CHAPTER 2

REVIEW OF LITERATURE
In order to assess water resources on spatial and temporal scale in two watersheds located in the Kopili river basin, attempts were made to use hydrological modeling tool and techniques. In addition to assess water resources, the potential utilization hydropower generation was also investigated. The hydrological processes are inherently complex as these processes interact with heterogeneous soil and climate distributed over space and time. The modeling technique, supported by good hydrological data made job easier for prediction of such complex processes. Available literature citing research works on hydrological processes (rainfall–runoff) study, hydrological modeling efforts, application of hydrological modeling, and assessment of hydro power potentiality have been reviewed and presented in this chapter under the following sections:

1. Hydrological (Rainfall-runoff) processes
2. Hydrology modeling
3. Application of hydrological model
4. Assessment of model performance
5. Assessment of potential hydro power.

2.1 Rainfall-Runoff processes

Runoff has been utilized by mankind for various purposes. With the advancement of different sections of sciences hydrology also progressed. Simultaneously investigation on rainfall-runoff processes drew attention of many researchers world wide. Scientists and engineers recognized the importance of estimating water availability from the available hydrologic data for the purposes of planning water resource projects even in nineteenth century. However, paucity of adequate data perhaps forced to adopt simple correlation for the estimation of runoff. One of the most common methods is to correlate runoff with rainfall and fit a linear or exponential regression line for very rough estimation. Numbers of similar literature are available covering
varied aspects on it. Literatures of a few such works relevant to present study are presented below.

Rational formula for estimating runoff from rainfall is traced back to mid nineteenth century (Mulvany, 1850). This is still most widely used method in small watersheds. Although valid criticisms have been raised about the adequacy of this method, it continues to be used for storm design for land use planning because of its simplicity. The idea behind the rational method is that if a rainfall of intensity \( i \) begins instantaneously and continues indefinitely, the rate of runoff will increase until the time of concentration \( t_c \), i.e., when all of the watershed is contributing to flow at the outlet. The product of rainfall intensity and watershed area is the inflow rate for the system, and the ratio of this rate to the rate of peak discharge \( Q \) (which occurs at time, \( t_c \) is termed as runoff coefficient \( C \) (0 \( \leq C \leq 1 \)).

The ways to derive discharge hydrographs from rainfall events have been studied extensively since early 1930s (Mutreja, 1990). One method that is receiving considerable attention is called the unit hydrograph method. Sherman (1932) advanced the theory of the unit hydrograph related to the surface runoff phenomenon. The theory is considered even today as one of the most important contribution to hydrology. A unit hydrograph is a discharge hydrograph resulting from 1 cm of rainfall excess generated uniformly over the watershed area at a uniform rate during a specified period of time.

The fundamental Green and Ampt infiltration model which was developed about 100 years ago using Darcy's law is still applied in various situations including watersheds modeling. The Green and Ampt equation was developed to predict infiltration assuming excess water at the surface at all times. The equation assumes that the soil profile is homogenous and antecedent moisture is uniformly distributed in the profile. As water infiltrates into the soil, the model assumes the soil above the wetting front is completely saturated and there is a sharp break in moisture content at the wetting front. Some users claim that Green and Ampt equation is advantageous being theoretically derived with physically based parameters (Neitsch et al., 2002).
Soil Conservation services Curve Number (SCS-CN) model has been considered most appropriate model to study hydrologic response (Wurbs and James 2002, Mishra and Singh 2002). The curve number is an integer value varying between zero and hundred. From empirical analyses of rainfall-runoff data on small watersheds and hill-slope areas, the National Resource Conservation Service (NRCS) proposed a table of CN values with four defining parameters viz., Land Use Land Cover, hydrologic condition, hydrologic soil group and Antecedent Moisture Conditions (AMC) (NRCS, 1985). Accordingly curve number is generated relating the abstraction of rainfall for generating runoff. The Soil Conservation services Curve Number has been widely used in many hydrological assessment studies extending many regions of the world (Svoboda, 1991; Mishra and Singh, 1999; Yu et al., 1997; Beven, 2000; Mishra et al., 2003; Dutta et al., 2006). The usefulness and application of the curve number technique have been further increased with the introduction of hydrological process modeling.

