CHAPTER 6
CONCLUSION AND RECOMMENDATIONS

The objectives of this study are (1) to obtain a better understanding of the various methods used for groundwater recharge estimation; and (2) to reassess groundwater recharge of Chiang Mai basin using Water Table Fluctuation method. Accurate estimation of groundwater recharge is important for proper and effective management of groundwater resources. Many different approaches are available to quantify groundwater recharge. These approaches can be divided into three groups based on data from different hydrologic zones. These are (1) surface water approaches (2) unsaturated zone approaches and (3) groundwater zone approaches, and their limitations and uncertainties are reviewed. General considerations in order to choose a technique for recharge estimation are (1) climate of the study area (2) space and time scale (3) range of recharge rate (4) reliability and (5) cost. Groundwater zone approaches generally provide recharge estimates that are most reliable because they estimate actual recharge. Whereas surface water and unsaturated zone approaches usually provide estimate of potential recharge. However, recharge estimates are normally subject to large errors and uncertainties arising from the validity of assumptions itself, and measurement or calculation of parameter values. In order to give reliable results, several approaches of recharge estimation should be applied.

Previous studies on groundwater recharge estimates of Chiang Mai basin (Suvagondha, 1979; Suvagondha and Jitapunkul, 1982; Intrasuta, 1983; Wongpornchai, 1990 and Tatong, 2000) are based mainly on data from surface and groundwater zones e.g. meteorological data, stream stage and groundwater level. The present study reassess groundwater recharge of Chiang Mai basin using Water-Table Fluctuation (WTF) method. The method provides a simple and quick estimate of groundwater recharge and is considered as a groundwater zone approach.

Hypothesis of the WTF method is that rises in groundwater table during the rainy season are only due to recharge water, or effective rainfall, arriving at the water table. Groundwater recharge is calculated by multiplying the specific yield with the total rise in groundwater table over a specific period. Specific yield is the property of aquifer to absorb or yield water and can be obtained from (1) the water budget approach and (2) the pumping test approach. Rises in groundwater table is measured directly from monitoring well hydrograph.

Data used in the present study are existing data from several Thai Department, including (1) meteorological data i.e. rainfall, temperature, relative humidity, cloudiness and wind speed data from Northern Meteorological Center, Thai Meteorological Department (2) average monthly streamflow of Mae Nam Ping at Nawarath Bridge from Hydrological and Water Management Center for Upper North

Region, Royal Irrigation Department and (3) monthly groundwater level from 19 monitoring wells and pumping test data from 41 wells from Department of Groundwater Resources. These available data are between 1967-2001 (35 years). The monitoring wells and pumping test wells are representative of Chiang Mai basin aquifers including Central Alluvial Channel, Colluvial and Alluvial Deposits, Colluvail Deoposits, Mae Kuang Alluvial Fan and Nam Wang-Nam Mae Khan Subbasin. Aquifer type of the study area is defined as semi-confined aquifer.

Specific yield that determined by the water budget approach is the volume of change in groundwater storage per unit surface area of the aquifer per change in groundwater table over the inventory period. The data requirements for calculation of the volume of change in groundwater storage are monthly rainfall, monthly potential evapotranspiration and monthly runoff in volume. Potential evapotranspiration is calculated by Penman's method. Groundwater table fluctuation is measured directly from hydrograph. These data are applicable when collected or measured during the inventory periods of June-September, July-September, July-October, and August-November. The aquifer recharge areas are calculated from the digital map. Range of calculated specific yield from the water budget approach is 0.0001-0.1007 in fraction. The maximum value, 0.1007, is found in Central Alluvial Channel.

Using pumping test approach to obtain specific yield, pumping test data from 41 pumping test wells are analyzed by Infinite Extent software based on Walton graphical method. It should be noted that there are no observation wells, and that all pumping test data are from measurement in the pumped well itself (single well test data). Radius of the pumped well is, therefore, used as distance from the pumped well to the observation well. Range of analyzed specific yield from this approach is 0.0703-0.3280 in fraction. The maximum value, 0.3280, is found in Colluvial Deposits.

The specific yield values obtained from pumping test data analysis can be of low accuracies due to the pumping disturbance effect in the well. Moreover, the analyzed aquifers is not properly followed the theoretical assumptions. Calculated specific yield of each deposits from the two different approaches, water budget approach and pumping test approach, vary to a certain degree. Hydrogeologic properties of the Central Alluvial Channel are generally the best. Specific yield of this aquifer should be higher than in Colluvial Deposits that is confirmed by the water budget approach. So, specific yield as determined by the water budget approach is more reliable than the pumping test approach.

