CHAPTER 3 SURVEYS AND INVESTIGATIONS

3.1 Topographic Survey

3.1.1 Geography and Topography in the Vicinity of the Study Area

Siem Reap Town is located about 20 km north of Lake Tonle Sap in the terrace of the lake having its elevation from 10 to 15 m. In the northern area of Angkor heritages, Kulen Mountain ranges (Max. elevation 487 m) run continuously in the east-west direction. These are flat-topped mountains.

The topographic characteristics of the Study area are as follows.

1) The Study area is some 40 km wide both in east-west and north-south direction. The elevation of this gentle fan plain is lowered to the southward in the direction of the lake. The elevation of the plain is 25-30 m at the north end of the study area, and 1 m along the lake shore line. The gradient is less than 1/1,000.
2) The plain consists of the fan deposits of the Siem Reap River and the Roluos River. These rivers flow from north to south or northeast to southwest. Therefore, the fan plain starts at north or northeast and the contour follows north to south or northeast to southwest with slight bending towards southward.
3) The Study area is located near the downstream end of the river course. Coarse sand is dominant in the north area of gently undulating hill and fine sand to silt is dominant in the south area of marshland.
4) Several isolated peaks are located on the plain, the peaks are Phnom Cok (EL: 200 m) about 2 km east of Banteay Srei heritage, Phnom Bok (EL:212 m) near Roluos River, Phnom Baken (EL:90 m) near Angkor Wat heritage, Phnom Krom (EL:140 m) near the lake. At the west of the study area near West Baray, very low hills of basement rock and/or Pleistocene sediments are outcropped at the undulating hill.
5) By the ancient construction, many artificial topographic changes were made such as Baray dike, moats, canals and reclamation at Angkor Wat and Angkor Thom area. It is archeologically clarified that the former Siem Reap River course is located at the area between the airport and the old outlet of West Baray. The present course of the river was, therefore, artificially formed in the vicinity of the heritage area.
6) At Prasat Keo, the present Siem Reap Riverbed is 6 to 7 m lower from the old intake floor. The lowering of the riverbed can be concluded by the reasons of the artificial short cut of the river course and thus forming the high gradient of the riverbed at present.

Siem Reap River

The Siem Reap River drains a catchment area of 670 km^2. The river originates about 50 km north-northeast of the Siem Reap Town at the Kulen Mountain at EL. 420 m. The main stream that collects the runoff from the southeast block of the Kulen Mountain flow first to a northeast direction for about 15 km, then, it reaches a gorge from where it changes the flow direction to southeast. According to the brief site reconnaissance to the upstream of the river in December 1998, the mountain in the upstream area is mostly covered with secondary forest of less than 30 years old. The original big trees were cut during the Pol Pot regime. Local people are also clearing some areas for upland cultivation. The productions of charcoal and wood for cooking and housing are the most important industry in this area. There exist many unconfirmed heritages in this area in addition to Kbal Spian heritage. It is strongly suggested that without thorough investigation, no dam site selection should be done.

The river discharges through this gorge to the plains at EL. 50 m where ancient rock quarry sites for the construction of the heritages are located. The river continues to flow to southeast direction towards the ancient diversion structure constructed 950 years ago at Phnum Khat. The tributaries are the O'Rassef streams at Phnom Kbal Sean and Stoeng Stoch streams at Phum Khlat. The original ancient bed of the main stream continues in a southwest direction, and is known presently as the O'Phaat and O'Tassiv streams. Running along the northern side of the West Baray to the northwest corner, these tributaries turn their direction southwest in a hardly recognizable bed and become lost in the marshland of the lake. The investigation by electric sounding and additional electromagnetic sounding was carried out to find the original river course in and around the south area of the West Baray. The result indicates that the original course might be in the area between airport and the present outlet for irrigation of the West Baray. The detail is described in the Section 3.3.

One staff gauge was installed by a NGO (SEILA) at O'Tassif stream near the northwest corner of the West Baray in 1998 for the purpose of restoration of old bridges which were heavily damaged by the flood in 1997. The ancient arch shaped bridge made by stone is found in this area. It is said that an ancient causeway had connected Angkor heritage to Thailand. The floor of the bridge is about 3 m higher than the present riverbed. It means that the riverbed was lowered about 3 m during the period of about 1,000 years, though the main stream of the Siem Reap was not running in this course.

The present Siem Reap River course is diverted at Phum Khat and arrives at the Angkor area near the northwest corner of the East Baray and the northeast corner of Angkor Thom. The river flows through the Siem Reap Town first in south direction, and then mildly southeastward direction. The river eventually discharges into the lake at around 5-6 km downstream of Phnom Krom. The total length of the river is about 90 km with an average gradient of 1/190. Gradient of the riverbed in the plain just after Kulen Mountain is roughly 1/1,400. The gradient in the study area is 1/2,000 in average.

West Baray

The baray is located at 3 km west of Bayon Temple, Angkor Thom, and 10 km northwest of Siem Reap Town. The baray was constructed by Suryavarman-I in the second quarter of the 11th century for the purpose of irrigation, drinking, bathing and water feeding for cattle. The size is 2 km in north-south direction, and 8 km in east-west direction. Average water depth is 3 m. The western part of the baray is deep and the eastern part is shallow. After restoration of the baray by American aid in 1959, it is well operating to contribute flood mitigation for Siem Reap Town, irrigation and recreation.

Lake Tonle Sap

The lake, the biggest lake in Southeast Asia, has an area of 2,000 to 3,000 km^2 in the dry season and 10,000 km^2 in the rainy season. The lowest elevation of the lake is only 1 m though it is located about 300 km upstream from the Mekong River mouth into the South China Sea. During the rainy season, the level of the Mekong River and the Bassac River rises above that of the Tonle Sap River. The river overflows backwards into the lake. The maximum water level of the lake is 10 to 12 m from September to October. The water forest with about 30 km band is submerged in the rainy season. Fish spawn there in the rainy season.

3.1.2 Topographic Survey for the Study

From March to April 1997, the following topographic survey was carried out by the JICA Study Team for the Study:

List of Topographic Survey Work (March-April 1997)

Location	Type of Survey	Quantity	Survey Purpose
Siem Reap River	Longitudinal and Cross section survey	27 km long in total 31 cross sections	To determine the river gradient and river width for the interpretation of the hydrologic study.
West Baray	Cross section survey	9 cross sections(x-x') 2 cross sections(y-y')	To check the storage capacity in the reservoir.
Takav Channel	Longitudinal and Cross section survey	7 km long in total 10 cross sections	To find the intake level, canal capacity to divert the Siem Reap water to the Baray.
Level Survey for the selected hydrological measuring points or important structures	Level survey	13 spots including the cross section survey points of 7 locations	To find the elevation at the important gauging stations, hydrological point and existing structures such as bridges and intakes.
Inventory survey of some 100 nos of existing well	Level survey	83 spots from the nearby existing bench mark	To find the elevation of the existing wells for the observation of groundwater fluctuation.
New 8 drilling points	Level survey	8 spots from the nearby existing bench mark	To obtain the elevation for the drilling spots.
Lake Tonle Sap	Level survey	1 spot from the existing bench mark	To confirm the elevation of staff gauging station.
Entire Study Area	Aerial Photograph Interpretation	1992 FINMAP and 1997 JICA	Understanding of present land use, geography and hydrology

The topographic survey was carried out with the support from the JICA Topographic Mapping Team from March 1997 to April 1997.

