

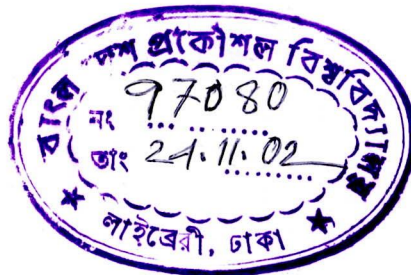
RUNOFF COMPUTATION OF HALDA RIVER BASIN USING SOIL MOISTURE ACCOUNTING METHOD

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Recommendation of the board of Examiners

We hereby recommend that the thesis prepared by Syeda Roushan Ara entitled "**Runoff computation of Halda river basin using Soil Moisture Accounting Method**" be accepted as fulfilling this part of the requirements for the degree of Masters of Engineering.

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ABSTRACT

In this study basin runoff was simulated using the computer model of the Hydrologic Engineering Centre-Hydrologic Modeling System, called HEC-HMS for the upper part of the Halda river basin given rainfall and catchment parameters. The graphical user interface of the HEC-HMS was used to edit, execute and view model data. Data needed for this study included soil, land use, digital elevation model, point elevation, contour line, stream network, rainfall, evaporation, and river discharge. Detailed stream network was created using topographic maps of 1:50000 scale. Required maps and data were collected from Water Resources Planning Organisation (WARPO), Institute of Water Modeling, and Soil Resources Development Institute. The HEC Data Storage System (DSS) was used for storage and retrieval of time series data. Geographic Information System (GIS) tools e.g. Arc/Info 8.02 and Spatial Analyst of ArcView 3.2 were used for delineating watershed and stream network from Digital Elevation Model (DEM).

The chosen basin area was divided into sub-basins and the loss rate parameters such as interception, infiltration and base flow were estimated. Most of the parameters i.e. canopy interception and surface storage, soil profile and tension zone depth of Soil Moisture Accounting (SMA) model were calibrated during simulation. No groundwater zone was considered in this study region because percolation rate became zero as model suggested.

Flow directions, flow accumulation points, flow path lengths, sub-basin areas were determined from DEM. Hydrologic modeling parameters (i.e. length of longest flow path, SCS curve number, lag time, stream velocity, Muskingum X, Muskingum K etc.) and appropriate rainfall station weightage were estimated using ArcView GIS as input parameter of the model. The rainfall excess was transformed into direct runoff using Soil Conservation Service (SCS) unit hydrograph method. Runoffs from subbasins were combined at the confluences and hydrographs routed through a channel network using Muskingum channel routing.

The simulated daily runoff for the entire year was compared with the observed runoff and that computed using another lumped conceptual model called NAM model of the Danish Hydraulic Institute.

The peak flow of simulated runoff was 426.08 m³/s on 24th June and observed runoff was 202 m³/s on 24th June. NAM computed peak flow was 405.61 m³/s on 25th June. Thus HEC-HMS overestimated the peak runoff by 52.3% as compared to observed peak runoff and by 4.8% as compared to peak runoff by NAM model. HEC-HMS and NAM results agreed reasonably well.

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Acronyms

AML	Arc Macro Language
ARC/INFO	GIS software developed by ESRI
ARCVIEW	GUI based software developed by ESRI, USA
AVENUE	An object oriented programming (script language) runs under ARCVIEW GIS software
BARC	Bangladesh Agricultural Research Council
BMD	Bangladesh Meteorological Department
BUET	Bangladesh University of Engineering & Technology
BWDB	Bangladesh Water Development Board
CA	Catchment Area
CN	Curve Number
CRWR	Center for Research in Water Resources
DEM	Digital Elevation Model
DHI	Danish Hydraulic Institute
EGIS	Environment and GIS support project for Water Sector Planning
ERH	Excess Rainfall Hyetograph
ESRI	Environment System Research Institute
ET	Evapotranspiration
FPS	Foot-Pound-Second system
GIS	Geographical Information System
GRID	A cell based GIS analysis extension of ARC/INFO
GUI	Geographical User Interface

HDDS	Hydrologic Data Development System
HEC-1	Hydrologic Modeling Software developed by US Army Corps of Engineers.
HEC-DSS	The HEC's Data Storage System
HEC-HMS	Hydrologic Modeling Software developed by US Army Corps of Engineers
ISPAN	Irrigation Support Projects for Asia & Nearest
IWM	Institute of Water Modeling
MKS (SI)	Meter Kilogram Second System (International System)
MPO	Master Plan Organization
NAM	Nedbor-Afstromnings-Model
NWMP	National Water Management Plan
PWD	Public Works Department
SCS	Soil Conservation Service
SMA	Soil Moisture Accounting
SOB	Survey of Bangladesh
SPOT Panc.	SPOT Panchromatic Image (1 band)
SPOT XS	SPOT Multispectral (3 bands) Satellite image
SRDI	Soil Resources Development Institute
STATSGO	State Soil Geographic Data Base
SWMC	Surface Water Modeling Center
UH	Unit Hydrograph
UNIX	An Operating System
USACE	United States Association of Civil Engineers

USDA

United States Department of Agriculture

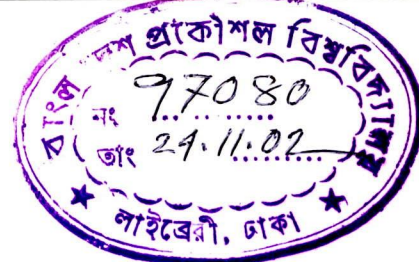
USGS

United States Geological Survey

WARPO

Water Resources Planning Organization

CHAPTER 1 INTRODUCTION



1.1 Importance of the Study

The rainfall-runoff relationships are among the most complex hydrologic phenomena to comprehend due to tremendous spatial and temporal variability of watershed characteristics, precipitation patterns as well as a number of variables involved in modeling the physical process. Hydrologic models have been developed to improve understanding of surface runoff generated from complex watersheds. Ideally surface runoff model should capture the essence of the physical controls of soil, vegetation and topography on runoff production. For many years hydrologists have attempted to understand transformation of rainfall and snow to runoff in order to forecast stream flow for various purposes. A variety of surface runoff models are available and these models are commonly classified as either lumped models or distributed parameter models.

Lumped parameter modeling of the flow of water through a watershed is carried out by dividing the watershed into a series of subbasins and using the stream network to route the runoff hydrographs from each subbasin outlet to form the runoff hydrograph at the watershed outlet. The lumped model are especially suited for the simulation of the rainfall-runoff process in a catchment and ignore spatial variations and when the hydrologic time series are sufficiently long for a model calibration. On the other hand, the distributed parameter model has a finer spatial resolution and thus more spatial computational units. A purely distributed modeling accounts grid-cell level flow simulation mechanism and cell-to-cell level flow routing is considered and accomplished. In black box models no intention is made to represent and to understand the phenomena taking place in the catchment; input is converted into output through a mathematical function known as the transfer function. Only data on input and output of the system are required for calibration and high computational speed is achieved. Soil moisture accounting (SMA) method, a lumped, empirical and continuous model is used in this study for computing runoff.

SMA model is patterned after Leavesley's Precipitation-Runoff Modeling system and is described in details in Bennet (1998). The model simulates the movement of water through and storage of water on vegetation, on the soil surface, in the soil profile, and in the ground water layers. Given precipitation and potential evapotranspiration (ET), the model computes basin surface runoff, groundwater flow, losses due to ET, and deep percolation over the entire basin. Since the Arc/Info GIS are capable of accessing large amount of spatially varying or spatially related data and also analyze data spatially, GIS software such as Arc/Info (GRID), TIN and ArcView and 3D Analyst were used for creating digital elevation model and stream network as well as determining flow direction and flow accumulation point etc. The upper part of Halda basin i.e. CA-08 has been chosen for this study taking Panchpukuria discharge station as outlet point.

1.2 Objectives of the study

For lumped parameter hydrologic models the GIS usually plays the role of a preprocessor that translate data from the data structure of the GIS to the data structure of the hydrologic model. Also it has spatial resolutions that allows for the manipulation of the shape, parameters and computational methods of the individual hydrologic computational units. In this research keeping all this information back in mind the following objectives were mentioned.

1. to setup the continuous hydrologic (SMA) model, calibrate it and validate this model by using data of Halda basin.
2. to compare runoff using a lumped model (NAM) with the results of SMA.

To achieve the above broad objectives, GIS software such as Arc/Info, Arc View Spatial and 3D Analyst is used for identification of hydrological parameters (such as drainage area, slope, flow path length, stream network, SCS curve number, Lag time, Muskingum X, Muskingum K etc). These hydrologic analyses are compiled during the execution of CRWR-PREPRO by using a digital elevation model of the study region along with its stream and subbasin coverages and then written an ASCII file called a basin file which is an input of HEC-HMS model.

1.3 Selection of study area

In Bangladesh most of the river catchments area are very large and lies outside of the country. The entire catchment of Halda is within Bangladesh and the CA-08 of Halda basin has been selected for the study area. Panchpukuria discharge station lies in the downstream of CA-08 which is an outlet point and forms a watershed.

The river Halda originates in the hilly ranges of Ramgarh, in the district of Chittagong Hill Tracts. Dhurang Khal, Sarta Khal, Talpari Khal, and Sua khal, are its principal tributaries. It falls into the Karnafuli River at Enayet Hat. It is a flashy river and remains perennial and navigable throughout the year. This river frequently crosses the danger level almost each year in the monsoon period causing wide spread regional flooding due to high intensity of rainfall in the hilly catchments area.

The headwaters of all the tributary streams of the Halda rise in the adjacent hill areas. The hills, west of the river, known as the Sitakunda Range, are not very high, reaching elevation of 150 to 500 feet. This escarpment is the western rampant of the Chittagong hills in this locality and its western front faces the Bay of Bengal. The westward drainage from this ridge consists of numerous small short streams which debouch from west east oriented ravines and flow eastward to the Halda. To the east of the Halda the ridges are much higher, reaching elevation of 1000 to 1800 feet and the terrain is more rugged and broken. The tributary streams are larger and longer and flow in a, generally, southwesterly direction to the Halda. The three main tributaries, Sarta khal, Talpari khal, and Dhurang khal all arise in the eastern hills.

The main branch of the Halda emerges from the hills near Narayanhat and the valley floor then becomes quite flat, gently slopping from north to south.

The Halda is a meandering stream where it flows through the valley with a number of ox-bow bends, several of these cutoffs was made by excavations. The river had a very flat gradient and the valley is subject to flooding by overflows from the Halda and from poor drainage of surface water during the monsoons.

The Chittagong and Chittagong Hill Tracts districts are sharply differentiated topographically from the rest of the country, as the terrain in these districts is hilly and mountainous. The hill slopes are forested or bear cutover scrub, while the lower stream valleys are generally cultivated. The Chittagong hills comprise a series of steeply folded parallel ridges having a, generally, north south axis. The formation consists of shales and firm grained sandstones of early tertiary (probably Eocen) age. The sandstones are poorly consolidated, weak and friable. Both shales and sandstones weather radically upon exposure. As a result, the hills erode easily; forming deeply eroded transverse ravines and weathered debris, and is carried to the lower valleys. The present floor of the lower valleys is probably composed of mixed deposits of marine and alluvial origin from the adjacent hills. Along the meandering streams flood banks have been built up.

1.4 Methodology

Data needed for this study may be divided into two types, namely, meteorologic data and basin data. Meteorologic data include daily rainfall, evaporation and discharge. Basin data include basin area, slope, point elevation, stream network, canopy interception, surface detention storage, soil profile depth, tension zone depth, maximum soil infiltration rate, maximum soil percolation rate etc.

- Flow direction, flow accumulation, flow path length, stream network, Digital Elevation Model (50m resolution) and drainage areas of sub-catchments were determined using GIS tools such as Arc/Info and Arc View. Stream network was digitized from topographic maps (1:50000 scale).
- Canopy interception storage, surface detention, soil profile depth, tension zone depth, maximum infiltration rate, percolation rate are calibrating parameters and were adjusted during calibration.
- Hydrologic modeling parameters i.e. Length of longest flow path, SCS curve number, lag time, stream velocity, Muskingum X, Muskingum K etc were estimated as input parameters.
- Runoff was computed for each sub-catchment (calculating overall basin response as the weighted sum of the cell responses) using the soil moisture accounting method. Runoff for sub catchments was added and routed sequentially up to the basin outlet and runoff hydrograph was obtained using HEC-HMS 2.1.3 software.

- Finally, runoff hydrograph of SMA model was compared with NAM model runoff and with the observed runoff.

The steps of the methodology have been described in a flow chart given in figure 1.1.

1.5 Literature review

Bhaskar et al (1992) used Arc/Info to estimate hydrologic parameter for the watershed hydrology Simulation model. Examples of those parameters are stream length, watershed area and watershed perimeter, while computation of other parameters required significant user interaction. Distributed parameter hydrologic models have been constructed on raster GIS data and solved using finite-difference or finite element methods. For lumped parameter hydrologic models, the GIS usually play the role of a preprocessor that translate data from the data structure of the GIS to the data structure of the hydrologic model.

Warwick and Hanes (1994) also used Arc/Info for determining hydrologic parameters for the HEC-1 hydrologic model. Arc/Info commands were used to determine most of the required parameters directly (e.g. Sub-basin area), while a separate line coverage defining the runoff routes was created manually.

Ferdinand et al. (1999) presented a schematic diagram or node-arc network describing how hydrologic elements (sub-basins, reaches, junctions, reservoirs, diversions, sources and sinks) are spatially connected a set of associated tabular attributes describing the elements, and a file containing this information that is suitable for input to a hydrologic model. The analysis is contained in a program called CRWR-PREPRO that supports HEC-HMS by taking Arc/Info coverages of sub-basin and stream networks producing the diagram as Arc/Info coverage, and then writing an ASCII file called a basin file.

A study on runoff computation in the Jamuneswari river basin using Soil Conservation Service method was done by Hasan (2001). In his study, the GIS and HEC-HMS interface was clearly understood.

A number of online documents are available in the internet of the study of GIS and HEC-HMS interface under the leadership of Professor Dr. David R. Maidment and Dr. Francisco Olivera, Department of Civil Engineering, University of Texas at Austin.

Previous works on Halda basin

NAM model: Institute of Water Modeling (IWM) applied NAM, the rainfall runoff model (IWM/NWMP, 1995, Technical report no. 5, EHRM) for Karnafuli and Halda river basins, of catchment area of 3106 square km including the study area of CA-08 of 665.07 square km and located in the southeast of Bangladesh. The Karnafuli flows east to west, having its artificial headwaters at Kaptai Dam and discharges directly to the Bay of Bengal. The Halda River, the main tributary of the Karnafuli in its lower part flows approximately north-south. Under the scope of work of the Eastern Hill Region

Model (EHRM), the Ichamati River-the other tributary of the Karnafuli besides the Halda was included in the sub model. As a result, the Karnafuli-Halda basin consists of 5 catchments (CA-08, CA-09, CA-10, CA-13 and CA-14), two of which are upstream catchments of the Halda and Ichamati rivers (CA-08 and CA-13 respectively).

Mathematical model study of Passur-Sibsa river system and Karnafuli river entrance (DANIDA, 1993, Final report of Karnafuli river and Chittagong Port, Annex-2: Model calibration and testing schemes): A mathematical model study of Passur-Sibsa river system and Karnafuli river entrance was carried out in 1995 with two river reaches. One is Karnafuli River, from Kaptai dam to Khal no. 18 (total length of 72.585 km) and the other is Halda River, from Panchpukuria to the Halda-Karnafuli confluence (total length 44.575 km).

Badiuzzaman (1978) developed the unit hydrographs at Narayanhat, South Sunderpur and Panchpukuria stations in the Halda river basin using rainfall intensity information from auto rain gage charts at Patenga. In his study, the validity of the unit hydrographs had been justified in finding direct runoff hydrographs (synthesized) and comparing them with the actual ones, by using effective rainfall runoff relation curves.

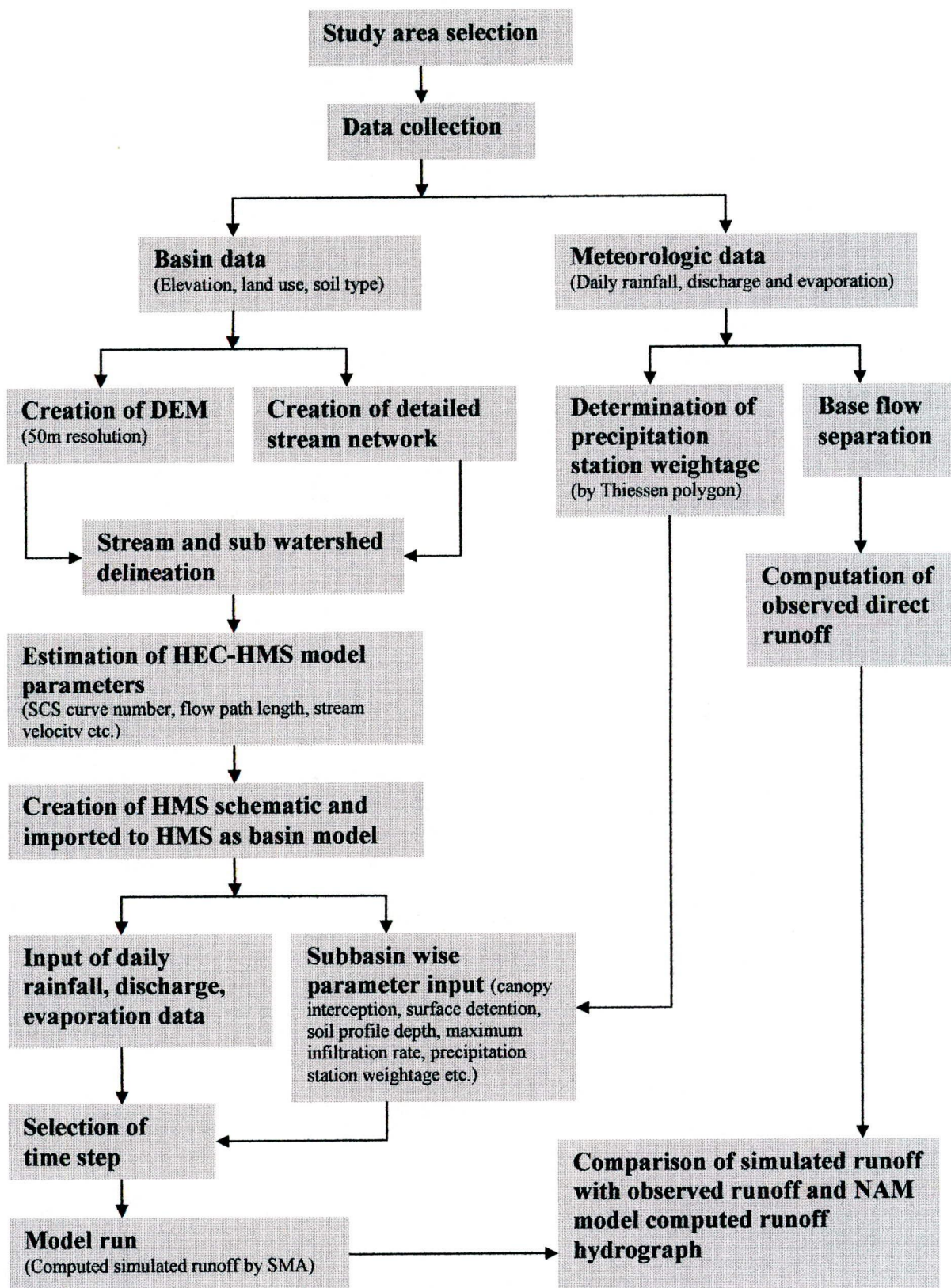


Figure: 1.1: Flow chart describing steps of Methodology

CHAPTER 2

CONCEPT OF HYDROLOGIC SYSTEMS

2.1 Hydrologic process and hydrologic cycle

A hydrologic system is defined as a structure or volume in space, surrounded by a boundary, that accepts water and other inputs, operates on them internally, and produces them as outputs. Although the concept of the hydrologic cycle is simple, the phenomenon is enormously complex and intricate. The components of the hydrologic system are precipitation, evaporation, runoff and other phases of the hydrologic cycle. These components can be grouped into subsystems of the overall cycle; to analyze the total system. Although the total volume of water in the global hydrologic system remains essentially constant, the distribution of this water is continually changing on continents, in regions, and within local drainage basins.

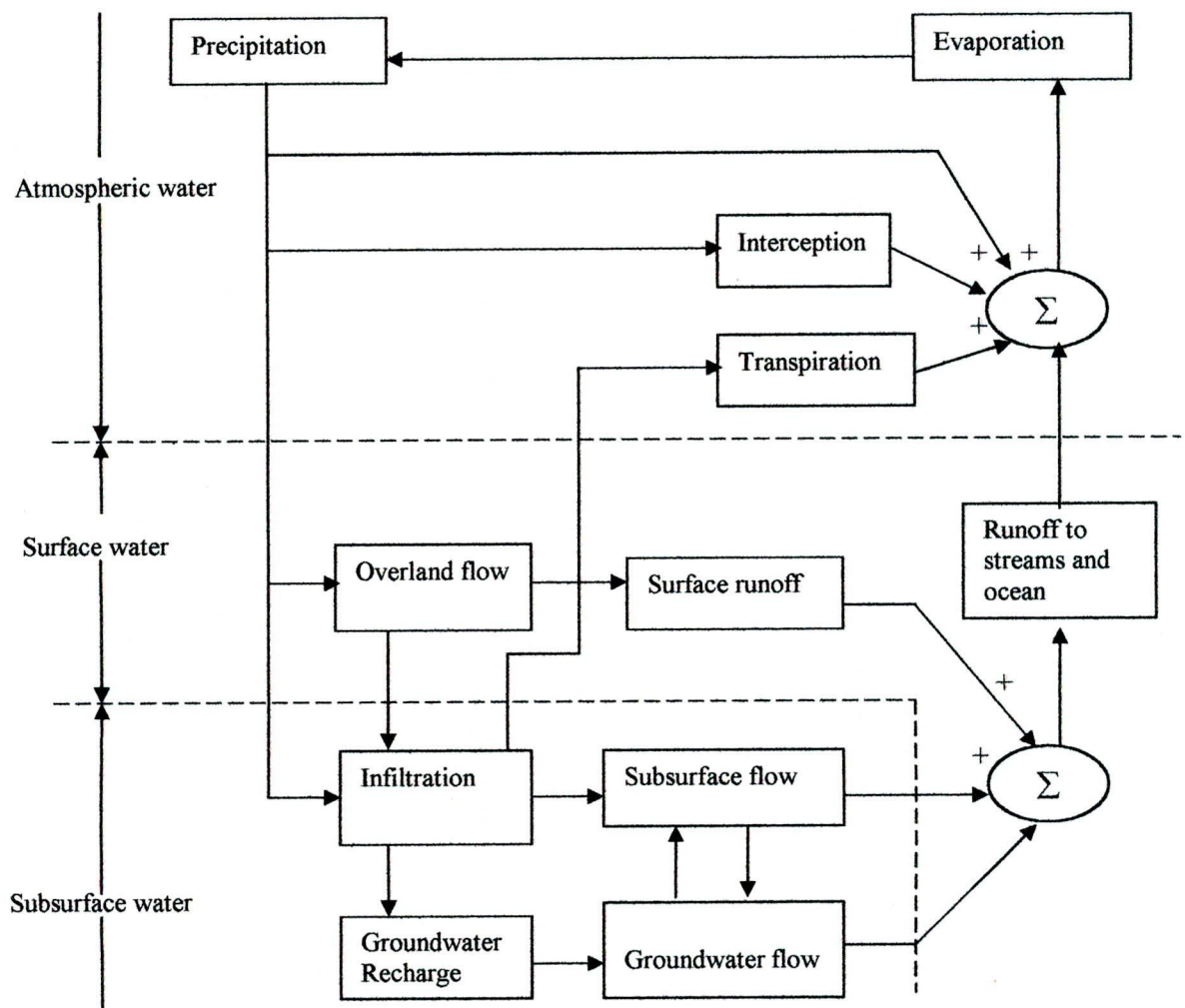


Figure: 2.1: Block – diagram representation of the Global Hydrologic Cycle

In figure 2.1, the global hydrologic cycle is represented as a system. The dashed lines divide it into three subsystems; the atmospheric water system containing the process of precipitation, evaporation, interception and transpiration; the surface water system containing the process of overland flow, surface runoff, sub-surface and groundwater outflow, and runoff to streams and the ocean; and the subsurface water system containing the process of infiltration, groundwater recharge, subsurface flow and ground water flow.

2.2 Rainfall runoff models

A model is a simplified representation of a complex process or phenomenon. Since studying the real world processes could be extremely time consuming, expensive and even dangerous, models are constructed to study pertinent system responses. Therefore, a model is a decision making tool which provides approximate but reasonable description of the behavior of a complex system.

Models can be broadly classified into two major groups: Scale models and Mathematical models. In Scale model, the actual system is reproduced in a reduced scale with the same essential features to be studied. When a model uses quantitative or mathematical expressions to describe the system behavior, it is called a Mathematical model.

Hydrological model: a hydrological model can be envisaged as an attempt to describe the natural processes which transform precipitation into runoff. Alternatively, it represents an attempt to model a physical system (the hydrologic cycle) as realistically as possible.

Mathematical model is a quantitative expression of a process or phenomenon one is observing, analyzing, or predicting which simulate processes accompanying the transformation from rainfall to runoff in catchments. Some categorization of Mathematical models has been described below:

2.2.1 Event or Continuous model: A deterministic hydrologic simulation model includes event simulation models for modeling a single rainfall-runoff event whose storm duration ranges from a few hours to a few days, and Continuous simulation model which simulates a longer period, predicting watershed response both during and between precipitation events. Example of event simulation model is; the US Army Corps of Engineers (1999) HEC-1 flood hydrograph model and HEC-HMS (hydrologic Engineer Center-Hydrologic Modeling System) SMA (Soil Moisture Accounting) is an example of continuous simulation model that simulates both wet and dry weather behavior.

2.2.2 Lumped or Distributed model: One of the most important ingredients of lumped model is that they ignore spatial variations of precipitation, water flow and other related processes and deal only with spatially averaged inputs, outputs and parameter values. In lumped models, the equations are semi-empirical, but with a

physical basis. Lumped models are basically one-dimensional. Typical fields of application include the extension of short stream flow records based on rainfall records and real-time rainfall runoff simulations for flow forecasting. Example: NAM model of Danish Hydraulic Institute.

On the other hand, Distributed model takes account of spatial variations in all variables and parameters. In essence, distributed models are physical-based. A physically based model describes the natural system using the basic mathematical representations of the flow of mass, momentum and various forms of energy. Distributed hydrological model is based on the principle that the flow of water from catchments is quite variable owing to spatial heterogeneity in surface topography and are typically structured such that it is advantageous to use the data currently available in GIS format. GIS technology can be used in preparing appropriate input files for the models. Example: MIKE-SHE of Danish Hydraulic Institute.

2.2.3 Empirical or Conceptual model: This distinction focuses on the knowledge base upon which the mathematical models are built. A conceptual model is built upon a base of knowledge of the pertinent physical, chemical, and biological processes that act on the input to produce the output. An empirical model, on the other hand, is built upon observation of input and output, without seeking to represent explicitly the process of conversion. HEC-HMS includes both empirical and conceptual models. For examples, Snyder's Unit Hydrograph (UH) model is empirical: the model is fitted with observed precipitation and runoff. The kinematics-wave runoff model is conceptual: it is based upon fundamental principles of shallow free-surface flow.

2.2.4 Deterministic or Stochastic model: If all input, parameters and processes in a model are considered free of random variation and known with certainty, then the model is a deterministic model. If instead the model describes the random variation and incorporates the description in the predictions of output, the model is a stochastic model. All models included in HEC-HMS are deterministic.

2.2.5 Measured or Fitted parameter model: This distinction is critical in selecting models for application when observations of input and output are unavailable. A measured parameter model is one in which model parameters can be determined from system properties, either by direct measurement or by indirect methods that are based upon the measurements. A fitted parameter model, on the other hand, includes parameters that cannot be measured. Instead, the parameters must be found by fitting the model with observed values of the input and the output. HEC-HMS includes both measured parameter models and fitted parameter models. For example, the base flow models mention here is empirical, so its parameters cannot be measured. Instead, for a selected watershed, the base flow model parameters are found by calibration. On the other hand, the Green and Ampt. loss model has parameters that are based upon soil characteristics that can be sampled.

2.3 NAM Model

Numerous mathematical models have been developed for the purpose of simulating various hydrological phenomena and systems. The characteristic that distinguishes the models considered from rational method is that they attempt to represent the runoff process in more detail. This can include consideration of the hydraulics of runoff, the routing of runoff through temporary storage within the drainage basin, and the arrangement or topology of the stream network. For valid application, it is important for the user to understand the principle embodied in the procedure, and the assumptions and simplifications involved.

In Bangladesh, rainfall-runoff model called NAM developed by Danish Hydraulic Institute is being used for hydrologic studies (DANIDA, 1993, Mathematical model study of Pussur-Sibsa river system and Karnafuli river entrance). It consists of a set of linked mathematical statements describing, in a simplified quantitative form, the behavior of the land phase of the hydrological cycle. The NAM is the abbreviation of the Danish word "Nedbor Afstromnings-Model" meaning precipitation runoff model. This is so called deterministic, conceptual, lumped type of model with moderate input data requirements. NAM simulates the rainfall runoff process. It operates by continuously accounting for the moisture content in four different and mutually interrelated storage which represents physical elements of the catchment as shown in figure 2-2. Water falling on a catchment due to rainfall is split into different hydrological components: evapotranspiration, overland flow, interflow, base flow, infiltration etc. The parameter represents the characteristics of the catchments size, shape, soil type, and aquifer type etc. The model is calibrated against observed discharge with observed groundwater level. Once the model is calibrated, it is expected to suit for all types of rainfall occurring in the catchment.

The input data to the model are: precipitation, potential evapotranspiration, groundwater abstraction and temperature (only if the snow routine is used). On this basis, it produces, as its main results, runoff and groundwater level values as well as information about other elements of the land phase of the hydrological cycle, such as the temporal variation of the soil moisture content and the groundwater recharge.

Runoff quantities in NAM are estimated by applying a set of parameters. These parameters are gross representations of catchments characteristics, topography, soil type and vegetative cover etc. the rainfall input in the catchment is distributed according to the values of these parameters fixed through the process of calibration. The important NAM parameters have been described in this section.

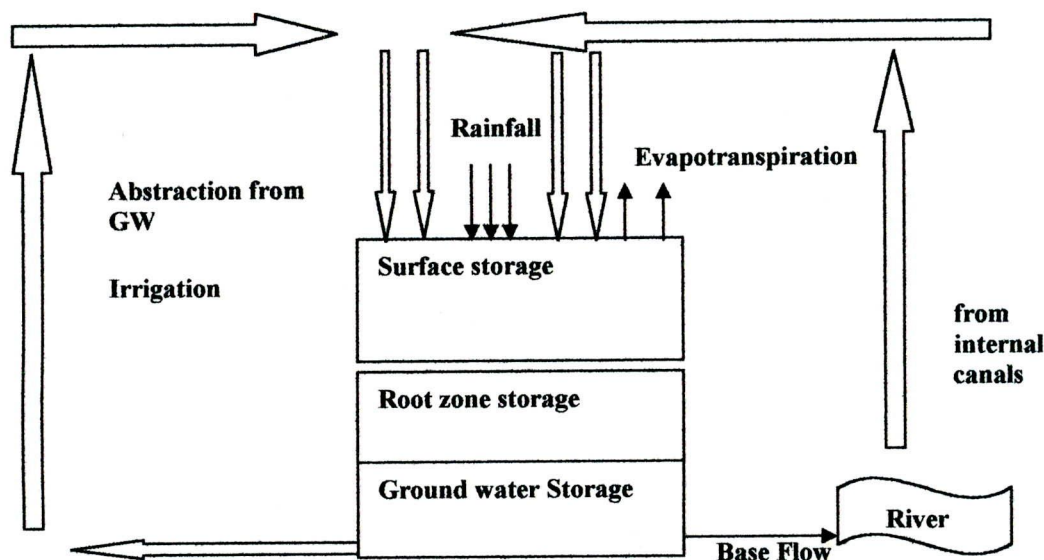


Figure: 2.2: NAM Rainfall Runoff Model

- i) **Surface storage capacity (U_{max}):** Defines the maximum water content in the surface storage and reflects that the surface storage is representing the interception storage (on vegetation), the surface depression storage and the uppermost few cm of the ground. Actual evapotranspiration is highly dependent on this storage. This value is one of the parameter by which the water balance in the simulation is to be determined.
- ii) **Lower zone storage capacity (L_{max}):** Defines the maximum water content in the root zone. L_{max} can be interpreted as the maximum soil moisture content in the root zone available for vegetative transpiration. Ideally, L_{max} can then be estimated by multiplying the difference between field capacity and wilting point of the actual soil with the effective root depth. However, L_{max} represents the average value for an entire catchment; averages are for the various soil types and root depths of the individual vegetation types. Therefore, L_{max} cannot in practice be estimated from field data but an expected interval, can be defined.
- iii) **Time constant for over & interflow co-efficient (CK_1 & CK_2):** The time constants for routing interflow and overland flow depend on the size of the catchment and how fast it responds to rainfall. The constants are found through calibration on peaks. The simulated peak discharges too low and late arriving may be adjusted by decreasing these time constants, and vice versa.
- iv) **Specific yield (S_y):** Porosity is an index of how much water can be stored in an aquifer but certainly it is not an index of its ability to yield water. The yield rate of an aquifer is a function of pore size and their interconnection. When water is drained from a saturated material by gravity only a part of the

total volume stored is released. This portion of the stored water released is called specific yield. The specific yield, S_y depends on the soil type and has typical as values of 0.01 to 0.30. These values of specific yield for the ground water storage may often be assessed from hydrological data e.g. test pumping.

- v) **Infiltration factor ($K_{o_{inf}}$):** It defines the infiltration rate at field capacity. When root zone depth is saturated the infiltration rate $K_{o_{inf}}$ may equalize the saturated hydraulic conductivity of the soil (K_s). When partly saturated the flow dynamics of the root zone becomes very complicated and are not properly described in a lumped model like NAM.
- vi) **Time constant for interflow (CKIF):** As interflow is not a dominant stream flow component, the time constant is not a very important parameter. The amount of interflow decreases with higher values of the time constant which can be given values of 500-1000 hours.
- vii) **Time constant for base flow (CKBF):** This time constant can be estimated from the base flow recession curves in the beginning of a dry season. A value in the range of 500-5000 hours can be expected.
- viii) **Threshold value for overland flow (TOF):** No overland flow is generated as long as the moisture content in the root zone is less than this threshold value. The parameters is only important in areas with alternating dry and wet seasons, and has an impact only during the first, few weeks of the wet season.
- ix) **Threshold value of interflow (TIF):** These parameters have the same function for interflow as TOF has for the overland flow. It is not a very important parameter and it can in most cases be given the value 0.
- x) **Threshold value for groundwater recharge (TG):** This threshold value has the same effect on recharge as TOF has on the overland flow. It is an important calibration factor for simulating the rise of the groundwater table during the beginning of a wet season.
- xi) **Capillary flux:** The capillary flux of water from the groundwater table to the lower zone storage is assumed to depend on the depth of the groundwater table below ground surface, GWL as well as on the relative moisture content, L/L_{max} of the lower zone storage.

