ANNEX 3.5.1

WATER QUALITY

THE STUDY ON WATER SUPPLY SYSTEM
FOR SIEM REAP REGION IN CAMBODIA

FINAL REPORT
Vol. III SUPPORTING REPORT

ANNEX 3.5.1 WATER QUALITY

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ANNEX 3.5.1 WATER QUALITY

1. Introduction

Water quality of the four alternative sources are discussed here in order to find out required treatment facilities for each of the water sources. In this Supporting Report, results from the water quality tests conducted under this Study are presented. Tests are carried out in Siem Reap, Phnom Penh, Tokyo 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, tests were carried out by PDIME and Siem Reap Waterworks. 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, tests were done by sub contractor 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 also conducted in Japan periodically for difficult test items and 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.

Considering the data reliability, only the results tested in Tokyo are shown in the Main Report Section 3.5. However, in the Supporting Report, the results tested by PDIME are also taken into consideration to grasp the seasonal variation of the test items.

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.

2. Water Quality

2.1 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 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.

Sampling location: Listed in Table 2.5 and Table 2.6.

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 2.5

2.2 Water Quality Raw Data

1) Groundwater

Water quality tests of WT4 were conducted for a total of 18 times. The results are shown in Table 2.1. For two occasions, in order to get more comprehensive water quality data; samples from WT4 were analyzed for heavy metals and other sensitive parameters in Tokyo. The result is also given in Table 2.1.

2) West Baray

Water quality of West Baray was tested 17 times. The result is given in Table 2.2. The water of the Baray is actually taken from the Siem Reap 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 Siem Reap River water are similar up to certain extent especially in rainy season.

3) Siem Reap River

Water quality of Siem Reap River was tested 21 times. The sampling point is Angkor Bridge. The result is given in Table 2.3.

4) Lake Tonle Sap

Water quality of Lake Tonle Sap was tested 20 times. The sampling point is near the boat station. The result is given in Table 2.4.

5) Water Quality Tested in Japan

The results tested in Japan are given in Table 2.5 (December 1999) and Table 2.6 (October 1999). These data are considered more reliable since tests were conducted by the authorized laboratory in Japan.

