ANNEX 4.2.1

GROUNDWATER SIMULATION

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

FINAL REPORT
Vol. III SUPPORTING REPORT

ANNEX 4.2.1 GROUNDWATER SIMULATION

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ANNEX 4.2.1 GROUNDWATER SIMULATION

1. Objectives

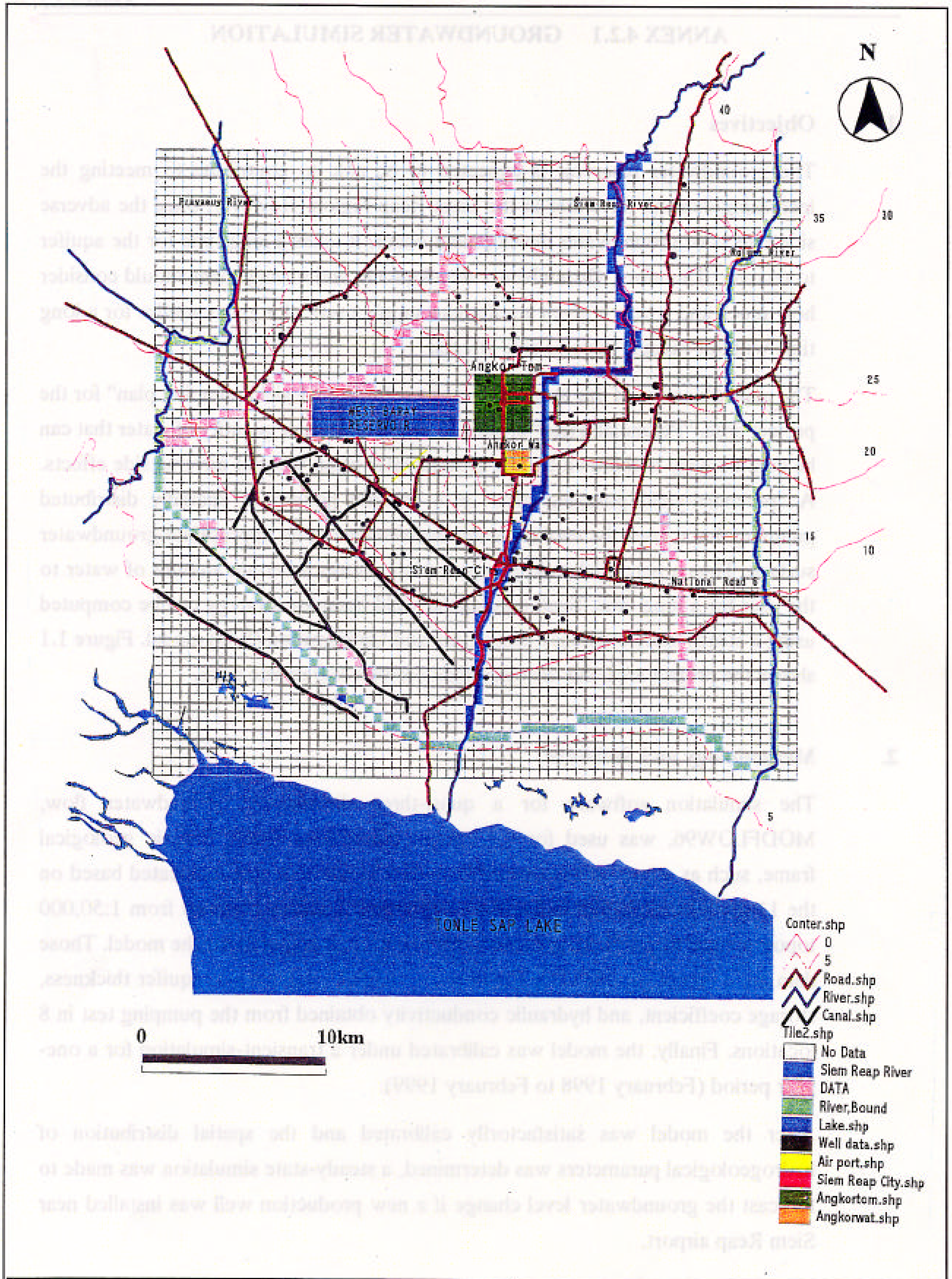
The groundwater reservoir is expected to be able to contribute to meeting the increasing demand for water in the Siem Reap region. However, once the adverse side effects of groundwater development occur, it takes a long time for the aquifer to recover. Therefore, Groundwater development and management should consider how much and where a given aquifer can supply users of a given aquifer for a long time without causing adverse side effects.

