CHAPTER 3

SUBSURFACE GEOLOGIC SETTING

The objective of this study is to find type and thickness of aquifers that were identified by subsurface geologic setting. The geological data and geophysical survey were analyzed and interpreted. The geological data included lithologic logs and stratigraphic units that defined and classified type of aquifers. The geophysical survey are resistivity survey, vertical electrical sounding, these data determined type and thickness of aquifers. The results can be constructed to hydrostratigraphic model.

3.1 Stratigraphic units

The study area is located in Quaternary deposits of the southern part of Chiang Mai basin. The Quaternary deposits can be divided into 2 groups namely, low terrace and alluvial deposits. The alluvial deposits of Mae Kuang River consist of clay, silt and sand.

Lithologic logs data of 21 wells were recorded by Department of Groundwater Resources (DGR), 5 wells by Department of Environmental Promotion Quality (DEPQ), and 30 wells by Chiang Mai University (CMU). The locations of these wells are shown in Figure 3.1 and Table 3.1. All lithologic log data are shown in Appendix A. These data have been used in delineating the subsurface geology. Three sequences are proposed as Sequence I of depth 0-20 meter, Sequence II of depth 20-45 meter, and Sequence III of depth 45-100 meter. Each sequence generally consists of clay, sand and gravel with difference detailed properties.

The stratigraphic correlation of cross-section, A-B, C-D, E-F, G-H, I-J, K-L and M-N, are shown in Figure 3.2, Figure 3.3, Figure 3.4, Figure 3.5, Figure 3.6, Figure 3.7, and Figure 3.8. Three identified sequences were as followed:

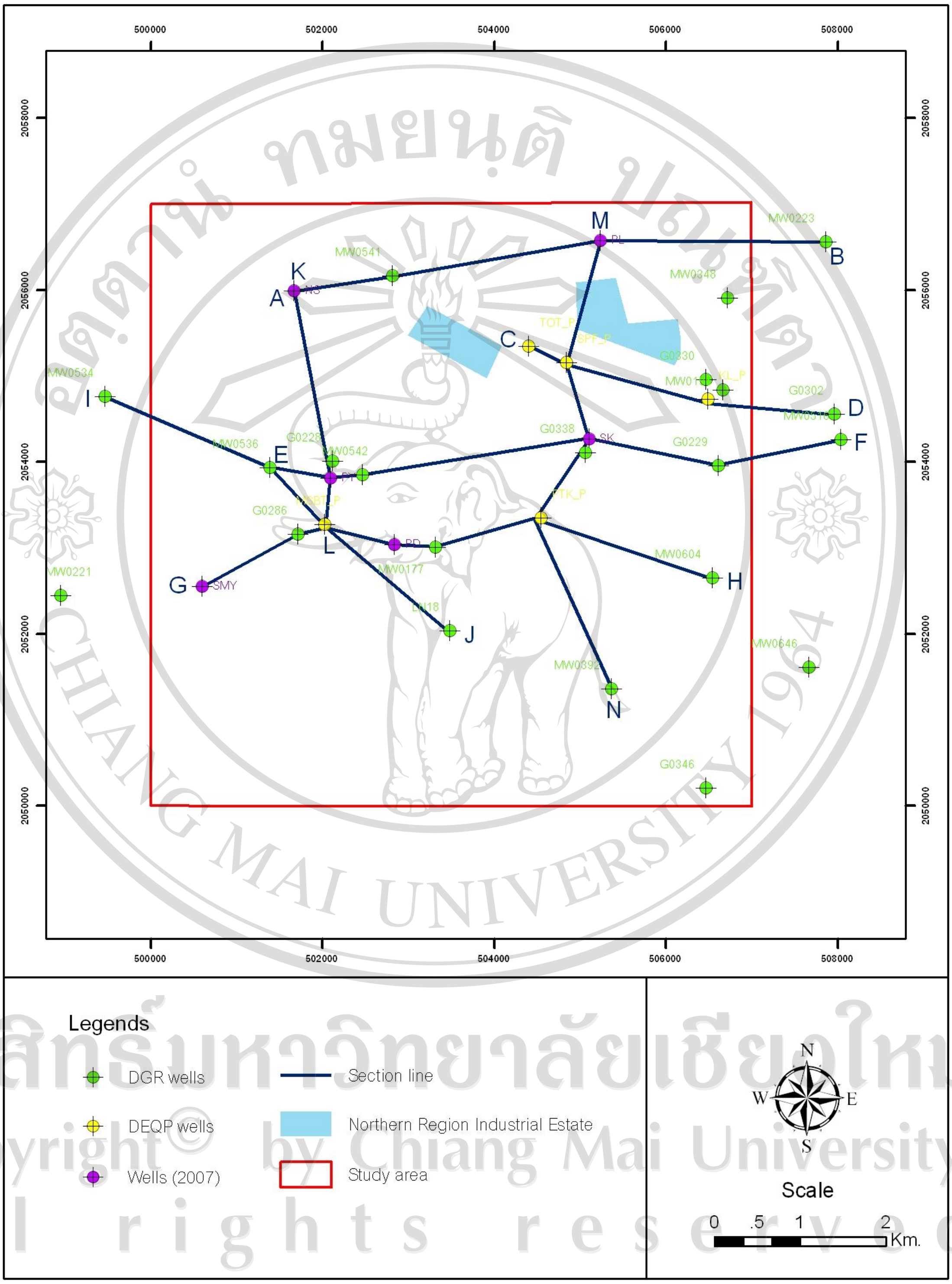

Figure 3.1 Location of wells and geologic cross sections.

Table 3.1 Location of lithologic log wells.

Well Number	Grid (UTM WGS 47N)		Record Owner	Well Number	Grid (UTM WGS 47N)		Record Owner
	East	North			East	North	
G0228	502116	2054005	DGR	PL01	505177	2056607	CMU
G0229	506616	2053955	DGR	PL02	505175	2056608	CMU
G0286	501716	2053155	DGR	PL03	505184	2056610	CMU
G0302	507966	2054555	DGR	PL04	505183	2056611	CMU
G0330	506466	2054955	DGR	SK01	505063	2054307	CMU
G0338	505066	2054105	DGR	SK02	505062	2054306	CMU
G0346	506466	2050205	DGR	SK03	505106	2054280	CMU
LN18	503488	2052032	DGR	SK04	505105	2054279	CMU
MW0177	503316	2053005	DGR	SMY01	500595	2052552	CMU
MW0195	506663	2054832	DGR	SMY02	500596	2052551	CMU
MW0221	498956	2052445	DGR	SMY03	500608	2052539	CMU
MW0223	507866	2056555	DGR	SMY04	500609	2052538	CMU
MW0348	506716	2055905	DGR	PD01	502828	2052993	CMU
MW0392	505366	2051355	DGR	PD02	502829	2052992	CMU
MW0516	508036	2054255	DGR	PD03	502835	2052984	CMU
MW0536	501386	2053935	DGR	PY01	502085	2053798	CMU
MW0541	502816	2056160	DGR	PY02	502085	2053799	CMU
MW0542	502466	2053845	DGR	PY03	502086	2053800	CMU
MW0544	499466	2054755	DGR	PY04	502096	2053817	CMU
MW0604	506546	2052645	DGR	PY05	502097	2053818	CMU
MW0646	507666	2051605	DGR	PY06	502097	2053819	CMU
KL_P	506491	2054725	DEQP	NS01	501706	2055923	CMU
MSBT_P	502026	2053272	DEQP	NS02	501706	2055922	CMU
SPF_P	504843	2055157	DEQP	NS03	501706	2055921	CMU
TOT_P	504407	2055346	DEQP	NS04	501684	2055912	CMU
PTK_P	504549	2053348	DEQP	NS05	501685	2055912	CMU
PK01	504615	2053312	CMU	NS06	501686	2055912	CMU
PK02	504615	2053312	CMU	MY01	505670	2054540	CMU

