CHAPTER 4
DATA COMPILATION AND DATA ANALYSIS

Required data for calculating groundwater recharge in the present study are (1) groundwater level data and (2) specific yield. Rise in groundwater table is determined from analysis of the groundwater level data of monitored wells. While the specific yield is determined from analysis the hydrometeological data and pumping test data. Groundwater table fluctuation method is based on the premise that rises in groundwater table are due to recharge water arriving at the water table. The main source of data is groundwater zone. The recharge calculation using this method will be actual recharge.

4.1 Hydrometeorological data

Understanding the big picture of water circulation, hydrologic cycle, can be helpful in explaining local phenomenon. The cyclic movement of water has no beginning and no end. A description of the hydrologic cycle can begin at any point and return to that same point (Fowler, 1949). Water evaporates from the surface of the oceans into the atmosphere by the power of solar radiation. It becomes atmospheric water vapor. Some of this moisture falls to land as precipitation. Rainfall that reaches the land surface by precipitation, some may evaporate where it falls, some may infiltrate the soil, and some may run off overland (surface runoff) to evaporate or infiltrate elsewhere or to enter streams. Plant roots absorb the infiltrated water and evaporate or transpire the water by its leaf. Some water percolates downward to ground water reservoirs. Water that reaches the reservoirs may flow directly into streams or into the ocean or seepage. Sometime it moves close to the land surface to evaporate or transpirate. Stream water can be evaporated or transpired by riparian vegetation, seep downward into the groundwater zone, or flow back into the ocean, where the cycle begin again. The hydrologic cycle is show in Figure 4.1. Water system of the hydrologic cycle can be divided into three groups based on the water zone. They are surface and atmospheric water system, subsurface water system and groundwater system. Relationship of these systems is shown in Figure 4.2. Surface and atmospheric water system comprise the process of evaporation, transpiration, precipitation, interception, overland flow, surface runoff, subsurface outflow and groundwater outflow. Subsurface water system comprises the process of infiltration and subsurface runoff. Groundwater system comprises the process of groundwater recharge and groundwater flow. Total volume of water from these systems is called water budget.

Precipitation or actual rainfall is the main source of recharging water. Evaporation, transpiration and runoff are the main processes by which the water is discharged before it reaches the aquifer. Relationship of these parameters can be helpful in calculating specific yield for the equation of groundwater recharge calculation. Effective rainfall controls the pattern of groundwater recharge. It is defined as the actual rainfall less evapotranspiration.

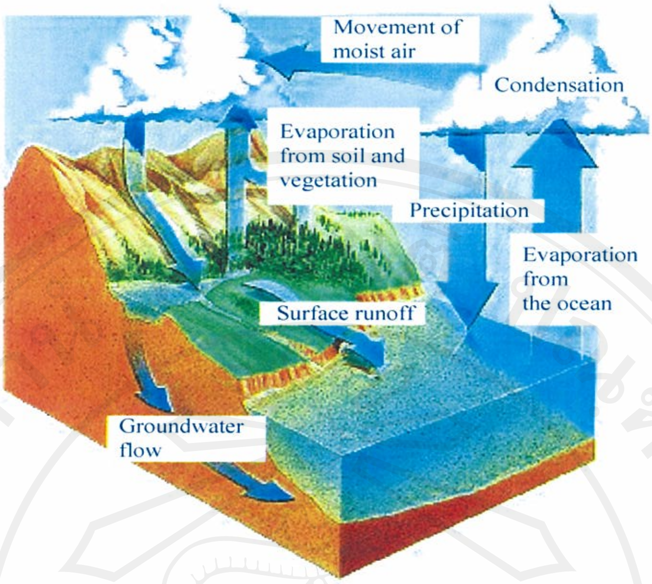


Figure 4.1 The hydrological cycle (modified from International Christian University, 2003).

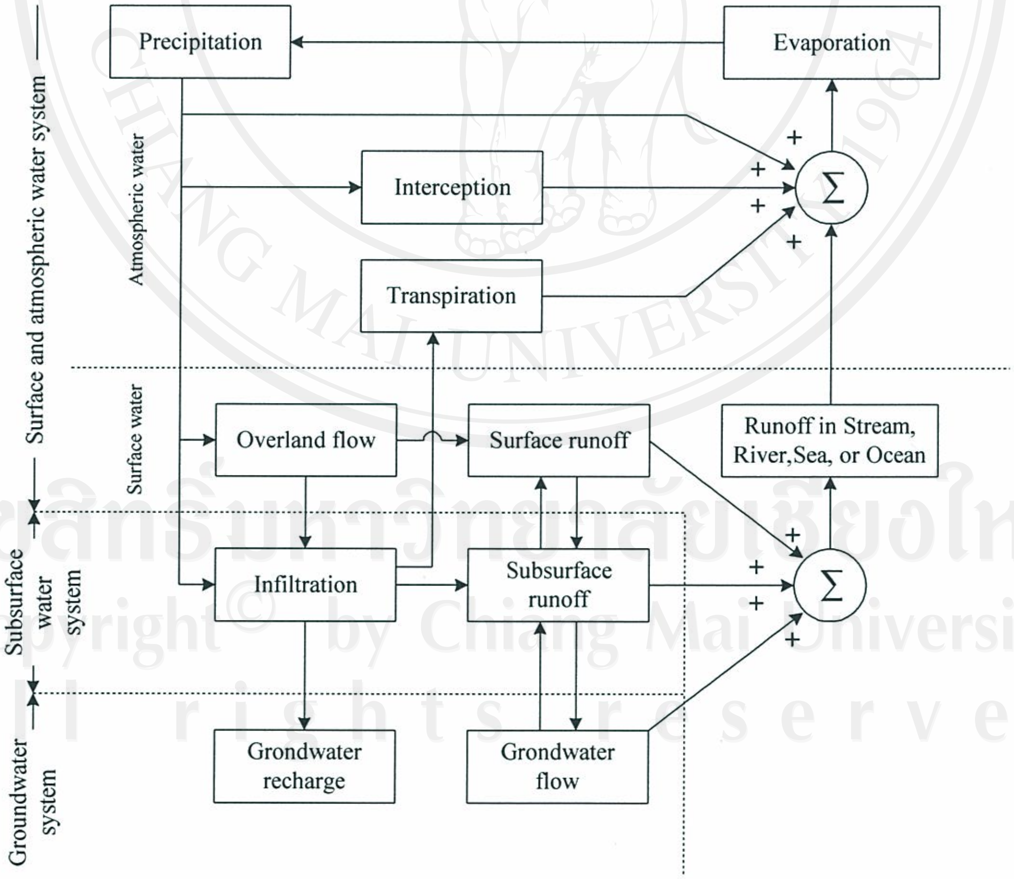


Figure 4.2 Schematic drawing of the hydrologic cycle (modified from Leewatchanakul, 2000).

4.1.1 Precipitation

Precipitation is all water that falls from the atmosphere to the land. It occurs in two forms, liquid (rain and drizzle) and solid (snow, hail, and sleet). Precipitation is the primary source of the earth's supplies. It is the input to the hydrologic system and the main source of recharge water. Precipitation in the study area is in the form of rainfall. Rainfall compilation for the present study are collected by the Northern Meteorological Center (or Chiang Mai Station), Thai Meteorological Department, Ministry of Information and Communications Technology. Although there are twelve rain gauge stations in the study area, only the Chiang Mai station has the completed monthly rainfall records available for the inventory period between 1967 and 2001. The monthly rainfall data in the periods of June-September, July-September, July-October and August-November are analyzed and prepared for the calculation of specific yield. Figure 4.3 shows the annual rainfall in this period (35 years). The average annual rainfall is 1,159.67 mm. The highest annual rainfall is 1,563.40 mm (year 1970). The lowest annual rainfall is 738.70 mm (year 1993).

Rainfall is obtained from measurements in rain gauge each day. It is measured in the vertical water depth (mm) that is the same as the depth of rain falling on a large area around the gauge. The rain gauge in used has cylindrical shape and made from stainless steel (Figure 4.4). It consists of a 8-inch diameter cylinder with a chamber upper edge. The chamber collects the rain and allows it to drain through a funnel into a removable container. The rain in the removable container will be poured into a graduated glass measuring cylinder.

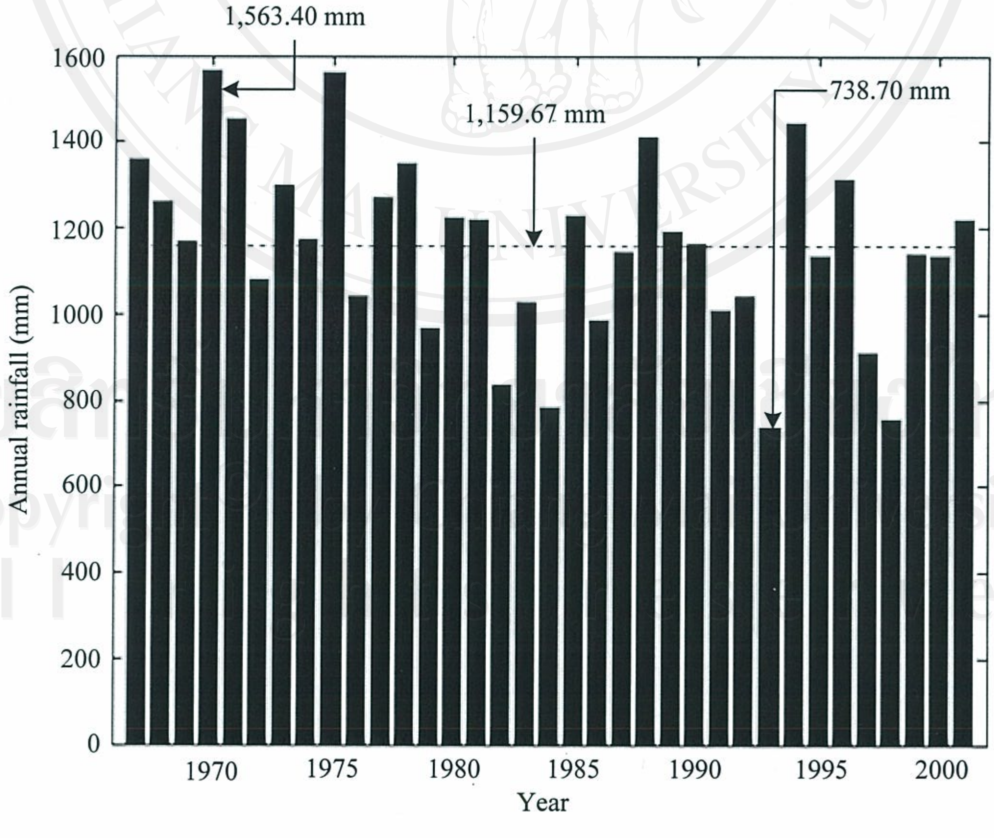


Figure 4.3 Annual rainfall in the study area, period 1967-2001 (35 years).

Figure 4.4 The rain gauge. A is an upper cylinder with a 8-inch diameter. Its chamber collects the rain and allows it to drain through a funnel. B is a lower cylinder. It has 8-inch diameter. C is a removable container put in the lower cylinder. D is a glass measuring cylinder.

4.1.2 Runoff

Runoff is the total amount of water that flow in a stream channel. Runoff process occurs when water originating in precipitation flows on the earth surface or percolates to the groundwater reservoir. The precipitation may arrive in the stream channel by one of four flowpaths: (a) channel precipitation; (b) overland flow; (c) interflow; and (d) groundwater flow. Figure 4.5 shows the flow paths of the sources of the streamflow.

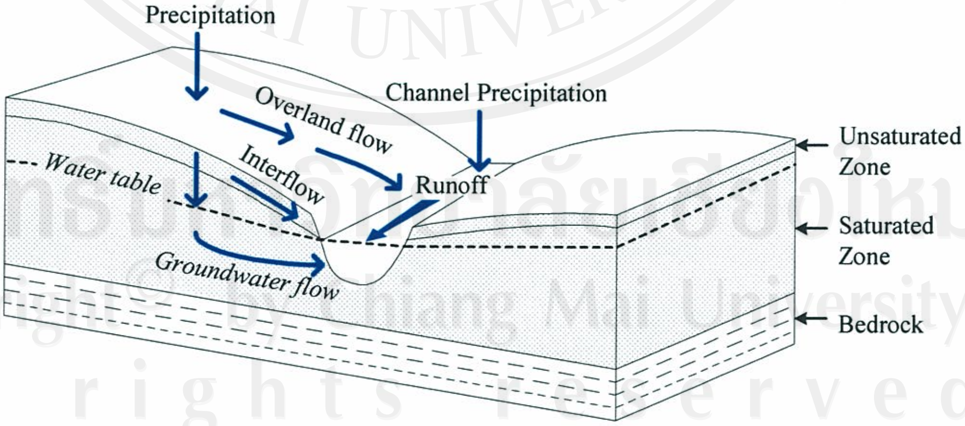


Figure 4.5 Paths of the water flowing.