The main objective of this study is to make a "perennial-yield pumping plan" for the project area. "Perennial Yield" is defined as the maximum quantity of water that can be continuously withdrawn from a groundwater basin without adverse side effects. A "perennial-yield pumping plan" is a specific pattern of spatially distributed pumping that causes the evolution and maintenance of an appropriate groundwater surface. Thus a perennial-yield pumping plan assures a certain amount of water to the user for a long time. Such a perennial-yield pumping strategy can be computed using a steady-state combined Simulation and Optimization (S/O) model. Figure 1.1 shows the project area and the discretization with 500 m size grids.

2. Methodology and Software

The simulation software for a quasi-three dimensional groundwater flow, MODFLOW96, was used for the aquifer simulation. First, a basic geological frame, such as a layered system and boundary conditions, was delineated based on the 11 geological profiles and surface drainage conditions obtained from 1:50,000 topographical maps. Next, geohydrological data was prepared for the model. Those data are a recent groundwater distribution, rainfall, evaporation, aquifer thickness, storage coefficient, and hydraulic conductivity obtained from the pumping test in 8 locations. Finally, the model was calibrated under a transient-simulation for a one-year period (February 1998 to February 1999).

After the model was satisfactorily calibrated and the spatial distribution of hydrogeological parameters was determined, a steady-state simulation was made to forecast the groundwater level change if a new production well was installed near Siem Reap airport.



The Study on Water Supply System for Siem Reap Region in Cambodia	Figure 1.1 The Project Area and Model Discretization
Japan International Cooperation Agency	

Further, an optimal spatial distribution of pumping was determined for sustainable groundwater development by planning a candidate production well field in the south of the West Baray. The combined simulation and optimization (S/O) model was formulated to maximize the perennial-yield (steady) pumping rate from the candidate production well field. The same spatial distribution of hydro-geological parameters used for the simulation model is involved in the S/O model. Because of the great concern about land subsidence around the Ankor heritage area by pumping, constraints are 1) allowable maximum withdrawal rates from the well field and 2) allowable drawdowns at the Angkor heritage area.

3. Boundary, Hydrogeological Parameters for Models

1) Hydrological Boundary

The area is assumed surrounded by a no-flow boundary on the north side. On the south side, a constant-head boundary is used to permit inflow into the Lake Tonle Sap. On the east and west sides, constant-head boundaries are used along the rivers. In addition, it is assumed that this boundary condition will not change in the future. The boundaries are shown in Figure 1.1 and described below:

North : around 10-km north of Angkor Wat heritage

South : along the shoreline of El. 6 m. The constant head of 6 m is assumed along the lakeshore although the lake water level fluctuates from 1m in the dry season to 9m in the rainy season.

East : Roluos River course

West : Srok River course

2) Aquifers

Based on the interpreted 11 geological profiles, the following layers were defined:

G1: Alluvial deposits layer

G2: Diluvial deposits layer

G3: Pliocene clay stone layer(aquiclude)

G4: Basement of Mesozoic to Palaeozoic sedimentary rocks and intrusive. Consistent with the generalized profile of the aquifer (Annex 3.3.1, Figure 3.3), the simulation model consists of two aquifers:

Layer 1: Upper unconfined aquifer(= G1 and G2 layers) of around 20 to 40m thickness

Layer 2: Lower confined aquifer(=G4 layer)

Layer 1 involves a quasi-three-dimensional saturated flow under water table conditions, discharge from drains, flow between the aquifer and the Siam Reap River. Transmissivity of Layer 1 is treated as a function of head. Most of wells for domestic use penetrate this aquifer.

In Layer 2, a transmissivity is assumed to be constant. The quasi-three-dimensional saturated flow under pressure is simulated.

Flow within the aquitard between the aquifers is not simulated, but vertical flow through the aquitard is simulated.

3) Model Discretization and Cell Cize

The discretization and cell types for Layar 1 are shown in Figure 1.1. A block-centered, finite-difference cell with a size of 500m is used. The grid consists of 70 columns and 68 rows.

4) Geo-Hydrological Parameters

Hydrological parameters were obtained from the pumping test and the spatial distribution was determined through the calibration as follows:

Layer 1(upper unconfined layer):
Hydraulic conductivity: 2.0×10^{-4} m/sec to 8.0×10^{-4} m/sec and 5×10^{-4} m/sec on average. Hydraulic conductivity values estimated from the pumping test are 1.403×10^{-3} m/sec, 2.51×10^{-4} m/sec and 1.10×10^{-4} m/sec for three different locations.
Storativity: 0.1 to 0.2

Aquitard between Layer 1 and Layer 2:
Permeability: 2.0×10^{-8} m/sec

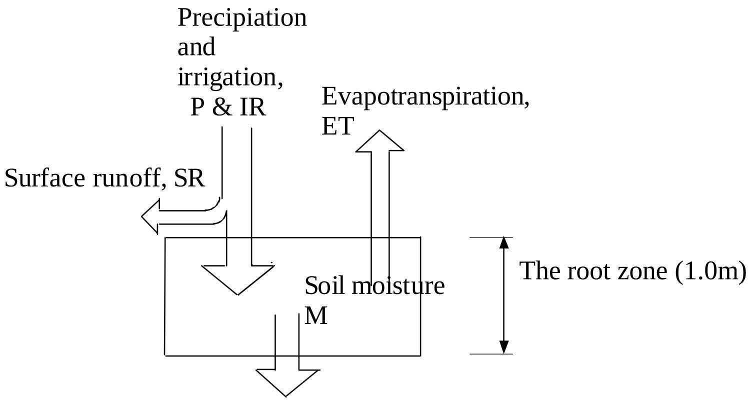
Layer 2 (lower confined layer):
Transmissivity: 2.5×10^{-4} m/sec, assuming the thickness of Layer 2 and hydraulic conductivity are is 25m and 1.0×10^{-5} m/sec, respectively.
Storativity: 2.0×10^{-5} m/sec.

5) Land Use in the Study Area

Based on the site investigation and 1:100,000 topographical map, land use was classified for each cell to estimate recharge to the aquifer. The classified land uses in the project area are lake/pond, built-up area/village, Siem Reap City, dense forest/jungle, clear forest, inundation area, marsh/swamp, irrigated paddy field, and rainfed paddy field.

6) Estimation of Deep Percolation

Deep percolation (DP) can be estimated from a water balance around the root zone. The components of the water balance are illustrated below:



Deep percolation was estimated for each land use. For example, the deep percolation from the irrigated paddy filed was estimated using the water balance over the root zone described by:

$M(t+\Delta t)=M(t)+(IR+P-ET-SR)\ \Delta t$

where,

M: moisture content (mm/day)

IR: net irrigation requirement (mm/day)

P: precipitation (mm/day)

ET: evapotranspiration (mm/day)

SR: surface runoff (mm/day)

Δt: 1 day

The storage behavior of the root zone is simulated by assuming that deep percolation will only take place if the input (IR+P-ET-SR) Δt increases the stored water volume above the field capacity FC.

Thus,

$DP\Delta t=0$ if $M(t)+(IR+P-ET-SR)\ \Delta t<FC$

$DP\Delta t=M(t)+(IR+P-ET-SR)\ \Delta t$ if $M(t)+(IR+P-ET-SR)\ \Delta t>FC$

The daily values for P, ET, SR, and IR were simply estimated by dividing the monthly data by numbers of days of each month. The monthly average rainfall, pan-evaporation at Siem Reap airport was involved in the calculation. The surface runoff was assumed to be 15% of the precipitation. The evapotranspiration was estimated from the reference evaporation (0.63 x pan-evaporation at Siem Reap airport) and crop coefficients. Table 3.1 shows the monthly average of deep percolation rate, obtained from the daily-based water balance estimation from March 1998 to February 1999.

Table 3.1 Deep Percolation for Various Land Uses

	Rainfed paddy		Irrigated paddy		Siem Reap city		Village		Deep forest		Clear forest/others	
	sum(mm)	ave.(mm/day)	sum(mm)	ave.(mm/day)	sum(mm)	ave.(mm/day)	sum(mm)	ave.(mm/day)	sum(mm)	ave.(mm/day)	sum(mm)	ave.(mm/day)
Mar-98	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Apr-98	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
May-98	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Jun-98	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Jul-98	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Aug-98	25	0.81	0	0.00	4	0.14	21	0.66	0	0.00	11	0.36
Sep-98	131	4.21	122	3.94	99	3.18	120	3.86	100	3.22	131	4.22
Oct-98	72	2.39	71	2.37	54	1.79	65	2.17	66	2.22	72	2.39
Nov-98	83	2.68	46	1.48	44	1.42	54	1.73	63	2.03	63	2.03
Dec-98	83	2.77	56	1.87	44	1.47	53	1.78	63	2.10	63	2.10
Jan-99	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Feb-99	0	0.00	6	0.35	0	0.00	0	0.00	0	0.00	0	0.00
total	393	1.12	301	0.86	245	0.70	312	0.89	292	0.83	340	0.97

For the steady-state simulation, the monthly average of deep percolation was estimated from the monthly average rainfall for the last 10 years at Siem Reap airport in the same manner as the transient-simulation.

7) Flow between the Siem Reap River and the Aquifer

Flow between the aquifer and the Siem Reap River is formulated as a function of the water table elevation. The river bottom elevation and width for each cell containing the river, obtained from the longitudinal survey results of the Siem Reap were involved in the model. The cells containing the Siem Reap River are shown in Figure 1.1.

8) Discharge from the Drains

Especially in the wet season, considerable discharge comes from the previous course of the Siem Reap River and natural drains on the low lands along the lake shore side. The discharge quantity was estimated from the relationship between the groundwater level and the drain bottom elevation at each cell. Such simulated drain cells are shown in Figure 1.1.

9) Present Groundwater Withdrawal from the Existing Wells

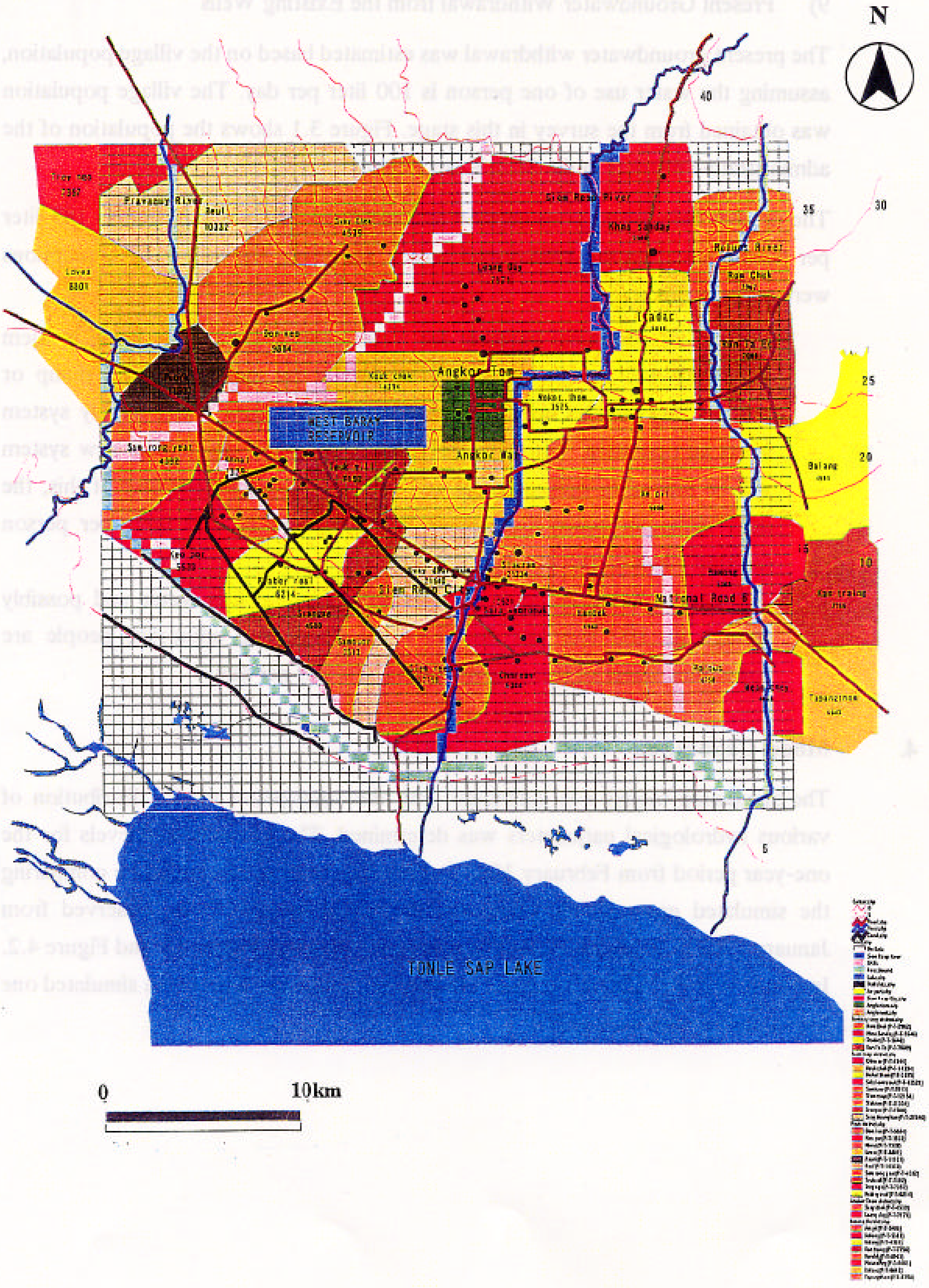
The present groundwater withdrawal was estimated based on the village population, assuming the water use of one person is 100 liter per day. The village population was obtained from the survey in this stage. Figure 3.1 shows the population of the administrative districts in the Siem Reap Region

The present daily water consumption in Siem Reap city was reported as 183 liter per person based on the 1998 social survey. However, the following assumptions were made in this stage.

- Because of additional payment for water charge, the people living in Siem Reap city will use the present groundwater by their own hand pump or shallow dug well as much as possible, even if a new water supply system starts an operation. Thus, the daily maximum water use for the new system will be limited to only drinking and cooking purposes. Because of this, the daily minimum water requirement is assumed to be 100 liters per person (around a half of 183 liters per person).
- The people living in the rural area will consume less water and possibly enough by 100 liter per day. In other developing countries, people are consuming water of less than 100 liters of water per day.

4. Model Calibration

The simulation model was calibrated until the appropriate spatial distribution of various hydrological parameters was determined. The groundwater levels for the one-year period from February 1998 to February 1999 were verified by comparing the simulated groundwater levels and the actual monthly ones, observed from January 1997 to February 1999. The results are shown in Figure 4.1 and Figure 4.2. In Figure 4.2, 60 and 60s means an observed groundwater level and a simulated one for an observation well no.60.



The Study on Water Supply System for Siem Reap Region in Cambodia	Figure 3.1 Population and Administrative Boundary
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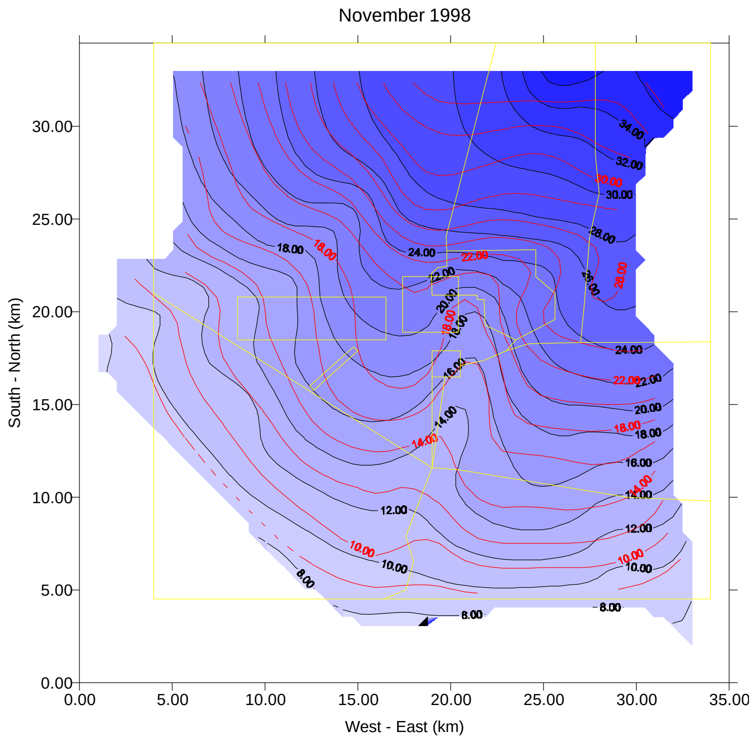

Figure 4.1 Contour Map of Groundwater Level in November 1998

(Red contour line: observed record)

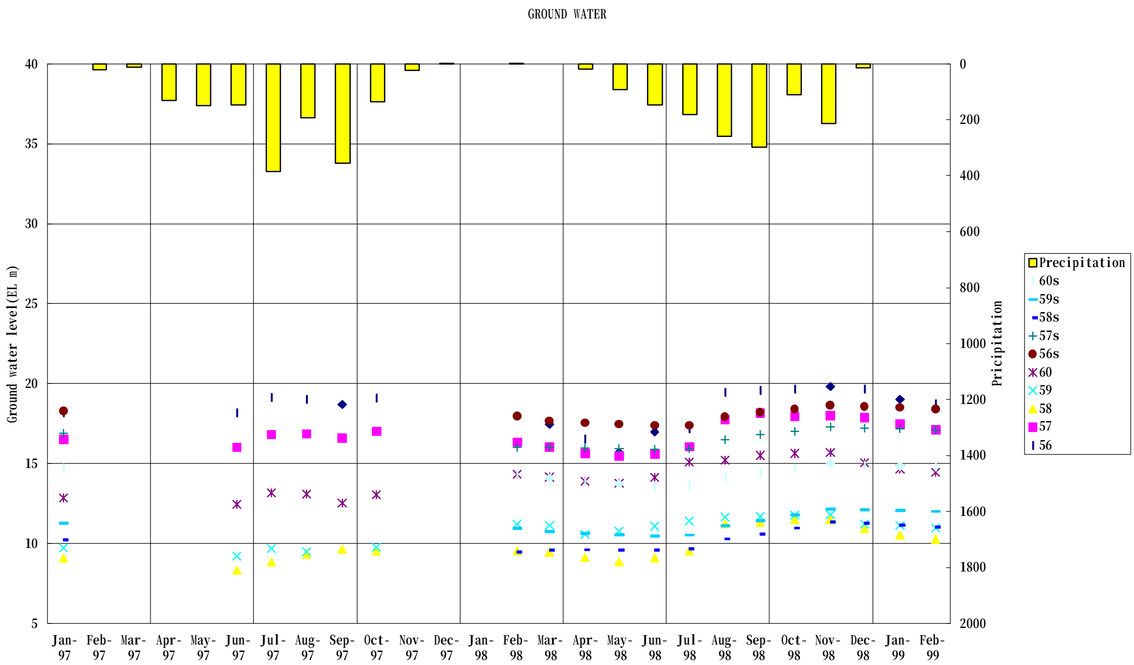

Figure 4.2 Comparison with Simulation and Observation Data along the National Road No.6

(In a legend, 60 an observed record of observed 60s: a simulation result)