

## CHAPTER 5

### GROUNDWATER POTENTIAL AND RECHARGE

Groundwater potential and recharge is carried out by considering the total volume of water stored in an aquifer and the long-term average recharge to the aquifer. The various methods for estimate groundwater recharge can be classified as hydrologic budget, tracers, water table fluctuation, or numerical modeling approach. Choosing appropriate methods for quantifying groundwater recharge in varying space and time scale are of importance and depend on various hydrogeological characteristic and condition. Assessment of groundwater recharge in this study will be carried out by the hydrologic budget method, and a combination of GIS database and permeability testing.

#### 5.1 Hydrologic budget

The hydrologic budget or water budget method is based on a simple statement of the law of mass conservation. It may be expressed as (Fetter, 1988):

$$\text{Inflow} = \text{Outflow} \pm \text{Change in storage} \quad (\text{Eq. 5.1})$$

This method involved the components of the hydrologic cycle (Figure 5.1): precipitation, evapotranspiration, and surface water runoff. The outflows in the equation include evapotranspiration, groundwater outflow, groundwater abstraction, and surface water outflow. The components of inflow include precipitation, surface water inflow, imported water, and groundwater inflow. The change necessary to balance the hydrologic equation include changes in the volume of (1) surface water in streams, rivers, lakes, and ponds, (2) soil moisture in the vadose zone, (3) ice and snow at the surface, (4) temporary depression storage, (5) intercepted water on plant surface, and (6) groundwater below the water table.

Hydrologic budget can be applied to system of any size. It is as useful for a small reservoir as it is for an entire continent. The equation is time-dependent. The

element of inflow must be measured over the same time periods as the outflow. Hydrologic budget for an annual period would take the form:

$$P = Q + E + \Delta S_s + \Delta S_G \quad (\text{Eq. 5.2})$$

Where P = precipitation

Q = runoff

E = evapotranspiration

$\Delta S_s$  = the change in storage of the surface water reservoir

$\Delta S_G$  = the change in storage of the groundwater reservoir (both saturated and unsaturated) during the annual period

If data are average over many years, it can be assumed that  $\Delta S_s = \Delta S_G = 0$  and equation (5.2) becomes

$$P = Q + E \quad (\text{Eq. 5.3})$$

The watershed comprised a recharge area, and discharge area from hydrologic budget equation (Equation 5.2) can be written in two hydrologic budget equations, one of the recharge area and one for discharge area.

In the recharge area:

$$R = P - Q_s - E_R \quad (\text{Eq. 5.4})$$

Where R = the annual average groundwater recharge

$Q_s$  = the surface water component of average annual runoff

$E_R$  = the average annual evapotranspiration from recharge area

In the discharge area:

$$Q = Q_s + D - E_D \quad (\text{Eq. 5.5})$$

Where  $D$  = the average annual groundwater discharge

$E_D$  = the average annual evapotranspiration from the discharge area

This study assumed that the study area is mainly a recharge area and that its discharge area is a very small percentage of the area. The major recharge components are precipitation and the major discharge components are evapotranspiration and surface water runoff. The analysis of groundwater recharge based on the hydrologic equation is as follows (Equation 5.4):

### 5.1.1 Precipitation

Precipitation is the major factor control the hydrology in the area. It is the input to the hydrologic system and the main source of recharge water. Precipitation is essential to understanding of soil moisture, groundwater recharge and river flow.

Precipitation in the study area is in the form of rainfall. Rainfall compilation for the study area were collected from Climatology Division, Meteorological Department, and are measured at the Chachoengsao station. The monthly distribution of average rainfall, 15 years period during 1989-2004, in the study area is shown in Figure 5.2. Average annual rainfall of the area is 1,276.9 millimeters.

### 5.1.2 Evapotranspiration

Evapotranspiration is the combined process of transpiration from vegetation and evaporation from both soil and free water surface. Potential evapotranspiration is the maximum loss of water through evapotranspiration.

There are several techniques to measure evapotranspiration, which include direct and indirect measurements. The direct approach utilizes evapotranspiration tents, phytometers, a heat pulse method, lysimeters, and evaporation pans. The indirect methods are strictly empirical formula that use climate data to calculate the potential evapotranspiration rates. One such mostly used is the Thornthwaite equation (Tavener and Iqbal, 2003). Thornthwaite method used air temperature and latitude of the site to estimate evapotranspiration and is widely used. The Thornthwaite formula for evapotranspiration is (Chen *et al.*, 2004):

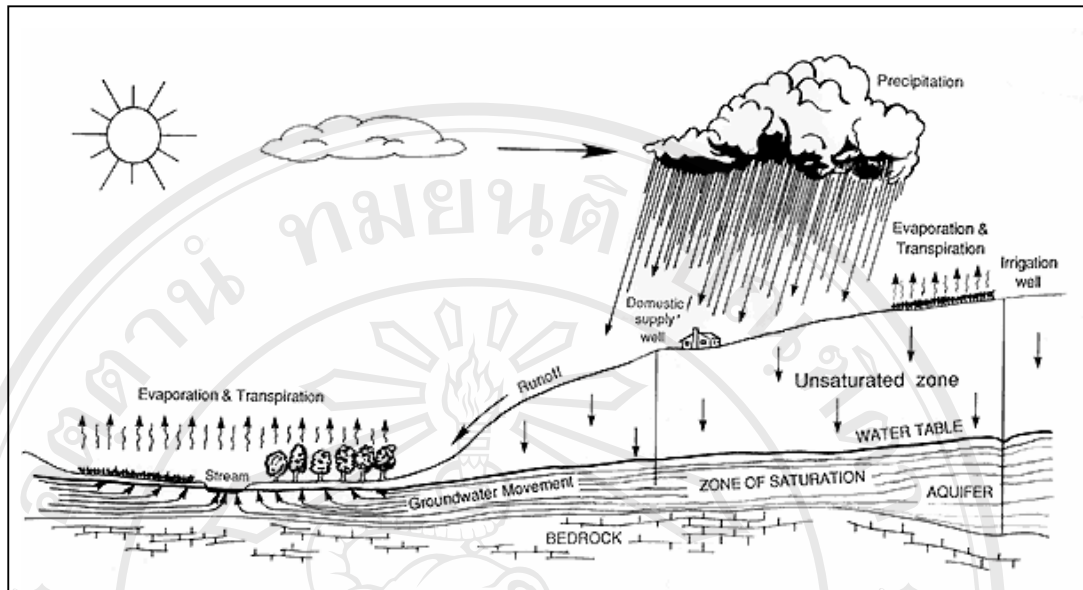


Figure 5.1 Component of the hydrologic cycle (from Kranz *et al.*, 1996).

