CHAPTER 4

DRASTIC METHOD

4.1 Principle

The fundamental principle of a groundwater vulnerability map is that all groundwater is vulnerable (Armando and Carbonel, 1993). Groundwater vulnerability is defined as the intrinsic sensitivity of land to contamination or natural vulnerability. Vulnerability is a relative indicator of where contamination will occur if the contaminant sources are introduced at the land surface and groundwater vulnerability is a relative property, not absolute.

The degree of groundwater vulnerability depends on hydrogeological characteristics, the topography of the area, and meteorological conditions. Hydrogeological factors such as flow paths, thickness of the vadose or unsaturated zones, and composition of soil media greatly influence the degree of groundwater vulnerability. Materials composition above the groundwater level will act as a barrier either to attenuate or accelerate contaminant movement. This chemical reaction e.g., ion exchange, and physical reaction e.g., adsorption will reduce contaminant concentration.

Generally, geographic information system are used as a tool for preparation of a groundwater database (Arthur and Pollock, 1998). Various methods have been used worldwide, including overlay and index methods, process-based methods for vulnerability mapping, and statistical methods. Each of these methods requires adequate available hydrogeological data related to groundwater contamination. The most widely used are the DRASTIC overlay and index methods. The DRASTIC method employs seven layers of hydrogeological parameters: depth of aquifer, net recharge, aquifer media, soil media, topography, vadose zone impact, and hydraulic conductivity. Each of these layers was manipulated in the ArcView® program software as a grid data map and was rated and ranked from 1 to 10 according to its relative degree of vulnerability to contaminants (Aller and others, 1987). The rated maps were considered solely on the basis of hydrogeological properties and conditions. The seven layers were relatively weighted from 1 to 5 by their importance in terms of vulnerability to each other. Geographic information systems, and thematic maps derived from groundwater spatial database analyzes were overlaid. The rated and weighted thematic maps will show different levels of vulnerability to contamination (Jaroslav and Alexander, 1994), very low, low, medium, high and extremely high vulnerability. Hydrogeological data from the DRASTIC method in the Chiang Mai basin were grouped and rated. The vulnerability maps were used as tools for prioritizing areas where a high degree of vulnerability area was demonstrated the need for groundwater protection..

4.2 Geographic information system (GIS)

Advances in computers have greatly enhanced the effectiveness of GIS for a wide variety of mapping. GIS is a computer aid for analyzing spatial data in the DRASTIC method. GIS has two major parts, graphic objects and attribute data, which are linked to each other. Graphical objects in GIS have two forms; vector and raster data. Vector data has a magnitude and directionstored in three features; point, line, and polygon. Raster data is a picture or photograph stored in pixel format as a grid (square area). The pixel is used for resolution of the photograph. The advantage of using the raster format is the seamless layer is applicableboth one time or for many layers in a single analysis.

All seven parameters of DRASTIC methods were imported to the ArcView® programand various methods and functions were applied to DRASTIC parameters. Interpolation and extrapolation grid modules were applied to the point feature of groundwater level, rainfall, impact of vadose zone and hydraulic conductivity. A conversion into Grid module was applied to polygon features of aquifer and soil media. Spatial 3-D analsys extension module was applied to contour lines and its elevation height to derive the percentage of slope of terrain. Overlay technique and Map calculator module was applied to calculate rate and weight of DRASTIC layers to produce vulnerability index map of contamination.

4.3 Data processing

The seven parameters of the DRASTIC method, depend on hydrogeological characteristics and physical properties and were imported into ArcView® program as shape files, point, lines, and polygon format. The seven files were gridded for each layer by function operator as shown in Table 4.1. The land area was subdivided into a regular square grid raster of cell size of 100*100 meters. The regular square grid raster of the same size (100*100 meters) was assigned to all seven layers as the default in the DRASTIC method.

Table 4.1 Operator used in manipulated DRASTIC data

Layer	File name	Feature Type	operator	Out put file name
Depth to water level	Well_cm_lp	Point	Interpolated grid	Depthgrd
Net recharge	Rainfall_cmln	Point	Interpolated grid	Raingrd
Aquifer media	Aquifer_cmln	Polygon	Gridding	Aquigrd
Soil media	Cmlp_soil1	Polygon	Gridding	Soilgrd
Topography	Edit_contour	Point	TIN, Derive slope	Topogrd
Impact of vadose zone	Vadose _cut	Point	Interpolated grid	Imvadosgrd
Hydraulic conductivity	Pumping_c_k_t	Point	Interpolated grid	Condgrd_kj

4.3.1 Depth to groundwater

Groundwater well data tables with its co-ordinate, easting and northing, were used to create the groundwater well location map. Aquifer depths in Chiang Mai basin vary from 5 meters deepat the edge of the basin to 320 meters deep or more in the central basin, with an average depth of 56 meters. The groundwater levels ranged between a half meter in alluvium flood plains to 98 meters below land surface, and the average groundwater depth was about 9 meters. Groundwater levels were interpolated by using Interpolated Grid extension module of the ArcView® program to obtain the distribution of groundwater levels in every grid cells. The program calculated each cell size by using inverse distance weighting methods (IDW) of power two and the number of neighbors of 12 points. 9 equal classes intervals were calculated using the program (Figure 4.1).

Groundwater levels near land surface of a few meters were considered as highly vulnerable and were rated as 9-10, whereas deeper groundwater levels of more than 50 meters were rated at a lower number of 1 or 2 as shown in Table 4.1. Groundwater levels and their values were classified according to DRASTIC ratings, as mentioned above, into 9 classes, from high vulnerable 10 to low vulnerable 1 The interpolation function of ArcView® program was used to generate 9 equal classes (interval of 10) of depth to groundwater level.. The grid map of depth of groundwater level shown in Table 4.2, shows range of depth to groundwater levels where high ratings were assigned to low groundwater levels, and vice versa (Figure 4.2).

High ratings of groundwater levels were found in the north of Chiang Dao district, a small area in Mae Taeng district, down to the San Patong district of Chiang Mai Province and Pa Sang district of Lumphun Province.

Table 4.2 Rated and weight of depth to groundwater level.

Depth to groundwater level	
Range (meters)	Rating
0-2	10
2-5	9
5-10	7
10-20	5
20-30	3
30-50	2
> 50 +	1
Weight: 5	

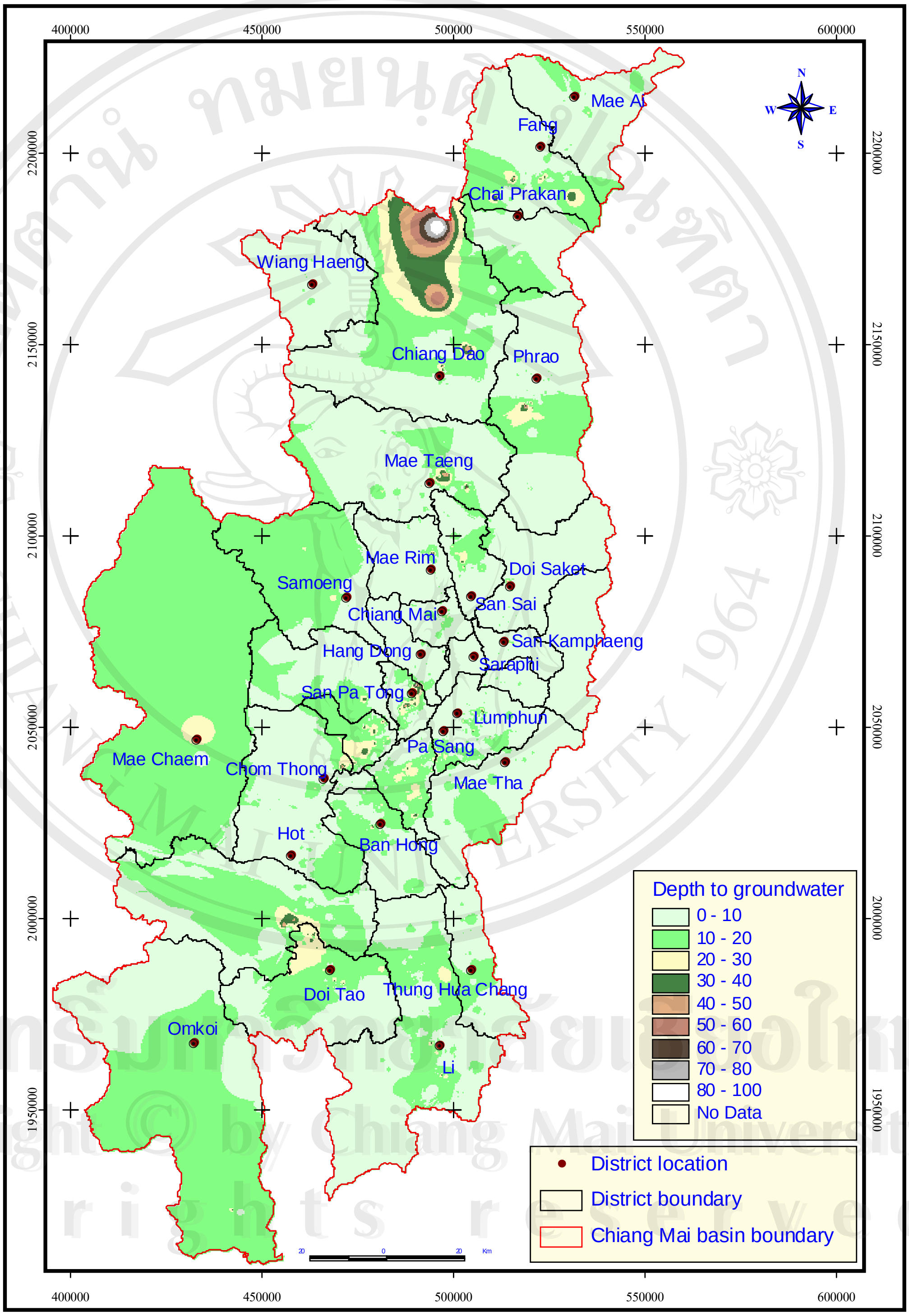

Figure 4.1 Depth to groundwater level map.

