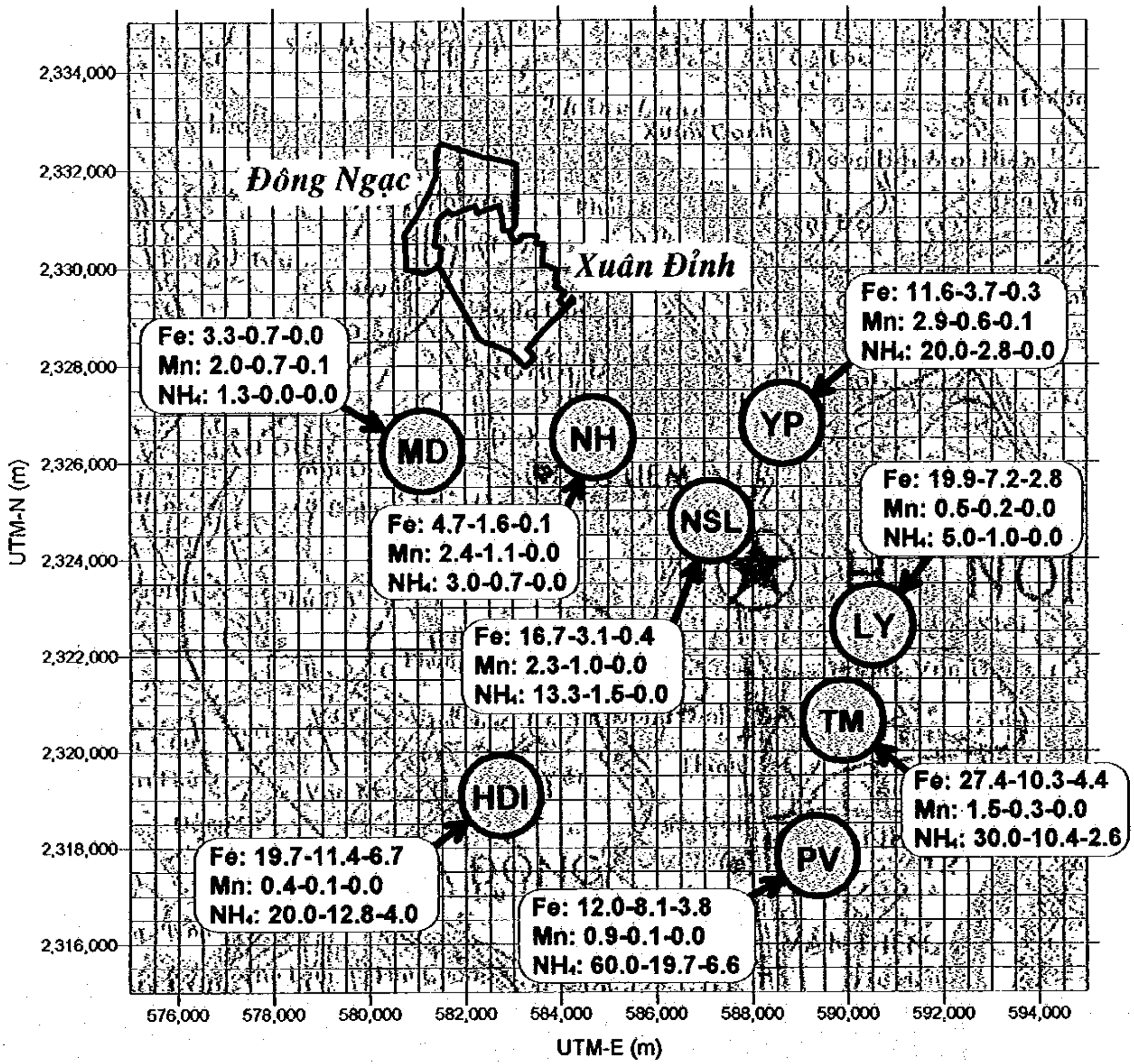


Figure 3.4 Stiff Diagram of JICA Test Wells

THE STUDY ON GROUNDWATER DEVELOPMENT IN THE RURAL PROVINCES OF NORTHERN PART IN THE SOCIALIST REPUBLIC OF VIETNAM

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

Groundwater Quality of Well Fields in Hà Nội Area



Water Quality of Production Wells by Well Field

Fe: Max-Avg-Min
Mn: Max-Avg-Min
NH_4: Max-Avg-Min

(Unit: mg/l)

<u>Name of Well Field</u>

MD:	Mai Dich
NH:	Ngoc Ha
YP:	Yen Phu
NSL:	Ngo Si Lien
LY:	Luong Yen
TM:	Tuong Mai
HDI:	Ha Dinh
PV:	Phap Van

[Data source: JICA (1997)]

Figure 3.5	**Groundwater Quality of Well Fields in Hà Nội Area**

THE STUDY ON GROUNDWATER DEVELOPMENT IN THE RURAL PROVINCES OF NORTHERN PART IN THE SOCIALIST REPUBLIC OF VIETNAM

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

CHAPTER 4 GEOPHYSICAL PROSPECTING

4.1 Geophysical Prospecting Method

The geologic structure in the target communes was estimated, and to obtain basic data for the selection of test well drilling points, the following three types of geophysical prospecting operations were conducted:

- Vertical Electric Sounding (VES)
- Resistivity Image Profiling (RIP)
- Very Low Frequency (VLF)

The Schlumberger electrode configuration was adopted for vertical electric sounding. The maximum survey line length for outside electrodes (AB/2) was set at 200 m. The pole-pole electrode configuration was adopted for resistivity image profiling; the current electrode and the potentiometric electrode used as remote electrodes were installed at distances at least 5 times the maximum survey line length. The measured electrodes were installed at equal intervals on the survey line, and then another current electrode was set using a controller to measure the electric potential difference.

The very low frequency method is an electromagnetic prospecting method using ultra long waves, transmitted between 15 and 30 kHz worldwide for military reasons (submarine communication), to detect resistivity in the shallow layers in order to determine any anomaly (fractured zones in the basement, boundaries of rock facies, etc.) in the geological structure.

Based on the results of the hydrogeological field survey in the target communes, the survey points and survey lines were distributed in 18 communes, in places considered essential to understanding the geologic structure. Prospecting operations covered 212 points for VES, 15 lines for RIP, and 18 lines for VLF.

