CHAPTER 4

HYDROGEOLOGIC CHARACTERISTICS AND HYDROSTRATIGRAPHIC MODEL

4.1 Hydrogeologic characteristics

The hydrogeologic characteristic of the study area was analyzed and interpreted from subsurface geologic setting (chapter 3), groundwater level and groundwater quality. These data were defined to classified the types, characteristic and distribution of aquifers, estimate hydraulic properties and analyze direction of groundwater flow.

4.1.1 Hydrostratigraphic units

Geologic information, including geologic maps, cross sections, and well logs, ware combined with information on hydrogeologic properties to defined hydrostratigraphic units

In this study, hydrostratigraphic units comprise of geologic units of similar hydrogeologic properties. Several geologic formations were combined into a single hydrostratigraphic unit. The hydrostratigraphic units in the study area are shown in figure 4.1. Three main aquifers can be characterized as follow:

1) Aquifer I; this aquifer is located at the depth of 0 to 20 m. The uppermost and lowermost hydrogeologic units consist of thick layer of clays. The middle portion is the main aquifer consisting of non-continuous gravelly sand lenses with varying thickness. Sands are typically medium to coarse. In some areas clayey gravel is also common.

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2) Aquifer II; this aquifer is located at the depth of 20 to 45 m. The aquifer is multiple medium- to fine-sand lenses inter-fingering with clays. The thickness of the aquifer is not uniform and lack of continuity. In some areas, gravel is also found.

3) Aquifer III; this aquifer is located at the depth of 45 to 100 m. The aquifer consists of mostly coarse sand with some existence of gravel. Similar to the first aquifer, thickness and lateral continuity are spatially variable.

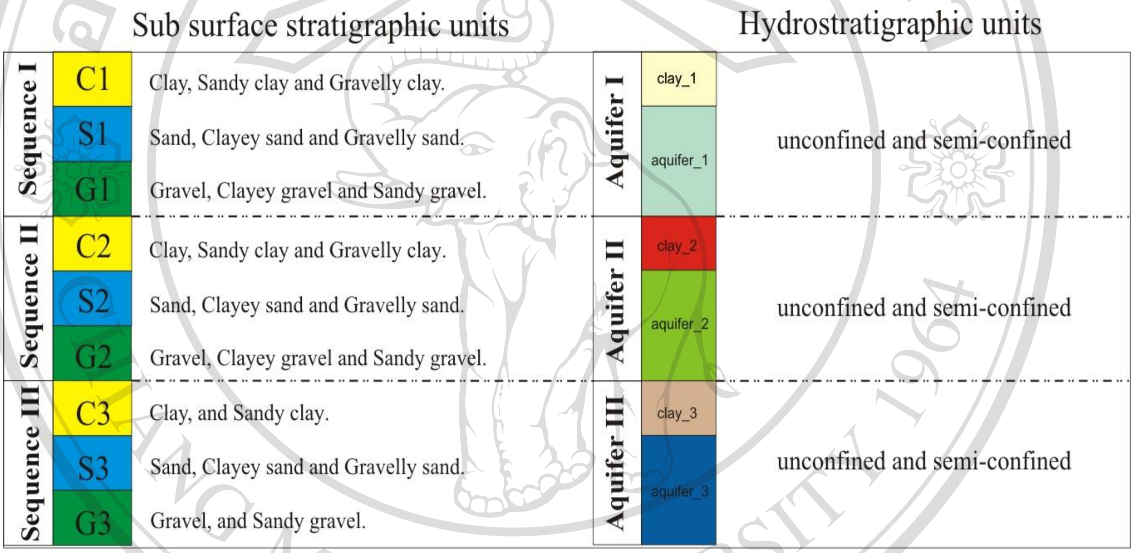

Figure 4.1 Hydrostratigraphic units of the study.

4.1.2 Hydraulic Properties of Aquifers

Hydraulic properties of aquifer that are of important for groundwater flow study. These included hydraulic conductivity (K), transmissivity (T), and storage coefficient (S).

Hydraulic conductivity (K) is defined as the quantity of water flowing in one unit time through a face of unit area under a driving force of one unit of hydraulic head change per unit length (Domenico and Schwartz, 1990). Transmissivity (T) is a measure of the amount of water that can be transmitted horizontally through a unit width by the full saturated thickness of the aquifer under a unit hydraulic gradient.

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Therefore, transmissivity is the product of the formation thickness and hydraulic conductivity. The storage coefficient, or storage coefficient (S), is the volume of water that a permeable unit will absorb or expel from storage per unit surface area per unit change in head. It is a dimensionless quantity (Fetter, 1988).

The pumping tests used several methods that depended on the characteristics and yield of aquifers. This study consist of pumping test and slug test methods. High permeable aquifer is suitable pumping test method and slug tests can be preformed to determine the hydraulic conductivity of the small volume of aquifer.

Pumping test data is analyzed to determine the hydraulic properties of aquifer and specific capacity. The three types of pumping test most often uses are: the bailer test, constant-rate pumping, and step-drawdown pumping test. In the study area, constant rate pumping test were used to obtain the hydraulic properties. Various methods can be used to evaluate pumping test data, such as Thiem method that is applicable to steady state condition, Theis method and Cooper & Jacob method that is applicable to non-steady state or non-equilibrium condition.

In the present study, eleven pumping test data and six slug test data carried out by Department of Groundwater Resources in 2007 are analyzed. Location of pumping test well in the study area is shown in Figure 4.2 and Table 4.1. Analysis of the pumping test data to determine the transmissivity (T) and storage coefficient (S) were carried out by WTAQ (Barlow and Moench, 1999) and UCODE (Poeter and Hill, 1998) programs (Figure 4.3). The slug test data was processed by type-curve matching method. An example of the analysis is shown by graph (Figure 4.4). Hydraulic conductivity of the aquifer can be calculated from equation:

$$K = \frac{T}{b}$$

Where K = hydraulic conductivity (L/T; m/d or ft/d)

T = transmissivity (L^2/T; m^2/d or ft^2/d)

b = the aquifer thickness (L; m or ft)

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In this study, several hydraulic tests were conducted to obtain parameters needed for subsequent setup of groundwater flow and solute transport models. Eleven pumping tests and six slug tests were carried out for aquifers in all sequences. The values of transmissivity (T), hydraulic conductivity (K), storage coefficient (S), and aquifer anisotropy (K_v/K_h) were determined based on these results and shown in Table 4.2.

