2-5 Other Relevant Issues

2-5-1 Environment Considerations

(1) Conservation of Unknown Buried Ruins in the Proposed Construction Facilities Area

Zone II (Archeological Resources Area) of Zones I～V is designated as the proposed area for construction facilities for the Project as shown in Figure 2.23. It is located in the outer skirt of Zone I (The Angkor Monument Conservation Area), and is planned and designed as a buffer zone for conservation of the Angkor Monument. At present, there were no buried ruins at the proposed sites for groundwater sources development and for construction of a water purification plant. However, many unknown ruins may have been buried at the west side area of the West Baray Reservoir, where the first capital (Banteay Chhoeu) was constructed. As reference information, a ruin map around the project area, confirmed by French Institute of East Asian Studies (EFEO) is shown in Figure 2.24.

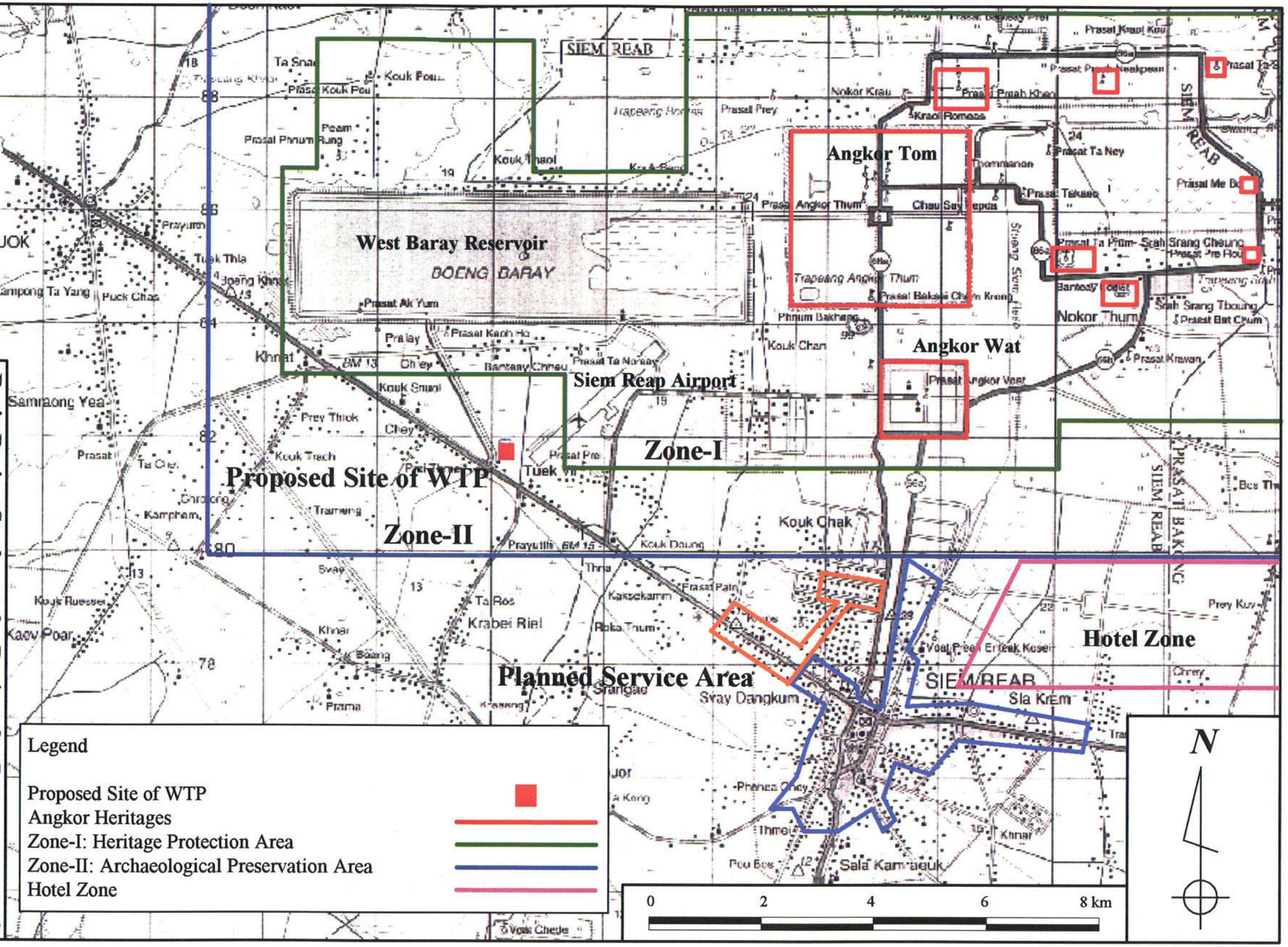
(2) Influence of land subsidence to the areas around the Angkor Wat Monument that may be caused by groundwater development

According to groundwater simulation result conducted in the Feasibility Study (1996-2000), the groundwater drawdown that may probably be caused by groundwater development is about 10 cm. Observation wells for land subsidence (LTb-1 &2) recorded the fluctuation of groundwater level and ground level in the dry and rainy seasons (January to December, 1999). This data indicated the fluctuation of groundwater level of about 3.5 m and ground level of about 1.5 mm in a shallow aquifer (depth: 40 m), and that of groundwater level of about 1.5 m and ground level of about 1.0 mm in a deep aquifer (depth: 80 m) in natural condition. The data also showed the recovery of ground levels with the increase of groundwater level in the rainy season.

As a result, the F/S concluded that the fluctuation of groundwater level caused by groundwater development is less than in natural condition, and the land subsidence due to pumpage of the groundwater development is anticipated to be less than 1 mm. The scale of land subsidence was evaluated to be negligible to the Angkor.

To reevaluate the influence on land subsidence probably caused by groundwater pumpage during the implementation of the Project and the hotel's private wells, recording data at land subsidence facilities located at the Siem Reap Town and Angkor Wat Monument need to be utilized. However, some observation facilities and equipment were damaged and lost. The analysis based on additional observation data became impossible due to unavailability of data. Thus, the observation facilities were rehabilitated under the B/D scheme in August 2003.