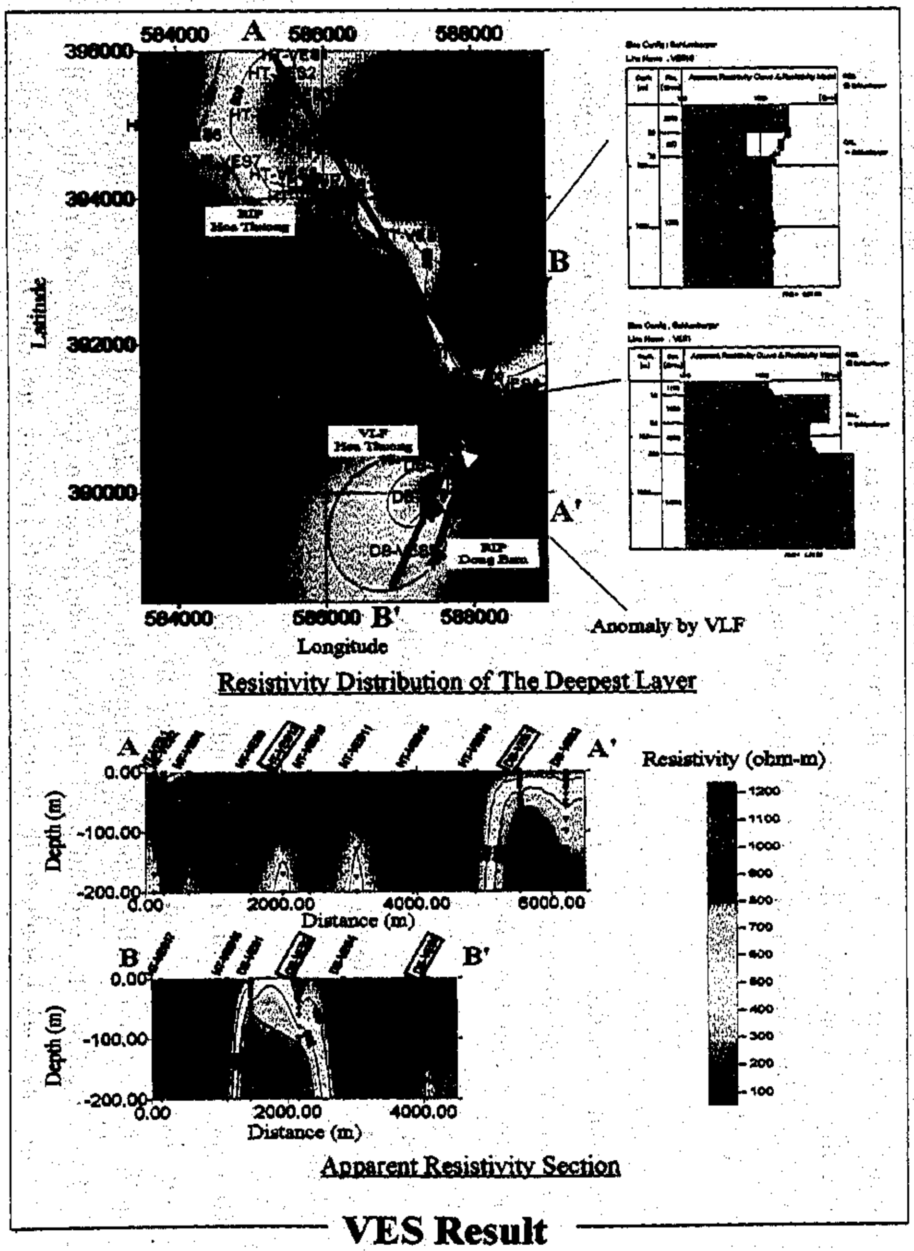
4.2 Results of Analysis

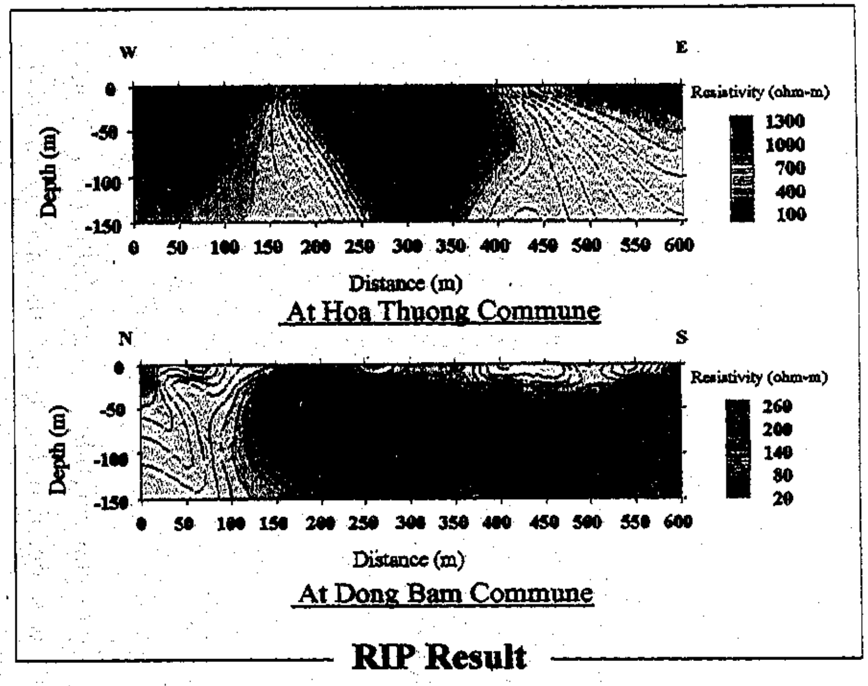
The underground geologic structure was estimated based on the vertical resistivity distribution surveyed at each point by VES, the detailed resistivity profiles along the survey lines surveyed using RIP, and the anomalous distribution in the basement rock detected by VLF.

In Thai Nguyen, basement rock resistivity in Hoa Thuong Commune was confirmed to be low in the northeast and high in the southwest. Resistivity was also low in the southwest of Dong Bam Commune, although a high basement rock resistivity is presumed in the NW-SE direction. Moreover, the RIP results indicate sudden changes in basement rock resistivity values in narrow areas, and VLF prospecting showed a clear anomaly in the sudden changes in basement rock resistivity values in the NNE-SSW direction in Dong Bam. Based on the hydrogeological survey, it was estimated that limestone makes up the high resistivity zone in the NW-SE direction, while sandstone and shale make up the low resistivity zones. The fault and fractured zones are presumed to form the boundary. Consequently, two test wells were drilled targeting the limestone of the fault and fractured zone. The drilling encountered a fractured limestone (including a cave) where a daily groundwater yield of 1,000 m^3 was obtained.

Such sudden changes in the basement rock resistivity values were detected in Quang Son and Dong Phong in Ninh Binh, and Vinh Thanh and Thieu Hung in Thanh Hoa. With the VLF, anomalies were found in Thinh Duc and Nam Tien in Thai Nguyen, and in Dong Phong, Yen Thang and Quang Son in Ninh Binh.

Resistivity in the target communes of Ha Tinh was low overall, even in the deep layers (between 60 and 100 m) where it was between 20 and 60 ς-m. Before the test drilling, the underground geology was presumed to consist of fine sediments or that electric conductivity in the groundwater was high. The results of the test drilling confirmed that the Neogene basement is mainly composed of weakly consolidated clay stones, and that low resistivity is attributed to high electric conductivity in the groundwater.





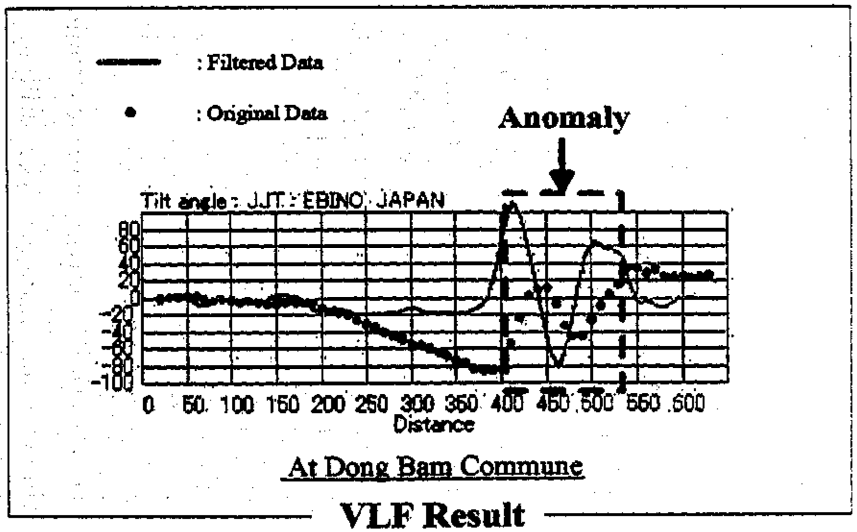


Figure 4.1 The Result of Geophysical Survey at Dong Bam and Hoa Thuong Commune in Thai Nguyen Province.

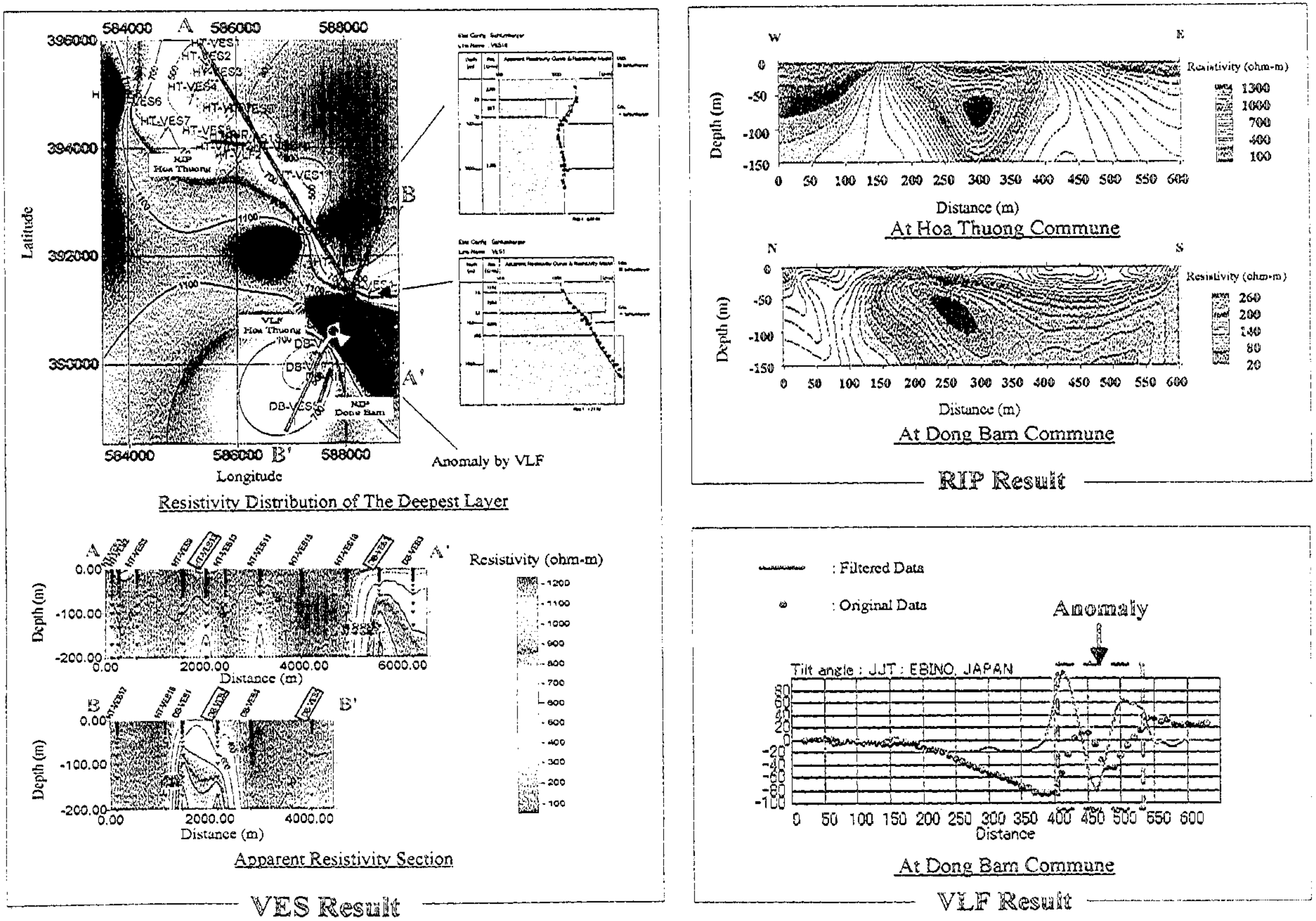


Figure 4.1 The Result of Geophysical Survey at Dong Bam and Hoa Thuong Commune in Thai Nguyen Province.

