MINISTRY OF INDUSTRY, MINES AND ENERGY
SIEM REAP WATER SUPPLY AUTHORITY
THE KINGDOM OF CAMBODIA

THE PREPARATORY STUDY
ON
THE SIEM REAP WATER SUPPLY EXPANSION PROJECT
IN
THE KINGDOM OF CAMBODIA

FINAL REPORT 2

VOLUME I

SUMMARY

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JAPAN INTERNATIONAL COOPERATION AGENCY

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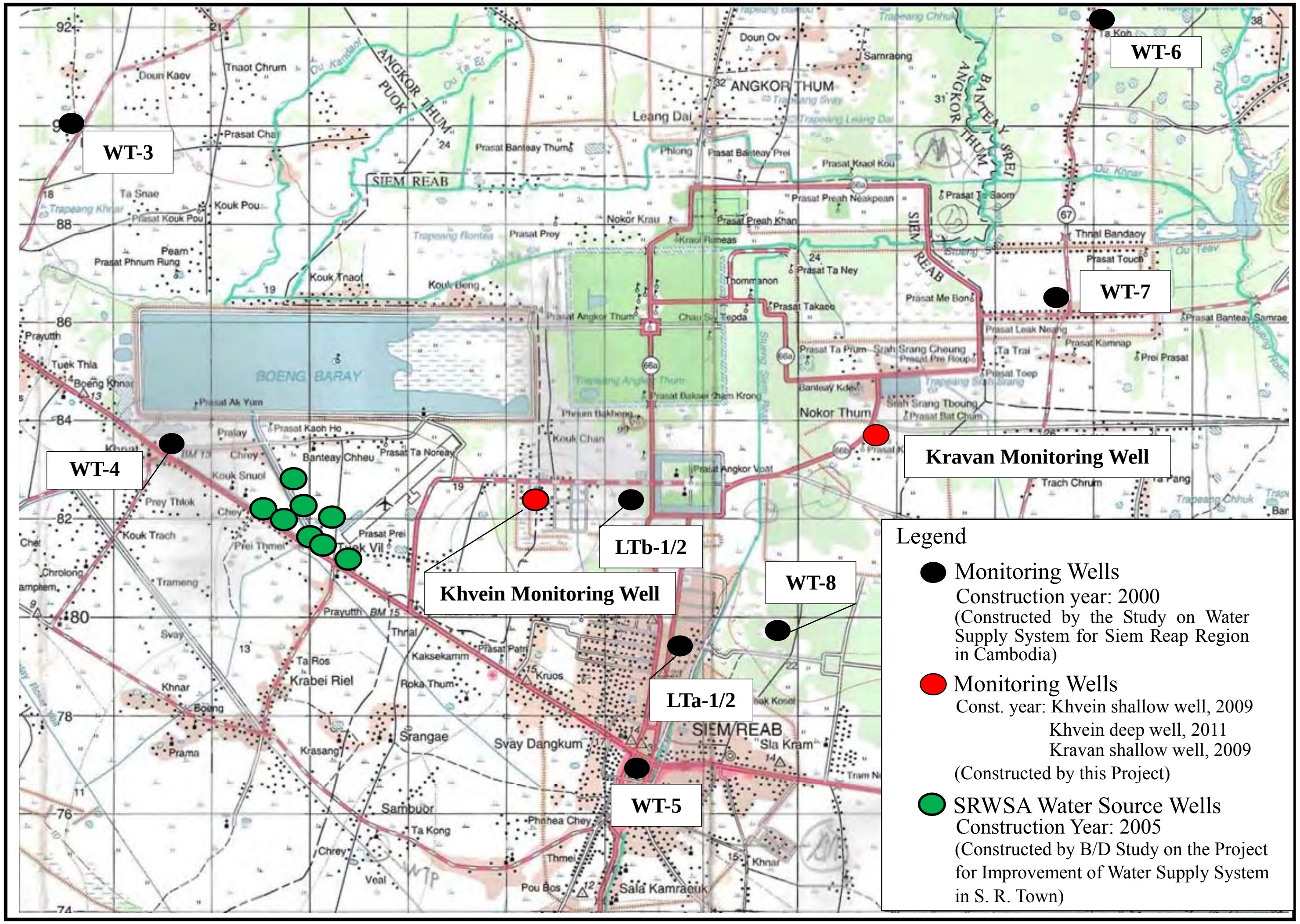

THE STUDY AREA

PHOTOS ON GROUNDWATER STUDY (1/2)

Photo 1: General View of Siem Reap Area near West Baray

Photo 2: West Baray

Photo 3: Canal Outlet from West Baray

Photo 4 : Siem Reap River

Photo 5: SRWSA Water Purification Plant (Japan Grant Aid Project)

Photo 6: Control Room (Check of Operating Condition of SRWSA Production Wells)

Photo 7: SRWSA Production Well (PW-4) located along Canal

Photo 8 : SRWSA Production Well (PW-4) & Control Box

PHOTOS ON GROUNDWATER STUDY (2/2)

Photo 9: LTb-1 Monitoring Well
(Location: In Front of Angkor Wat)

Photo 10: Monitoring Facility of Land subsidence and Groundwater Level

Photo 11: WT-4 Monitoring Well

Photo 12 : Monitoring Equipment & Well (WT-4)

Photo 13: Khvein Monitoring Well (Completion Date: May 2011)

Photo 14: Kravan Monitoring Well (Completion Date: October 2009)

Photo 15: Monitoring Equipment & Well
(Kravan Monitoring Well)

Photo 16 : Water Supply Facility of Private Hotel
(Water Source: Groundwater)

EXECUTIVE SUMMARY

1. Background of the Project

1.1 Authorization

The Preparatory Study on The Siem Reap Water Supply Expansion Project is in pursuance to the Scope of Work, signed on 29th January 2009, between the Ministry of Industry, Mines and Energy (MIME), the Siem Reap Water Supply Authority (SRWSA), and Japan International Cooperation Agency (JICA).

The Study started in May 2009, and completed in August 2011. During the approximately 28-month period, the Study Team will undertake the study in close cooperation with the MIME and SRWSA counterpart officials. This Final Report presents the results of the activities in the field of groundwater study.

1.2 Objective of the Study

The objectives of the Study are:

1) To select new water sources(s) for an efficient and sustainable water supply system in Siem Reap;
2) To conduct surveys of existing wells and assess the potential yield of groundwater
3) To identify an urgent water supply expansion project to satisfy the estimated water demand for Siem Reap up to a selected target year of the Project;
4) To conduct a feasibility study for the proposed water supply expansion project, provided that the Project is to be implemented under finance by the Japan's ODA loan;
5) To formulate a long-term water supply development plan up to year 2030; and
6) To pursue technology transfer to the Cambodian counterpart during the course of the Study.

1.3 Study Area

The study area covers all the communes of the newly established Siem Reap City and one adjacent commune of the City, for a total of 14 communes.

1.4 Target Year

The year 2030 has been set as the target year for the proposed long-term water supply development plan, as agreed by and between the JICA mission and Cambodian side in January 2009.

1.5 Methodology of the Study and Component of Final Report 2

The methodology envisaged by the Team in their Inception Report was kept through the study. Since the Study was conducted in three phases, Final Report 1 (water supply planning) and Final Report 2 (groundwater study) were prepared in the course of the Study.

In the field of groundwater study, Phase 1 included basic study such as well inventory survey, electric sounding, water use awareness survey, and basic examination on possibility of groundwater development by computer simulation. Phase 2 was mainly formed by preparation of facility development plans and the feasibility study in the field of water supply. Phase 3 was conducted based on basic information from Phase 1.

- Phase 1 — Basic Study on Structure of Groundwater Basin, Well Inventory, and Basic Examination on Possibility of Groundwater Development by Computer Simulation
- Phase 2 — Preparation of facility development plans and the feasibility study
- Phase 3 — Study on groundwater use and assessment

1.6 Contents of the Final Report 2

This Final Report 2 deals with the results of the study for Phase 1 and 3.

2. Survey Results for Groundwater Sources

2.1 Geophysical Survey

A Vertical Electrical Sounding (VES) was conducted in the zone along the shore of Tonle Sap lake extending 30 km on the east and west side of Phnon Kraom hill. In the Study on Water Supply System for Siem Reap Region in Cambodia (2000), a four-layer subsurface structure was established as a result of the analysis. By reference to results of the study (2000), the geophysical survey data of this study were analyzed and the analyzed geological structures are shown in Table 2.2.

Geological and Hydrogeological Characteristics of the Layers in the Study Area

Layer Sign	Age	Thickness (m)	Description	Hydrogeological Characteristics
1. Qal	Quaternary (Holocene)	10 – 20	Alluvial deposits Silty sand with coarse particles. Very loose sand in the middle part.	Static water level: 0.855 m (1997 May) Permeability: 1.87-1.67x 10^{-2} (cm/sec) Discharge:444 liters/min With 0.73 m drawdown.
2. Qsd	Quaternary (Pleistocene)	10 - 30	Diluvium deposits Containing silt (stone) from the lower formation. Clayey sand (stone) with coarse matrix. At the bottom, gravelly sand and core lost by loose matrix.	
3. Tcy	Tertiary (Pliocene)	20 - 50	Pliocene formation Sandy clay stone. Cylindrical core.	Aquiclude – Aquifer*
4. Mbr	Mesozoic	-	Bedrock: Weathered tuff of Mesozoic sedimentary rocks.	Unknown

Note :Table was compiled and modified from the data in the Study on Water Supply System for Siem Reap Region in Cambodia (2000). The Study on Water Supply System for Siem Reap Region in Cambodia (2000) revealed that geological structures in Siem Reap area were formed by 4 ones and the layer 1 and 2 above are the major aquifers. The geophysical survey data of this study were analyzed by reference to the survey results of the above study (2000).

2.2 Well Inventory Survey

Well Inventory survey was conducted mainly to obtain basic data for groundwater use and demand estimation. The survey targets are large consumers of groundwater consisting of 280 establishments.

All the surveyed establishments use wells deeper than 20 m and 15 % of hotels and guesthouses use more than 2 wells. On the other hand, 35 % of the hotels, guesthouses, and restaurants use public water supply system as well.

Average Number of Wells and Depth of Wells (m^3/day/establishment)

Category	Hotel	Guest house	Restaurant	Factory	Other
Number of wells	1.37	1.06	1.40	1.60	1.03
Depth *(GL-m)	45.5	30.9	31.0	43.6	32.1

*In each establishment with more than 2 wells, depth of frequently-used well was adopted. Above table shows average depth of the wells.

The data for water use amount had to be estimated due to the lack of measurement record. Thus, it was estimated based on pump capacity, tank volume, and operational hours of pumps. The results are summarized in the following table.

Estimated Daily Average Water Use Amount by Category (m^3/day/establishment)

Category	Hotel	Guest house	Restaurant	Factory	Other
Rainy Season Mean	30.35	4.62	8.89	39.00	8.89
Dry Season Mean	47.27	5.65	9.91	85.4	8.51

Due to the increased number of tourists, the water use during the dry season is much larger except under category "Other" where majority of the establishments are car wash places.

Majority of respondents under tourism related categories (hotel, guesthouse, and restaurants) are aware of the possible negative effect (lowering of groundwater level and occurrence risk of land subsidence) of groundwater pumping to the surrounding environment as can be seen in the table below.

Ratio of Awareness on Possibility of Occurrence of the Groundwater Issues

Category	Hotel	Guest house	Restaurant	Factory	Other
Ratio of Awareness (%)	64	53	65	10	17.5

Many of the surveyed establishments are willing to connect to the public supply system when it becomes available. The main reason is to cut down the operational cost of current groundwater pumping system.

The information for the 280 surveyed establishments have been converted to a MS-Access database and handed over to SRWSA.

2.3 Important Findings from the Inventory Data

The total amount of daily groundwater use in Siem Reap at present (year 2009) was estimated using the data obtained in the well inventory survey. The following set of data and conditions were adopted to estimate the daily groundwater use amount for both dry and wet seasons.

Summary of Estimated Present Groundwater Use Amount in Siem Reap

Category	Use amount (m^3/day)		Conditions of estimation
	Wet season	Dry season	
Large establishments with own groundwater pumping facilities	3,908	5,786	- Total from 280 establishments Based on the inventory. Separately calculated for dry and wet seasons.
Large establishments connected to public water supply of SRWSA except the above establishments	3,739	5,009	- Number of : hotels = 61, Guesthouses = 43, Restaurants = 190 (source: SRWSA list of registered customers), - Average pumping amount data for the above category was taken from the inventory data. . - Some part of water is supplied by their own groundwater pumping facilities
Small establishments and ordinary houses	21,569	24,418	- Population of Siem Reap in 2009 = 203,483 (source: department of planning Siem Reap province) - Part of the water is supplied by SRWSA's public supply system - Unit water use amount = 0.106 m^3/day/capita for wet season , 0.120m^3/day/capita for dry season
Total	29,216	35,213	

The data for monthly average O/M cost and installation cost of water supply facilities obtained in the inventory survey were used to estimate the unit water production cost (US$ per one cubic meter of water) for each category. The result is shown below. The figures are also larger than the current water tariff of public water supply system.

Water Production Cost of Groundwater Users

Category	Hotel	Guest House	Restaurant	Factory	Other
Average unit water production cost* (US$/$m^3$)	0.781 – 0.815	0.802 – 0.835	0.734 – 0.745	0.446 – 0.460	1.028 – 1.048

(Note): Production cost* : production cost range was calculated by estimation that major repair cost of main facilities correspond to 30-35 % of construction cost.

2.4 Field Water Quality Tests

The quality of groundwater in the areas of possible groundwater sources for the water supply was tested in the field. The water samples were taken mainly from tube wells with a hand pump and tested for the following indicators. The results were compiled, for the three areas of west of Siem Reap, East of Siem Reap and Phnon Kraom as shown in the table below.

Average Value of Water Quality by Area (Unit: mg/L)

Item	pH	EC (μS/cm)	Fe	Mn	NH_3-N
*DWS**	*6.5 – 8.5*	*1600*	*0.3*	*0.1*	*1.5*
East	*5.43*	*48*	*1.21*	*0*	*0.18*
West	*5.60*	*83*	*2.08*	*0*	*0.15*
Phnon Kraom	*4.90*	*518*	*0.45*	*0.17*	*0.15*

(Note) DWS*: Drinking Water Quality Standards, January 2004, Ministry of Industry, Mines, and Energy

Similar to the water quality test results of the Well Inventory Survey, the water quality of the samples were characterized by low pH and sporadic high iron concentration. In every area, average values of pH and iron concentration exceed drinking water quality standards and it may need water treatment for drinking.

2.5 Survey Result of Core Sample

Under this study, a monitoring well (shallow well) was constructed in the premise of Kravan primary school on October 2009 and two monitoring wells (shallow and deep wells) were constructed in Khvein primary school on October 2009 and May 2011, respectively.

At the same time, in the same locations as the monitoring wells, a core boring of 80 m in depth were conducted at each site on October 2009 and the observation survey for the core samples was followed on January 2011. In addition, in the observation survey, core samples which JSA (Japanese Government Team for Safeguarding Angkor) carried out in the yards of Angkor ruins (Angkor Wat and Bayon) in 1995 were also observed as reference samples.

The survey results were different from accepted concept on geological structures in Siem Reap area based on the study results of "the Study on Water Supply System for Siem Reap Region in Cambodia (2000)", namely, geological structures that Quaternary formations of Alluvium and Diluvium were underlain by claystone (equivalent formations of Tertiary). In the depth of ground surface to 80 m, non consolidated formations are continuously distributed and it can be deemed to be continuous formations.

According to the above study (2000), in Siem Reap area, geological structures are made up of 4 ones: Alluvium and Diluvium are distributed in the depth of ground surface to about 30 m to 50 m and are underlain by Tertiary formations with layer thickness of about 40 to 50 m, and basement rocks of sandstone, siltstone, shale, and tuffaceous breccias of Upper Jurassic, andesite, basaltic intrusive rocks, and diorite of Late Mesozoic to Tertiary are distributed in the depth of about 70 m to 80 m.

However, according to the observation results of the core samples in both sites of Khvein and Kravan, the following results were revealed: (1) In the depth of ground surface to 80 m, non consolidated formations continuously distributed and it can be deemed to be continuous formations. (2) Formations equivalent to Tertiary formations does not exist in core samples as a result of core observation. These facts are also identified in the core samples of Angkor ruins by JSA.

3. Current Status of Groundwater Use

3.1 Present Status of Groundwater Monitoring

In the Study Area, 10 monitoring wells were constructed under the Study on Water Supply System for Siem Reap Region in Cambodia (2000). SRWSA has collected the monitoring data every month. Manual measurement of groundwater level has been conducted once a month to confirm the reliability of monitoring systems since July 2007.

However, Activities done by SRWSA so far is not necessarily enough in reference to recommendations made in the Basic Design Study (report) on the Project for Improvement of Water Supply System in Siem Reap Town in the Kingdom of Cambodia (2003). As shown in "Chapter 3, Table 3.2 Existing Monitoring Wells, Reliability of Monitoring Data, and Necessity of Calibration", equipment of many monitoring wells normally does not function and needs its calibration. SRWSA should take proper measures such as restoring of mal-functioned monitoring equipment to improve this situation as described in "Chapter 6, Conclusion and Recommendation."