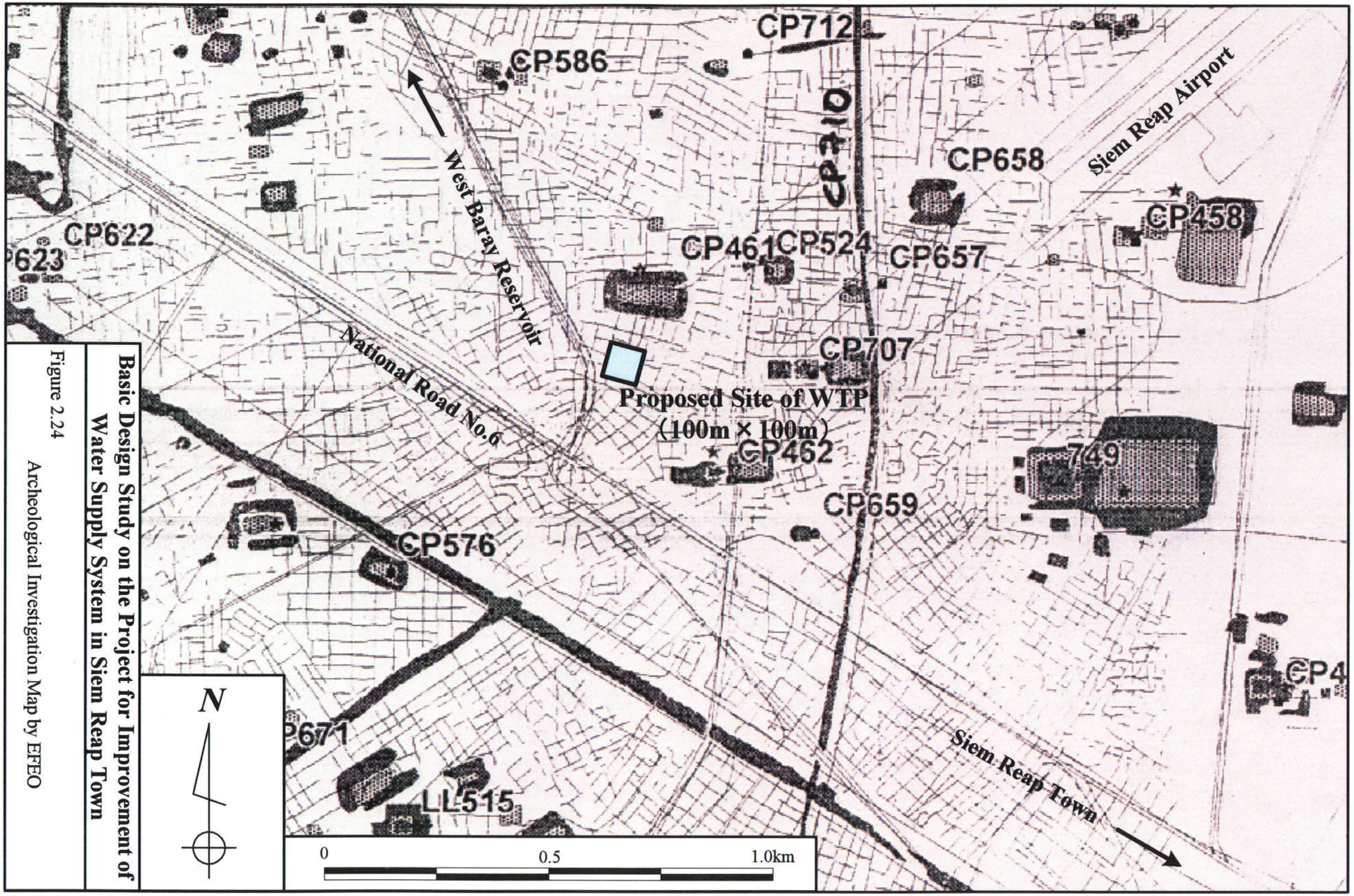
To investigate the actual situation of the influence on land subsidence by Hotel's groundwater pumpage, seven hotels with comparatively large scales were selected and surveyed. The hotel managers and/or engineers stated that there were no basis on land subsidence and the reason for the occurrence of cracks on building base and the leaning of constructed buildings were not known. As to the present status of the monument on the influence, a expert (Dr. of Civil Engineer and Registered Engineer) of the Japanese Government Team For Safeguarding Angkor (JSA) implied that unequal settlement can be seen at the Plasat Ruins, where in the same structure bases, the portions of heavy structures settlement with large scale and that of light structures settlement with little ratio. At the Angkor Wat Monument, the Study Team also observed uneven settlements, and this may be because of the weight and softness of the ground bases of the Monument.



Basic Design Study on the Project for Improvement of Water Supply System in Siem Reap Town

Figure 2.23

Zone Map in the Siem Reap Angkor Region



Basic Design Study on the Project for Improvement of Water Supply System in Siem Reap Town

Figure 2.24 Archeological Investigation Map by EFEO

The latest data recorded by the rehabilitated facilities was collected in early October 2003 during a mission for draft final report explanation in Cambodia and was analyzed in comparison to the data collected in the F/S period. Based on the groundwater development plans for the Project, the following section analyzes the theoretical influence of the proposed groundwater withdrawal on the drawdown of the groundwater level and the associated land settlement using monitoring data of both the groundwater level and the ground level.

i) Theoretical Analysis

Seven production wells are planned to be located on a straight line at equal intervals of 450 m. An additional well is planned to be located to the southeast about 470 m from the line of the seven wells as shown in Figure 2.25. Each well is planned to have a pumping rate of 1,100 m^3/d with the total delivery amounting to $8,800m^3/d$. Each well casing diameter is 200mm and the well depth 60m. The Angkor Heritage site is located to the northeast of the groundwater development area, at a distance of about 7.5 km. The aquifers comprise geological formations in Quaternary and Tertiary deposits, and according to test well results, the aquifers are able to abstract groundwater from a wide layers.

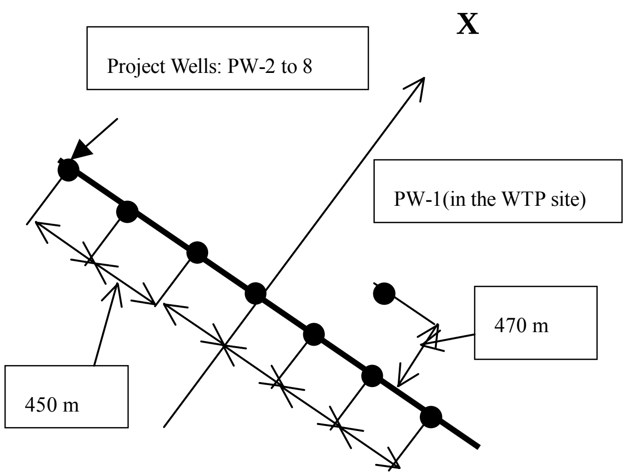


Figure 2.25 Outline Map of Location of the Project Wells

The theoretical analysis is based on the drawdown being proportional to the distance from the wells when all the wells are pumping at the same rate. Supposing 'X' is the axis in a direction at right angles to the group of wells located on a straight line, the drawdown at a distance of 'x' m can be calculated as shown below. The production well (PW1) located to the east of the multiple wells is treated as a displaced multiple well after calculating the interference radius resulting from the pumping effect of the linear wells. The influence of pumping from a linear well located to the west of well (PW1) can be neglected by the shielding effect.

On the condition that the multiple wells are located on a straight line, are finite in number, that each well has the same pumping rate (Q_o), and all are supplied by input of shallow groundwater, then, the drawdown of groundwater level at a given location in the (X) direction is shown in the following equation.

$$s = \frac{Q_0}{2\pi km} \Sigma K_0 \left(\frac{\sqrt{x^2 + (y - nb)^2}}{\lambda} \right) \quad \text{(Equation 1)}$$

where, λ : Leakage facto (m), K_0 : Bessel function , b : Interval between wells (m), n : Number of group wells (-), s : Groundwater drawdown (m), Q_0 : Pumpage/well (m^3/s), k : Permeability (m/s), m : Aquifer thickness (s)

According to the water source development survey data, transmissivity (T) ranges from 235 to 250 $m^3/d/m$. Adopting the median T value 242.5$m^3/d/m$, and a well pumping rate (Q_0) of 1,100 m^3/d in each well, the drawdown can be computed. In this equation, T: transmissivity $\lambda = \sqrt{(Tc)}$ and 'c' is the leakage resistance.

Equation 1 is solved by the following approximate expression:

$$s = \frac{Q_0}{2\pi km} \left\{ \frac{\pi\lambda}{b} e^{-x/\lambda} - \frac{1}{2} \ln\left(1 - 2e^{-2\pi x/b} \cos\frac{2\pi y}{b} + e^{-4\pi x/b}\right) \right\} \quad \text{(Equation 2)}$$

The drawdown of groundwater level ('s' mm) at the Angkor Heritage site, substituting 7.5 km for the influence distance ('x' m), is calculated to be 0.16 mm. This drawdown amount is very small compared to the yearly fluctuation in the groundwater level of 2.3 m monitored at wells LTb-1 and 2 reported in the F/S. Influence distance related to a drawdown ('s' mm) of 1 cm groundwater level, which is measurable by monitoring equipment and useful index for settlement analysis, is calculated to be 4,442 m. The predicted drawdown is very small and will not give rise to groundwater-related damage such as land settlement as discussed in the following section in details.

Groundwater level drawdown	Distance from the proposed wells
1 cm	4,442 m
0.16 mm	7,500 m

Figure 2.26 shows the influence range related to the predicted drawdown of the groundwater level. It is apparent that with a drawdown of 1 cm, the influence range does not extend to either the Angkor Wat or the Angkor Tom monuments. Based on the calculations for the linear production wells, groundwater development associated with this Project will have no influence on the Angkor Heritage site.

This result is similar to that reported in the F/S that concluded from a computer simulation that there would be no influence on the Angkor Heritage site for a total continuous pumping rate of 12,000 m^3/d over a period of five years. It should be noted that the theoretical calculation above computes a fixed influence distance irrespective of the pumping period since it is based on a steady state condition. However, since both approaches give essentially the same result, and since both methods utilize equations that have been developed over many years in similar situations, it is considered that the predictions can be accepted with confidence.

