ADDIS ABABA UNIVERSITY

School of Graduate Studies
Master's Thesis

Rainfall-Runoff Modelling for Sustainable Water Resources Management: The Case of Gumara Watershed, Ethiopia

By
Yibeltal Ayenew

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Advisor:

Dagnachew Legesse (PhD)

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APPROVAL BY THESIS COMMITTEE

This thesis has been approved on the date shown below:

Dr. Balemual Atnafu (Chairman)	Date
Dr. Tenalem Ayenew (Examiner)	Date
Dr. Suryabhagavan.V.K (Examiner)	Date
Dr. Dagnachew Legesse (Advisor)	Date

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Abstract

Flow estimation at a point in a river is vital for a number of hydrologic applications including flood forecasting, water resource management, and for development applications. This paper presents the result of a watershed scale rainfall-runoff modeling on gaged part of Gumara watershed using the hydrologic model HEC-HMS in a GIS environment.

The model in combination with GIS extension HEC-GeoHMS, was used to convert the precipitation excess to overland flow and channel runoff. Rainfall data used gaged precipitation alone from nine meteorological stations. The simulation was done for a period of 5 years. The predicted hydrograph was calibrated against observed one and the model parameters were optimized for good simulation. The predicted peak discharge, using rain gage data, was close to the observed value and the smaller discharges followed the observed trend. But the simulated peak value was very far apart .The simulated peak discharge has a value of 578.9 m^3/s while the observed discharge is 256.9 m^3/s, which has a difference of 322 m^3/s.

The model framework developed in the study considered the spatial variation in the runoff response of the watershed through the use of curve numbers based on soil type and land use, and the spatial distribution of the rainfall in the watershed by using rainfall data from a number of rain gage stations located in different parts of the basin.

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1. INTRODUCTION

1.1 General

Runoff is one of the most important hydrologic variables used in most of the water resources applications. Sound information on quantity and rate of runoff from land surface into streams and rivers is vital for integrated water resource management. This information is needed in dealing with many watershed development and management problems. Physically distributed hydrologic models for prediction of river discharge require considerable hydrological and meteorological data. However, traditional data collection is expensive, error prone, time consuming and a difficult process. To alleviate this problem remote sensing and geographic information systems (geoinformatics) are sound technologies.

The use of hydrological modeling systems for water resources planning and management is becoming increasingly popular. Since these hydrological models mostly deal with land phase of hydrological cycle, data related to topography and physical parameters of watershed are a necessary pre-requisite for these models. Computer based geographic information system furnish this requirement efficiently. These systems link land cover data to topographic data and to other information related to geographic locations. When applied to hydrologic systems, non-topographic information can include description of soils, land use, ground cover, ground water conditions, as well as man-made systems and their characteristics on or below the land surface.

Ethiopia has three physiographic regions (Mesfin, 1972); the Northwestern plateau, Southeastern plateau and Rift valley. From the 12 major river basin of the country the 9 river basins drainage system originated from centrally situated highlands and makes their way down to the peripheral or outlying lowlands. During the rainy season these major perennial rivers and their numerous tributaries forming the countries drainage system carry their peak discharge. Therefore, owing to its topographic and altitudinal characteristics with the contribution of anthropologic effects on the environment flooding as a natural phenomenon is not new to Ethiopia. It has been occurring at different places and times with varying magnitude. Some parts of the country face major flooding. Most prominent ones include: extensive plain fields surrounding Lake Tana, which is feed by the perennial rivers of Megech, Gilgel Abay, Gumara and Ribb Rivers in Amhara Regional State. (Tessema Selemone, 2006)

Gumara watershed, which is the thematic area of this research, is located in south Gonder zone of the Amhara National Regional State. Gumara River is the main river of the watershed that drains from the upper peak part of Gunna Mountain to Lake Tana. Dera, Farta, Fogera and some part of Estie Wereda are part of this watershed. Overflow of the river frequently flooded downstream areas cause frequent loss of property and life. To alleviate these problem different hydrological studies were conducted. Since 1998 Ethiopia has given special attentions for water resource development. Previous works indicate that the area is susceptible to land degradation and sediment run-off from the surface and that goes directly into the lake.

As any development relies mostly on proper utilization of natural resources, the government has also given focus on water resource development both for domestic and irrigation water supply. As part of this water resource development, integrated master plan study of various River basins has been undertaken in the country since 1998. Among them is the Abay River basin. Gumara irrigation project has been identified as one of the project for feasibility study during the Abay River master plan study.

1.2 Research problem and relevance of the study

The water resources of Lake Tana sub-basin are highly vulnerable to climate change that affects the magnitude of seasonality of surface flow. The change increases the frequency of extreme events such as drought and floods predicted to occur as it has been shown varying from model to model. But all the models agree that river flow will be reduced by amounts ranging from15% to 80% of the monthly mean, in some months of the year all over the basin (Aynekulu etal, 2008). The decrease in river flow might cause small streams to dry up completely, and the magnitude of flow of the medium to large rivers will decrease significantly.

There is no reservoir in the sub-basin, so most of the small-scale water developments’ existing water supply schemes draw directly on rivers or natural lakes. The supply of drinking water for humans and livestock depends mainly on river flow. Hence, a decrease in the flow will have a severe impact. Since agriculture in the basin is mainly rain fed, an uneven distribution of rainfall and a decrease in or total failure of rainfall, deficient of soil moisture due to minimal infiltration and high evapotranspiration cause crops to fail.

On the other hand, the predicted increase in river flow in some months of the year will cause floods as the natural river and stream channels may not be able to accommodate the amount of flow. Overflowing of the channels of the minor and major rivers and an abnormal rise in the level of the lakes will flood agricultural fields and human settlements. To alleviate or minimize these problem and ensures sustainable management of land and water resources onsite and timely research is the first alternative. Moreover, the integration of geoinformations with hydrological models boosts sound solutions for areas which have complex environmental problems.

The rapid increase in population necessitates an adequate management of land and water resources. As more than 85% of the country's population depends on agriculture, it is difficult to utilize the resource without proper management of land and water. Hence, wise utilization and sound management of these resources shall be everybody's responsibility. Agriculture could be effective only when it gets sufficient water at the right time. Therefore, to ensure sustainable agricultural development, there should be reliable supply of land and water as well as land and water management systems. If people engaged in agriculture get sufficient water throughout the year, it is possible to harvest higher yields from a smaller size of land and keep labor busy on production throughout the year.

The integration of geographic information systems, remote sensing and HEC-HMS hydrologic modeling systems for water resources planning and management is becoming increasingly popular. Since HEC-HMS model mostly deals with land phase of hydrological cycle, data related to topography and physical parameters of the catchments is a necessary pre-requisite for these model. Remotely sensed data and geographic information system furnish this requirement efficiently. Therefore, the integration of HEC-HMS with GIS and remote sensing technique ensures the quality of the output, demand less labour and human resource, ends timely and becomes economical. Hence, the result from such integrated models is important for sound decision making and benefits the community at large.

1.3 Objective of the study

Different researchers have studied the Lake Tana basin water resources potential assessment. With all these previous studies carried out in this basin, water resource potential question still persists with the need for a better description of hydro-system. Therefore, this thesis work bases at answering the core question that asks "How much water resource is available for development in the basin particularly in Gumara watershed?" Accordingly, the development work in water resources could be made lying on sound engineering bases providing with more confidence in decision to the implemented developments and 'no regret development decisions' can be carried out in the watershed. Therefore, this thesis work will have a significant contribution for the future development of water resources programs in Lake Tana basin in general and in this watershed in particular.

1.3.1 General objective

The main objective of the research is to estimate the Rainfall-Runoff condition of Gumara watershed, which helps to predict and forecast storm events for proper management of water resources.

1.3.2 Specific objectives:

- To model the rainfall-runoff interaction
- To assess the influence of land use/cover change of the hydrologic condition of the catchment;
- To predict and forecast the peak storm events to minimize the risk caused by flooding and drought

1.4 Research questions

- Does the amount of flood generated from the catchment directly related to the amount of rainfall of the area?
- Does the change in land use /land cover have direct impact on the watershed hydrology?
- Which watershed characteristic contributes more for runoff yield of the watershed?
- Who are affected more by this hydrologic change, the upstream dwellers or the downstream dweller

2. DESCRIPTION OF THE STUDY AREA

2.1 Location and accessibility

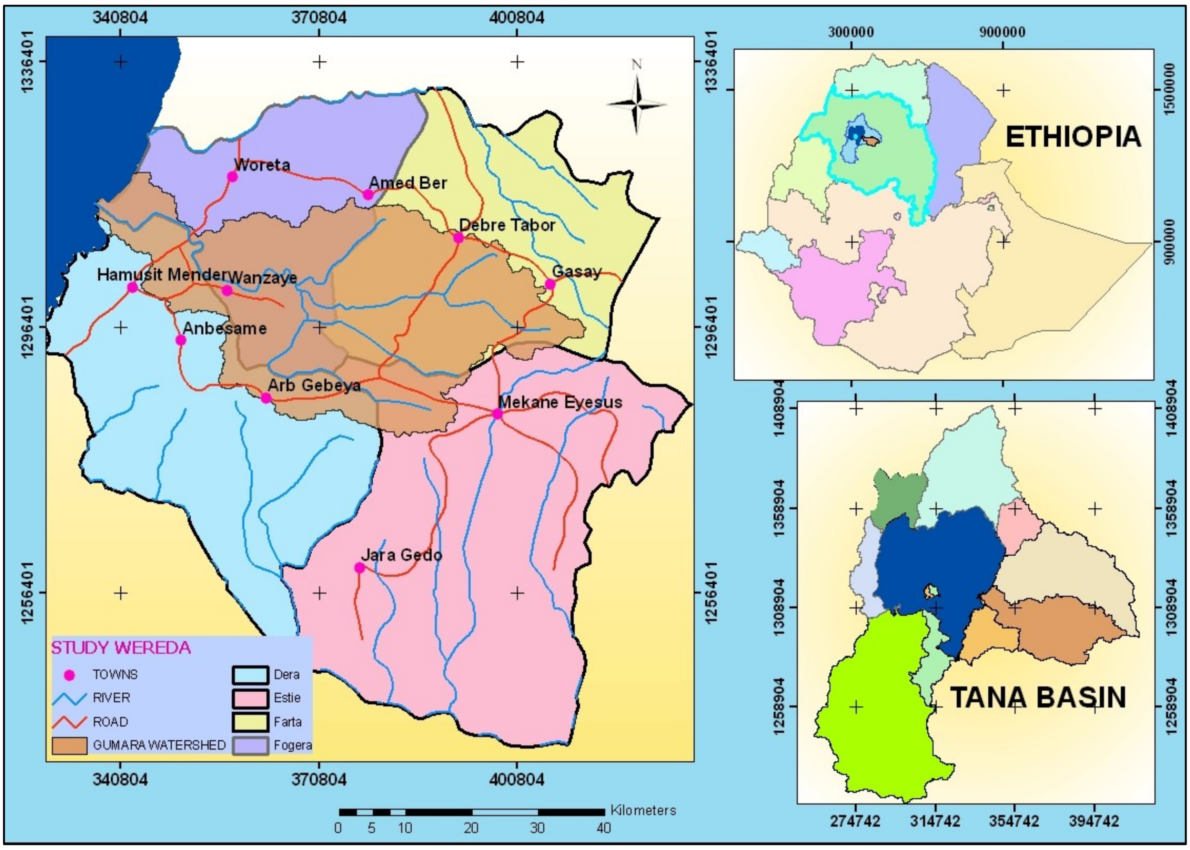
Gumara watershed, drained by Gumara Rivers, is located in south Gonder zone of the Amhara National Regional State, at 624 KM North of Addis Ababa. This watershed is part of the Abay Basin and more particularly part of Lake Tana sub-basin which is situated on the North Eastern side of Lake Tana. It drains Dera, Farta, Fogera and some part of Estie Wereda. The geographical location of the watershed is between 11^0 34’ 41.41” N and11^0 56 ‘36.95”N latitude to 37^0 29’ 30.48” E and 38^0 10’ 58.01”E longitude. Gumara River originates on the high plateau to the east, which is characterized by mountainous, highly rugged and dissected topography with step slops and drains to the plain in the west, characterized by valley floor with flat to gentle slopes where the river overflows its bank during the rainy season.. As the river flows to the low land area the gradient decreases and forms meander.

The basin is a key surplus food producing area of Ethiopia. It is therefore, critically important in terms of national agricultural economy and for national food security.

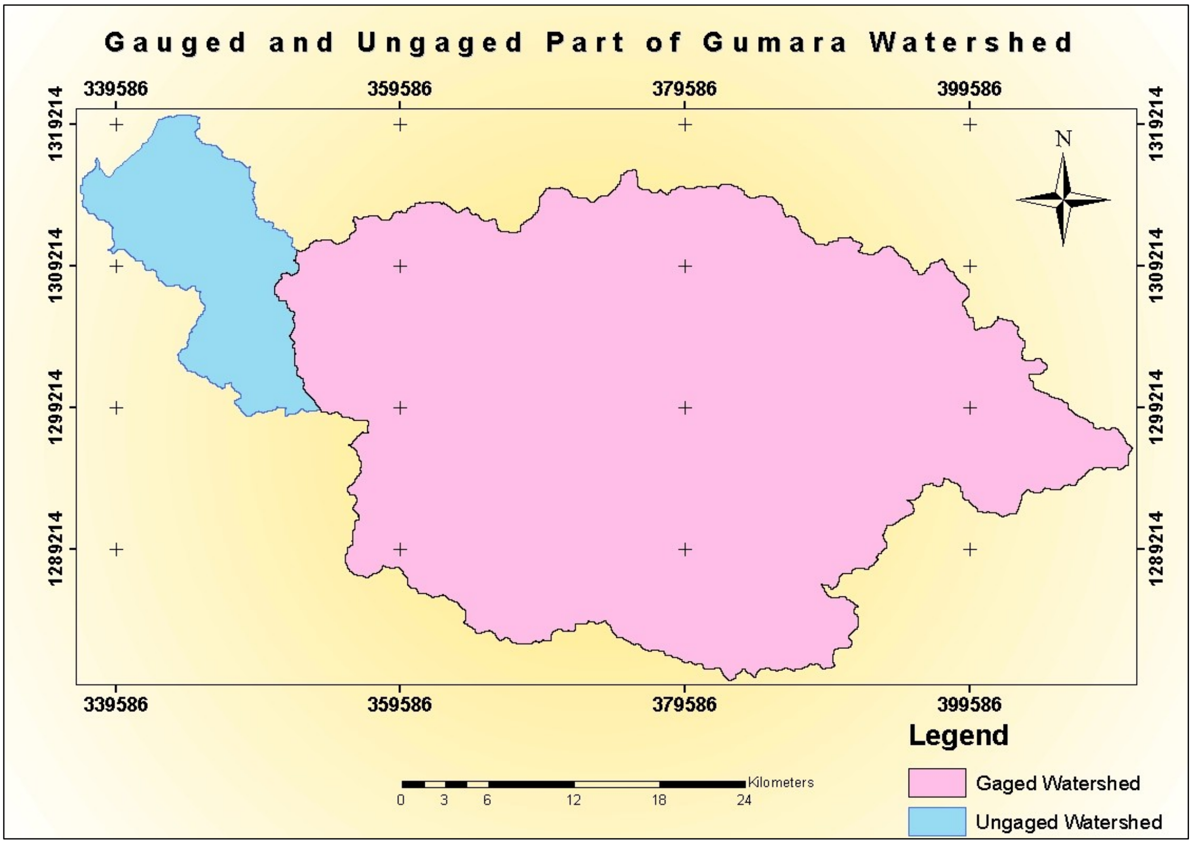
The main asphalted road from Bahir Dar to Gonder crosses the study area. The area is also accessed by other gravel roads which connect Wereta, Amed Ber, Debre Tabor, Gassay, Mekane Eyesus, Arb Gebeya, Anbesame and Wanzaye.