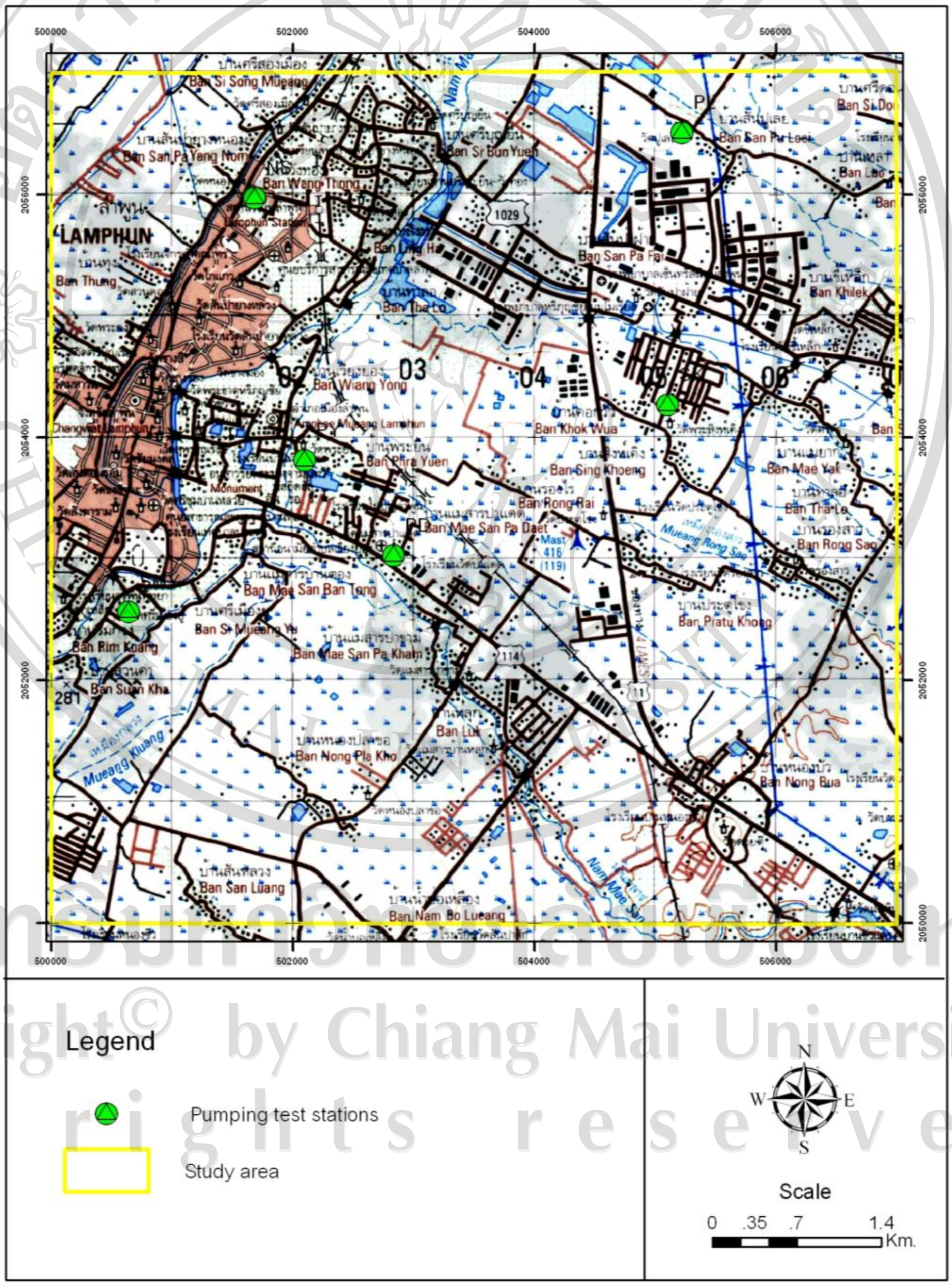

Figure 4.2 Location of pumping test.

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Table 4.1 Detailed of Pumping test.

Set No.	Location	Test well	Observation well	Method	Remark
1	Wat Nong Seang	NS01/50	NS04/50	Pumping test	Aquifer III
2	Wat Nong Seang	NS02/50	NS05/50	Pumping test	Aquifer I
3	Wat Mae San Pa Daet	PD01/50	-	Pumping test	Aquifer II
4	Wat Pu Loei	PL02/50	PL04/50	Pumping test	Aquifer I
5	Wat Sri Mueang Yu	SMY02/50	SMY04/50	Pumping test	Aquifer I
6	Wat Nong Seang	NS03/50	NS06/50	Pumping test	Aquifer III
7	Wat Pu Loei	PL01/50	PL03/50	Pumping test	Aquifer II
8	Wat Mae San Pa Daet	PD02/50	PD03/50	Pumping test	Aquifer I
9	Wat Sri Mueang Yu	SMY01/50	SMY03/50	Pumping test	Aquifer II
10	Wat Phra Yuen	PY01/50	PY04/50	Pumping test	Aquifer III
11	Wat Phra Yuen	PY02/50	PY05/50	Pumping test	Aquifer II
12	Wat Phra Yuen	PY03/50	-	Slug test	Aquifer I
13	Ban Sing Khoeng	SK01/50	-	Slug test	Aquifer II
14	Ban Sing Khoeng	SK02/50	-	Slug test	Aquifer I
15	Wat Phra Yuen	PY06/50	-	Slug test	Aquifer I
16	Ban Sing Khoeng	SK03/50	-	Slug test	Aquifer I
17	Ban Sing Khoeng	SK04/50	-	Slug test	Aquifer I

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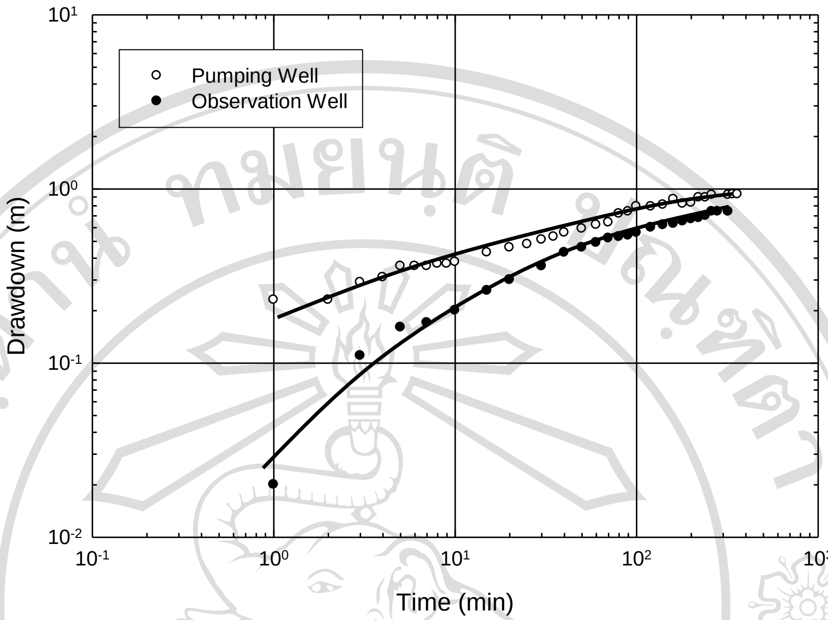

Figure 4.3 Pumping test analysis using WTAQ (Barlow and Moench, 1999) and UCODE (Poeter and Hill, 1998) programs.