2.3.1.1 Overland Flow Routing

The overland flow routing is based on the linear reservoir concept with the two parameters CK1 and CK2, but with variable time constants.

$$CK = \begin{cases} CK_{par} & OF \leq OF_{min} \\ CK_{par} CK_{OF} \left(\frac{OF}{min} \right)^{-\beta} & OF_{min} \geq OF \end{cases} \quad (2.1)$$

Where, OF = overland flow depth (mm/h)

CK_{par} = model parameter, CK1 or CK2 (hour)

OF_{min} = Lower limit for non-linear routing dynamics = 0.4mm/hr

2.3.1.2 Base flow and Groundwater levels

The base flow is calculated as the outflow from a linear reservoir with time constant CKBF. The ground water level is calculated from a continuity consideration according for recharge G, capillary flux CAFLUX, net groundwater abstraction GWPUMP, and base flow BF. The groundwater storage can be treated in two different ways, either as a simple linear reservoir or as a shallow groundwater reservoir.

2.3.1.3 Linear reservoir description

The outflow from the groundwater reservoir (base flow) is proportional to the water level in the groundwater storage divided by the time constant of the reservoir.

$$BF = \begin{cases} H (CK_{BF})^{-1} & \text{for } H \geq GWLBF_0 \\ 0 & \text{for } H < 0 \end{cases} \quad (2.2)$$

$$BF = \begin{cases} H (CK_{BF})^{-1} & \text{for } H \geq GWLBF_0 \\ 0 & \text{for } H < 0 \end{cases} \quad (2.3)$$

Where, CKBF is the base flow time constant.

2.4 Models included in HEC-HMS

HEC-HMS (U. S. Army Corps of Engineers, 2000) uses a separate model to represent each component of the runoff process including;

- Models that compute runoff volume
- Models of direct runoff (overland flow and interflow)
- Models of base flow
- Models of channels flow

The HEC-HMS models that compute runoff volume are listed in Table 2.1. These models address questions about the volume of precipitation that falls on the watershed and computes runoff volume by computing the volume of water that is intercepted, infiltrated, stored, evaporated, or transpired and subtracting it from the precipitation. Interception and surface storage are intended to represent the surface storage of water by trees or grass, local depressions in the ground surface, cracks and crevices in parking lots or roofs, or a surface area where water is not free to move as overland flow. Infiltration represents the movement of water to areas beneath the land surface. Interception, infiltration, storage, evaporation and transpiration collectively are referred to in the HEC-HMS program and documentation as losses.

The HEC-HMS models of direct runoff are listed in Table 2.2. These models describe what happens as water that has not infiltrated or been stored on the watershed moves over or just beneath the watershed surface. Table 2.3 lists the HEC-HMS models of base flow. These simulate the slow subsurface drainage of water from the system into the channels. The choices for modeling channel flow with HEC-HMS are listed in Table 2.4. These so-called routing models simulate one-dimensional open channel flow.

Table 2.1: Runoff-Volume models (HEC-HMS, Technical Reference manual, March 2000)

Model	Categorization
Initial and constant-rate	Event, lumped, empirical, fitted parameter
SCS curve number (CN)	Event, lumped, empirical, fitted parameter
Gridded SCS CN	Event, distributed, empirical, fitted parameter
Green and Ampt	Event, distributed, empirical, fitted parameter
Deficit and constant rate	Continuous, lumped, empirical, fitted parameter
Soil moisture accounting (SMA)	Continuous, lumped, empirical, fitted parameter
Gridded SMA	Continuous, distributed, empirical, fitted parameter

Table 2.2: Direct-runoff models (HEC-HMS, Technical Reference manual, March 2000)

Model	Categorization
User-specified unit hydrograph (UH)	Event, lumped, empirical, fitted parameter
Clark's UH	Event, lumped, empirical, fitted parameter
Snyder's UH	Event, lumped empirical, fitted parameter
SCS UH	Event, distributed, empirical, fitted parameter
ModClark	Event, distributed, empirical, fitted parameter
Kinematic wave	Event, lumped, conceptual, measured parameter

Table 2.3: Base flow models (HEC-HMS, Technical Reference manual, March 2000)

Model	Categorization
Constant monthly	Event, lumped, empirical, fitted parameter
Exponential recession	Event, lumped, empirical, fitted parameter
Linear reservoir	Event, lumped, empirical, fitted parameter

Table: 2.4: Routing models (HEC-HMS, Technical Reference manual, March 2000)

Model	Categorization
Kinematic wave	Event, lumped, conceptual, measured parameter
Lag	Event, lumped, empirical, fitted parameter
Modified Puls	Event, lumped, empirical, fitted parameter
Muskingum	Event, lumped, empirical, fitted parameter
Muskingum-Cunge Standard Section	Event, lumped, quasi-conceptual, measured parameter
Muskingum-Cunge 8-point Section	Event, lumped, quasi-conceptual, measured parameter
Confluence	Continuous, conceptual, measured parameter
Bifurcation	Continuous, conceptual, measured parameter

2.5 Computing runoff volume with HEC-HMS

HEC-HMS computes runoff volume by computing the volume of water that is intercepted, infiltrated, stored, evaporated or transpired and subtracted it from the precipitation. For estimation of runoff volume models are listed in the HEC-HMS technical reference manual such as:

- ❑ Initial and constant rate
- ❑ SCS curve number
- ❑ Grided SCS CN
- ❑ Green and Ampt
- ❑ Deficit & Constant rate
- ❑ Soil Moisture Accounting (SMA) &
- ❑ Grided SMA

2.5.1 Runoff computation by Soil Moisture Accounting (SMA) method

This method has been selected for loss estimation for this study. The method is described below.

2.5.1.1 Components of the model

The SMA algorithm uses a series of storage volumes to keep track of the current volume of water in each land-based component of the hydrologic cycle. The storage volumes represented in the model are canopy interception, surface interception, the soil profile and a variable number of groundwater layers.

The SMA model represents the watershed with a series of storage layers. Rates of inflow to and outflow from and capacities of the layers control the volume of water lost or added to each of these storage components. Current storage contents are calculated during the simulation and very continuously both during and between storms. The different storage layers in the SMA model are:

a) Canopy-interception storage: Canopy interception represents precipitation that is captured on trees, shrubs, and grasses, and does not reach the soil surface. Precipitation is the only inflow into this layer. When precipitation occurs, it first fills canopy storage. Only after this storage is filled does precipitation become available for filling other storage volumes. Water in canopy interception storage is held until it is removed by evaporation.

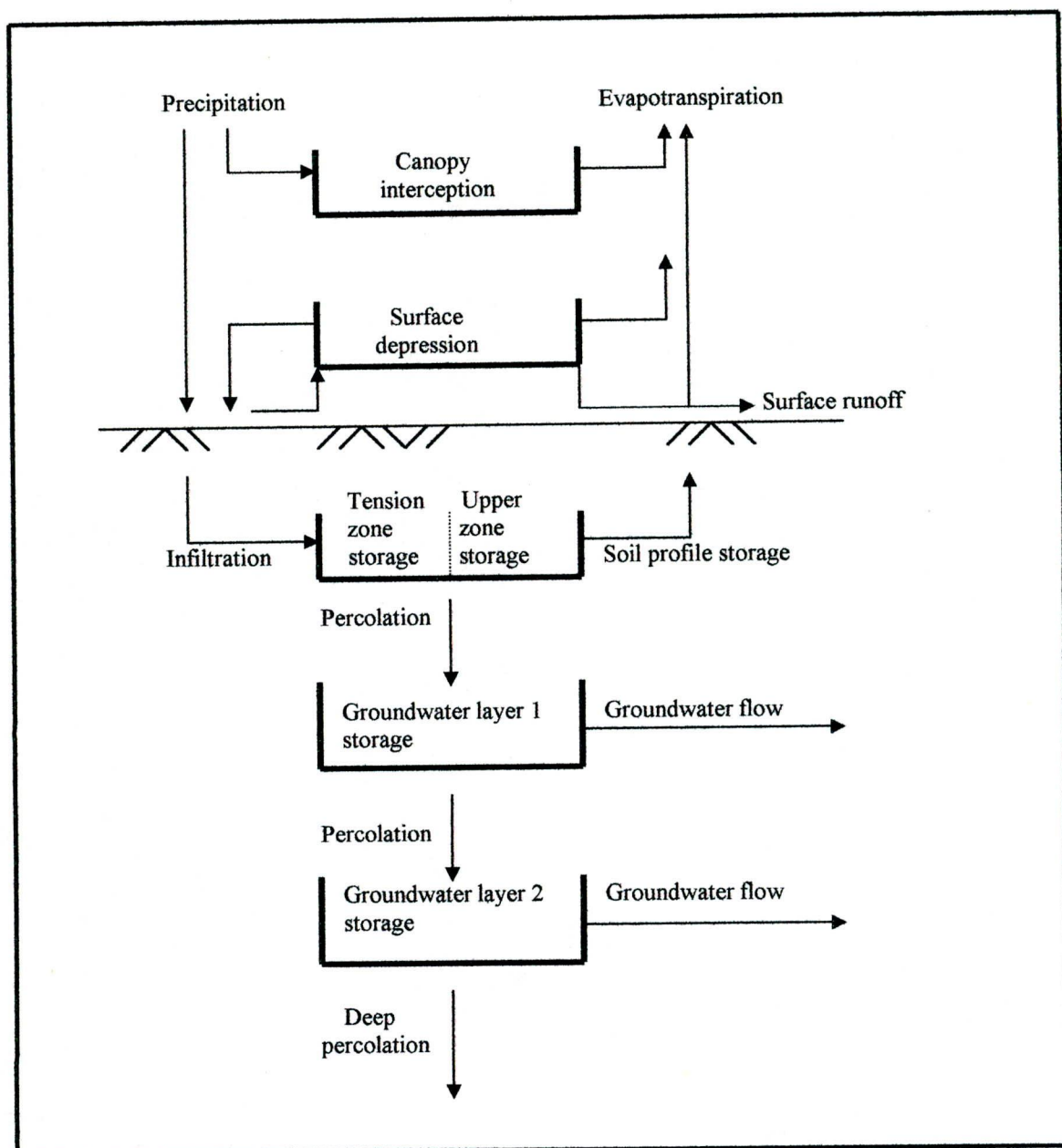


Figure: 2.3: Conceptual schematic of the continuous soil moisture accounting algorithm (Bennett, 1998)

b) Surface-interception storage: Surface depression storage is the volume of water held in shallow surface depressions. Inflows to this storage come from precipitation not captured by canopy interception and in excess of the infiltration rate. Outflows from this storage can be due to infiltration and evapotranspiration. Any contents in surface depression storage at the beginning of the time step are available for infiltration. If the water available for infiltration exceeds the infiltration rate, surface infiltration storage is filled. Once the volume of surface interception is exceeded, this excess water contributes to surface runoff.

c) Soil-profile storage: The soil profile storage represents water storage in the top layer of the soil. Inflow is infiltration from the surface. Outflows include percolation to a groundwater layer and ET. The soil profile zone is divided into regions, the upper zone and the tension zone. The upper zone is defined as the portion of the soil profile that will lose water to ET and/or percolation. The tension zone is defined as the area that will lose water to ET only. The upper zone represents water held in the pores of the soil. The tension zone represents water attached to soil particles. ET occurs from the upper zone first and tension zone last. Evaporation rates from the soil profile decrease when the current soil profile volume falls below the maximum tension zone depth. This represents the natural increasing resistance in removing water attached to soil particles. ET can only be limited to the volume available in the upper zone during specified winter month, depicting the end of transpiration by annual plants.

d) Ground water storage: The ground water component is the slow component in the runoff phenomenon. The ground water flow increases due to filling of the reservoir by percolation of infiltrated rainfall down to the phreatic table or decreases by release of water from the ground water storage in absence of recharge. During the dry season it is the only component that contributes to the catchment runoff.

Ground water layer in the SMA represent horizontal interflow processes. The SMA model can include either one or two such layer. Water percolates into groundwater storage from the soil profile. The percolation rate is a function of a user-specified maximum percolation rate and the current storage in the layers between which the water flows. Losses from a groundwater storage layer are due to groundwater flow or to percolation from one layer to another. Percolation from the soil profile enters the first layer. Stored layer can then percolate from layer 1 to groundwater layer 2 or from layer 2 to deep percolation. In the later case, this water is considered lost from the system; aquifer flow is not modeled in the SMA.

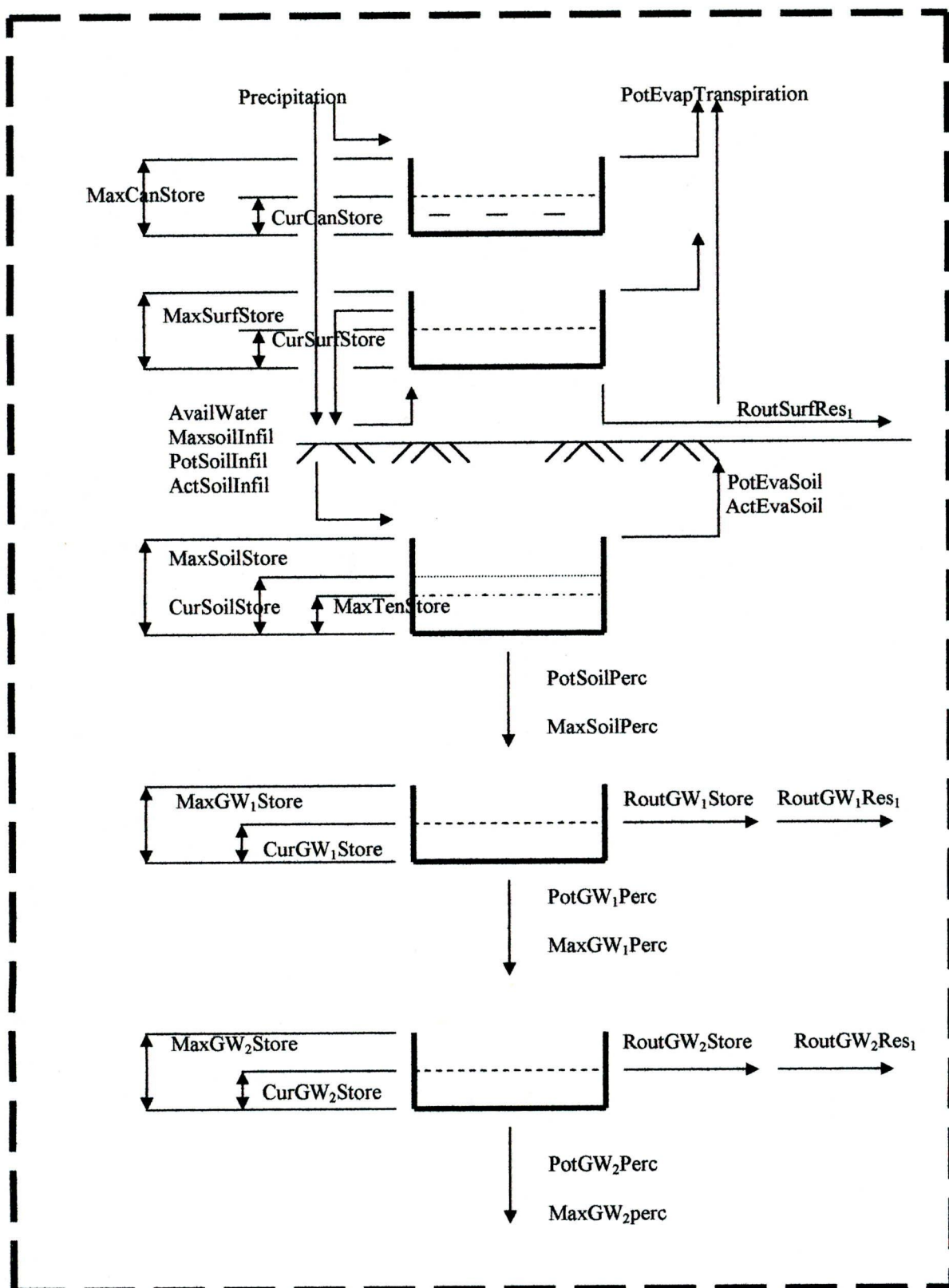


Figure: 2.4: Parameters of Soil Moisture Accounting Algorithm (Bennett, 1998)

Table: 2.5: Identification of Storage Volume, Rate, and Required Input Parameters

Parameter	Required Input Parameter	Storage Volume	Rate	Transform Parameter
MaxCanStore	Yes	X		
CurCanStore	Yes*	X		
MaxSurfStore	Yes	X		
CurSurfStore	Yes*	X		
RoutSurfRes ₁ **	Yes			X
Avail Water	No	X		
MaxSoilInfil	Yes		X	
PotSoilInfil	No		X	
ActSoilInfil	No		X	
MaxSoilStore	Yes	X		
CurSoilStore	Yes*	X		
MaxTenStore	Yes	X		
PotSoilPerc	No		X	
MaxSoilPerc	Yes		X	
MaxGW ₁ Store**	Yes	X		
CurGW ₁ Store**	Yes*	X		
PotGW ₁ Perc	No		X	
MaxGW ₁ Perc	Yes		X	
RoutGW1Res ₁ **	Yes			X
PotEvapTrans	Yes		X	
PotEvapSoil	No		X	
ActEvapSoil	No		X	

* indicates that the current storage volume is set equal to the required input value at the beginning of the simulation.

** for each groundwater layer and/or linear reservoir.

2.5.1.2 Order of model computations

Flow into and out of storage layers is computed for each time step in the HEC-HMS SMA model. The order computation in each time step depends upon occurrence of precipitation or ET, as follows:

- If precipitation occurs during the interval, ET is not modeled. Precipitation contributes first to canopy-interception storage. Precipitation in excess canopy-interception storage, combined with water already in surface storage, is available for infiltration. If the volume available is greater than the available soil storage, or if the calculated potential infiltration rate is not sufficient to deplete this volume in the determined time step, the excess goes to surface-depression storage. When surface depression storage is full, any excess is surface runoff.

Infiltrated water enters soil storage, with the tension zone filling first. Water in the soil profile, but not in the tension zone, percolates to the first groundwater layer. Groundwater flow is routed from the groundwater layer 1, and then any remaining water may percolate to the groundwater layer 2. Percolation from layer 2 is to a deep aquifer and is lost to the model.

- If no precipitation occurs, ET is modeled. Potential ET is satisfied first from canopy storage, then from surface storage. Finally, if the potential ET is still not satisfied from surface sources, water is removed from the upper-soil profile storage. The model then continues as described above for the precipitation periods.

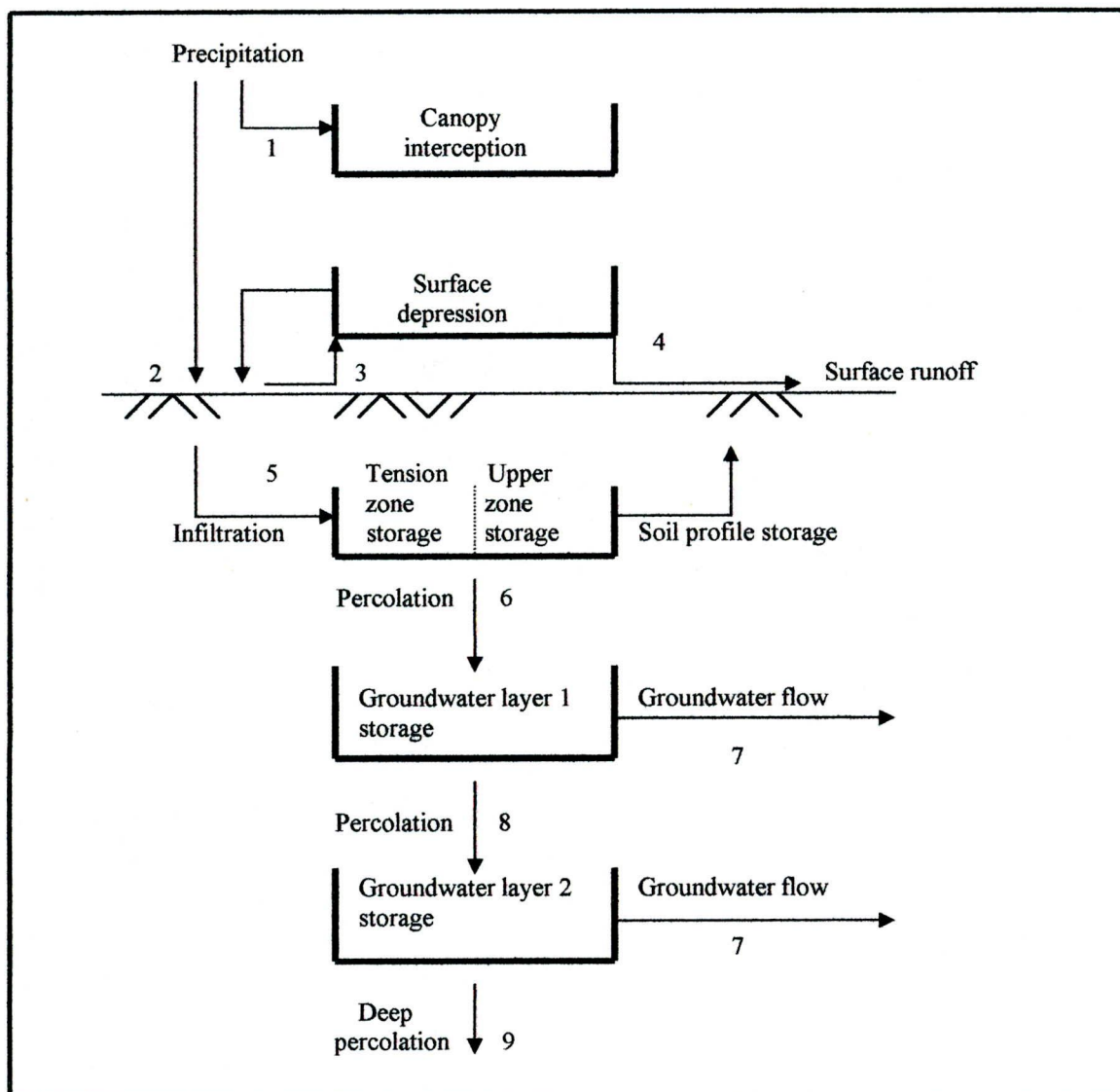


Figure: 2.5: Order of Model Computation during Precipitation Periods

- (1) Canopy storage is filled first
- (2) Precipitation from the current time step that exceeds the maximum canopy storage is combined with any surface storage that exists at the beginning of the time step, and becomes available for infiltration.
- (3) Any water from (2) that exceeds the computed infiltration rate fills surface storage.
- (4) Water exceeding the maximum surface storage volume is routed out the soil moisture accounting model.
- (5) The water that has infiltrated fills the soil surface.
- (6) Water percolates from the soil profile to groundwater storage.
- (7) Groundwater is routed out of the soil moisture accounting model.
- (8) Water percolates downward to the next groundwater layer.
- (9) Deep percolation occurs from the lowest groundwater layer and out of the soil moisture accounting model.

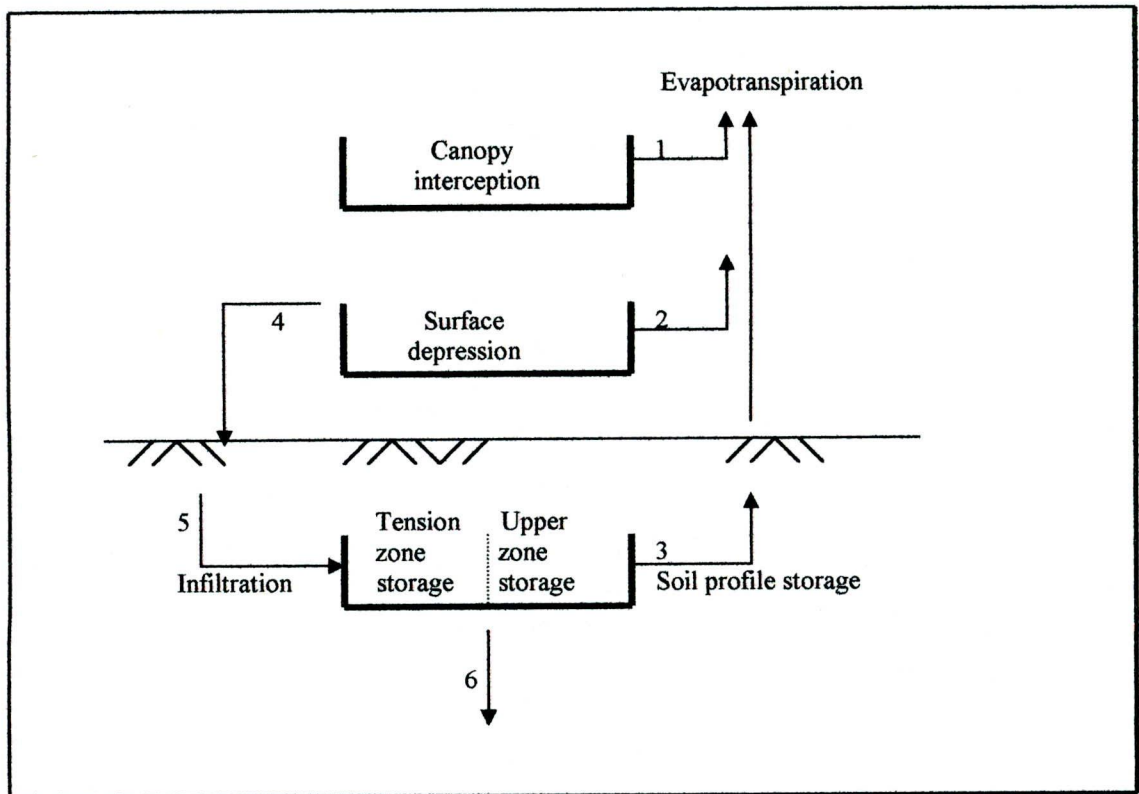


Figure: 2.6: Order of Model Computations during Periods of Evapotranspiration

- (1) Potential evapotranspiration is first satisfied from canopy storage.
- (2) Surface storage is then depleted once the canopy storage is empty and if the potential ET has not been met.
- (3) Water is next removed from the Tension Zone and/or the Upper Zone of the soil profile if the potential ET is not satisfied.
- (4) Any water remaining in surface storage is available for infiltration.
- (5) The water that has infiltrated fills the soil profile.
- (6) Model simulations continue for percolation and groundwater as in precipitation periods.

2.6 Modeling Direct Runoff with HEC-HMS

HEC-HMS describes the following models that simulate the process of direct runoff of excess precipitation on a watershed as transformation of precipitation excess into point runoff.

- ❑ User-Specified Unit Hydrograph (UH)
- ❑ Clark's UH
- ❑ Snyder's UH
- ❑ SCS UH
- ❑ ModClark
- ❑ Kinematic Wave

The SCS UH method is used for direct runoff in this project among all of the methods available in HEC-HMS.

2.6.1 SCS unit hydrograph method

The Soil Conservation Service developed a method for computing abstractions from storm rainfall. For the storm, as a whole, the depth of excess precipitation or direct runoff is always less than or equal to the depth of precipitation. The model is based upon averages of unit hydrograph derived from gauged rainfall and runoff for a large number of agricultural watersheds throughout the United States. Parametric equations are used to compute the hydrograph peak and time base from the lag. Hydrograph ordinates are subsequently computed from the peak, time base, and a dimensionless unit hydrograph. Once the parameter is required, the SCS lag in minutes or hours. The lag is stored internally in minutes.

At the heart of the SCS UH model is a dimensionless, single peaked UH. This dimensionless UH, which is shown in figure 2.7, expresses the UH discharge, U_t , as a ratio to the unit hydrograph peak discharge, U_p for any time t , a fraction of T_p , the time to UH peak.

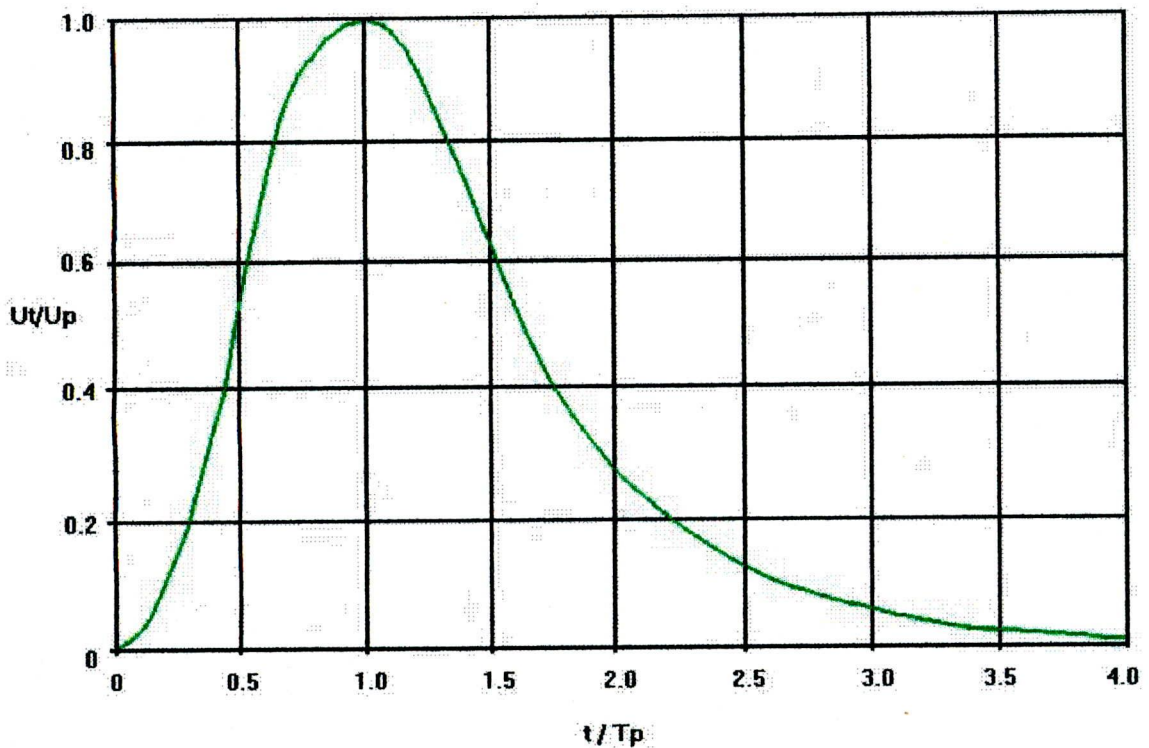


Figure 2.7: SCS dimensionless unit hydrograph

Research by the SCS suggests that the UH peak and time to UH peak are related by:

$$U_p = C \frac{A}{T_p} \text{-----}(2.4)$$

In which A = watershed area; and C = conversion constant (2.08 in SI and 484 in FPS). The time of peak (also known as the time of rise) is related to the duration of the unit of excess precipitation as:

$$T_p = \frac{\Delta t}{2} + t_{lag} \text{-----}(2.5)$$

In which, Δt = the excess precipitation duration (which is also the computational interval in HEC-HMS); and t_{lag} = the basin lag defined as the time difference between the center of mass of rainfall excess and the peak of the UH. [For adequate definition of the ordinates on the rising limb of the SCS UH, a computational interval, Δt that is 29 percent less than of t_{lag} must be used when the lag time is specified, HEC-HMS solves equation (2.5) to find the time of UH peak, and equation (2.4) to find the UH peak. With U_p and T_p known, the UH can be found from the dimensionless form, which is included in HEC-HMS, by multiplication.

$$t_{lag} = 3.5 t_{interval} \text{-----}(2.6)$$

Where, $t_{interval}$ = time interval for channel routing
 t_{lag} = lag time in minutes.

2.7 Modeling Base flow with HEC-HMS

Three alternatives models of base flow are included in the HEC-HMS.

- ☐ Constant, monthly-varying value
- ☐ Exponential recession model
- ☐ Linear-reservoir volume accounting model.

2.7.1 Linear reservoir model

The linear reservoir base flow model is used in conjunction with the continuous soil moisture accounting model. It is best calibrated using procedures consistent with those used to calibrate that model. This base flow model simulates the storage and movement of sub-surface flow as storage and movement of water through reservoirs. The reservoirs are linear: the outflow at each time step of the simulation is a linear function of the average storage during the time step. Mathematically, this is identical to the manner in which Clark's UH model represents watershed runoff.

The outflow from groundwater layer 1 of the SMA is inflow to one linear reservoir, and the outflow from groundwater layer 2 of the SMA is inflow to another. The outflow from the two linear reservoirs is combined to compute the total base flow for the watershed.

2.8 Modeling Channel Flow with HEC-HMS

The models of channel flow those are included in HEC-HMS known as routing models. The routing models available in HEC-HMS include

- ☐ Lag
- ☐ Muskingum
- ☐ Modified Plus also known as storage routing
- ☐ Kinematic-wave
- ☐ Muskingum Cunge

2.8.1 Muskingum Method

Storage is a function of the outflow. Also, the storage and outflow are assumed as functions of water level. These assumptions are valid for a channel, if the flow in the channel reach is uniform. However, for non-uniform flow, the storage depends upon the inflow and outflow. The storage in a channel reach may be divided into prism storage where S is proportional to O and wedge storage where S is proportional to the difference between inflow and outflow. Based on the assumptions a procedure was presented in 1938 to do flood routing on the Muskingum River by U.S. Army Corps of Engineers. Nowadays, this procedure is commonly called Muskingum Routing.

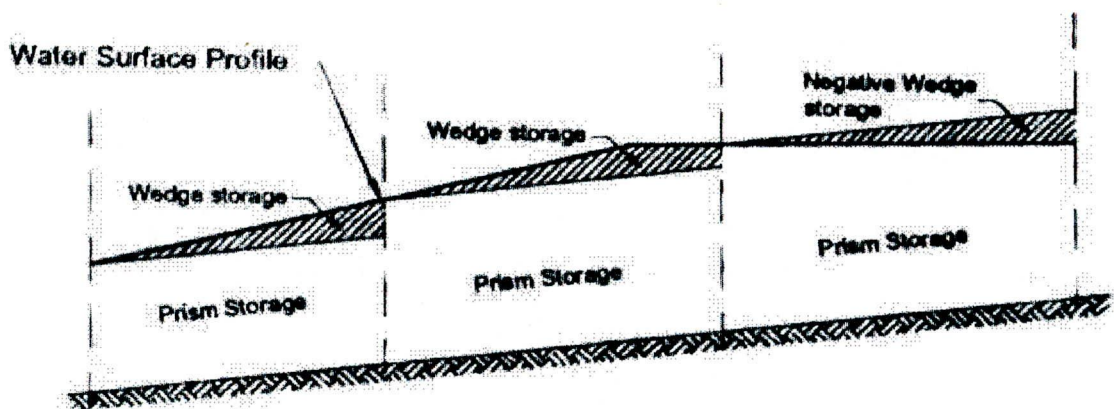


Figure: 2.8: Prism and Wedge storage of Muskingum method

The Muskingum routing model uses a simple finite difference approximation of the continuity equation.

$$\left[\frac{I_{t-1} + I_t}{2} \right] - \left[\frac{O_{t-1} + O_t}{2} \right] = \frac{S_t - S_{t-1}}{\Delta(t)} \quad (2.7)$$

In this method, the storage in a channel reach is expressed as a function of inflow and outflow as,

$$S_t = KO_t + KX(I_t - O_t) = K[XI_t + (1-X)O_t] \quad (2.8)$$

Where, K = travel time of the flood wave through routing reach; and
 X = dimensionless weight

The quantity $X I_t + (1 - X) O_t$ is a weighted discharge. If storage in the channel is controlled by downstream conditions, such that storage and outflow are highly correlated, then $X = 0$. If $X = 0$, equal weight is given to inflow and outflow, and the result is a uniformly progressive wave that does not attenuate as it moves through the reach.