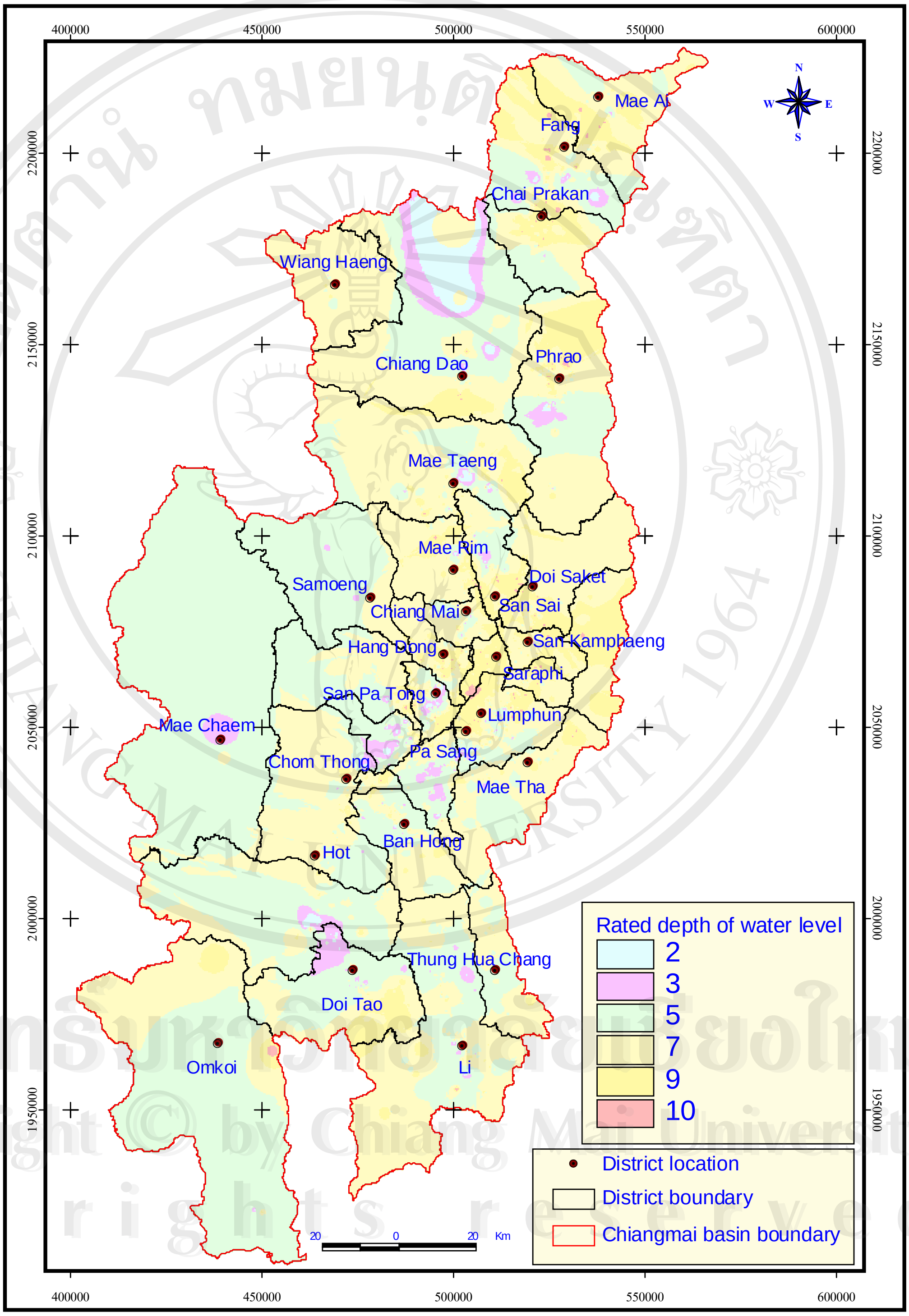

Figure 4.2 Rated depth to groundwater level map.

4.3.2 Net Recharge

Net recharge was defined as the amount of annual rainfall (in millimeters per year) that penetrated groundwater. A total of 60 rain gauge stations were found in Chiang Mai basin. The amount of rainfall in each month and annual rainfall were stored in a table as the rainfall database. The amount of rainfall intensity ranged from 663 to 1,669 millimeter per year, with the average annual rainfall at about 1,071 mm/y. High intensity rainfall of about 1,200-1,600 mm/y was found in the northern part and western part of the basin, where high mountain rages are situated, whereas less rainfall intensity was found in the southern part of the basin.

The amounts of annual rainfall from 60 rain gauge stations were calculated by Interpolated Grid function by default parameters of cell size 100*100 meters, IDW methods and number of neighbors of 12 for calculating distribution of rainfall intensity throughout the basin (Figure 4.3).

The rating number 9 was assigned to the area where high density (more than 2,000 mm/year) of precipitation was found; on the other hand, low precipitation ranging from 0 to 200 was rated as a number of 1 (Table 4.3). The raster grid file of rainfall distribution was re-classified to 5 classes from 1 to 5 (Figure 4.4).

Table 4.3 Rated and weight of net recharge.

Net recharge	
Range (mm/y)	Rating
0-200	1
200-500	3
500-1000	5
1000-2000	8
> 2000	9
Weight: 4	

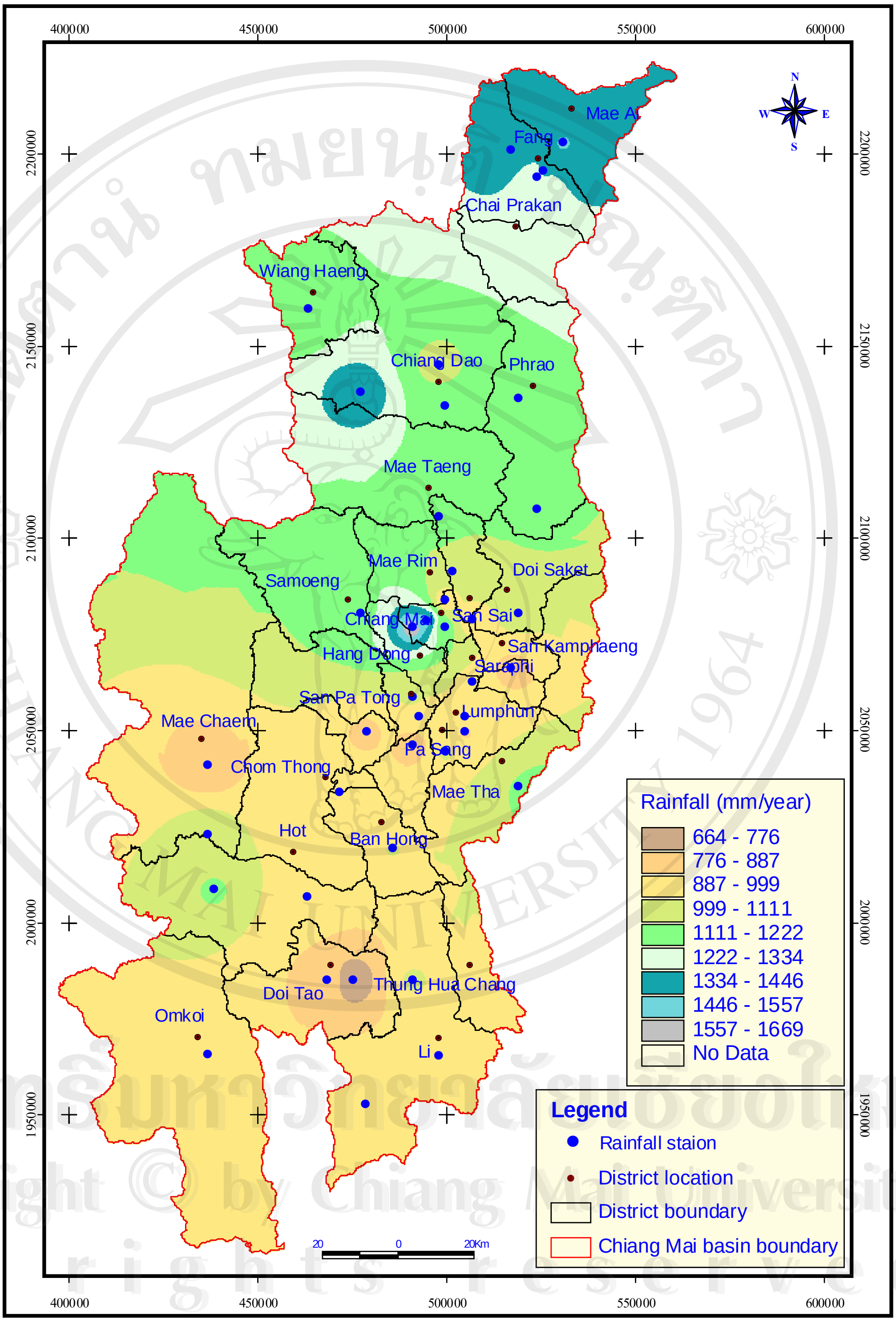

Figure 4.3 Map of rainfall intensity.

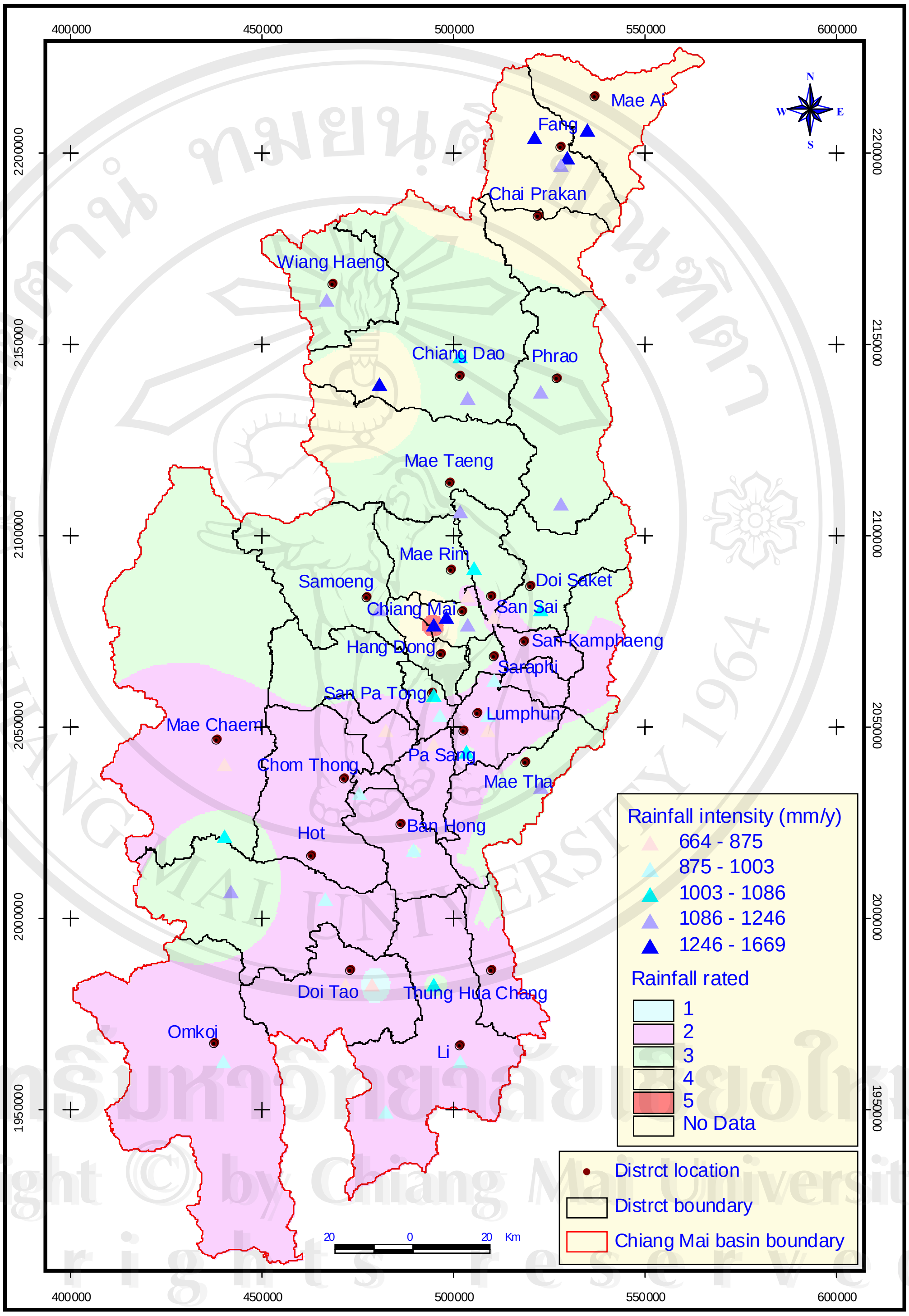

Figure 4.4 Rated annual rainfall map.