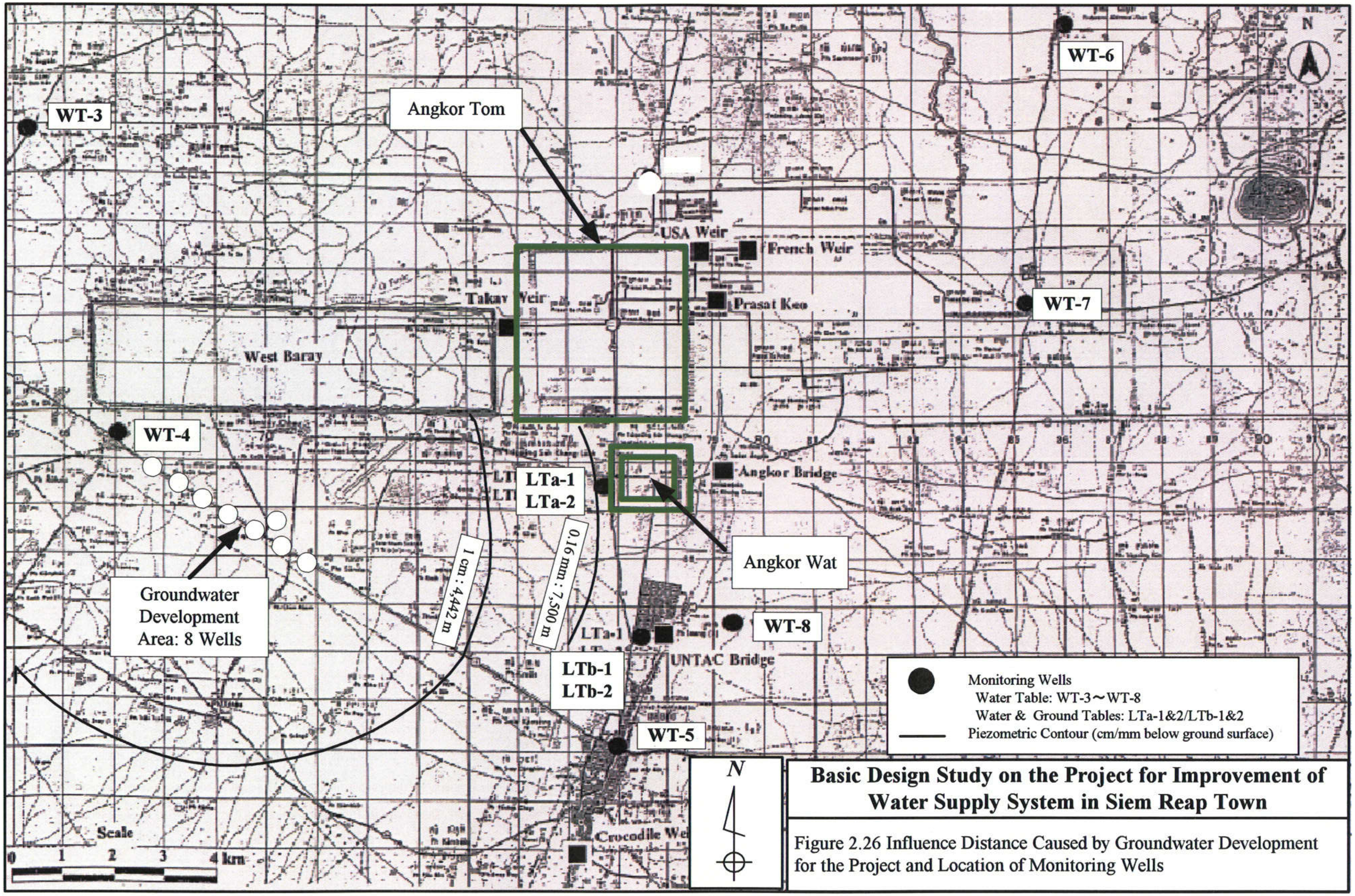


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Figure 2.26 Influence Distance Caused by Groundwater Development for the Project and Location of Monitoring Wells

ii) Analysis of Data From Monitoring Wells

Following restoration of the monitoring wells, data were collected from middle August up to the beginning of October 2003 when the draft final report was prepared. The analysis of the monitoring data indicated that pumping from adjacent wells influences groundwater levels at wells WT-3 and WT-5, and whilst groundwater levels at wells WT-4, WT-6, and WT-7 are not influenced by adjacent pumping wells, they are influenced by fluctuations in the water levels of irrigation canals and streams, as well as by rainfall. Well WT-8 has no fluctuation of groundwater level because it is dependent on a separate deep aquifer. Data for wells LTa-1&2 and LTb-1&2 indicate very small fluctuations in both groundwater level and ground level, but these are very small and are within an acceptable tolerance from the point of view of any adverse impact on the Angkor Heritage site.

The analysis results are shown in the Appendix-6 “Groundwater Level & Land Settlement Monitoring Data”. These monitoring results are useful in the evaluation of the current and future predicted influence of over-pumping of groundwater on the Angkor Heritage site, and the objective of this report is to provide guidelines on data analysis that can be adopted as part of the new Water Supply System from the point of view of operating and maintaining the monitoring wells.

The analysis results of the present status of fluctuations in groundwater level and ground level, based on the data in each monitoring well are described below. The data were analyzed over a monitoring period of several days, one month, and 1.5 months. The characteristics and purpose of each monitoring well are shown in Table 2.34 below.

Table 2.34 Details of Monitoring Wells

No.	Well No.	Screen Depth (mbgs)	Monitoring Factor
1	WT-3	20.38-32.20	Groundwater Level
2	WT-4	13.38-25.20	Groundwater Level
3	WT-5	42.38-54.20	Groundwater Level
4	WT-6	13.38-25.20	Groundwater Level
5	WT-7	44.38-56.20	Groundwater Level
6	WT-8	67.38-79.20	Groundwater Level
7	LTa-1	63.62-71.90	Groundwater Level & Ground Level
	LTa-2	26.61-34.90	Groundwater Level & Ground Level
8	LTb-1	64.61-72.90	Groundwater Level & Ground Level
	LTb-2	31.61-39.90	Groundwater Level & Ground Level

1) WT-3 Groundwater Level Monitoring

Fig. 1-1, Present Status on Fluctuation of Groundwater Level (Monitoring Period: Aug.12 to 15) indicates the same diurnal pattern of lowering and recovery of the groundwater level. The drawdown ranges from 5 to 8 cm. This phenomenon depends on the influence of pumping wells in the vicinity, and from the longer term point of view, the groundwater level generally has a tendency to increase during the rainy season (refer to *Fig. 1-2*).

2) WT-4 Groundwater Level Monitoring

No regular fluctuation in the groundwater level as a result of the influence of adjacent pumping wells was observed. However, a large daily drawdown of the groundwater level with range of 20 cm was observed (refer to *Fig. 2-2*). The drawdown pattern is irregular and shows repeat small daily fluctuations with a larger drawdown impact every week. As the irrigation canal connecting to West Baray runs near the WT-4 site, the fluctuation may be caused by water level fluctuations in the canal, or by groundwater recharge from rainfall since the groundwater level has a tendency to rise during the rainy season.

3) WT-5 Groundwater Level Monitoring

The well is located in the yard of the Siem Reap Water Supply System and in the same yard production wells for water supply are operated every day. *Fig. 3-1* shows that the groundwater level of the monitoring well fluctuates from day to day with the same pattern of 50 to 70 cm lowering and recovery. This pattern appears to be unchanged even over a long period (refer to *Fig. 3-2*). As a result of the analysis, it maybe concluded that because of rainy season, during which this monitoring period was carried out, the groundwater level is sustainable from the macro point of view and may indicate that there is no over-pumping.