If equation (2.7) is substituted into equation (2.8) and the result is rearranged to isolate the unknown values at time t , the result is;

$$O_t = \left(\frac{\Delta t - 2KX}{2K(1 - X) + \Delta t} \right) I_t + \left(\frac{\Delta t + 2KX}{2K(1 - X) + \Delta t} \right) I_{t-1} + \left(\frac{2K(1 - X) + \Delta t}{2K(1 - X) + \Delta t} \right) O_{t-1} \quad (2.9)$$

HEC-HMS solves equation (2.9) recursively to compute ordinates of the outflow hydrograph, given the inflow hydrograph ordinates (I_t for all t), an initial condition ($O_t = 0$), and the parameters, K & X

2.8.1.1 Estimating the Muskingum Model Parameters

Constraints on the parameters: As noted, the feasible range for the parameter X is (0, 0.5). However, these other constraints apply to selection of X and the parameter K :

- As with other routing models, an accurate solution requires selection of appropriate time steps, distance steps and parameters to ensure accuracy and stability of the solution. With Muskingum routing, as with Modified Puls routing, the distances step, Δx , is defined indirectly by the number of steps into which a reach is divided for routing. And as with other models, $\Delta x / \Delta t$ is selected to approximate c , where c = average wave speed over a distance increment Δx , with the Muskingum model, the wave speed is K / L , so the number of steps should be approximately $k / \Delta t$.
- The parameters K and X and the computational time step Δt also must be selected to ensure that the Muskingum model, as represented by equations (2.11) and (2.12), is rational. That means that the parenthetical terms must be non-negative; the values K and X must be chosen so that the combination falls within the shaded region shown in figure (2.9)

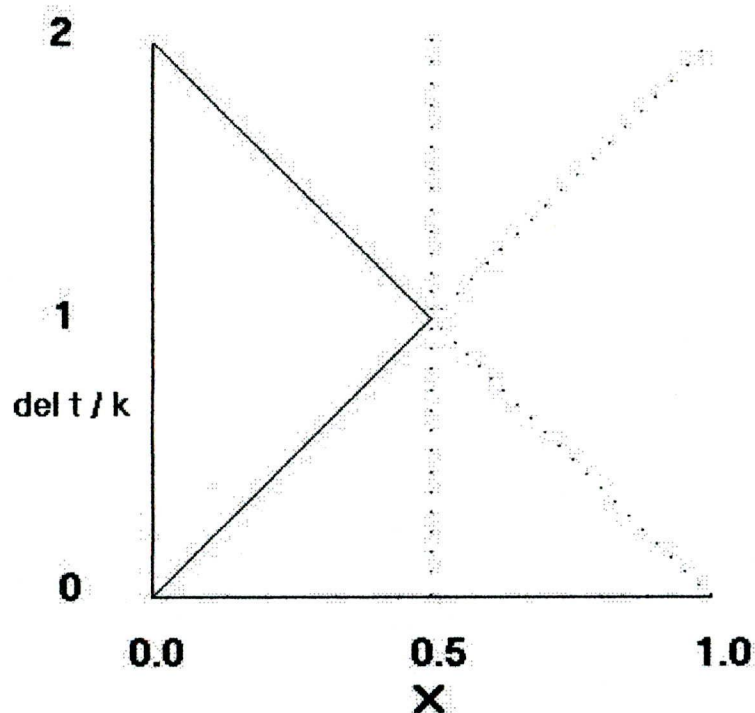


Figure: 2.9: Feasible region for Muskingum model parameters

2.8.1.2 Calibrating the model using observed flows

If observed inflow and outflow hydrographs are available, the Muskingum model parameter K can be estimated as the interval between similar points on the inflow and outflow hydrographs. For example, K can be estimated as the elapsed time between the centroid of areas of the two hydrographs, as the time between the hydrograph peaks, or as the time between midpoints of the rising limbs. Once K is estimated, X can be estimated as trial and error.

2.8.1.3 Estimating the parameters for ungaged watersheds

If gaged flows are not available for a watershed, K and X can be estimated from channel characteristics. For example EM 1110-2-1417 proposes estimating K as follows:

- Estimate the flood wave velocity, V_w , using Seddon's law as

$$V_w = \frac{1}{B} \frac{dq}{dy} \quad \text{-----} (2.10)$$

Where B = top width of the water surface, and dq / dy = slope of the discharge rating curve at a representative channel cross section. As an alternative, EM 1110-2-1417

suggests estimating the flood wave velocity as 1.33 – 1.67 times the average velocity, which may be estimated with Manning's equation and representative cross-section geometric information

- Estimate K as

$$K = \frac{L}{V_w} \text{-----}(2.11)$$

Experience has shown that for channels with mid slopes and over bank flow, the parameter X will approach 0.0. For steeper streams, with well-defined channels that do not have flows going out of bank, X will be closer to 0.5. Most natural channels lie somewhere in between these two limits, leaving room for engineering judgment, Cunge (1969) estimated X as

$$X = \frac{1}{2} \left[1 - \frac{Q_o}{BS_o C \Delta x} \right] \text{-----}(2.12)$$

Where, Q_o = a reference flow from the inflow hydrograph; B = top width of flow area; S_o = friction slope or bed slope; C = flood wave speed (celerity); and Δx = the length of reach. The reference flow is an average value for the hydrograph, midway section between the base flow and the peak flow (Ponce, 1983).

2.9 Hydrologic Soil Groups

Hydrologic condition indicates the effect of cover type and treatment on infiltration and runoff and is generally estimated from density of plant and residue cover on sample areas. Good hydrologic condition indicates that the soil usually has a low runoff potential for that specific hydrologic soil group, cover type and treatment. Some factors to consider in estimating the effect of cover on infiltration and runoff are (a) canopy or density of lawns, crops or other vegetative areas; (b) amount of year round cover; (c) amount of grass or close-seeded legumes in rotations; (d) percent of residue cover; and (e) degree of surface roughness.

Four hydrologic soil groups was found from literature based on infiltration rates namely groups A, B, C and D which is described in Table 2.6.

Table 2.6: Description of different Hydrologic Soils Groups

Soil Group	Description
Group A	Soils having a low runoff potential due to high infiltration rates even when saturated (0.30 – 0.45 in/hr). These soils consist primarily of deep sands, deep loess and aggregated silts.
Group B	Soils having a moderately low runoff potential due to moderate infiltration rates when saturated (0.15 – 0.30 in/hr). these soils consists primarily of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures (shallow loess, sandy loam).
Group C	Soils having a moderately high runoff potential due to slow infiltration rates (0.05 – 0.15 in/hr if saturated). These soils consists primarily of soils in which a layer near the surface impedes the downward movement of water or soils with moderately fine to fine texture (clay loams, shallow sandy loams, soils low in organic content, and soils usually high in clay).
Group D	Soils having a high runoff potential due to very slow infiltration rates (less than 0.05 in/hr if saturated). These soils consists primarily of clays with: High swelling potential, Soils with permanently high water tables, Soils with a clay pan or clay layer at or near the surface, Shallow soils over nearly impervious parent material (soils that swell significantly when wet, heavy plastic clays, and certain saline soils).

CHAPTER 3

DATA COLLECTION AND PROCESSING

3.1 Introduction

Various types of data are required for runoff computation for this study. Although there has been limited work done in this area of hydrologic modeling, this GIS-HEC-HMS study would be a valuable tool for capturing these variable-source-runoff effects in a watershed. The study basin is located in hilly terrain and detailed data was not available. Some data was assumed for initial calibration value and finally it was adjusted.

3.2 Stream Network

Stream Network has been created as arc coverage from topographic maps (1:50,000 scale) of Chittagong and Chittagong Hill Tracts district. Other sources e.g. SPOT panchromatic maps or SPOT XS image maps were not available for the study region. The topographic maps were collected from the Institute of Water Modeling (IWM). This task has been done within the Arc/Info environment 8.02 using digitizing facilities of National Water Resources Database (NWRD) developed by EGIS-II. The river identified from the above-specified sources is the perennials one. But for the hydrologic analysis, delineation of ephemeral rivers, creeks, small canals and khals play an important role to carry surface runoff to the subdominant or dominant rivers within catchments when monsoon occurs.

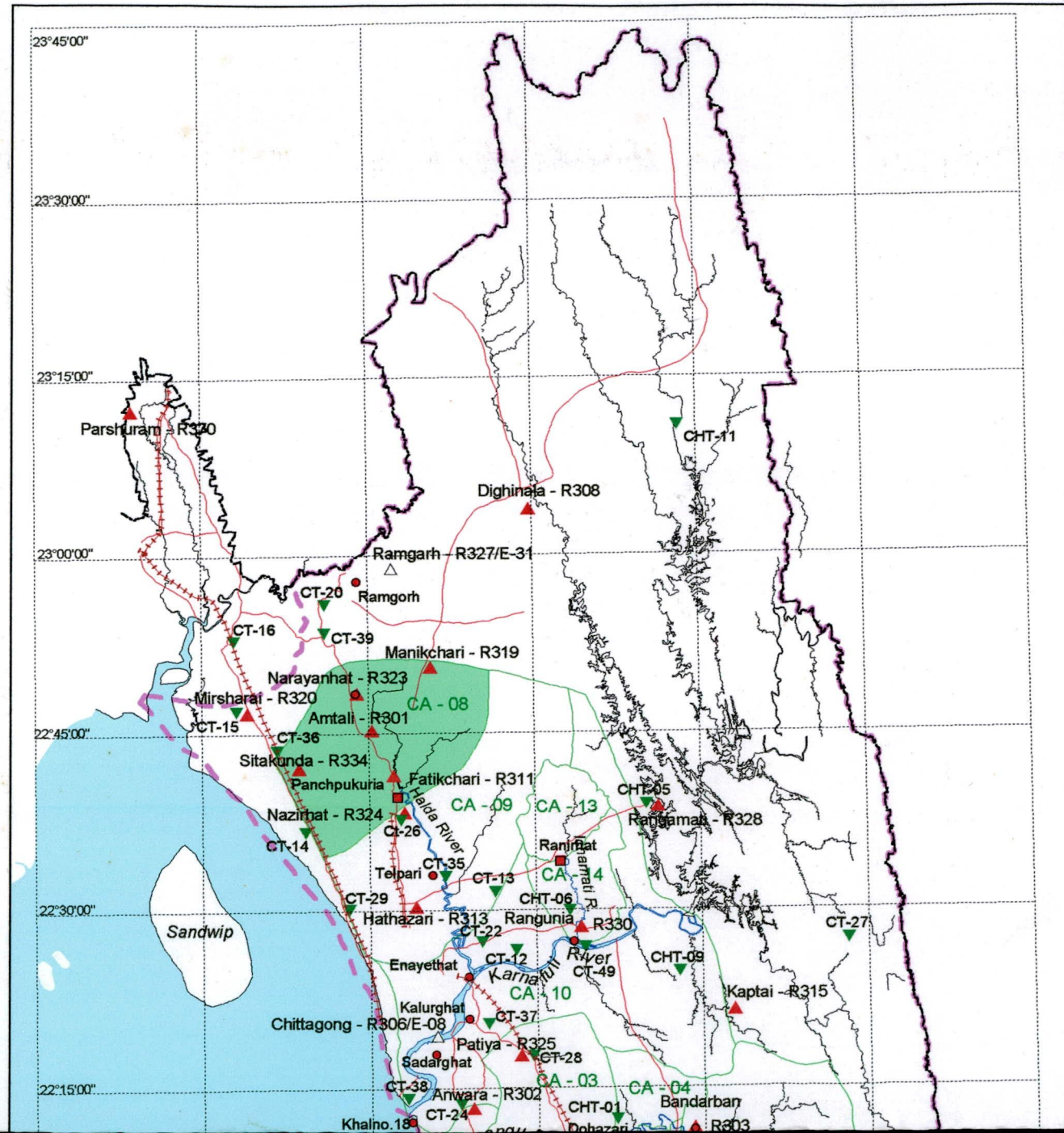
3.3 Topography or Digital Elevation Model

The flow of water is dependent on the topographic characteristics of the landform such as landscape and slope. In Chittagong Hill Tracts the altitudes of some of the ridges reach 1000m. A comprehensive land elevation analysis had been carried out in National Water Management Plan (NWMP). It includes preparation of a topographical map of the scale 1:50,000 with one meter contour interval, determination of area-elevation curves, preparation of flood depth maps of various recurrence intervals and determination of storage volume.

For preparation of digital elevation model, point elevation data which has been shown in figure 3.1 at interval of 500m in digitized form, was collected from Environmental Geographical Information System (EGIS-II). Various method are available to interpolate surface at user specified grid size (called cell size) among those are IDW, SPLINE (with or without Tension) and KRIGING (with many options of semi-variogram) widely used. IDW method was selected to create 50m resolutions of new DEM for better resolutions. The 300m resolutions DEM has been shown in figure 3.3 and 50m resolution DEM has been shown in figure 4.1.

Eastern Hill Region Model

Validation Year : 1998-1999



LEGEND:

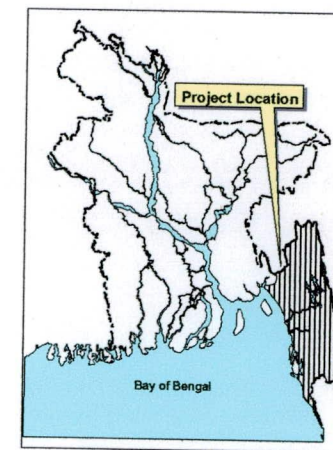
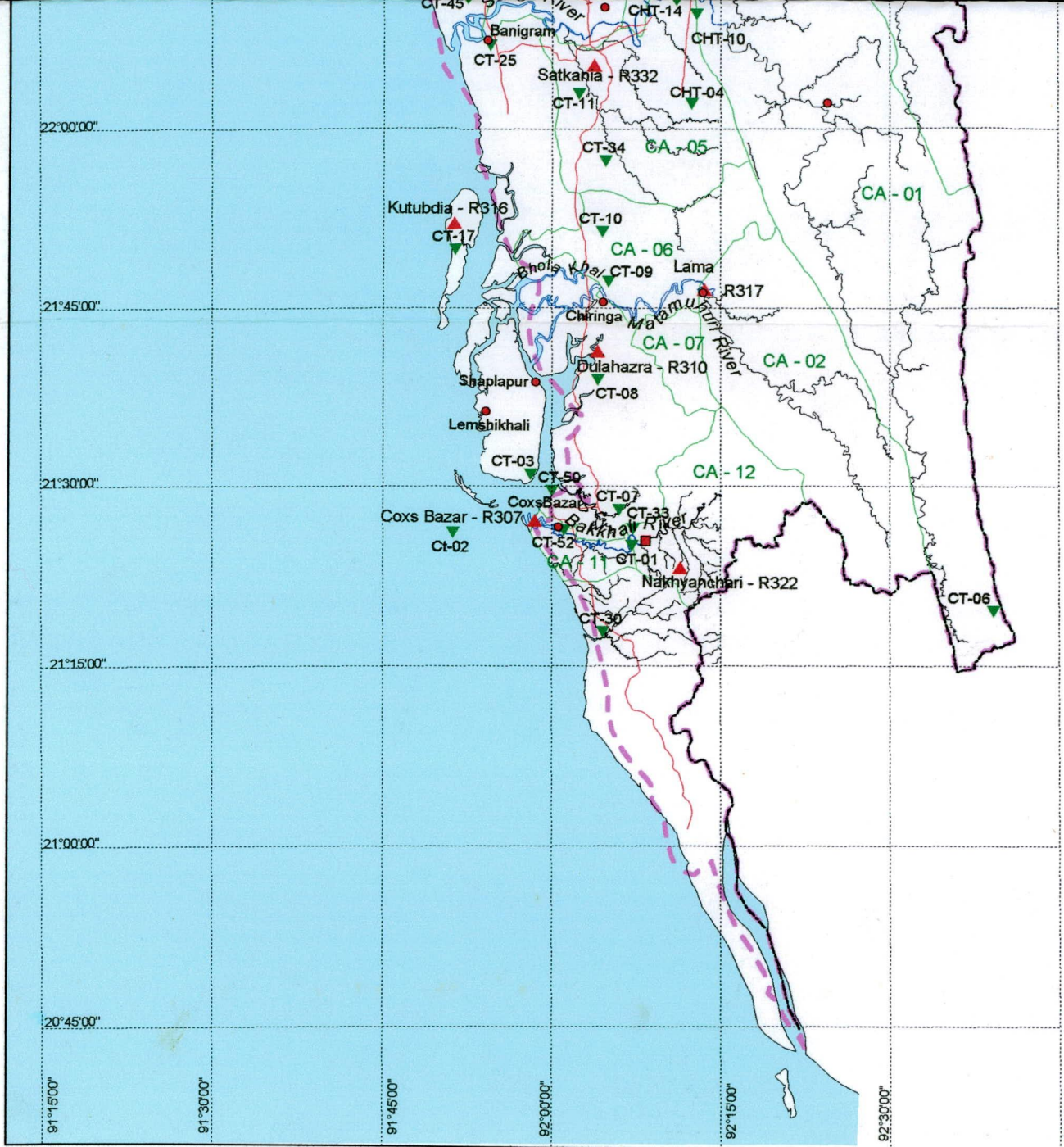
- International Boundary
- Model Boundary
- Schematized River
- Non Schematized River
- Railway
- Roads
- CA-11 Name of the Catchment Area
- Catchment Boundary

Hydrometric Stations

- Water Level
- Water Level & Discharge

Hydrometeorological Stations

- Rainfall
- Rainfall and Evaporation
- Groundwater Well



Drawing No. EHRM-01

INSTITUTE OF WATER MODELLING
(erstwhile Surface Water Modelling Centre)



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EHRM_for_buet_student.apr [*STH* 10 November 2002]
Layout: EHR - HDL and HDM - A3

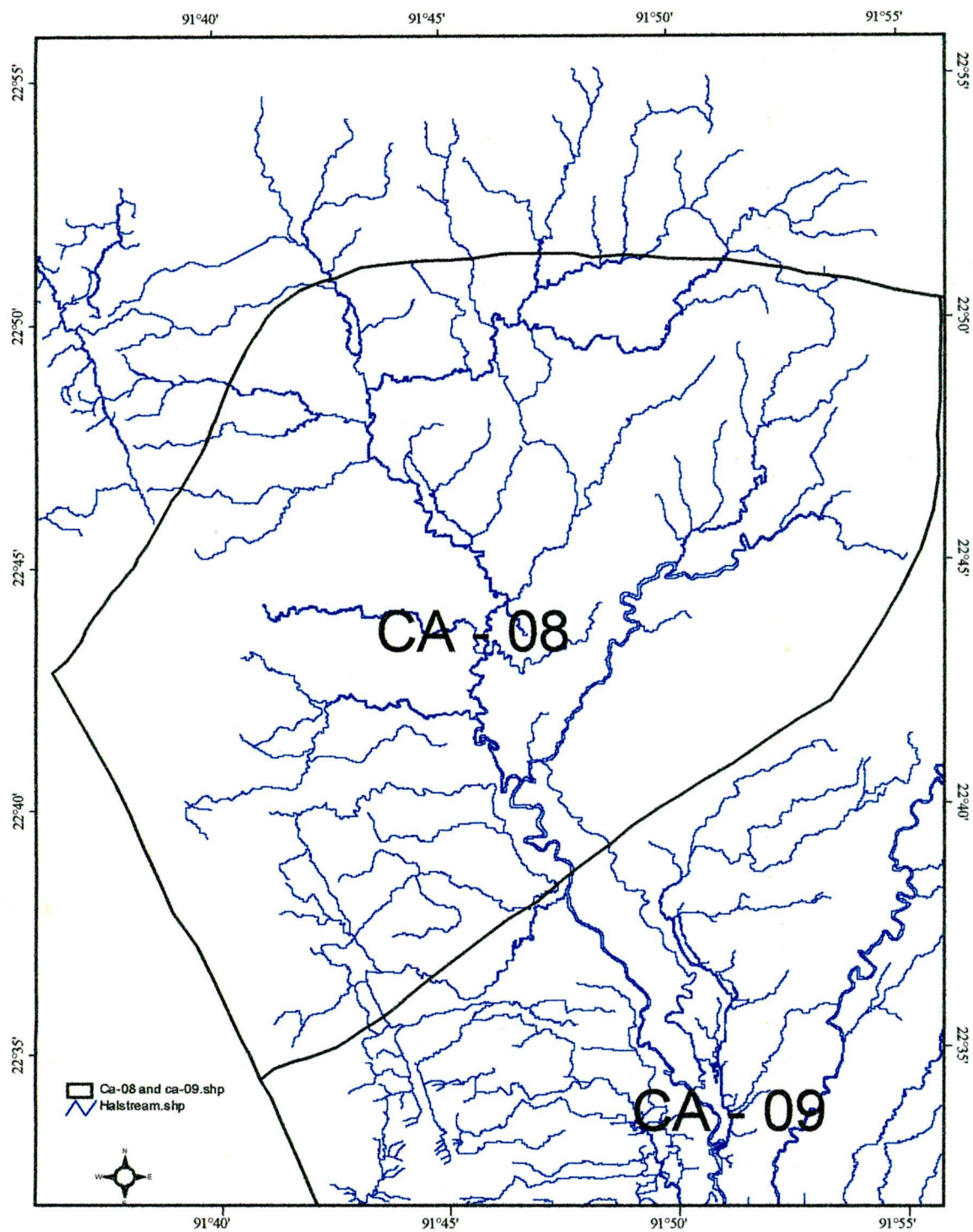


Figure: 3.1: Stream Network with CA-08 basin boundary

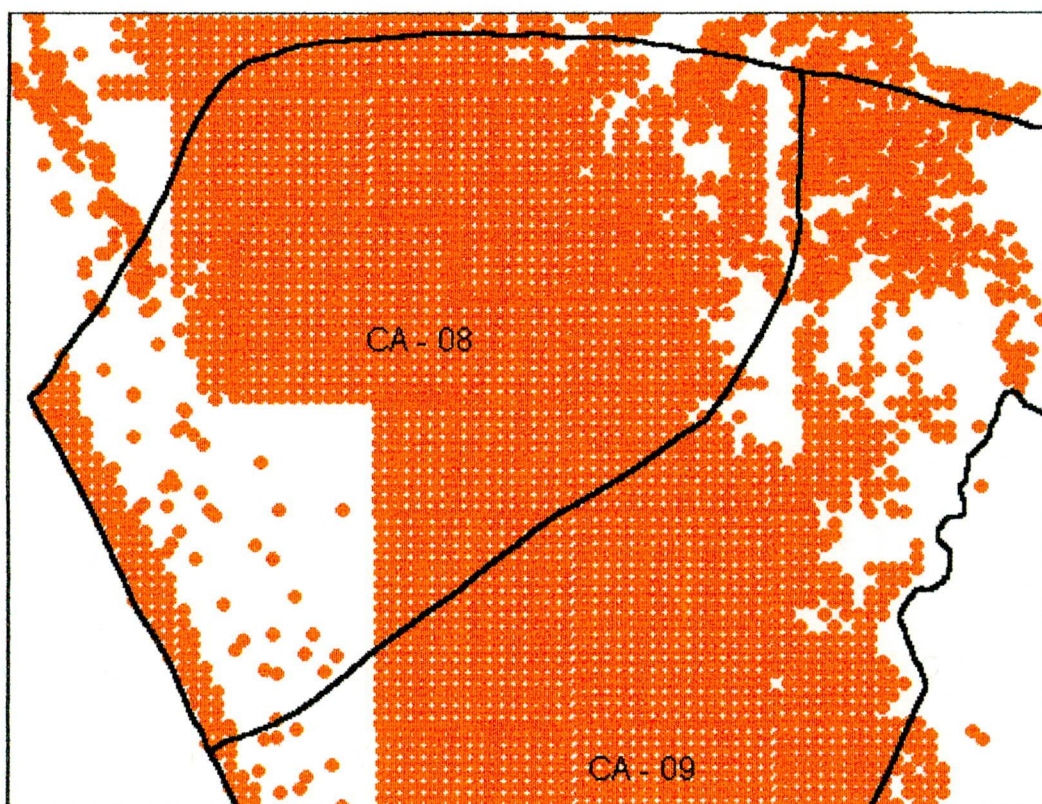


Figure: 3.2: Raw point data used for DEM creation of Halda basin

3.4 Canopy interception

Canopy interception storage holds the precipitation that falls in a vegetated area, be it trees, shrubs, or grasses, and is held on the vegetation until it is evaporated. The quantity of interception depends on the species type, density, and age of the vegetation, and may change during the year. For example, the leaf density of plants may vary, as in the case of annual plants becoming dormant or deciduous trees losing their leaves during the winter. Some suggested values for initial estimates of required input parameters have been shown in table 3.1.

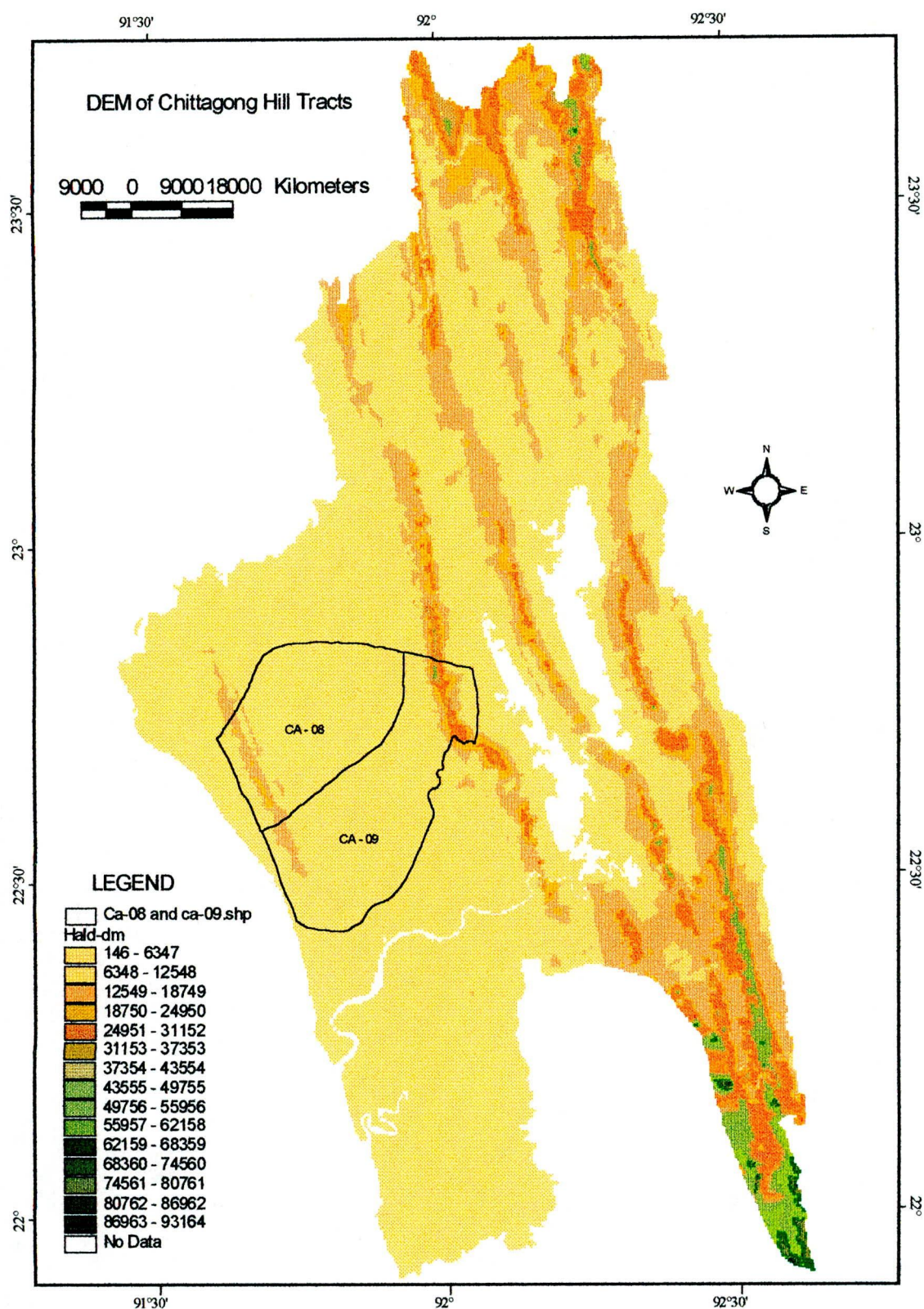


Figure: 3.3: DEM of Chittagong Hill Tracts

Table 3.1: Suggested values for Initial Estimates of Required Input Parameters

Input Parameter	Initial Estimate	Comments
Maximum Canopy Interception Storage	0.05 inches	Typically upto 0.08 inches for grasses, up to 0.10 inches for trees, maximum of 0.36 inches
Maximum Surface Interception Storage	Upto 2 inches	Classification based on soil cover
Maximum Infiltration Rate	Use Saturated Hydraulic Conductivity	Ranges based on soil type and cover
Maximum Percolation Rate	Maximum base flow in observed hydrograph	
Maximum Soil Profile Storage	From Soil database of Bangladesh	
Tension Zone Storage	Select based on frequency of runoff	
Maximum Groundwater Layer Storage	From Soil database of Bangladesh	
Surface Runoff and GW Routing Coefficients	Fit to observed hydrograph	
Evapotranspiration	From National water resources database of EGIS-II	

3.5 Rainfall, Discharge and Evaporation stations in the study region

The following rainfall, discharge and evaporation stations are situated in and around the CA-08 catchment of Halda river basin. For this study daily rainfall, discharge and evaporation data were collected for the year 1992.

Rainfall stations:		
No.	Code No.	Name
1.	R-301	Amtali
2.	R-311	Fatikchari
3.	R-319	Manikchari
4.	R-323	Narayanhat
5.	R-324	Nazirhat
Discharge station		
1.	Q-119.1	Panchpukuria

Evaporation station		
No.	Code No.	Name
1.	E-06	Chittagong

The study region has a subtropical monsoon climate. It is observed that the monsoon season proper lasts from June to September during which period depressions moving in from the Bay of Bengal bring periods of heavy rainfall. The cool dry season lasts from November to February (BWDB, 1992, Annual Flood Report).

The mean annual rainfall ranges from about 80 inches (2000mm) in the center north to about 150 inches (3750mm) on the southeastern border. Over the 80 percent of the mean rainfall occurs between May and September. Pre-monsoon and monsoon rainfall typically is in torrential downpours, which creates severe hazards of soil erosion on the prevailing steep slopes and of flash floods in the valleys.

3.6 Evapotranspiration data

Pan Evaporation values for various locations in Bangladesh are available from Mean Monthly, Seasonal, and Annual Pan Evaporation. Calculated direct ET values of Chittagong station have been found from National Water Resources Database (NWRD) of EGIS-II. SMA model requires separate values of evaporation and Pan co-efficient. The Pan co-efficient value was taken 0.9.

3.7 Surface Interception Storage

Depression storage is the precipitation detained in depressions and hollows proceeding, during, and after a rainfall event. Impervious areas, such as roads and parking lots, may also have a significant amount of depression storage.

Chow reports lateral average surface depression storage, from various authors, generally ranging between 0.125 to 0.50 inches (and potentially higher) for a variety of conditions. Paved impervious areas may store from 0.125 to 0.25 inches. Pervious soils, on moderate or gentle slopes, can hold on average, approximately 0.25 to 0.5 inches of water. Natural meadows and forestland can hold even more.

Dunne (1978) reports volumes of depression storage ranging from 0.04 inches on steep, smooth hill slopes, to 2 inches on relatively flat-sloped agricultural lands that have been furrowed or terraced specifically to catch this water.

Bennett's suggested initial estimates for the maximum surface storage depth are summarizes in table 3.2 based on topography and land cover.

Table 3.2: Initial Estimate and Range of Maximum Surface Interception Storage

	Range (inches)
Paved impervious areas	0.125-0.25
Steep, smooth slopes	0.04
Moderate to gentle slopes	0.25-0.50
Flat, furrowed land	2.0

3.8 Soil data

Soil coverage was clipped (a process of extracting data from a coverage that resides entirely within the boundaries of features of another coverage) from the Bangladesh Soil database. The most extensive hill soils are brown, loamy and strongly acid with rapid permeability and a low moisture holding capacity.

3.8.1 Soil Profile depth

Though a range of values for the depth of soil profile up to approximately 20 inches, the analyzing depth of assumed 8 inches or 203.2 mm for the study region. But in the calibration process this value becomes higher. The soil column starting at the surface consists of 8 inches of mostly silt loam and others are sandy clay, loam, silty clay, silty clay loam, sandy clay loam, clay loam, sandy loam and loam. The maximum depth of the soil profile was estimated 8 inches portraying the first, more permeable layer. The calibrated value of this parameter should be smaller than this value since the model represents the volume of storage and not the actual depth of the soil profile.

3.8.2 Tension zone depth

The tension zone would be the estimate of the soil profile depth minus estimate for the upper soil profile depth.

Table 3.3: Approximation for depth of the Upper Soil Profile

Frequency of Runoff	Initial Estimates (inches)
Nearly Every Event	0.4 – 0.6
Every Moderate Event	0.6 – 1.0
Only During the Largest Event	1.0 – 1.6
Never	> 1.6

3.8.3 Maximum Soil Infiltration rate

The maximum infiltration rate required for the SMA algorithm could be determined from the soil type in the watershed. Soil classifications of areas within the Bangladesh are available from the Soil Resources Development Institute (SRDI) or Bangladesh Agricultural Research Council (BARC).

A range for maximum infiltration rate for a given soil type could approximately by the hydraulic conductivity of the soil. This approach will give a large range of values as hydraulic conductivity can vary over a magnitude of three to five. For example, the range for silty sand is approximately 0.01 inches/hour to 100 inches/hour (Freeze, 1979).

The saturated hydraulic conductivity of silt loam is approximately 0.2677 inches per hour and was used as an initial estimate of the maximum infiltration rate.

3.8.4 Maximum Soil Percolation rate

A maximum percolation rate was approximated from analysis of the observed hydrograph. This rate could be estimated from the maximum rate of base flow. This would be calculated by taking a period from the observed hydrograph, where the change in base flow over time is relatively constant, and then determining a rate. A method similar to this is used in the Generalized Stream flow Simulation System (Burnash, 1973).