4.3.3 Aquifers media

Hydrogeological units of aquifers were regrouped and rated by their properties: permeability and primary and secondary porosities. Primary porosity is void between grains of materials during depositional process and normally occurrs in unconsolidated aquifers e.g. gravel, sand, silt and clay. Secondary porosity is void after solidification processes e.g. fractures and faults, normally found in igneous rocks (granite or basalt), sedimentary rocks (limestone or shale) and metamorphic rocks (schist or phyllite). Aquifer units were rated by type and porosity; high numbers were assigned to aquifers which had high porosity and continuity (Figure 4.5). Dense hard rocks with less fractures were assigned alower number, while soluble limestone (cavern) or karst aquifers were assigned a higher number (Table 4.4).

Table 4.4 Rated and weight of aquifers media.

Aquifer media	
Range	Rating
Thick shale (more than 5 m.)	2
Metamorphic rocks/granite	3
Weathered rock/decomposed zones	4
Gravel	5
Bedded sandstone/shale/limestone	6
Thick-bedded sandstone	6
Thick-bedded limestone	6
Gravel and sand	8
Basalt (vesicular)	9
Karst limestone	10
Weight: 3	

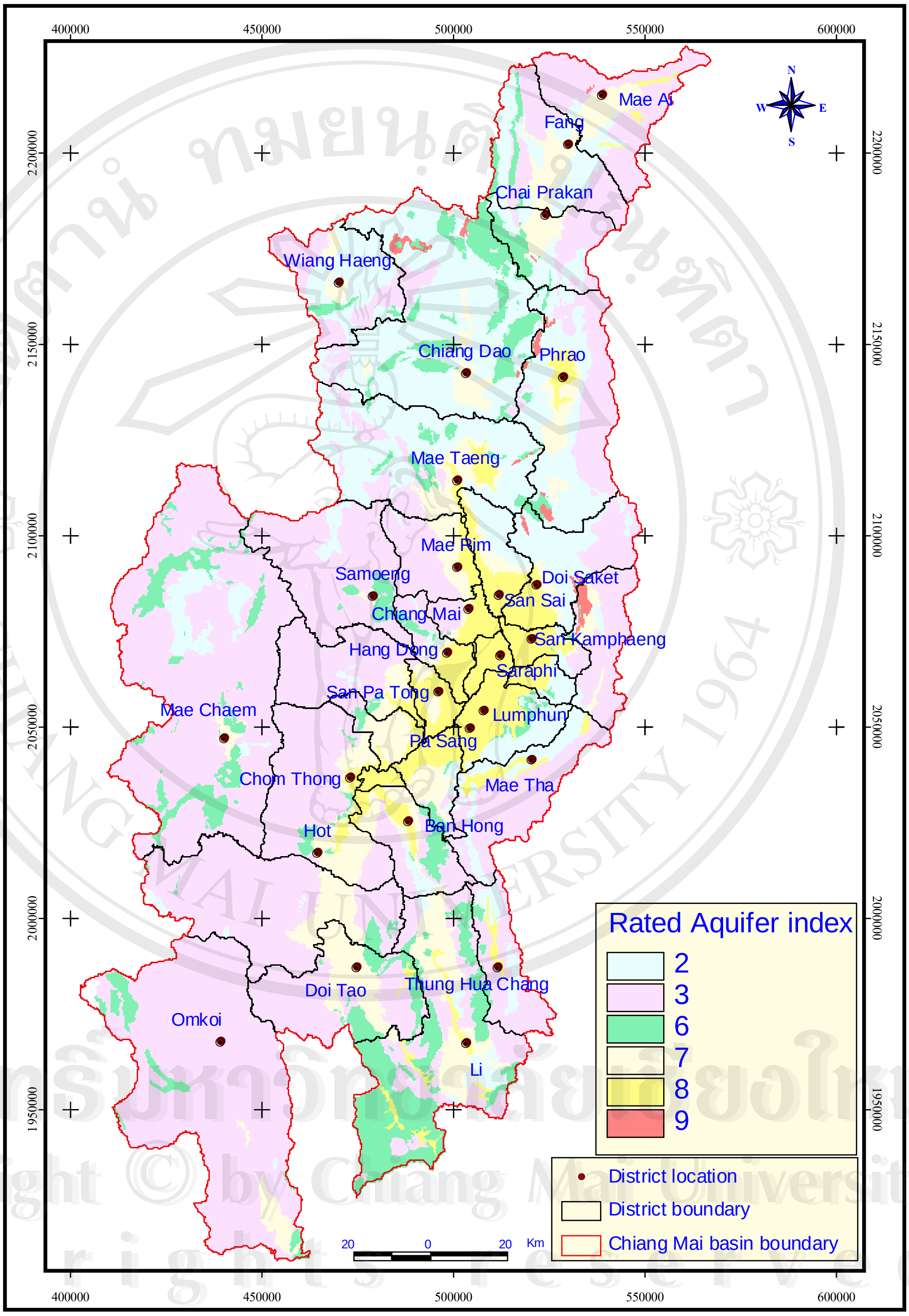

Figure 4.5 Rated aquifer map.

4.3.4 Soil media

Soil maps of the Department of Land Development were modified by using soil properties and soils series were also regrouped (Chophaka, 1998). Soil series were rearranged by soil types into sand, sandy loam, loam, silty loam, clayey loam, and loam. (Figure 4.6). The Soil map database was restructured by assigning soil media types and ratings according to the DRASTIC method (Table 4.5). Soil types were rated in the same manner as aquifers media types; soil media which had high permeability was rated with high scores up to 10 e.g. gravel and sand, whereas soil media which had a high clay content and low permeability was rated lowerThin soil or absent soil was also rated with a higher score of 10 (Figure 4.7).

Table 4.5 Range and rating of soil media.

Soil media	
Range	Rating
Thin or absent, Gravel	10
Sand	9
Sandy loam	6
Loam	5
Silty loam	4
Clayey loam	3
Clay	2
Weight: 2	

Soil media map is converted to raster grid file by function of Coverting to Grid of ArcView® program and reclassified by rating scores into 7 classes.

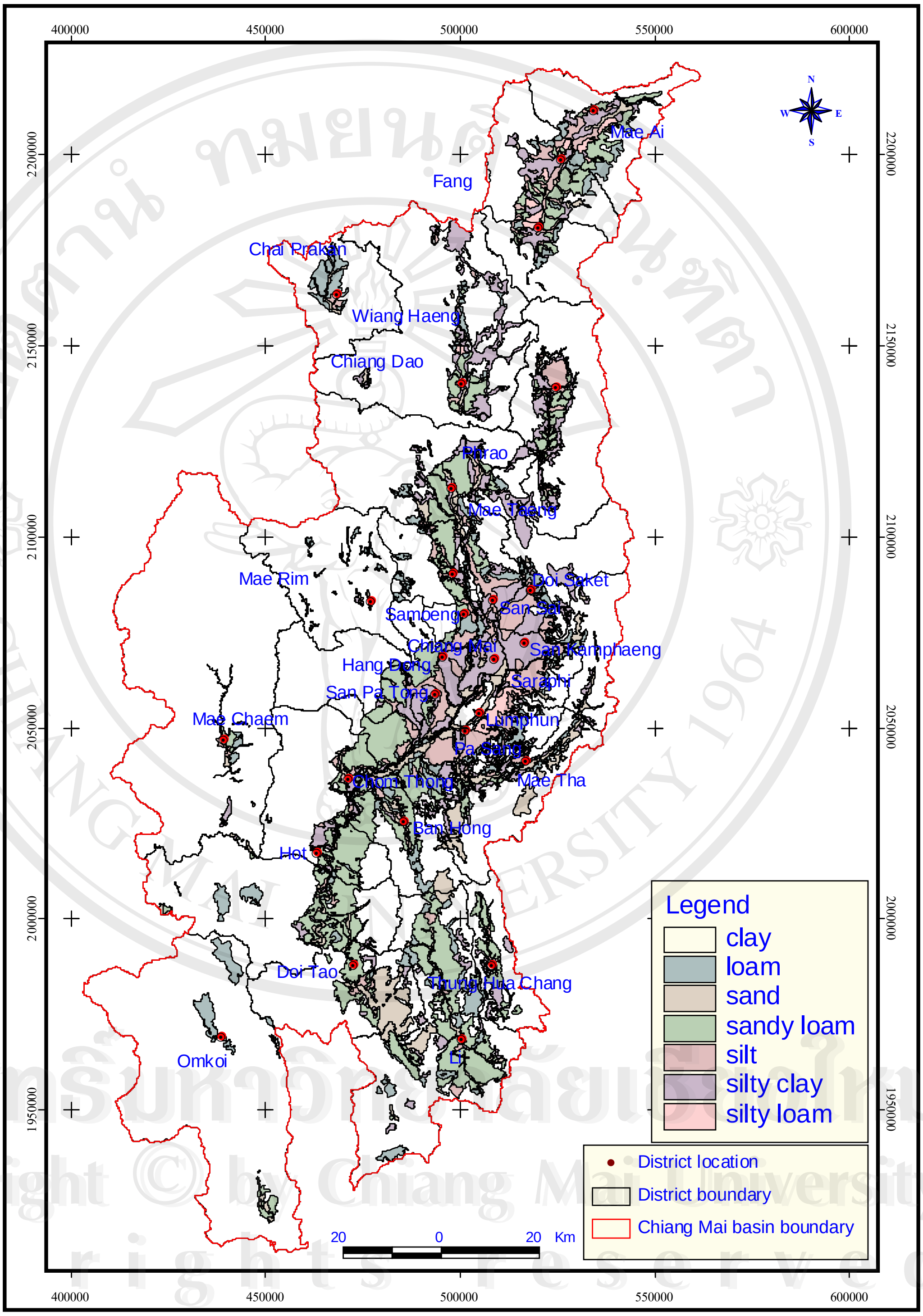

Figure 4.6 Soil type map.