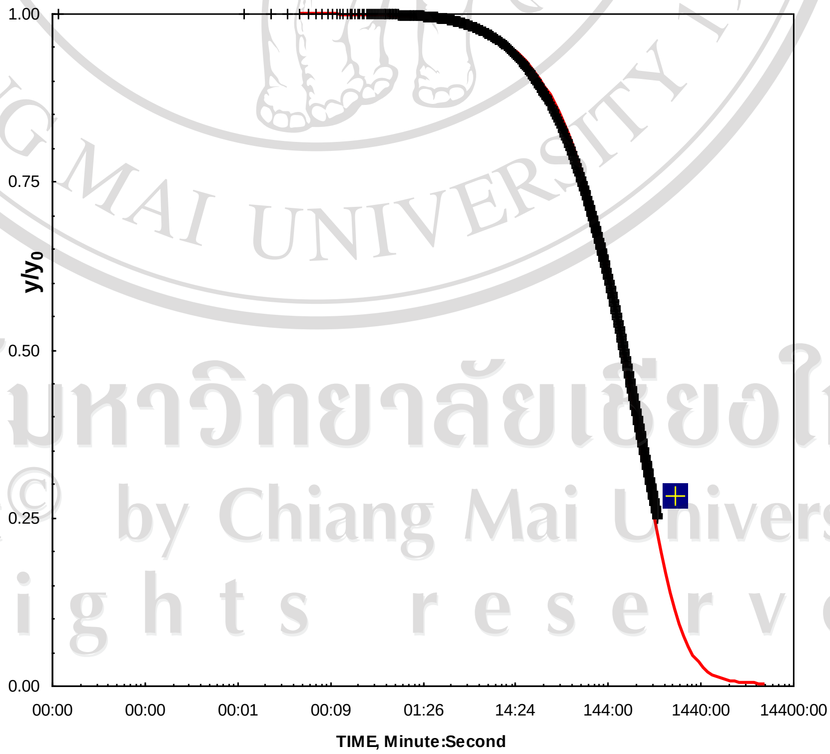

Figure 4.4 Slug test analysis using type-curve matching method.

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Table 4.2 Pumping test results.

Aquifer	Depth	T (m^2/day)	K (m/day)	S(-)	Anisotropy (K_v/K_h)
I	0-20	31.2-138.0	2.6-11.5	2.45×10^{-3}-5.75×10^{-7}	0.81-1.0
II	20-45	0.39-55.2	0.049-6.9	1.63×10^{-3}-8.76×10^{-4}	0.77 – 1.0
III	45-65	8.88-77.6	1.11-9.7	1.72×10^{-3}-6.79×10^{-3}	0.68-1.0

4.1.3 Groundwater Levels and Flow Directions

The flow occurs because the potential energy head drives the water from areas of higher head to areas of lower head. The construction of flow net consists of two lines (Figure 4.5): one curve representing the flow line, which indicate the direction of groundwater flow in the area, can be determined by using groundwater elevation data from a minimum of 3 wells. Intersecting the groundwater flow line at right angles is called equipotential lines, which are lines of equipotential lines. Flow net is used to define area of recharge and discharge, that flow lines diverge in areas of recharge and converge in areas of discharge, and located new wells.

In this study, groundwater level were collected from 67 wells, including 40 wells of dug wells and 27 wells of drilled wells, as shown in Table 4.3, and Table 4.4. Groundwater flow pattern are constructed from the average groundwater level, which were measured between January 2010 to July 2010, as all groundwater level were recorded. The shallow groundwater levels of the dug wells were in the range of 1-10 meters, while groundwater levels of drilled wells were in the range of 5-25 meters. The groundwater flow directions in both shallow and deep aquifers flow toward the western and northwestern parts of the study area with some of the flow lines directing toward the north (Figures 4.6 and 4.7). It should be noted that shallow groundwater flow directions were more variable than deep aquifer. This could be due to the lateral

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discontinuity and variable thickness of the aquifers. Another possibility could arise from differential water use in some areas compared to the others. All groundwater level data were presented in Appendix C.

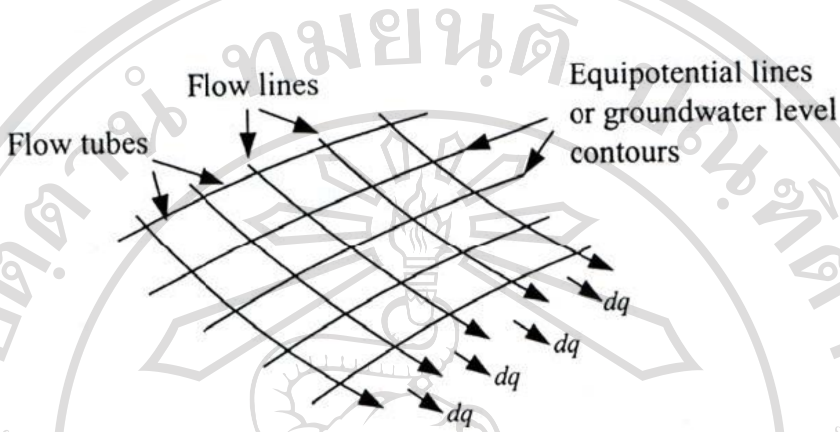

Figure 4.5 Flow net in two dimensional approximations (from Hamill and Bell, 1986).

Table 4.4 The measured water level location of dug wells.

Well No.	Location (WGS84) East	North	Elevation (msl.)	Depth (m.)	Well No.	Location (WGS84) East	North	Elevation (msl.)	Depth (m.)
LP01	505200	2056554	291.21	6.95	N1	506906	2058514	293.71	4
LP02	506053	2057298	291.89	9.5	N2	507668	2058868	295.16	3.7
LP03	507466	2056746	297.45	12.7	N3	509156	2058225	303.12	8.2
LP04	508413	2056083	301.61	7.3	N4	509376	2057663	303.84	5.85
LP05	508494	2055313	300.96	4.3	N5	506702	2055865	296	9.3
LP06	507939	2054344	300.05	8.8	N6	506655	2055966	297.23	12.3
LP07	506520	2054704	297	10.1	N7	507778	2056005	298.42	5.3
LP08	505703	2054443	295.99	6.8	N8	509057	2055781	304.65	8.04
LP09	506221	2052939	299.42	4.3	N9	508556	2054281	305.72	5.9
LP10	505035	2054035	294.72	14.3	N10	507445	2053985	299.4	5.53
LP11	504659	2054214	293.93	4.6	N11	506645	2053622	297.26	7.7
LP12	507709	2051339	305.46	6.7	N12	506557	2053919	294.12	4.45
LP13	505436	2050836	304.98	3	N13	504851	2055090	292.43	4.83
LP14	503426	2052102	292.15	8	N14	503132	2056540	289.73	8.2
LP15	504570	2053309	295.5	9.65	N15	502158	2056760	290.63	5.76
LP16	503568	2055819	290.26	8.35	N16	501647	2055962	290.84	5.8
LP17	506732	2058292	294.25	4.2	N17	501250	2054937	288.87	5
LP18	509172	2058330	304.23	6.6	N18	500938	2054319	290.92	8.7
LP19	509428	2054188	308.31	7.9	N19	502195	2053833	288.74	4.2
LP20	509164	2053116	307.13	5.7	N20	502838	2053064	288.95	8.5

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Table 4.4 The measured water level location of drilled wells.

