CHAPTER 5
ASSESSMENT OF GROUNDWATER RECHARGE

5.1 Groundwater recharge pattern

Groundwater recharge pattern describes the duration and time needed for recharge water to reach the aquifer. The pattern serves as additional information to the groundwater management.

5.1.1 Duration of groundwater recharge

Duration for recharge water to infiltrate and reach groundwater table can be studied from the available meteorological data, namely: actual rainfall (P_a) and evapotranspiration (PET) which have been described in Section 4.1. During recharge period, when actual rainfall is higher than evapotranspiration, effective rainfall will be available. The effective rainfall is defined as the actual rainfall less evapotranspiration. The effective rainfall will infiltrate into the ground. The water will be stored in the unsaturated zone as soil moisture. When soil moisture deficits is fully satisfied, excess rain water will then percolate to the groundwater zone, causing the water table to rise. Having established monthly actual rainfall and monthly evapotranspiration, the groundwater recharge pattern of the study area can then be made. The calculation procedure of effective rainfall is illustrated in Table 5.1. Average monthly actual rainfall, evapotranspiration and effective rainfall are plotted in Figure 5.1. From Table 5.1 and Figure 5.1, it is apparent that aquifer of the study area are dominantly recharge through the period of July-September months. The average annual effective rainfall in the study area, as a whole, is 218.56 mm/y or 18.85 % of actual rainfall. However, monthly actual rainfall and monthly evapotranspiration are varying from year to year. Table 5.2 shows the pattern of effective rainfall during 1967-2001. It is evident that effective rainfall confined itself mainly in July-Aug-September. Maximum effective rainfall is generally recognized to be in August.

5.1.2 Time of groundwater recharge

Rises in groundwater level is due to the effective rainfall but with a time-lag. Time-lag is the time taken for effective rainfall to infiltrate downward until it reaches the water table. It depends on various causes, such as the duration and intensity of the effective rainfall, thickness of the unsaturated zone, vertical unsaturated hydraulic conductivity and others. Time-lag can be estimated from well hydrograph analysis where monthly effective rainfall and monthly groundwater level are plotted and correlated. Time-lag is roughly the difference between the time of highest effective rainfall and the time of peak rises in groundwater level. Example of time-lag analysis is shown in Figure 5.2., where groundwater level records of well G0135 at year 2000-2001 are considered. In year 2000, time-lag of one month is

Table 5.1 Calculation of effective rainfall in the study area (period 1967-2001).

Month	P_a (mm)	PET (mm)	Soil Moisture Deficits (mm)	Effective Rainfall (mm)
Jan	7.02	92.16	85.14	-
Feb	7.94	116.39	108.45	-
Mar	19.89	150.85	130.96	-
Apr	54.41	177.13	122.72	-
May	161.35	165.38	4.03	-
Jun	126.79	144.05	17.26	-
Jul	159.24	130.89	-	28.35
Aug	236.22	123.63	-	112.59
Sep	207.85	130.24	-	77.61
Oct	113.39	129.47	16.08	-
Nov	48.48	107.76	59.28	-
Dec	17.12	88.84	71.72	-
Total	1,159.70	1,556.79	615.66	218.55