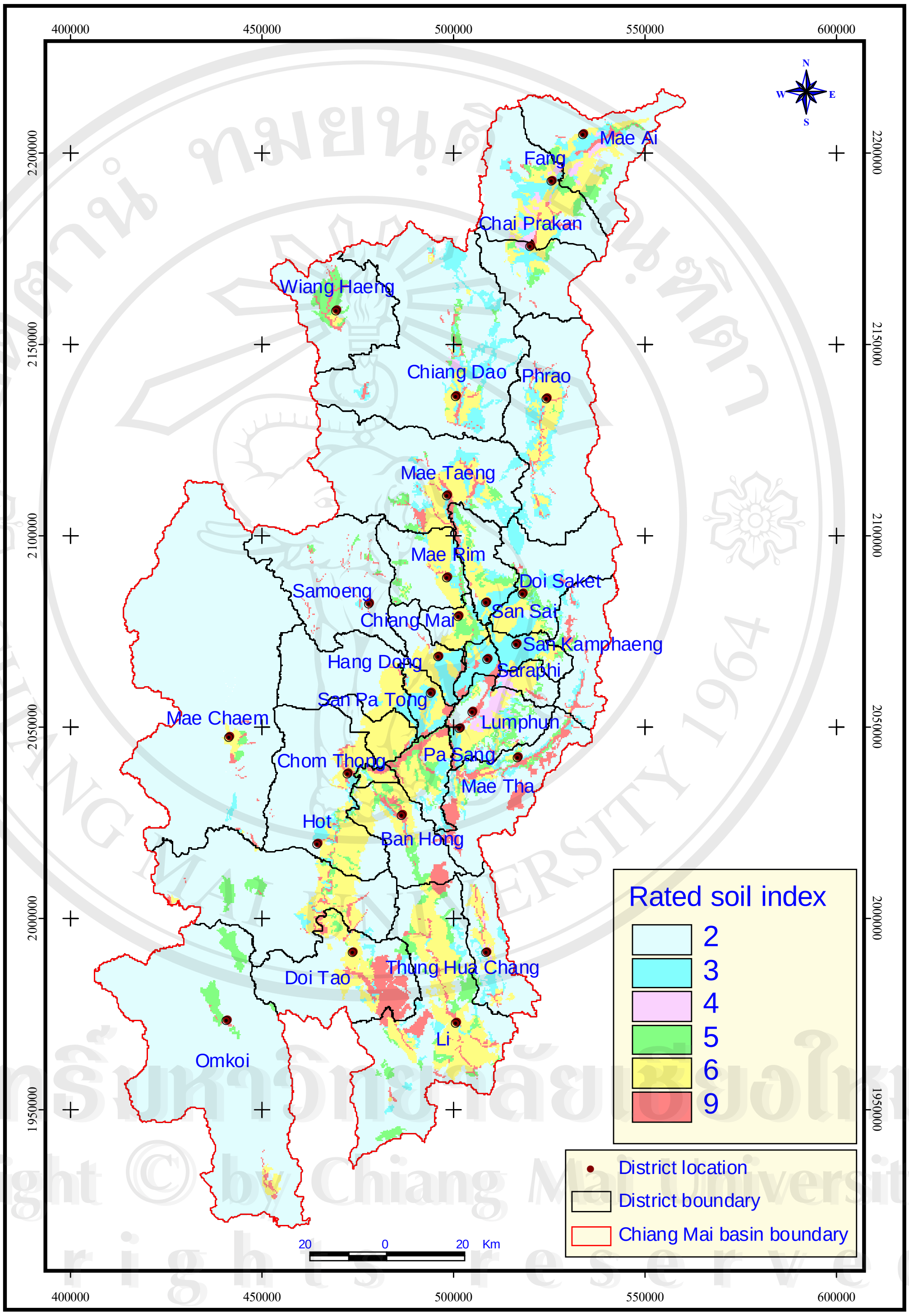

Figure 4.7 Rated soil map.

4.3.5 Topography

Topographic maps with contour lines of Chiang Mai, Lumpang and Lumphun Provinces were merged together to construct the Chiang Mai basin contour map. The 3D-analyst functionof the ArcView® program was applied to create Triangular Irregular Networks of terrain (TIN grid file), which used contour elevation and spot height for calculating slope of the basin (Figure 4.8). The slope in percentage was derived from the grid file of TIN grid file, and could be rated by percent of slope (Table 4.6). A shallow incline of terrain or flat plain terrain allows the surface water to dissolve a higher amount of contaminant to aquifer, whereas a steep inclinein terrainwill result in water rapidly passing through land surface. In these cases there is not enough time for water to interact with contaminants and results in the surface water dissolveing a smaller amount of contaminants. Therefore, flat plain terrain of less than 2 percent slope, will have a higher rating than the steep slopes of more than 18 percent. (Figure 4.9).

Table 4.6 Range and rated of slope of terrain.

Topography	
Percent Slope (range)	Rating
0-2	10
2-6	9
6-12	6
12-18	3
18+	1
Weight: 1	

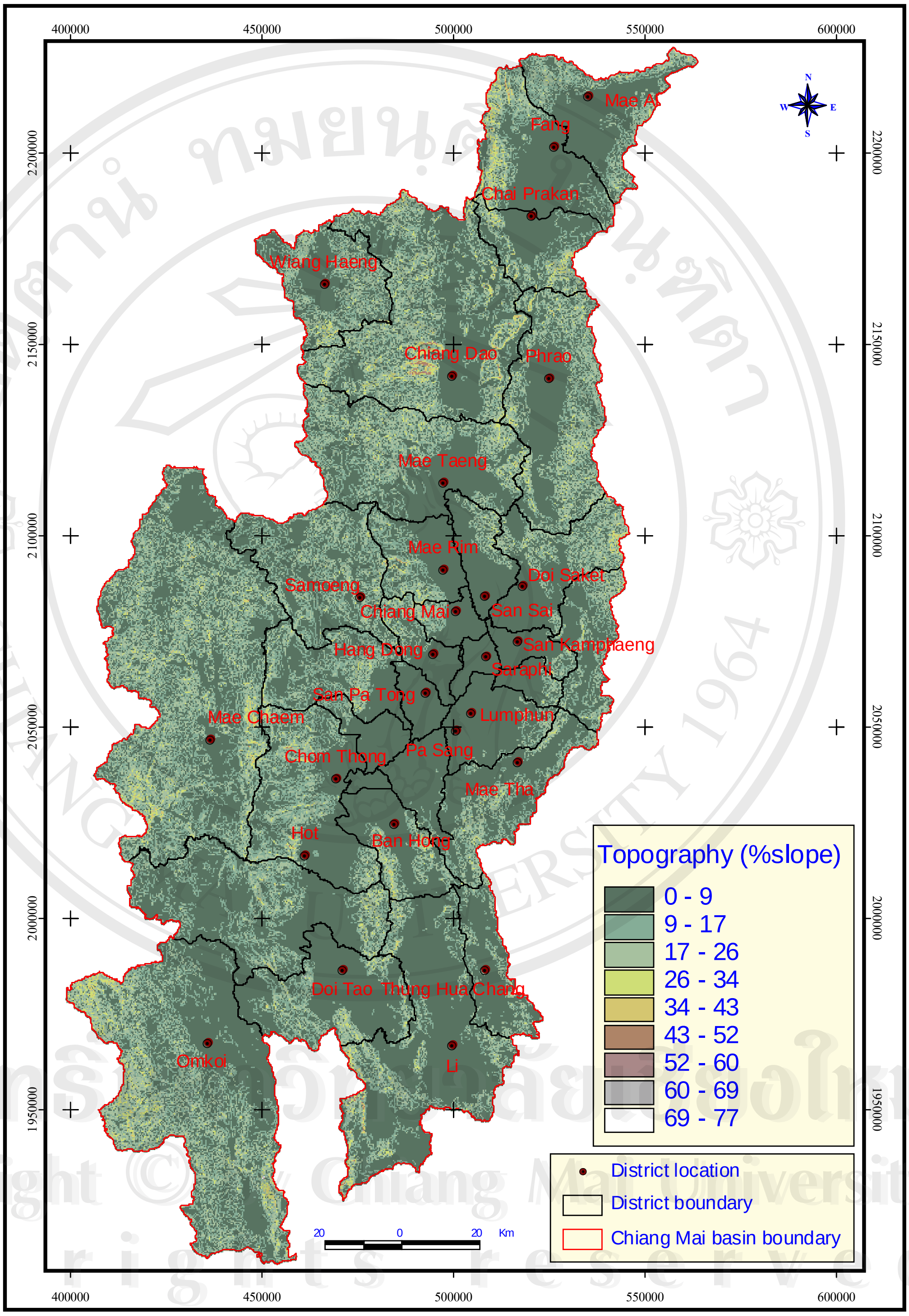

Figure 4.8 Percent slope of topography.