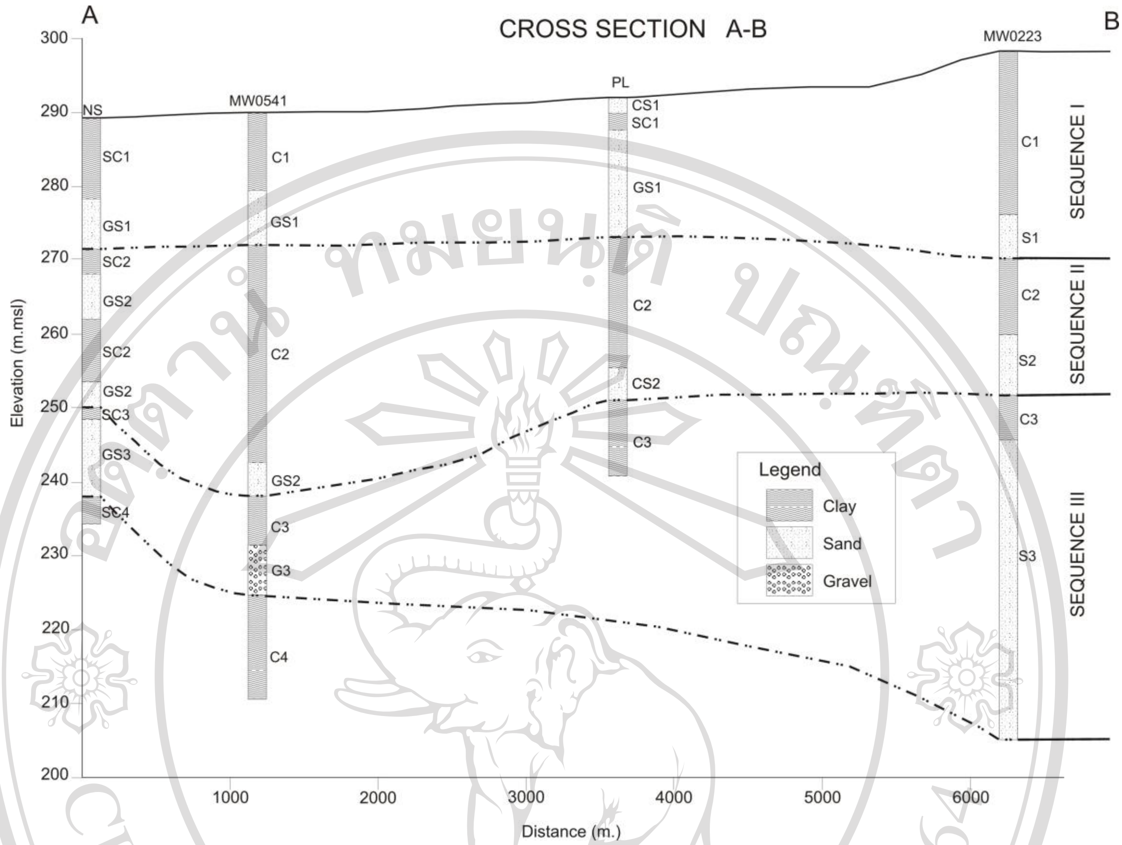

Figure 3.2 Subsurface geologic cross-section of line A-B.

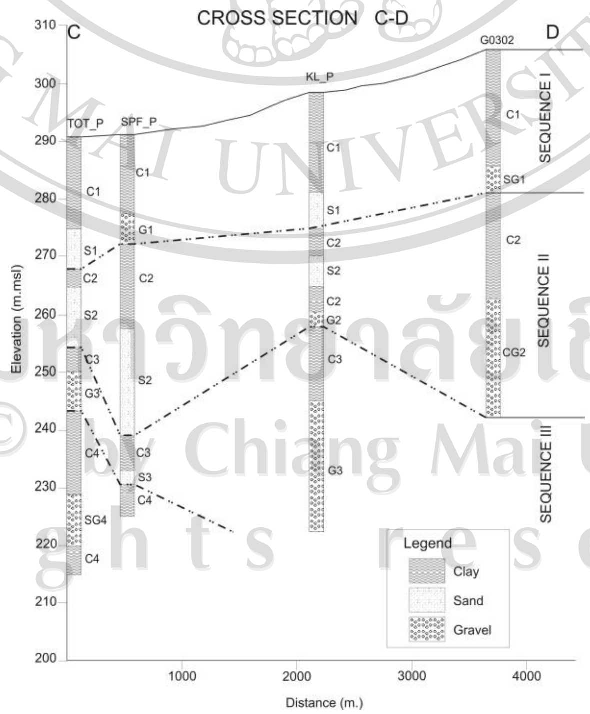

Figure 3.3 Subsurface geologic cross-section of line C-D.

