ANNEX 3.4.1

HYDROGEOLOGY

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

FINAL REPORT
Vol. III SUPPORTING REPORT

ANNEX 3.4.1 HYDROGEOLOGY

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1. Introduction

Hydrogeological study was started from January 1997 and completed by January 2000 with the groundwater simulation. The investigation method included an aerial photo interpretation of which material was prepared by JICA, monthly simultaneous groundwater level observation for approximately 100 existing wells, and finally groundwater simulation study.

The continuos automatic recording has been going on for the groundwater level of 8 observation wells and land movement of 4 observation wells. These wells were constructed by February 1998. All the results of simultaneous groundwater level observation and monitoring record were effectively used for the study of groundwater resources by groundwater simulation as well as the geological survey result.

This supporting report is compiled the necessary data regarding hydrogeological investigation result until November 1999. The simulation analysis is mentioned in Main Report, Chapter 4.2.4.

The groundwater chemical analysis was carried out to understand their quality in the study area. It was mainly carried out in the beginning stage of the Master Plan study from December 1996 to June 1997 for the existing wells. The result is shown in Data Book..

The monitoring system by the continuos and automatic recording for the groundwater level and land subsidence or movement were established by the beginning of February 1998, and they have been working until now. All the available data of the monitoring station collected by August 1999 are also attached in this report (Attachment-1).

The additional hydrological investigation and collection of meteorological data were continued from February 1999 to November 1999 for the analysis of hydrogeology and groundwater simulation. The investigation methods included iron contents analysis for the existing wells in and around the possible well field as well as the electromagnetic survey. The result is described in this report, Chapter 5.4.

The result of the drilling of two pilot wells including their pumping test conducted on November to December 1999 is described in the Main Report.

2. Hydrogeological Data Collection and Analysis

Both the previously collected and newly acquired documents were reviewed for the geological and hydrological interpretation. The lists of collected documents are in Attachment-2.

The analysis and interpretation were made mainly by using the latest data and the available information such as aerial photos and water management in the Angkor area (June 1993). The new information from the existing data for the geological and hydrological study can be summarized as 1) the old river course of the Siem Reap River may be located at the west side of the present river course starting from about 10 km upstream of Angkor area, and 2) the Angkor Wat and Angkor Thom area may be artificially raised by using excavated materials from moat.

The information that the old river course is located at the western side of the present river course, was carefully checked by core drilling and electric sounding method. It was clarified by the investigation that the location of the original river course may be near the west corner of the West Baray.

The excavation depths of the existing wells are usually within 5 meters. However, the depth of the wells Nos.86, 87, and 88 located at Angkor Thom area reached 8 to 9 meters, although the course of the groundwater level is well correlate with that of surrounding area. Therefore, the area might be artificially reclaimed in the period of the Yasodharapura of Yasodvarman I (AD 889 to 910).

3. Interpretation of Aerial Photos for Hydrogeological Study

Two kinds of aerial photos are available for the project area, i.e., 1) photos taken in 1992 by FINMAP, which are kept by Mekong Committee, and 2) photos taken in February 1997 by JICA Topographic Mapping Team.

1) Photos taken in 1992

These photos, which are in scale of 1:25,000 were collected in the beginning of January 1997. These are used for the following purposes.

- Interpretation of land use in the study area
- Preliminary interpretation for geology and hydrogeology
- Bird's-eye view to check for the site conditions at the beginning of the field works

The interpretation of aerial photos was conducted for environmental, geological and hydrogeological studies. Main items checked were land use, topography, accessibility, river and canal distribution, housing condition, and so forth. After the interpretation of these photos, site reconnaissance of the study area was carried out to check whether there is some difference or not after the photos were taken in 1992.

2) Photos taken in February 1997

These photos, which are in the scale of 1:25,000 were borrowed in May 1997 from the JICA Office in Tokyo. These photos show the present features in February 1997. Both photos of Mekong Committee and JICA Topographic Mapping Team are mutually checked to find whether there is any change or not during the past five years from 1992 to 1997. The result shows that the road distribution is developed at several places and several new hotels were constructed along the National Road No.6.

4. Site Reconnaissance for Groundwater Use

Most of the people in Siem Reap region are using shallow groundwater by dug well, driven well, and hand pump installed well. Most houses in Siem Reap Town have hand pump well or driven well.

In the rural area, open dug well without protection and driven well with concrete lining are commonly used. Hand pump wells that are mostly donated by NGO's are sporadically seen. The hand pump wells may not function well in future for shortage of the cost required for securing spare parts. In fact, the two hand pump installed wells of No.13 and No.66 among the 17 hand pump wells were out of order after the first well inventory work in January 1997.