Well No.	Location (WGS84)		Elevation	Screen	Depth of Well
	East	North	(msl.)	Interval (m.)	(m.)
PL01	505177	2056607	292.0	36-44	54
PL02	505175	2056608	292.0	8-20	24
PL03	505184	2056610	292.0	32-40	54
PL04	505183	2056611	292.0	8-20	24
SK01	505063	2054307	292.0	40-48	54
SK02	505062	2054306	292.0	24-32	36
SK03	505106	2054280	292.5	40-48	54
SK04	505105	2054279	292.5	24-32	36
SMY01	500595	2052552	288.0	34-50	54
SMY02	500596	2052551	288.0	6-18	20
SMY03	500608	2052539	288.0	34-50	54
SMY04	500609	2052538	288.0	6-18	20
PD01	502828	2052993	290.0	50-66	70
PD02	502829	2052992	290.0	22-30	36
PD03	502835	2052984	290.0	22-30	36
PY01	502085	2053798	288.0	38-46	50
PY02	502085	2053799	288.0	18-26	30
PY03	502086	2053800	288.0	4-8	10
PY04	502096	2053817	288.0	38-46	50
PY05	502097	2053818	288.0	18-26	30
PY06	502097	2053819	288.0	4-8	10
NS01	501706	2055923	290.0	42-50	54
NS02	501706	2055922	290.0	12-16	20
NS03	501706	2055921	290.0	21-28	30
NS04	501684	2055912	290.0	42-50	54
NS05	501685	2055912	290.0	12-16	20
NS06	501686	2055912	290.0	21-28	30

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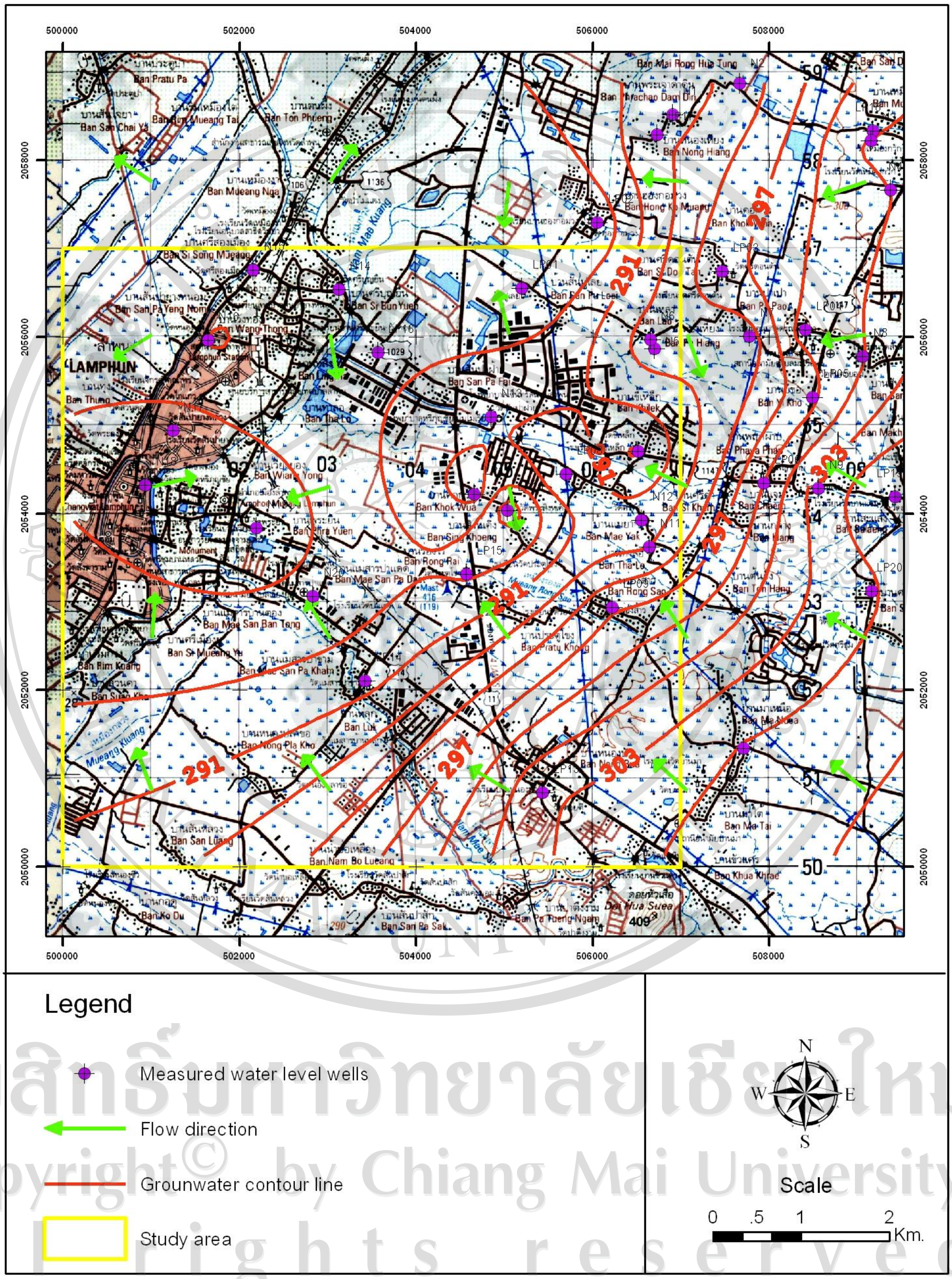

Figure 4.6 Flow direction of the shallow aquifer.

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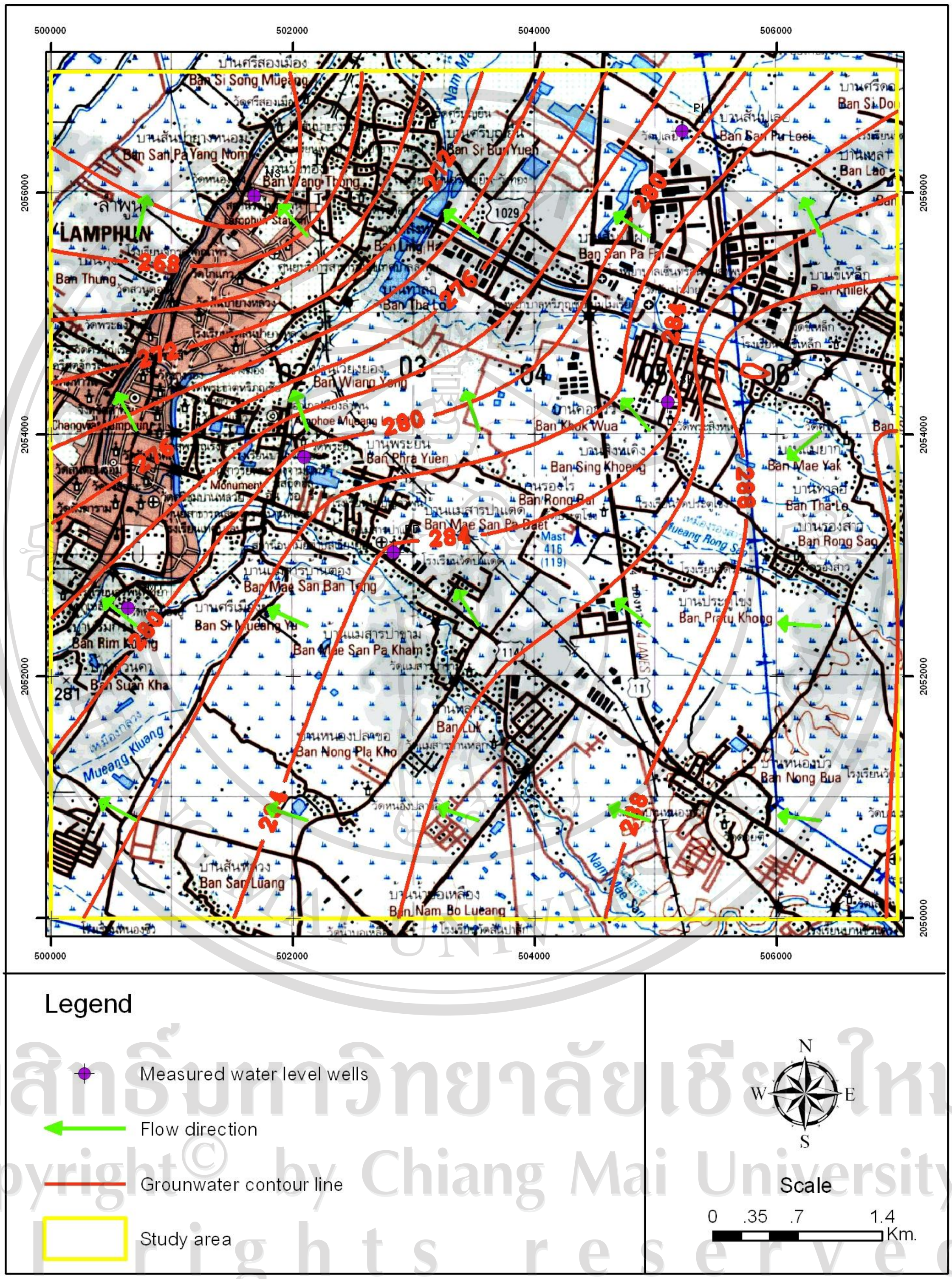