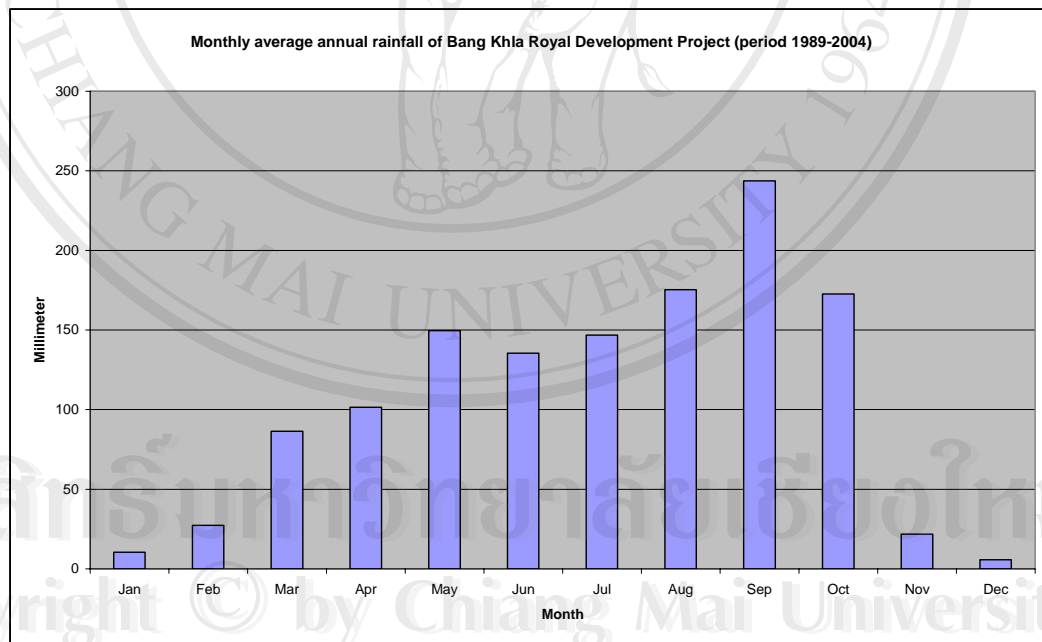


Figure 5.2 Monthly distribution of average annual rainfall of the study area, period 1989-2004 (from Climatology Division, Meteorological Department, 2004).

$$\text{PET month} = 16(10T/I)^a \times \text{CF} \quad (\text{Eq.5.6})$$

Where PET = potential evapotranspiration (in millimeter)

T = average monthly temperature (in °C)

I = annual thermal index = sum of monthly indices i

$$i = (T/5)^{1.514}$$

a = an empirically determined exponent which is a function of I

$$= (6.751 \times 10^{-7}I^3) - (7.711 \times 10^{-5}I^2) + (1.7921 \times 10^{-2}I) + 0.49239$$

CF = a correction factor

The correction factor (CF) depend on latitude and month as shown in Table 5.1. The correction factor of the study area at about 13° north latitude. The calculated potential evapotranspiration using Thornthwaite method is shown in Table 5.2. Average monthly potential evapotranspiration ranges from approximately 108.45 to 226.68 millimeters, while the annual average potential evapotranspiration is 2,043.02 millimeters.

### 5.1.3 Infiltration and runoff

The precipitation may be run over the ground surface and into stream to ocean, or may infiltration into the ground (Walton, 1970).

#### 5.1.3.1 Infiltration

Infiltration is that process by which precipitation moves downward through the surface of the earth and replenishes soil moisture, recharge aquifer, and ultimately supports stream flows during dry periods. Commonly used methods for determining infiltration capacity are hydrograph analyses and infiltrometer studies (Viessman and Lewis, 2003).

#### 5.1.3.2 Runoff

Runoff is the portion of water supplied through precipitation that is converted to overland flow. It is the surface discharge component of the hydrologic cycle. The precipitation may arrive in the stream channel by one of four flow paths: (1) channel

Table 5.1 Correction factor depend on the latitude and month (from Chen *et al.*,2004).

Lat.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
50N	0.74	0.78	1.02	1.15	1.33	1.36	1.37	1.25	1.06	0.92	0.76	0.70
40N	0.84	0.83	1.03	1.11	1.24	1.25	1.27	1.18	1.04	0.96	0.83	0.81
30N	0.90	0.87	1.03	1.08	1.18	1.17	1.20	1.14	1.03	0.98	0.89	0.88
20N	0.95	0.90	1.03	1.05	1.13	1.11	1.14	1.11	1.02	1.00	0.93	0.94
10N	1.00	0.91	1.03	1.03	1.08	1.06	1.08	1.07	1.02	1.02	0.98	0.99
0	1.04	0.94	1.04	1.01	1.04	1.01	1.04	1.04	1.01	1.04	1.01	1.04
10S	1.08	0.97	1.05	0.99	1.01	0.96	1.00	1.01	1.00	1.06	1.05	1.10
20S	1.14	1.00	1.05	0.97	0.96	0.91	0.95	0.99	1.00	1.08	1.09	1.15
30S	1.20	1.03	1.06	0.95	0.92	0.85	0.90	0.96	1.00	1.12	1.14	1.21
40S	1.27	1.06	1.07	0.93	0.86	0.78	0.84	0.92	1.00	1.15	1.20	1.29
50S	1.37	1.12	1.08	0.89	0.77	0.67	0.74	0.88	0.99	1.19	1.29	1.41

Table 5.2 Potential evapotranspiration (PET) of the study area, using Thornthwaite method (Climatological data period 1989-2004).