4) WT-6 Groundwater Level Monitoring

Fig. 4-1 shows that there is no fluctuation of the groundwater level as a result of the neighboring pumping wells. However, monitoring data over a long period indicate that there are large fluctuations of 10 cm every few days and that these fluctuations appear to follow no pattern. It is considered that the well may be influenced by the water level fluctuation of the irrigation canal located nearby, or through groundwater recharge by stream water or rainfall. The monitoring well is located at the secondary school in a rural area with few houses and no influence from production wells.

5) WT-7 Groundwater Level Monitoring

Figs. 5-1 and *5-2* show that well WT-7 is not influenced by neighboring production wells, like the situation of well WT-6. The groundwater level at well WT-7 indicates a large fluctuation of more than 15 cm every few days like WT-6, and it is surmised that this is caused by water level fluctuations in the neighboring canal, or by groundwater recharge by streams and/or rainfall. The monitoring well is located at the secondary school in a rural area with few houses and no influence from nearby production wells.

6) WT-8 Groundwater Level Monitoring

The groundwater level over a short period of time appears to be stable with no apparent influence of either pumping wells or rainfall. The same tendency is apparent in the monitoring data over a longer period (refer to *Fig. 6-1 and 2*). This observation can possibly be explained by the fact that the well screen is deep (67.38 to 79.20 m) such that the tapped aquifer is not connected to shallow aquifers and is therefore different from the other monitoring wells.

7) LTa-1 and 2 Groundwater Level and Ground Level Monitoring

a) Groundwater Level

Table 2.34 indicates that the screen depth of well LTa-1 is in the range of 63.62 to 71.90 m, and that of LTa-2 in the range of 26.61 to 34.90 m. According to the results of the short-term monitoring data in *Fig. 7-1*, the groundwater level of the shallower well (LTa-2) is shallower than that of the deeper well (LTa-1) by a difference of about 1.0 m. The groundwater levels of both wells are not influenced by neighboring pumping wells. Over the longer period, the monitoring data indicate that the groundwater levels of both wells are generally stable, except that those of the shallower well do indicate a small daily fluctuation (refer to *Fig. 7-2*).

b) Ground Level

The monitoring data for ground level in both wells fluctuate in the range of several tenths of mm, and indicate both lowering and recovery. It is considered that this fluctuations results the elastic nature of the geological formations, however, the fluctuation range is very small and it may include measuring errors. It is recommended that long term monitoring is indispensable.

8) LTb-1 and 2 Groundwater Level and Ground Level Monitoring

a) Groundwater Level

The monitoring well is located at the southwest corner of the Angkor Wat Monument. Table 2.34 indicates that the screen depth of well LTb-1 is in the range of 64.61 to 72.90 m, and that of well LTb-2 in the range of 31.61 to 39.90 m. The groundwater level in the deeper well (LTb-1) is shallower than that in the shallower well (LTb-2) with range of 50cm. Thus, the deeper well is in an artesian condition. On the other hand, the groundwater level in the shallow well fluctuates over a range of several cm over the longer term although over the short term the level is stable (see *Fig. 8-1*). This indicates that the well is not influenced by the large hotels that are located to the south at a distance of 2km. Since the long-term daily fluctuation of groundwater level is of the order of several cm, the cause of this fluctuation needs to be confirmed, potential causes are groundwater recharge by rainfall or pumping from the hotels wells located at 2km south from Angkor Wat (see *Fig. 8-2*).

b) Ground Level

Land levels at both the shallow and deep wells fluctuate. As shown in *Fig.8-3*, a cyclical fluctuation with a range of several tenths of mm is observed in the shallow well (LTb-2) over a short term. This fluctuation shows that either the geological formation is elastic and/or that the land elevation may be changing as a result of fluctuations of the groundwater level.

iii) Utilization of Monitoring Data in the Future and Necessity for Data Analysis by MIME/SRWSS

From the data analysis, it is apparent that at present some monitoring wells are influenced by adjacent pumping wells whereas other monitoring wells are not. Current groundwater and ground level fluctuations are, however, small and can be considered not to have any influence on the Angkor Heritage site. There is a risk that groundwater development in the Siem Reap area in the future will expand in an uncontrolled manner unless adequate laws and regulations are introduced to exercise control. It will be essential, therefore, to implement continuous monitoring of both groundwater and land levels, and to devise and implement coping strategies should unacceptable level fluctuations arise.

MIME/SRWSS must take on the responsibility for continuously monitoring and analyzing the monitoring well data so as to be in a position to confirm whether or not over-pumping is occurring and to define which wells could influence the situation at the Angkor Heritage site. The key points to take into account in such analysis are as follows:

- Over-pumping in the regional area can only be evaluated on the basis of judgment as to whether or not the lowering of the groundwater level is different from historical patterns and is not a repetitive seasonal effect.

In other words it is necessary to carry out a rolling review of long-term groundwater level fluctuations.

- Monitoring data in several monitoring wells indicate the influence of adjacent pumping wells. Of these wells, the monitoring data of wells LTb-1 and 2 located near Angkor Wat, as well as wells LTa-1 and 2 situated near the center of the city, are particularly relevant. When the level fluctuation trend is regular and daily, it is likely that the lowering is a result of the effect of adjacent pumping wells. This relationship can be verified from an analysis of pumping times in the production wells and the times of groundwater level lowering in the monitoring wells. If it is proved that the production wells are the cause of the lowering, then abstraction controls will be necessary on the production wells. It will, of course, also be necessary to check if the fluctuation is the result of rainfall rather than the production wells.
- The relationship between the fluctuation of the groundwater and ground level in two monitoring wells (LTa-1 and 2, LTb-1 and 2) must be analyzed continuously. If the fluctuation of the groundwater level has the same relationship as the fluctuation of the ground level, and the latter is close to the permissible values, then groundwater development will have to be controlled by the implementation of laws and regulations.
- In the case of over-pumping across a wide area occurring, a new large-scale groundwater development study will be necessary.

iv) Analysis of Relationship Between Lowering of Groundwater Level and Fluctuation of Land Level by Land Settlement Theory

Land settlement occurs based on different mechanisms which are related to the geological formations. The two mechanisms are as shown below.

a) Settlement due to Consolidation

Clay formations tend to be distributed horizontally and continuously, and since groundwater is abstracted vertically the upper or lower aquifers in the clay formation, the groundwater replenishment which flows in a horizontal direction does not match the pumping rate. In this condition, settlement due to consolidation occurs as a result of shrinkage of the clay formation following the reduction in the water content of the clay formation. This consolidation process occurs slowly over a long term.

b) Immediate Settlement

In the case of the aquifer being located in elastic formations, the presence of heavy materials on the ground results in immediate settlement. However, when the heavy materials are removed, land settlement is reversed and the original level is recovered. This process is known as immediate settlement.

From a review of core boring data conducted for the F/S, it is apparent that impervious layers of clay are not present, hence settlement due to consolidation is not prevalent in the project area. The geological formations are mostly made up of layers of sand, silty sand, and clayey sand. Clay stones underlay the lower portions and provide a basement for groundwater. From the point of view of groundwater development, the aquifers mainly correspond to the upper formations rather than the basement.

These upper formations of sand and silt are generally elastic. Lowering of the groundwater level through abstraction of groundwater will occur, and under these conditions the degree of immediate settlement can be estimated using the geological specific gravity. In the Development Study, the specific gravity for every formation at well sites WT-4 and WT-7 was measured up to depth of 60 m. Based on the results, the specific gravity in most of the upper formation (alluvium) relative to lowering of the groundwater level was adapted at S_p=2.60.

In the case of groundwater pumping, lowering of the groundwater level occurs in the unconfined aquifer. The resultant load due to earth pressure becomes slightly light because of the buoyancy resulting from the fact that the sand layers are in float condition in groundwater. After abstraction of the groundwater, the load increases because of the disappearance of buoyancy and immediate settlement soon occurs. This concept of occurrence of immediate settlement is shown in the following figures.