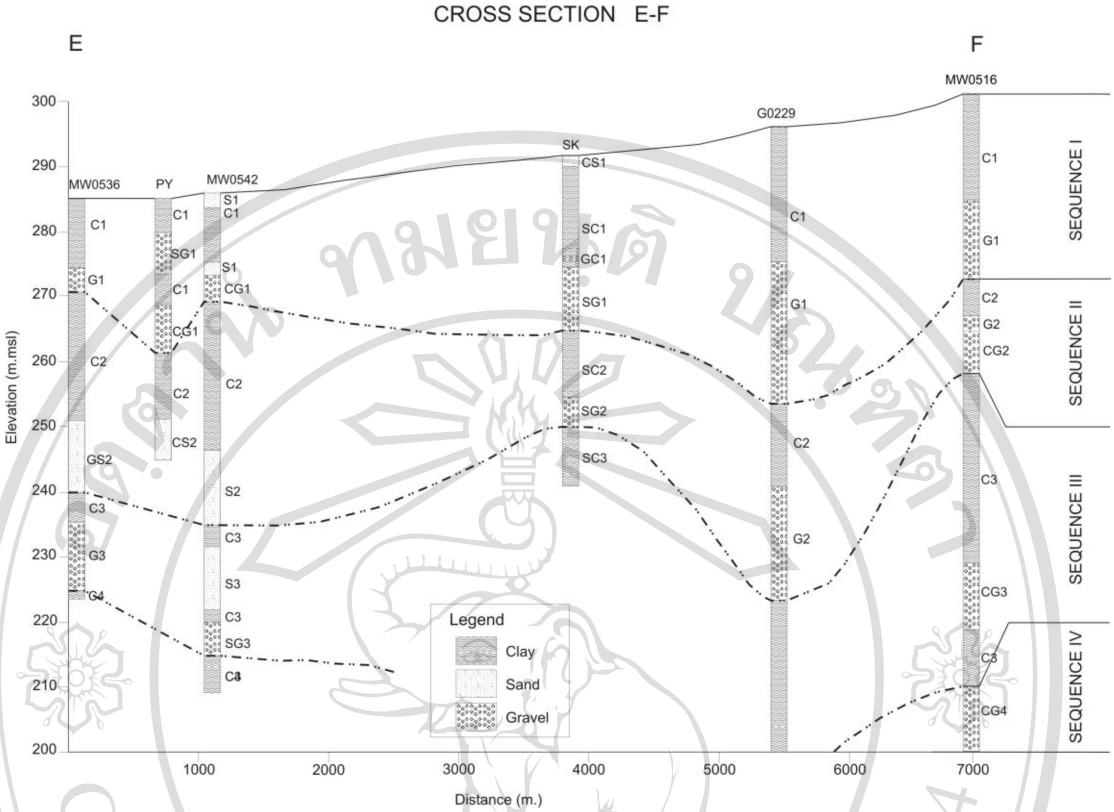

Figure 3.4 Subsurface geologic cross-section of line E-F.

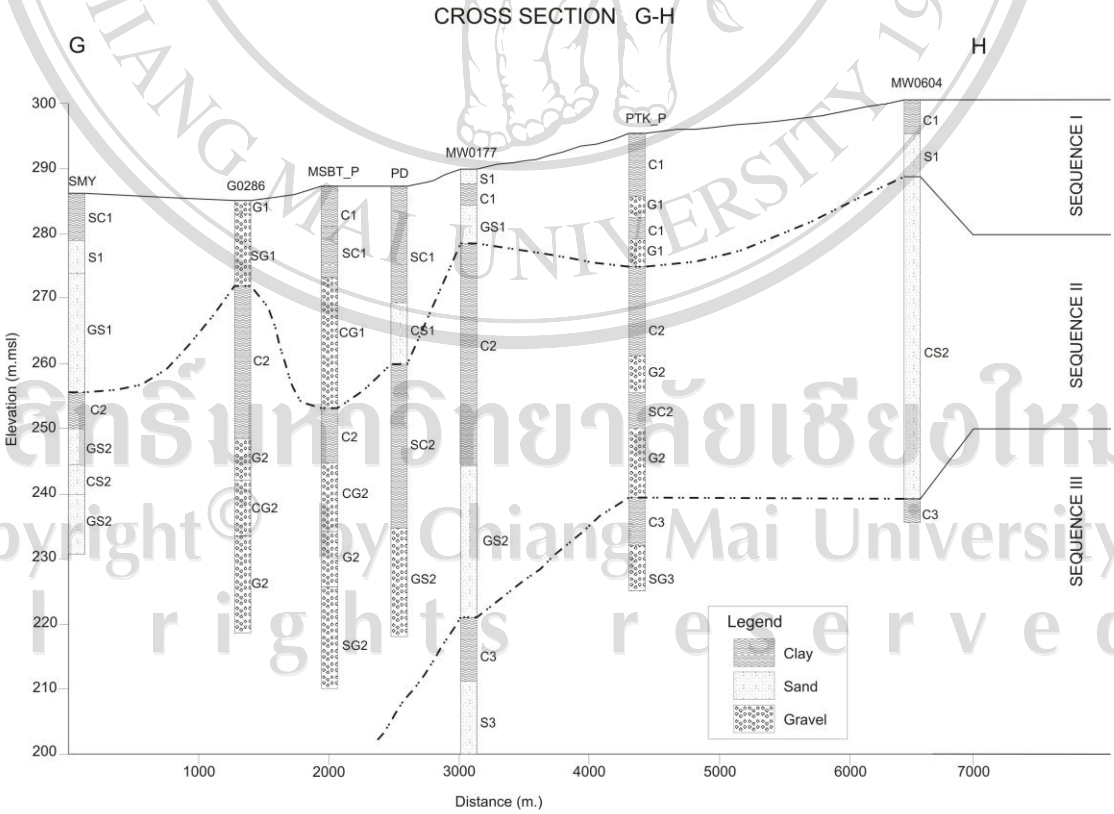

Figure 3.5 Subsurface geologic cross-section of line G-H.

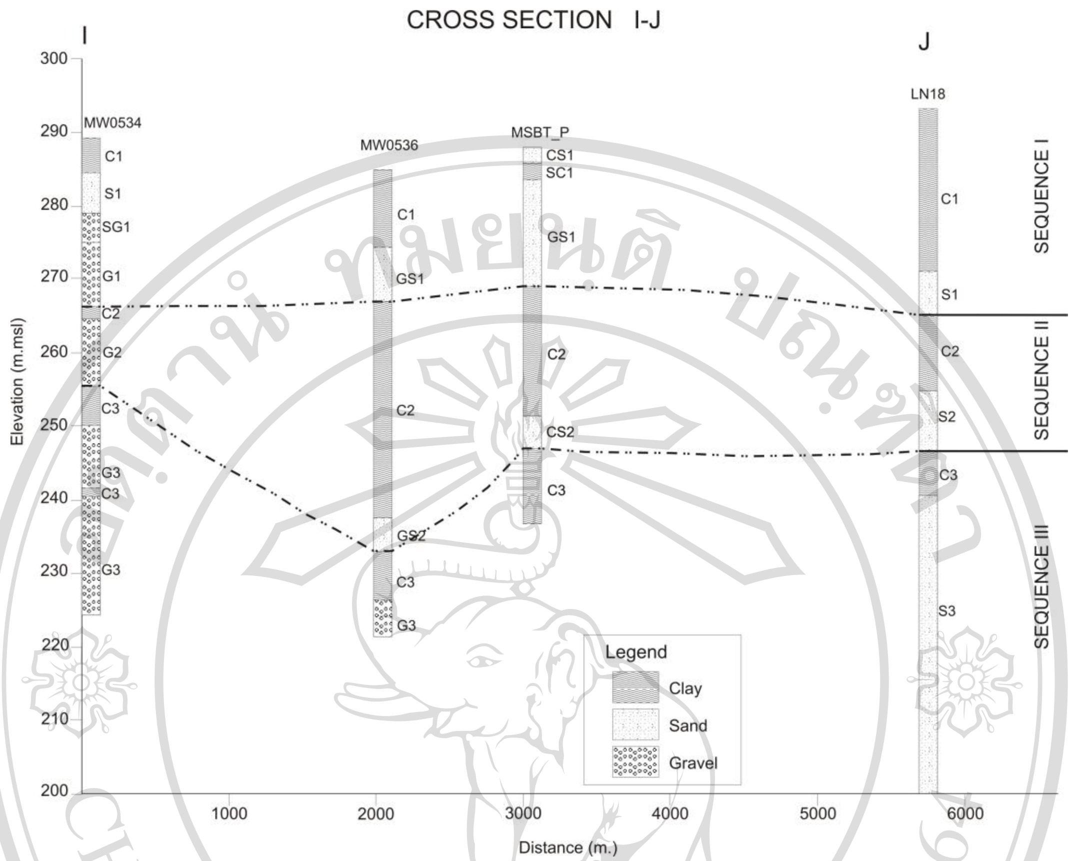

Figure 3.6 Subsurface geologic cross-section of line I-J.