CHAPTER 5 TEST WELL DRILLING

5.1 Location

Excluding the 2 communes in Hanoi, hydrogeological surveys and geophysical prospecting were carried out in the 18 target communes, and the test well drilling locations were selected in 13 communes. In the first phase of the study, 10 test wells were drilled, while 3 more were drilled in the second phase. However, two more wells were additionally drilled in the first phase. These test wells were drilled in Thanh Hoa and Ha Tinh to confirm hydrogeological conditions in the area. The total number of test wells drilled was 15. The list of the drilled test wells is shown in Table 5.1.

5.2 Aquifer

The test drilling activity extracted cutting samples and carefully checked drilling conditions with extreme caution. The drilling depth was decided based on the hydrogeological conditions of the drilling location. After drilling was completed, geophysical logging was immediately carried out to determine the hydrogeological condition of the area surrounding the drilled section, assess the depth of the aquifer, and decide the depth for screen installation and the casing program to adopt. Depending on the well, the screen installed at one (1) to three (3) layers.

The geological condition of the aquifer of the test wells is shown in Table 5.1. The screen was installed in the limestone (basement rock section) with fissures and/or covernous zones. In sandstone and shale layers, the screen was installed in sections rich in fissures and cracks. For wells assumed to produce low groundwater volume, however, screens were also installed within the Quaternary gravel layer. In Ha Thinh, the clay layer of the Neogene period overlain by the Quaternary is assumed to hardly produce groundwater, hence a screen was installed in the sandstone layer in Neogene clayey stone and the gravel layer of the Quaternary formation.

After the installation of the casing and the screen pipe, well development was carried out using the airlift pump and submersible pump. The completion of the well took time in the aquifer in the fractured limestone layer due to the weathered clay in the cracks. In Dong Bam in Thai Nguyen, the ground near the well collapsed on the second day of the well development work leading to the termination of the field work and the conduct of the site reparation work.

5.3 Groundwater Pumpage

Except for Dong Bam in Thai Nguyen, 14 of the test wells were subjected to step-drawdown pumping tests. Submersible motor pumps were used for the test, which was generally carried out in 4 steps, each step for 4 hours. The test results obtained per step were analyzed to determine aquifer loss, well loss and the relationship between pumpage and drawdown. Table 5.2 shows the step-drawdown pumping test results.

It has been confirmed that aquifer loss (B) in the sandstone having low permeability and limestone with cracks filled up with clay will tend to increase. Well loss (C) is estimated to range widely; well loss in Hoa Thuong in Thai Nguyen, Dong Phong in Ninh Binh, Thieu Hung and Dinh Tuong in Thanh Hoa, was small from 1.0E-7 to 1.0E-8 day^2/m^5. The test wells in Quang Son and Yen Thang in Ninh Binh were estimated to have large well losses (1.0E-4 to 2.7E.4 day^2/m^5) which is mainly attributed to the well structure and screen clogging.

The results of the step-drawdown tests showed that wells in Thinh Duc in Thai Nguyen and Don Phong in Ninh Binh had an average well efficiency of over 90 %, whereas test wells in Hoa Thuong in Thai Nguyen, Vinh Thanh in Thanh Hoa, Duc Yen and Trung Le in Ha Tinh showed less than 60 % average well efficiency. The results also showed a maximum pumpage of over 1,000 m^3/day for wells in Hoa Thuong in Thai Nguyen, Dong Phong in Ninh Binh, Thieu Hung, Dinh Tuong, Vinh Thanh, and Thieu Do in Than Hoa. Wells in Nam Tien and Thinh Duc in Thai Nguyen have a maximum pumpage of under 200 m^3/day.

5.4 Aquifer Constant

After the drawdown that resulted from the step-drawdown tests was recovered, continuous pumping tests and recovery tests were carried out. The continuous pumping test was carried out for 48 hours, while the recovery test lasted for 12 hours. The results of the former were analyzed using the Cooper-Jacob method and Theis method (Hantush method was used for some of the analysis), and the latter by the recovery method.

5.4.1 Transmissivity (*T*)

The transmissivity indicates the productive capabilities of an aquifer and was calculated using the three methods aforementioned. The results using either equation were almost the same. Figure 5.2 shows the range of the transmissivity by province. The logarithmic average by province was calculated as follows: highest in Thanh Hoa at 201.5 m^2/day, followed by Ninh Binh at 69.7 m^2/day, Thai Nguyen at 44.8 m^2/day, and Ha Tinh at 11.1 m^2/day.

5.4.2 Hydraulic Conductivity (*k*)

The hydraulic conductivity is calculated by dividing the transmissivity by the screen length. The logarithmic average by province is: highest in Thanh Hoa at 7.68 m/day, followed by Thai Nguyen at 2.23 m/day, Ninh Binh at 2.01 m/day, and the lowest in Ha Tinh at 0.49 m/day (see Figure 5.3).

5.4.3 Correlation Between Transmissivity (T) and Specific Capacity (*Sc*)

The specific capacity is calculated by dividing pumpage by the drawdown. The correlation between the transmissivity and the specific capacity is roughly calculated at *T51.22 Sc* (Logan, 1964). However, this is reported to vary depending on well loss, leakage, and hydrogeological conditions (Shibasaki, 1996).

Figure 5.4 shows the correlation between *T* and *Sc* by province. Specific capacity was calculated at 9.6 to 244.4 m^2/day in Thanh Hoa and 4.2 to 197.0 m^2/day in Ninh Binh. The *T-Sc* plot of either province is on the upper level of *T*51.22 *Sc*. Thai Nguyen has a specific capacity of 10.1 to 259.5 m^2/day which is diagonal to the upper line. The *Sc* is large and will be plotted below the line. JICA No. 13 well in Trung Le in Ha Tinh was calculated with very low *T* and *Sc* values.

Figure 5.5 shows the *T-Sc* correlation by the geological characteristics of the aquifer. As shown in the figure, the range of the *T-Sc* plotting varies by aquifer geology. Wells that use aquifers in the Quaternary layer have high transmissivity: 30 to 1,000 m^2/day. For aquifers in limestone, the *T* was calculated at 30 to 200 m^2/day, and the *Sc* at 5 to 300 m^2/day. For aquifers in sandstone and clay layers, the *T* was at 20 to 200 m^2/day and the *Sc* at 5 to 50 m^2/day.

Table 5.1 List of Test Wells Drilled by the Study

Test Well No.	Commune District Province	UTM-E (m)	UTM-N (m)	Drilling Depth (m)	Well Depth (m)	Screen Depth(s) (m)	Screen Length (m)	Geology	Bedrock Depth (m)	Aquifer Geology
JICA-1	Đồng Bẩm Đồng Hỷ Thái Nguyên	587420	2369687	100	76	40 to 72	32.0	Quaternary/ Limestone	18.6	Limestone
JICA-2	Hoá Thượng Đồng Hỷ Thái Nguyên	586578	2393846	150	92	24 to 32 56 to 64 76 to 88	28.0	Quaternary/ Limestone/ Sandstone	12.8	Limestone
JICA-3	Nam Tiến Phổ Yên Thái Nguyên	590257	2366017	100	21.5	5.5 to 17.5	12.0	Quaternary/ Sandstone/ Siltstone	15.4	Quaternary gravel & Sandstone
JICA-4	Thịnh Đức Thị trấn Thái Nguyên Thái Nguyên	584201	2380475	100	88	8 to 16 52 to 60 68 to 84	32.0	Quatemaly/ Claystone/ Sandstone	16.5	Quaternary gravel & Sandstone
JICA-5	Quang Sơn Thị trấn Tam Điệp Ninh Bình	592553	2228660	150	120	72 to 116	44.0	Quaternary/ Limestone	9.4	Limestone
JICA-6	Yên Thắng Yên Mỗ Ninh Bình	600941	2228665	150	136	76 to 84 92 to 104 124 to 132	28.0	Quaternary/ Limestone	44.0	Limestone
JICA-7	Đồng Phong Nho Quan Ninh Bình	577617	2246929	150	130	92 to 126	34.0	Top Soil/ Limestone	2.0	Limestone
JICA-8	Vạn Thắng Nông Cống Thanh Hoá	565030	2170050	150	150	99 to 119	20.0	Quaternary/ Sandstone with Siltstone	6.0	Sandstone
JICA-9	Thiệu Hưng Thiệu Hoá Thanh Hoá	571655	2199306	80	52	32 to 48	16.0	Quaternary/ Sandstone	48.0	Quaternary gravel
JICA-10	Định Tường Yên Định Thanh Hoá	568421	2207260	91.2	91.2	23.2 to 39.2 47.2 to 63.2	32.0	Quaternary/ Sandstone and Claystone	34.8	Quaternary gravel & Sandstone
JICA-11	Vĩnh Thành Vĩnh Lộc Thanh Hoá	564793	2216162	148	80	32 to 48 60 to 76	32.0	Quatsrnary/ Limestone	23.0	Limestone
JICA-12	Đức Yên Đức Thọ Hà Tĩnh	563705	2048152	106	104	20 to 28 84 to 100	24.0	Quaternary/ Neogene clay	28.0 *	Quaternary gravel & Neogene clay
JICA-13	Trung Lễ Đức Thọ Hà Tĩnh	566783	2046329	100	100	58 to 82	24.0	Quaternary/ Neogene clay	68.4 *	Quaternary gravel & Neogene clay
JICA-14	Thiệu Đô Thiệu Hoá Thanh Hoá	572185	2197515	70	68	18 to 50 58 to 64	38.0	Quaternary/ Limestone	33.5	Quaternary gravel & Limestone
JICA-15	Trung Lễ Đức Thọ Hà Tĩnh	567186	2046557	70	40	16 to 36	20.0	Quaternary/ Neogene clay	35.4	Quaternary gravel