Channel precipitation is precipitation that falls directly into a water surface of stream. It normally represents a small percentage of the total amount of water flowing in the streams.

Overland flow is the flow of water on a ground surface towards a stream channel as sheet flow. It generally occurs when the direct precipitation unable to infiltrate the soil surface.

Interflow is the water, which moves laterally in the unsaturated zone during and immediately after the event of precipitation. The water moving as interflow discharge towards the stream channels.

Groundwater flow is the flow of water through openings in sediment and rock, which occurs in the saturation zone. The groundwater moves from the high to lower potential zones. It takes place below the ground water table. Groundwater flow is a characteristically slow process. After the occurrence of precipitation, the outflow of groundwater may spend several days, weeks, or often years into the stream channel.

Runoff is usually expressed in term of either volume (m^3) or flow rate (m^3/s). Flow rate of discharge at a cross-section or gauging station usually varies in time. Its value at any time is local discharge. The local discharge values can be integrated over a period of time to give the runoff volume for the entire period. Runoff is expressed in term of depth units by dividing the runoff volume by the drainage area to obtain an equivalent spatially average runoff depth. There are three related operations in the measurement of runoff. The first of these involves the determination of the river stage, the second involves the determination of the average velocity of the water flowing in the river, and the last involves the derivation of a known relationship between river stage and the discharge.

Ping River is the main stream in the study area. Gauging station on the Ping River at Nawarath Bridge, Amphoe Muang Chiang Mai, is the main station of measuring water stage and streamflow data (Figure 4.6). A horizontal float recorder measures river stages. It is usually set in the building. Measurement of streamflow that operated here uses direct measurement by current meters. This method involves measuring the width, depth, and velocity of flow in each of about 20 to 30 subsections of the river cross section. The calculated discharge in each subsection is the product of width, depth and mean velocity. The total discharge is derived by summing the discharges in every subsection. Figure 4.7 illustrates the meter locations at which velocity measurements are made. The hatched area is a subsection whose vertical boundaries are halfway between the adjacent verticals. The equipment used to measure flow velocity is the cup-type current meter. The meter consists of cups that are rotated by the action of flowing water. The speed of the rotation depends on the velocity of the water passing by the cups. The number of revolutions and the elapsed time can be determined electronically with a current-meter digitizer, which displays the velocity at the location of the meter. Rating operation and the cup-type current meter are shown in Figure 4.8.

Compilation of runoff data, as measured at Nawarath bridge gauging station, are carried out by Hydrological and Water Management Center for Upper Northern Region, Royal Irrigation Department, Ministry of Agriculture and Cooperatives. The monthly runoff data in the periods of June-September, July-September, July-October and August-November are analyzed and prepared for the calculation of specific yield.

Figure 4.6 The Nawarath Bridge gauging station. A and B are the building and a horizontal-float recorder. C is staff gauge.

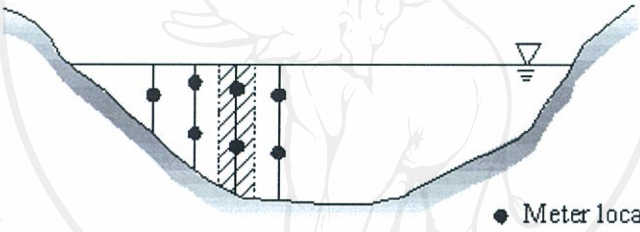


Figure 4.7 River cross section showing meter locations for a discharge measurement.

Figure 4.8 Velocity measurement of water flowing by current meter method. Components of the cup-type current meter are shown in the downright photograph. (Courtesy of Vachirasak Suraintaranggoon).

4.1.3 Evapotranspiration

Evaporation is the process by which water passed from the liquid to the vapor phase. Transpiration is the process by which water in plants is transferred as water vapor to the atmosphere. The process of evaporation from soil or water surface and transpiration from growing plants are the primary component of the hydrologic cycle that returns precipitated water to the atmosphere as vapor. Under field hydrology it is not possible to separate evaporation from transpiration. These are usually combined as evapotranspiration. Evapotranspiration is normally expressed as a depth of water in mm.

In groundwater studies, potential evapotranspiration is required. Potential evapotranspiration (PET) is the evapotranspiration that would occur under given climatic conditions (maximum rate) if there were unlimited moisture supply. A number of empirical equations have been developed for estimating PET from available meteorological data. Penman's equation is a complex equation that is the most widely used. It has so far taken into account the most factors that have been known to power PET such as temperature, solar radiation, wind speed and relative humidity. Penman invented a formula for PET which combined the turbulent transfer and the energy balance approaches (Leewatchanakul, 2000). The Penman's equation can be written as:

$$PET = \left(\frac{\Delta}{\Delta+\gamma}\right)H + \left(\frac{\gamma}{\Delta+\gamma}\right)E_a \tag{4.1}$$

where

PET is the potential evapotranspiration (mm/d),
Δ is the slope of the saturation vapor pressure curve for water at the mean air temperature ($\text{mm Hg}/^\circ\text{C}$),
γ is the psychrometric constant ($0.49\ \text{mm Hg}/^\circ\text{C}$),

The ratio $\frac{\Delta}{\Delta+\gamma}$ depends on temperature and

$$\frac{\gamma}{\Delta+\gamma} = 1 - \frac{\Delta}{\Delta+\gamma} \tag{4.2}$$

H is the net solar radiation converted to evaporation equivalent (mm/d),

$$\begin{aligned} H = {} & I_o(1-r)(0.18+0.55n/N) \\ & -\sigma T^4(0.56-0.092\sqrt{e_{sd}})(0.10+0.90n/N) \end{aligned} \tag{4.3}$$

where

I_o	is Angot's value or the radiation received at the top of the atmosphere. It is equivalent to the water evaporation at at $20^{\circ}\mathrm{C}$. I_o is related to latitude and month of the year,
r	is the reflection coefficient or Albedo (r = 0.20 for the green land),
n/N	is the ratio of actual and possible hours of bright sunshine (hr). It is relative with cloudiness,

$$\frac{n}{N} = 0.622 + 0.078C_c - 0.012C_c^2 \tag{4.4}$$

where

C_c	is cloudiness (0-10),
σ	is the Stefa-Bolzman's constant,
T	is Temperature ($^{\circ}\mathrm{C}$),
σT^4	is the theoretical terrestrial radiation which would leave the area. It depends on temperature,
e_{sd}	is the actual vapor pressure at the mean air temperature (mb) that can be determined from

$$e_{sd} = f \times e_s \tag{4.5}$$

where

f	is Relative humidity (%),
e_s	is the saturation vapor pressure of water at the mean air temperature (mb),
E_a	is evaporation from water surface that is powered by wind speed and the saturation vapor pressure. It is expressed in mm/d. E_a can be calculated by

$$E_a = 0.262(e_s - e_{sd})(1 + 0.0062U_2) \tag{4.6}$$

U_2	is the average wind speed at a height of two meters above the ground surface (km/d), and

$$U_2 = U_1 \frac{\log 2}{\log h} \tag{4.7}$$

U_1	is the average wind speed at h meters from the ground surface (km/d). It is measured by the wind speed measurement.

In the present study, average monthly *PET* of the study area between 1967-2001 are calculated by the Penman's equation, using MATLAB code. Climatic data required are collected by the Northern Meteorological Center. Ramingwong (1976), Suvagondha (1979), Anawatchapong (1980) and Wongpornchai (1990) also calculated *PET* in Chiang Mai basin by Penman method. Figure 4.9 shows the comparison of monthly *PET* values between the present study and other studies. From Figure 4.9 it is apparent that the curve in the present study is nearly similar to the curve of Anawatchapong (1980) and Suvagondha (1979). Their highest *PET* points are in April. While the highest *PET* point of Wongpornchai (1990) and Ramingwong (1976) are in May and January, respectively. The average monthly *PET* of Wongpornchai (1990) is higher than in the others. The differences are mainly due to different period of estimation, the accuracy of calculation, influence factors and constant values. However, the forms of the all curves are analogous except that of Ramingwong (1976). In the present study, *PET* in May is the highest. The average annual *PET* is 1,556.78 mm. The monthly *PET* data in the June-September, July-September, July-October and August-November months are analyzed and prepared for calculation of specific yield.

4.1.4 Calculation of specific yield using water budget approach

As previously described, specific yield can be determined by laboratory and field approaches (Healy and Cook, 2002). For the present study, two methods of the field approaches are used. These are (a) the water budget approach and (b) pumping test approach (Section 4.3).

As stated earlier, the change in groundwater storage is the change in mean groundwater level during an inventory period multiplied by the specific yield of the deposits within the zone of groundwater fluctuation (Walton, 1970). Volume of groundwater storage change is done by multiply the change in groundwater storage, in mm, over the inventory months with the area of the study area (2,771 km^2). Specific yield of each aquifer is the volume of change in groundwater storage per unit surface area of the aquifer per change in groundwater level over the inventory months. Equation 3.22 may be rewritten as:

$$S_{y(WBA)} = \frac{\Delta S_g \times A_s}{\Delta H \times A_a} \tag{4.8}$$

where

$S_{y(WBA)}$ is the specific yield determined by the water budget approach,

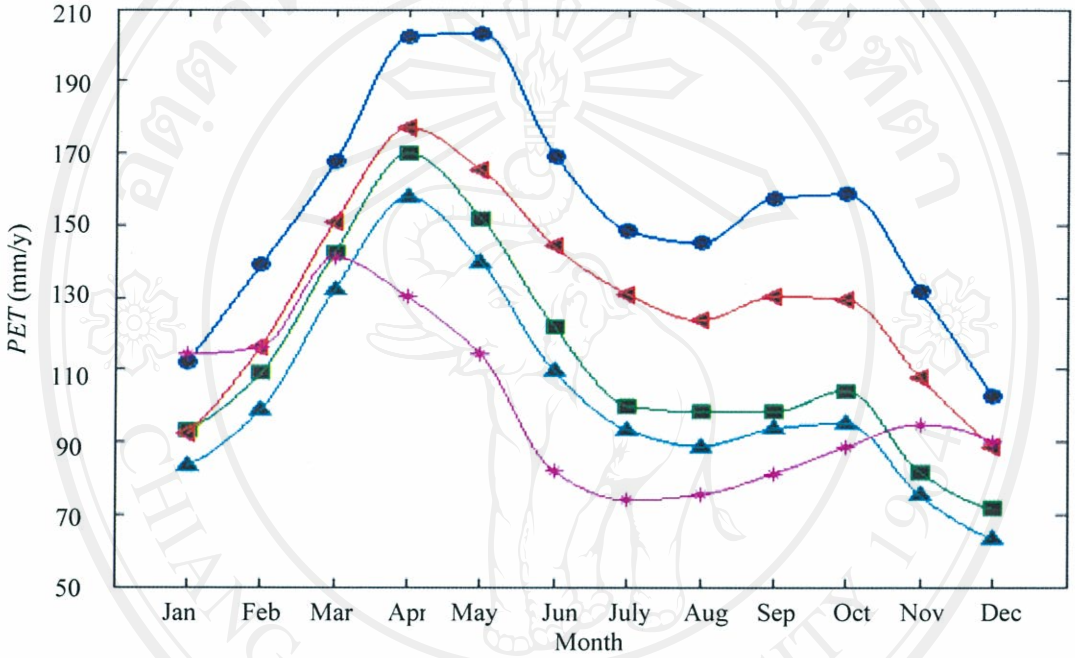
ΔS_g is the change in groundwater storage;

$\Delta S_g = P_a - PET - R_u$ (mm/the inventory months),

ΔH is the change in groundwater level (mm/the inventory months),

A_s is the study area (km^2), and

A_a is the surface area of aquifer (km^2).



Symbol	Author	Period of study	*PET* (month)
●	Wongpornchai (1990)	1958-1984	1,799.97
◀	Present study	1967-2001	1,556.78
■	Anawatchapong (1980)	1969-1977	1,323.00
▲	Suvagondha (1979)	1969-1976	1,231.30
*	Ramingwong (1976)	1969-1975	1,201.40

Figure 4.9 Average monthly potential evapotranspiration in the study area.

The Equation 4.8 can be rewritten as:

$$S_{y(WBA)} = \frac{\Delta S_g}{\Delta H \times A_e} \tag{4.9}$$

where

A_e is the effective area for groundwater recharge (km^2/ km^2), where $A_e = A_a / A_s$.