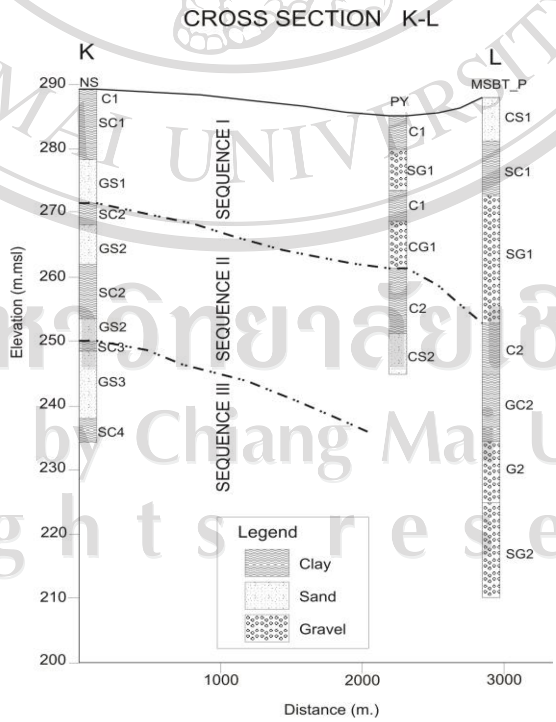

Figure 3.7 Subsurface geologic cross-section of line K-L.

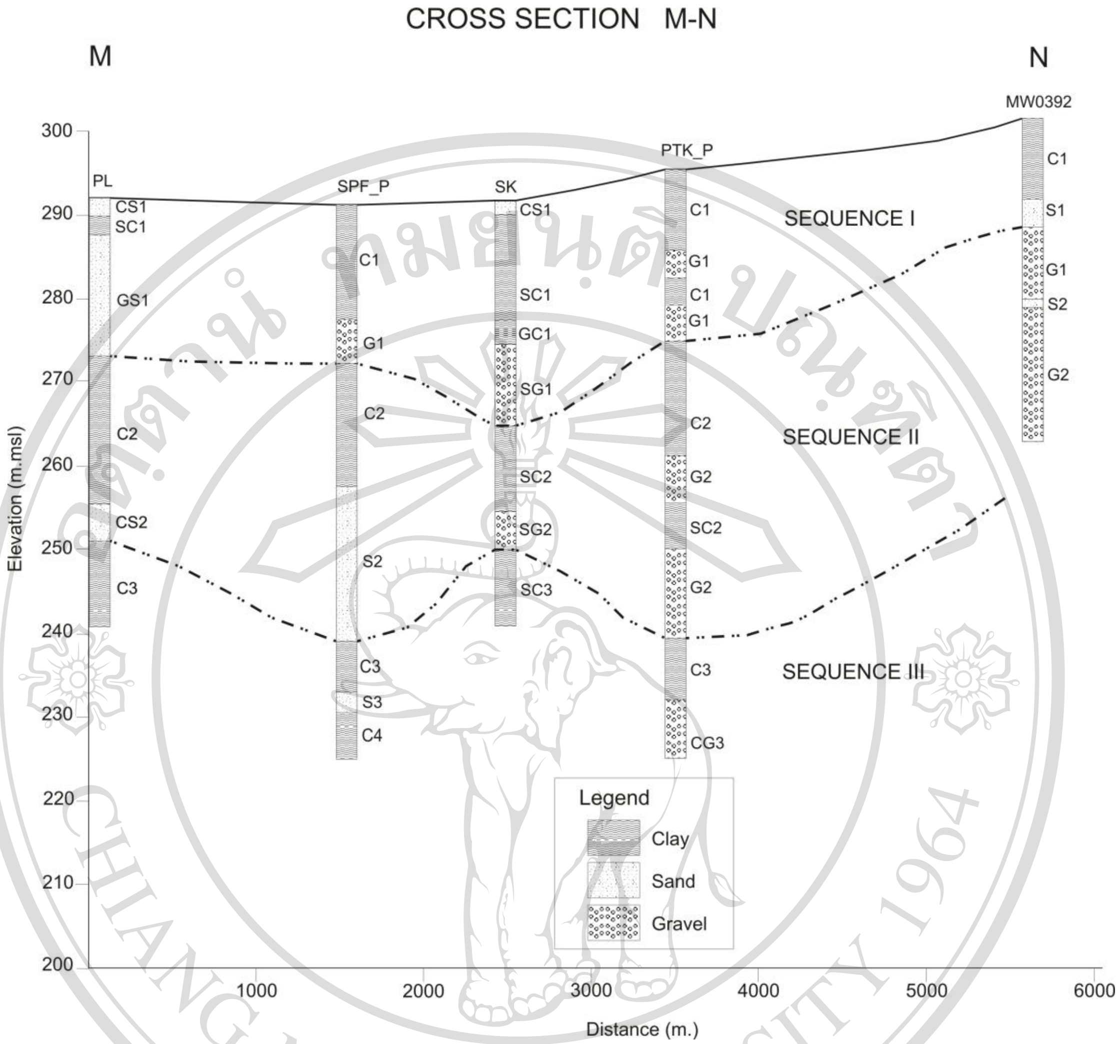

Figure 3.8 Subsurface geologic cross-section of line M-N.

Sequence I

This sequence was founded at depth 0 to 20 meters. The thickness ranges from 3 to 20 meters. There can be divided in three lithofacies as followed:

<u>1. Clay 1 (C1)</u>

This lithofacies mainly consisted of clay sediment. The thickness variable ranges from 3 to 20 meters. This facies can be divided into two types as followed:

Clay (C1); composed of 100 % of clay, light brown color, high plasticity. Thickness ranges from 3 to 15 meters.

Sandy clay (SC1); composed of 15% of sand and 85% of clay, light brown color, high plasticity. Thickness ranges from 3 to 12 meters.

2. Sand 1 (S1)

This lithofacies mainly consisted of sand sediment. Thickness ranges from 3 to 18 meters. This facies can be divided three types as followed:

Sand (S1); composed of 100 % of sand, yellowish brown color, fine to medium grained and well sorted. Thickness is about 3 to 5 meters.

Clayey sand (CS1); composed of 30% of clay and 70% of sand, yellowish brown color, fine grained and and well sorted. Thickness is about 2 to 3 meters.

Gravelly sand (GS1); composed of 10% of gravel and 90% of sand, yellowish brown color, fine to very coarse grained and poorly sorted. Thickness is about 3 to 18 meters.