The survey result is summarized in the Supporting Report. The result was effectively used for the preparation of hydrological study, geological interpretation, and hydrogeological study.

Some of the major findings are as follows:

1) Elevation of the Lake Tonle Sap water level in May is the lowest water level in the year.
2) Elevation of the Siem Reap Town ranges from 10 to 18 m in most places.
3) Average gradient of the the Siem Reap River is 1/900 from the Kring Kroch bridge to UNTAC bridge for first 5.5 km section, 1/1,850 from the UNTAC bridge to the Crocodile Weir for 7.5 km section, and 1/2,550 from the Crocodile Weir to the Lake for 14 km section.
4) Average river width of the Siem Reap River is 15 m at the first 5.5 km long, 20 to 40 m in the town, and 20 to 30 m for the downstream near the lake.
5) The artificial moat and canal of total 7 km long from the French Weir to the West Baray has the width of 10 m in average. The head between the French Weir to the entrance of the reservoir is 1.5 m with the gradient of 1/4,700.

Additional topographic survey was conducted for the new water supply facilities planned, such as water works and water distribution system in the Feasibility Study (October – November, 1999).

The work done at that time include:

- Topographic mapping survey required for the newly proposed water supply system,
- Route survey along major pipeline, and
- Leveling survey.

This additional investigation for Feasibility Study is explained in Section 5.2.

3.2 Hydrological Investigation

3.2.1 Introduction

The hydrological investigation was carried out for the following three surface water sources for the purpose of water supply in the Study area:

1) Siem Reap River;
2) West Baray; and
3) Lake Tonle Sap.

The details can be found in Supporting Report. Major observations and results are provided in the following sections.

3.2.2 Hydrological Condition of Siem Reap River

(1) General Meteorology

The tropical climate, occurring over Cambodia is characterized by two seasonal monsoons: the southwest monsoon (the rainy season) and the northeast monsoon (the dry season). Annual rainfall varies between 1,100 mm - 1,800 mm, with an average of 1,418 mm (average in 20 years from 1979 to 1998). About 88% of annual rainfall (1,248 mm) falls during the rainy season from May to October. The peak rainfall occurs in September with 265 mm. On the contrary, only 12% of annual rainfall (170 mm) happens during the dry season from November to April. January and February are the driest months with 6.2 and 4.1 mm rainfall, respectively.

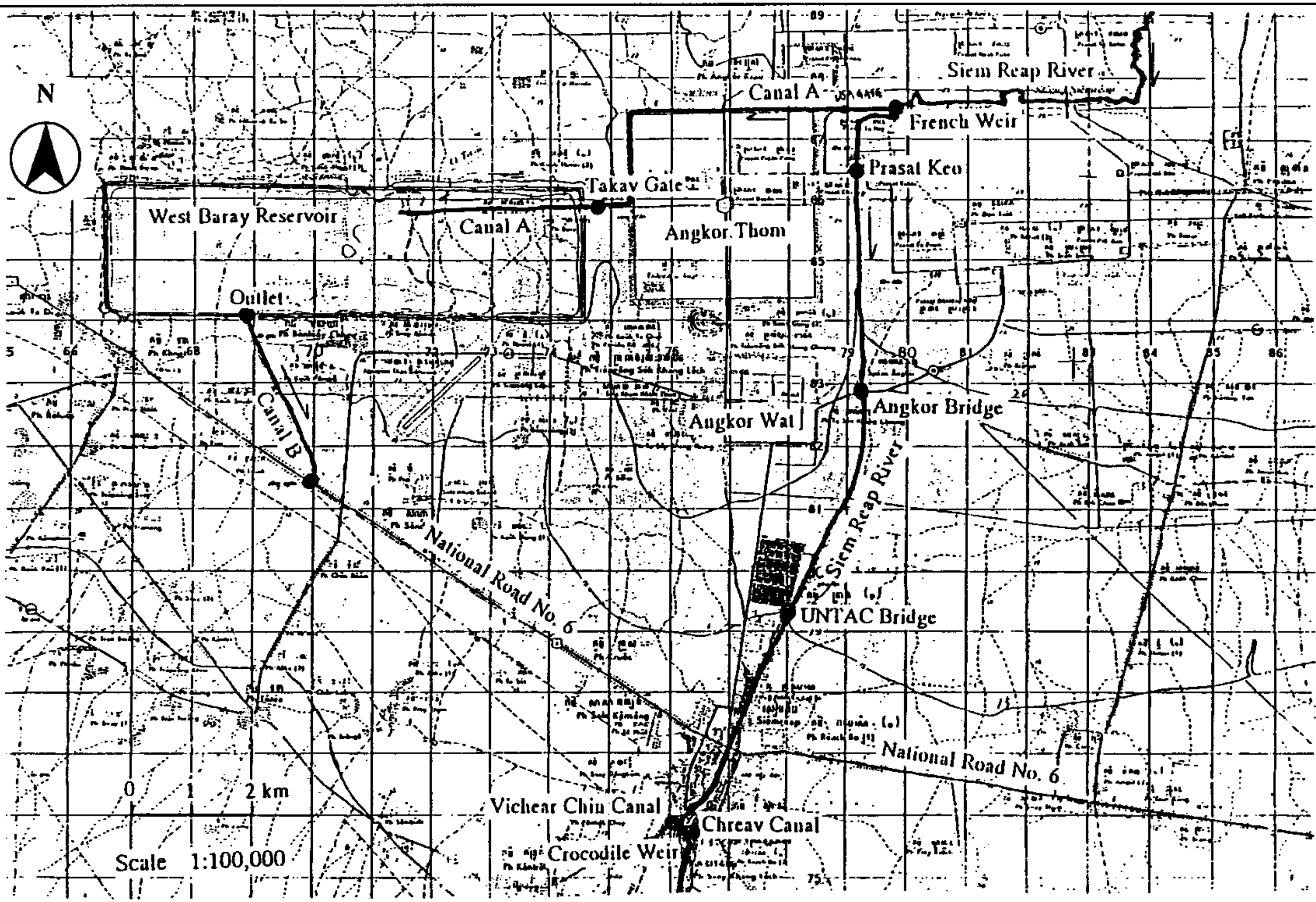
The climate in the Study area is modified by the local topography, dominated by the Lake Tonle Sap and the Kulen Mountains. Breezes reinforced over the lake are forced upwards due to the presence of Kulen Mountains and, on cooling, induce showers in the rainy season.

The mean daily temperature varies only slightly between a high of 29.9 ºC in April to a low of 24.5 ºC in December. Average relative humidity ranges from 70 % in March to 86 % in September. The annual pan evaporation is 1,542 mm.