Equation 4.9 can be applied to several periods of the selected inventory months to give the best specific yield values. Choosing the suitable periods can be considered from the available meteorological data, namely: actual precipitation (P_a) and evapotranspiration (PET) which have been previously described. In some months, especially in the rainy months, when actual precipitation is higher than evapotranspiration, thus, effective rainfall will be available. The effective rainfall will seep into the ground (infiltration), where the surface soil is porous (recharge area). The water will be stored in the unsaturated zone as soil moisture. Excess soil moisture will be then pulled downward, reaching groundwater table, by gravity. Because of this phenomenon, there is no soil moisture deficits and groundwater table will rise. This is considered the period of rising. The months with high actual precipitation and exceeding evapotranspiration, therefore, should be first considered. However, the months with actual precipitation less than evapotranspiration can also be used if the soil moisture deficits is small. The water stored in an aquifer will move as groundwater flow through the porous media until it discharges as seepage into the river (Figure 4.1). Groundwater storage is reduced in this situation. The groundwater table will decline. This is considered the period of recession. Equation 4.9 can be rewritten for the rising period as:

$$S_{y,r} = \frac{\Delta S_{g,r}}{\Delta H_r \times A_e} \tag{4.10}$$

where

$S_{y,r}$ is specific yield in the rising period that determined by the water budget approach (dimensionless),

$\Delta S_{g,r}$ is groundwater storage rises (mm/the inventory months),

ΔH_r is groundwater table rises (mm/the inventory months), and

A_e is the effective area for groundwater recharge.

Similarly, for the recession (declining) periods, the specific yield can be estimated by the following formula:

$$S_{y,d} = \frac{\Delta S_{g,d}}{\Delta H_d \times A_e} \tag{4.11}$$

where

$S_{y,d}$ is specific yield in the recession period that determined by the water budget approach (dimensionless),
$\Delta S_{g,d}$ is groundwater storage declines (mm/the inventory months), and
ΔH_d is groundwater table declines (mm/the inventory months).

In the present study, the inventory periods of June-September, July-September, July-October, and August-November are chosen for the specific yield estimation. Evapotranspiration and soil moisture deficit are very small in these periods in which Equation 4.10 and Equation 4.11 are applicable. The changes in groundwater storage during the inventory months are expressed in millimeter over the unit area of each aquifer zone (Table 4.1). From Table 4.1, the positive and negative values indicated the rising and recession period, respectively. The groundwater table fluctuation (both of rise and decline) can be determined directly from the hydrograph during the selected periods. Groundwater level data analyzed here are from the groundwater level monitoring wells of Chiang Mai basin. There are altogether 19 wells, in which 6 wells are in the Central Alluvial Channel, 1 well in the Colluvial and Alluvial Deposits, 9 wells in the Colluvial Deposits, 2 wells in the Mae Kuang Alluvial Fan and 1 well in the Nam Wang-Nam Mae Khan Subbasin.

Table 4.2 shows examples of specific yield calculation using water budget approach. The positive and negative values in groundwater storage changes indicated the rising (increasing) and recession (decreasing) period, respectively. Groundwater level data in used are from well G0135, Central Alluvial Channel, year 1967-2001. The inventory months are from July to September. As an example of rising case, year 1989, change in groundwater storage over the Central Alluvial Channel during the months of July to September has been calculated at 31.20 mm/Jul-Sep months. Rise in groundwater table can be determined directly from the hydrograph (Figure 4.10). From Figure 4.10, the water table rises from point A to point C. The rise in water table measured from the hydrograph is 0.64 m or 640 mm over the Jul-Sep months. Using groundwater storage change of 31.20 mm/Jul-Sep months, the water table rise of 640 mm/Jul-Sep months, from Equation 4.10 the calculated specific yield is therefore 0.0488. As an example of recession case, year 1988, change in groundwater storage over the Central Alluvial Channel during July to September is calculated at -5.39 mm/Jul-Sep months indicating a storage decline. From Figure 4.11, the water table declines from point B to C. It is -0.12 m/Jul-Sep months or -120 mm/Jul-Sep months. Using groundwater storage change of -5.39 mm/Jul-Sep months, the water table decline of -120 mm/Jul-Sep months, from Equation 4.10 the calculated specific yield is therefore 0.0449.

Table 4.1 Change in groundwater storage (ΔS_g , mm) of Chiang Mai basin aquifers during the different periods.

Year	Central Alluvial Channel				Colluvial and Alluvial Deposits				Colluvial Deposits				Mae Kuang Alluvial Fan				Nam Wang-Nam Mae Khan Subbasin			
	Jun-Sep	Jul-Sep	Jul-Oct	Aug-Nov	Jun-Sep	Jul-Sep	Jul-Oct	Aug-Nov	Jun-Sep	Jul-Sep	Jul-Oct	Aug-Nov	Jun-Sep	Jul-Sep	Jul-Oct	Aug-Nov	Jun-Sep	Jul-Sep	Jul-Oct	Aug-Nov
1967	76.91	72.76	56.86	31.51	13.14	12.44	9.72	5.39	59.99	56.75	44.35	24.58	40.55	38.36	29.98	16.62	10.91	10.32	8.06	0.31
1968	49.09	28.57	43.68	-3.78	8.39	4.88	7.47	-0.65	38.29	22.28	34.07	-2.95	25.88	15.06	23.03	-1.99	6.96	4.05	6.19	0.20
1969	23.01	37.51	14.24	3.42	3.93	6.41	2.43	0.58	17.95	29.25	11.11	2.67	12.13	19.78	7.51	1.80	3.26	5.32	2.02	0.09
1970	29.07	14.80	8.99	-41.69	4.97	2.53	1.54	-7.13	22.67	11.54	7.01	-32.52	15.33	7.80	4.74	-21.98	4.12	2.10	1.28	0.12
1971	26.77	22.21	15.14	-35.62	4.58	3.80	2.59	-6.09	20.88	17.33	11.81	-27.78	14.12	11.71	7.98	-18.78	3.80	3.15	2.15	0.11
1972	-7.31	5.96	-33.06	-6.64	-1.25	1.02	-5.65	-1.14	-5.70	4.65	-25.79	-5.18	-3.85	3.14	-17.43	-3.50	-1.04	0.85	-4.69	-0.03
1973	6.98	17.01	-24.38	-55.42	1.19	2.91	-4.17	-9.47	5.44	13.27	-19.02	-43.23	3.68	8.97	-12.85	-29.22	0.99	2.41	-3.46	0.03
1974	10.24	20.88	14.32	2.10	1.75	3.57	2.45	0.36	7.99	16.29	11.17	1.64	5.40	11.01	7.55	1.11	1.45	2.96	2.03	0.04
1975	26.52	26.81	26.05	-2.77	4.53	4.58	4.45	-0.47	20.69	20.91	20.32	-2.16	13.98	14.14	13.73	-1.46	3.76	3.80	3.69	0.11
1976	-6.85	6.18	4.87	-5.06	-1.17	1.06	0.83	-0.86	-5.34	4.82	3.80	-3.95	-3.61	3.26	2.57	-2.67	-0.97	0.88	0.69	-0.03
1977	25.20	36.41	26.37	10.27	4.31	6.22	4.51	1.76	19.65	28.40	20.57	8.01	13.28	19.20	13.91	5.42	3.57	5.16	3.74	0.10
1978	40.95	60.95	17.12	-43.74	7.00	10.42	2.93	-7.48	31.94	47.54	13.35	-34.12	21.59	32.14	9.03	-23.06	5.81	8.64	2.43	0.16
1979	-1.59	-3.98	-13.93	-32.40	-0.27	-0.68	-2.38	-5.54	-1.24	-3.10	-10.87	-25.27	-0.84	-2.10	-7.34	-17.08	-0.23	-0.56	-1.98	-0.01
1980	-8.01	-4.95	-4.96	-29.17	-1.37	-0.85	-0.85	-4.99	-6.25	-3.86	-3.87	-22.75	-4.22	-2.61	-2.62	-15.38	-1.14	-0.70	-0.70	-0.03
1981	12.97	19.07	-7.82	-30.50	2.22	3.26	-1.34	-5.21	10.11	14.87	-6.10	-23.79	6.84	10.05	-4.12	-16.08	1.84	2.70	-1.11	0.05
1982	-2.41	15.10	-24.80	-31.93	-0.41	2.58	-4.24	-5.46	-1.88	11.78	-19.34	-24.91	-1.27	7.96	-13.08	-16.84	-0.34	2.14	-3.52	-0.01
1983	-24.93	-7.05	-16.36	12.55	-4.26	-1.21	-2.80	2.14	-19.44	-5.50	-12.76	9.79	-13.14	-3.72	-8.63	6.62	-3.54	-1.00	-2.32	-0.10
1984	-26.53	-21.81	-30.93	-45.75	-4.53	-3.73	-5.29	-7.82	-20.69	-17.01	-24.13	-35.68	-13.99	-11.50	-16.31	-24.12	-3.76	-3.09	-4.39	-0.11
1985	24.43	15.19	3.71	-2.84	4.18	2.60	0.63	-0.49	19.06	11.85	2.90	-2.22	12.88	8.01	1.96	-1.50	3.47	2.15	0.53	0.10
1986	-34.00	-19.53	-31.50	-31.35	-5.81	-3.34	-5.38	-5.36	-26.52	-15.24	-24.57	-24.46	-17.93	-10.30	-16.61	-16.53	-4.82	-2.77	-4.47	-0.14
1987	31.67	42.50	3.33	22.69	5.41	7.26	0.57	3.88	24.70	33.15	2.60	17.70	16.70	22.41	1.76	11.96	4.49	6.03	0.47	0.13
1988	25.40	-5.39	42.52	-1.29	4.34	-0.92	7.27	-0.22	19.82	-4.20	33.17	-1.00	13.39	-2.84	22.42	-0.68	3.60	-0.76	6.03	0.10
1989	24.00	31.20	25.88	-3.00	4.10	5.33	4.42	-0.51	18.72	24.34	20.19	-2.34	12.66	16.45	13.65	-1.58	3.40	4.43	3.67	0.10
1990	-17.58	4.31	-18.37	9.64	-3.00	0.74	-3.14	1.65	-13.71	3.36	-14.33	7.52	-9.27	2.27	-9.69	5.09	-2.49	0.61	-2.61	-0.07
1991	27.91	35.95	12.49	3.46	4.77	6.14	2.13	0.59	21.77	28.04	9.74	2.70	14.72	18.96	6.58	1.82	3.96	5.10	1.77	0.11
1992	37.84	52.57	34.01	-5.24	6.47	8.98	5.81	-0.90	29.51	41.00	26.53	-4.09	19.95	27.72	17.93	-2.76	5.37	7.45	4.82	0.15
1993	-30.08	-8.14	-41.28	-32.45	-5.14	-1.39	-7.06	-5.55	-23.46	-6.35	-32.20	-25.31	-15.86	-4.29	-21.77	-17.11	-4.27	-1.15	-5.85	-0.12
1994	27.57	30.59	11.42	-6.93	4.71	5.23	1.95	-1.18	21.50	23.86	8.91	-5.41	14.53	16.13	6.02	-3.65	3.91	4.34	1.62	0.11
1995	21.37	27.67	3.21	-27.92	3.65	4.73	0.55	-4.77	16.67	21.58	2.50	-21.78	11.27	14.59	1.69	-14.72	3.03	3.92	0.45	0.09
1996	0.45	12.84	18.55	20.70	0.08	2.19	3.17	3.54	0.35	10.01	14.47	16.15	0.24	6.77	9.78	10.92	0.06	1.82	2.63	0.00
1997	-9.51	20.05	-12.78	-18.77	-1.62	3.43	-2.18	-3.21	-7.42	15.64	-9.97	-14.64	-5.01	10.57	-6.74	-9.90	-1.35	2.84	-1.81	-0.04
1998	-28.58	-6.49	-50.09	-39.66	-4.89	-1.11	-8.56	-6.78	-22.30	-5.06	-39.07	-30.94	-15.07	-3.42	-26.41	-20.91	-4.05	-0.92	-7.10	-0.11
1999	-19.30	-5.65	-24.39	-23.39	-3.30	-0.97	-4.17	-4.00	-15.05	-4.41	-19.03	-18.24	-10.18	-2.98	-12.86	-12.33	-2.74	-0.80	-3.46	-0.08
2000	-20.88	-25.12	-8.78	-22.05	-3.57	-4.29	-1.50	-3.77	-16.29	-19.59	-6.85	-17.20	-11.01	-13.25	-4.63	-11.63	-2.96	-3.56	-1.25	-0.08
2001	24.74	34.69	32.69	17.54	4.23	5.93	5.59	3.00	19.29	27.05	25.50	13.68	13.04	18.29	17.24	9.25	3.51	4.92	4.64	0.10

Table 4.2 Example of specific yield calculation using water budget approach ($S_{y(WBA)}$). Data from well G0135, Central Alluvial Channel, year 1967-2001. The inventory period is from July to September.