3. Sandy Gravel (SG1)

This lithofacies mainly consisted of gravel sediment. Thickness ranges from 3 to 15 meters. This facies can be divided in three types as followed:

Gravel (G1); composed of 100% of gravel, yellowish brown color, granule to pebble grained and poorly sorted. Thickness ranges from 5 to 18 meters.

Sandy gravel (SG1); composed of 30% of sand and 70% of gravel, grayish orange color, granule to pebble grained and poorly sorted. Thickness ranges from 3 to 8 meters.

Clayey gravel (CG1); composed of 5% of clay and 70% of gravel, grayish orange color, granule to pebble grained and moderately sorted. Thickness ranges from 3 to 15 meters.

Sequence II

This sequence was founded at depth 20 to 45 meters. Thickness ranges from 5 to 25 meters. There can be divided into three lithofacies as followed:

1. Clay 2 (C2)

This lithofacies mainly consisted of clay sediment. The thickness variable ranges from 1.5 to 8 meters. This facies can be divided in three types as followed:

Clay (C2); composed of 100% of clay, yellowish brown and grayish orange colors, high plasticity. Thickness ranges from 4 to 8 meters.

Sandy clay (SC2); composed of 15% of sand and 85% of clay, light brown color, high plasticity. Thickness ranges from 6 to 8 meters.

Gravelly clay (GC2); composed of 30% of gravel and 70% of clay, light brown and yellowish orange colors, moderately plasticity. Thickness ranges from 1.5 to 4 meters.

2. Sand 2 (S2)

This lithofacies mainly consisted of sand sediment. Thickness ranges from 0.5 to 6 meters. This facies can be divided in three types as followed:

Clayey sand A (CS2); composed of 20% of clay and 80% of sand, yellowish brown, light brown and grayish orange colors, fine to medium grained and well sorted. thickness is about 0.5 to 2 meters.

Clayey sand B (CS2); composed of 10% of gravel, 15% of clay and 75% of sand, yellowish orange color, fine to very coarse grained and poorly sorted. Thickness is about 2 to 5 meters.

Gravelly sand (GS2); composed of 10% of gravel and 90% of sand, yellowish brown color, fine to very coarse grained and poorly sorted. Thickness is about 5 to 15 meters.

3. Gravel 2 (G2)

This lithofacies mainly consisted of gravel sediment. The thickness variable ranges from 3 to 15 meters. This facies can be divided in three types as followed:

Gravel (G2); composed of 100% of gravel, yellowish brown color, granule to pebble grained and poorly sorted. T Thickness ranges from 3 to 15 meters.

Sandy gravel (SG2); composed of 40% of sand and 60% of gravel, grayish orange and yellowish orange colors, granule to pebble grained and poorly sorted. Thickness ranges from 3 to 15 meters.

Clayey gravel (CG2); composed of 5% of clay and 95% of gravel, grayish orange color, granule to pebble grained and moderately sorted. Thickness ranges from 2 to 5 meters.

Sequence III

This sequence was founded at depth 45 to 100 meters. The thickness ranges from 5 to 50 meters. There can be divided into three lithofacies as followed:

1. Clay 3 (C3)

This lithofacies mainly consisted of clay sediment. The thickness variable ranges from 1.5 to 8 meters. This facies can be divided in two types as followed:

Clay (C3); composed of 100% of clay, yellowish orange color, high plasticity. Thickness ranges from 3 to 12 meters.

Sandy clay (SC3); composed of 15% of sand and 85% of clay, yellowish orange and grayish orange color, high plasticity. Thickness ranges from 1.5 to 10 meters.

2. Sand 3 (S3)

This lithofacies mainly consisted of sand sediment. The thickness variable ranges from 0.5 to 6 meters. This facies can be divided in two types as followed:

Sand (S3); composed of 100% of sand, yellowish brown color, medium to very coarse grained and moderately sorted. The thickness is about 2 to 40 meters.

Clayey sand (CS3); composed of 15% of clay and 85% of sand, yellowish, orange color, fine to very coarse grained and poorly sorted. Thickness is about 3 to 9 meters.

Gravelly sand (GS3); composed of 5% of clay, 10% of gravel and 85% of sand, yellowish orange color, medium to very coarse grained and moderately sorted. Thickness is about 1 to 3 meters.

3. Gravel 3 (G3)

This lithofacies mainly consisted of gravel sediment. The thickness variable ranges from 3 to 15 meters. This facies can be divided in three types as followed:

Gravel (G3); composed of 100% of gravel, various colors, granule to pebble grained and poorly sorted. Thickness ranges from 3 to 25 meters.

Sandy gravel (SG3); composed of 5% of clay, 40% of sand and 55% of gravel, light brown color, granule to pebble grained and poorly sorted. Thickness ranges from 4 to 8 meters.

Clay thickness of sequence I

Lithologic logs data suggests that the clay thickness of the uppermost sequence is relatively thick with extensive clay layer covering most part of the study area. The isopach map of clay thickness shown in Figure 3.9 was constructed using bore hole data. According to the isopach map, the clay thickness generally thins out toward south and southeast, as the west and east region contains the thickest part of the clay and the clay thickness of Northern Region Industrial Estate ranging from 6 meters to 18 meters. Since the clay unit composed of media of low permeability and where thick layer of clay are present, potential recharge water probably cannot infiltrate in this layer. This result implied that the south and southeast part of study area were in high risk of groundwater contamination.