From Figure 3.4, some observed values of constant base flow are,

January to February	= base flow is 5 to 10 m ³ /sec
March 1 st to June 15	= base flow is < 5 m ³ /sec
July to October 30	= base flow is 15 to 25 m ³ /sec
November to December	= approximately 10m ³ /sec

If we consider these values and dividing these values by the basin area, and converting to an hourly rate yields become:

= 0.0001259 m/hour for 20m ³ /sec/catchment area
= 0.0001574 m/hour for 25m ³ /sec/catchment area
= 0.00006296 m/hour for 10 m ³ /sec/catchment area
= 0.00001498 m/hour for 2.38 m ³ /sec<5/catchment area

From the above results it has shown that there was relatively no base flow in the observed hydrograph and the small percolation approximation, the maximum percolation rate was estimated to be zero and no ground water zones were used.

Discharge Hydrograph of Panchpukuria

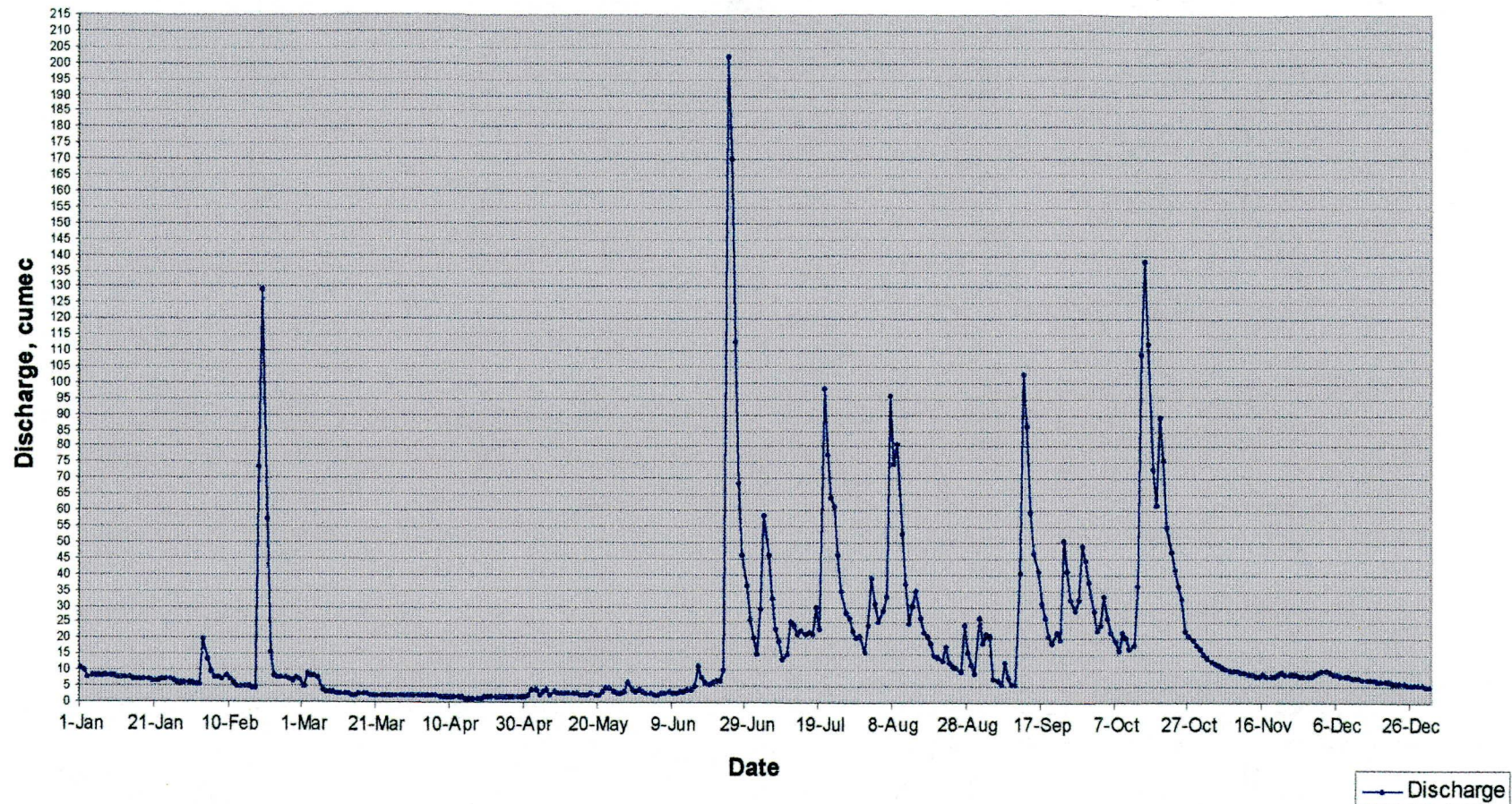


Figure: 3.4: Panchpukuria discharge hydrograph of 1992

3.9 Base flow separation

In many hydrograph analyses a relationship between the surface-flow hydrograph and the effective rainfall (i.e. rainfall minus losses) is sought to be estimated. The surface-flow hydrograph is obtained from the total storm hydrograph by separating the quick-response flow from the slow-response runoff. It is usual to consider the interflow as a part of the surface flow in view of its quick response. Thus only the base flow is to be deducted from the total storm hydrograph to obtain the surface runoff hydrograph.

There are several methods to separate the base flow from the observed hydrograph. The straight-line method was used for this study. In this method a line is drawn tangential to both the limbs (i.e. rising and falling limbs) at hydrograph's lower portion. This method is very simple but is approximate. The value was taken 1.19 cumec at the rising limb at 18th April 92 and falling limb at 29th December and connected both the point.

3.10 Land use data

To compute runoff volume using the SMA method, land use classification is essential to determine direct runoff volume by the SCS method. The land use polygons, the soil association polygons and polygons associated soil group percentage table are the basic input for estimating SCS curve number of each watershed. Hydrologic soil group wise CN values are shown in table 3.4 which is based on TR-55 Technical documentation (Second edition, 1986) (Table-2a, 2b and 2c) (Olivera, 1998, HEC PrePro v. 2.0).

Table 3.4: Anderson land use code and their CN value and surface velocity

Lu-code	Land use	Detail	Hyd_a	Hyd_b	Hyd_c	Hyd_d	Surface velocity, v
2124	Row-crops	C&T-good	62	71	78	81	3.72
2125	Row-crops	C&T+CR	65	73	79	81	3.90
2126	Small-grain	SR-poor	65	76	84	88	3.90
2128	Small-grain	SR-good	63	75	83	87	3.78
2129	Small-grain	SR+CR-poor	64	75	83	86	3.84
2131	Small-grain	C-poor	63	74	82	85	3.78
2132	Small-grain	C-good	61	73	81	84	3.66
2133	Small-grain	C+CR-poor	62	73	81	84	3.72
411	Oak-aspen	Poor	55	66	74	79	3.30
431	Woods-grass	Poor	57	73	82	86	3.42
432	Woods-grass	Fair	43	65	76	82	2.58
2111	Fallow	Bare-soil	77	86	91	94	4.62
2112	Fallow	CR-poor	76	85	90	93	4.56
2118	Row-crops	C-poor	70	79	84	88	4.2
111	Residential	1/8 acre	77	85	90	92	4.62
112	Residential	1/4 acre	61	75	83	87	3.42

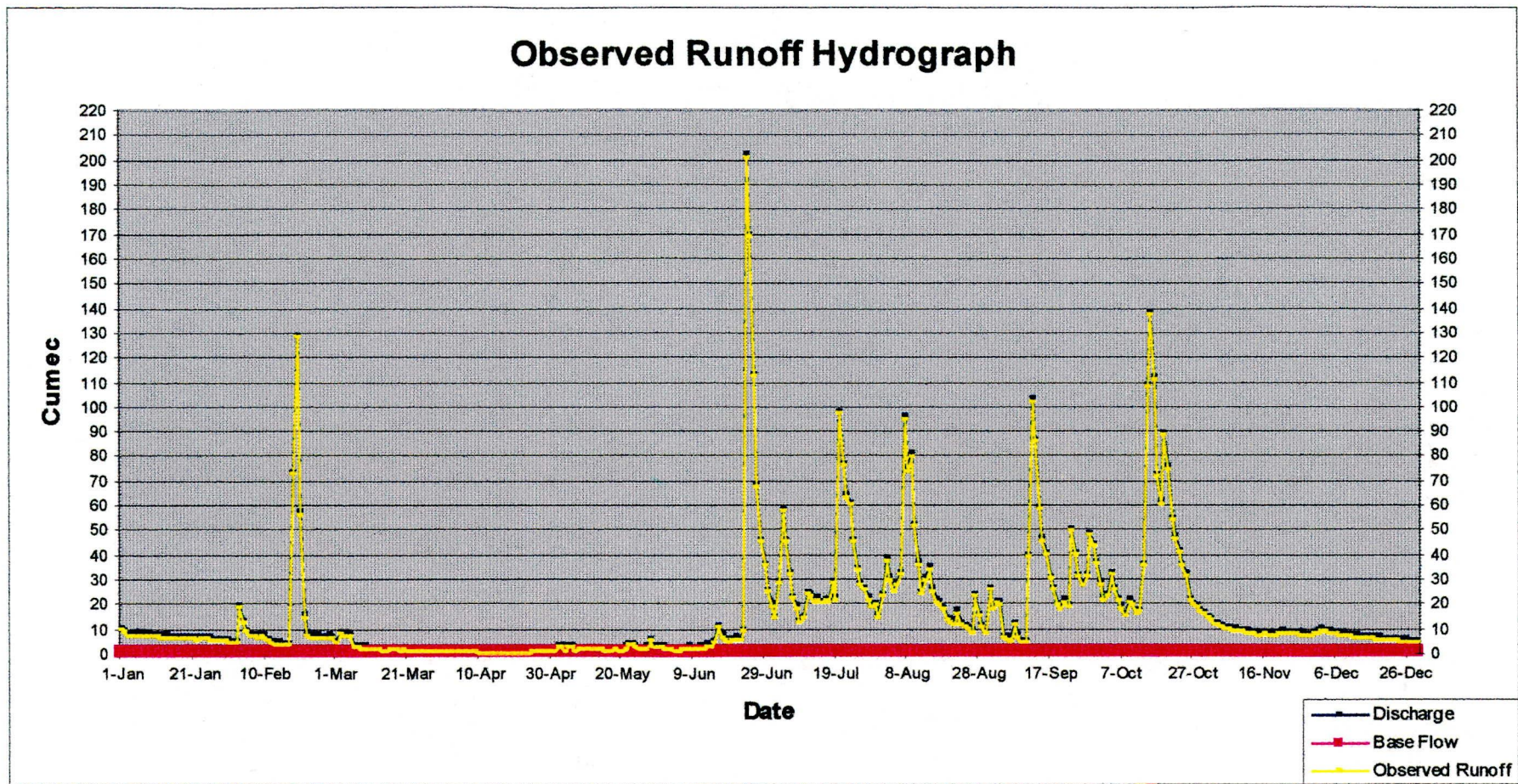


Figure: 3.5: Observed runoff hydrograph of Panchpukuria station of 1992

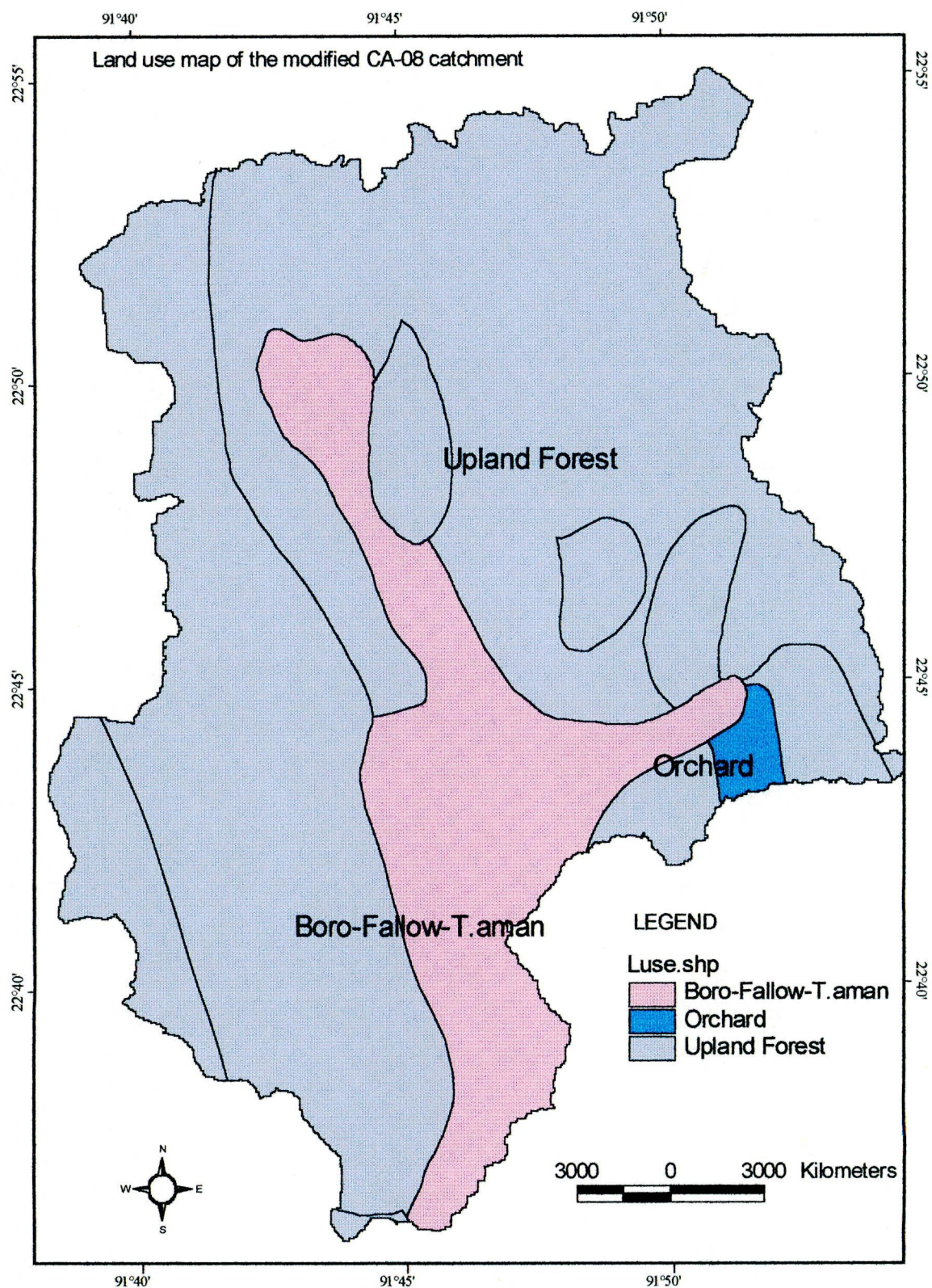


Figure: 3.6: Land use map of the modified CA-08 catchment

CHAPTER 4

DELINEATION OF STREAM AND WATERSHED

One of the most important tasks for hydrologic modeling is stream network and watershed delineation. Arc/Info has built-in functions for watershed using Digital Elevation Models (DEM). The ArcView GIS and its Spatial Analyst extension provide tools such as CRWR PrePro, the hydrologic modeling tools (Sample), or developing own tools based on the need using the sample scripts provided in ArcView.

4.1 Creation of DEM (50 m resolution)

To identify the detailed level information for runoff computation it is necessary to provide better resolution of DEM. The source data were collected on a 300m*300m grid from NWRD developed by EGIS-II. The combination of spot elevation points and contour line results in a much better DEM. ArcView (Spatial Analyst) 3.2 has been used for surface creation in this project. From the surface menu, by choosing interpolate Grid; analysis extent has been set for cell size 50m for the output grid theme. IDW method has been used for creation of DEM.

4.2 Burn in the stream

Burn means to raise the land surface cells that are off the streams by an actual elevation amount so that the streams delineated from the DEM exactly match those in stream network. After burning it can be seen that the stream cell elevations remain as they were on the original DEM surface but land surface elevation have been raised higher. This is an artificial terrain and it can be seen that the effect of burning in the streams is to make them distinct in the DEM landscape. So the stream network should be continuous and there should not any gaps between each stream segment for stream burning.

4.3 Fill the sinks of DEM

Filling sinks tells ArcView to fill the sinks such that they are level with the surrounding terrain. A sink is a cell or set of spatially connected cells whose flow direction cannot be assigned one of the eight valid values in a flow direction grid. Only tiny sinks will be filled, large sinks such as lakes, are real sinks and will not be removed from the DEM. Sinks in elevation data are most commonly due to errors in the data. These errors are often due to sampling effects and the rounding of elevations to integer numbers. A digital elevation model that has been processed to remove all sinks is referred to as a depressionless DEM. The identification and removal of sinks when trying to create a depressionless, is an iterative process. When a sink is filled, the boundaries of the filled area may create new sinks that then need to be filled.

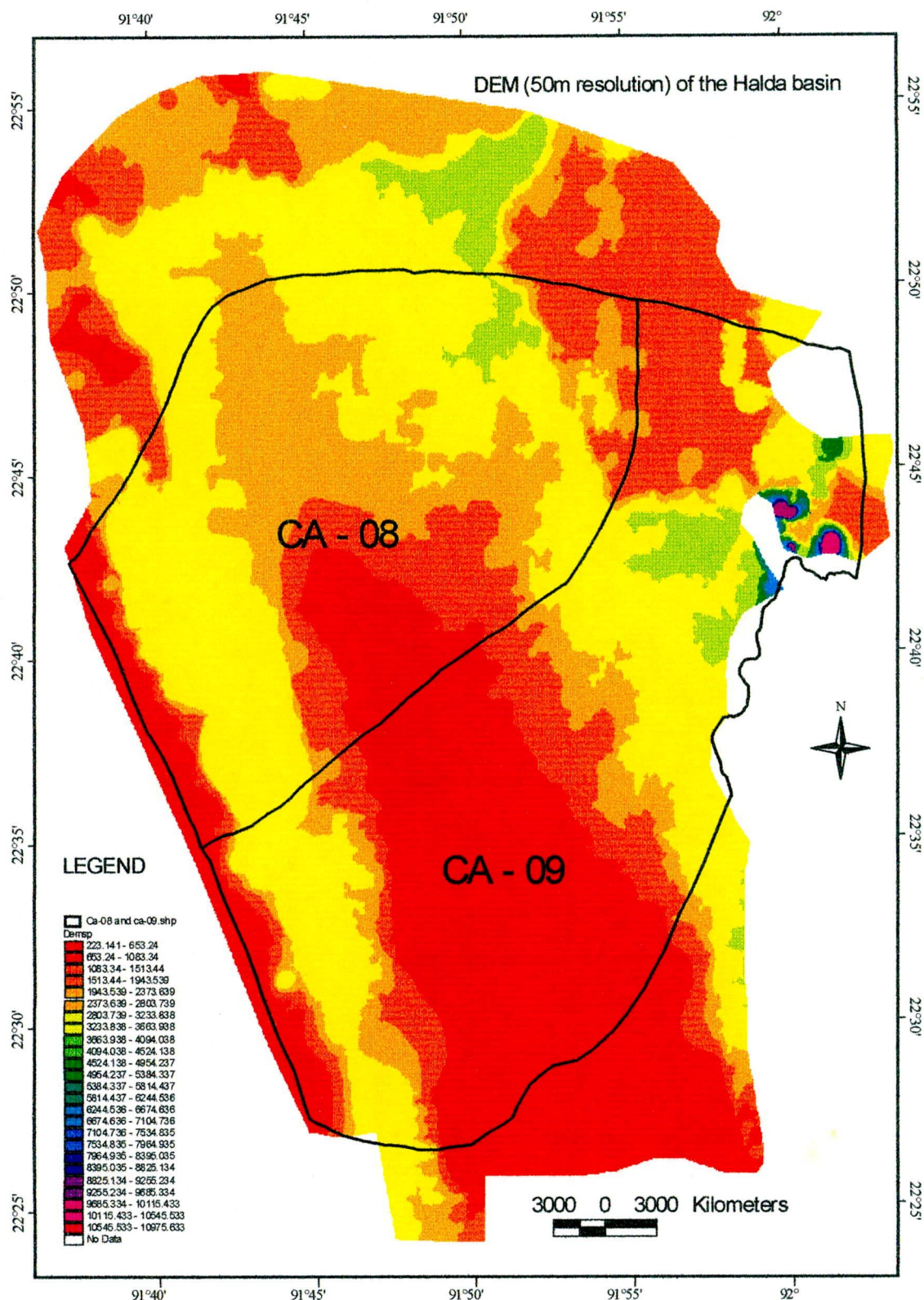


Figure: 4.1: Digital Elevation Model (50m) of the Halda basin

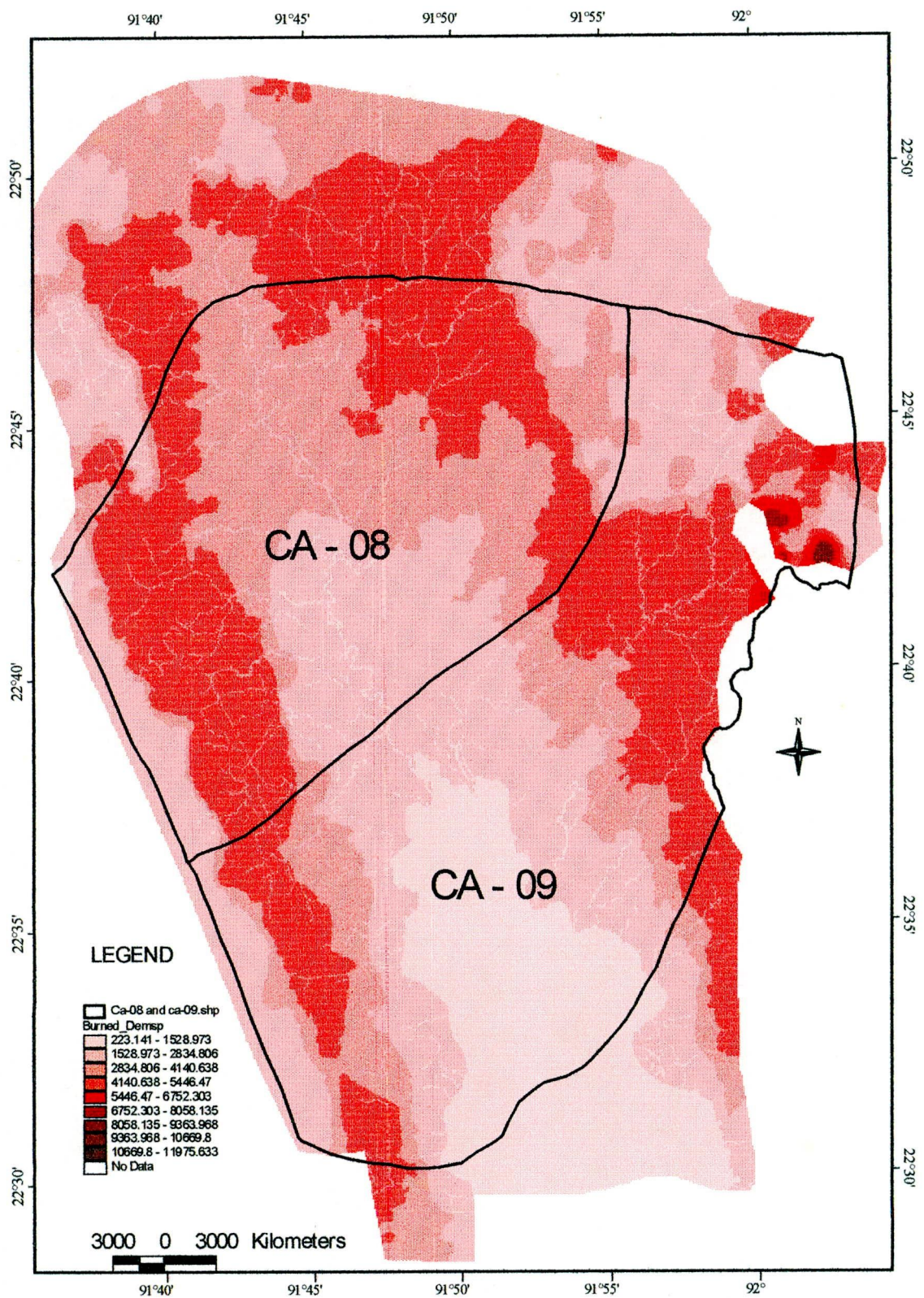


Figure: 4.2: Burned DEM of Halda basin

Burn in the stream, fill the sink of DEM and all other delineation steps can be done by two ways. One is the Arc/Info GRID command and another is using hydrologic modeling watershed delineation tool or CRWR-PREPRO under ArcView Spatial Analyst.

4.4 Flow direction using Burnt DEM

Since water flows downhill when unobstructed, flow direction command considers every cell in the DEM grid and decides which of the eight cells surrounding the considered cell offers the steepest elevation gradient.

In Arc/Info, FLOWDIRECTION command and in ArcView Spatial Analyst, hydrologic modeling tool or CRWR-PREPRO/Flow direction is available to complete this step. In this project the later option is used. The values under flow direction which way water will flow from a given grid point are that 1 indicates east, 2 southeast corner, 3 south and so fourth (Figure 4.3).

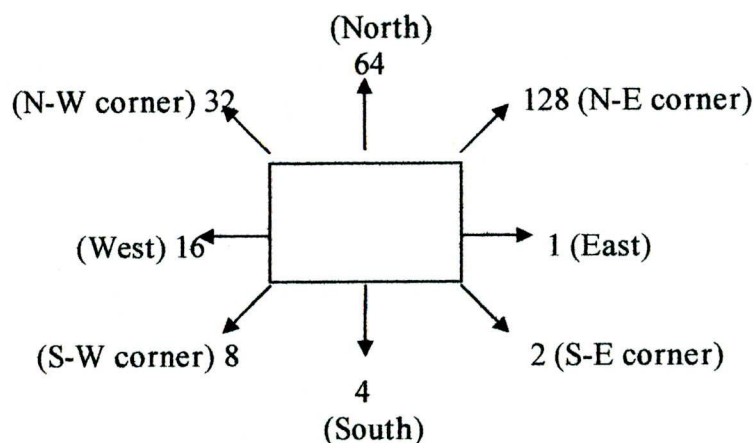


Figure 4.3: Flow Directions of indicated numbers for figure

4.4

4.5 Flow Accumulation

The flow accumulation tells how many cells drain into each cell contained in a given stream segment. Flow accumulations are important because they allow us to locate cells with high cumulative flow. Flow accumulation grid of Halda basin is shown in figure 4.5.

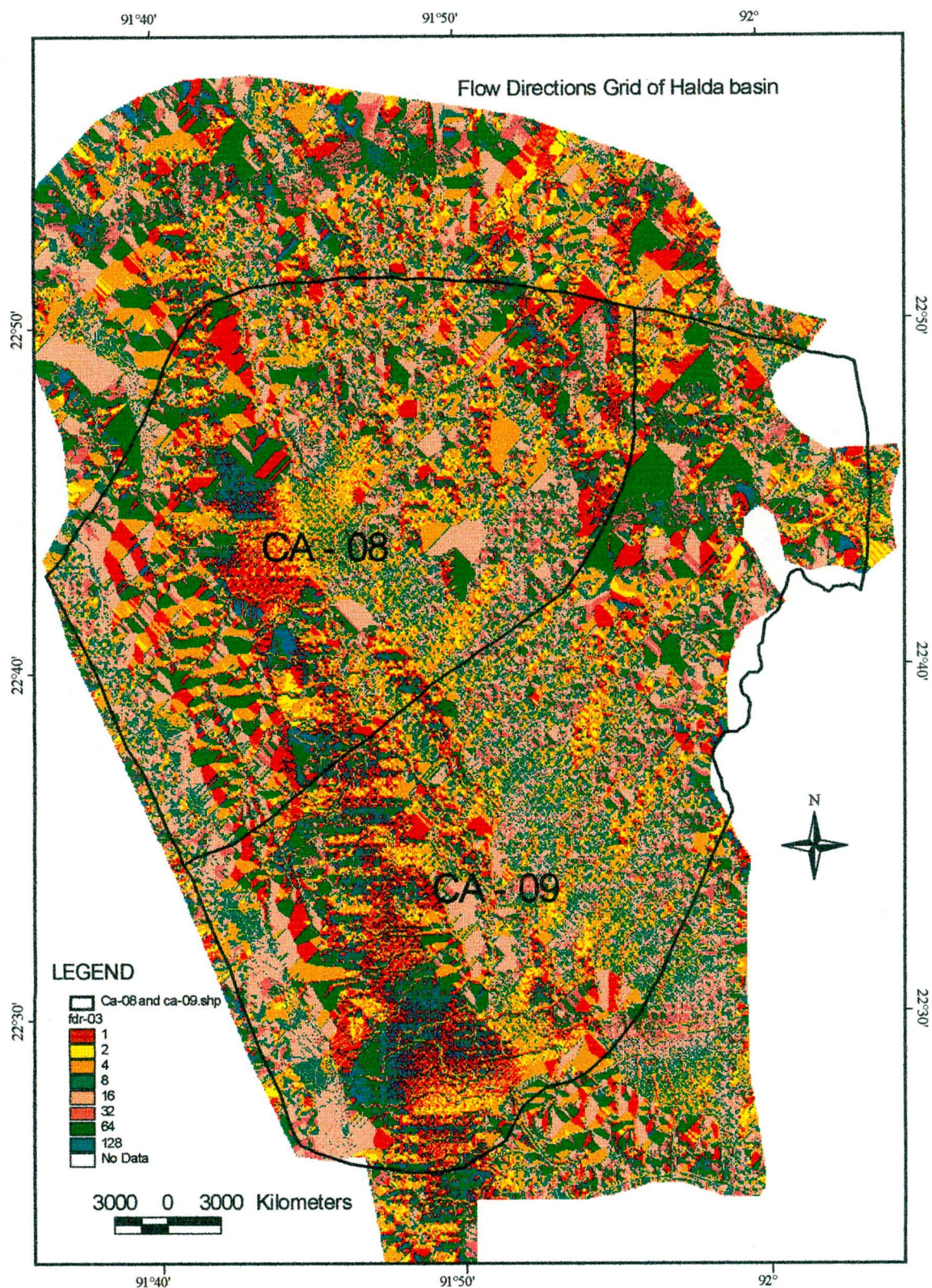


Figure: 4.4: Flow directions grid of Halda basin

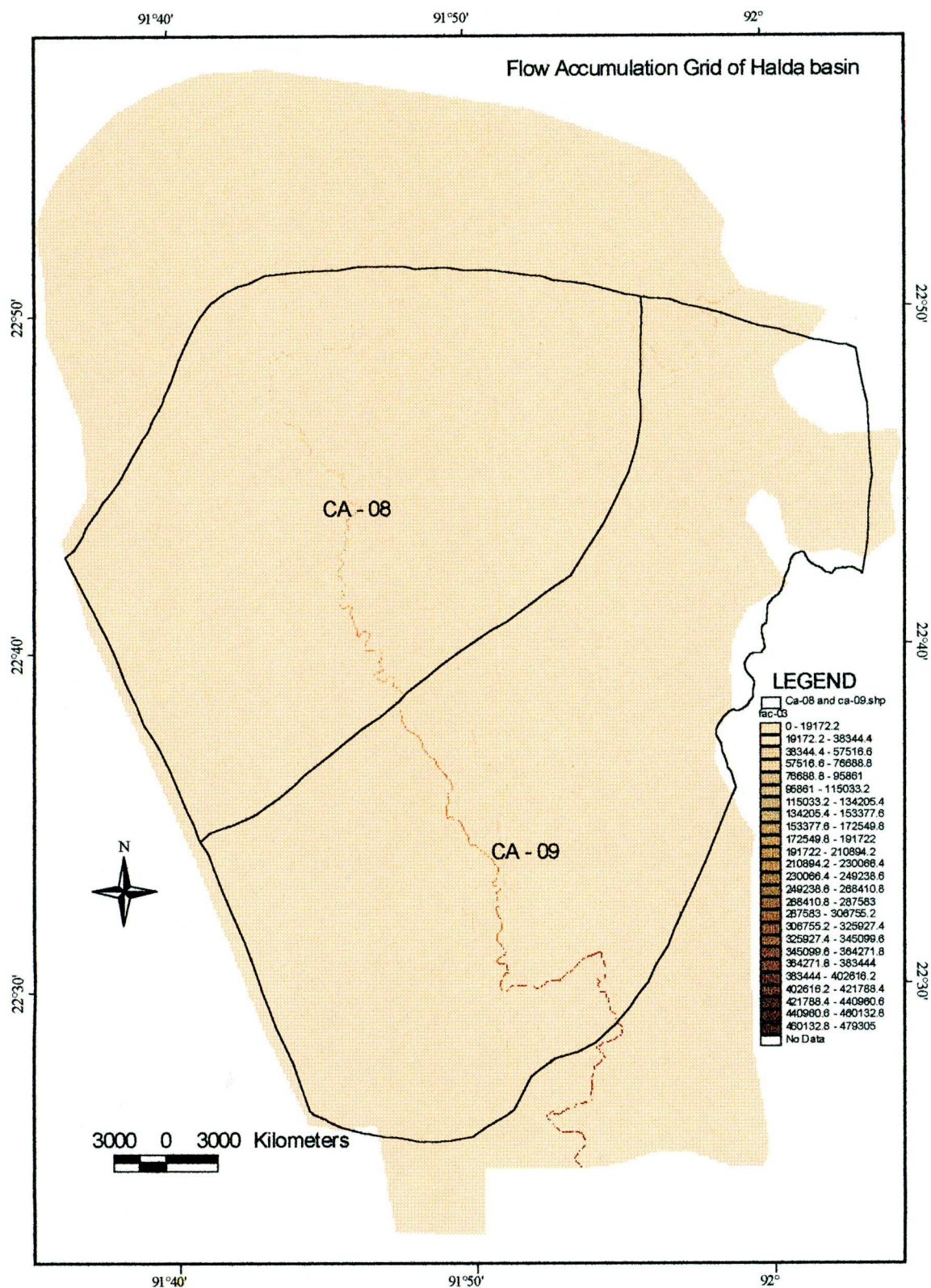


Figure: 4.5: Flow Accumulation grid of the Halda basin

4.6 Construction of Basic Stream Network

Before constructing the stream network, it has to define the cell threshold or minimum drainage area. From CRWR-PREPRO menu/Stream Definition (threshold) value of 9000 cells was chosen and 2250 hectare (9000 cells in 50m square cell grid) was considered to be the minimum drainage area to form streams. The input theme is automatically populated with the flow accumulation grid and output theme is Halda basin stream grid. The stream grid has a value of 1 in each flow accumulation value larger than 9000, and NODATA on all other cells.

A stream segment or link starts at either the beginning of a stream or where two streams intersect and end at a downstream split in the stream or at the exit point of the system.

The stream link function gives each stream segment a unique identification, so that it can be easily distinguished from the stream system as a whole. These links are demarcated using Arc/Info STREAMLINK command and also in ArcView.

Further preparation for the HEC-HMS requires ArcView to pinpoint the end of each link. The resulting grid is a scattered set of single cells, each the farthest downstream cell of a stream link. Each link has its own outlet. Outlet cell is the cell in each link that has the largest flow accumulation value. All of the cells upstream of the outlet cell flow into the outlet cell.