* Depth to Neogene clay

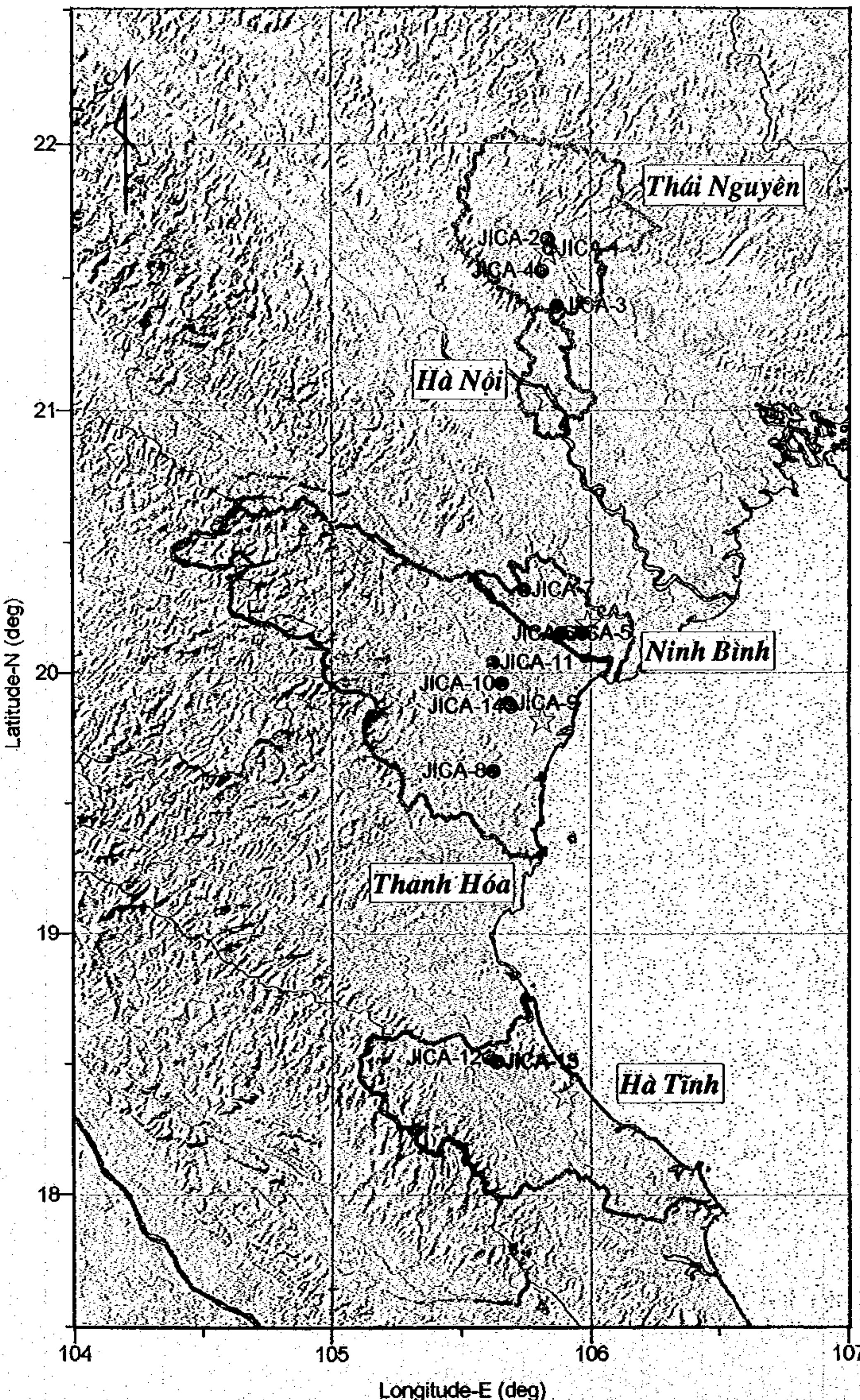
Table 5.2 Results of Step-Drawdown Test at JICA Test Wells

Test Well No.	Commune District Province	UTM-E (m)	UTM-N (m)	Drilling Depth (m)	Well Depth (m)	Screen Depth(s) (m)	Step-drawdown Test Date(dd/mm/yy) Static Water Level (m below G.L.)	Q1(m^3/day) s1(m) So1(m^2/day)	Q2(m^3/day) s2(m) So2(m^2/day)	Q3(m^3/day) s3(m) So3(m^2/day)	Q4(m^3/day) s4(m) So4(m^2/day)	Aquifer Loss Coefficient B (d/m^2)	Well Loss Coefficient C (d^2/m^5)	Average Well Efficiency (%)
JICA-1	Đồng Bẩm Đồng Hỷ Thái Nguyên	587420	2389687	100	76	40 to 72	-	-	-	-	-	-	-	-
JICA-2	Hoá Thượng Đồng Hỷ Thái Nguyên	586578	2393846	150	92	24 to 32 56 to 64 76 to 88	03/06/1999 3.10	360.00 0.55 654.55	720.00 1.80 400.00	1080.00 2.21 488.69	1440.00 3.76 382.98	1.14E-03	9.62E-07	54.90
JICA-3	Nam Tiến Phổ Yên Thái Nguyên	590257	2386017	100	21.5	5.5 to 17.5	15/04/1999 1.50	69.12 1.75 39.50	138.24 3.66 37.77	- - -	- - -	2.42E-02	1.67E-05	93.49
JICA-4	Thịnh Đức Thị trấn Thái Nguyên Thái Nguyên	584201	2380475	100	88	8 to 16 52 to 60 68 to 84	27/05/1999 2.00	43.20 4.37 9.89	94.18 9.50 9.91	146.88 14.72 9.98	188.35 18.80 10.02	1.02E-01	-9.59E-06	101.48
JICA-5	Quang Sơn Thị trấn Tam Điệp Ninh Bình	592553	2228660	150	120	72 to 116	05/03/1999 10.80	86.40 8.00 10.80	172.80 15.20 11.37	259.20 21.90 11.84	345.60 43.00 8.04	7.44E-02	1.06E-04	78.20
JICA-6	Yên Thắng Yên Mô Ninh Bình	600941	2228665	150	136	76 to 84 92 to 104 124 to 132	17/03/1999 1.23	57.60 10.87 5.30	115.20 22.89 5.03	172.80 35.77 4.83	230.40 54.97 4.19	1.69E-01	2.74E-04	81.77
JICA-7	Đông Phong Nho Quan Ninh Bình	577617	2246929	150	130	92 to 126	23/05/1999 0.60	432.00 2.07 208.70	864.00 4.56 189.47	1296.00 6.48 200.00	1728.00 8.54 202.34	4.96E-03	4.01E-08	99.26
JICA-8	Vạn Thắng Nông Cống Thanh Hoá	585030	2170050	150	150	99 to 119	05/02/1999 5.70	158.40 9.83 16.11	271.54 20.98 12.94	475.20 41.60 11.42	633.60 56.53 11.21	5.80E-02	5.48E-05	74.95
JICA-9	Thiệu Hưng Thiệu Hoá Thanh Hoá	571655	2199306	80	52	32 to 48	10/02/1999 4.00	352.80 2.40 147.00	705.60 4.55 155.08	1058.40 7.12 148.65	1411.20 10.01 140.98	5.79E-03	9.14E-07	85.65
JICA-10	Định Tường Yên Định Thanh Hoá	568421	2207260	91.2	91.2	23.2 to 39.2 47.2 to 63.2	10/04/1999 4.90	432.00 1.26 342.86	864.00 3.02 286.09	1296.00 4.92 263.41	1728.00 7.04 245.45	2.63E-03	8.73E-07	74.81
JICA-11	Vĩnh Thành Vĩnh Lộc Thanh Hoá	564793	2216162	148	80	32 to 48 60 to 76	24/04/1999 7.55	362.00 1.86 194.62	734.40 4.90 149.88	1123.20 9.80 114.61	1512.00 14.27 105.96	3.85E-03	3.90E-06	54.39
JICA-12	Đức Yên Đức Thọ Hà Tĩnh	563705	2048152	106	104	20 to 28 84 to 100	05/03/1999 2.90	108.00 1.36 79.41	216.00 3.24 66.67	324.00 6.11 53.03	432.00 9.27 46.60	9.36E-03	2.82E-05	57.50
JICA-13	Trung Lễ Đức Thọ Hà Tĩnh	566783	2046329	100	100	58 to 92	08/04/1999 2.60	12.96 2.56 5.06	25.92 14.60 1.78	- - -	- - -	-	-	-
JICA-14	Thiệu Đô Thiệu Hoá Thanh Hoá	572185	2197515	70	68	18 to 50 58 to 64	29/03/1999 2.85	475.20 2.08 228.46	950.40 4.21 225.75	1425.60 7.01 203.37	1900.80 13.67 139.05	3.00E-03	1.89E-06	59.75
JICA-15	Trung Lễ Đức Thọ Hà Tĩnh	567186	2046557	70	40	16 to 36	01/04/1999 2.48	64.80 0.85 76.24	129.60 1.80 72.00	259.20 3.09 83.88	345.60 6.93 49.87	6.69E-03	6.61E-05	47.16