The number of dug wells and hand pump wells is rapidly increasing since 1992, mostly by NGO's and foreign assistance. Deep tube wells equipped with motor pump in hotels are mostly in very good conditions except with high iron content.

5. Hydrogeology

5.1 Explanation of Geology

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

Alluvial deposits are of coarse sand in the northern part of the study area, and fine sand to silt along the shore of Lake Tonle Sap. The color is pale red to pale gray. Topsoil of cultivated upland, paddy field and the bottom of the Barays are organic clay and silty clay. N-value of Alluvial deposits ranges from 10 in part and 30 in general. The lower N-value of 10 will be clayey to silty sand. Soil sample for the laboratory test was mostly taken from the sections of lower N value. Total thickness of alluvial deposits is 20-30 m in the south area, and 10-20 m in the north area.

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. Firstly, the area was filled with material excavated from the moats of Phnom Baken temple in Yashdarapula period. Secondly, the excavated soil of the moat in Angkor Thom was added on the first layer. Then, the excavated material of Angkor Wat was finally spread on it. Its thickness might be 2 m in average, judging from the trench record of Banteai Kdei study group of Sophia University. This area covered the most of Angkor Heritages. The three layers of reclamation soil are of fine particles with low permeability.

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. N value of the layer is more than 30 in general and very rarely small, below 20.

Before West Baray Construction in the 12th century, it is believed that the former Siem Reap River courses was located on the west side of West Baray near the present river course of Ou Phaat River. The 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. The groundwater along the former river course has, therefore, very low content of iron with pale gray color sand.

Pleistocene sediments are of pale red Pliocene clay stone. N value is more than 50. Permeability coefficient is expected to be in very low degree.

Mesozoic sedimentary rocks comprise sandstone in general. Alternation of sandstone and shale are developed very frequently. Shale and tuff breccia are developed in small parts only. Tuff breccia is mostly developed in the southeast area. Ryolitic tuff is narrowly developed at the western side. It was found out by the WT 4 drilling core.

Paleogene volcanic and igneous rocks are granodiorite in the West Baray, and andesite dykes in the north east area.

5.2 Well Inventory

In order to clarify the groundwater using condition, fluctuation of groundwater level and its quality in the area, 96 wells in total are selected from the following criteria.

1) Well was selected as representative one in each site.
2) Density of the well in each area was evenly distributed as much as possible.
3) Well was located along good access road even in monsoon season.
4) Well was selected from various well types.

Result of the Simultaneous Groundwater Level Measurement

The selected existing 96 wells were for the purpose of the measurement of the groundwater level and water quality monitoring. The location is shown in Figure 5.2.1 "Location map of existing wells". More information by the well survey for monitoring purposes is given below:

Table 5.2.1 Selected Existing Wells for Monitoring

Well type	Nos. (Level survey)	Purposes for monitoring
Open dug well without protection	14 (9)	GWL and quality test
Open dug well with protection	54 (47)	GWL and quality test
Hand pump	17 (16)	quality test
Deep tube well(l<40m)	8 (8)	quality test
Deep tube well(40m<l)	3 (3)	quality test
Total	96 (83)	

The elevations of 83 well were surveyed in 1997 and 1998. The level survey work of 100 points had been completed including 8 drilling spots and 9 places for hydrological stations such as Tonle Sap staff gauge, Siem Reap River gauge and West Baray.

The detail of the level survey is described in Annex 3.1.1 “Topographic Survey”.

The simultaneous groundwater level measurement has been carried out from January 1997 to June 1997, and from February 1998 to November 1999. "Groundwater contour map from January 1997 to November 1999" is shown in Attachment-3.

These records indicate the following regional characteristics:

Well Group: No. 56, No. 84, No. 86, No. 88, No. 89

These wells are located in the vicinity of Angkor Heritage area. As explained in clause 5.1, the area is covered with thin reclamation layer of aquiclude in Khmer Kings by 3 times. In addition the area is located near the French Weir, where the river is dammed up by 5 or 6 m to divert the water to West Baray in rainy season. Due to artificial surface water raise at the French Weir and very flat topography with very limited drains and ditches of artificial moats, the groundwater is recharged very locally. The GWL fluctuation of 4 to 5 m was caused by from the above mentioned special conditions.