Year	ΔS_g (mm/A_a)	ΔH (mm)	$S_{y(WBA)}$	Year	ΔS_g (mm/A_a)	ΔH (mm)	$S_{y(WBA)}$
1967	72.76	-	-	1985	15.19	640	0.0237
1968	28.57	-	-	1986	-19.53	-60	0.3255
1969	37.51	1,950	0.0192	1987	42.50	2,220	0.0191
1970	14.80	1,070	0.0138	1988	-5.39	-120	0.0449
1971	22.21	1,120	0.0198	1989	31.20	640	0.0488
1972	5.96	1,070	0.0056	1990	4.31	700	0.0062
1973	17.01	-	-	1991	35.95	940	0.0382
1974	20.88	1,130	0.0185	1992	52.57	1,310	0.0401
1975	26.81	1,100	0.0244	1993	-8.14	-	-
1976	6.18	1,220	0.0051	1994	30.59	1,490	0.0205
1977	36.41	1,440	0.0253	1995	27.67	6,130	0.0045
1978	60.95	-	-	1996	12.84	1,130	0.0114
1979	-3.98	-	-	1997	20.05	850	0.0236
1980	-4.95	-	-	1998	-6.49	-	-
1982	15.10	-	-	1999	-5.65	-	-
1983	-7.05	-	-	2000	-25.12	-	-
1984	-21.81	-	-	2001	34.69	1,540	0.0225
				Average $S_{y(WBA)}$ for 35 years			0.0346

Data from all 19 monitoring wells were analyzed to obtain the calculated specific yield using the above described techniques and procedures (Appendix A). Table 4.3 shows the specific yield values of different aquifer zones, as calculated from different inventory periods. Ranges of specific yield values depend on properties of each aquifer, such as grain size, shape and distribution of pores, compaction of the sediments, and others. Central Alluvial Channel gives the highest value of specific yield.

4.2 Groundwater level data

A groundwater level is the elevation of atmospheric pressure of an aquifer. It is the water table of an unconfined aquifer or the potentiometric surface of a confined aquifer. The term water table or groundwater level is used in the present study, and is not specific to the real unconfined aquifer. The aquifer type of Chiang Mai basin has been previously described in details and is defined here as semi-confined aquifer. Changes in groundwater level response to many different phenomena over different time scales. Long-term water table fluctuations can be attributed to climatic changes (naturally occurring) and human activities such as over

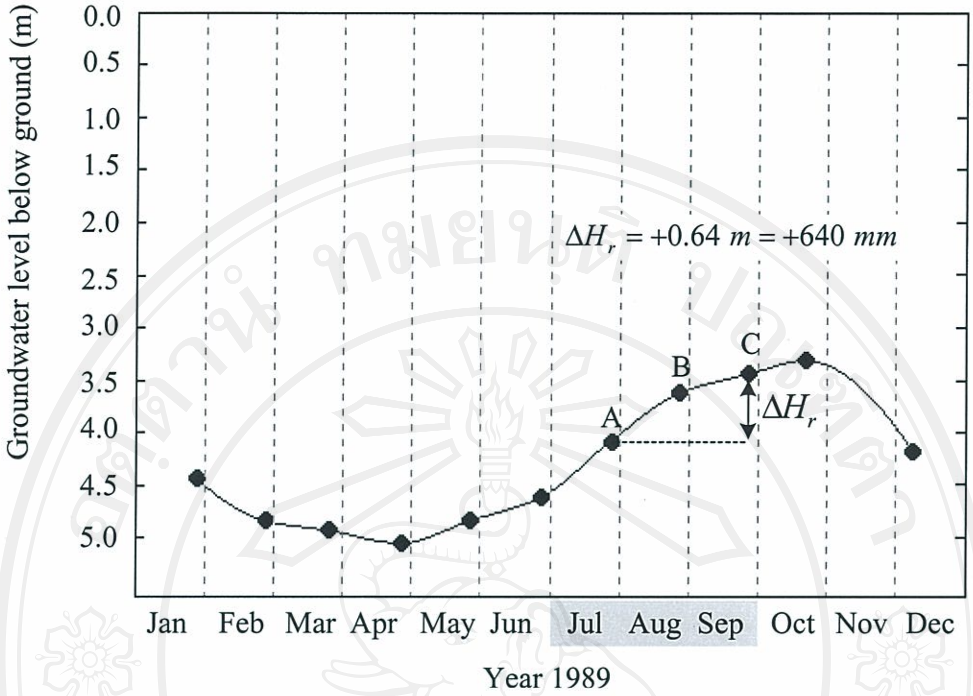


Figure 4.10 Groundwater level hydrograph showing the rise in groundwater level during the period from July to September. Data from well G0135, Central alluvial channel, year 1989.

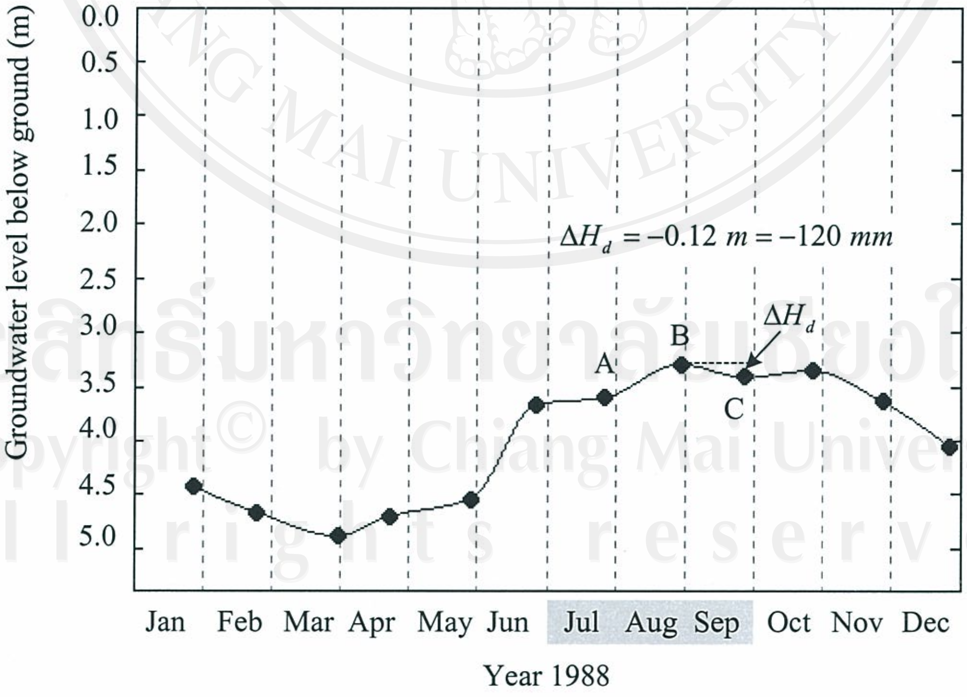


Figure 4.11 Groundwater level hydrograph showing the decline in groundwater level during the period from July to September. Data from well G0135, Central alluvial channel, year 1988.

Table 4.3 Calculated specific yield of Chiang Mai basin aquifers using the water budget approach ($S_{y(WBA)}$).

Aquifer type	Well name	Jul-Sep months	Jul-Oct months	Jun-Sep months	Aug-Nov months	Range of $S_{y(WBA)}$
Central Alluvial Channel	AUG1	0.0328	0.0575	0.0616	0.0359	0.0819-0.1007
	AUG3	0.1528	0.1102	0.1502	0.0983	
	AUG5	0.1473	0.2088	0.1829	0.2038	
	G0135	0.0942	0.1130	0.1299	0.0618	
	G0263	0.0223	0.0247	0.0223	0.0217	
	G0486	0.0743	0.0548	0.0572	0.0696	
	Average	0.0873	0.0948	0.1007	0.0819	
Colluvial and Alluvial Deposits	G0147	0.0122	0.0130	0.0154	0.0102	0.0102-0.0154
Colluvial Deposits	AUG4	0.0676	0.0345	0.0339	0.0268	0.0641-0.0963
	G0244	0.0311	0.0356	0.0388	0.0288	
	G0292	0.1012	0.0756	0.1004	0.1608	
	MW0187	0.0176	0.0199	0.0163	0.0232	
	MW0224	0.011	0.0160	0.0004	0.0179	
	MW0244	0.0395	0.1243	0.0984	0.1209	
	Q49	0.0768	0.0945	0.0954	0.0757	
	Q50	0.1835	0.1970	0.3480	0.3399	
	Q60	0.0483	0.0775	0.0621	0.0728	
	Average	0.0641	0.0750	0.0882	0.0963	
Mae Kuang Alluvial Fan	AUG2	0.0754	0.0878	0.0695	0.0786	0.0602-0.0882
	G0781	0.1009	0.0617	0.0733	0.0417	
	Average	0.0882	0.0748	0.0714	0.0602	
Nam Wang-Nam Mae Khan Subbasin	G1020	0.0038	0.0029	0.0033	0.0001	0.0001-0.0038

pumping. Short-term water table fluctuations are attributed to rainfall, pumping, barometric-pressure fluctuation in groundwater well, or other phenomena. Estimating the groundwater recharge using the WTF method requires identification of the water level rise, i.e. rainfall reaches the water table. This method is best applied for the short-term fluctuation.

4.2.1 Groundwater level data of monitoring wells

Groundwater level data are compiled from the existing data collected by the Department of Groundwater Resources (Formerly Groundwater Division, DMR). Groundwater level of the monitoring wells is recorded on the monthly basis. Although there are around 30 monitoring wells in the study area, only 19 wells have been analyzed here. These are 6 wells in the Central Alluvial Channel, 1 well in the Colluvial and Alluvial Deposits, 9 wells in the Colluvial Deposits, 2 wells in the Mae Kuang Alluvial Fan and 1 well in the Nam Wang-Nam Mae Khan Subbasin. There are no groundwater monitoring well data in the High Terrace and Mae Tha Alluvial Fan. The locations of all groundwater level monitoring wells in the study area are shown in Figure 4.12. Details of groundwater level monitoring well are presented in Table 4.4.

Among the 19 monitoring wells used in the present study, 12 wells have groundwater level data of more than 10 years; including 5 wells in Central Alluvial Channel, 1 well in Colluvial and Alluvial Deposits, 3 wells in Colluvial Deposits, 2 wells in Mae Kuang Alluvial Fan, and 1 well in the Nam Wang-Nam Mae Khan Subbasin. Four wells located in Colluvial Deposits have groundwater level records of 5-10 years. Three wells with groundwater level records of less than 5 years are 1 well located in the Central Alluvial Channel and 2 wells in the Colluvial Deposits.

The water level device named chart recorder (continuous recording capability) is used to record level-measurement data. Figure 4.13 shows the chart recorder of well G0135, Central Alluvial Channel. The chart recorder is positioned directly above the well on the constructed platform. The device uses a drum system onto which a chart is placed. The water level position in the well is tracked by having a weighted float connected to a beaded cable that passes over the drum and is connected to a counterweight. As the drum rolls backward or forward with the movement of the water level, a stationary ink pen marks the chart. The pen moves in horizontal to correspond with time set by a timer. Timers can be set for one month or up to three months. Chart paper is grid paper. The column line represents 8 hours. The row lines mark the vertical water level fluctuation. The information from the chart has then converted into numbers for data analysis.

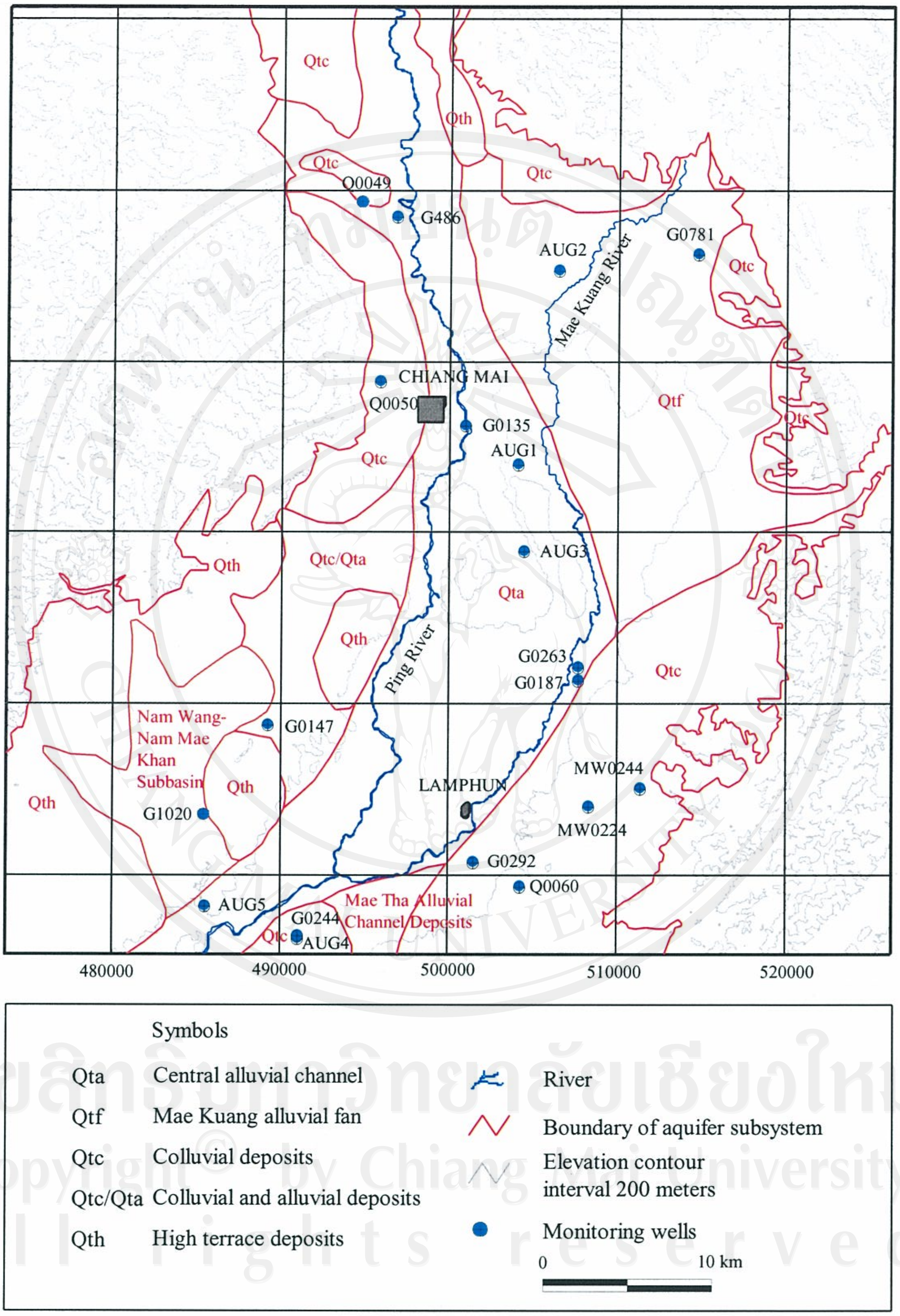


Figure 4.12 Location of groundwater level monitoring wells.