Figure 4.7 Flow direction of the deep aquifer.

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4.1.4 Groundwater Quality

The groundwater quality data concerning the groundwater in this study were provided by Department of Groundwater Resources (DGR, 2008). The thirty shallow groundwater samples from dug wells and thirty deep groundwater samples from drilled wells (Figure 4.8) were collected and analyzed for physical and chemical properties including heavy metal contents, twice during wet and dry seasons (September 2007 and December 2007). It was found that most of the shallow groundwaters were not suitable for use as drinking water supply according to the regulated standards in the following categories: turbidity, hardness, total dissolved solids, anions contents (chloride, fluoride, nitrate, and sulfate) and iron and manganese contents. For deeper aquifers, it was found that groundwater at some locations were not potable due to the same reason mentioned above. Nevertheless, the contamination of heavy metals was not detected except in some samples where zinc content was high but still lower than standards.

Hydrochemical facies is used to differentiate bodies of groundwater in an aquifer on the basis of chemical composition. The facies is a function of the lithology, solution kinetics, and flow pattern of aquifer (Fetter, 1988). Classification of water hydrochemical facies is based on ion composition and is most commonly represented by tri-linear diagrams or Piper diagrams. The Piper diagrams are plotted ion concentration’s percentages, with each point representing a chemical analysis. Therefore, the Piper diagram has the potential to represent a large number of analyses and is convenient for showing the mixing of two waters of difference sources. The classification of hydrochemical facies in this study used the ROCKWORK2000® program. In plotting a Piper diagram, the error value for an imbalance between sum of anions and cations was set to a maximum of 10 percent. The hydrochemical facies of shallow groundwater (dug wells) samples are sodium-calcium-bicarbonate facies (Figure 4.9 and Figure 4.10) and the deep groundwater (drilled wells) samples are sodium-calcium-bicarbonate-chloride facies (Figure 4.11 and Figure 4.12).

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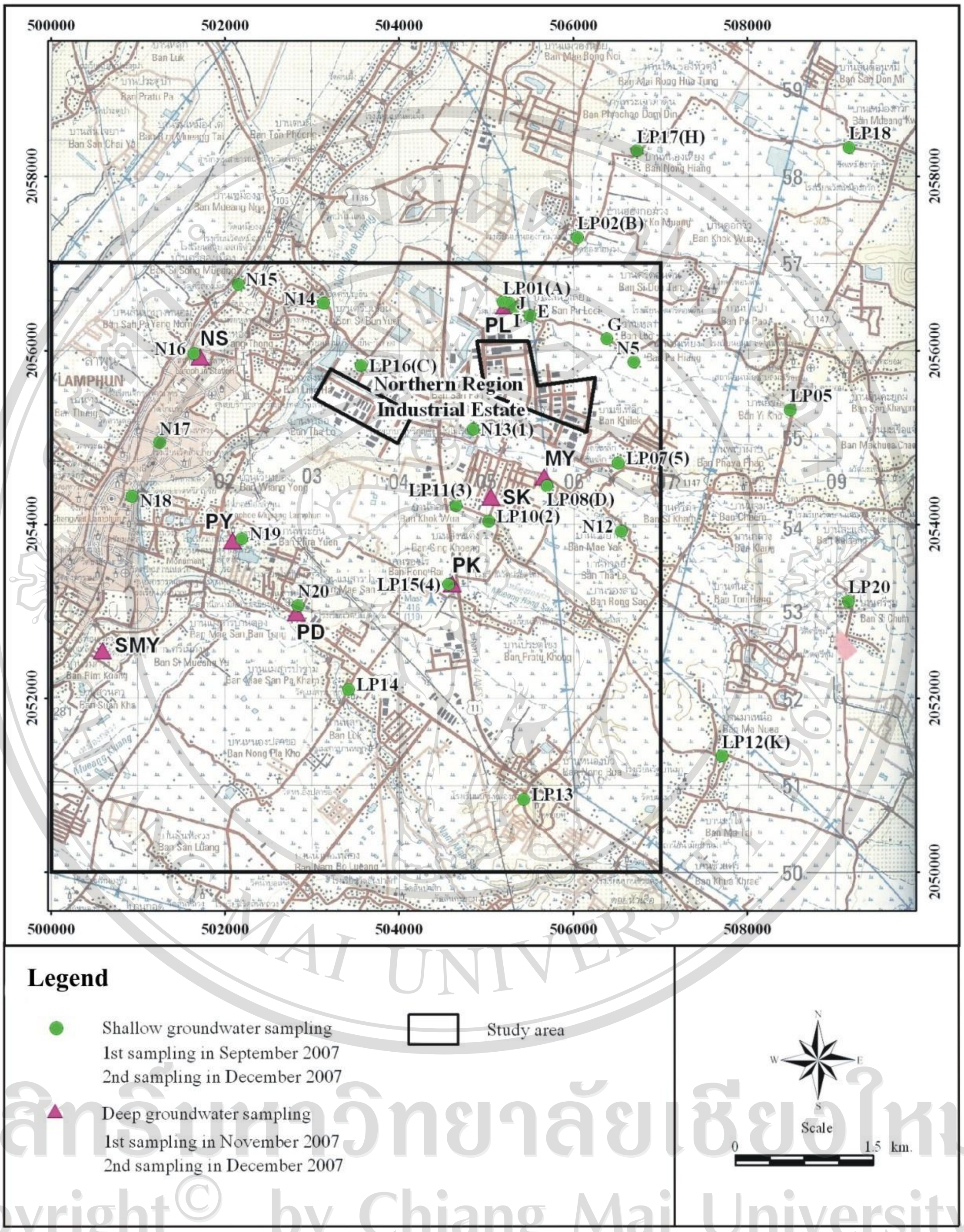

Figure 4.8 Sampling locations of shallow and deep groundwaters (modified from DGR, 2007).