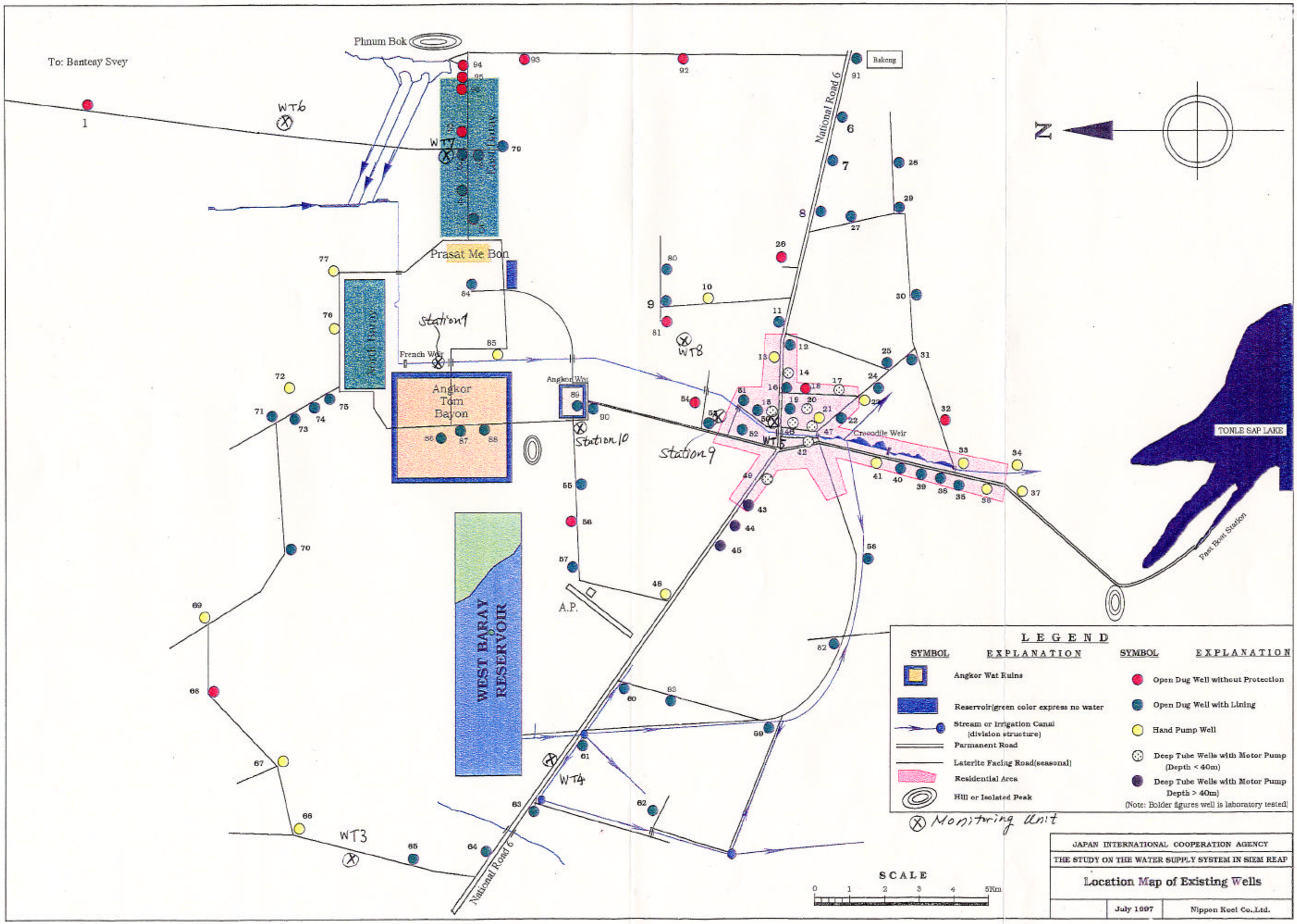


Figure 5.2.1 Location Map of Existing Wells

Well Group: WT5, No. 18, No. 19, No. 22, No. 28

These wells are located in the town area. The annual fluctuation reaches up to 4m in maximum for WT5 well, where several deep tube wells are concentrated. The wells are mostly affected by groundwater exploitation from shallow wells. Probably, total daily withdraw reaches more than 7,000 to 10,000 cubic meters. However, as the permeable sandy top layer infiltrates rainfall easily and percolation from the river in full season by dammed up of the Crocodile Weir, the lowest GWL occurs from April to May, which is high water consumption period in dry season. It is noted that the neighboring and surrounding wells of Siem Reap Town are not having much fluctuation by the withdraw from Siem Reap Town.

