APPLICABILITY OF BTOPMC MODEL AND TANK MODEL IN SUB- CATCHMENTS OF SUN KOSI BASIN, NEPAL

By

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A thesis in partial fulfillment of the requirement for the degree of Master of Science in Water Resources Engineering

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April, 2001

Dedicated to
my Daddy Mr. Shanker Mani Pradhan
and
my Uncle Mr. Santosh Kumar Pradhan

CERTIFICATE

This is to certify that this thesis entitled "Applicability of BTOPMC Model and Tank Model in Sub-catchments of Sun Kosi Basin, Nepal" submitted by Mr. Nawa Raj Pradhan in partial fulfillment of the requirements for the award of the degree of " Master of Science in Water Resources Engineering. This thesis work carried out by him under my supervision and guidance. The thesis fulfills the requirements related to the nature and standard of the work for the award of M.Sc. in Water Resources Engineering and no part of this work has been published or submitted for the award of any degree else where.

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ABSTRACT

BTOPMC – a physically based distributed hydrological model based on the blockwise use of TOPMODEL with Muskingum-Cung flow routing method- was selected to evaluate the applicability in Sun Kosi watershed, Nepal. The major rivers of Nepal like the Sun Kosi river originates from the Tibetan plateau where the data information is not available. Thus to cope with this problem further modification in the model was suggested that lead to the development of BTOPMC version II. To suit the Nepalese catchment further modification in the model was suggested that lead to the development of BTOPMC version II. The quality of simulation is classically judged by comparing the simulated flow with observed flow. Model performance was judged by a range of quantitative and qualitative measures of fit applied to both the calibration and validation periods. The daily stream flow estimation in Sun Kosi river basin was promising. BTOPMC can be successfully used as a tool for integrated water resources investigation in large watershed, mountain physiographic region, of Nepal.

On the other hand Tank Model was used in small subcatchments of Jhikhu Khola watershed. The result proved that storage and land use effect played a dominant role in rainfall runoff process of small catchments. From the results of Jhikhu subcatchments it was found that parameters estimated for one subcatchment did not match the next subcatchment response. However, from the results of Sun Kosi catchments-large scale- the estimated parameters for one large-scale subcatchment also proved to give good response for the next large scale subcatchment. It was also concluded that if the basin is large, the effects of random hydrological phenomenon will cancel each other out and the change will be minimal. However, in a small basin these effects of random hydrological and geomorphological phenomenon may cause instability. All these analysis of homogeneity was based on Tank Model response. Thus Tank Model is not a mere black box but has physical meaning.

ACKNOWLEDGEMENTS

I wish to express my heartfelt gratitude to Dr. Raghunath Jha for his keen interest and able guidance to supervise this important study work as a part of the M. Sc. degree. His cooperative nature has always been an impetus not only to complete the present study but also to carry out such research works in future. I am equally grateful to Dr. Narendra Man Shakya for his consistent effort to prepare this thesis and all the necessary support needed for completion of this study. My sincere thanks are due to Dr. Diwas Basnet, Mr. Durga Sangraula, Mr. Hari Prasad Pandit, Dr. Laxmi Prasad Devkota, Mr. Purusottom Shrestha, Dr. J. N. Nayak and Dr. P. C. Jha for their kind cooperation.

I would like to express my sincere gratitude to Prof. Dr. Kuniyoshi Takeuchi and Mr. Tianqi Ao of Yamanashi University, Japan, for their valuable suggestions, encouragement and for providing useful materials. Acknowledgement is due to INCEDE, International Center for Disaster Mitigation Engineering, Tokyo University for providing useful materials. I would also like to express my sincere gratitude to Mr. Juerg Merz (PARDYP, ICIMOD) for supporting this thesis work in various ways.

Acknowledgement is due to the Department of Hydrology and Meteorology and WECS, Ministry of Water Resources, H. M. G, Nepal, for providing the data and references.

A sacred tribute of eternal dedication and devotion goes to my late grandparents whose blessings are always with me. My love and respect goes to my Daddy who has always taught to lead a disciplined life and to smile to the world. My gratitude goes to my Mummy for her love, the love that melts softer than tears, and the liberty to leave me for my studies since I was a child. My love and respect goes to my Uncle who has shared all my difficulties and has always bolstered my self-confidence. He is my ideal personality and I always tried to follow his footsteps. My gratitude and love goes to my Aunt for her love and understanding. Thanks to my beloved brothers Bishan, Subodh, Sumit and my beloved sister Selina for their respect and love. Thanks are also extended to all my relatives and friends in Nepal and abroad for their moral support.

Last but not the least, I would like to express my heartfelt thanks to one and all who is one way or the other, directly or indirectly helped me for achieving this thesis work.

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1. INTRODUCTION

1.1 Introduction to the field of study

Originally the water resource management was very sub-sectional, mostly in relation to water supply, sanitation and irrigation. Recently there is a growing consensus in the need for Integrated Water resource management approaches. Water Resources Management can be considered as a process including all activities of planning, design, construction and operation of water resources system. Integrated water resources management takes account of all the natural aspects of the water resources, the spatial variation of resources and demands besides relevant policy frame works.

Integrated Water Resource Management can be effectively done within a spatial unit called watershed with the help of an instrument known as modeling. Watershed (catchment) models are mainly used for prediction runoff components and stream flows generated by precipitation. Such models also have been widely used for flood forecasting. In principle, the technique of catchment modeling is applicable to catchments of any size. In practical, however, catchment-modeling applications are generally confined to the analysis of catchments for which the description of temporal/or spatial variations of precipitation is warranted. Usually this is the case for mid size and large catchments.

The use of computers has led to increased emphasis on catchment modeling. Catchment modeling comprises the integration of key hydrological processes into a modeling entity i.e. a catchment model, for purpose of analysis, design, long-term runoff-volume forecasting, or real-time flood forecasting.

A typical catchment modeling application consists of the following: (1) selection of model type, (2) model formulation and construction, (3) model testing and (4) model application. There are several models and it is not possible to identify clearly which model should be used for a specific hydrological problem. One of the reasons for this 'flood of models' is that this large scale and complexity of rainfall – runoff phenomena make description of the system rather difficult; in practice, even a small drainage has a complicated structure. Another important reason is that there are no efficient criteria for evaluating those models. Evaluation of rainfall – runoff models has become one of the most significant themes in hydrology.

1.2 Need of the study

Research work is the genesis to create a guanine manpower. Able manpower shapes the fate of the national economy. But, determination alone is not the solution. The academically sound environment, reliable technology and the guidance of the specialists in the research field are rather more important.

Nepal, with an area of 147,181 sq. km. has more than 6000 rivers stretching from the Great Himalayas with an elevation of more than 8800m to the southern plain called "terai' with an elevation of 100m within a mere 200 km width. This provides a dense network of rivers with steep topographical conditions and concentration of 80% of the total annual rainfall in a relatively short period of about four months. These peculiar characteristics lead to a set of hazards including frequent floods.

The country has been regarded as one of the richest nations of the world in water resources having annual average surface water availability of 15,21,934 m^3 /sq. km and 11,200 m^3 per capita. Nepal is a country with vast hydroelectric resources. The total hydropower potential of Nepal is estimated to be 83,000 MW. Moreover Nepal is an agriculture-based country. Nepal being an underdeveloped country, her hopes towards the development lies in Water Resources.

While water resources has a vital role to play in shaping the fate of the national economy, its successful utilization remains equally challenging from various standpoints. The first challenge stems from the non-availability of hydrological data itself, systematic collection of which started only since 1960. Even the available data has not been used in an optimal way. The second obstacle is the rugged terrain. The Highest Himalayan region in the northern part is almost inaccessible and the streams in this region are very rapid, therefore they rarely provide ideal measurement sites. Moreover direct measurements of runoff by river gauging, though useful, is a costly process and hence the necessity of establishing a relation between the rainfall and the runoff. The hydrological network in Nepal is quite poor in head water regions, fair in the mountainous region and also poor in the southern plain Terai region. The establishment of a minimum network is necessary for the reliable assessment of water resources to understand more correctly the hydrological behavior of different rivers.

The large rivers of Nepal like Koshi, Narayani, Carnali and Mahakali are debauching from the hills, causing immense damage to the Terai plain during the monsoon period. The other medium sized rivers are also posing potential threats from time to time. Even though floods can neither be stopped nor totally protected, the damage can be significantly reduced by various means including physical (for instance, large reservoirs, and by timely forecasting the flood and warning the people at lower reaches.

In view of the important role that water resource can play in Nepal and the need to harness it in a sustainable manner, it is essential to know the various facets of water resource. Depending on the situation, different approaches to it's use are needed to be designed, sometimes to 'keep the water away from the people', and the other times 'keep the people away from the water'. Suitably selected models can help to identify issues which are useful for planning various development projects with minimum risk of flood disasters, alerting people to keep away from such disasters in time and providing planners an information about water for use in various development projects like hydropower, irrigation etc.. Until now, quite a few such models have been tested in Nepal. Moreover, it is often challenging to have a correct model that can work in different harsh topographical conditions. An adequate and reliable data source is the sign of well beginning of a water resource project. Hydrology data is the preliminary and most important data source used in water resource sector. But the bitter fact is Nepal is deprived of this data source. Thus analysis and development of a simple and user friendly model is a must to generate data source. With the advancement of technology, GIS and satellite images has played a vital role for the easy access of wide range of data. The model, which can incorporate such data, can be very fruitful for the country like Nepal where only a few scattered and less reliable data source is available.

Even though the present work is confined to Sun Kosi river basin, the selection has been made to represent various topographical zones of Nepal so that it can be successfully used in many other basins on the proper assessment of the results.

1.3 Objectives of the study

The principle objectives of this study are:

1) To evaluate the applicability of the BTOPMC – a physically based distributed hydrological model based on the block wise use of TOPMODEL with Muskingum-Cung flow routing method - in large scale Nepal's watershed like Sun Kosi basin.
2) To calculate and validate the block-wise distributed parameters of BTOPMC MODEL so that these parameters can be used with fair accuracy in the later years.
3) To analyze the concept of homogeneity in small* scale watersheds and large** scale watersheds by applying the simple logic of tank model and to study the reliability of tank model for different spatial resolutions.
4) To analyze the storage and land use effects in model analysis of small catchments.

1.4 Hypothesis

The set of hydrologic and hydraulic representing parameters of a subcatchment can be used to estimate runoff for other subcatchments in the same basin with fair accuracy.

1.5 Expected output

- Tentative values of the distributed parameters according to the land use variation in different topographic and climatic conditions of large-scale watershed of Nepal.
- Results and performance of the models used with respect to the objective of the study.
- Analysis of the concept of homogeneity in small-scale and large-scale watersheds.

2. LITERATURE REVIEW

2.1 Integrated Water Resource Management and Watershed models

The advancement of computer technology has brought a "virtual revolution to watershed models as Vijay P. Singh says in the preface of his book, Computer models of watershed hydrology (**V. P. Singh**, 1995). He continues, "they, in addition to hydrology, simulate water quality, geology, risk and uncertainty, environmental impact, etc. Furthermore, they are equipped to take advantage of GIS capability for database management and computer input data received directly from remote sensing and satellite technology." This is exactly the basic technology necessary for sustainable management of water resources.

Water quantity and quality management is important for an integrated approach to the sustainable management of water resources. That task requires the integration of all aspects of water resources management, such as water use and environmental conservation, quantity and quality content of surface water and groundwater, regulation of low flows and high flows, development of downstream and upstream basins, source control and channel control of floods, sediments etc. For such implementation, all available methodologies and organizational mechanisms should be utilized, such as physical and managerial means, economic and institutional means, primate and public initiatives, governmental and nongovernmental initiatives, local community and central government initiatives, etc. For all these aspects, the means of basin-wide hydro-environmental simulation is a valuable planning and operational tool.

Technological advances make it possible to combine information from various platforms, such as stereo aerial photographs, multi-spectral micro-wave and thermal images, through image fusion, and links to existing thematic data through GIS operation. It is therefore possible to use information on the spatial variation of terrain factors, which influence hydrology. However, the interactions of surface and subsurface hydrological processes cannot be observed directly on the images. In general, the conceptualization of the hydrological processes by semi-qualitative hydrological reasoning is based on the analytical interpretation of the stereo model and other images (**A. M. J. Meijerink et al.**, 1997). Use is made of the natural associations of geology, geomorphology and soils, and often land cover.

The analysis of spatially distributed runoff generation in hydrological catchment areas belongs to scale problems in hydrology that is difficult to solve (**G. Peschke et al.**, 1997). The components that is of concern are the so-called quick runoff components representing the direct response to a storm event and including surface runoff – Hortonian overland flow and saturation excess surface runoff– and interflow. These quick runoff components occur predominantly in mountains regions where the hill slope response, rather than network response, prevails.

The main runoff generation mechanisms operating at a given site within the catchment under consideration depend heavily on the various controlling factors. Factors such as precipitation and evapotranspiration determine the initial soil moisture and topography; soil type, vegetation, land use and the river network each play a decisive role in the overall runoff generation process. Amongst these influencing factors the topography, the soils and the vegetation show a considerable degree of spatial heterogeneity. Very dissimilar value combinations of these variables naturally result in different runoff generation mechanisms. From this the first goal of investigation can be derived. Understanding of the runoff production process at the local scale, which results from the particular combination of attributes of the controlling factors, is important (**G. MULLER**, 1997). This will also show great spatial variability across the scales from the site or field, through the hill slope to the subcatchment and the catchment. Apart from the spatial heterogeneity of the controlling factors, the antecedent soil moisture shows a considerable temporal variability that also highly influences the runoff generation. The contributing saturated area can change widely depending on the initial soil moisture and the characteristics of the storm event. Regionalization involves the transfer of information from one catchment (location) to another. Clearly, regionalization focuses on the space domain while scaling refers to both space and time.

2.2 Conditions for Hydro-Environmental Simulation Models

In many countries, including Nepal, there are large un-gauged catchments awaiting development and management that would benefit from the use of hydro-environmental simulation models to assist with basin planning. The selection of a hydro-environmental simulation model should consider a number of practical constraints present in such basins. These include:

a) precipitation, runoff, evaporation and other hydro-climatological data are seldom available;

b) land-use, geology, vegetation, soil type and other basin characteristic data are also seldom available;

c) extensive anthropogenic disturbances such as deforestation, urbanization and other basin developments are present;

d) basin hydrology is artificially regulated: few stations measure natural flows and available measurements are of regulated and disturbed flows; the quantitative identification of the degree of disturbance is often impractical; and

e) the scale of basins subject for managerial consideration ranges from less than one thousand to more than a hundred thousand km^2.

Meanwhile electronically transmittable data become available to increasingly more users. For example, the National Geophysical Data Center, NOAA, USA provides CD-ROMs of geographical elevation maps that cover about 60% of the global terrain's with about a 1 km guide (NGDC, 1997) which can replace seldom available local topographical maps. Also large amounts of satellite and other remote-sensing data are available at various wavelengths. These conditions prescribe the basic properties that a model has to have namely:

a) Digital elevation maps (DEMs) are used replacing a conventional stream network and topography map.

b) satellite data can be utilized to identify land surface characteristics of the basin such as interception, soil types, infiltration capacity, evapotranspiration etc: and

c) Satellite and other remote sensing data can be utilized for spatially distributed and temporally continuous precipitation measurement.

In addition to these data-oriented criteria, the model should satisfy user requirements such as:

a) water quality dynamics, including sediment yields and transport, and biochemical processes along streams, can be simulated:

b) both floods and low flows at arbitrary points in a basin at an arbitrary time can be simulated;

c) large basins can be simulated;

d) Effects of water resource systems such as dams, canals, paddy fields, irrigation network, municipal water distribution and use etc. can be incorporated in the model and simulated.

e) land-use changes as well as elumatological variation can be simulated; and the model is capable of transfer to a variety of different types of basin.

2.3 Topmodel

The TOPMODEL approach has become widely used for hydrological catchment modeling. The representation of topographic effects in hydrology by a topographic index allows the simulation of distributed groundwater levels in a simple way..

In most catchments the spatial patterns of hydrological storage and fluxes are dependent on the topography. The TOPMODEL approach developed by Beven & Kirkby has become widely used for hydrological catchment modeling, because it allows the consideration of topography while avoiding the complexity of fully distributed models. In contrast to other models the catchment is not divided into homogeneous units, but natural heterogeneity (i.e. topography) and its effects on hydrological processes are represented by distribution function (**Jan Seibert,** 1997). Therefore, the distribution of wetness states over a catchment can be simulated easily and with low computational demand. This made the model very popular, especially since digital elevation models (DEMs) became readily available, not only for hydrological catchment modeling but also as part of ecological, geomorphological or geo-chemical models, where information about local groundwater levels (or surface wetness) within a catchment is of importance. Furthermore, the TOPMODEL approach has been used to aggregate Soil-Vegetation-Atmosphere Transfer (SVAT) models to larger scales. However, validation of spatial variation of groundwater levels (or surface wetness) simulated by TOPMODEL, often has not been successful (e.g. Jan Seibert, 1997).

2.3.1 Theory of Topmodel

The topographic index of TOPMODEL is defined as $I=\ln(a/\tan\beta)$, where a is the local up-slope catchment area per unit contour length and β is the slope angle of the ground surface.

The index describes the tendency of water to accumulate (a) and to be moved down slope by gravitational forces (β). For steep slopes at the edge of a catchment a is small and β is large which yields a small value for the topographic index. High index values are found in areas with a large up-slope area and a small slope, e.g. valley bottoms. The TOPMODEL theory can be formulated either using local storage deficits, S (L water needed for saturation up to surface), or groundwater levels, z (L below surface). Both formulations are directly inter-changeable, therefore, only one of the formulation using groundwater levels is shown here.

Assuming the transmissivity to decrease exponentially with increasing depth to the groundwater table, zi (L below ground surface), the hydraulic gradient to equal the surface gradient, tan β (-) and lateral flow in the unsaturated zone to be neglectable, the down-slope flow at a certain location i is given by equation (1). Ti ($L^2\ T^{-1}$) is the transmissivity if the groundwater level is at the ground surface nd f (L^{-1}) is a shape factor describing the exponential decrease of conductivity with depth.

$$q_i = Ti \tan\beta i \exp(-f\ z_i) \qquad (1)$$

Equation (1) provides the outflow from a certain location. Assuming steady state conditions in all locations and a spatially uniform vertical input rate R ($L\ T^{-1}$) to the saturated zone, the mass balance for each location simplifies to equation (2), where ai (L) is the up-slope area drained through location i per unit contour length.

$$a_i R = T_i \tan\beta_i \exp(-f\ z_i) \qquad (2)$$

Equation (2) can be rearranged to equation (3). It should be noted that the rearrangement is only possible if the recharge, R, is larger than zero. A mean depth to the water table $\bar{z}$, is given by equation (4). The bar always denotes the mean over the catchment area, A (L^2).

$$z_i = -\frac{1}{f} \ln\left(\frac{a_i R}{T_i \tan\beta_i}\right) = -\frac{1}{f}\left[I_i + \ln\left(\frac{R}{T_i}\right)\right] \qquad (3)$$

$$\bar{z} = \frac{1}{A}\int_A z_i dA = -\frac{1}{fA}\int_A I_i - \ln T_i + \ln R\ dA = -\frac{1}{f}(\bar{I} - \ln \bar{T} + \ln R) \qquad (4)$$

Subtracting equation (4) from equation (3), yields a relationship between $\bar{z}$, and the local water table at each single location i:

$$z_i = \bar{z} - \frac{1}{f}\left[I_i - \bar{I} - \left(\ln T_i - \overline{\ln T}\right)\right] \qquad (5)$$

Due to the steady-state assumption the total specific runoff from the saturated zone, q_{GW} ($L\ T^{-1}$) equals the recharge R and can be written as a function of $\bar{z}$, by rearranging equation (4) to equation (6).

$$q_{GW} = \exp\left[-f\ \bar{z} - \left(\bar{I} - \overline{\ln T}\right)\right] \qquad (6)$$

In model application, $\bar{z}$, is updated at every time step Δt using equation (7) where q_v (L T^{-1}) is the simulated vertical flow down to the saturated zone and S is the storage coefficient of the soil.

$$\bar{z}t + \Delta t = \bar{z}^t + \frac{q_{GW} - \overline{q}_v}{S} \Delta t \mathrm{T} \tag{7}$$

In summary, there are two central equations derived by the TOPMODEL theory. The first relates the mean groundwater level within the catchment, $\bar{z}$, to the local groundwater level at any location i within the catchment (equation (5)). The second links the catchment runoff from the saturated zone, q_{GW}, to $\bar{z}$, (equation (6)).

The following assumptions have been made to derive the equations:

(a) hydraulic gradient equals surface gradient,

(b) exponential decrease of transmissivity with depth to water table,

(c) lateral groundwater flow,

(d) no lateral unsaturated flow,

(e) steady state flow rates, and

(f) spatially uniform recharge (always larger than zero).

Assumption (a) – (f) often have been found to be reasonable. Assumption (a) can be relaxed using the concept of reference levels and other than exponential functions can be used to describe the decrease of transmissivity (b). Assumption (e) and (f) are difficult to relax within the framework of TOPMODEL and their impacts may be somewhat puzzling (**Jan Seibert,** 1997). Thus Jan Seibert has tried to motivate the need for further research before TOPMODEL can be used to simulate groundwater dynamics.

2.4 BTOPMC – Physically based distributed hydrological model based on the block-wise use of TOPMODEL with Muskingum-Cung flow routing method.

The distributed modelling of hydrological interactions by numerical simulation model soon faces a problem known as parameter estimation crises. Particularly in areas with constraints on data availability, the question arises of how the hydrology of such areas can be better understood. In this contribution, attention is drawn to the qualitative information contained in remotely sensed images and to the follow up by using conceptual models (**Takeuchi et al.**, 1999).

There are many river basin simulation models. Each has different temporal and spatial characteristics and data requirements. Thus selection of the most appropriate model for a given purpose and conditions is an important decision. Following a review of a number of different models that could be adapted for use as hydro-environmental simulation models, it was revealed that a model applicable to a large ungauged basin is still missing. Thus this proposed a block-wise use of TOPMODEL with the Muskinguni-Cunge routing method to fill the gap. Some uses were made that showed the potential use of the new model: one for the 3570 km^2 Fuji-kawa basin, central Honshu. Japan and the other for the 20750 km^2

northern part of Minjiang basin, an upper branch of Changjiang (the Yangtze River), China. The Fuji-kawa case was an example where ample hydrological, land-use, and geological data were available, while the Minijiang case demonstrate the application to a river basin where only geographical elevation data and some precipitation data were available.

2.4.1 Theory of the Hydrological Simulation Model (BTOPMC)

This section briefly introduces the basic framework of the hydrological simulation model that forms the governing scheme of the eventual hydro-environmental simulation including water quality dynamics. It is made up of the block wise use of TOPMODEL for flow-generation and the Muskingum-Cunge method for flow routing. The description below is by no means comprehensive but focuses on the advantageous characteristics of the model for a large ungauged basin and identifies the specific assumptions used in this study. A more detailed description of the model is given in **Ao et al.** (1999).

Flow generation – block-wise use of TOPMODEL

In TOPMODEL, the discharge is composed of overland flow and baseflow where:

- overland flow occurs as saturation excess from the saturated zone; the saturated zone is called the contributing area; infiltration excess runoff may be added but is not considered in the standard TOPMODEL,
- groundwater discharge is considered semi-steady depending on the saturation deficit; the hydraulic gradient is assumed parallel to the ground surface.

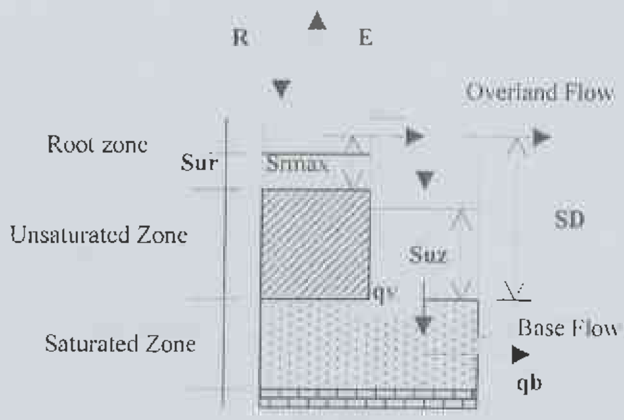


Fig. 1 TOPMODEL structure for a single grid cell.

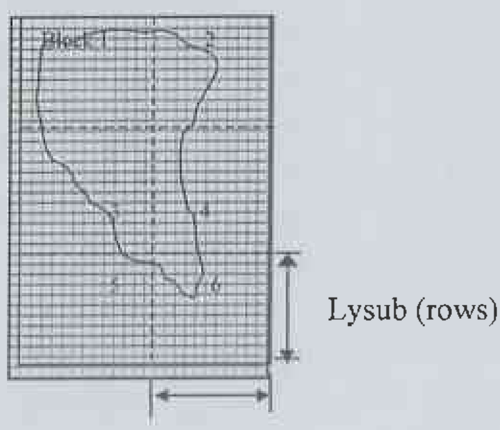


Fig.2.Sub-division of a large basin into blocks, each block is made up of a number of grids

The saturation deficit controls the discharge from the local area. The local saturation deficit is determined from its basin or block average with the deviation depending upon local soil-topographic index $\ln[a/(T_0 \tan\beta)]$ relative to its sub-basin (or block) average γ. The critical control on discharge is the soil-topographic index that is a function of topography and soil types.

The basis of the model structure is described below and shown in Figs 1 and 2.

Grid: The basin is described by a digital terrain model with the grid size, 30"x30" or the order of 0.7-1.0km.

Block: The basin is divided into a suitable member of blocks. The size of blocks depends on the scale of the basin and the heterogeneity of the basin topography and land cover. It should be within a manageable size for which the parameters can be identified by satellite information.

Average saturation deficit: In each block, the saturation deficit $\overline{SD}$ (expressed in m, i.e. volume per unit area) is calculated with the initial condition being $\overline{SD}$ (0). $\overline{SD}$ is the space available in the unsaturated zone for further recharge. $\overline{SD}$ at time t can be successively calculated as:

$$\overline{SD}(t+1) = \overline{SD}(t) - Q_v(t) + Q_b(t)$$

where Q_v (t) (a sum of $q_v(t)$ over all grids in a block) is input to groundwater from the unsaturated zone and $Q_h(t)$ (a sum of $q_b(t)$ over all grids in a block) is the groundwater discharge to the stream (both expressed in m. volume per unit area). Thus the saturatin deficit decreases with net groundwater recharge and vice versa.

Local saturation deficit: The saturation deficit for the ith grid cell. SD (i,t) at time t is calculated from the block average deficit. SD (t), using the magnitude of the local soil-topographic index $\ln[a/(T_0\tan\beta)]$ relative to its block average γ. (a and β are different for each grid cell while T_0 is constant over a block). Thus:

$$SD(i,t) = \overline{SD}(t) + m(\gamma - \ln[a/(T_0\tan\beta)])$$

Where m is a decay factor of lateral transmissivity with respect to saturation deficit (m). Note that the second term of the right hand side $(m(\gamma - \ln[a/(T_0\tan\beta)])$ is a constant unique to the i^{th} grid cell and is independent of the average block saturation deficit $\overline{SD}(t)$. This implies that the spatial variation pattern of saturation deficit is always same within a block and only its base level changes over time. *This equation provides the link between the lumped model and distributed modelling concepts.*

Root zone: Rainfall on the ith grid cell is first received by the "root zone" storage, which represents interception, depression storage and initial soil moisture storage at moisture contents below field capacity. The maximum capacity of the root zone is S_{rmax}. Until it is filled, no water can percolate under gravity to the unsaturated zone. The storage in root zone S_{rz} (i,t) changes over time as:

$$S_{rz}(i,t) = \{S_{rz}(i, t\text{-}1)+R(i,t)\text{-}E(i,t)\}^+$$

Where R is precipitation, E is evapotranspiration and $\{ . \}^+$ indicates the value of $\{ . \}$if it is non negative and zero if negative.

Unsaturated zone: The excess of roet zone storage goes into the unsaturated zone and initially increases the unsaturated zone storage S_{ug} as:

$$S_{uz}(i,t) = S_{uz}(i,t\text{-}1)+\{S_{rz}(i,t)\text{-}S_{r\,max}(i,t)\}^+$$

Groundwater recharge: Drainage from the unsaturated zone goes, groundwater and is controlled by the local saturation deficit and infiltration capacity K_0 according to:

$$q_v(i,t) = \min\{K_o e^{\text{-}SD(i,t)/m}, S_{uz}(i,t)\}$$

S_{uz} is revised as:

$$S_{uz}(i,t) = S_{uz}(i,t) \text{-} qv(i,t)$$

Overland flow: If drainage to the unsaturated zone exceeds its storage capacity, the local storage deficit, SD (i,t), the excess becomes overland flow as:

$$q_{of}(i,t)=\{S_{uz}(i,t) - SD(i,t)\}^+$$

If SD (i,t) is negative it is replaced by zero and all S_{uz} (i,t) becomes overland flow. The storage is revised as

$$S_{uz}(i,t)=\{S_{uz}(i,t) - q_{of}(i,t)$$

Groundwater How: The groundwater discharge is determined by the local saturation deficit, the gradient of the local surface and the parameters relating to transmissivity of the block, T_o and m. as:

$$q_b(i,t)=T_o e^{\text{-}SD(i,t)/m}\tan\beta$$

The discharge from the ith grid cell to the stream is the sum of qo_f (i,t) and q_b(i.t). Both are dependent on local saturation deficit SD (i,t). Rainfall R(i,t) affects discharge through S_{uz} and the saturation deficit for the following time step.

Flow routing (muskingum-Cunge) method used in BTOPMC

The Muskingum cunge method is useful for simulating a large stream network since it can successively calculate the flow rates at all stream-network modes at a single time without being disturbed by the time differences of flow wave arrivals at each junction of streams. However, it cannot allow for backwater effects.

The channel section at the ith grid point is assumed to be of wide rectangular shape with the width β as a function of the upper catchment area A (km^2) at the point as:

$$B=\alpha A^c$$

Where α and c are constants and Manning's roughness n at each grid is determined by:

$$n=n_0(\tan\beta/\tan\beta_0)^{1/3}$$

Where β is the surface gradient as defined above and subscript θ indicates the average value for the block.

2.5 Tank Model

The tank model is usually classified as a deterministic parametric lumped model and it is considered as a black box model by many hydrologists. However, if it is a mere black box, how can such a simple tank model successfully simulate river discharge from high flood to low base flows? There must be some physical meaning in the tank model (**M.Sugawara**, 1984). The tank model had its origin in the idea that to represent surface runoff and intermediate runoff two water storage are necessary. Two more storage was introduced to represent base flow and the present form of the tank model was obtained. This can include the water storage for the base flow. To some extent these are the physical meaning of the tank model. On the surface of the ground there are river channels by which the most part of surface water transportation is carried out. However, the area of the river channel is negligibly small compared with the whole area of a basin. Therefore, if random sample points are picked up in a basin, the probability that some sample points fall on a river channel must be very small, probably near to zero, even if the sample size is very large. Similarly if we select some small random sample area in the basin, the possibility that the sample area would include a river channel is also very small. This means that, by such a random sampling method, we cannot catch the real image of water transportation on the ground surface. The structure under the ground surface cannot be observed but can be imagined that the transportation of groundwater is mostly carried out through some singular domains such as sediment layers, faults, fissures etc. and that the total volume of such singular domains is very small compared with the whole volume. Even in a homogeneous sediment layer, water is imagined to transfer mostly through routes of three-dimensional networks, which is somewhat similar to river channels on the ground surface. Of course, these water routes are not stable. Some routes will be stopped by sedimentation and other routes will be opened by washing away of sand and silt. In spite of such an unstable microstructure of three-dimensional network-like water routes, the sediment layer seems to be homogeneous in microscopic outlook. The structure of ground water movement in a basin may be somewhat similar to this but on a larger scale. In the case of such a structure in which water transfer occurs mostly through a singular domain with comparatively very small volume, research or experiments carried out by sample points or by small sample areas cannot be reliable. This may be a reason why experimental basins are not so useful and why transfer of the results obtained from experimental basins to large basins is very difficult. There is another difficult fundamental problem concerned with such structures. A water route will be stopped when it is blocked only at one point along the route and an impermeable layer will pass water freely when there is only one hole somewhere in it. The total response of such structures is very difficult to analyze as a total by some macroscopic method. Moreover, we expect that the tank model is such a sort of approach by total response. In the early days, the trial and error procedures were carried out by manual calculations regarding as a numerical experiment; with much information accumulated through trial and error procedures. It was troublesome hard work and it took a long time but model calibration by trial and error method proved possible. In later days, computers are used in trial and error method. A feedback cycle composed of a computer and human judgement was very effective and efficient. Automatic and semi-automatic methods for parameter estimation have been developed in Tank Model. Trial and error method by human subjective judgement is the most important way (**M. Sugawara**, 1984)

RWBAT is a regional water balance model based on the concept of the Tank Model. The purpose of the study on the RWBAT modal is to develop the hydrological model assessing the variation of water resources and soil moisture over wide area with the spatial resolution of 0.5*0.5 degrees in longitude and latitude on a daily basis, when extraordinary fluctuation of Asian Monsoon activity is occurred or large-scale reclamation is carried out. RWBAT model uses the Tank Models because the concept of the Tank Model is so simple and presents adequate hydrological response in the basin by using four simple Tanks lied vertically. Moreover, the Tank Model is used in various regions from arid to humid area and from tropical to snow covered area. If parameters of Tanks are derived from the catchment characteristics, such as topography, surface geology and vegetation indexes, reasonably, the RWBAT model could give precise information for water resources against an extraordinary weather condition (**Kazurou Nakane**. 1997).