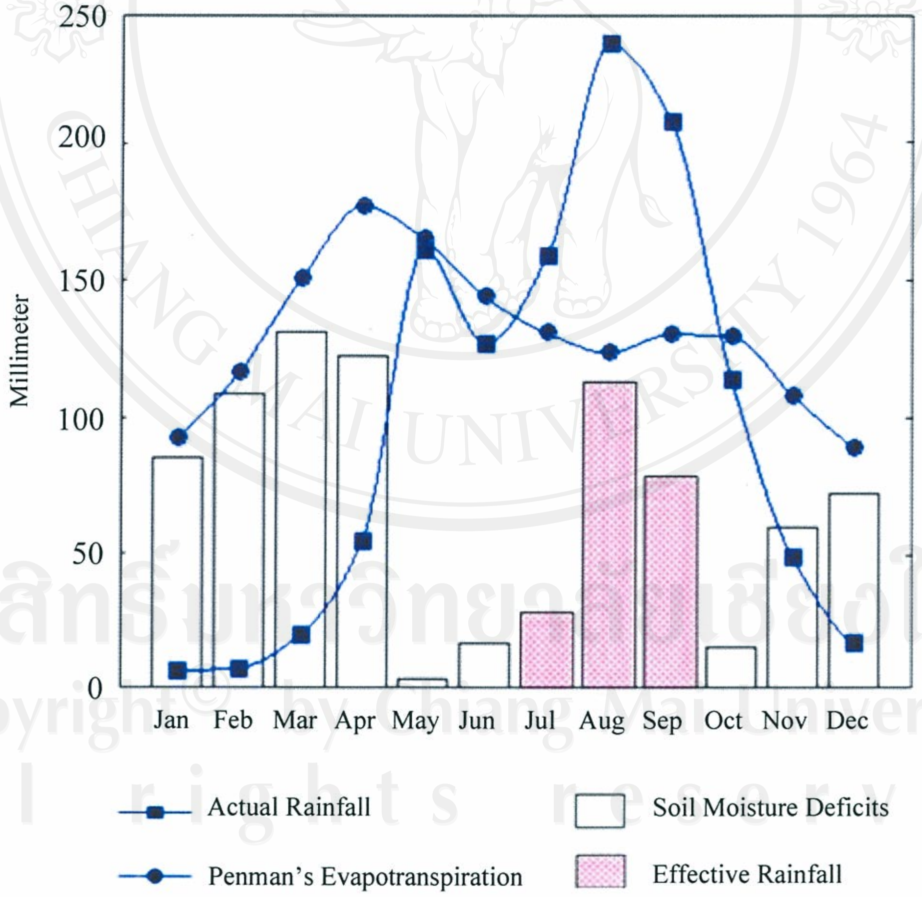


Figure 5.1 Average monthly actual rainfall, evapotranspiration, soil moisture deficits, and effective rainfall for Chiang Mai basin (1967-2001).

Table 5.2 Pattern of effective rainfall (mm) during 1967-2001.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1967	-	-	-	-	-	36.06	71.52	23.30	424.21	-	-	-	555.09
1968	-	-	-	-	-	119.12	21.63	185.00	53.78	-	-	-	379.53
1969	-	-	-	-	69.10	-	22.46	290.40	33.58	-	-	-	415.54
1970	-	-	-	-	201.89	115.34	65.48	234.25	73.26	-	-	-	690.22
1971	-	-	-	-	88.81	47.19	188.27	215.38	63.27	9.37	-	-	612.29
1972	-	-	-	-	-	-	-	150.50	60.97	-	60.17	-	271.64
1973	-	-	-	-	16.63	-	113.62	218.02	180.34	-	-	-	528.61
1974	-	-	-	-	-	-	31.52	81.88	158.27	46.22	-	-	317.89
1975	-	-	-	-	15.02	50.68	60.35	264.43	118.73	41.51	-	-	550.72
1976	-	-	-	-	28.38	-	-	95.23	65.56	98.49	-	-	287.66
1977	-	-	-	-	-	-	7.25	108.56	191.01	51.67	-	-	358.49
1978	-	-	-	-	40.10	-	332.25	157.59	90.51	-	-	-	620.45
1979	-	-	-	-	21.71	37.83	-	28.43	68.37	-	-	-	156.34
1980	-	-	-	-	60.63	9.08	58.73	17.30	49.13	21.48	-	-	216.35
1981	-	-	-	-	0.61	-	133.30	72.47	70.55	-	11.35	-	288.28
1982	-	-	-	-	-	-	-	-	216.78	-	-	-	216.78
1983	-	-	-	-	-	-	-	54.44	61.29	74.59	30.73	-	221.05
1984	-	-	-	-	-	-	-	28.41	6.20	1.27	-	-	35.88
1985	-	-	-	-	-	59.18	0.75	88.89	60.14	-	65.37	-	274.33
1986	-	-	-	-	-	-	-	-	25.76	12.56	-	-	38.32
1987	-	-	-	-	-	-	-	312.54	84.44	-	-	-	396.98
1988	-	-	-	-	64.74	197.79	-	54.47	25.02	75.90	-	-	417.92
1989	-	-	-	-	69.63	-	61.29	108.49	65.94	40.66	-	-	346.01
1990	-	-	-	-	136.12	-	-	49.65	37.50	-	47.35	-	270.62
1991	-	-	-	-	-	-	10.86	225.63	1.26	-	-	-	237.75
1992	-	-	-	-	-	-	171.11	31.99	115.95	-	-	7.96	327.01
1993	-	-	-	-	-	-	-	-	63.56	-	-	-	63.56
1994	-	-	-	-	49.96	2.68	22.04	228.99	133.64	-	-	-	437.31
1995	-	-	-	-	-	-	108.34	219.95	11.74	-	-	-	340.03
1996	-	-	-	36.86	-	-	-	95.06	89.43	92.28	-	-	313.63
1997	-	-	-	-	-	-	78.23	85.40	4.51	12.42	-	-	180.56
1998	-	-	-	-	-	-	-	66.72	-	-	-	-	66.72
1999	-	-	-	-	180.57	-	-	34.14	39.76	-	-	-	254.47
2000	-	-	-	-	34.66	43.51	-	17.10	1.80	63.72	-	-	160.79
2001	-	-	-	-	16.04	-	39.95	188.70	-	44.26	-	-	288.95
Average	-	-	-	-	-	-	28.35	112.59	77.61	-	-	-	218.55