Well Group: No. 28, No. 29, No. 30, No. 35, No. 64, No. 90, No. 91, WT7

Annual GWL fluctuation of these wells ranges mostly from 2 m to 3 m, which is slightly lower than the average 2.4 m. Because they are located in the area under control hydrogeological boundary and/or the shoreline of the Lake without large artificial exploitation.

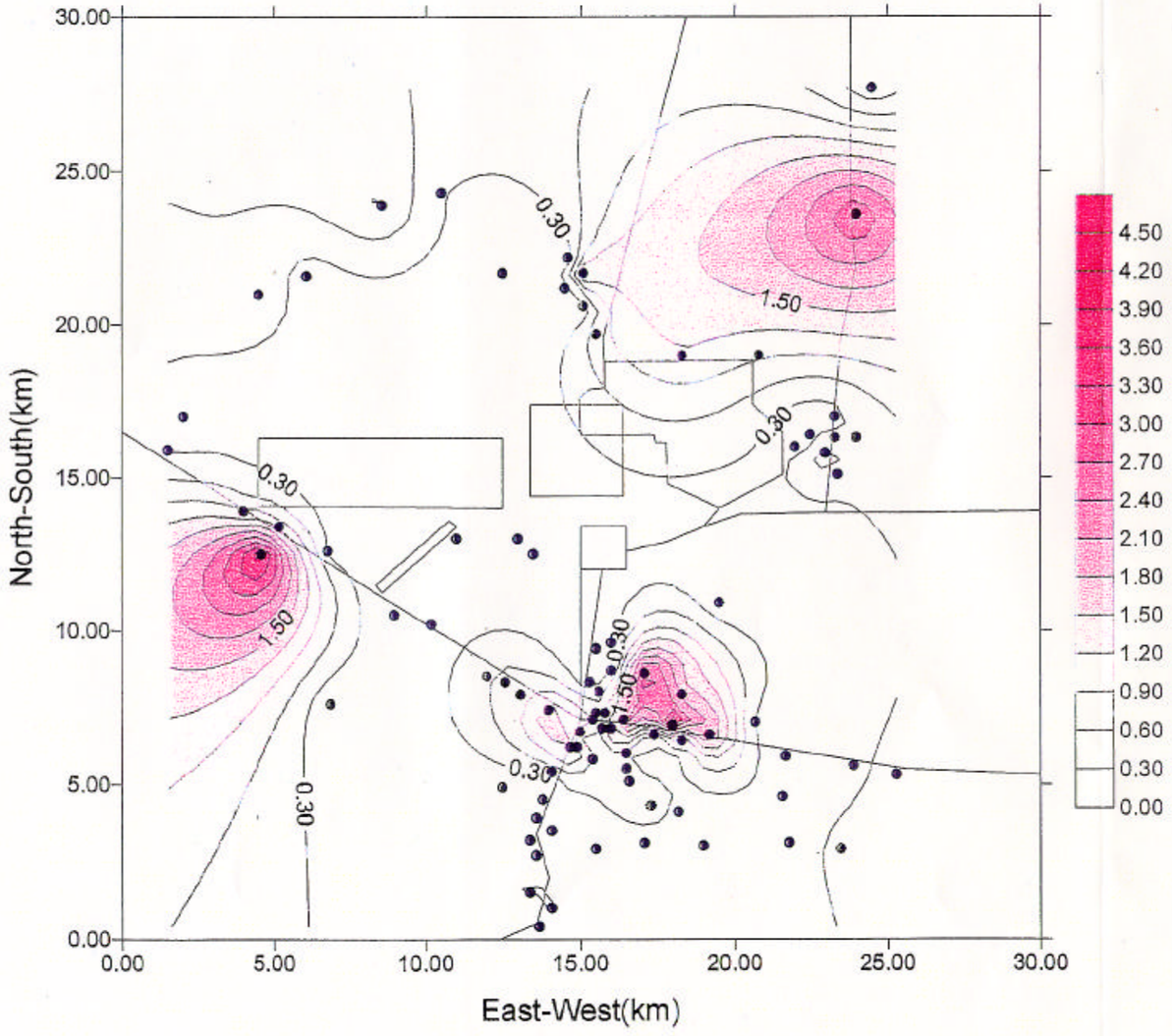
Well Group: No. 3, No. 27, No. 31, No. 32, No. 38, No. 39, No. 40, No. 52, No. 59, No. 60, No. 61, No. 63, No. 83D, No. 96, WT4

These wells are characterized by the surface water interference such as the Roluos River and the downstream reaches of the Siem Reap River, constant in and out flow of groundwater without large withdraw along the former river course, and the downstream reaches of the Siem Reap River course.

