CHAPTER I

INTRODUCTION

1.1 Statement of the Problem

The world's supply of water is obtained almost entirely as precipitation resulting from evaporation of seawater. The transfer of moisture from the sea to the land and back to the sea again is known as the hydrologic cycle. Water is essential for human consumption; for industrial processes, and for the production of agricultural products. Thailand has long been one of the world's major agricultural countries in producing and exporting rice, rubber, and etc. With increasing demand in the nation's agribusiness, the water resources are becoming one of the country's most important assets. Based on the reports by the Department of Water Resources and the Department of Groundwater Resources, Ministry of Natural Resources and Environment, Thailand has suffered flood and drought periodically with the estimated damages of 23,700 million baht on average. It is urgent for the country to call for proper planning, design, operation, and management of the existing water resources using advanced technologies. One of the principal components in the development of water resources is the estimation of the streamflow. Exclusion of the water withheld as basin recharge, rainwater may follow three paths to a stream: overland flow (or surface runoff), interflow (or subsurface flow), and groundwater runoff. Overland flow and interflow are usually grouped together as "direct runoff". Practically, there is no need to differentiate between direct and groundwater runoff after they have been intermixed in the stream. Runoff prediction for an event of rainfall can be achieved by various techniques of hydrograph analysis. Designs of drainage systems or flood mitigation generally require the estimated runoff in accordance with available rainfall data.

For several decades, the simulation approach for runoff has been based on rational formulas from deterministic model or probabilistic formulas from stochastic analysis. Reliable forecasts of streamflow or runoff are essential to many water resources applications (such as drought management, flood control, operation of water supply utilities, and etc.). Conceptual rainfall-runoff model structures are generally given a priori in order to simplify the physical processes. Hence, this type of model is much less complex and easier to implement for general practice than a physically-based model. There are many existing and reliable conceptual rainfall-runoff models such as HEC-HMS and Tank model. However, under limited hydrologic and climatic data, these models can predict runoff with significant errors. Recently, a novel non-parametric approach, namely the artificial neural network has been introduced as an alternative tool in water resources. This technique has been used for solving various problems in different fields of science and engineering. The distinctive characteristic of artificial neural networks is that they are powerful for modeling system where the explicit form of the relationship between the variables involved is not known a priori. This thesis concerns the implementation of artificial neural network to forecast the streamflow discharge in the studied area subject to limited hydrologic data. Data for model calibration and validation are obtained from the only one hydrologic station at the Mae Tuen River in Om Koi District, Chiang Mai Province, which is located in the northern part of Thailand. The watershed area is approximately 503 square kilometers.

1.2 Research Objective

The objective of this thesis is to apply ANNs for modeling the rainfall-runoff relationship. Specifically, it is aimed to forecast the three hourly discharge in a small watershed with limited hydrologic data. This is, indeed, a major problem in many underdeveloped rural areas of Thailand. Here, the designated catchment area of Mae Tuen river in Om Koi District, Chiang Mai Province in the north of Thailand is used as the studied area. This watershed covers the area of approximately 503 square kilometers. It has distinct hydrologic features with insufficient information on topography and runoff data. Hydrologic data including hourly rainfall and three hourly runoff discharges were collected by the Royal Irrigation Department of Thailand. The three hourly discharges were recorded only during daytime, whereas the hourly rainfall was partially incomplete due to the failure of automatic rain gauge or probably human factors. Data used for model calibration and validation were collected during the period between April 1996-December 2005. A feedforward backpropagation ANN is used to model and forecast the three hourly discharges. Rainfall-runoff relationship in this studied area was previously investigated by Pukdeboon (2001). He used the Tank model, originally proposed by Sugawara (1974) to forecast the three hourly discharges for the wet- and dry- periods. Based on the same set of hydrologic data, comparison of the predicted discharge from the Tank model and ANN is presented. In addition, statistical evaluation of these two models for performance comparison are presented and discussed.

1.3 Literature Review of Rainfall-Runoff Modeling

During a rainfall period, water is trapped by plants, trees or on the ground and also infiltrate underneath the ground. Excess water generally contributes mostly to the overland flow which will be directed to the lower-land area such as rivers or canals, known as the runoff discharge. Since this runoff discharge concerns most of the water from each rainfall event, it is important for water resources design and planing in hydrology to find the relationship of rainfall and runoff.

Modeling the rainfall-runoff relationship requires complete description of the hydrologic processes such as evaporation, transpiration, evaportranspiration, overland and subsurface flows. It is one of the essential components in water supply evaluation. The hydrologic cycle is very complex due to both temporal and spatial variability. The use of descriptive models of rainfall-runoff process developed for a certain watershed is occasionally limited. There are two general approaches that can be employed to derive a mathematical model namely the knowledge-driven and the data-driven approaches. Brief descriptions of these concepts are summarized as follows.