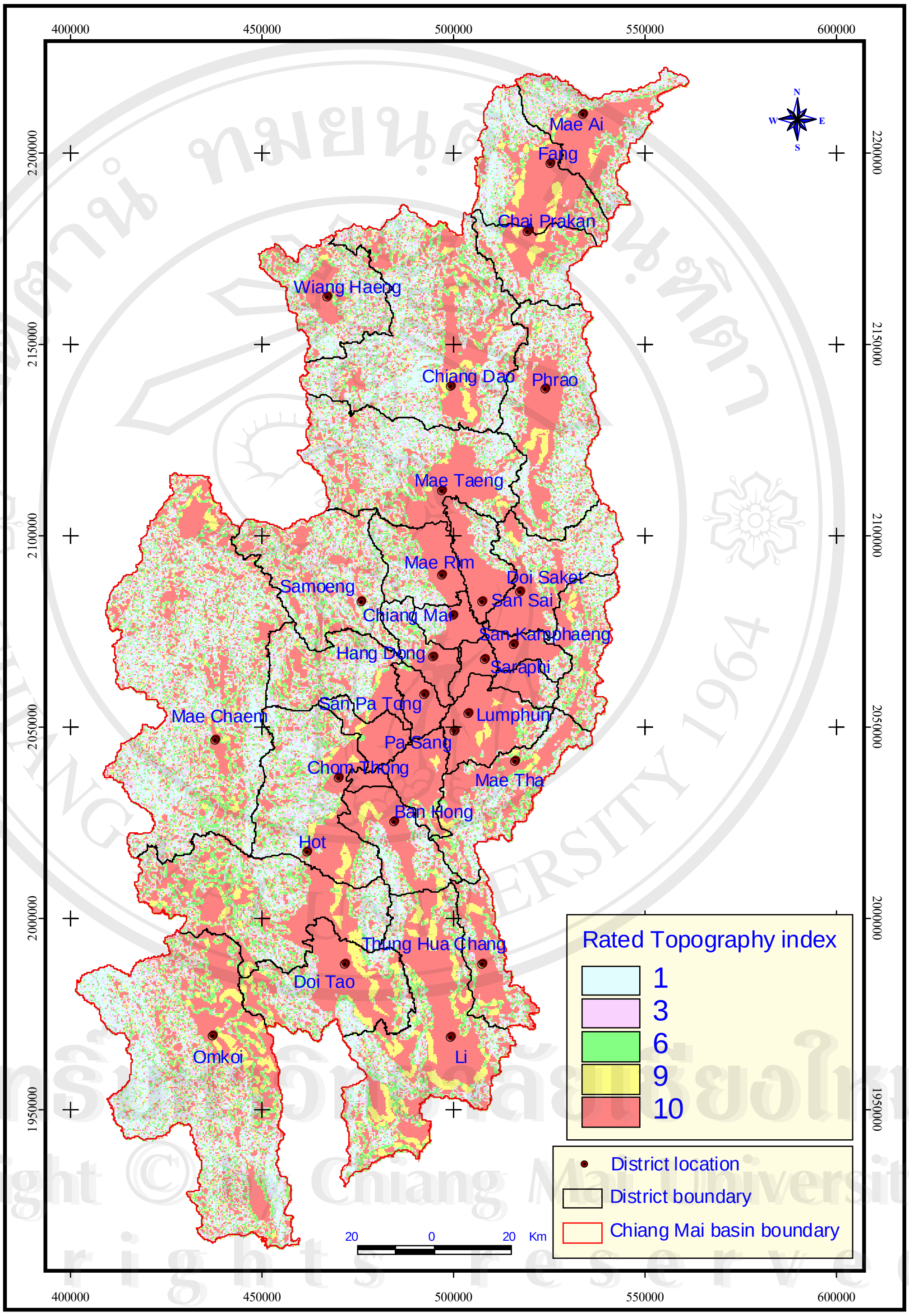

Figure 4.9 Rated percent slope of topography.

4.3.6 Impact of vadose zone

The soils or rocks above the saturated zone of aquifers are defined as the vadose zone. The zone describes the groundwater flow path, i.e. water may easily transmit or slow down contaminants according to thickness and porosity. A confined layer has a low rating as impermeable beds on top and below aquifers will act as a barrier to contaminants passing through to the aquiclude beds. The thickness and rock type was taken into consideration simultaneously and was manually assigned to attributes of the database of well locations where samples of the drilled welllogs were analyzed.

Table 4.7 Example of drilled log of well in Chiang Mai basin (DGR, 2002).

GEOLOGIC LOG

Groundwater Investigation Section Department of Groundwater Resources

Report Date 24/06/2002

G0198CM37

Mea-Cho Agriculture Station Chiang Mai Province

Depth 225 m. Aquifer type gravel & sand Perforation interval 30-42, 54-72, 96-102,4 m.

Logged by Prakob Ukong Checked by Prakob Ukong

	Depth (m.)	
CLAY:	0 - 8	brown, limonitic, slightly plastic, sligthly compacted.
CLAY:	8 – 18	brownish yellow, limonitic, slightly plastic, sligthly compacted.
GRAVEL:	18 - 24	brown and yellow, fine gravel to coarse gravel, subangular to subrounded, well sorted, composed of quartz with sandstone fragments with chert fragments.
CLAY:	24 - 29	yellow, limonitic, slightly plastic, sligthly compacted.
GRAVEL:	29 - 60	brown and yellow, fine gravel to coarse gravel, subangular to subrounded, well sorted, composed of quartz with sandstone fragments with chert fragments.
CLAY:	60 - 78	brown, gravelly, very coarse sand to very fine gravel, angular, well sorted, composed of quartz, chert.
GRAVEL:	78 - 111	grayish brown, very fine gravel to medium gravel, subrounded, well sorted, composed of quartz.
GRAVEL:	111 - 132	yellowish brown, very fine gravel, angular to subangular, well sorted, composed of quartz, chert interbedded.
CLAY:	132 - 147	grayish brown, limonitic, slightly plastic, compacted.
GRAVEL:	147 - 162	various colors, fine gravel to medium gravel, subangular to subrounded, well sorted, composed of quartz, chert.
GRAVEL:	162 - 225	various colors, clayey, very fine gravel, subrounded, well sorted, composed of quartz, chert.

The drilledwell log l No. G0198 CM 37 (Table 4.7) had a total drilled depth of about 225 metersand the aquifer type was gravel and sand at depths of 30-42 m, 54-72m, and 96-102 m below surface level, respectively. However, the top stratum was clay (from 0-18 meters) for vadose zone media hence, it was considered as clay media instead of gravel or sand. All available well logs were used to identified vadose zone and manually inputed to the well database. Rated values were assigned to vadose zone as shown in Table 4.8. Thin rocks or gravel bed were assigned a high rating of 8 or 10 while thick beds of clay or confined aquifer were assigned low ratings from 1 to 2 (Figure 4.10).

Table 4.8 Type and Rating of impact of vadose zone.

Impact of vadose zone	
Type	Rating
Confined layer	1
Silt/clay	3
Shale	3
Sand & gravel	4
Limestone	6
Sandstone, bedded limestone, sandstone, shale	5
Sand and gravel with significant silt and clay	6
Metamorphic/igneous rocks	8
Basalt (vesicular)	8
Karst limestone	10
Weight: 5	

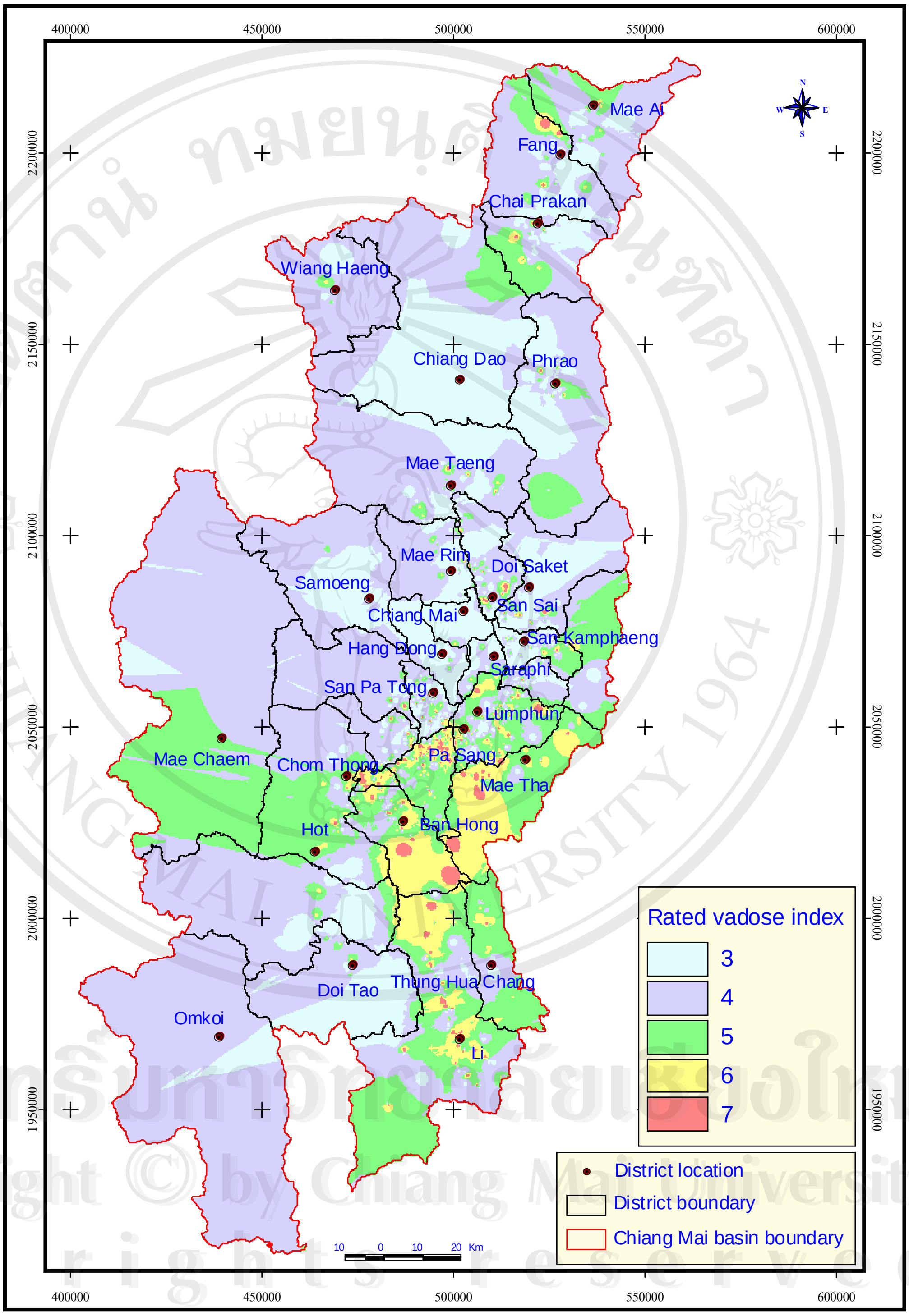

Figure 4.10 Rated impact of vadose zone map.

4.3.7 Hydraulic conductivity

During groundwater development a well pumping test measurement was carried out for calculating aquifer properties by applying a constant pumping rate (Q) and mean while drawing down in the boreholefor a period of 8 hours or until there was no change in groundwater level (Table 4.9). The results from the pumping test were plotted between time and drawdown of water levels (Walton, 1970). The THEIS and JACOB methods from Aquitest software were employed for calculation (time–drawdown curve) in order to obtain the tranmissivity (m^2/min) of the aquifer. Hydraulic conductivity was derived from the tranmissivity divided by the thickness of the aquifer (Figure 4.11).

The hydraulic conductivity was ranged and rated as shown in Table 4.10.Ranged hydraulic conductivity was calculated into 9 equal classes as shown in Figure 4.12 and was rated according to degree of vulnerability (Figure 4.13).

Table 4.9 Pumping test analysis chart of well No. C0006.