5.3 Result of VLF Electromagnetic Prospecting in December 1998

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, where it is expected to have large quantity of good quality groundwater with low iron.

The result is shown in Figure 5.3.1. 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 insection of road No.6 and airport road to 2 km east of WT4 showed such resistivity. The area having the resistivity value less than 10 ohm/m may be occupied by contaminated groundwater with iron, and/or by unfavorable layer containing much clayey materials or finer particles. It might be younger than that of the lower resistivity layer.



Contour map of Fe 1997 (unit:mg/litter)

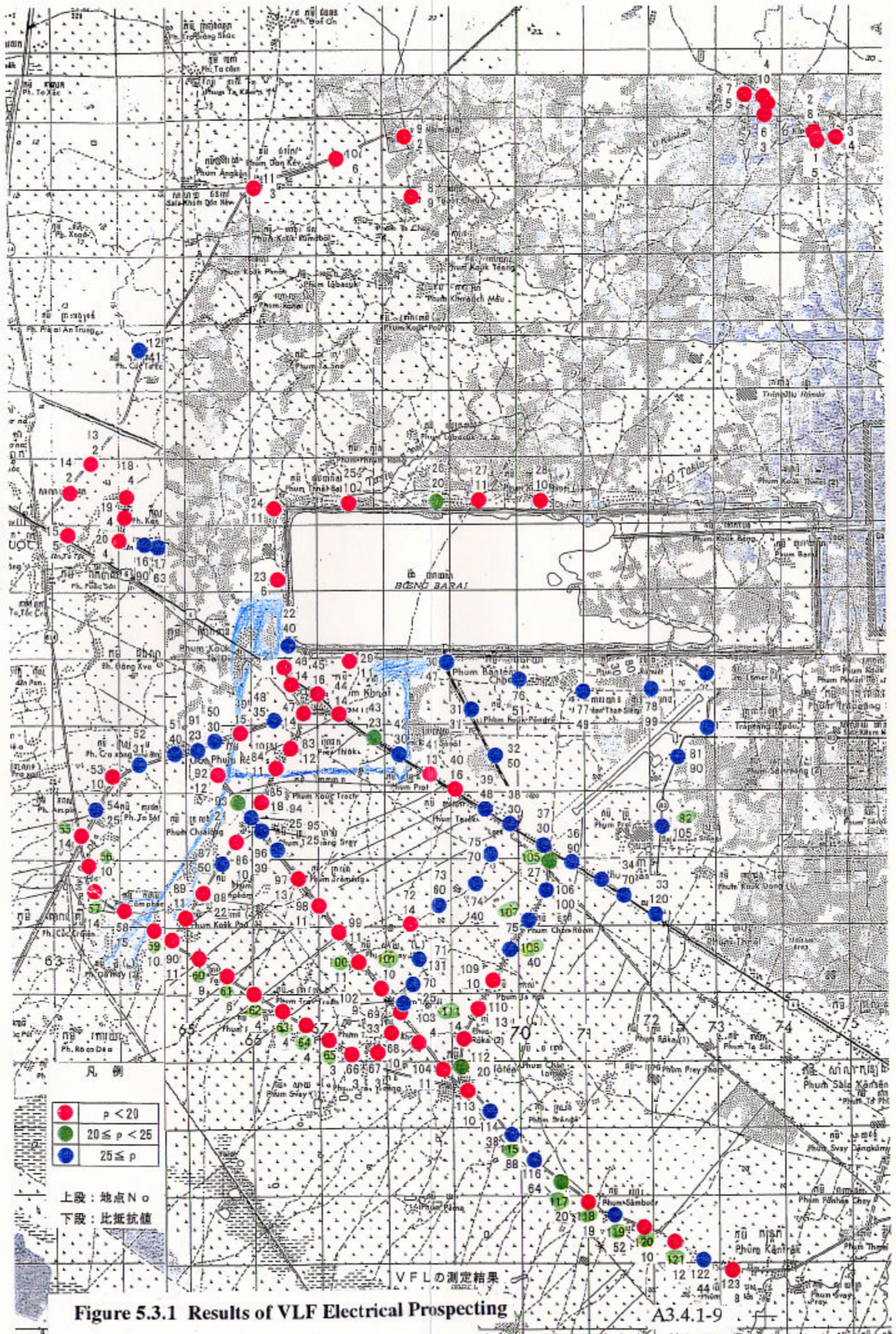


Figure 5.3.1 Results of VLF Electrical Prospecting