The main Gumara River covers a total length of about 72 km up to the gage station. It has diverse altitudinal difference which ranges from 1790 m to 3600 meters above sea level. The study is concentrated on the upper /gaged part of the watershed, which has area coverage of 1350.25Km^2.

Figure 1. A. Map of the study area.



B. Gumara Watershed Map



2.2 Topography

Gumara watershed is a land with varying topography ranging from1778 masl on the flood plain near to Lake Tana to 3707 masl at the high plateau of Gunna Mountain. Tertiary volcanism and subsequent weathering and denudation processes are responsible for the present day landscape of the area. The high to low relief dissected hills and mountains are the result of volcanism. Erosion and deposition by Major Rivers are forming relatively wide, flat and marshy flood plains. The topography of the area has an important contribution for surface runoff and soil erosion processes. Therefore, the topographic effect of the area has significant effect on generation of direct runoff from precipitation

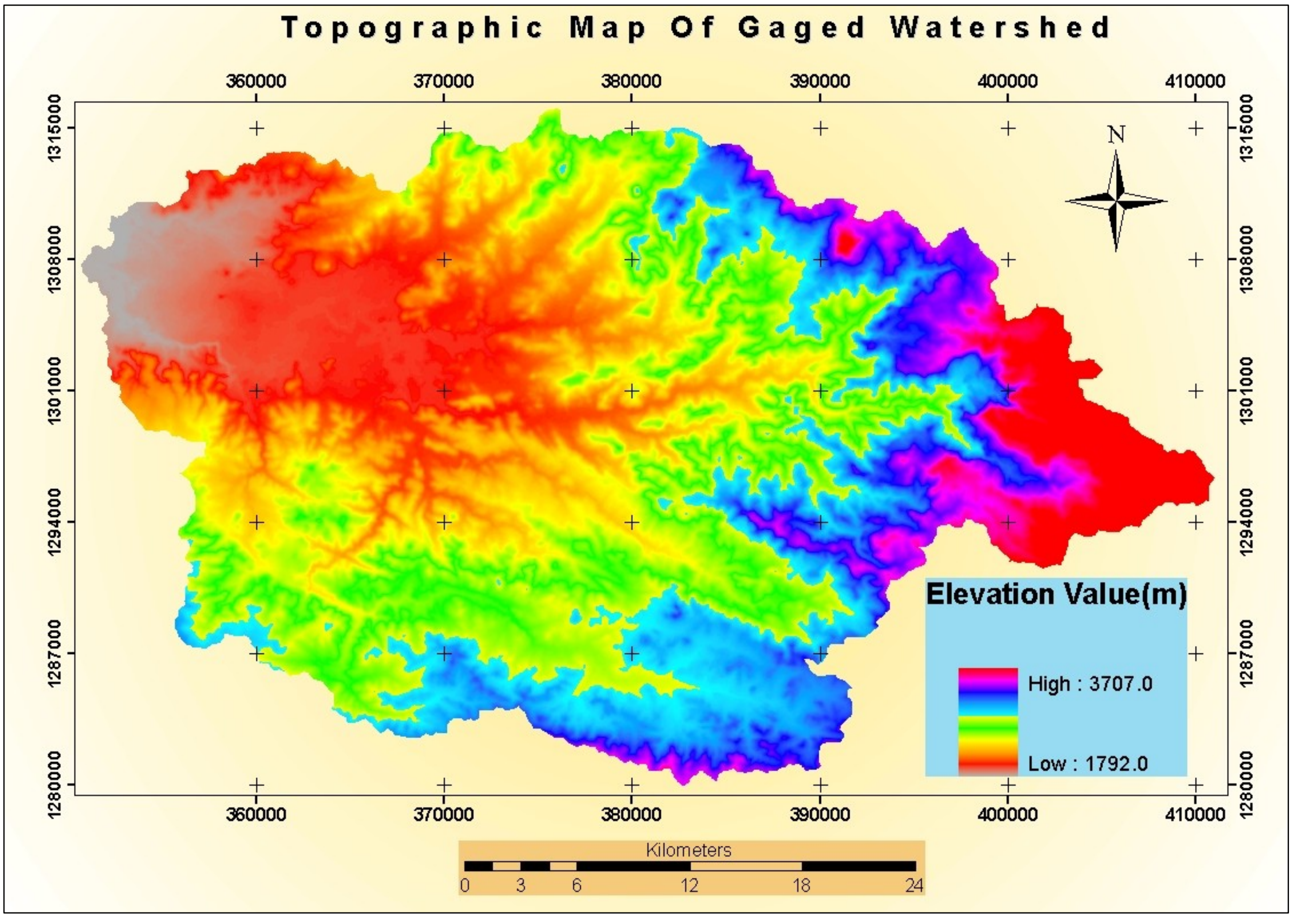
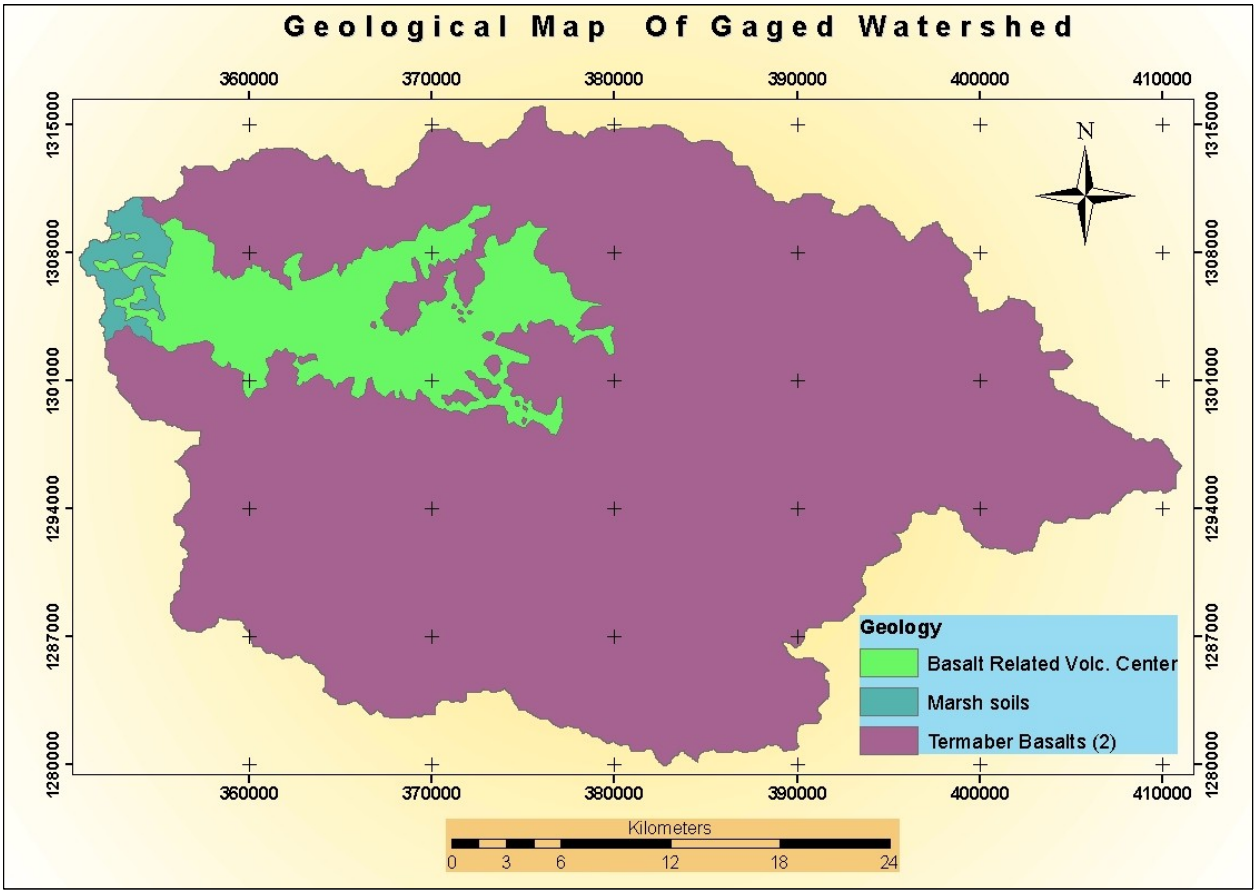


Figure 2. Map showing relief of the study area.

2.3 Geology

The area is comprises of basaltic and acidic lava flows and falls such as ignimbrite and pyroclastic falls. It is also consists of lacustrine sediments of various sizes ranging from clay through sand and gravel to boulders, especially concentrated along rivers and streams as well as along the side of the lake as a result of recession.

Figure 3. Geological map of Gumara watershed (Source: Ministry of Water resources).



2.4 Soil

The lowland flat plains of the watershed are dominated with Vertisols and Fluvisols which have a dominant textural class of sandy clay and sandy loam respectively. Shallow Leptisols are the dominant soil types found in the mountain and hills of the watershed. The watershed is characterized by four major dominant soil groups: Chromic Luvisols, Eutric Fluvisols, Haplic Luvisols and Eutric Leptosols.

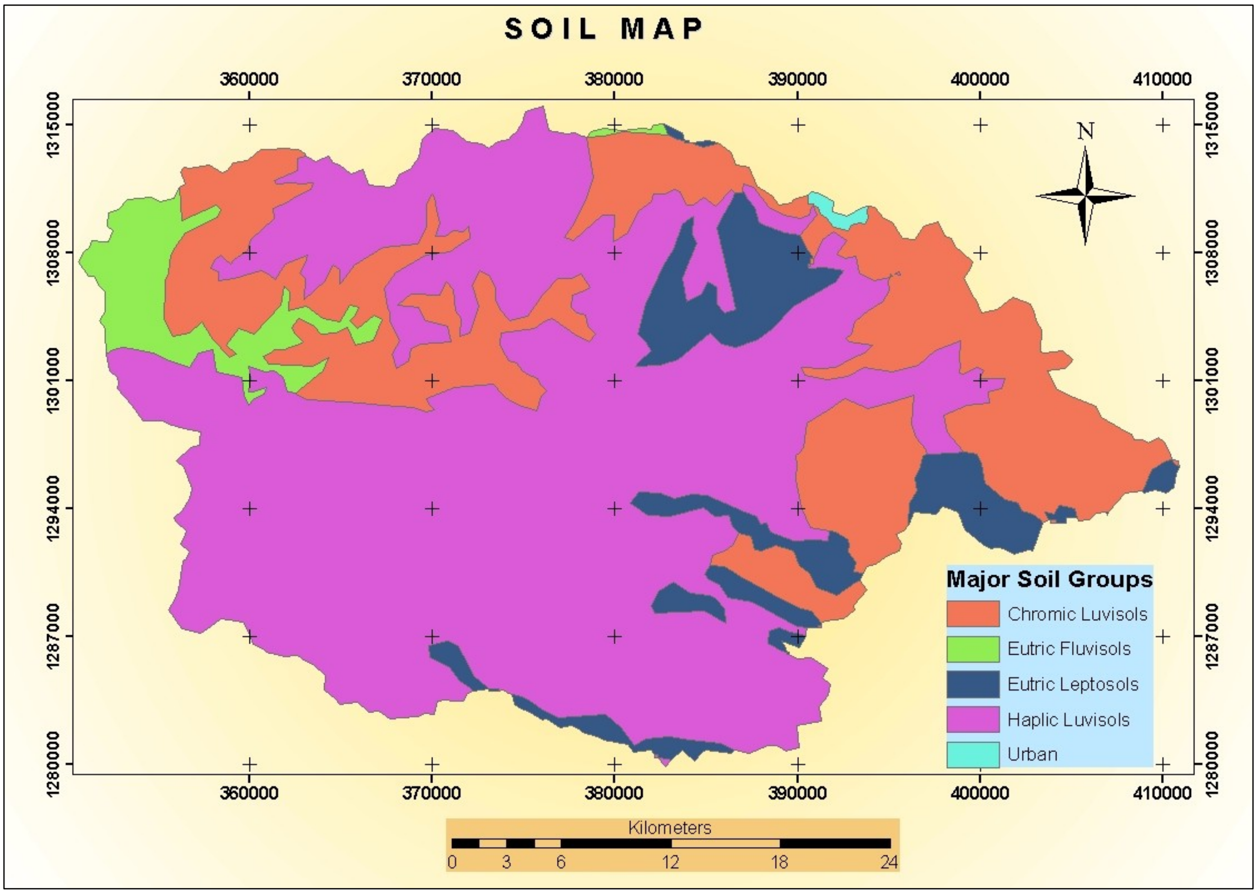


Figure 4. Soil map of Gumara Watersheds.

2.5 Climate

Rainfall

Based on the rainfall pattern, the year is divided into two seasons: a rainy season mainly centered on the months of June to September, and a dry season from October to March. April and May are an intermediate season where minor rains often occur. Of the total annual rainfall, 70% to 90% occurs in the June to September rainy season. The mean annual rainfall of the area is 1279mm though there is slight spatial variation with in the area.

Temperature

The mean monthly temperature at Bahir Dar is in the range 16.9 to 21.6 ^{o}c. The monthly mean maximum temperature varies from 22 ^{o}c in August to more than 33^{o}c in April; the monthly mean minimum temperature varies from 3^{o}c in January and December to 16.7 ^{o}c in May. The highest mean temperatures were always in March or April.

2.6 Land use

The land use/cover types of Gumara watershed is classified as urban, agriculture, pasture and agro-pasture. In the entire watershed resource-intensive economic activities often precipitate environmental degradation. This is particularly the case when prevailing production and consumption patterns are unsustainable.