Under this study, a monitoring well (shallow well) was constructed in the premise of Kravan primary school on October 2009 and 2 monitoring wells (shallow and deep wells) were constructed in Khvein primary school on October 2009 and May 2011, respectively.

3.2 Private Wells

Current status of groundwater use by private wells distributed in Siem Reap area was examined by using well inventory information and monitoring well data.

- Tapped Aquifers and Withdrawal Volume of Groundwater

  Private wells pumping up more than 10 m^3/day and owned by large establishments are concentrated in the city center areas. Those private wells with a pumping capacity of more than 10 m^3/day extract 96 % of the total amount of groundwater usage (5,786 m^3/day) surveyed by well inventory survey. The extracting volume of groundwater by private wells is 5,554 m^3/day in the dry season. These private wells mainly extract groundwater from Diluvium formation distributed in the depths of 20 m to 50 m and partially from Tertiary formation distributed in depth of 60 m to 70 m.

- Influence of Pumping up

  Influence of pumping up by the private wells was examined by using WT-5, and LTb-1 and LTb-2 well data collected on the same day on 7 to 9 January 2008. The automatic monitoring results of groundwater levels often include low reliability data during some period due to malfunction of monitoring equipment. Reliability of the data was confirmed by comparison between automatic and manual measuring data and only data with high reliability were used for data analysis.

The WT-5 well is located in the center of the city and it monitors groundwater level in Tertiary formation. The monitoring data of WT-5 well with the lowering of groundwater level of 3 to 6 cm indicates the influence of pumping of groundwater by private wells in the Tertiary formation in Siem Reap City area. It also suggest that its pumping have not an influence LTb-1 monitoring site (due to no fluctuation of groundwater level), tapped to the same Tertiary formation, where is located apart 5 km from WT-5 monitoring well.

The screens of LTb-2 are set in the Diluvium formation. In the same day, the lowering of groundwater level of LTb-2 was larger than that of WT-5 because extracting volume of groundwater from the Diluvium formation by private wells shall be much larger than that of the Tertiary formation.

3.3 SRWSA Production Wells

- Tapped Aquifers and Withdrawal Volume of Groundwater

  Eight (8) SRWSA wells intake groundwater from aquifers distributed in the lower part of Alluvium and main portions of Diluvium. The current water supply amount is recorded to be over 9,000 m^3/day

- Influence of Pumping up

  Influence of pumping of the SRWSA production wells was examined by using WT-4 and Khvein shallow wells' data.

  Monitoring data was collected on 8 and 9 January 2008. Operating condition of the SRWSA production wells was fully operated on January 9 and was halted to pump up for 4 hours during the mid-night time on January 8. Under these different operating conditions, fluctuation of groundwater level in WT-4 monitoring well was compared. If pumping up of SRWSA wells causes some influence to groundwater level of WT-4, depression of cone shape in groundwater level by pumping up shall expand and influence to monitoring water level located in far place from pumping wells and cause lowering of groundwater level. As a result, at the WT-4 monitoring well located 2.6 km away from and in NW of SRWSA production wells, the influence of pumping by SRWSA wells was not detected. The same tendency was confirmed on the monitored data of December 14-16, 2007.

  By using similar method applied to WT-4 well to check influence of pumping of SRWSA production wells, monitoring data of Khvein shallow well were examined. Screens of SRWSA wells and Khvein shallow well are set up in the same aquifer. The examination was conducted for 4 days from May 7 to 10, 2010. As a result, it can be concluded that SRWSA production wells do not have an influence against environment of the Khvein monitoring well which is located 4.1 km away from and in NE of the SRWSA wells.

4. Hydrological Conditions in Siem Reap

4.1 Available Meteorological and Groundwater Monitoring Data

Data from five (5) meteorological stations and eight (8) groundwater monitoring wells have been collected to be used for groundwater recharge analysis. A strict inspection has conducted for data availability checking to avoid using wrong data in analysis.

4.2 Groundwater Recharge Analysis

Of the many methods of groundwater recharge analysis, the tank model was selected because it is excellent for obtaining relatively high precision results by directly linking the precipitation, evaporation and groundwater level fluctuation.

The annual groundwater recharge is calculated as 341 mm/year, corresponding to an annual groundwater recharge amount of 435,517,000 m^3 in the whole recharge area.

Considering the groundwater basin structure, the recharge amount in upstream area near the Kulen mountain range has little effect on the water supply area in Siem Reap. Then, groundwater recharge amount in the Siem Reap area can be calculated as 188,320,000 m^3/year, corresponding to a daily amount of 516,000 m^3.

This value is far more than the maximum daily water demand of 86,300 m^3/day. However, the water supply area is a sensible area on land subsidence by groundwater level drawdown because of the existence of many world famous heritages. And groundwater drawdown is unavoidable when groundwater is withdrawn. Hence, the magnitudes of groundwater drawdown in different groundwater use plans should be taken as the main issue for groundwater evaluation.

4.3 Simultaneous Groundwater Observation

To make clear the groundwater level distribution and fluctuation in different seasons in Siem Reap, simultaneous groundwater observations were conducted twice, in the rainy and dry seasons. The observation for the rainy season was conducted at the end of September 2009, and the observation for the dry season at the end of April, 2010.

As a survey result, a relative large groundwater level drawdown in the dry season can be found in town area, when comparing the water level in the rainy season. This large drawdown in town area can be considered as the result of large amount of groundwater use by many private wells in town area of Siem Reap.

4.4 Comparison of Groundwater Level Observation Result

In the Study on Water Supply System for Siem Reap Region in Cambodia (2000), 79 wells have been used for monthly groundwater level observation from February 1998 to November 1999. More than 25 wells were extracted from the each of two studies for comparison.

The following 2 tables show the water level in rainy season and dry season in different months and years. The values in the tables give the water level (m) below the ground surface.

Comparison of Water Level in Rainy Season in Town Area

Time	Sept_09	Sep_98	Oct_98	Nov_98	Sep_99	Oct_99	Nov_99
Average (m)	1.63	1.41	1.2	1.32	1.24	0.85	0.6
Maximum (m)	5.12	3.51	3.1	3	3.26	2.9	2.32
Minimum (m)	0.2	0.1	0	0.3	0.23	-0.28	-0.41

Comparison of Water Level in Dry Season in Town Area

Time	Apr_10	Apr_98	May_98	Apr_99	May_99
Average (m)	4.19	3.5	3.5	2.5	2
Maximum (m)	7.4	5	5.1	4.6	4.81
Minimum (m)	2.6	2.35	2.25	1.46	0.82

Compared to the average of observation result in 1998 and 1999, the groundwater level in 2009 got down in a range from 0.22 m* to 1.03 m* in rainy season and 0.69 m* to 2.19 m* in dry season. That is, obviously the groundwater drawdown has happened in the town are in Siem Reap.

(Note: 0.22 m* = {1.63 m (2009/9) – 1.41 m (1998/9)}, 1.03 m* = {1.63 m (2009/9) – 0.6 m (1999/11)}, 0.69 m* = {4.19 m (2010/4) – 3.5 m (1998/4)}, 2.19 m*= {4.19 m (2010/4) – 2 m (1999/5)}

5. Groundwater Simulation

Daily water demand in Siem Reap has been estimated at a maximum of 86,300 m^3/day in 2030, about one sixth of the groundwater recharge amount of 516,000 m^3/day. However, for groundwater simulation, not only the balance between groundwater recharge and withdrawal, but also the effect of groundwater development has to be taken into consideration. In Siem Reap the most important effect from groundwater development is the groundwater level drawdown, because the groundwater drawdown can cause land subsidence.

In this study, several scenarios which combined surface water and groundwater as water supply sources were supposed. The effect of these scenarios was evaluated by a groundwater simulation model created on the basis of hydrogeological survey results and other relative surveys.

5.1 Groundwater Simulation Model Structure

The domain of the groundwater simulation model covers whole water supply service area and surrounding area, with a extent of 39 km in the west-east direction and 46.5 km in the north-south direction.

5.2 Layer Specification

5 layers area is specified in the model: Layer 1 and Layer 2: Shallow aquifer / Layer 3: Aquiclude / Layer 4: Deep Aquifer / Layer 5: Basement rock. (Note: as shown in " Table 2.2 Geological and hydrological characteristics of 2-1 Geophysical Survey", a part of Tertiary formation forms aquifer. Thus, Tertiary formation in this simulation model is supposed to divide into an aquiclude of 3rd layer and a deep aquifer of 4th layer. As a result, the model including basement rocks (5th layer) assumed 5 layers as groundwater basin structures.)

5.3 Boundary Condition Specification

Therefore the following features were specified into the model as constant water boundaries. Siem Reap River / Angkor Wat moat / West Baray (Reservoir) and its channels for water conveyance in its upstream and downstream sides / Tonle Sap Lake

5.4 Parameter Specification

Hydraulic conductivities are specified for each layer based on the pumping test results of the Study on Water Supply System for Siem Reap Region in Cambodia (2000). Other parameters are specified for Storage Coefficient, Effective Porosity, and Specific Yield based on empirical values.

5.5 Model Calibration

1) Steady Flow Simulation: Steady flow simulation is conducted for model convergence and general parameter's specification confirmation.
2) Transient Flow Simulation: Transient flow simulation is conducted for parameter calibration by using the last 3 years (2006 - 2008) relative data of precipitation, evaporation, groundwater withdrawal amount.

5.6 Model Specification for Groundwater Prediction

1) Specification of External Factors

Precipitation and Evaporation: The last 20 years of observation results from 1989 to 2008 in meteorological station Siem Reap City were taken for precipitation specification.
Water Head for Constant Head Boundary: The result of hydrological observation and the last 10 years water level observation results of Tonle Sap Lake were used for constant head boundary specifications.

2) Specification of Scenarios

Scenario 1: Natural condition without any groundwater use.

Scenario 2: Continue groundwater use by the present amount.
{Total withdrawal volume = average 22,176 m^3/day: (SRWSA wells' extraction volume = 9,000 m^3/day) + (private wells' extraction volume)}

Scenario 3: Expending groundwater supply capability by an amount of 77,000 m^3/day.

{Total withdrawal volume = 86,000 m^3/day: (SRWSA wells' extraction volume = 9,000 m^3/day) + (Groundwater development volume by new wells 77,000 m^3/day)}

Scenario 4: Taken KTC project into consideration and then expending groundwater supply capability by an amount of 43,000 m^3/day.

{Total withdrawal volume = 52,000 m^3/day: (SRWSA wells' extraction volume = 9,000 m^3/day) + (Groundwater development volume by new wells 4,300 m^3/day)}

Scenario 5: Also taken KTC project into consideration, but the expanding amount is set following maximum water demand to be 60,000 m^3/day.

{Total withdrawal volume = 69,000 m^3/day: (SRWSA wells' extraction volume = 9,000 m^3/day) + (Groundwater development volume by new wells 60,000 m^3/day)}

Scenario 6: Don't Build New Wells on the East Side of Siem Reap River, and then set the expanding amount as 30,000 m^3/day.

{Total withdrawal volume = 39,000 m^3/day: (SRWSA wells' extraction volume = 9,000 m^3/day) + (Groundwater development volume by new wells 30,000 m^3/day)}

Scenario 7: Stop all deep wells withdrawal except SRWSA production wells, using surface water as water supply source.

(Total withdrawal volume = SRWSA wells' extraction volume = 9,000 m^3/day)

5.7 Simulation Results

1) Groundwater Level

Five (5) provisional observation wells (deep wells) are specified in deep aquifer under and near main heritages. The maximum groundwater level drawdown in these wells are calculated and summarized in the table below.

Summary of Water Level Drawdown

(Unit: m)

Scenario	Near_ANW*	ANW*	ANT*	Near WB*	WB*
Scenario 2	0.73	0.59	0.57	1.34	1.17
Scenario 3	0.7	0.65	0.74	3.31	2.12
Scenario 4	0.41	0.38	0.49	2.31	1.62
Scenario 5	0.51	0.47	0.6	2.83	1.9
Scenario 6	0.45	0.38	0.49	1.71	1.34
Scenario 7	0.13	0.12	0.23	1.16	0.96

（Note）: (Column heading＊) is the code of each provisional observation well and the locations of each provisional observation well are shown in Figure 5.18.
Each location which is indicated by each well number is as follows:

ANW: under Angkor Wat
Near ANW: near Angkor Wat
ANT: under Angkor Thom
WB: under West Baray
Near West Baray: near West Baray

2) Land Subsidence

The potential land subsidence amount are calculated and shown in the tables below.

Potential Land Subsidence Amount Prediction

(Unit: mm)

Location	Near_ANW*	ANW*	ANT*	Near WB*	WB*
Scenario 2	7.02	5.67	5.48	5.84	5.1
Scenario 3	6.73	6.25	7.12	14.43	9.24
Scenario 4	3.94	3.65	4.71	10.07	7.06
Scenario 5	4.9	4.52	5.77	12.34	8.28
Scenario 6	4.33	3.65	4.71	7.46	5.84
Scenario 7	1.25	1.15	2.21	5.06	4.19

(Note): (Column heading＊)is the code of each provisional observation well and the locations of each provisional observation well are shown in Figure 5.18.

Each location which is indicated by each well number as follows:

ANW: under Angkor Wat
Near ANW: near Angkor Wat
ANT: under Angkor Thom
WB: under West Baray
Near West Baray: near West Baray

Potential Land Subsidence Amount Prediction for Heritage Site of Bakong

(Unit: mm)

Scenario	S 2	S 3	S 4	S 5	S 6	S 7
Shallow A	1.59	48.73	20.45	29.93	1.9	0.34
Deep A	0.71	24.23	11.19	16.51	0.92	0.11
Total	2.3	72.96	31.64	46.44	2.82	0.45

(Note) Shallow A: potential land subsidence amount in shallow aquifer.
Deep A: potential land subsidence amount in deep aquifer.
S: Scenario
Total: Sum of potential land subsidence amount of both shallow and deep aquifers

3) Evaluation of All Considerable Plans

The simulation results reveal that potential land subsidence would occur in all water supply expansion plans. The following table summarizes the amount of groundwater production and the potential land subsidence amount in the main heritage sites.

Effect Evaluation of All Considerable Scenarios

Scenario	PA (m^3/d)	LD_ANW	LD_WB	Bakong	Risk Level
Scenario 3	77,250	6.25	9.24	72.96	1
Scenario 2	0	5.67	5.1	2.3	2
Scenario 5	60,250	4.52	8.28	46.44	3
Scenario 4	43,060	3.65	7.06	31.64	4
Scenario 6	30,000	3.65	5.84	2.82	5
Scenario 7	0	1.15	4.19	0.45	6

(Note) PA: production amount from new wells (well locations are shown in Figure 5.16.) Existing production amount of SRWSA wells is not included in the figure.
LD_ANW: potential land subsidence (mm) under the Angkor Wat heritage site.
LD_WB: potential land subsidence (mm) under the West Baray heritage site.

Bakong: potential land subsidence (mm) under the Bakong heritage site.
Risk Level: the primary standard for risk level setting is the magnitude of the effect to the most important heritage, Angkor Wat; while the second standard setting is the effect to the second most important heritage, West Baray.

The scenario 7 has the smallest effect to the heritages. However the effect is not zero. Therefore, it is indispensible to examine if the scenario 7 is really an adaptable plan or not.

The effect on Angkor Wat is 1.15 mm. It is nearly unimaginable to cause inspectable uneven settlement by this amount of land subsidence. Therefore, it can be considered as safe for Angkor Wat and other heritages, such as Angkor Thom, which is further than Angkor Wat from the existing SRWSA well sites.

The effect for West Baray might reach a magnitude of 4.19 mm. Considering the structure of the heritage West Baray, it was created mainly using clay, which has almost the highest plasticity among construction materials. On the hand, the groundwater drawdown is not a suddenly occurring event, but a gradually changing process. For a clay created work on a scale of several km^2 like West Baray, the plasticity is more than enough to compensate for land subsidence on a magnitude not more than 4.19 mm in a period of several months. Therefore, not only the deformation would not be detected, because 4.19 mm is too small to be perceived by humans in a work with the size of West Baray, but also no breaks or cracks could be predicated from the viewpoint of experience and geotechnical engineering. Therefore, the effect on heritage of West Baray form the scenario 7 can also be considered sufficiently small as to be ignored.

The potential land subsidence including both shallow aquifer and deep aquifer for Bakong is as small as 0.45 mm, smaller than the effect to the Angkor Wat and West Baray. Therefore, the effect of scenario 7 to Bakong heritage group can be considered as within safe limits.

6. Conclusion and Recommendation

6.1 Conclusion

Survey purposes for the Study are to evaluate groundwater use at present and in the future and to assess the influence to world heritage-Angkor Wat ruins by pumping of much groundwater due to rapid increase of tourists and tourist facilities such as hotels and restaurants in recent years in the Siem Reap City, and to review the reinforcement of groundwater monitoring system.