4.7 Creation of watershed polygons

Before creating watersheds, it is needed to define their outlets. Watershed outlets or pour points must be considered in cells of high cumulative flow or at the most downstream cells of each stream segment, and at the flow gagging stations. For example one watershed boundary can be obtained in this project using Panchpukuria as pour point. The others pour points are considered within the high-flow network and these outlet points will create watershed. The resulting watershed boundary is the sum of all sub-watershed areas and would be the modified catchment boundary of CA-08 based on the topographic characteristics defined in the DEM.

4.8 Subwatershed delineation

Sub watershed delineation consists of determining the incremental drainage area of each outlet. The watershed GIS function is used to delineate the areas draining to each sub basin outlet. A one-to-one relation between stream segments and sub-basins is maintained because a unique segment was identified for each sub basin outlet which is shown in figure 4.6 and figure 4.7.

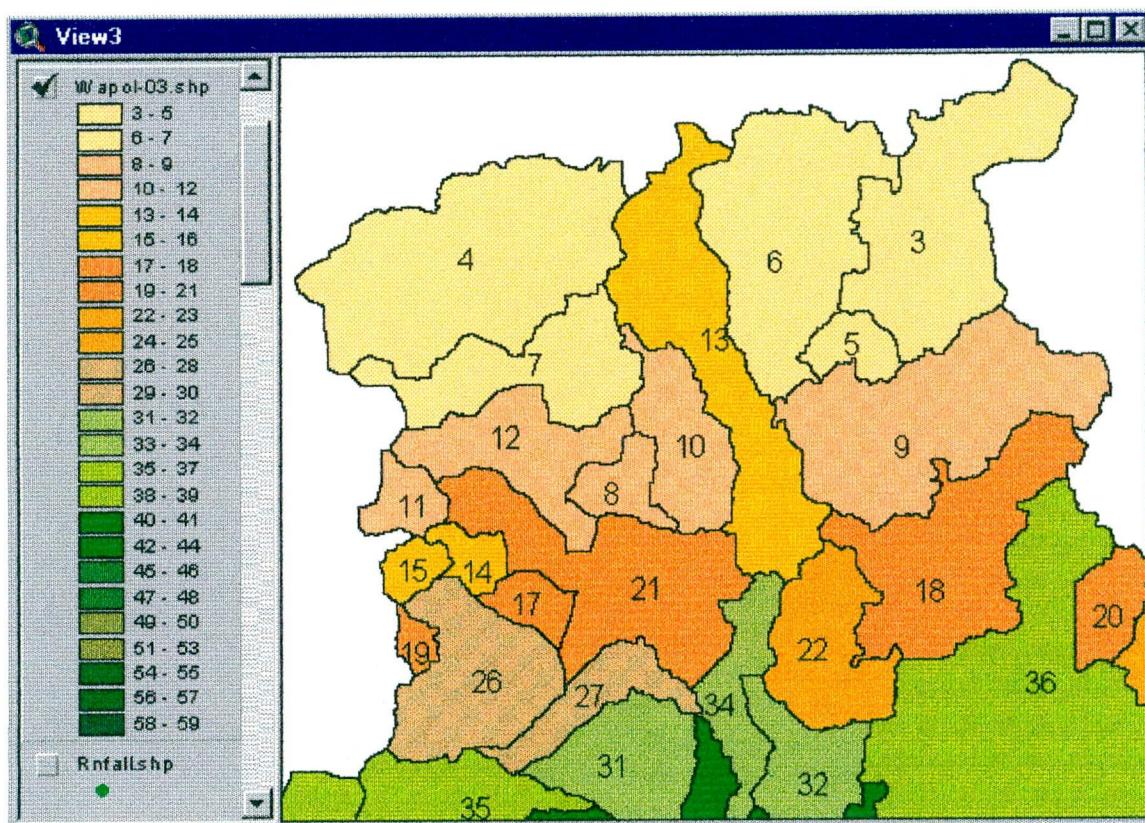


Figure: 4.6: Sub-watershed polygons of CA-08

4.9 Vectorization of streams & watersheds

Vectorization of streams and watershed consists of converting their raster presentation into a vector presentation, because HEC-HMS cannot handle these raster data. This process generates a polygon theme of sub watersheds and a polyline theme of streams. The reason for this vectorization is that the number of hydrologic elements (streams and sub basins) in the system is usually small captured with the number of grid cells, and further processing and modeling is faster in the vector domain. This step requires the Spatial Analyst version 1.1 or the Gridline function in Arc/Info can be used instead.

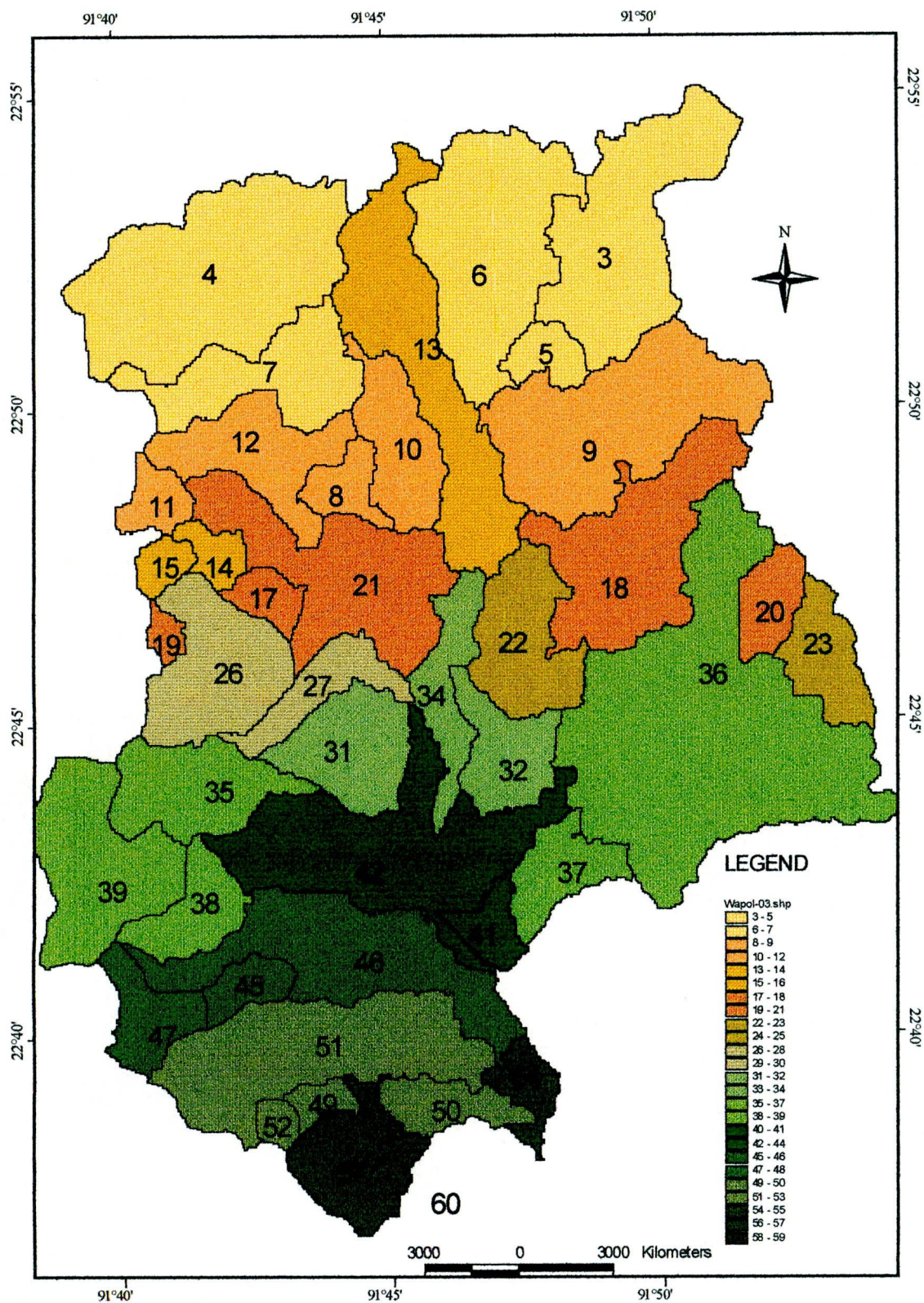


Figure: 4.7: Delineated Subwatershed of study area

4.10 Cleaning up Dangling Polygons

Vectorizing watersheds can create an item referred to as a dangling polygon. These occur when Arcview has trouble converting a grid to a vector; the end result is basically a super-tiny watershed that does not really exist. To eliminate this problem, we can use Hydro menu/Dissolve Dangling polygons.

4.11 Determination of watershed and stream attributes

One of the last things to do before moving to the HEC-HMS system is to include SCS curve-number data for the region. The HEC-HMS requires this information to perform runoff calculations. The steps of Soil Group Percentages and Curve Number Grid can be skipped from CRWR-PREPRO menu, because they are time consuming and they result in an SCS curve number grid that will just import for using in this project work. After completing these steps, we can calculate watershed attributes by choosing CRWR-PREPRO/Calculate Attributes menu and complete the table so that the weighted curve number for each watershed may be determined.

4.12 Computation of Hydrologic Element Parameters

The sub-basin parameters calculated by CRWR-PrePro are area, lag-time and average curve number. Other parameters needed for estimating the lag-time, such as length and slope of the longest flow path, are also calculated and stored in the sub-basin attribute table. Depending on the algorithm used to calculate the lag-time, it might depend entirely on spatial data, i.e., DEM, land use and soils, or it might require additional externally supplied input. In this study the average curve number is used to calculate the sub-basin lag-time and the soil moisture accounting is used to calculate sub-basin loss rate.

The sub basin area is calculated automatically in the process of vectorizing the sub basin polygons.

The length of longest flow path is defined as the set of cells of the sub basin for which the sum of the downstream flow length to the watershed outlet and the upstream flow length to the sub basin boundary is a maximum.

The downstream flow length to the watershed outlet is equal to the distance along a flow path from a grid cell to the outlet of the sub basin in which it is located. The (downstream) flow length GIS function-which calculates the flow distance to the border of the analysis window or to a nodata cell (whichever is found first)-the downstream flow length to the watershed outlet is calculated as the difference between the flow length value of the cell and the flow length value of its corresponding outlet cell.

The upstream flow length to the sub basin boundary is equal to the distance along a flow path from a grid cell to the most upstream location within its watershed, and does not necessarily the main channel. After assigning nodata values to all sub

basin outlet cells, the (upstream) flow length GIS function—which calculates the flow distance to the most upstream cell of the analysis window or to a nodata cell—is used to calculate the upstream flow length to the sub basin boundary. Nodata values are assigned to the sub basin outlets to keep the flow length function from searching for longer flow paths in the upstream sub basins.

The slope of the longest flow path is determined as the elevation drop between two arbitrarily defined points of the flow path, divided by their distance along the channel. The points can be located at any user-defined distance from the sub-basin outlet, expressed as a percentage of the length of the longest flow path.

The sub basin lag time is calculated with the SCS formula and is given by (Chow et. al., 1988)

$$T_p = 0.6 \frac{100 (L_w)^{0.8}}{1900 S^{0.5}} \left\{ \frac{100}{CN} - 9 \right\}^{0.7} \text{-----} (4.1)$$

Where, T_p = sub basin lag time (minutes), L_w = Length of the longest flow path (feet), S = (percentage) is the slope of the longest flow path, CN = is the average curve number in the sub basin. However, because in HMS the analysis time step has to satisfy the condition of being smaller than 0.29 times the lag time of the basin, the lag time is taken as the value given above or 3.5 times the analysis time step.

The reach parameters determined by CRWR-PrePro are the length, the routing method (either Muskingum or pure lag), the Muskingum K and the number of sub-reaches into which the reach is subdivided in case the Muskingum method is used for routing, and the flow time in case pure lag is used for routing. Other reach parameters like the flow velocity and the Muskingum X cannot be computed from spatial data and must be calculated externally and supplied as input.

4.13 Determination of gage weight factors

Thiessen Polygon:

Thiessen polygons are used to establish the area of influence of each precipitation gage. Thiessen polygons are constructed by drawing perpendiculars at the midpoints of the segments that connect the gages, so that all points within a polygon are closer to the polygon gage than to any other gage. By intersecting the Thiessen polygons with the sub-basin polygons, a new set of smaller polygons is defined in such a way that each new polygon is related to one (and only one) Thiessen polygon and one (and only one) sub-basin polygon. Figure 4.8 shows the intersection of subbasin polygons with Thiessen polygons.

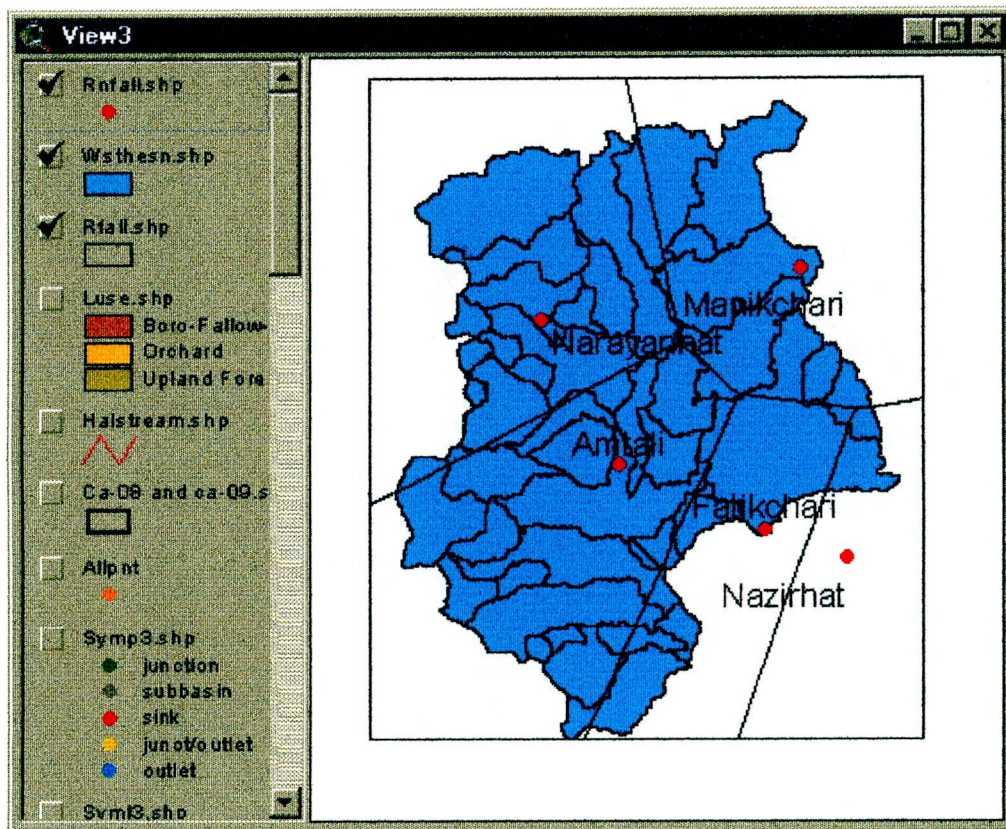


Figure: 4.8: Intersection of sub-basin polygons with Thiessen polygons. Red dots indicate precipitation drainage gages.

The ratio of the area of a new polygon to the area of its corresponding sub-basin polygon represents the weight of the gage for the sub-basin. This can also be expressed as

$$w_{ij} = \frac{A_{ij}}{S_j}$$

Where A_{ij} is the area of the polygon generated by intersecting sub-basin j with the Thiessen polygon of gage i , S_j is the area of sub-basin j , and w_{ij} is the weight of gage i for sub-basin j . The sum of the weights of a sub-basin should add up to one. In figure 4.9, the four selected polygons originally formed a complete sub-basin, and their weight is proportional to their area.

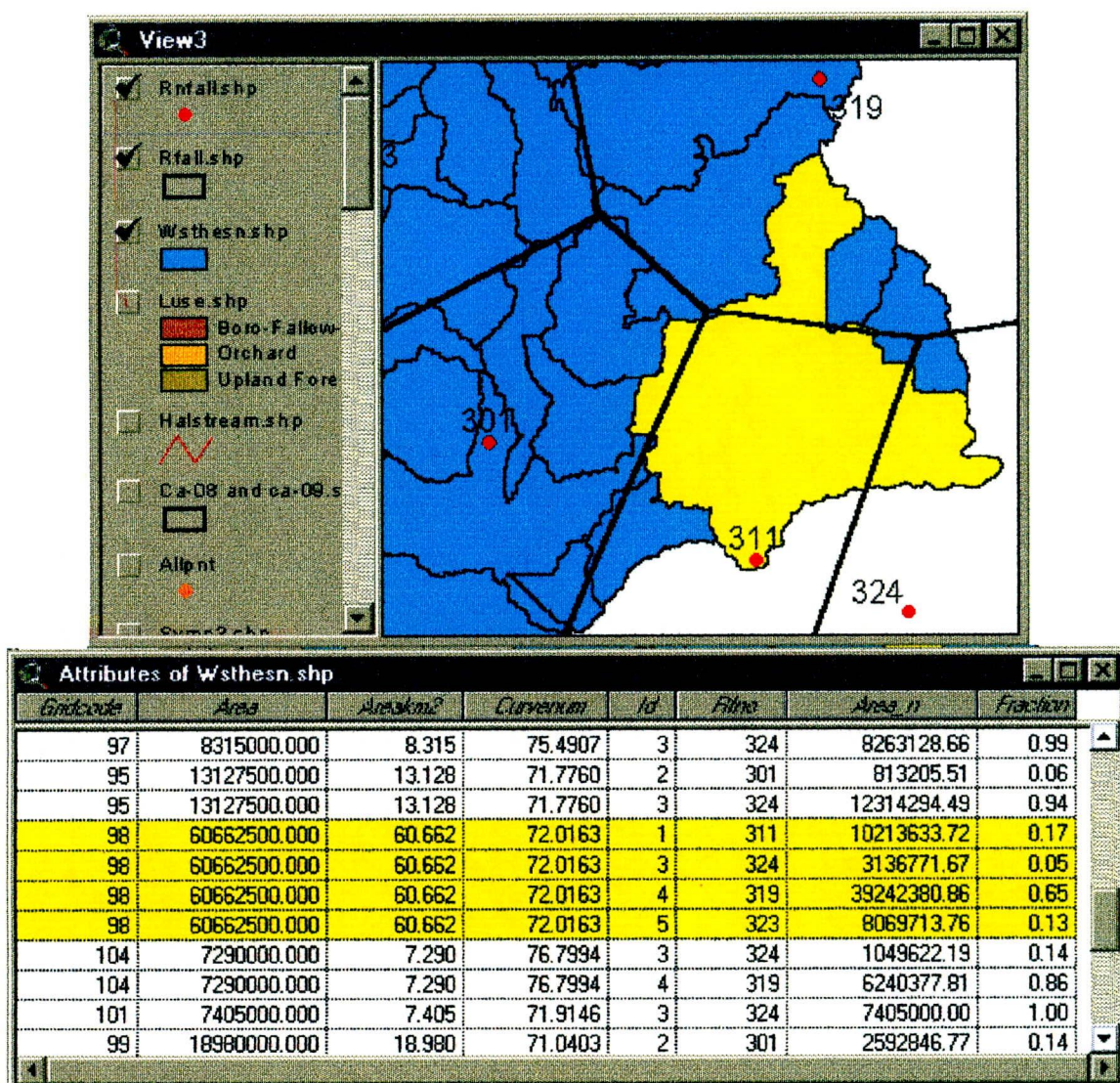
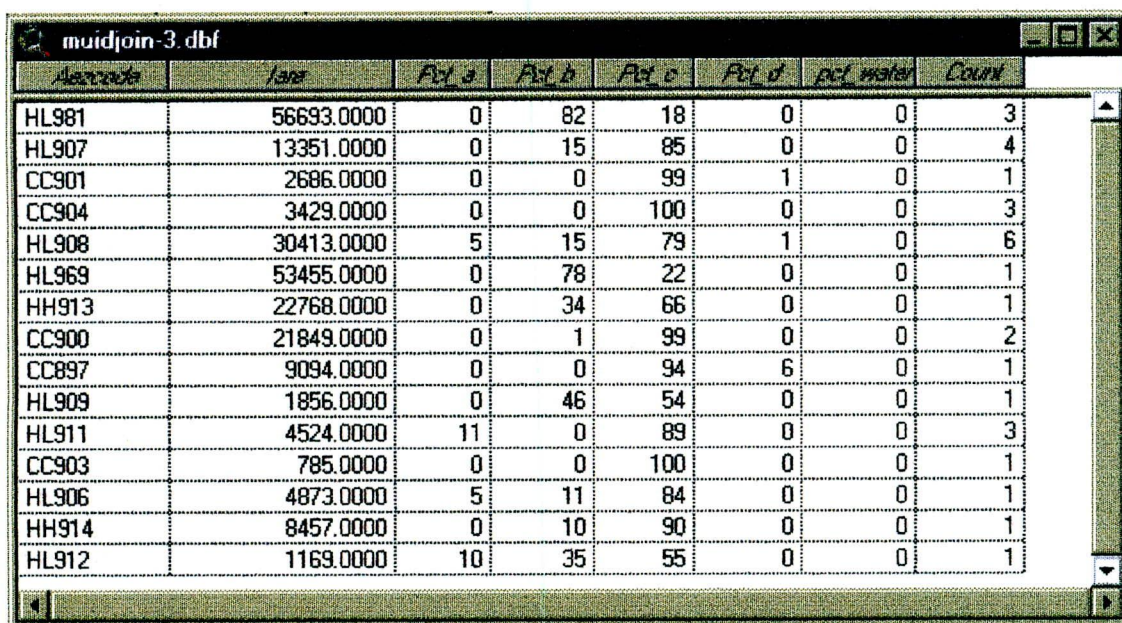


Figure: 4.9: Intersection of a sub-basin polygon with the Thiessen polygons. In the above table, the area of each of the yellow polygons is stored in the field Area, the sub-basin area in the field Area_n and the weights (the ratio of these two areas) in the field Fraction

After establishing the weight values based on the sub-basin and Thiessen polygon data sets, an ASCII file readable by HEC-HMS is used to record the gage and sub-basin information. The gage information consists of the gage name, location, type (i.e., incremental or cumulative), and reference to the precipitation time series in the DSS file. The sub-basin information consists of the sub-basin name or identification code, and the name of each gage with its corresponding weight.

4.14 Derivation of Curve Number Grid

The land use coverage for the study area was clipped out by specifying analysis extent to sub-watershed theme as obtained from delineated catchment. Three types of land use data were identified in the study region, Borrow Fallow-T-aman, Upland forest and Orchard. Land use grid having Anderson land use code classes as the grid cell value were created for a land use zoning database for the study area. Hydrologic soil group (A, B, C & D) wise SCS Curve Number (CN) values were estimated based on its land use type and treatment. The script that was used to calculate sub-watershed CN value in this research project was found from the CRWR (PrePro04.apr).



AreaCode	Area	Pct_a	Pct_b	Pct_c	Pct_d	pct_water	Count
HL981	56693.0000	0	82	18	0	0	3
HL907	13351.0000	0	15	85	0	0	4
CC901	2686.0000	0	0	99	1	0	1
CC904	3429.0000	0	0	100	0	0	3
HL908	30413.0000	5	15	79	1	0	6
HL969	53455.0000	0	78	22	0	0	1
HH913	22768.0000	0	34	66	0	0	1
CC900	21849.0000	0	1	99	0	0	2
CC897	9094.0000	0	0	94	6	0	1
HL909	1856.0000	0	46	54	0	0	1
HL911	4524.0000	11	0	89	0	0	3
CC903	785.0000	0	0	100	0	0	1
HL906	4873.0000	5	11	84	0	0	1
HH914	8457.0000	0	10	90	0	0	1
HL912	1169.0000	10	35	55	0	0	1

Figure 4.10: Look up table of Soil polygon of CA-08

In figure 4.10, AEZ indicates Agro-Ecological Zone and Pct_a, Pct_b, Pct_c, Pct_d are the hydrologic soil group percentage in the study area. The SCS curve number values were found to range from 67 to 81. Figure 4.11 indicates total landuse polygons area, their perimeter, landuse identification, landuse code and mainuse etc.

Shape	Area	Perimeter	Landuse	Landuse id	Code	Unit	Name	Lusecode
Polygon	8651467776.0	2266140.000	345	214	14b	14b	Upland Forest	411
Polygon	350655616.00	100705.023	415	114	14a	14a	Upland Forest	411
Polygon	13116862.000	15466.021	452	114	14a	14a	Upland Forest	411
Polygon	768487232.00	253666.891	453	204	4b	4b	Boro-Fallow-T.aman	2125
Polygon	262451744.00	114840.266	457	214	14b	14b	Upland Forest	411
Polygon	12642587.000	15171.591	463	114	14a	14a	Upland Forest	411
Polygon	8818801.000	11441.684	464	114	14a	14a	Upland Forest	411
Polygon	107645176.00	70273.211	476	114	14a	14a	Upland Forest	411
Polygon	8771494.000	13365.697	480	13	13	13	Orchard	431
Polygon	62062296.000	44099.789	483	214	14b	14b	Upland Forest	411

Figure: 4.11: Attribute table of watershed landuse shape with Anderson's land use code

4.15 Adds CRWR-PrePro Transfer Table: Before executing the CRWR-PrePro, one last item needs to be addressed. Since we did not give CRWR-PrePro any of these tables to use, clicking on the table's icon in project menu and selecting add from HEC-PrePro directory and choosing hecdiv.dbf, hecjunct.dbf, hecreach.dbf, hecres.dbf, hecsink.dbf, hecsourc.dbf and hecsub.dbf. It is extremely important that the entire database files for CRWR-PrePro to work correctly and it has been checked that all of these have transferred.

4.16 Run HEC-PrePro: To determine the schematic and write the basin file for HMS, making the Riv-03.shp and wapol-03.shp themes active and selecting CRWR-PrePro ⇒ HMS Schematic. In the HEC-PrePro window filling the six blanks with the following strings or values: yes default, 36 for tolerance 2, since 50m DEM is used in this study. CA-08 for output file and Chittagong Hill Tract is for output description. CRWR-PrePro determines which streams and channels (Hydrop and Hydrol) that carry water from subwatershed outlets and define a schematic layout over the drainage basin and stream network showing how it is hydrologically connected (Symp and Syml).

CHAPTER 5

MODEL SETUP AND RUNOFF COMPUTATION

5.1 Description of HEC-HMS modeling procedure

To view the basin model in the HEC-HMS environment, we first need to start the model using start/program/HMS and creating a new HMS project by clicking on File/New project CA-08. In the HMS*NEW PROJECT window, writing CA-08 in the project slot and Chittagong Hill Tracts in the description slot.

To import the CA-08 basin file, clicking on Edit/Basin/Model/Import and in the HMS basin model*IMPORT BASIN MODEL window, navigating the directory where the basin file (CA-08 basin) was created, HEC-HMS will display the file name. Now clicking the import button, it automatically displays the basin model, with the GUI of the basin model. The imported basin model for the CA-08 is shown in the Figure 5.1.

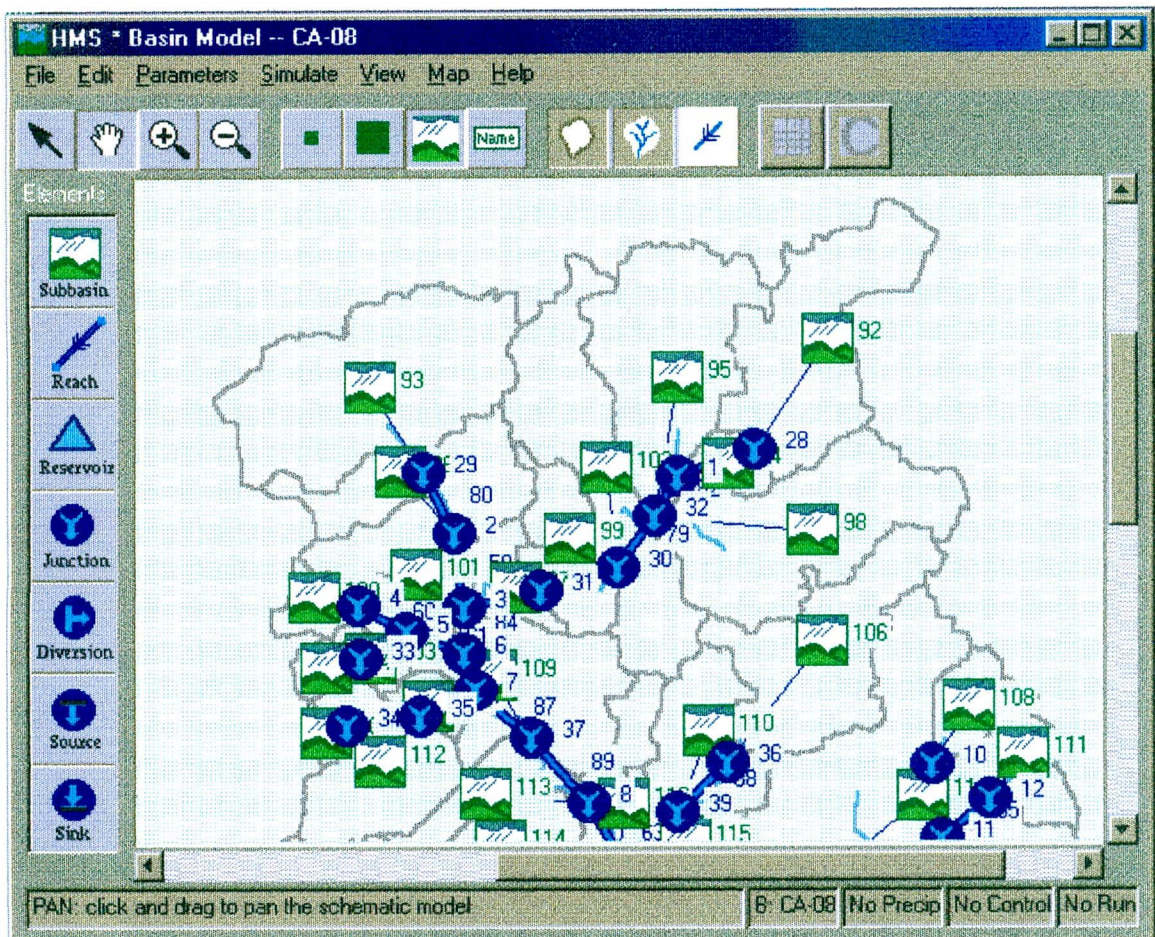


Figure: 5.1: CA-08 basin model after import

The basin model schematic diagram that geographically locates the hydrologic elements is thus created as a symbolic coverage within the GIS. The elements are:

-  Subbasin Creates a sub basin drainage area within the basin model
-  Reach Establish river reaches within the model
-  Reservoir Places a reservoir in the model
-  Junction Connects two or more river reaches at a point in a sub-basin
-  Diversion Allows some water to pass while diverting a portion out of the river
-  Source An input of flow to the system
-  Sink An output of flow to the system

The model figure: 5.1 represents the resulting symbolic coverage, which contains 133 hydrologic elements made up of 42 sub basins, 45 junctions, 45 reach and 1 sink. No lakes, reservoirs, or diversions were contained in this model because the grid representation of the stream system is a simplified version of the more complex real system network. Each element is represented by an identification number and the next downstream element is also noted. For example, sub basin 115 drains to junction 9; reach 63 drains to junction 9; junction 9 drains to reach 49; and so on. HEC-HMS uses these object-to-object connections to build its own model schematic for the watershed.

In the basin model the hydrologic elements represents the following information:

Subbasin stores the canvas coordinates, area, downstream junction number and subwatershed modeling parameters e.g. Loss method, Transform method, CN-curve numbers, Lag time etc.

Reach stores reach canvas coordinates, downstream junction number, routing parameters e.g. routing method, Muskingum X, Muskingum K and number of reaches in the river.

Junction stores canvas coordinates of the junction, identification number of the downstream stream number. It also stores flow record file (.dss format) of an observed flow data.

Sink stores sink canvas coordinates and observed .dss file.

Since an integral part of modeling a system involves understanding the modeling software it is important to investigate the model itself through some steps and realize what is truly happening at each step. The region of interest includes four subbasins (labeled 120, 121, 124 and 126 in the image). When executed, the model performs calculations in the following order:

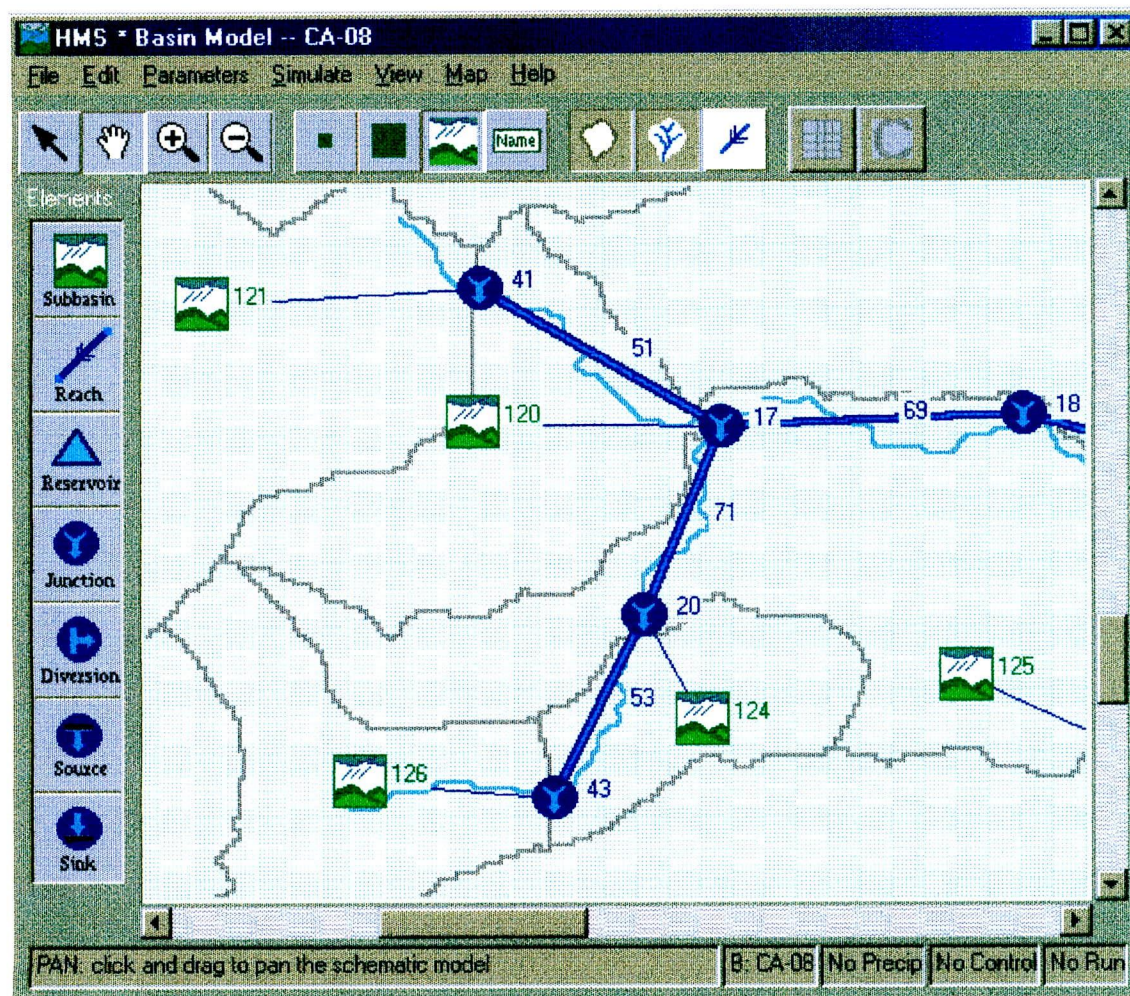


Figure: 5.2: Basin model region of interest performs through calculation

In figure 5.2,

- For subbasin 126, separate excess rainfall from total rainfall
- Calculate the output hydrograph of subbasin 126 at junction 43
- Route this outflow through river reach 53
- For subbasin 124, separate excess rainfall from total rainfall.
- Calculate the output hydrograph of subbasin 124 at junction 20
- Take both hydrographs now at junction 20 and combine them into one hydrograph.