2.6 Hydrological Model Calibration and Verification

Model calibration is the process by which the values of models parameters are identified for use in a particular application. It consists of the use of rainfall-runoff data and a procedure to identify the model parameter. Identification can be accomplished manually, by trial and error, or automatically, by using mathematical optimization techniques.

Calibration implies the existence of stream-flow data; for ungaged catchments, calibration is simply not possible. The overall importance of calibration varies with the type of model. For instance, a deterministic model is generally regarded as highly predictive; therefore, it should require little or no calibration. In practice, however, deterministic models are usually not entirely deterministic, and therefore, a certain amount of calibration is often necessary.

In conceptual modeling, calibration is extremely important, since the parameters bear no direct relation to the physical processes. Therefore, calibration is required in order to determine appropriate values of these parameters. Practical estimates of conceptual model parameters, based on local experience, are sometimes used in lieu of calibration. However. such practice is risky and can lead to gross errors. Calibration also plays a major in the determination of parameters of empirical models.

The calibration needs of time-invariant and time-variant process and models are different. To evaluate the predictive accuracy of a time-invariant model, it is customary to divide the calibration process into two distinct stages: (1) calibration and (2) verification. For this purpose, two independent sets of rainfall-runoff data are assembled. The first set is used in the calibration per set, whereas the second set is used in model verification, i.e., a measure of the accuracy of the calibration. Once the model has been calibrated and the parameters verified it is ready to be used in the predictive stage of the modeling.

With time-variant process and models, the calibration is quite involved. Since the parameters vary in time (and with the model variables), a calibration and verification in the liner sense is only possible within a narrow variable range. A practical alternative is to select several variable ranges, e.g., low flow, average flow, and high flow, and to perform a calibration and verification for each flow level. In this way, a set of model parameters for each of several variable ranges can be identified. A typical example of multilevel (i.e., multistage) calibration is that of stream channel routing. The routing parameters for inbank flow is likely to be quite different from those of over-bank flow. Therefore, several calibrations are needed, encompassing a wide range of flow levels.

Lumped and distributed models pose altogether different calibration problems. Lumped models have a relatively small number of parameters as compared to distributed models. For lumped conceptual models, calibration in the liner sense is possible. In this case, parameter estimations can often be obtained with automatic calibration impractical and sometimes misleading. Accordingly, it is often advisable to limit the model parameters within physically realistic ranges and to perform trial-and-error calibrations (**Vijay P. Singh**, 1984).

2.7 Sensitivity Analysis in Catchment Modeling

Uncertain in catchment-modeling practice have led to increased reliance on sensitivity analysis, the process by which a model is tested to establish a measure of the relative change in model results caused by a corresponding change in model parameters. This type of analysis is a necessary complement to the modeling exercise, especially since it provides information on the level of certainly (or uncertainty) to be placed on the result of the modeling.

The issue of model sensitivity to parameter variation is particularly important in the case of deterministic models having some conceptual components. Because of the conceptual components, calibration are strictly valid only within narrow variable ranges; therefore, errors in parameter estimation needed to be ascertained in a qualitative way.

Sensitivity is usually analyzed by isolating the effect of a certain parameter. If a model is highly sensitive to a given parameter, small changes in the value of this parameters may cause correspondingly large change in the model output. It is therefore necessary to concentrate the modeling effort into obtaining good estimates of this parameter. On the other hand, insensitive parameters can be relegated to a secondary role.

In catchment modeling, the choice of parameters for sensitivity analysis is largely a function of problem scale. For instance, in small catchments, the models output is highly sensitive to the abstraction parameter(s), e.g., the runoff coefficient in the rational method. Therefore, it is imperative that the runoff coefficient be estimated in the best possible way. For low-frequency events, higher values of runoff coefficient are generally justified.

In midsize catchment modeling, the model's sensitivity usually hinges on the temporal rainfall distribution, infiltration parameters, and unit hydrograph shape. The selection of rainfall distribution is crucial from the design standpoint. Catchment models are usually very sensitive to infiltration parameters, which need to be evaluated carefully, with particular attention to the physical process. For instance, a high-intensity, short-duration storm may result in a high flow peak, due primarily to the high rainfall intensity. However, a low-intensity, long-duration storm may also result in a high flow peak, this time due to the long rainfall duration, which causes the hydrologic abstractions to be reduced to a minimum.

In large-catchment modeling, the modeling, the model's sensitivity focuses on the spatial distribution of the storm, although the temporal distribution and infiltration parameters continue to play a significant role. In any case, a careful evaluation of model sensitivity is needed for increased confidence in the modeling results.

Sensitivity analyses provide an effective means of coping with the inherent complexities of catchment modeling, including the associated parameter uncertainties. In this sense, distributed models, while being widely regarded as deterministic, can often show a distinct probabilistic flavor (**Vijay P. Singh**, 1984).

3. BTOPMC - A DISTRIBUTED HYDROLOGIC MODEL

3.1 Introduction

The BTOPMC is a physically based distributed hydrological model based on the block-wise use of TOPMODEL with Muskingum-Cunge flow routing method (Ao, Ishidaira, Takeuchi. 1999; Takeuchi, Ao. Ishidaira. 1999), for which the computer programs are written in standard FORTRAN77 source code. This is the first version by which the runoff simulation for Multiple sub-basins in a large catchment can be conducted simultaneously by using the GIS and remote sensing oriented data.

It is a part of the recent research results developed by **Takeuchi/Ishidaira Laboratory, Department of Civil and Environmental Engineering, Yamanashi University, Kofu, Japan**. Ao Tianqi wrote this version in 1998 under the supervision of Professor Kuniyoshi Takeuchi and Dr. Hiroshi Ishidaira at Yamanashi University. It has been under developing and revising until now and will be further developed in the future.

Up to now, this version has been applied to the daily and hourly runoff simulation for the 3500 km^2 Fujikawa basin in Japan and to the daily simulation for the 19 000 km^2 sub-basin of Minjiang catchment in China. The results presented are encouraging to suggest that the proposed model can be reasonably applied to large basins with DEM and other GIS oriented data.

3.1.1 The component models for this distributed rainfall-runoff model

a) Runoff Generation Model:

In this version the block-wise use of TOPMODEL is proposed: the model parameters and the average Soil-Topographic-Index are calibrated or computed for each block , respectively. The original TOPMODEL was development by Professor Beven, K. J. and Professor Kirkby, M. J. in 1979, which is a physically based variable contributing area model of basin hydrology. It has two distinct advantages to be applied in developing areas with little hydrological observations. One is that it has both advantages of lumped model and distributed model, i.e., few parameters to be identified and the capability of simulating the impacts of land use changes and water resource system developments. The other is that the soil-topographic index that the model greatly depends on may be easily identified through satellite information.

b) Routing Model:

The variable coefficient Muskingum-Cunge routing method was used. By which the river reach characteristics can be considered and the velocity, discharge and etc. for any grid can be obtained simultaneously.

c) Terrain model:

River stream network are produced from the DEM with sinks removed automatically by the algorithm developed by us.

d) Precipitation model:

Approximated by Thiessen Method: for any grid cell, the rainfall is given the value of the nearest rain gauge, basin averaged rainfall can also be used.

e) Evapotranspiration model:

In this first version, the program to calculate the potential or actual evapotranspiration is not supplied. It can be done by the user and the result should be used as input data for the related input data files. The monthly constant and hourly constant patterns are assumed for annual lowflow and short period flood simulation, respectively.

3.1.2 What can BTOPMC do?

1) The catchment boundary, drainage area, the length of the main stream and the detailed information about the river stream network can be obtained automatically.

2) The model calibrating can be conducted interactively as the program runs.

3) The lowflow or flood runoff for multiple subcatchments in large watersheds with DEM and other GIS oriented data can be simulated simultaneously.

4) Be capable of considering the impact of the variability of topography, climate, land-use, vegetation and soil characteristics on basin hydrological response characteristics.

5) With the availability of both lumped block-scale and distributed grid-scale initial conditions.

6) All the necessary results are output as data files which can be used to graphing by suitable, software, and some important assessment indices are pint out on the screen.

3.1.3 Limitations of The Current Version

At present time, because of the limitation of the memory of the related arrays, basin rainfall-runoff simulation can be conducted with the following limitations.

Total time steps: □**27000 steps** (e.g., hourly successive simulation for 3 years.)

The amount of observed discharge: □**9100 times /station**.

The DEM grid size has **no limitation**, but the total grid cells of the DEM should be □**80000 grids**. The whole basin can be divided into □**1000 rectangular blocks**.

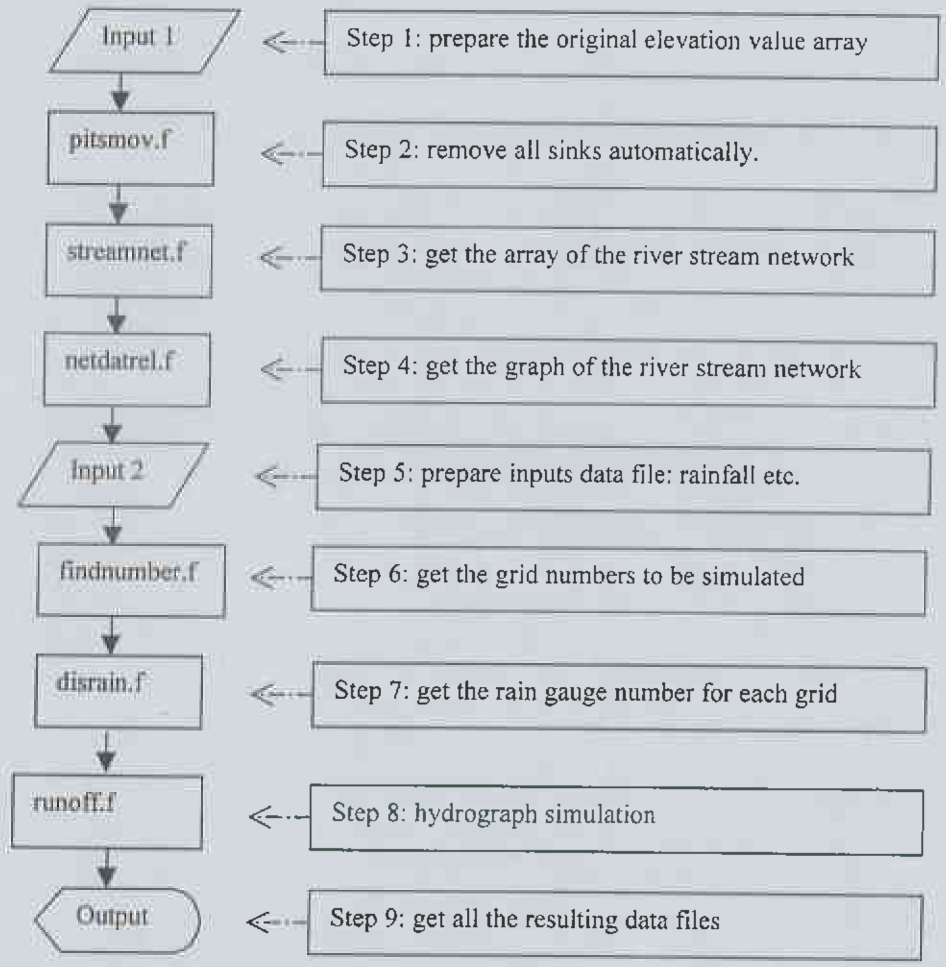
The number of gauging stations or the total number of sites to be simulated simultaneously in a run: □**20 places** (the related simulation results such as discharge for only □20 points can be output as a data file.)

The total number of rain gauge stations: □**100 places**.

3.2 The Use of Version 1.0

The program files are supplied in **standard Fortran77 code**, and should be compiled with any Fortran 77 compiler. The objectives, input and output data for some programs are described bellow .

3.2.1 The Flowchart of BTOPMC-1.0



3.2.2 The input data

- In order to make the programs easy to use, two methods for inputting the required data are designed for all the programs supplied.
- The first one is by key board interactively as the program is running. By which the program optional or controlling variables will be input. The brief guiding sentences will appear on the screen.
- The second one is to read in the input data files by some main program or subroutine automatically. The input data files must be prepared by manual input or by other program before or as the program runs. The file names of all the input data fills are **10 letters** defined by a character variable **fname** which will be input by hand for each program, accordingly, the names of all the output data files will be the same as the input except for the expanded file names.
- Be careful to the format of the input data: integer or real.

3.2.3 The calibrating of the model

There are only 5 parameters, described in table 3.1, that need to be calibrated by trial-and-error method interactively and successively until satisfied as the program runs, namely on-line calibrating.

Table 3-1: BTOPMC model parameters

Symbol	definition	the referential value
T_0	The saturated transmissivity of soils	0.1—100 m²/h
m	The decay factor of T_0	0.01—0.3 m
Sr_{max}	The capability of root zone storage	0.001—0.02 m
$S_{bar}0$	The initial saturation deficit of soil	0.05—0.80 m
n	The Manning roughness coefficient	0.01—0.08

The main criterion to evaluate the model performance is the Nash efficiency, near to 100% is the best. In addition to this, the comparison of the calculated and observed average discharge, peak time as well as the ratio of the total volume can also be used to evaluate the simulation results, respectively. In each run, all those assessment indices for each sub-basin are printed out on screen and as resulting data file.

3.3 Description of the Computer Programs

In this part, 3 programs, the **pitsmov.f streamnet.f runoff.f** will be described separately. Note that the explanation of the other 3 programs, **findnumber.f, disrain.f** and **netdatrel.f**, are not included, but are self explanatory since they are written in a dialogue type. The latter 3 programs are used to find out the grid numbers of simulation sites according to their drainage area, to produce the data file **fname.sit** containing the rain gauge number for each grid, to rearrange the format of the data file **fname.vct** to make stream network graphing feasible for the software DeltaGraph 4.0, respectively.

1) **Program pitsmov.f**

It is used to remove the sinks in the original DEM by an automatic algorithm proposed by us. A new DEM without sinks will be print out as a data file which will be used repeatedly in other programs.

a) **The input and output data files**

Table 3-2: Input and output data files for pitsmov.f

Item	File Name	Description
Input	fname.hhh	The original elevation data file prepared by the user. It is a two dimensional integer array which must have the format described in.
Output	fname.rst	A modified real format DEM data file without sinks, it will be read in directly by the other programs.
	fname.dhv	Contains the elevation increment of each grid after modification, it's format is the same as fname.rst.
	fname.pup	Elevation variance analysis, now it's useless.
	fname.cpa	Contains the elevation variance, useless.

b) The format of the original elevation data file

fname.hhh is a raster elevation matrix, a two dimensional integer array prepared by yourself, and with a volume of **maxro×maxco**,

where, **maxco=120ncol+1□1201** is the maxmum column,

maxro=120nrow+1□1201 is the maxmum row of the array, respectively.

The original DEM file **fname.hhh** will be read in from the upleft corner to the lowest right corner by row by row.

To prepare for this array, the value of **nrow** and **ncol** must be decided from a map by

which the whole basin will be covered, here **nrow** and **ncol** is the amount of the sub-DEMs in horizontal and vertical direction, respectively, each sub-DEM has a volume of 121×121grids. A sample was shown in Fig. 3

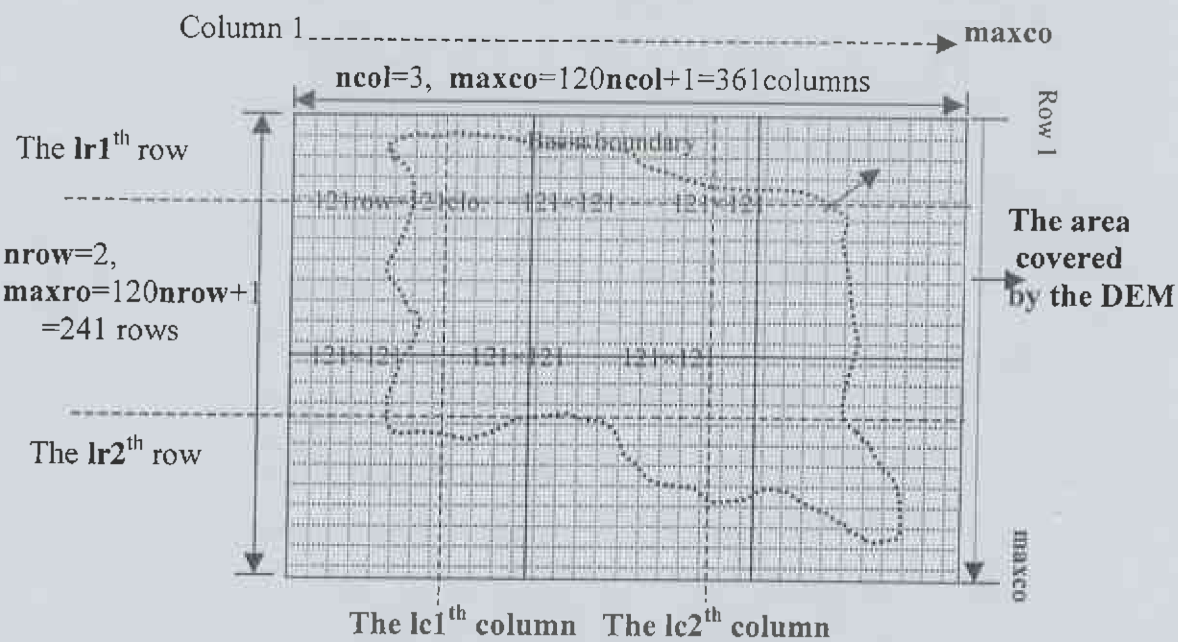


Fig. 3 The format of file fname.hhh and the definition for some variables.

c) The Input Variables By Hand

As the program is running, the user will be asked to input the following optional and controlling variables by keyboard interactively.

Symbol	**value (format)**	**description**
nrow, ncol:	integer	The values should be decided as in fig. 3.
h_0	0.1	It is our numerical experimental result.
nt	integer	The total times for the program to circle to remove all the sinks in the DEM, say more than 5000.
fname	10 characters	The name of all the input and output data files.

lr1, lr2, lc1, lc2 integers To abstract a small study area from the DEM, which begins from the lr1th row, the lc1th column, ends at the lr2th row and the lc2th column, as shown in Fig. 5. In this case, the stream net for **only this area** can be gotten.

2) Program streamnet.f

It is used to obtain the river stream network.

a) List of the input and output data files

Table 3-3: Input and out put data files for strument.f

Item	File Name	Description
Input	fname.rst	The DEM with sinks being removed by program **pitsmov.f**
	fname.slp	Contains the detailed information of the stream net.
	fname.see	Contains the main results and evaluate indices such as the basin area ,the length of the main stream and so on.
Output	fname.map	Contains the original elevation values for graphing.
	fname.vct	Contains the information to produce the graph of the stream net.
	fname.mve	The flow direction of water pathway in each grid, useless.
	fname.riv	Contains the information to produce the graph of the stream net

b) List of the variables input by hand

fname 10 characters The file name for all the input and output data files.

nrow, ncol integers As shown in Fig. 3.

dx, dy real The horizontal and vertical grid size, **in m**.

nchek1 integer; □48 The times to check the minus slope (2 is enough).

nchek2 integer The times to check the flow directions (2 is enough).

krule integer The stream net information for the grids with drainage area less than **krule** grids won't be written in file fname.riv. 1-30 is often used.

mpot positive integer Used to check the basin boundary.

rlenth 1.0-15.0 Used to calculate the length of the main stream, beginning from the grids with drainage area more than **rlenth** grids.

netord 3, 5, 10 In this version, they are not used.

c) **The format of data file fname.slp**

```
11616.0 5048.0 0.025652 3437.2409668 736.20 4.0 11617.0 586.28 0.0 666.0 83.0
```

Grid Number	Slop	Drainage area, Km^2	Length of the reach, m	Width of the
↓ 11616.0	↓ 0.025652	↓ 3437.2409668	↓ 736.20	↓ 586.28

3) **Program runoff.f**

It is the control program which direct the sequence of operations for the runoff simulation. Appropriate subroutines are called from **runoff.f** as needed for reading data, for finding out the sub-basin boundaries, for calculating the runoff in each grid cell, for flow routing, for optimizing the model parameters, for evaluating the model performance, and for outputting data.

In which

SUBROUTINE INPUT□reads in parameters and observed discharge data.

SUBROUTINE BASIN□decides the boundaries of the basin and sub-basins.

SUBROUTINE PARA□calibrates the model parameters.

SUBROUTINE ATANB calculates the topographic-soil-indices.

SUBROUTINE TOPMOD□calculates surface and subsurface flow, conducts flow routing and evaluates the model performance. The time increment loop is controlled by it.

3.3.1 List of the input and output data files

Table 3-4: Input and out put data files of runoff.f

Item	Full Name	Description
Input data files	fname.rst	The modified elevation array from program pitsmov.f
	fname.inp	Contains temporal variables, observed streamflow discharge and position variables for each subcatchment. By hand.
	fname.slp	A array containing the information of the stream network produced by program streamnet.f
	fname.coe	Contains the information of evapotranspiration, flow routing, and parameters for each block. By hand.
	fname.pri	Contains precipitation of all the rain gage stations. By hand or other program written by the user.
	fname.sit	Contains the number of rain gage for each grid within the basin. Used when distributed rain is needed. Produced by program disrain.f
Input Data Files	fname.rut	Contains the information of routing order, by this program.
	fname.mos	Contains the grid numbers for each subcatchment, by this program
	fname.ot0 fname.in0 fname.srz fname.uzi fname.sd0 fname.sb0	The grid-scale distributed initial values produced by this program. Cann't be used individually. It is not necessary to use them.
Output Data Files	fname.qsm	Contains the information of simulated and observed hydrography for the simulated places, and the rainfall and block average deficit for each time step are included.
	fname.eva	Contains all the evaluate indices such as Nashy effcience, peak time and etc. for all the subcatchments from all the successive runs.
	fname.qqq	Contains discharge information easy to produce hydrography when successively sensitivity analyze is conducted.
	fname.sat	Contains the saturated grids in the basin at the selected time steps.
	fname.con	Contains the total saturated times of each grids during the event.
	fname.ele	Contains aver. Elevation, slop, and total grids for each block.
	fname.tan	Contains the values of the topographic-soil-index for each grid in basin.
	fname.den	Contains the density distribution of the topographic-soil-index.
	fname.acp	Contains the cumulative distribution of the topographic-soil-index.

3.3.2 The format of the input data files prepared by hand or by other program

1) fname.inp

```
12574 8760.0 1.0 8760 7 1.0            ——>     nout, timsum, timstp, ntime, ngaug, hrs

11616 7317 5420 ......                 ——>     np1, np2, np3, ......
15.43 15.45 15.16 14.08 13.75 13.48 15.12 17.94 17.77 15.60       } The observed discharge
15.53 15.84 15.43 14.75 14.60 20.47 25.21 22.85 17.76 18.00       } at grid np1, in m3/s
..........................................................................
20.50 34.35 30.07 21.74 23.60 17.90 15.38 15.17 14.09 14.56 14.77 } The observed discharge
14.69 14.28 14.08 15.47 16.08 13.75 14.00 14.12 13.52 15.49       } at grid np2, in m3/s
..........................................................................
15.94 13.53 12.49 12.39 16.67 104.03 48.47 20.95 14.44 12.72      } The observed discharge
12.08 11.96 11.50 11.14 11.04 10.86 11.25 13.17..............     } at grid np3, in m3/s
..........................................................................
```

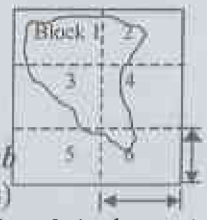
where:
nout is the grid number of the outlet for the whole basin obtained from program streamnet.f
timsum is the total time to be simulated, in hours.
timstp is the time step in hour.
ntime is the the total times for the program to circle, equals to **timsum / timstp**
nguag is the total numbers of the rain gages.
hrs is a converting factor, equals to **timstp**.
np1, np2, np3, ... are the grid numbers at which runoff will be simulated simutaneously. These numbers can be find out by program **findnumber.f**. Please note that the order **must be** arranged from the grid with the biggest drainage area to the grid with the smallest drainage area.

2) fname.pri the precipitation data file in **mm/h**.

No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	....	The rain gage number
2.00	2.00	2.00	2.00	2.00	3.00	3.00	...	time step 1
3.00	5.00	4.00	2.00	3.00	3.00	4.00	...	time step 2
5.00	3.00	3.00	4.00	5.00	5.00	5.00	...	time step 3
5.00	6.00	7.00	5.00	8.00	9.00	5.00	...	
1.00	3.00	3.00	3.00	2.00	2.00	5.00	...	
1.00	2.00	2.00	1.00	2.00	0.00	2.00	...	
1.00	2.00	2.00	2.00	2.00	3.00	2.00	...	

3) fname.coe

1000.0 →	The potential evapotranspiration E_p, in mm/year
1.1 0.6 10 →	**K, X, N**, where **K, X** is the Muskingum routing con., **N** is the total times to output the saturation information in the basin.
10 1 26 2 27 3 29 4 30 5 31 6 32 7 34 8 36 9 38 10 →	t_1, 1, t_2, 2, ,........, t_N, N; t_i means time step
31 28 31 30 31 30 31 31 30 31 30 31 →	**days** in each month from Jan. to Dec.
0.0238 0.0504 0.0837 0.1272 0.1439 0.119 →	$e_1, e_2, \ldots, e_{12}$; e_i (i=1-12) is the percentage
0.124 0.1214 0.0874 0.068 0.0352 0.016 →	of E_p in each month from Jan. to Dec..
31 59 90 120 151 181 212 243 273 304 334 365 →	$d_1, \ldots d_{12}$; d_i (i=1-12) is the days from Jan. 1 to the end of the i[th] month.
6.00 0.0365 0.005 0.00023 0.1200 0.085 0.0	Parameters for block 1
22.0 0.0385 0.005 0.00023 0.0500 0.088 0.0	Parameters for block 2
20.0 0.0385 0.005 0.00023 0.1290 0.035 0.0	Parameters for block 3
22.0 0.0385 0.005 0.00023 0.0500 0.088 0.0	Parameters for block 4
20.0 0.0385 0.005 0.00023 0.0345 0.035 0.0	Parameters for block 5
20.0 0.0385 0.005 0.00023 0.0345 0.035 0.0	Parameters for block 6



lysub (rows)

lxsub (columns)

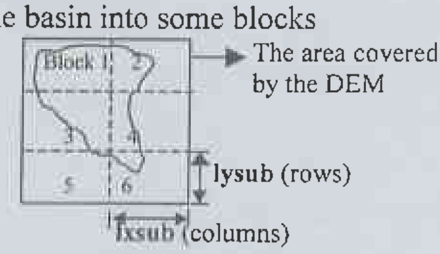
↓ T_0 ↓ m ↓ Sr_{max} ↓ evp ↓ S_{bar0} ↓ n_0 ↓ *no meaning*

Where parameter *evp* is a constant of evapotranspiration in m/h for short period floods simulation.

Note: the total blocks (□1000) can be determined by the user using the block size variables ***lxsub*** and ***lysub*** with the unit of columns and rows respectively.

3.3.3 List of the optional and controlling variables input by hand:

Symbol	Value (format)	Description
fname	10 characters	The name of the all input and output data files.
nrow, ncol	integer	As shown in Fig 3.
dx, dy	real	The horizontal and vertical size of a grid in the DEM, in Km.
nriver	integer	Controlling factor bigger than the total grids in the basin.
nlga:	integer (30 or 60)	A fact to classify the topographic-index into **nlga** grades.
nbsm	integer	The grid number which has the biggest drainage area among all the grids to be simulated.
keyq0	1	The initial discharge used to routing for each grid is given by program, the 6 data files of the distributed initial conditions which can be used in the next run will be produced.
	2	All the 6 kinds initial values will be read in from the data files produced by the previous run automatically.
inidat	integer (1-20)	The initial discharge used to routing in the first time step for the grids with drainage area less than **inidat** grids will be given 0.
inintl	integer (□**Timsum/kqfac**)	The time step at which all the 6 kinds distributed initial condition data files will be produced.
keyq02:	0	Produce the 6 kinds initial conditions by time step inintl.
	2	Produce the 6 kinds initial conditions by given discharge.
keyrout	1 (don't use it)	The surface and subsurface flow will be routed separately.
	2	The surface and subsurface flow will be routed all together.
rtmd	1.0	To use the Muskingum routing method.
	2.0	To use he Muskingum-Cunge routing method.
rainptn	1.0	The basin averaged rain will be used for all the grids.
	2.0	Distributed rainfall will be used.
kqfac	**ntime/N_{ob}**	A converting factor used to calculate all the evaluation indices of the model performance, where N_{ob} is the total numbers of observed discharge at a gauge station, e.g., **kqfac**=1and 24 for the case of hourly simulation, given hourly observed discharge and daily observed discharge, respectively.
keysub	0	The basin is seemed as 1 block
	2	Intend to divide the basin into some blocks
lxsub	proper integer	block size
lysub	proper integer	block size



Symbol	Value (format)	Description
kkevp	1	For short period flood simulation, hourly constant evapotranspiration in **fname.coe** will be used
	2	For lowflow simulation, monthly constant evapotranspiration in **fname.coe** will be used.
krtdat	0	The routing order data file **fname.rut** is not yet, and will be created in this run automatically.
	2	Read in the prepared data file **fname.rut** directly.
stphr	1.0	A constant.
nrunof	integer	Total amounts of places to be simulated(**<21**) simutaneously, for which the observed discharge should have been prepared

		in **fname.inp**, the assessment indices for each simulated place such as Nash efficience, the maximum peak time, maximum peak and average discharge of both observed and calculated, the average total rainfall, the outflow ratio, as well as the percentage of subsurface flow will be printout by both on screen and in data file **fname.eva**, respectively.
mosdat	0	Data file **fname.mos** does not exist, to be produced in this run automatically.
	2	**fname.mos** already exits, and will be read in by program.
ncicl	1	The program will run one time only, you can't calibrate any parameter, all the resulting files will be output.
	2	The program will run any time, you can optimize the model parameters until the satisfied results are gotten, all the resulting files can't be output during the calibrating runs unless **ncicl=1**. but the assessment indices will be printout on the screen.
cali	0.0	Model parameter calibrating is not intended to be done.
	2.0	Want to do.
nofsub	integer N	Some parameters for N^{th} block are intended to be calibrated
ncali	integer M□6	The M^{th} parameter of block N are intended to be changed. From 1 to 6, the corresponding order of the 6 parameters are arranged as: T_0, m, Sr_{max}, evp, S_{bar0}, n
val	any real data p	The value of the M^{th} parameter of block N will be changed to p from the previous value as you like.
h	1.0	a power used to calculate the soil-topographic index
key	1 or 8	The flow direction of water in a grid. Value 1 for single direction is often used; value 8 means multiple direction method.
khortn	0	The infiltration excess flow are not considered.
	1	The infiltration excess flow will be account for. In this version, selecting 0 is recommended.