Table 5.3 Results of Continuous Pumping Test at JICA Test Wells

Test Well No.	Commune District Province	UTM-E (m)	UTM-N (m)	Drilling Depth (m)	Well Depth (m)	Screen Depth(s) (m)	Screen Length (m)	Continuous Pumping Test					Theis Method			Cooper-Jacob Method			Recovery Test Recovery Method	
								Date (dd-mm-yy)	Static Water Level (m below G.L.)	Pumping Rate, Q (m^3/day)	Final Drawdown, s (m)	Specific Capacity, So (m^2/day)	T (m^2/day)	k (m/day)	S	T (m^2/day)	k (m/day)	S	T (m^2/day)	k (m/day)
JICA-1	Đồng Bẩm Đồng Hỷ Thái Nguyên	587420	2389687	100	76	40 to 72	32.0	-	-	-	-	-	-	-	-	-	-	-	-	-
JICA-2	Hoá Thượng Đồng Hỷ Thái Nguyên	586578	2383846	150	92	24 to 32 56 to 64 76 to 88	28.0	04/06/1999	3.10	1440.00	5.55	259.46	173.00	6.18E+00	3.01E+01	129.34	4.62E+00	1.37E+02	145.86	5.20E+00
JICA-3	Nam Tiến Phổ Yên Thái Nguyên	590257	2366017	100	21.5	5.5 to 17.5	12.0	16/04/1999	1.50	138.24	4.75	29.10	24.00	2.00E+00	7.09E-01	23.8	1.98E+00	8.48E-01	28.12	2.34E+00
JICA-4	Thịnh Đức Thị trấn Thái Nguyên Thái Nguyên	584201	2380475	100	88	8 to 16 52 to 60 68 to 84	32.0	28/05/1999	2.00	188.35	18.58	10.14	33.20	1.04E+00	3.71E-15	36.4	1.14E+00	1.93E-16	11.4	3.56E-01
JICA-5	Quang Sơn Thị trấn Tam Điệp Ninh Bình	592553	2228660	150	120	72 to 116	44.0	07/03/1999	10.80	345.60	42.60	8.11	Hantush's method 1.21	2.75E-02 c = 1.84E+00 (day)	2.15E-01	35.69	8.11E-01	7.73E-22	102.6	2.33E+00
JICA-6	Yên Thắng Yên Mô Ninh Bình	600941	2228665	150	136	76 to 84 92 to 104 124 to 132	28.0	18/03/1999	1.23	230.40	54.79	4.21	15.30	5.46E-01	5.42E-18	17.59	6.28E-01	1.01E-20	54.85	1.96E+00
JICA-7	Đồng Phong Nho Quan Ninh Bình	577617	2246929	150	130	92 to 126	34.0	24/05/1999	0.60	1728.00	8.77	197.04	862.00	2.54E+01	6.82E-19	1096.3	3.22E+01	2.51E-25	627.8	1.05E+01
JICA-8	Vạn Thắng Nông Cống Thanh Hoá	585030	2170050	150	150	99 to 119	20.0	06/02/1999	5.00	613.16	63.50	9.64	47.00	2.35E+00	1.66E-24	151.93	7.60E+00	2.78E-81	134.03	6.70E+00
JICA-9	Thiệu Hưng Thiệu Hoá Thanh Hoá	571655	2199306	80	52	32 to 48	16.0	12/02/1999	4.00	1411.20	10.02	140.84	Hantush's method 118.00	7.38E+00 c = 4.73E-01 (day)	1.87E-03	672.57	4.20E+01	1.93E-22	895.18	5.59E+01
JICA-10	Định Tường Yên Định Thanh Hoá	568421	2207260	91.2	91.2	23.2 to 39.2 47.2 to 63.2	32.0	11/04/1999	4.90	1728.00	7.07	244.41	674.00	2.11E+01	1.34E-10	759.31	2.37E+01	3.48E-12	681.7	2.13E+01
JICA-11	Vĩnh Thành Vĩnh Lộc Thanh Hoá	564793	2216162	148	80	32 to 48 60 to 76	32.0	27/04/1999	7.55	1512.00	16.29	92.82	86.90	2.72E+00	2.52E-01	80.56	2.52E+00	4.78E-01	77.76	2.43E+00
JICA-12	Đức Yên Đức Thọ Hà Tĩnh	563705	2048152	106	104	20 to 28 84 to 100	24.0	06/03/1999	3.20	432.00	14.43	29.94	51.30	2.14E+00	5.41E-02	54.18	2.26E+00	3.53E-02	61.75	2.57E+00
JICA-13	Trung Lễ Đức Thọ Hà Tĩnh	566783	2046329	100	100	58 to 82	24.0	09/04/1999	2.80	25.92	22.76	1.14	0.49	2.05E-02	1.59E+00	0.461	1.92E-02	1.89E+00	0.356	1.48E-02
JICA-14	Thiệu Đô Thiệu Hoá Thanh Hoá	572185	2197515	70	68	18 to 50 58 to 64	38.0	30/03/1999	2.85	1900.80	14.19	133.95	Hantush's method 141.00	3.71E+00 c = 3.98E-01 (day)	1.98E-02	140.07	3.69E+00	2.90E-02	144.07	3.79E+00
JICA-15	Trung Lễ Đức Thọ Hà Tĩnh	567186	2046557	70	40	16 to 36	20.0	02/04/1999	2.46	259.20	6.75	38.40	43.50	2.18E+00	2.67E-02	43.79	2.19E+00	2.46E-02	100.45	5.02E+00

c: Hydraulic Resistance



JICA Test Well

Figure 5.1	Location of JICA Test Wells
THE STUDY ON GROUNDWATER DEVELOPMENT IN THE RURAL PROVINCES OF NORTHERN PART IN THE SOCIALIST REPUBLIC OF VIETNAM	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	