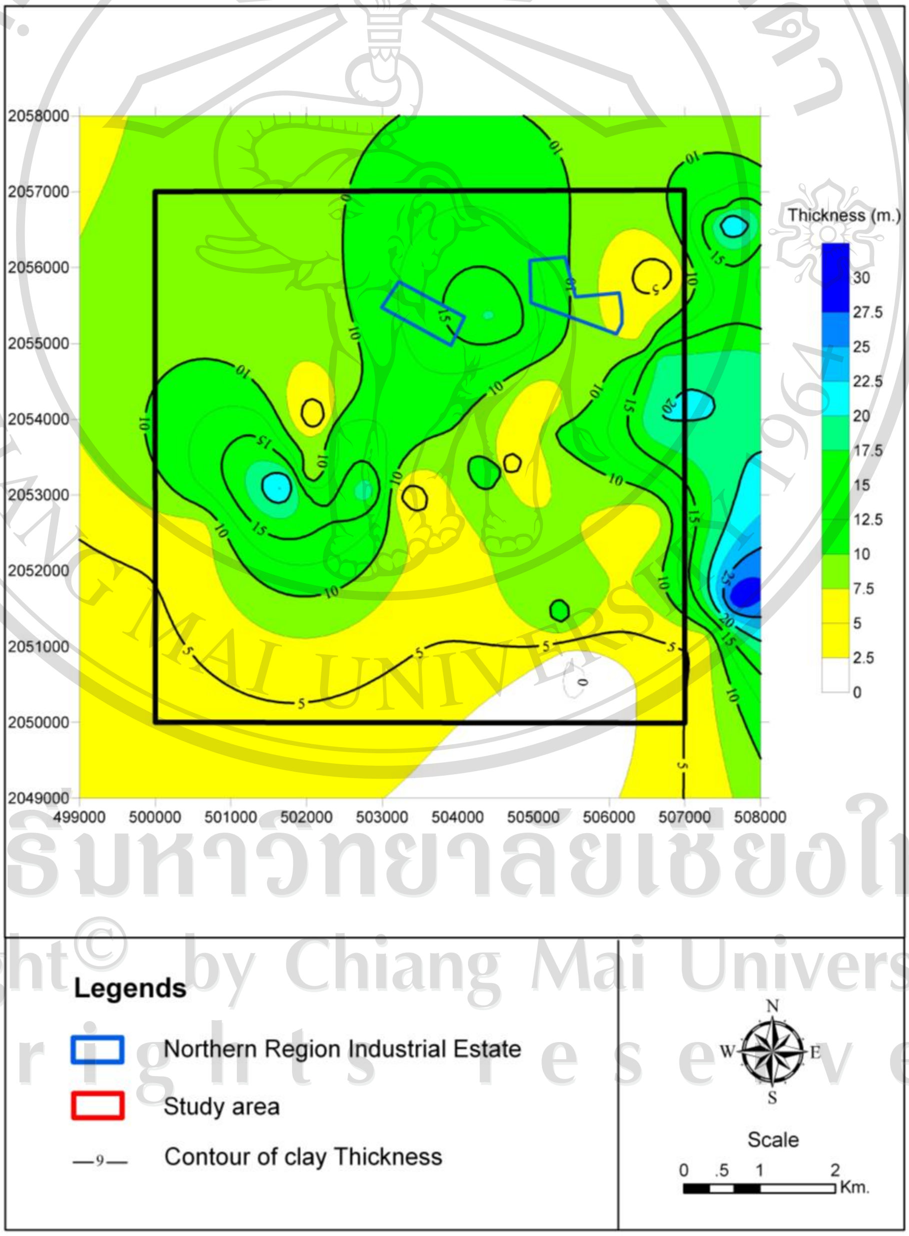

Figure 3.9 The isopach map of clay thickness in the sequence I.

3.2 Resistivity survey

The objective of this study was to find the character and thickness of aquifer. The depth sounding resistivity method was used for ground water exploration. These methods use electrical resistivity data to determined depth and thickness of sediment units.

The resistivity method is well established in geophysics and is particularly used to determine depth to rock units, quality of water, and spreading plumes of contaminant. The method is used in the study of horizontal and vertical discontinuities in the electrical properties of the ground, measuring the apparent resistivity of the ground that is caused by compositional variations.

The resistivity of a material may be defined as the resistance of cylinder that has a cross section of unit area and a unit length. The resistivity value, ρ, is expressed by the formula:

$$\rho = \frac{R \times A}{L}$$

where R is resistance of a conducting cylinder and L is the length of a cylinder that has a cross-section area of A

The unit of resistivity is ohm-m, Ω-m. The resistivity of rock material vary over a wide range, depending on the density, porosity, pore size, shape, water content, water quality, and temperature.

There are no fix limits for resistivity of various rocks. Table 3.2 shows some resistivity values for water-bearing rock.

Actual resistivity is determined from an apparent resistivity that is computed from measurements of current and potential differences between pairs of electrodes placed on the ground surface. The procedure involves measuring the potential difference between two electrodes that results from a current applied through two other electrodes outside, but in line with, the potential electrodes (Figure 3.10).

The common resistivity geometries are Wenner, Schlumberger, pole-dipole, and dipole-dipole (Figure 3.11). Schlumberger and Wenner resistivity surveys are very sensitive to vertical resistivity changes. Pole-dipole and dipole-dipole resistivity surveys are very sensitive to lateral resistivity changes. However, Schlumberger resistivity surveys are common in ground water exploration. Schlumberger resistivity surveying was used in this study (Telford and others, 1990). The field procedure used the vertical electrical sounding approach, which is used mainly in the study of horizontal interface and can determine vertical variation of resistivity.

The Schlumberger configuration (Figure 3.11b) included potential electrodes, P1 and P2, and current electrodes, C1 and C2. In vertical sounding surveys, the potential electrodes remain fixed and the current electrodes are expanded symmetrically about the center of the spread with very large of *L*. The apparent resistivity values are defined from:

$$\rho a = \frac{\pi}{2l} \frac{(L^2 - x^2)^2}{(L^2 + x^2)^2} \frac{\Delta V}{I}$$

Where *x* is the separation of the mid point of the potential and current electrode. When used symmetrically, *x* = 0, so,

$$\rho a = \frac{\pi L^2}{2l} \frac{\Delta V}{I}$$

The first term is an array constant, *k*, which depends on the distance of the electrode. The second term is a resistant value, *R*, so,

$$\rho \mathrm{a} = k.R$$

The apparent resistivity values of the field procedure were plotted as double-logarithm graph between electrode spacing. The Schlumberger sounding were plotted as ρa on the y axis and electrode spacing as *L* on the x axis. These curves were calculated by other methods.

The evaluation of a sounding curve can be made using several methods, including: (1) the manual auxiliary-point methods for multilayered cases utilizing special curve sets, (2) the comparison with set of printed master curves and (3) using digital software with inversion programs. The evaluation result should always be the determination of the number of beds, the thickness of individual beds, and the resistivity of individual beds.

Table 3.2 Resistivity of some common rocks and other materials (modified from Telford and others, 1990, Vogelsang, 1995, and Loke 1999).

Common Rocks/Materials	Resistivity (ohm-meters)
Topsoil	50-100
Sediments	
Clay	1-100
Sandy clay	30-100
Clayey sand	150-315
Sand	50-800
Gravel (dry)	1,400
Gravel (saturated)	90-120
Rock	
Limestone	500-10,000
Sandstone	200-8,000
Conglomerate	2,000-10,000
Slate	500-500,000
Schist (calcareous and mica)	20-10,000
Marble	100-250,000,000
Quartzite	500-800,000
Granite	100-100,000
Granite (weathered)	50-600
Basalt	200-100,000
Syenite	100-1,000,000
Diorite	10,000-1,000,000
Gabbro	1,000-1,000,000

The vertical electrical sounding method has two important limitations: (1) some beds are omitted and the principle of equivalence. Very thin beds are omitted because they cannot be derived from sounding curve at great depth. The principle of equivalence may produce several equivalent solutions for sounding curve. In practice, the result that agrees best with the known geological and hydrological structures of the ground is selected. Also, the selected result can be compared to neighboring sounding (Vogelsang, 1995).

3.2.1 Resistivity data acquisition

The field surveying included 40 sounding locations and shown in Figure 3.12. The instrument system used for data acquisition included a resistivity meter (ABEM TERAMETER SAS 4000), four sets of electrode cables, twenty seven stainless steels of electrodes, hammers, and various connections. The field procedures to carry out Schlumberger measurements are show in Figure 3.13. The current electrode, A and B, and potential electrode, M and N, were placed into the ground at specific distances. The electrode arrays were set up using half-current electrode separations, AB/2 of, 1, 1.5, 2, 3, 4.5, 7, 10, 15, 20, 30, 45, 70, and 100 meters, respectively. The half-current electrode separations, MN/2, started at 0.25 meter and were increased to 1, 2.5, and 10 meters, respectively, to avoid a decrease of instrument sensitivity when AB/2 increased.