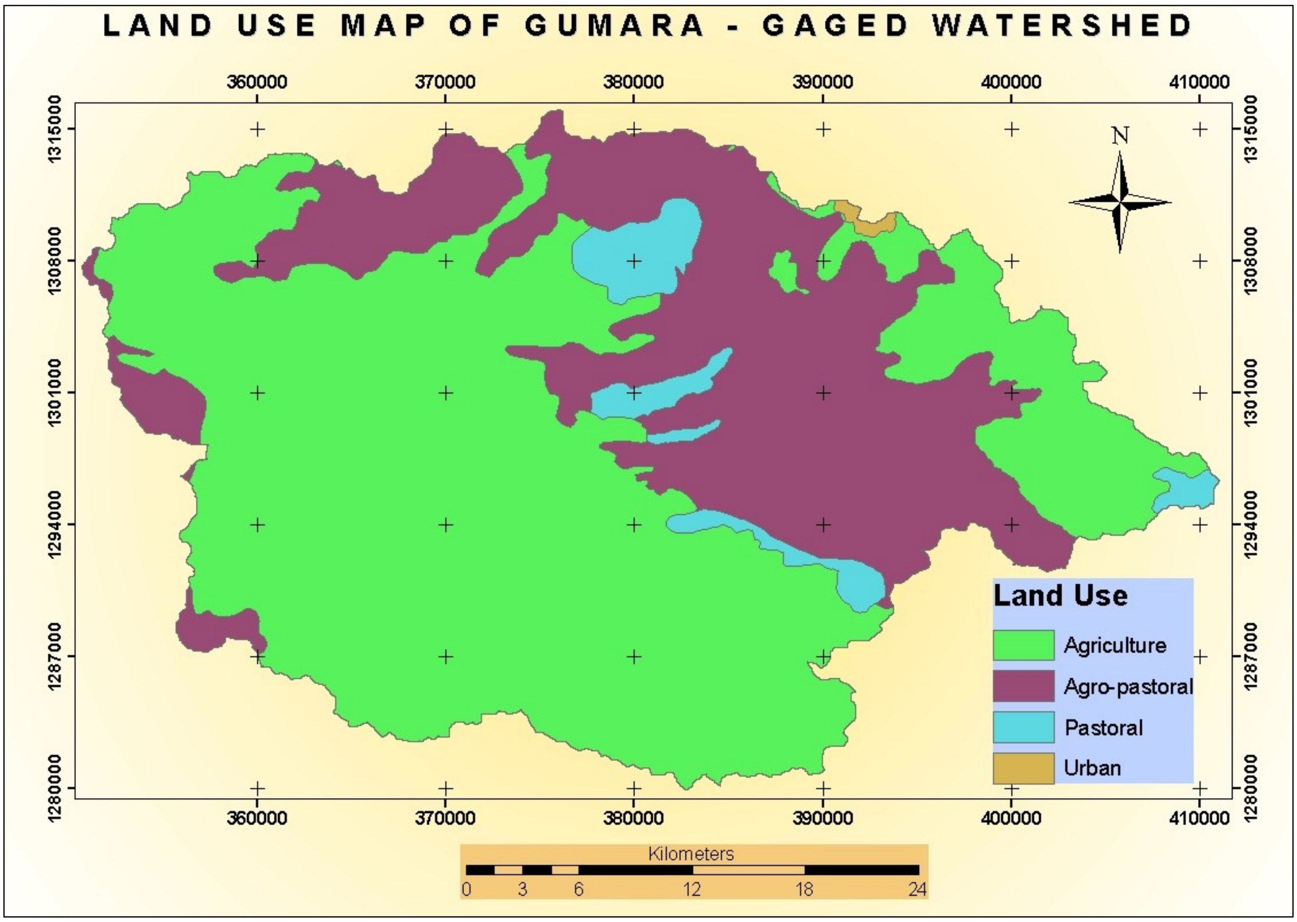


Figure 5. Land use map of the study area.

3. Theoretical background and Literature Reviews

3.1 Theoretical background

HEC-HMS is designed to simulate the precipitation-runoff processes of dendritic watershed systems. It is the successor to HEC-1 and provides a similar variety of options but represents a significant advancement in terms of both computer science and hydrologic engineering. In addition it provides unit hydrograph analysis, hydrologic and reservoir routing options, capabilities include a linear quasi-distributed runoff transform (Mod Clark) for use with girded precipitation, continuous simulation with either a one-layer or more complex five-layer soil moisture method, and a versatile parameter estimation option. The software is designed for interactive use in a multi-tasking, multi-user network environment, and can be used with both XP-Windows and Microsoft Windows.

The program is a generalized modelling system capable of representing many different watersheds. A model of the watershed is constructed by separating the hydrologic cycle into manageable pieces and constructing boundaries around the watershed of interest. Any mass or energy flux in the cycle can then be represented with a mathematical model. In most cases, several model choices are available for representing each flux. Each mathematical model included in the program is suitable in different environments and under different conditions. Making the correct choice requires knowledge of the watershed, the goals of the hydrologic study, and engineering judgment.

The program features a completely integrated work environment including a database, data entry utilities, computation engine, and results reporting tools. A graphical user interface allows the seamless movement between the different parts of the program. Program functionality and appearance are the same across all supported platforms.

HEC-HMS provides a variety of options for simulating precipitation-runoff processes. In addition to unit hydrograph and hydrologic routing options similar to those in HEC-1, capabilities currently available include: a linear-distributed runoff transformation that can be applied with girded (e.g., radar) rainfall data, a simple "moisture depletion" option that can be used for simulations over extended time periods, and a versatile parameter optimization option. The latest version also has capabilities for continuous soil moisture accounting and reservoir routing operations.

For precipitation-runoff-routing simulation, HEC-HMS provides the following components:

Precipitation-specification options which can describe an observed (historical) precipitation event, a frequency-based hypothetical precipitation event, or a event that represents the upper limit of precipitation possible at a given location.

- Loss models which can estimate the volume of runoff, given the precipitation and properties of the watershed.
- Direct runoff models that can account for overland flow, storage and energy losses as water runs off a watershed and into the stream channels.
- Hydrologic routing models that account for storage and energy flux as water moves through stream channels.
- Models of naturally occurring confluences and bifurcations
- Models of water-control measures, including diversions and storage facilities.

These models are similar to those included in HEC-1. In addition to these, HEC-HMS includes a distributed runoff model for use with distributed precipitation data, such as the data available from weather radar, and a continuous soil-moisture-accounting model used to simulate the long-term response of a watershed to wetting and drying.

HEC-HMS also includes an automatic calibration package that can estimate certain model parameters and initial conditions, given observations of hydro meteorological conditions. It also links to a database management system that permits data storage, retrieval and connectivity with other analysis tools available from HEC and other sources.

3.1.1 Features

HEC-HMS is comprised of a graphical user interface (GUI), integrated hydrologic analysis components, data storage and management capabilities, and graphics and reporting facilities. The Data Storage System, HEC-DSS, is used for storage and retrieval of time series, paired-function, and gridded data, in a manner largely transparent to the user.

The Graphical User Interface (GUI) provides a means for specification of watershed components, inputting data for the components, and viewing the results. The GUI has capability for schematic representation of a network of hydrologic elements (e.g. sub-basins, routing reaches, junctions, etc.). You can configure the schematic by selecting and connecting icons that represent the elements. Once a schematic is developed, pop-up menus can be invoked from the element icons. A menu provides access to an editor for entering or editing data associated with the hydrologic element, and enables display of results of a simulation for that element. The GUI also contains global editors for entering or reviewing data of a given type (e.g., values for Green & Ampt parameters) for all applicable elements.

The results of the active run can be viewed and printed in tabular or graphical form. Three types of tabular data are available: (1) **a master summary table** with a single line of information for each hydrologic element, (2) **an element summary table** with information tailored to the element type, and (3) **an element time series table** that shows results for each time interval. A graphical display is also available for each element type.

3.1.2 Technical Capabilities

The basic framework for simulation of basin runoff is similar to that in HEC-1. We can also import data from an HEC-1 input file. Hydrologic elements are arranged in a dendritic network, and computations are performed in an upstream-to-downstream sequence. Computations are performed with SI (Systeme International d`Unites) units. However you can enter input and view output with units in the U.S. Customary system, and can readily convert input/results from one unit system to the other.

The execution of a simulation, called a "run", requires specification of three sets of data. The first, labeled Basin Model - contains parameter and connectivity data for hydrologic elements. Types of element are: sub-basin, routing reach, junction, reservoir, source, sink, and diversion. The second set, labeled Precipitation Model - consists of meteorological data and information required to process it. The model may represent historical or hypothetical conditions. The third set, labeled Control Specifications - specifies time-related information for a simulation. A Project is used to hold the different data sets and can contain many of each type.

The program is multi-platform capable, meaning it operates on more than one kind of computer operating system. The CD-ROM versions contain executable files and installation instructions for Windows XP/2000/NT/98/95 systems.

3.1.3 Watershed Physical Description

The physical representation of a watershed is accomplished with a basin model. Hydrologic elements are connected in a dendritic network to simulate runoff processes. Available elements are: sub-basin, reach, junction, reservoir, diversion, source, and sink. Computation proceeds from upstream elements in a downstream direction. An assortment of different methods is available to simulate infiltration losses. Options for event modeling include initial constant, SCS curve number, gridded SCS curve number, exponential, and Green Ampt. The one-layer deficit constant method can be used for simple continuous modeling. The five-layer soil moisture accounting method can be used for continuous modeling of complex infiltration and evapotranspiration environments. Gridded methods are available for both the deficit constant and soil moisture accounting methods. Several methods are included for transforming excess precipitation into surface runoff. Unit hydrograph methods include the Clark, Snyder, and SCS techniques. User-specified unit hydrograph or s-graph ordinates can also be used. The modified Clark method, ModClark, is a linear quasi-distributed unit hydrograph method that can be used with gridded meteorological data. An implementation of the kinematic wave method with multiple planes and channels is also included.

Multiple methods are included for representing base flow contributions to sub-basin outflow. The recession method gives an exponentially decreasing base flow from a single event or multiple sequential events. The constant monthly method can work well for continuous simulation. The linear reservoir method conserves mass by routing infiltrated precipitation to the channel.

A variety of hydrologic routing methods are included for simulating flow in open channels. Routing with no attenuation can be modeled with the lag method. The traditional Muskingum method is included along with the straddle stagger method for simple approximations of attenuation. The modified Puls method can be used to model a reach as a series of cascading, level pools with a user-specified storage-discharge relationship. Channels with trapezoidal, rectangular, triangular, or circular cross sections can be modeled with the kinematic wave or Muskingum-Cunge methods. Channels with overbank areas can be modeled with the Muskingum-Cunge method and an 8-point cross section.

Water impoundments can also be represented. Lakes are usually described by a user-entered storage-discharge relationship. Reservoirs can be simulated by describing the physical spillway and outlet structures. Pumps can also be included as necessary to simulate interior flood area. Control of the pumps can be linked to water depth in the collection pond and, optionally, the stage in the main channel.

3.1.4 Meteorology Description

Meteorological data analysis is performed by the meteorological model and includes precipitation, evapotranspiration. Four different methods for analyzing historical precipitation are included. The user-specified hyetograph method is for precipitation data analyzed outside the program. The gage weights method uses an unlimited number of recording and non-recording gages. The Thiessen technique is one possibility for determining the weights. The inverse distance method addresses dynamic data problems. An unlimited number of recording and non-recording gages can be used to automatically proceed when missing data is encountered. The gridded precipitation method uses radar rainfall data.

3.1.5 Hydrologic Simulation

The time span of a simulation is controlled by control specifications. Control specifications include a starting date and time, ending date and time, and a time interval. A simulation run is created by combining a basin model, meteorological model, and control specifications. Run options include a precipitation or flow ratio, capability to save all basin state information at a point in time, and ability to begin a simulation run from previously saved state information. Simulation results can be viewed from the basin map. Global and element summary tables include information on peak flow and total volume. A time-series table and graph are available for elements. Results from multiple elements and multiple simulation runs can also be viewed. All graphs and tables can be printed.

3.1.6 Parameter Estimation

Most parameters for methods included in subbasin and reach elements can be estimated automatically using optimization trials. Observed discharge must be available for at least one element before optimization can begin. Parameters at any element upstream of the observed flow location can be estimated. Six different objective functions are available to estimate the goodness-of-fit between the computed results and observed discharge. Two different search methods can be used to minimize the objective function. Constraints can be imposed to restrict the parameter space of the search method.

3.1.7 Analyzing Simulations

Analysis tools are designed to work with simulation runs to provide additional information or processing. Currently, the only tool is the depth-area analysis tool. It works with simulation runs that have a meteorological model using the frequency storm method. Given a selection of elements, the tool automatically adjusts the storm area and generates peak flows represented by the correct storm areas.

3.1.8 GIS Connection

The power and speed of the program make it possible to represent watersheds with hundreds of hydrologic elements. Traditionally, these elements would be identified by inspecting a topographic map and manually identifying drainage boundaries. While this method is effective, it is prohibitively time consuming when the watershed will be represented with many elements. A geographic information system (GIS) can use elevation data and geometric algorithms to perform the same task much more quickly. A GIS companion product has been developed to aid in the creation of basin models for such projects. It is called the Geospatial Hydrologic Modeling Extension (HEC-GeoHMS) and can be used to create basin and meteorological models for use with the program.

3.1.9 Documentation

The program's revised **User's Manual** describes how to use program features. The program's Technical Reference Manual contains descriptive information on the mathematical models used in the program. A new Applications Guide for HEC-HMS is now also available. It completes the basic documentation set for the program. All manuals are provided in PDF file format for easy online viewing and self printing.

The **Technical Reference Manual** is currently being updated. The current manual continues to accurately describe the simulation methods in Version 3.1.0 even though the manual was not updated with the new release. However, new simulation methods added for Version 3.0.0 are not included in the manual. The updated manual will add information to the manual on all of the new simulation methods that have been added to the program. The updated manual will also expand the amount of information for each method. The goal is to provide complete information on the source and derivation of the equations used in each method. Information will also be provided on parameter estimation. Finally, numeric solution details will be provided on how the equations are solved inside the program.

The **Applications Guide** is currently being updated. The current manual continues to accurately describe how to incorporate hydrologic simulation into project work. However, Version 3.0.0 includes some new features that can make the work simpler to perform. The manual also includes some screen pictures that are no longer accurate. The user should be careful to interpret the current manual in the context of interface changes made for Version 3.1.0. The updated guide will include accurate screen pictures and suggestions for better use of the program to conduct project work.

3.1.10 HEC-GeoHMS 4.1 Version Beta

The geo-spatial Hydrologic Modeling Extension (HEC-GeoHMS) is a software package for use with the ArcGIS Geographic Information System. GeoHMS uses ArcGIS and Spatial Analyst to develop a number of hydrologic modeling inputs. Analyzing digital terrain information, HEC-GeoHMS transforms the drainage paths and watershed boundaries into a hydrologic data structure that represents the watershed response to precipitation. In addition to the hydrologic data structure, capabilities include the development of: grid-based data for linear quasi-distributed runoff transformation (ModClark), the HEC-HMS basin model, physical watershed and stream characteristics, and background map file.

HEC-GeoHMS provides an integrated work environment with data management and customized toolkit capabilities, which includes a graphical user interface with menus, tools, and buttons. The program features have terrain-preprocessing capabilities in both interactive and batch modes. Additional interactive capabilities allow users to construct a hydrologic schematic of the watershed at stream gages, hydraulic structures, and other control points. The hydrologic results from HEC-GeoHMS are then imported by the Hydrologic Modeling System, HEC-HMS, where simulation is performed. **HEC-GeoHMS** is now included on the HEC-HMS, HEC-Combo Pack or HEC-Works CDs (including all three Program Manuals in PDF format) at no additional cost.