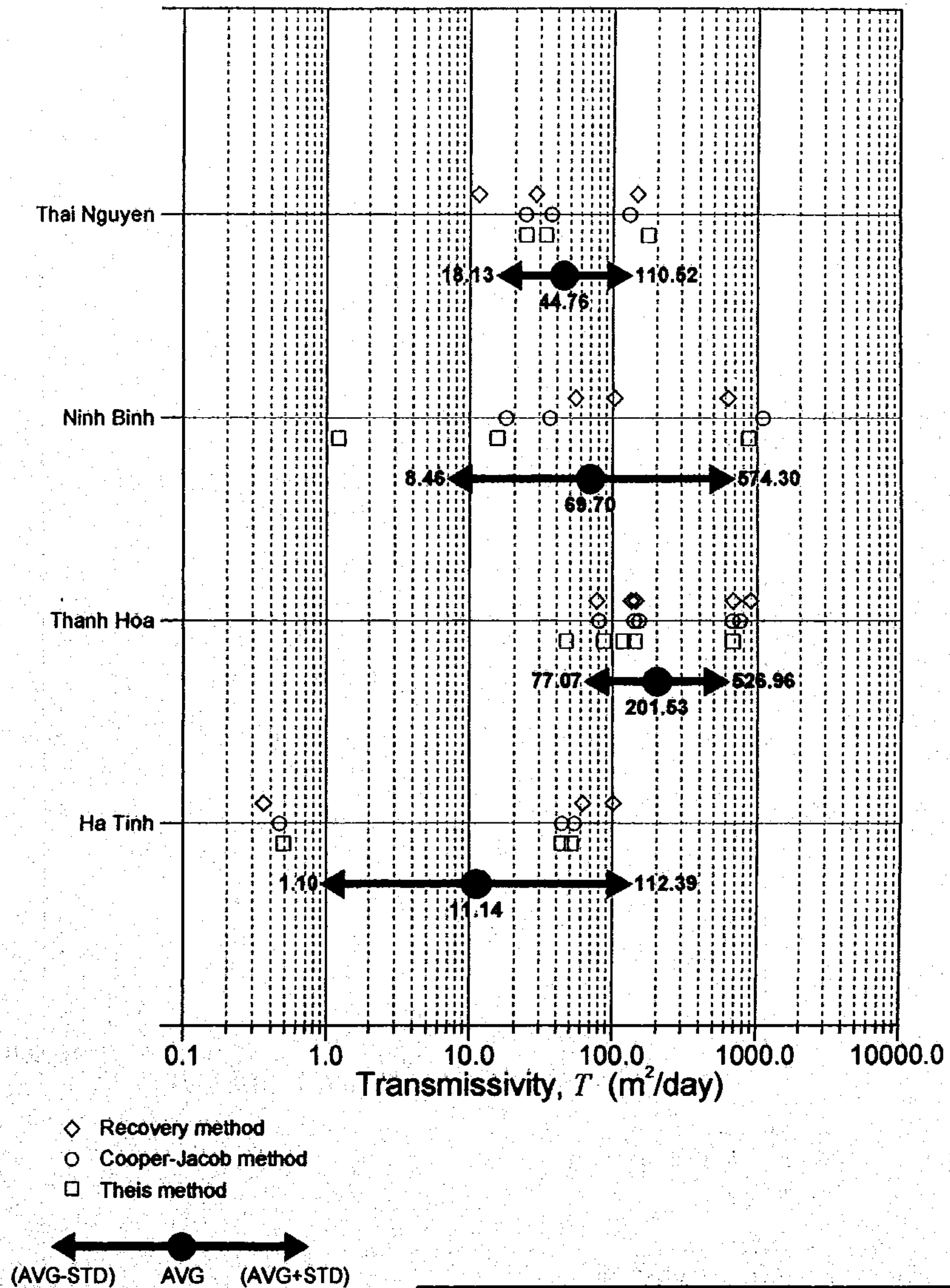


Figure 5.2	STATISTICAL ANALYSIS OF *T* DISTRIBUTION BY PROVINCE
	THE STUDY ON GROUNDWATER DEVELOPMENT IN THE RURAL PROVINCES OF NORTHERN PART IN THE SOCIALIST REPUBLIC OF VIETNAM
	JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

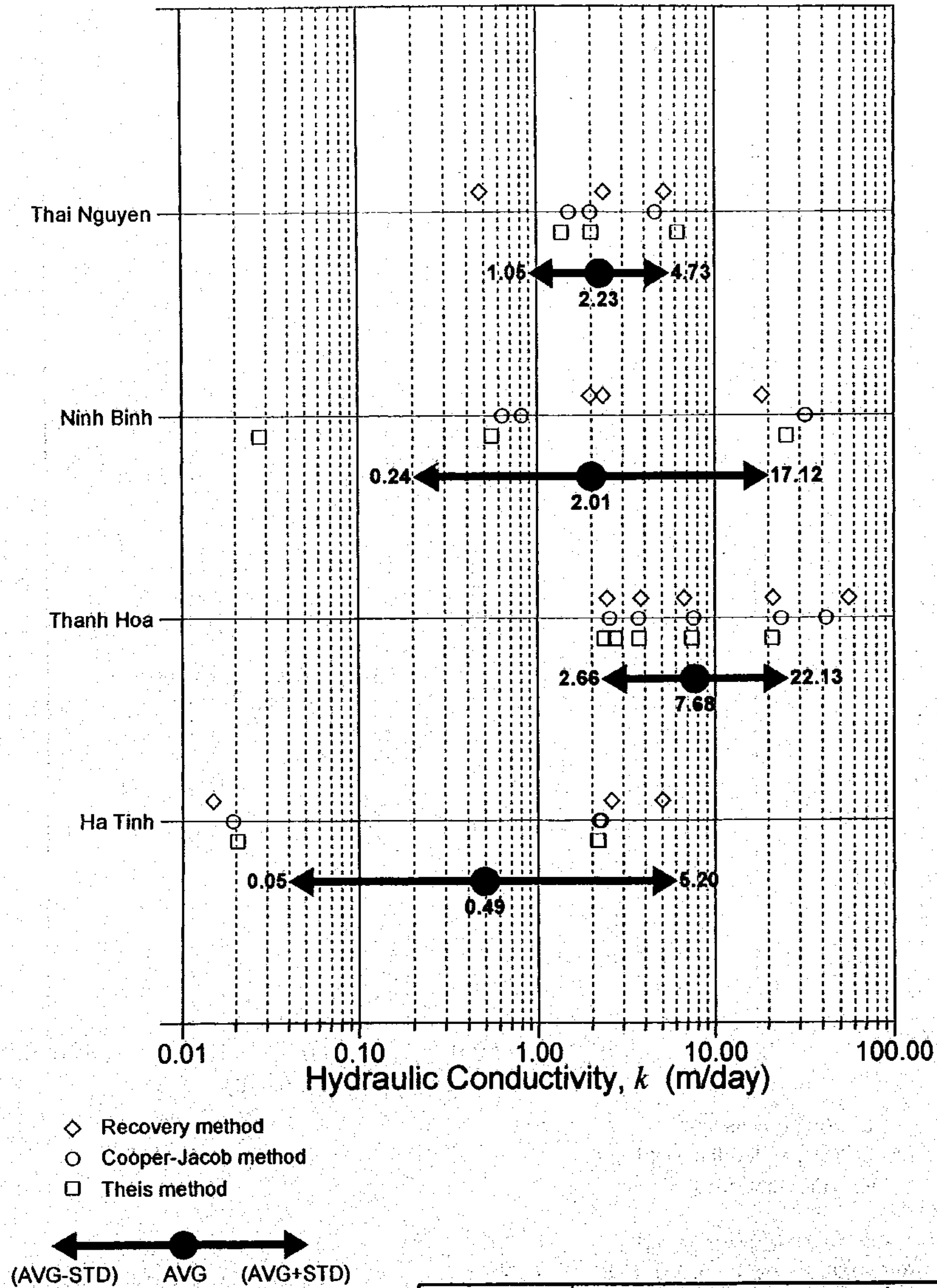


Figure 5.3	**STATISTICAL ANALYSIS OF *k* DISTRIBUTION BY PROVINCE**
THE STUDY ON GROUNDWATER DEVELOPMENT IN THE RURAL PROVINCES OF NORTHERN PART IN THE SOCIALIST REPUBLIC OF VIETNAM	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	