Table 4.4 Details of groundwater monitoring wells (Department of Groundwater Resources).

No.	Well Name	Aquifer Zone	UTM_E	UTM_N	Location	Drilling Date	ALT (m msl)	SWL (m bgl)	Screen Intervals (m)	No. Screen	Screen Length (m)
1	G0263	Central Alluvial Channel	507600	2062135	Ban mae yak	1973	297	4.84	48-54,60-72	2	18
3	G0135	Central Alluvial Channel	500850	2076250	Chiangmai regional forestry	1966	298	1.50	11-17	1	6
3	G0486	Central Alluvial Channel	496750	2088450	CMU aggricuture trainning	1981	310	3.40	24-30,43-49,58-64	3	18
4	AUG1	Central Alluvial Channel	504000	2074000	Wat bo sang	-	298	-	-	-	-
5	AUG3	Central Alluvial Channel	504400	2068900	Sarapri district office	-	298	-	-	-	-
6	AUG5	Central Alluvial Channel	485500	2048200	Mae khan school	-	285	-	-	-	-
7	G0147	Colluvial and Alluvial Deposits	489250	2058800	Amphoe sun pa tong	1967	298	3.03	18-24,30-36,48-60	3	24
8	AUG4	Colluvial Deposits	491050	2046350	Wat sapung luang	-	290	-	-	-	-
9	G0244	Colluvial Deposits	491050	2046550	Wat pa hiang(ban kong ngam)	1972	290	4.55	30-36	1	6
10	G0292	Colluvial Deposits	501450	2050750	Ban nong pla kho	1975	297	5.45	54-66	1	12
11	MW0187	Colluvial Deposits	507600	2061350	Wat pong chai	-	294	-	36-48,69-81	2	24
12	MW0224	Colluvial Deposits	508300	2054000	Ban phraya phap	1984	307	11.47	45-57	1	12
13	MW0244	Colluvial Deposits	511350	2055050	Ban pa tung	1984	300	2.4	36-42,48-54	1	12
14	Q0049	Colluvial Deposits	494650	2088950	Military agricuture trainning	-	320	-	18-30,48-60	2	24
15	Q0050	Colluvial Deposits	495800	2078800	Northern region geological c.	1964	-	14.90	61-90	1	29
16	Q0060	Colluvial Deposits	504200	2049350	Wat ban pa sak	1965	304	6.82	57-81	1	24
17	AUG2	Mae Kuang Alluvial Fan	506400	2085300	Ban san luang school	-	315	-	-	-	-
18	G0781	Mae Kuang Alluvial Fan	514700	2086250	Doi sa ket district office	1985	331	3.10	18-30,66-72	2	18
19	G1020	Nam Wang-Nam Mae Khan Subbasin	486190	2053750	Ban thong fai school	1989	300	36.36	39-57	1	18

Table 4.4 Details of groundwater monitoring wells (continued).

No.	Well Name	Started water level recording	Selected period of recording the monthly water level	Number of selected year	Average water level (m bgl)	Deepest water level	Well status	Remark
1	G0263	1995	2000-2001	2	28.56	31.15	Active	Rehabilitation recommended
2	G0135	1966	1967,1969-1977,1981-2001	31	3.93	6.25	Active	Near Ping River
3	G0486	1990	1991,1993-1998,2000-2001	9	5.33	6.76	Active	6 nearby wells
4	AUG1	1969	1969-1977,1979,1981-1991	21	3.31	6.25	Discontinued	-
5	AUG3	1969	1969-1979,1981-1997	27	3.12	3.90	Active	-
6	AUG5	1969	1969-1979,1981-1992,1995-1997	25	1.45	3.47	Active	-
7	G0147	1967	1969-1978,1981-1990, 1992-1997,2000-2001	27	1.70	11.93	Active	Near creek
8	AUG4	1969	1969-1978,1981-1997	26	2.38	5.30	Active	-
9	G0244	1993	1993-2001	9	8.43	12.80	Active	Strong influence from nearby pumped wells?
10	G0292	1995	1996-1997,2000-2001	4	5.97	7.93	Active	-
11	MW0187	1991	1992,1995-1998,2000-2001	7	12.07	18.17	Active	-
12	MW0224	1995	1996	1	7.38	8.07	Active ?	-
13	MW0244	1995	1996-2001	6	4.02	6.52	Active	-
14	Q0049	1969	1970-1998,2000-2001	31	4.38	6.12	Active	-
15	Q0050	1967	1969-1972	4	2.04	2.80	Discontinued	-
16	Q0060	1987	1988-2001	14	2.48	4.30	Active	-
17	AUG2	1969	1970-1979,1981-1997	27	1.25	3.89	Active	-
18	G0781	1990	1991-1998,2000-2001	10	2.48	6.80	Active	-
19	G1020	1990	1991-1997,1999-2001	10	34.85	46.51	Active	-

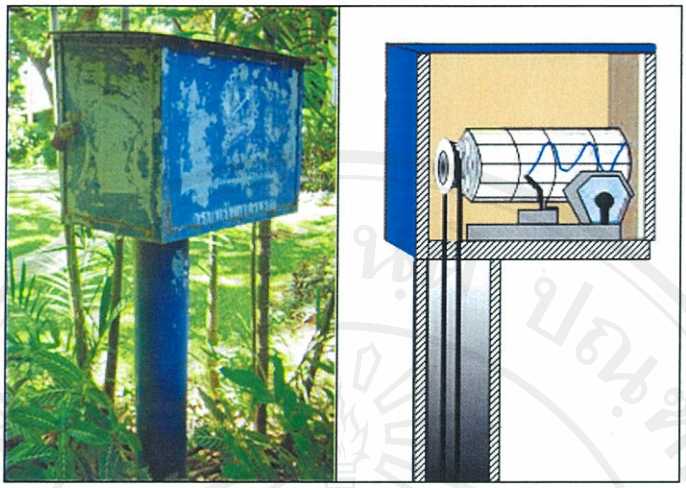


Figure 4.13 Groundwater level chart recorder.

4.2.2 Hydrograph analysis

Records of groundwater level fluctuation of these wells are used to (a) analyze the rise in groundwater level (Δh) that respond to groundwater recharge; (b) estimate specific yield ($S_{y(WBA)}$) (Section 4.1) and (c) analyze groundwater recharge pattern (Section 5.1). In order to calculate groundwater recharge by means of groundwater table rise, groundwater level data that monitored more than 5 years are required. However, wells that have recorded data less than 5 years are useful for the estimation of specific yield ($S_{y(WBA)}$) using water budget approach.

Determination of groundwater level rise (Δh) can be done by well hydrograph analysis. Example of the well hydrograph analysis is shown in Figure 4.14. The rise of groundwater level (Δh) is defined and measured by (a) the recession curve and (b) the horizontal line that are extrapolated from the lowest groundwater level (Point A and C).

(a) The recession curve method In Figure 4.14, the groundwater level rises occur in two periods (AB and CD). The rise of groundwater level is set equal to the difference between the peak of the rise (point B and D) and low point (point E and F) of the extrapolated recession curve (AE and CF line) at the time of the peak rise. The recession curve is the trace that the graph would have followed in the absence of the rise-producing rainfall.

(b) The horizontal line method The rise of groundwater level is measured by the horizontal line extrapolated from point A and C (Figure 4.14). Point B and D are the highest rising points immediately followed the lowest groundwater level. The rise in groundwater level can be measured directly from the graph (GB and HD as shown).

Each water level rise is measured and added up as the total annual rise. In Figure 4.14, Δh measured by the recession curve and horizontal line method are 1.95 m/y or 1,950 mm/y and 1.81 m/y or 1,810 mm/y, respectively. The measured

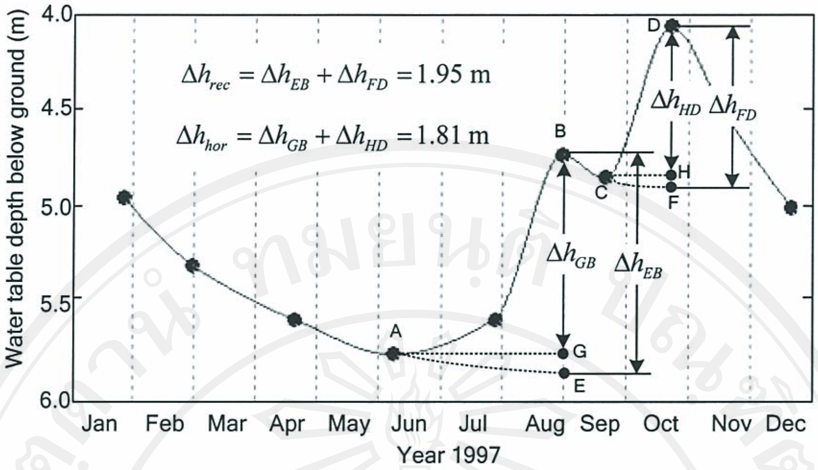


Figure 4.14 Hydrograph analysis using horizontal line and recession curve techniques. Data from well G0135, Central Alluvial Channel, year 1997.

Δh from the recession curve method gives the higher value than the horizontal line method. Average values of total rises in groundwater table of Chiang Mai basin aquifers are shown in Table 4.5. Ranges of the average total rises measured by the recession curve ($\Delta h_{act,rec}$) and the horizontal line methods ($\Delta h_{act,hor}$) are 0.39-9.41 m. and 0.34-8.74 m., respectively. These values will be discussed more with their associated error in Section 4.2.3. The average groundwater table rises in well G0244 and MW0187 from both methods are too high for Colluvial Deposits compared with the groundwater table rises in other wells over the same aquifer type. They range from 0.39 to 3.24 in the recession curve method and 0.34 to 2.94 m. in the horizontal line method, respectively. The values from these wells will be discussed more in Section 5.3.

4.2.3 Error analysis of groundwater level rises

Groundwater table fluctuation method is based on the premise that rises in groundwater table are due to recharge water, effective rainfall, arriving at the water table. Based on this hypothesis, the peak of groundwater table should rise after the peak of effective rainfall occurred. Therefore, error of groundwater recharge calculation is due to the water table rises that occur without effective rainfall. Error of total rises in groundwater table can be calculated by:

$$E_h = \frac{\Delta h_{act} - \Delta h_{hyp}}{\Delta h_{act}} \times 100 \tag{4.12}$$

where

E_h is error of total rises in groundwater table (%),

Δh_{act} is the actual rises or total rises of groundwater table that analyzed from well hydrograph (m), and

Δh_{hyp} is the total hypothesis groundwater table rises that respond to effective rainfall (m).

Equation 5.5 can be rewritten as:

$$E_h = \frac{\Delta h_{err}}{\Delta h_{act}} \times 100 \tag{4.13}$$

where

Δh_{err} is the total rises in groundwater table without effective rainfall (m).

Figure 4.15 shows the water table rises without effective rainfall. Data from well G0135 (Central Alluvial Channel) year 1972. The Δh_{err} occurs in April. Groundwater table rises measured by horizontal line method are Δh_{err} =0.25 m. and Δh_{act} = 0.25+1.19 = 1.44 m. Percentage error of total rises in groundwater table can be calculated with Equation 4.12 as:

$$E_h = \frac{0.25}{1.44} \times 100 = 17.36\,\%$$

Analysis of Δh_{err}, Δh_{hyp}, Δh_{act}, and E_h for each year are carried out. Table 4.5 shows the average errors of total rises in groundwater table (E_h) of each aquifer types. It is apparent that the errors from the recession curve and the horizontal line method are 8.73 % and 8.15 %, respectively. Measurement of groundwater table rises using the horizontal line method gives the lower error value than the recession curve method used. It is 0.32 %. The horizontal line method is more accurately, at this stage.