Month	Average monthly temperature (T), °C	$i = (T/5)^{1.514}$	$UPE = 16(10T/I)^a$	CF	Average monthly PET (mm)
Jan	26.5	12.49	129.22	1.00	129.22
Feb	27.6	13.28	153.87	0.91	140.02
Mar	29.1	14.39	193.11	1.03	198.90
Apr	30.0	15.07	220.08	1.03	226.68
May	29.6	14.77	207.76	1.08	224.38
Jun	28.9	14.24	187.47	1.06	198.72
Jul	28.5	13.94	176.59	1.08	190.72
Aug	28.1	13.65	166.19	1.07	177.82
Sep	28.0	13.58	163.67	1.2	166.94
Oct	27.5	13.21	151.49	1.02	154.52
Nov	26.5	12.49	129.22	0.98	126.63
Dec	25.5	11.78	109.55	0.99	108.45
	Annual average = 27.98	$I = \sum i = 162.89$	$a = 4.29239$		Annual total = 2,043.02

precipitation, (2) overland flow, (3) interflow, and (4) groundwater flow. Surface runoff is commonly represented in the form of a hydrograph, which is a time record of stream surface elevation or stream discharge at a given cross-section of the stream (Davis and DeWiest, 1966).

No runoff data were available for this study. Therefore, the only discharge of the area is from wells abstraction as shown in Table 5.3. The total abstraction from the area is approximately 177.84 cubic meters per day when all five wells are pumped.

## **5.2 Groundwater recharge pattern and potential**

It is readily apparent that, for the optimization of groundwater resources development, an accurate assessment of recharge is needed. Climatological data is used to estimate groundwater potential that represented in groundwater recharge pattern.

### **5.2.1 Groundwater recharge pattern**

Groundwater recharge pattern determine the period that recharge water, controlled by effective rainfall, reach to the aquifer. Effective rainfall will be available when actual rainfall is higher than evapotranspiration. The effective rainfall will infiltrate into the ground. Water contained in the unsaturated zone as soil moisture. However, soil moisture is deficient when actual rainfall is less than evapotranspiration. Groundwater recharge pattern in the study area is estimated using the actual rainfall and evapotranspiration data of period 15 years (during 1989-2004). The calculation of effective rainfall is shown in Table 5.4 and plotted in Figure 5.3.

From Table 5.4 and Figure 5.3, the effective rainfall in the study area occurs in September to October. The annual effective rainfall is 94.94 millimeters per year or 1,139,280 cubic meters per year. This amount is 7.43 % of actual rainfall.

### **5.2.2 Groundwater potential**

Groundwater potential is defined as the amount of water that stored in the aquifer in the one time. It is estimated from annual aquifer recharge, as calculated from equation (5.4) as follows:

Table 5.3 Groundwater abstraction in the study area.

No.	Well No.	Grid		Depth (m)	Diameter (mm)	Pumping rate (m <sup>3</sup> /d)
		UTM E	UTM N			
1.	TV387CCS001	739751	1512553	178	150	82.24
2.	TV388CCS002	739885	1512746	180	150	20.00
3.	TV389CCS003	739687	1512919	168	150	12.60
4.	TV390CCS004	739768	1512834	120	150	13.00
5.	TV391CCS005	739790	1512617	162	150	50.00

Table 5.4 Calculation of effective rainfall in the study area (period 1989-2004).

Month	Actual rainfall (mm)	Evapotranspiration (mm)	Soil moisture deficits (mm)	Effective rainfall (mm)
Jan	10.5	129.22	118.72	-
Feb	27.2	140.02	112.82	-
Mar	86.4	198.90	112.50	-
Apr	101.5	226.68	125.18	-
May	149.7	224.38	74.68	-
Jun	135.5	198.72	63.22	-
Jul	146.8	190.72	43.92	-
Aug	175.4	177.82	2.42	-
Sep	243.7	166.94	-	76.76
Oct	172.7	154.52	-	18.18
Nov	21.8	126.63	104.83	-
Dec	5.7	108.45	102.75	-
Total	1,276.9	2,043.02		94.94

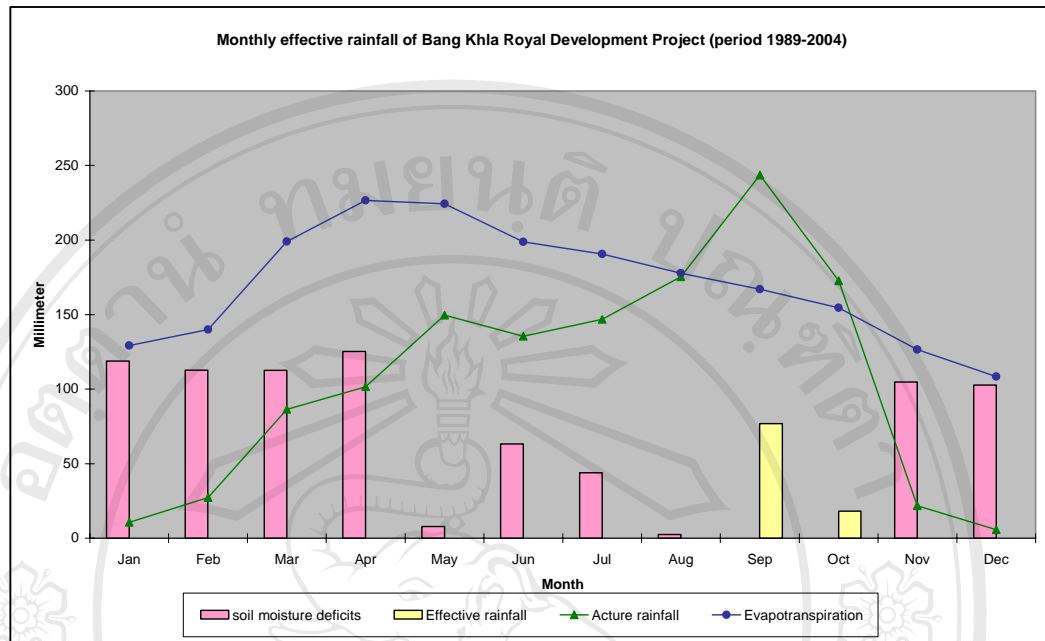


Figure 5.3 Average monthly rainfall, evapotranspiration, soil moisture deficits, and effective rainfall in the study area (period 1989-2004).