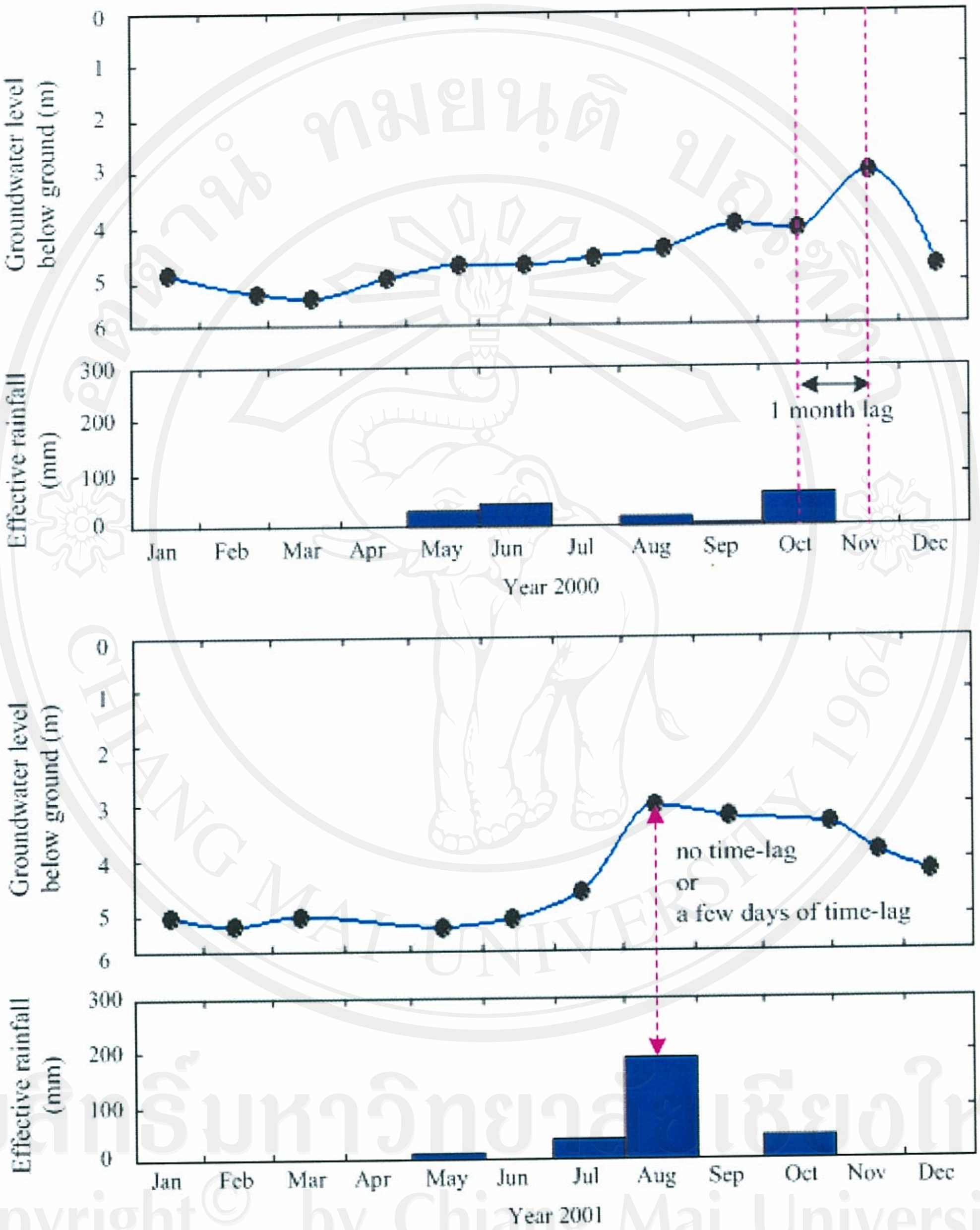


Figure 5.2 Time-lag analysis. Data from well G0135, Central Alluvial Channel, year 2000-2001.

observed. However, in 2001, no time-lag is evident. This demonstrates that time-lag can be different and the amount of effective rainfall can be the explanation of this phenomenon. The 2001 effective rainfall is much higher than in 2000. Time-lag analysis were made on all 19 monitoring wells for the period of 1967-2001, and presented in Table 5.3. Table 5.4 shows average time-lag of groundwater recharge in various part of Chiang Mai basin. These time-lag can serve as a general guide line for groundwater management.

5.2 Groundwater recharge calculation

Using groundwater table fluctuation method, as previously mentioned, groundwater recharge can be calculated by multiply specific yield with total rises in groundwater table over a specific period. Specific yield of the aquifers are obtained by the water budget approach and the pumping test approach as previously described. Total rises of groundwater table can be measured by the recession curve method and the horizontal method. However, error of the total rises, due to the groundwater table rises without effective rainfall, can be observed throughout. The total rises of groundwater table that respond to effective rainfall are then analyzed. It is apparent that groundwater recharge calculation, using groundwater table fluctuation method, can be obtained under many different conditions. These conditions, however, can be grouped into two groups based on analysis of error of the total rises. These are (1) groundwater recharge calculated using all measured groundwater table rises (real groundwater recharge) and (2) groundwater recharge calculated using only measured groundwater table rises that respond to effective rainfall (hypothesis groundwater recharge). Each group can be subdivided into four conditions, as follows:

Group 1: Real groundwater recharge. Calculation of recharge can be made from the following equations.