Water buoyancy including earth pressure to the bottom plain in sedimentary formation A is lost by lowering of the groundwater level. At that time, added earth pressure load to the unit bottom plain is as follows.

$$W_{add}=(W_{initial}-W_{second})\times L_1\times L_2\times(S_p-(S_p-1))$$

Where, W_{add}: Added earth pressure load, $W_{initial}$: Initial groundwater level (m), W_{second}: Lowered groundwater level (m), L_1 、L_2 : Length of cubic edge (m), S_p: Specific gravity, S_p-1 :Load influenced by buoyancy when formations bear groundwater (kg)

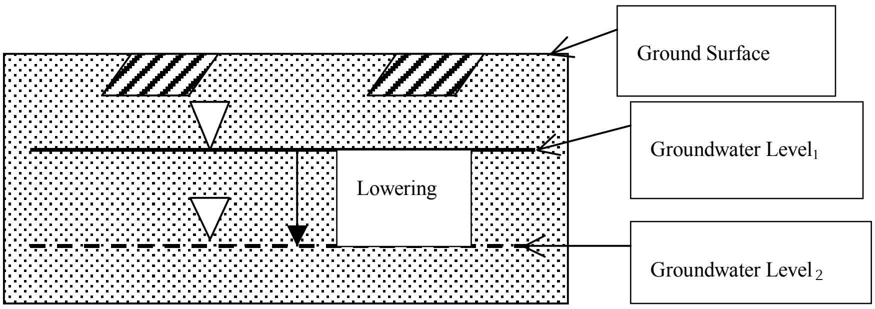


Figure 2.27 Concept Map of Occurrence Mechanism of Immediate Settlement

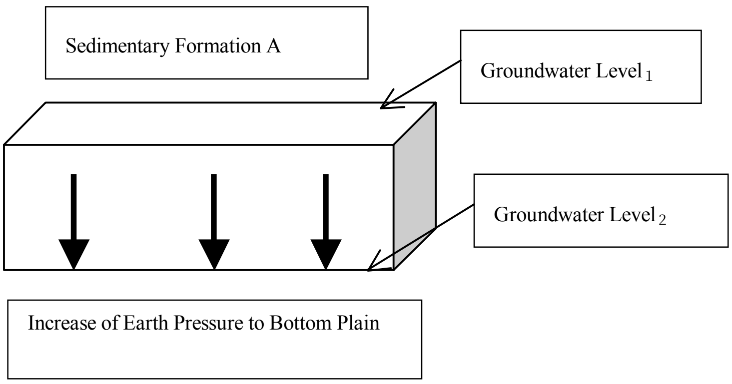


Figure 2.28 Concept Map of Increase of Earth Pressure Load Against Lowering of Groundwater Level

1) Estimation of Degree of Land Settlement

In this estimation, monitoring data from the well most affected by adjacent production wells (well WT-5) are used in order to estimate the likely worst-case land settlement. For this well the maximum observed groundwater level fall was 50 cm. The increased load by buoyancy lost per unit area (m^2) resulting from the lowering of the groundwater level is calculated to be 500 kg/m^2. The results of unconfined compression tests are shown in Table 2.35. This test measures the degree of compression when test loads are applied in the vertical direction. In a number of tests undertaken in this region the results were all very close and in this case the results for well WT-4 located near the groundwater development area have been applied.

Table 2.35 Result of Unconfined Compression Test at WT-4 Monitoring Well

Vertical Strain (%)	Vertical Stress (ton/m_2)
0.00	0.00
0.09	1.20
0.17	1.54
0.26	2.06
0.34	2.49

Note: This table indicates a part of test results.

The geological formations in the Siem Reap area are fairly uniform, consisting of fine sand formations, silty fine sand formations, and clayey fine sand formations. Thus, based on the core boring data of well WT-4 located near the groundwater development area for the Project, the amount of land settlement can be estimated. The core boring data are derived from the Development Study. The formations subject to influence by the lowering of the groundwater level are the alluvium layers and the core boring data indicate that alluvium in this area has a thickness of 14 m. The resultant vertical compression resulting from the increased load of 500 kg/m^2, in the context of a formation thickness of 14m at the WT-4 monitoring well equals 0.00375 %, hence the land settlement amounts to 0.525 cm, namely 5.25 mm.

2) Comparison Between Estimated and Permissible Degree of Land Settlement

According to the design guidelines for building foundations in Japan (Architectural Institute of Japan, 1988), the permissible degrees of settlement that can be tolerated are as shown in Table 2.36.

Table 2.36 Permissible Total Land Settlement Amount (Immediate Settlement) in cm

Structure Type	Hollow Concrete Brick	Reinforced Concrete		
Base Type	Continuous Strip Footing	Isolated Foundation	Continuous Strip Footing	Floating Foundation
Standard Value	1.5	2.0	2.5	3.0 - (4.0)
Maximum Value	2.0	3.0	4.0	6.0 - (8.0)

Note: ( ) means to have large rigidity by double slab structures

The Angkor Heritage Monument was built using stones without cement. Although, the structures are not the same as the present Japanese building standards, it could be considered that a structure using hollow concrete bricks is reasonably similar to the dry stone-wall technique used at Angkor Wat. In this case the permissible design land settlement is a maximum of 2.0 cm.

In case of a lowering of groundwater level by 50 cm as observed above, the land settlement amount would be 5.25 mm, which is well within the permissible range (20 mm maximum and 15 mm standard design value). The data in Table 2.37 set out the groundwater lowering associated with the permissible land settlement values.

According to monitoring well data, daily fluctuations of groundwater level vary from 50 to 70 cm at well WT-5 and 7 cm at well WT-3, in both cases the result of the influence of adjacent pumping wells. In neither case has evidence of land settlement been observed. It can be construed from these results that within this range of groundwater lowering resulting from nearby production wells that land settlement will not arise. Also, these values are less than the limiting groundwater level associated with land settlement as set out in Table 2.37. In the LTb-2 monitoring well, which effectively monitors shallow groundwater level, the daily level fluctuates upwards and downwards within about 10cm, and is associated with a ground level fluctuation upwards and downwards within 0.2 mm. According to the Development Study, in a year from 1998 to 1999, the groundwater level at LTb-1 and 2 monitoring wells fluctuated about 2.3 m and the ground level fluctuated about 1.3 mm; both phenomena being reversible. The reversible daily land settlement revealed by this study corresponds to a more detailed and analytical result than that reported in the F/S. It is presumed that the groundwater level fluctuates as a result of groundwater recharge with rainfall. The observation the ground level exhibits regular upwards and downwards daily fluctuations implies that the geological formation is rigid and in the condition of immediate settlement.

Table 2.37 Lowering of Groundwater Level Corresponding to the Permissible Land Settlement

Structure Type	Hollow Concrete Brick	Lowering of Groundwater Level
Standard Value	1.5 cm	96.9 cm
Maximum Value	2.0 cm	129.0 cm

v) Conclusion

The potential influence of groundwater development for the new water supply scheme proposed for Siem Reap town on land settlement at the Angkor Heritage site has been examined using group wells theory and land settlement theory. The results of the study show that there will be no land settlement problem provided that acceptable groundwater abstraction rates are adopted as developed from computer simulations carried out during the F/S.

As a part of this study, the damaged monitoring wells were rehabilitated and real-time monitoring data obtained and analyzed. Although the monitoring period was relatively short, the results of the analyses support the conclusion that land settlement can be avoided. The groundwater development area for the Siem Reap water supply scheme is located about 7.5 km from the cultural site, but many large private tourist hotels are being constructed in the Siem Reap area, some of these being only 2 km from Angkor Wat. There is a risk that these hotels could give rise to land settlement problems in the future should the groundwater be over-pumped, and whilst the monitoring data suggests that the situation can be kept under control, it would be prudent to continue to monitor the situation on a continuous basis. It is recommended that the network of monitoring wells be operated and maintained in good condition by the implementing agency, MIME as necessary, so that a database of both groundwater and land levels can be maintained.

vi) Recommendations

Based on the study results, the following actions are recommended:

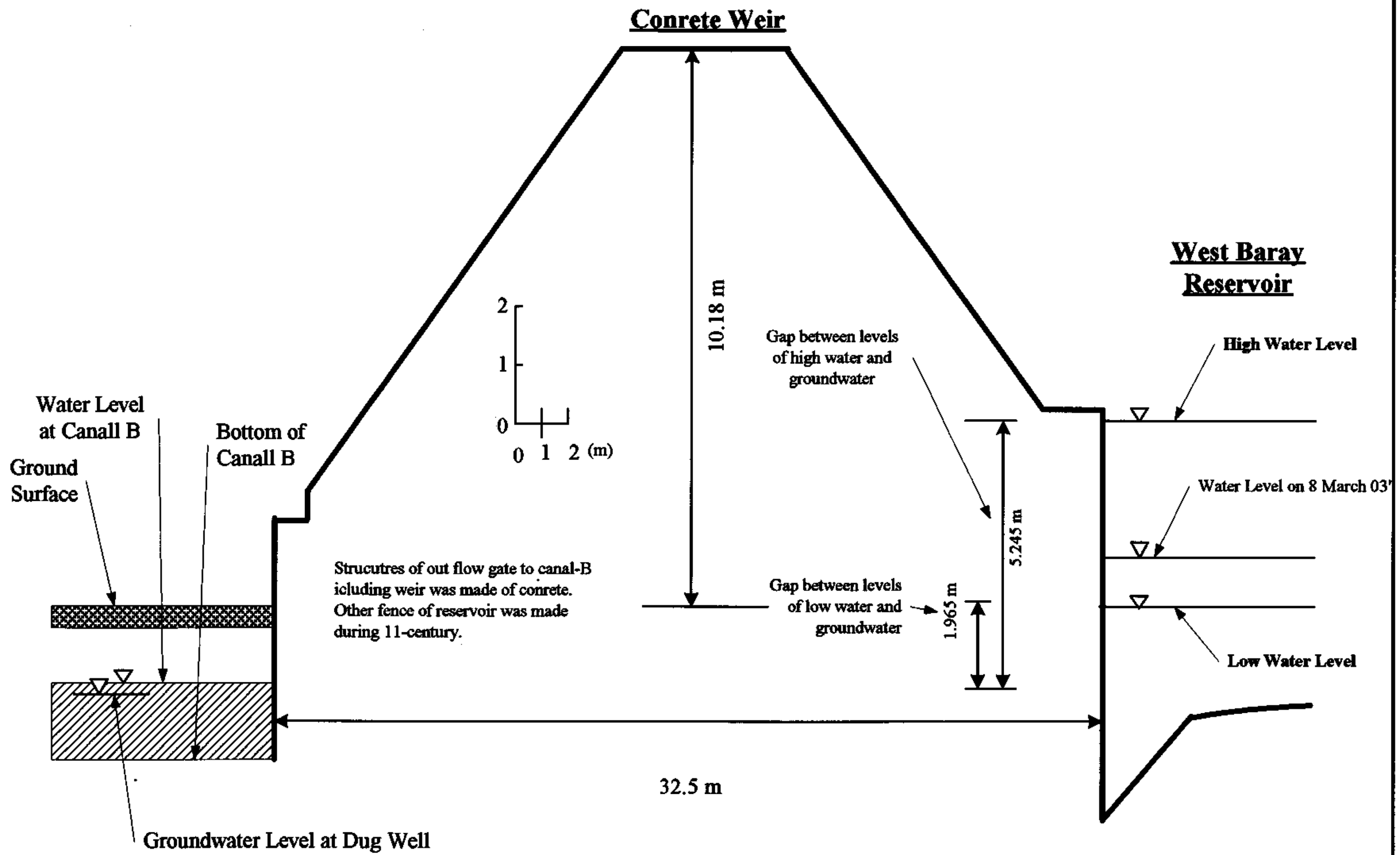
- Should long-term monitoring of groundwater levels indicate that over-pumping is occurring across the Siem Reap region, a comprehensive large-scale groundwater survey will be necessary in order to identify alternative groundwater resources.

- If monitoring data and subsequent analyses indicate that lowering of the groundwater level is occurring as a result of the influence of other production wells, such that land settlement has a high possibility of occurring in the future, warning must be given to the owners of the production wells under the relevant laws and regulations such that pumping rates are controlled to within acceptable limits such that land settlement does not occur.
- The relationship between fluctuations of the groundwater level and rainfall needs to be investigated and quantified so as to improve the reliability of future predictive computations.
- The longevity of the lead sealed batteries used at the monitoring wells is about three years, hence programs need to be put in place to replace the batteries with new ones every three years. Similarly, regular inspections should be carried out to verify the status of other monitoring equipment and to replace defective items as necessary.
- The Siem Reap Water Supply System should improve its monitoring organization through the preparation of annual budgets and the provision of funds, as well through the designation of an official to take full responsibility for the monitoring exercise.
- The Siem Reap Water Supply System should be responsible for making sure that the monitoring wells are always functioning as intended. This will require regular monthly field inspections of all wells. Assistance in ensuring the preservation and continuous operation of the monitoring wells should be provided as necessary by relevant departments of the Siem Reap Provincial Government, the APSARA office, and others.
- The Siem Reap Water Supply System should analyze the monitoring data and evaluate the output by reference to the procedures set out in this report, and publish the results in a regular annual groundwater monitoring report.

(3) Influence to Leakage from West Baray Reservoir That may be Caused by Groundwater Development

King Udayadiebaruman II at 11th centuries, constructed the West Baray Reservoir being used for agricultural irrigation. The reservoir wall has a measurement of 10 m height and 32 m section length. Based on the result of the survey, the wall slope was confirmed to have been constructed by compacted ash-blue colored clay (eastern portion, yellow clay) including artificial cracked gravel with size of 3 to 15 cm from the base portion. This clay structure is considered to be constructed by artificial compaction of mixed clay and gravel. The slope was planted by weeds and trees to prevent its collapse. The reservoir bank is thickly covered by brown fine sand. Figure 2.29 indicates the relationship among the reservoir structure section, water level, and groundwater level.

There was no leakage in the reservoir wall due to its compacted clay structures. As measured, the height difference between the groundwater level of existing shallow well located near the reservoir and the water level of the reservoir is 2.6 m. During the highest stage of the reservoir in rainy season, the height difference shall become 5.2 m in maximum provided that the groundwater level is constant (refer to Figure 2.29). If the reservoir base has leakage characteristics, both water levels shall move to balance within short period. Therefore, the base structure of the reservoir is considered to have enough capacity to prevent leakage. Hence, the West Baray Reservoir is estimated to have little leakage in its present status.



Note: Dimensions and levels on this sectional drawing were measured by the Team. Groundwater level was measured at existing dug well (400m from weir).

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Figure 2.29

Structure of West Baray Reservoir

As mentioned, the leakage from the West Baray Reservoir is expected to be very minimal, if groundwater is developed at the proposed area at southwest side of the Reservoir. In the observation well (WT-4) of groundwater level near the Reservoir at F/S study time, the natural fluctuation of about 4 m was observed. The drawdown of less about 4 m is considered to have no large influence to the leakage from the Reservoir because it is within the range of natural fluctuation of groundwater level. However, the drawdown of localized groundwater level may happen, and it may cause settlement in a part of the base structure of the Reservoir. After completion of wells for the Project, seasonal adjustment of pumping rate will be needed if the extraordinary leaning of the base structures of the Reservoir is observed.

(4) Influence to Shallow Groundwater and Irrigation Canal

Production wells will be designed with screen portions in both deep and shallow aquifers. The upper aquifer is currently used for the existing population relying on groundwater. When the new wells proposed in this project are used for the SRWSS, the new production wells may affect the water levels in the existing wells. Table 2.38 shows the existing households and wells within 350 m of each proposed new production well.

Table 2.38 Resident and Water Source Numbers

Well ID	Resident	Water Source			Note
		Dug	Driven	Tube	(refer to Figure 2.14)
DW-01	4	1	4	0	in the WTP
DW-02	27	2	18	0	Test Well PP-3
DW-03	10	3	6	0	
DW-04	13	6	2	1	
DW-05	13	3	5	0	
DW-06	14	9	2	0	near Test Well PP-1
DW-07	13	3	6	0	
DW-08	11	2	3	0	
Total	105	29	46	1	

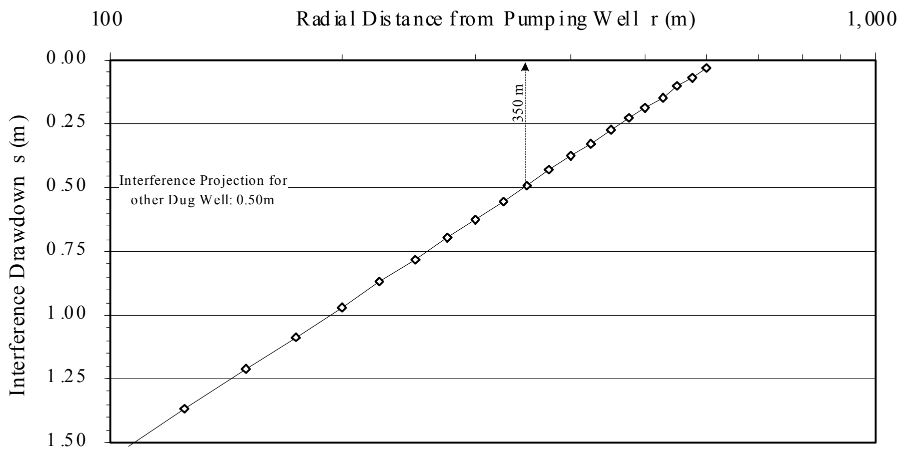

Figure 2.30 Radial Distance and Interference Drawdown Graph

The existing dug wells are typically constructed using a concrete pipe of 900 mm diameter with depth 2 to 5 m. The depth of water in the wells is estimated at about 0.5 to 1.5 m, and they are easily affected by variations in the surrounding water level. Other well types such as driven and tube wells may not be affected by the operation of production wells, because the critical water level including interference is still shallower than the pump head. Dug wells are generally used for households of two residents. It is estimated dug wells serving approximately 60 households may dry-up in the future as a result of the development of the well field.

In the case of prolonged operation using 8 wells (refer to Figure 2.14) the area with 0.5 m or larger drawdown from SWL (Static Water Level) will be located within 350 m radial distance from the production wells (refer to Figure 2.30). Figure 2.31 shows such a general profile of the predicted interference.

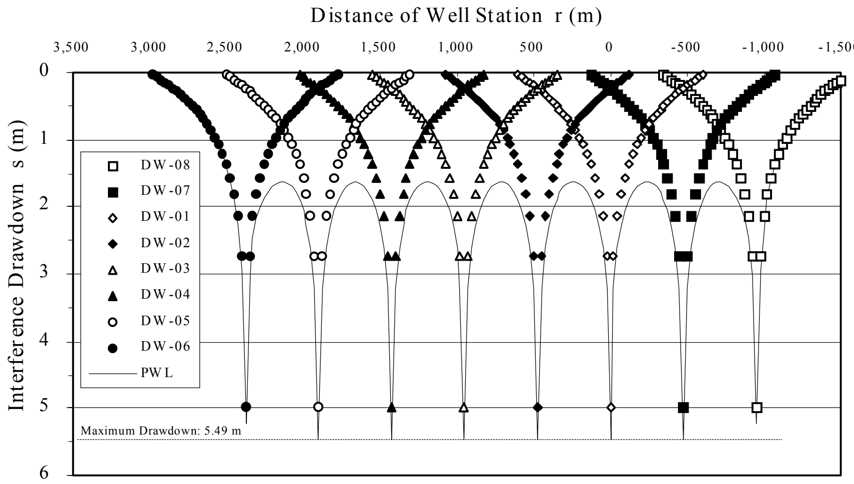

Figure 2.31 General Interference Drawdown Profile

It is essential that MIME as the implementing agency obtains the understanding and cooperation from the people in the affected area for implementing the Project. Thus, MIME agreed to take the following measures in the discussions with the explanatory mission for the draft report in early October 2003 as shown in (6) "countermeasure for dug wells near the proposed intake facilities", 5 "Other Relevant Issues", the Minutes of Discussions attached in Appendix 4-2.

- Before the project implementation, MIME will inform the affected residents of the Project through commune and individual meetings and will obtain full concurrence of all the afected residents for the Project implementation, including payment for service pipe connection fee and water tariff,
- During and/or after the project implementation, MIME will supply the drinking water to the affected residents from the proposed WTP at their request on condition that they will agree to pay the service pipe connection fee and the water tariff as set in the proposed water supply areas.
- MIME will install the required service pipe using the consumer flow meters to be procured under the Project to the affected residents at MIME's cost by tapping the distirbution pipelines (4 km) to be installed under the Project as schematized in Figure 2.32.

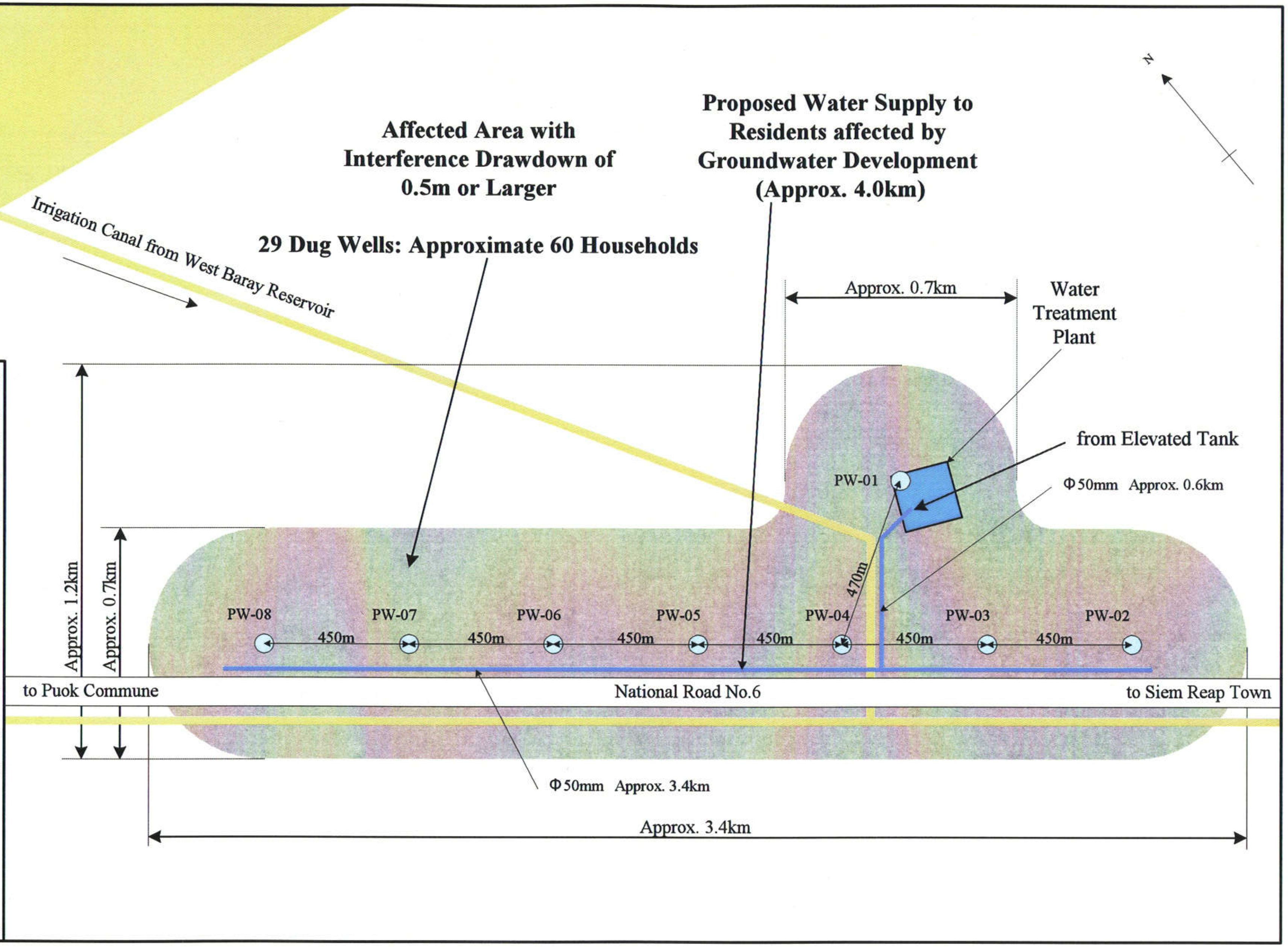

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Figure 2.32
Water Supply to the Affected Area with Interference Drawdown by Groundwater Development

(5) Influence to Irrigation Canal

Groundwater level of existing dug wells is higher at the area around the Irrigation Canal B discharging from the West Baray Reservoir and lower at the distant area from the Canal B. This phenomenon may indicate that shallow groundwater is predicted to recharge by irrigation water of Canal B. According to simple measurement of water discharge at Canal B on March 9, 2003, the discharge was estimated about 240,000 m^3/day. If part of the discharge recharges shallow groundwater, a total of planned pumping rate, 8,800 m^3/day is limited only to be about 3.7 percent of the discharge from the West Baray Reservoir. The pumping rate is very little compared with the total discharge for irrigation. Considering that the canal discharge is increasing with progress of dry season and it is spread in a wide irrigated area, the influence of groundwater exploitation to the irrigation canal is considered to be little.