$$R = P - Q_s - E_R$$

Where  $Q_s$  = the surface water component of average annual runoff

$P - E_R$  = effective rainfall

Therefore:

$$R = (P - E_R) - Q_s \quad (\text{Eq. 5.7})$$

In calculating groundwater potential in the study area, the effective rainfall ( $P - E_R$ ) is 94.94 millimeters per year, or 18,988 cubic meters per year, the surface area is 0.2 square kilometers, and no runoff data were available for this study. Therefore, the estimated groundwater recharge in the study area using the hydrologic budget method from equation (5.7) is 94.94 millimeters per year or 18,988 cubic meters per year that is about 7.43 % of the annual rainfall. In the study area the total abstraction from the area is 324.56 millimeters per year or 64,911.6 cubic meters per year when all five

wells are pumped. Considering the annual groundwater recharge and annual groundwater abstraction, assuming that all five wells are pumped continuously through the year, it is evident that the groundwater recharge is less than groundwater abstraction. Therefore, and if this is the case, it is necessary to control groundwater development activity of the study area.

It should be pointed out here that the calculated groundwater recharge in the study area is similar to that reported by the Asian Institute of Technology and the Department of Mineral Resources (1982). The Asian Institute of Technology and the Department of Mineral Resources studied groundwater recharge of the upper Chao Praya basin and reported that the average annual groundwater recharge is 95.9 millimeters or 8 % of the basin total rainfall. In the study area, situated in the lower Chao Praya basin, the calculated groundwater recharge is 94.94 millimeters per year or 7.43 % of the annual rainfall.

### **5.3 Combination of Geographic Information System, Database, and Permeability Testing**

Permeability is property of porous soils indicating how rapidly water will be transmitted through soils toward the groundwater. It depends on several following factors: (1) the size of soil grains, (2) the properties of pore fluids, (3) the void ratio of the soil, (4) the shapes and arrangement of pores, and (5) the degree of saturation (Department of Civil Engineering, SIUE, 2001).

The state of water movement is called percolation, the measure of it is called permeability, and the factor relating permeability to unit conditions of control is called the coefficient of permeability. The coefficient of permeability is commonly measured in Darcy's law that is defined as (U.S. Department of the Interior, Bureau of Reclamation, 1974):

$$k = \frac{QL}{Ah} = \frac{v}{i} \quad (\text{Eq. 5.8})$$

Where  $k$  = coefficient of permeability

$Q$  = quantity of water per unit of time

A = gross cross-sectional area through which Q flows

h = pressure head lost

L = distance through which the head is lost

v = discharge velocity

i = hydraulic gradient, that is, the ration of the head lost to the distance in which it is lost

The permeability test method is a measure of the rate of the flow of water through soil. The measurement of field permeability is carried out by augering the hand auger into the soil at the depth of 2 meters. Then, PVC tube, 3 inches in diameter, is placed as casing in the hole. The casing was then filled with water. The amount of water that was lost, due to infiltration, during a specific time interval was recorded. The constant level is rarely obtained and a surging of the level within a few minutes at a constant rate of flow for about 10 minutes in considered satisfactory (U.S. Department of the Interior, Bureau of Reclamation, 1974). In the study area, the permeability test was carried out at 13 stations, as is shown in Figure 5.4. Figure 5.5 shows the permeability test in the study area.

The field permeability test was calculated using U.S. Department of the Interior, Bureau of Reclamation (1974) equations, as follows:

$$k = \frac{Q}{5.5rH} \quad (\text{Eq. 5.9})$$

Where k = permeability

Q = constant rate of flow into the hole

r = internal radius of casing

H = differential head of water

For the field calculation, Q is the volume of water in millimeters divided by time in seconds. H is the length of the casing that is above the water table. If the water table is not found or the depth to the water table is greater than the length of the