(2) River Morphology

The Siem Reap River is the only permanent stream in Siem Reap Region (Figure 3.2.1). The present river course does not follow its original course. The French Weir constructed in 1937 is located in the northeastern part of the heritage area. An artificial canal (Canal A) constructed in 1939 diverts flow from just upstream of the weir and stores the rainy season flow in the West Baray. The river then flows through Siem Reap Town southward and it eventually discharges into the Lake Tonle Sap downstream of Phnom Krom.

The road to Banteay Srei running north-south in Pradak district forms the watershed boundary between the Siem Reap and Roluos Rivers. Field reconnaissance confirmed that there is no surface water flow from the Roluos Reservoir to the Siem Reap River.



The Study on Water Supply System for Siem Reap Region in Cambodia	Figure 3.2.1 Location of Hydrometry Points
Japan International Cooperation Agency	

(3) Hydrometry

At the beginning of the Study, no hydrological data on the river was available, neither in the Hydrology Office in Siem Reap nor in the Ministry of Agriculture, Forest and Fisheries (MOA) in Phnom Penh. Thus, the establishment of a hydrological observation network in the Study area was urgently required. Therefore, the Study Team has installed several stream gauges along the river and has conducted intensive hydrometry not only along the river but also on irrigation canals since 1997. The water level of the West Baray has also been measured frequently by the Study Team to supplement the data by the Hydrology Office in Siem Reap, MOA (Hydrology Office).

The rating curves are prepared at Prasat Keo and the Angkor bridge by using the hydrometry records of 1997 and 1998.

(4) Estimate of Daily Flow of Siem Reap River in 1998

The water levels and flows measured by the Study Team from January 1997 to January 1999 shows that flow patterns in 1997 and 1998 contrast sharply. The former shows a rainy year pattern with remarkably big floods from September to October, which caused severe inundation in the Siem Reap Town. On the other hand, the latter shows typical drought year pattern without any particular water level rises.

The peak discharge at the UNTAC bridge in September 30, 1997 is roughly estimated around 150 m^3/s. The flow gradually decreases from the end of the rainy season in November and reaches annual minimum value at the end of the dry season in April and May. The observed minimum flows at Prasat Keo in 1997 and 1998 are 0.80 m^3/s and 0.56 m^3/s, respectively. The observed minimum flow in 1998 at the French Weir and the Angkor bridge are found to be 0.65 m^3/s and 0.81 m^3/s, respectively.

It is essential to estimate the extended flow regime for 10 years of the river to analyze the availability of raw water. The estimation was done by utilizing and interpreting hydrographs at Prasat Keo, inflow hydrograph to the West Baray and rainfall pattern in this study.

(5) Irrigation System

1) Irrigation Area

Two major irrigation systems, namely the West Baray System and the Crocodile Weir System occupy the majority of the irrigated area in the Study area. The water intake amount for irrigation is unknown, since no regulation exists on water right for the Siem Reap River and the West Baray. Therefore, the flow rate on the irrigation canals has measured by the Study Team since 1997.

2) West Baray Irrigation System

The West Baray irrigation system, principal system in the Study area, is supplied water from the baray. In the rainy season, the baray water is fed by the inflow from the river and by direct rainfall. In the dry season, the water is supplied for irrigation from the baray outlet structure to Canal B and then distributed to several canals at the distribution structure located beside the National Road No. 6. The flow capacity of Canal B is 9 m^3/s. The average irrigated area is approximately 6,300 ha. According to the periodical flow measurements by the Study Team, the intake amount is approximately 2 m^3/s in average.

The sluice gate at the French Weir is closed generally in June in the rainy season to store the water of the river to the baray via the Canal A. The American and Takav Weir are opened at that time. The weirs are closed and then the sluice of the weir is opened to stop the inflow from the river after the water level of the baray reaches to the standard level at 25 m (approx. 19.6 m, MSL) around October to December.

The water supply from the baray is started generally from the end of November until May. The supply is once stopped to harvest rice in the beginning of February.

The main function of the American and Takav weirs is to stop and/or regulate the flood flow from the river in the rainy season. The water to the moat of Angkor Wat from the Canal A is supplying by close the Takav weir only at the time of Water Festival.

3) Crocodile Weir Irrigation System

The Crocodile weir irrigation system is supplied water from the river. Water is supplied through two irrigation canals, namely the Vichear Chin Canal on the right bank and the Chreav Canal on the left bank, by damming up the water level of the river by the Crocodile weir. These two canals have no intake gate.

The average irrigated area is approximately 2,400 ha. According to the periodical flow measurement conducted by the Study Team on the canals, the intake amount is approximately 1 m^3/s on average. However, it is practically impossible for the river to secure 1 m^3/s in the driest season judging from the flow pattern in 1998.

3.2.3 Hydrological Condition of West Baray

(1) Height, Area and Volume of Reservoir

A topographic survey in the West Baray was carried out by the Study Team in March 1997 to prepare bathometric contour map. The height, area and volume curve of the baray was prepared based on the contour. The effective capacity is estimated 48.6 million m^3 at present standard level of 25.0 m (approx. 19.6 m, MSL). The dead storage below the outlet gate is estimated only around 0.2 million m^3.

(2) Daily Water Level

The daily water level of the baray is one of the most important hydrological data in the Study area in order to investigate the water balance of the baray. The level has been measured daily by the Hydrology Office since October 1992. This data has been partly supplemented by the Study Team measurement since 1997.

The maximum water level in 1997 once reached up to 25.15 m (approx. 19.75 m, MSL) on September 30. The lowest level was observed in the end of irrigation season in May 1998, when the level was lowered to around 19.50 m (approx. 14.10 m, MSL).

(3) Preliminary Water Balance Review

The preliminary water balance review of the baray is conducted based on the rising and falling curves (hydrographs) of the water level of the baray since 1992. The storage by rainfall and loss by evaporation are also taken into account.

The supplied amount of water for irrigation is 32.0 million m^3 on average, which accounts for 66% of the total effective capacity. Around 6% of effective capacity is lost by evaporation during the dry (irrigation) season.

The remainder of irrigation use reaches 8.1 million m^3 on average, which equates to 22,100 m^3/day for 12 months. The uncharged capacity also reaches 5.4 million m^3 on average, which equals 14,800 m^3/day for 12 months. However, more water resources can be produced from the baray by introducing an effective integrated reservoir operation.

3.2.4 Hydrological Condition of Lake Tonle Sap

This is the largest lake in Southeast Asia. Thus, water quantity is not a limiting factor for possible water abstraction. Water level will be the crucial factor in such case. In the Study area, the daily water level of the lake has been measured continuously by Fisherman's Office in Siem Reap, MOA since May 1996. The probable maximum and minimum water level are analyzed as follows:

Probable Water Level of Lake Tonle Sap

Return Period	Maximum Water Level (m, MSL)	Minimum Water Level (m, MSL)
2-year	9.23	1.05
5-year	9.69	0.84
10-year	9.94	0.75
20-year	10.15	0.68

3.3 Geological and Geotechnical Investigation

3.3.1 Geophysical Prospecting

(1) Electric Sounding by Wenner Method

Electric sounding had been carried out at a total of 103 spots in the first field survey. The apparent resistivity curves are shown in the Data Book 2.