- Route this combine hydrograph through river reach 71 to junction 17
- For subbasin 121, separate excess rainfall from total rainfall
- Compute the output hydrograph of subbasin 121 at junction 41
- Route this hydrograph through river reach 51 to junction 17
- Combine these two hydrographs at junction 17 into one hydrograph.
- For subbasin 120, separate excess rainfall from total rainfall
- Compute the output hydrograph of subbasin 120 at junction 17
- Combine these two hydrographs at junction 17 into one hydrograph
- Route this combine hydrograph through river reach 69 at junction 18

This hydrograph goes to the final hydrograph at Panchpukuria outlet of modeled region through other steps

After setting up the basin model it is necessary to enter gage information i.e. discharge and precipitation gages.

5.2 Overview of gage data

Hydrologic models require time-series of precipitation data for estimating rainfall. A time-series of flow data, often called observed flow or observed discharge is helpful for calibrating a model and is required for optimization. Time-series data is stored in a project as a gage. The program separates different types of data with different gage types. Both precipitation and discharge gages are similarly managed and subsequent examples will be with precipitation gages.

Gage data only has to be entered one time. Basin and meteorological models refer to the gage by named; so changes to the gage data are automatically updated everywhere the gage is referenced.

The gage manager screen is used to create and manage gages. It is accessed by selecting the Data / precipitation gages menu item on the project definition screen. The data menu contains menu items for precipitation and discharge gages. Selecting one of the menu items on the data menu will open the gage manager screen for that data type. Figure 5.3 is the precipitation gage manager screen with five inputted rainfall gages. The data was inputted as daily rainfall. Rainfall graph of Amtali from June to November is shown in figure 5.4. The storm of 24th June 1992 at Narayanhat rainfall station is shown in figure 5.5 and at Fatikchari station is shown in figure 5.6. Inputted daily discharge of Panchpukuria of discharge gage manager screen is shown in figure 5.7.

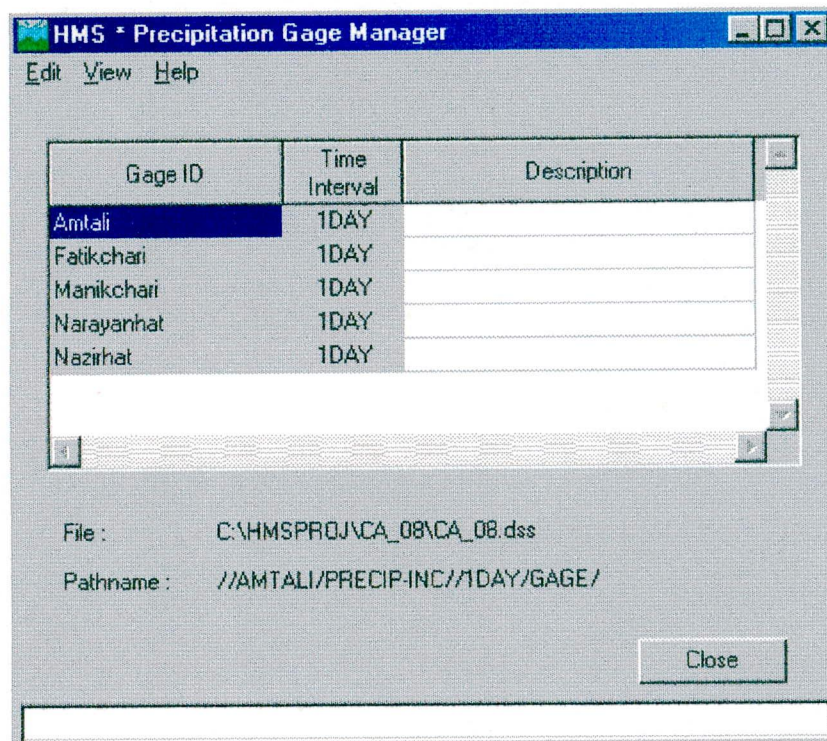


Figure 5.3: Precipitation Gage Manager screen

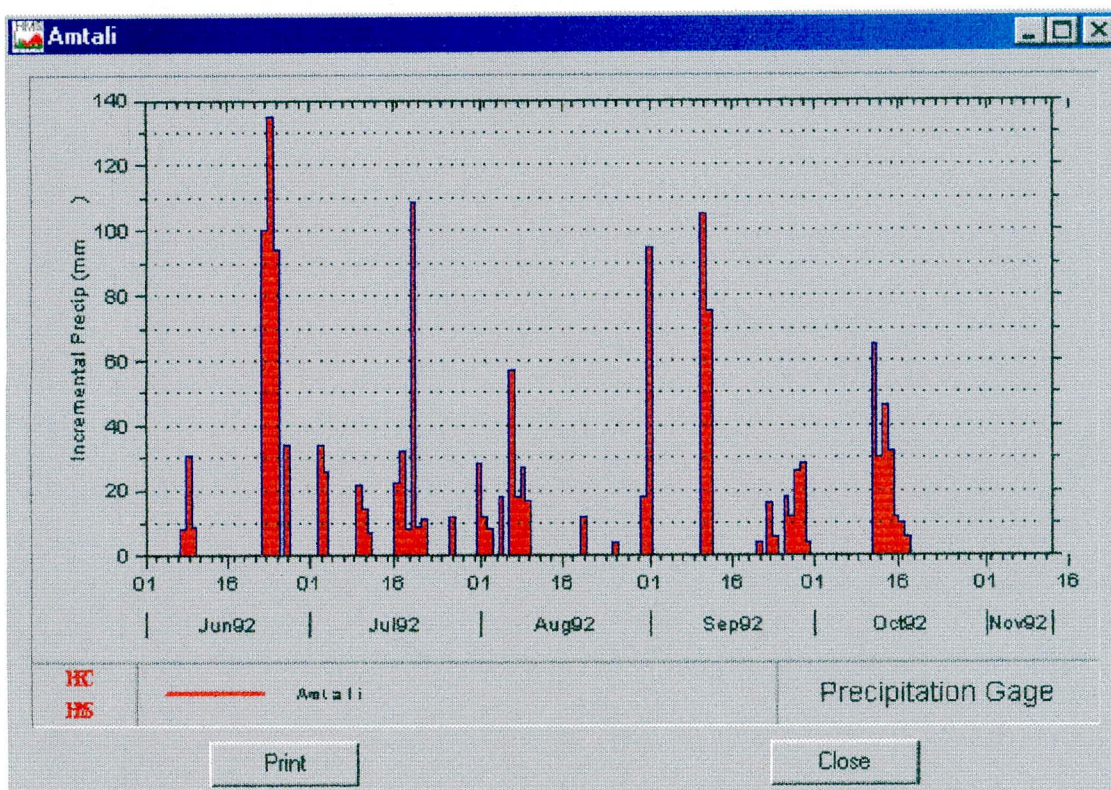


Figure 5.4: Gage data of Amtali (June to October)

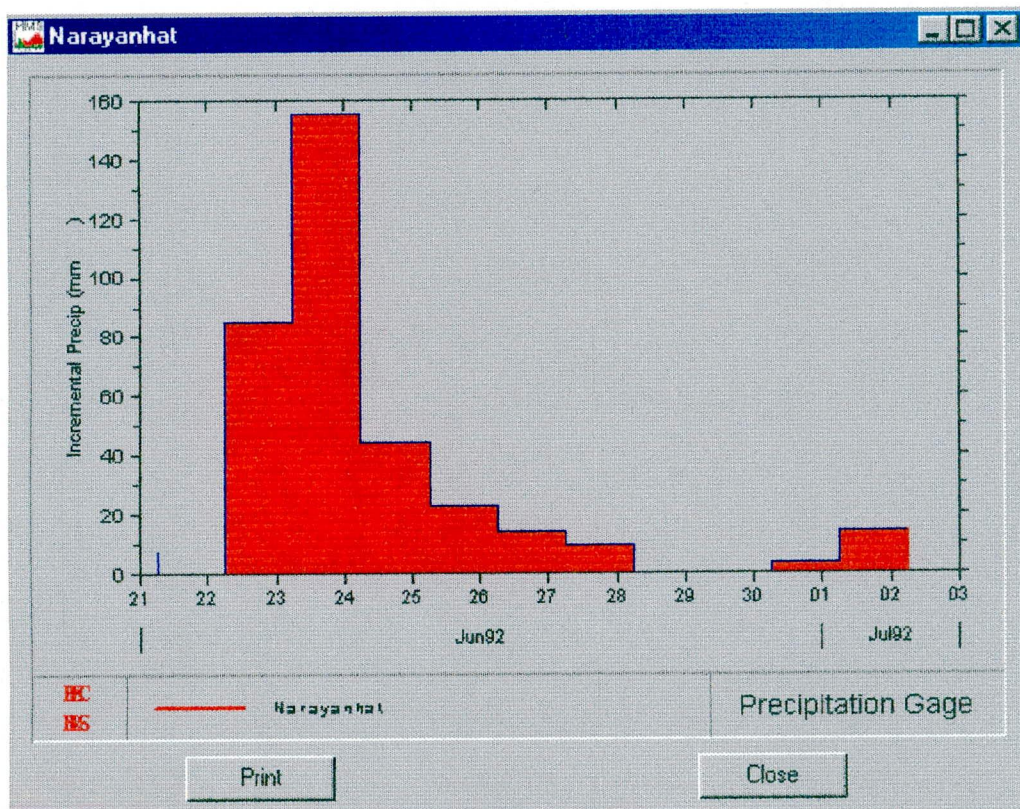


Figure: 5.5: Rainfall data of Narayanhat station for the period of 21st June to 2nd July

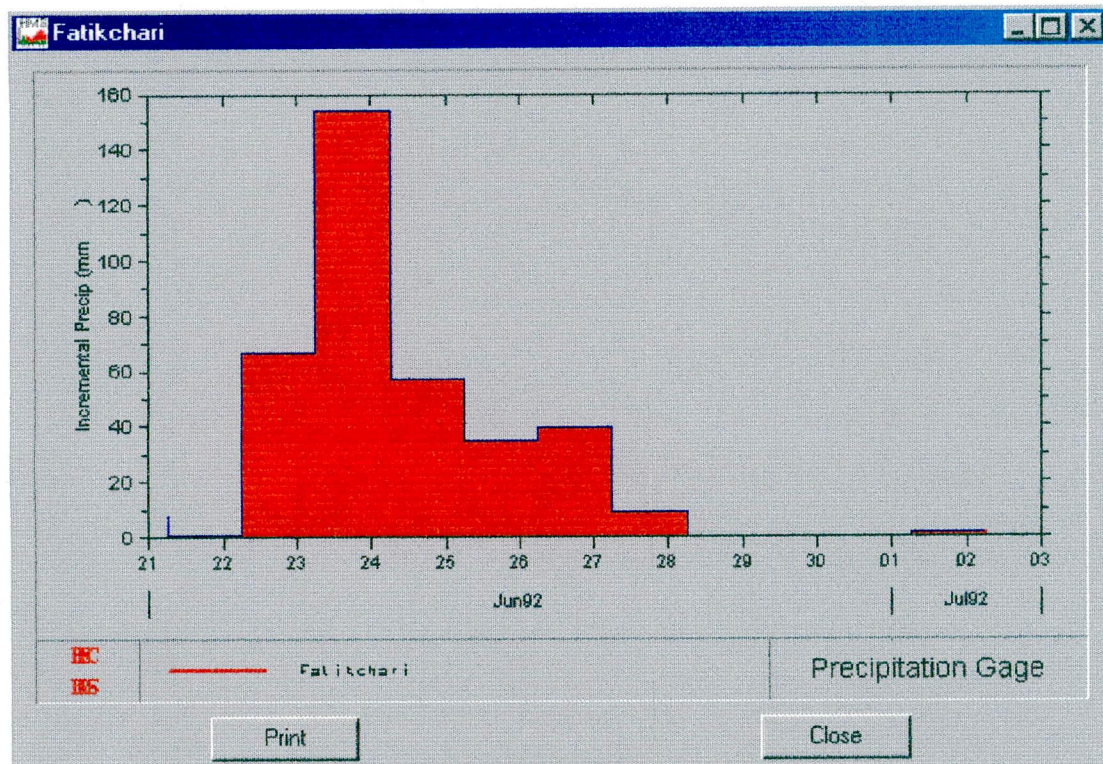


Figure: 5.6: Rainfall data of Fatikchari station for the period of 21st June to 2nd July

The precipitation gage ID and data paths have been defined and at that time connected the .dss file with the HEC-HMS for proper linkage to view the data for graph and time series table format. Data can also be entered manually instead of External DSS option.

In the similar way, Discharge gage record also created with gage ID and .dss file from the gage manager screen.

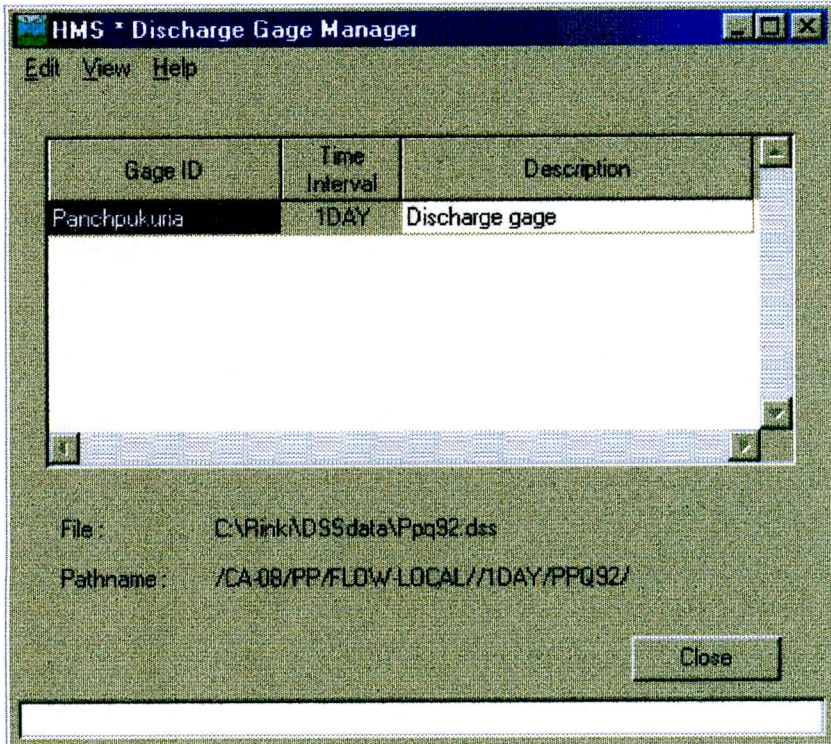


Figure: 5.7: Discharge Gage Manager screen

5.3 Setting the appropriate SMA modeling parameters

SMA unit will be identified at first for each subbasin and each subbasin uses a unit can have a different set of initial conditions. Calibration techniques have been used to set the appropriate parameter to get final results.

CHAPTER 6

RESULTS AND DISCUSSIONS

6.1 Introduction

HMS is comprised of a graphical user interface (GUI), integrated hydrologic analysis components, data storage and management capabilities, graphics and reporting facilities. The beauty of the HMS lies in its graphical user interface which provides a means for specifying model elements (i.e. sub-basins, sources, reaches, reservoirs, diversions and sink) and their interconnectivity, imputing data for the elements and viewing hydrographs. The following tasks have been undertaken for computing runoff for HEC-HMS-SMA model setup:

1. Starting a new computation
2. Gage data creation
3. Input of basin model data
4. Input of meteorologic data
5. Control specifications
6. Model run
7. Viewing results

6.2 Starting a new computation

A project in the HMS refers to all of the data sets associated with a particular model. In this case, the project is called CA-08. The description bar underneath the project name allows typing a detailed name for the actual short project name. In the components section of the project definition, there are three sub-sections: the basin model, the precipitation model and the control specifications. Each component represents a different element of the model. The basin model, for instance, contains information relevant to the physical attributes of the model, such as basin areas, river reach connectivity etc. likewise, the precipitation model holds rainfall data. Finally, the control specifications section contains information pertinent to the timing of the model such as when a storm occurred and what type of time interval user want to use in the model.

6.3 Gage data creation

Time series data is stored in a project as a gage. A time series of flow data called observed flow or observed discharge, is helpful for calibrating a model and is required for optimization. The program separates different types of data with different gage types. Both precipitation and discharge gages are subsequent examples of precipitation gages. To calculate basin rainfall/evaporation data from the station level data, it is required to calculate weight of each rain gage station for each sub basin. The meteorological file (ASCII format) keeps records of all the information. The weight of each gage is calculated using GIS based on the spatial location of each gage with respect to

basins/sub basins. To calculate weight Thiessen polygon is determined first, and then overlaid on the sub basin shape file.

```
Gage: Panchpukuria
  Description: Discharge gage
  Gage Type: Flow
  Units: M3/S
  Local to Project: NO
  Start Time: 1 January 1992, 06:00
  End Time: 31 December 1992, 06:00
  DSS File: C:\Rinki\DSSdata\Ppq92.dss
  Pathname: /CA-08/PP/FLOW-LOCAL//1DAY/PPQ92/
End:

Gage: Amtali
  Description: Precipitation gage
  Latitude: 0
  Longitude: 0
  Gage Type: Precipitation
  Precipitation Type: Incremental
  Units: MM
  Local to Project: YES
  Start Time: 1 January 1992, 06:00
  End Time: 31 December 1992, 06:00
  Pathname: /CA-08/AMTALI/PRECIP-INC//1DAY/GAGE/
End:

Gage: Fatikchari
  Description: Precipitation gage
  Latitude: 0
  Longitude: 0
  Gage Type: Precipitation
  Precipitation Type: Incremental
  Units: MM
  Local to Project: YES
  Start Time: 1 January 1992, 06:00
  End Time: 31 December 1992, 06:00
  Pathname: /CA-08/FATIKCHARI/PRECIP-INC//1DAY/GAGE/
End:
Other precipitation gages are continued in the above format
```

Figure: 6.1: Part of Gage File containing flow and rain gage information

The gage information file created automatically through the HEC-HMS when the gage information is added, using the entering gage data option.

The Gage Manager screen is used to create and manage gages. It is accessed by selecting the Data/Precipitation Gages menu item on the project definition screen. The data menu contains menu items for precipitation and discharge gages. Selecting one of the menu items on the data menu will open the gage manager screen for that data type.

6.4 Input of Basin model data

The first of the components user will consider is the Basin Model. To view this aspect of the model, select Edit/Basin Model/open from the menu bar on the Project Definition. In this case, basin model CA-08 is appeared and selecting this model by double clicking. For describing the basin model data first enter data in the SMA unit with details of subbasins.

6.4.1 Soil Moisture Accounting Unit: SMA unit contains storage and maximum infiltration rate specifications. Units are created and managed separately from basin models and subbasin elements that use the SMA loss method. Units must be specified before a subbasin can reference them. Select the Data / Soil Moisture Accounting Units menu item on the project definition screen to access the SMA unit editor screen for managing unit and entering data. The SMA unit editor screen uses five tabs for inputting data for the five storage layers: canopy, surface, soil profile, groundwater 1 and groundwater 2.

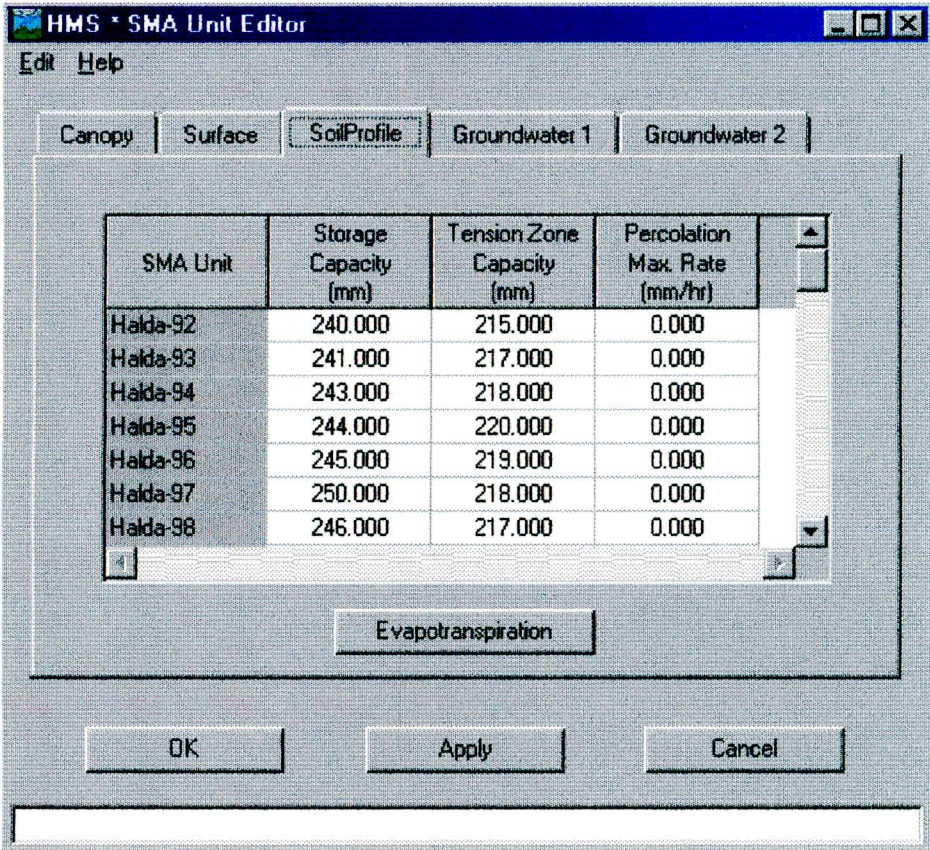


Figure: 6.2: SMA Unit Editor screen

The only required parameter on the “canopy” tab is the storage capacity. All capacities are entered as uniform depths over the entire area of the unit. Required parameters on the “surface” tab are storage capacity and soil infiltration maximum rate. Required parameters on the “soil profile” tab are storage, tension zone capacity and percolation maximum rate. Totally 42 SMA units were created for 42 subbasins and named as Halda-92 to Halda-133. In Figure 6.2, Halda-92 to Halda-98 soil profile storage depth values is shown. Each subbasin that uses a unit can have a different set of initial conditions. Optionally evapotranspiration can be turned off for any month of the year by pressing the evaporation button. It has been found that maximum percolation rate becomes zero from observed discharged hydrograph that is why no groundwater zones were used for this model.

6.5 Input of Meteorologic data

From HMS project definition screen, Component/Meteorologic model/New/Halda_CA-08_GageWts has been entered to create meteorologic model. The subbasin list screen opens automatically whenever a meteorologic model is opened and the subbasin list is empty. Adding subbasin names (i.e. 92 to 133) by selecting the CA-08 basin model. Both precipitation and evaporation data is necessary for this application. Five precipitation stations were inputted with the add gage recording button with the user gage weighting method which is shown in Figure 6.3

HMS * Meteorologic Model

File Edit Help

Meteorologic Model: Halda_CA-08_Gagewts Subbasin List

Description:

Precipitation | Evapotranspiration

Method: User Gage Weighting

☒ Gages ☐ Subbasins ☐ Weights

	Gage ID	Gage Type	Total Storm Depth (in)	Index Precip (in)
Add Gage	Amtali	R		
Recording	Fatikchari	R		
Add Gage	Manikchari	R		
Total Storm	Narayanhat	R		
	Nazirhat	R		

OK Apply Cancel

Figure: 6.3: Meteorologic model showing precipitation gage ID and gage type

Setting the gage weights for each subbasin in the weights section. In Figure 6.4 selecting subbasin 109 from the list and enter the “Total storm gage weight” for each gage. Entering “Temporal gage weight” of 1 for Amtali and Fatikchari gage and the gage weight percent for Amtali is 0.85 and for Nazirhat is 0.15. This procedure is followed for the remaining subbasins.

HMS * Meteorologic Model

File Edit Help

Meteorologic Model: Halda_CA-08_Gagewts Subbasin List

Description:

Precipitation | Evapotranspiration

Method: User Gage Weighting

☐ Gages ☐ Subbasins ☒ Weights

Subbasin: 109

Gage ID	Gage Type	Total Storm Gage Weight	Temporal Gage Weight
Amtali	R	0.85	1
Nazirhat	R	0.15	

OK Apply Cancel

Figure: 6.4: Gage weight percent of subbasin 109

The second part of meteorologic model is Evapotranspiration portion and only used for Soil Moisture Accounting method. In this study, Chittagong evaporation station (E-06) has been used for surface runoff modeling. The monthly average evaporation and evapotranspiration co-efficient values are collected form EGIS-II (Source: Draft Development Strategy: Annex C Appendix 4, August 2000).

6.6 Control Specifications

The final piece of the model setup involves establishing the models time limit. The starting date and time of a run and also the ending date and time are set in the control specifications of Figure 6.5. A time interval was selected for the first trial as duration of 21st June to 2nd July named as Season 92. Finally 30 minutes time step were adjusted well.

HMS * Control Specifications

File Help

Control Specs ID : Season 92

Description :

Starting Date : 21 Jun 1992 Starting Time : 06:00

Ending Date : 02 Jul 1992 Ending Time : 06:00

Time Interval : 30 Minutes

OK Apply Cancel

Figure: 6.5: Control specifications with analysis time step

6.7 Model run

After setting all of the required parameters it is needed to manage and execute runs. Select the Simulate/Run Configuration menu item to open the Run Configuration screen. Select the CA-08 basin model, Halda_CA-08_Gagewts in the meteorologic model and Season 92 in the control specifications.

The trial message log contains errors, warnings and note entries generated during the optimization. At the end, Season 92 run becomes successful with messages shown in figure 6.6.

HMS * Compute

Run : Season 92

100%

Compute Successful.

☐ Errors

☐ Warnings

☐ Notes

View Log Close

Figure: 6.6: Computation of Season 92 Run view

6.8 Viewing Results

HMS allows viewing results in tabular or graphical form. To view results for each element within the model, select an element in the model (for example: Reach 79) with the left mouse button, hold down the right mouse button, and choose the view results from the pop-up menu which appears. Pick from graph, summery table and time series table. The graph for reach 79 is shown in figure: 6.7.

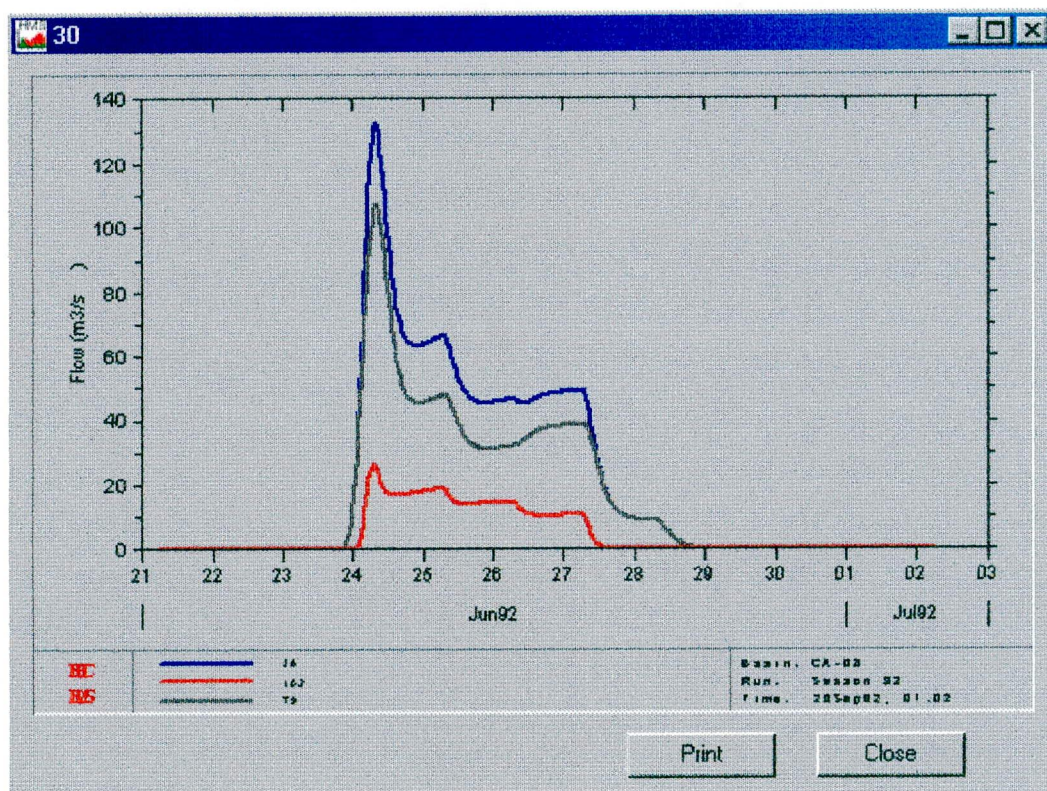


Figure: 6.7: Simulated Hydrograph through river reach 79 to Junction 30

To view the results for some of the subbasins in graphical form, toward the top of the results window of a given sub-basin, it is easy to view the rainfall hyetograph for that subbasin. Figure 6.8 indicates the simulated hydrograph of subbasin 121 at junction 41 and Figure 6.9 is the simulated flow at junction 17 from 21st June to 2nd July. In Figure 6.10, red part indicates total precipitation blue is loss and the outflow hydrograph of subbasin 122.

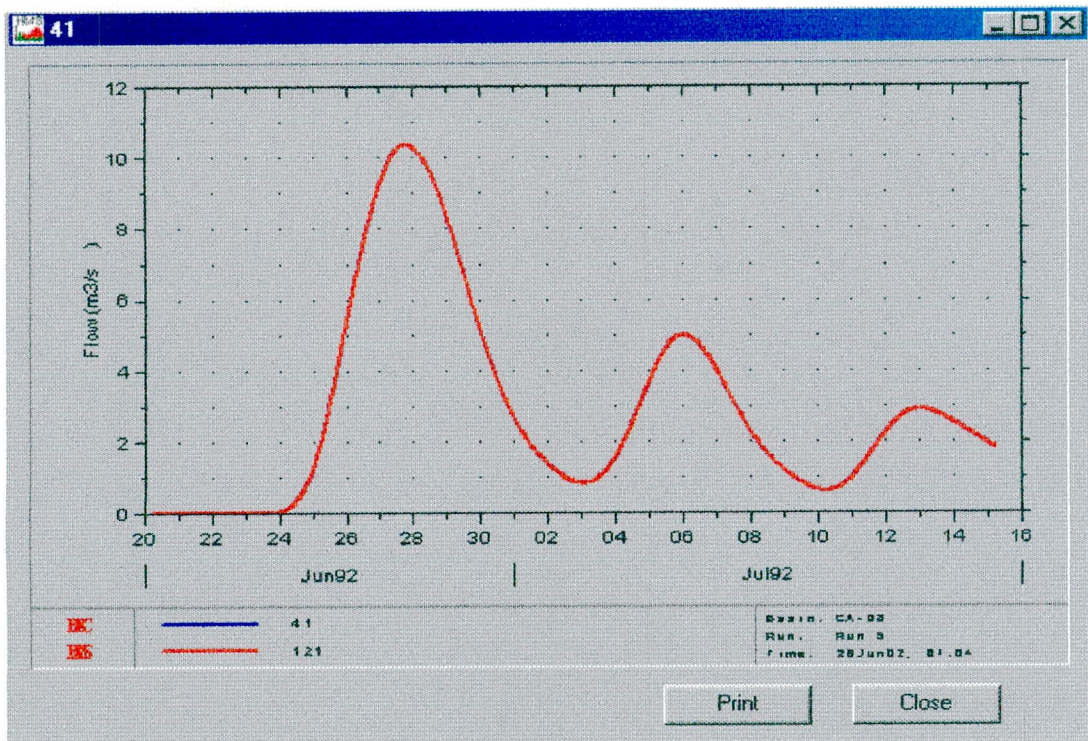


Figure: 6.8: Simulated Hydrograph of subbasin 121 at junction 41

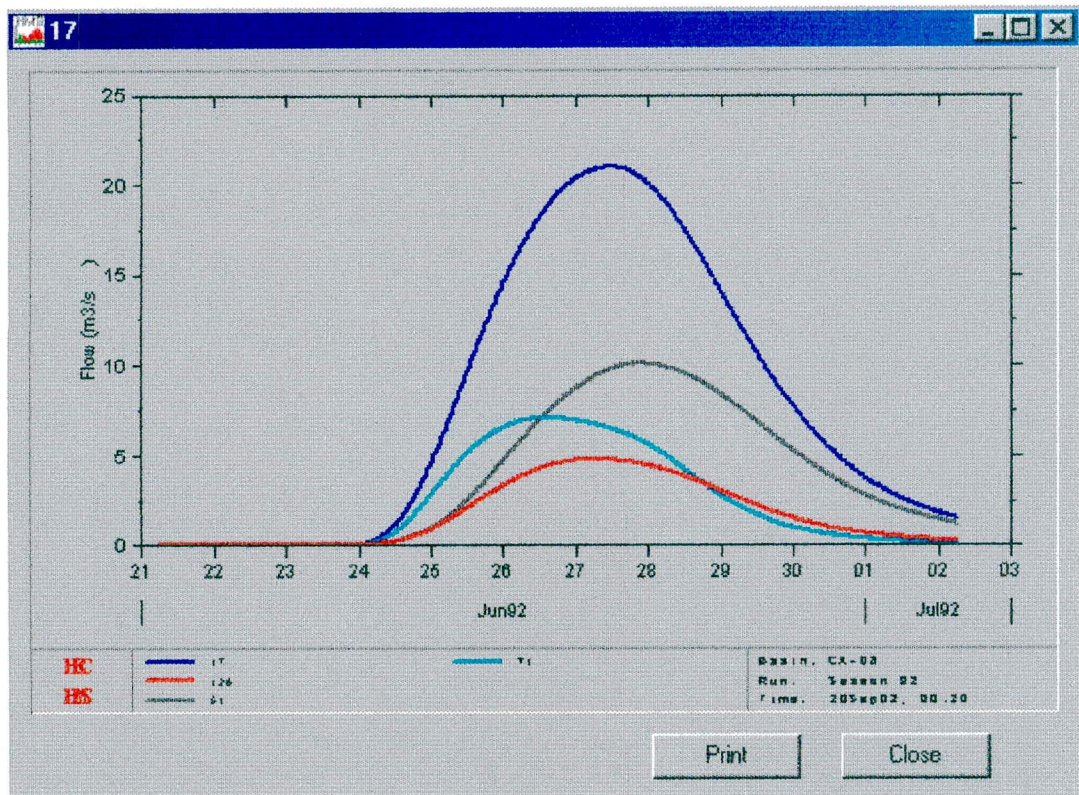


Figure: 6.9: Simulated Flow in the Junction 17 from 21st June to 2nd July

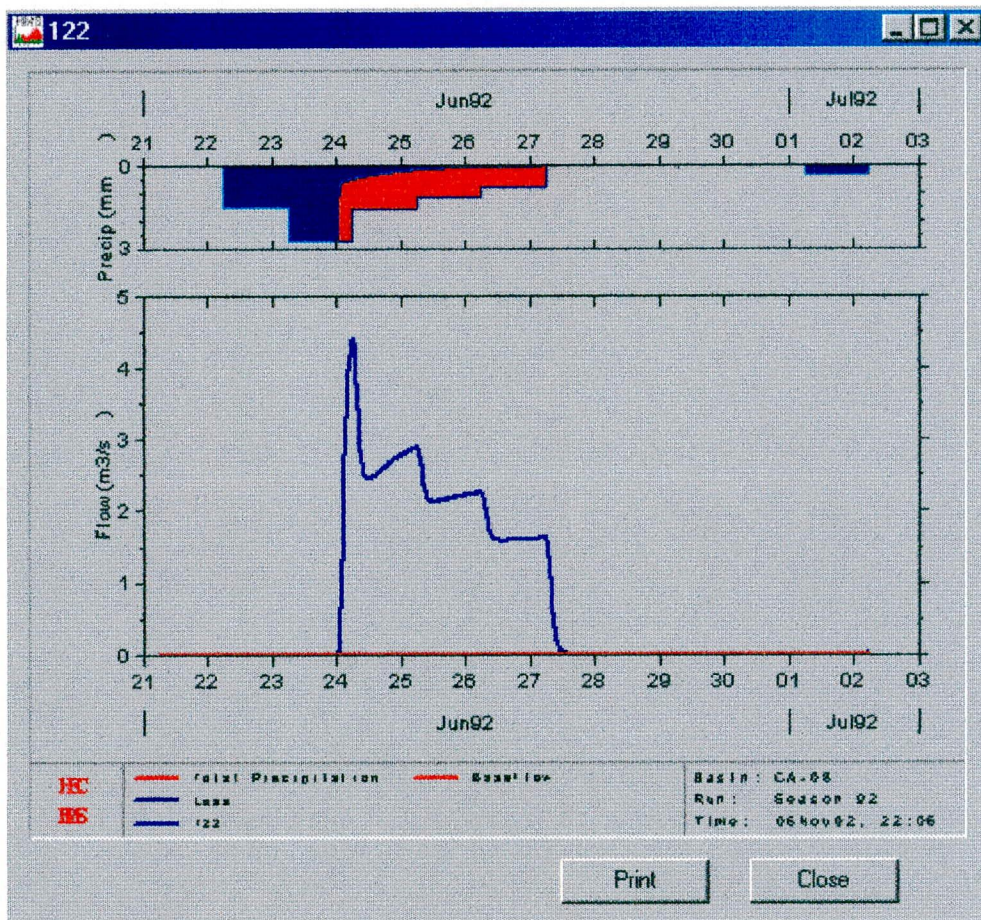


Figure 6.10: Simulated Flow in sub basin 122 from 21st June to 2nd July

Soil Moisture Accounting Results:

Subbasins set to use the soil moisture accounting loss method have special result displays in addition to the standard displays. The displays include a graph (figure: 6.11), summary table (figure: 6.12) to show additional data computed by the method.