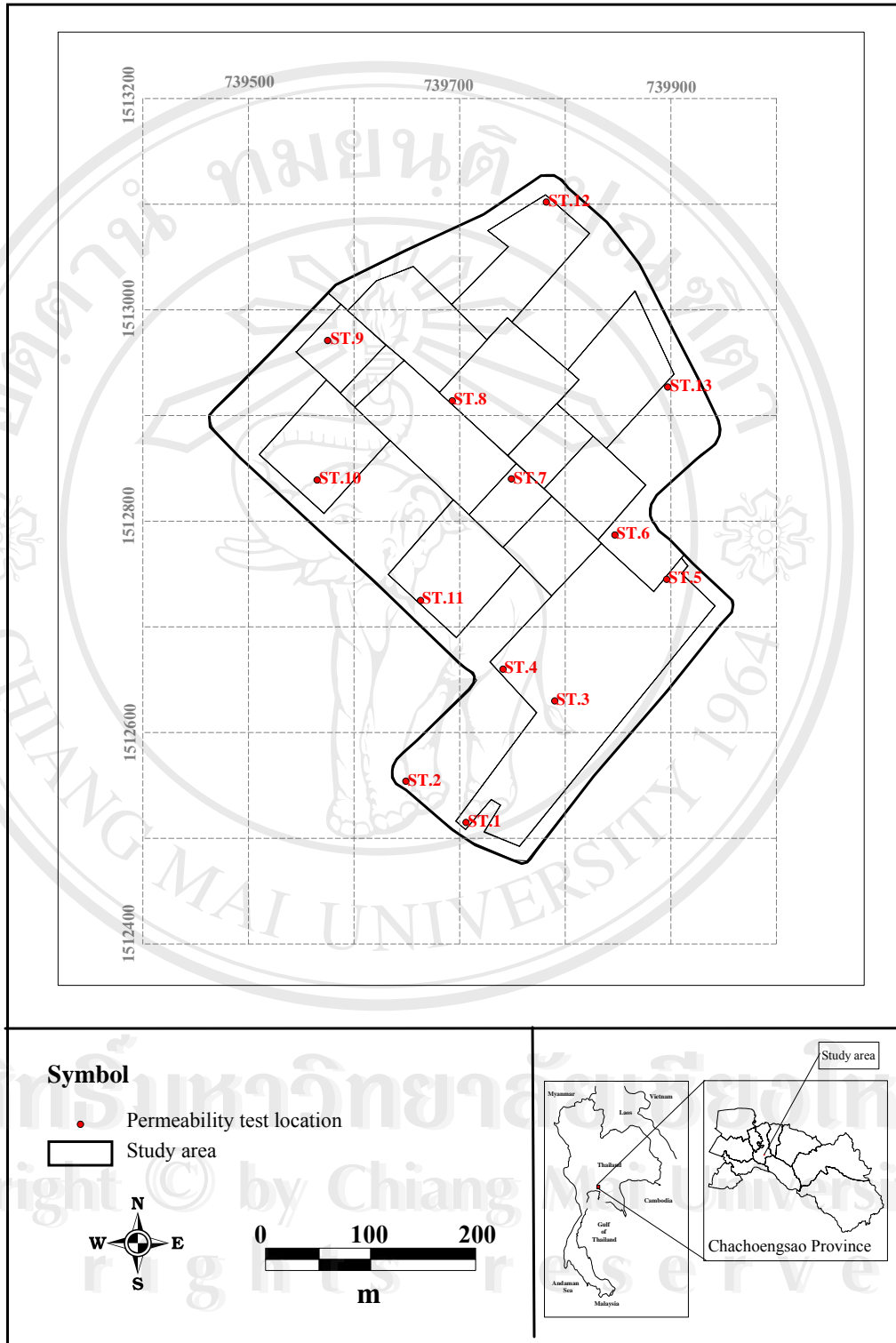


Figure 5.4 The location of permeability test in the study area.

casing, the total length of casing would be used as H. The field measurement of the permeability test is shown in Figure 5.6. Field data of the permeability test is shown in Table 5.5. Permeability value range from  $6.36 \times 10^{-7}$  to  $3.181 \times 10^{-6}$  centimeters per second or 0.00229 to 0.0144 centimeters per hour. Table 5.6 show hydraulic conductivity in the study area, obtained from pumping test analysis, range from 0.01278 to 0.1296 centimeters per hour. Considering the reliability of permeability and hydraulic conductivity as obtained from both methods, the hydraulic conductivity is more reliable than permeability. Hydraulic conductivity is obtained and represented the rate of water that flow through a large portion of aquifer unit but permeability is obtained and represented the rate of the flow of water through a limited area of soil.

Hydrogeologically, the field permeability test area is underlain by unconsolidated sediment. The obtained permeability values range from  $9.16 \times 10^{-3}$  to  $1.03 \times 10^{-2}$  centimeters per hour. The hydrologic soil group is a direct reflection of the infiltration rate of the soil. Soil classification based on permeability values, using final infiltration rate of the U.S. Soil Conservation Service hydrologic soil groups, are shown in Table 5.7. Using the soil classification criteria of Table 5.7, it was found that in the study area only hydrologic soil group D is presented. The soils have high runoff potential. They have very low infiltration rates when thoroughly wetted and consist mainly of clay soils with a high swelling potential, soil with a permanent high-water table, soils with a clay pan or clay layer at or near the surface, and shallow soils over a nearly impervious material. Table 5.8 and Figure 5.7 show the hydrologic soil group in the study area.

Slope gradient is inclination of a soil's surface from the horizontal plane. It is normally measured by the hand level or computed from topographic map and expressed in terms of percentage (U.S. Department of Agriculture, Bureau of Plants Industry, Soils, and Agricultural Engineering, 1962). Overland flow is the flow of water over a land surface due to direct precipitation. Overland flow generally occurs when the precipitation rate exceeds the infiltration capacity of the soil and depression storage is full (Fetter, 1988). Rate of overland flow vary with soil type and slope gradient that infiltration into soil. The greater the slope gradient, the greater the overland flow, and the less water that can infiltrate into the soil. Table 5.9 shows the



Figure 5.5 The permeability test in the field.