2.2 Hydrological modeling

The rational method, unit hydrograph method, Green and Ampt infiltration method and SCS-CN method were the landmark contribution to the science of hydrology. However, each one of them has limitation and cannot represent entire spectrum of hydrology. Hydrology is a combination of several phenomenons all of which can be conceptualized by scientific principles and thus can be modeled. The use of above concepts in isolation or in combination could be seen in the development of hydrological modeling.

The term model may be defined as mathematical representation of a real world system. A “watershed hydrology model” is an assemblage of component models mimicking hydrological processes involving soil, climate and geography. As mentioned earlier there has been growing need for development of physically based watershed hydrological model all over the world. A number of physically based hydrological models have been developed over the years for many hydrologic applications at the watershed scale. Reviews of some of these models are discussed below.
Storm Water Management Model (SWMM)

In an effort of analyzing quantity and quality of urban runoff, the Storm Water Management Model (SWMM) was developed in 1971 by Metacalf and Eddy Inc., Water Resources Engineer Inc., and the University of Florida (Metacalf and Eddy, 1971, Huber and Dickinson, 1988). Basically the model was developed for Environmental Protection Agency, USA. Both single-event and continuous simulation could be performed on catchments having storm sewers, or combined sewers and natural drainage, for prediction of flows, and pollutant concentrations. It is claimed that this model was useful for accurate simulation of backwater, looped connections, surcharging, and pressure flow. Further, it is stated that it could simulate all aspects of the urban hydrologic cycles, including rainfall, snow melt, surface and subsurface runoff, flow routing through drainage network, storage and treatment. Statistical analysis could be performed on long-term precipitation data and also on output from continuous simulation. The model also incorporated planning module for an overall assessment of urban runoff problem or evaluating proposed abatement options. The application of the model for evaluation of urban development strategies is seen by many workers. Recently Jang et al., (2007) used SWMM for hydrological impact assessment in four urban watersheds in Korea.

Hydrologic Modeling System (HEC-HMS)

HEC-HMS and its predecessor, the HEC-1 Flood Hydrograph package (Wurbs and James, 2002), are one of the popular watershed computer models. The model has been applied to watersheds ranging from small urban areas of less than 1sq km to large river basins of several hundred thousand sq km. HEC-HMS, first released in 1997, is an object oriented, menu driven update of HEC-1 that has evolved through various versions dating back to 1968. The model computes discharge hydrographs at pertinent locations from observed precipitation events or synthetic design storms. Rainfall depths for each time increment of a storm are inputs. Snowfall and snowmelt are simulated using either degree-day or energy budget methods. A unit hydrograph can be either input or synthesized by the model using the NRCS
dimensionless, Snyder, Clark or Modified Clark method. The storage-outflow method is used for reservoir routing. An optimization routine facilitates parameter calibration in HEC-HMS. In a recent effort Knebl et al., (2005) demonstrated the application of HEC-HMS model in San Antonio river basin (10000 sq km) in USA and commented that the model is useful for flood forecasting on a regional scale that causes severe flash flooding.

Agricultural Non-Point Sources (AGNPS)

Agricultural Non Point Source (AGNPS) is a distributed parameter model developed by Agricultural Research Service (ARS) scientist and engineers. It predicts soil erosion and nutrient transport loadings from agricultural watersheds for real or hypothetical storms (Young et al., 1994). As such AGNPS is an event based model. Erosion modeling is built upon the Universal Soil Loss Equation applied on a storm basis. Its hydrology is based on the SCS technique. AGNPS incorporates another model (CREAMS: Chemical Runoff and Erosion from Agricultural Management System) to predict nutrient and pesticides and soil particle size generation and interaction. The delineation of study watershed into uniform grids is required. The simulation of models requires 22 parameters for each grid pertaining to its antecedent conditions, physical characteristics (e.g. soil type and slope steepness), management practices and rainfall. Amongst the several AGNPS users, Bhuyan et al., (2002) applied AGNPS model in a watershed in Cheney reservoir in Kansas, USA for estimating nutrient loading of different sub watersheds. They calibrated and validated the model in each sub watersheds and concluded that the model was more effective in smaller watersheds with adequate rainfall data. In another attempt, Mohammed et al., (2004) tested and validated AGNPS model in Kori watershed in Ethiopia to simulate surface runoff, peak runoff and sediment yield and obtained high degree of agreement. The model could identify the erosion prone areas needing treatment.

Areal Non Point Source Watershed Environmental Response Simulation (ANSWERS)
ANSWERS is a hydrological model (Areal Nonpoint Source Watershed Environmental Response Simulation) developed by Department of Biological Systems Engineering, Virginia Tech, Blacksburg, Virginia, USA (Beasley et al., 1980). It is a distributed model designed to simulate the processes of flow, erosion and transport of the sediments form agricultural catchments. The interception of the rain by the vegetation, the infiltration and surface detention are modeled successively by modules of ANSWERS. The detachment of the sediments by the rain and their transport, their deposit or their recoveries were also simultaneously simulated in ANSWERS.

TOPMODEL

TOPMODEL is a simple but physically based hydrological model that aims to represent the effects of catchment heterogeneity and, particularly, topography on the dynamics of hydrological response (Beven and Kirby, 1979). It is a topography based watershed hydrology model that has been used to study a range of features, including spatial scale effects on hydrological process, topographic effects on water quality, topographic effects on stream flow, climate change effects on hydrological processes, the geomorphological evolution of basins, and the identification of hydrological flow paths. The TOPMODEL is a variable contribution area conceptual model in which the predominant factors determining the formation of runoff are represented by the topography of the basin and a negative exponential law linking the transmissivity of the soil with the vertical distance from the ground level. In this model the total flow is calculated as the sum of two terms, surface runoff and the flow in the saturated zone. According to model developer, though TOPMODEL is a conceptual model, it can be described as "physically based" in the sense that its parameters are measured directly in situ. Jain and Soni (1998) observed the TOPMODEL as one of the few conceptual models that accounts explicitly for the saturation excess overland flow mechanism and integrates the variable contributing area concept, both of which are essential to model the catchment accurately. While testing TOPMODEL (Gallart et al., 2006) with data from the Can Vila research basin (Valicebre, Spain) to verify its adequacy for simulating runoff and the relative
contributions from saturated overland flow and groundwater flow, satisfactory agreement was obtained for overland flow simulation. However, the uncertainty of prediction of the contribution from groundwater was extremely large. The conditioning on water table records and the distribution of parameters obtained from point observations strongly reduced such uncertainty of predictions.

**MIKE SHE Model**

The MIKE SHE (Systeme Hydrologique Europeen) (Abott et al., 1986a,1986b) developed by the Danish Hydraulic Institute (DHI) is a distributed parameter, physically based, deterministic, continuous catchment modeling system. The developer claims that the model is useful for the simulation of all major hydrological processes occurring on the land phase of the hydrologic cycle. It simulates water flow, water levels, water quality and sediment transport. The model discretizes the watershed into orthogonal grid network. The model consists of several individual modules, allowing user to add specific modules for various types of hydrological simulation. The catchment and the channel network system are modeled by the rainfall runoff module. Runoff computations are based on the lumped conceptual type model. The model simulates snow melt, canopy interception, ET, overland and channel flow, saturated and unsaturated sub surface flow. Overland and channel flow are simulated using a simplification of St Venant equations. Unsaturated flow is simulated using Richards equation, and the saturated flow is represented by a two dimensional Boussinesq equation.

**Soil Water Assessment Tool (SWAT)**

The Soil Water Assessment Tool (SWAT) is a distributed parameter, continuous time hydrologic model (Arnold, et al., 1993, 1998). It is the continuation of a long-term effort of non-point source pollution modeling with the USDA - Agricultural Research Services (ARS). SWAT allows division of basin into grids or sub watersheds. It is claimed that SWAT incorporates better characteristics of lateral flow, ground water flow channel transmission losses and routing of sediment and chemical through the watershed (Arnold,
et al., 1993, 1998). The model uses a modified form of SCS-CN technique (USDA-SCS, 1972) to calculate surface runoff.

2.3 Application of hydrological model (SWAT)

The seven major hydrological models and some of their specific uses are discussed above. The present investigation used SWAT for water resources assessment of two hilly watersheds located in northeastern regions of India. The consultation of earlier review indicated wide range of application of SWAT for water resources planning and management world wide. Some of the relevant applications of SWAT in hydrological studies are reviewed below:

Bingner (1996) simulated runoff for a watershed in northern Mississippi using SWAT model for ten years period. Reasonably acceptable agreement in the simulation of runoff on daily and annual basis were obtained in all the delineated sub basins with area varying from 0.05 to 21.3 sq km, variation in land cover was found to influence the prediction as the simulated runoff in sub basin covered with forest cover was in disagreement with observed results.

In another use of SWAT, Arnold et al., (1999) evaluated stream flow and sediment yield data in Texas Gulf Basin with drainage area ranging from 2253 to 304260 sq km. They used data of 1000 stream monitoring gauges during a period of 1969 to 1989 to calibrate and validate the model. Their results indicated that predicted average monthly flows for three basins were 5% higher than the measured flow with standard deviation between measured and predicted flow within 2%.

While using SWAT for analyzing hydrology in small watersheds in North Syria, Bruggeman and Meijden (2003) obtained 225 mm average annual precipitation from the weather generation module of SWAT. The module considers 100 years of simulation period. Additionally, the model predicted 11% recharge of ground water resources.

Another notable application of SWAT has been watershed prioritization. Pandey et al., (2002) prioritized sub watersheds in Banikdih
watershed of Gowai river system in two states (Jharkhand and West Bengal) of India on the basis of sediment yield characteristics using SWAT2000. The close agreement between observed and modeled sediment yield at the outlet of the watershed for the year 1998 and 2000 were found.

Similarly Tripathi (2003) applied SWAT model to prioritize sub watershed in Jharkhand (India). Simulated water yield and sediment yield in a small watershed (92.46 sq km) were used for prioritization after successfully validating the simulated results. The weather generator module of SWAT (Markov chain model) was also used for simulating precipitation which was successfully validated.

Mishra (2004) used SWAT model to a small multi-vegetated Banha watershed in Jharkhand (India) to simulate the hydrologic processes and associated transport of non point source of pollutant (NPS). The calibration and validation of the model revealed satisfactory predictability for daily, monthly and season runoff, sediment yield and NPS pollutant. The sensitivity analysis conducted in the watershed indicated that runoff was most sensitive to initial soil moisture whereas sediment yield was sensitive to mannings ‘n’ for tributary channel flow. The prediction of SWAT also indicated that small multi-vegetated watershed were more prone to channel than field erosion.

Thus SWAT has been used to model hydrological processes of watershed to obtain runoff, sediment yield, ground water and non point source of pollution. Apart from conventional uses of water resource and sediment assessment, SWAT has also been used for other purposes. In such a varied approach, Gossain et al., (2003) studied the impact of climate change on water availability of 12 river basins of India. They observed that impact of climate change is varying across the river basins and sub basins. Their study revealed that future scenarios may deteriorate in terms of severe drought or severe floods and there is general perception of reduction of available runoff in future. SWAT also predicted flood scenario of Mahanadi basin (India) with the peak discharge increasing from the present level of 20000 cumecs to 37000 cumecs.
Similarly Sintondji (2005) conducted a study in Terou-Igbomakoro basin (2336 sq km) in West Africa dominated by wood lands in the form of tree and shrub savannah, followed by deciduous forest and crop land. The aim of the study was to adapt a regional model for the rainfall-runoff system and sediment yields, taking into account climate and land cover dynamics and socio-economic practices using SWAT model. High goodness of fit was observed between simulated and modeled results. The goodness of fit on monthly time were obtained through coefficient of determination ($R^2 = 0.7$), Nash and Sutcliffe efficiency ($E = 0.7$) and Index of agreement ($d > 0.9$). Shallow aquifer flow was identified as an important component of the total discharge within the study area by the SWAT. While evaluating some futuristic scenario, the impact of future land use and climate change on hydrology indicated reduction of discharge from 241 mm to 106 mm in 25 years (2000-2025). However, the scenario for erosion predicted unchanged with the year 2000 probably because of decrease in rainfall and changes in land surface.

From the literature it could also been seen that SWAT has been used to model the transport processes of agricultural chemical for identifying suitable management option. One such study was conducted by Tolson and Shoemaker (2007) for simulating hydrologic process in Cannonsville reservoir watershed (1178 sq km) in US which is the major source of water for New York City. According to the investigators, the reservoir was subjected to water quality problems particularly phosphorus loading and thus attempted to model the hydrologic processes for identifying management options. They used seven years data for calibration and 4 years data for validation. Model performance was assessed using $R^2$ (coefficient of determination) and $E$ (Nash and Sutcliffe) criteria and found satisfactory.

In a recently completed related study, Abbaspour et al., (2007) used SWAT to model hydrologic processes and transport processes for Thur river basin (1700 sq km) in Switzerland. They calibrated discharge using the data from the year 1991 to 1995 and validated for the years 1996 to 2001. The SWAT simulated discharge and nitrate to a good agreement and sediment
and phosphorus loading to a reasonable extent. In this study the degree of uncertainty ($d$ factor) was considered. The value of calculated $d$ factor for calibration period and validation period were 1.0 and 0.95, respectively, whereas a value of less than 1 is considered to be desirable measure.

Gossain and Rao, (2005) demonstrated the use of SWAT model for selection of hydro power sites in hilly state of Nagaland located in the North Eastern region of India. SWAT model was used to identify locations of adequate discharge. GIS tool was then used to extract the longitudinal profile of the drainage system and hence drops along the profile. From the discharge available through SWAT simulation, flow duration curves were generated for hydro power assessment.

Thus it can be seen that SWAT has been used world wide for various purposes. The various fields where the model has been applied were for assessment of water resources, simulating sediment yield, prioritization of watershed for planning treatment measures, studying the impact of climate on the water resources, to model loading of agricultural chemicals in the water bodies and also to assess hydro power potential.

### 2.4 Efficiency criteria for assessment of model performance

Usefulness of a model depends upon its performance i.e. accuracy of prediction of required events for the situation under study. The variability and uncertainty at different levels viz., model development, data collection, calibration and simulation may accumulate to negatively affect the end results. The situation would vary from case to case. Therefore, it is inevitable to test the performance of hydrological model for each case. There have been lots of studies on performance assessment of hydrological modeling. Comparative assessment studies based on multi-criteria were also being found. The reviews of these works are presented below:

Abbot and Refsgaard (1996) reviewed several hydrological models as part of assigned studies for Commission for the European Communities (SAST, 1992). The evaluation was made on the basis of five criteria viz.,
adequacy of scientific basis, level of scientific test, validation status, practical applicability and constraints for practical application. A number of practical field problems such as water resources assessment, irrigation, soil erosion, pollution transport, effect of management practices, climate change, aquatic ecology and on line forecasting were incorporated for evaluation of several models. A number of models have been developed for each of the above uses. They analyzed and found that most of these models have limitations as far as set of criteria are concerned. However, performance of some models could pass their evaluation test including hydrological modeling for surface water resources assessment. According to the study, models with adequate scientific basis, scientifically well tested and validated were available for water resources assessment.

The necessity of evaluating model performance based on calculated efficiency criteria and identifying the areas of where model improvement is required were emphasized by Krause et al., (2005). Some selected efficiency criteria viz., coefficient of determination ($R^2$), Nash and Sutcliffe efficiency ($E$) and index of agreement ($d$) in isolation or in combination were commonly used in hydrological studies. These criteria were applied on Wilde Gera (13 sq km) watershed in Germany for the period of November, 90 to April, 91. The results indicated that each of the criteria had some limitations and therefore, suggested to judge their merit during model calibration and evaluation.

Gassman et al., (2007) reviewed 113 case of SWAT applications all over the world and observed that $R^2$ and $E$ were the most widely used statistics for hydrologic calibration and validation for daily, monthly and annual hydrological events. The range for $R^2$ is from 0 to 1 (0 means no correlation and 1 indicates perfect fit) and $E$ ranges from $-\infty$ to 1 (the values of 1 shows perfect fit and values equal to or lower than 0 indicates mean of the observed data is better predictor than the predicted value). While compiling the results of 113 modeled cases it was observed that values of $R^2$ varied from 0.01 to 1 and $E$ varied from -35.7 to 0.9 for both calibration and validation.
2.5 Assessment of hydro power potential

One of the objectives of the present study was to estimate the hydro power potential of Myntriang and Umkhen watershed from the simulated water resources. Some of the aspects related to assessment of hydro power potential were reviewed and are presented below.

Punys and Pelikan (2007) reviewed various technical aspects related to the status of small hydropower (SHP) in the enlarged European Union (EU) and countries wishing to join EU. They found that in fifteen member countries of European Union there are about 14000 SHP with a total capacity of 10000 MW with average size of each plant of about 0.7 MW. In almost all analyzed countries hydropower is a dominant source of energy in renewable electricity production and SHP occupies the second contributor (after large hydro). The survey also indicated that in most of surveyed countries more than a half of total SHP plants are low head power plants (gross head < 5 m). This fact is especially common in Central and Eastern European countries. The countries located mostly in Southern Europe (Slovenia, Bulgaria, Romania and Turkey) have the highest share of high head (>15 m) SHP plants.

In another study conducted in Uganda for planning rural electricity using GIS technology, Kaijuka (2007) mentioned that small-scale hydro installations in rural areas could offer considerable financial benefits to the beneficiary communities, particularly where careful planning identifies income-generating uses for power. The study also stated that small-hydro schemes not only provide renewable energy, but are also cheaper to maintain, given basic training to the users. The main advantage of small-hydro schemes has been attributed to simpler construction and absence of dam and storage facility. It simply diverts water from the river, channels into a valley and ‘drops’ into a turbine via ‘penstock’ (pipeline). This type of hydro generating would thus avoid the damaging environmental and social effects that larger hydroelectric systems can cause.

An effort was made by Dudhani et al., (2006) to demonstrate a methodology to extract information through remote sensing technologies for
identification and assessment of water resources and its associates such as inhabitation and settlement pattern, forest and vegetation coverage, snow coverage and selection of probable sites for small hydropower projects. They expected that use of technology would save manpower and time required for surveying and updating the information of the potential and will result into significant impact on the cost.

A study was conducted by Nunes and Genta (1996) to assess mini and micro hydro power in Uruguay for the power above 1 MW and up to 5 MW (small hydropower utilization). The generating potential was assessed all around the country, featuring sites according to the length and height of the dam and volume of water to turbinate, by means of a coefficient which relates the volume of the lake to the power to be installed. They started with mapping from 1:500,000 hypsographic charts with contour lines every 50 meters. Altogether 107 points were identified to locate micro dams. Further they commented that if power lower than 1 MW or lower than 100 KW was considered, the information available on the maps with contour lines, including in those of a 1:500000 scale is not enough to identify the most adequate places. Instead the knowledge of the place is indispensable in these cases.

Das and Paul (2006) in their study attempted identification of suitable sites for setting small hydel power plant in Himalayan region in India using GIS tools. Distributed curve number method was used to calculate the average monthly runoff for the identified site. The base flow was measured at an accessible point in different watersheds/sub-watersheds having similar characteristics. As all the streams were ungauged so regression analysis was done to arrive at an equation for calculation of the base flow on the basis of number of pixels draining at the point of measurement and the average slope of the watershed/sub watershed. The base flow at the site in the sub watershed was ascertained on relational basis. Knowing the total flow and the head the power generating capacity at the site was ascertained.

The information of the research work related to hydrological processes, hydrological modeling, application of hydrological model, assessment of
model performance and assessment of potential hydro power as discussed above will be useful for the present investigation.

2.6 Summary

In this chapter literature was reviewed on hydrological processes, hydrological modeling, application of hydrological model, assessment of model performance and assessment of potential hydro power. The review identified various methods for modeling runoff processes, its advantages and associated constraints. It was found that SCS-CN method was suitable for the present study areas and the method was adopted in the thesis. Number of hydrological models were also reviewed and its application world wide was also studied. The advantages, availability and applicability was also studied and SWAT was found to be suitable in the present context. The criteria for evaluation of hydrological model as suggested by Krause et al., (2005) helped in adopting the methodology and was further strengthened by Gassaman et al., (2007) where they reviewed 113 SWAT application world wide using the selected criteria as suggested by Krause et al., (2005). The methods used by Nunes and Genta (1996) and Das and Paul (2006) was adopted in the present study for assessment of hydro power potential.