3.5 Water Quality

Water Samples

Except for the test conducted in PDIME, Siem Reap and Phnom Penh, the following pre-treatment had been carried out for the samples before transporting them to the subcontractor's laboratory, Bangkok (date: January 1999), and Tokyo (date: December 1999).

Sampling location: Sampling locations are listed in Table 3.5.1 and Table 3.5.2.

Sampling methods:

Groundwater: Samples were collected from wells only after the well has been pumped sufficiently.

River: Samples were collected in the middle of the river.

Lake, Reservoir: Samples were collected slightly far from the bank by using boat.

The samples pre-treated: WT4, Lake Tonle Sap, Siem Reap River, West Baray, and 2 pilot wells (PP-99-1, PP-99-2).

Sampling date: 25 November 1999 (for WT4 and the surface water samples) and 4 December 1999 (for 2 pilot wells).

Pre-Treatment Method

Item	Pre-Treatment	Effective Period for the Test	
Cd, Hg, Pb, Se, As, Cr, Zn, Fe, Cu, Na, Mn, K, Hardness	Added Nitric acid 10 ml/l	Hg: Other items:	2 weeks 1 month
CN	NaOH (4%) to keep pH within 6-8	CN:	The same day
Cl. pH, Color, Turbidity, EC, Si, SO_4, HCO_3, B, F, NO_3, NO_2	No pre-treatment	pH, Color, Turbidity, HCO_3: EC, F: Other items: NO_3, NO_2 :	The same day 2 weeks 1 month Until next day

Note: The above pre-treatment was adopted for the result shown in Table 3.5.1

The samples were taken in three types of containers depending on the pre-treatment.

Water quality of the four alternative sources are discussed here in order to find out required treatment facilities for each of the water sources. Very few data are available for the water quality before the present Study, only water quality data found were the data for the Siem Reap River and the Lake Tonle Sap in 1994 and 1995. In this section, results from the water quality tests conducted under this Study are presented. Tests were carried out in Siem Reap, Phnom Penh, Japan, and Bangkok. Because of various reasons, not all types of parameters were tested every time. Also, frequency of the tests were not uniform.

In Siem Reap, PDIME and Siem Reap Waterworks carried out the water quality tests. All instruments were provided by JICA. These include HACH portable analysis kit, handheld pH and EC meters, digital titration meter, COD reactor and bacteriological test papers. In Bangkok, a subcontractor carried out a test once each in 1997 and 1998. Some test items like pH, EC, and turbidity were tested at the laboratory of Phnom Penh Water Supply Authority in June 1999. Tests were conducted in Japan periodically for mutual check.

For the planning of future treatment plant facilities, present water quality is assumed to prevail. Measures should be planned in order to improve or at least maintain the present water quality for all possible sources. All the data is compiled in Supporting Report 3.5.1 for references. In this section the interpretation was made mainly based on the results from authorized laboratory in Japan from the viewpoint of data reliability. It was difficult for PDIME to do the water quality test properly by itself. Errors might occur in the testing likely caused by lack of experienced staff.

3.5.1 West Baray

The interpretation is mainly from the test conducted in Japan, and the data is given in Table 3.5.1.

As explained before in Section 3.2, the water of the Baray is actually taken from the river via French Weir which is located about 3 km upstream of the Angkor Bridge site. Therefore, water quality of the West Baray water and the river water are similar up to certain extent especially in rainy season.

The pH of West Baray is 6.7 by the latest test in Japan. From the Supporting Report 3.5.1, it is inferred that seasonal variation of pH is ranging from 7 to 7.5 until May 1998, and 6.6 to 6.7 after October 1998. It is known that the Baray was once emptied in June 1998 to repair it due to the 1997 flood, and was entirely refilled after that. This is probably the reason for the pH change before and after that.