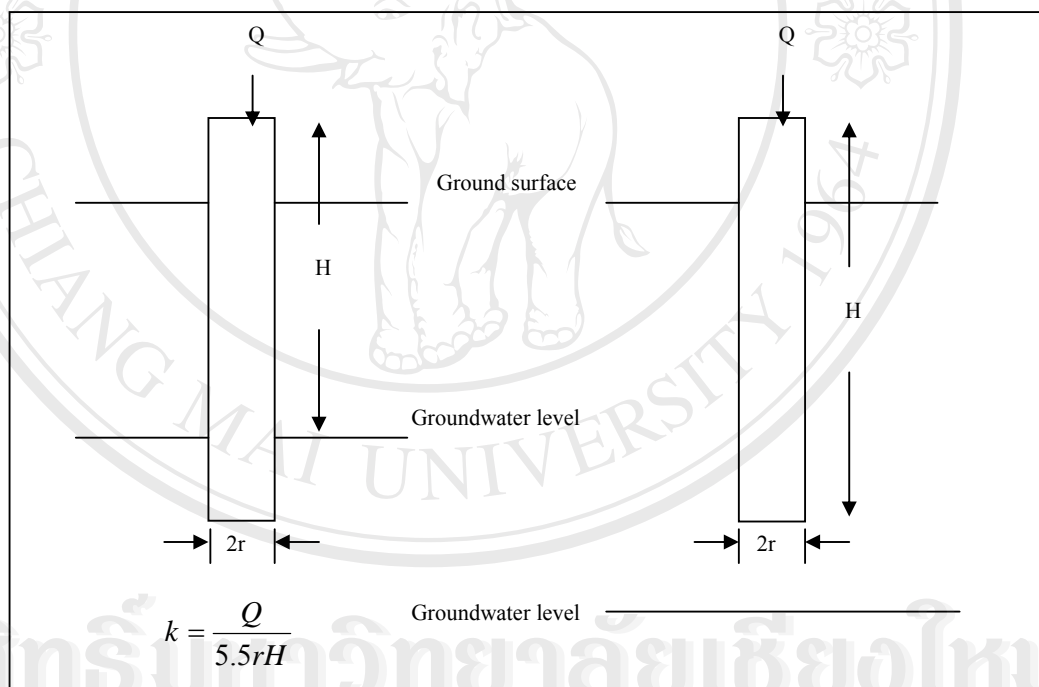


Figure 5.6 Field permeability test method (modified from U.S. Department of the Interior, Bureau of Reclamation, 1963).

Table 5.5 Field data of the permeability test in the study area.

Station No.	Grid		Depth (cm)	Differential head of water (cm)	Volume of water (ml)	Time (sec)	Permeability, k (cm/sec)
	UTM_E	UTM_N					
ST.1	739706	1512515	200	250	6	600	0.000001908
ST.2	739649	1512554	200	250	10	600	0.000003181
ST.3	739790	1512630	200	250	**	600	-
ST.4	739741	1512660	200	250	8	600	0.000002545
ST.5	739896	1512745	200	250	**	600	-
ST.6	739847	1512787	200	250	9	600	0.000002863
ST.7	739749	1512840	200	250	3	600	0.000000954
ST.8	739693	1512914	200	250	5	600	0.000001590
ST.9	739575	1512971	200	250	10	600	0.000003181
ST.10	739565	1512839	200	250	5	600	0.000001590
ST.11	739663	1512725	200	250	2	600	0.000000636
ST.12	739782	1513102	200	250	3	600	0.000000954
ST.13	739897	1512927	200	250	3	600	0.000000954

Remark: \*\* invalid

Table 5.6 Hydraulic conductivity in the study area.

Well No.	Grid		Depth (m)	Screen (m)	Hydraulic conductivity (cm/h)
	UTM_E	UTM_N			
TV0387	739751	1512553	178	94-178 (open hole)	0.1104
TV0388	739885	1512746	180	70-80	0.0858
TV0389	739687	1512919	168	86-168 (open hole)	0.01278
TV0390	739768	1512834	120	115-120 (open hole)	0.1296

Table 5.7 The U.S. Soil Conservation Services infiltration rate (modified from Tindall and Kunnel, 1999).

Hydrologic soil group	Characteristic	Soil texture	Infiltration (cm/h)
A	Soils have low runoff potential and high infiltration rates even when thoroughly wetted. They consist mainly of deep, well-to-excessively drained sand or gravel.	Sand, and sandy loam	>0.76
B	Soils have moderate infiltration rates when thoroughly wetted and consist mainly of moderately deep to deep, moderately well to well-drained soils with moderately fine to moderately coarse textures.	Silt loam and loam	0.38-0.76
C	Soils have low infiltration rates when thoroughly wetted and consist mainly of soils with a layer that impedes downward movement of water and soils with moderately fine to fine texture.	Sandy clay loam	0.13-0.38
D	Soils have high runoff potential. They have very low infiltration rates when thoroughly wetted and consist mainly of clay soils with a high swelling potential, soil with a permanent high-water table, soils with a clay pan or clay layer at or near the surface, and shallow soils over a nearly impervious material.	Clay loam, silty clay loam, sandy clay, silty clay, and clay	0.0-0.13

Table 5.8 The hydrologic soil group in the study area.

Station No.	Permeability, k (cm/h)	Hydrologic Soil Group
ST.1	0.00687	D
ST.2	0.0114	D
ST.3	-	-
ST.4	0.00916	D
ST.5	-	-
ST.6	0.0103	D
ST.7	0.00343	D
ST.8	0.00572	D
ST.9	0.0114	D
ST.10	0.00572	D
ST.11	0.00229	D
ST.12	0.00343	D
ST.13	0.00343	D