(1) Evaluation of Groundwater use at Present and in the Future

In Siem Reap City area, current status of groundwater use of large establishments was surveyed by well inventory survey. As a result, the survey revealed that there were 280 establishments of tourist facilities such as hotels and public facilities including schools and factories in the city area and they withdraw groundwater of about 5,786 m^3/day in the dry season. In addition, SRWSA pumps up groundwater of about 9,000 m^3/day for water supply and ordinary houses use groundwater of about

24,000 m^3/day by shallow wells. Thus, it is estimated that groundwater of 38,000 m^3/day is presently at least extracted in the city area.

On the other hand, a part of world heritage ruins are located near the city center area and many tourist facilities such as hotels are also concentrated in the area. If in the future, a large number of tourist facilities are continuously constructed in the city center area and withdrawal volume of groundwater increases, it is supposed that groundwater level (hydraulic head) in the area is lowered and land subsidence by consolidation may be caused and they may have an impact to world heritage.

To identify this phenomenon, monitoring data of groundwater level of existing observation wells were analyzed. As a result, in monitoring data, small fluctuation of groundwater level influenced by pumping wells near monitoring wells was identified but constant and large drawdown of groundwater level was not observed. In addition, lowering of groundwater level by pumping of SRWSA production wells in WT-4 monitoring well was not observed. WT-4 well is located along National Road No.6 and apart about 2.6 km from SRWSA wells. As a result, the influence of groundwater withdrawal was not identified under existing conditions.

To review the influence to world heritage in future water demand, groundwater simulation was conducted. In this simulation, the following 6 scenarios to deal with future water demand (86,000 m^3/day) for water supply planning year 2030 were prepared and reviewed.

Scenario	Scenario Condition
Scenario 2	To continue groundwater use by the present amount.
Scenario 3	To use groundwater as the only source for water supply.
Scenario 4	To use irrigation canal water from West Baray reservoir for water supply and diminish a part of groundwater development volume (Withdrawal volume including SRWSA production wells: 52,000 m^3/day – 69,000 m^3/day)
Scenario 5	
Scenario 6	To lessen the impact to Bakong ruins, new production wells are not planned in eastern bank area of the Siem Reap River.
Scenario 7	As water sources for water supply, pumping by existing wells excluding SRWSA production wells are halted. Only lake water of Tonle Sap is used.

(Note) Scenario 1 is natural condition without groundwater use and a case for comparison for other scenario and for calculation. Thus, it was omitted.

Groundwater development as future water sources for the above scenarios was planned to construct new production wells in the area of more than 10 m in elevation and about 4 - 5 km in south of National Road No.6 with width of about 30 km in East – Northwest direction (Well locations are shown in Figure 5.16).

The simulation results revealed that potential drawdown of groundwater level and land subsidence to world heritage would occur in all scenarios in a dry year of 50 return years. Especially, of these scenarios, scenario 3 which used groundwater as the only source for water supply resulted in the largest land subsidence and the highest risk. Subsequently, scenario 2 which continued groundwater use by the present amount had secondary higher risk. Furthermore, scenarios 4 to 6 also did not recommend having impact to world heritage. Of these scenarios, scenario 7 which utilized lake water of Tonle Sap as future source for water supply had the lowest risk.

For these results, to use lake water of Tonle Sap as alternative water sources without new groundwater development in Siem Reap area for future water demand was concluded to be reasonable.

(2) Enforcement of Monitoring System

Since Angkor Wat ruins which are important world heritage are formed by architectural structures with only piling stones without cements, they are very weaken against land subsidence. Thus, to conserve ruins from drawdown of groundwater level and land subsidence which may be caused by over-pumping of groundwater in the city area in the future is very important. In Siem Reap area, 9 monitoring wells for groundwater levels at 8 sites and 4 observation wells for land subsidence at 2 sites has been constructed and they monitor groundwater levels and land subsidence. However, it was revealed by this study that a part of these facilities normally did not function and their monitoring data had not high reliability. Operating conditions and necessity of calibration of monitoring equipment in each monitoring wells are shown in Chapter 3. SRWSA which manages these monitoring wells presently collects and keeps the data as routine works. They should be able to collect high reliable data by restoring malfunction monitoring equipment.

In Siem Reap area, in addition to SRWSA, Monitoring of groundwater levels by APSARA is conducted. Though DOWRAM presently does not have any groundwater monitoring system, they own position to conduct study and research on water resources utilization of the area. At present, there is no linkage among these organizations. In the future, to conserve important world heritage in Siem Reap area, it is necessary to enforcement groundwater monitoring systems by creating their linkage.

6.2 Recommendation

(1) In a dry year of 50 return years, groundwater simulation results revealed that potential land subsidence to world heritage would occur, not only scenario 3 which used groundwater as the only source for water supply but also scenario 2 which continued groundwater use by the present amount. To improve these situations, it is hoped that new water supply system which is supplied by lake water of Tone Sap as water source is completed as soon as possible.

(2) If new water supply system which is supplied by lake water of Tonle Sap is completed in the future, the ban of pumping by private large establishments' wells should be conducted. For this purpose, ordinances and regulations by Siem Reap Province and APSARA should be

enforced together with campaign to enhance residence's awareness.

(3) SRWSA generally collects monitoring data of groundwater levels and land subsidence once a month from monitoring wells and also conducts manual measurement of groundwater level to check data reliability at the same time. However, collected data of manual measurement often lack for mismatch of collecting time. SRWSA should keep and conduct thoroughly setting manners for data collection.

(4) SRWSA should check reliability of auto monitoring data by comparison between manual measurement and auto monitoring data. It is necessary to compare and put manual measurement and auto monitoring data at the same observation day/time in the same table and to check the difference of groundwater levels and correlation by drawing on graph.

(5) SRWSA immediately should restore mal-function monitoring equipment. Present conditions of each monitoring wells are described in "Chapter 3, 3-1 Current Status of Groundwater Monitoring."

(6) SRWSA should builds up mechanism and structure for sharing and putting each monitoring data to practical use with APSARA and DOWRAM.

FINAL REPORT 2

THE PREPARATORY STUDY ON
THE SIEM REAP WATER SUPPLY EXPANSION PROJECT
IN THE KINGDOM OF CAMBODIA

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS

AMSL	Above Mean Sea Level
ANT	Angkor Thom
ANW	Angkor Wat
BOT	Build Operate Transfer
CA	Concession Agreement
D/D	Detailed Design
DOWRAM	Department of Water Resources and Meteorology
DWL	Dynamic Water Level
EC	Electric Current
EIA	Environmental Impact Assessment
EIRR	Economic Internal Rate of Return
E/N	Exchange of Notes
FIRR	Financial Internal Rate of Return
GDP	Gross Domestic Product
GPS	Global Positioning System
GW	Groundwater
I/P	Implementation Program
JICA	Japan International Cooperation Agency
JPY	Japanese Yen
L/A	Loan Agreement
L/s	Liter per second
MIME	Ministry of Industry, Mines and Energy
MOWRAM	Ministry of Water Resources and Meteorology
M/P	Master Plan
NPV	Net Present Value
ODA	Official Development Assistance
O&M	Operation and Maintenance
PS	Pumping Station
PVC	Polyvinyl Chloride
SAPROF	Special Assistance for Project Formation
SRWSA	Siem Reap Water Supply Authority
STEP	Special Terms for Economic Partnership
SWL	Static Water Level
TOR	Terms of Reference
UTM	Universal Transverse Mercator
VES	Vertical Electric Sounding
WB	West Baray
WMO	World Meteorological Organization

Chapter 1.
Background of the Project

Chapter 1. Background of the Project

1-1 Authorization

The Preparatory Study on The Siem Reap Water Supply Expansion Project is in pursuance to the Scope of Work, signed on 29th January 2009, between the Ministry of Industry, Mines and Energy (MIME), the Siem Reap Water Supply Authority (SRWSA), and Japan International Cooperation Agency (JICA).

The Study started in May 2009, and completed in August 2011. During the approximately 28-month period, the Study Team will undertake the study in cooperation with the MIME and SRWSA counterpart officials.

This Final Report presents the results of the activities in the field of groundwater study, based on an agreement for the scope of works for Feasibility Study confirmed in the Board Meeting held on January 22, 2010. It also presents the evaluation of findings, the recommendation and conclusion in the field of the groundwater study.

1-2 Objective of the Study

The objectives of the Study are:

1) To select new water sources(s) for an efficient and sustainable water supply system in Siem Reap;

2) To conduct surveys of existing wells and assess the potential yield of groundwater

3) To identify an urgent water supply expansion project to satisfy the estimated water demand for Siem Reap up to a selected target year of the Project;

4) To conduct a feasibility study for the proposed water supply expansion project, provided that the Project is to be implemented under finance by the Japan's ODA loan;

5) To formulate a long-term water supply development plan up to year 2030; and

6) To pursue technology transfer to the Cambodian counterpart during the course of the Study.

1-3 Study Area

The study area covers all the communes of the newly established Siem Reap City and one adjacent commune of the City, for a total of 14 communes.

1-4 Target Year

The year 2030 has been set as the target year for the proposed long-term water supply development plan, as agreed by and between the JICA mission and Cambodian side in January

2009.

1-5 Methodology of the Study and Component of Final Report 2

The methodology envisaged by the Study Team in their Inception Report has been maintained. Since the Study has been conducted in three phases, as described below, several reports were prepared in the course of the Study.

In the field of groundwater study, Phase 1 includes basic study such as well inventory survey, electric sounding, water use awareness survey, and basic examination on possibility of groundwater development by computer simulation. Phase 2 is mainly formed by preparation of facility development plans and the feasibility study in the field of water supply. Phase 3 is conducted based on basic information from Phase 1.

Phase 1 Basic Study on Structure of Groundwater Basin, Well Inventory, and Basic Examination on Possibility of Groundwater Development by Computer Simulation

Phase 2 Preparation of Facility Development Plans and the Feasibility Study

Phase 3 Study on Groundwater Use and Assessment.

1-6 Contents of the Final Report 2

This Final Report 2 deals with the results of the study for Phase 1 and 3.

Chapter 2.
Survey Results for Groundwater Sources

Chapter 2. Survey Results for Groundwater Sources

2-1 Geophysical Survey

2-1-1 Background and Outline

The use of groundwater in the plain area along the shore of Tonle Sap Lake was proposed by the team of JICA preliminary study (conducted in 2009) for this preparatory study as a possible alternative source for water supply to the city of Siem Reap. The Study on Water Supply System for Siem Reap Region in Cambodia (2000) had already been conducted and had clarified the underground geology of the urban and suburban areas of Siem Reap city. However, there has been little geological information available on the zone along the shore of Tonle Sap Lake. For this reason, the entire survey area extended about 30 km on both western and eastern sides of Phnon Kraom hill along the shore of Tonle Sap Lake. The surveyed points are shown in Figure 2.1. The outline of the survey is summarized below:

Table 2.1 Outline of the Geophysical Survey

Survey period	July 13 to 30, 2009
Type of sounding	Vertical resistivity sounding (VES)
No. of survey points	53
Electrode array	Schlumberger
Target depth	150 m

2-1-2 Results

In the Study on Water Supply System for Siem Reap Region in Cambodia (2000), a four-layer subsurface structure was established as a result of the analysis. By reference to the above study result, the geophysical survey data of this study were analyzed and the analyzed geological structures are shown in Table 2.2.

Table 2.2 Geological and Hydrogeological Characteristics of the Layers in the Study Area

Layer Sign	Age	Thickness (m)	Description	Hydrogeological Characteristics
1. Qal	Quaternary (Holocene)	10 – 20	Alluvial deposits Silty sand with coarse particles. Very loose sand in the middle part.	Static water level: 0.855 m (1997 May) Permeability: 1.87-1.67x 10^{-2} (cm/sec) Discharge:444 liters/min With 0.73 m drawdown.
2. Qsd	Quaternary (Pleistocene)	10 - 30	Diluvium deposits Containing silt (stone) from the lower formation. Clayey sand (stone) with coarse matrix. At the bottom, gravelly sand and core lost by loose matrix.	
3. Tcy	Tertiary (Pliocene)	20 - 50	Pliocene formation Sandy clay stone. Cylindrical core.	Aquiclude – Aquifer*
4. Mbr	Mesozoic	-	Bedrock: Weathered tuff of Mesozoic sedimentary rocks.	Unknown

Note : Table was compiled and modified from the data in the Study on Water Supply System for Siem Reap Region in Cambodia (2000). the Study on Water Supply System for Siem Reap Region in Cambodia (2000) revealed that geological structures in Siem Reap area were formed by 4 ones and the layer 1 and 2 above were the major aquifers. The geophysical survey data of this study were analyzed by reference to the survey results of the above study (2000).

Based on the analysis results and in consideration of horizontal geological continuity, several cross-sections of resistivity structure of the surveyed area were prepared and presented as Figure 2.2–Figure 2.4.

(1) Bedrock

The analysis revealed that the depth to the bedrock is likely to be 50 to 80 m below ground level, except around Phnon Kraom hill where the bedrock is exposed and forms the hill. The drilling logs mentioned above show that the bedrock is located deeper than 30 m, a few hundreds of meters away from the hill. This suggests that this topographic rise of the bedrock is limited to this point. These rocks have resistivity values of more than 1000 ohm-m and interpreted as impermeable rocks such as siliceous acidic tuff and fresh crystalline diorite.

(2) Overlying layers

There are three overlying layers above the bedrock. The first layer from the ground is alluvial deposits made up of alternation of thin layers of sand, silt, and clay. The thickness of this layer is variable, ranging from 10 to 25 m, and the resistivity values range from 5 to 1000 Ohm-m.

The second layer consists of sandy deposits characterized by relatively higher resistivity values as compared to the third layer underneath. The thickness ranges from 5 to 35 m and the resistivity values are generally between 30 to 500 Ohm-m.

The third layer is characterized by low resistivity values of normally less than 100 ohm-m. The layer is much thicker than the overlying two layers and the thickness ranges from 10 to 55 m.