Table 3.5.1 Results of Water Quality Analysis Tested in Japan in December 1999

No	ITEM	Unit Location	Surface Water			Groundwater		
			West Baray	Angkor Bridge (Siem Reap River)	Lake Tonle Sap	WT4 well	PP-99-1 Well (Pilot Well)	PP-99-2 Well (Pilot Well)
2	pH		6.7	6.0	7.2	5.5	5.5	5.4
3	Colour	TCU	40	79	24	21	3	6
4	Electric Conductivity	μS/cm	19	18	75	32	42	23
5	Hardness（Ca, Mg）	mg/l	4.8	7.1	27.2	11.8	1.0	0.8
6	Nitrite (NO_3)	mg/l	< 0.09	0.196	< 0.09	< 0.09	< 0.09	< 0.09
7	Nitrate (NO_2)	mg/l	0.012	0.027	0.322	0.007	0.014	0.013
9	Manganese (Mn)	mg/l	0.052	0.024	0.020	0.029	0.017	0.016
10	Total-Fe	mg/l	0.185	1.12	0.207	0.071	0.176	0.099
11	Chloride (Cl)	mg/l	2.25	2.49	4.32	3.76	5.43	2.49
12	Calcium (Ca)	mg/l	1.12	2.05	7.66	4.54	0.17	0.16
13	Magnesium (Mg)	mg/l	0.49	0.48	1.96	0.12	0.13	0.10
18	Potassium (K)	mg/l	0.93	0.64	1.66	0.60	0.68	0.65
19	Silica (Si)	mg/l	0.16	0.21	0.11	0.27	0.29	0.29
22	Sulphate (SO_4)	mg/l	0.17	< 0.1	2.67	3.55	1.35	0.97
26	Arsenic (As)	mg/l	0.0003	0.0003	0.0006	0.0003	0.0001	0.0001
27	Chromium (Cr)	mg/l	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
28	Lead (Pb)	mg/l	< 0.001	0.001	< 0.001	0.001	< 0.001	0.001
29	Selenium (Se)	mg/l	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
30	Total-mercury (Hg)	mg/l	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005	< 0.0005
31	Cadmium (Cd)	mg/l	< 0.0003	< 0.0003	< 0.0003	< 0.0003	< 0.0003	< 0.0003
32	Zinc (Zn)	mg/l	0.0151	0.0216	0.0053	0.0058	0.173	0.229
33	Copper (Cu)	mg/l	0.0008	0.0011	0.0031	0.0011	0.0009	0.0009
34	Cyanide (CN)	mg/l	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
35	Sodium (Na)	mg/l	1.59	1.52	3.88	5.64	6.86	3.34
36	Boron (B)	mg/l	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	< 0.004
37	Fluoride (F)	mg/l	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	0.06
38	Turbidity	NTU	7.7	10.2	2.4	2.9	0.6	1.3

Note: * Formation Potential

Pre-Treatment method for water samples is described in Section 3.5.1

The EC value is 19 μS/cm by the latest test in Japan. As shown in Supporting Report 3.5.1, the value of EC is mostly ranging from 20 to 30 μS/cm throughout year. No conspicuous seasonal variation is found in the EC values after June 1998, because huge storage amount of 50,000,000 m^3 allows only gentle change of water quality even there is an inflow from the River during the rainy season.

It is to be noted that the baray water has around half of the Ca content of that of the river water, and has similar range for Na content. It is inferred that the variation of cation is within a minor range and metal concentrations are rather small. This water condition of the baray is the second best quality among the 4 alternative sources.

3.5.2 Siem Reap River

The sampling point is Angkor Bridge along the river near Angkor heritage. The major findings are as follows:

The pH of Siem Reap River is 6.0 by the latest test in Japan. As shown in Supporting Report 3.5.1, the seasonal variation of pH of the river water ranges from 5.2 to 6.8 in rainy season, and 6.0 to 7.2 in dry season of December to May.

The EC is 18 μS/cm by the latest test in Japan. EC is mostly ranging from 18 to 80 μS/cm throughout year as shown in Supporting Report 3.5.1. It is inferred that EC value of rainy season has a tendency of higher value than that of dry season, due to its high turbidity with metal ions.

As shown in Annex 3.5.1, the seasonal variation is from 0.7 to 2.0 mg/l for Fe, and from 0.4 to 0.6 mg/l for K. It is to be noted that the Fe content is the highest among the 4 alternative water resources. From March to May in dry season, rather high Fe content are measured because the river water is fed by the groundwater through laterite soil in the eastern side of the river. Also, Fe content in flood season increases suddenly due to erosion of laterite soil. Rather small contents of As and NO_2 are found from the river water compared with the rake water.