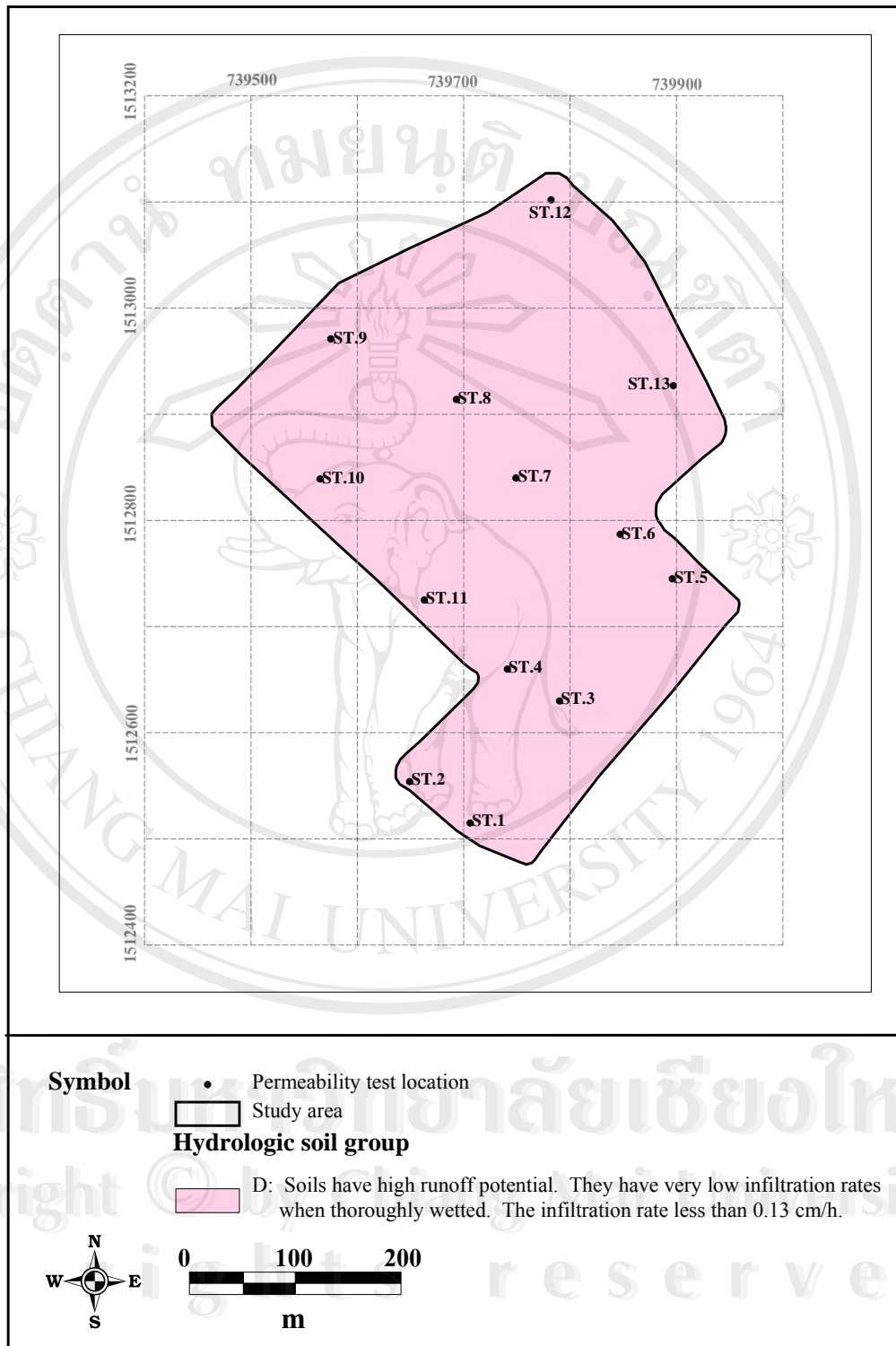


Figure 5.7 The hydrologic soil map.

Table 5.9 Relationship between slope gradient, overland flow, and infiltration  
(from Intermountain Resources Inventories Inc., 1997).

<b>Slope gradient (degree)</b>	<b>Overland flow (%)</b>	<b>Infiltration (%)</b>
0	0.00	100.00
10	11.11	88.89
20	22.22	77.78
30	33.33	66.67
40	44.44	55.56
50	55.55	44.45
60	66.66	33.34
70	77.77	22.23
80	88.88	11.12
90	100.00	0.00

relationship between slope gradient, overland flow, and infiltration that represent in percentage. The study area is a flat terrain with a very small slope. Therefore, the overland flow is less with greater infiltration into the soil.

In this study, the estimated infiltration potential of the soil was calculated using the permeability values of soil (Figure 5.8). Geographic Information System database, including, the hydrologic soil map and the permeability values were combined, representing the potential recharge map. This map can be used to calculate the amount of water that flow into the aquifer each year. The potential recharge map in the study area (Figure 5.9), that is the recharge volume, is 16,642.70 cubic meters per year or 83.21 millimeters per year.

Assessment of groundwater recharge in the study area was carried out using the two methods, namely: hydrologic budget method and combination of Geographic Information System, database, and permeability testing method. These two methods gave similar groundwater recharge, as follows: 18,988 cubic meters per year using hydrologic budget method, and 16,642.70 cubic meters per year using combination of Geographic Information System, database, and permeability testing method. This is theoretically the safe yield of the area and should be useful in future groundwater development and management.