3.3.4 Description of the principal output data files

1) **fname.eva**

R symbol sub-basin 1 sub-basin 2 sub-basin 3

The R^{th} Run

R	symbol	sub-basin 1	sub-basin 2	sub-basin 3		
1.0	Grid	5084.00	3147.00	1340.00	0.00	→ Grid number of the outlet
1.0	Rain	3.64	2.86	2.84	0.00	→ Total average rain in m.
1.0	Ep	3.60	3.60	3.60	0.00	→ Potential evapotranspiration in m.
1.0	Ea	0.78	0.85	0.92	0.00	→ Actual evapotranspiration,m
1.0	Qsim	2.75	2.11	2.25	0.00	→ Total simulated runoff, m
1.0	Qobs	2.01	2.26	2.30	0.00	→ Total observed runoff, m.
1.0	AvQs	151.00	71.79	32.54	0.00	→ Simulated aver. Discharge, m^3/s
1.0	AvQo	110.40	76.86	33.33	0.00	→ Observed aver. Discharge, m^3/s
1.0	Frat	0.76	0.74	0.79	0.00	→ Outflow ratio.
1.0	efif	88.15	82.59	91.30	0.00	→ **The Nash efficiency**.
1.0	rati	1.37	0.93	0.98	0.00	→ The ratio of volume.
1.0	bala	0.11	-0.11	-0.33	0.00	→ Water balance
1.0	pkTs	627.00	627.00	627.00	0.00	→ The peak time of simulation.
1.0	pkTo	627.00	627.00	627.00	0.00	→ The peak time of observation.

2) **fname.qsm**

Time Step	Surface Discharge m³/s	Subsurface Discharge m³/s	Total Discharge m³/s	Observed Discharge m³/s	Average Rainfall m/timstp	Average Saturation Deficit Sbr (m)		Sbr, in m for each sub-basin
1.00000	66.82320	64.89819	66.82320	65.43000	0.00027	0.09256	……	… 0.09256..
2.00000	64.98856	63.10693	64.98856	65.45000	0.00000	0.09413	……	0.09413
3.00000	63.22343	61.41070	63.22343	65.16000	0.00000	0.09567	……	0.09567
4.00000	61.53910	59.80854	61.53910	64.08000	0.00000	0.09716	……	0.09716
5.00000	59.94517	58.29432	59.94517	63.75000	0.00000	0.09862	……	0.09862

For sub-basin 1 **For sub-basin 2,……**

4. GENERAL DESCRIPTION OF THE TANK MODEL

4.1 Structure of the tank model

The tank model is a simple model composed of several tanks arranged vertically in series, as shown in Fig.4 Rainwater is put into the top tank. Water in each tank partially discharges through a side outlet or outlets and partially infiltrates through a bottom outlet to the next lower tank. River discharge can be simulated as the sum of outputs from the side outlets. Tank model represents a zonal structure of groundwater.

4.2 Behavior of the tank model

shows various types of response corresponding to various types of input rainfall. Let us consider a tank model composed of three tanks, where the top tank corresponds to surface flow, the second tank to intermediate flow and the third tank to base flow.

If the amount of rainfall is small or its intensity is light, the water storage in the top tank and the second tank would not rise up to the level of the side outlet and so the input water would infiltrate into the third tank without any discharge from the top and the second tanks, as shown in Fig.5a. As the base flow is largely constant because of the large amount of ground water storage, it would show little change from a small supply of rainwater. Accordingly, there would appear little change in the river discharge after a small rainfall or after rainfall of light intensity.

If there is some larger amount of rainfall (still with a light intensity) the water storage in the top tank will not rise up to the level of the side outlet but water storage in the second tank will rise up to a level higher than the side outlet, from which intermediate flow would discharge, as shown in Fig.5b. In this case, the river discharge would slowly increase and then gradually reduce.

In the case of a larger rainfall with a heavy intensity, the tank model would appear as in Fig.5c. In this case, the discharge, mainly composed of surface flow. would be large. The surface flow would be large. The surface flow would decrease quickly until what remained would be intermediate flow representing the recession component of the peak discharge.

In the case of very heavy rainfall with a short duration, the tank model would appear as in Fig.5d. with a large surface flow appearing without intermediate flow. After a while, this state would revert to the one shown in Fig.5c, and intermediate discharge would appear.

In the rare case of rainfall with short duration, only surface flow would appear, without any intermediate flow.

The tank model can simulate many such types of response corresponding to various types of rainfall input.

4.3 Time constants of the tank model

Each tank of the model can be changed into an approximation to a linear tank by moving the side outlet or outlets to the bottom, as shown in Fig.6. This linear tank model is called an incomplete integral or a first order lag system with a time constant $1/(\alpha+\beta)$, where the storage volume and both outputs – discharge and infiltration-decrease exponentially in the form of the function $Ce^{-(\alpha+\beta)t}$; assuming that there is no input supply.

With such a linear approximation, the discharge computed by the tank model will be composed of several exponential components, each of them with its own characteristic time constant. For analysis of daily discharge based on daily input data, we usually use a tank model with four tanks as shown in Fig.7, where the time constant of the first tank component is one day or a few days, that of the second tank is up to about ten days, and time constant of the third and the fourth tank components are several months and years, respectively.

4.4 The tank model for flood analysis

For flood analysis, usually a tank model with only two or three tanks are used. Usually the lower tanks are neglected because of their long time constants. The components from these tanks are stationary and, consequently, they would show only a small change during a flood period and, moreover, would be very small compared with the flood components. We can, therefore, assume that these components are constant during a flood and use some constant discharge from the lower tanks instead of calculating these components.

The time constant of the top tank of the tank model for flood analysis is nearly proportional to the square root of the catchment area. From the experience, using Japanese river basins, the relation is

$$T = 0.15\sqrt{S} ,$$

Where T (hour) is the time constant and S (km^2) is the catchment area. The time constant of the second tank is usually about five times longer than that of the top tank.

4.5 The tank as a sort of filter

In Tank model each tank can be considered as a sort of non-linear filter, which lets those components with short time constant discharge through the side outlet (s) and lets those components with long time constants infiltrate through the bottom outlet to the next lower tank.

4.6 Tank Model with Soil Moisture Structure

The tank model shown in Fig.7 has a soil moisture structure in the top tank. When the storage XA in the top tank is not greater than S1, water can neither infiltrate nor discharge as shown in Fig 6a.

In such a case XA represents primary soil moisture storage and there is no free water in the top tank, i.e. when XA≤S1, XP=XA, XF=0, where XP is primary soil moisture storage and XF is free water. When XA is greater than S1, the excess part will infiltrate or discharge through the outlets as shown in Fig.6.b. In such a case the primary soil moisture is saturated as XP=S1 where S1 is the saturation capacity of the primary soil moisture and the free water is given by XF=XA-S1, i.e. when XA>S1, XP=S1, XF=XA-S1. To put it simply, water fill the top tank from the bottom up and the lowest part forms primary soil moisture storage as shown in Fig.6. There is no soil moisture structure in the lower tanks since they are considered to be always saturated.

Free water in each tank discharges partly through the side outlet or outlets and partly infiltrates through the bottom outlet to the next lower tank. The amount of runoff or infiltration per unit time through an outlet is proportional to the head of water at the outlet. For convenience, the tanks are labeled A,B,C and D from the top, and consequently the runoff coefficients for each tank are called A1, A2, B1, C1 and D1; the infiltration coefficients for each tank are called A0, B0 and C0; and the heights of the side outlets of each tank are called HA1, HA2, HB and HC as shown in Fig.1. Similarly, variables such as water storage in each tank (X), runoff amount from the side outlet (Y) and infiltration amount from the bottom outlet (Z) give the suffix A,B,C or D as shown partly in Fig.10 where the symbol [ ] means that [X] = X when X is not negative, and [X]=0 when X is negative. In some cases runoff is assumed to be proportional to the square of the available head.

Along with the primary soil moisture storage there is secondary soil moisture storage and is situated alongside of the primary soil moisture storage. Input (rain and snowmelt) fills, at first, the primary soil moisture storage, and then, gradually, penetrates the secondary soil moisture storage Fig.9. Evaporation, when it occurs, is subtracted from the storage XA and the primary soil moisture storage becomes dry, then gradually, water returns from secondary soil moisture storage. The volume of water exchange between primary and secondary soil moisture storage is assumed to be

$$K2x\ (XP/S1-XS/S2),$$

Where K2 is some constant, XP (XS) is the volume of primary (secondary) soil moisture storage and S1 (S2) is the saturation capacity of primary (secondary) soil moisture storage. If this term is positive, water transfers from the primary soil moisture storage to secondary and vice versa. As XP/S1 and XS/S2 define the relative humidity of both soil moisture storage, this term also means that water transfers from the wet part to the dry part of the soil, with the rate proportional to the difference of their relative humidities.

When the primary soil moisture storage is not saturated, water is supplied to this storage from the free water is the lower tank. The volume of water is given by the expression.

$$K1x\ (1-XP/S1).$$

As XP/S1 is the relative humidity of the primary soil moisture storage, the above term means that the primary soil moisture structure absorbs the water from free water in the lower tank at a rate proportional to its relative dryness. The water supply to the primary soil moisture storage from free water is subtracted from the second tank, if there is some free water, and if the second tank is empty, water supply is subtracted from the third tank, if there is water, and so on.

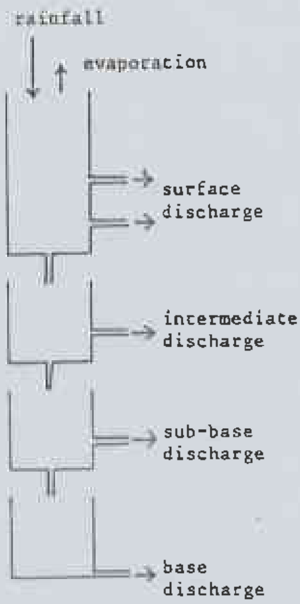


Fig. 4 Arrangement of tanks

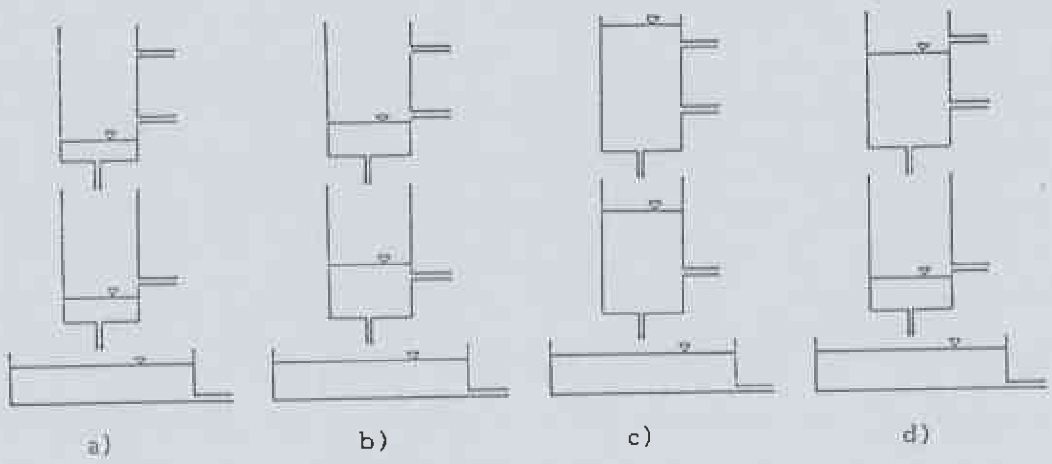


Fig. 5 Tank behavior

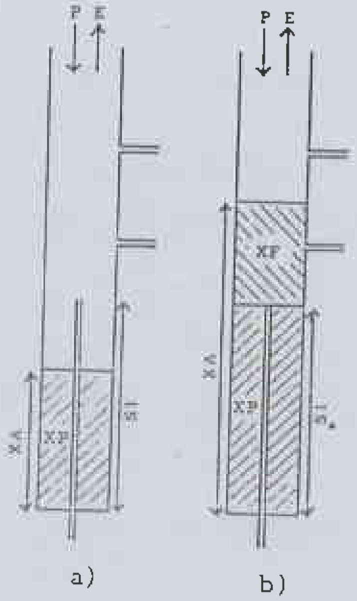


Fig. 6 Water storage in the top tank

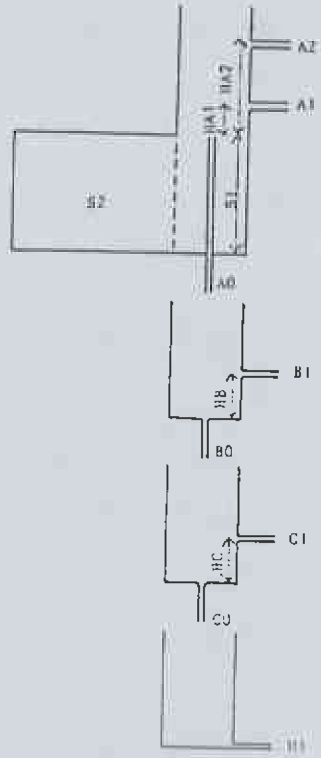


Fig. 7 Tank model with soil moisture structure

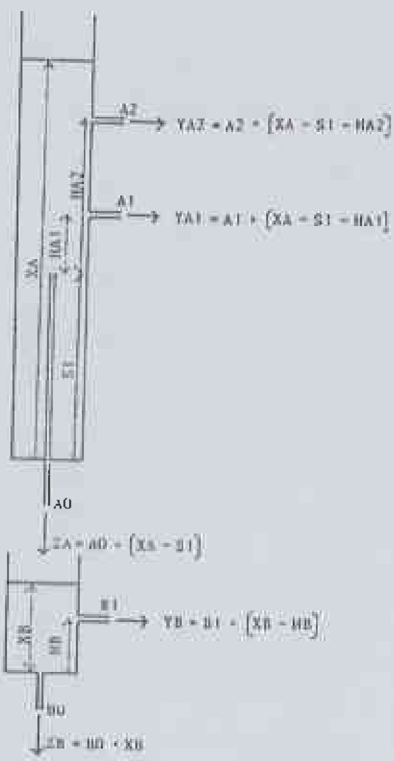


Fig. 8 Runoff and infiltration

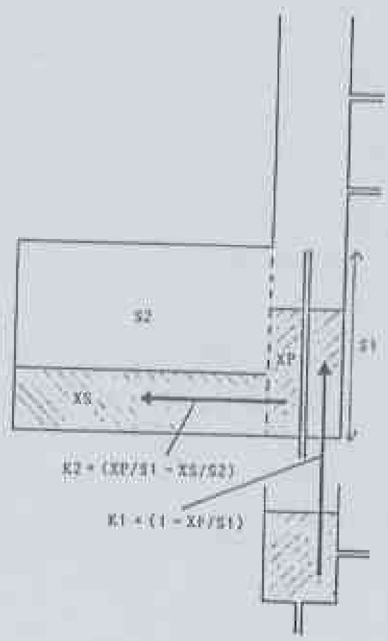


Fig. 9 Water transfer of soil moisture

5. STUDY AREA

5.1 General Characteristics of the country - Nepal

5.1.1 Location and Natural Features

Nepal is a landlocked Kingdom on the southern slopes of the Himalayan Mountains, the nearest sea coast being about 1,127 km form it's boarder. Located between northern latitudes of 26^0 22' and 30^0 27' and eastern longitudes of 80^0 4' and 88^0 12', it is bordered by the Tibetan region of China to the north and Indian to the south, east and west.

The country, with a total land area of 141,000km^2, is divided physically into the following 3 ecological zones stretching from east to west.

a) The Mountain Zone situated at an altitude exceeding 3,000m, accounts for 34% of the total area but only 5% of cultivated land.

b) The hill zone lying between 300-3,000m is a subtropical belt and occupies 43% Of the total area and 30% of cultivated land.

c) The Terai Zone lying below 300m forms the southern belt extending along the Indian boarder and accounts for 23% of the total area and 65% of cultivated land.

An alternative classification can be applied to Nepal based on three major river basins; 1) the Koshi Basin; 2) the Gandaki Basin; and 3) the Carnal Basin. These rivers, originating in the Himalayan Mountains, are snow-fed, perennial flows with significant discharge even in the dry season, and, as such, offer promising water resources for the development of irrigation, hydropower and other potentials.

5.1.2 Climate

Weather conditions vary from region to region. Annual mean temperatures range from high (25 ^{o} C) in the Terai Zone, to moderate (18 ^{o} C) in the Hill Zone, and to low (7.5 ^{o} C) in the Mountain Zone. Nepal has a monsoon climate, with average annual rainfall estimated at 1,600mm. On an average, about 80% of precipitation is confined to the rainy period (June – October).

5.1.2.1 Climatological features

The Himalayan Ranges has a great role over the meteorological conditions in Nepal. They prevent the dry cold air of the Tibetan region from moving into Nepal and impede the northward flows of warm moisture-laden air from the southeast monsoons. The climate of Nepal is divided into two seasons, the summer monsoon wet season which generally lasts from June to September and the relatively dry winter season.

5.1.2.2 Rainfall

The climate of most of Nepal is mainly characterized by the rainy season monsoon from June to September. It's intensity decreases from eastern part to the western part of country. The months from Oct. to May are mainly dry. Winter monsoon coming from the south-west

Arabian sea has stronger influences in the western parts of the country. Precipitation ranges from about 2,500 mm in many parts of the country to 250 mm in the extreme north-west. Maximum precipitation occurs mainly in the Terai Belt and near the gorges in the Mahabharat ranges. Precipitation as hail during the months of February and March is a local phenomenon in Nepal.

5.1.2.3 Temperature

The climate of Nepal is classified into four zones depending upon altitudes, viz. Subtropical-up to 1,000m, warm temperature – 1,000-2,000 m; cool temperature – 2,000-3,000 m; and alpine above 3,000 m. A tropical climate is in south and alpine climate is in the north. The temperature is lowest in the winter and increases as spring advances. Previous investigators found that the mean annual temperature of Nepal holds a linear relationship with altitude with a gradient of about 5 ^{0} C/km (Water and Energy Commission, 1982)

5.1.2.4 Wind and Snow

Wind has only a moderate influence on the climate of Nepal. Snow falls rarely below 1,500 m and regularly in winter above 2,000 m.

5.1.2.5 River basins and hydrology

There are thousands of rivers in Nepal. They are grouped in four major river basins: Carnal River Basin, located in the western part of the country, Gandaki River Basin, in the central region, Saptakoshi River Basin in the eastern part and southern River Basin. Besides above mentioned river basins there are two other basins, the Mahakali River Basin in the western and the Mechi River Basin in the eastern boarders with India. Major river basins are shown in Fig. 10 with the location of the gaging stations with corresponding rivers.

The three river basins extending to the Himalayan or on the Tibetan Plateau is in part snow or glacier fed, thus, having relatively high-sustained flow while the fourth is a rain fed basin.

Snowmelt and rainfall contribute mainly to the river discharges. Large flows are observed during the monsoon from middle of June to the middle of September, then the flow gradually decreases until the end of February. From March to the middle of the June, the end of the dry season, there is a gradual increase in flow due to snowmelt. But the effect of snowmelt becomes negligible for those rivers originating south of the Mahabharat range.

a) Saptakoshi river basin

It is the largest river basin of Nepal having total catchment area 81,152 sq.km of which 60% lies in Tibet. The rivers of this basin are comparatively steep and mainly snow and rain fed. The major rivers included in this basin are:

1) Bhotekosi	2) Balephi	3) Sunkosi
4) Tamakosi	5) Khimti	6) Likhu
7) Dudkosi and	8) Tamor	

b) Gandaki river basin

It lies in the central part of Nepal. The total drainage area of this basin is 31,000 sq. km. The river of this basin mainly snow fed. The major rivers of this basin are:

1) Kali Gandaki 2) Seti Gandaki 3) Marsayangadi

4) Chepe 5) Budi Gandaki 6) Trisuli and 7) Narayani

c) Karnali river basin

It is located in the western part of the country. The drainage area above Chisapani is 42.8900 sq. km. The main stem of this basin is the karnali, which originates from the Tibet. The major rivers of this basin are:

1) Surnagad 2) Carnal 3) Seti and 4) Bheri

d) Southern river basin

These are not influenced by snowmelt. The drainage area of most of the rivers doesn't go beyond the elevation of 3,000 m. msl. Maximum flow in these rivers occurs during monsoon and followed by a marked decrease through October, with a further gradual decrease until the beginning of the next season. Most of the rivers are dry for the considerable period before monsoon. The following are the major rivers included in this basin:

1) Babai 2) Mari 3) West Rapti 4) Manahari

5) Andhi 6) East Rapti 7) Lothar 8) Nakhu

9) Bagmati 10) Thado 11) Kulakhani and 12) Rosi

The numbering of the stations in these basins begins from the western part of the country and ends to the eastern part. Therefore, for convenience Region 1 refers to Carnal River Basin, Region 2 to Gandaki River Basin, Region 3 to Saptakosi River Basin and Region 4 to Southern River Basin.

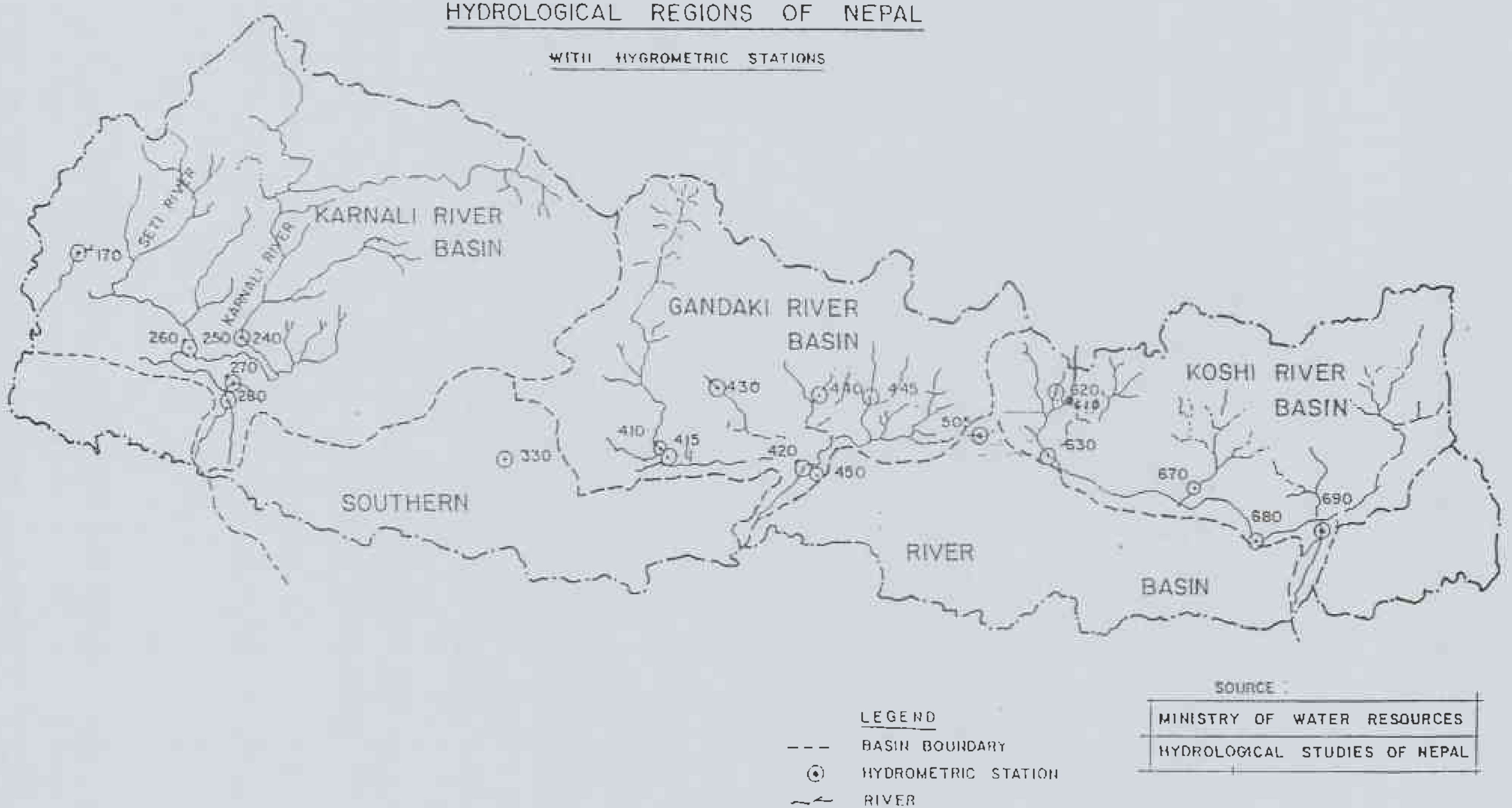


Fig. **10** major river basins

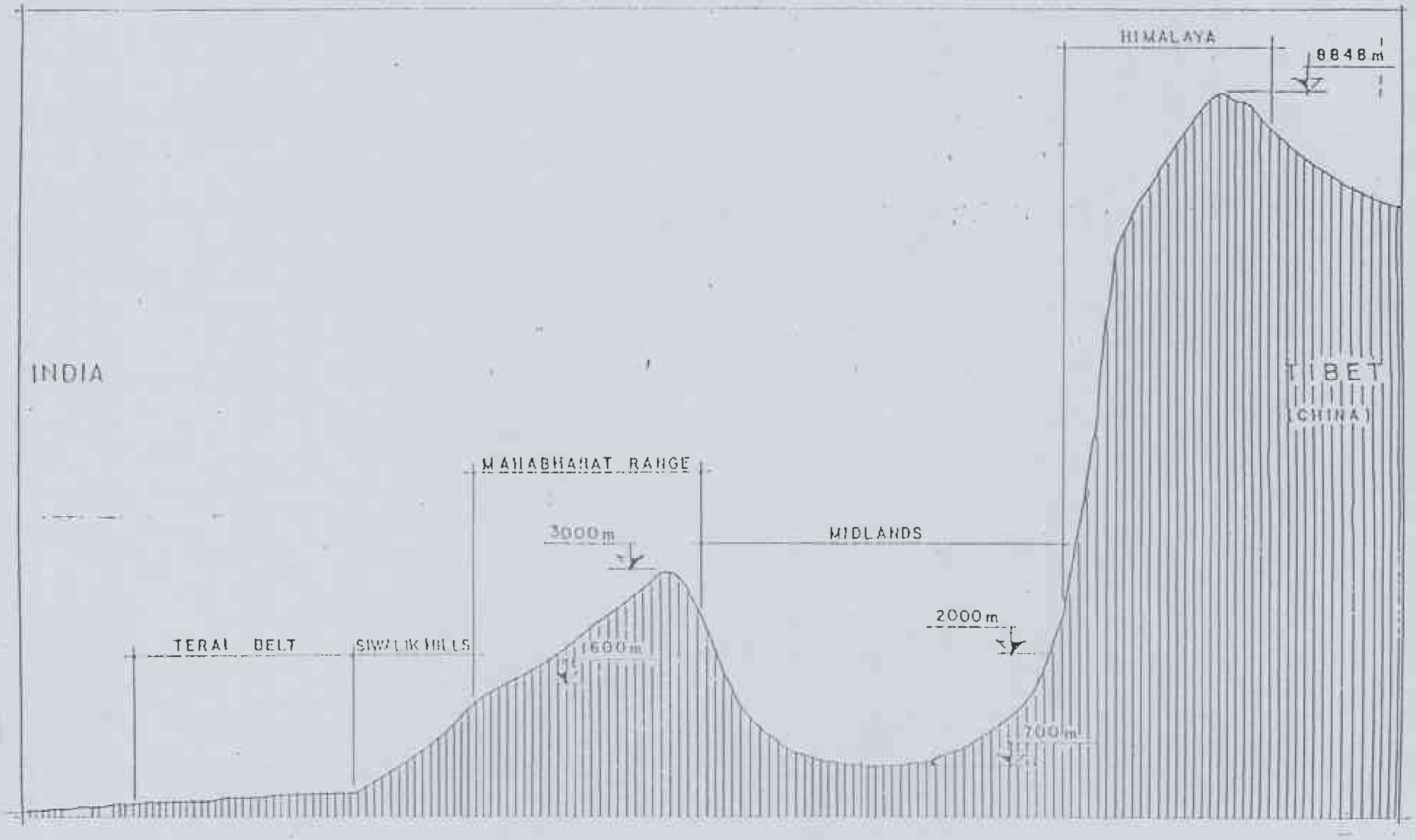


Fig. 11 SCHEMATIC PROFILE OF NEPAL

5.2 Physical Features of the Study Area (large-scale watershed, Sun Kosi basin)

5.2.1 Location and Topography

The study area – Sun Kosi river basin – lies with in the kosi basin. The study area is located in the eastern part of Nepal. The Kosi Basin is one of Nepal's 3 major river systems and lies between northern latitudes of 26 ° 50` and 28 ° and eastern longitudes of 85 ° 30' and 88 ° 12`. The catchment of the whole Kosi basin within Nepal is estimated to be 33,000 km^2.

Kosi basin is divided into three major topographic and ecological areas: the Mountain Area in the north, the hill area in the midland and the terai area in the south. Sunkosi basin lies in between the mountain area and the hill area. The mountain area is situated at an altitude exceeding 3,000m, with the highest point reaching to more than 8,000m. The hill area lying between 3,000-300m consists of high riges and steep slopes including the Mahabharat range and Siwalik Hills. The Terai area, lying below 300m, forms the southern belt extending along the Indian border. The fig. 13 below provides the topographical profile of eastern Nepal.

5.2.2 Geology and Soils

The Study area consists of three major geological zones: 1) Himal Group (granite, gneiss and schist); 2) Midland Group (clastic rock and carbonate). Moving from north to south, the rocks become softer and the rate of erosion consequently becomes more intense.

The geotectonic lines, which determine the geological structure of the area, consist of 2 major thrusting faults; the Main Central Thrust and the Main Boundry Fault. These faults extend in an E-W trend across Nepal, acting as the major division between the formation groups.

The mountainous region is in the process of large scale erosion, and sediment produced from the same is carried by the rivers to the lower reaches. Sediment volume in each river is great because of: 1) steep terrain; 2) young orogenic movement; 3) location in the subtropical monsoon belt and rainfall of over 2,000mm during rainy season (June to October) resulting in sediment runoff; 4) weathering of bedrock due to climatic conditions of high humidity and heavy rainfall, and location in the tectonic belt; 5) steep river gradient; 6) poor vegetation on the steep mountain slopes; 7) soil composition of easily eroded unconsolidated sediments; and lack of river treatment and soil erosion control schemes in both the mountains and lowland.

5.2.3 Climate

The area has two distinct seasons; dry season from November-May and the rainy season from June-October. Prevailing wins during the dry season are westerly while those in the rainy season are easterly, changing direction from the months of April to May, and October to November. During the above periods winds in the upper atmosphere are light and weather conditions are generally fair and stable.

Rainfall during the rainy season has a cycle of about 10-15 days; however, rainfall does not occur in every of the basin at the same time. Rainfall conditions also differ according to elevation. Areas over 3,000m have a high percentage of drizzle while those lower than 2,000m are subject to heavy downpours.

The study area has a difference in annual average temperature ranging from about 5-25 ° C. With the end of the rainy season and the coming of strong westerly winds in November, temperature drops rapidly reaching minimum temperatures in January. As temperatures during the dry season rise during sunshine hours and decrease quite suddenly with nightfall, daily fluctuation in temperature averages about 15-20 ° C.

Humidity during the rainy season has a monthly average of about 80%, with little daily variation in humidity. Humidity in the dry season, on the other hand, varies widely during a one-day period and is much lower than of the rainy season.

The majority of precipitation in this basin is borne from Bengal Bay by airflow during the rainy season. These air flows cross the Terai area to the Mahabharat range and the Himalayan Mountains with heavier rainfall along the plain and between the 2 mountain ranges, decreasing as the air-flows reach the higher altitudes in the Himalayan Mountains and pass over to the northern side.

Rainfall distribution in the Sunkosi basin is in a concentric circular pattern. Maximum rainfall in the Sun Kosi is 3,500mm with a minimum of 2,000mm and rainfall is particularly heavy in the upper reaches of the Sun Kosi along the Bhote Kosi basin where rainfall exceeds 3,500mm.

5.2.4 More about Sun Kosi River Study Area.

The total length of the Sun kosi River is approximately 330km, of which 280km lies in Nepalese territory. The river gradient is approximately 1/210 throughout the entire length of its course in Nepal and 1/450 between Tribeni and Dolalghat. The Sun Kosi, Tamur and Arun rivers meet at Tribeni and the Indrawati river joins the Sun Kosi River at Dolalghat. The Sun Kosi study area was taken above Pachour Ghat (gauging station No. 630). More information is shown in table 5-1.

Table 5-1: General Information of Sun kosi basin

River	Catchment Area (km^2)	Annual Runoff ($10^6 m^3$)	Annual Sediment (m^3)	Sediment Load (suspension) (m^3/km^2)
Sapt Kosi	61,000 (100%)	50,900 (100%)	118,400,000	1,920
Sun Kosi	19,000 (31%)	22,400 (44%)	54,200,000	2.818

BTOPMC a phisically based distributed hydrological model based on the block-wise use of TOPMODEL with Muskingum-Cung flow routing method and Tank model were selected for the Sun Kosi basin (large-scale) watershed study.

5.2.5 Data collection for Sun kosi basin:

DEM (Digital Elevation Map) of resolution 30 arc second, GIS (Geographic Information System) oriented data were taken from GTOPO30 (USGS-United states of Geological and Survey-internet site). Necessary Hydrometeorological (precipitation, discharge and evapotranspiration) data were collected from Department of Hydrology and Meteorology, Nepal, as an input for BTOPMC and for tank model. More information regarding acquired data are shown in tables 5-2, 5-3 and 5-4. Necessary Figure as shown in 10, 11, 12, 13, 14, and 15.

Table 5-2: Meteorological stations taken for precipitation data for Sun Kosi River basin study

S.No.	Station	Index No.	Latitude	Longitude	Elevation
1	Baunepati	1018	27° 47'	85° 34'	845 m
2	Dhap	1025	27° 55'	85° 38'	1240 m
3	Pachuwar Ghat	1028	27° 34'	85° 45'	633 m
4	Panchkhal	1036	27° 41'	85° 38'	865 m
5	Gumthang	1006	27° 52'	85° 52'	2000 m
6	Tarke Ghyang	1058	28° 00'	85° 33'	2480 m

Table 5-3: Gauging stations taken for observed discharge data for Sun Kosi River basin stuby

S. No	Station No.	Location	River	Latitude	Longitude	Basin Area
1	610	Barabise	Bhota Kosi	27° 47' 10"	85° 53' 20"	2400 sq. km.
2	620	Jalbire	Balephi	27° 48' 20"	85° 46' 10"	700 sq. km.
3	630	Pachuwar Ghat	Sun Kosi	27° 33' 30"	85° 45' 10"	4882 sq. km

Table 5-4: Climatological station taken for evapotranspiration data for Sun Kosi and Jhikhu catchment study

S.No.	Station	Index No.	Latitude	Longitude	Elevation
1	Panchkhal	1036	27° 41'	85° 38'	865 m

- **Data processing:**

  Calibration and validation– derivation of daily hydrographs for calculated and observed discharges – were done using the necessary data defined above as input to the computer programs.

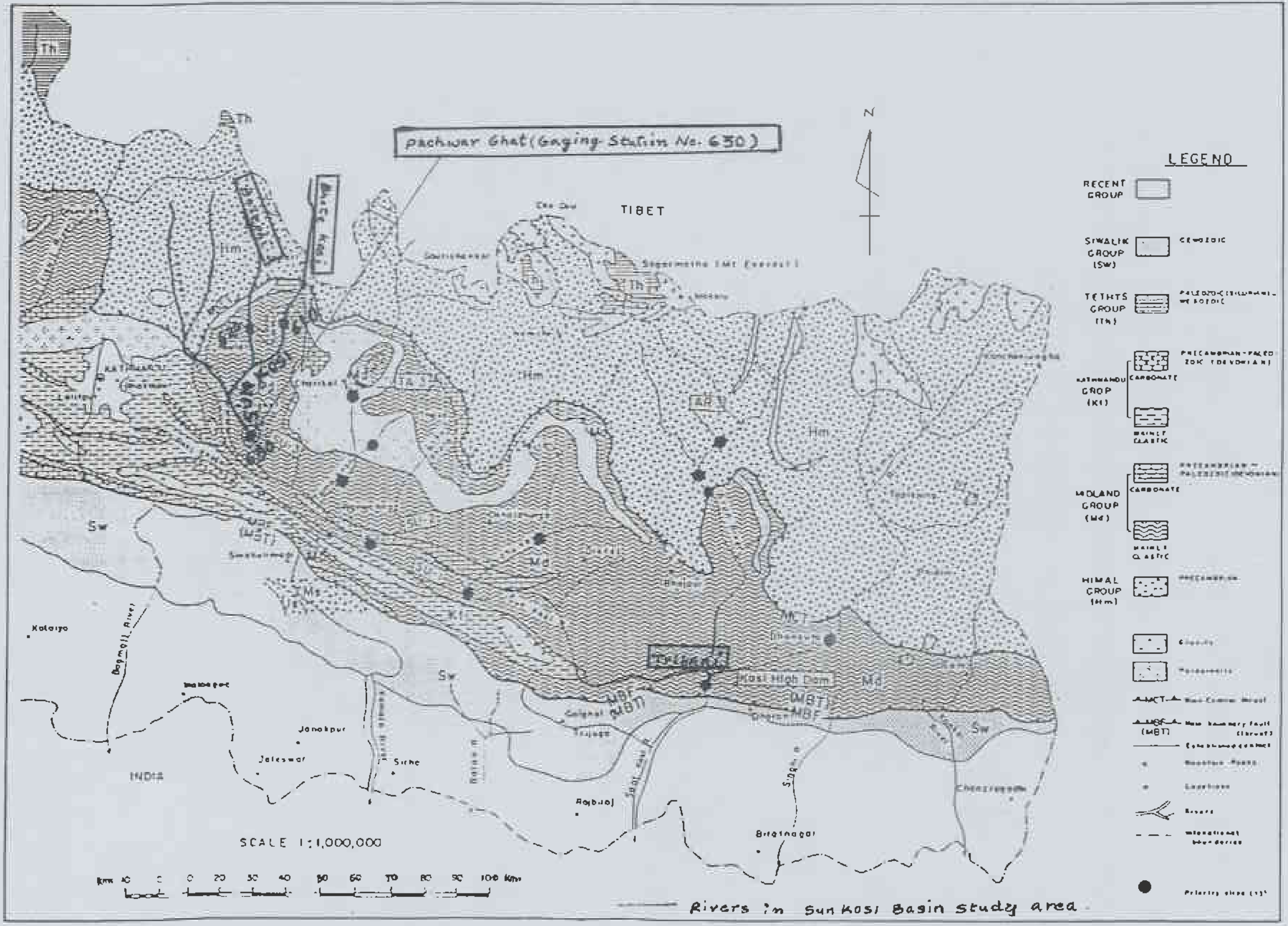


Fig 12 GEOLOGICAL MAP OF EASTERN NEPAL

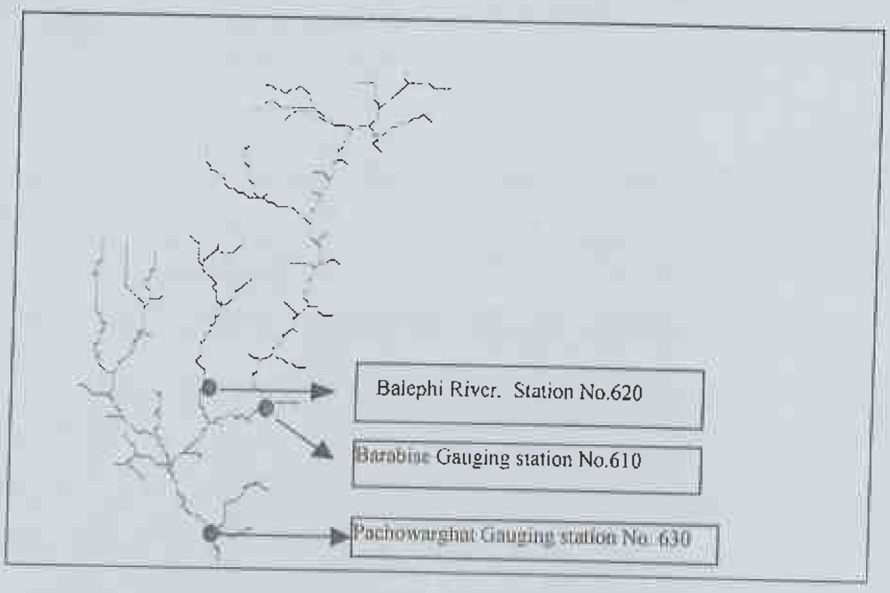


Fig 13: Stream Network of Sun Kosi Catchment above Pachowar Ghat gauging station No. 630(ARC/INFO as GIS package)

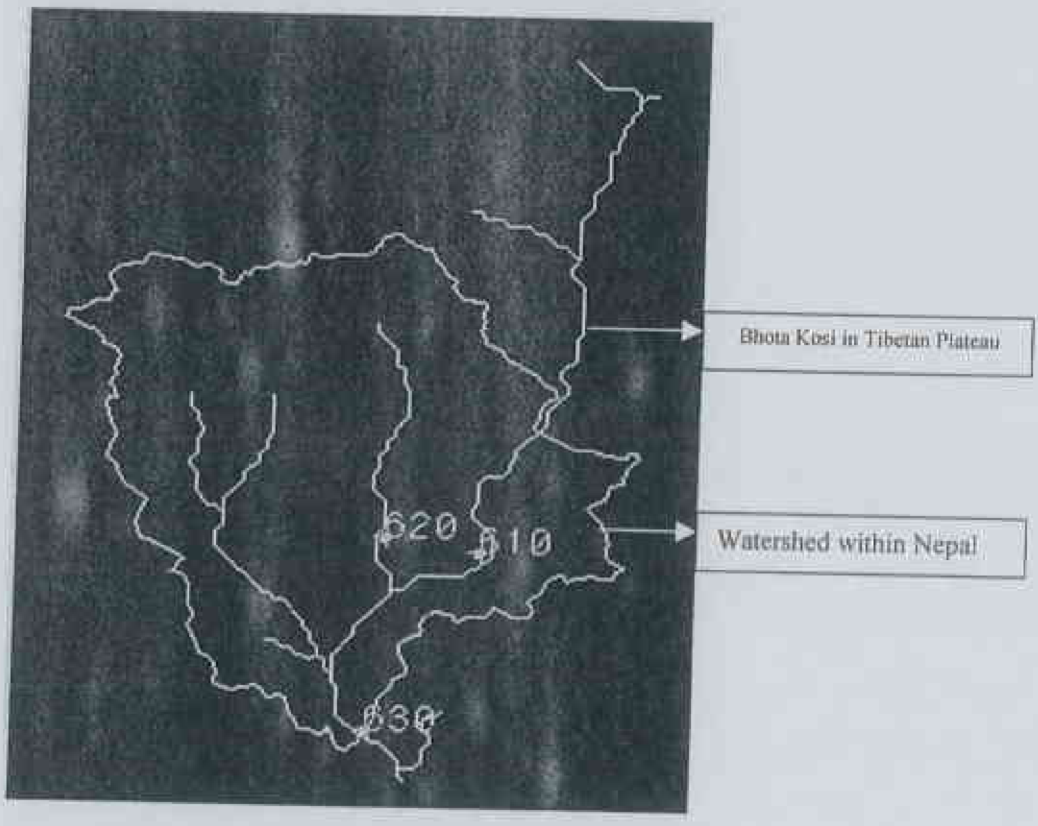


Fig. 14: Sun Kosi watershed above Pachowar Ghat gauging station No.610 (ARC/INFO used as GIS package)

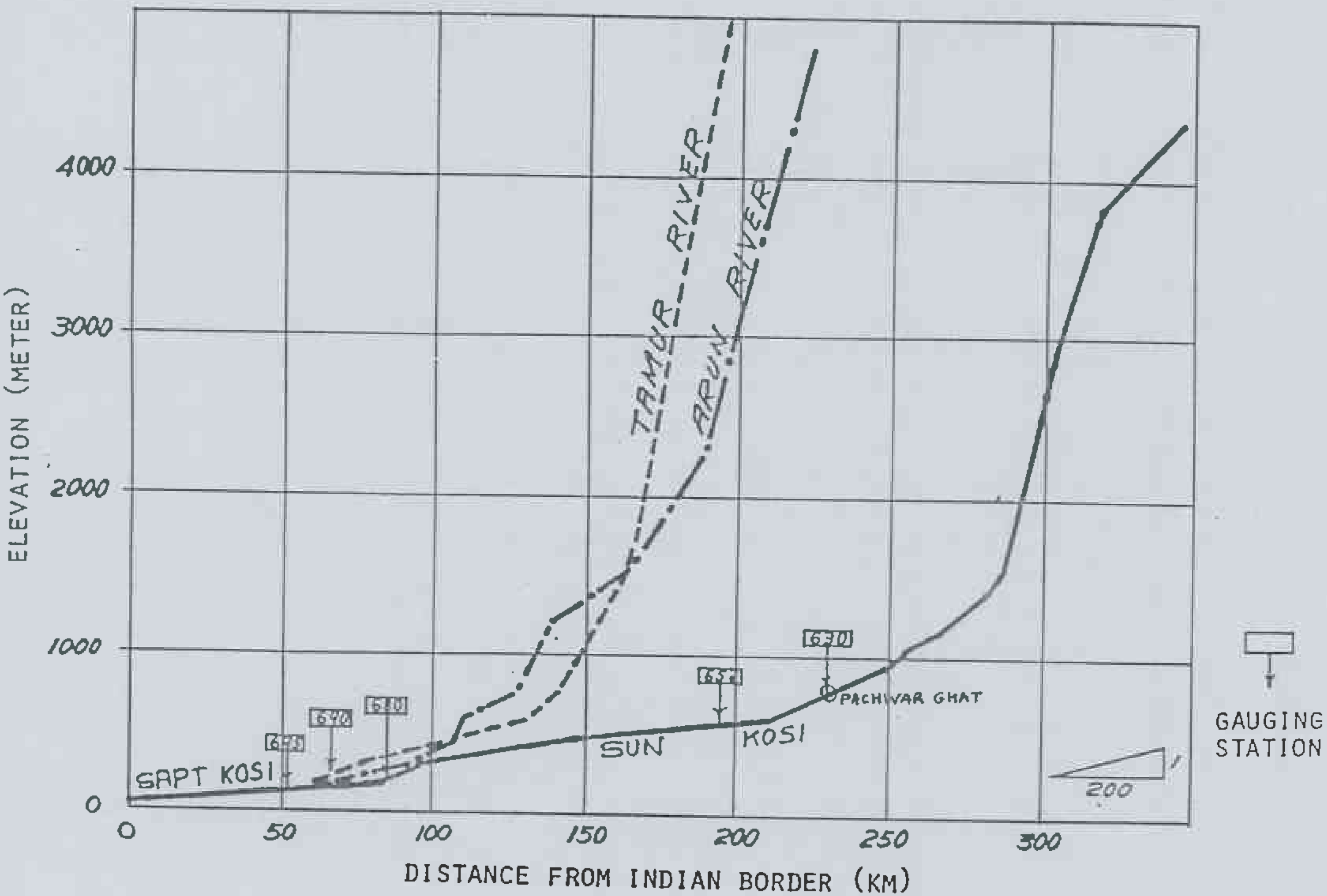


Fig. 15 LONGITUDINAL PROFILES AND LOCATIONS OF GAUGING STATIONS

5.2.6 Physical Features of the Study Area (small-scale watershed, Jhikhu river watershed)

Jhikhu watershsed was chosen for the study of the small catchments. The watershed is located in the Kabhrepalanchok district some 40 km east of Kathmandu (Fig: 16) and covers 11,141 ha. Jhikhu river watershed is a small watershed included in the Sun Kosi basin. The elevation ranges from 750-2,100 m, and the watershed is subjected to a monsoon climate with an extensive dry season from October to May. The Jhikhu watershed is one of the most intensively used Middle Mountains areas of Nepal, and is commonly associated with population growth, agricultural intensification and deforestation in a marginal environment. The watershed has all of the infrastructure and make-up of a typical Middle Mountain valley. What sets it apart is that the watershed can be reached by motorable road and the Arnico highway, which connects Kathmandu with Tibet, passes through the center of the watershed. This road can be reached from the most remote village by a five-hour walk, and the distance to Kathmandu is about 40 km. Jhikhu Khola watershed is a futuristic Middle Mountain watershed and should allow us to document possible development opportunities that may be applied to other watersheds within the Middle Mountain region.

The subcatchments included in this watershed as study area are Lower Andheri, Upper Andheri, Kukhuri and Kubinda basins covering 539 ha, 183 ha, 74 ha and 157 ha. The Kukhuri and Upper Andheri basins forms part of the headwaters of the Lower Andheri sub-watershed. The streams of these basins are extremly steep with slopes of 5-15 degrees in the Kukhuri basin reducing to 2-5 degrees in the lower reaches of the Andheri basin. The slope of the Kubinda basin is relatively less steep.

Tank Model was selected for the hydrological analysis of the small watershed mentioned in above paragraph. Hydrometrological data for Jhikhu Sub-catchments' study are presented in tables 5-5 and 5-6.

5.2.7 Data collection of Jhikhu Sub-watershed:

Hydrometeorological (precipitation, discharge and evapotranspiration) data were collected from PARDIP, ICIMOD and Department of Hydrology and Meteorology, Nepal as input for tank model. Necessary figure are shown in figure 16, 17, 18 and 19.

Table 5-5: Meteorological stations taken for pricipitation data for Jhikhu catchment study.

S. No.	Used for	Site Name	Site No.
1	Kukhuri, Lower & upper Andheri	Bela	6
2	Lower Andheri	Acharya Tole	3
3	Kubinda	Kubinda Gaun	14

Table 5-6: Gauging stations taken for the observed discharge data for Jhikhu catchment study

S. No.	Used for	Site Name	Site No.	Catchment area
1	Kukhuri	Bela	7	74 ha.
2	Upper Andheri	Bela	8	183 ha.
3	Lower Andheri	Dhaireni	2	539 ha.
4	Kubinda	Shree Ram Pati	13	157 ha.

- **Data processing:**

  Calibration and validation– derivation of daily hydrographs for calculated and observed discharges – were done using the necessary data defined above as input to the computer programs.

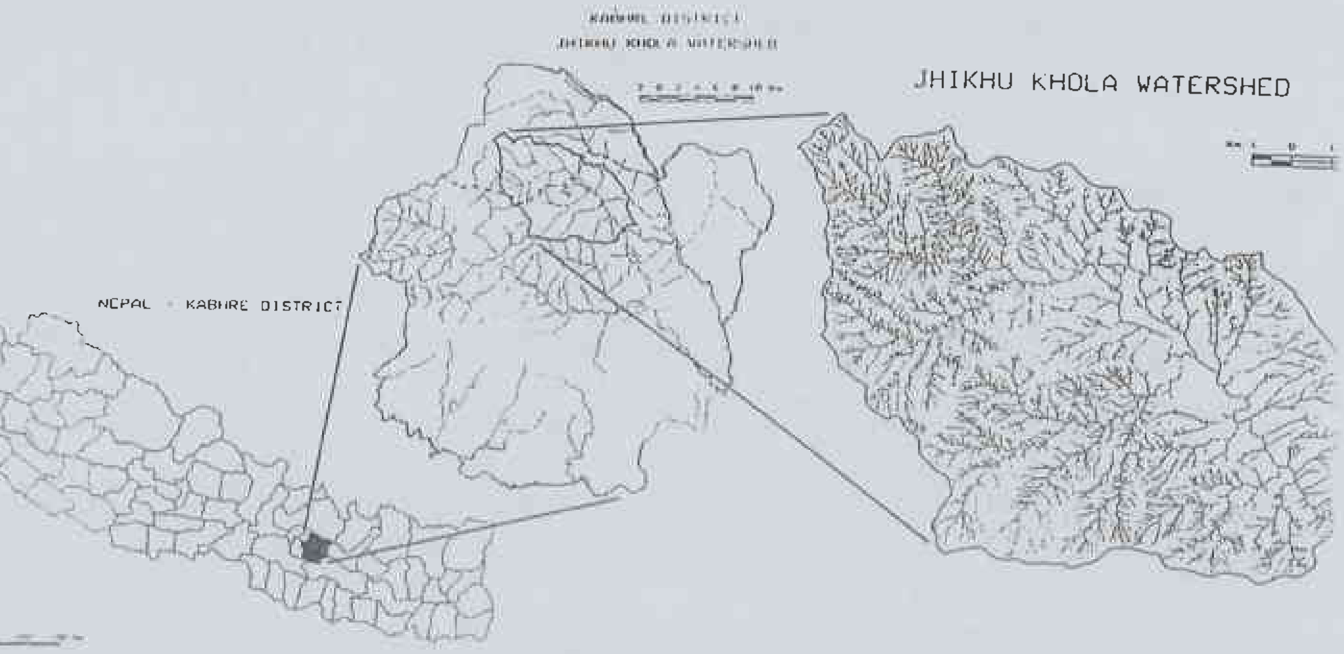


Fig. 16 . Location of Jhikhu Khola watershed.

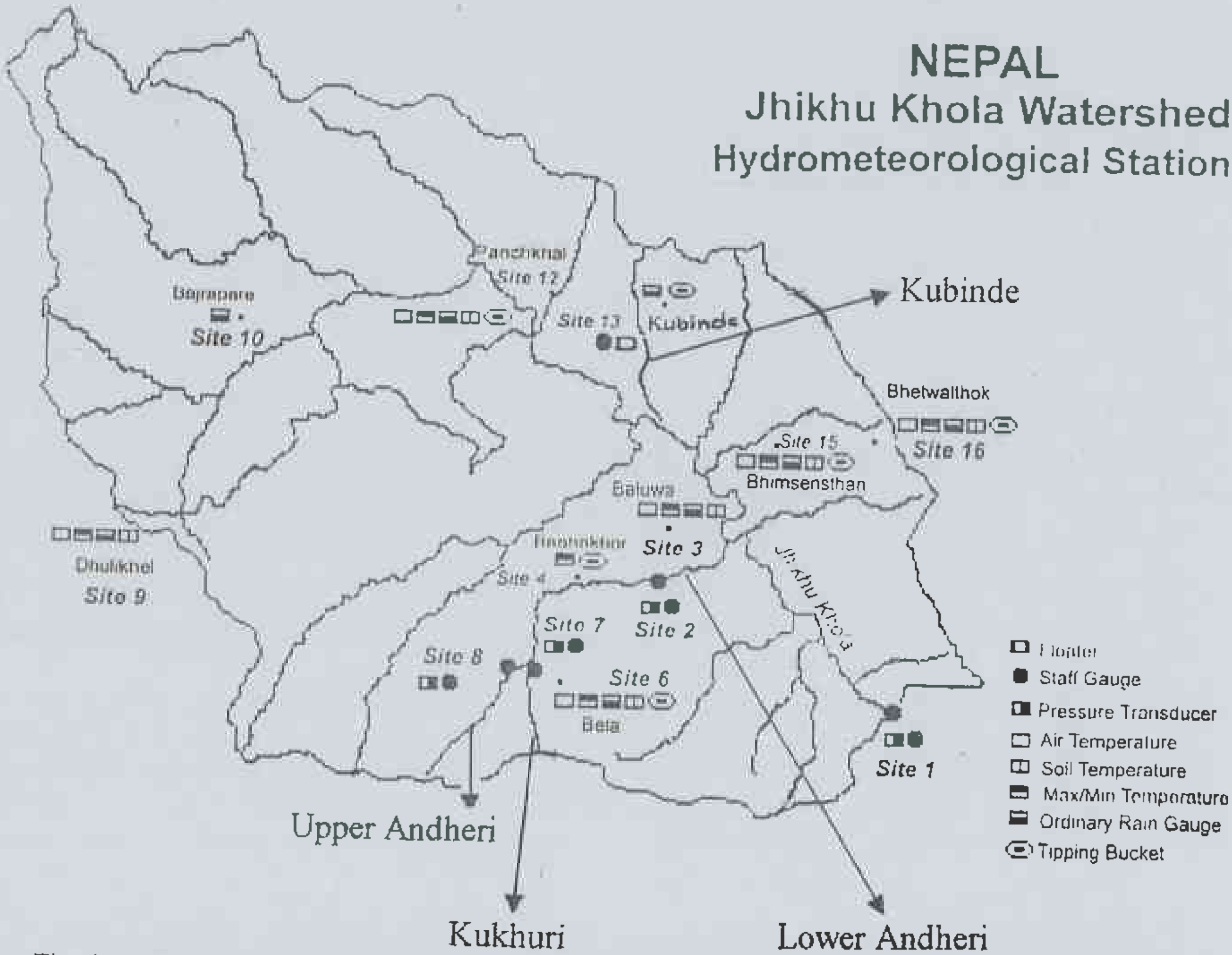


Fig. 17 Rivers of small catchment study area (subcatchment of Jhikhu watershed) indicated by the arrows.

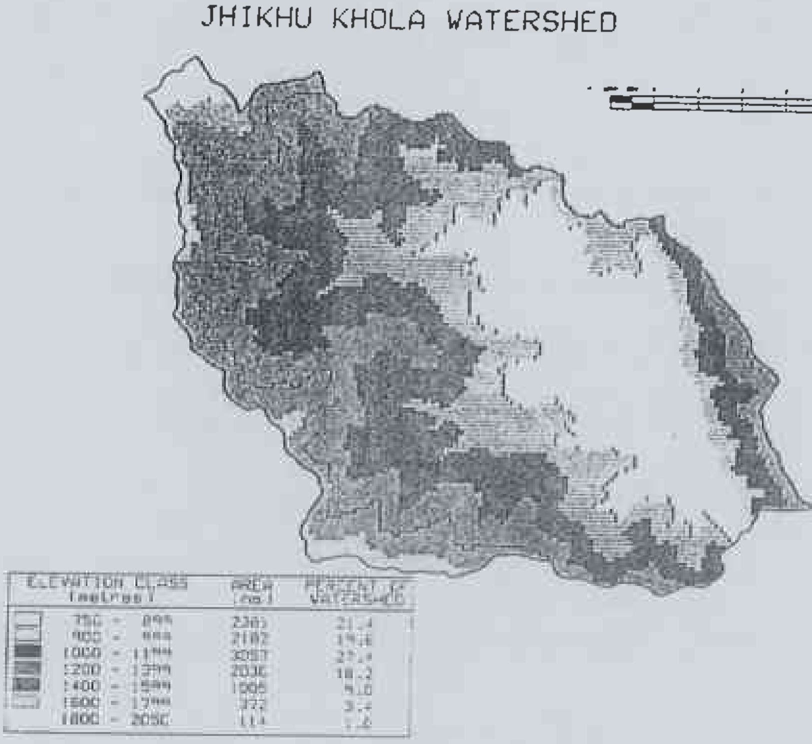


Fig. 18.Elevation slice map.

Fig. 19 : Potentially Unstable Sites

6. ANALYSIS, RESULTS AND DISCUSSIONS

6.1 Results and Discussion on the BTOPMC model performance in Sunkosi catchment.

All the parameter calibration was done by trial and error method. This gave an opportunity to better understand the model. The whole catchment area under study was approx. 5000 sq. km. This study area was divided into 8-blocks (See 2.4.1 of Chapter 2 and Refer Chapter 3 too). Apart from the distributed soil topographic index (DEM data processed) eight set of parameters were estimated altogether (one set for each block). In this duration the author devoted much of time in sensitivity analysis of the parameters. Even though, the parameters used are very few for a distributed model, BTOPMC model seems effective to incorporate all the geomorphological features. This was why each and every parameter was found with equally sensitive on their part. Anyway, regarding the volumetric analysis 'To', lateral transitivity (see 3.2.3 of chapter 3), played the most important role whose increment highly changed the base flow during the rainy season. This increment was found very tough to recess down even after the monsoon was over. The probable reason for this (remembering a simple equation: q=Kb. dH/dL) may be due to the high gradient of the catchment area with excess rain. But the nature seemed to balance the flow with less lateral transitivity. Hence in the calibration by trial and error process the values of 'To' are very low as shown in table B.1 (appendix-B).

The increment of manning's roughness coefficient decreased the peaks by shifting them backward (counting the days from Jan.).

Increment in the Decay factor of To increased the rate of decrease of the values of saturation deficit of soil leading to increase in surface runoff and peaks. This also gave rise to lesser amount of increase in ground water flow.

Increase in saturation deficit of soil gave rise to decrease in peak flows.

The stream network of Sun Kosi was produced using DEM via. Arc/info

All the output form calibration for 1991 data is shown in table 6-1 and fig.20. The result was good enough with 80.01% Nash efficiency*, Water Balance ratio of 1.08, difference in mean 18 m3/s.

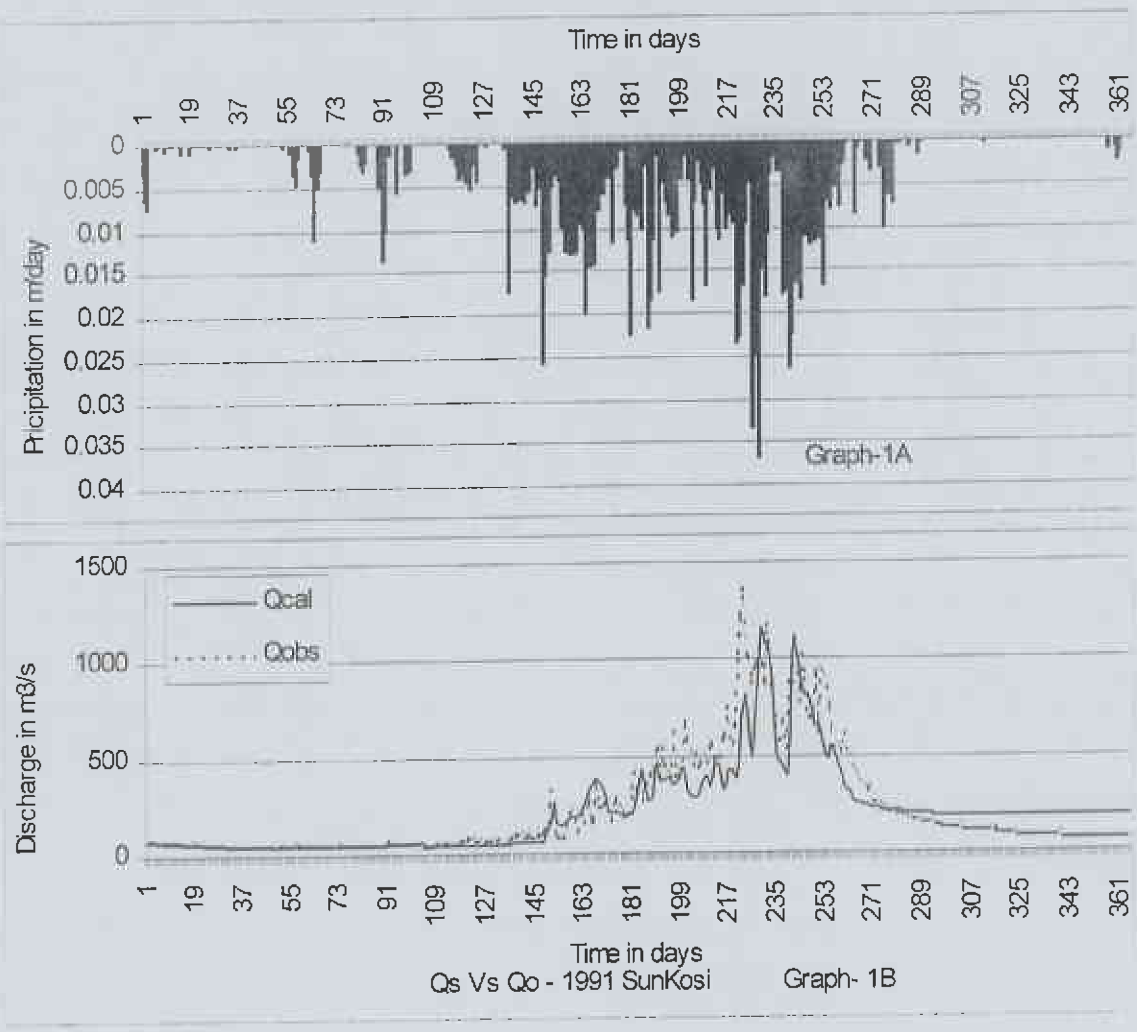
* see appendix - A

Year 1991 Sun Kosi at Pachour Ghat Results

Table-6-1: Description of the principle output data files-fname.eva.

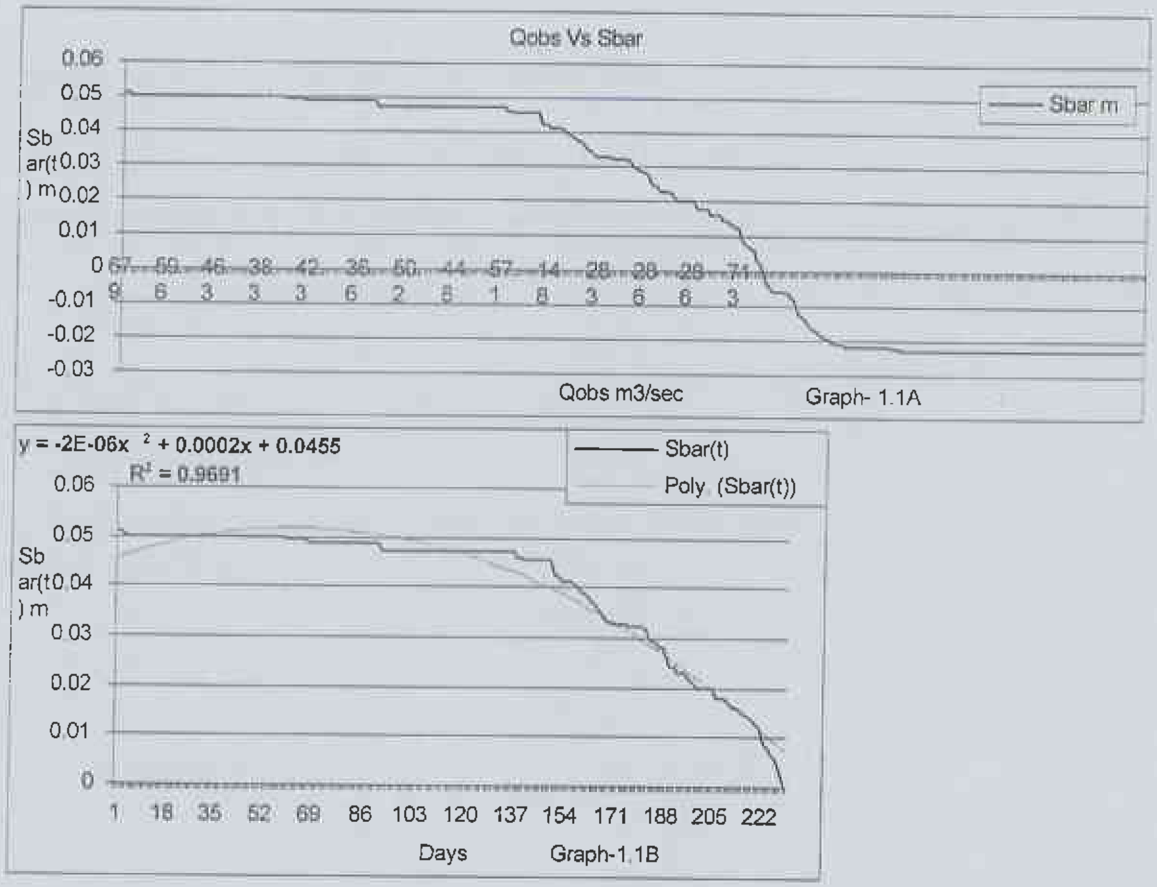
S.N				
1	Out	10792	>>>>>>	*Grid number of the outlet*
2	Grids	4883	>>>>>>	*Catchment Area of the outlet*
3	AvQs	211.327	>>>>>>	*Simulated average Discharge. m3/s*
4	AvQo	229.001	>>>>>>	*Observed average Discharge, m3/s*
5	Frati	0.97	>>>>>>	*Outflow Ratio*
6	Effi	80.011	>>>>>>	*The Nash efficiency.*
7	Ratio	0.923	>>>>>>	*The ratio of volume*
8	Balan	-0.289	>>>>>>	*Water Balance*
9	PkTs	229	>>>>>>	*The peak time of simulation*
10	PKTo	222	>>>>>>	*The peak time of observation*
11	Qsmx	1162.667	>>>>>>	*Simulated max. peak discharge, m3/s*
12	Qomx	1360	>>>>>>	*Observed max. peak Discharge, m3/s*

Fig. 20: BTOPMC MODEL Calibration for Sun Kosi River - 1991 - at Pachour Ghat



The variation of saturation deficit for block 8 was analyzed. The regression analysis for saturation deficit and discharge was performed. In that case the polynomial equation gave the best-fit trend line with 0.9691 efficiency. The figure and equation are shown in fig. 21.

Fig.21: Saturation deficit analysis



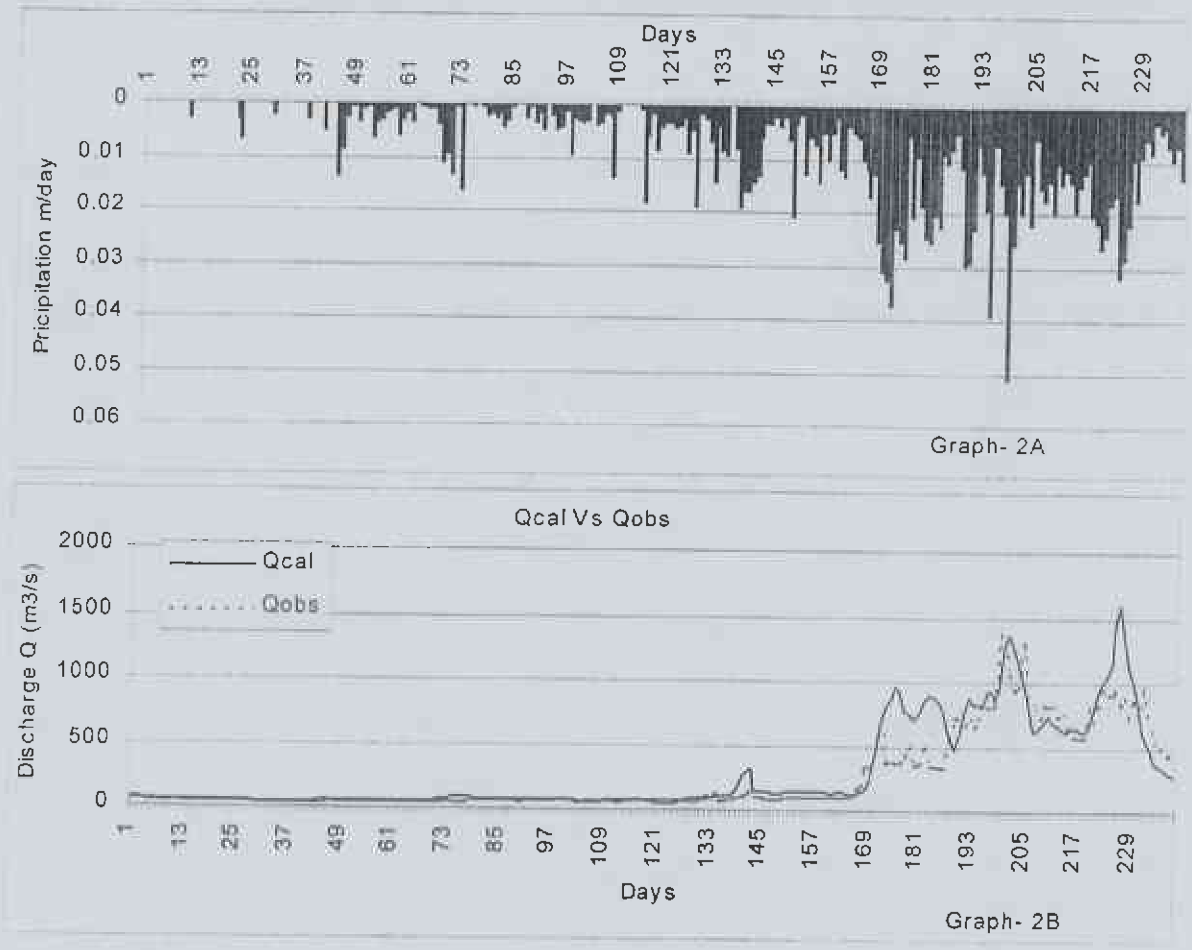
Single response split sample test was adopted using independent data for verification. The same parameters were used for verification for the years 1990. The result was good enough with 75.847% Nash efficiency. The output results are shown in table 6-2 and fig. 23.

Year 1990 Sun Kosi at Pachour Ghat Results

Table-6-2: Description of the principle output data files-fname.eva.

1	Out	10792	>>>>>>	Grid number of the outlet
2	Grids	4883	>>>>>>	Catchment Area of the outlet
3	AvQs	284.05	>>>>>>	Simulated average Discharge, m3/s
4	AvQo	253.739	>>>>>>	Observed average Discharge, m3/s
5	Frati	0.63	>>>>>>	Outflow Ratio
6	Effi	75.847	>>>>>>	The Nash efficiency.
7	Ratio	1.119	>>>>>>	The ratio of volume
8	Balan	-0.216	>>>>>>	Water Balance
9	PkTs	226	>>>>>>	The peak time of simulation
10	PKTo	199	>>>>>>	The peak time of observation
11	Qsmx	1597.927	>>>>>>	Simulated max. peak discharge, m3/s
12	Qomx	1410	>>>>>>	Observed max. peak Discharge, m3/s

Fig.22 BTOPMC MODEL Verification for Sun Kosi River - 1990 - at Pachour Ghat



For the 1991 simulation the rate of recession for the ground water was too low which gave poor water balance for the later dry season of the year (see fig.20). For this reason for verification these later dry seasons were not taken into account.

6.1.1 Modification in BTOPMC Model:

The total length of the Sun Kosi River is approximately 330 Km. of which 280 Km. lies in Nepalese territory. Rest of the length lies in the Tibetan Plateau where the data information was not available (see fig. 13 and fig. 14 in chapter-5). Thus to cope with the problem, BTOPMC version II. was developed under the suggestion of the author. In this newly developed version, the observed discharge is given as an input so that the catchment above that gauging station can be removed. Thus the observed discharge of Barabise, gauging station no. 610 was given as an input for the respective years and the catchment lying above this point (catchment in the Tibetan plateau) was removed by the program added named by 'kill.f'.

6.2 Analysis, Results and Discussions on the Tank Model Performance in small and large catchments.

6.2.1 Discussion on the Result of Tank Model Performance in Jhikhu catchment

Tank model was used as a rainfall runoff model for the Jhikhu river sub-catchments. (See 5.2.6 of chapter-6 and fig.17 in chapter-5).

The sub-catchments under study were as follows:

1) Kukhuri river
2) Upper Andheri river
3) Lower Andheri river and
4) Kubinda river

a) Simulation results from Kukhuri sub-catchment.

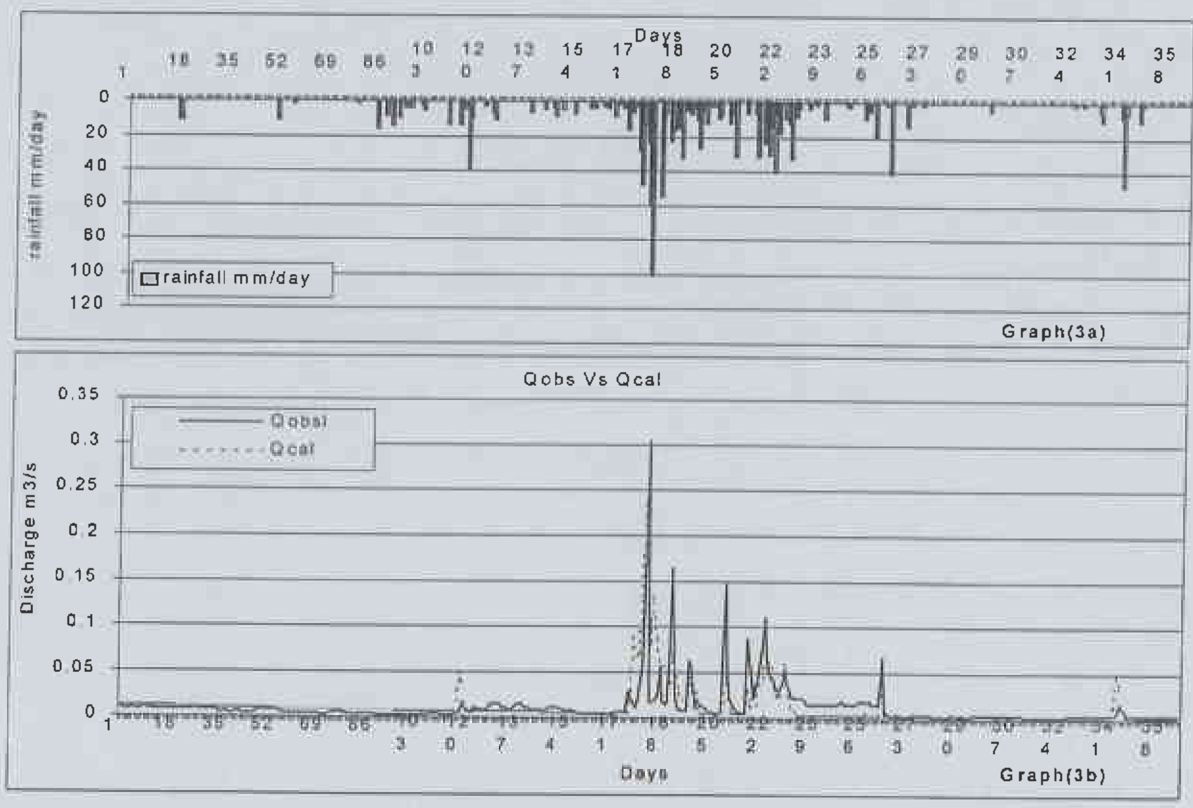
In spite of several dams built up in the stream course the simulation result for the year 1997 gave the results shown in table- 6-3.

Table-6-3: Simulation results from Kukhuri sub-catchment

Correlation Coefficient	Nash Efficiency	Cum.Qcal / Cum.Qobs
0.574	0.21	1.08

The comparison of the rainfall and runoff hydrographs (observed and simulated for the year 1997) are shown in Fig.23.

Fig. 23 Tank model calibration for Kukhure River - 1997, Jhikhu sub-catchment



b) Simulation results from Upper Andheri sub-catchment.

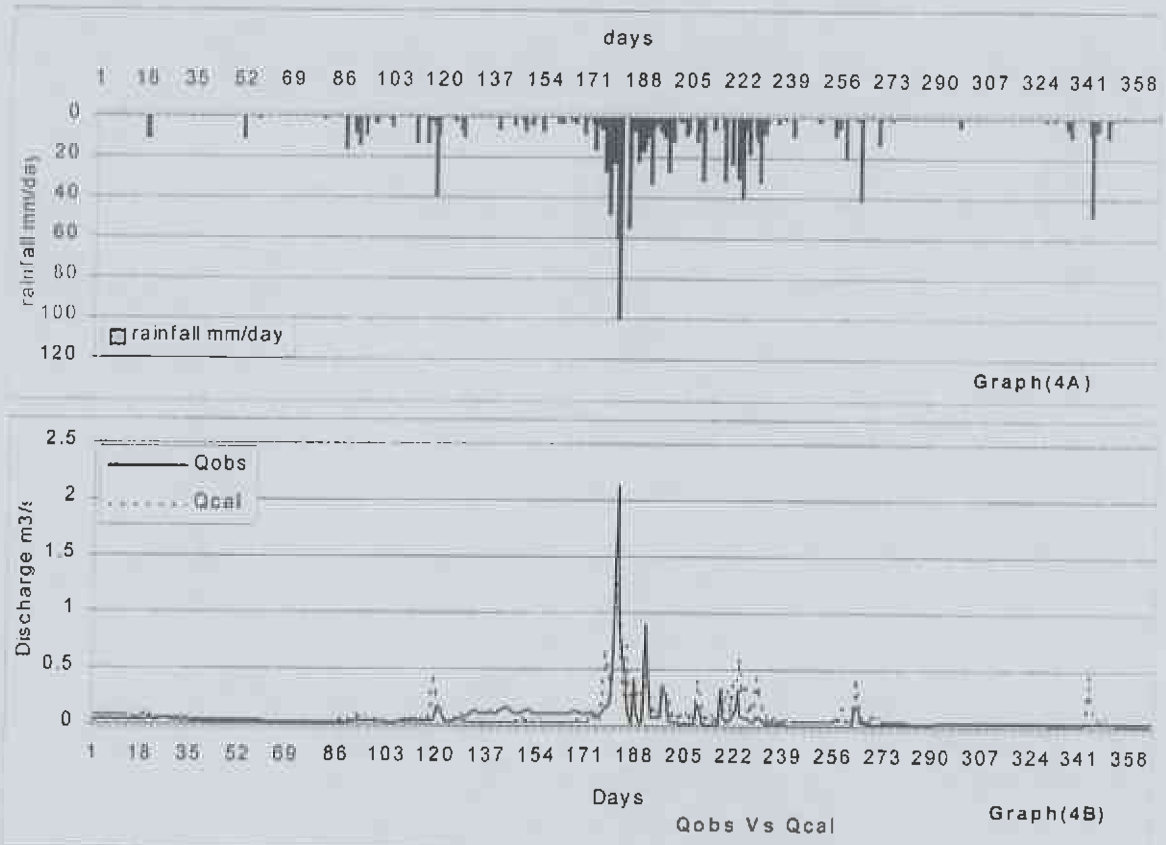
In spite of several dams built up in the stream course the simulation result for the year 1997 gave the results shown in table-6-4.

Table-6-4: Simulation results from Upper Andheri sub-catchment

Correlation Coefficient	Nash Efficiency	Cum.Qcal / Cum.Qobs
0.76	0.55	1.36

The comparison of the rainfall and runoff hydrographs (observed and simulated for the year 1997) are shown in Fig.24.

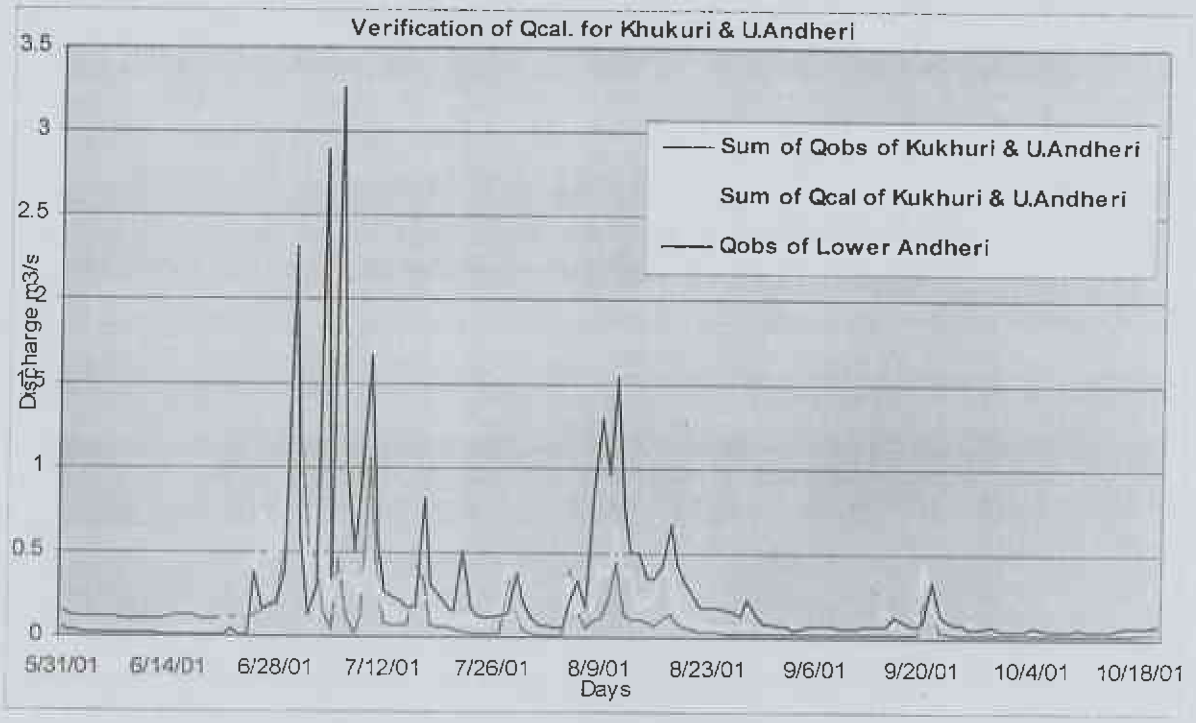
Fig.24:Tank model calibration for Upper Andheri River – 1997, Jhikhu sub-catchment



c) Reliability of the simulation out comes of Khukuri and Upper Andheri.

Fig. 17 of chapter-5 shows that the gauging stations for Khukuri and Upper Andheri are just near to the point where they meet to form Lower Andheri. To check the reliability, the simulated outcomes of Khukuri and Upper Andheri were added. Both the stream's observed runoff data were also added. Then the observed runoff of the lower Andheri for the same year (year 1997) was compared with the summed up observed and simulated runoff (see fig. 25). The simulated summed up runoff gave better trend than the observed runoff added when compared to Lower Andheri observed runoff. This verified the reliability of the simulated runoff data for both the streams, Khukuri and Upper Andheri.

Fig. 25: Verification of Discharge Simulated for Kukhuri & Uppre Andheri



d) Simulation results from Kubinda sub-catchment.

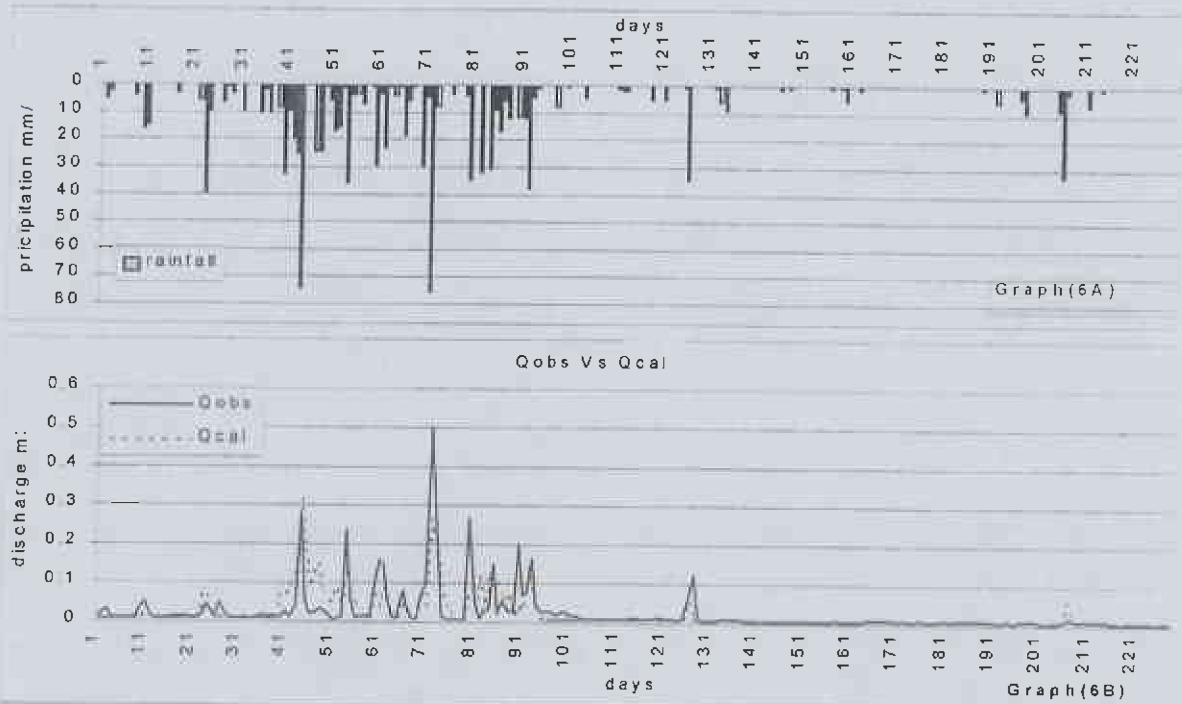
The simulation result for the year 1997 gave the results shown in Table-6-5.

Table- 6-5: Simulation results from Kubinda sub-catchment

Correlation Coefficient	Nash Efficiency	Cum.Qcal / Cum.Qobs
0.714	0.56	1.1

The comparison of the rainfall and runoff hydrographs (observed and simulated for the year 1997) are shown in Fig. 26.

Fig. 26 Tank Model Calibration for Kubinda Khola - 1997, Jhikhu Sub-catchment



The catchment area of Upper Andheri and Kubinda happens to be 183 ha and 157 ha. Though both the sub catchments are nearly of the same area; both are sub catchments of the Jhikhu (Jhikhu is a very small catchment) but the parameters decided in calibration are very different from each other.

One of the possible reasons for this can be the runoff loss in the unstable soil type shown in figure 19, chapter-5. Moreover the slope of Kubinda subcatchment is much lesser than the slope of U. Andheri sub-catchment. The next reason can be due to much more storage effect because of highly agricultural area in Kubinda subcatchment. Low elevation (see figure 18, chapter 5) less slope and storage effect does not permit hortonian overland flow. Thus very less discharge was observed in Kubinda in comparison to U.Andheri.

e) Simulation results from Lower Andheri.

Before going through analysis portion the author wants to reveal the water management schemes, Irrigation distribution systems and the relevant pragmatism of the local people in the Andheri Khola, sub-watershed.

Water Management schemes in the Andheri Khola sub-watershed

In the Andheri Khola, all irrigation systems are organized and operated by farmers who are responsible for measuring the supplies, water allocation, frequency of use. construction and routine maintenance of the irrigation systems. Jurisdictional arrangements are of particular importance since the dependence on water is increasing due to agricultural intensification and population growth. Rain is the main source of water and most leaves the area as run-off while only a small portion infiltrates through voids into the soil matrix and superficial materials to provide ground water supplies. The water availability is very uneven in the watershed with the largest communities receiving the lowest quantity on a per household basis. Thirty-five natural springs were identified in the sub-watershed and these serve as drinking water supplies to the residents and provide the only source of stream flow during the dry season. The irrigation water in Bela is primarily used for winter crops such as garlic, onions, radishes, tomatoes, cabbage, cauliflower and potatoes. Those vegetable products have higher economic values. Moreover, transportation facility and the capital city being at a short distance the local farmers have rapidly increased their interest to those products.

Irrigation distribution systems

Untapped spring wastewater, surface and subsurface flow areas are the main sources of irrigation water. Farmers tap the stream water from every possible site through a network of several diversion dams for irrigation. Most of them does not operate in wet season. These dams were established at various distances along the river, depending on ownership, channel conditions and topography. Construction of new dams is difficult, but the farmers can and do readily modify existing dams, weirs and channels.

Dams in Andheri Khola watershed

The channel cross-section of the indigenous system vary from 0.1m to 0.8 m and the average size of a dam is 0.85 m in height and 5.8m in length. Stream response to storms can have serious consequences in a high gradient river like Andheri. Peak flows can destroy all the dams (eg; July/ August 1992,August 1993), and the resulting damage can require massive construction efforts (Pradhan, 1989).

Local materials are used in the construction of the dams, with emphasis being placed on simple construction that can be repaired rapidly.

As shown in fig. 27 diversion dams consist of simple stacking of rounded and sub-rounded stones, which are interlocked by twigs. Gravel, sands are used as packing material to minimize seepage. During flooding periods water can easily overflow the dam and canal.

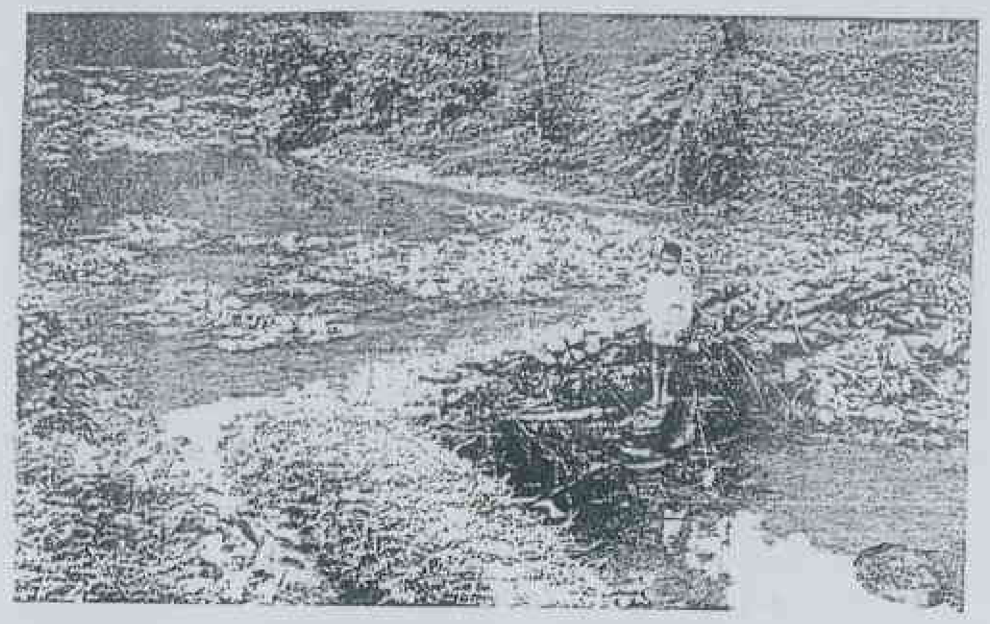


Fig. 27 Diversion dam in the lower reaches of the Andheri Khola.

[Water-balance consistency check]

Water-balance consistency checks are relevant for discharge and stage (reservoir level) data, and such controls should be made at least once a year. The procedure is to calculate local runoff for as many partial catchments in a watercourse as possible. If there are any reservoirs in the catchment, the storage changes are corrected for.

Inflow computation:

$$Qloc = Qout - Qin + \Delta S/\Delta t$$

Or,

$$Qloc + \Delta S/\Delta t = Qout - Qin \qquad (a)$$

Where,

Qin is upstream inflow to the reach/reservoir in question

Qout is outflow

ΔS is storage changes

Δt is the observation interval

Qloc is the local inflow.

Normally, the local inflow should be non-negative. High evapotranspiration from large water bodies, extensive irrigation schemes or river ded infiltration to ground water can cause negative values over longer periods.

This analysis was carried out for observed runoff hydrograph of Lower Andheri as Qout and summation of simulated hydrographs of Upper Andheri and Khukuri (table-C.5 , appendix-C). In table-C.5, appendix-C mostly the left hand side of equation (a) gave negative values. This was mainly due to extensive irrigation schemes. The extensive irrigation was carried out in the dry seasons. Thus to perform a reliable calibration the high flow analysis was carried out (From the month of June to the month of October). Moreover, in the transition phase farmers are more interested to fill the dam to the maximum capacity. In addition, at the high flood time the dams seemed to be destroyed which gave very irregular observed runoff as shown in fig. 28. Thus, the transition phase was also excluded. Final calibrated results are shown in table-6-6 and fig. 29.

Fig. 28: Analysis to achieve the best simulation period for Lower Andheri Khola

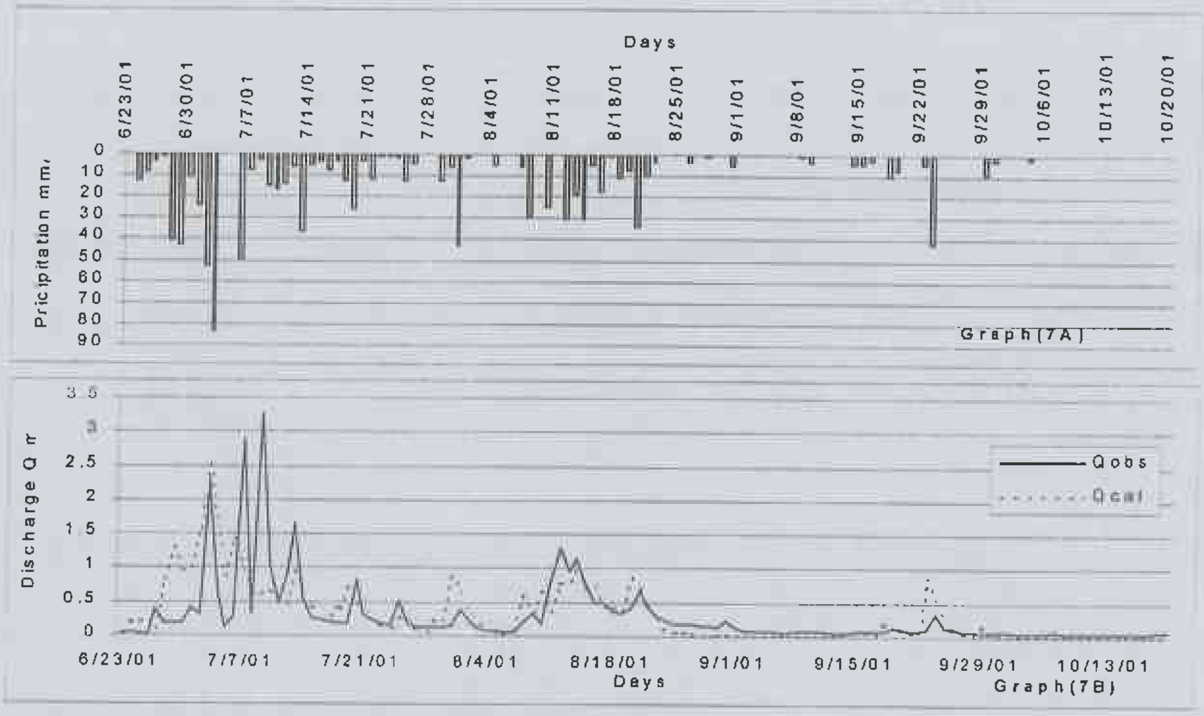
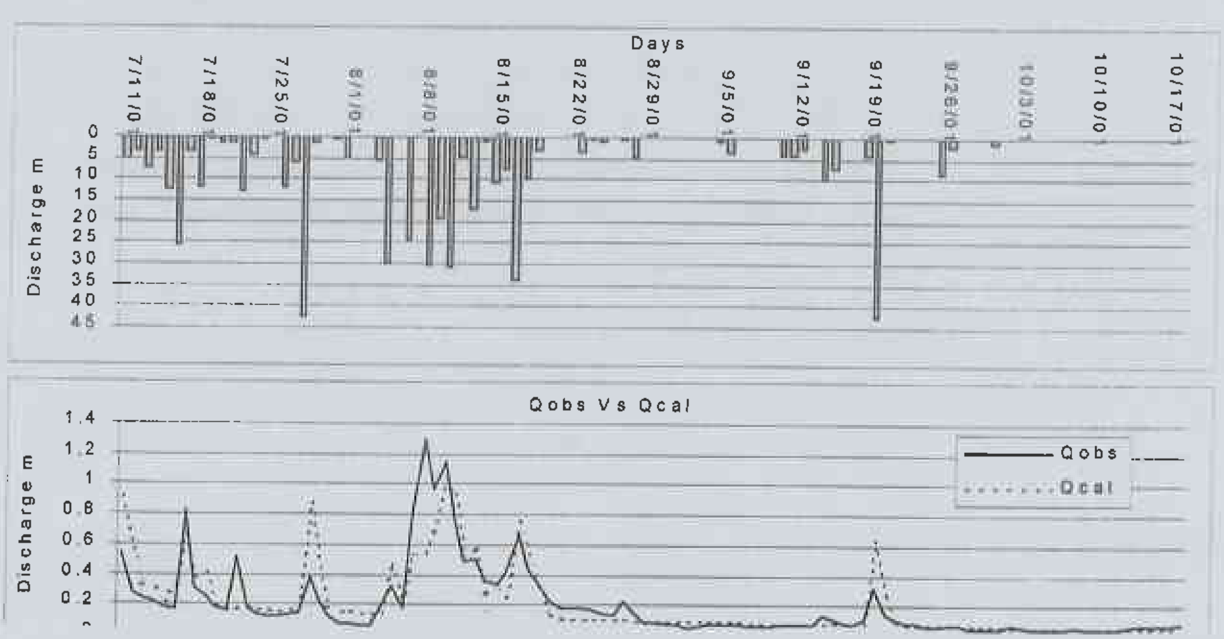


Table 6-6: Simulation results from Lower Andheri

Correlation Coefficient	Nash Efficiency	Cum.Qcal / Cum.Qobs
0.83	0.68	1.05

Fig.29: Tank Model Calibration for Lower Andheri Khola - 1997, Jhikhu Sub-catchment



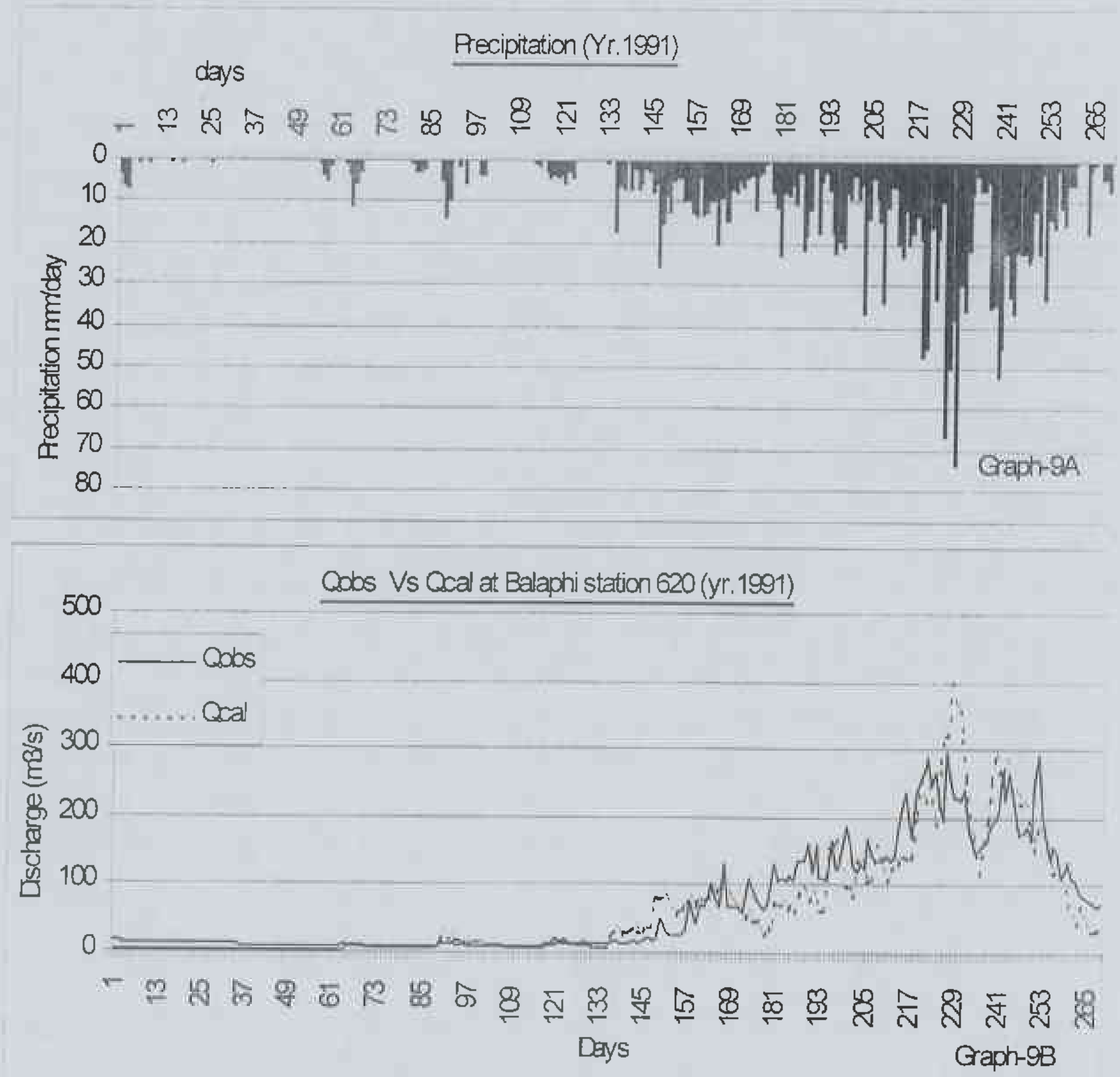
6.2.2 Discussion on the Result of Tank Model Performance in Sun Kosi River Basin (large catchment, refer figures of 7.1 of chapter 7 and fig. 15 and fig. 16).

The calibrated parameters for Balaphi River –year 1991, gauging station 620 and watershed area of 700 km^2, gave Nash Efficiency of 82.6% and the ratio of cumulative observed discharge by cumulative calculated discharge of 1.05. See table- 6-7 and fig. 30.

Table-6-7 : Simulation Results from Balaphi River

Qobs Mean	Qcal Mean	Nash Efficiency	Qobs/Qcal
50.9028	48.163946	0.826716	1.056865

Fig. 30: Calibration for Balaphi River



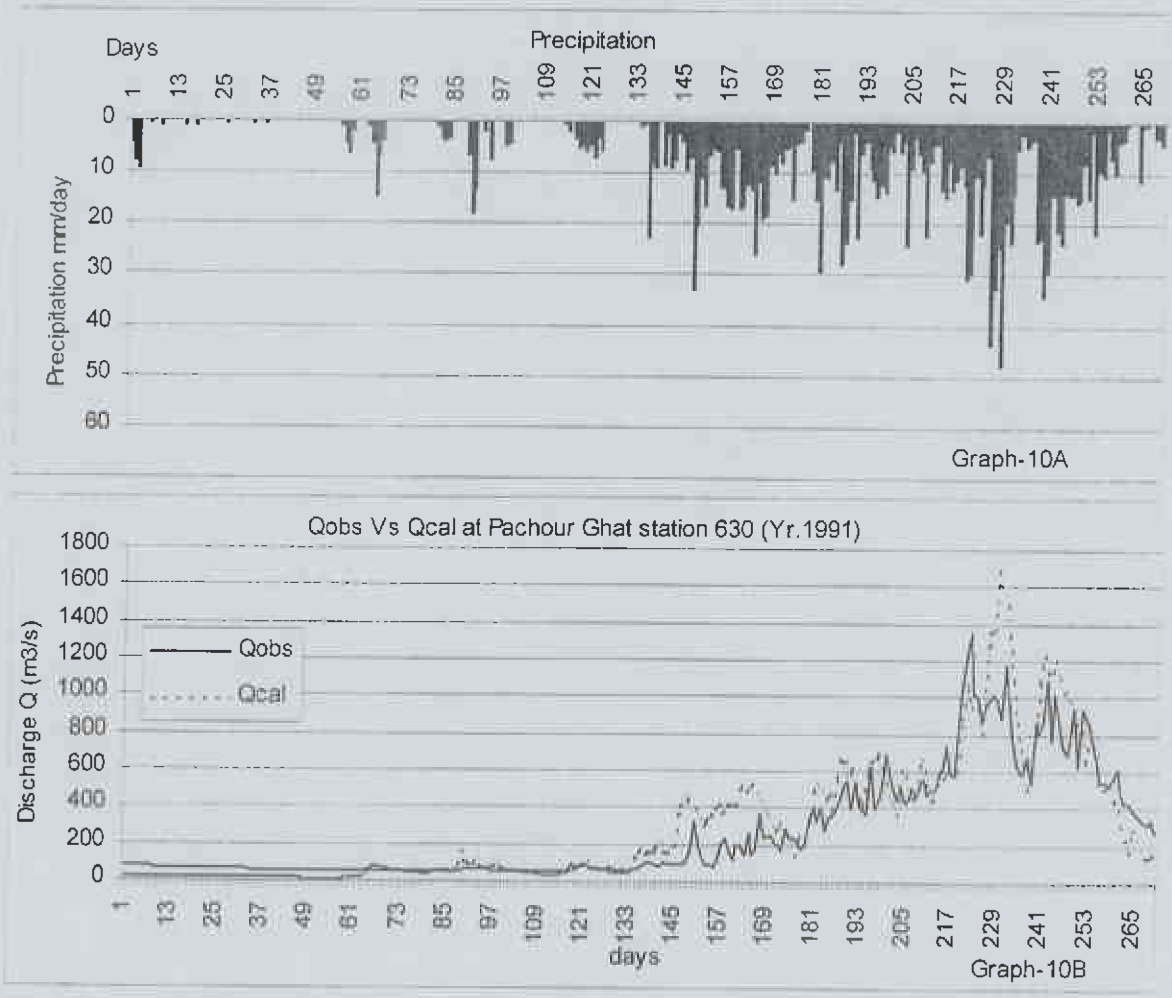
Same parameters calibrated for Balaphi River (year-1991) was used to Sun Kosi River basin at Pachour Ghat –year 1991, gauging station 630 and watershed area of 4882 km^2, gave Nash

Efficiency of 77% and the ratio of cumulative observed discharge by cumulative calculated discharge of 1.1. See table-6-8 and fig. 31.

Table-6-8: Simulation Results from Sun Kosi at Pachour Ghat

Qobs Mean	Qcal Mean	Nash Efficiency	Qcal/Qobs
268.57407	306.1269	0.77	1.139823

Fig. 31 : Results for Sun Kosi River at Pachour Ghat - Yr.1991,Sun Kosi Catchment (Using the same Tank Model Calibrated Parameters for Balaphi River)



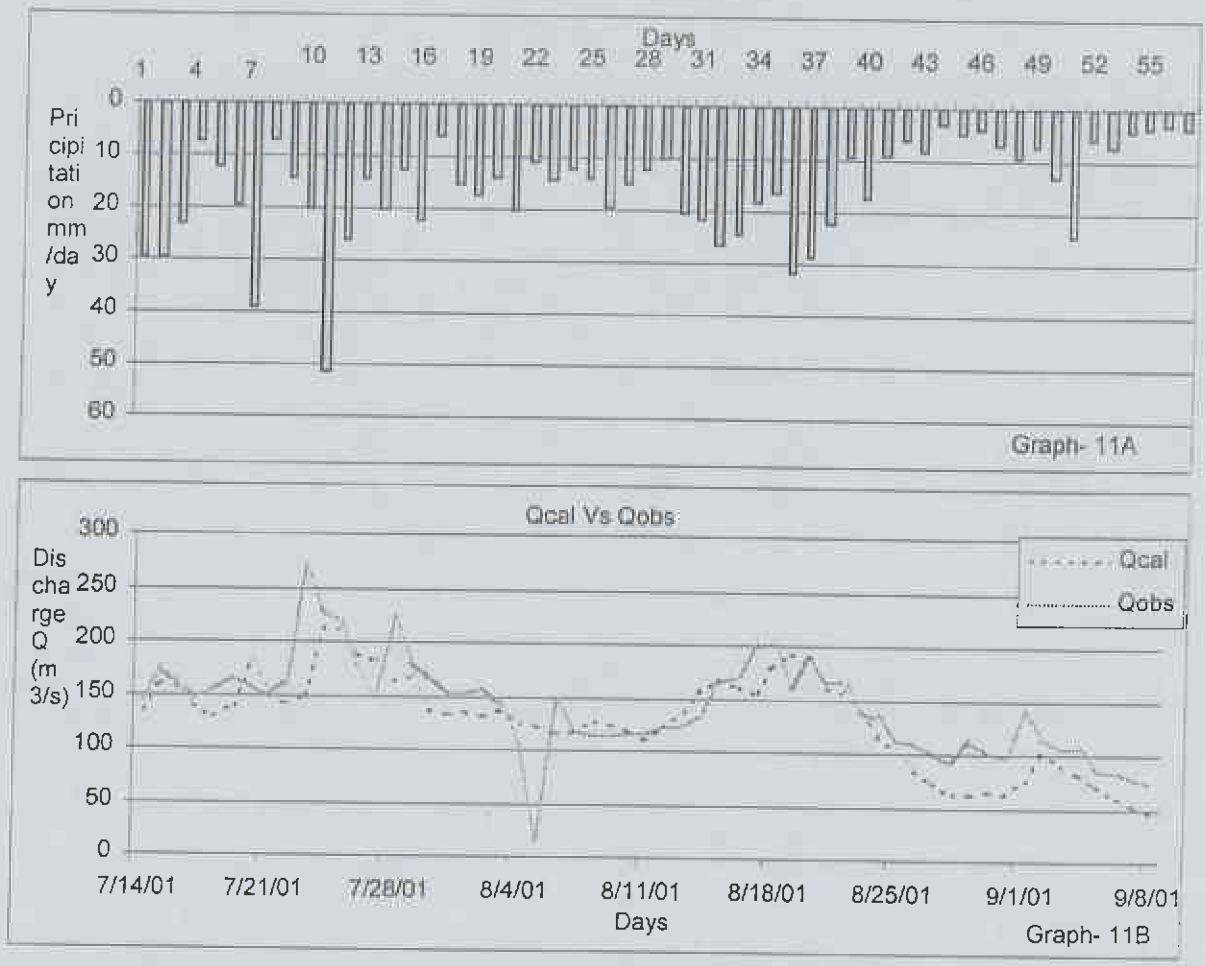
Sticking to the fact that rainfall is heavier in the higher altitudes of Sun Kosi basin, within Nepal, the average rainfall was constantly increased to some extent during the extreme wet season in Balaphi River watershed.

For verification, same parameters calibrated for Balaphi River, year 1991, was used in Balaphi River, year 1990, gave Nash Efficiency of 81% and the ratio of cumulative observed discharge by cumulative calculated discharge of 1.09. See table-6-9 and fig. 32.

Table-6-9 : Simulation Results from Balaphi River (Year 1990)

Qcal Mean	Qobs Mean	Nash Efficiency	Qobs/Qcal
130.00186	141.97018	0.8175535	1.0920627

Fig. 32 : **Results for Extreme Rainy Season at Balaphi River, gauging sta. 620 - Yr.1990 Sun Kosi Catchment (Using the same Tank Model Calibrated Parameters for the same station in 1991)**



6.2.3 Role of the number of tanks included in the Tank Model for small-scale and large-scale catchments

For Jhikhu River catchment – small scale- three tanks were included vertically in the Tank Model program. The middle tank did not play a significant role. But in the study of larger catchments, Sun Kosi River Basin, one more Tank had to be added in the Tank Model program to achieve better performance. This made four tanks vertically arranged. Thus it made clear that the number of tanks needed in the Tank Model are more for larger scale catchments to achieve better performance.

6.2.4 Discussions on results based on the concept of homogeneity in small scale and large scale catchments by applying the logic of Tank Model.

From the results of Jhikhu subcatchments it was found that one subcatchment's parameters did not match for the next sub-catchment in calibration process.

Generally speaking, small basins are difficult to analyze. Contrary to what might be expected, it is not easy to get uniformity in small basins. Every basin is a sort of integrator in space and in time. The effect of time can be approximated by an incomplete integral operator with a time constant T, which is approximately proportional to the square root of the catchments area. Therefore, for the analysis of a small basin we must use a short time unit. However, precipitation during a short time unit shows a larger fluctuation in space than over a longer time unit. This is the basic factor for precipitation, which is the most important hydrological phenomenon.

In a river basin it is believed that many hydrological phenomenon occur randomly. For example, there are many water routes both on and under the ground surface. Some of them are blocked or reduced by sedimentation of sand or silt but other routes will open or become enlarged by erosion of sand and silt. If the basin is large, the effects of such random phenomenon will cancel each other out and the change will be minimal. However, in a small basin these effects of random hydrological phenomena may cause instability.

Although the physical phenomenon can't be explained directly by the tank model, there are some logic points to ponder which shows that tank model is not a mere black box.

- If it is a mere black box, how can such a simple tank model successfully simulate river discharge from high flood flows to flows to low base flows?
- It is rather difficult to find hydrological experimental data or phenomena that correspond directly to the tank model.

On the surface of the earth, there are many rivers and lakes which transfer and store water. As the surface area of these rivers and lakes is usually very small compared with the basin area, if we pick up some random sample points in some basin, it is unlikely that they would be located on a river or lake surface. It is especially unlikely that the point would be on a river surface because the area of a river surface is negligible compared with the basin area. However, water transfer in the basin is carried out mainly through these river channels. If it rains heavily, surface flow will occur which does not appear in the form of a thin homogeneous layer but usually in the form of some network of small channels. *It appears that nature likes singular discontinuous structures, in contrast to mathematicians who like uniform and homogeneous structures for simplicity.*

Though underground hydrological phenomena can't be observed directly, it can be supposed that discontinuous structures also play an important part. For example, water infiltrates through a permeable layer with a certain speed, but if there were some holes or gapes caused by faults or other reasons, water could go through these routes at a much higher speed. Even if the total area of such discontinuous structures were small, their effect would be large and could play the main part in the vertical transfer of water.

Moreover there is an important logic question. An aquifer is assumed which has been tested at many points and all tests show that the water conductivity is high. Even though many points are tested, the aquifer could not transfer water well, if it was blocked at some untested point. Again in the case of an impermeable layer, which has been tested at many points and every test showed that the layer is impermeable. However, if there is a hole or gap at some point, the layer would not be impermeable as a total.

In these cases, the response of the total structure could not be found from point data or point experiments even if the number of points were large. We can get the characteristics of the total response of the whole. Point data and their averages are useless for such phenomena.

Runoff and infiltration coefficients of tank model are related to such phenomena. They show the total response of the basin. The structures of movement and storage of underground water must be very complicated and the tank model is a sort of approximation, which represents their total response, and probably this is the physical meaning of the tank model. Moreover tank model is expected as a sort of structural approach to the discontinuous structure such as faults, gaps and fissures.

Because of the logic discussed so far and the fact that uniformity is not easy to get in small catchments, the hypothesis - estimated parameters for a small subcatchment can be used efficiently to near by other subcatchments of the same basin – was rejected. This was the final conclusion drawn from the study of Jhikhu river sub-cathments and the relevant concept of tank model for small subcatchments, discussed in the above paragraphs, was proved true.

Following the same logic of Tank Model the Model was applied to large scale catchments. Sun Kosi River basin catchments. Remarkably, the result proved that the estimated parameters for large scale subcatchment can be used efficiently to other large scale subcatchments of the same basin provided that the physically based variables does not vary significantly from one subcatchment to another. Sticking to the fact that rainfall is heavier in the higher altitudes of Sun Kosi basin, within Nepal, the average rainfall was constantly increased to some extent during the extreme wet season in Balaphi River watershed. This was the next significant result drawn from the study of Sun Kosi River subcatchments and the relevant concept of Tank Model for larger subcatchments, discussed in the above paragraphs, was proved true.

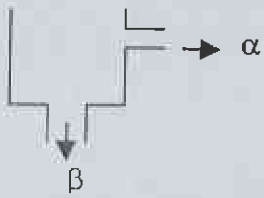
6.2.5 Sensitivity analysis of the parameters in Tank Model

The results of the sensitivity analysis on the basis of Lower Andheri Khola data is presented in fig. 33, fig. 34, fig. 35, fig. 36 and fig. 37.

The conclusions drawn are the following;

1) The ratio α/β has the role in volume change. Increase in ratio increases the volume and decrease in ratio decreases the volume As shown in fig. 33 and fig. 34.

2) The sum α+β has the role in shape change. Increase in sum makes the hydrograph steeper and decrease in sum makes the hydrograph flatter and broad as shown in fig. 36 and fig. 38.



3) The parameters in the middle tank remained dormant for small catchments analysis.

4) The bottom outlet of the bottom tank was found to be the most sensitive for the ground water change, fig. 35.

5) More tanks had to be added in tank model program when shifting from the study of hydrological analysis of small catchment (Jhikhu subcatchment) to was larger one (Sun Kosi basin).

Sensitivity Analysis of Tank Model Parameters

Table-6-10:Original *(Calibrated Parameters,for Upper Andheri Khola,1997, Jhikhu subcatchment)*

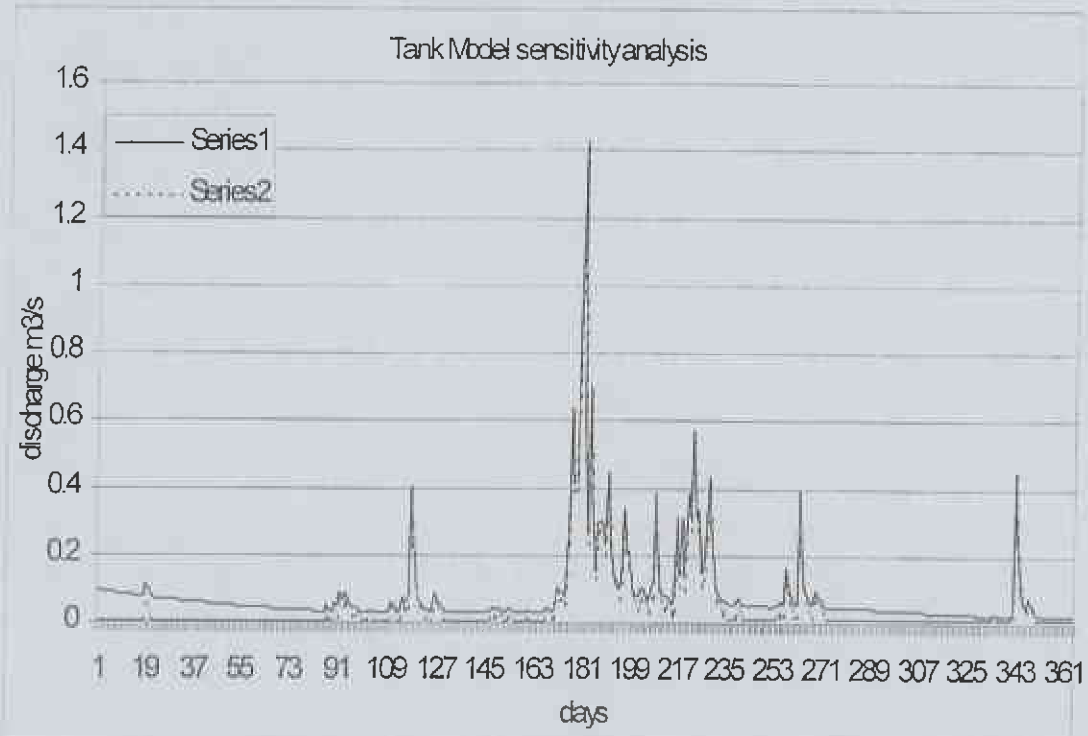
For reference see fig 24 and figures 8,9 of chapter-4

122,3	>>>>>>	No. of timesteps, No.of Tank
rfs2810e	>>>>>>	Rainfall Data
qsnle	>>>>>>	Qobs Data
spe327e	>>>>>>	Evapotranspiration Data
3	>>>>>>	Topmost Tank
0.115,0.21,0.3,14,26,40,14	>>>>>>	Ao , A1, A2, HA1, HA2, XA, S1
-1,99,18	>>>>>>	K1, nomeaning constant, K2
2	>>>>>>	Middle Tank
0.075,0.075,10.0,500.,20	>>>>>>	Bo, B1, HB, XB, S2
1,10,3	>>>>>>	K1, nomeaning constant, K2
1	>>>>>>	Bottom Tank
0.015,300.	>>>>>>	Co, HC
2,99,0	>>>>>>	K1, nomeaning constant, K2

(i) When A2=0.6

Dotted line (series 2)- Parameter changed calculated discharge graph AND
Undotted line (series 1) - Original calculated discharge graph

Fig. : 33

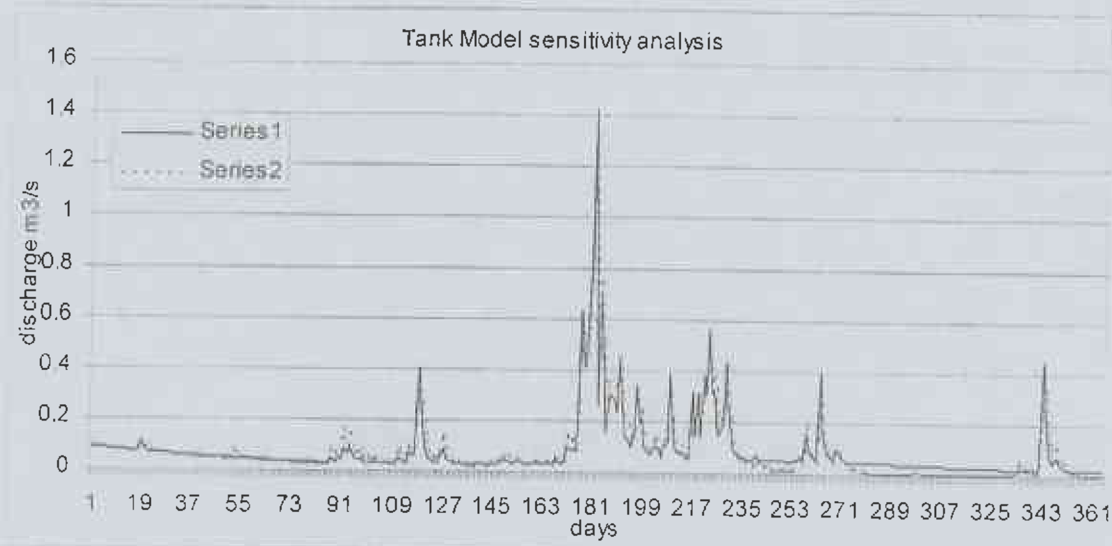


Remarks: The peaks have been increased but the base flow remains the same

(iv) When Ao=0.015, A2=0.2 (Ao and A2 sutracted by 0.1)

Dotted line (series 2)- Parameter changed calculated discharge graph AND
Undotted line (series 1) - Original calculated discharge graph

Fig. 34

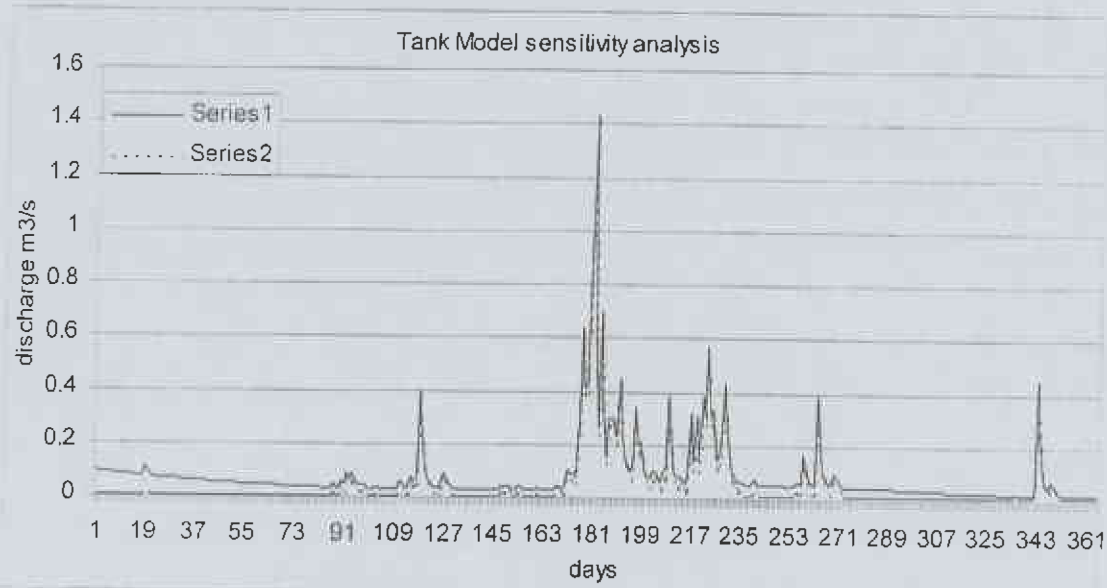


Remarks: The recession limbs became flatter with decrease in wet season base flow.

(v) When Co=0.001

Dotted line (series 2)- Parameter changed calculated discharge graph AND
Undotted line (series 1) - Original calculated discharge graph

Fig. 35

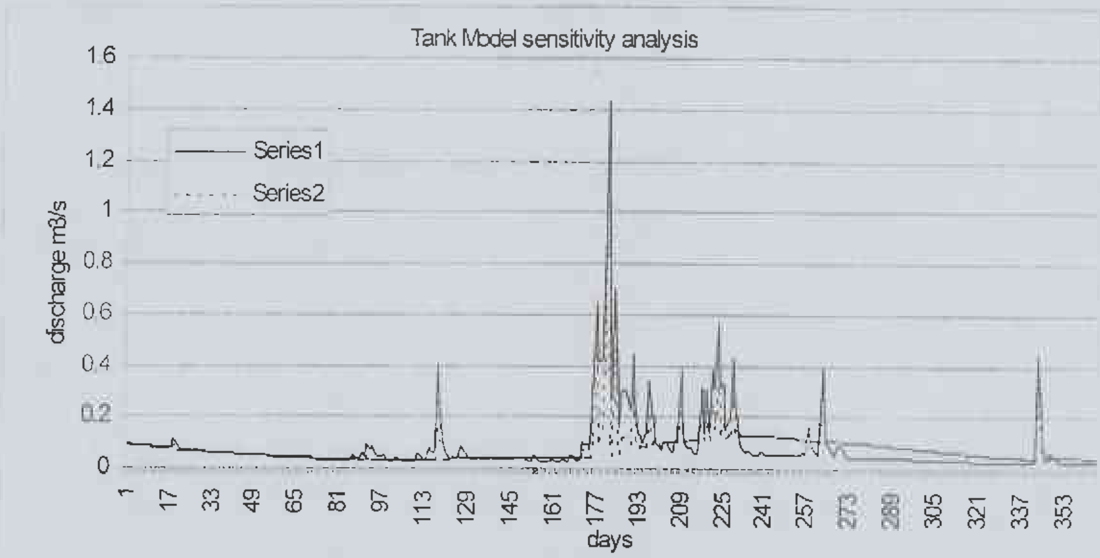


Remarks: The base flow decreased throughout the year (more significantly in the early dry season).

(ii)When Ao=0.4

Dotted line (series 2)- Parameter changed calculated discharge graph AND
Undotted line (series 1) - Original calculated discharge graph

Fig. 36

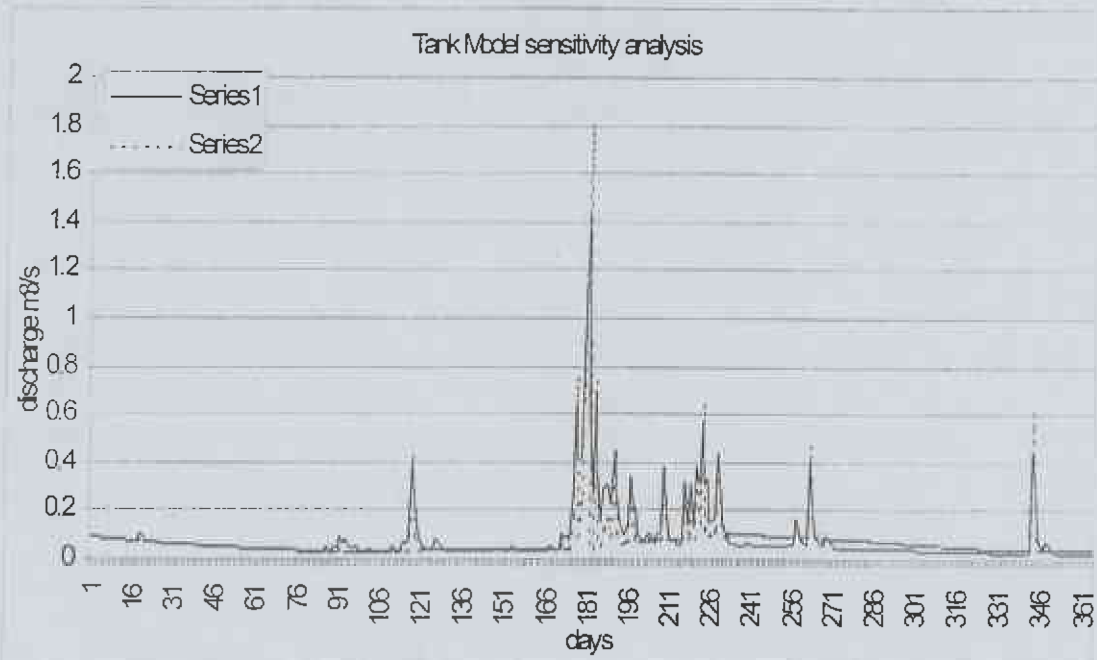


Remarks: The peak flows decreased and there was significant increase in base flow during and after wet season

(iii) When Ao=0.5, A2=0.7 (Ao and A2 added by

Dotted line (series 2)- Parameter changed calculated discharge graph AND
Undotted line (series 1) - Original calculated discharge graph

Fig. 37



Remarks: The recession limbs of the peak flows became steeper with significant increase in peaks and wet season

7. CONCLUSIONS AND RECOMMENDATIONS.

7.1 Conclusion

- Water resources has a vital role to play in shaping the fate of the national economy, it's successful utilization remains equally challenging from various standpoints. The first challenge stems from the non-availability of hydrological `data itself. Even the available data has not been used in an optimal way. There are large ungauged catchments awaiting development and management that would benefit from the use of hydro-environmental simulation models to assist with basin planning. The second obstacle is the rugged terrain. Moreover, The major river basins of Nepal extend towards the Tibetan Plateau where the information of the data is not available. Evaluation of rainfall-runoff models that incorporates all these challenges has become one of the most significant themes in the context of Himalayan kingdom of Nepal. Thus to overcome all the complexities and difficulties, BTOPMC – a physically based distributed hydrological model based on the blockwise use of TOPMODEL with Muskingum-Cung flow routing method- was selected to evaluate the applicability in Nepalese catchment. To suit the Nepalese catchment further modification in the model was suggested that lead to the development of BTOPMC version II (see 6.1.1 of chapter-6). The quality of simulation is classically judged by comparing the simulated flow with observed flow. Model performance was judged by a range of quantitative and qualitative measures of fit applied to both the calibration and validation periods. The daily stream flow estimation in Sun Kosi river basin was promising. BTOPMC can be successfully used as a tool for integrated water resources investigation in large watershed, mountain physiographic region, of Nepal.
- Tank Model was used for small and large catchments to analyze the concept of homogeneity. Despite it's simple logic to understand and operate, it could effectively respond the hydrological and geomorphological phenomenon – that is far from simple- in various scales of catchments.Tank Model was used in small subcatchments of Jhikhu Khola watershed. The result proved that storage and land use effect played a dominant role in rainfall runoff process of small catchments (see 6.2.1 (e) of chapter-6). From the results of Jhikhu subcatchments it was found that parameters estimated for one subcatchment did not match the next subcatchment response. But from the results of Sun Kosi catchments-large scale- the estimated parameters for one large-scale sudbcatchment also proved to give good response for the next large-scale subcatchment. It was also concluded that if the basin is large, the effects of random hydrological phenomenon will cancel each other out and the change will be minimal (see 6.2.4 of chapter-6). However, in a small basin these effects of random hydrological and geomorphological phenomenon may cause instability. All these analysis of homogeneity was based on Tank Model response. Thus Tank Model is not a mere black box but has physical meaning.

7.2 Recommendations

- Water quantity and quality require the integration of all aspects of water resources management, such as water use and environmental conservation, quantity and quality content of surface water and groundwater, regulation of low flows and high flows, development of downstream and upstream basins, source control and channel control of floods, sediments etc. For such implementation, all available methodologies and organizational mechanisms should be utilized, such as physical and managerial means, economic and institutional means, private and public initiatives, governmental and nongovernmental initiatives, local community and central government initiatives, etc. For all these aspects, the means of basin-wide hydro-environmental simulation is a valuable planning and operational tool. There are many large ungauged basins in the world including Nepal, which need integrated planning and administration for development and management and where the lack of data is a serious barrier for any application of a basin-wide hydro-environmental simulation model. To overcome such a barrier, the use of satellite observations can play an important role. For this purpose a method is required that can make use of remotely sensed data. For sustainable basin-wide integrated water resources management and development, a reference table linking fitted model parameters (BTOPMC MODEL parameter) to satellite data is recommended to establish.

- The concept of the Tank Model is so simple and presents adequate hydrological response in the basin by using simple tanks lied vertically. Moreover, the Tank Model is used in various regions from arid to humid area and from tropical to snow-covered area. So for the future days to come, this model is recommended to be used in different regions of Nepal for continuous as well as event rainfall runoff analysis sake. Event rainfall runoff analysis is very important to avoid flood risks. Usually in flood analysis, the lower tanks are neglected because of their long time constants. The time constant of the top tank of the tank model for flood analysis is proportional to the square root of the catchment area. The relation suggested by the tank model is

$$T = 0.15 \sqrt{S}$$

(For Nepal's watershed the value can be different from 0.15 which can be find out and is recommended to get that value in the future study)

Where T (hours) is the time constant and S (sq. km.) is the catchments area. Now it is obvious that for the flood analysis, first tank plays the important role and the time constant for this tank is short. Thus the meteorological department and other responsible institutes should give due importance in achieving short time event data – on minute basis.

The fundamental principle of snow flow as per the tank model is simple and easy to understand. When the air temperature T°C is below or equal to the freezing point, precipitation is assumed to be snow and is added to the existing snow deposit, if any. When the air temperature T°C is above the freezing point, precipitation P is assumed to be in the form of rain and snowmelt, which is assumed to be proportional to air temperature, occurs. At the same time snowmelt is caused by rain itself, the rain temperature being assumed equal to air temperature. Therefore, the amount of snowmelt is given by

$$SMELT * T + (1/80) * P * T$$

Where SMELT is some coefficient.

Thus snow component is also recommended to incorporate in the future study analysis.

8. REFERENCES

1. A. M. J. Meijerink, M. Lubczynski & P. Wolski, *Remote sensing, hydrological analysis and hydrotopes*, Resionalization in Hydrology, Proceedings of a conference held at Braunschweig, March 1999, IAHS Publ. No. 254, pp.137-145, 1999.
2. Anund Killingtveit and Nils Roar Saelthun, *Hydrology, Hydropower Development* Vol. 7, Norwegian Institute of Technology Division of Hydraulic Engineering.
3. Ao T. Q., K. Takeuchi and H. Ishidaira, 1999b, BTOPMC, 1.0: *User's guide to the computer programs*, 1999.
4. Ao Tianqi, Kuniyoshi Takeuchi, Hiroshi Ishidaira, Kazuhiko Fukami and Makoto Kaneki, *The Naka River Floods Analyses by BTOPMC MODEL*- A Preliminary Report, Proceedings of International Symposium on Floods and Droughts, Nanjing, China, 18-20 October 1999.
5. *Estimation of saturation excess overland flow areas: comparison of topographic index calculations with field mapping*, Proceedings of a conference held at Braunschweig, March 1999, IAHS Publ. No. 254, pp.203-210, 1999.
6. *Ecology of High mountain Areas*, Proceedings of International conference on Eco-hydrology of High mountain Area, Katmandu, Nepal 27-28, By Mountain Natural resource Division, ICIMOD ,Katmandu, March 1996.
7. Gopal Nakarmi, *Indigenous Water Management Systems in the Andheri Khola Sub-Watershed.* Issues and Overview, Challenges in Mountain Resource Management in Nepal, Processes, Trends, and Dynamics in Middle Mountain Watersheds, Proceedings of a workshop held in Kathmandu, Nepal, pp 211-225, 10-12 April, 1995.
8. G. Peschke, C. Etzenberg, J. Topfer, S. Zimmermann and G. Muller, *Runoff generation regionalization: analysis and a possible approach to a solution,*. Proceedings of a conference held at Braunschweig, March 1999,.IAHS Publ. No. 254, pp.147-156, 1999.
9. Kazurou Nakane, *Regional Water Balance Model Based on the Concept of the Tank Model*, The Third International Study Conference on GEWEX in Asia and GAME, Seogwipo KAL Hotel, Cheju, Korea, 26^{th} – 28^{th} March, 1997.
10. Jan Seibert- *On TOPMODEL's ability to simulate groundwater dynamics,*. Proceedings of a conference held at Braunschweig, March 1999,.IAHS Publ. No. 254, pp.211-220, 1999.
11. J. Doorenbos, W. O. pruitt, *Guidelines for predicting crop water requirements*, FAO Irrigation and Drainage Paper, 24 revised 1977.
12. Jha Raghunat, *Development of distributed hydrological model incorporation surface flow interactions and its application to large tropical catchment.*

13. Jha Raghunath, Herath Srikanth and Musiake Katumi, *Application of IIS Distributed Hydrological Model (IISDHM) in Nakhon Sawan Catchment*, Thailand. Journal of Hydroscience and Hydraulic Engineering Vol.18, No.1, 21-27 May, 2000.

14. Juerg Merz, Bhawani S. Dongol, Rolf Weingartner, Gopal Nakarmi, *Impact of Land Use on Generation of High Flows in the Yarsha Khola Watershed, Nepal.*, The People and Resource Dynamics Project, Proceedings of a Workshop held in Baoshan Yunnan Province China), pp-185-198, March 2-5, 1999.

15. Kirsten Hennrich, Jochen Schmidt & Richard Dikau, *Regionalization of geomorphometric parameters in hydrological modeling using GIS*. Proceedings of a conference held at Braunschweig, March 1999, IAHS Publ. No.254, pp.181-202, 1999.

16. *Master Plan Study of the Kosi River Water Resources Development*, Japan International Co-operation Agency, March 1985.

17. M. Sugawara, I. Watanabe, E. Ozaki and Y. Katsuyama, *Tank Model with Snow Component*, Research notes of the National Research Center for Disaster Prevention No. 65, National Research Center for Disaster Prevention, Science and Technology Agency, Japan, November 1984.

18. P. B. Shah and H. Schreier, *Introduction to Watershed Project. Issues and Overview, Challenges in Mountain Resource Management in Nepal*, Processes, Trends, and Dynamics in Middle Mountain Watersheds, Proceedings of a workshop held in Kathmandu, Nepal, 10-12 April, pp. 122-140, 1995.

19. Sadra Brown and Bhuban Shrestha, *Land Use Dynamics and Intensification. Issues and Overview, Challenges in Mountain Resource Management in Nepal*, Processes, Trends, and Dynamics in Middle Mountain Watersheds, Proceedings of a workshop held in Kathmandu, Nepal, pp. 141-154, 10-12 April, 1995.

20. Takeuchi K., T.Q.Ao and H. Ishidaira, *Hydro, environmental simulation of a large ungauged basin --- introduction of block-wise use of TOPMODEL and Muskingum-Cunge method*. Hydrological Sciences Journal, 44(4) 633-646, 1999.

21. Vector Miguel Ponce, *Engineering hydrology Principles and Practices*, San Diego State University, 1989.

22. Vijay P. Singh, *Computer models of watershed hydrology*, 1995.

23. Vijay P. Singh, *Elementary Hydrology*, Louisiana State University, 1994.

APPENDIXES

APPENDIX – A
(STATISTIC INVOLVED)

Two main Types of methods to determine the goodness of fit of simulated and observ hydrographs are subjective method and objective method.

1) Subjective Method:

It is usually based on study of plots of input data and observed and comput hydrographs.

2) Objective method:

When using an objective method an error function has to be defined, to uniqu (objectively) define the goodness of fit. Several types of error functions are used in mo calibration, all based on a function of type f (Q_{obs}-Q_{sim}). Widely used is Eq. (A) which based on the explained variance as a criterion.

$$R^2 = \frac{\Sigma(Q_o - \overline{Q}_o)^2 - \Sigma(Q_s - Q_o)^2}{\Sigma(Q_o - \overline{Q}_o)^2} \qquad (A)$$

Where, Q_o = Observed runoff, $\overline{Q}_o$ = Average runoff, Q_s = Simulated runoff.

R^2 is often termed the Nash efficiency criterion. The numerical value of the error functi uniquely defines the goodness of fit for the model, hence the term objective. The R^2 err function can vary from -∞ to +1.0, higher the value the better the model fit. This criteri was applied in the study to determine the goodness of fit.

APPENDIX – B

GRAPH AND TABLES

(BTOPMC Model used in Sun Kosi Basin)

Table B.1: BTOPMC Calibrated Parameters for year 1991 and used in Verification for the years 1990.

block / parameters	1	2	3	4	5
1	0.51	0.03	0.008	0.501	0.01
2	0.1	0.013	0.004	0.21	0.01
3	0.15	0.015	0.003	0.06	0.01
4	0.03	0.01	0.002	0.021	0.05
5	10.05	0.02	0.002	0.82	0.02
6	10.02	0.02	0.003	0.81	0.01
7	2.5	0.023	0.002	0.01	0.01
8	0.01	0.05	0.002	0.051	0.01

Parameter	Symbol	Defination
1 →	*To*	The saturated transmissivity of soils
2 →	*m*	The decay factor of To
3 →	Sr_{max}	The capability of root zone storage
4 →	$S_{bar}0$	The initial saturation deficit of soil
5 →	*n*	The Manning roughness coefficient

Fig. B.1: Cumulative observed discharge, cumulative calculated discharged Vs time

Fig. B.1a: Year 1991

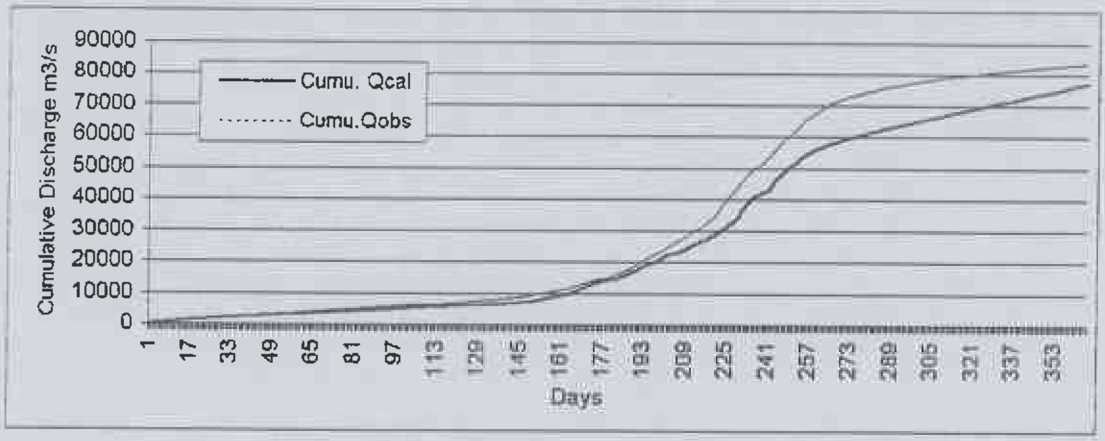
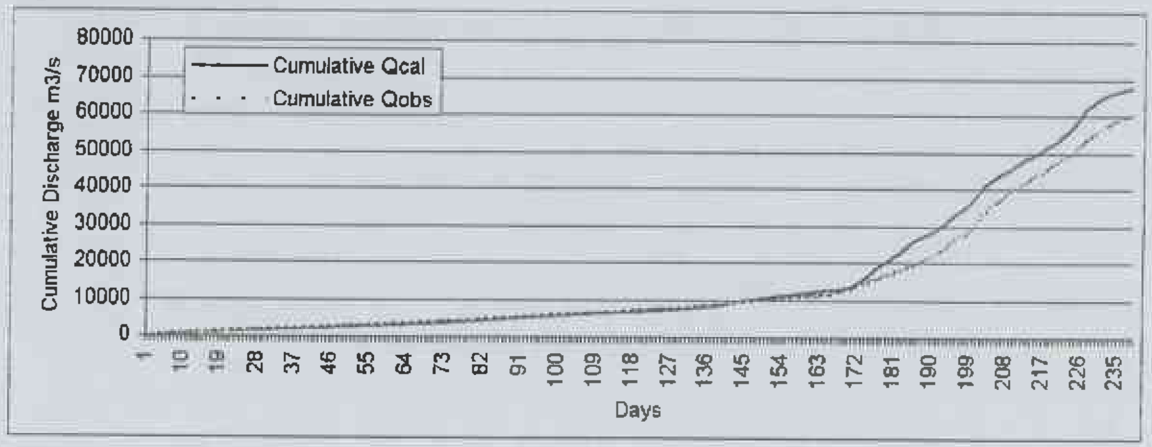


Fig. B.1b: year 1990



APPENDIX – C

TABLES

(Tank Model used in Jhikhu sub-catchments)

Tables of calculated parameters for the Jhikhu subcatchments.

Table C.1 :*Calibrated Parameters, for Kukhuri Khola,1997, Jhikhu subcatchment*

365,3	>>>>>>	No. of timesteps, No.of Tank
rfs2810e	>>>>>>	Rainfall Data
qsnle	>>>>>>	Qobs Data
spe327e	>>>>>>	Evapotranspiration Data
3	>>>>>>	Topmost Tank
0.23,0.01,0.175,14,26,40,14	>>>>>>	Ao , A1, A2, HA1, HA2, XA, S1
-1,99,18	>>>>>>	K1, nomeaning constant, K2
2	>>>>>>	Middle Tank
0.075,0.075,10.0,500.,20.	>>>>>>	Bo, B1, HB, XB, S2
1,10,3	>>>>>>	K1, nomeaning constant, K2
1	>>>>>>	Bottom Tank
0.005,300.	>>>>>>	Co, HC
2,99,0	>>>>>>	K1, nomeaning constant, K2

Table C.2:*Calibrated Parameters,for Upper Andheri Khola,1997, Jhikhu subcatchment*

365,3	>>>>>>	No. of timesteps, No.of Tank
rfs2810e	>>>>>>	Rainfall Data
qsnle	>>>>>>	Qobs Data
spe327e	>>>>>>	Evapotranspiration Data
3	>>>>>>	Topmost Tank
0.115,0.21,0.3,14,26,40,14	>>>>>>	Ao , A1, A2, HA1, HA2, XA, S1
-1,99,2	>>>>>>	K1, nomeaning constant, K2
2	>>>>>>	Middle Tank
0.075,0.075,10.0,500.,20.	>>>>>>	Bo, B1, HB, XB, S2
1,10,3	>>>>>>	K1, nomeaning constant, K2
1	>>>>>>	Bottom Tank
0.001,300.	>>>>>>	Co, HC
2,99,0	>>>>>>	K1, nomeaning constant, K2

Table C.3 :*Calibrated Parameters,for Kubinda Khola,1997, Jhikhu subcatchment*

228,3	>>>>>>	No. of timesteps, No.of Tank
rfs2810e	>>>>>>	Rainfall Data
qsnle	>>>>>>	Qobs Data
spe327e	>>>>>>	Evapotranspiration Data
3	>>>>>>	Topmost Tank
0.23,0.01,0.175,14,26,40,14	>>>>>>	Ao , A1, A2, HA1, HA2, XA, S1
-1,99,18	>>>>>>	K1, nomeaning constant, K2
2	>>>>>>	Middle Tank
0.075,0.075,10.0,500.,20.	>>>>>>	Bo, B1, HB, XB, S2
1,10,3	>>>>>>	K1, nomeaning constant, K2
1	>>>>>>	Bottom Tank
0.002,300.	>>>>>>	Co, HC
2,99,0	>>>>>>	K1, nomeaning constant, K2

Table C.4 :*Calibrated Parameters,for Lower Andheri Khola,1997, Jhikhu subcatchment*

122,3	>>>>>>	No. of timesteps, No.of Tank
rfs2810e	>>>>>>	Rainfall Data
qsnle	>>>>>>	Qobs Data
spe327e	>>>>>>	Evapotranspiration Data
3	>>>>>>	Topmost Tank
0.22,0.02,0.3,14,26,40,14	>>>>>>	Ao , A1, A2, HA1, HA2, XA, S1
-1,99,18	>>>>>>	K1, nomeaning constant, K2
2	>>>>>>	Middle Tank
0.075,0.075,10.0,500.,20.	>>>>>>	Bo, B1, HB, XB, S2
1,10,3	>>>>>>	K1, nomeaning constant, K2
1	>>>>>>	Bottom Tank
0.012,300.	>>>>>>	Co, HC
2,99,0	>>>>>>	K1, nomeaning constant, K2

Extensive storage-irrigation- effect analysis of Andheri catchment

Storage effect analysis is done from the equation:

Qloc = Qout - Qin + DS/DT

The (-) Values shows the Extensive storage effect due to several Dams built for irrigation.

The dry seasons are more effected than the wet seasons

Table C.5

1	2	3	4	5	6	7	8	9	10
days	Qobs upper Andheri	Qcal upper Andheri	Qobs Kukhuri	Qcal Khukuri	Obs. Sum U Andheri $ Khukuri	Cal. Sum U Andheri $ Khukuri	Qobs Lower Andheri	Qout-Qin (8)-(6)	Qout-Qin (8)-(7)
1-Jan	0.038	0.0956	0.011	0.0129	0.049	0.1085	0.003	-0.046	-0.1055
2-Jan	0.038	0.0943	0.01	0.0128	0.048	0.1071	0.003	-0.045	-0.1041
3-Jan	0.04	0.0931	0.007	0.0128	0.047	0.1059	0.003	-0.044	-0.1029
4-Jan	0.045	0.0919	0.008	0.0128	0.053	0.1047	0.003	-0.05	-0.1017
5-Jan	0.039	0.0907	0.011	0.0127	0.05	0.1034	0.003	-0.047	-0.1004
6-Jan	0.04	0.0895	0.01	0.0127	0.05	0.1022	0.003	-0.047	-0.0992
7-Jan	0.045	0.0883	0.007	0.0126	0.052	0.1009	0.003	-0.049	-0.0979
8-Jan	0.039	0.0871	0.008	0.0126	0.047	0.0997	0.003	-0.044	-0.0967
9-Jan	0.038	0.086	0.011	0.0126	0.049	0.0986	0.003	-0.046	-0.0956
10-Jan	0.038	0.0848	0.011	0.0125	0.049	0.0973	0.003	-0.046	-0.0943
11-Jan	0.04	0.0836	0.01	0.0125	0.05	0.0961	0.003	-0.047	-0.0931
12-Jan	0.045	0.0825	0.008	0.0124	0.053	0.0949	0.003	-0.05	-0.0919
13-Jan	0.039	0.0813	0.01	0.0124	0.049	0.0937	0.003	-0.046	-0.0907
14-Jan	0.038	0.0802	0.007	0.0123	0.045	0.0925	0.003	-0.042	-0.0895
15-Jan	0.038	0.0791	0.007	0.0123	0.045	0.0914	0.004	-0.041	-0.0874
16-Jan	0.038	0.078	0.007	0.0122	0.045	0.0902	0.006	-0.039	-0.0842
17-Jan	0.038	0.0769	0.007	0.0122	0.045	0.0891	0.006	-0.039	-0.0831
18-Jan	0.038	0.0758	0.007	0.0121	0.045	0.0879	0.006	-0.039	-0.0819
19-Jan	0.04	0.1114	0.007	0.0126	0.047	0.124	0.007	-0.04	-0.117
20-Jan	0.047	0.0933	0.007	0.0122	0.054	0.1055	0.009	-0.045	-0.0965
21-Jan	0.046	0.0804	0.007	0.0119	0.053	0.0923	0.008	-0.045	-0.0843
22-Jan	0.039	0.072	0.007	0.0119	0.046	0.0839	0.006	-0.04	-0.0779
23-Jan	0.038	0.0712	0.008	0.0118	0.046	0.083	0.003	-0.043	-0.08
24-Jan	0.04	0.0704	0.01	0.0118	0.05	0.0822	0.003	-0.047	-0.0792
25-Jan	0.047	0.0695	0.008	0.0117	0.055	0.0812	0.003	-0.052	-0.0782
26-Jan	0.048	0.0687	0.011	0.0117	0.059	0.0804	0.003	-0.056	-0.0774
27-Jan	0.046	0.0679	0.01	0.0116	0.056	0.0795	0.003	-0.053	-0.0765
28-Jan	0.037	0.0672	0.007	0.0116	0.044	0.0788	0.003	-0.041	-0.0758
29-Jan	0.03	0.0664	0.007	0.0115	0.037	0.0779	0.003	-0.034	-0.0749
30-Jan	0.029	0.0656	0.007	0.0115	0.036	0.0771	0.003	-0.033	-0.0741
31-Jan	0.027	0.0649	0.007	0.0114	0.034	0.0763	0.003	-0.031	-0.0733
1-Feb	0.024	0.0641	0.007	0.0114	0.031	0.0755	0.003	-0.028	-0.0725
2-Feb	0.029	0.0633	0.007	0.0113	0.036	0.0746	0.003	-0.033	-0.0716
3-Feb	0.027	0.0626	0.007	0.0112	0.034	0.0738	0.003	-0.031	-0.0708
4-Feb	0.022	0.0618	0.006	0.0112	0.028	0.073	0.003	-0.025	-0.07
5-Feb	0:022	0.0611	0.004	0.0111	0.026	0.0722	0.003	-0.023	-0.0692
6-Feb	0.024	0.0603	0.005	0.0111	0.029	0.0714	0.003	-0.026	-0.0684
7-Feb	0.027	0.0596	0.006	0.011	0.033	0.0706	0.003	-0.03	-0.0676
8-Feb	0.022	0.0589	0.004	0.011	0.026	0.0699	0.003	-0.023	-0.0669
9-Feb	0.022	0.0581	0.004	0.0109	0.026	0.069	0.002	-0.024	-0.067

10-Feb	0.022	0.0574	0.005	0.0109	0.027	0.0683	0.002	-0.025	-0.0663
11-Feb	0.022	0.0567	0.007	0.0108	0.029	0.0675	0.002	-0.027	-0.0655
12-Feb	0.024	0.0559	0.006	0.0108	0.03	0.0667	0.002	-0.028	-0.0647
13-Feb	0.027	0.0552	0.004	0.0107	0.031	0.0659	0.002	-0.029	-0.0639
14-Feb	0.021	0.0545	0.004	0.0107	0.025	0.0652	0.002	-0.023	-0.0632
15-Feb	0.016	0.0538	0.004	0.0106	0.02	0.0644	0.002	-0.018	-0.0624
16-Feb	0.016	0.0531	0.004	0.0106	0.02	0.0637	0.002	-0.018	-0.0617
17-Feb	0.016	0.0524	0.005	0.0105	0.021	0.0629	0.002	-0.019	-0.0609
18-Feb	0.016	0.0517	0.007	0.0104	0.023	0.0621	0.002	-0.021	-0.0601
19-Feb	0.016	0.051	0.007	0.0104	0.023	0.0614	0.002	-0.021	-0.0594
20-Feb	0.016	0.0503	0.007	0.0103	0.023	0.0606	0.002	-0.021	-0.0586
21-Feb	0.016	0.0496	0.007	0.0103	0.023	0.0599	0.002	-0.021	-0.0579
22-Feb	0.016	0.049	0.007	0.0102	0.023	0.0592	0.002	-0.021	-0.0572
23-Feb	0.016	0.0484	0.007	0.0102	0.023	0.0586	0.003	-0.02	-0.0556
24-Feb	0.016	0.0478	0.007	0.0101	0.023	0.0579	0.003	-0.02	-0.0549
25-Feb	0.015	0.0473	0.007	0.0101	0.022	0.0574	0.003	-0.019	-0.0544
26-Feb	0.011	0.0467	0.006	0.01	0.017	0.0567	0.003	-0.014	-0.0537
27-Feb	0.011	0.0462	0.004	0.01	0.015	0.0562	0.003	-0.012	-0.0532
28-Feb	0.011	0.0457	0.004	0.0099	0.015	0.0556	0.003	-0.012	-0.0526
1-Mar	0.011	0.0451	0.004	0.0099	0.015	0.055	0.003	-0.012	-0.052
2-Mar	0.011	0.0446	0.004	0.0098	0.015	0.0544	0.003	-0.012	-0.0514
3-Mar	0.011	0.0441	0.004	0.0098	0.015	0.0539	0.003	-0.012	-0.0509
4-Mar	0.011	0.0436	0.004	0.0097	0.015	0.0533	0.003	-0.012	-0.0503
5-Mar	0.011	0.0431	0.004	0.0097	0.015	0.0528	0.003	-0.012	-0.0498
6-Mar	0.011	0.0426	0.004	0.0096	0.015	0.0522	0.003	-0.012	-0.0492
7-Mar	0.011	0.0421	0.004	0.0096	0.015	0.0517	0.003	-0.012	-0.0487
8-Mar	0.011	0.0416	0.004	0.0096	0.015	0.0512	0.003	-0.012	-0.0482
9-Mar	0.011	0.0411	0.004	0.0095	0.015	0.0506	0.003	-0.012	-0.0476
10-Mar	0.011	0.0407	0.004	0.0095	0.015	0.0502	0.003	-0.012	-0.0472
11-Mar	0.011	0.0402	0.004	0.0094	0.015	0.0496	0.003	-0.012	-0.0466
12-Mar	0.012	0.0397	0.002	0.0094	0.014	0.0491	0.003	-0.011	-0.0461
13-Mar	0.015	0.0392	0.002	0.0093	0.017	0.0485	0.003	-0.014	-0.0455
14-Mar	0.011	0.0387	0.002	0.0093	0.013	0.048	0.003	-0.01	-0.045
15-Mar	0.011	0.0382	0.004	0.0092	0.015	0.0474	0.003	-0.012	-0.0444
16-Mar	0.011	0.0378	0.005	0.0092	0.016	0.047	0.003	-0.013	-0.044
17-Mar	0.011	0.0373	0.006	0.0091	0.017	0.0464	0.006	-0.011	-0.0404
18-Mar	0.011	0.0368	0.005	0.0091	0.016	0.0459	0.006	-0.01	-0.0399
19-Mar	0.011	0.0364	0.006	0.009	0.017	0.0454	0.006	-0.011	-0.0394
20-Mar	0.011	0.0359	0.004	0.009	0.015	0.0449	0.006	-0.009	-0.0389
21-Mar	0.011	0.0354	0.004	0.009	0.015	0.0444	0.006	-0.009	-0.0384
22-Mar	0.011	0.035	0.004	0.0089	0.015	0.0439	0.006	-0.009	-0.0379
23-Mar	0.011	0.0345	0.004	0.0089	0.015	0.0434	0.006	-0.009	-0.0374
24-Mar	0.011	0.0341	0.002	0.0088	0.013	0.0429	0.006	-0.007	-0.0369
25-Mar	0.011	0.0336	0.004	0.0088	0.015	0.0424	0.006	-0.009	-0.0364
26-Mar	0.012	0.0332	0.004	0.0087	0.016	0.0419	0.006	-0.01	-0.0359
27-Mar	0.015	0.0327	0.004	0.0087	0.019	0.0414	0.008	-0.011	-0.0334
28-Mar	0.011	0.0507	0.004	0.009	0.015	0.0597	0.006	-0.009	-0.0537
29-Mar	0.012	0.0387	0.004	0.0086	0.016	0.0473	0.003	-0.013	-0.0443
30-Mar	0.017	0.0317	0.004	0.0086	0.021	0.0403	0.008	-0.013	-0.0323
31-Mar	0.023	0.0573	0.002	0.0087	0.025	0.066	0.004	-0.021	-0.062