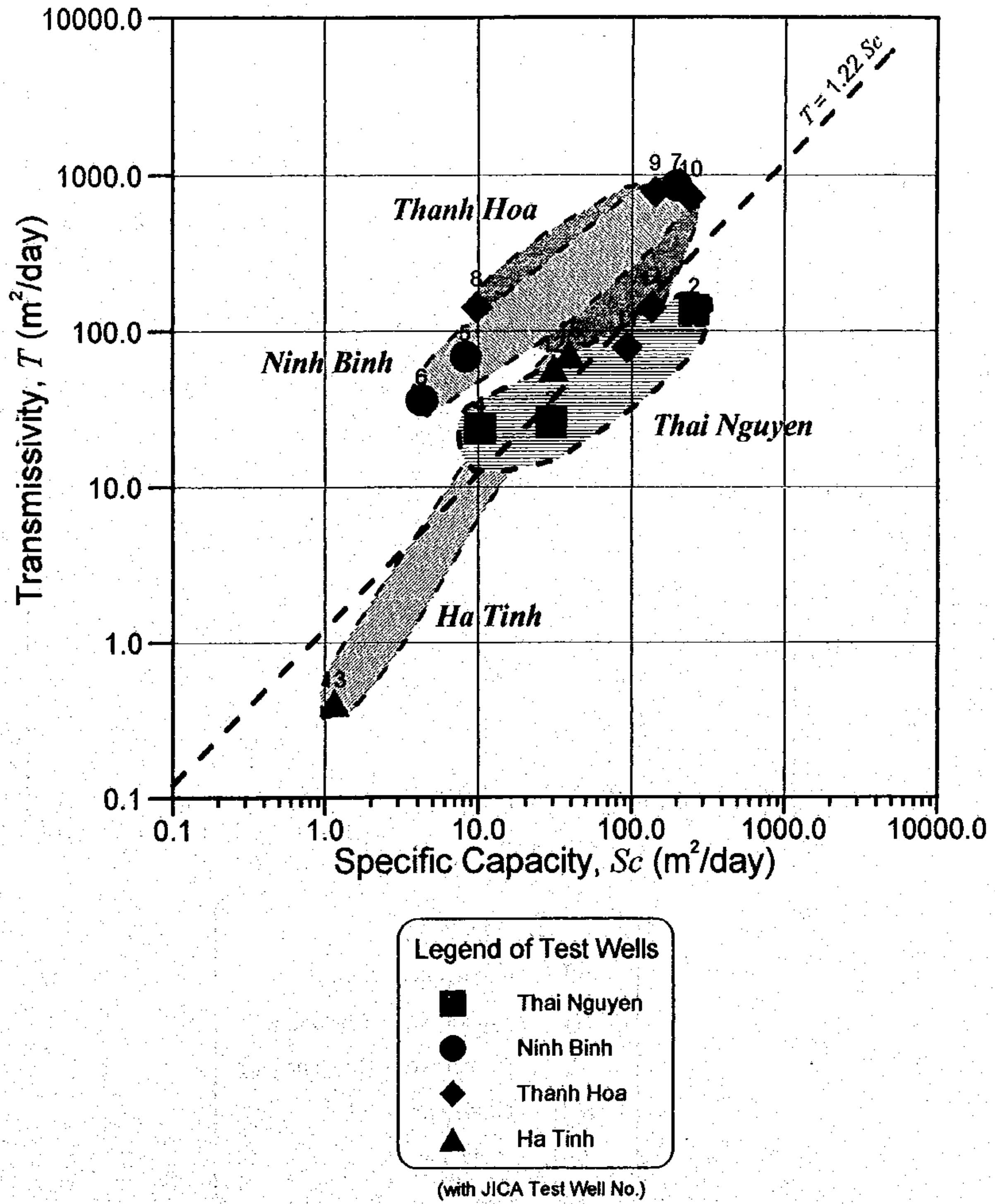


Figure 5.4	RELATIONSHIP BETWEEN T AND Sc FROM PUMPING TEST OF TEST WELLS
THE STUDY ON GROUNDWATER DEVELOPMENT IN THE RURAL PROVINCES OF NORTHERN PART IN THE SOCIALIST REPUBLIC OF VIETNAM	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	

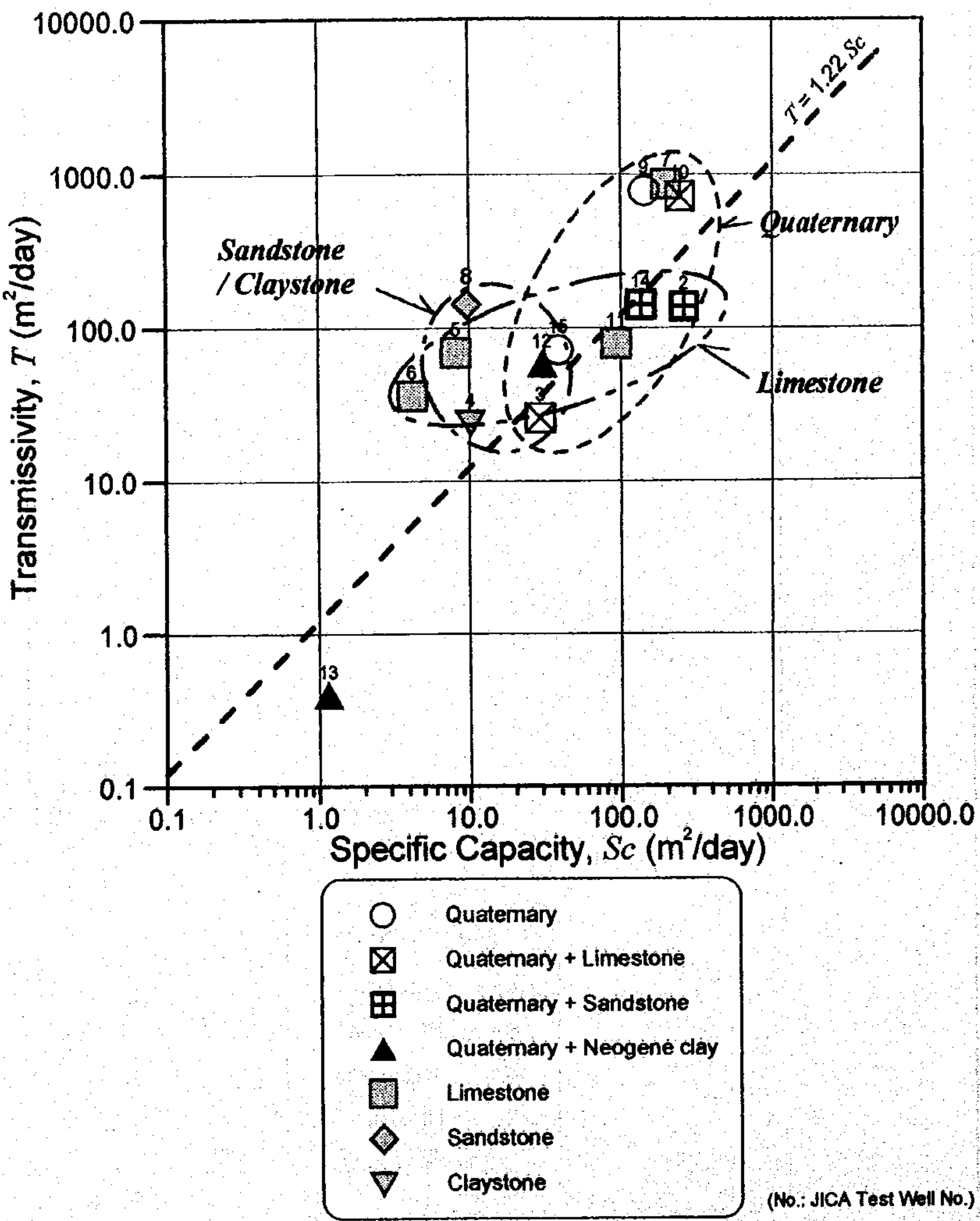


Figure 5.5	RELATIONSHIP BETWEEN *T* AND *Sc* BY AQUIFER GEOLOGY
THE STUDY ON GROUNDWATER DEVELOPMENT IN THE RURAL PROVINCES OF NORTHERN PART IN THE SOCIALIST REPUBLIC OF VIETNAM	
JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	

CHAPTER 6 GROUNDWATER RESOURCE EVALUATION

6.1 Water Balance Analysis

6.1.1 Rainfalls

Rainfall data for the past 30 years show Hanoi having the lowest mean annual rainfall amount at 1,683.8 mm and Ha Tinh with the highest at 2,719.9 mm, followed by Thai Nguyen with 2,049.7 mm, Ninh Binh with 1,860.6 mm, and Thanh Hoa with 1,728.8 mm.

The rainy season generally starts from May and lasts to October. Mean monthly rainfall data for the past 30 years shows a peak occurs early in the north and late in the south. Rainfall peaks in July in Thai Nguyen (402.2 mm), August in Hanoi (293.7 mm), September in Ninh Binh (381.8 and 387.1 mm), and October in Ha Tinh (736.9 mm).

Figure 6.1 plots the annual rainfall probability in these five areas, as well as the drought years and annual flooding probability. According to the figure, rainfall under a drought year with a 10 year probability amounts to: 1,180 mm/year in Thanh Hoa (the lowest), 1,280 mm/year in Hanoi, 1,330 mm/year in Ninh Binh, 1,660 mm/year in Thai Nguyen, and 1,905 mm/year in Ha Tinh (the highest). Under a 50 year probability, precipitation is lowest in Thanh Hoa at 1,040 mm/year and highest in Ha Tinh at 1,700 mm/year, followed by Thai Nguyen at 1,450 mm/year, Hanoi at 1,230 mm, and Ninh Binh at 1,100 mm. Accordingly, precipitation is small in Thanh Hoa and Ninh Binh rather than in Hanoi in times of drought. It is assumed, therefore, that groundwater recharge volume in this period is small in these two provinces.

In Ha Tinh, about 60 % of the mean annual rainfall amount falls from September to November, for 3 months. Rainfall in this province in the early half of the rainy season is smaller that other areas. Rainfall in these three months is influenced by the typhoon originating from the East Sea (South China Sea). Rainfall in this province varies widely from a maximum of 2,611.8 mm to a minimum of 640.8 mm. Annual rainfall particularly fluctuates in the month of October: minimum of 142.1 mm, maximum of 2,047.8 mm.

6.1.2 Evaporation

In the entire study area, evaporation is small in February and March, and high from May to July. With the exception of Ha Tinh, monthly mean evaporation in the other 4 areas peaks from May to July, and in October. Fluctuation in monthly evaporation ranges from 60 to 100 mm in Thai Nguyen and Hanoi, 40 to 105 mm in Ninh Binh and Thanh Hoa, and 25 to 135 mm in Ha Tinh. Monthly evaporation fluctuates sharply in the south. Mean annual evaporation is highest in Hanoi at 976.5 mm, followed by Thai Nguyen at 956,9 mm, Ninh Binh at 851.6 mm, Thanh Hoa at 816.0 mm, and Ha Tinh at 800.9 mm.

6.1.3 Surface Water Runoff

Generally, surface water runoff varies depending on the topography, vegetation, soil, and rainfall pattern. There are no detailed data on surface runoff in the study area. However, according to the Vietnam National Atlas (1996), the mean annual surface runoff is 400 to 600 mm in Thai Nguyen, about 400 mm in Hanoi, about 300 mm in Ninh Binh and Thanh Hoa, and 400 to 800 mm in Ha Tinh.

6.1.4 Groundwater Recharge

Aside from the amount that evaporates, undergoes evapotranspiration, and discharged (surface runoff), rainfall also permeates the ground and recharges groundwater resources. Some of the amount, however, is absorbed by the soil (moisture content). Groundwater recharge is generally estimated based on actual surveys on or estimates of every item in the water balance equation. The existence of actual daily precipitation and evaporation values would enable the calculation of the water balance through the use of a tank model that estimates the generation of surface runoff, in order to determine groundwater recharge. To verify the suitability of the mode, actual groundwater level records would be necessary.