4.3 Pumping test data analysis

The specific yield of an aquifer can be determined by mean of a pumping test or aquifer test. Pumping tests are generally carried out by monitoring the water level over time in the pumping well and in each observation well (if available), while the pumping well is being discharged at a constant rate. The pumping test data, time-drawdown, are then interpreted to obtain the aquifer hydraulic properties, including the specific yield. Specific yield or unconfined storativity may range from 0.02 to 0.3 (Walton, 1970).

There is no real unconfined aquifer in the study area because of its hydrogeological conditions. There are interfingering between different types of sedimentation of each aquifer unit (Section 2.4). The pumping test wells may be located in the aquifers that are overlain or underlain by lens of clay layer. It is postulated that the aquifer type of the study area is semi-confined (leaky) aquifer.

Table 4.5 Average values of total rises in groundwater table (m/y) and errors calculated by the recession curve and horizontal line method.

Aquifer type	Well name	Recession curve method			Horizontal line method		
		$\Delta h_{act,rec}$	$\Delta h_{hyp,rec}$	E_h (%)	$\Delta h_{act,hor}$	$\Delta h_{hyp,hor}$	E_h (%)
Central Alluvial Channel	AUG1	3.09	2.83	8.41	2.58	2.37	8.14
	AUG3	0.98	0.88	10.20	0.89	0.80	10.11
	AUG5	1.60	1.52	5.00	1.50	1.41	6.00
	G0135	2.03	1.89	6.90	1.96	1.83	6.63
	G0263	1.30	1.30	0.00	1.01	1.01	0.00
	G0486	4.24	3.73	12.03	1.29	1.15	10.85
Colluvial and Alluvial Deposits	G0147	1.75	1.66	5.14	1.58	1.51	4.43
Colluvial Deposits	AUG4	3.13	2.84	9.27	2.85	2.69	5.61
	G0244	5.99	5.30	11.52	5.36	4.79	10.63
	G0292	1.18	1.18	0.00	1.01	1.01	0.00
	MW0187	9.41	8.31	11.69	8.74	7.72	11.67
	MW0224	1.97	1.27	35.53	1.63	1.08	33.74
	MW0244	3.24	3.06	5.56	2.94	2.82	4.08
	Q49	1.92	1.88	2.08	1.79	1.75	2.23
	Q50	0.39	0.37	5.13	0.34	0.32	5.88
	Q60	1.56	1.54	1.28	1.43	1.41	1.40
Mae Kuang Alluvial Fan	AUG2	1.44	1.29	10.42	1.22	1.08	11.48
	G0781	1.11	1.06	4.50	0.91	0.86	5.49
Nam Wang-Nam Mae Khan Subbasin	G1020	5.98	5.73	4.18	5.20	4.98	4.23
Average		2.75	2.51	8.73	2.33	2.14	8.15

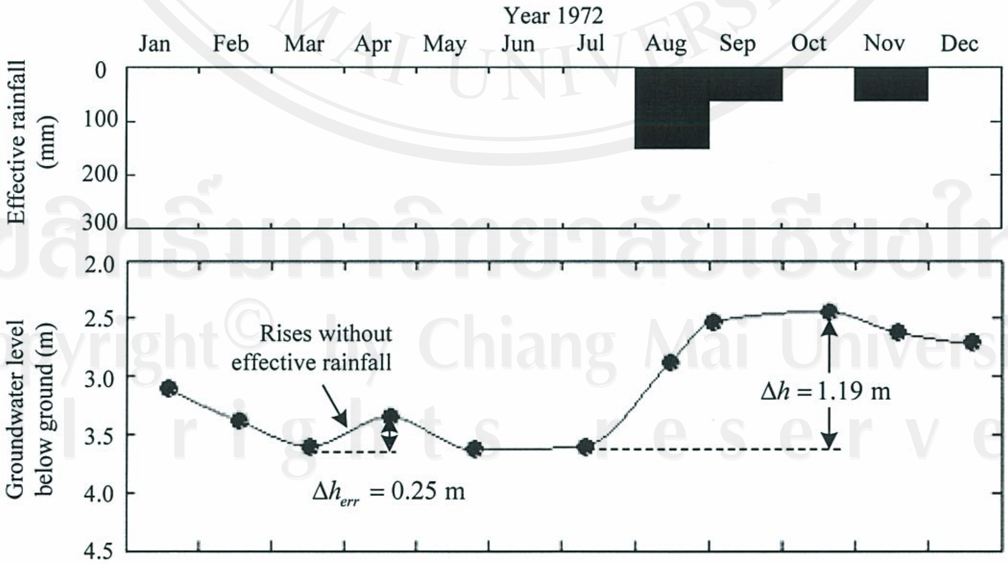


Figure 4.15 Hydrograph showing water table rises without effective rainfall. Data from well G0135, Central alluvial channel, year 1972.

The Walton graphical method for estimating the storativity is therefore selected. The assumptions for leaky aquifer are as follows (Kruseman and Ridder, 1991):

1) The aquifer is leaky.
2) The aquifer and aquitard have a seemingly infinite areal extent.
3) The aquifer and aquitard are homogeneous, isotropic, and of uniform thickness over the area influenced by the test.
4) Prior to pumping, the piezometric surface is horizontal (or nearly so) over the area that will be influenced by the test.
5) The aquifer is pumped at a constant discharge rate.
6) The well penetrates the entire thickness of the aquifer and thus receives water by horizontal flow.
7) The flow in the aquitard is vertical.
8) The drawdown in the aquitard is negligible.
9) Well storage can be neglected.
10) The water removed from storage in the aquifer and the water supplied by leakage from the aquitard is discharged instantaneously with decline of head.

The Hantush-Jacob formula is:

$$T = \frac{Q}{4\pi(h_0 - h)} W(u, r/L) \tag{4.14}$$

where

T is the transmissivity of the semi-confined aquifer (m^2/d),
Q is the pumping rate (m^3/d),
$h_o - h$ is the lowering of the water level in the aquifer resulting from pumping of wells or drawdown (m), and
$W(u, r/L)$ is the well function for leaky artesian aquifers.

$$S = \frac{4Tut}{r^2} \tag{4.15}$$

where

S is the storativity of the semi-confined aquifer (dimensionless),
u is the constant value (dimensionless),
t is the time since pumping began (d), and
r is the radial distance from the pumping well to the observation well where measure drawdown (m).

Estimating *r/L* for leaky aquifers:

$$r/L = r/(KDD'/K')^{1/2} \tag{4.16}$$

where

L is leakage factor (m),
K is aquifer hydraulic conductivity (m/d),
K' is aquitard hydraulic conductivity (m/d),
D is aquifer thickness (m), and
D' is aquitard thickness (m).

Walton (1970) developed a graphical means of solution to the Hantush-Jacob equations (Equation 4.13, 4.14 and 4.15) to find the hydraulic properties of the leaky aquifer. Walton graphical method is applied for the situation of non-equilibrium radial flow in the leaky aquifer with fully penetrating wells, constant-discharge, and without water released from storage in the semipervious layer. The type curves are plots on logarithmic paper of the *W(u,r/L)* as a function of *1/u* for various values of *1/u* and *r/L*. Values of *W(u,r/L)* against *u* are presented in Table 4.6. The type curve can be plotted by hand using the data from Table 4.6. However, a computer program can also be used to plot the type curve. Figure 4.16 shows Walton type curve that created by the aquifer pump test analysis software, Infinite Extent (Starpoint Software Inc., 2000). Type curves are displayed for different values of *r/L*, ranging from 0.0 to 5.0. As *r/L* increases, the leakage from the aquitard increases. The value of *r/L* equal to zero is the Theis solution.

Field data are plotted as drawdown, the lowering of water level resulting from pumping of wells, versus time (minus). The field data curve is superimposed over the type curve with the axes parallel. The position of field-data curve is adjusted until the data points overlie the type curve. It should match one of the type curves for *r/L* or match the imaginary curve that interpolated between two *r/L* lines.

A match point must then be selected. Any arbitrary point may be used. The coordinates on both the field-data plot and the type curve yield the values of *W(u,r/L)*, *1/u*, $t, h_o - h$ and r/L. These values are substituted into the Hantush-Jacob equations to estimate aquifer storativity.

Table 4.7 and Figure 4.16 provide an example of the pumping test analysis using Walton's graphical method for the Hantush-Jacob formulas. Infinite Extent software is used to estimate aquifer storativity. Well MW1000, Central Alluvial Channel, was pumped at a rate of 274.08 m^3/d for 400 min. The leaky aquifer is 12 m thick. Time-drawdown data from measurements in the pumped well itself are shown in Table 4.7. The radius of the pumped well is used as the distance from the pumped well to the observation well ($r = 0.075$ m). Figure 4.16 shows the match of field-data plot from well MW1000, Central Alluvial Channel, to type curve of leaky artesian aquifer (Starpoint Software). In Figure 4.16, the specific yield, the hydraulic conductivity, and the transmissivity analyzed by the Starpoint Software based-on the Walton graphical method are 0.1316 in fraction, 0.1338 m/d, and 1.605 m^2/d, respectively.

Pumping test wells in the study area were drilled by Department of Groundwater Resources, Ministry of Natural Resources and Environment. Although there are a number of test wells drilled in the study area, covering all aquifer zones, only 41 test wells drilled in 5 aquifer zones are selected for further pump test analysis.

Table 4.6 Values of W(*r*/*L*) against *u* (Fetter, 1994).

u \ *r*/*L*	0.002	0.004	0.006	0.008	0.01	0.02	0.04	0.06	0.08	0.1	0.2	0.4	0.6	0.8	1	2	4	6	8
0	12.70	11.30	10.50	9.89	9.44	8.06	6.67	5.87	5.29	4.85	3.51	2.23	1.55	1.13	0.842	0.228	0.0223	0.0025	0.0003
0.000002	12.10	11.20	10.50	9.89	9.44														
0.000004	11.60	11.10	10.40	9.88	9.44														
0.000006	11.30	10.90	10.40	9.87	9.44														
0.000008	11.00	10.70	10.30	9.84	9.43														
0.00001	10.80	10.60	10.20	9.80	9.42	8.06													
0.00002	10.20	10.10	9.84	9.58	9.30	8.06													
0.00004	9.52	9.45	9.34	9.19	9.01	8.03	6.67												
0.00006	9.13	9.08	9.00	8.89	8.77	7.98	6.67												
0.00008	8.84	8.81	8.75	8.67	8.57	7.91	6.67												
0.0001	8.62	8.59	8.55	8.48	8.40	7.84	6.67	5.87	5.29										
0.0002	7.94	7.92	7.90	7.86	7.82	7.50	6.62	5.86	5.29										
0.0004	7.24	7.24	7.22	7.21	7.19	7.01	6.45	5.83	5.29	4.85									
0.0006	6.84	6.84	6.83	6.82	6.80	6.68	6.27	5.77	5.27	4.85									
0.0008	6.55	6.55	6.54	6.53	6.52	6.43	6.11	5.69	5.25	4.84									
0.001	6.33	6.33	6.32	6.32	6.31	6.23	5.97	5.61	5.21	4.83	3.51								
0.002	5.64	5.64	5.63	5.63	5.63	5.59	5.45	5.24	4.98	4.71	3.50								
0.004	4.95	4.95	4.95	4.94	4.94	4.92	4.85	4.74	4.59	4.42	3.48	2.23							
0.006	4.54				4.54	4.53	4.48	4.41	4.30	4.18	3.43	2.23							
0.008	4.26				4.26	4.25	4.21	4.15	4.08	3.98	3.36	2.23							
0.01	4.04				4.04	4.03	4.00	3.95	3.89	3.81	3.29	2.23	1.55	1.13					
0.02	3.35				3.35	3.35	3.34	3.31	3.28	3.24	2.95	2.18	1.55	1.13					
0.04	2.68				2.68	2.68	2.67	2.66	2.65	2.63	2.48	2.02	1.52	1.13	0.842				
0.06	2.30				2.30	2.29	2.29	2.28	2.27	2.26	2.17	1.85	1.46	1.11	0.839				
0.08	2.03					2.03	2.02	2.02	2.01	2.00	1.94	1.69	1.39	1.08	0.832				
0.1	1.82						1.82	1.82	1.81	1.80	1.75	1.56	1.31	1.05	0.819	0.228			
0.2	1.22						1.22	1.22	1.22	1.22	1.19	1.11	0.996	0.857	0.715	0.227			
0.4	0.702						0.702	0.702	0.701	0.700	0.693	0.665	0.621	0.565	0.502	0.210			
0.6	0.454						0.454	0.454	0.454	0.453	0.450	0.436	0.415	0.387	0.354	0.177	0.0222		
0.8	0.311						0.311	0.310	0.310	0.310	0.309	0.301	0.289	0.273	0.254	0.144	0.0218		
1	0.219									0.219	0.218	0.213	0.206	0.197	0.185	0.114	0.0207	0.0025	
2	0.049										0.049	0.048	0.047	0.046	0.044	0.034	0.011	0.0021	0.0003
4	0.0038											0.0038	0.0037	0.0037	0.0036	0.0031	0.0016	0.0006	0.0002
6	0.0004														0.0004	0.0003	0.0002	0.0001	0
8	0																		0

Table 4.7 Time-drawdown data of well MW1000.

Time (min)	Drawdown (m)	Time (min)	Drawdown (m)
1	3.04	80	3.40
2	3.04	100	3.44
3	3.04	120	3.48
4	3.04	140	3.53
5	3.10	160	3.55
6	3.12	180	3.56
7	3.13	200	3.56
8	3.13	220	3.57
9	3.14	240	3.58
10	3.14	260	3.56
15	3.14	280	3.56
20	3.18	300	3.57
25	3.20	320	3.58
30	3.23	340	3.57
40	3.27	360	3.57
50	3.31	380	3.58
60	3.35	400	3.58

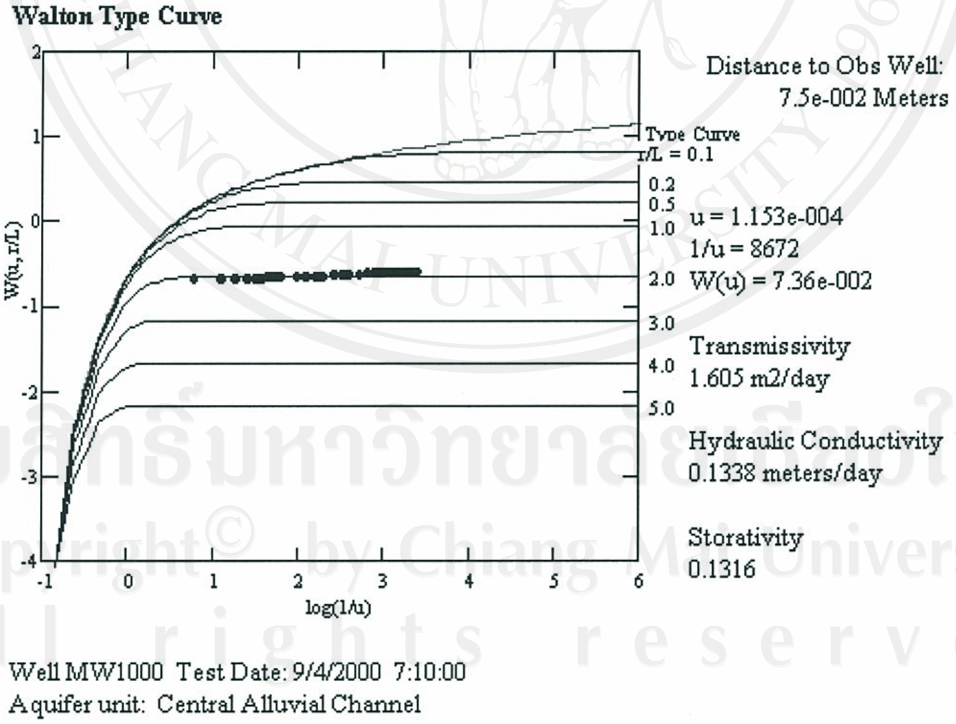


Figure 4.16 Match of field-data plot (from well MW1000, Central Alluvial Channel) to type curve of leaky artesian aquifer (Starpoint Software, 2000). Specific yield is 0.1316 in fraction.

These are 17 wells in the Central Alluvial Channel, 2 wells in the Colluvial and Alluvial Deposits, 15 wells in the Colluvial Deposits, 6 wells in the Mae Kuang Alluvial Fan and 1 well in the Nam Wang–Nam Mae Khan Subbasin. Details of the pumping test wells and calculated specific yield values are shown in Table 4.8 and 4.9, respectively. Location of the pumping test wells are shown in Figure 4.17. Table 4.10 shows the specific yield values of the study area as calculated by the pumping test approach. The specific yield ranges from 0.0766 to 0.3280. Due to the lack of observation well, all pumping test data are from measurement in the pumped well itself. Radius of the pumped well is used as distance from the pumped well to the observation well. The accuracy of the estimating aquifer specific yield using the single well pump test is therefore low.

Table 4.8 Details of pumping test wells (Department of Groundwater Resources).

No.	Well name	Aquifer unit	UTM_E	UTM_N	Location
1	MW1000	Central Alluvial Channel	503700	2055730	Ban Nong Pet, Moo 4, Tambon Ban Klang, Amphoe Muang Lamphun, Changwat Lamphun
2	MW1019	Central Alluvial Channel	498350	2056490	Wat Phra Chedi Khao, Moo 5, Tambon Rim Ping, Amphoe Muang Lamphun, Changwat Lamphun
3	TG0224	Central Alluvial Channel	489554	2051135	Ban San Hao, Moo 7, Tambon Ban Klang , Amphoe San Pa Tong, Changwat Chiang Mai
4	TG0245	Central Alluvial Channel	500250	2063500	Ban Tha Kwang, Moo 6, Tambon Ta Kwang, Amphoe Saraphi, Changwat Chiang Mai
5	TG0246	Central Alluvial Channel	499334	2070620	Ban Chai Sathan, Moo 1, Tambon Pa Bong , Amphoe Saraphi, Changwat Chiang Mai
6	TG0248	Central Alluvial Channel	505233	2070249	Ban Ton Chok Luang, Moo 1, Tambon Chai Sathan, Amphoe Saraphi, Changwat
7	TG0261	Central Alluvial Channel	498850	2067900	Ban Tamnak School, Moo 1, Tambon Don Kaeo, Amphoe Saraphi, Changwat Chiang Mai
8	TG0262	Central Alluvial Channel	504944	2071101	Ban Si Song Muang, Moo 2, Tambon Chai Sathan, Amphoe Saraphi, Changwat Chiang Mai
9	TG0263	Central Alluvial Channel	504950	2071330	Ban Si Song Muang, Moo 2, Tambon Chai Sathan, Amphoe Saraphi, Changwat Chiang Mai
10	TG0264	Central Alluvial Channel	504890	2071700	Ban Si Bun Buang, Moo 3, Tambon Chai Sathan, Amphoe Saraphi, Changwat Chiang Mai
11	TG0265	Central Alluvial Channel	505890	2071500	Wat Ban Pa Bong Luang, Moo 4, Tambon Pa Bong, Amphoe Saraphi, Changwat
12	TG0274	Central Alluvial Channel	497200	2084900	Wat Ban San Muang, Moo 7, Tambon Don Keaw, Amphoe Mae Rim, Changwat Chiang Mai
13	TG0286	Central Alluvial Channel	495160	2094300	Phra Porn Chai Church, Moo 1, Tambon San Pong, Amphoe Mae Rim, Changwat Chiang Mai
14	TG0287	Central Alluvial Channel	491200	2090350	Wat Ampawan, Moo 5, Tambon Mae Ram, Amphoe Mae Rim, Changwat Chiang Mai
15	TG0295	Central Alluvial Channel	490300	2049800	Ban San Kong Ket, Moo 10, Tambon Ban Klang, Amphoe San Pa Tong, Changwat Chiang Mai
16	TG0318	Central Alluvial Channel	506092	2075286	Wat Ban San Klang Nua, Moo 3, Tambon San Klang, Amphoe San Kamphaeng, Changwat
17	TG0339	Central Alluvial Channel	500246	2091752	San Sai Wittayakom School, Moo 10, Tambon Nong Han, Amphoe San Sai, Changwat Chiang Mai
18	TG0127	Colluvial and Alluvial Deposits	491100	2055850	Royal Project Area, Moo 4, Tambon Ma kham Luang, Amphoe San Pa Tong, Changwat Chiang Mai
19	TG0294	Colluvial and Alluvial Deposits	491000	2056400	Ban San Chi Kong, Moo7, Tambon Thung Tom, Amphoe San Pa Tong, Changwat Chiang Mai
20	DC0577	Colluvial Deposits	494730	2074220	Ban Huai Sai, Moo 4 ,Tambon Suthep, Amphoe Muang Chaing Mai, Changwat Chiang Mai
21	DC0578	Colluvial Deposits	493810	2072900	Wat Pa Chi, Moo 3, Tambon Mae Hia, Amphoe Muang Chaing Mai, Changwat Chiang Mai
22	MW0806	Colluvial Deposits	502232	2049409	Ban San Luang,Moo 12, Tambon Pa Sak, AmphoeMuang Lamphun, Changwat Lamphun
23	MW0989	Colluvial Deposits	498205	2047046	Ban Bo Chong, Moo 1, Tambon Nong Nam, Amphoe Muang Lamphun, Changwat Lamphun
24	MW1007	Colluvial Deposits	507520	2049450	Ban Hua Khrae, Moo 4, Tambon Si Bua Ban, Amphoe Muang Lamphun, Changwat Lamphun
25	MW1018	Colluvial Deposits	516750	2066200	Ban Huai Sai Tai, Moo 8, Tambon Huai Yap, Amphoe Ban Thi, Changwat Lamphun
26	MW1024	Colluvial Deposits	499420	2046510	Ban Ko Khoi School, Moo 6, Tambon Nong Nam, Amphoe Muang Lamphun, Changwat Lamphun
27	MW1038	Colluvial Deposits	505650	2050950	Ban Nong Bua, Moo 2, Tambon Pa Sak, Amphoe Muang Lamphun, Changwat Lamphun
28	MW1046	Colluvial Deposits	516700	2063800	Ban Huai Muang, Moo 3, Tambon Huai Yap, Amphoe Ban Thi, Changwat Lamphun
29	MW1070	Colluvial Deposits	503898	2053398	Ban Phra Yuen (Rong Rai), Moo 1, Tambon Wiang Yong, Amphoe Muang Lamphun, Changwat Lamphun
30	TG0132	Colluvial Deposits	493786	2091157	Mae Rim Witthayakhom School, Moo 1, Tambon Rim Tai, Amphoe Mae Rim, Changwat Chiang Mai
31	TG0285	Colluvial Deposits	494750	2072020	Wat Siri Mungkalajarn, Moo 1, Tambon Mae Hia, Amphoe Muang Chaing Mai, Changwat Chiang Mai
32	TG0314	Colluvial Deposits	515838	2083455	Ban Pa Yang Ngam, Moo 7, Tambon Pa Pong, Amphoe Doi Saket, Changwat Chiang Mai
33	TG0324	Colluvial Deposits	516555	2086587	Wat Pathum Sararam, Moo 12, Tambon Choeng Doi, Amphoe Doi Saket, Changwat Chiang Mai
34	TG0345	Colluvial Deposits	492810	2071800	Mae Hia Samukkee School (Ban Bo), Moo 2, Tambon Mae Hia, Amphoe Muang Chaing Mai, Changwat Chiang
35	TG0033	Mae Kuang Alluvial Fan	510149	2079062	Ban Pa Muat, Moo 5, Tambon Samran Rat, Amphoe Doi Saket, Changwat Chiang Mai
36	TG0229	Mae Kuang Alluvial Fan	508838	2072079	Ban Tan, Moo 12, Tambon San Kamphaeng, Amphoe San Kamphaeng, Changwat Chiang Mai
37	TG0230	Mae Kuang Alluvial Fan	505194	2081506	Ban Mae Yoi, Moo 1, Tambon San Sai Noi, Amphoe San Sai, Changwat Chiang Mai
38	TG0231	Mae Kuang Alluvial Fan	518500	2078175	Wat Ban Nong Sae, Moo 2, Tambon Huai Sai, Amphoe San Kamphaeng, Changwat Chiang Mai
39	TG0275	Mae Kuang Alluvial Fan	502080	2089690	Continued Study Center, Mae Jo University, Moo 5, Tambon Nong Han, Amphoe San Sai, Changwat Chiang Mai
40	TG0313	Mae Kuang Alluvial Fan	513220	2075850	Ban Pa Sak Noi, Moo 1, Tambon Mae Pu Kha, Amphoe San Kamphaeng, Changwat Chiang Mai
41	TG0036	Nam Wang-Nam Mae Khan	485255	2053502	Wat-Phara Sad School, Moo 6, Tambon Thung Satok, Amphoe San Pa Tong, Changwat Chiang Mai

Table 4.8 Details of pumping test wells (continued).

No.	Well name	Drilling date		Depth drill	SWL	Screen	No.	Screen	Well
		Started	Completed	(m)	(m)	Diameter (mm)	screen	length (m)	Status
1	MW1000	12/23/99	12/30/99	76.50	9.00	150	1	12.00	Active
2	MW1019	09/12/00	09/19/00	46.50	2.00	150	1	8.00	Active
3	TG0224	-	-	215.00	1.65	150	1	13.00	Active
4	TG0245	06/16/99	06/20/99	54.00	5.00	150	1	4.00	Active
5	TG0246	-	-	66.00	5.46	150	1	8.00	Active
6	TG0248	-	-	60.00	5.05	150	1	8.00	Active
7	TG0261	11/07/99	11/14/99	48.00	6.00	150	1	3.00	Active
8	TG0262	-	-	52.50	5.28	150	1	3.00	Active
9	TG0263	11/23/99	11/30/99	60.00	5.00	150	1	6.00	Active
10	TG0264	12/01/99	12/08/99	60.00	5.00	150	1	6.00	Active
11	TG0265	12/09/99	12/15/99	54.00	7.00	150	1	6.00	Active
12	TG0274	02/18/00	02/23/00	60.00	9.00	150	1	6.00	Active
13	TG0286	09/13/00	09/19/00	58.50	3.50	150	1	4.00	Active
14	TG0287	09/20/00	09/30/00	96.00	2.00	150	1	8.00	Active
15	TG0295	11/05/00	11/08/00	66.00	2.00	150	2	8.00	Active
16	TG0318	03/26/01	03/30/01	70.50	6.00	150	1	4.00	Active
17	TG0339	06/23/01	06/26/01	70.50	7.00	150	1	8.00	Active
18	TG0127	12/21/96	12/30/96	159.00	21.00	100	1	9.00	Active
19	TG0294	11/01/00	11/04/00	64.50	5.00	150	3	12.00	Active
20	DC0577	11/13/00	11/15/00	124.50	27.00	150	4	24.00	Active
21	DC0578	11/16/00	11/18/00	105.00	27.00	150	2	24.00	Active
22	MW0806	12/14/95	12/18/95	71.00	16.00	150	1	6.00	Active
23	MW0989	10/16/99	10/20/99	58.50	11.50	150	1	12.00	Active
24	MW1007	02/16/00	02/21/00	43.50	5.00	150	3	34.50	Active
25	MW1018	09/05/00	09/11/00	82.50	12.00	150	2	7.50	Active
26	MW1024	10/13/00	10/17/00	100.50	12.00	150	2	12.00	Active
27	MW1038	01/15/01	01/19/01	70.50	24.00	150	2	46.50	Active
28	MW1046	03/07/01	03/12/01	52.50	3.00	150	3	19.50	Active
29	MW1070	11/10/01	11/14/01	70.50	9.00	150	1	6.00	Active
30	TG0132	02/11/97	02/18/97	114.00	15.00	150	2	16.00	Inactive
31	TG0285	09/05/00	09/12/00	72.00	3.50	150	2	8.00	Active
32	TG0314	03/01/01	03/06/01	121.50	2.00	150	2	67.50	Active
33	TG0324	04/25/01	04/30/01	73.50	3.00	150	2	37.50	Active
34	TG0345	09/10/01	09/14/01	76.50	16.00	150	2	8.00	Active
35	TG0033	-	-	63.00		200	3	22.50	Active
36	TG0229	-	-	87.00	6.25	150	2	12.00	Active
37	TG0230	04/01/99	04/04/99	42.00	6.20	150	1	6.00	Active
38	TG0231	-	-	42.00	3.00	150	1	6.00	Active
39	TG0275	02/24/00	02/29/00	60.00	6.00	150	1	6.00	Active
40	TG0313	02/22/01	02/28/01	120.00	6.00	150	3	20.00	Active
41	TG0036	-	-	77.00	3.40	125	3	18.00	Active

Table 4.9 Calculated hydrogeologic properties by computerized Walton graphical method (Starpoint Software, 2000).

No.	Well name	Date pumping test	Pumping rate		Drawdown	T	K	$S_{y(PTA)}$	Yield (m³/d)	
			(m³/h)	(m³/d)	(m)	(m²/d)	(m/d)	(dimensionless)	Maximum	Obtimum
1	MW1000	04/09/00	11.42	274.08	3.58	1.6050	0.1338	0.1316	10.01	6.71
2	MW1019	11/17/00	9.00	216.00	23.96	7.9590	0.9949	0.2547	294.00	197.00
3	TG0224	10/26/00	11.43	274.32	8.36	2.3610	0.1816	0.0936	31.25	20.94
4	TG0245	05/23/00	4.50	108.00	11.09	2.4860	0.6215	0.2996	54.47	36.49
5	TG0246	10/14/99	11.93	286.32	2.32	16.8900	2.1110	0.1936	53.65	35.95
6	TG0248	10/16/99	12.33	295.92	1.31	1.2850	0.1606	0.2818	3.37	2.26
7	TG0261	01/24/00	12.31	295.44	1.32	1.2830	0.1603	0.2695	3.39	2.27
8	TG0262	01/26/00	12.31	295.44	1.90	0.8728	0.2909	0.2695	3.54	2.37
9	TG0263	05/21/00	10.04	240.96	13.81	4.2910	0.7152	0.2965	100.90	67.59
10	TG0264	01/28/00	12.15	291.60	2.21	2.5100	0.4183	0.2340	9.84	6.60
11	TG0265	01/30/00	12.15	291.60	2.58	2.1150	0.3525	0.2898	10.24	6.86
12	TG0274	03/26/00	11.59	278.16	1.50	1.0620	0.1771	0.2885	3.33	2.23
13	TG0286	02/22/01	9.16	219.84	17.37	6.8270	1.7070	0.2706	187.80	125.80
14	TG0287	03/27/01	4.23	101.52	19.03	2.6570	0.3321	0.2698	90.19	60.43
15	TG0295	01/24/01	11.59	278.16	20.36	0.2589	0.0324	0.0766	11.17	7.49
16	TG0318	01/23/02	15.97	383.28	5.62	39.4200	9.8560	0.2705	287.30	192.50
17	TG0339	07/18/02	15.11	362.64	12.64	3.8650	0.4832	0.1980	83.04	55.64
18	TG0127	03/10/97	10.65	255.60	9.64	1.8540	0.2060	0.2047	28.90	19.36
19	TG0294	02/25/01	15.11	362.64	7.28	11.7500	0.9794	0.1532	118.80	79.59
20	DC0577	03/22/01	4.80	115.20	10.30	7.0920	0.2955	0.2693	115.00	77.07
21	DC0578	02/18/01	4.24	101.76	19.72	0.1077	0.0045	0.2591	6.86	4.60
22	MW0806	06/30/97	7.12	170.88	12.39	0.0802	0.0134	0.2103	3.28	2.20
23	MW0989	11/13/99	12.73	305.52	1.45	0.4004	0.0334	0.1668	1.31	0.88
24	MW1007	06/27/01	10.04	240.96	18.88	6.3070	0.1828	0.2842	191.60	128.40
25	MW1018	12/19/01	3.13	75.12	24.50	0.7351	0.0981	0.2934	42.36	28.38
26	MW1024	12/15/00	11.43	274.32	13.13	2.9240	0.2437	0.0977	59.51	39.87
27	MW1038	11/22/01	8.19	196.56	8.33	0.0602	0.0013	0.1646	1.70	1.14
28	MW1046	11/24/01	5.14	123.36	32.01	2.3940	0.1228	0.3280	146.10	97.88
29	MW1070	01/30/02	4.00	96.00	13.29	3.2470	0.5412	0.2779	78.82	52.81
30	TG0132	06/04/97	10.38	249.12	5.65	5.9850	0.3741	0.2273	52.93	35.46
31	TG0285	01/22/01	3.60	86.40	32.10	1.1900	0.1488	0.2968	78.71	52.74
32	TG0314	02/24/02	5.14	123.36	21.00	2.7210	0.0403	0.2647	103.60	69.38
33	TG0324	02/23/02	8.19	196.56	6.47	7.2440	0.1932	0.1578	69.87	46.81
34	TG0345	01/25/02	5.14	123.36	15.20	1.9330	0.2416	0.0703	47.73	31.98
35	TG0033	01/16/00	34.93	838.32	3.84	29.6000	1.3150	0.2265	158.60	106.30
36	TG0229	12/13/00	12.97	311.28	13.49	5.5430	0.4620	0.0975	107.40	71.95
37	TG0230	11/28/00	8.97	215.28	4.94	11.1700	1.8620	0.2650	82.06	54.98
38	TG0231	11/26/00	5.00	120.00	7.24	9.5490	1.5920	0.1829	100.30	67.18
39	TG0275	04/29/00	4.58	109.92	10.67	5.0160	0.8360	0.2921	89.05	59.67
40	TG0313	01/22/02	8.19	196.56	6.31	16.3300	0.8163	0.2750	152.20	102.20
41	TG0036	11/28/94	44.93	1078.32	3.86	143.4000	7.9650	0.2788	780.80	523.10

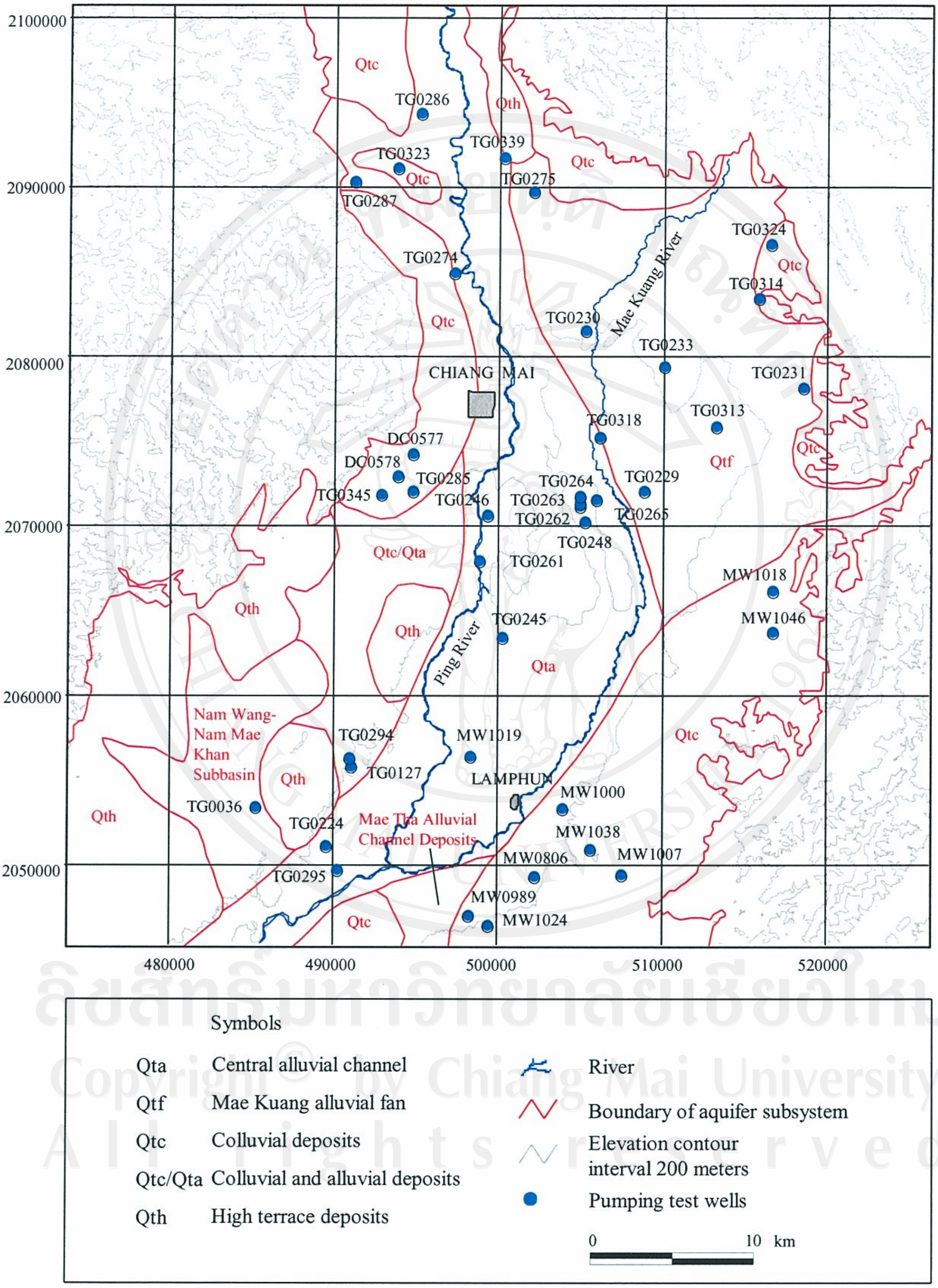


Figure 4.17 Location of the pumping test wells.

Table 4.10 Calculated aquifer specific yield by means of pumping test approach ($S_{y(PTA)}$).

Aquifer unit	Storativity ($S_{y(PTA)}$)
Central Alluvial Channel	0.0766-0.2996
Colluvial and Alluvial Deposits	0.1532-0.2047
Colluvial Deposits	0.0703-0.3280
Mae Kuang Alluvial Fan	0.0975-0.2921
Nam Wang-Nam Mae Khan Subbasin	0.2788*

*Only one specific yield value is available.