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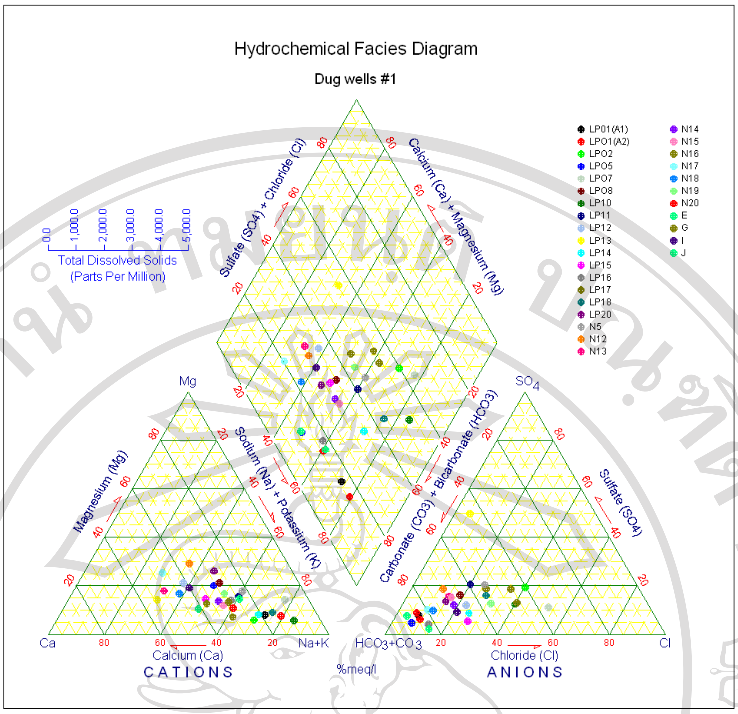

Figure 4.9 Hydrochemical facies classification of the dug wells samples at first sampling, September 2007 (DGR, 2007).

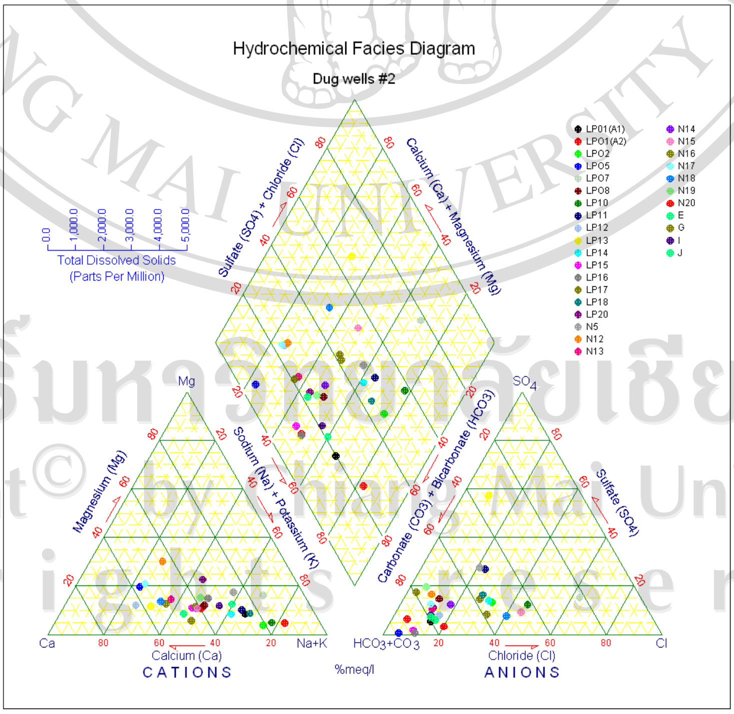

Figure 4.10 Hydrochemical facies classification of the dug wells samples at second sampling, December 2007 (DGR, 2007).

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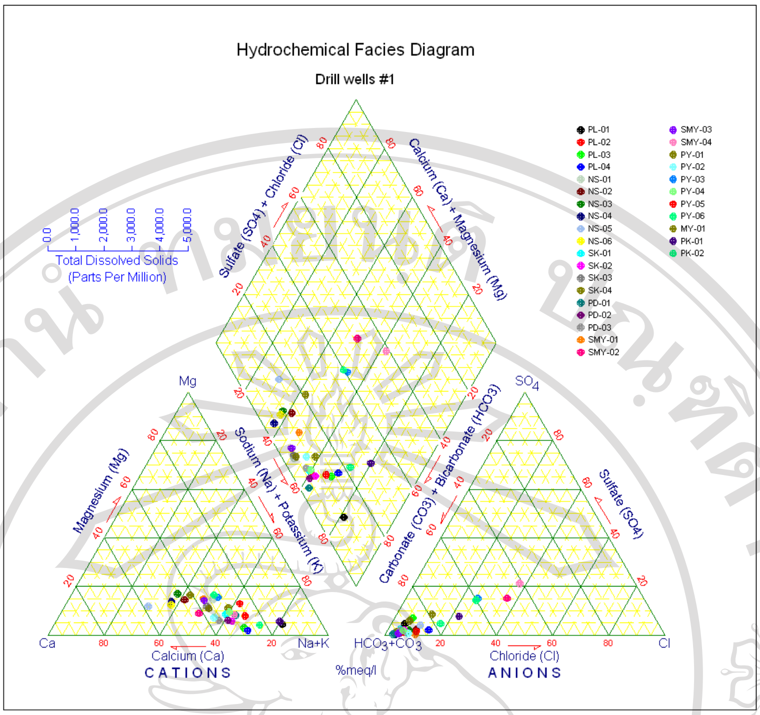

Figure 4.11 Hydrochemical facies classification of the drilled wells samples at first sampling, September 2007 (DGR, 2007).

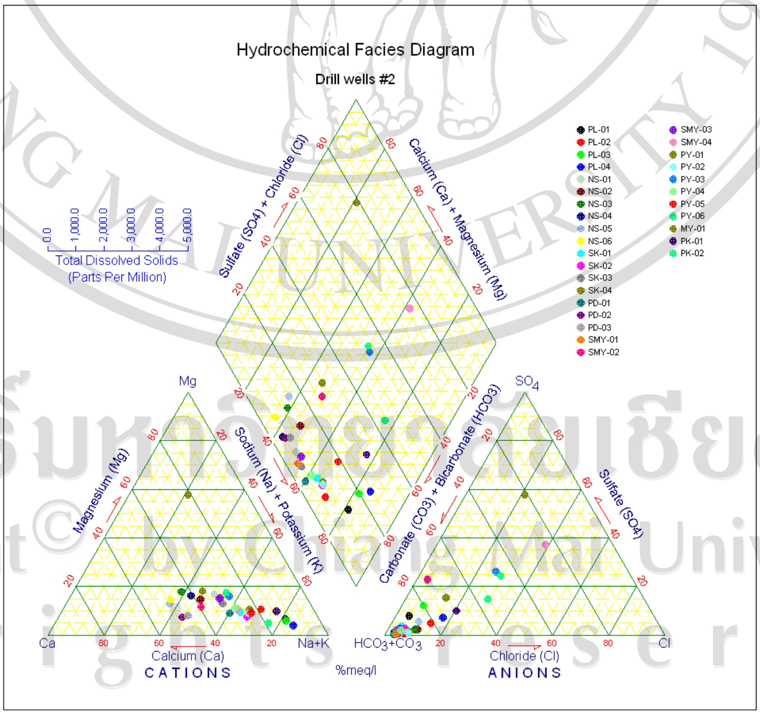

Figure 4.12 Hydrochemical facies classification of the drilled wells samples at second sampling, December 2007 (DGR, 2007).