Waterloo Hydrogeologic 180 Columbia St. W. Waterloo,Ontario,Canada ph.(519)746-1798	Pumping test analysis Recovery method after THEIS & JACOB Confined aquifer	Date: 21.10.2004	ä¿¿éÒ, Page 2
		Project: Groundwater Potential Assessme	
		Evaluated by: kanchana	
Pumping Test No. C0006		Test conducted on:	
C0006		C0006	
Discharge 5.000 m³/h		Distance from the pumping well 0.050 m	
Static water level: 0.240 m below datum		Pumping test duration: 4320.00 min	

	Time from end of pumping [min]	Water level [m]	Residual drawdown [m]
1	1.00	7.960	7.720
2	2.00	7.220	6.980
3	3.00	6.930	6.690
4	4.00	6.860	6.620
5	5.00	6.720	6.480
6	6.00	6.600	6.360
7	7.00	6.520	6.280
8	8.00	6.480	6.240
9	9.00	6.260	6.020
10	10.00	6.240	6.000
11	15.00	5.880	5.640
12	20.00	5.620	5.380
13	25.00	5.480	5.240
14	30.00	5.300	5.060
15	40.00	5.190	4.950
16	50.00	4.870	4.630
17	60.00	4.580	4.340
18	80.00	4.370	4.130
19	100.00	4.250	4.010
20	120.00	4.180	3.940
21	140.00	4.090	3.850
22	160.00	4.020	3.780
23	180.00	3.950	3.710
24	200.00	3.890	3.650
25	220.00	3.840	3.600
26	240.00	3.790	3.550

Table 4.10 Range and rating of hydraulic conductivity.

Hydraulic conductivity	
Range (cubic meter / day)	Rating
0.005-0.50	1
0.50-1.50	2
1.50-3.50	4
3.50-5.00	6
5.00-10.00	8
10.00 +	10
Weight: 3	

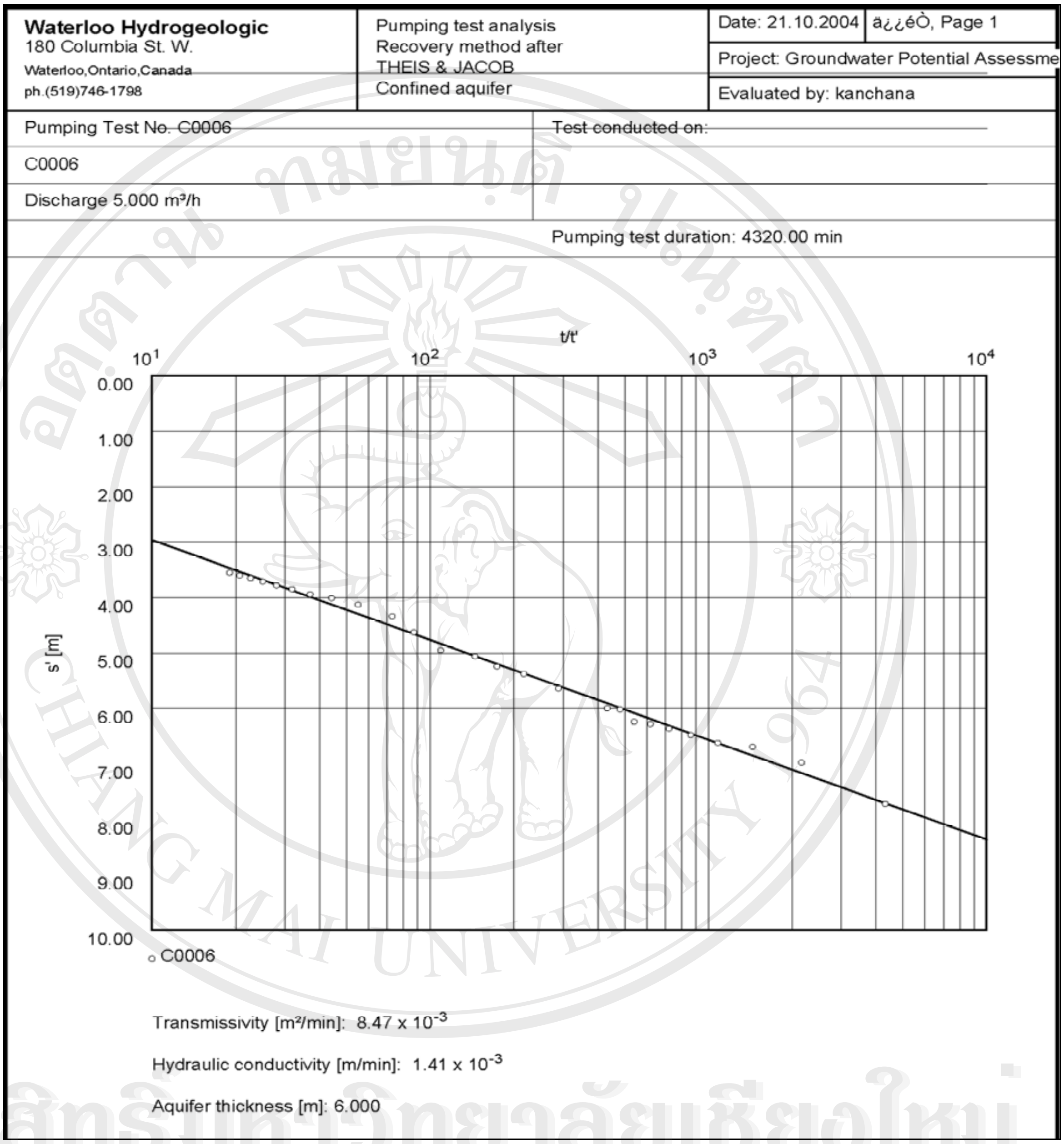

Figure 4.11 Calculated hydraulic conductivity of well No. C0006.

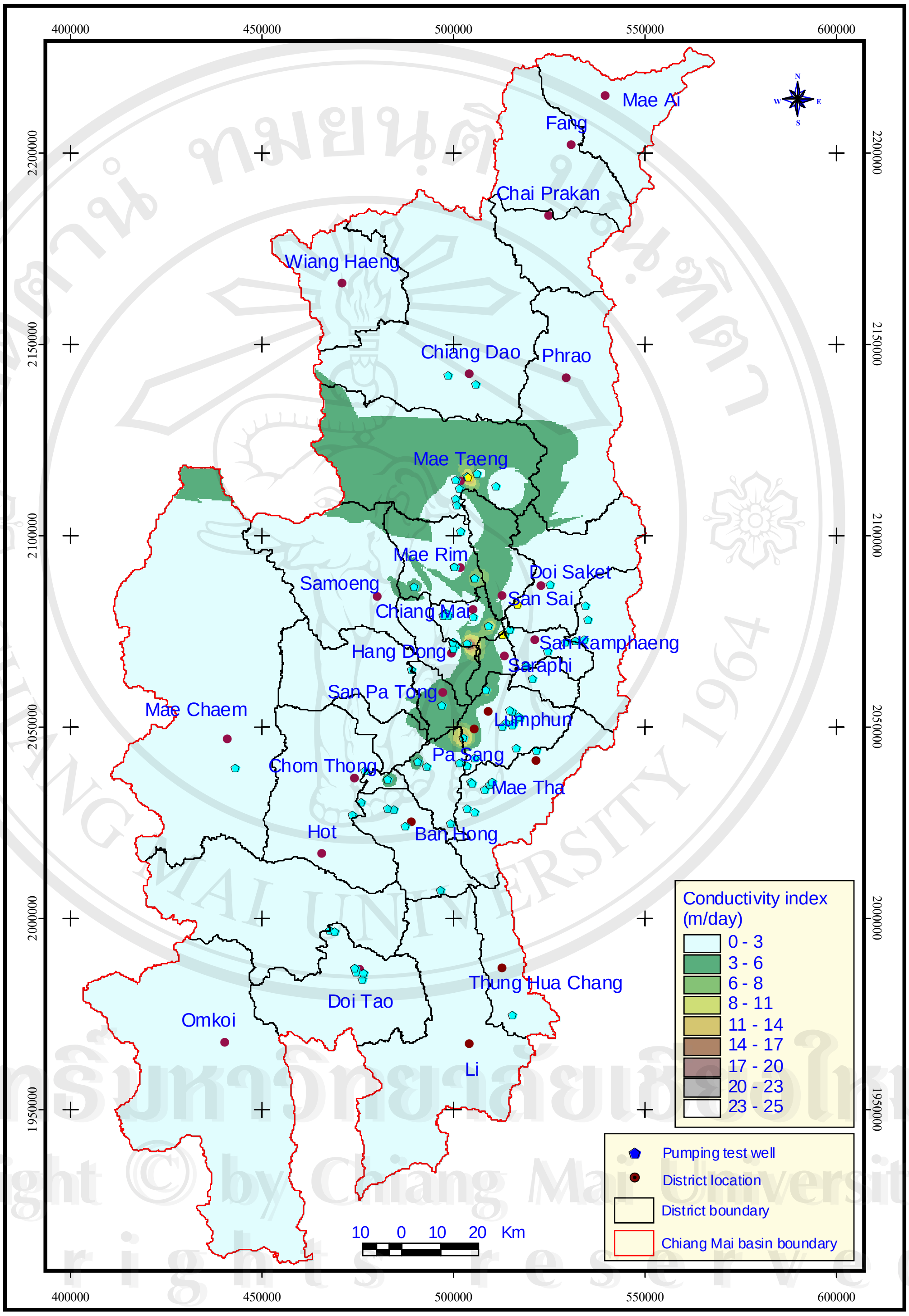

Figure 4.12 Hydraulic conductivity distribution map.