Table 2.1 Water Quality Analysis of Groundwater from the Well No. WT4

		Place of Test	MIME	BKK	TYO	MIME	MIME	MIME	MIME	BKK	MIME	MIME	MIME	MIME	MIME	MIME	MIME	TYO	MINE	TYO
	Test Item	Date / Unit	6/6/97	26/6/97	14/7/97	3/3/98	27/5/98	28/9/98	21/12/98	17/12/98	12/1/99	5/2/99	13/3/99	9/5/99	16/6/99	19/7/99	19/8/99	25/10/99	25/11/99	1/12/99
1	Temperature	°C	29.7			27.0	30.6		29.3	29.1	29.0	30.0	29.1	28.4	28.5	28.1	29.0		29.4	
2	pH	--	8.0	5.1		5.3	7.1		5.0	5.3	9.4	5.2	5.9	7.2	5.96	6.33	6.25	6.0	5.37	5.5
3	Color	Color Unit		15		12	6		12	25	2	0	13	68	1	9	11		10	21
4	EC	µs/cm	35			28	29	29	32	40	38	36	104	16	34.3	5.91	1.87	42	3.28	32
5	Hardness	mg/l	0.78	1.00	1.07	0.57	0.52		0.50	1.00	0.56	0.80	0.90	0.70	1.19	1.4	3.58		2.30	11.8
6	Nitrite	mg/l	0.01	N.D		0.01	0.07		0.01	0.01	0.01	0.02	0.03	0.01	0.03	0.01	1.87		0.00	<0.1
7	Nitrate	mg/l	2.20	1.80		5.72	5.72		5.72	0.30	7.92	1.70	2.50	1.80	3.52	6.16	0.005		8.36	<0.1
8	Ammonium	mg/l	0.22	1.60		0.29	0.13		0.01	0.02	0.02	0.32	0.04	0.20	0.06	N.D	N.D		0.30	
9	Manganese	mg/l	N.D	0.03	<0.05	0.50	0.40		0.20	0.01	0.30	0.40	0.20	0.50	0.4	0.3	0.3		0.50	0.03
10	Total-Fe	mg/l	0.47	N.D	0.14	0.86	0.48	0.20	0.49	0.42	0.89	0.87	0.60	0.25	0.03	0.05	0.07	<0.05	0.14	0.07
11	Chloride	mg/l	3.60	5.00		3.00	2.20	0.70	3.30	4.20	2.20	3.20	6.70	3.70	1.5	3.8	1.9		5.70	3.76
12	Calcium	mg/l	0.16	N.D	0.33	6.16	0.32		0.12	N.D	0.14	0.03	0.70	0.17	0.35	0.44	0.57		0.70	4.54
13	Magnesium	mg/l	0.05	0.30	0.06	0.05	0.11		0.04	0.30	0.04	0.01	0.07	0.11	0.07	0.08	0.12		0.80	0.12
14	COD	mg/l	9.00							nil					25				N.D	
15	General Bacteria					0				negative							positive		positive	
16	Coliform Group					0				negative							positive		positive	
17	Carbon dioxide	mg/l		140		57	31	27	46	99	56	39	70	63	19	47			47	
18	Potassium	mg/l		0.10		0.17	0.54		0.41	0.40	0.53	3.90	3.70	27.00	56	45				0.60
19	Silica	mg/l				9.17	4.45		2.80	14.00	2.12	5.70	6.70	2.90	15	8.7	8.42		12	0.27
20	TDS	mg/l		39		13	13		15	36	16	14	20	17	27	28	15		2	
21	Salt	mg/l				N.D	N.D	N.D	N.D						0	0	0		0	
22	Sulphate	mg/l		2.00						5.10	3.79				1	N.D	1		1	4
23	Bicarbonate	mg/l		11.00						11.00	9.00									8.40
24	Tri-halo-methane*	mg/l			0.016					nil	N.D									
25	DO	mg/l								3.70										
26	Arsenic	mg/l			0.007					N.D								<0.05		0.0003
27	Chromium	mg/l			<0.01					N.D										<0.001
28	Lead	mg/l			<0.01					N.D										0.001
29	Selenium	mg/l			<0.01					N.D										<0.0001
30	Total-Mercury	mg/l			<0.0005					N.D										<0.0005
31	Cadmium	mg/l			<0.01					N.D										<0.0003
32	Zinc	mg/l			<0.01					N.D										0.0058
33	Copper	mg/l			<0.01					N.D										0.0011
34	Cyanide	mg/l			<0.01					N.D										<0.0001
35	Sodium	mg/l			5.04															5.64
36	Boron	mg/l																		<0.004
37	Fluoride	mg/l																		<0.1
38	Turbidity	NTU																		2.94

Note :

- By the same sample taken at the same time and same place
- MIME : Ministry of Industry, Mines and Energy
- BKK : Bangkok
- PNH : Phnom Penh
- TYO : Tokyo
- * : Formulation Potential
- Data out of Statistical Significance (as screened out in section 3)
- Assumed that the results tested in Tokyo are the most reliable
- N.D : Not Detected

Table 2.2 Water Quality Analysis of West Baray Reservoir

		Place of Test	MIME	MIME	MIME	MIME	MIME	MIME	BKK	MIME	MIME	MIME	MIME	PNH	MIME	MIME	TYO	MIME	TYO
	Test Item	Date / Unit	20/2/97	29/3/97	22/4/97	15/5/97	10/6/97	26/5/98	17/12/98	12/1/99	5/2/99	13/3/99	9/5/99	9/6/99	19/7/99	19/8/99	25/10/99	28/11/99	1/12/99
1	Temperature	°C	29.8	31.7	31.0	30.1	32.0	30.5	24.3	27.8	29.2	29.2	31.2		26.8	30.2		29.2	
2	pH	--	7.3	8.2	7.8	1.4	8.2	7.3	6.2	10.4	6.2	6.3	6.3	6.6	8.2	7.9	6.7	6.71	6.7
3	Color	Color Unit						123	58	94	95	67	7		36	40		59	40
4	EC	µs/cm	19	76	39	24	54	25	23	20	23	22	2.6	20.5		19	27	2.08	19
5	Hardness	mg/l	7.75	8.00	10.20	7.8	25.00	3.50	6.00	2.73	4.20	3.2	2.7		2.67	2.13		4.79	4.80
6	Nitrite	mg/l	0.003	0.003	0.01	0.01	0.02	0.05	N.D	0.07	0.03	0.07	N.D		N.D	N.D		0.9	<0.1
7	Nitrate	mg/l	2.64	1.70	0.30	N.D	N.D	4.48	0.10	5.74	0.20	3.60	2.40		4.84	3.51		2.75	<0.1
8	Ammonium	mg/l	0.32	0.13	0.50	0.18	0.17	0.78	0.61	0.67	0.28	0.30	0.60		0.01	0.01		N.D	
9	Manganese	mg/l	0.10	0.10	N.D	N.D	0.10	0.20	0.07	0.20	0.10	N.D	0.50		0.2	0.3		0.02	0.052
10	Total-Fe	mg/l	0.16	0.18	0.20	0.43	0.19	0.85	0.43	0.45	0.09	0.40	0.30		0.7	0.12	0.22	0.04	0.185
11	Chloride	mg/l	1.60	8.70	7.60	4.20	9.70	3.70	0.80	2.10	1.70	4.90	2.40		0.6	1.7		2.7	2.25
12	Calcium	mg/l	2.10	3.75	4.00	2.00	10.50	1.32	1.40	1.72	2.30	1.30	1.50		0.8	1.5		1.95	1.12
13	Magnesium	mg/l	0.60	2.19	1.70	0.65	7.40	0.39	0.60	0.50	0.72	0.90	0.80		0.02	0.7		1.07	0.49
14	COD	mg/l	10.00	20.00	50.00	72.00	20.00		10.00									25	
15	General Bacteria	nos/milli liter	20	10	8	80	3		negative						positive	positive			
16	Coliform Group	nos/milli liter	0	0	0	3	0		negative						positive	positive			
17	Carbon dioxide	mg/l						32	11	42	36	50	42		28	31		79	
18	Potassium	mg/l						0.94	0.80	0.97	0.87	0.80	0.60		17				0.93
19	Silica	mg/l						4.20	7.80	2.70	5.21	4.20	3.70		6.2	5.84		8.17	0.16
20	TDS	mg/l						12	21	38			25		12	15		9	
21	Salt	mg/l						N.D		N.D					N.D	N.D		N.D	
22	Sulphate	mg/l							1.90						N.D	N.D		1	0.17
23	Bicarbonate	mg/l							11.00										7.5
24	Tri-halo-methane*	mg/l							10.00										
25	DO	mg/l							6.40										
26	Arsenic	mg/l							N.D								<0.005		0.0003
27	Chromium	mg/l							N.D										<0.001
28	Lead	mg/l							N.D										<0.001
29	Selenium	mg/l							N.D										<0.0001
30	Total-Mercury	mg/l							N.D										<0.0005
31	Cadmium	mg/l							N.D										<0.0003
32	Zinc	mg/l							N.D										<0.001
33	Copper	mg/l							N.D										0.0008
34	Cyanide	mg/l							N.D										<0.0001
35	Sodium	mg/l																	1.59
36	Boron	mg/l																	<0.004
37	Fluoride	mg/l																	<0.1
38	Turbidity	NTU												15					7.7

Note :

	By the same sample taken at the same time and same place
MIME :	Ministry of Industry, Mines and Energy
BKK :	Bangkok
PNH :	Phnom Penh
TYO :	Tokyo
* :	Formulation Potential
	Data out of Statistical Significance (as screened out in section 3)
N.D :	Not detedted.

Table 2.3 Water Quality Analysis of Siem Reap River Water at Angkor Bridge

		Place of Test	TYO	MIME	MIME	MIME	MIME	MIME	TYO	MIME	MIME	BKK	MIME	MIME	MIME	MIME	PNH	MIME	MIME	MIME	TYO	MIME	TYO
	Test Item	Date / Unit	19/2/97	20/2/97	29/3/97	22/4/97	15/5/97	10/6/97	14/7/97	26/5/98	28/9/98	17/12/98	12/1/99	5/2/99	13/3/99	9/5/99	9/6/99	16/6/99	19/7/99	19/8/99	25/10/99	27/11/99	1/12/99
1	Temperature	°C	17.0	28.4	31.7	30.0	30.1	28.7	23.0	30.2	28.3	23.5	26.8	23.9	29.5	30.8		28.5	29.1	30		29.2	
2	pH	--	6.8	6.3	7.2	8.5	10.6	8.2	6.7	6.9	5.5	5.2	10.0	4.7	5.7	6.7	6.45	6.25	6.52	6.67	7.2	6.04	6.0
3	Color	Color Unit	44							176		68	87		79	8		165	152	113		128	79.0
4	EC	µs/cm	16	18	75	35	25	71	63	184	22	22	22	21	25	12.5	22	25	29	4.45	36	1.6	18.0
5	Hardness	mg/l	4.49	4.97	8.20	7.70	4.21	20.50	9.25	5.20	0.89	4.80	3.45	6.70	7.60	6.3		3.65	3.7	2.4		2.7	7.1
6	Nitrite	mg/l	<1	nil	0.02	0.17	0.07	0.01	0.01	0.01		0.05	nil	0.01	0.02	0.10		N.D	0.01	0.01		0.01	<0.1
7	Nitrate	mg/l	<1	0.44	0.71	8.01	12.76	0.80	2.20	1.32		0.10	5.28	0.42	0.51	1.20		5.72	4.5	5.28		2.5	<0.1
8	Ammonium	mg/l	0.07	0.14	0.14	0.20	0.16	0.12		0.76		0.22	0.18	0.31	0.70	0.70		0.07	0.07	N.D		0.1	
9	Manganese	mg/l	0.07	N.D	0.20	0.10	N.D	0.20	<0.01	0.20		0.05	0.20	0.03	N.D	0.60		0.3	0.2	0.4		0.2	0.024
10	Total-Fe	mg/l	1.30	1.25	0.92	0.70	1.51	0.31	<0.03	1.99	0.70	1.35	1.14	0.80	0.90	0.40		1.31	1.15	1.36	0.98	0.68	1.12
11	Chloride	mg/l	1.80	1.40	14.00	10.90	0.00	0.70	6.20	2.30	0.80	1.10	2.80	1.51	5.70	4.60		3.9	3.8	3.6		2.7	2.49
12	Calcium	mg/l		1.34	5.10	3.70	1.13	9.70	3.16	2.10		1.10	0.91	0.82	0.79	0.70		1.61	1.5	1.2		1.5	2.05
13	Magnesium	mg/l		0.39	2.30	1.90	0.35	4.80	0.30	0.59		0.50	0.28	0.41	0.30	0.20		2.04	0.95	0.75		0.8	0.48
14	COD	mg/l		27.00	29.00	70.00	81.00	89.00				nil						19				N.D	
15	General Bacteria	nos/milli liter	0	11	12	5	7	0	0			positive						positive	positive	positive		positive	
16	Coliform Group	nos/milli liter	0	5	3	0	20	0	180			positive						positive	positive	positive		positive	
17	Carbon dioxide	mg/l								48	40	91	54	68	77	27		14	21	19		27	
18	Potassium	mg/l								0.54		0.40	0.42	0.43	0.54	26.00			24				0.64
19	Silica	mg/l								3.79		11.00	5.60	10.20	15.20	2.60		4.52	4.12	6.5		7.9	0.21
20	TDS	mg/l								9		24	9	17	21	15		12	12	20		8	
21	Salt	mg/l								N.D	N.D							N.D	N.D	N.D		N.D	
22	Sulphate	mg/l										3.70						N.D	N.D	1		1	<0.1
23	Bicarbonate	mg/l										8.60											6.0
24	Tri-halo-methane*	mg/l	<0.01									nil											
25	DO	mg/l										6.80											
26	Arsenic	mg/l							N.D			N.D									<0.005		0.0003
27	Chromium	mg/l							<0.01			0.01											<0.001
28	Lead	mg/l							<0.01			N.D											0.001
29	Selenium	mg/l							<0.01			N.D											<0.0001
30	Total-Mercury	mg/l							<0.0005			N.D											<0.0005
31	Cadmium	mg/l							<0.01			N.D											<0.0003
32	Zinc	mg/l							<0.01			N.D											0.0216
33	Copper	mg/l							<0.01			N.D											0.0011
34	Cyanide	mg/l							<0.01			0.01											<0.0001
35	Sodium	mg/l																					1.52
36	Boron	mg/l																					
37	Fluoride	mg/l																					
38	Turbidity	NTU															42						10.2

Note :

	By the same sample taken at the same time and same place
MIME :	Ministry of Industry, Mines and Energy
BKK :	Bangkok
PNH :	Phnom Penh
TYO :	Tokyo
* :	Formulation Potential
	Data out of Statistical Significance (as screened out in section 3.5.5)
N.D :	Noe Detected

Table 2.4 Water Quality Analysis of Lake Tonle Sap

		Place of Test	MIME	MIME	MIME	MIME	MIME	MIME	MIME	MIME	BKK	MIME	MIME	MIME	MIME	PNH	MIME	MIME	MIME	TYO	MIME	TYO
	Test Item	Date / Unit	20/2/97	29/3/97	22/4/97	15/5/97	10/6/97	26/5/98	28/9/98	16/12/98	17/12/98	12/1/99	5/2/99	13/3/99	9/5/99	9/6/99	16/6/99	19/7/99	19/8/99	25/10/99	27/11/99	1/12/99
1	Temperature	°C	30.1	31.2	31.5	30.1	32.0	30.1	28.3	21.7	24.5	27.7	23.3	27.9	30.7		28.3	28.3	29.2		29.2	
2	pH	--	6.7	7.7	8.7	10.4	9.7	7.2	6.5	5.6	6.4	10.1	4.7	6.7	6.0	6.46	6.67	6.95	6.82	7.2	6.11	7.2
3	Color	Color Unit						716		493	65	1125	997	1857	596		910	1050	972		29	24
4	EC	µ s/cm	45	55	167	149	180	135	82	256	78	95	100	123	12	48.4	66.2	62.2	18	81	9.92	75
5	Hardness	mg/l	17.50	19.20	8.75	9.75	7.10	2.30	0.53		35.00	9.35	18.20	20.40	7.20		13.5	14	9.7		7.29	27.2
6	Nitrite	mg/l	0.00	0.01	0.02	N.D	N.D	0.02		0.90	0.06	0.30	0.05	0.70	0.50		0.5	0.6	0.4		0.01	<0.1
7	Nitrate	mg/l	5.28	0.90	0.30	N.D	N.D	1.00		23.30	0.30	67.32	0.12	1.90	1.80		5.2	4.9	5.1		N.D	<0.1
8	Ammonium	mg/l	0.13	0.13	0.30	0.55	0.10	0.08		0.16	0.03	0.89	0.07	0.09	0.40		0.8	0.5	0.2		N.D	
9	Manganese	mg/l	N.D	0.10	0.00	N.D	0.10	0.20		5.20	0.03	5.20	0.20	0.10	0.20		0.9	0.3	0.4		0.1	0.020
10	Total-Fe	mg/l	0.74	0.79	0.50	0.80	0.60	3.70	0.90	5.50	0.71	6.95	0.80	0.90	0.90		3.2	2.9	0.98	1.62	0.09	0.207
11	Chloride	mg/l	2.00	15.00	37.00	35.50	17.00	47.00	0.90	37.70	1.50	39.20	4.70	8.70	5.80		18.7	19.1	5.2		4.2	4.32
12	Calcium	mg/l	4.65	6.20	2.90	3.70	8.50	1.56			8.20	2.47	7.10	7.90	5.20		3.4	2.4	1.3		1.42	7.66
13	Magnesium	mg/l	1.40	2.90	0.51	0.67	6.00	0.44			3.50	0.77	2.12	2.50	1.40		1.97	0.5	0.8		1.08	1.96
14	COD	mg/l	18.00	20.00	70.00	115.00	90.00				nil						15					
15	General Bacteria	nos/milli liter	8	5	20	70	50				positive						positive	positive	positive		positive	
16	Coliform Group	nos/milli liter	11	12	17	40	31				positive						positive	positive	positive		positive	
17	Carbon dioxide	mg/l						30		17	31	46	49	54	59		17	18	14		37	
18	Potassium	mg/l						0.69		1.85	1.60	1.23	0.90	1.70	0.80		1.6	1.12				1.66
19	Silica	mg/l						4.58		1.80	4.80	2.67	5.70	8.50	4.20		3.72	4.23	5.6		N.D	0.11
20	TDS	mg/l						63	38	122	49	34	38	50	57		48	42	38		43	
21	Salt	mg/l						N.D	N.D	N.D							N.D	N.D	N.D		N.D	
22	Sulphate	mg/l									2.70						2.5	3	2		1	2.67
23	Bicarbonate	mg/l									43.00											35.9
24	Tri-halo-methane*	mg/l									5.00											
25	DO	mg/l									6.60											
26	Arsenic	mg/l									N.D									0.007		0.0006
27	Chromium	mg/l									N.D											<0.001
28	Lead	mg/l									N.D											<0.001
29	Selenium	mg/l									N.D											<0.0001
30	Total-Mercury	mg/l									N.D											<0.0005
31	Cadmium	mg/l									N.D											<0.0003
32	Zinc	mg/l									N.D											0.0053
33	Copper	mg/l									N.D											0.0031
34	Cyanide	mg/l									N.D											<0.0001
35	Sodium	mg/l																				3.88
36	Boron	mg/l																				<0.004
37	Fluoride	mg/l																				<0.1
38	Turbidity	NTU														1008						2.4

Note :

	By the same sample taken at the same time and same place
MIME :	Ministry of Industry, Mines and Energy
BKK :	Bangkok
PNH :	Phnom Penh
TYO :	Tokyo
* :	Formulation Potential
	Data out of Statistical Significance (as screened out in section 3.5.5)
N.D :	Not Detected

Table 2.5 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

Table 2.6 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

3. Data Screening

It can be observed in the water quality data as given in Table 2.1, Table 2.2, Table 2.3 and Table 2.4, some values are deviated from the trend. This can happen due to testing methods, accuracy and condition of the instrument, skill level of the analyst, misreading or misunderstanding of the scale measured and time gap for the transportation of the sample to the laboratory. A statistical method is applied to screen out statistically insignificant values.

Data screening was performed by using Thompson's method. (Ref: Water Quality Analysis Methods, 2nd edition, 1985, published by Maruzen, Tokyo, in Japanese). This method assumes a "normal distribution" of N data. According to this method,

$$d = X_m - \overline{X}$$

Where,
$\overline{X}$ is the mean of the series,
X_m is the value of one data, and
d is deviation for one value from the mean.

The significance ratio is defined as,

$$t = |d| / S$$

Where,
t is significance ratio, and
S is standard deviation of the series.

For different N value, certain maximum fixed value for t can be found under this method for different significance level. Considering a 95% confidence level in the present case, value for t was found for each set of data. Any X value for which the t value exceeds the limit was rejected.

Attachment-1 shows all the data for all four water source marked with the values which are statistically insignificant. Attachment-2 shows the graphical representation of the water quality result after discarding the insignificant values. Correlation of each parameter with all other parameter for each of the 4 sources can be found in the Data Book.

4. Interpretation

4.1 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 matter 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 4.1 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 4.2. 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:

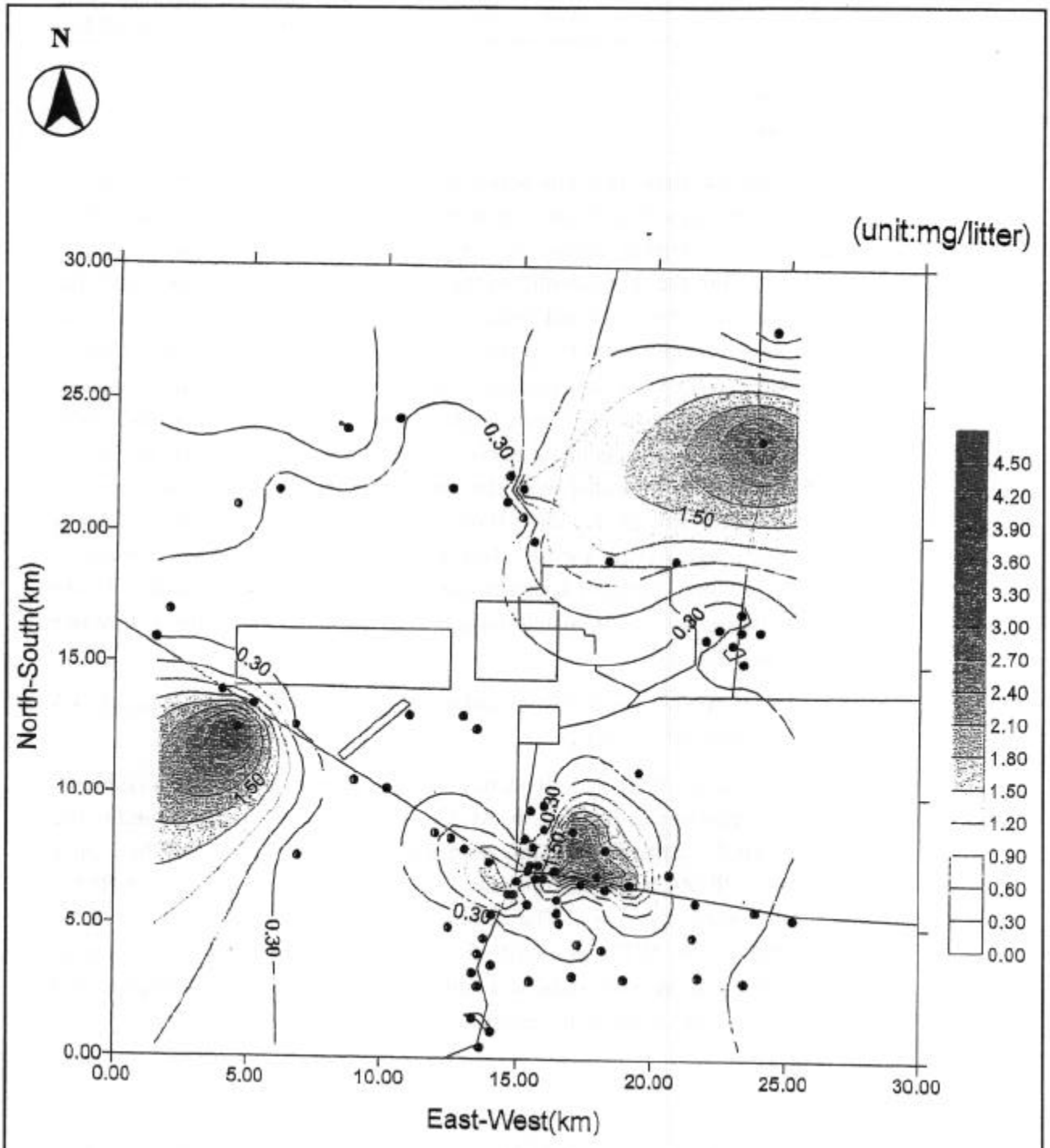
The pH value of the WT4 water is in acidic range of 5.4 to 5.5. Ca content is 4.5 mg/l and Fe content is 0.07 mg/l

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.

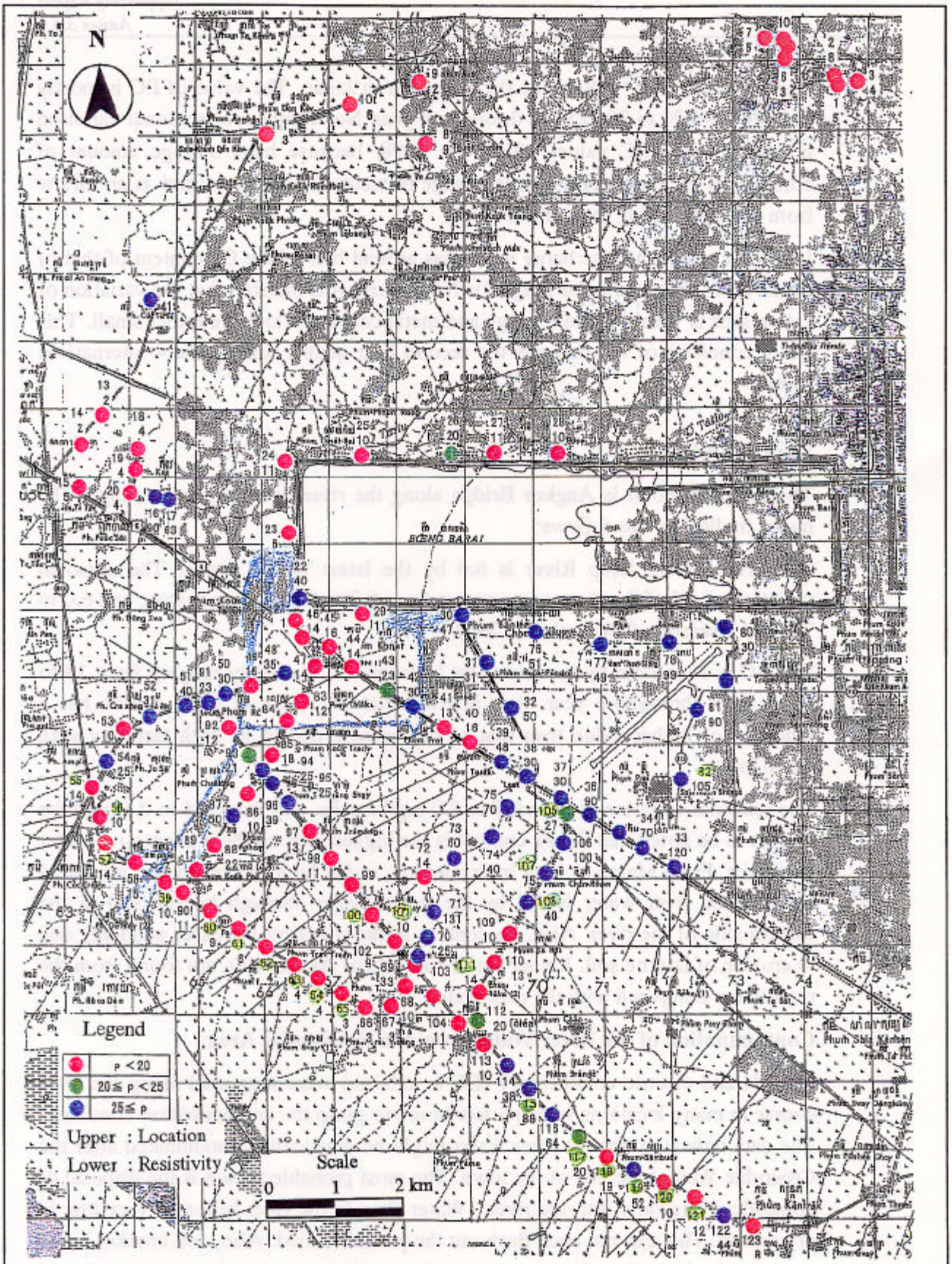
4.2 West Baray

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. 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 water 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 changing before and after.



The Study on Water Supply System for Siem Reap Region in Cambodia	**Figure 4.1 Contour Map of Fe (1997)**
Japan International Cooperation Agency	



The Study on Water Supply System for Siem Reap Region in Cambodia	**Figure 4.2 Result of VLF Electrical Prospecting**
Japan International Cooperation Agency	

The EC value is 19 μS/cm by the latest test in Japan. 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 similar range for Na content. It is inferred that the variation of cation ions 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 alternatives source.

4.3 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. 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. 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.

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.

4.4 Lake Tonle Sap

The pH of Lake Tonle Sap is 7.2 by the latest test in Japan. 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. 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 the 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.

4.5 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 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.

4.6 Turbidity

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

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.

4.7 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 2.6. The test was done by both methods of without filtering and after filtering by 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 WT 4 well water though the other surface water could test. 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.

4.8 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.