(6) Meeting on Conservation of Angkor Wat Monument between the Study Team, APSARA and UNESCO

The study team had the meeting on conservation of the Angkor Wat Monument with the deputy director-general of APSARA, Dept. of Monument & Archaeology as well as UNESCO. Though buried ruins are not presently found at the proposed site for the WTP construction, in reference to Figure 2.24. APSARA and UNESCO requested that an excavation survey be carried out to determine that the proposed area is free of buried ruins prior the development. The excavation survey shall be conducted at the proposed WTP and well construction sites by MIME before January 2004 when the detailed design site survey will be commenced by the Consultants.

(7) Establishment of Groundwater Regulation in Siem Reap Town

This project for the groundwater-fed water supply system was planned as based on the study results of; i) the low cost for construction and maintenance, ii) easy operation of the system and iii) minimal environmental impact. In the last two to three years, tourist number to visit to Angkor Heritage site was dramatically increased by the annual rate of approximately 30%. The development plan for the hotel zone locating northeast side of town proper near the Angkor Heritage site is undertaking. When groundwater is selected as their water source, large amount of groundwater will be exploited that may affect much larger interference of water level in the heritage sites.

The F/S proposed the stepwise approaches for restriction of groundwater usage. They were; (a) stop commercial use, (b) stop deep wells and (c) stop mechanical withdrawal (by electric pump) for control of un-regulated development. Additionally, a user charge was also introduced for conservation of groundwater. This study rehabilitated the monitoring facilities of groundwater level and land subsidence. MIME should make use of the data collected to analyze the physical impact in the area. Comprehensive protection law of the environment, particularly in terms of protective of the Angkor Heritage, shall be prepared to establish groundwater usage, restriction of new construction of wells, and over-exploitation shall be considered.

(8) Land Expropriation and Squatter

At present, there is no squatter at proposed land area for construction of water source wells and WTP. The proposed groundwater development area is spread in public land and WTP construction site is owned by one person. The land expropriation of the proposed construction areas shall be taken care of by MIME, based on the Cambodian laws and rules.

(9) Endangered Species at Proposed Development Area

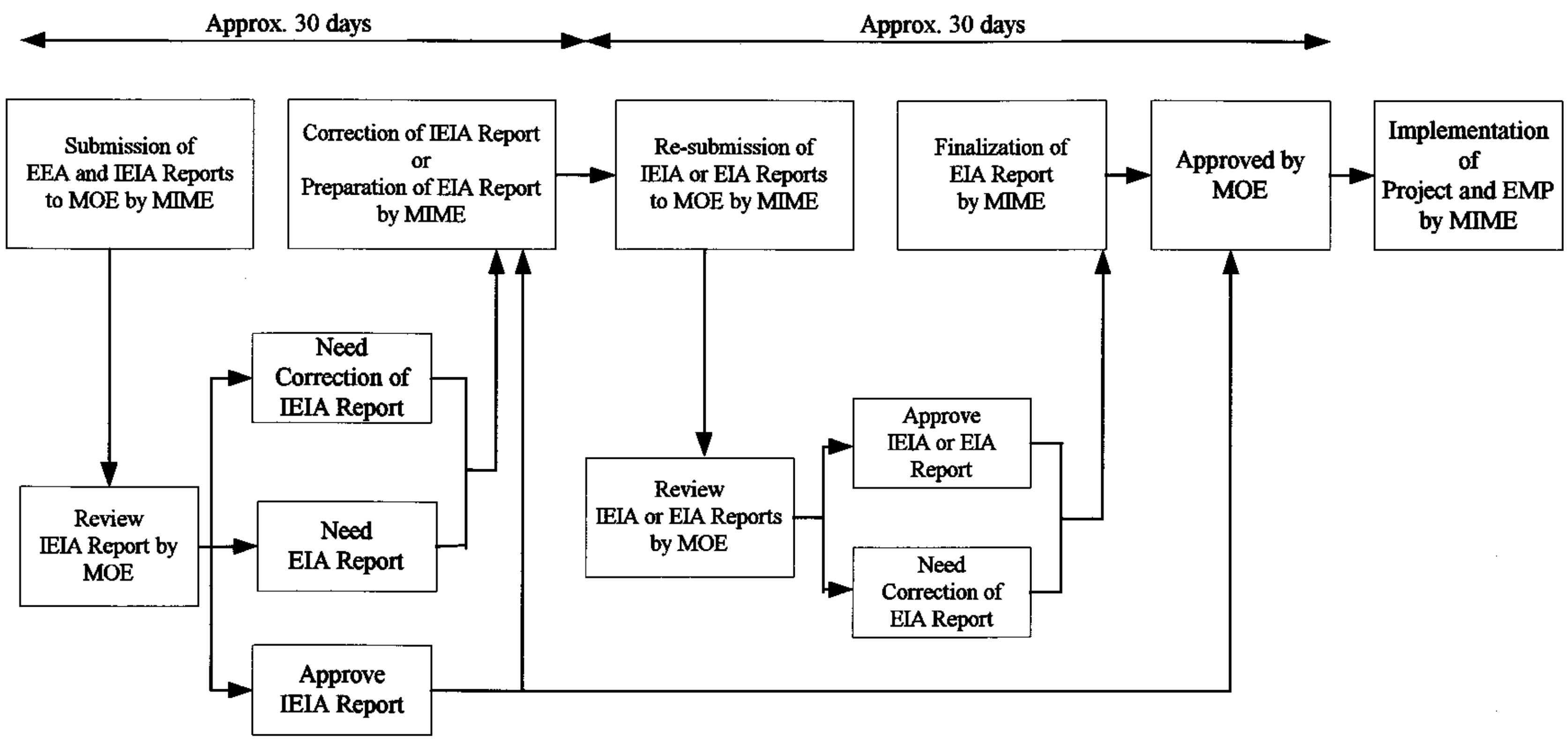
Information on survey reports and conservation laws for endangered species at the proposed development area were collected through the interviews with provincial and environmental offices. Based on the collected information results, there were no conservation laws and no endangered species, therefore, there are no problems on endangered species at proposed development area.

(10) EIA (Environment Impact Assessment) Procedures

Based on the Cambodian laws (Sub-degree on EIA, 11 August 1999), all projects are required to submit and pre-authorize reports of an Initial Environment Impact Assessment (IEIA) and/or an Environment Impact Assessment (EIA) to Cambodia Development Council (CDC), the Ministry of Environment (MOE) or provincial environmental Office (PEO). These procedures are shown in Figure 2.33.

As the implementation agency for the Project, MIME is required to submit the IEIA or the EIA documents to MOE and pre-authorize from the office. Generally, it needs about two months as processing period from the submission to the pre-authorization.

The Study Team has recently confirmed that MIME submitted the required documents to MOE for their evaluation and MOE has given the clearance to MIME.



Notes: EEA (Environment Examination Application)
IEIA (Initial Environment Impact Assessment)
EIA (Environmental Impact Assessment)
EMP (Environmental Management Plan)

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Figure 2.33 EIA Procedures