3.1.11 Arc Hydro

Arc Hydro is a geospatial and temporal data model for water resources. It has an associated set of toolset developed jointly by ESRI and CRWR that operates in the ArcGIS platform. The Arc Hydro toolset populates attributes of the features in the data framework, interconnects features in different data layers and supports hydrologic analysis (Maidment, 2002). The Arc Hydro framework consists of a geodatabase with feature dataset, feature classes, geometric network and relationship classes. A geodatabase is a relational database in the Microsoft access format (filename.mdb). A feature dataset is a folder within the geodatabase that has a defined projection and a specified coordinate system. Feature datasets contain feature classes that can either be point, line or polygon features. In the Arc Hydro jargon, a point feature class is called Hydro Edge, a line feature class is called Hydro Junction and a polygon feature class is called Watershed. Thus, in a basin the stream network is typically called Hydro Edge, the control points have a one to many relationship with Hydro Junctions since more than one control point can exist at the same location and the area delineated for each control point or stream reach is called Watershed

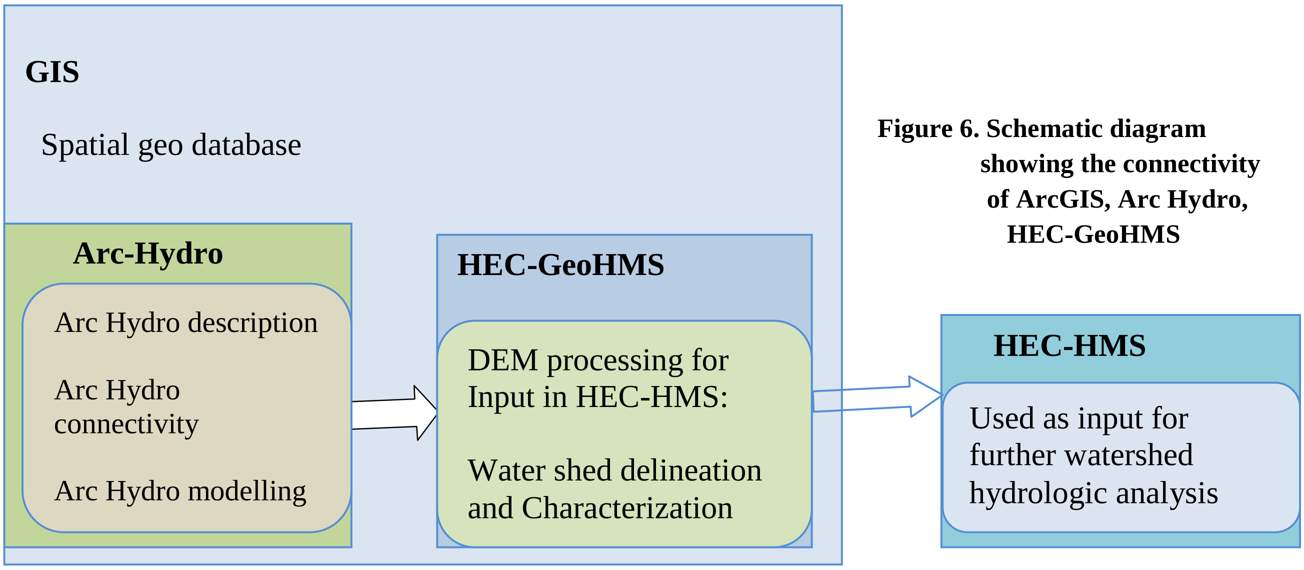


Figure 6. Schematic diagram showing the connectivity of ArcGIS, Arc Hydro, HEC-GeoHMS

3.2 Literature Review

Remote sensing data and geographic information systems are increasingly becoming an important tool in Hydrology and water resources development. This is due to the fact that most of the data required for hydrological analysis can easily be obtained from Remote sensed images. The greatest advantage of using Remote sensed data for hydrological modeling is its ability to generate information in spatial and temporal domain (Jagadeesha, 1999), which is very crucial for successful model analysis, prediction and validation.

Hydrological modeling is a powerful technique of Hydrological systems investigation for both the research hydrologist and practicing water resources engineers involved in the planning and development of integrated approach for the management of water resources (Seth et al. 1999).

According to a report by ASCE task committee on GIS modules and distributed models of the watershed (DeBarry et al. 1999), the increase in the availability of data and software for processing spatial information has changed the way people look at hydrological systems. With advances in computational power and the growing availability of spatial data, it is possible to accurately describe watershed characteristics when determining runoff response to rainfall input.

Land cover maps derived from remote sensed images are the basis of hydrological response units for modeling (Seth et al. 1999). For the understanding of the hydrology of areas with little available data, better insight into the distribution of the physical characteristics of the catchment are provided by image processing techniques.

The possibility of rapidly combining data of different types in a geographic information system has led to significant increase in its use in Hydrological applications. One of the typical applications is the use of digital elevation model for extraction of hydrological catchment properties such as elevation matrix, flow direction matrix, ranked elevation matrix and flow accumulation matrix.

From the paper by (De Silva and Taylor, 1999) on spatiotemporal hydrological modeling, people argued that most of the hydrological models are numerical and computer based. They assume some form of spatial averaging process for parameter definition, where as geographic information systems models are well suited for spatial modeling with large and complex databases but have a limitation in temporal variations. Hence GIS and hydrological modeling can be considered as complimentary.

A study by (Stuttard et al. 1995), on monitoring lakes in Kenya: an environmental analysis methodology for developing countries, data modeling techniques were found to be very effective in ensuring the GIS inputs to the hydrological model were correct. Maps were digitized, tabular data capture was carried out for meteorological data, Land sat images, soils and land use maps were integrated. Procedures were devised and implemented for creating a land reference unit (LRU) map and accompanying tables required for input to the hydrological model.

4. Research Approaches and Data Sources

4.1 Data source and availability

Climate data

There are about 9 meteorological stations within the study area and its surroundings monitored by Ethiopian Meteorological Agency. Out of which Bahir Dar and Debre Tabor are first classes while others are second and third class stations. Generally there is data limitation on second and third class stations. The problem is more pronounced on the third classes namely Amed Ber and Gassay. Bahir Dar and Debre Tabor are the only stations where measurements of pitche evaporation, wind speed, humidity and sunshine hour's data are available; the remaining stations contain either rainfall or rainfall and temperature data only.

Stream flow

Majority of the Gumara watershed (88.8%) is controlled by a single gauging station while the remaining small portion of the area 11.2%) remains without it. Since gaged data are vital for model calibration, the gaged part of the watershed is the theme of this research. Gaged data for the River are collected from Ministry of water resources. Five years of daily stream flow data have been used for calibration of the model.

Land feature

GIS Dataset of Soil, Land use and Landover information are available at the ministry of water resource. The data was compiled during master plan study of the Abay river basin study since 1996. The soil data basically contain information of general soil group as per FAO classification. Land use and Landover datasets contain information such as general description of land cover classification, bare area coverage, percentage of impervious area and land use classification.

GIS maps of global soil data are also available from FAO. The FAO-UNESCO Soil Map of the World was published between 1974 and 1978 at 1:5.000.000 scale. GIS layers were derived based on this Soil Map of the World. The legend of the soil map of the World contains information regarding, major soil units, Phases, Textural classes and Slope classes at different layer of soil depth. This data set was acquired from the internet and was used in this research work.

Digital Elevation Model (DEM)

The Shuttle Radar Topography Mission (SRTM) provided a near-global digital elevation model (DEM) of the Earth using a measurement method called radar interferometry. The SRTM was the main payload on the Space Shuttle Endeavour. During the month of February, 2000 it flew for 11 days to conduct a global mapping exercise. During that time the SRTM mapped the continents between 60 degrees North and 56 degrees South latitude, which comprises almost exactly 80% of the total landmass of Earth.

The SRTM data for the world were processed into geographic "tiles," each of which represents one by one degree of latitude and longitude. It is part of the world's first high-resolution, near-global elevation model. The resolution of the publicly released data is three arc-seconds (1/1,200 of a degree of latitude and longitude), which is about 90 meters (295 feet).

Tiles covering the Gumara watershed were taken from Addis Ababa University, GIS and Remote sensing β laboratory. These tiles were merged and clipped in the extent of the watershed boundary and were used to derive catchment morphology and for the purpose of sub-basins delineation.

4.2 Research Approaches

The methodology applied to the rainfall-runoff estimation of Gumara watershed is conducted by integrating GIS and Remote sensing techniques with HEC-HMS hydrologic modeling software. HEC-HMS is a very flexible program that allows the user to choose among different loss rate, sub-basin routing, and base flow models for the sub-basins, as well as different routing methods for the reaches. The HEC_HMS depend on hydrologic parameters that cannot be extracted from readily available spatial data. Hence, to make the spatial data readily available to the model the integration of ArcGIS9.1 with its water resource utility extensions namely APframe work -9, Arc Hydro -9 and HEC-GeoHMs 4.1 v. beta are vital. Using these softwares the determination of the spatial parameters the watershed for HEC-HMS rainfall-runoff modeling is the first precondition to accelerate the process. The process of generating input data for the basin component and the overall activities of the research is set here in the diagram below.

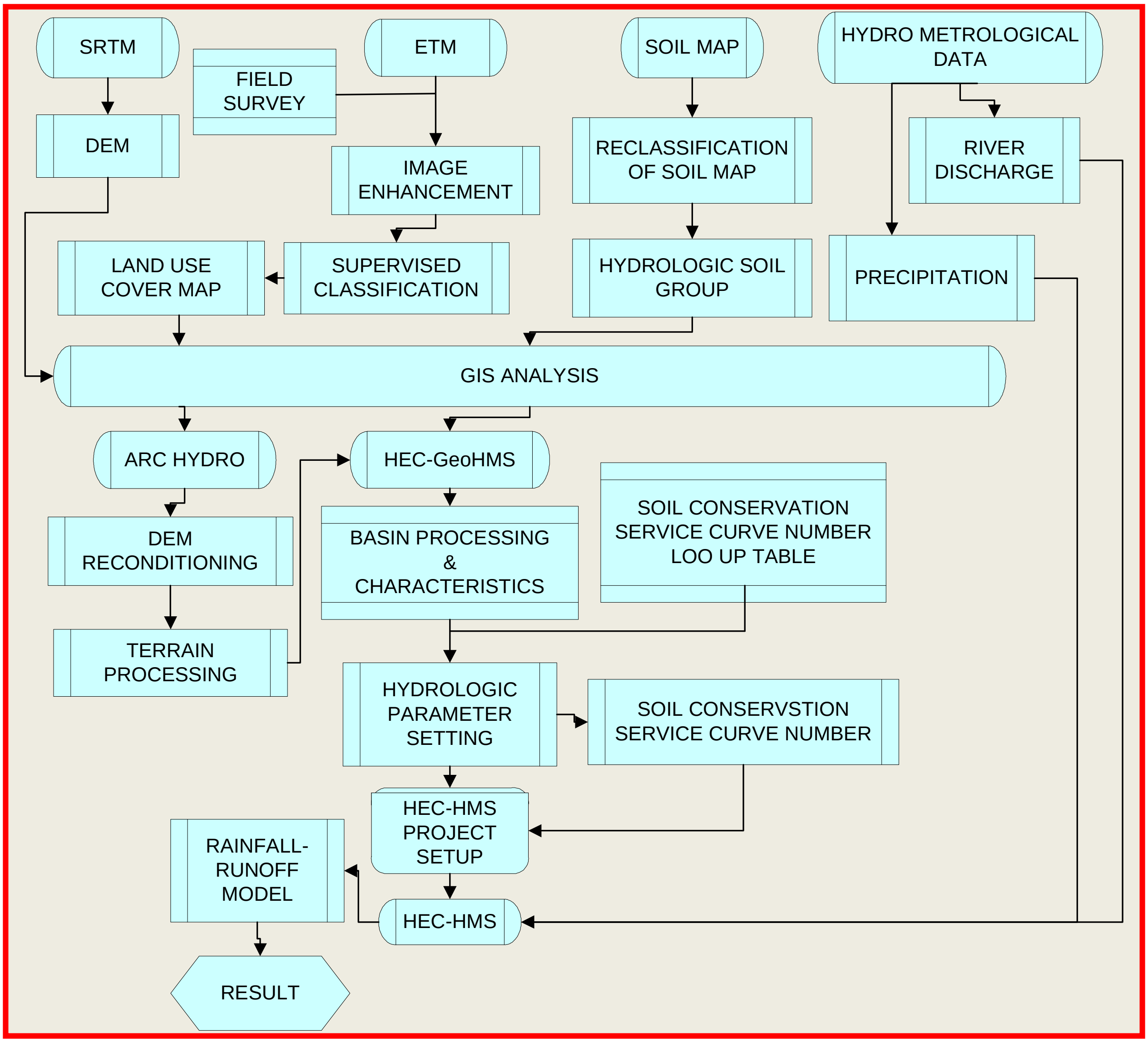


Figure 7. Schematic diagram showing the overall research methodology approach.

4.3 Data Analysis

4.3.1 Climate data analysis

Rainfall

Most of the rainfall recorded from the stations has missing data ranging from 10 to 50 %. Therefore before using the data to runoff modeling it was first essential to apply a gap filling techniques.

The technique that is used to fill the missing data gaps was through the use of multiple regression techniques from nearby stations. After the missing gaps are filled and the short records are extended, with the procedure mentioned above, the point rainfall was then converted to spatial rainfall by using Thiessen polygon method

Using Empirical Formula

The missed rainfall amount for a day or less from the rain gage stations were estimated by the formula

$$p_x = \frac{p_1 + p_2 + p_3}{3}$$

(i) (Provided N_1, N_2, N_3 differs with in 10%of N_x)

$$p_x = \frac{p_1 Nx}{N_1} + \frac{p_2 Nx}{N_2} + \frac{p_3 Nx}{N_3}$$

(ii) (Provided any of N_1, N_2, & N_3 differs from N_x by more than 10%)

Where:

- N_1, N_2, N_3 & N_x represents the average annual rainfalls at a station 1, 2, 3, and x respectively.
- P_1, P_2, P_3, and P_x represents their respective precipitation data of the day for which the data missing at station x.

To apply the above empirical formula, three rain gage stations as close to and as evenly spaced around the station with the missing record (i.e. station x) as possible are first of all chosen. The rainfall data for these three stations (i.e. 1, 2, & 3) on the day for which the data at station x is missing are now collected. The average annual rainfall values at all the four stations should also been known. Now if the average annual rainfall at each of these three index station x (i.e. the station with missing data), then a simple arithmetic average of the precipitation (corresponding to the missing precipitation) at the three index stations will give as the estimated quantity.

Multiple Regression Analysis

For rainfall data missing from a station for a month or months and even for years will be estimated and filled by applying multiple regression analysis with other nearby gaging station. Hence, the best fit and highly correlated rainfall data of the accounted station were used for the missed period.

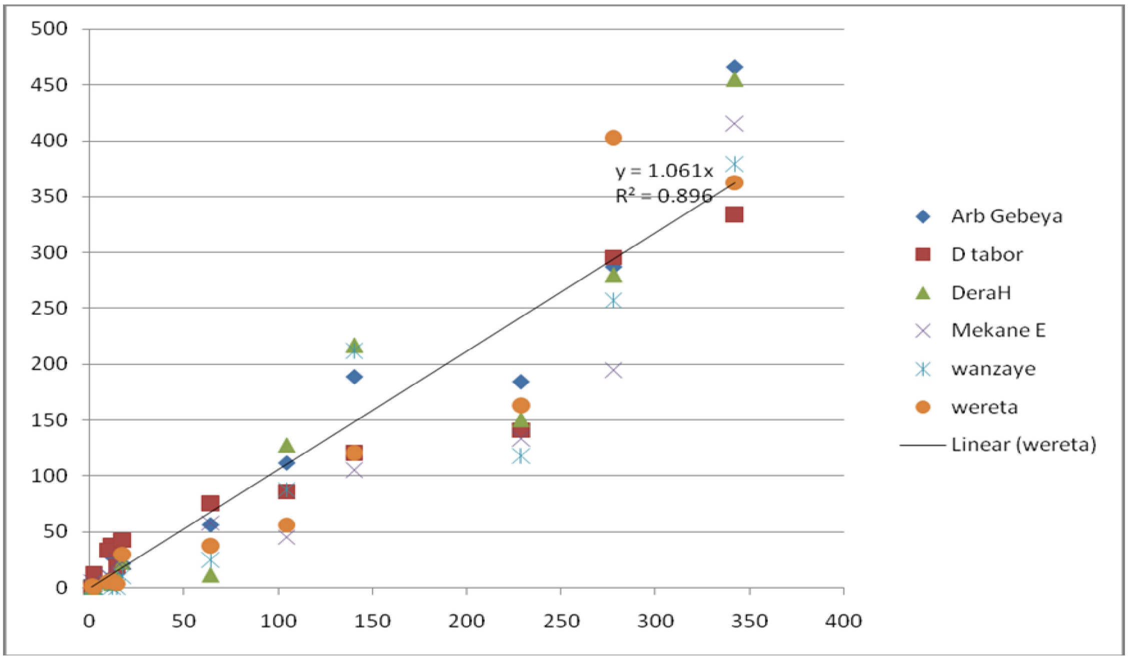


Figure 8: Regression graph of meteorological stations

Thiessen's Mean Method

In a drainage basin rain catch at one station may be different from that of a second station in the same basin. An average value of these rain catches is worked out, so as to get an idea of average precipitation on the entire basin. For this research work to calculate the aerial rainfall of the basin Thiessen's polygon mean method were used. In this method adjacent stations are joined by straight lines, thus dividing the entire area in to a series of triangles. Perpendicular bisectors are erected on each of these lines, thus forming a series of polygons each containing one and only one rainfall station. It is assumed that the entire area within any polygon near to the rainfall station that is included in the polygon than to any other rainfall station. The rainfall recorded at that station is, therefore, assigned to that polygon. If p is the mean rainfall on the basin, and area of the basin is A, then

$$P = \frac{A_1 p_1 + A_2 p_2 + \ldots + A_n p_n}{A}$$

, (iii) where P_1, P_2, …pn represent rainfalls at respective stations, whose surrounding polygons have an areas of A_1, A_2, …An respectively.