Contamination of the River Water from the Residential Area:

The pH and electric conductivity (EC in μS/cm) were measured along the river course in many locations within a few hours to grasp the contamination condition. The data indicated that the river water might be drastically contaminated after the Crocodile Weir at the end of the town. The most probable reason is the disposal of domestic wastewater into the river. Water flow in the river becomes very low in dry season. This can not even flash out the pollution load. Also, soil erosion in the upstream is degrading the water environment. A comprehensive measure should be taken in order to improve the water environmental condition of the river. This will also contribute in the tourism sector. This seasonal variation in quality may be required for careful operation to purify.

3.5.3 Lake Tonle Sap

The pH of Lake Tonle Sap is 7.2 by the latest test in Japan. As shown in Supporting Report 3.5.1, the seasonal variation of pH of the lake water is ranging from 7.0 to 7.2. It is inferred that the pH value is higher in the impounding period by the Mekong river, and lower in lowering period of the lake water.

The EC is 75 μS/cm by the latest test in Japan. As shown in Supporting Report 3.5.1, the EC value widely ranging from 50 to 170 μS/cm. It is inferred that the EC in the period of low water level has a tendency of higher value than that of the impounding period, due to the effect of highly polluted Siem Reap River water. Ca content is higher in high water level, and lower in low water level. It is clear that the water quality of the lake is influenced by the inflow of the Mekong river. Rather higher values of Ca are obtained compared with the other 3 alternatives. As and HCO_3 contents are the highest among the 4 alternatives. It is to be noted that the water quality variation of the lake water has wide range among the 4 alternatives.

Variation of the Lake Water Quality in December 1998:

In order to select the most suitable water intake place from water quality viewpoint, water samples were taken from four different locations on the same day and tested. The four locations are: 1) present boat station near the mouth of the Siem Reap River, 2) 4 km southeast from the boat station, 3) 8 km southeast from the boat station and 4) 12 km southeast from the boat station. The results are given below:

Water Quality Variation of the Lake

Test Item/ Location	Boat Station	4 km southeast	8 km southeast	12 km southeast
pH	5.6	6.4	6.6	6.7
Color (TCU)	493	80	52	37
Electric conductivity (μS/cm)	256	53	89	85
Nitrite (NO_2 in mg/l)	0.90	0.01	0.02	0.02
Nitrate (NO_3 in mg/l)	23.3	7.5	8.4	7.9
Ammonium (NH_4 in mg/l)	0.16	0.03	0.02	0.02
Ferrite (Fe in mg/l)	5.5	0.7	0.1	0.1
TDS in mg/l	122	25	42	42

These results indicate that the samples from 4 km, 8 km, and 12 km from the boat station are nearly at the same level of contamination. However, there is a significant difference between the water sample of boat station and the rest. Therefore, a suitable water intake point from the lake may be around 4 km southeast from an economical viewpoint and water availability in dry season. Because of much variations of quality in the lake water, and necessity of careful