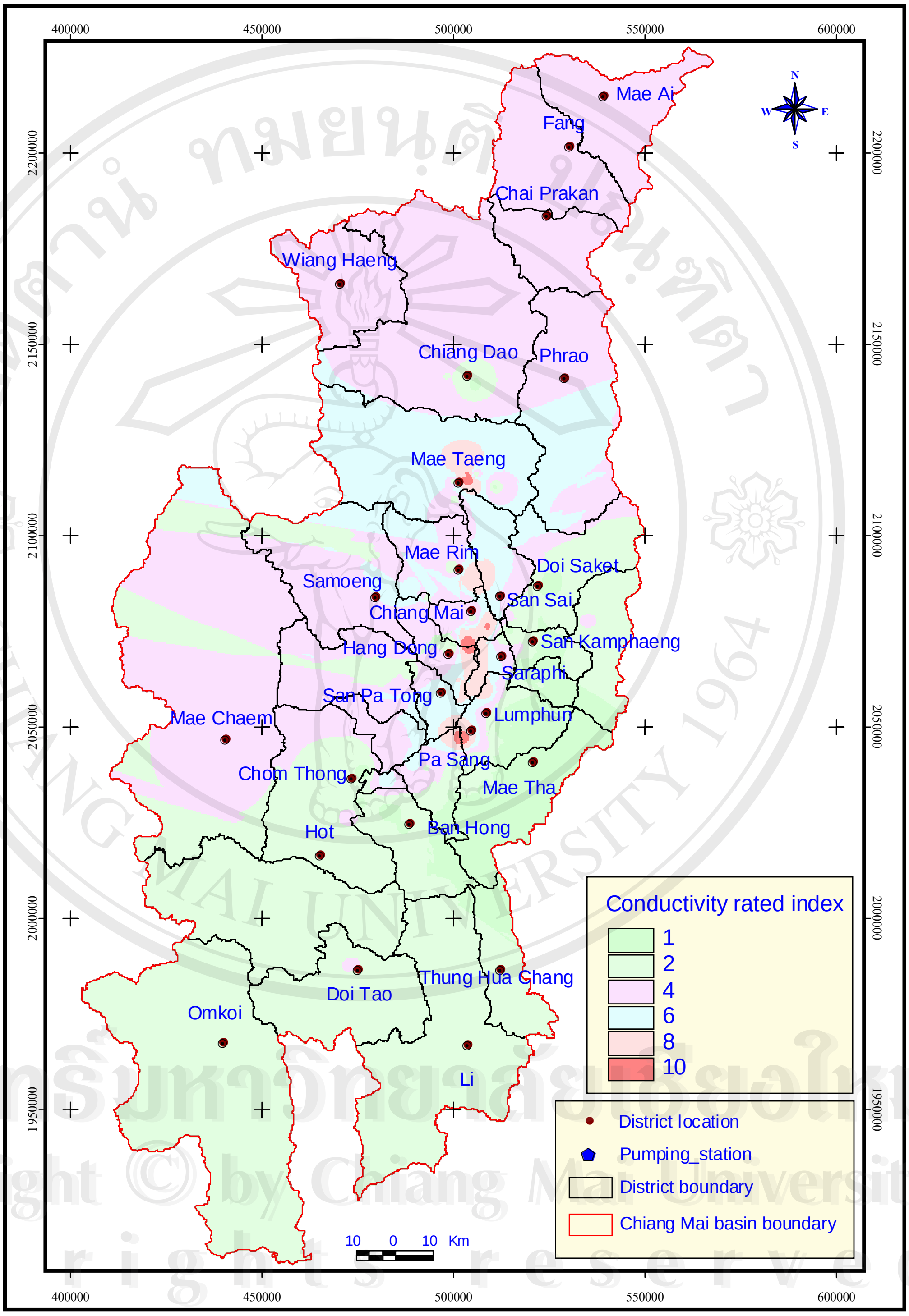

Figure 4.13 Rated hydraulic conductivity map.

4.4 Drastic vulnerability processing map

The seven layers of the DRASTIC map used in rating were constructed by using overlay technique and Map calculator module of the ArcView® Program to calculate the DRASTIC index. The DRASTIC model was equal to the sum of each parameter's rating times and each parameter's weight. Ratings ranged from one to ten, and represented the relative significances of each type within each parameter. Weighting ranged from one to five, and represented the relative importance of each of DRASTIC parameter. The higher DRASTIC index indicated higher vulnerability over an area. The DRASTIC index was calculated using this formula:

V = Dr*5 + Rr*4 + Ar*3+ Sr*2 + Tr + Ir*5 + Cr*3 **(4-1)**

Where:

V = DRASTIC Vulnerability Index
Dr = Rating of Depth to groundwater level
Rr = Rating of Net recharge
Ar = Rating of Aquifer media
Sr = Rating of Soil media
Tr = Rating of Topography
Ir = Rated of Impact of vadose zone
Cr = Rating of Hydraulic conductivity

The DRASTIC index value was automatically divided by the default of the ArcView® program into 9 equal interval classes (Table 4.11). The summation of all layers of the DRASTIC index value had a minimum value of 46 and maximum value of 174 (Figure 4.14). The vulnerability index values were reclassified into 5 classes of intervals (Figure 4.15) and colored according to its degree of vulnerability (Jaroslav and Alexander, 1994). In order to show location of vulnerable areaf, ranges of the area were shaded in color as shown in Table 4.12; ranging from very low, low, medium, high to extremely high vulnerability.

Table 4.11 Drastic index value of Chiang Mai basin.

Classes	Range
1	46 - 60
2	61 - 74
3	75 - 88
4	89 - 102
5	103 - 117
6	118 - 131
7	132 - 145
8	146 - 159
9	160 - 174

Table 4.12 Typical color assigned to vulnerability index map (Jaroslav, 1994).

Vulnerability	**Value**	**Color**
Extremely High	149-174	Red orange
High	123-148	Rose
Medium	98-122	Yellow
Low	72-92	Light olive green
Very Low	46-71	Dark olive green

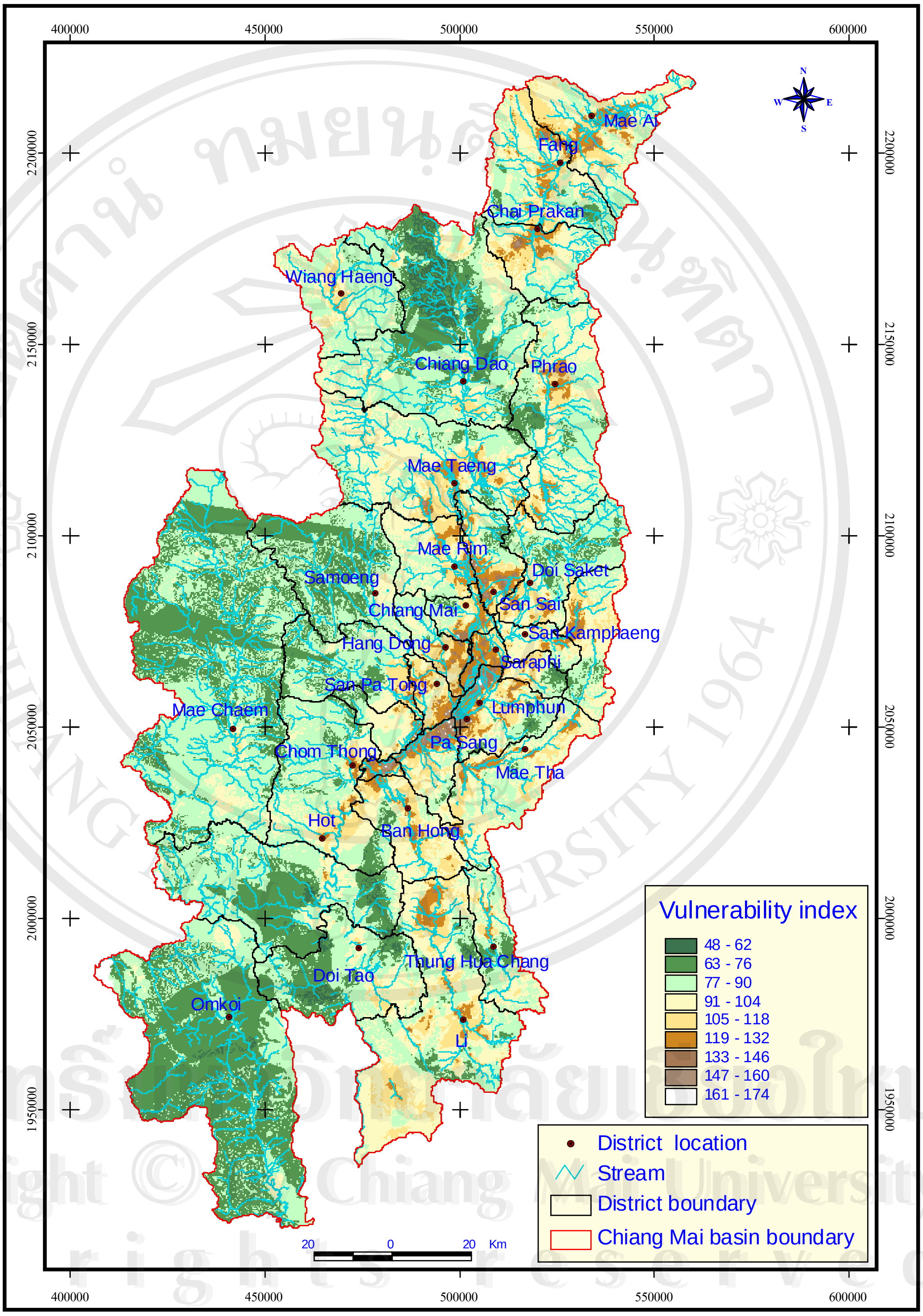

Figure 4.14 Vulnerability index value map.

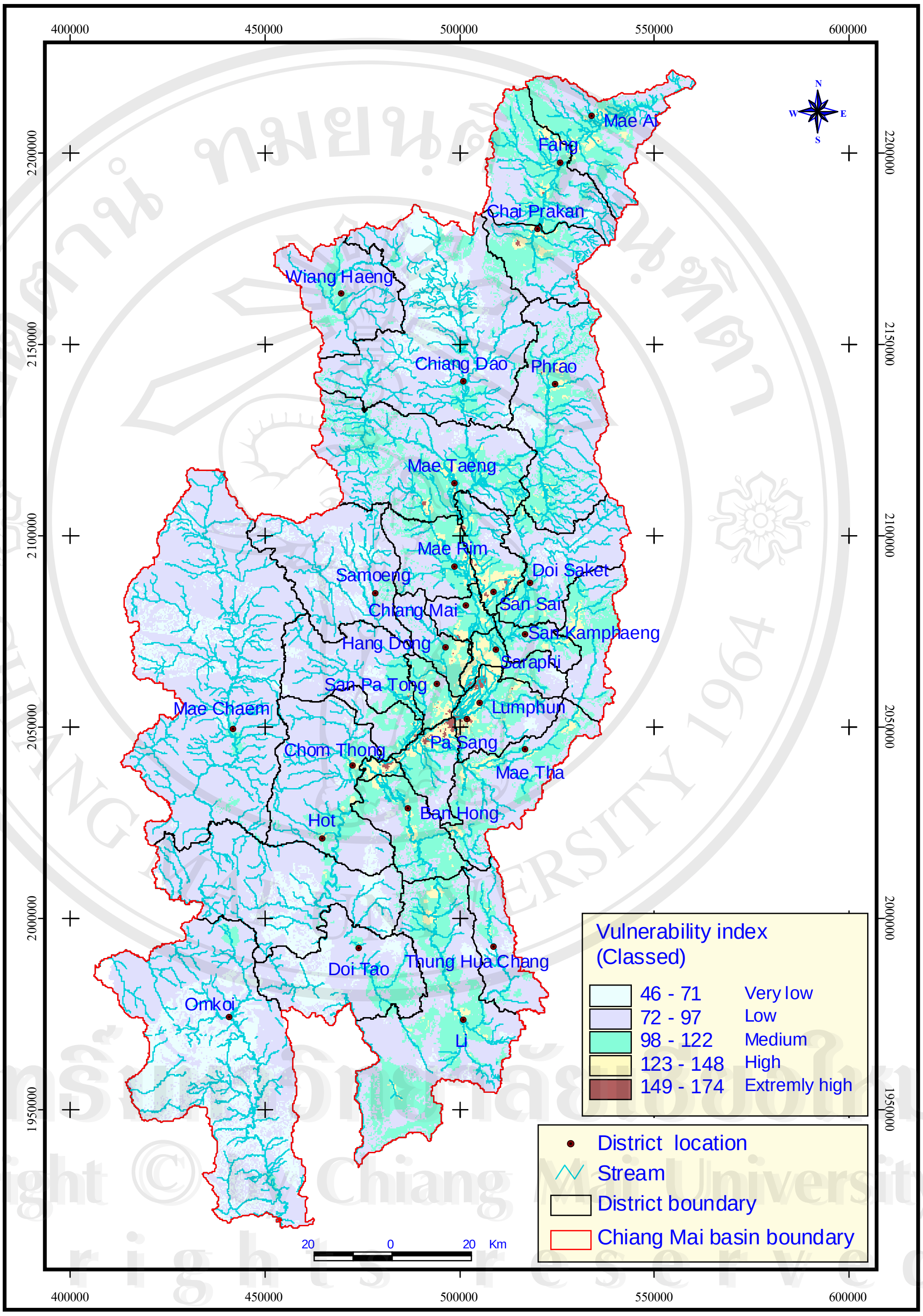

Figure 4.15 Re-class vulnerability index map.