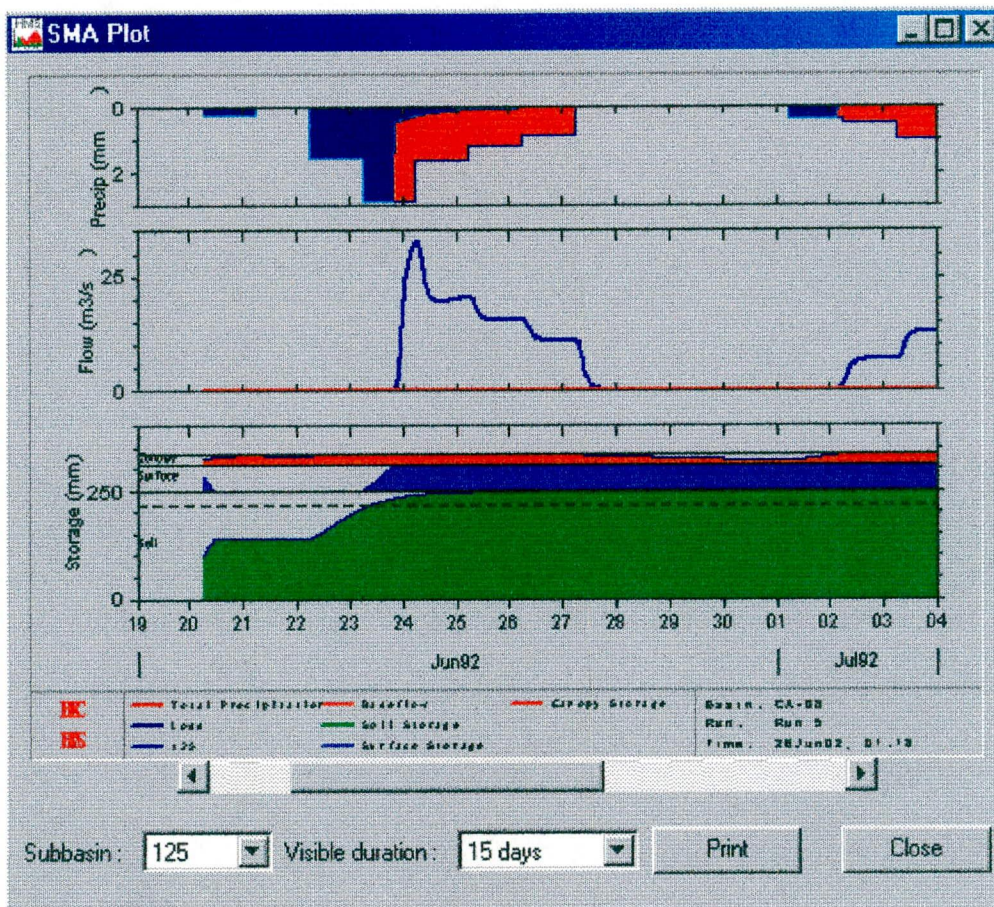


Figure: 6.11: Soil Moisture Accounting subbasin 125 results graph

In the above figure, it has shown that Green indicates Soil profile storage depth which is 249 mm for subbasin 125, Blue indicates Surface storage and the value is 63 mm and at last Red indicates Canopy storage depth which is 21 mm for subbasin 125.

HMS * Summary of Results for Subbasin 125

Project : CA-08
Run Name : Run 5
Subbasin : 125

Start of Run : 20Jun92 0600
End of Run : 15Jul92 0600
Execution Time : 26Jun02 0042

Basin Model : CA-08
Met. Model : Halda_CA-08_Gagewts
Control Specs : Pre-monsoon 92

Volume Units : ☒ Millimeters ☐ Thousand Cubic Meters

Computed Results

Peak Discharge : 32.463 [cms]
Peak Stage :

Date/Time of Peak Discharge : 24 Jun 92 0630

Total Precipitation : 566.5 (mm)
Total Loss : 207.7 (mm)
Total Excess : 358.8 (mm)

Total Direct Runoff : 358.8 (mm)
Total Baseflow : 0.0 (mm)
Total Discharge : 358.8 (mm)

Soil Moisture Accounting :

Canopy Overflow : 532.2 (mm)
Soil Infiltration : 144.4 (mm)
Percolation to GW 1 : 0.0 (mm)
Percolation to GW 2 : (mm)
Deep Percolation : (mm)
GW 1 Outflow : (mm)
GW 2 Outflow : (mm)

Change in Canopy Storage : 3.6 (mm)
Change in Surface Storage : 29.0 (mm)
Change in Soil Storage : 144.4 (mm)
Change in GW 1 Storage : (mm)
Change in GW 2 Storage : (mm)
Canopy ET : 30.7 (mm)
Surface ET : 0.0 (mm)
Soil ET : 0.0 (mm)

Figure: 6.12: Soil moisture accounting subbasin 125 results summary table

6.9 Comparison of generated flow with NAM runoff

The model result of computed runoff for 30 June 92 to 15 July 92 is shown in figure 6.13. From the graph we observed that the computed peak is on 24th June around afternoon and the Nam result peak is 25th June. The volume of computed result is 429.75 cumec and the NAM volume is 405.61 cumec.

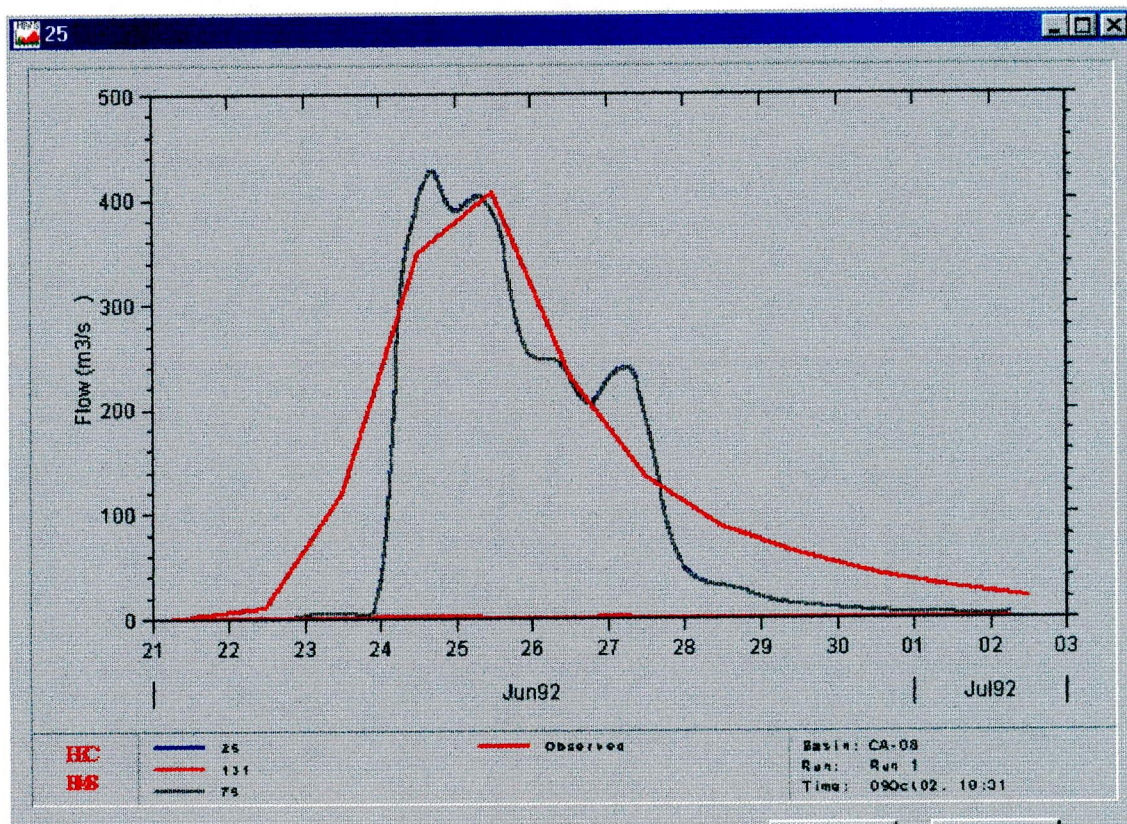


Figure: 6.13: Flow comparison graph of simulated and NAM runoff.

The red hydrograph is the NAM runoff and the black is computed runoff at Panchpukuria outlet.

6.10 Comparison of Computed CA-08 runoff, NAM runoff and Observed runoff

The final comparison graph has been shown in figure 6.14. In this study base flow is separated from observed discharge using straight line method.

Comparison graph of Computed runoff, NAM runoff and Observed runoff of 1992 at Panchpukuria

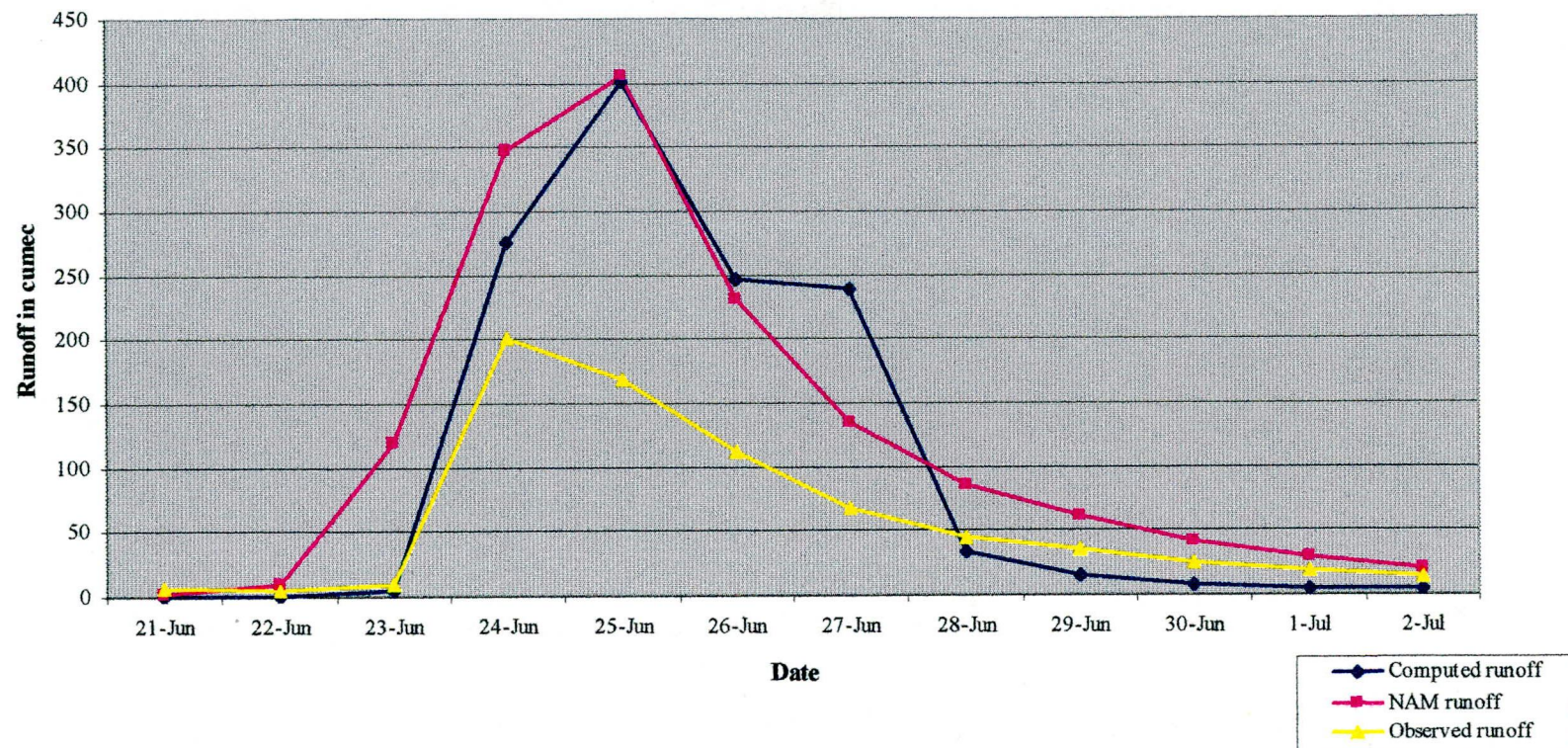


Figure: 6.14: Comparison of Simulated runoff, Observed runoff and NAM computed runoff

6.11 Results

The following results have been found in this study.

- Detailed stream network was created for Halda basin which is stored in a GIS data base and would be used in future for hydrologic modeling.
- From elevation data DEM was prepared, which is one of the basin input for stream delineation. IDW method was evaluated based on elevation point data of Halda basin.
- Considering Panchpukuria as the outlet of the whole CA-08 catchment, an updated watershed boundary was obtained based on the analysis of the flow direction and flow accumulation grids derived from the detailed DEM of the catchment.
- Parameters of all the 42 sub-basins and their channels, coordinates, junction's sinks and connectivity of the junctions/sinks with the channels were written to the basin file. This basin file was successfully imported into the HEC-HMS model without any error.
- Sub watershed parameters i.e. the SCS CN value, length of longest flow path, land slope, SCS UH lag time and overland flow velocity were computed using the landuse data layer, hydrologic soil groups layers and DEM. The estimated CN values ranges from 67 to 81 which shows the watershed is flushy runoff characteristics.
- Muskingum method was used for channel routing in all long reaches. In short reaches, in which the flow time is shorter than the time step, the pure lag method was used. Stream velocity was assumed as 1m/sec for all the streams and Muskingum X was assumed as 0.2
- Hydraulic conductivity of the study soil was taken equivalent to maximum infiltration rate and finally which changed during calibration and become ranges form 11 to 15 mm/hr.
- Different time steps were tried for model run and finally 30 min time step was adjusted well.
- The final runoff hydrograph was compared with observed and with the NAM model runoff and from the three comparison graphs, it was found that simulated runoff were higher than the observed runoff.

6.12 Discussions

After a first round of calibration the parameters were re-adjusted, partly because changes in one component often affect the other components or the water balance to some extent.

The simulated results were greater than the observed peaks and the maximum infiltration rate was increased to allow these higher percolation rates to infiltrate into the soil profile. Temporarily modifying model parameters (i.e. increase the depth of the soil profile) insured that the potential infiltration rate was approximately equal to the maximum infiltration rate.

Adjustment of the soil profile depth:

When the simulated flows were greater than the observed flows the depth of the soil profile was increased which increased the infiltration rate.

Adjustment of ET loss:

When simulated hydrograph was too large the amount of ET loss was increased by:

- Increasing canopy and surface interception storage
- Increasing the depth of the soil profile while keeping the depth of the tension zone constant.

Infiltration rate and depth of both the tension zone and the soil profile are the most sensitive parameter to change the results compared to the other input parameters in the SMA method. In addition, adjusting one of these parameters can affect calibration of other parameters. Consequently, fitting these parameters was an iterative process.

Canopy and surface interceptions have less impact on the simulated hydrograph than the maximum infiltration rate, soil profile and tension zone parameters and were modified after these later parameters had been established.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

The conclusions of this study are as follows:

- With the current state of GIS database development in Bangladesh and hydrologic data availability, a successful integration of GIS tools for hydrologic modeling using the HEC-HMS and ArcView 3.2 software, runoff computation is done in Halda river basin in this research.
- A GIS database comprising the hydrography, soils, stream network and land use of Halda watershed is created and can be updated (whenever needed) and used for hydrological modeling.
- Comparison of simulated and NAM runoff over time and peak values showed that the SMA algorithm does relatively well in replicating observed values.
- Parameter calibration was an iterative process where some suggested steps (Bennett, 1998) were followed numerous times. Most of these techniques were common sense.

7.2 Recommendations:

The following recommendations were made in this study:

- A limited data were obtained to create DEM for hydrologic analysis and further study should include detail data.
- The CA-08 catchment boundary was changed according to DEM. It proves that catchment boundary should be re-delineated.
- In the future, with standardized means of land surface terrain analysis and tools like CRWR-PrePro and HEC-HMS, it will be possible to routinely study hydrologic regions of the area of states or larger, to build hydrologic models of runoff over whole cities or countries and to more readily construct very detailed hydrologic models of small watersheds.

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APPENDIX-A

CA-08 Basin File

Basin: CA-08

Description: Chittagong Hill Tract

Last Modified Date: 23 June 2002

Last Modified Time: 22:42:22

Version: 2.1.3

Default DSS File Name: C:\HMSPROJ\CA_08\CA_08.dss

Unit System: SI

Map File: C:\HEC_Data\tmp\CA-08.map

End:

Subbasin: 92

Description: 67

Canvas X: 687614.910

Canvas Y: 531297.300

Label X: 16

Label Y: 0

Area: 25.93

Downstream: 28

LossRate: Soil Moisture Account

Percent Impervious Area: 0.0

Soil Moisture Unit: Halda-92

Initial Canopy Storage Percent: 65

Initial Surface Storage Percent: 45

Initial Soil Storage Percent: 35

Initial Gw1 Storage Percent: 0

Initial Gw2 Storage Percent: 0

Transform: SCS

Lag: 347.568000

Baseflow: None

End:

Subbasin: 93

Description: 68

Canvas X: 673889.910

Canvas Y: 529872.300

Label X: 16

Label Y: 0

Area: 36.185

Downstream: 29

LossRate: Soil Moisture Account

Percent Impervious Area: 0.0

Soil Moisture Unit: Halda-93

Initial Canopy Storage Percent: 70
Initial Surface Storage Percent: 56
Initial Soil Storage Percent: 40
Initial Gw1 Storage Percent: 0
Initial Gw2 Storage Percent: 0

Transform: SCS
Lag: 113.973000

Baseflow: None
End:

Subbasin: 94

Description: 70
Canvas X: 684589.910
Canvas Y: 527547.300
Label X: 16
Label Y: 0
Area: 3.697
Downstream: 1

LossRate: Soil Moisture Account
Percent Impervious Area: 0.0
Soil Moisture Unit: Halda-94
Initial Canopy Storage Percent: 71
Initial Surface Storage Percent: 57
Initial Soil Storage Percent: 40
Initial Gw1 Storage Percent: 0
Initial Gw2 Storage Percent: 0

Transform: SCS
Lag: 105.000000

Baseflow: None
End:

Subbasin: 95

Description: 71
Canvas X: 683089.910
Canvas Y: 530172.300
Label X: 16
Label Y: 0
Area: 27.297
Downstream: 32

LossRate: Soil Moisture Account
Percent Impervious Area: 0.0
Soil Moisture Unit: Halda-95
Initial Canopy Storage Percent: 68
Initial Surface Storage Percent: 50
Initial Soil Storage Percent: 35

Initial Gw1 Storage Percent: 0
Initial Gw2 Storage Percent: 0

Transform: SCS
Lag: 191.477000

Baseflow: None
End:

Subbasin: 96

Description: 73
Canvas X: 674814.910
Canvas Y: 527322.300
Label X: 16
Label Y: 0
Area: 14.783
Downstream: 2

LossRate: Soil Moisture Account
Percent Impervious Area: 0.0
Soil Moisture Unit: Halda-96
Initial Canopy Storage Percent: 70
Initial Surface Storage Percent: 54
Initial Soil Storage Percent: 40
Initial Gw1 Storage Percent: 0
Initial Gw2 Storage Percent: 0

Transform: SCS
Lag: 105.000000

Baseflow: None
End:

Subbasin: 97

Description: 77
Canvas X: 678289.910
Canvas Y: 523822.300
Label X: 16
Label Y: 0
Area: 4.163
Downstream: 3

LossRate: Soil Moisture Account
Percent Impervious Area: 0.0
Soil Moisture Unit: Halda-97
Initial Canopy Storage Percent: 65
Initial Surface Storage Percent: 54
Initial Soil Storage Percent: 37
Initial Gw1 Storage Percent: 0
Initial Gw2 Storage Percent: 0

Transform: SCS
Lag: 105.000000

Baseflow: None
End:

Subbasin: 98

Description: 72
Canvas X: 687139.910
Canvas Y: 525572.300
Label X: 16
Label Y: 0
Area: 29.173
Downstream: 32

LossRate: Soil Moisture Account
Percent Impervious Area: 0.0
Soil Moisture Unit: Halda-98
Initial Canopy Storage Percent: 66
Initial Surface Storage Percent: 53
Initial Soil Storage Percent: 41
Initial Gw1 Storage Percent: 0
Initial Gw2 Storage Percent: 0

Transform: SCS
Lag: 297.627000

Baseflow: None
End:

Subbasin: 99

Description: 75
Canvas X: 679889.910
Canvas Y: 525322.300
Label X: 16
Label Y: 0
Area: 10.3
Downstream: 31

LossRate: Soil Moisture Account
Percent Impervious Area: 0.0
Soil Moisture Unit: Halda-99
Initial Canopy Storage Percent: 65
Initial Surface Storage Percent: 50
Initial Soil Storage Percent: 42
Initial Gw1 Storage Percent: 0
Initial Gw2 Storage Percent: 0

Transform: SCS
Lag: 105.000000

Baseflow: None
End:

Subbasin: 100

Description: 76
Canvas X: 672239.910
Canvas Y: 523547.300
Label X: 16
Label Y: 0
Area: 3.72
Downstream: 4

LossRate: Soil Moisture Account
Percent Impervious Area: 0.0
Soil Moisture Unit: Halda-100
Initial Canopy Storage Percent: 67
Initial Surface Storage Percent: 52
Initial Soil Storage Percent: 42
Initial Gw1 Storage Percent: 0
Initial Gw2 Storage Percent: 0

Transform: SCS
Lag: 105.000000

Baseflow: None
End:

Subbasin: 101

Description: 79
Canvas X: 675264.910
Canvas Y: 524222.300
Label X: 16
Label Y: 0
Area: 13.12
Downstream: 6

LossRate: Soil Moisture Account
Percent Impervious Area: 0.0
Soil Moisture Unit: Halda-101
Initial Canopy Storage Percent: 71
Initial Surface Storage Percent: 56
Initial Soil Storage Percent: 45
Initial Gw1 Storage Percent: 0
Initial Gw2 Storage Percent: 0

Transform: SCS
Lag: 105.000000

Baseflow: None
End:

Subbasin: 102

Description: 74
Canvas X: 680964.910
Canvas Y: 527447.300
Label X: 16
Label Y: 0
Area: 26.068
Downstream: 30

LossRate: Soil Moisture Account
Percent Impervious Area: 0.0
Soil Moisture Unit: Halda-102
Initial Canopy Storage Percent: 68
Initial Surface Storage Percent: 56
Initial Soil Storage Percent: 40
Initial Gw1 Storage Percent: 0
Initial Gw2 Storage Percent: 0

Transform: SCS
Lag: 167.463000

Baseflow: None
End:

Subbasin: 103

Description: 78
Canvas X: 673939.910
Canvas Y: 521722.300
Label X: 16
Label Y: 0
Area: 2.843
Downstream: 5

LossRate: Soil Moisture Account
Percent Impervious Area: 0.0
Soil Moisture Unit: Halda-103
Initial Canopy Storage Percent: 69
Initial Surface Storage Percent: 56
Initial Soil Storage Percent: 41
Initial Gw1 Storage Percent: 0
Initial Gw2 Storage Percent: 0

Transform: SCS
Lag: 105.000000

Baseflow: None
End:

Subbasin: 104

Description: 80
Canvas X: 672589.910

Canvas Y: 521422.300
Label X: 16
Label Y: 0
Area: 2.43
Downstream: 33

LossRate: Soil Moisture Account
Percent Impervious Area: 0.0
Soil Moisture Unit: Halda-104
Initial Canopy Storage Percent: 67
Initial Surface Storage Percent: 54
Initial Soil Storage Percent: 35
Initial Gw1 Storage Percent: 0
Initial Gw2 Storage Percent: 0

Transform: SCS
Lag: 105.000000

Baseflow: None
End:

Subbasin: 105
Description: 81
Canvas X: 675639.910
Canvas Y: 520272.300
Label X: 16
Label Y: 0
Area: 3.205
Downstream: 7

LossRate: Soil Moisture Account
Percent Impervious Area: 0.0
Soil Moisture Unit: Halda-105
Initial Canopy Storage Percent: 72
Initial Surface Storage Percent: 54
Initial Soil Storage Percent: 43
Initial Gw1 Storage Percent: 0
Initial Gw2 Storage Percent: 0

Transform: SCS
Lag: 105.000000

Baseflow: None
End:

Subbasin: 106
Description: 85
Canvas X: 687439.910
Canvas Y: 522197.300
Label X: 16
Label Y: 0

Area: 23.023
Downstream: 36

LossRate: Soil Moisture Account
Percent Impervious Area: 0.0
Soil Moisture Unit: Halda-106
Initial Canopy Storage Percent: 67
Initial Surface Storage Percent: 51
Initial Soil Storage Percent: 44
Initial Gw1 Storage Percent: 0
Initial Gw2 Storage Percent: 0

Transform: SCS
Lag: 158.735000

Baseflow: None
End:

Subbasin: 107
Description: 83
Canvas X: 672589.910
Canvas Y: 519472.300
Label X: 16
Label Y: 0
Area: 1.483
Downstream: 34

LossRate: Soil Moisture Account
Percent Impervious Area: 0.0
Soil Moisture Unit: Halda-107
Initial Canopy Storage Percent: 66
Initial Surface Storage Percent: 52
Initial Soil Storage Percent: 45
Initial Gw1 Storage Percent: 0
Initial Gw2 Storage Percent: 0

Transform: SCS
Lag: 105.000000

Baseflow: None
End:

Subbasin: 108
Description: 86
Canvas X: 691814.910
Canvas Y: 520247.300
Label X: 16
Label Y: 0
Area: 5.255
Downstream: 10

LossRate: Soil Moisture Account
Percent Impervious Area: 0.0
Soil Moisture Unit: Halda-108
Initial Canopy Storage Percent: 68
Initial Surface Storage Percent: 54
Initial Soil Storage Percent: 41
Initial Gw1 Storage Percent: 0
Initial Gw2 Storage Percent: 0

Transform: SCS
Lag: 105.000000

Baseflow: None
End:

Subbasin: 109

Description: 84
Canvas X: 677539.910
Canvas Y: 521172.300
Label X: 16
Label Y: 0
Area: 23.207
Downstream: 37

LossRate: Soil Moisture Account
Percent Impervious Area: 0.0
Soil Moisture Unit: Halda-109
Initial Canopy Storage Percent: 65
Initial Surface Storage Percent: 55
Initial Soil Storage Percent: 35
Initial Gw1 Storage Percent: 0
Initial Gw2 Storage Percent: 0

Transform: SCS
Lag: 207.340000

Baseflow: None
End:

Subbasin: 110

Description: 89
Canvas X: 684064.910
Canvas Y: 519497.300
Label X: 16
Label Y: 0
Area: 12.828
Downstream: 39

LossRate: Soil Moisture Account
Percent Impervious Area: 0.0
Soil Moisture Unit: Halda-110

Initial Canopy Storage Percent: 67
Initial Surface Storage Percent: 57
Initial Soil Storage Percent: 42
Initial Gw1 Storage Percent: 0
Initial Gw2 Storage Percent: 0

Transform: SCS
Lag: 105.000000

Baseflow: None
End:

Subbasin: 111

Description: 87
Canvas X: 693439.910
Canvas Y: 518822.300
Label X: 16
Label Y: 0
Area: 7.723
Downstream: 12

LossRate: Soil Moisture Account
Percent Impervious Area: 0.0
Soil Moisture Unit: Halda-111
Initial Canopy Storage Percent: 68
Initial Surface Storage Percent: 56
Initial Soil Storage Percent: 40
Initial Gw1 Storage Percent: 0
Initial Gw2 Storage Percent: 0

Transform: SCS
Lag: 105.000000

Baseflow: None
End:

Subbasin: 112

Description: 82
Canvas X: 674214.910
Canvas Y: 518622.300
Label X: 16
Label Y: 0
Area: 15.952
Downstream: 35

LossRate: Soil Moisture Account
Percent Impervious Area: 0.0
Soil Moisture Unit: Halda-112
Initial Canopy Storage Percent: 64
Initial Surface Storage Percent: 53
Initial Soil Storage Percent: 42

Initial Gw1 Storage Percent: 0
Initial Gw2 Storage Percent: 0

Transform: SCS
Lag: 105.000000

Baseflow: None
End:

Subbasin: 113

Description: 88
Canvas X: 677339.910
Canvas Y: 517597.300
Label X: 16
Label Y: 0
Area: 6.9
Downstream: 8

LossRate: Soil Moisture Account
Percent Impervious Area: 0.0
Soil Moisture Unit: Halda-113
Initial Canopy Storage Percent: 66
Initial Surface Storage Percent: 58
Initial Soil Storage Percent: 41
Initial Gw1 Storage Percent: 0
Initial Gw2 Storage Percent: 0

Transform: SCS
Lag: 119.314000

Baseflow: None
End:

Subbasin: 114

Description: 96
Canvas X: 677839.910
Canvas Y: 516047.300
Label X: 16
Label Y: 0
Area: 11.763
Downstream: 14

LossRate: Soil Moisture Account
Percent Impervious Area: 0.0
Soil Moisture Unit: Halda-114
Initial Canopy Storage Percent: 67
Initial Surface Storage Percent: 53
Initial Soil Storage Percent: 44
Initial Gw1 Storage Percent: 0
Initial Gw2 Storage Percent: 0

Transform: SCS
Lag: 105.000000

Baseflow: None
End:

Subbasin: 115

Description: 93
Canvas X: 683364.910
Canvas Y: 516197.300
Label X: 16
Label Y: 0
Area: 8.725
Downstream: 9

LossRate: Soil Moisture Account
Percent Impervious Area: 0.0
Soil Moisture Unit: Halda-115
Initial Canopy Storage Percent: 68
Initial Surface Storage Percent: 55
Initial Soil Storage Percent: 42
Initial Gw1 Storage Percent: 0
Initial Gw2 Storage Percent: 0

Transform: SCS
Lag: 105.000000

Baseflow: None
End:

Subbasin: 116

Description: 97
Canvas X: 681489.910
Canvas Y: 517347.300
Label X: 16
Label Y: 0
Area: 8.315
Downstream: 15

LossRate: Soil Moisture Account
Percent Impervious Area: 0.0
Soil Moisture Unit: Halda-116
Initial Canopy Storage Percent: 71
Initial Surface Storage Percent: 53
Initial Soil Storage Percent: 42
Initial Gw1 Storage Percent: 0
Initial Gw2 Storage Percent: 0

Transform: SCS
Lag: 105.000000

Baseflow: None
End:

Subbasin: 117

Description: 95
Canvas X: 674114.910
Canvas Y: 514797.300
Label X: 16
Label Y: 0
Area: 13.128
Downstream: 38

LossRate: Soil Moisture Account
Percent Impervious Area: 0.0
Soil Moisture Unit: Halda-117
Initial Canopy Storage Percent: 72
Initial Surface Storage Percent: 56
Initial Soil Storage Percent: 43
Initial Gw1 Storage Percent: 0
Initial Gw2 Storage Percent: 0

Transform: SCS
Lag: 112.506000

Baseflow: None
End:

Subbasin: 118

Description: 98
Canvas X: 690414.910
Canvas Y: 517572.300
Label X: 16
Label Y: 0
Area: 60.662
Downstream: 40

LossRate: Soil Moisture Account
Percent Impervious Area: 0.0
Soil Moisture Unit: Halda-118
Initial Canopy Storage Percent: 64
Initial Surface Storage Percent: 51
Initial Soil Storage Percent: 40
Initial Gw1 Storage Percent: 0
Initial Gw2 Storage Percent: 0

Transform: SCS
Lag: 162.451000

Baseflow: None
End:

Subbasin: 119

Description: 104
Canvas X: 685464.910
Canvas Y: 512197.300
Label X: 16
Label Y: 0
Area: 7.29
Downstream: 42