The summary of field Resistivity data is show in Table 3.3. Figure 3.14 shows the area of Resistivity survey. Field data acquired from all Resistivity survey locations are listed in Appendix B.

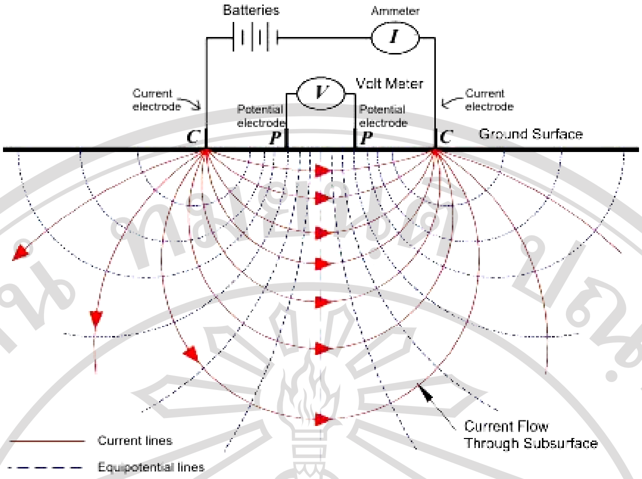

Figure 3.10 The electrical field between two electrodes for resistivity surveys (modified from Todd, 1980).

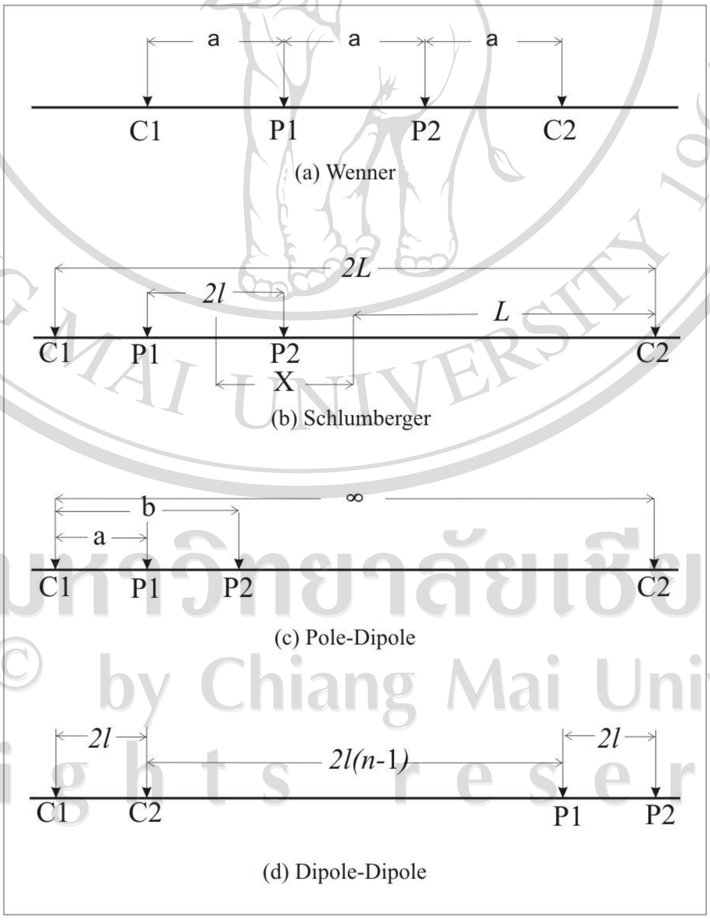

Figure 3.11 Electrode array in common (modified from Todd, 2005).

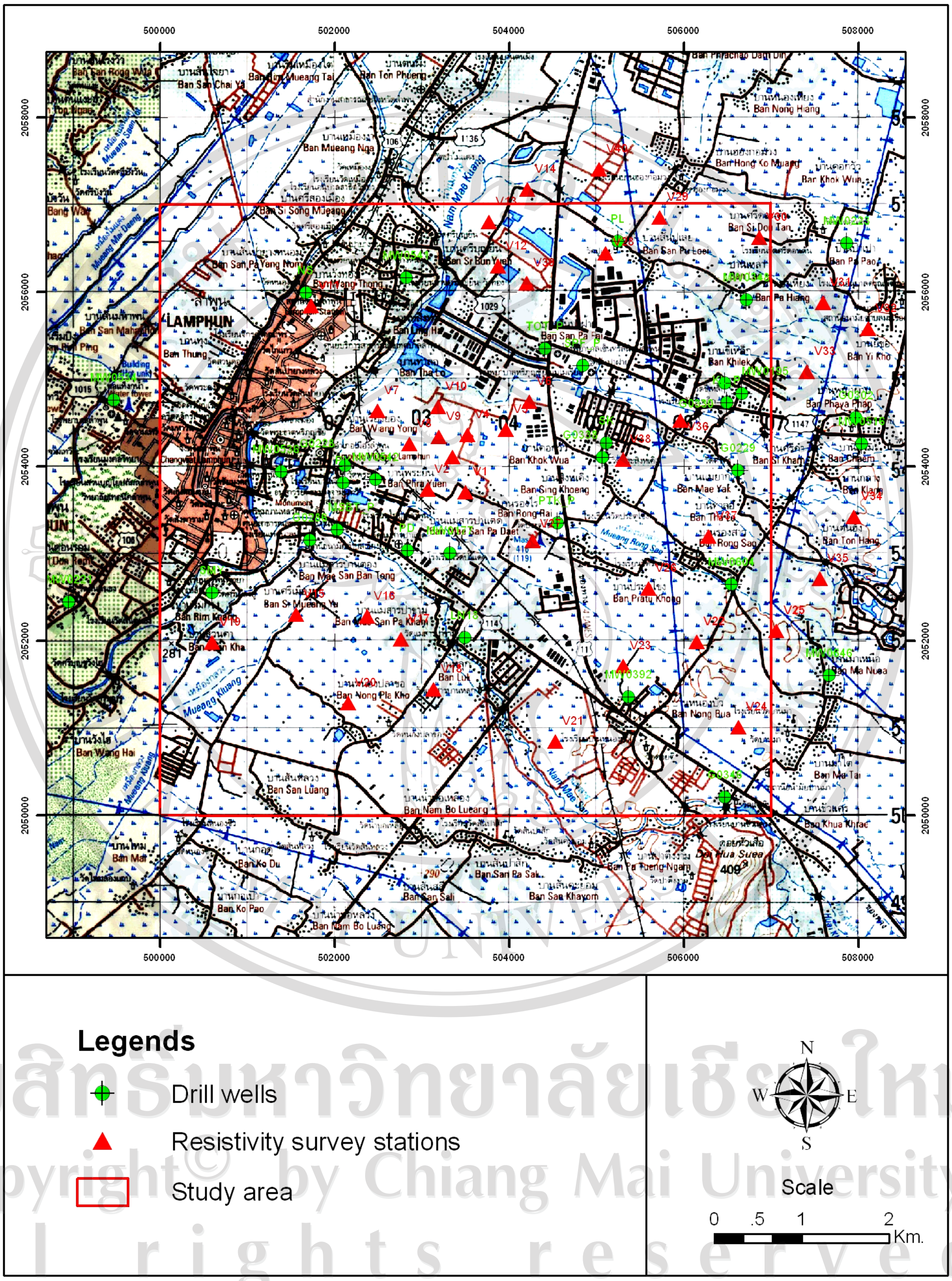

Figure 3.12 Resistivity surveys locations.