Using parameters $S_{y(WBA)}$ and $\Delta h_{act,rec}$:

$$R_1 = S_{y(WBA)} \frac{\Delta h_{act,rec}}{\Delta t} \tag{5.1}$$

Using parameters $S_{y(WBA)}$ and $\Delta h_{act,hor}$:

$$R_2 = S_{y(WBA)} \frac{\Delta h_{act,hor}}{\Delta t} \tag{5.2}$$

Using parameters $S_{y(PTA)}$ and $\Delta h_{act,rec}$:

$$R_3 = S_{y(PTA)} \frac{\Delta h_{act,rec}}{\Delta t} \tag{5.3}$$

Using parameters $S_{y(PTA)}$ and $\Delta h_{act,hor}$:

Table 5.3 Time-lag analysis.

Year	M_{eff}	AUG1		AUG3		AUG5		G0135		G0263		G0486		G0147		AUG4		G0244	
		M_{peak}	T_{lag}	M_{peak}	T_{lag}	M_{peak}	T_{lag}	M_{peak}	T_{lag}	M_{peak}	T_{lag}	M_{peak}	T_{lag}	M_{peak}	T_{lag}	M_{peak}	T_{lag}	M_{peak}	T_{lag}
1967	9	-	-	-	-	-	-	9	0	-	-	-	-	-	-	-	-	-	-
1968	8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1969	8	10	2	9	1	9	1	8	0	-	-	-	-	9	1	9	1	-	-
1970	8	-	-	8	0	8	0	8	0	-	-	-	-	8	0	8	0	-	-
1971	8	9	1	8	0	8	0	9	1	-	-	-	-	8	0	8	0	-	-
1972	8	11	3	9	1	10	2	10	2	-	-	-	-	10	2	10	2	-	-
1973	8	-	-	9	1	9	1	9	1	-	-	-	-	9	1	9	1	-	-
1974	9	10	1	10	1	10	1	11	2	-	-	-	-	10	1	10	1	-	-
1975	8	9	1	9	1	9	1	9	1	-	-	-	-	9	1	9	1	-	-
1976	10	11	1	11	1	10	0	-	-	-	-	-	-	10	0	10	0	-	-
1977	9	10	1	9	0	10	1	1	0	-	-	-	-	9	0	9	0	-	-
1978	7	-	-	9	2	10	3	-	-	-	-	-	-	7	0	10	3	-	-
1979	9	10	1	10	1	10	1	-	-	-	-	-	-	-	-	-	-	-	-
1980	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	8	3	-	-
1981	7	9	2	8	1	9	2	8	1	-	-	-	-	9	2	8	1	-	-
1982	9	-	-	-	-	11	2	11	2	-	-	-	-	-	-	11	2	-	-
1983	10	11	1	11	1	11	1	10	0	-	-	-	-	10	0	11	1	-	-
1984	8	10	2	8	0	10	2	9	1	-	-	-	-	9	1	11	3	-	-
1985	8	-	-	11	3	12	4	9	1	-	-	-	-	11	3	12	4	-	-
1986	9	11	2	9	0	10	1	9	0	-	-	-	-	10	1	10	1	-	-
1987	8	9	1	9	1	11	3	8	0	-	-	-	-	9	1	10	2	-	-
1988	6	10	4	8	2	10	4	8	2	-	-	-	-	8	2	10	4	-	-
1989	8	9	1	8	0	10	2	10	2	-	-	-	-	10	2	10	2	-	-
1990	5	11	6	11	6	10	5	11	6	-	-	-	-	9	4	10	5	-	-
1991	8	10	2	9	1	10	2	9	1	-	-	11	3	-	-	10	2	-	-
1992	7	-	-	9	2	10	3	9	2	-	-	-	-	10	3	10	3	-	-
1993	9	-	-	-	-	-	-	11	2	-	-	10	1	10	1	10	1	10	1
1994	8	-	-	9	1	9	1	8	0	-	-	11	3	9	1	8	0	9	1
1995	8	-	-	9	1	9	1	9	1	-	-	10	2	9	1	8	0	9	1
1996	8	-	-	8	0	10	2	9	1	-	-	9	1	10	2	9	1	9	1
1997	8	-	-	10	2	10	2	10	2	-	-	11	3	10	2	10	2	10	2
1998	8	-	-	-	-	-	-	9	1	-	-	9	1	-	-	-	-	9	1
1999	5	-	-	-	-	-	-	9	4	-	-	9	4	9	4	-	-	9	4
2000	10	-	-	-	-	-	-	11	1	11	1	-	-	-	-	-	-	12	2
2001	8	-	-	-	-	-	-	8	0	12	4	8	0	-	-	-	-	11	3

Where M_{eff} is the month of maximum effective rainfall, M_{peak} is the month of water level peak, T_{lag} is time-lag (month).

Table 5.3 Time-lag analysis (continued).