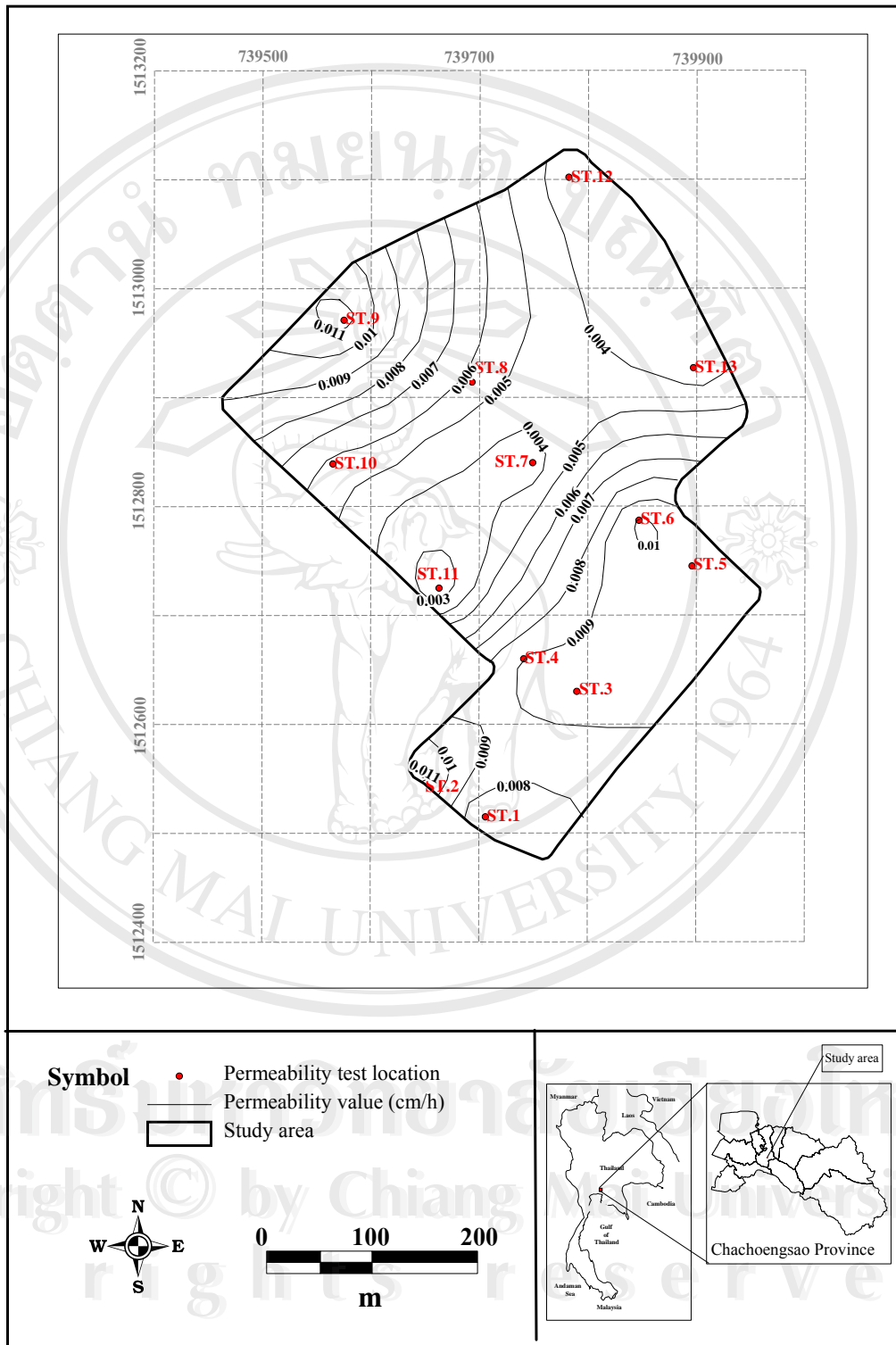


Figure 5.8 The permeability value map of the study area.

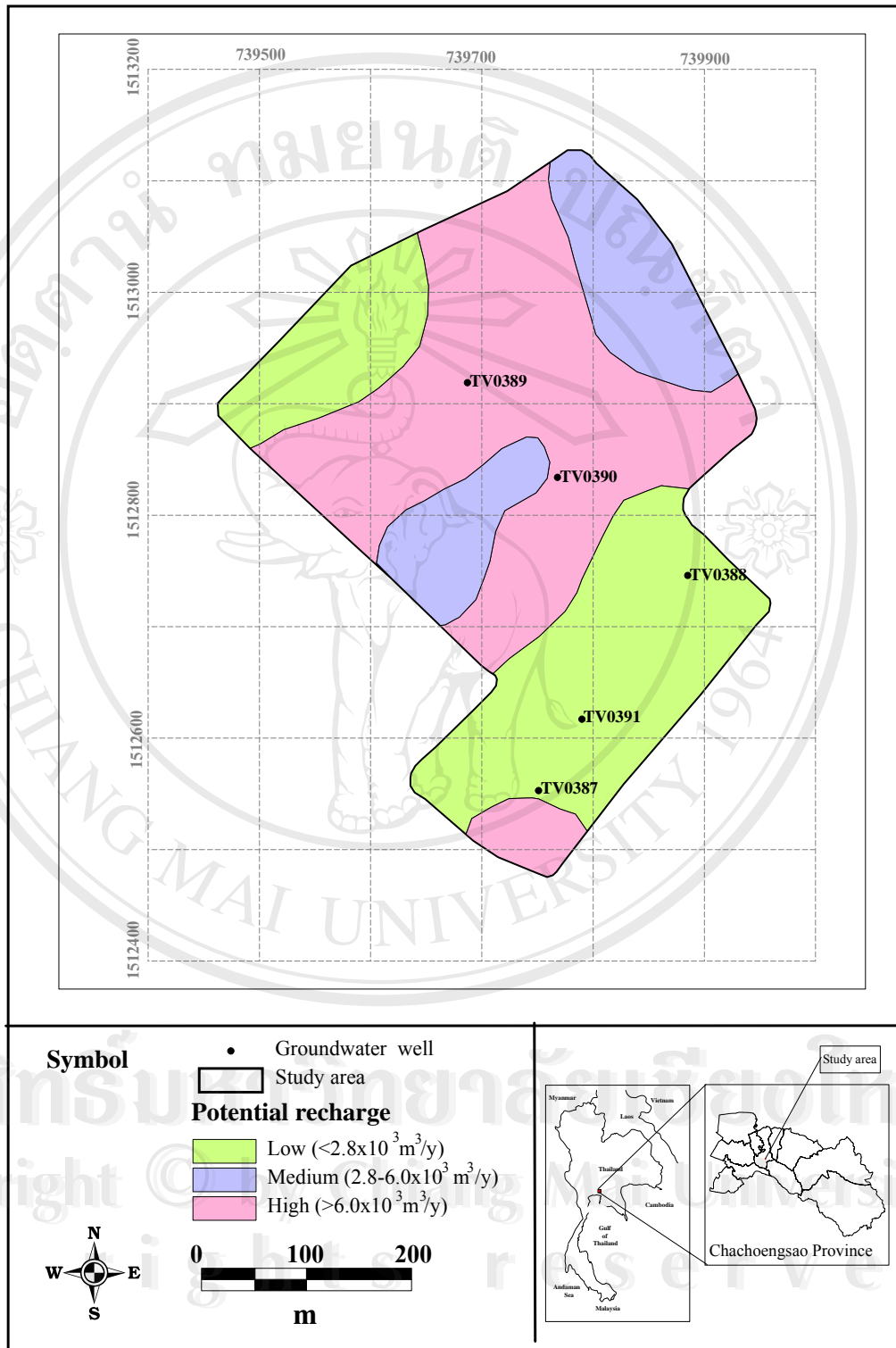


Figure 5.9 The potential recharge map.