3.2.2 Resistivity data processing

The resistivity data were processed by computer. These data were modeled using the RESIST 87® program. This program supports Wenner, Schlumberger, dipole-dipole arrays. It compares resistivity values that are derived from field procedures with master curves. It then computes the resistivity values and thickness or depth of each layer. The result is a one-dimensional resistivity model (Figure 3.15)

For processing Schlumberger array resistivity data were loaded into the program. The program selected number of layer models to be computed and compared to master curves. Computation of data followed this. The result is representative resistivity values and thickness or depth of each layer. The reliability of the model is shown as root mean square-error values. These values are used as model accuracy when compared to the master curve model. In the study, a root mean square-error of five percent was considered reliable. All resistivity models of sounding locations are shown Appendix B.

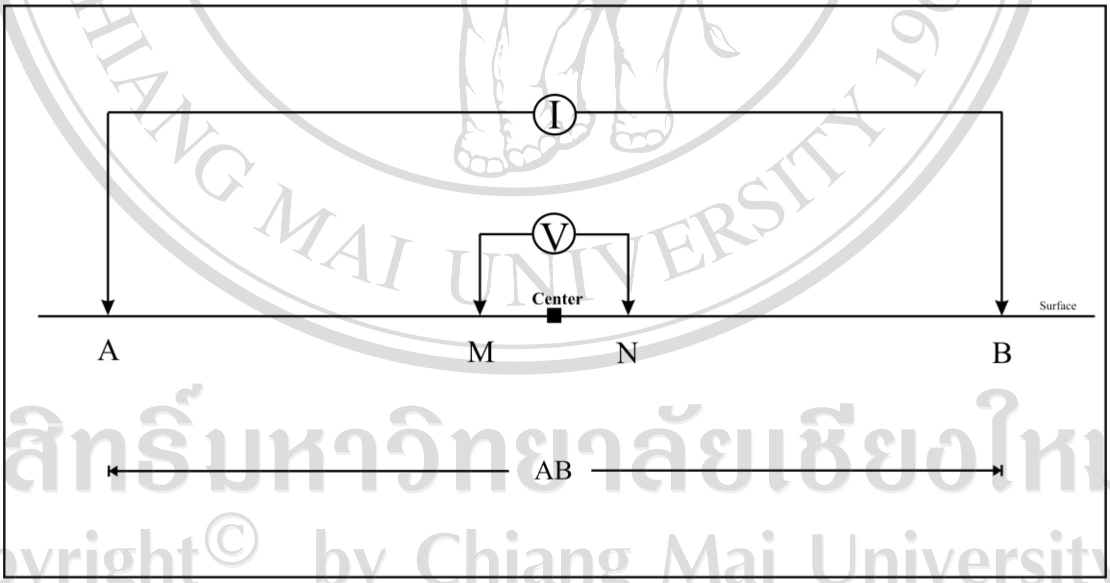

Figure 3.13 Schlumberger field survey electrode array (modified from Todd, 1980).

Table 3.3 Resistivity survey locations.

Station no.	Location (WGS 84)	
	East	North
V1	503501	2053709
V2	503063	2053736
V3	503353	2054111
V4	503520	2054364
V5	503961	2054421
V6	504231	2054740
V7	502490	2054643
V8	502856	2054256
V9	503193	2054341
V10	503185	2054681
V11	501732	2055837
V12	503873	2056298
V13	503765	2056805
V14	504208	2057178
V15	501561	2052306
V16	502370	2052277
V17	502763	2052021
V18	503135	2051445
V19	500599	2051982
V20	502154	2051288
V21	504526	2050847
V22	506145	2051987
V23	505301	2051710
V24	506625	2051010
V25	507060	2052116
V26	505593	2052603
V27	504267	2053149
V28	505105	2056448
V29	505723	2056853
V30	506862	2056620
V31	507592	2055875
V32	508110	2055576
V33	507408	2055090
V34	507947	2053425
V35	507560	2052715
V36	505959	2054525
V37	506281	2053202
V38	505303	2054078
V39	504198	2056099
V40	505028	2057410

Figure 3.14 Electrical resistivity field surveys.

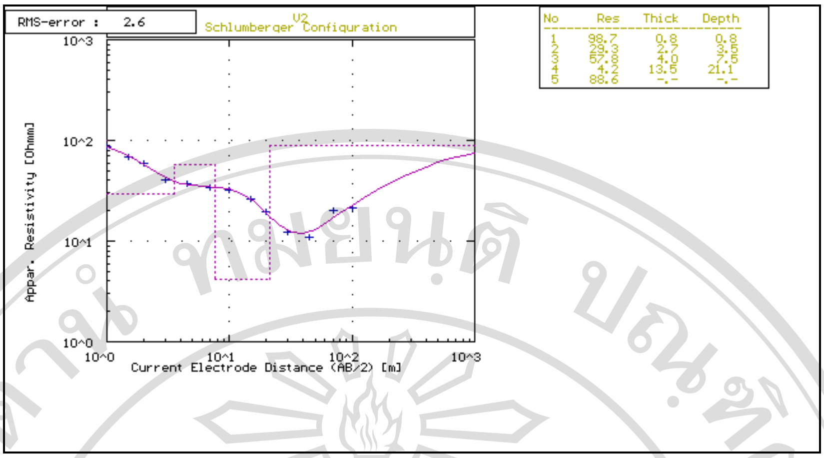

Figure 3.15 Resistivity modeling example.

3.2.3 Resistivity data interpretation

The interpretation of resistivity data were done by computer modeling to obtain layer resistivity and thickness. The resistivity values were correlated with lithologic log of wells in the study area. All resistivity data interpretation is shown in Appendix B.

Resistivity interval classification was done to determine the lithology of each resistivity location. The resistivity values from the model can be divided into 4 layers by resistivity values as followed:

Layer 1; lower 10 ohm-meter resistivity values, the thickness ranges from 1.6 to 13.8 meters, located varies at depth 2 to 40 meters from surface, the lithology are sandy clay and gravelly clay.

Layer 2; 10 to 30 ohm-meter resistivity values, the thickness ranges from 0.6 to 56.4 meters, located varies at depth 1 to 56 meters from surface, lithology are clayey sand, sand, and clayey gravel.

Layer 3; 30 to 100 ohm-meter resistivity values, the thickness ranges from 1 to 30.3 meters, located varies at depth 2 to 43 meters from surface, lithology are gravelly sand, sand, sandy gravel, and gravel.

Layer 4; over 100 ohm-meter resistivity values, the thickness ranges from 0.9 to 8.8 meters, located varies at depth 1.5 to 13 meters from surface, lithology are sandy clay and clay.