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4.1.5 Groundwater Quality with Respect to Volatile Organic Compounds

Bunyasit Kiwduangta, Fongsaward Suvagondha Singharajwarapan, Sunanta Wangkarn, and Schrach Saenton (2009) studied Volatile Organic Compounds (VOCs) contamination covered the Northern Region Industrial Estate Vicinity in Lamphun Province. The sixty groundwater samples were collected from dug wells and groundwater wells twice during wet and dry seasons. The samples were analyzed for thirteen commonly found volatile organic compounds including 1,1- dichloroethylene ; trans-1,2-dichloroethylene ; cis-1,2-dichloroethylene ; chloroform ; 1,2-dichloroethane ; benzene ; trichloroethylene ; 1,1,2-trichloroethane ; toluene ; tetrachloroethylene ; ethylbenzene ; *p*-xylene and *o*-xylene, in order to assess the groundwater contamination. The results of analyses indicated that at least one or more volatile organic compounds in the aforementioned list were detected in 12 out of 30 dug wells (Figure 4.13) and 18 out of 30 groundwater wells (Figure 4.14). Although VOCs concentrations in groundwater did not exceed maximum contaminant levels of the groundwater standard, but some VOCs concentration is obviously high. This result implied that groundwater contamination in the study area was of anthropogenic origin. It was speculated that there would be significant impacts on public health and groundwater resource in the area.

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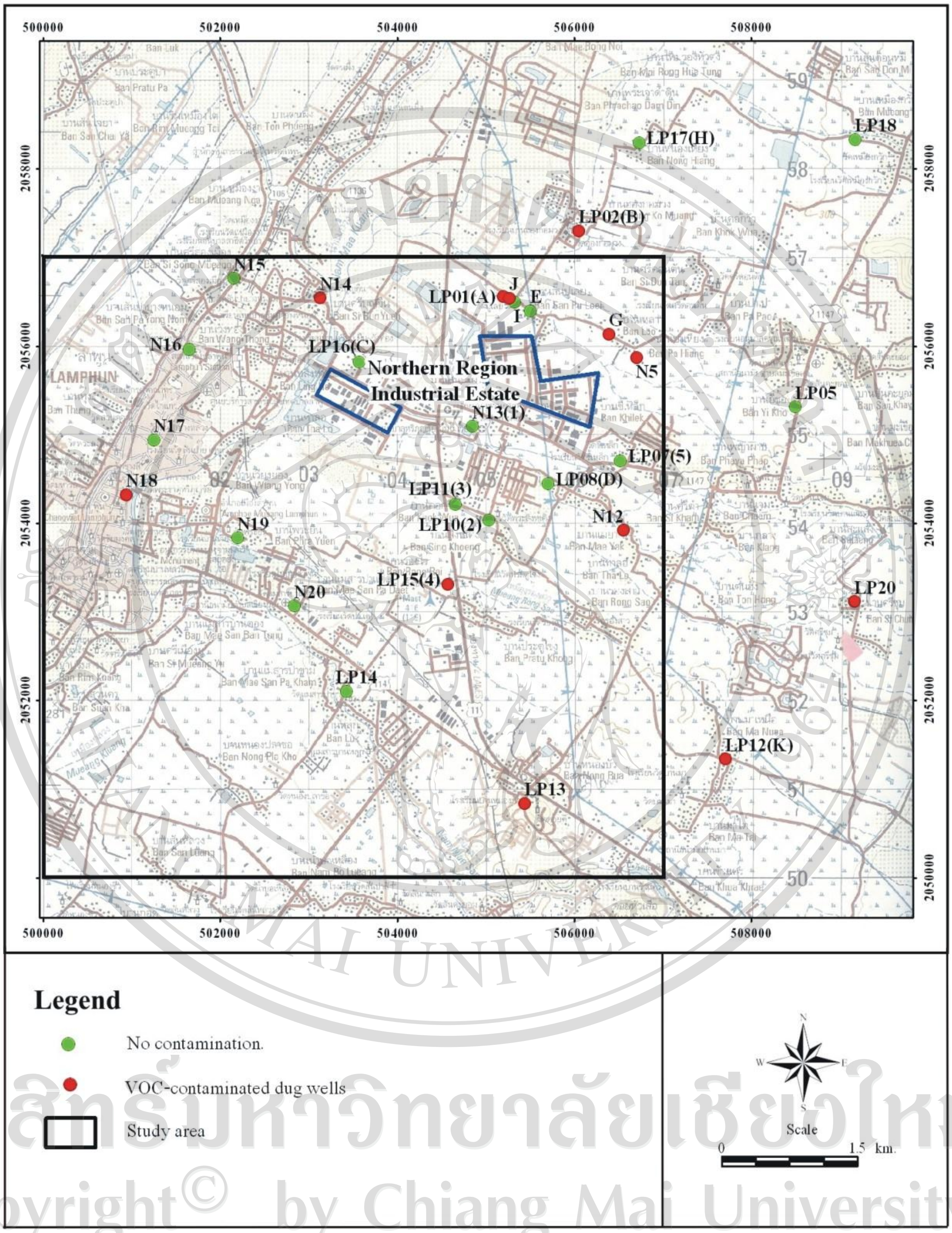

Figure 4.13 Locations of dug wells that were contaminated with VOCs.