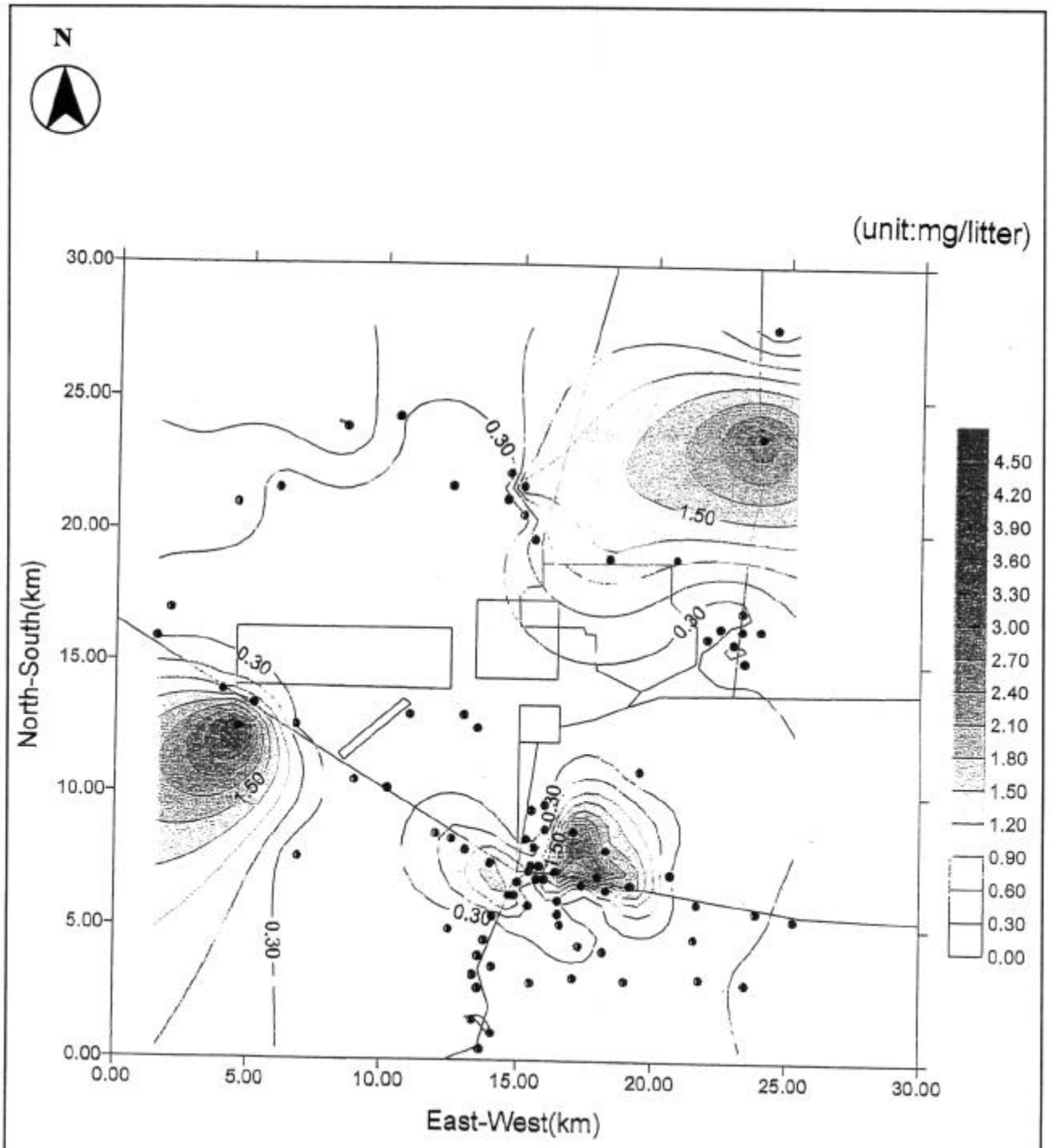
operation to purify, the lake water is judged to be the worst among the 4 alternatives.

3.5.4 Groundwater

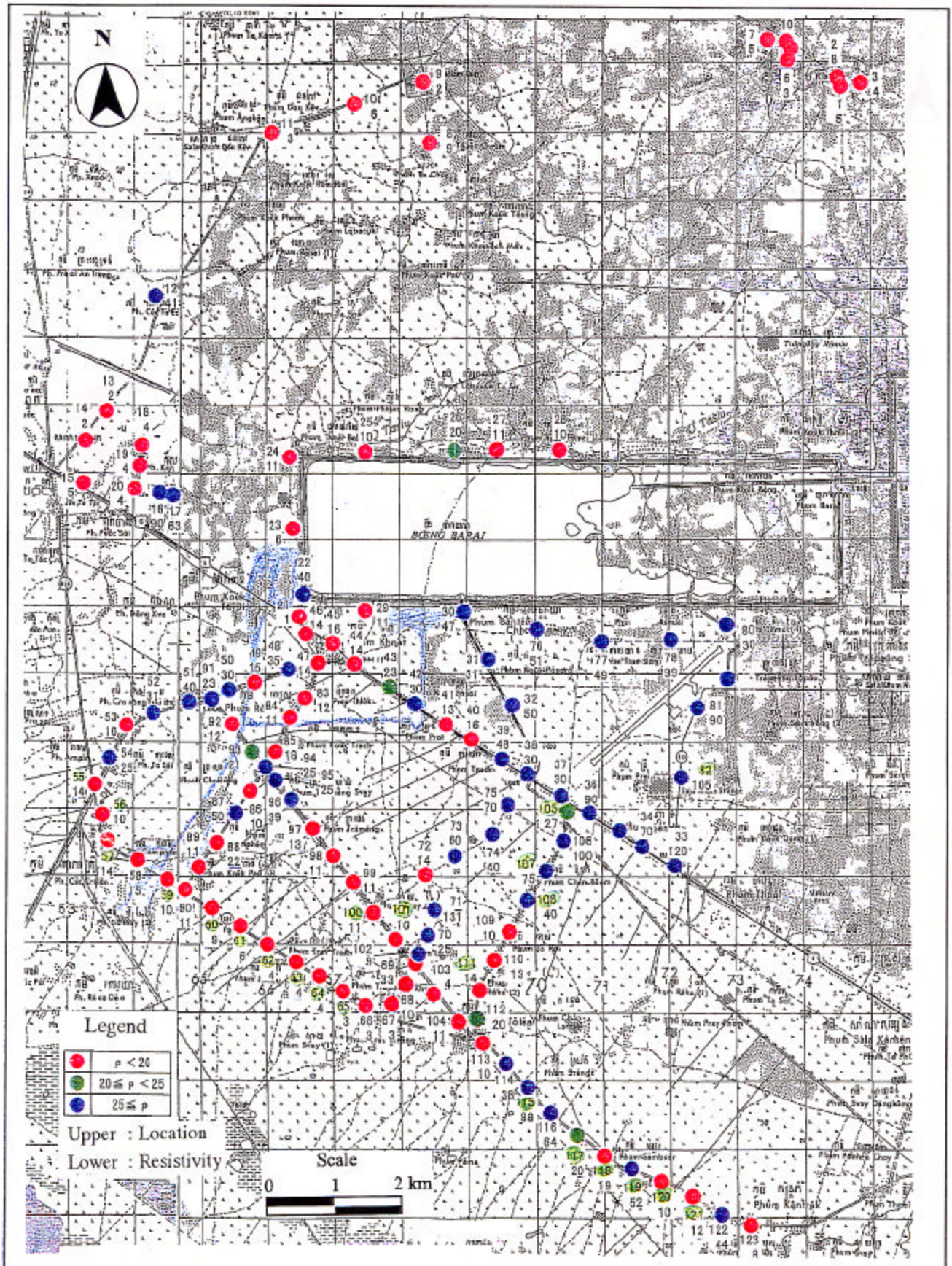
Quality test for the existing wells was conducted in 1997 and 1998 for the 79 wells. In the study area, it is the most concerned matters whether the ferrite content in groundwater is within allowable range or not. Therefore, the test was concentrated to find the groundwater of the low ferrite content. It was found that Fe content was varied by regional hydrogeological condition. It is indicated that the area along the former Siem Reap River course seems to have low iron content without or thin laterite layer, and eastern area of the town have high iron contents. Figure 3.5.1 show the contour map of Fe content tested for the existing wells (1997). At the same time, electromagnetic survey by VLF method was carried out as given in Figure 3.5.2. Both results show that the former river course is suggesting at the area from the north of the West Baray to the south of the airport. WT4 is located at the fringe of the former river course. The result of WT4 water is mentioned hereinafter. General bacteria were found in most open wells. Waters from tube wells are not contaminated. Details can be found in Data Book 4. Major findings are as follows:

The pH value of the WT4 water is in acidic range of 5.5. Ca content is 4.5 mg/l and Fe content is 0.07 mg/l as given in Table 3.5.1.

As shown in Supporting Report 3.5.1, it can be expected that there is no tendency of the seasonal change of ion contents. Very small contents of Cd, Hg, Se, Pb, As, Cr, CN, B, F, and NO_2 are found in the groundwater. HCO_3 content is ranging from 8 to 11 mg/l for WT4 and the 2 pilot wells (PP-99-1, PP-99-2), there is no clear tendency of seasonal variation in HCO_3, as well as the other anion ions. The groundwater quality of the 2 pilot wells is better than that of the WT4, as expected. The result of groundwater for 2 pilot wells reveal that it is the most suitable quality among the 4 alternative sources and under WHO standard for the tested items.



The Study on Water Supply System for Siem Reap Region in Cambodia	**Figure 3.5.1 Contour Map of Fe (1997)**
Japan International Cooperation Agency	



The Study on Water Supply System for Siem Reap Region in Cambodia	Figure 3.5.2 Result of VLF Electrical Prospecting
Japan International Cooperation Agency	

3.5.5 Organic Contents and Trihalomethane Formation Potential

The organic contents were interpreted from the COD, DO and bacteria analysis. However, bacteriological tests conducted by PDIME are doubtful as tests were conducted by using test papers of April 1998. The paper may have been contaminated under high humidity condition of tropical climate.

The results shown in Supporting Report 3.5.1 indicate that the water quality of West Baray is varied by season. The environmental conditions will not change in future because the baray is located in the protected area. However, there remains a possibility of deterioration of water quality due to future human activities in the upstream of the Siem Reap River because the water is coming from the river.

The result of the river shows rather bad quality in terms of organic contents following the lake. The poor quality may be due to the drain water from paddy area and organic contamination from the human activities. A future environmental change should be taken into account, as the quality will become worse due to urbanization.

The present water quality of the lake is the worst among the 4 alternative water sources. It is not expected that the water quality will be improved in future, as far as no sanitation projects are implemented in the Mekong River Basin and the town.

Result of Trihalomethane Formation Potential

(Unit: mg/l)

Date \ Place	West Baray	Siem Reap	Tonle Sap	WT4
14th July 1997#				0.016
17th December 1998*	10.0	Nil	5.0	Nil

Note: # Laboratory in Bangkok, *: Laboratory in Tokyo

Trihalomethane formation potential is very low for groundwater and rather high for West Baray and the lake. The result demonstrates that the water quality of the deep tube well is not affected by organic contamination. The well is located in the paddy field without high residence. It is expected that the future environmental condition around the well field will not be changed drastically.

3.5.6 Turbidity

Turbidity was tested in Phnom Penh on 9 June 1999 and Tokyo on 1 December 1999 as shown in the following table.

Results of Turbidity

(Unit: NTU)

Date \ Place	West Baray	Siem Reap	Tonle Sap	WT4/Pilot wells
9 June 1999	15	42	1,008	- (WT4)
1 December 1999	7.7	10.2	2.4	0.6 (PP-99-1) 1.3 (PP-99-2) 2.9 (WT4)

The surface water has considerably higher turbidity values than groundwater. All the data of the surface water exceed the standard value.

3.5.7 Confirmation of Fe and As Contents

Hydrogeologically, the Fe content in tropical zone has higher tendency than other area, due to formation of iron rich laterite layer. In Mekong river basin, As is reported to have a higher content. In order to check this, Fe and As were analyzed in Japan (October 1999) for the various kinds of water sources as given in Table 3.5.2. The test was done by both methods of without filtering and after filtering through membrane. Both tests result shows that Fe and As, as well as other metals, are containing on the fine particles. Therefore, soluble ionized Fe and As contents are rare. Fe content without filtering is below the resolution of the test method for the WT4 well water. As content without filtering is below the resolution of the test method except with the Lake water. The test result shows that the groundwater of WT4 is safe and under the WHO standard.

3.5.8 Conclusion

It can be said that groundwater is the best among the 4 alternatives from the water quality point of view. However, pH neutralization may be required in case iron made water pipe and asbest concrete pipe is used. Water treatment is a must in case of the other 3 water sources if they are adopted as drinking water source.

Table 3.5.2 Analysis of Soluble Ferrite and Arsenic Ions (25 October 1999)

Sample Number	Location	Sample Without Treatment			After Filtrating by 0.45 um Membrane	
		EC (μ S/cm)	As (mg/l)	Fe (mg/l)	As (mg/l)	Fe (mg/l)
1	West Baray	27	<0.005	0.22	-	<0.05
2	Moat of Angkor Wat	9	<0.005	0.31	-	<0.05
3	Siem Reap River (Angkor Bridge)	36	<0.005	0.98	-	0.17
4	Lake Tonle Sap	81	0.007	1.62	<0.005	<0.05
5	WT 4 monitoring well	42	<0.005	<0.05	-	<0.05
6	Shallow Well in Siem Reap Airport	33	<0.005	1.39	-	<0.05
7	Well of Nokor Phnom Hotel	24	<0.005	<0.05	-	<0.05
8	Well of High School near Airport	37	<0.005	<0.005	-	<0.05
9	Well of Siem Reap Diamond Hotel	202	<0.005	<0.05	-	<0.05
10	Well of Water Works (raw water)	71	<0.005	0.58	-	<0.05
11	Well of Water Works (after treatment)	140	<0.005	<0.05	-	<0.05
Test Method		JIS K 0102 13	JIS K 0102 61.3	JIS K 0102 57.4	JIS K 0102 61.3	JIS K 0102 57.4