1.3.1 Knowledge-driven approach

Knowledge-driven approach is based on fundamental laws of physics and mechanics, which eventually lead to mathematical descriptions of hydrologic processes. Models developed by this approach usually involve physical or geometrical parameters, which must be obtained from available data. There are two types of model that can be derived from this approach: physically-based models and lump conceptual models. Physically-based models generally employ a mathematical framework derived from mass, momentum and energy conservations in a physically distributed model. Parameters in the model are directly related to the catchment's characteristics. Governing equations normally consist of a set of coupled partial differential equations. Initial and boundary conditions are essential and must be carefully chosen to better describe the characteristic of watershed. Examples of this type of model include distributed models such as SHE (Abbott *et al.*, 1986), IHDM (Beven *et al.*, 1987) and SWATCH model (Morel-Seytoux and Al Hassoun, 1989). The physically-based models are usually restricted to limitations, such as excessive data requirement, large computational demand due to the complexity of the rainfall-runoff processes. To simplify the model a higher degree of empiricism can be incorporated in the model. Most of conceptual models are derived from the mass balance or water budget in the watershed with empirical representatives of hydrological processes. These empirical descriptions are introduced to minimize the use of momentum and energy equations. All parameters and variables in the models represent the average quantities over the entire catchment area. Hence, the model parameters cannot assess from field data. They must be obtained from calibration process. There are various examples of lumped conceptual models such as Tank model, Stanford watershed model (SWM) and Sacramento Soil Moisture Accounting (SAC-SMA) etc. The SWM was developed by Crawford and Linsley (1966) is a very well accepted model for simulation of the land phase of the hydrologic cycles (Singh, 1988). Lee and Singh (2005) applied Tank Model with sediment yield on an upland watershed in northwestern Mississippi and compared with the instantaneous unit sediment graph (IUSG). Hogue *et al.* (2006) developed multi-step automated calibration scheme to estimate parameters for

SAC-SMA to forecast operational streamflow in various hydrologic and climatic regimes.

1.3.2 Data-driven approach

Data-driven approach, well known as the black box model, is based on extracting the information that is implicitly contained in hydrologic data without directly taking into account the physical laws. This approach is practically less complex to develop and implement for real world application. It provides an alternative way to represent a complex system. The black box models are empirical, involving mathematical relations obtained via learning calibration processes. The models are not concerned with the physical processes in the catchment area, instead they are based on analyses of concurrent input and output. Examples of black box models are the unit hydrographs and the artificial neural networks (ANNs). Yue and Hashino (2000) utilized unit hydrographs to model the variation of streamflow runoff. The model is verified using observed rainfall-streamflow data from an actual basin. The computed streamflows showed good correspondence with the observed data. The use of artificial neural networks (ANNs) has been rapidly increasing among researchers during the past decades. Due to the simplicity and the ability to model both linear and nonlinear systems, ANN models have gained popularity in different branches of science and engineering. It provides a powerful computational technique for modeling a system in which explicit form of the relationship between the variables is not known in advance.

It is evident from previous studies that the ANNs are suitable for the complex rainfall–runoff process and can outperform the conventional modeling techniques. Smith and Eli (1995) used a feedforward network to estimate the peak runoff value and the corresponding peak time for spatially distributed rainfall. However, their trainings were performed by using simulated data. Concised review of neural network applications for water resources problems can be found in Maier *et al.* (2000). Luk *et al.* (2001) studied rainfall forecasting problem by using various ANNs and discussed the accuracies and discrepancies among these networks. Riad *et al.* (2004) developed ANN to model the rainfall-runoff relationship in a catchment located in a semiarid climate in Morocco.

Recently, Valenca *et al.* (2005) used a constructive neural network (NSRBN, Nonlinear Sigmoidal Regression Blocks Networks) to forecast daily river flows for the Boa Esperanca Hydroelectric power plant. In addition, ANNs can be used with a simple linear regression model to construct a daily rainfall-runoff model (Rajurkar *et al.* 2004).

1.4 Outline of the Thesis

This thesis is organized as follows. Chapter II describes the overview of the artificial neural networks (ANNs) and the learning process of the network via weight adjustment. The procedures of ANN implementation for rainfall-runoff modeling are presented in chapter III. Experimental results and discussion of ANN forecasting in comparison with the observed discharge are given in chapter IV. Chapter V concludes this work.