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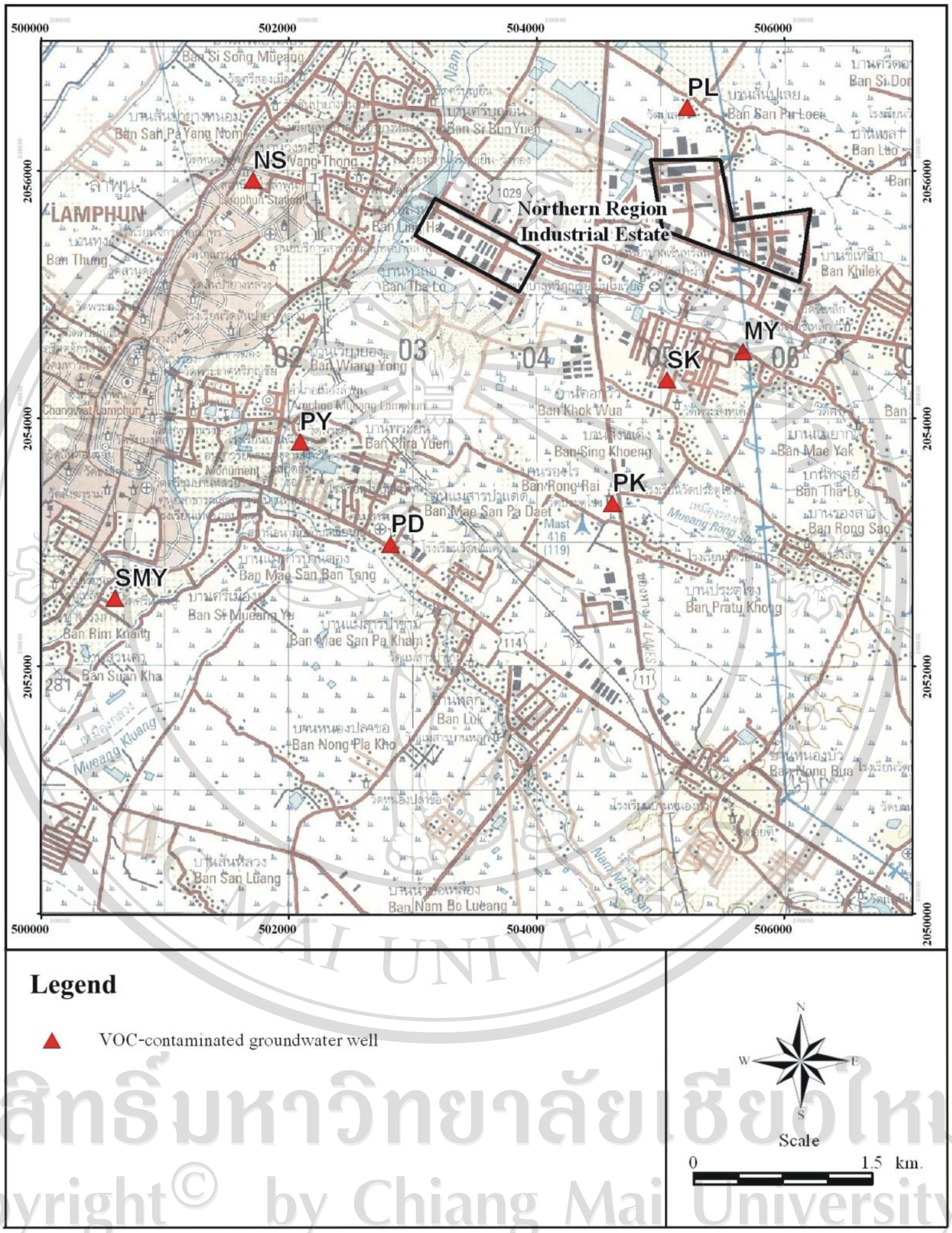

Figure 4.14 Locations of groundwater wells that were contaminated with VOCs.

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4.2 Hydrostratigraphic model

The hydrostratigraphic model was constructed by hydrostratigraphic units and groundwater dynamic (Figure 4.15). Many hydrostratigraphic cross sections were constructed fence diagram that can be translated to the solid model. The groundwater dynamic including hydraulic properties and groundwater flow directions. The combination between this solid model and groundwater dynamic were use to the hydrostratigraphic model. The model has 14 layers of three aquifers; consist of 70 rows and 70 columns. The uniform mesh size is of 100 × 100 meters. All layer types are assigned as unconfined/semi confined. The elevation data for the top layer 1, the outcrop of layer 2, and layer 3 were interpolated from a digital elevation model (DEM). The top elevation data of part of layer 2 to layer 14 were interpolated from available borehole drilling data. The bottom of layer 14 was assigned an elevation of 200 meters below mean sea level. This depth is based on the drilling data from chapter 3. This hydrostratigraphic model is used to indicate the conceptual model.

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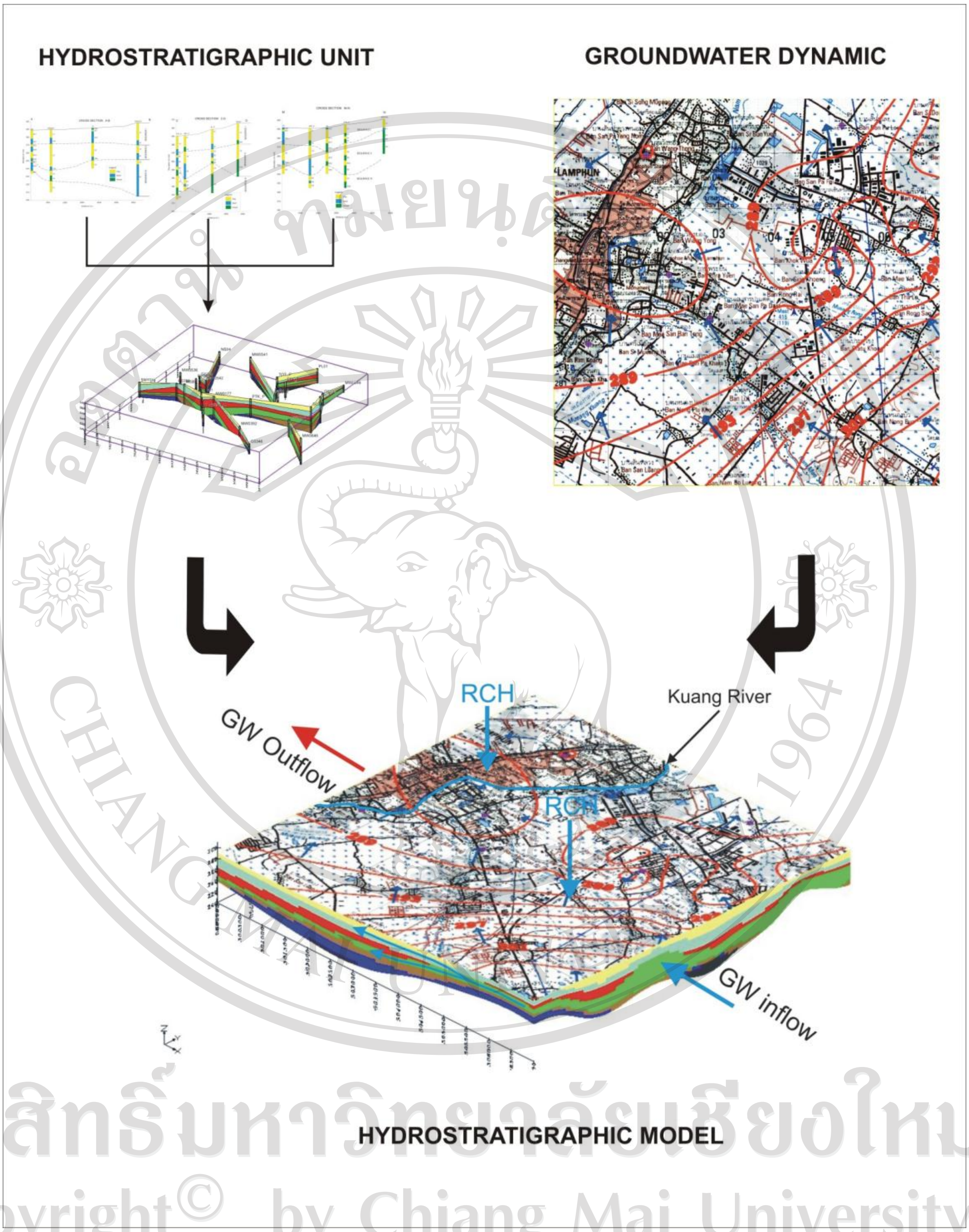

Figure 4.15 The construction of hydrostratigraphic model.

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