In the analysis of potential evapotranspiration, it is noted that pattern of annual fluctuation in the present study is similar to other previous studies (Suvagondha, 1979; Anawatchapong, 1980; and Wongpornchai, 1990) except that of Ramingwong (1976). The differences of the calculated values are mainly due to different period of estimation, possible accuracy of calculation, different influencing factors and constant values. In the present study, the average annual evapotranspiration is 1,556.78 mm and the highest value occurs in May.

In the hydrograph analysis, the height of groundwater table rises is measured by (1) the recession curve method and (2) the horizontal line method. Groundwater table height is set equal to the difference between the peak of the rise and low point of the extrapolated antecedent recession curve and the extrapolated horizontal line at the time of the peak, respectively. These are traces that the well hydrograph would have followed in the absence of the rise-producing precipitation. Each measured water table rise is added up as the total annual rise. Error of the analysis occurs whenever there is no effective rainfall and yet the groundwater table rises up. Error of total groundwater table rises from the recession curve method and the horizontal line method are found to be 8.73 % and 8.15 %, respectively. So, the horizontal line method is more suitable for the analysis. The average total rises of the study area, due to the effective rainfall, as measured by the horizontal line method is approximately 2.14 m.

The effective rainfall controls groundwater recharge pattern (duration and time of movement of water that reaches the aquifers). The effective rainfall is defined as the actual rainfall less potential evapotranspiration. In some months, potential evapotranspiration is high and exceeds the actual rainfall, there is no effective rainfall and soil moisture is deficient. In the study area, the effective rainfall occurs during July-September months. The time taken for effective rainfall to infiltrate downward until it reaches the water table (time-lag) is approximately 1-3 months. The average annual effective rainfall is 218.56 mm/y or 60.56×10^{6} m^3/y. These established values can be taken as a general guide line for groundwater management.

Annual groundwater recharge of the study area is calculated by multiply the specific yield, from the water budget approach, with the total rises in groundwater table that measured by horizontal line method. The mean calculated groundwater recharge is found to be 349.48×10^{6} m^3/y or 126.12 mm/y. This is approximately 11 % of the annual rainfall (1,160 mm/y), and is comparable to that 6-21 % of the annual rainfall 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 be taken as 14 % of the annual rainfall. This result can be used efficiently for the future groundwater resources development of this basin.

It is clear that these different approaches cannot guarantee accuracy. It is difficult to decide what approach is more accurate because each approach has uncertainties. However, the simplicity of estimating groundwater recharge from groundwater table fluctuation data is attractive. Moreover, all the needed data used in the analysis and recharge calculation are normally routine and readily available data in every groundwater studies. The WTF method also provides the estimates of actual recharge while the other approaches provide estimates of potential recharge. The method, however does have its limitations (Healy and Cook, 2002):

(1) The method is best applied to shallow water tables that display sharp water-level rises and declines. However, the method has been applied to systems with thick unsaturated zones that display only seasonal water-level fluctuations.

(2) Typically, recharge rates vary substantially within a basin, owing to differences in elevation, geology, land-surface slope, vegetation, and other factors. Location of monitoring water levels are therefore must be representative of the catchment.

(3) The method cannot account for a steady rate of recharge. For example, if the rate of recharge were constant and equal to the rate of drainage away from the water table, water levels would not change and the WTF method would predict no recharge.

It is recommended that in order to obtain a more reliable and accurate recharge estimation of Chiang Mai basin, using Water Table Fluctuation method, the following should be considered:

(1) Because meteorological and hydrological data used in the present study are limited only from Chiang Mai station and Nawarath Bridge station, more widespread data over the study area are needed.

(2) The monitoring wells used in the present study are usually not design to monitor the hydraulic-head information for recharge study but rather they are designed as production wells. The monitoring wells should be designed to locate over the study area that would represent all hydrogeologic characteristics of the basin.

(3) Groundwater level of monitoring wells used in this study are recorded on a monthly basis, it is recommended that a weekly basis should be carried out. This will yield a more reliable groundwater level data.

(4) It is difficult to explain the situation where groundwater level rises without effective rainfall. The lateral groundwater movement from elsewhere could explain the situation.

(5) A correct and reliable specific yield value is necessary in the recharge estimation, therefore, the specific yield should be obtained from several methods based on laboratory or field approaches. However, the present study shows that the estimated specific yield from the water budget approach is more reliable than the pumping test approach.

(6) Because of the hydrograph recession curve drawn in the present study is drawn arbitrary, it is recommended that mathematical solution should be studied and applied here in order to obtain a more reliable result.