It can be seen that areas ofextremely high vulnerability or low vulnerability corresponded to the seven layers of the DRASTIC method criteria. However, some degree of error commonly results from the process of interpolation, extrapolation and intersecting of GIS method.

High vulnerability index values ranging from 149-174 were situated along the alluvium flood plain of the Mae Ping River and its tributary (Figure 4.16) from the north of Mae Ai district, Saraphi district, Chom Tong district and San Patong district of Chiang Mai Province down to Pa Sang district of Lumphun Province and further down to the southern part of the basin. Typical characteristics of an extremely high vulnerability value are flat terrain, gravelly or sandy aquifers and high hydraulic conductivity where high permeability and porosity are found. The extremely high vulnerability areas were situated in the western side of the Mae Ping River which is defined by high permeability of alluvium and gravelly and sandy aquifers. High to medium vulnerabilitys area were located some distancefrom extremely high vulnerability areas and in the alluvium aquifers. Mountainous areas with a steep slope, hard rock aquifers and low hydraulic conductivity showed low vulnerability.

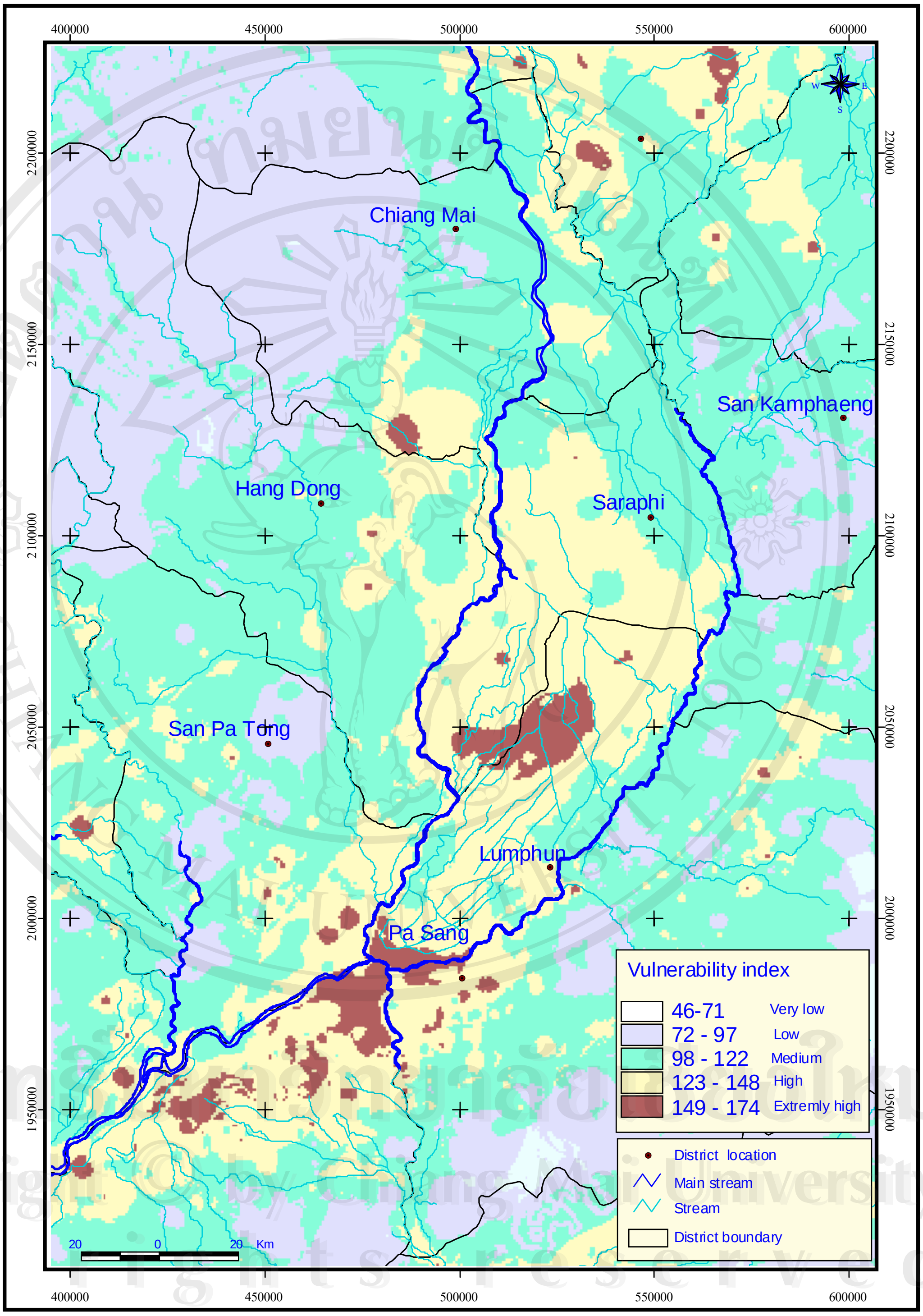

Figure 4.16 Re-classed vulnerability index map (in unconsolidated aquifers).

4.5 Comparison of DRASTIC and waste disposal site

In order to compare the results of the DRASTIC assessment with the results from waste disposal site selection withthick clay beds of at least 5 meters, deep groundwater levels and environment were used as criteria to delineate high potential in waste disposal sites (Dorn and Tantiwanit, 2002). Vulnerability and waste disposal site maps were overlaid on one another. The DRASTIC map shows high vulnerability to contaminants in an area while the recommended waste disposal site shows areas where there is a low potential for contamination. These are therefore thebest places for waste disposal.. Forthis reason waste disposal sites should not be placed in high vulnerability areas. The vulnerability maps and recommended waste disposal sites were superimposed on each other (Figure 4.17). The result clearly shows that waste disposal areas are located only in the medium (value 72-122, yellow and green color) to low vulnerability areas There were no waste disposal sites in the extremely high vulnerability areas as determined by to the DRASTIC vulnerability map.

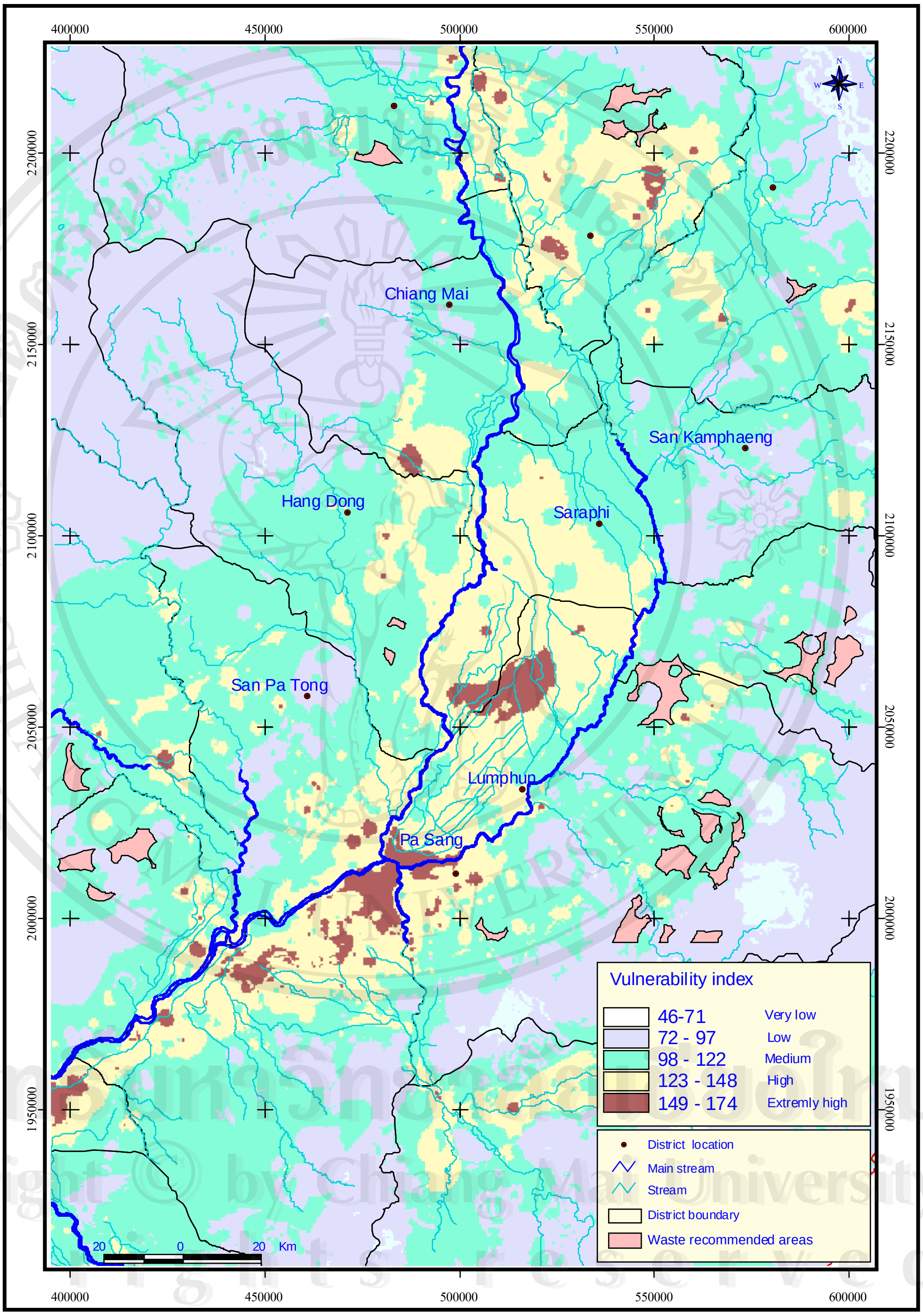

Figure 4.17 Vulnerability locations and waste disposal sites of Chiang Mai Province.