1-Apr	0.029	0.0431	0.001	0.0085	0.03	0.0516	0.003	-0.027	-0.0486
2-Apr	0.031	0.0932	0.001	0.0093	0.032	0.1025	0.003	-0.029	-0.0995
3-Apr	0.038	0.0681	0.001	0.0088	0.039	0.0769	0.003	-0.036	-0.0739
4-Apr	0.038	0.0884	0.002	0.0092	0.04	0.0976	0.003	-0.037	-0.0946
5-Apr	0.038	0.0648	0.001	0.0087	0.039	0.0735	0.003	-0.036	-0.0705
6-Apr	0.036	0.0482	0.001	0.0083	0.037	0.0565	0.003	-0.034	-0.0535
7-Apr	0.03	0.0478	0.001	0.0082	0.031	0.056	0.003	-0.028	-0.053
8-Apr	0.029	0.0488	0.001	0.0082	0.03	0.057	0.003	-0.027	-0.054
9-Apr	0.029	0.037	0.001	0.0081	0.03	0.0451	0.003	-0.027	-0.0421
10-Apr	0.029	0.0301	0.001	0.0081	0.03	0.0382	0.005	-0.025	-0.0332
11-Apr	0.029	0.0301	0.001	0.0081	0.03	0.0382	0.003	-0.027	-0.0352
12-Apr	0.027	0.03	0.002	0.008	0.029	0.038	0.003	-0.026	-0.035
13-Apr	0.021	0.0417	0.002	0.008	0.023	0.0497	0.003	-0.02	-0.0467
14-Apr	0.015	0.032	0.002	0.0079	0.017	0.0399	0.003	-0.014	-0.0369
15-Apr	0.011	0.0299	0.002	0.0079	0.013	0.0378	0.006	-0.007	-0.0318
16-Apr	0.017	0.0299	0.003	0.0079	0.02	0.0378	0.006	-0.014	-0.0318
17-Apr	0.037	0.0298	0.002	0.0078	0.039	0.0376	0.009	-0.03	-0.0286
18-Apr	0.04	0.0298	0.004	0.0078	0.044	0.0376	0.012	-0.032	-0.0256
19-Apr	0.045	0.0297	0.004	0.0077	0.049	0.0374	0.009	-0.04	-0.0284
20-Apr	0.039	0.0296	0.004	0.0077	0.043	0.0373	0.006	-0.037	-0.0313
21-Apr	0.04	0.0574	0.004	0.0079	0.044	0.0653	0.003	-0.041	-0.0623
22-Apr	0.047	0.0428	0.004	0.0076	0.051	0.0504	0.003	-0.048	-0.0474
23-Apr	0.046	0.0327	0.002	0.0076	0.048	0.0403	0.008	-0.04	-0.0323
24-Apr	0.041	0.0294	0.002	0.0076	0.043	0.037	0.009	-0.034	-0.028
25-Apr	0.042	0.0754	0.002	0.008	0.044	0.0834	0.009	-0.035	-0.0744
26-Apr	0.027	0.0621	0.002	0.0077	0.029	0.0698	0.01	-0.019	-0.0598
27-Apr	0.035	0.0649	0.003	0.0078	0.038	0.0727	0.017	-0.021	-0.0557
28-Apr	0.032	0.4071	0.003	0.0483	0.035	0.4554	0.013	-0.022	-0.4424
29-Apr	0.068	0.2655	0.01	0.0381	0.078	0.3036	0.02	-0.058	-0.2836
30-Apr	0.167	0.1069	0.017	0.0174	0.184	0.1243	0.122	-0.062	-0.0023
1-May	0.149	0.07	0.011	0.0083	0.16	0.0783	0.117	-0.043	0.0387
2-May	0.061	0.052	0.006	0.0078	0.067	0.0598	0.092	0.025	0.0322
3-May	0.039	0.0394	0.004	0.0074	0.043	0.0468	0.09	0.047	0.0432
4-May	0.038	0.0409	0.011	0.0073	0.049	0.0482	0.09	0.041	0.0418
5-May	0.043	0.0317	0.01	0.0071	0.053	0.0388	0.092	0.039	0.0532
6-May	0.059	0.0565	0.007	0.0073	0.066	0.0638	0.116	0.05	0.0522
7-May	0.057	0.0881	0.008	0.0079	0.065	0.096	0.118	0.053	0.022
8-May	0.051	0.0648	0.012	0.0074	0.063	0.0722	0.119	0.056	0.0468
9-May	0.066	0.0486	0.015	0.0071	0.081	0.0557	0.118	0.037	0.0623
10-May	0.092	0.0373	0.015	0.007	0.107	0.0443	0.1	-0.007	0.0557
11-May	0.111	0.0313	0.015	0.0069	0.126	0.0382	0.059	-0.067	0.0208
12-May	0.127	0.0314	0.014	0.0069	0.141	0.0383	0.055	-0.086	0.0167
13-May	0.124	0.0314	0.011	0.0069	0.135	0.0383	0.054	-0.081	0.0157
14-May	0.109	0.0315	0.011	0.0068	0.12	0.0383	0.046	-0.074	0.0077
15-May	0.108	0.0315	0.01	0.0068	0.118	0.0383	0.035	-0.083	-0.0033
16-May	0.108	0.0315	0.008	0.0068	0.116	0.0383	0.031	-0.085	-0.0073
17-May	0.112	0.0315	0.012	0.0067	0.124	0.0382	0.037	-0.087	-0.0012
18-May	0.122	0.0315	0.015	0.0067	0.137	0.0382	0.03	-0.107	-0.0082
19-May	0.109	0.0315	0.015	0.0067	0.124	0.0382	0.023	-0.101	-0.0152
20-May	0.112	0.0314	0.014	0.0066	0.126	0.038	0.019	-0.107	-0.019

21-May	0.132	0.0314	0.011	0.0066	0.143	0.038	0.029	-0.114	-0.009
22-May	0.15	0.0313	0.011	0.0066	0.161	0.0379	0.029	-0.132	-0.0089
23-May	0.156	0.0312	0.01	0.0065	0.166	0.0377	0.02	-0.146	-0.0177
24-May	0.163	0.0311	0.007	0.0065	0.17	0.0376	0.028	-0.142	-0.0096
25-May	0.126	0.0311	0.008	0.0065	0.134	0.0376	0.019	-0.115	-0.0186
26-May	0.109	0.031	0.01	0.0064	0.119	0.0374	0.018	-0.101	-0.0194
27-May	0.108	0.0309	0.007	0.0064	0.115	0.0373	0.018	-0.097	-0.0193
28-May	0.112	0.0469	0.008	0.0064	0.12	0.0533	0.024	-0.096	-0.0293
29-May	0.127	0.0358	0.011	0.0063	0.138	0.0421	0.08	-0.058	0.0379
30-May	0.133	0.0459	0.011	0.0063	0.144	0.0522	0.043	-0.101	-0.0092
31-May	0.145	0.0351	0.011	0.0063	0.156	0.0414	0.045	-0.111	0.0036
1-Jun	0.125	0.0305	0.011	0.0062	0.136	0.0367	0.039	-0.097	0.0023
2-Jun	0.109	0.0305	0.01	0.0062	0.119	0.0367	0.036	-0.083	-0.0007
3-Jun	0.108	0.0485	0.007	0.0062	0.115	0.0547	0.021	-0.094	-0.0337
4-Jun	0.108	0.0369	0.007	0.0061	0.115	0.043	0.026	-0.089	-0.017
5-Jun	0.108	0.0304	0.007	0.0061	0.115	0.0365	0.023	-0.092	-0.0135
6-Jun	0.108	0.0303	0.007	0.0061	0.115	0.0364	0.018	-0.097	-0.0184
7-Jun	0.108	0.0303	0.006	0.0061	0.114	0.0364	0.018	-0.096	-0.0184
8-Jun	0.108	0.0302	0.004	0.006	0.112	0.0362	0.018	-0.094	-0.0182
9-Jun	0.108	0.0302	0.004	0.006	0.112	0.0362	0.019	-0.093	-0.0172
10-Jun	0.108	0.0346	0.004	0.006	0.112	0.0406	0.028	-0.084	-0.0126
11-Jun	0.108	0.0301	0.004	0.0059	0.112	0.036	0.019	-0.093	-0.017
12-Jun	0.108	0.0301	0.004	0.0059	0.112	0.036	0.018	-0.094	-0.018
13-Jun	0.108	0.03	0.004	0.0059	0.112	0.0359	0.017	-0.095	-0.0189
14-Jun	0.112	0.0327	0.004	0.0058	0.116	0.0385	0.007	-0.109	-0.0315
15-Jun	0.127	0.0299	0.004	0.0058	0.131	0.0357	0.006	-0.125	-0.0297
16-Jun	0.128	0.0299	0.004	0.0058	0.132	0.0357	0.006	-0.126	-0.0297
17-Jun	0.124	0.0484	0.004	0.0058	0.128	0.0542	0.007	-0.121	-0.0472
18-Jun	0.109	0.0397	0.004	0.0057	0.113	0.0454	0.012	-0.101	-0.0334
19-Jun	0.108	0.0306	0.004	0.0057	0.112	0.0363	0.013	-0.099	-0.0233
20-Jun	0.104	0.038	0.004	0.0057	0.108	0.0437	0.01	-0.098	-0.0337
21-Jun	0.099	0.1073	0.005	0.0065	0.104	0.1138	0.016	-0.088	-0.0978
22-Jun	0.117	0.0878	0.006	0.0064	0.123	0.0942	0.048	-0.075	-0.0462
23-Jun	0.096	0.0925	0.005	0.0065	0.101	0.099	0.016	-0.085	-0.083
24-Jun	0.103	0.0741	0.006	0.0061	0.109	0.0802	0.009	-0.1	-0.0712
25-Jun	0.099	0.2928	0.027	0.0309	0.126	0.3237	0.386	0.26	0.0623
26-Jun	0.136	0.6377	0.019	0.0883	0.155	0.726	0.17	0.015	-0.556
27-Jun	0.172	0.4093	0.012	0.0688	0.184	0.4781	0.188	0.004	-0.2901
28-Jun	0.221	0.4217	0.018	0.0729	0.239	0.4946	0.189	-0.05	-0.3056
29-Jun	0.502	0.8238	0.038	0.1336	0.54	0.9574	0.402	-0.138	-0.5554
30-Jun	2.129	1.4328	0.056	0.2354	2.185	1.6682	2.314	0.129	0.6458
1-Jul	0.899	0.6149	0.304	0.1405	1.203	0.7554	0.613	-0.59	-0.1424
2-Jul	0.543	0.2605	0.017	0.081	0.56	0.3415	0.135	-0.425	-0.2065
3-Jul	0.441	0.7013	0.016	0.1307	0.457	0.832	0.293	-0.164	-0.539
4-Jul	0.138	0.3701	0.021	0.0852	0.159	0.4553	2.887	2.728	2.4317
5-Jul	0.026	0.1554	0.027	0.0462	0.053	0.2016	0.348	0.295	0.1464
6-Jul	0.409	0.295	0.056	0.0558	0.465	0.3508	3.265	2.8	2.9142
7-Jul	0.107	0.3072	0.017	0.0547	0.124	0.3619	1.029	0.905	0.6671
8-Jul	0.01	0.2826	0.015	0.0495	0.025	0.3321	0.5	0.475	0.1679
9-Jul	0.058	0.2269	0.063	0.0396	0.121	0.2665	0.901	0.78	0.6345

29-Aug	0.007	0.0614	0.015	0.004	0.022	0.0654	0.139	0.117	0.0736
30-Aug	0.007	0.0539	0.015	0.004	0.022	0.0579	0.082	0.06	0.0241
31-Aug	0.007	0.051	0.015	0.004	0.022	0.055	0.085	0.063	0.03
1-Sep	0.007	0.0509	0.015	0.0039	0.022	0.0548	0.074	0.052	0.0192
2-Sep	0.007	0.0508	0.015	0.0039	0.022	0.0547	0.066	0.044	0.0113
3-Sep	0.006	0.0507	0.015	0.0039	0.021	0.0546	0.05	0.029	-0.0046
4-Sep	0.004	0.0505	0.015	0.0039	0.019	0.0544	0.057	0.038	0.0026
5-Sep	0.004	0.0503	0.015	0.0039	0.019	0.0542	0.067	0.048	0.0128
6-Sep	0.005	0.0501	0.016	0.0038	0.021	0.0539	0.068	0.047	0.0141
7-Sep	0.007	0.0499	0.018	0.0038	0.025	0.0537	0.069	0.044	0.0153
8-Sep	0.006	0.0496	0.015	0.0038	0.021	0.0534	0.073	0.052	0.0196
9-Sep	0.004	0.0494	0.015	0.0038	0.019	0.0532	0.063	0.044	0.0098
10-Sep	0.004	0.0491	0.015	0.0038	0.019	0.0529	0.057	0.038	0.0041
11-Sep	0.005	0.0544	0.015	0.0037	0.02	0.0581	0.063	0.043	0.0049
12-Sep	0.007	0.057	0.016	0.0037	0.023	0.0607	0.068	0.045	0.0073
13-Sep	0.007	0.0694	0.019	0.0038	0.026	0.0732	0.068	0.042	-0.0052
14-Sep	0.007	0.0566	0.018	0.0037	0.025	0.0603	0.068	0.043	0.0077
15-Sep	0.007	0.1692	0.016	0.0063	0.023	0.1755	0.074	0.051	-0.1015
16-Sep	0.007	0.0956	0.018	0.0044	0.025	0.1	0.126	0.101	0.026
17-Sep	0.006	0.0748	0.015	0.004	0.021	0.0788	0.102	0.081	0.0232
18-Sep	0.004	0.0603	0.015	0.0036	0.019	0.0639	0.08	0.061	0.0161
19-Sep	0.004	0.0545	0.015	0.0036	0.019	0.0581	0.074	0.055	0.0159
20-Sep	0.183	0.3986	0.037	0.0411	0.22	0.4397	0.111	-0.109	-0.3287
21-Sep	0.165	0.1742	0.066	0.0179	0.231	0.1921	0.328	0.097	0.1359
22-Sep	0.036	0.0958	0.005	0.0047	0.041	0.1005	0.141	0.1	0.0405
23-Sep	0.032	0.0749	0.003	0.0041	0.035	0.079	0.108	0.073	0.029
24-Sep	0.026	0.0602	0.002	0.0037	0.028	0.0639	0.087	0.059	0.0231
25-Sep	0.026	0.0499	0.003	0.0035	0.029	0.0534	0.08	0.051	0.0266
26-Sep	0.026	0.1005	0.003	0.0043	0.029	0.1048	0.055	0.026	-0.0498
27-Sep	0.026	0.0838	0.003	0.004	0.029	0.0878	0.06	0.031	-0.0278
28-Sep	0.026	0.0663	0.002	0.0036	0.028	0.0699	0.075	0.047	0.0051
29-Sep	0.026	0.0541	0.002	0.0034	0.028	0.0575	0.066	0.038	0.0085
30-Sep	0.026	0.0461	0.002	0.0034	0.028	0.0495	0.049	0.021	-0.0005
1-Oct	0.026	0.046	0.003	0.0034	0.029	0.0494	0.047	0.018	-0.0024
2-Oct	0.026	0.0459	0.003	0.0034	0.029	0.0493	0.047	0.018	-0.0023
3-Oct	0.026	0.0458	0.003	0.0034	0.029	0.0492	0.053	0.024	0.0038
4-Oct	0.026	0.0456	0.003	0.0033	0.029	0.0489	0.067	0.038	0.0181
5-Oct	0.026	0.0454	0.003	0.0033	0.029	0.0487	0.063	0.034	0.0143
6-Oct	0.026	0.0453	0.003	0.0033	0.029	0.0486	0.052	0.023	0.0034
7-Oct	0.026	0.0451	0.003	0.0033	0.029	0.0484	0.047	0.018	-0.0014
8-Oct	0.026	0.0448	0.002	0.0033	0.028	0.0481	0.047	0.019	-0.0011
9-Oct	0.026	0.0446	0.002	0.0033	0.028	0.0479	0.052	0.024	0.0041
10-Oct	0.026	0.0443	0.002	0.0032	0.028	0.0475	0.057	0.029	0.0095
11-Oct	0.026	0.044	0.002	0.0032	0.028	0.0472	0.052	0.024	0.0048
12-Oct	0.026	0.0437	0.002	0.0032	0.028	0.0469	0.047	0.019	1E-04
13-Oct	0.026	0.0434	0.002	0.0032	0.028	0.0466	0.047	0.019	0.0004
14-Oct	0.026	0.0431	0.003	0.0032	0.029	0.0463	0.052	0.023	0.0057
15-Oct	0.026	0.0428	0.003	0.0032	0.029	0.046	0.063	0.034	0.017
16-Oct	0.026	0.0424	0.002	0.0031	0.028	0.0455	0.068	0.04	0.0225
17-Oct	0.026	0.0421	0.003	0.0031	0.029	0.0452	0.068	0.039	0.0228

18-Oct	0.028	0.0417	0.003	0.0031	0.031	0.0448	0.068	0.037	0.0232
19-Oct	0.034	0.0413	0.002	0.0031	0.036	0.0444	0.075	0.039	0.0306
20-Oct	0.034	0.0409	0.002	0.0031	0.036	0.044	0.083	0.047	0.039
21-Oct	0.034	0.0405	0.002	0.0031	0.036	0.0436	0.061	0.025	0.0174
22-Oct	0.034	0.0401	0.003	0.003	0.037	0.0431	0.072	0.035	0.0289
23-Oct	0.034	0.0397	0.003	0.003	0.037	0.0427	0.046	0.009	0.0033
24-Oct	0.036	0.0393	0.003	0.003	0.039	0.0423	0.026	-0.013	-0.0163
25-Oct	0.042	0.0389	0.003	0.003	0.045	0.0419	0.024	-0.021	-0.0179
26-Oct	0.04	0.0385	0.003	0.003	0.043	0.0415	0.02	-0.023	-0.0215
27-Oct	0.034	0.0381	0.003	0.003	0.037	0.0411	0.017	-0.02	-0.0241
28-Oct	0.034	0.0377	0.003	0.003	0.037	0.0407	0.011	-0.026	-0.0297
29-Oct	0.034	0.0373	0.003	0.0029	0.037	0.0402	0.005	-0.032	-0.0352
30-Oct	0.036	0.0369	0.003	0.0029	0.039	0.0398	0.005	-0.034	-0.0348
31-Oct	0.04	0.0365	0.003	0.0029	0.043	0.0394	0.005	-0.038	-0.0344
1-Nov	0.034	0.0361	0.003	0.0029	0.037	0.039	0.005	-0.032	-0.034
2-Nov	0.034	0.0357	0.003	0.0029	0.037	0.0386	0.005	-0.032	-0.0336
3-Nov	0.034	0.0353	0.003	0.0029	0.037	0.0382	0.005	-0.032	-0.0332
4-Nov	0.034	0.0349	0.003	0.0029	0.037	0.0378	0.005	-0.032	-0.0328
5-Nov	0.034	0.0344	0.003	0.0028	0.037	0.0372	0.005	-0.032	-0.0322
6-Nov	0.034	0.034	0.003	0.0028	0.037	0.0368	0.005	-0.032	-0.0318
7-Nov	0.036	0.0336	0.003	0.0028	0.039	0.0364	0.005	-0.034	-0.0314
8-Nov	0.04	0.0332	0.002	0.0028	0.042	0.036	0.005	-0.037	-0.031
9-Nov	0.034	0.0328	0.002	0.0028	0.036	0.0356	0.005	-0.031	-0.0306
10-Nov	0.036	0.0324	0.002	0.0028	0.038	0.0352	0.007	-0.031	-0.0282
11-Nov	0.04	0.032	0.002	0.0028	0.042	0.0348	0.005	-0.037	-0.0298
12-Nov	0.034	0.0316	0.002	0.0027	0.036	0.0343	0.005	-0.031	-0.0293
13-Nov	0.034	0.0312	0.002	0.0027	0.036	0.0339	0.005	-0.031	-0.0289
14-Nov	0.034	0.0308	0.002	0.0027	0.036	0.0335	0.007	-0.029	-0.0265
15-Nov	0.034	0.0304	0.002	0.0027	0.036	0.0331	0.005	-0.031	-0.0281
16-Nov	0.034	0.03	0.001	0.0027	0.035	0.0327	0.005	-0.03	-0.0277
17-Nov	0.034	0.0296	0.001	0.0027	0.035	0.0323	0.005	-0.03	-0.0273
18-Nov	0.034	0.0293	0.001	0.0027	0.035	0.032	0.005	-0.03	-0.027
19-Nov	0.034	0.0289	0.001	0.0026	0.035	0.0315	0.005	-0.03	-0.0265
20-Nov	0.034	0.0285	0.002	0.0026	0.036	0.0311	0.005	-0.031	-0.0261
21-Nov	0.034	0.0281	0.002	0.0026	0.036	0.0307	0.005	-0.031	-0.0257
22-Nov	0.034	0.0277	0.002	0.0026	0.036	0.0303	0.005	-0.031	-0.0253
23-Nov	0.034	0.0273	0.003	0.0026	0.037	0.0299	0.005	-0.032	-0.0249
24-Nov	0.034	0.027	0.003	0.0026	0.037	0.0296	0.005	-0.032	-0.0246
25-Nov	0.034	0.0266	0.003	0.0026	0.037	0.0292	0.005	-0.032	-0.0242
26-Nov	0.034	0.0263	0.003	0.0026	0.037	0.0289	0.008	-0.029	-0.0209
27-Nov	0.034	0.0259	0.003	0.0025	0.037	0.0284	0.008	-0.029	-0.0204
28-Nov	0.034	0.0256	0.003	0.0025	0.037	0.0281	0.005	-0.032	-0.0231
29-Nov	0.034	0.0252	0.003	0.0025	0.037	0.0277	0.008	-0.029	-0.0197
30-Nov	0.034	0.0249	0.003	0.0025	0.037	0.0274	0.008	-0.029	-0.0194
1-Dec	0.034	0.034	0.003	0.0026	0.037	0.0366	0.008	-0.029	-0.0286
2-Dec	0.034	0.0248	0.003	0.0025	0.037	0.0273	0.013	-0.024	-0.0143
3-Dec	0.034	0.0241	0.003	0.0025	0.037	0.0266	0.016	-0.021	-0.0106
4-Dec	0.034	0.0239	0.003	0.0025	0.037	0.0264	0.006	-0.031	-0.0204
5-Dec	0.034	0.0237	0.003	0.0024	0.037	0.0261	0.005	-0.032	-0.0211
6-Dec	0.034	0.0235	0.003	0.0024	0.037	0.0259	0.005	-0.032	-0.0209

7-Dec	0.034	0.0234	0.003	0.0024	0.037	0.0258	0.005	-0.032	-0.0208
8-Dec	0.034	0.0312	0.003	0.0024	0.037	0.0336	0.005	-0.032	-0.0286
9-Dec	0.034	0.4514	0.004	0.0508	0.038	0.5022	0.036	-0.002	-0.4662
10-Dec	0.034	0.2518	0.009	0.0335	0.043	0.2853	0.16	0.117	-0.1253
11-Dec	0.034	0.0972	0.016	0.0127	0.05	0.1099	0.052	0.002	-0.0579
12-Dec	0.034	0.0628	0.009	0.0033	0.043	0.0661	0.074	0.031	0.0079
13-Dec	0.034	0.0448	0.006	0.0029	0.04	0.0477	0.068	0.028	0.0203
14-Dec	0.034	0.0741	0.004	0.0033	0.038	0.0774	0.122	0.084	0.0446
15-Dec	0.034	0.0551	0.004	0.0029	0.038	0.058	0.085	0.047	0.027
16-Dec	0.034	0.0396	0.004	0.0025	0.038	0.0421	0.08	0.042	0.0379
17-Dec	0.034	0.0288	0.004	0.0023	0.038	0.0311	0.069	0.031	0.0379
18-Dec	0.034	0.0239	0.003	0.0023	0.037	0.0262	0.052	0.015	0.0258
19-Dec	0.034	0.024	0.003	0.0023	0.037	0.0263	0.047	0.01	0.0207
20-Dec	0.034	0.0241	0.003	0.0023	0.037	0.0264	0.047	0.01	0.0206
21-Dec	0.034	0.0242	0.003	0.0023	0.037	0.0265	0.047	0.01	0.0205
22-Dec	0.034	0.0242	0.004	0.0022	0.038	0.0264	0.047	0.009	0.0206
23-Dec	0.034	0.0243	0.004	0.0022	0.038	0.0265	0.046	0.008	0.0195
24-Dec	0.034	0.0243	0.004	0.0022	0.038	0.0265	0.039	0.001	0.0125
25-Dec	0.034	0.0243	0.003	0.0022	0.037	0.0265	0.038	0.001	0.0115
26-Dec	0.034	0.0243	0.003	0.0022	0.037	0.0265	0.023	-0.014	-0.0035
27-Dec	0.034	0.0243	0.003	0.0022	0.037	0.0265	0.008	-0.029	-0.0185
28-Dec	0.034	0.0243	0.003	0.0022	0.037	0.0265	0.008	-0.029	-0.0185
29-Dec	0.034	0.0242	0.003	0.0022	0.037	0.0264	0.008	-0.029	-0.0184
30-Dec	0.034	0.0242	0.003	0.0022	0.037	0.0264	0.008	-0.029	-0.0184
31-Dec	0.034	0.0241	0.003	0.0021	0.037	0.0262	0.008	-0.029	-0.0182

APPENDIX – D
GRAPHS AND TABLES
(Tank Model used in Sun Kosi Basin)

Table D.1:*Tank Model Calibrated Parameters,for Balephi River at gauging stastion No. 620 and* for Sun Kosi River station No. 610 (Year 1990, Sun Kosi Basin - large catchment - study) Same parameters were used in validation of Balaphi, Year 1990.

365,4	>>>>>>	No. of timesteps, No.of Tank
rfs2810e	>>>>>>	Rainfall Data
qsnle	>>>>>>	Qobs Data
spe327e	>>>>>>	Evapotranspiration Data
4	>>>>>>	Topmost Tank
0.18,0.06,0.18,10,50,80,20	>>>>>>	Ao , A1, A2, HA1, HA2, XA, S1
-1,99,01	>>>>>>	K1, nomeaning constant, K2
3	>>>>>>	Middle Tank
0.05,0.01625,10,0,30,.5	>>>>>>	Bo, B1, HB, XB, S2
1,99,2	>>>>>>	K1, nomeaning constant, K2
2	>>>>>>	Middle Tank
0.0325,0.001,0,0,30,.1	>>>>>>	Co, C1, HC, XC, S3
3,99,1	>>>>>>	K1, nomeaning constant, K2
1	>>>>>>	Bottom Tank
0.01,60,	>>>>>>	Co, HD
4,99,0	>>>>>>	K1, nomeaning constant, K2

Fig. D.1: Cumulative observed discharge, cumulative calculated discharged Vs time

Fig. D.1a: Tank Model, Balaphi River - Yr. 1991,Sun Kosi Catchment

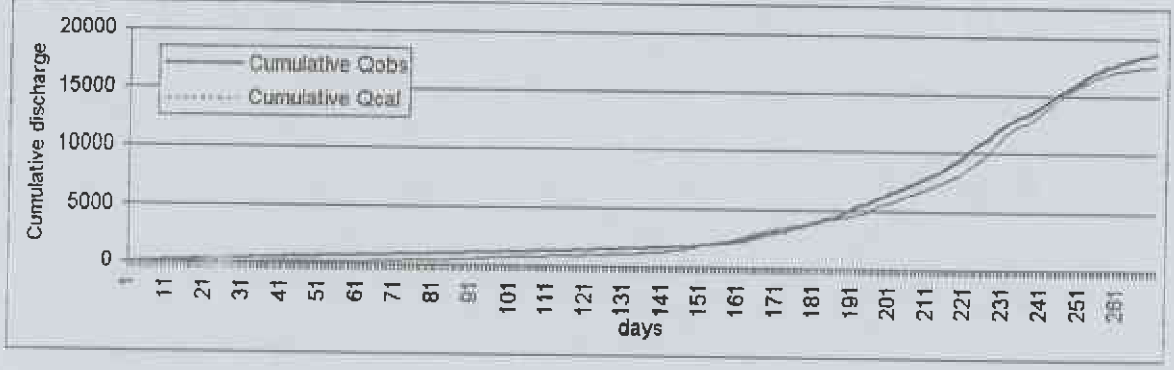


Fig. D.1b: Sun Kosi River at Pachour Ghat - Yr.1991,Sun Kosi Catchment
(Using the same Tank Model Calibrated Parameters for Balaphi River)

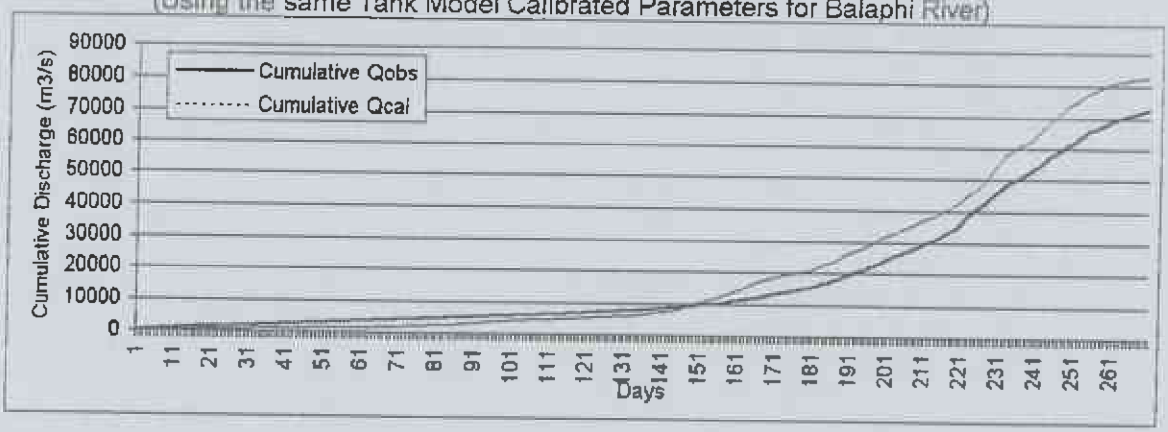


Fig. D.1c: For Extreme Rainy Season at Balaphi River, gauging sta. 620 -Yr.1990 Sun Kosi Catchment
(Using the same Tank Model Calibrated Parameters for the same station in 1991)