Year	M_{eff}	G0292		MW0187		MW0224		MW0244		Q49		Q50		Q60		AUG2		G781		G1020	
		M_{peak}	T_{lag}	M_{peak}	T_{lag}	M_{peak}	T_{lag}	M_{peak}	T_{lag}	M_{peak}	T_{lag}	M_{peak}	T_{lag}	M_{peak}	T_{lag}	M_{peak}	T_{lag}	M_{peak}	T_{lag}	M_{peak}	T_{lag}
1967	9	-	-	-	-	-	-	-	-	-	-	12	3	-	-	-	-	-	-	-	-
1968	8	-	-	-	-	-	-	-	-	-	-	6	2	-	-	-	-	-	-	-	-
1969	8	-	-	-	-	-	-	-	-	-	-	12	4	-	-	-	-	-	-	-	-
1970	8	-	-	-	-	-	-	-	-	8	0	8	0	-	-	9	1	-	-	-	-
1971	8	-	-	-	-	-	-	-	-	8	0	8	0	-	-	8	0	-	-	-	-
1972	8	-	-	-	-	-	-	-	-	11	3	12	4	-	-	10	2	-	-	-	-
1973	8	-	-	-	-	-	-	-	-	9	1	-	-	-	-	9	1	-	-	-	-
1974	9	-	-	-	-	-	-	-	-	9	0	-	-	-	-	10	1	-	-	-	-
1975	8	-	-	-	-	-	-	-	-	9	1	-	-	-	-	9	1	-	-	-	-
1976	10	-	-	-	-	-	-	-	-	11	1	-	-	-	-	10	0	-	-	-	-
1977	9	-	-	-	-	-	-	-	-	10	1	-	-	-	-	9	0	-	-	-	-
1978	7	-	-	-	-	-	-	-	-	9	2	-	-	-	-	10	3	-	-	-	-
1979	9	-	-	-	-	-	-	-	-	10	1	-	-	-	-	10	1	-	-	-	-
1980	5	-	-	-	-	-	-	-	-	9	4	-	-	-	-	-	-	-	-	-	-
1981	7	-	-	-	-	-	-	-	-	9	2	-	-	-	-	8	1	-	-	-	-
1982	9	-	-	-	-	-	-	-	-	11	2	-	-	-	-	9	0	-	-	-	-
1983	10	-	-	-	-	-	-	-	-	11	1	-	-	-	-	10	0	-	-	-	-
1984	8	-	-	-	-	-	-	-	-	10	2	-	-	-	-	10	2	-	-	-	-
1985	8	-	-	-	-	-	-	-	-	12	4	-	-	-	-	10	2	-	-	-	-
1986	9	-	-	-	-	-	-	-	-	9	0	-	-	-	-	10	1	-	-	-	-
1987	8	-	-	-	-	-	-	-	-	10	2	-	-	11	3	8	0	-	-	-	-
1988	6	-	-	-	-	-	-	-	-	8	2	-	-	11	5	10	4	-	-	-	-
1989	8	-	-	-	-	-	-	-	-	9	1	-	-	10	2	10	2	-	-	-	-
1990	5	-	-	-	-	-	-	-	-	9	4	-	-	11	6	9	4	-	-	-	-
1991	8	-	-	-	-	-	-	-	-	9	1	-	-	11	3	10	2	9	1	11	3
1992	7	-	-	10	3	-	-	-	-	10	3	-	-	10	3	9	2	10	3	9	2
1993	9	-	-	-	-	-	-	-	-	10	1	-	-	10	1	10	1	10	1	9	0
1994	8	-	-	9	1	-	-	-	-	9	1	-	-	8	0	8	0	8	0	12	4
1995	8	11	3	9	1	-	-	-	-	9	1	-	-	9	1	9	1	9	1	9	1
1996	8	11	3	10	2	10	2	9	1	10	2	-	-	9	1	9	1	9	1	11	3
1997	8	12	4	10	2	-	-	10	2	10	2	-	-	10	2	10	2	10	2	10	2
1998	8	-	-	9	1	-	-	9	1	9	1	-	-	9	1	-	-	9	1	11	3
1999	5	12	7	-	-	-	-	9	4	11	6	-	-	11	6	-	-	9	4	8	3
2000	10	10	0	11	1	-	-	10	0	10	0	-	-	12	2	-	-	8	2	10	0
2001	8	11	3	10	2	-	-	10	2	8	0	-	-	9	1	-	-	9	1	10	2

Where M_{eff} is the month of maximum effective rainfall, M_{peak} is the month of water level peak, T_{lag} is time-lag (month).

Table 5.4 Time-lag of groundwater recharge of Chiang Mai basin.

Aquifer unit	Time-lag (month)
Central Alluvial Channel	1-3
Colluvial and Alluvial Deposits	1
Colluvial Deposits	2-3
Mae Kuang Alluvial Fan	1-2
Nam Wang-Nam Mae Khan Subbasin	2

$$R_4 = S_{y(PTA)} \frac{\Delta h_{act,hor}}{\Delta t} \tag{5.4}$$

Group 2: Hypothesis groundwater recharge. Calculation of recharge can be made from the following equations.

Using parameters $S_{y(WBA)}$ and $\Delta h_{hyp,rec}$:

$$R_5 = S_{y(WBA)} \frac{\Delta h_{hyp,rec}}{\Delta t} \tag{5.5}$$

Using parameters $S_{y(WBA)}$ and $\Delta h_{hyp,hor}$:

$$R_6 = S_{y(WBA)} \frac{\Delta h_{hyp,hor}}{\Delta t} \tag{5.6}$$

Using parameters $S_{y(PTA)}$ and $\Delta h_{hyp,rec}$:

$$R_7 = S_{y(PTA)} \frac{\Delta h_{hyp,rec}}{\Delta t} \tag{5.7}$$

Using parameters $S_{y(PTA)}$ and $\Delta h_{hyp,hor}$:

$$R_8 = S_{y(PTA)} \frac{\Delta h_{hyp,hor}}{\Delta t} \tag{5.8}$$

where

R_1 is real groundwater recharge calculated using parameters $S_{y(WBA)}$ and $\Delta h_{act,rec}$ (mm),

R_2	is real groundwater recharge calculated using parameters $S_{y(WBA)}$ and $\Delta h_{act,hor}$ (mm),
R_3	is real groundwater recharge calculated using parameters $S_{y(PTA)}$ and $\Delta h_{act,rec}$ (mm),
R_4	is real groundwater recharge calculated using parameters $S_{y(PTA)}$ and $\Delta h_{act,hor}$ (mm),
R_5	is hypothesis groundwater recharge calculated using parameters $S_{y(WBA)}$ and $\Delta h_{hyp,rec}$ (mm),
R_6	is hypothesis groundwater recharge calculated using parameters $S_{y(WBA)}$ and $\Delta h_{hyp,hor}$ (mm),
R_7	is hypothesis groundwater recharge calculated using parameters $S_{y(PTA)}$ and $\Delta h_{hyp,rec}$ (mm),
R_8	is hypothesis groundwater recharge calculated using parameters $S_{y(PTA)}$ and $\Delta h_{hyp,hor}$ (mm),
$S_{y(WBA)}$	is the specific yield determined by the water budget approach (dimensionless),
$S_{y(PTA)}$	is the specific yield determined by the pumping test approach (dimensionless),
$\Delta h_{act,rec}$	is the actual rises or summation of all groundwater table rises measured by the recession curve method (m),
$\Delta h_{act,hor}$	is the actual rises or summation of all groundwater table rises measured by the horizontal line method (m),
$\Delta h_{hyp,rec}$	is the hypothesis rises or total rises in groundwater table that respond to effective rainfall and measured by the recession curve method (m),
$\Delta h_{hyp,hor}$	is the hypothesis rises or total rises in groundwater table that respond to effective rainfall and measured by the horizontal line method (m), and
Δt	is time (y).

Table 5.5 shows real groundwater recharge as calculated by Equation 5.1-5.4. Table 5.6 shows hypothesis groundwater recharge as calculated by Equation 5.5-5.8. Calculated groundwater recharge (R_1-R_8) for each year of Chiang Mai basin aquifers are shown in Appendix G. From Table 5.5 and Table 5.6, it is apparent that $R_3 > R_4 > R_1 > R_2$ and $R_7 > R_8 > R_5 > R_6$.

5.3 Discussions

As mentioned earlier, specific yield of each deposits as calculated from the water budget approach and the pumping test approach varies to a certain degree (Table 4.3 and Table 4.10). However, calculated specific yield using the water budget approach is believed to be more reliable than the pumping test approach. Considering the hydrogeologic properties of the Central Alluvial Channel which is

Table 5.5 Groundwater recharge of Chiang Mai basin aquifers calculated from the actual rises in groundwater table (Δh_{act}).

Aquifer type	Well name	R_1		R_2		R_3		R_4	
		min	max	min	max	min	max	min	max
Central Alluvial Channel	*AUG1*	267.04	328.33	211.42	259.95	249.75	976.84	197.74	773.40
	AUG3	80.48	98.95	72.56	89.21	75.27	294.38	67.86	265.42
	AUG5	131.27	161.40	122.78	150.97	122.77	480.20	114.84	449.16
	G0135	165.93	204.02	160.68	197.57	155.28	607.32	150.28	587.80
	G0486	115.84	142.43	105.29	129.46	108.35	423.77	98.47	385.15
	Range of R	80.48	328.33	72.56	259.95	75.27	976.84	67.86	773.40
Colluvial and Alluvial Deposits	*G0147*	17.85	26.95	16.14	24.37	268.10	358.23	242.40	323.88
Colluvial Deposits	*AUG4*	200.83	301.72	182.44	274.09	220.26	1,027.65	200.09	933.54
	G0244	576.62	383.82	343.58	516.17	420.94	1,963.99	376.81	1,758.08
	MW0187	603.27	906.32	559.96	841.25	661.62	3,086.95	614.12	2,865.31
	MW0244	207.47	311.69	161.72	242.95	227.54	1,061.63	206.92	965.41
	Q49	122.97	184.74	114.74	172.38	137.11	639.71	125.84	587.12
	Q60	99.72	149.82	91.62	137.64	109.37	510.27	100.48	468.81
	Range of R	99.72	906.32	91.62	841.25	109.37	3,086.95	100.48	2,865.31
Mae Kuang Alluvial Fan	*AUG2*	86.96	127.40	73.24	107.31	140.84	421.92	118.63	355.39
	G0781	67.06	98.25	54.72	80.18	108.62	325.40	88.63	265.52
	Range of R	67.06	127.40	54.72	107.31	108.62	421.92	88.63	355.39
Nam Wang-Nam Mae Khan Subbasin	*G1020*	0.66	25.01	0.52	19.77	1,834.78*		1,450.60*	

* Only one specific yield value is available.

Table 5.6 Groundwater recharge of Chiang Mai basin aquifers calculated from the hypothesis rises in groundwater table (Δh_{hyp}).

Aquifer type	Well name	R_5		R_6		R_7		R_8	
		min	max	min	max	min	max	min	max
Central Alluvial Channel	*AUG1*	244.08	300.10	195.90	240.87	228.28	892.85	181.47	709.77
	AUG3	72.41	89.03	65.20	80.17	67.72	264.87	60.98	238.51
	AUG5	120.72	148.43	114.11	140.30	112.91	441.61	106.72	417.41
	G0135	154.74	190.26	149.52	183.85	144.72	566.05	139.45	546.97
	G0486	101.92	125.32	93.59	115.07	95.33	372.84	87.53	342.35
	Range of R	72.41	300.10	65.20	240.87	67.72	892.85	60.98	709.77
Colluvial and Alluvial Deposits	*G0147*	16.93	25.56	15.38	23.22	260.61	348.22	231.05	308.72
Colluvial Deposits	*AUG4*	182.27	273.83	167.65	251.86	199.90	932.66	183.59	856.58
	G0244	518.73	345.28	306.61	460.64	378.68	1,766.82	346.11	1,614.87
	MW0187	533.13	800.95	494.52	742.94	584.70	2,728.05	542.35	2,530.46
	MW0244	195.83	294.20	180.44	271.09	214.77	1,002.04	197.90	923.33
	Q49	120.26	180.67	112.57	169.12	132.21	616.85	123.46	576.01
	Q60	98.39	147.82	90.43	135.85	107.91	503.48	99.17	462.71
	Range of R	98.39	800.95	90.43	742.94	107.91	2,728.05	99.17	2,530.46
Mae Kuang Alluvial Fan	*AUG2*	77.95	114.20	65.19	95.51	126.25	378.22	105.58	316.29
	G0781	63.99	93.76	51.20	75.02	103.64	310.50	82.93	248.45
	Range of R	63.99	114.20	51.20	95.51	103.64	378.22	82.93	316.29
Nam Wang-Nam Mae Khan Subbasin	*G1020*	0.63	23.96	0.37	13.93	1,758.11*		1,388.14*	

* Only one specific yield value is available.

generally the best aquifer, the specific yield as calculated by the water budget approach yielded the highest value that conform with the hydrogeologic properties. On the contrary, the specific yield as calculated by the pumping test approach gave the highest specific yield over the Colluvial Deposits instead. In Section 4.3.2, it is found that measurement of groundwater table rises using the horizontal line method gives lower error value (8.15 %) than the recession curve method (8.73 %). The lower error value indicates that the horizontal line method is more accurate than the recession curve method. Moreover, the hypothesis groundwater recharge is more reliable than real groundwater recharge. This is because all the errors involved with groundwater table rises have been analyzed. Therefore, it is concluded that groundwater recharge calculation using Equation 5.6 is the best method and that R_6 is the most reliable value.

Theoretically, the calculated groundwater recharge from Equation 5.6 or R_6 should not be higher than the effective rainfall. From Table 5.7, however, it is found that there are several calculated groundwater recharge of R_6 which is higher than the effective rainfall. These are the results of well G0244, MW0187, and MW0244 (only the maximum calculated recharge). These are unreliable and ignored. It is difficult to explain the situation where groundwater table rises without effective rainfall. The possible explanation for the case is leakage from other aquifer. Moreover, the rises in well G0244 and MW0187 maybe effected from nearby unknown pumped wells. The average hypothesis groundwater table rises that measured by the horizontal line method ($\Delta h_{hyp,hor}$) in well G0244 (4.79 m.) and MW0187 (7.72 m.) are too high values for Colluvial Deposits compared with the rises in the other wells including Well MW0244 over the same deposits that range from 0.32 to 2.82 m. (Table 4.5).

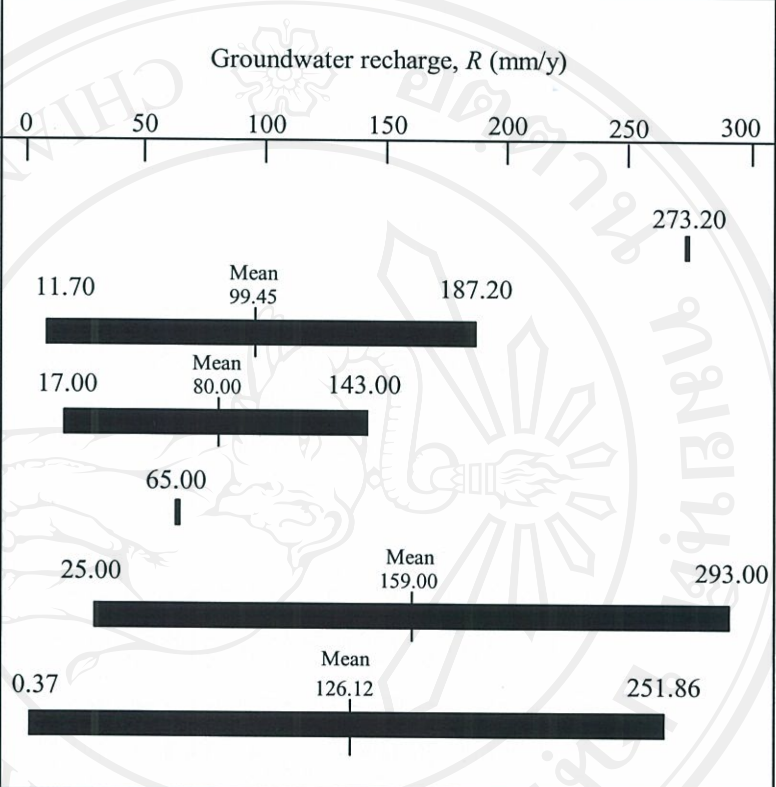
Ranges of mean calculated groundwater recharge calculation of Chiang Mai basin aquifers are 1-15 % of the annual rainfall (Table 5.7). These are 1 % in Nam Wang-Nam Mae Khan subbasin, 2 % in Colluvial and Alluvial deposits, 6 % in Mae Kuang Alluvial Fan, 13 % in Central Alluvial Channel, and 15 % in Colluvial deposits, respectively. The mean calculated groundwater recharge of Chiang Mai basin as a whole is approximately 11 % of the annual rainfall (349.48×10^6 m^3/y or 126.12 mm/y) and is comparable to that 6-21 % of the annual rainfall (Table 5.8) from other previous studies with different approaches (Suvagondha, 1979; Suvagondha and Jitapunkul, 1982; Intrasuta, 1983; Wongpornchai, 1990 and Tatong, 2000). It can be concluded that groundwater recharge of Chiang Mai basin is around 6-21 % of the annual rainfall. The mean value of groundwater recharge can then be taken as 14 % of the annual rainfall.

Table 5.7 Comparison of effective rainfall and calculated groundwater recharge (R_6) during the available period.

Aquifer type	Well name	Available period of recording the monthly water level	Effective rainfall (mm/y)	R_6 (mm/y)		Range of R_6		R_{mean} % of annual rainfall
				min	max	(mm/y)	% of annual rainfall	
Central Alluvial Channel	AUG1	1969-1977,1979,1981-1991	330.16	195.90	240.87	65.20-240.87	5.62-20.77	13
	AUG3	1969-1979,1981-1997	329.14	65.20	80.17			
	AUG5	1969-1979,1981-1992,1995-1997	335.19	114.11	140.30			
	G0135	1967,1969-1977,1981-2001	315.00	149.52	183.85			
	G0486	1991,1993-1998,2000-2001	232.14	93.59	115.07			
Colluvial and Alluvial Deposits	G0147	1969-1978,1981-1990, 1992-1997,2000-2001	332.79	15.38	23.22	15.38-23.22	1.33-2.00	2
Colluvial Deposits	AUG4	1969-1978,1981-1997	335.54	167.65	251.86	90.43-251.86	7.80-21.71	15
	G0244	1993-2001	234.00	306.61*	460.64*			
	MW0187	1992,1995-1998,2000-2001	239.67	494.52*	742.94*			
	MW0244	1996-2001	210.85	180.44	271.09*			
	Q0049	1970-1998,2000-2001	313.22	112.57	169.12			
	Q0060	1988-2001	264.67	90.43	135.85			
Mae Kuang Alluvial Fan	AUG2	1970-1979,1981-1997	264.67	65.19	95.51	51.20-95.51	4.42-8.24	6
	G0781	1991-1998,2000-2001	241.63	51.20	75.02			
Nam Wang-Nam Mae Khan Subbasin	G1020	1991-1997,1999-2001	260.41	0.37	13.93	0.37-13.93	0.003-1.20	1
Total study area				0.37	251.86	0.37-251.86	0.003-21.71	11

* The calculated groundwater recharge is unreliable and ignored because it is higher than the effective rainfall.

Table 5.8 Comparison of the calculated groundwater recharge of Chiang Mai basin from different studies.

Method of	Study period	Months of recharge	Average annual rainfall (mm/y)	Groundwater recharge, R (mm/y) 	R_{mean} (% of annual rainfall)
Suvagondha, 1979	1967-1976 (8 years)	Jul-Oct	1,300	273.20	21
Suvagondha and Jitapunkul, 1982	1967-1976 (8 years)	Jul-Oct	1,300	11.70 Mean 99.45 187.20	8
Intrasuta, 1983	1981-1982 (2 year)	No study	1,200	17.00 Mean 80.00 143.00	7
Wongpornchai, 1990	1958-1984 (27 years)	Aug-Sep	1,150	65.00	6
Tatong, 2000	1988-1997 (10 years)	Jul-Oct	1,020	25.00 Mean 159.00 293.00	16
Present study	1967-2001 (35 years)	Jul-Sep	1,160	0.37 Mean 126.12 251.86	11