LossRate: Soil Moisture Account
Percent Impervious Area: 0.0
Soil Moisture Unit: Halda-119
Initial Canopy Storage Percent: 69
Initial Surface Storage Percent: 55
Initial Soil Storage Percent: 44
Initial Gw1 Storage Percent: 0
Initial Gw2 Storage Percent: 0

Transform: SCS
Lag: 105.000000

Baseflow: None
End:

Subbasin: 120

Description: 101
Canvas X: 673164.910
Canvas Y: 511572.300
Label X: 16
Label Y: 0
Area: 7.405
Downstream: 17

LossRate: Soil Moisture Account
Percent Impervious Area: 0.0
Soil Moisture Unit: Halda-120
Initial Canopy Storage Percent: 67
Initial Surface Storage Percent: 51
Initial Soil Storage Percent: 41
Initial Gw1 Storage Percent: 0
Initial Gw2 Storage Percent: 0

Transform: SCS
Lag: 2831.970000

Baseflow: None
End:

Subbasin: 121

Description: 99
Canvas X: 670739.910

Canvas Y: 512647.300
Label X: 16
Label Y: 0
Area: 18.98
Downstream: 41

LossRate: Soil Moisture Account
Percent Impervious Area: 0.0
Soil Moisture Unit: Halda-121
Initial Canopy Storage Percent: 71
Initial Surface Storage Percent: 50
Initial Soil Storage Percent: 34
Initial Gw1 Storage Percent: 0
Initial Gw2 Storage Percent: 0

Transform: SCS
Lag: 3471.230000

Baseflow: None
End:

Subbasin: 122
Description: 102
Canvas X: 682589.910
Canvas Y: 510897.300
Label X: 16
Label Y: 0
Area: 3.717
Downstream: 16

LossRate: Soil Moisture Account
Percent Impervious Area: 0.0
Soil Moisture Unit: Halda-122
Initial Canopy Storage Percent: 68
Initial Surface Storage Percent: 52
Initial Soil Storage Percent: 34
Initial Gw1 Storage Percent: 0
Initial Gw2 Storage Percent: 0

Transform: SCS
Lag: 112.548000

Baseflow: None
End:

Subbasin: 123
Description: 103
Canvas X: 679639.910
Canvas Y: 513322.300
Label X: 16
Label Y: 0

Area: 31.09
Downstream: 19

LossRate: Soil Moisture Account
Percent Impervious Area: 0.0
Soil Moisture Unit: Halda-123
Initial Canopy Storage Percent: 72
Initial Surface Storage Percent: 51
Initial Soil Storage Percent: 36
Initial Gw1 Storage Percent: 0
Initial Gw2 Storage Percent: 0

Transform: SCS
Lag: 105.286000

Baseflow: None
End:

Subbasin: 124
Description: 105
Canvas X: 675214.910
Canvas Y: 508897.300
Label X: 16
Label Y: 0
Area: 3.708
Downstream: 20

LossRate: Soil Moisture Account
Percent Impervious Area: 0.0
Soil Moisture Unit: Halda-124
Initial Canopy Storage Percent: 71
Initial Surface Storage Percent: 54
Initial Soil Storage Percent: 45
Initial Gw1 Storage Percent: 0
Initial Gw2 Storage Percent: 0

Transform: SCS
Lag: 1692.200000

Baseflow: None
End:

Subbasin: 125
Description: 108
Canvas X: 677564.910
Canvas Y: 509297.300
Label X: 16
Label Y: 0
Area: 23.425
Downstream: 22

LossRate: Soil Moisture Account
Percent Impervious Area: 0.0
Soil Moisture Unit: Halda-125
Initial Canopy Storage Percent: 68
Initial Surface Storage Percent: 54
Initial Soil Storage Percent: 42
Initial Gw1 Storage Percent: 0
Initial Gw2 Storage Percent: 0

Transform: SCS
Lag: 197.173000

Baseflow: None
End:

Subbasin: 126
Description: 107
Canvas X: 672139.910
Canvas Y: 508347.300
Label X: 16
Label Y: 0
Area: 6.71
Downstream: 43

LossRate: Soil Moisture Account
Percent Impervious Area: 0.0
Soil Moisture Unit: Halda-126
Initial Canopy Storage Percent: 67
Initial Surface Storage Percent: 53
Initial Soil Storage Percent: 36
Initial Gw1 Storage Percent: 0
Initial Gw2 Storage Percent: 0

Transform: SCS
Lag: 2315.880000

Baseflow: None
End:

Subbasin: 127
Description: 110
Canvas X: 677489.910
Canvas Y: 505447.300
Label X: 16
Label Y: 0
Area: 2.015
Downstream: 46

LossRate: Soil Moisture Account
Percent Impervious Area: 0.0
Soil Moisture Unit: Halda-127

Initial Canopy Storage Percent: 66
Initial Surface Storage Percent: 54
Initial Soil Storage Percent: 40
Initial Gw1 Storage Percent: 0
Initial Gw2 Storage Percent: 0

Transform: SCS
Lag: 105.000000

Baseflow: None
End:

Subbasin: 128

Description: 113
Canvas X: 681814.910
Canvas Y: 505497.300
Label X: 16
Label Y: 0
Area: 5.518
Downstream: 23

LossRate: Soil Moisture Account
Percent Impervious Area: 0.0
Soil Moisture Unit: Halda-128
Initial Canopy Storage Percent: 69
Initial Surface Storage Percent: 54
Initial Soil Storage Percent: 42
Initial Gw1 Storage Percent: 0
Initial Gw2 Storage Percent: 0

Transform: SCS
Lag: 105.000000

Baseflow: None
End:

Subbasin: 129

Description: 109
Canvas X: 677514.910
Canvas Y: 506547.300
Label X: 16
Label Y: 0
Area: 26.538
Downstream: 45

LossRate: Soil Moisture Account
Percent Impervious Area: 0.0
Soil Moisture Unit: Halda-129
Initial Canopy Storage Percent: 66
Initial Surface Storage Percent: 54
Initial Soil Storage Percent: 41

Initial Gw1 Storage Percent: 0
Initial Gw2 Storage Percent: 0

Transform: SCS
Lag: 149.231000

Baseflow: None
End:

Subbasin: 130

Description: 111
Canvas X: 676089.910
Canvas Y: 504922.300
Label X: 16
Label Y: 0
Area: 1.635
Downstream: 44

LossRate: Soil Moisture Account
Percent Impervious Area: 0.0
Soil Moisture Unit: Halda-130
Initial Canopy Storage Percent: 66
Initial Surface Storage Percent: 52
Initial Soil Storage Percent: 42
Initial Gw1 Storage Percent: 0
Initial Gw2 Storage Percent: 0

Transform: SCS
Lag: 1039.440000

Baseflow: None
End:

Subbasin: 131

Description: 117
Canvas X: 683814.910
Canvas Y: 505697.300
Label X: 16
Label Y: 0
Area: 4.09
Downstream: 25

LossRate: Soil Moisture Account
Percent Impervious Area: 0.0
Soil Moisture Unit: Halda-131
Initial Canopy Storage Percent: 68
Initial Surface Storage Percent: 50
Initial Soil Storage Percent: 38
Initial Gw1 Storage Percent: 0
Initial Gw2 Storage Percent: 0

Transform: SCS
Lag: 116.288000

Baseflow: None
End:

Subbasin: 132

Description: 114
Canvas X: 678664.910
Canvas Y: 504047.300
Label X: 16
Label Y: 0
Area: 11.717
Downstream: 26

LossRate: Soil Moisture Account
Percent Impervious Area: 0.0
Soil Moisture Unit: Halda-132
Initial Canopy Storage Percent: 73
Initial Surface Storage Percent: 58
Initial Soil Storage Percent: 42
Initial Gw1 Storage Percent: 0
Initial Gw2 Storage Percent: 0

Transform: SCS
Lag: 105.000000

Baseflow: None
End:

Subbasin: 133

Description: 116
Canvas X: 680839.910
Canvas Y: 502522.300
Label X: 16
Label Y: 0
Area: 16.035
Downstream: 24

LossRate: Soil Moisture Account
Percent Impervious Area: 0.0
Soil Moisture Unit: Halda-133
Initial Canopy Storage Percent: 74
Initial Surface Storage Percent: 56
Initial Soil Storage Percent: 42
Initial Gw1 Storage Percent: 0
Initial Gw2 Storage Percent: 0

Transform: SCS
Lag: 105.000000

Baseflow: None
End:

Reach: 47

Description: 104
Canvas X: 683639.910
Canvas Y: 510547.300
From Canvas X: 685439.910
From Canvas Y: 513347.300
Label X: 16
Label Y: 0
Downstream: 42

Route: Muskingum
Muskingum K: 1.2478
Muskingum X: 0.2
Muskingum Steps: 1

End:

Reach: 48

Description: 96
Canvas X: 679989.910
Canvas Y: 514397.300
From Canvas X: 677489.910
From Canvas Y: 514947.300
Label X: 16
Label Y: 0
Downstream: 14

Route: Muskingum
Muskingum K: 0.9034
Muskingum X: 0.2
Muskingum Steps: 1

End:

Reach: 49

Description: 33
Canvas X: 681139.910
Canvas Y: 513347.300
From Canvas X: 681789.910
From Canvas Y: 515147.300
Label X: 16
Label Y: 0
Downstream: 15

Route: Muskingum
Muskingum K: 0.7089
Muskingum X: 0.2
Muskingum Steps: 1

End:

Reach: 50

Description: 34

Canvas X: 681089.910

Canvas Y: 511147.300

From Canvas X: 683639.910

From Canvas Y: 510547.300

Label X: 16

Label Y: 0

Downstream: 16

Route: Muskingum

Muskingum K: 0.8004

Muskingum X: 0.2

Muskingum Steps: 1

End:

Reach: 51

Description: 36

Canvas X: 675389.910

Canvas Y: 511547.300

From Canvas X: 673239.910

From Canvas Y: 512797.300

Label X: 16

Label Y: 0

Downstream: 17

Route: Muskingum

Muskingum K: 0.8244

Muskingum X: 0.2

Muskingum Steps: 1

End:

Reach: 52

Description: 39

Canvas X: 680889.910

Canvas Y: 510847.300

From Canvas X: 681089.910

From Canvas Y: 511147.300

Label X: 16

Label Y: 0

Downstream: 19

Route: Lag

Lag: 8.5355

End:

Reach: 53

Description: 105

Canvas X: 674689.910

Canvas Y: 509847.300

From Canvas X: 673889.910

From Canvas Y: 508197.300
Label X: 16
Label Y: 0
Downstream: 20

Route: Muskingum
Muskingum K: 0.6127
Muskingum X: 0.2
Muskingum Steps: 1

End:

Reach: 54

Description: 108
Canvas X: 683289.910
Canvas Y: 506647.300
From Canvas X: 681789.910
From Canvas Y: 508847.300
Label X: 16
Label Y: 0
Downstream: 22

Route: Muskingum
Muskingum K: 1.2559
Muskingum X: 0.2
Muskingum Steps: 2

End:

Reach: 55

Description: 43
Canvas X: 684339.910
Canvas Y: 504947.300
From Canvas X: 682339.910
From Canvas Y: 505797.300
Label X: 16
Label Y: 0
Downstream: 23

Route: Muskingum
Muskingum K: 0.6778
Muskingum X: 0.2
Muskingum Steps: 1

End:

Reach: 56

Description: 48
Canvas X: 684339.910
Canvas Y: 504147.300
From Canvas X: 682689.910
From Canvas Y: 503747.300
Label X: 16
Label Y: 0

Downstream: 24

Route: Muskingum
Muskingum K: 0.5944
Muskingum X: 0.2
Muskingum Steps: 1

End:

Reach: 57

Description: 110
Canvas X: 678689.910
Canvas Y: 505247.300
From Canvas X: 676789.910
From Canvas Y: 505097.300
Label X: 16
Label Y: 0
Downstream: 46

Route: Muskingum
Muskingum K: 0.7793
Muskingum X: 0.2
Muskingum Steps: 1

End:

Reach: 58

Description: 114
Canvas X: 680989.910
Canvas Y: 504447.300
From Canvas X: 678689.910
From Canvas Y: 505247.300
Label X: 16
Label Y: 0
Downstream: 26

Route: Muskingum
Muskingum K: 0.798
Muskingum X: 0.2
Muskingum Steps: 1

End:

Reach: 59

Description: 5
Canvas X: 676739.910
Canvas Y: 523247.300
From Canvas X: 676439.910
From Canvas Y: 525497.300
Label X: 16
Label Y: 0
Downstream: 3

Route: Muskingum

Muskingum K: 0.7415
Muskingum X: 0.2
Muskingum Steps: 1
End:

Reach: 60
Description: 19
Canvas X: 674989.910
Canvas Y: 522497.300
From Canvas X: 673539.910
From Canvas Y: 523297.300
Label X: 16
Label Y: 0
Downstream: 5

Route: Muskingum
Muskingum K: 0.5585
Muskingum X: 0.2
Muskingum Steps: 1
End:

Reach: 61
Description: 22
Canvas X: 676739.910
Canvas Y: 521847.300
From Canvas X: 674989.910
From Canvas Y: 522497.300
Label X: 16
Label Y: 0
Downstream: 6

Route: Muskingum
Muskingum K: 0.6083
Muskingum X: 0.2
Muskingum Steps: 1
End:

Reach: 62
Description: 24
Canvas X: 677089.910
Canvas Y: 520797.300
From Canvas X: 676739.910
From Canvas Y: 521847.300
Label X: 16
Label Y: 0
Downstream: 7

Route: Lag
Lag: 23.2496
End:

Reach: 63

Description: 26

Canvas X: 681789.910

Canvas Y: 515147.300

From Canvas X: 680489.910

From Canvas Y: 517397.300

Label X: 16

Label Y: 0

Downstream: 9

Route: Muskingum

Muskingum K: 1.1276

Muskingum X: 0.2

Muskingum Steps: 1

End:

Reach: 64

Description: 29

Canvas X: 690989.910

Canvas Y: 516297.300

From Canvas X: 690739.910

From Canvas Y: 518547.300

Label X: 16

Label Y: 0

Downstream: 11

Route: Muskingum

Muskingum K: 0.8617

Muskingum X: 0.2

Muskingum Steps: 1

End:

Reach: 65

Description: 28

Canvas X: 690989.910

Canvas Y: 516297.300

From Canvas X: 692439.910

From Canvas Y: 517497.300

Label X: 16

Label Y: 0

Downstream: 11

Route: Muskingum

Muskingum K: 0.5768

Muskingum X: 0.2

Muskingum Steps: 1

End:

Reach: 66

Description: 31

Canvas X: 687639.910

Canvas Y: 515147.300
From Canvas X: 690989.910
From Canvas Y: 516297.300
Label X: 16
Label Y: 0
Downstream: 13

Route: Muskingum
Muskingum K: 1.1361
Muskingum X: 0.2
Muskingum Steps: 1
End:

Reach: 67
Description: 32
Canvas X: 681139.910
Canvas Y: 513347.300
From Canvas X: 679989.910
From Canvas Y: 514397.300
Label X: 16
Label Y: 0
Downstream: 15

Route: Muskingum
Muskingum K: 0.695
Muskingum X: 0.2
Muskingum Steps: 1
End:

Reach: 68
Description: 35
Canvas X: 681089.910
Canvas Y: 511147.300
From Canvas X: 681139.910
From Canvas Y: 513347.300
Label X: 16
Label Y: 0
Downstream: 16

Route: Muskingum
Muskingum K: 0.8924
Muskingum X: 0.2
Muskingum Steps: 1
End:

Reach: 69
Description: 100
Canvas X: 678089.910
Canvas Y: 511647.300
From Canvas X: 675389.910
From Canvas Y: 511547.300

Label X: 16
Label Y: 0
Downstream: 18

Route: Muskingum
Muskingum K: 0.9125
Muskingum X: 0.2
Muskingum Steps: 1
End:

Reach: 70
Description: 37
Canvas X: 680889.910
Canvas Y: 510847.300
From Canvas X: 678089.910
From Canvas Y: 511647.300
Label X: 16
Label Y: 0
Downstream: 19

Route: Muskingum
Muskingum K: 1.0351
Muskingum X: 0.2
Muskingum Steps: 1
End:

Reach: 71
Description: 38
Canvas X: 675389.910
Canvas Y: 511547.300
From Canvas X: 674689.910
From Canvas Y: 509847.300
Label X: 16
Label Y: 0
Downstream: 17

Route: Muskingum
Muskingum K: 0.6428
Muskingum X: 0.2
Muskingum Steps: 1
End:

Reach: 72
Description: 106
Canvas X: 681789.910
Canvas Y: 508847.300
From Canvas X: 680889.910
From Canvas Y: 510847.300
Label X: 16
Label Y: 0
Downstream: 21

Route: Muskingum
Muskingum K: 0.9077
Muskingum X: 0.2
Muskingum Steps: 1
End:

Reach: 73
Description: 41
Canvas X: 684339.910
Canvas Y: 504947.300
From Canvas X: 683289.910
From Canvas Y: 506647.300
Label X: 16
Label Y: 0
Downstream: 23

Route: Muskingum
Muskingum K: 1.1391
Muskingum X: 0.2
Muskingum Steps: 1
End:

Reach: 74
Description: 46
Canvas X: 684339.910
Canvas Y: 504147.300
From Canvas X: 684339.910
From Canvas Y: 504947.300
Label X: 16
Label Y: 0
Downstream: 24

Route: Lag
Lag: 14.0237
End:

Reach: 75
Description: 117
Canvas X: 684389.910
Canvas Y: 503872.300
From Canvas X: 684339.910
From Canvas Y: 504147.300
Label X: 16
Label Y: 0
Downstream: 25

Route: Lag
Lag: 5.3452
End:

Reach: 76

Description: 44
Canvas X: 682689.910
Canvas Y: 503747.300
From Canvas X: 680989.910
From Canvas Y: 504447.300
Label X: 16
Label Y: 0
Downstream: 27

Route: Muskingum
Muskingum K: 0.6117
Muskingum X: 0.2
Muskingum Steps: 1

End:

Reach: 77

Description: 7
Canvas X: 683089.910
Canvas Y: 527247.300
From Canvas X: 685439.910
From Canvas Y: 528047.300
Label X: 16
Label Y: 0
Downstream: 1

Route: Muskingum
Muskingum K: 0.843
Muskingum X: 0.2
Muskingum Steps: 1

End:

Reach: 78

Description: 75
Canvas X: 679039.910
Canvas Y: 523797.300
From Canvas X: 681339.910
From Canvas Y: 524447.300
Label X: 16
Label Y: 0
Downstream: 31

Route: Muskingum
Muskingum K: 0.8952
Muskingum X: 0.2
Muskingum Steps: 1

End:

Reach: 79

Description: 74
Canvas X: 681339.910
Canvas Y: 524447.300

From Canvas X: 682439.910
From Canvas Y: 525997.300
Label X: 16
Label Y: 0
Downstream: 30

Route: Muskingum
Muskingum K: 0.925
Muskingum X: 0.2
Muskingum Steps: 1

End:

Reach: 80

Description: 73
Canvas X: 676439.910
Canvas Y: 525497.300
From Canvas X: 675539.910
From Canvas Y: 527347.300
Label X: 16
Label Y: 0
Downstream: 2

Route: Muskingum
Muskingum K: 0.6337
Muskingum X: 0.2
Muskingum Steps: 1

End:

Reach: 81

Description: 18
Canvas X: 676739.910
Canvas Y: 523247.300
From Canvas X: 679039.910
From Canvas Y: 523797.300
Label X: 16
Label Y: 0
Downstream: 3

Route: Muskingum
Muskingum K: 0.8593
Muskingum X: 0.2
Muskingum Steps: 1

End:

Reach: 82

Description: 11
Canvas X: 682439.910
Canvas Y: 525997.300
From Canvas X: 683089.910
From Canvas Y: 527247.300
Label X: 16

Label Y: 0
Downstream: 32

Route: Lag
Lag: 26.9873
End:

Reach: 83
Description: 82
Canvas X: 675389.910
Canvas Y: 519947.300
From Canvas X: 673239.910
From Canvas Y: 519697.300
Label X: 16
Label Y: 0
Downstream: 35

Route: Muskingum
Muskingum K: 0.6998
Muskingum X: 0.2
Muskingum Steps: 1
End:

Reach: 84
Description: 20
Canvas X: 676739.910
Canvas Y: 521847.300
From Canvas X: 676739.910
From Canvas Y: 523247.300
Label X: 16
Label Y: 0
Downstream: 6

Route: Lag
Lag: 26.7851
End:

Reach: 85
Description: 23
Canvas X: 674989.910
Canvas Y: 522497.300
From Canvas X: 673639.910
From Canvas Y: 521697.300
Label X: 16
Label Y: 0
Downstream: 5

Route: Muskingum
Muskingum K: 0.503
Muskingum X: 0.2
Muskingum Steps: 1

End:

Reach: 86

Description: 25

Canvas X: 677089.910

Canvas Y: 520797.300

From Canvas X: 675389.910

From Canvas Y: 519947.300

Label X: 16

Label Y: 0

Downstream: 7

Route: Muskingum

Muskingum K: 0.5944

Muskingum X: 0.2

Muskingum Steps: 1

End:

Reach: 87

Description: 84

Canvas X: 678739.910

Canvas Y: 519347.300

From Canvas X: 677089.910

From Canvas Y: 520797.300

Label X: 16

Label Y: 0

Downstream: 37

Route: Muskingum

Muskingum K: 0.7099

Muskingum X: 0.2

Muskingum Steps: 1

End:

Reach: 88

Description: 89

Canvas X: 683139.910

Canvas Y: 517097.300

From Canvas X: 684639.910

From Canvas Y: 518597.300

Label X: 16

Label Y: 0

Downstream: 39

Route: Muskingum

Muskingum K: 0.7276

Muskingum X: 0.2

Muskingum Steps: 1

End:

Reach: 89

Description: 88
Canvas X: 680489.910
Canvas Y: 517397.300
From Canvas X: 678739.910
From Canvas Y: 519347.300
Label X: 16
Label Y: 0
Downstream: 8

Route: Muskingum
Muskingum K: 0.9829
Muskingum X: 0.2
Muskingum Steps: 1

End:

Reach: 90

Description: 27
Canvas X: 681789.910
Canvas Y: 515147.300
From Canvas X: 683139.910
From Canvas Y: 517097.300
Label X: 16
Label Y: 0
Downstream: 9

Route: Muskingum
Muskingum K: 0.8014
Muskingum X: 0.2
Muskingum Steps: 1

End:

Reach: 91

Description: 98
Canvas X: 685439.910
Canvas Y: 513347.300
From Canvas X: 687639.910
From Canvas Y: 515147.300
Label X: 16
Label Y: 0
Downstream: 40

Route: Muskingum
Muskingum K: 0.8182
Muskingum X: 0.2
Muskingum Steps: 1

End:

Junction: 1

Canvas X: 683089.910
Canvas Y: 527247.300
Label X: 16

Label Y: 0
Downstream: 82
End:

Junction: 2
Canvas X: 676439.910
Canvas Y: 525497.300
Label X: 16
Label Y: 0
Downstream: 59
End:

Junction: 3
Canvas X: 676739.910
Canvas Y: 523247.300
Label X: 16
Label Y: 0
Downstream: 84
End:

Junction: 4
Canvas X: 673539.910
Canvas Y: 523297.300
Label X: 16
Label Y: 0
Downstream: 60
End:

Junction: 5
Canvas X: 674989.910
Canvas Y: 522497.300
Label X: 16
Label Y: 0
Downstream: 61
End:

Junction: 6
Canvas X: 676739.910
Canvas Y: 521847.300
Label X: 16
Label Y: 0
Downstream: 62
End:

Junction: 7
Canvas X: 677089.910
Canvas Y: 520797.300
Label X: 16
Label Y: 0
Downstream: 87
End:

Junction: 8

Canvas X: 680489.910

Canvas Y: 517397.300

Label X: 16

Label Y: 0

Downstream: 63

End:

Junction: 9

Canvas X: 681789.910

Canvas Y: 515147.300

Label X: 16

Label Y: 0

Downstream: 49

End:

Junction: 10

Canvas X: 690739.910

Canvas Y: 518547.300

Label X: 16

Label Y: 0

Downstream: 64

End:

Junction: 11

Canvas X: 690989.910

Canvas Y: 516297.300

Label X: 16

Label Y: 0

Downstream: 66

End:

Junction: 12

Canvas X: 692439.910

Canvas Y: 517497.300

Label X: 16

Label Y: 0

Downstream: 65

End:

Junction: 13

Canvas X: 687639.910

Canvas Y: 515147.300

Label X: 16

Label Y: 0

Downstream: 91

End:

Junction: 14

Canvas X: 679989.910

Canvas Y: 514397.300
Label X: 16
Label Y: 0
Downstream: 67
End:

Junction: 15
Canvas X: 681139.910
Canvas Y: 513347.300
Label X: 16
Label Y: 0
Downstream: 68
End:

Junction: 16
Canvas X: 681089.910
Canvas Y: 511147.300
Label X: 16
Label Y: 0
Downstream: 52
End:

Junction: 17
Canvas X: 675389.910
Canvas Y: 511547.300
Label X: 16
Label Y: 0
Downstream: 69
End:

Junction: 18
Canvas X: 678089.910
Canvas Y: 511647.300
Label X: 16
Label Y: 0
Downstream: 70
End:

Junction: 19
Canvas X: 680889.910
Canvas Y: 510847.300
Label X: 16
Label Y: 0
Downstream: 72
End:

Junction: 20
Canvas X: 674689.910
Canvas Y: 509847.300
Label X: 16
Label Y: 0

Downstream: 71
End:

Junction: 21
Canvas X: 681789.910
Canvas Y: 508847.300
Label X: 16
Label Y: 0
Downstream: 54
End:

Junction: 22
Canvas X: 683289.910
Canvas Y: 506647.300
Label X: 16
Label Y: 0
Downstream: 73
End:

Junction: 23
Canvas X: 684339.910
Canvas Y: 504947.300
Label X: 16
Label Y: 0
Downstream: 74
End:

Junction: 24
Canvas X: 684339.910
Canvas Y: 504147.300
Label X: 16
Label Y: 0
Downstream: 75
End:

Junction: 26
Canvas X: 680989.910
Canvas Y: 504447.300
Label X: 16
Label Y: 0
Downstream: 76
End:

Junction: 27
Canvas X: 682689.910
Canvas Y: 503747.300
Label X: 16
Label Y: 0
Downstream: 56
End:

Junction: 28
Canvas X: 685439.910
Canvas Y: 528047.300
Label X: 16
Label Y: 0
Downstream: 77
End:

Junction: 29
Canvas X: 675539.910
Canvas Y: 527347.300
Label X: 16
Label Y: 0
Downstream: 80
End:

Junction: 30
Canvas X: 681339.910
Canvas Y: 524447.300
Label X: 16
Label Y: 0
Downstream: 78
End:

Junction: 31
Canvas X: 679039.910
Canvas Y: 523797.300
Label X: 16
Label Y: 0
Downstream: 81
End:

Junction: 32
Canvas X: 682439.910
Canvas Y: 525997.300
Label X: 16
Label Y: 0
Downstream: 79
End:

Junction: 33
Canvas X: 673639.910
Canvas Y: 521697.300
Label X: 16
Label Y: 0
Downstream: 85
End:

Junction: 34
Canvas X: 673239.910
Canvas Y: 519697.300

Label X: 16
Label Y: 0
Downstream: 83
End:

Junction: 35
Canvas X: 675389.910
Canvas Y: 519947.300
Label X: 16
Label Y: 0
Downstream: 86
End:

Junction: 36
Canvas X: 684639.910
Canvas Y: 518597.300
Label X: 16
Label Y: 0
Downstream: 88
End:

Junction: 37
Canvas X: 678739.910
Canvas Y: 519347.300
Label X: 16
Label Y: 0
Downstream: 89
End:

Junction: 38
Canvas X: 677489.910
Canvas Y: 514947.300
Label X: 16
Label Y: 0
Downstream: 48
End:

Junction: 39
Canvas X: 683139.910
Canvas Y: 517097.300
Label X: 16
Label Y: 0
Downstream: 90
End:

Junction: 40
Canvas X: 685439.910
Canvas Y: 513347.300
Label X: 16
Label Y: 0
Downstream: 47

End:

Junction: 41

Canvas X: 673239.910

Canvas Y: 512797.300

Label X: 16

Label Y: 0

Downstream: 51

End:

Junction: 42

Canvas X: 683639.910

Canvas Y: 510547.300

Label X: 16

Label Y: 0

Downstream: 50

End:

Junction: 43

Canvas X: 673889.910

Canvas Y: 508197.300

Label X: 16

Label Y: 0

Downstream: 53

End:

Junction: 44

Canvas X: 676789.910

Canvas Y: 505097.300

Label X: 16

Label Y: 0

Downstream: 57

End:

Junction: 45

Canvas X: 682339.910

Canvas Y: 505797.300

Label X: 16

Label Y: 0

Downstream: 55

End:

Junction: 46

Canvas X: 678689.910

Canvas Y: 505247.300

Label X: 16

Label Y: 0

Downstream: 58

End:

Sink: 25

Canvas X: 684389.910

Canvas Y: 503872.300

Label X: 16

Label Y: 0

End:

APPENDIX-B

Panchpukuria Discharge File – Input of DSSTS program

C:\Rinki\DSSTdata\PPQ92.dss

/CA-08/PP/FLOW-LOCAL/01JAN1992/1DAY/PPQ92/

cms

per-aver

1-Jan-92, 0600

10.5,9.86,8.05,8.62,8.55,8.69,8.5,8.31,8.44,8.26,8.13,7.59,7.71,7.78,7.49,7.16,7.12,7.36,7.2,6.99,
6.95,6.9,7.42,7.38,7.05,6.73,6.43,6.39,6.35,6.05,6.01,
5.5,5.46,19.4,13.5,9.72,7.92,7.87,7.52,8.26,7.54,6.09,5.3,5.05,5.02,4.78,4.74,4.51,73.4,129,57,15.
7,8.45,7.64,7.59,7.72,7.29,6.99,7.76,7.18,
5.18,8.86,8.7,8.55,8.08,3.73,3.55,3.33,3.12,2.97,2.94,2.75,2.6,2.35,2.39,2.67,2.57,2.59,2.49,2.52,
2.42,2.44,2.35,2.3,2.27,2.2,2.2,2.11,2.12,2.51,2.26,
2.14,2.07,2.32,2.32,2.24,2.01,1.87,1.9,1.72,1.62,1.54,1.51,1.41,1.37,1.34,1.31,1.22,1.19,1.61,1.57
,1.47,1.54,1.54,1.61,1.69,1.71,1.77,1.78,1.86,1.94,
2.1,3.82,3.95,2.43,3.58,3.85,2.5,3.09,3.08,2.77,2.65,2.87,2.57,2.56,2.4,2.49,2.36,2.76,2.51,2.42,3.
35,4.73,4.65,3.48,3.04,2.86,3.29,6.13,3.93,3.4,3.88,
3.27,2.79,2.55,2.47,2.39,2.73,2.75,3.29,3.01,3.02,3.33,3.23,4.06,4.03,5.29,11.4,7.8,6.13,5.85,6.24
,6.63,6.54,10,202,170,113,68.3,46,36.6,25.8,
20,15.3,29.1,58.6,46,32.6,23,19.3,13.5,15.2,25.1,24,21.5,22.7,21.5,22.1,21.6,29.5,22.8,98.5,77.3,
64.2,61.4,46,34.8,28.2,26.4,22.6,20,20.7,15.6,
24,38.7,30.6,25.5,28.4,32.9,95.9,74.8,81.5,52.5,36.8,24.9,30.5,35,26.2,21.9,20.9,18.7,14.4,14,13.1,
17.5,12.3,11.4,10.7,9.54,24,15.8,11.8,8.71,
18.8,21.6,21.7,1.6,83,5.8,12.6,7.76,5.45,5.44,40.2,103,86.6,59.4,46.5,40.7,31.1,26.4,20.7,18.8,21.
9,19.7,50.5,40.7,32.1,28.4,32,48.9,44.5,37.4,
28.8,22.7,24.2,32.9,26.5,22.1,19.3,16.1,21.7,20.3,16.8,17.9,36.3,109,138,112,72.8,61.7,89.3,75.7,
55.1,47.3,41.7,36.6,32.5,22.4,20.5,19.5,18.1,16.7,15.4,
14.1,12.8,12.5,11.6,11,10.7,10.3,10.2,9.85,9.64,9.33,9.03,8.98,8.69,8.65,8.75,8.56,8.43,8.69,9.17,
9.29,9.26,9.02,8.89,8.76,8.63,8.5,8.38,8.25,8.95,
9.33,10.3,9.93,9.31,9.08,8.85,8.63,8.41,8.19,7.98,7.78,7.67,7.51,7.4,7.21,7.07,6.88,6.82,6.56,6.5,
6.44,6.19,6.14,5.97,5.84,5.79,5.56,5.51,5.46,5.28,5.26

END

FINISH

APPENDIX-C

HEC-HMS (Ver. 2.1.3) GAGE FILE FORMAT FOR 1992 DATA

Gage: Panchpukuria

Description: Discharge gage

Gage Type: Flow

Units: M3/S

Local to Project: NO

Start Time: 1 January 1992, 06:00

End Time: 31 December 1992, 06:00

DSS File: C:\Rinki\DSSdata\Ppq92.dss

Pathname: /CA-08/PP/FLOW-LOCAL//1DAY/PPQ92/

End:

Gage: Amtali

Description: Precipitation gage

Latitude: 0

Longitude: 0

Gage Type: Precipitation

Precipitation Type: Incremental

Units: MM

Local to Project: YES

Start Time: 1 January 1992, 06:00

End Time: 31 December 1992, 06:00

Pathname: /CA-08/AMTALI/PRECIP-INC//1DAY/GAGE/

End:

Gage: Fatikchari

Description: Precipitation gage

Latitude: 0

Longitude: 0

Gage Type: Precipitation

Precipitation Type: Incremental

Units: MM

Local to Project: YES

Start Time: 1 January 1992, 06:00

End Time: 31 December 1992, 06:00

Pathname: /CA-08/FATIKCHARI/PRECIP-INC//1DAY/GAGE/

End:

Gage: Manikchari

Description: Precipitation gage

Latitude: 0

Longitude: 0

Gage Type: Precipitation
Precipitation Type: Incremental
Units: MM
Local to Project: YES
Start Time: 1 January 1992, 06:00
End Time: 31 December 1992, 06:00
Pathname: /CA-08/MANIKCHARI/PRECIP-INC//1DAY/GAGE/

End:

Gage: Narayanhat

Description: Precipitation gage
Latitude: 0
Longitude: 0
Gage Type: Precipitation
Precipitation Type: Incremental
Units: MM
Local to Project: YES
Start Time: 1 January 1992, 06:00
End Time: 31 December 1992, 06:00
Pathname: /CA-08/NARAYANHAT/PRECIP-INC//1DAY/GAGE/

End:

Gage: Nazirhat

Description: Precipitation gage
Latitude: 0
Longitude: 0
Gage Type: Precipitation
Precipitation Type: Incremental
Units: MM
Local to Project: YES
Start Time: 1 January 1992, 06:00
End Time: 31 December 1992, 06:00
Pathname: /CA-08/NAZIRHAT/PRECIP-INC//1DAY/GAGE/

End:

