CHAPTER 4 WATER SUPPLY MASTER PLAN

4.1 Population, Service Area and Water Demand

For a competent water supply master plan, population projection, fix of service area and water demand in the target year are significant. Based on the water required, a suitable water source can be selected.

(1) Future Population Forecast

The target year of the Study is 2010. A most probable scenario was set for the estimation of population in the Siem Reap Region.

According to the general population census held in 1998, total populations of Siem Reap Province and entire Cambodia are 695,485 and 11,426,223, respectively. The population growth of the province in the year 1995-1998 is 2.95%, a little higher than the country growth of 2.4%. The Siem Reap District population in the year 1998 is 103,752 with a growth of 4.17% over 1993-1998.

Not all communes of Siem Reap District will come under the service area. The proposed service area of Siem Reap comprises area that lies in the communes of Svay Dangkum, Sala Kamraeuk and Sla Kram. To make the projection most realistic, different growth rates are considered for each communes rather than single growth rate for the whole service area.

Tourist arrival to Siem Reap shows that in 1996, highest 55,560 tourists purchased tickets to enter Angkor heritage area. It is found that peak season for tourist is from November to March. Annual growth rate of tourists in Siem Reap is 93.8% over 1993-1996. It was also found that the share of official delegates, members of NGOs, UN agencies and other international organizations working in Siem Reap, and tour leaders among the total number of tourists is around 24%. The average length of stay is 1.77 in days.

For the future tourist projection, the most rational scenario was considered as an annual increase of 50,000. Also, a future average stay was considered as 2 days for tourists and tour leaders, 6 days for delegations, and 30 days for the members of NGOs, UNOs and IOs. According to this scenario, the expected tourist visits in 2000, 2005, and 2010 are 255,560, 505,560, and 755,560, respectively. Since it is considered that average stay is 2 days per tourist, this effectively means that average number of tourists per day in 2000, 2005, and 2010 are 1,400, 2,770, and 4,140, respectively.

The projected number of tour leaders and foreigners working in various international organizations and the number of foreign delegates are considered in a most reasonable way. The projected number of foreigners including tourists in Siem Reap per day are 1,931, 3,394, and 4,856 in 2000, 2005, and 2010, respectively.

(2) Service Area

Service area was selected in such a way that maximum benefit could be obtained given that the system would be sustainable. Considering present urban use and potential future growth, the service area is proposed by dividing into two stages (Stage 1 and Stage 2). The service area is shown in the Figure 4.1.1. The proposed service area of Stage 1 is 345 ha. The expansion will take place in 2006 and the total service area at the end of Stage 2 will be 436 ha.

Different population growth rates are considered for each commune in the service area and sometimes for each village. This shows future populations of 37,028 in 2005 in the Stage 1 service area. The future population of the service area in the Stage 2 is 53,151 in 2010.

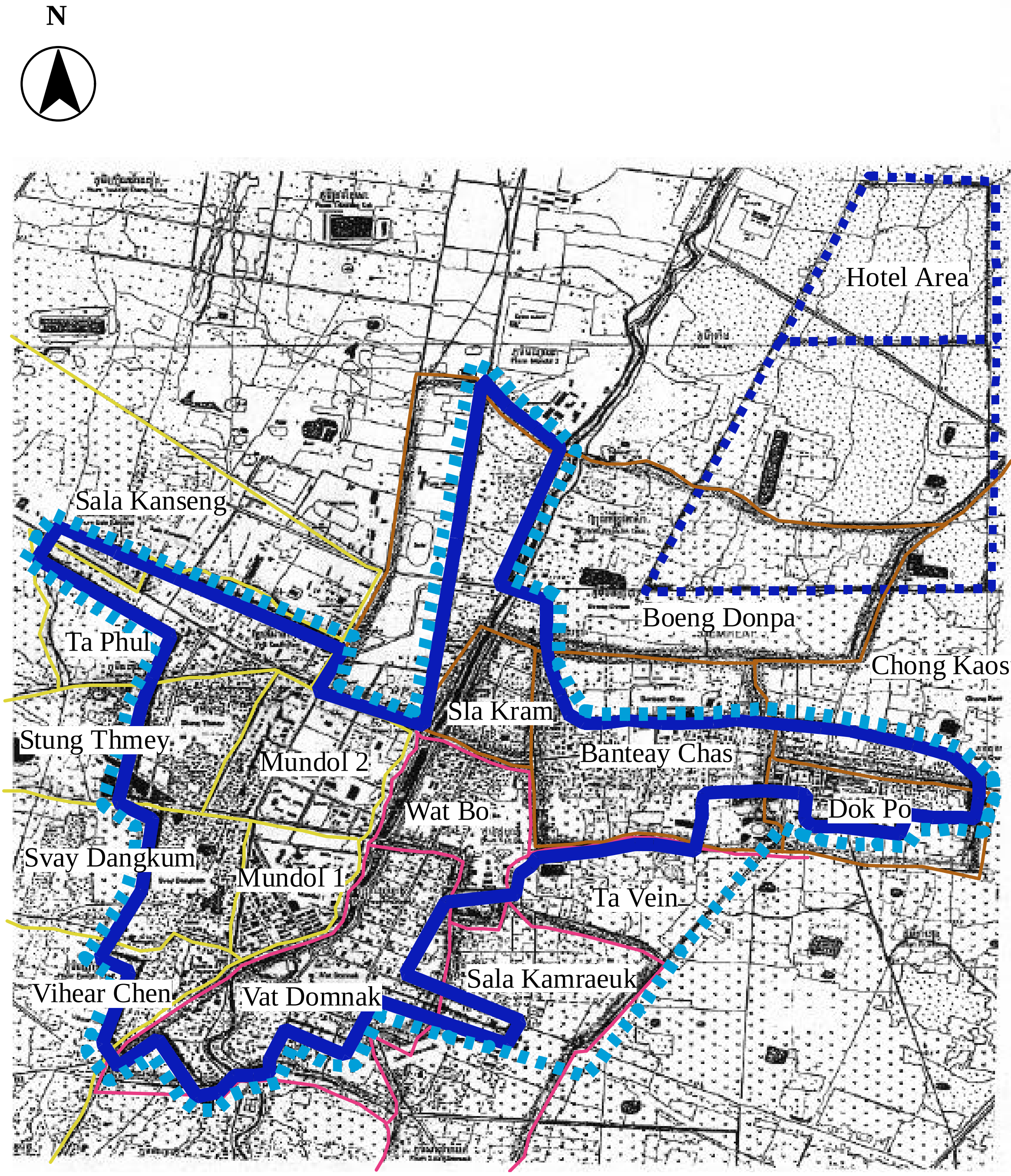
(3) Water Demand

Water demand is calculated separately for domestic demand, tourism water demand, and special use demand. Special use includes water demand for hospitals, schools, government offices, royal residence, temples, and markets. Summation of all these demands will give the total water demand in 2010.

Based on the present design consumption of 100 lpcd and other baseline data, the Study Team proposes to consider a unit consumption of 100 lpcd in 2002. The unit consumption is considered to follow a linear growth up to 2006 to reach a unit consumption of 120 lpcd. However, it is considered to remain at that level until the target year 2010. This gives a potential domestic demand of 6,380 m^3/day in 2010.

Service ratio will be low in the beginning of the service. In 2002, it is assumed to be 30%. However, given the expected urbanization and relative ease of water availability, it is expected to reach the 75% level in 2008. Further increase is relatively difficult in any situation. Service ratio is expected to remain at the 75% level until the target year 2010. This gives a service population of 39,863 in 2010 and a net average domestic demand of around 4,800 m^3/day.

Unit water demand for visitors is estimated as 500 lpcd. A peak demand is also calculated adjusting the demand for peak tourist season. Peak month of tourists is November when 13.1% of the annual tourists are concentrated, which results in a peaking factor of 1.57. The average visitors water demands for 2000, 2005 and 2010 are 965, 1,697, and 2,428 m^3/day, respectively. A separate restaurant water



Legend

(blue solid line)	Service Area in 2006	(brown line)	Village Boundaries Commune:Sla Kram
(blue dotted line)	Service Area in 2010	(yellow line)	Village Boundaries Commune:Svay Dangkum
Dok Po	Village Name	(pink line)	Village Boundaries Commune:Sala Kamraeuk

Scale
0 500 1,000 m

The Study on Water Supply System for Siem Reap Region in Cambodia	**Figure 4.1.1 Service Area**
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demand was calculated with a growth rate of 20%. A uniform unit water demand of 100 liters/table/day gives the restaurant water demand in 2010 as 431 m^3/day.

The service ratios for both the visitor water demand and restaurant water demand are assumed as 50% in 2002. Because of potential business profit, this ratio can be expected to rise quickly and reach a maximum value of 95% in 2005. Thus, the total water demands for daily average tourism in 2002, 2005, and 2010 are 738, 1,895, and 2,718 m^3/day, respectively.

In the category of special use, the Study considers water demands in hospitals, schools, government offices, royal residence, temples, and markets. The potential water demands in the year 2010 for hospital, school, government offices, royal residence, temples, and markets are 176, 21, 19, 20, 20, and 20 m^3/day, respectively.

The total potential water demand for special use is 276 m^3/day. Considering same growth pattern for service ratio as for the domestic demand (that is 30% in 2002 to 75% in 2010), the required demand in 2002, 2005, and 2010 are 63, 139, and 207 m^3/day, respectively.

The total water demand in net average is the sum of net average water demands for domestic, tourism, and special uses. In 2010, the total net average demand is around 7,700 m^3/day. For the present system, unaccounted for water for the entire service period until the target year of 2010 is assumed as 15%. For Siem Reap Water Supply System, a peaking factor is assumed as 1.2 for domestic and special water demand. The peak factor for the tourism demand is considered as 1.57. Thus, the gross peak water demand in 2010 comes to 12,000 m^3/day.

4.2 Development Potential of Water Sources

Based on the basic investigation conducted in the Study as discussed in Chapter 3, water availability from the four alternative sources is assessed in this section. This is compared with the future water demand presented in Section 4.1.

(1) West Baray

Water availability from West Baray is calculated based on field investigation. The minimum potential capacity is estimated as 40.7 millions m^3 (34.1 millions m^3: inflow plus 6.6 millions m^3: storage by rainfall). Considering the maximum irrigation use of 36 millions m^3, the remainder will still be 4.7 millions m^3. The remainder can provide a water supply of around 12,900 m^3/day for the whole year.

(2) Siem Reap River

The possible amount of intake from the river is estimated by taking into account the methodology widely applied in Japan :

Possible amount of intake =10-year drought flow - Maintenance flow - Vested water use

The calculated possible amount of intake becomes 0 m^3/s and accordingly the Siem Reap River option can be completely discarded from alternative water sources. Some kind of storage is required if Siem Reap River water is used as the source. One possibility is to construct a dam in the upstream of the river in the vicinity of Kulen Mountain. Another possibility is to renovate the North Baray to store water in rainy season and to release it in dry season.

(3) Lake Tonle Sap

Lake Tonle Sap is the largest freshwater lake in Southeast Asia and its storage is more than 1,300 millions m^3 even at the lowest water level. The possible yield from the lake can be considered practically as unlimited. From a hydrological viewpoint, the intake should be secured even when water level becomes below approximately EL. 0.7 m, which is 20-year return period minimum water level in the dry season. Therefore, the available intake site is recommended to be located at least 4 km offshore from the existing boat house. The distance from the town center will exceed 19 km. It is naturally impossible to convey the raw water by gravity to the town center.

(4) Groundwater

1) 1st Computer Simulation

As explained in Section 3.4, the wells of WT4, LTa-2 and LTb-2 installed in alluvial and diluvial sand layer have a good capacity, and a discharge of more than 444 liters/minute can be expected. At the same time, careful consideration has to be given to the fact that excessive groundwater abstraction will cause land subsidence in and around the well field including Angkor Wat area. So the maximum yield from the well field near WT4 will be governed by the maximum allowable land subsidence. In order to find out the allowable maximum groundwater abstraction, the 1st computer simulation was conducted considering various cases.

The maximum allowable groundwater drawdown in Angkor heritage area was assumed to be 0.30 m. Judging from the records of land subsidence monitoring near Angkor Wat, the drawdown of 0.30 m by new production wells would cause land subsidence of less than 1.6 mm.

Seven cases are considered for various upper bounds on allowable discharge by different pumping locations. This is summarized in the following table. The reason that the permeability coefficient of 1 x 10^{-2} cm/s was adopted for the 1st simulation by using the tested result of WT4, of which value is too much larger than normal condition, is by considering the maximum affects to Angkor heritage.

Optimization Results

	GWL drawdown in Angkor area	GWL drawdown in the well field	Upper bound on allowable discharge (m^3/s/cell)	Daily Maximum allowable discharge in total (m^3/day)	Number of pumping cells
Case-0	0.30m	3.00m	0.20	16,330	6
Case-1	0.30m	1.00m	0.01	9,850	31
Case-2	0.30m	2.00m	0.01	14,170	18
Case-3	0.30m	3.00m	0.01	14,342	17
Case-4	0.30m	1.00m	0.02	9,850	31
Case-5	0.30m	2.00m	0.02	14,947	10
Case-6	0.30m	3.00m	0.02	15,638	10

The Case-5 was judged to be the best groundwater exploitation plan. However, the maximum allowable pumping rate should be considered around 12,000 m^3 per day to be more conservative (80% of the pumping rate obtained from the model). Then it is judged to be safe enough for the existing wells and Angkor heritage.

2) Pilot Well Construction and Water Quality

In order to confirm the feasibility of the groundwater development and to check its yield and quality of the groundwater, two pilot wells were constructed at the well field based on the 1st simulation information. The two pilot wells are located at both ends of the proposed Stage 1 well field along the National Road No. 6. The location of the two pilot wells is shown in Figure 4.2.1.The yields of these two wells were confirmed as around 800 m^3/day for the 5 m drawdown. The daily water demand of 8,000 m^3 can be satisfied by total 10 production wells including these two pilot wells.

Water Quality

During the Feasibility Study stage, in addition to routine monthly water tests, 11 water samples were sent to Tokyo for the test of arsenic (As) and iron (Fe) content. It was found that arsenic contents in all samples are <0.01 mg/l which is less than the recommended value of WHO. In case of iron, groundwater near proposed well field has lower iron content than WHO standard of 0.3 mg/l.

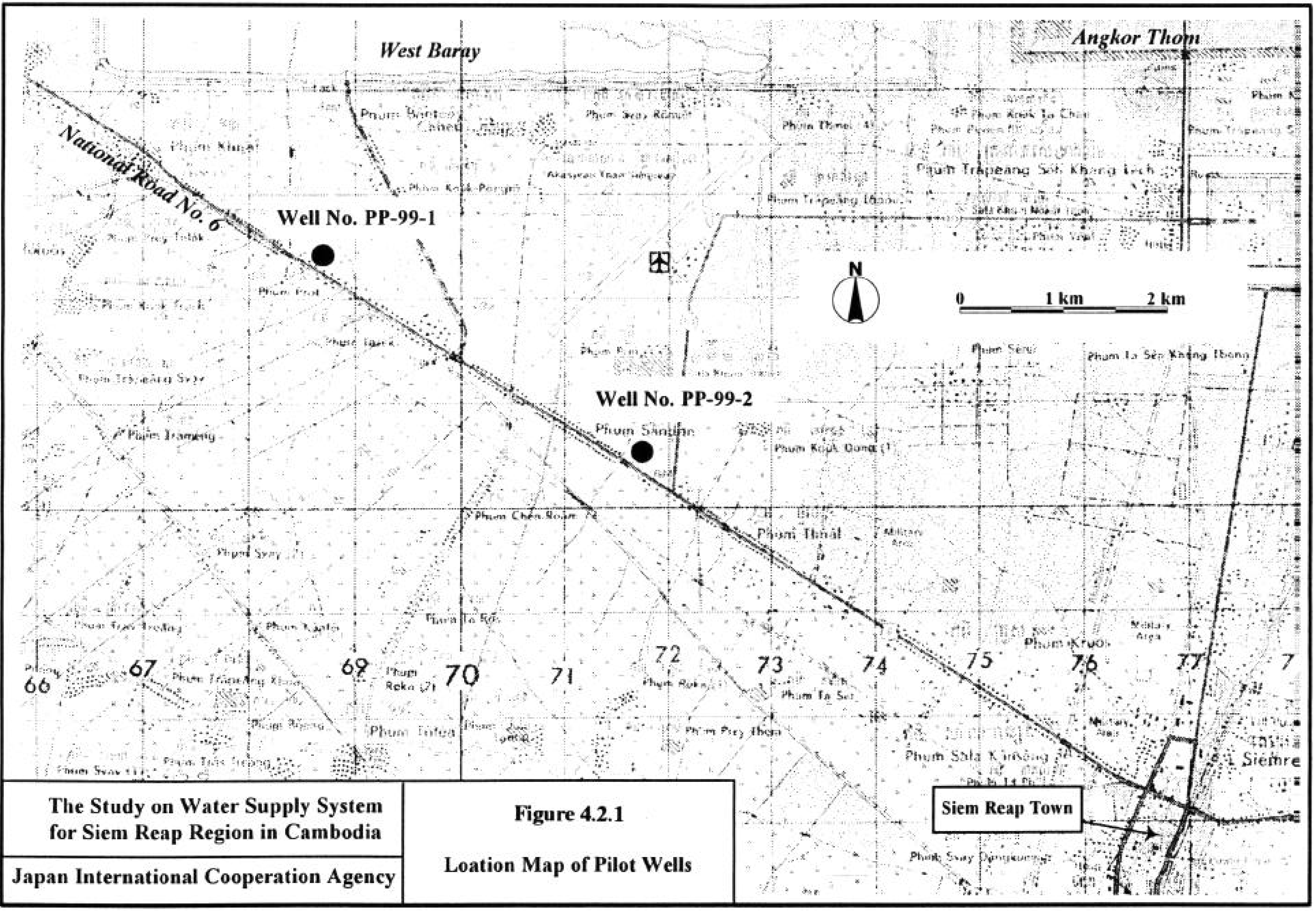

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Figure 4.2.1

Loation Map of Pilot Wells

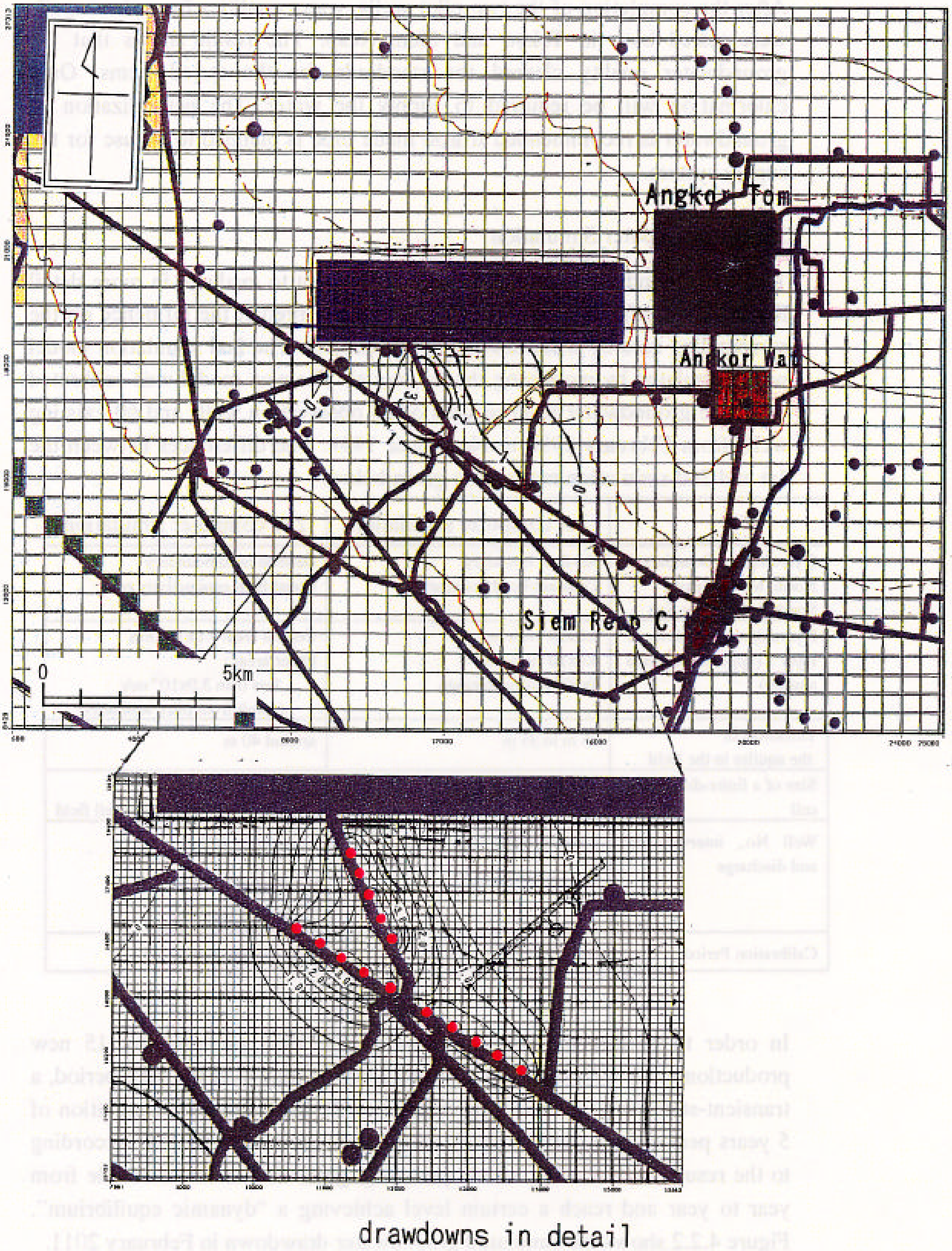
After the completion of the two pilot wells, water qualities from these wells were tested both in Tokyo and Siem Reap. The result shows that the groundwater quality cleared the standards for the tested items. Only chlorination will be required to supply the water. The neutralization of groundwater is recommended if iron made pipe is planned to be use for the supply system.

3) 2nd Computer Simulation

The 2nd groundwater simulation was carried out to evaluate in more detail for modified pumping plan of the 15 wells and predict the influence on the surrounding area by withdrawing by this project. The 2nd simulation model was formulated by modifying the 1st model. The new model was calibrated using the groundwater level records of 10 observation wells and 60 existing wells from February 1998 to November 1999. The differences between the 1st and 2nd simulation models are given below.

	1st computer simulation	2nd computer simulation
Hydrological Boundary North: Mountainside South: Lake Tonle Sap	No-flow boundary Constant-head boundary	General head boundary Quasi-high conductivity zone
Hydraulic conductivity of layer 1 (upper unconfined aquifer)	2.0×10^{-4} m/s to 8.0×10^{-4} m/s and 5×10^{-4} m/s on average.	Central area: 7.0×10^{-5} m/s Other areas : less than 3.0×10^{-4} m/s (result from pilot well test)
Thickness of the aquifer in the field	25 m to 35 m	around 40 m
Size of a finite-difference cell	500 m x 500 m only	500 m x 500 m + 100 m x 100 m in the well field
Well No., interval "@" and discharge	20 wells @ 500 m, Total 14,947 m^3/day	15 wells @ 400 m, 800 m^3/day for each well Total 12,000 m^3/day
Calibration Period	Feb. 1998 to Feb. 1999	Feb. 1998 to Nov. 1999

In order to predict the influence due to full time pumping by 15 new production wells with total capacity of 12,000 m^3/day over the long period, a transient-state simulation was performed by the 2nd computer simulation of 5 years period from 2006 to 2011 using a new calibrated model. According to the result, after starting steady pumping, groundwater levels recede from year to year and reach a certain level achieving a "dynamic equilibrium". Figure 4.2.2 shows the simulated groundwater drawdown in February 2011.



The Study on Water Supply System for Siem Reap Region in Cambodia	Figure 4.2.2 The Simulated Drawdown Contours in 5 Years
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Both results of 1st and 2nd simulations reveal that the influence is limited in and around the well field and does not extend to the Angkor heritage. The drawdowns around the Angkor heritage and at the well field are less than 0.10 m and less than 4.5 m, respectively. The drawdown of more than 2.0 m due to pumping does not cause stopping or less production of the shallow wells, and does not extend the area where many shallow wells exit. Therefore, it is considered that this pumping plan will not cause a land subsidence problem around the Angkor heritage and not cause stopping or less production of the shallow wells. However, the monitoring of groundwater level at the observation wells should be continued so that the pumping plan can be modified to avoid the problems due to pumping which cannot be forecasted at present.

4.3 Comparative Study on Alternative Water Sources

(1) Method of Comparison

Four alternative water sources are considered as potential water sources for future water supply in Siem Reap Town. These are Groundwater, West Baray, Siem Reap River, and Lake Tonle Sap. For the comparison, not only the costs of water source development but also the costs required for the respective water supply system are comprehensively considered and compared. These water supply systems were planned based on the capacity of 12,000 m^3/day.

For the selection of the best water source, the following criteria are considered.

1) Lower Cost (both investment cost and O&M cost)
2) Easy Operation and Maintenance
3) Less Impact to Angkor heritage
4) Reliability
5) Stable and Suitable Water Quality
6) Flexibility of the System, and
7) Less Impact to Environment

(2) Alternatives

Water supply facilities for four alternative water sources are shown on Figure 4.3.1.