An electrical sounding method does not always reflect geological boundaries, especially for the overburden layers such as alluvial and diluvial layers, because their boundaries are in unconformity. The upper portions of the layers of Pliocene clay stone, Paleogene to Mesozoic rocks are deteriorated along unconformity boundary. It is inferred that the resistivity boundaries might appear below the exact unconformity boundaries. The interpretation for the geological profiles had been made by mutual check with the drilling logs. After careful interpretation by using the both data of drilling result and sounding, geological profiles are drawn as shown in the Supporting Report.

The resistivity value for each layer is as follows:

Resistivity of alluvial deposits ranges 50 - 3,000 ohm/m for the northeast area, and 50 - 1,000 ohm/m for the south area. This reflects the rich groundwater bearing in the south area. Resistivity by electric logging is correlative with the sounding results. Resistivity of diluvial deposits ranging 74 - 1,900 ohm/m for coarse sand is found in the north side, and 20 - 400 ohm/m for medium to fine sand is found in the southern side. Resistivity of Pliocene clay stone ranging 10 - 200 ohm/m by the electric sounding, and 5-20 ohm/m by the logging were also found in certain areas. In addition, basement rocks include shale, sandstone and silt stone, rhyolitic tuff, tuff breccia, granodiorite, and andesite dike have higher resitivity values than that of the upper layers.

(2) Result of VLF Electromagnetic Prospecting

VLF electromagnetic prospecting of a total of 123 spots was carried out in the vicinity of the south area along the envisaged former river course to clarify an expected large quantity of good quality groundwater with low iron content. The prospecting is an additional survey to obligatory scope for the Study Team.

The result is shown in Supporting Report ANNEX 3.4.1. Average resistivity value of alluvial and diluvial sand layer is 20 ohm/m. Resistivity value higher than 20 ohm/m indicates the existence of former river traces. The area having the resistivity value less than 10 ohm/m may be occupied by iron contaminated groundwater, and/or by unfavorable layer containing much clayey materials or finer particles than that of clean coarse sand of the former river deposits. The area stretching from the crossing between road No.6 and airport road until 2 km east of WT4 shows an indication of former river course. Therefore, a candidate well field is planned in this area. The result is shown in Figure 3.5.2.

3.3.2 Geology

(1) Geology of the Study Area

The Study area is composed of Alluvial fan deposits, Diluvial deposits, Pleistocene sediments, Pliocene clay stone, Mesozoic sedimentary rocks and Paleogene volcanic rocks in descending order.

Alluvial deposits consisting of coarse sand is found in the northern part of the study area, and fine sand to silt along the shore of the Lake Tonle Sap. Topsoil of cultivated upland, paddy field and the bottom of the barays is organic clay and silty clay. Total thickness of alluvial deposits is 20-30 m in the southern area, and 10-20 m in the northern area. Diluvial deposits underlie the alluvial deposits. The layer is composed of coarser particles than that of alluvial deposits in general. The thickness is 20 m in most part. These alluvial and diluvial deposits are judged to have a free surface of ground water.

It is conceivable that artificial reclamation was done in the area of Angkor Wat and Thom heritages from the flat topographical condition and chronological record. The three layers of reclamation soil are of fine particles with low permeability.

Before West Baray construction in the 12th century, it is believed that the former Siem Reap River courses was located on the western side of West Baray near the present river course of Ou Phaat River. The Siem Reap River was diverted at Phum Khlat, some 10 km north of East Baray by king Rajendra Valuman-I. Lateritic soil in the surface of alluvial layer and diluvial layer is missing along the former river course by the former erosion. It is suggested that the groundwater along the former river course has, therefore, very low content of iron with pale gray color sand.

Permeability coefficient of Pleistocene sediments is expected to be in very low degree. Mesozoic sedimentary rocks comprise sandstone in general. Alternation of sandstone and shale are developed very frequently. Tuff breccia is mostly developed in the southeast area. Ryolitic tuff is narrowly developed at the western side. Paleogene volcanic and igneous rocks are granodiorite in the West Baray, and andesite dykes in the northeast area. These basement rocks below Pleistocene clay stone have confined ground water.

The geological map for alluvial and diluvial deposits, and basement rocks of Mesozoic and Paleogene are shown in Supporting Report Annex 3.3.1.

(2) Exploratory Well Drilling

As shown in Figure 3.3.1, eight core drillings were carried out in 1997. There were WT1, WT2 (=LTb-1 in the final naming), to WT8.

It was cleared by the eight core drilling that the alluvial deposits in the northern area has suitable characteristics comprising of coarser particles in general, but their thickness is smaller than that of the southern area. On the other hand, the southern area near the Lake Tonle Sap is composed of fine particles which is indicating low permeability.

Therefore, the location of WT4 is judged the most suitable groundwater potential. The geological sequence, thickness and pumping test result for WT4 is mentioned in the following table.

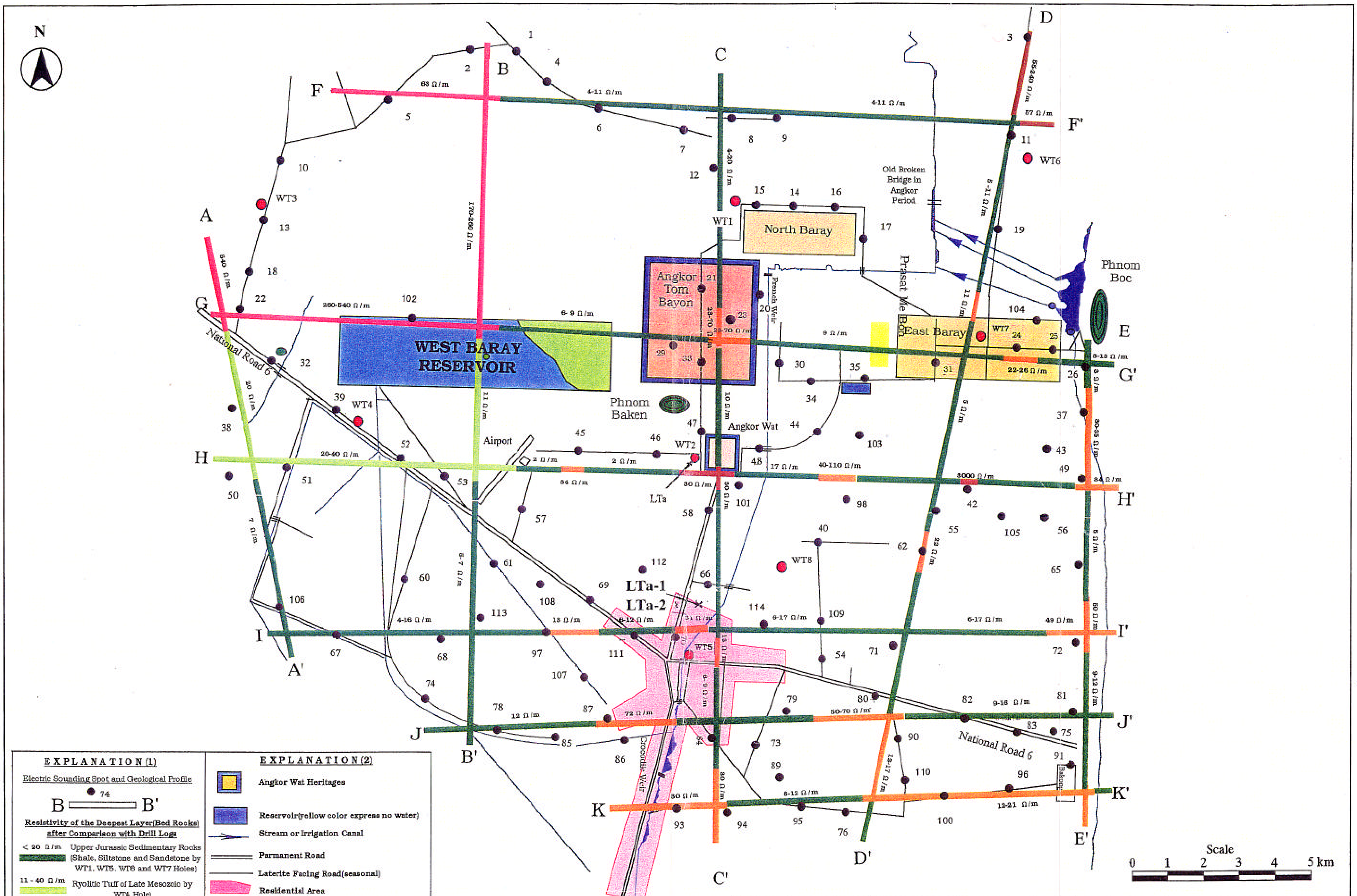


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Figure 3.3.1 Location Map of Electric Sounding Spots and Geological Profiles Showing Deepest Resistivities

Geological Log and Hydrogeological Characteristics

Formation	Thickness (m)	Description	Hydrogeologic Characteristics
Alluvial deposits	14	Silty sand with coarse particles. Very loose sand in the middle part.	Static water Level: 0.855 m (1997 May) Permeability: 1.87-1.67 x 10^{-2}(cm/sec) Discharge: 444 liters/min with 0.73 m drawdown.
Diluvial deposits	22	Containing silt (stone) from the lower formation. Clayey sand (stone) with coarse matrix. At the bottom, gravelly sand and core lost by loose matrix.	
Pliocene formation	36	Sandy clay stone. Cylindrical core.	Aquitard
Bed rock		Weathered tuff of Mesozoic sedimentary rocks.	Unknown

The pumping test result of WT4 is shown in Figure 3.3.2.

The 8 drilling logs and 11 geological profiles are shown in Supporting Report ANNEX 3.3.1, Attachment-2. The results were completely and effectively utilized for the simulation modeling.

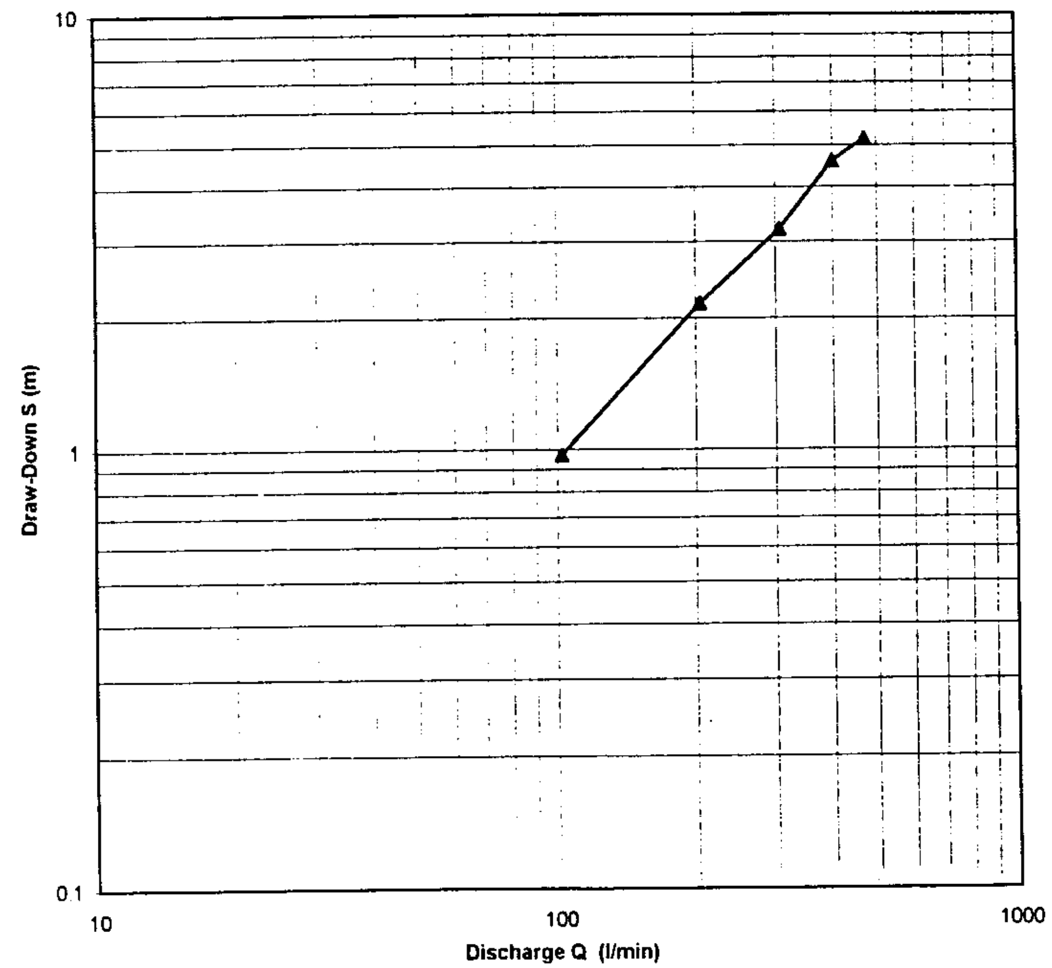
After the core drilling, 14 exploratory and observation wells were constructed. In the same locations of the core drilling except with WT1 and WT2, these observation wells were for groundwater level monitoring. Also, in the 2 land subsidence monitoring stations, 4 wells were constructed for land subsidence monitoring. For pumping tests, another 4 observation wells were constructed for the test.

Geological profile of 10 places is arranged by referring to the results of core drilling and electric sounding. As a result, the 4 main geological units were clarified. Boundaries of alluvium, pleistocene, pliocene, and bedrock are drawn in 3-dimention figures for easy understanding. Detail is shown in the Supporting Report.

Step Draw-Down Test

Date:31/05/ 97
Well No: WT-4
Depth : 29.00 m

Items	Discharge Q		Water Level	Draw-Down	Remark
Unit	(l / min)	(m^3 / hr)	GL - (m)	(m)	
step1	102.2	6.132	1.825	0.97	
step2	204.6	12.276	3.020	2.165	
step3	306.7	18.402	4.045	3.19	
step4	400.2	24.012	5.430	4.575	
step5	470.7	28.242	6.024	5.169	
step6					
step7					
Critical					
Aptitude					
S.W.L.	GL - 0.855	(m)			Static Water Level
Water temp.	29.7 (°C)				



CONTINUOUS TEST (WT-4)

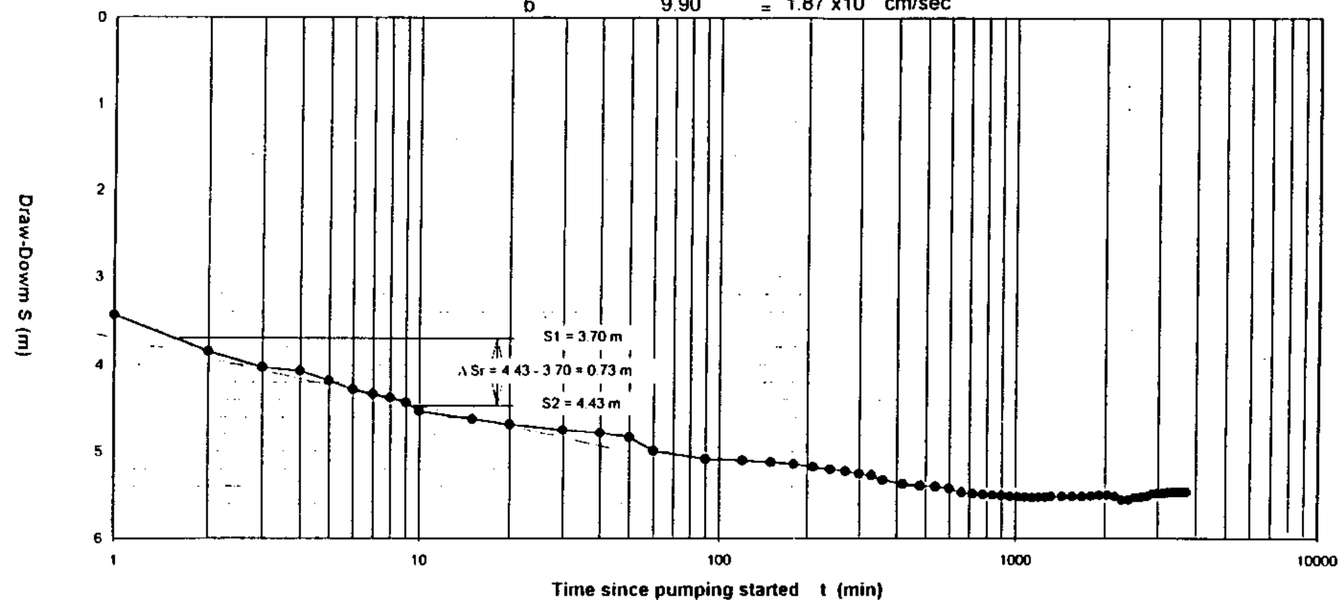
Method of Jacob
Coefficient of Transmissibility

$$T = \frac{0.183 \times Q}{\Delta S} = \frac{0.183 \times 0.4436}{0.73 \times 60} = 1.853 \times 10^{-3}\ m^2/sec$$

Coefficient of Permeability

$$K = \frac{T}{b} = \frac{1.853 \times 10^{-3}}{9.90} = 1.87 \times 10^{-4}\ m/sec = 1.87 \times 10^{-2}\ cm/sec$$

Static Water Level	GL - 0.855 m
Discharge	Q = 443.6 l/min
Draw-Down of 1 cycle of log t	Δ S = 0.73 m
Thickness of Aquifer	b = 9.90 m



RECOVERY TEST (WT-4)

Method of Draw-up
Coefficient of Transmissibility

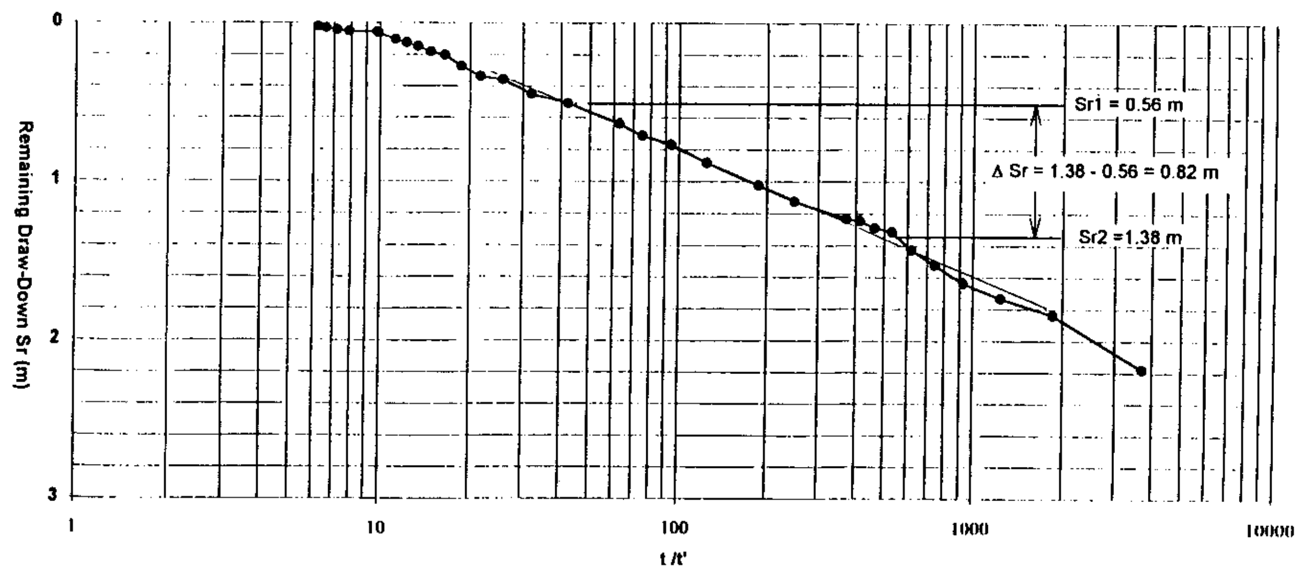
$$T = \frac{0.183 \times Q}{\Delta Sr} = \frac{0.183 \times 0.4436}{0.82 \times 60} = 1.65 \times 10^{-3}\ m^2/sec$$

Static Water Level	GL - 0.855 m
Discharge before Pumping Stop	Q = 443.6 l/min
Draw-Down of 1 cycle of log t/t'	Δ Sr = 0.82 m
Thickness of Aquifer	b = 9.90 m

Coefficient of Permeanbility

$$K = \frac{T}{b} = \frac{1.65 \times 10^{-3}}{9.9} = 1.67 \times 10^{-4}\ m/sec = 1.67 \times 10^{-2}\ cm/sec$$

$= 1.67 \times 10^{-2}$ cm/sec



The Study on Water Supply System for Siem Reap Region in Cambodia	Figure 3.3.2 Pumping Test Results of WT4
Japan International Cooperation Agency	

(3) Soil Laboratory Test

The data is shown in Data Book 1 . The elastic deformation coefficients from the unconfined compression result show a range from 1.64 x 10^{-06} kgf/cm^2 to 9.75 x 10^{-08} kgf/cm^2. The actual field records from the monitoring were used for the evaluation of an extent of land settlement.

In this Study period, 6 consolidation tests were carried out in addition to obligatory tests. The results are shown in Data Book 1 together with the above laboratory test. The results are similar to that of earlier tests carried out by Banteay Kdei Conservation Team of Sophia University.

3.4 Hydrogeological Investigation

3.4.1 Simultaneous Groundwater Measurement

A total of 96 existing wells were selected in January 1997 for the groundwater level monitoring. The location is shown in Supporting Report ANNEX 3.4.1. Elevation of 83 wells was surveyed in 1997 and 1998 to clarify the groundwater contour map. The groundwater contour maps were prepared by nearly monthly base. From these, the differences between the highest and the lowest groundwater level in one year period was prepared. All these can be found in Supporting Report ANNEX 3.4.1. The summary result is described hereinafter.

The groundwater level at the end of rainy season ranges 1 to 3.5 m below the ground surface in most cases. The deepest groundwater level was recorded 6.58 m below the surface exceptionally at the well No.86 in Angkor Thom. On the other hand, the groundwater level in the beginning of monsoon season was recorded from 2 to 4.5 m in most cases. It means that the groundwater level in early monsoon season is around 1 - 2 m lower than those of the end of monsoon season with some exceptions. The reason can be inferred that the recharge of groundwater has a time lag from the beginning of rainy season.

From the results of two years observation, it can be said that there is no notable difference in the seasonal fluctuation. This means that groundwater withdraw at present does not exceed the recharging quantity.

These records indicate the following regional characteristics:

Angkor Heritage Area

As explained earlier, this area is covered with an artificial thin reclamation layer of aquiclude. In addition, the area is located near the French Weir where the Siem Reap River water is dammed up by 5 or 6 m to divert the water to West Baray in rainy season. Due to the high river water at the French Weir and very flat topography with very limited drains, the groundwater is confined partly in rainy season or recharged very locally. It is resulted that the GWL fluctuation will come to the amount of 4 to 5 m from the above mentioned special conditions.

Siem Reap Town Area

The annual fluctuation reaches up to 4m in maximum where several deep tube wells are concentrated. The wells are mostly affected by groundwater exploitation from shallow wells. Daily withdraw reaches probably more than 7,000 or 10,000 cubic meters. However, as the permeable sandy layer infiltrates rainfall easily and percolation of all times from the river water dammed up by the Crocodile Weir, the lowest GWL occurs from April to May, which is highest water consumption period in dry season. It is noted that the GWL fluctuation in the surrounding wells of the Town are not much affected by ground water withdraw.

Southwest Area

Annual GWL fluctuation in the area ranges mostly from 2 - 3 m, which is slightly lower than the average annual fluctuation of whole area. It is resulted that the area is located near the lake shoreline without notable abstraction.

Southern and Eastern Areas

These wells in the area are characterized by the surface water interference from the Roluos River and the downstream reaches of the Siem Reap River. No remarkable concentration of the wells is found there.

3.4.2 Pumping Test of Monitoring Well

In total, 10 pumping tests were conducted in the course of the Study. The location of the observation wells is given in Figure 3.4.1. The pumping test results are given in the following table:

Well No.	Screen depth (m)	Discharge (l/min.)	Specific capacity	SWL-PWL
WT3	20.38 - 32.20	48	3	1.6 - 16.7
WT4	13.38 - 25.20	444	81	0.9 - 6.5
WT5	42.38 - 54.20	307	15	2.9 - 21.0
WT6	13.38 - 25.20	307	46	1.8 - 8.5
WT7	44.38 - 56.20	61	1	0.4 - 44.8
WT8	67.38 - 79.20	<1	-	4.9 - 60.0
LTa-1	63.62 - 71.90	-	-	1.9 - 63.0
LTa-2	26.61 - 34.90	417	129	3.6 - 6.9
LTb-1	64.61 - 72.90	9	0.6	3.3 - 18.2
LTb-2	31.61 - 39.90	417	46	2.1 - 11.1

Note: Screen lengths were 12m for all cases.
SWL: Static Water Level
PWL: Pumping Water Level

The pumping test result reveals that the wells of WT4, LTa-2 and LTb-2 installed in alluvial and diluvial sand layer have a good capacity. Also, WT5 and WT6 wells are second good performance group of wells. They are also having their screen within the alluvial and diluvial deposits. However, the WT 3 well installed in the same layers in the north area has very poor capacity due to thin aquifer of the alluvial deposits. The wells with the screen in deeper depth such as WT7, WT8, LTa-1, and LTb-1 had extremely low pumping discharge. No preferable aquifer was found in Pleistocene clay stone. When a screen is installed in longer than 12 m in the vicinity of WT4 or near the area of airport, a discharge of more than 444 liters/minute can be expected.

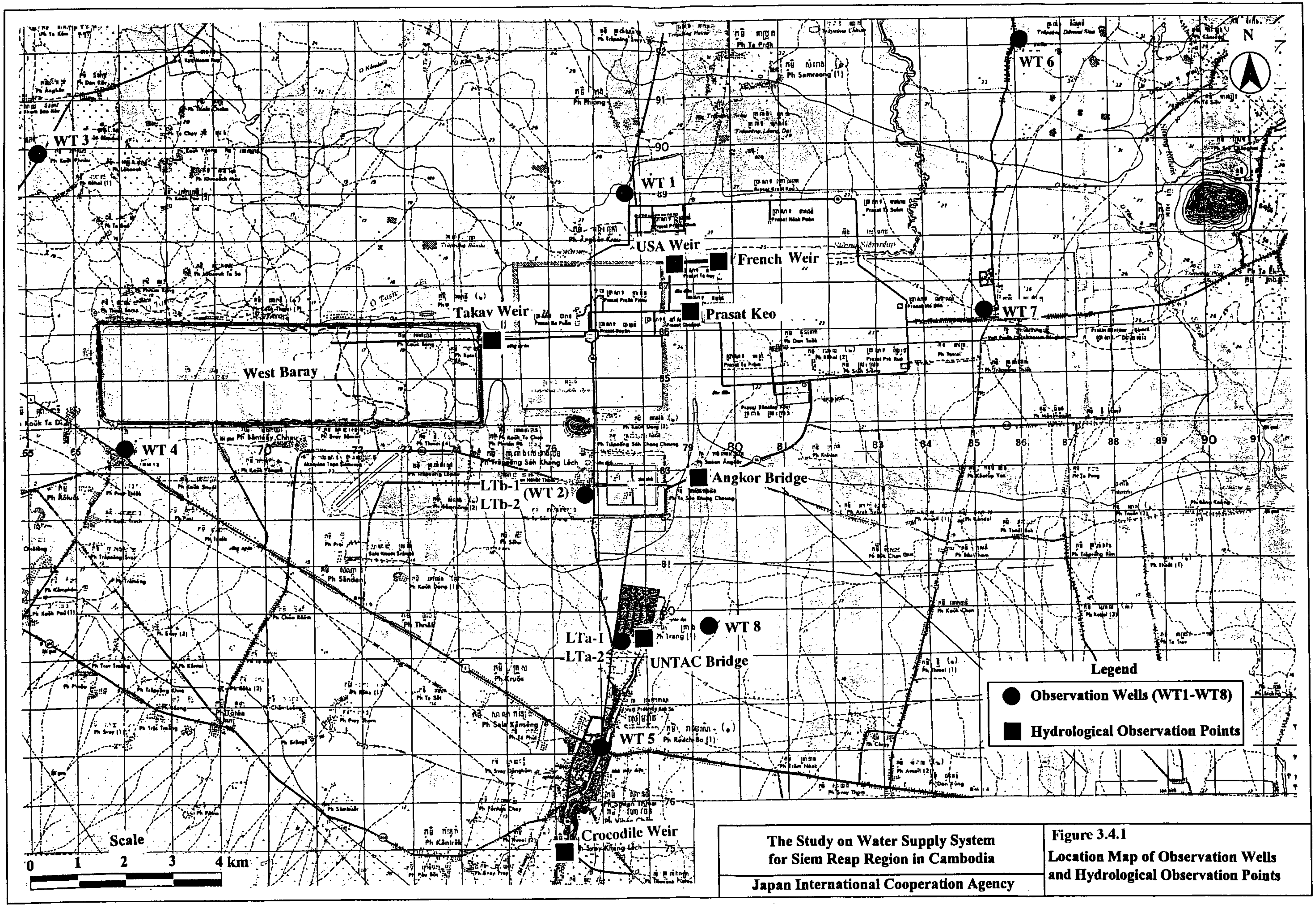


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Figure 3.4.1
Location Map of Observation Wells and Hydrological Observation Points

3.4.3 Monitoring of Groundwater Level and Land Settlement

(1) Monitoring Records of Groundwater Level

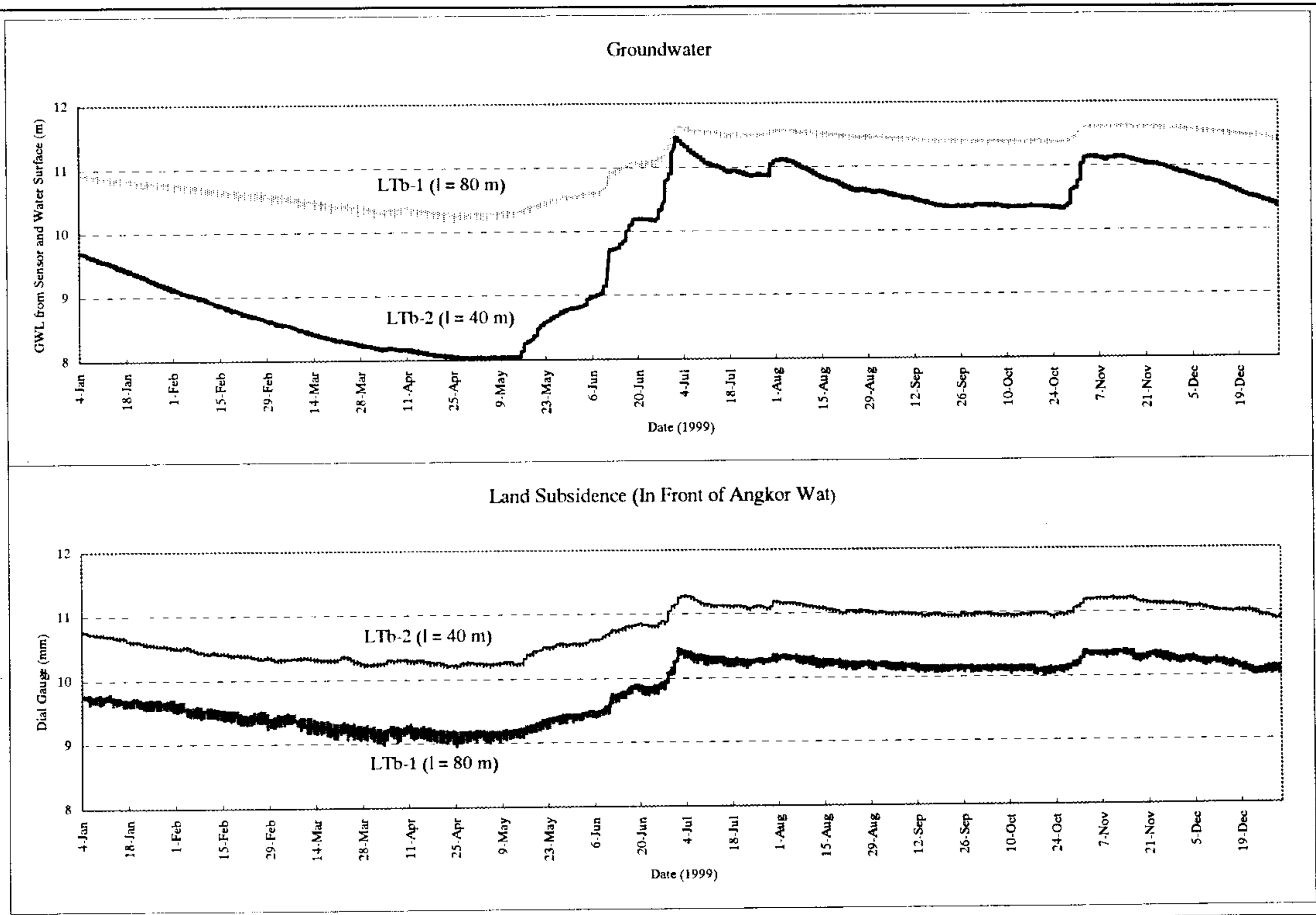
A total of eight automatic monitoring units were installed at the 8 locations. Almost all units had been well recording from February. 1998 to date. This was used for an interpolation of the monthly simultaneous data of the existing wells.

(2) Four units of Land Subsidence Monitoring and GWL Monitoring

The two sets of monitoring units for upper aquifer and deeper aquifer had been installed at the Teacher's Training school (LTa-1 and LTa-2) and in front of Angkor Wat (LTb-1 and LTb-2), respectively. The data from these stations was used for simulation model.

(3) Relationship between GWL Fluctuation and Land Settlement Records

The records of the LTb-1 and LTb-2 installed in front of Angkor Wat were effectively used in this study for the relation between land movement and GWL fluctuation. The data from February. 1998 to the end of January. 1999 reveal that the natural GWL fluctuation of 2.3 m was occurred. The land movement in the same period was recorded as 1.3 mm corresponding to the GWL fluctuation and it was found that the land movement is reversible. The record is shown in Figure 3.4.2.



The Study on Water Supply System for Siem Reap Region in Cambodia	Figure 3.4.2 GWL Fluctuation and Settlement in front of Angkor Wat
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