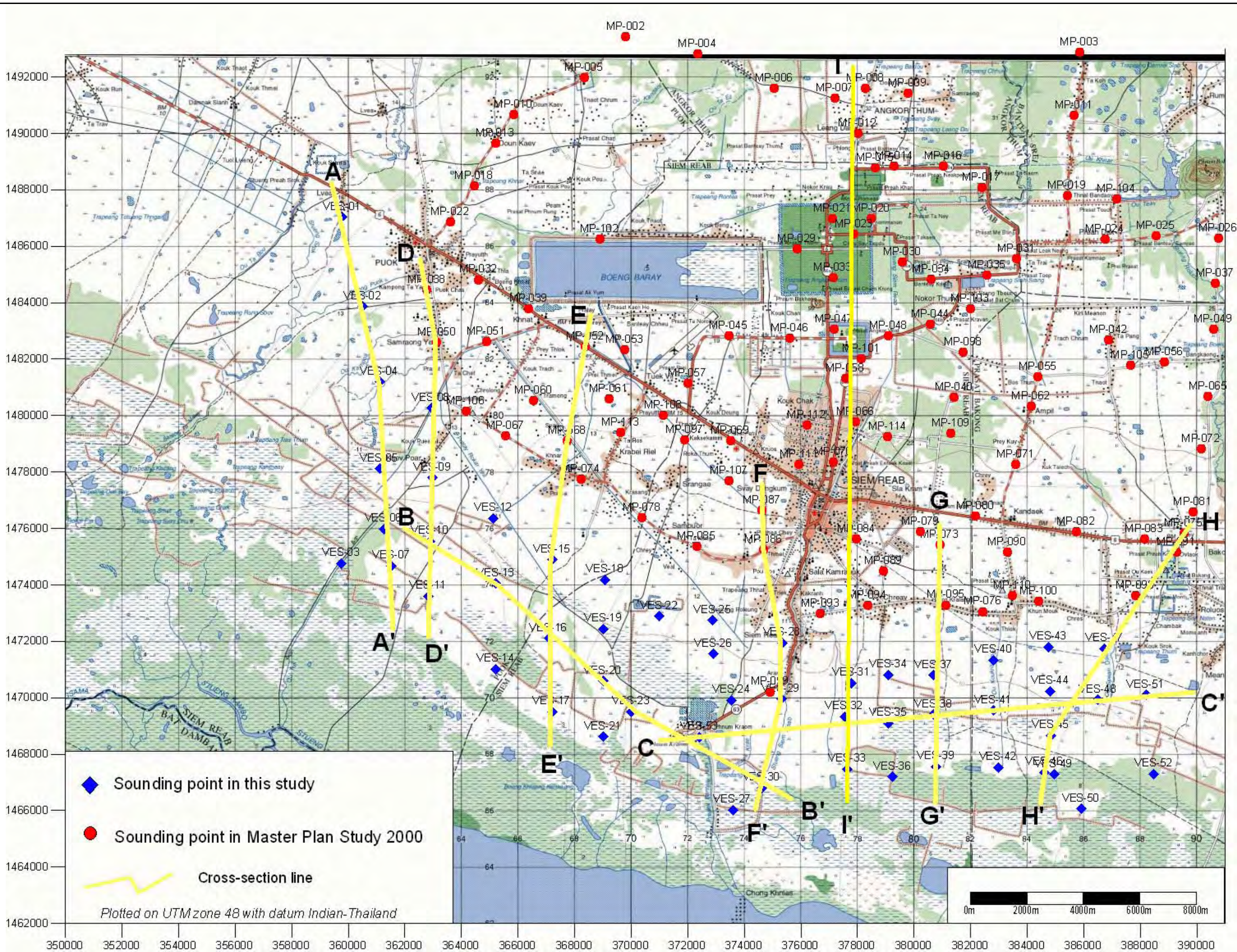

Figure 2.1 Geophysical Survey Point and Location of Resistivity Cross-Sections

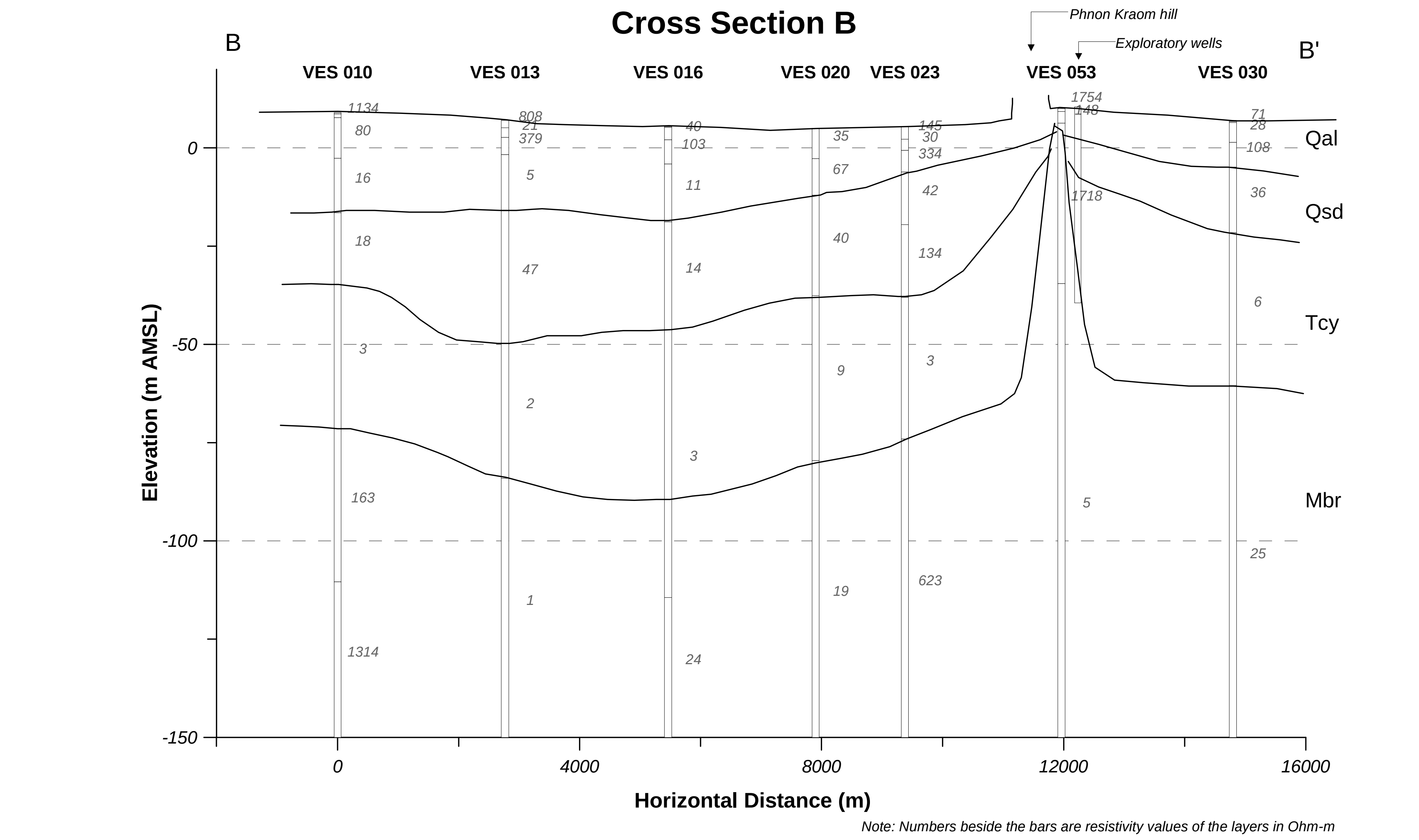

Figure 2.2 Cross-sectional View of the Layered Structure in the Surveyed Area (1/3)

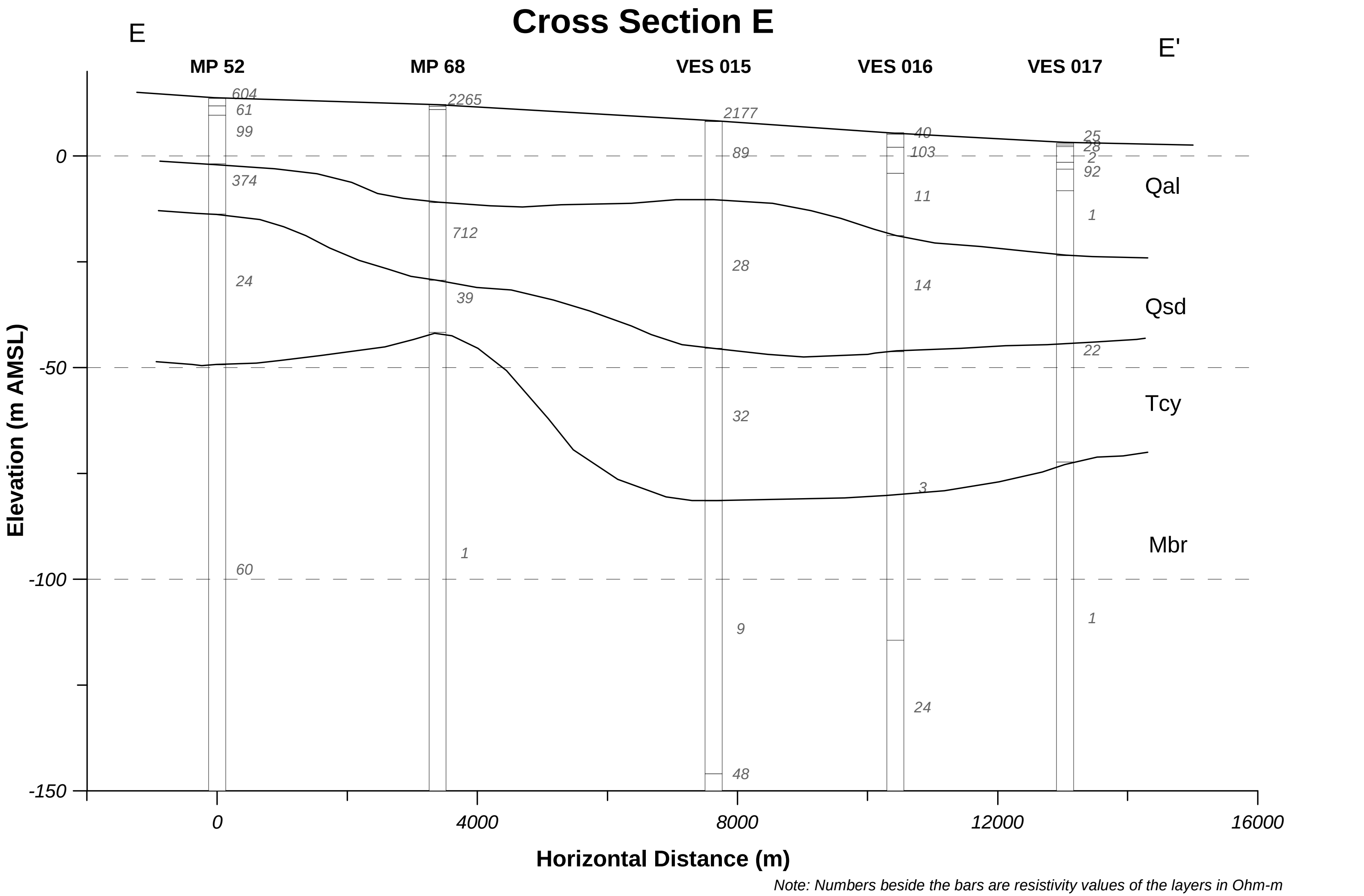

Figure 2.3 Cross-sectional View of the Layered Structure in the Surveyed Area (2/3)

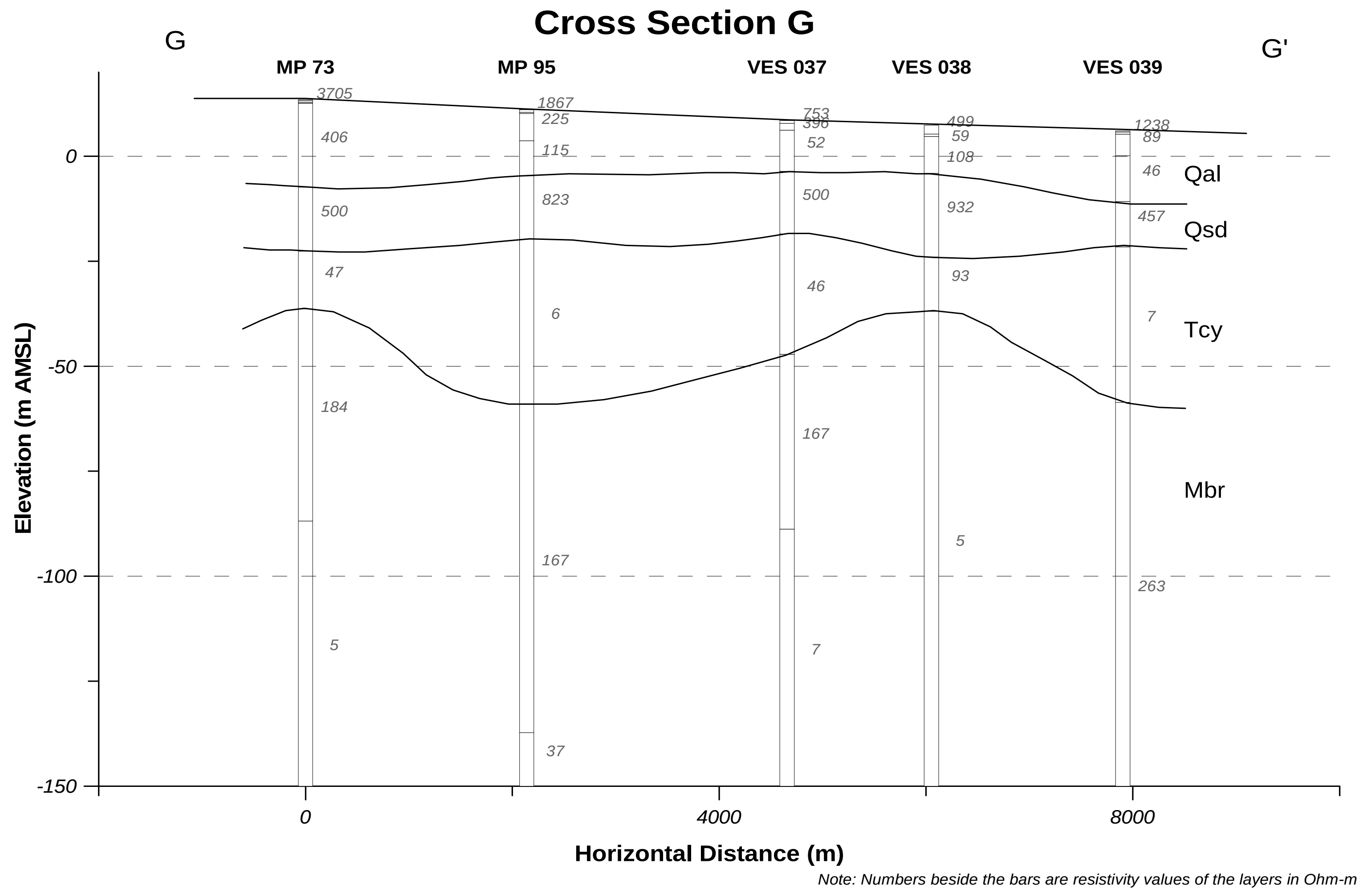

Figure 2.4 Cross-sectional View of the Layered Structure in the Surveyed Area (3/3)

2-2 Well Inventory Survey

2-2-2 Background and Outline

(1) Background

This survey was conducted to obtain basic data for groundwater use and demand estimation. The survey targets are large consumers of groundwater such as hotels, restaurants and schools, and an interview survey was conducted using a structured questionnaire. The location of surveyed establishments is shown in Figure 2.5.

Table 2.3 Outline of the Inventory Survey

Survey period	July 22 to August 29, 2009
Survey method	• Interview with structured questionnaire • On-site measurement
Major survey items	1. Basic information of the site 2. Basic information of the water supply system 3. Well Structure and water use 4. Water use awareness 5. Water quality
No. of survey targets	Total 280

(2) Survey target

The survey targets are mainly large commercial and public establishments that have a groundwater drawing system (borehole with a motor pump). A total of 280 establishments were surveyed as shown in Table 2.4.

Table 2.4 Surveyed Establishments by Category

Establishment	Detail	Q'ty	Total
Hotel		75	190
Guesthouse		115	
Restaurant		40	40
Factory/Manufacturer		10	10
Other	Car wash	31	40
	School	4	
	Entertainment	4	
	Clinic	1	
Total			280

(3) Survey method

The survey was conducted by two teams that are made up of two interviewers. The teams visited the person responsible, generally the manager or the owner, at each establishment and conducted an interview with a questionnaire form. The teams also conducted measurement of water levels in wells and checked the quality of water using a field test kit and portable pH and EC meters.

(4) Survey contents

The questions in the survey sheets are grouped into five sections. The following is the description of purposes and contents of each of the sections.

Section 1 (Basic information of the site): name of establishment, GPS data, Elevations, etc.

Section 2 (Basic information of the water supply system): water source type, purpose of use, no. of wells, pump type, with/without of treatment system, etc.

Section 3 (Well inventory): well depth, casing diameter, screen depth, pumping rate, SWL, DWL, operating hours, total O & M cost, etc.

Section 4 (Water use awareness survey): satisfaction (amount, quality), no. of O & M person, technical problems, etc.

Section 5 (Water quality test): EC, pH, Fe, Mn

The list of questions along with the explanation for each question given to the survey team is attached as Table 2.2.1, 2.2.2, 2.2.4 and Figure 2.2 of the Supporting Report.

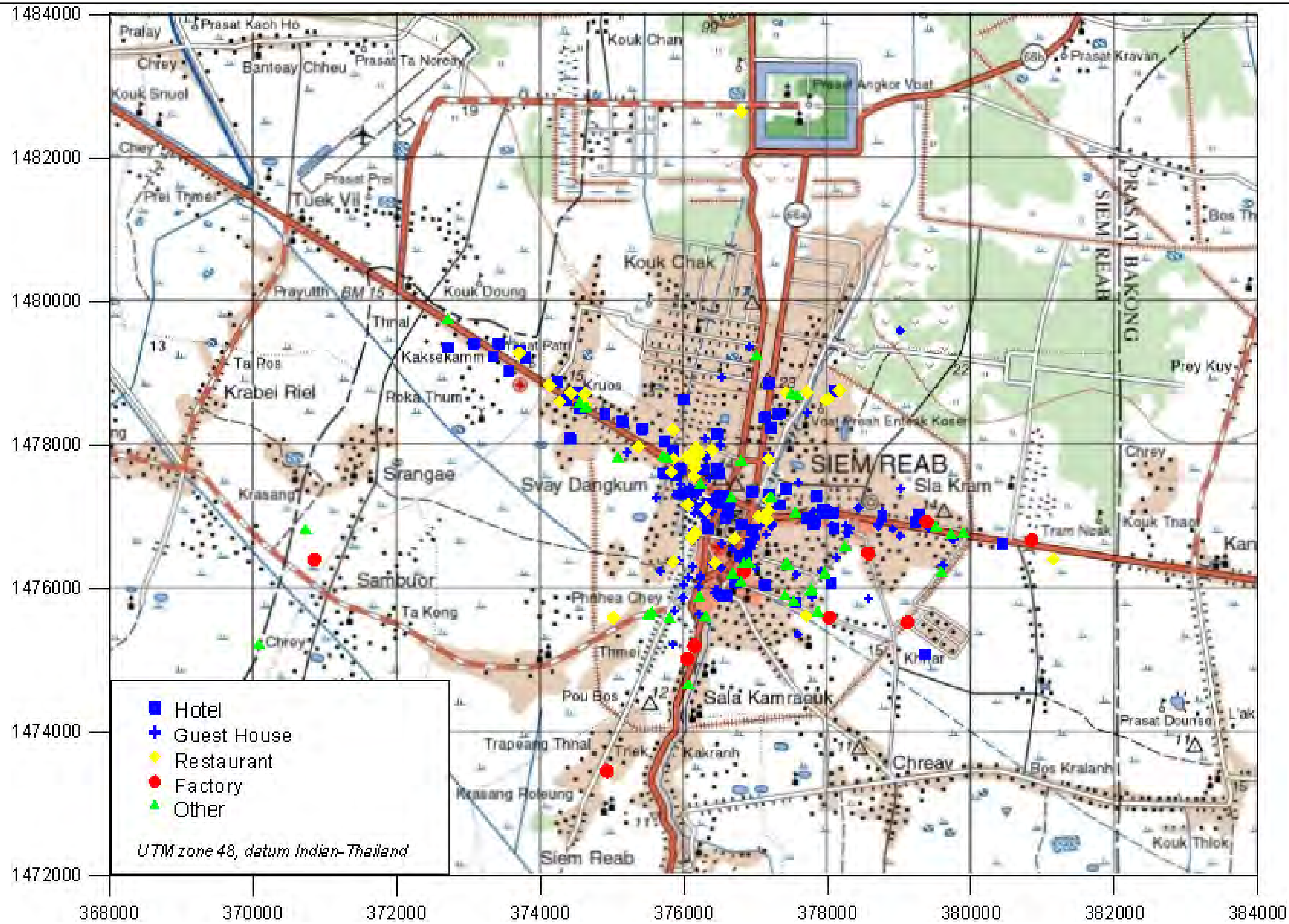

Figure 2.5 Location of Surveyed Establishments

2-2-3 Results

The following sections give detailed explanation of major finings extracted from the analysis of the survey data. A more comprehensive list of findings is presented as Table 2.12.

(1) Water supply facilities and water use

The water source for all the surveyed establishments has been found to be boreholes (tube wells) of at least 20 m deep. Approximately 15 % of the hotels and guest houses have more than two wells and the same ratio for restaurants and factories is approximately 23 % and 50 % respectively. A substantial proportion (around 35 %) of hotels, guest houses, and restaurants are also connected to the public water supply system. They generally use the public water supply as a backup or for specific purposes.

Table 2.5 Average Number of Wells and Depth of Wells

Category	Hotel	Guest house	Restaurant	Factory	Other
Number of wells	1.37	1.06	1.40	1.60	1.03
Depth *(GL-m)	45.5	30.9	31.0	43.6	32.1

* Depth of the main well ("well A" in the survey sheet) if there are more than 2 wells.

The depth of the wells ranges from 20 to 80 m and the average depth for hotels and factories are around 45 m and around 30 m for the other types of establishments. The use of water treatment is common in hotels and factories. The most commonly used treatment is sand filtration.

In most of the cases the surveyors had to estimate the amount of daily water use based on the capacity of the pump, the size of reservoir tank, and the operation hours of the pump. The results are summarized in the following table.

Table 2.6 Estimated Daily Average Water Use Amount by Category (m^3/day/establishment)

Category	Hotel	Guest house	Restaurant	Factory	Other
Rainy Season Mean	30.35	4.62	8.89	39.00	8.89
Dry Season Mean	47.27	5.65	9.91	85.4	8.51

The water consumption is higher during the dry season and lower in the rainy season for all the categories except for "Other". The reason for the decreased water use amount under "Other" is that most of the surveyed establishments are car wash places and cars become dirty less often during the dry season.

(2) Water use awareness

The survey revealed that the majority of the hotels, guest houses, and restaurants are aware of the possible negative effect (lowering of groundwater level and occurrence risk of land subsidence) of groundwater withdrawal on the environment. On the other hand, establishments under the other two categories are not quite aware of this issue. This is perhaps due to the effect of the environmental education designed for these tourist related businesses.

Table 2.7 Ratio of Awareness on Possibility of Occurrence of the Groundwater Issues

Category	Hotel	Guest house	Restaurant	Factory	Other
Ratio of Awareness (%)	64	53	65	10	17.5

Many of the surveyed establishments are willing to connect to the public water supply system when it becomes available and can supply enough water volume. The main reason is to cut down the operational cost of current groundwater pumping system.

(3) Water quality

The following items of water quality were tested at each establishment using field test kit and potable meters.

The shallow groundwater is characterized by 1) higher iron and manganese contents, 2) higher EC values, and 3) lower pH values. The quality of groundwater from deeper wells tends to be relatively better in these respects.

Shallow well users are mostly small establishments that cannot afford expensive water treatment facilities. Thus, they suffer from the water with high iron concentration. These small establishments are considered highly motivated to switch to the public water supply system when it is in place.

(4) Database construction

The information for the 280 surveyed establishments have been converted to a MS-Access database and handed over to SRWSA.

Table 2.8 Summary of the Database

Title	Well Inventory of Large Groundwater Consumers
Software	MS-Access
Recorded number	280 establishments
Contents	Corresponding to each section in the questionnaire except for section 4 (water use awareness survey):
Query	9 default queries
Language and units	English and metric system
Positional information	The data comes with GPS coordinates for each record and can be integrated into a GIS

(5) Important findings from the inventory data

1) Present groundwater use amount

The total amount of daily groundwater use in Siem Reap at present (year 2009) can be estimated using the data obtained in the well inventory survey. The following set of data and conditions were adopted to estimate the daily groundwater use amount for both dry and wet seasons.

Table 2.9 Summary of Estimated Present Groundwater Use Amount in Siem Reap

Category	Use amount (m^3/day)		Conditions of estimation
	Wet season	Dry season	
Large establishments with own groundwater pumping facilities	3,908	5,786	- Total from 280 establishments in the inventory. Separately calculated for dry and wet seasons.
Large establishments connected to public water supply of SRWSA except the above establishments	3,739	5,009	- Number of : hotels=61, Guesthouses=43, Restaurants=190 (source: SRWSA list of registered customers), - Average pumping amount data for the above category was taken from the inventory data (see table 2-6). - Some part of water is supplied by their own groundwater pumping facilities
Small establishments and ordinary houses	21,569	24,418	- Population of Siem Reap in 2009 = 203,483 (source: department of planning Siem Reap province) - Part of the water is supplied by SRWSA's public supply system - Unit water use amount = 0.106 m^3/day/capita for wet season , 0.120 m^3/day/capita for dry season
Total	29,216	35,213	

(Note) It should be noted that the figures for the total groundwater consumption calculated here are those of the collective consumption by domestic users, commercial users, and tourists regardless of the types of supply facilities. In other words, the groundwater consumption by SRWSA customers is also included.

2) Cost of operation and maintenance (O/M) for groundwater supply facilities

In the inventory survey, the cost of operating and maintaining various types of water supply facilities of each establishment was roughly estimated by the interviewers by using the information they obtained during the site visits.

Case A: Major repair cost is 30 % of the total installation cost, 3 times over 15 years

Case B: Major repair cost is 35 % of the total installation cost, 3 times over 15 years

Table 2.10 Summary of Water Production Cost of Groundwater Users (Case A)

	Category	Hotel	Guest house	Restaurant	Factory	Other
A)	Average water use in WS (m^3/day)	30.35	4.62	8.89	39.00	8.89
B)	Average water use in DS (m^3/day)	47.27	5.65	9.91	85.4	8.51
C)	Average O/M cost (US$/month)	413	59	169	491	203
D)	Average installation cost of water supply facilities (US$)	45,686	6,261	1,923	32,778	6,267
E)	Average cost for major repair of facilities (US$)	41,117	5,635	1,731	29,500	5,640
F)	Average unit water production cost (US$)	0.781	0.802	0.734	0.446	1.028

Table 2.11 Summary of Water Production Cost of Groundwater Users (Case B)

	Category	Hotel	Guest house	Restaurant	Factory	Other
A)	Average water use in WS (m^3/day)	30.35	4.62	8.89	39.00	8.89
B)	Average water use in DS (m^3/day)	47.27	5.65	9.91	85.4	8.51
C)	Average O/M cost (US$/month)	413	59	169	491	203
D)	Average installation cost of water supply facilities (US$)	45,686	6,261	1,923	32,778	6,267
E)	Average cost for major repair of facilities (US$)	47,970	6,574	2,019	34,417	6,580
F)	Average unit water production cost (US$)	0.815	0.835	0.745	0.460	1.048

Assumptions and equations applied:

- Duration of wet season (WS) is six months (May to October), One month is 30 days, One year is 365 days
- Installation cost is answered in a range and the range top figures are employed for calculation of D
- Amortization period is 15 years, Major repair required every 5 years costing 30 % and 35 % of the installation cost for Case A and Case B respectively,
- O/M cost = chlorine (disinfectant) and minor repair costs + Labor Cost + Energy cost

Formula to find unit water production cost : $F = [C/30 + (D + E)/(15 \times 365)] / [(A + B)/2]$

The result reveals that the production cost of one cubic meters of water differs from category to category. Factories that generally use large scale facilities are most efficient producers and “other” which is made up mostly of car wash stands is the least efficient producers. These figures are also larger than the current water tariff of public water supply system.

Table 2.12 Major Findings from Well Inventory Survey

Category	Findings
Surveyed number	･ 280 big water consumers
Water supply facilities	･ All the water sources are tube wells of at least 20 m with either a ground or a submersible pump. ･ *Majority (77 %) of establishments use only one borehole for water supply.* ･ *The average number of wells for hotels and guest houses is 1.37 for and 15 % of them has more than 2 wells.* ･ Less than 4 % of the establishments have water meters or observation pipes installed at their wells. ･ A little over 30 % of hotels, guest houses, and restaurants use both groundwater and public water supply. ･ *The average depth of wells is around 44 m for hotels and factories, and around 30 m for the other categories.* ･ Commonly used casing pipe is of 100 mm diameter for hotels and Factories and 49 mm for other categories. ･ Ground pumps are commonly used for all the categories but up to 36 % of hotels and factories also use submersible pumps. ･ Water treatment facilities are commonly used in large hotels and factories and the common type is sand filtration and related system. ･ Most of the systems were constructed after the year 2000 at the time of construction of the buildings ･ *The screen location varies depending on the depth of the well and average length is 9.6 m.* ･ *The static water levels were measured to be around 1.5 m and maximum is 2.9 m below ground.* ･ *The dynamic water levels were around 6 to 7 m below ground.* ･ Majority of establishments (except for Factories) responded that it is either easy or moderate to connect to the public water supply system in terms of construction work. ･ Majority of hotels (75 %) use both commercial and generator for power supply while majority of guest houses (86 %) depends only on commercial supply.
Water use and use amount	･ Daily water use had to be estimated based on pump capacity and operation hours of pumps due to lack of water meter or reliable record. ･ *Hotels and factories are the large water users with 30 to 40 m^3 of daily use.* ･ *All establishments use 1.1 to 1.5 times more water during the dry season except for car wash sites* ･ *Factories are large users of water although their number is small.* ･ Large restaurants use more water ･ *The water from both borehole and public supply is used mainly for general (multi) purposes.*
Awareness of environmental issues	･ Large establishments are mostly satisfied with both quantity and quality of current water supply but small establishments are less satisfied, especially so about the quality. ･ *Hotels, guest houses and restaurants are highly aware of the environmental issues (lowering of groundwater level and land subsidence) concerning groundwater use.*
Intention to switch to piped water supply by SRWSA	･ *Majority (70 to 90 %) of hotels, guest houses, and restaurants intend to switch to the public water supply system while factories intend to keep using groundwater.* ･ *Those that responded "depends" raised cost and usability as the conditions.* ･ The reasons for switching are the environmental obligation and also usability.
Water quality	･ *The water quality is similar to that of the city and surrounding area that is characterized by sporadic high iron contents and low pH.*

* The items in italic are discussed in more detail in this report

2-3 Field Water Quality Test

The quality of groundwater in the areas of possible groundwater sources for the water supply was tested in the field. The water samples were taken mainly from tube wells with a hand pump and tested for the following indicators. The location of sampling is shown in Figure 2.5.

Table 2.13 Items of Analysis and Method

Item	pH	EC	Fe	Mn	NH_3-N
Method	Portable pH meter	Portable EC meter	Pack test	Pack test	Pack test

The EC values are generally very low (acidic) except for some open hand-dug wells. Some wells showed a high iron concentration of 8 mg/L but it seems to be limited to small areas. Nitrogen in ammonium form (NH_3-N) is one of the indicators of immediate contamination by animal/human discharges and by fertilizers. The values are generally less than 0.2 mg/L with less than drinking water standards. The following table compiles the results of the water quality test for the three areas along the southern margin of Siem Reap City: East of Siem Reap River, West of Siem Reap River and the area around Phnon Kroam hill.

Table 2.14 Average Value of Water Quality by Area (Unit: mg/L)

Item	pH	EC (μS/cm)	Fe	Mn	NH_3-N
*DWS**	*6.5 – 8.5*	*1600***	*0.3*	*0.1*	*1.5*
East	5.43	48	1.21	0	0.18
West	5.60	83	2.08	0	0.15
Phnon Kraom	4.90	518	0.45	0.17	0.15

Note: water from hand-dug wells is not included in these calculations
* Drinking water quality standards, January 2004, Ministry of Industry, Mines, and Energy
** Defined as about double of TDS value measured in micro S/cm

Generally, the water quality of these areas is similar to that in the other parts of the city and its surroundings. As it has been known, it is characterized by low pH values and sporadic high Iron concentrations. In every area, average values of pH and iron concentration exceed drinking water quality standards and it may need water treatment for drinking.

2-4 Survey Result of Core Sample

Under this study, a monitoring well (shallow well) was constructed in the premise of Kravan primary school on October 2009 and two monitoring wells (shallow and deep wells) were constructed in Khvein primary school on October 2009 and May 2011, respectively.

At the same time, in the same locations as the monitoring wells, a core boring of 80 m in depth were conducted at each site on October 2009 and the observation survey for the core samples was followed on January 2011. In addition, in the observation survey, core samples which JSA (Japanese Government Team for Safeguarding Angkor) carried out in the yards of Angkor ruins (Angkor Wat and Bayon) in 1995 were also observed as reference samples.

The survey results were different from accepted concept on geological structures in Siem Reap area based on the study results of "the Study on Water Supply System for Siem Reap Region in Cambodia (2000)", namely, geological structures that Quaternary formations of Alluvium and Diluvium were underlain by claystone (equivalent formations of Tertiary). In the depth of ground surface to 80 m, non consolidated formations are continuously distributed and it can be deemed to be continuous formations.

According to the above study (2000), in Siem Reap area, geological structures are made up of 4 ones: Alluvium and Diluvium are distributed in the depth of ground surface to about 30 m to 50 m and are underlain by Tertiary formations with layer thickness of about 40 to 50 m, and basement rocks of sandstone, siltstone, shale, and tuffaceous breccia of Upper Jurassic, andesite, basaltic intrusive rocks, and diorite of Late Mesozoic to Tertiary are distributed in the depth of about 70 m to 80 m.

However, according to the observation results of the core samples in both sites of Khvein and Kravan, the following results were revealed: (1) In the depth of ground surface to 80 m, non consolidated formations are continuously distributed and it can be deemed to be continuous formations. (2) Formations equivalent to Tertiary formations does not exist in core samples as a result of core observation.

Outline of observation results of core samples are as follows: Observation results of core samples (columnar sections) are shown in Supporting Report, Chapter 3, SR 3-2 (1) Survey Results of Core Samples.

(1) Khvein Site

Clay layer is distributed in the depth of ground surface to 5 m. Under this layer, alternating layers of sand, sandy clay, and clayey sand with layer thickness of 1 m to 4 m are distributed. In the depth of 50 m to 63 m, these alternating layers are underlain by thick clay layer with layer thickness of about 12 m with interbeded layers of thin clayey sand (sandy clay) in the depth of 58 m and of 61m to 63 m. In the depth of 63 m to 80 m, fine sand layers are distributed.

According to this survey, geological formations of core samples can be deemed to be continuous ones and clay formations distributed in the depth of 50 m to 63 m are not consolidated ones that can be deemed to be equivalent formations of Tertiary.

(2) Kravan Site

In the depth of ground surface to 7 m, alternating layers of silt, sandy clay, sand, and clay are distributed. Under the layer, up to the depth of 80 m, fine and / medium sand layers are distributed.

As a result of this survey, in the similar way as Khvein site, it was revealed that geological formations of core samples can be deemed to be continuous ones and there are no equivalent formations of Tertiary.

(3) Core Sample of Angkor Ruins

JSA carried out core boring survey of 100 m and 87 m deep in the yard of Angkor Wat (Sample No. AV-1B) and Bayon (Sample No. BY-1B) on March 1995 for ground investigation in Angkor ruins. Those core samples were stored in JSA office in Siem Reap City and observation survey for the core samples by this study was conducted to confirm underground geological structure in Siem Reap area on January 2011.

The core samples have been fairly consolidated by drying with passage of time of about 16 years since core borings were conducted. Further, there were many parts of no core samples by the reason why sand layer could not be sampled.

Observation results of core samples were as follows, (1) Basement rocks were observed in the depth of 74.20 m in Angkor Wat site, and in the depth of 83.50 m in Bayon site. (2) JSA Annual Report on the Technical Survey of Angkor Monument 1996 (July 1996) reported the change of formation facies between the upper layers and the lower layers in the depth around 40 m. However, in observation results by this survey with passage of time of about 16 years after core sampling, the change of formation facies could not be identified. In addition, in these core samples, in the similar way to Khvein and Kravan sites, equivalent formations of Tertiary could not be observed.

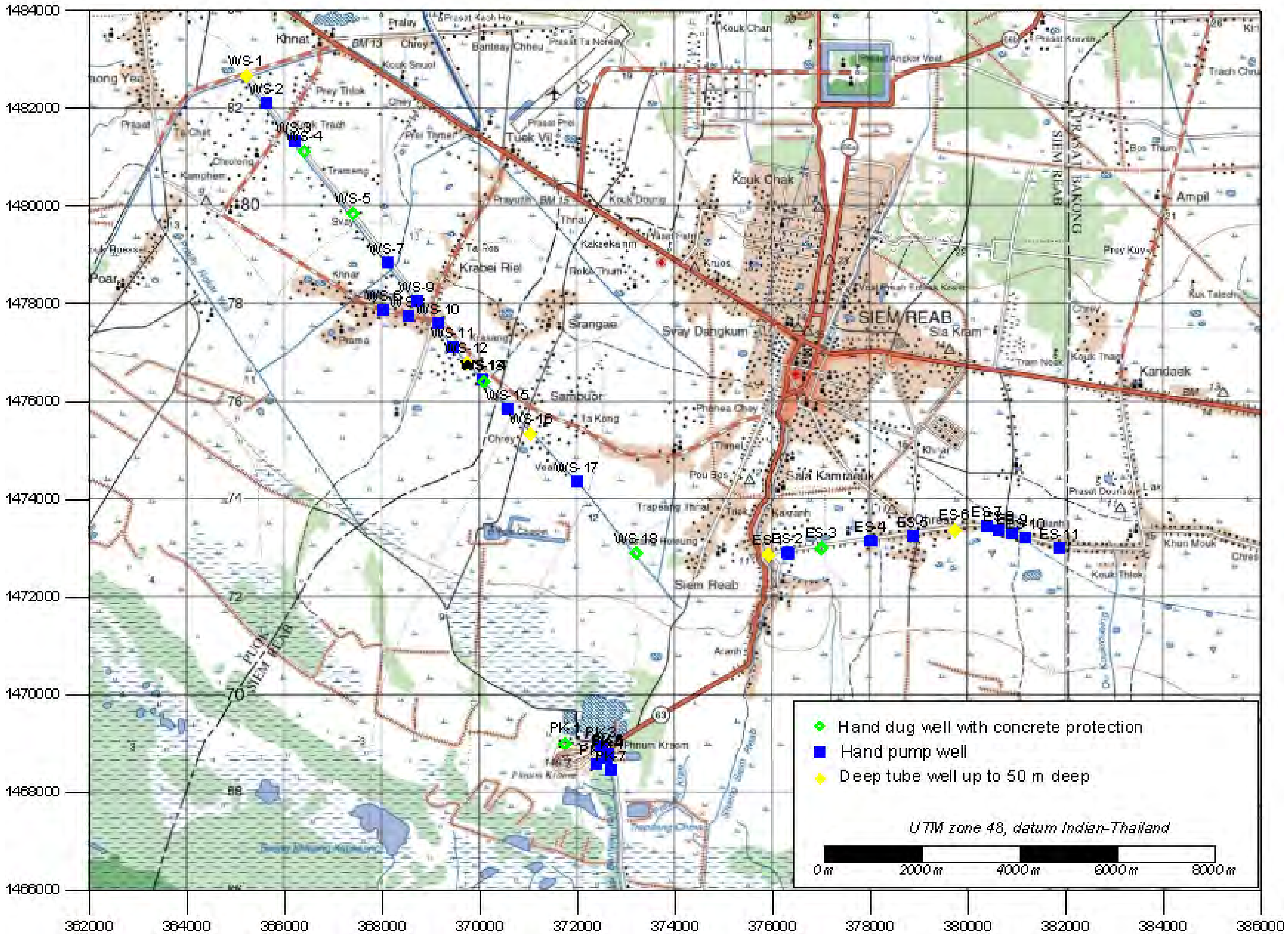

Figure 2.6 Location of Wells for Field Water Quality Tests

Chapter 3.
Current Status of Groundwater Use

Chapter 3. Current Status of Groundwater Use

3-1 Present Status of Groundwater Monitoring

(1) Monitoring Activities of SRWSA

In the Study Area, 10 monitoring wells were constructed under the Study on Water Supply System for Siem Reap Region in Cambodia (2000). SRWSA has collected the monitoring data every month. Manual measurement of groundwater level has been conducted once a month to confirm the reliability of monitoring systems since July 2007.

However, Activities done by SRWSA so far is not necessarily enough in reference to recommendations made in the Basic Design Study (report) on the Project for Improvement of Water Supply System on Siem Reap Town (2003). Recommendation conducted by the above Report and actual situations of SRWSA activities are shown in Table 3.1. In addition, existing monitoring wells, reliability of monitoring data, and necessity of calibration are shown in Table 3.2. SRWSA should take proper measures to improve this situation as described in “chapter 6, conclusion and recommendation”.

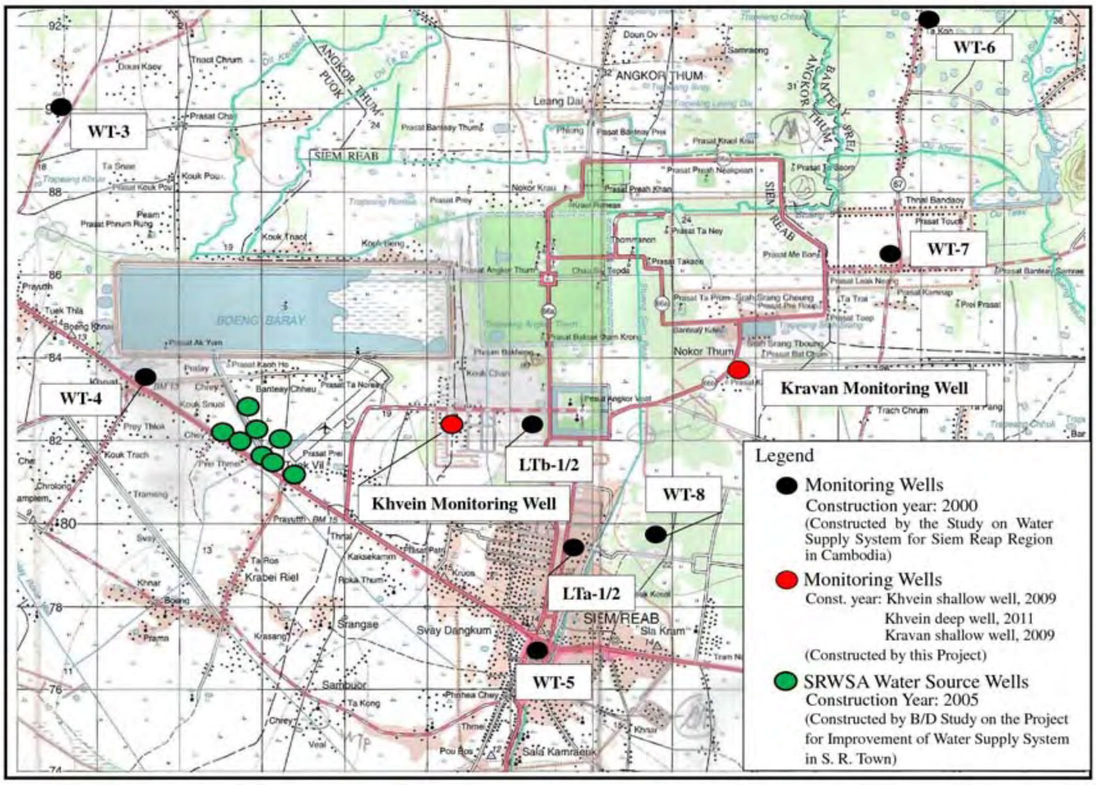

Figure 3.1 Location Map of New and Existing Monitoring Wells

Table 3.1 Monitoring Activities Done by SRWSA

No.	Recommendations made by 2003 B/D report*	Activities conducted by SRWSA
1.	Proper O&M for the supplied monitoring facilities	Some damaged equipment are being left at the sites without repair, resulting in missing data.
2.	Making good use of the monitoring data	Data collection has been done; however, analysis on the collected data was not made.
3	Taking proper countermeasures when abnormal monitoring data. are found.	Manual measurement of groundwater level has been done since July 2007. However, detailed analysis on the collected data has not been conducted by comparison between manual and automatic monitoring data.
4	Disclosure of collected information	Due to difficulties of confirmation of data reliability, SRWSA has not disclosed the data till now.

(Note) 2003 B/D report*: Basic Design Study (report) on the Project for Improvement of Water Supply System in Siem Reap Town in the Kingdom of Cambodia

Table 3.2 Existing Monitoring Wells, Reliability of Monitoring Data, and Necessity of Calibration

No.	Well No.	Well Depth (m)	Available Monitoring Data Period	Current Operating Condition and Reliability of Monitoring Data	Necessity of Calibration of Monitoring Equipment
1	WT-3	36	2003/8-2008/4	• Removal of monitoring equipment excluding solar panel and lightning rod (2008/8/21) <u>Removal Reason</u> As WT-6 and LTa monitoring sites were more important than WT-3 site due to locations near the city center and/or many important ruins with no monitoring function, SRWSA transferred WT-3 equipment to them. • Transfer of WT-3 cable sensor to WT-6 site. • Transfer of WT-3 data logger to LTa site Reliability of monitoring data before removal of the equipment have good reliability..	After May 2005, There is no monitoring equipment.
2	WT-4	29	2007/3-Present	Operational monitoring equipment • Monitoring data (2007/3-2008/3) have good reliability. . • Monitoring data after the date of 2008/3 show low reliability.	Necessity of calibration
3	WT-5	58	2007/3-Present	Operational monitoring equipment. Monitoring data have good reliability.	Not necessity of calibration
4	WT-6	29	2008/7- Present	Operational monitoring equipment. Monitoring data show low reliability.	Necessity of calibration
5	WT-7	60	2003/8- Present	Operational monitoring equipment Monitoring data have good reliability.	Not necessity of calibration
6	WT-8	83	2008/4-2010/9	• Operational monitoring equipment. • ASPARA museum building is under const-ruction. Monitoring facility is planned to be left in underground. Under the construction, the inside of monitoring facility was buried and submerged. Monitoring data show low reliability.	Necessity of calibration.
7	LTa-1	72	2008/8- Present	Operational monitoring equipment • Reliability of monitoring data is low. • At the transfer time of WT-3 data logger, equipment's connection error between	Necessity of calibration.

				shallow and deep wells was happened. Thus, monitored data of both wells inverted.	
	LTa-2	35	2008/8- Present	Operational monitoring equipment.	Necessity of calibration.
				• Reliability of monitoring data is low. • At the transfer time of WT-3 data logger, equipment's connection error between shallow and deep wells was happened. Thus, monitored data of both wells inverted.	
8	LTb-1	73	2003/9- Present	Operational monitoring equipment.	Not necessity of calibration
				Monitoring data have good reliability.	
	LTb-2	40	2003/9- Present	Operational monitoring equipment.	Not necessity of calibration
				Monitoring data have good reliability.	

(Note) Present condition of the above table is as of September 2009. On Khvein and Kravan monitoring wells, they were constructed after September 2009. As they kept accuracy of observation, their descriptions in the above table were omitted.

(2) Monitoring Activity by DOWRAM (Department of Water Resources and Meteorology)

The government of Cambodia enacted the "Water Resources Management Law" in June 2007 and the monitoring works for water resources were transferred from MIME to MOWRAM. At present, MOWRAM does not still carry out monitoring works on groundwater.

3-2 Construction of New Monitoring Wells

Under this study, a monitoring well (shallow well) was constructed in the premise of Kravan primary school on October 2009 and two monitoring wells (shallow and deep wells) were constructed in Khvein primary school on October 2009 and May 2011, respectively.

Table 3.3 Outline of Newly Constructed Monitoring Wells

No.	Well No.	Well Depth (m)	Casing Diameter and Materialas	Well Location	Construction Year
1	Khvein Well-1	40	UPVC 6"	Khvein Primary School	October 2009
2	Khvein Well-2	80	UPVC 6"		June 2011
3	Kravan Well	40	UPVC 6"	Kravan Primary School	October 2009

Number of newly constructed shallow and deep monitoring wells in Khvein and Kravan sites depends on hydrogeological conditions based on results of core sample survey with depth of 80 m in each site. In Khvein site, clay layers in depth of 50 m to 63.5 m are distributed. In the upper and lower parts of the clay layers, sand layers are distributed. The clay layers divide underground formations into 2 aquifers of shallow and deep ones. Thus, shallow and deep monitoring wells in Khvein site were constructed. On the other hand, in Kravan site, sand formations except ground surface are distributed up to the depth of 80 m and it forms one aquifer. Thus, only shallow monitoring well was constructed.

3-3 Private Wells

3-3-1 Distribution of Private Wells

Based on results of the well inventory survey conducted by this study, a total number of the private wells with a capacity of over 10m^3/day are 128 in the surveyed area. Hotels and factories share a largest rate over 70 % of the total number of private wells.

Numbers of the private wells with a pumping capacity of more than 10 m^3/day were identified by using GPS survey data. The locations are illustrated in 1 km x 1 km grids as shown in Figure 3.2. Figure 3.3 shows a total extracting volume by the private wells with a capacity of over 10m^3/day. Private wells with a capacity of over 10m^3/day are mostly distributed in the city center. The highest extraction of groundwater sources is located in the city center and along with the national road number 6.

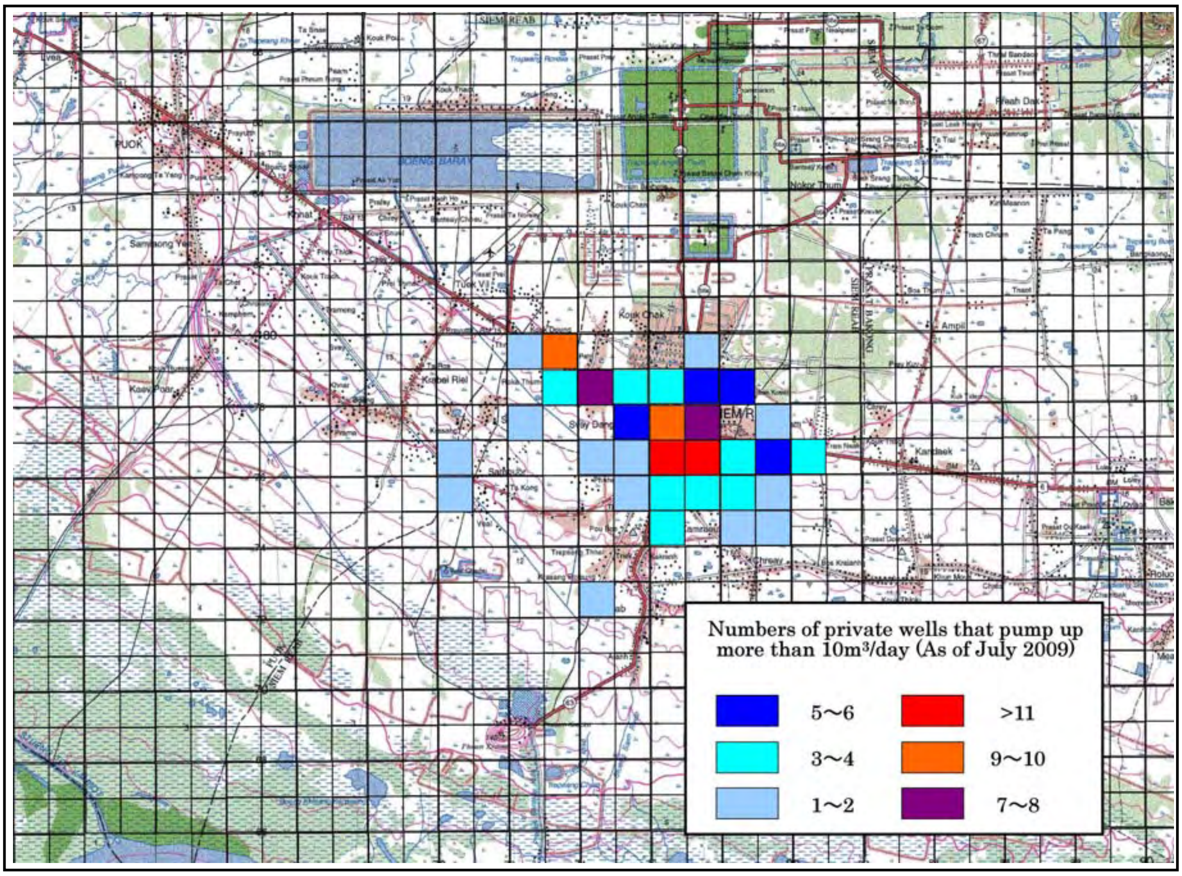

Figure 3.2 Distribution of Private Wells with Pumping Capacity of Over 10 m^3/day

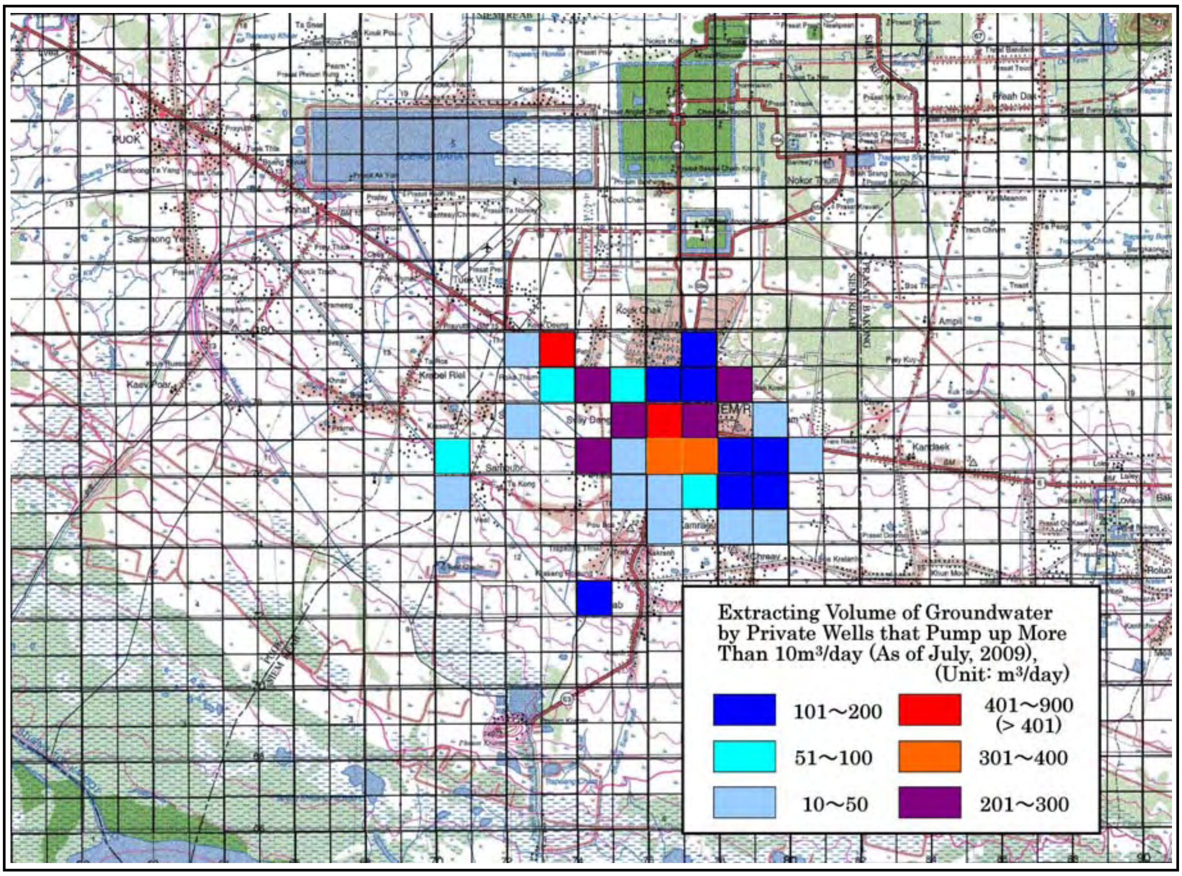

Figure 3.3 Distribution of Extraction Volume by Private Wells with Pumping Capacity of Over 10 m^3/day

3-3-2 Analysis on Tapped Aquifers and Withdrawal Volume

Based on information gathered in the well inventory survey, tapped aquifer and withdrawal volume of groundwater by the private wells were studied.

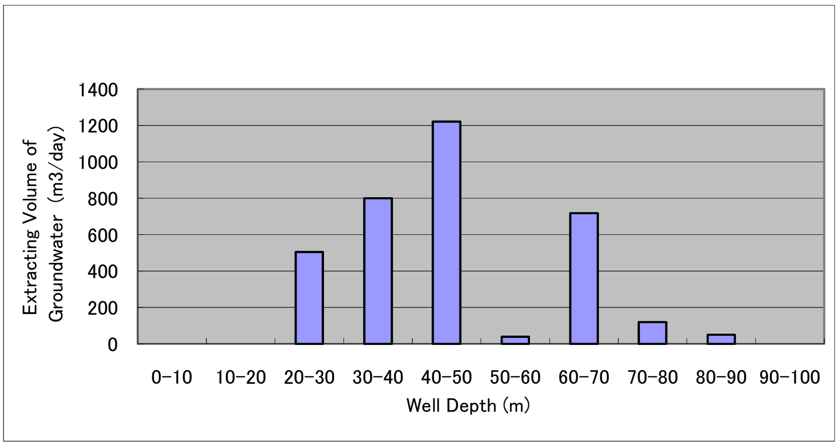

Figure 3.4 Well Depth and Extracted Volume of Groundwater by Private Wells

Figure 3.4 shows the relationship between well depth and extracted volume of groundwater of the private wells. Groundwater is mainly extracted in the depth of 20 to 50 m and 60 to 70 m.

The private wells mostly located in the city center. Thus, WT-5 monitoring well located in the city center was used for this analysis. The tapped aquifer of WT-5 was identified in the Study on Water Supply System for Siem Reap Region in Cambodia (2000) as illustrated in Figure 3.5.

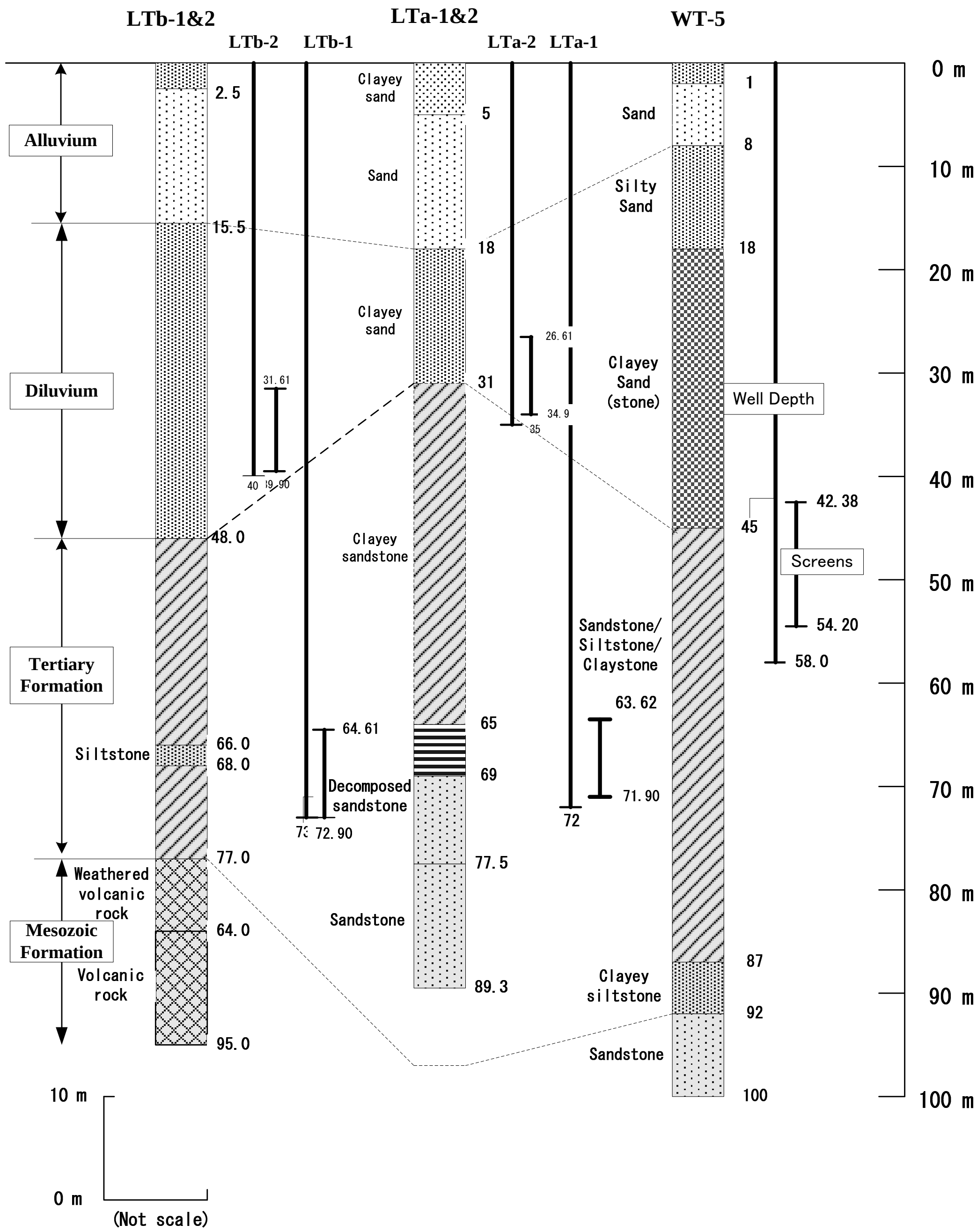

Figure 3.5 Well Structures and Geological Conditions of WT-5, LTa, and LTb

According to the Study on Water Supply System for Siem Reap Region in Cambodia (2000), Alluvium is distributed within the depth of 10 to 20 m. Diluvium is located within the depth of 10 to 40 m. Both layers are underlain by Tertiary layers with thickness of 40 to 50 m. Under Tertiary layers, Mesozoic volcanic rocks and sandstone are distributed.

Compared with the geological condition shown in Figure 3.5 and tapped aquifers of the private wells shown in Figure 3.4, the private wells are estimated to extract groundwater from the Diluvium and partially from a part of Tertiary formations.

3-3-3 Analysis on Influence of Pumping by Private Wells

Influence of pumping by the private wells was studied using data of WT-5 and LTb monitoring wells. WT-5 monitoring well is located in the yard of SRWSA office. The old treatment plant in the yard used three wells with a depth of about 60 m as water supply source until November to December, 2005. Thus, the monitoring data of WT-5 recorded before November to December 2005 indicated a large daily fluctuation pattern with lowering of water level of 140 to 157 cm as shown in Figure 3.6.

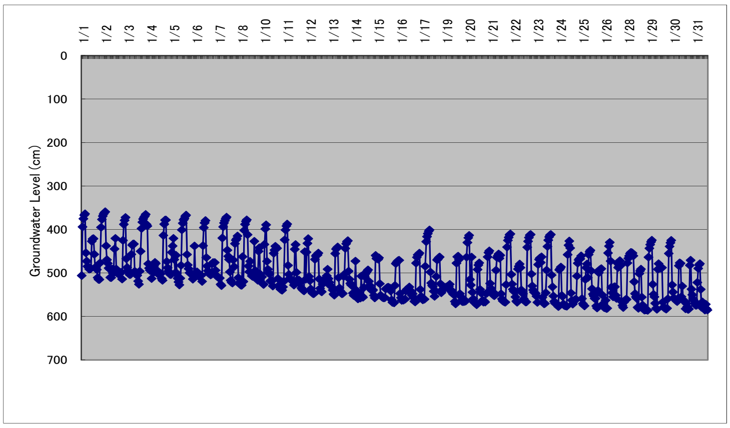

Figure 3.6 Groundwater Level at WT-5, January 2004

After the water treatment plant was abandoned, the monitoring data recorded from 7 to 9 January 2008 indicated small daily fluctuation pattern ranging from approximately 1 to 6 cm in the morning and in the evening. This range of water level fluctuation is considered to be influenced by exploitation of groundwater in the city. The example of daily fluctuation at WT-5 monitoring well from 7 to 9 January 2008 is shown in Figure 3.7.

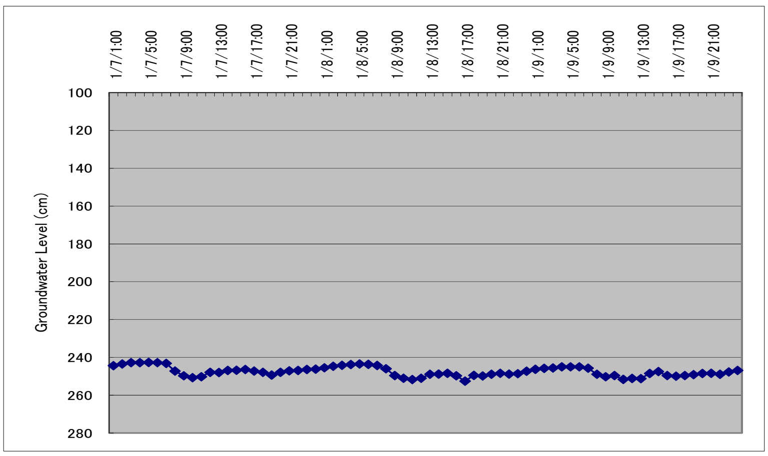

Figure 3.7 Groundwater Level at WT-5, 7-9 January, 2008

On the same day, LTb-2 shallow monitoring well recorded fluctuations from 15 to 17 cm in water level which was larger than that of WT-5. The WT-5 screen was set at the Tertiary aquifer. The LTb-2 screens were set in the Diluvium layers so that the lowering of groundwater level at LTb-2 can be larger than that of WT-5. Extracting volume of groundwater from Diluvium layers by the private wells is approximately 4 times of Tertiary layers. Daily groundwater fluctuation pattern at LTb-2 is shown in Figure 3.8.

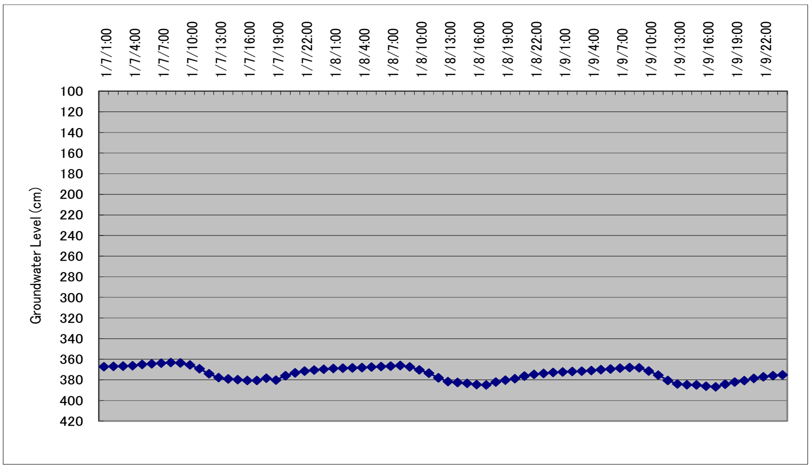

Figure 3.8 Recorded Daily Fluctuation of Groundwater Level at LTb-2, January 7-9, 2008

Monitoring data at LTb-1 deep well didn't indicate clear daily fluctuation pattern. Thus, the fluctuated monitoring data of WT-5 well, located in the city center, showing the lowering of groundwater level from 3 to 5 cm, can be translated to be influence of pumping of groundwater by the private wells in Tertiary formation. The pumping by private wells did not influence to the LTb-1 monitoring site where is located about 5 km from WT-5 monitoring well. Monitoring data of LTb-1 deep well on 7-9 January 2008 is shown in Figure 3.9.

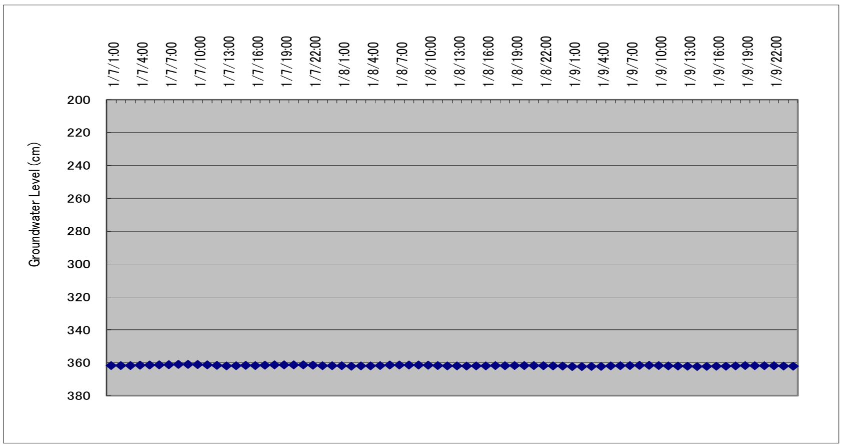

Figure 3.9 Recorded Groundwater Level at LTb-1 Deep Well, 7-9 January, 2008

3-4 SRWSA Production Wells

3-4-1 Well Structures and Intake Aquifers

Intake layers (aquifers) of the SRWSA production wells are reviewed by geological logs and well structures. SRWSA wells have the well depth of 60 m and its casing diameter is 250 mm. The well screens are set in the depth of 14 m to 45 m.

The columnar sections are classified by Alluvium, Diluvium, and Tertiary formation. Examination of the relationship between the geology and the setting depth of screens indicates that the wells intakes groundwater from aquifers distributed in the lower part of Alluvium and main portions of Diluvium. The relationship between geology and screen portions is shown in Figure 3.10.

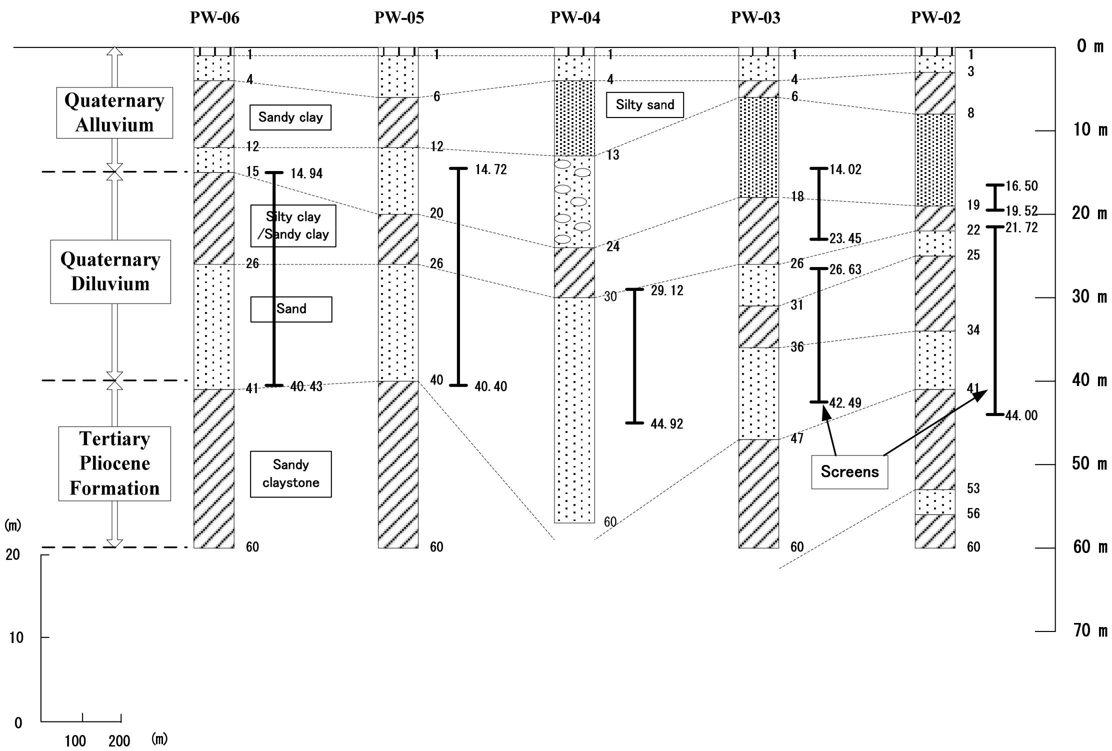

Figure 3.10 Intake Aquifers of SRWSA Production Wells

3-4-2 Operation of SRWSA Production Wells

The SRWSA production wells started pumping up in November 2005. In December 2007 the production capacity reached at 8,000 m^3/day and exceeded 9,000 m^3/day in August 2009.

3-4-3 Analysis on Influence of Pumping by SRWSA Production Wells

WT-4 and Khvein monitoring shallow wells were used to study influence of pumping by the SRWSA production wells.

(1) Well Structures and Aquifers of WT-4

The screens of WT-4 monitoring well are installed at the lower portion of Alluvium and main portion of Diluvium. This means the screens of WT-4 monitoring well are located at the same tapped aquifers as the SRWSA production wells. Figure 3.11 shows the geological conditions and the setting depth of screens of WT-4 monitoring well.

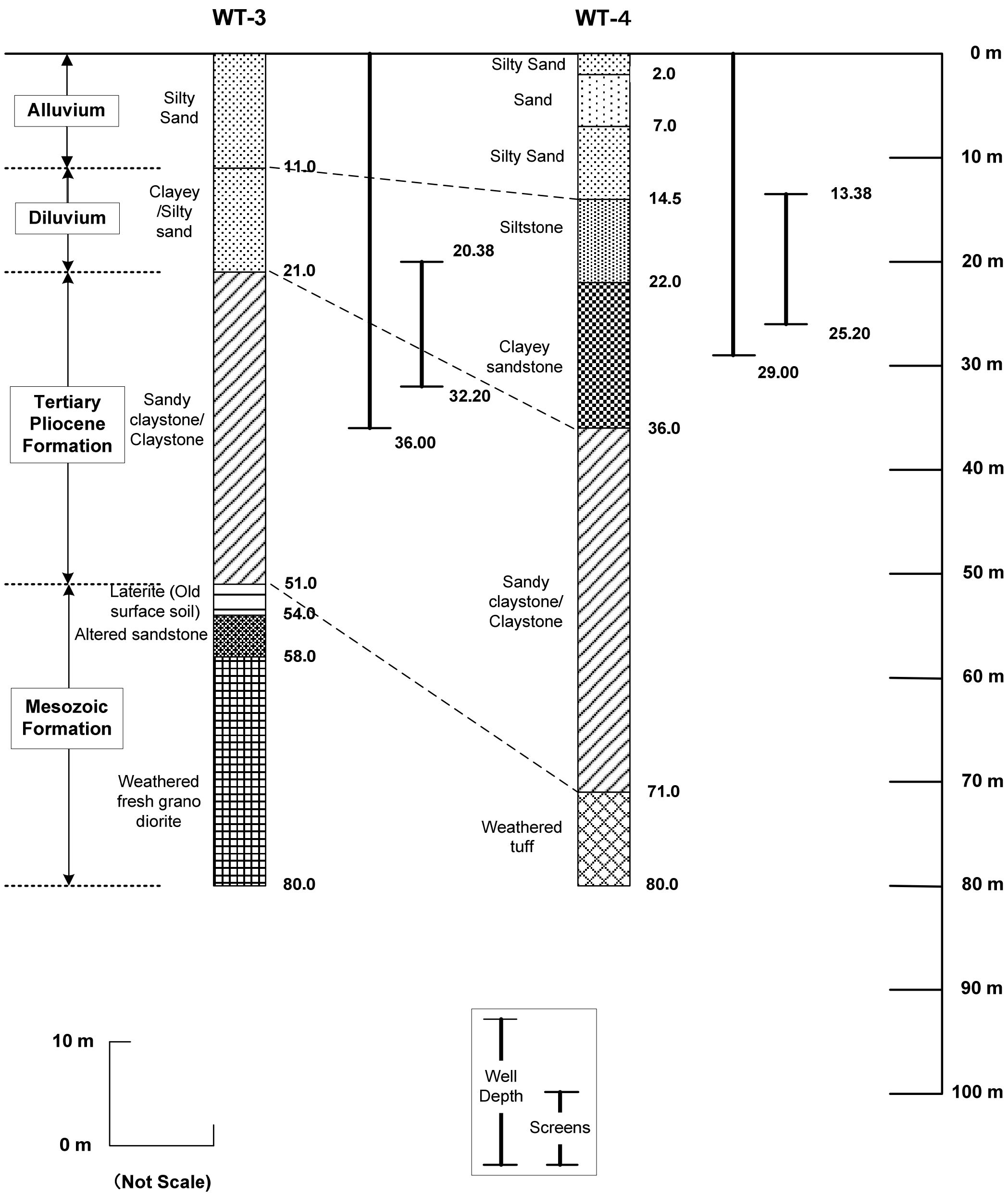

Figure 3.11 Geological Conditions and Depth of Screens of WT-4

(2) Analysis of WT-4 Data

This analysis was conducted by comparing those data when the SRWSA production wells were stopped withdrawal of groundwater source and the monitored groundwater levels at WT-4.

For analysis of WT-4 well, only monitoring data from March 2007 through February 2008 were indentified to be reliable by comparing the manual measurement data and the automatic recorded data. The monitoring data during this period were used for this analysis.

According to the Study on Water Supply System for Siem Reap Region in Cambodia (2000), yearly groundwater level fluctuation pattern was influenced by the seasonal precipitation. Only the data recorded during the dry season were selected to minimize influence of rainfall in this study.

Further, in order to minimize influence of pumping of neighboring private wells, this analysis was conducted using the mid-night data that pumping of the private wells were not in operation.

Monitoring data of two days on 8 and 9 January 2008 was then used as full pumping day on 9 January and halting day of pumping up of groundwater for about 4 hours on 8 January. Operating condition of SRWSA production wells on 8 and 9 January 2008 is shown in the below table and daily pattern of monitoring data in Figure 3.12 and Figure 3.13.

Operating Conditions of SRWSA production wells are as follows:

Day	Operating/Non- operating hours	Pumping rate
8 Jan. 2008	Full operating (0:00, 7:00-23:00) Halting of pumping up (2:00 – 5:00) Decrease of pumping rate (1:00, 6:00)	369 – 373 m^3/hour (Total: 7,062 m^3/day)
9 Jan. 2008	24 hours: Full operating	369 – 372 m^3/hour (Total: 8,901 m^3/day)

(Note): Full operating means operation of all production wells and halting means the halting of all production wells.

As shown in the following figure, fluctuation of groundwater level for two days has the lowering in the morning (5:00-10:00) and in the evening (17:00-19:00) with magnitude of 5 to 8 cm. The fluctuation of groundwater level is considered to occur by neighboring private wells.

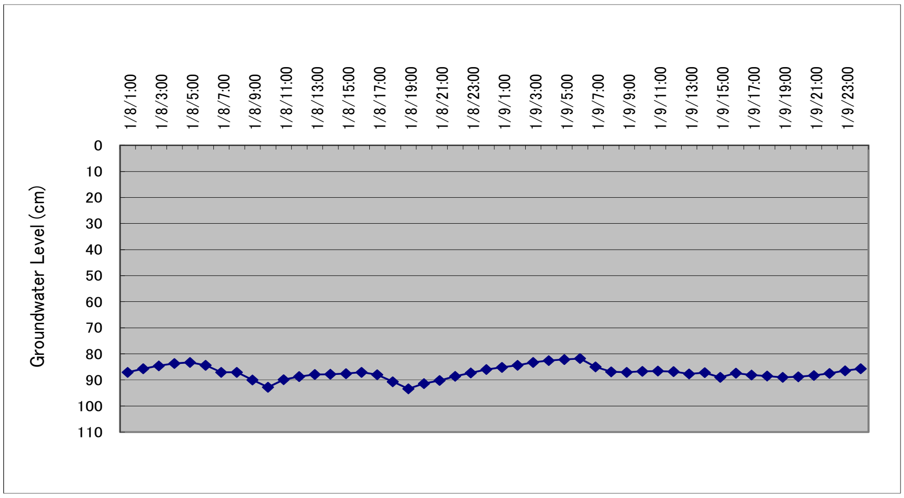

Figure 3.12 Daily Fluctuation of Groundwater Level of WT-4 on 8 and 9 January, 2008

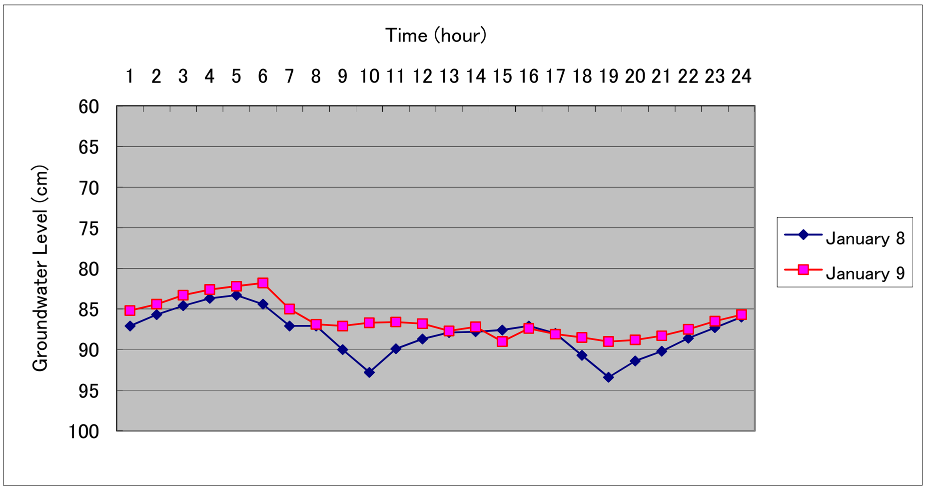

Figure 3.13 Comparison of Daily Fluctuation on 8 and 9 January 2008 of WT-4

Figure 3.13 shows comparison of daily fluctuation of groundwater level within 24 hours on two days on 8 and 9 January 2008. Their daily fluctuation patterns indicates that :

- Data on 8 Jan. 2008 shows that SRWSA stopped pumping up from 1:00. After 2:00 up to 5:00, the pumping was fully stopped. Then, from 5:00, pumping up was stated up again. However, fluctuation tendency of groundwater level showed the same as that of 9 January when SRWSA operated the pumps for 24 hours. This phenomena indicates that SRWSA wells does not give impact to WT-4. Because, if the SRWSA wells give some impact to the WT-4, the water level at that time between 2:00 to 5:00 on 9 January, should be lower than that of 8 January.
- Thus, interference radius of pumping of the SRWSA production wells is considered not to have a negative influence on monitored groundwater level of WT-4.
- The same tendency was confirmed on the monitored data on 14 to 16 December 2007.
- As a result, in WT-4 monitoring well located about 2.6 km away from the SRWSA production wells, the influence of pumping of SRWSA wells were not identified.

(3) Analysis of Khvein Shallow Well Data

Pumps of the SRWSA production wells was temporarily halted about two hours in the midnight on 7 and 9 May 2010. Based on the data recorded during the halting of the SRWSA wells, the influence against monitored water level at Khvein shallow well were analyzed.

Operating Conditions of SRWSA production wells are summarized below:

Day	Operating/Non- operating hours	Pumping rate
7 May 2010	Full operating (0:00, 5:00-23:00) Halting of pumping up (2:00 – 3:00) Decrease of pumping rate (1:00, 4:00)	387 - 389 m^3/hour (Total: 8,154 m^3/day)
8 May 2010	24 hours: Full operating	384 - 389 m^3/hour (Total: 9,306 m^3/day)
9 May 2010	Full operating (0:00, 5:00-23:00) Halting of pumping up (2:00 – 3:00) Decrease of pumping rate (1:00, 4:00)	386 - 389 m^3/hour (Total: 8,106 m^3/day)
10 May 2010	24 hours: Full operating	386 – 389 m^3/hour (Total: 9,285 m^3/day)

(Note): Full operating means operation of all production wells and halting means the halting of all production wells.

The fluctuation patterns of groundwater levels due to 24 hours full operation on 8 and 10 May 2010 and halting conditions of pumping of the SRWSA production wells for two hours on 7 and 9 May 2010 were compared as shown in Figure 3.14.

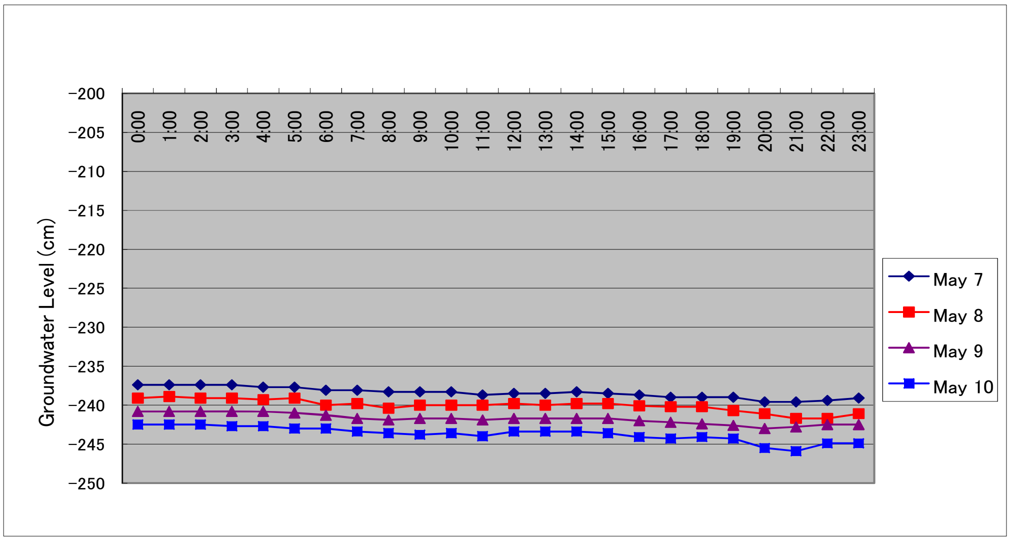

Figure 3.14 Comparison of Daily Fluctuation of Khvein Shallow Well, 7 to 10 May, 2010

Figure 3-14 indicates that:

- For this period, the recorded groundwater level generally lowers every day by 1.7 cm. It was in dry season. Though all of the SRWSA production wells were halted for two hours from 2:00 to 3:00 on 7 and 9 May 2010, groundwater level did not go up. All of the groundwater levels for these four days have shown the similar fluctuation patterns.
- If the SRWSA production wells gave some influence to the Khvein monitoring shallow well, the data recorded from 2:00 to 3:00 on 8 and 10 May 2010 should be lowered compared to those of the data recorded from 2:00 to 3:00 on 7 and 9 May 2010. The actual data shows that water levels recorded were not significantly different. Thus, it is

considered that the SRWSA production wells didn't influence to the Khvein monitoring shallow well.