In the study area, groundwater level was monitored through the test wells using a automatic water level recorder. However, only about several months worth of data has been obtained. In addition, precipitation and evaporation data in the same period are not published. These factors made it difficult for the study team to survey groundwater recharge in detail.

The Vietnam National Atlas (1996) indicates, however, an average annual groundwater recharge of about 600 mm near the study area.

Groundwater in areas along rivers are assumed to be recharged by river water when river water level exceeds groundwater level in the surrounding area. To determine the groundwater recharge volume, the following data would be required: discrepancy between river water level and groundwater level, data on river bed sediments, and the hydraulic conductivity of ground layers. Unfortunately, however, the study area has no such data available.

6.2 Optimal Pumpage

Except for the Hanoi area, the amount of groundwater developed in the study area for drinking water supply is comparatively smaller than the average groundwater recharge volume. In view of water balance, these areas are assessed to have the groundwater amount required for water supply. It is, however, important to conduct a study to determine the capacity of the aquifer, drawdown way beyond the permissible limit, well interference, and optimal pumpage to prevent any problems such as land subsidence and water quality contamination.

Except for Hanoi, no large scale groundwater development projects have been conducted in the study area. Studies will be carried out, therefore, to determine the capacity of target aquifers, the well structure, and optimal pumpage for the sustainable use of groundwater. Optimal pumpage in this study may be defined as the required water level in the well to be maintained despite continuous pumping operations.

Based on the well pumping test results, optimal pumpage and permissible dynamic water level are as shown in the following table.

Well Name	Commune	Optimal Pumpage (m^3/day)	Permissible Dynamic Water Level (GL-)
JICA-2	Hoa Thuong	1,000	10 m
JICA-3	Nam Tien	100	10 m
JICA-4	Thinh Duc	150	20 m
JICA-5	Quang Son	250	30 m
JICA-6	Yen Thang	120	30 m
JICA-7	Dong Phong	1,500	10 m
JICA-8	Van Thang	300	30 m
JICA-9	Thieu Hhun	1,400	15 m
JICA-10	Dinh Tuong	1,700	15 m
JICA-11	Vinh Thanh	1,500	20 m
JICA-12	Duc Yen	250	10 m
JICA-13	Trung Le	10	10 m
JICA-14	Thieu Do	1,800	20 m
JICA-15	Trung Le	250	15 m

CHAPTER 7 GROUNDWATER MODELING FOR HA NOI AREA

7.1 Model Structure and Parameters

To study the suitable groundwater development plan proposed for the two target communes in Hanoi, a three dimensional groundwater simulation model was made. The model structure was decided in consideration of the hydrogeological structure of Hanoi and the aquifer classifications. The model is made up of 4 layers with the cells forming a square as they horizontally measure 500 m in the north-south and 500 in the east-west. The areas covered by the model are 20 km east-west, 20 km north-south; the cells in the model total 6,400 (4034034).

The layers in the model were divided as follows: the uppermost layer is Layer-1 (clayey soil and silt layer, confined/unconfined conditions), Layer-2 (First Aquifer, confined/unconfined conditions), Layer-3 (clayey soil and silt layer, confined conditions), Layer-4 (Second Aquifer, confined conditions).

The boundaries of the model were established by assigning constant-head boundaries in the first cell that covers the Red River, Duong River, and West Lake, and water level of each cell was set based on the data of surface water levels. A no-flow boundary was also established encompassing the extent of the area covered by the model.

The parameters were based on existing data and arranged by layer before they were entered into each cell. The parameters were as follows: upper and lower elevation of every layer, effective porosity, specific storage, horizontal and vertical hydraulic conductivity, initial water level, recharge volume, groundwater pumpage. Table 7.1 shows the list of parameters.

7.2 Model Verification

To confirm whether the model developed can really simulate actual groundwater flow, steady-state calibration for a period of 30 years were carried out using observation records collected in May 1991 —this period is considered to comparatively have complete records. The 1991 pumping data was applied in the model to compare the estimated and actual groundwater level and correct the unreliable vertical hydraulic conductivity. The results could reasonably simulate the groundwater heads in pump wells in May 1991.

Afterwards, the groundwater level simulated by the aforementioned steady-state calibration was adopted as the initial water level and the amount of groundwater pumped from 1990 to 1996 was entered into the model to carry out a 7 year transient calibration. The results confirm that the groundwater level fluctuation estimate (1990~1996) and the groundwater head estimate (1996) reproduce actual surveyed values.

7.3 Prediction

In relation to the construction of two new wells in Dong Ngac and Xuan Dinh, future simulations were carried out using the aforementioned model, to study how the pumping of water from the second aquifer would impact the level and flow of surrounding groundwater. Assuming that these two communes will each be constructed with one well, the well location in the former is I=9, J=13, and I=9 and J=14 in the latter.

The pumpage proposed for the new wells is as follows:

First proposed pumpage:
Dong Ngac *1,260 m^3/day*
Xuan Dinh *2,850 m^3/day*

Second proposed pumpage:
Dong Ngac *1,890 m^3/day*
Xuan Dinh *4,275 m^3/day*

The first proposed pumpage is the design maximum pumpage, while the second is 1.5 times the first. The estimate is derived by comparing the water level estimated from the pumpage of the new wells and the water level estimated from the new wells without pumpage. The pumpage of the Ha Noi Water Supply is established taking into account the actual values until 1996 and the proposed well layout (DGM, 1998) along the Red River. Accordingly, the construction of the following is planned: 26 wells (total pumpage: 97,964 m^3/day) for the Cao Dinh well field, and an additional 13 wells in Yen Phu (total pumpage: 60,777 m^3/day).

The estimate was derived from a 10 year transient simulation. Assuming that the new wells in the target communes have no pumpage, calculations were carried out as the Case-0, and the calculation of the estimates shown in the first and second proposed pumpage ensued. The proposed head (Case-1 and Case-2) resulting from the 10 year transient simulation were compared with the calculated groundwater head done in the same period as the Case-0, to determine the impacts of the new well pumpage.

The Case-1 estimate calculation indicates a maximum 2.36 m decline in the groundwater level at the site targeted for the new well in Xuan Dinh: a more than 10 cm decrease about 5 km east and about 7 km south of Xuan Dinh. Of the areas where the sources of the Ha Noi Water Supply are located, a 15 to 30 cm decrease in groundwater level is forecast in the well field in Ngoc Ha near Xuan Dinh and the Mai Dich well field.

7.4 Impact Assessment

The results of the estimation indicate that the implementation of groundwater pumping under this study in the communes of Dong Ngac and Xuan Dinh would lead to a decline in groundwater level. A decline of over 10 cm is estimated to occur in the groundwater level in areas outside of these communes, in the western half of the West Lake, in Ngoc Ha well field and Mai Dich well field. Pumping 1.5 times the design maximum pumpage is forecast to result in a more than 10 cm drop in the groundwater level in central Ha Noi.

Groundwater pumping by the Ha Noi Water Supply significantly affects natural groundwater flow, and this is evidenced in the decline in groundwater levels in the central and southern areas of central Ha Noi. Groundwater in Ha Noi is observed to flow toward the central area where the level of groundwater from the second aquifer has declined. Groundwater pumping in the central area is as follows: 130 wells from the well field of the Ha Noi Water Supply System (330,000~390,000 m^3/day); about 250 wells of private industries and commercial (about 75,000 m^3/day as of 1998) according to the DGM (1998). Since the target groundwater amount to be developed under this study (about 4,100 m^3/day) is only about 1 % of the existing pumpage, the development of new groundwater resources would not have any significant impact on groundwater flow in Ha Noi.

Based on the results of the first proposed estimate calculation, Figure 7.9 was made to show the calculated groundwater flow in Ha Noi and the pathline of groundwater flow into the Dong Ngac / Xuan Dinh wells and the wells in the Cao Dinh well fields. Groundwater flowing into the Dong Ngac and Xuan Dinh wells is recharged from the surface near the well vicinity and from the west. Groundwater in the Cao Dinh well field is mainly recharged by flows from the Red River.

The result of Case-1simulation is as follows:

Pumpage in the Cao Dinh well field is assumed to be huge, resulting in a groundwater head lower than that of Dong Ngac and Xuan Dinh. The well field will block the direct inflow of the Red River to the wells in Dong Ngac and Xuan Dinh. It is, however, possible for Red River to directly flow into the Dong Ngac and Xuan Dinh area to recharge groundwater flow, if pumpage in the Cao Dinh well field is small.

According to JICA (1997), arsenic in the Red River (1994) exceeds the value (0.05 mg/ℓ) stipulated for drinking water in Vietnam at a maximum of 0.095 mg/ℓ. The river was also observed to contain chromium, lead, and nickel levels way over the drinking water standard of Vietnam and WHO. DDT levels in the river also exceeded the drinking water standard of Vietnam.

The development of new wells in the target communes would not only necessitate particular caution regarding the groundwater amount to develop but also the quality of the recharging or target resources. It is, therefore, important that a monitoring system be established to monitor groundwater level and water quality.