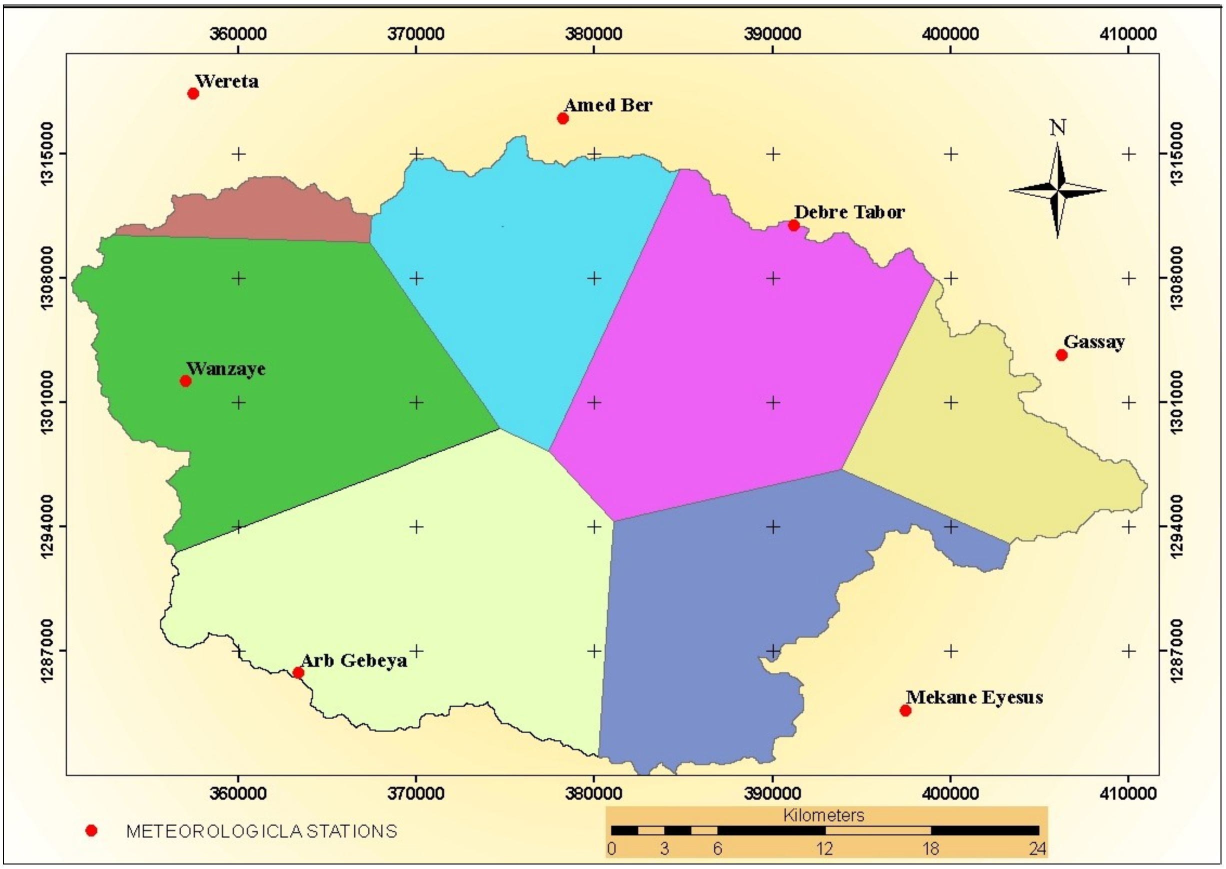


Figure 9. Thiessen polygon.

Temperature, Humidity, Wind speed, sunshine hours

Other available and collected meteorological data records in the study area include air Temperature records available from the two first class stations of Bahir Dar and Debre Tabor; humidity ,wind speed and sunshine hour records. These daily Climate record values were converted to aerial extents (by using their average value) and were later aggregated into the smallest unit of sub-basin division.

4.3.2 Soil data analysis

The soil resource data of the basin is classified in to different hydrologic soil groups by using look up tables (i.e. internationally developed hydrological soil group classification tables). Hydrologic soil groups are group of soils having similar runoff potential under similar storm and cover conditions. Soil properties that influence runoff potential are those that influence the minimum rate of infiltration for a bare soil after prolonged wetting and when not frozen. These properties are depth to a seasonally high water table, intake rate and permeability after prolonged wetting, and depth to a very slowly permeable layer

Based on this information Hydrological soil group was assigned for each soil type which is later used for computation of Curve Number (CN) to be used in the SCS method of runoff estimation. The hydrologic group designation for any soil type can be either A, B, C, or D, where the runoff potential increases from A to D. The following table summarizes the assigned hydrological soil group based on the soil physical property.

Major Soil	Area(m^2)	%	Soil Texture	Drainage Condition	HSG
Chromic Luvisols	347551488.1	25.74	Clay	moderately well to well drained	B
Eutric Fluvisols	56142952.65	4.16	Silty clay	Moderately well drained	B
Eutric Leptosols	115070721.1	8.52	Clay loam to clay	Moderately deep to deep	C
Haplic Luvisols	828684657.5	61.37	clay to Silty clay	well drained	B
Urban	2812621.46	0.21			D

Table 1.Major soil groups.

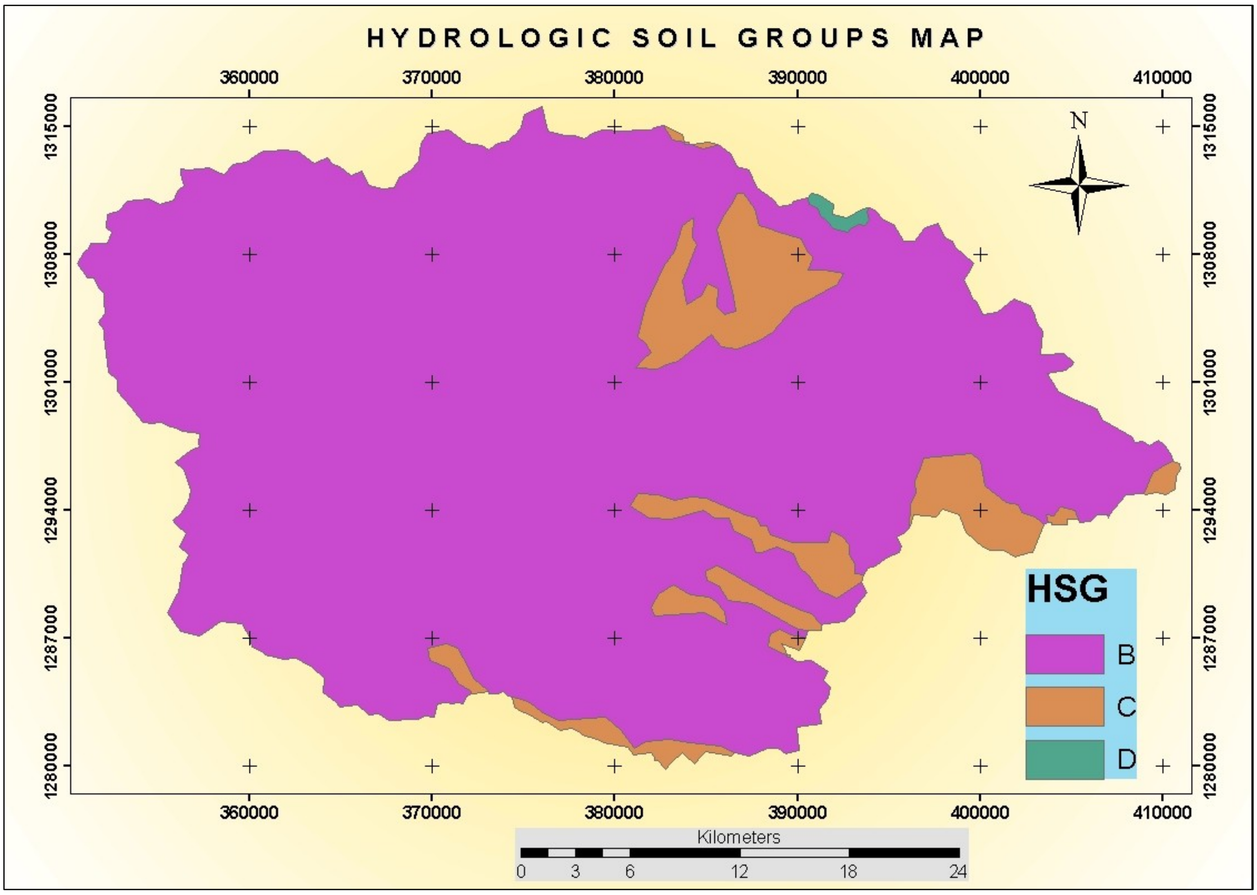


Figure 10. Hydrological soil group.

4.3.4 Land Use /Land cover data

Land use change is one of the major reasons for variations in the hydrological parameters of a watershed. Since the basin is an agricultural catchment there is dynamic land use/cove condition. With the information derived from remotely sensed data and conventional data stored in a GIS, land cover change and its impacts was dentified

Land use and Land cover information are equally useful as the soil data and hence accurate identification of land use and land cover information has a major impact on the runoff estimation result. In addition to the available land use land cover data that is obtained from the ministry of water resources, further validation and correction has been carried out with the help of LandSat ETM images.

Hybrid classification technique (supervised and unsupervised) was applied and the Landsat image was classified according to the pixel values.. Finally, a modified land use and land cover maps were produced

4.3.5 Estimating CN Values for Each Sub Basin

Soil Conservation Service Curve Number is used to account for spatial variability of runoff potential across the watershed. It describes the surfaces potential for generating runoff as a function of the soil type and land use present across the surface.

The Soil Conservation Service Curve Number (SCS CN) method is an efficient and widely used method for determining the direct runoff (effective rainfall) from a storm event for flood disaster assessment (rainfall-runoff modelling). The CN can be estimated based on the area's hydrologic soil group (HSG), land use/cover, and hydrologic condition.

The CN value of the watershed was determined by using the United States SCS (Soil Conservation Service, now called the Natural Resources Conservation Service) Runoff Curve Number (CN) method, it is the most popular method for computing surface runoff (USDA 1986, Burges *et al.*1998). Given its perceived advantages (simplicity, predictability and stability), this method has been widely used in many countries and successfully applied to situations ranging from simple runoff calculation, land use change assessment, to comprehensive hydrologic/water quality simulation (Burges *et al.* 1998).

The land use land cover data of the basin, along with the soil information obtained has been used while producing the polygon runoff curve number for the entire sub-basin.

Later the CN values were summarized to a single mean value for a sub-catchment using the spatial analysis. In sub-catchments where more than one soil groups are identified, and hence CN, the runoff curve numbers (CN) is determined by linear interpolation as suggested in

Engineering Manual SCS method The final output of CN values corresponding to major sub-basin is presented in the map below.

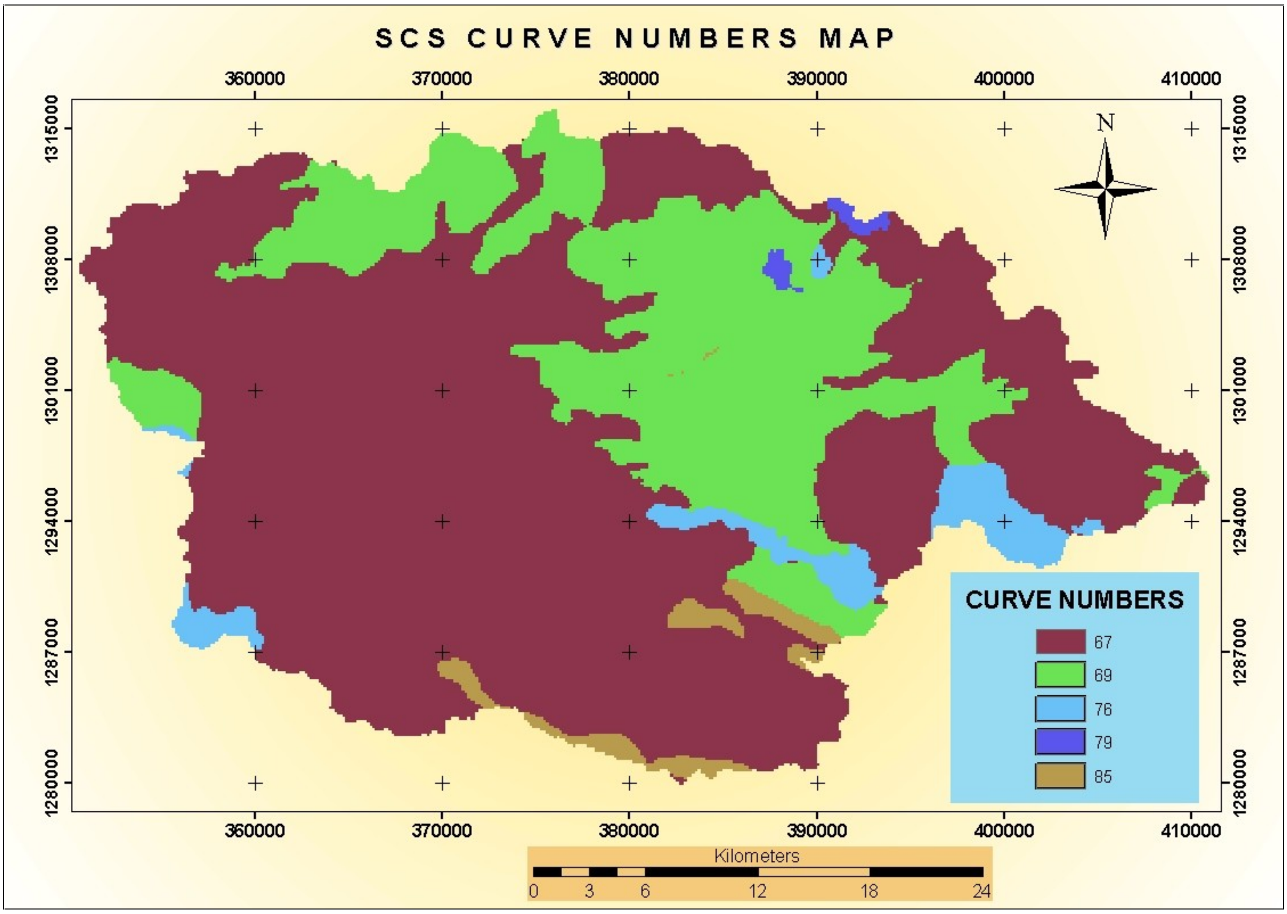


Figure 11. Soil Conservation Service Curve Number Map.

4.4 Input Data for the HEC-HMS Basin Component

The process of generating input data for the basin component has been divided into six conceptual modules: (1) raster-based terrain analysis; (2) raster-based sub-basin and reach network delineation; (3) vectorization of sub-basins and reach segments; (4) computation of hydrologic parameters of sub-basins and reaches; (5) extraction of hydrologic sub-basin (6) topologic analysis and preparation of the HEC-HMS basin file.

4.4.1. Raster-Based Terrain Analysis

Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) with spatial resolution of approximately 90 meter were obtained and pre-processed to fill missing void pixels and to geometrically correct into the required projection. This data was then used to identify the watershed geometry and the drainage pattern of the study area

ArcHydro utility was used to delineate the catchments in to selected spatial resolution and based on specified watershed division points. It is a GIS based geospatial and temporal data model for water resources. ArcHydro is a Geodatabase design and a set of accompanying tools geared for support of water resources applications in GIS environment**Error! Reference source not found.**. These tools can be used to process DEM data to produce watershed and drainage pattern networks.

The ArcHydro toolset has been developed jointly by ESRI and CRWR. It has five menus. This work does not use the Watershed Processing tools. All other tools used for this project are discussed below

Figure: ArcHydro Toolset

Terrain Pre-processing

It is used to pre-process the raw DEM for further analysis. The main steps are – DEM reconditioning, Fill sinks, Flow Direction, flow accumulation, stream definition, stream segmentation, catchment grid delineation, catchment polygon processing, drainage line processing and adjoint catchment processing.

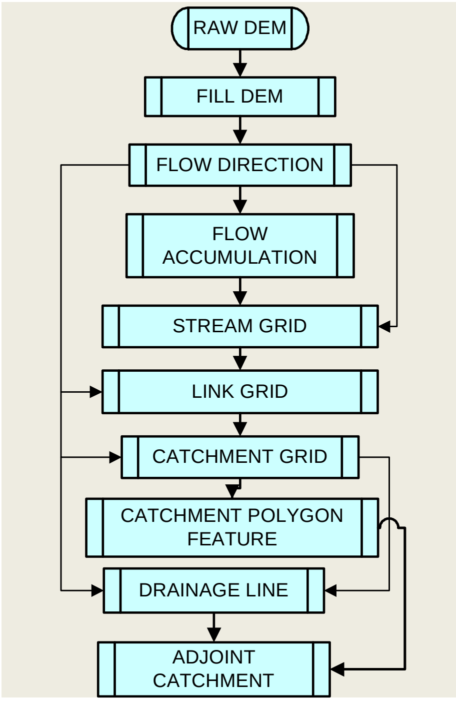


Figure 12. Steps in Terrain processing.

DEM reconditioning: The DEM reconditioning, also referred to as 'burning the DEM with the stream' is done to raise the elevation of the cells that surround the stream. This is done to ensure that all the water that falls on the basin is captured by the stream and the stream follows the same path as in a topographic map.

Fill Sink: The Fill sinks tool fills all the sinks in the reconditioned DEM. A sink is defined as any cell that has a value less than all its surrounding eight cells. Its value is raised to the value of the lowest surrounding cell. The flow direction tool assigns a value of flow direction to each cell in the grid according to the eight direction pour point method. The directions and values are as shown in Figure 10 below.

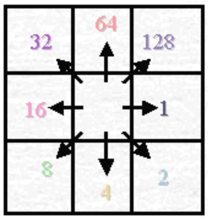


Figure 13.Eight pour point method for Flow Direction assignment.

Flow Direction: The Flow Direction function takes a grid ("Hydro DEM" tag) as input, and computes the corresponding flow direction grid ("Flow Direction Grid" tag). The values in the cell of the flow direction grid indicate the direction of the steepest descent from that cell.

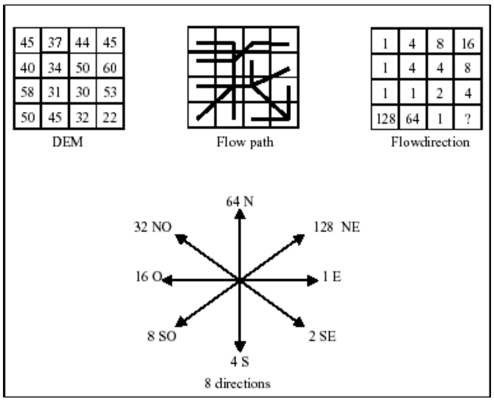


Figure 14.Flow direction

Flow accumulation: The Flow Accumulation function (Terrain Preprocessing menu) takes as input a flow direction grid ("Flow Direction Grid" tag). It computes the associated flow accumulation grid ("Flow Accumulation Grid" tag) that contains the accumulated number of cells upstream of a cell, for each cell in the input grid.

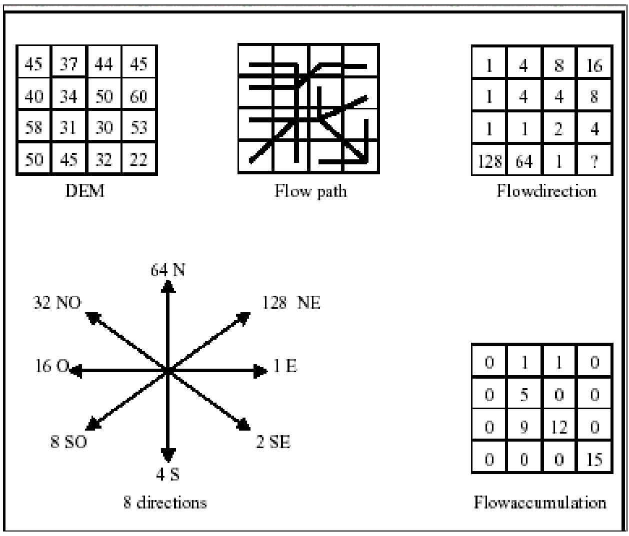


Figure 15.Flow accumulation.

Stream definition: The Stream Definition function (Terrain Preprocessing menu) takes a flow accumulation grid ("Flow Accumulation Grid" tag) as input and creates a Stream Grid ("Stream Grid" tag) for a user-defined threshold. This threshold is defined either as a number of cells (default 1%) or as a drainage area in square kilometers.

This initial stream definition (and related Catchments definition) has no meaning for later basin processing (except for performance during the extraction stage), since all parameters can be changed. In general, the recommended size for stream threshold definition (which in turn defines the sub basin delineation during pre-processing) is 1% of the overall area. For increased performance on large DEMs (over 20,000,000 cells), the size of the threshold may be increased to reduce the stream network and the number of catchments polygons.

Stream Segmentation: The Stream Segmentation function (Terrain Pre-processing menu) creates a grid of stream segments that have a unique identification. Either a segment may be a head segment, or it may be defined as a segment between two segment junctions. All the cells in a particular segment have the same grid code that is specific to that segment. If there is a grid theme that has a tag "Link Grid", it will be used as a default for the output grid. If not, the user needs to specify a grid name that will be tagged with the "Link Grid" tag at the end of the operation. If the output grid already exists, the user is prompted whether to remove the existing dataset.

Catchment grid: The Catchment Grid Delineation function (Terrain Preprocessing menu) creates a grid in which each cell carries a value (grid code) indicating to which catchment the cell belongs. The value corresponds to the value carried by the stream segment that drains that area, defined in the stream segment link grid.

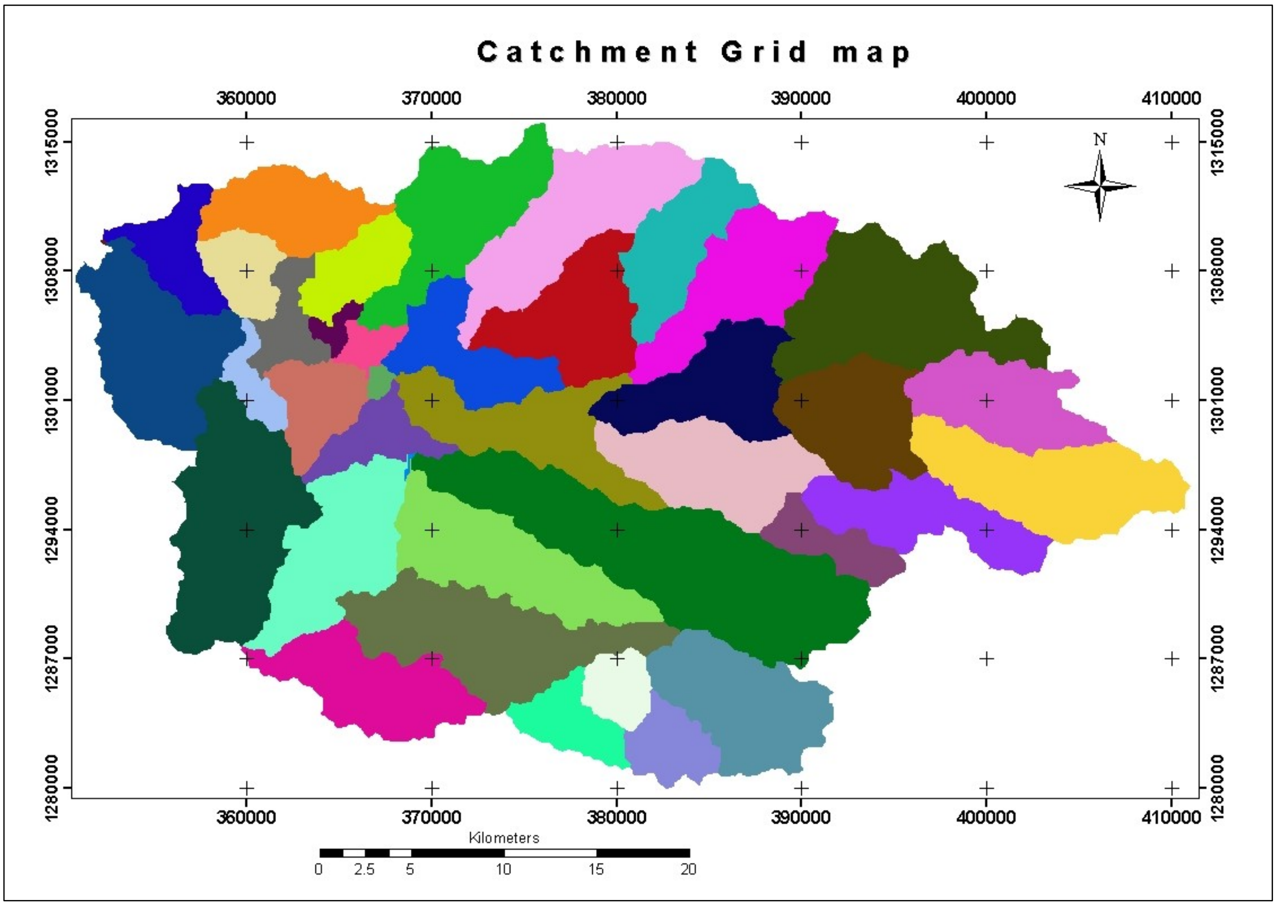


Figure 16. Catchment grid map.

Catchment polygon*:* The Catchment Polygon Processing function (Terrain Preprocessing menu) takes as input a catchment grid (‘Catchment Grid" tag) and converts it into a catchment polygon feature class ("Catchment" tag). The adjacent cells in the grid that have the same grid code are combined into a single area, whose boundary is vectorized. The single cell polygons and the "orphan" polygons generated as the artifacts of the vectorization process are dissolved automatically, so that at the end of the process there is just one polygon per catchment.

Drainage line Processing: The Drainage Line Processing function (Terrain Preprocessing menu) converts the input Stream Link grid into a Drainage Line feature class. Each line in the feature class carries the identifier of the catchment in which it resides.

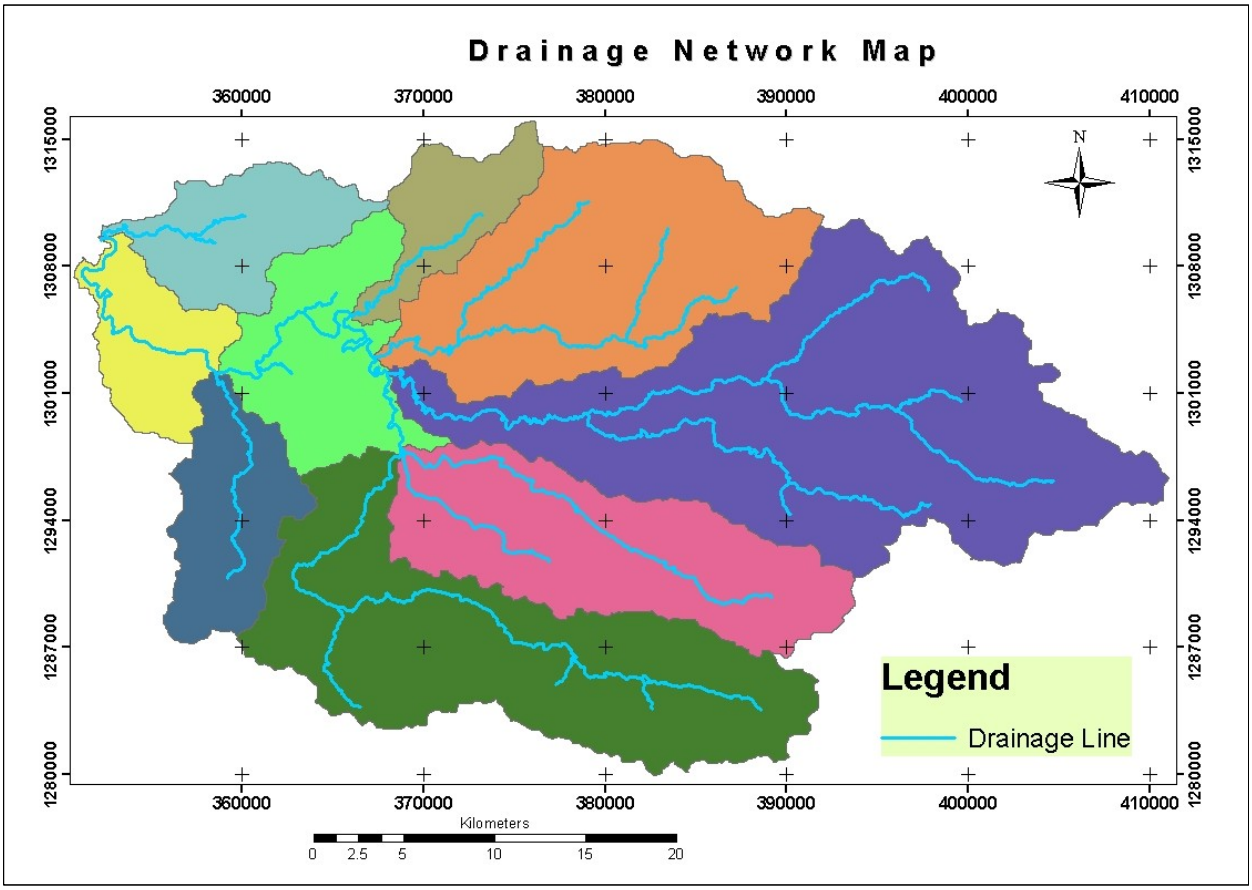


Figure 17.Drainage map.

Adjoint Catchment processing: The Adjoint Catchment Processing function (Terrain Preprocessing menu) generates the aggregated upstream catchments from the "Catchment" feature class. For each catchment that is not a head catchment, a polygon representing the whole upstream area draining to its inlet point is constructed and stored in a feature class that has an "Adjoint Catchment" tag. This feature class is used to speed up the point delineation process.

4.4.2 Raster-Based Sub-Basin and Reach Network Delineation

HEC-GeoHMS is a set of Geographic Information System (GIS) procedures, tools, and utilities that allow the user interactive data management and processing for use in HEC's Hydrologic Modeling System (HEC-HMS). It allows the user to interactively delineate subbasins from a DEM and calculates physical characteristics used for computation of hydrologic parameters. The GIS subbasin and stream themes are then used to generate hydrologic schematic from which input files for HEC-HMS can be generated. GeoHMS is not a replacement for HEC-HMS data editor, but rather it supplements it by providing simple export of spatial data about the hydrologic system that can be obtained from GIS. HEC-HMS still needs to be used to define which hydrologic techniques to use, to enter hydrologic parameters, and to define the model runs. GeoHMS does not provide any custom tools for HEC-HMS results processing.

GeoHMS is an extension to be used with ArcGIS (version, 9.1) with Spatial Analyst Extension. Other required components are defined in the installation package.

The HEC-GeoHMS Main View toolbar contains functions allowing defining and generating Geo-HMS projects. These functions are available in the HMS Project setup menu and as tools on the toolbar.

The HMS Project Setup menu (Main View toolbar) contains a set of functions allowing defining and generating a new project.

Geo-HMS manages the input/output to the tools by using tags that are automatically assigned by the functions to the selected inputs and outputs. A tag may be used as input by one function and as output by another one. For example, the "Project Point" tag is an output from Start New Project, and an input to Generate Project.

The Data Management function in the Main View toolbar provides a global view of the tags assignments for that menu in the active Map/Data Frame. The function also allows assigning, reassigning or resetting the tags. A tag may be reset by selecting "Null" as the corresponding layer. When a reset tag is used as output, the function presents the user with default layer name associated to the tag.

The DEM cells that form the reaches are defined as the union of two sets of grid cells. The first set consists of all cells whose flow accumulation is greater than a user-defined threshold value. This set identifies the reaches with the largest drainage area, but not necessarily with the largest flow because flow depends on other variables that are not related exclusively to topography. The second set is defined interactively by the user by clicking on a certain point on the map, which results in an automatic selection of all downstream cells. This capability allows the user to select a particular reach, which might have a small drainage area (low flow accumulation), without having to lower the threshold value for the entire system and defining unnecessarily a denser reach network. After the reach cells have been defined, a unique identification number or grid code is assigned to each reach segment.

Sub-basin outlets are also defined as the union of two sets of grid cells. The first set, based on the reach network, consists of all cells located just upstream of the junctions. Consequently, at a junction, two outlet cells are identified, one for each of the upstream branches. The system outlet is also identified as a sub-basin outlet. Since these outlets are the most downstream cells of the reach segments, their identification number or grid code is the same as their corresponding reach segment. The second set is defined interactively by the user by clicking on any cell of the reach network, such as those associated with flow gages, reservoirs or other water control points. The identification number or grid code of each new interactively-defined outlet is obtained by adding one to the highest grid code value available. Reach segments containing interactively-defined outlets are subdivided at the clicked cells, so that the new segments -- upstream of the new outlets -- are assigned the same grid code as their corresponding new outlet. Outlets associated with reservoirs can be identified so that HEC-HMS recognizes them as both, reservoirs and sub-basin outlets.

At this point, a one-to-one relation between reach segments and sub-basins is maintained because a unique sub-basin outlet has been identified for each reach segment. Due to this one-to-one relation, sub-basin and reach segment grid codes are equal.

HEC-GeoHMS provides an integrated work environment with data management and customized toolkit capabilities, which includes a graphical user interface with menus, tools, and buttons. The program features have terrain-preprocessing capabilities in both interactive and batch modes. Additional interactive capabilities allow users to construct a hydrologic schematic of the watershed at stream gages, hydraulic structures, and other control points. The hydrologic results from HEC-GeoHMS are then imported by the Hydrologic Modeling System, HEC-HMS, where simulation is performed. **HEC-GeoHMS** is now included on the HEC-HMS, HEC-Combo Pack or HEC-Works CDs (including all three Program Manuals in PDF format) at no additional cost.

4.4.3 Vectorization of Sub-Basins and Reach Segments

Because HEC-HMS applies lumped models within each hydrologic element, hydrologic parameters have to be calculated for the sub-basins and reach segments, and not for the individual grid cells. After the reach segments and their corresponding drainage areas have been delineated in the raster domain, a vectorization process is performed using raster-to-vector conversion functions. This process consists of creating a polylines feature data set of reaches, and a polygon feature data set of sub-basins. When doing so, the grid code values are transferred to the attribute tables of the feature data sets, thus preserving a way to directly link sub-basins and reaches. Further vector processing, i.e., merging of dangling polygons, might be necessary to ensure that each sub-basin is represented by a single polygon, and that the one-to-one reach/sub-basin relation established in the raster domain is preserved in the vector domain (Olivera et al. 1998a).

The one-to-one reach/sub-basin relation, though, can be relaxed by merging adjacent sub-basin polygons, so that a sub-basin contains more than one reach. In such a case, a new field is necessary in the attribute table of the reaches to account for the grid code of the sub-basin in which the reach is located after merging polygons. For merging two sub-basins, the polygons have to share the same outlet or drain one towards the other. Figure 6 shows the merging of two sub-basins that share the same outlet, as well as the attribute tables of the sub-basin and reach network data sets before and after the merging.

HEC-GeoHMS also has the capability of identifying, for each sub-basin polygon, all the sub-basin polygons located upstream of it, so that they can be easily retrieved when delineating a watershed from a point.

4.4.4 Computation of Hydrologic Parameters of Sub-Basins and Reaches

The sub-basin parameters calculated by HEC-GeoHMS 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. Depending on the method selected, the average curve number can be used to calculate the sub-basin lag-time and the sub-basin loss rate.

CN is calculated as the average of the curve number values within the sub-basin polygon. A curve number grid is calculated using land use data described by Anderson land use codes, percentage of hydrologic soil group (A, B, C and D) according to FAO soils data, and a look-up table that relates land use and soil group with curve numbers

Loss rate in the sub-basins can be calculated with either of the following methods: the SCS curve number method for which the average curve number is calculated, or the initial plus constant loss rate method for which the initial and constant rate values have to be supplied by the user. It is likely that in a near future it will be possible to establish a relation between terrain properties and loss rate parameters.

4.4.5 Extraction of Hydrologic Sub-System

Extraction of a hydrologic sub-system consists of detaching from the overall study area a set of sub-basin polygons and corresponding reach polylines for further hydrologic analysis with HEC-HMS.

Sub-systems can be defined either by: (1) manually selecting the sub-basin polygons, or (2) manually selecting the most downstream sub-basin polygon (and automatically selecting the sub-basin polygons of its contributing drainage area).

The first method is more flexible, although more tedious to implement. It has no restriction on the polygons that can be selected, and supports the use of inlets (sources according to the HEC-HMS terminology) to represent areas draining to the sub-system. Reach polylines contained within -- as well as those draining towards -- the selected polygons are selected automatically. Reach polylines draining towards the selected polygons are used to identify the sub-system inlets.

The second method is less flexible, but easier to implement. After manually selecting the downstream sub-basin polygon, it automatically identifies and selects all the sub-basin polygons located upstream, and consequently does not support the use of inlets. Reach polylines contained within the selected polygons are selected automatically. This method is convenient when dealing with a significant number of polygons in the study area

4.4.6 Topologic Analysis and Preparation of HEC-HMS Basin File

Establishing the topology of the hydrologic system consists of determining the element located downstream of each element. Since the HEC-HMS hydrologic schematic allows only one downstream element, no ambiguity is introduced in this process. After establishing the system topology based on the sub-basin and reach data sets, an ASCII file -- readable by HEC-HMS -- is used to record the type (i.e., sub-basin, reach, source, sink, reservoir or junction), hydrologic parameters, and downstream element of each hydrologic element of the system. A background map file -- also readable by HEC-HMS -- is used to graphically represent sub-basins and reaches, and ease the identification of hydrologic elements. These files constitute the input to the basin component of HEC-HMS.

This basin file, when opened with HEC-HMS, generates a topologically correct schematic network of hydrologic elements and displays it in the HEC-HMS - Schematic window together with the background map.

4.5 User-Specified Gage Weighting

Sub-basin precipitation time series are calculated as the weighted average of gage precipitation time series. For this purpose, a set of weights that capture the relative importance of the precipitation at each gage on the precipitation of each sub-basin is calculated. Precipitation time series at the gages are stored in Data Storage System (DSS) format (HEC 1995). Figure 14 shows precipitation data in text format.

Given a set of points that represent gages for which precipitation time series are known, 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 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. 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

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

To calculate these parameters, three data sets are defined: (1) sub-basin polygons, (2) precipitation cell polygons, and (3) flow length downstream to the sub-basin outlet grid. Sub-basin polygons are intersected with precipitation cell polygons yielding a new set of polygons, which are complete cells in case they were completely within a subbasin, or fractions of cells in case they were partially contained by two or more sub-basins. Each of these new polygons is called GridCell, and is related to one (and only one) sub-basin polygon. The average distance from the GridCell to the sub-basin outlet is calculated as the mean of the flow-length grid values within the GridCell.

After establishing the Grid Cell parameters, an ASCII file -- readable by HEC-HMS -- is used to record the sub-basin and Grid Cell information. The sub-basin information consists of the sub-basin name. The Grid Cell information consists of the location, area and distance to the sub-basin outlet.

4.6 Rainfall-Runoff Modeling Processes

4.6.1 The HEC-HMS Model

The primary, basic hydrologic model was composed with the help of the HEC-GeoHMS interface of Arc GIS 9.1 software using DEM of the region. The Gaged watershed was divided into 10 sub-basins (shown in

Figure 18) representing the main tributaries of the Gumara river. Then it was supplemented by suitable models of the catchment's components as follows:

• Models that compute runoff volume (loss rate): SCS Curve number

• Models of direct runoff (overland flow and interflow transform): SCS Unit Hydrograph

• Models of base flow: Recession

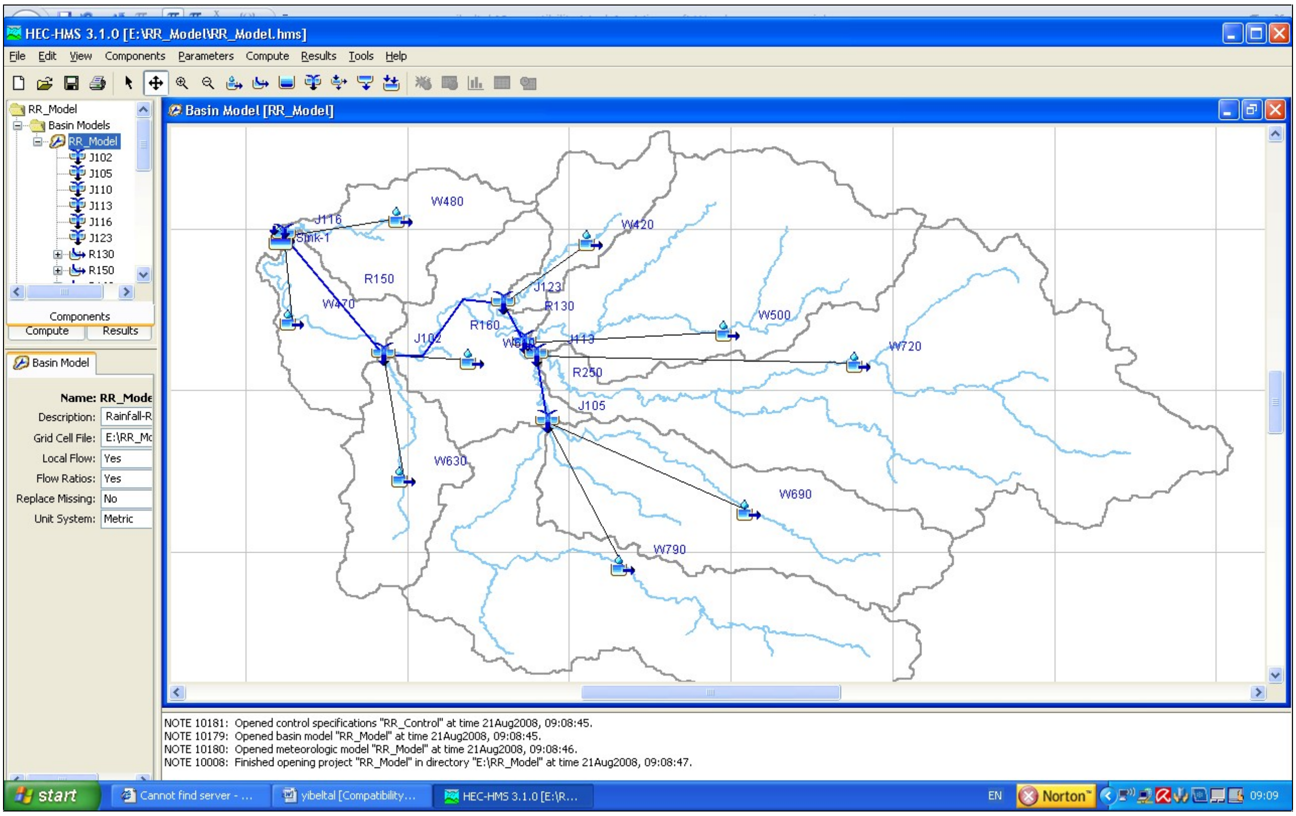


Figure 18: Gaged watershed model in HEC-HMS software window

The HEC-HMS model provides a variety of options for simulating precipitation-runoff processes. The hydrologic elements are arranged in a dendritic network, and computations are performed in an upstream-to-downstream sequence. Computations are performed in SI units. The execution of a simulation requires the specification of three sets of data. The first, labelled *Basin Model* contains parameter and connectivity data for hydrologic elements; types of elements are:

sub-basin, routing reach, junction, reservoir, source, sink and diversion. The second set, labelled *Precipitation Model* consists of meteorological data and information required to process them. The model represents historical or hypothetical conditions. The third set, labelled *Control Specifications* specifies time-related information for the simulation. A project can consist of a number of data sets of each type. A "run" is configured with one data set for basin model, precipitation model and control specifications.

To transfer the generated data layers as shape files into the HEC-HMS interface, the HEC-GeoHMS interface on ArcGIS software was used. The HEC-GeoHMS utility, on Arc GIS software interface, was designed and developed to extract topographic, topologic and hydrologic information from digital spatial data of a hydrologic system.

4.6.2 MODEL APPROACH

The model approach used to determine the runoff volume was the SCS-CN method (SCS, 1972). With this method, the precipitation excess is a function of cumulative precipitation, soil type, land use/cover and antecedent moisture. Considering the initial loss and the potential maximum retention, the precipitation excess can be calculated; the maximum retention and the basin characteristics are related through the curve number. The standard SCS curve number method is based on the following relationship between rainfall depth, P, and runoff depth, Q (USDA, 1986; Schulze et al., 1992):

$$Q = \frac{(P - 0.2\,S)^2}{(P + 0.8\,S)} \quad \text{for P > 0.2 S; otherwise Q = 0}$$

$$S = \frac{25400}{\text{CN}} - 254 \quad \text{(in mm)}$$

$$I_a = 0.\,2\,S$$

Where: *Q* is the surface runoff (mm), *P* is the precipitation, *S* is the soil retention (mm), I_a is the initial loss (mm), and, CN is the curve number.

To obtain volumes, *P* and *Q* (in millimetres) must be multiplied by the basin area. The potential maximum retention (*S*) represents an upper limit for the amount of water that can enter the basin through surface storage, infiltration, and other hydrologic losses. For convenience, *S* is expressed in terms of a CN, which is a dimensionless basin parameter ranging from 0 to 100. A CN of 100 represents a limit condition for a perfectly impermeable basin with zero retention, where all the rainfall becomes runoff. A CN of zero conceptually represents the other extreme, with the basin trapping all the rainfall with no runoff regardless of the rainfall amount. The basin parameter CN can be determined from empirical information. The SCS has developed tables of initial curve number (CNi) values as a function of the basin soil type and the land cover/use/condition. These are listed in Schulze *et al.* (1992). The hydrologic soil groups are defined in accordance to the standard SCS soil classification procedures.

To determine how the runoff is distributed over time we must introduce a time-dependent factor. The time of concentration (*t*c) is used in the SCS methods. The *t*c is most often defined as the time required for a particle of water to travel from the most hydrological remote point in the basin to the point of collection. There are several methods available for calculating *t*c, one of them is the SCS

Lag Method

$$t_L = \frac{L^{0.8}[\ (1000/CN) - 9\ ]^{0.7}}{1900 S^{0.5}}$$

$$t_c = 1.67\ t_L$$

4.6.3 INPUT DATA FOR THE HEC-HMS BASIN MODEL

The following procedure was adopted to construct a basin model for Gumara watershed. The first step is preparing a Digital Elevation Model (DEM), from the SRTM data of the region. The DEM data include pits or ponds that should be removed before being used in hydrological modeling. These are cells where water would accumulate when drainage patterns are being extracted. Pits are a sign of errors in the DEM arising from interpolation. These pits were removed by an algorithm known as SINK filling. This algorithm is built in the interface of the ARC Hydro utility.

After filling the DEM sinks, a flow direction map was computed by calculating the steepest slope and by encoding into each cell the eight possible flow directions towards the surrounding cells. Flow direction is then used to generate the flow accumulation map. The flow accumulation, generated by addressing each cell of the DEM, counts how many upstream cells contribute to flow through the given cell. Flow direction and accumulation maps are then used to delineate the stream network. The stream network can be divided into segments, which will determine the outlets of the basin. The generated stream network has a dendritic shape of third order.

The last step is the basin delineation process, which depends on the generated flow direction and accumulation map. Furthermore, it also depends on a user-specified number known as threshold. This threshold determines the minimum number of pixels within each delineated sub-basin.

4.6.4 COMPUTATION OF HYDROLOGIC PARAMETERS

The sub-basin parameters (area, lag-time and average curve number) were calculated with the HEC-GeoHMS utility. Other parameters, needed for estimating the lag-time, such as length and slope of the longest flow path, were also calculated and stored in the sub-basin attribute table. These files, when opened in HEC-HMS, automatically create a topologically correct schematic network of sub-basins and reaches with hydrologic parameters.

The following procedure was adopted to construct the rainfall-runoff model for the Gumara watershed. A schematic representation of the watershed network was created by dragging and dropping icons that represent hydrological elements, and connections between them were established. The hydrologic parameters for each sub-basin were entered using HEC-HMS sub-basin editor; required data consist of sub-basin area, loss rate method (SCS-CN method was used), transform method (SCS Unit Hydrograph method was used), and base flow method (Recession method). Considering that the time span of the storm event was short, it was assumed that evapotranspiration was zero.

A precipitation model is the next component of the HEC-HMS model. Gage weighting. The watershed precipitation depth was inferred from the depths at gage using an averaging scheme.

The method that was used for determining the gage weighting factors for mean area precipitation depth computation is the Thiessen polygon method. This is an area-based weighting scheme, based upon an assumption that the precipitation depth at any point within a watershed is the same as the precipitation depth at the nearest gage in or near the watershed. Thus, it assigns a weight to each gage in proportion to the area of the watershed that is closest to that gage.

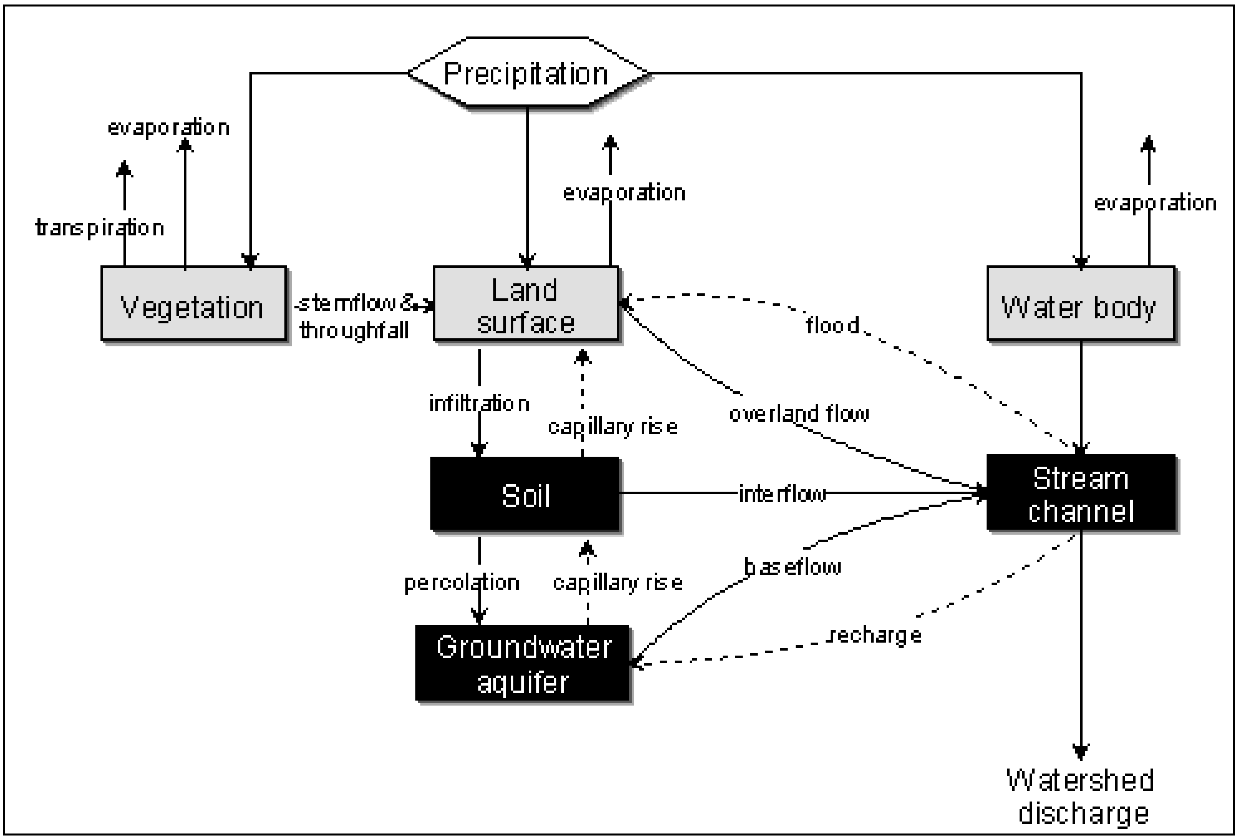


Figure 19: Systems diagram of the runoff process at local scale(after Ward, 1975)

4.6.5 MODEL CALIBRATION AND OPTIMIZATION

Model calibration is an essential process needed to assure that the simulation outputs are close to real observations. Once a model was developed and simulated for the initial parameter estimates, it was calibrated against known discharge runoff rates measured at the gaging station during a storm event that occurred between selected time events. The available hydro-climatic records of 9 meteorological stations and 1 stream flow gage stations were analyzed for selection of calibration and verification data for the HEC-HMS model. The calibration was done using daily data for the time period Jan 01, 2001 – Dec 31, 2005.

The model calibration was done by adjusting the curve number values until the results matched the field data. The process was completed manually by repeatedly adjusting the parameters, computing, and inspecting the goodness of fit between the computed and observed hydrographs. The process can also be done automatically by using the iterative calibration procedure called optimization. The measure of the goodness of fit is the objective function (Kathol *et al.*, 2003). HEC-HMS allows the user to calibrate the model to the best-fit condition by selecting various objective functions to provide the best calibration results (HEC, 2005). The objective function measures the variation between computed and observed hydrographs, and is equal to zero when the hydrographs are identical.

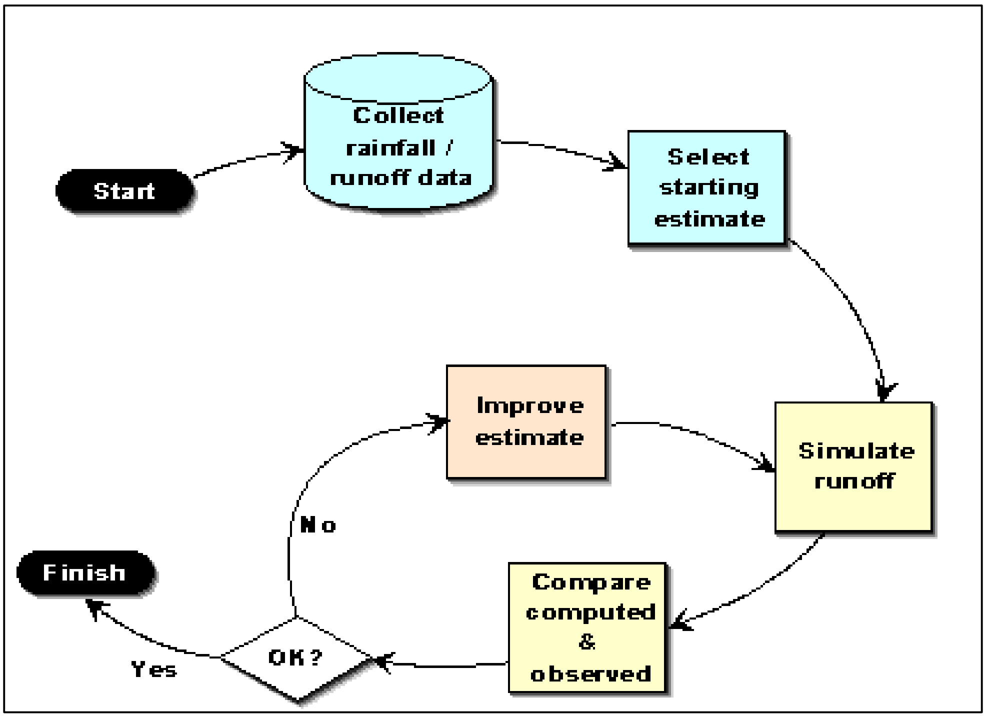


Figure 20: Schematic of Calibration Procedure

The automated calibration was used to adjust initial losses, curve number and lag time to minimize the objective function value and to find optimal parameters. When manual validation of the observed and simulated hydrograph was not acceptable, initial parameters were adjusted to provide a better optimization target value for the optimization process (USACE, 2000). The objective function used was the simulated absolute error. This objective function gave greater weight to large errors and lesser weight to small errors, in addition of giving greater overall weight to error near the peak discharge. The optimization procedure required the use of a search method for minimizing an objective function and finding optimal parameters. The search method used for this calibration was the univariate gradient method. This method evaluated and adjusted one parameter at a time while holding all other parameters constant. The search method estimates the optimal parameters but do not indicates which parameters had the greatest impact on the solution (Kathol *et al.*, 2003). Besides evaluating the objective function for determining if the process produced an accurate calibration, graphical comparisons were made between the fit of the model and the actual measured data. Graphical comparisons of scatter plots and time series plots of residuals between computed and observed flow were used to visually inspect the results of the calibration (Kathol *et al.*, 2003).

5. Results and Discussion

The results of the research findings are presented on the HEC-HMS hydrologic model. In this study the integration of remote sensing and Geographical Information Systems is vital for providing input parameters in the HEC-HMS model is emphasized. The main advantage of the integration approach is to utilize the synergism of RS and GIS techniques for the given objective

The HEC-HMS software has a self- calibrating utility based on optimization techniques that allows the user to select different combinations of objective function .Hence, the selected Gaged watershed was modeled and the results were calibrated using sum of absolute errors.

However, results have indicated that in all the selected three catchments the correlation coefficients were very small indicating little or no correlation(R^2=0.498) between the simulated and the observer stream flow

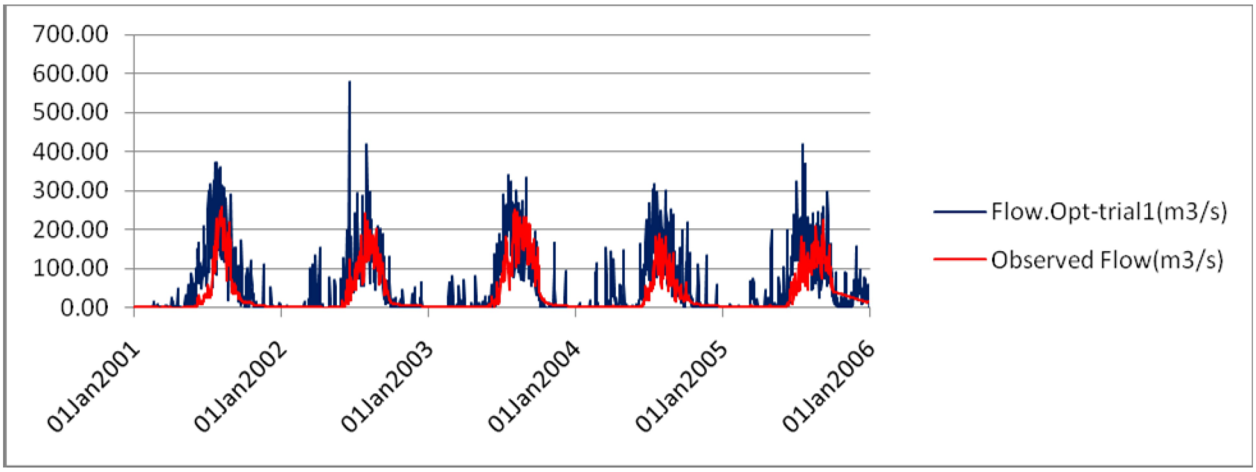


Figure 21: Daily simulated result of Gumara watershed(gaged)

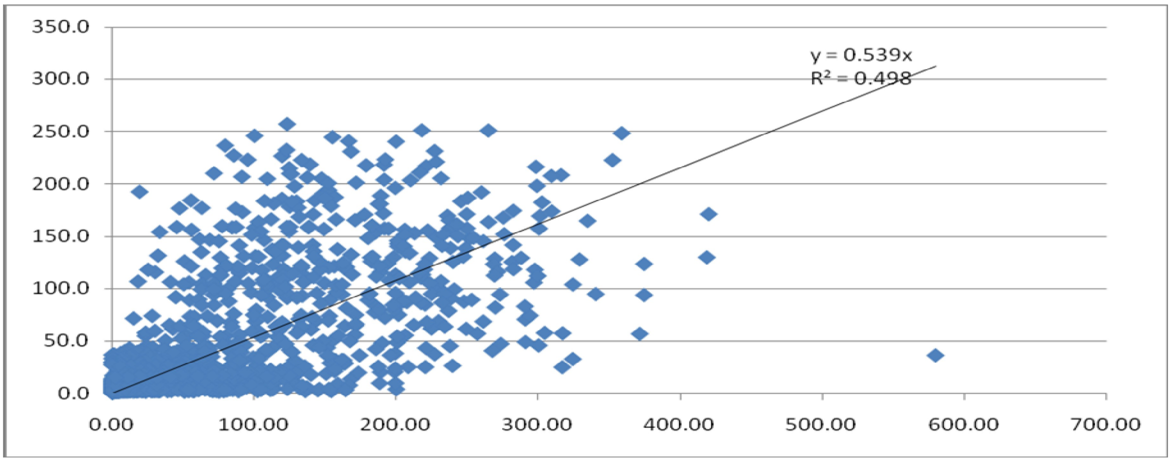


Figure 22: Correlation graph of Simulated and Observed hydrographs

The flow at the outlet is a combination of other subbasins above so that the flow from each subbasin passes through it. The combined flow is indicative of the sum of the flows from each subbasin at the gauge station.

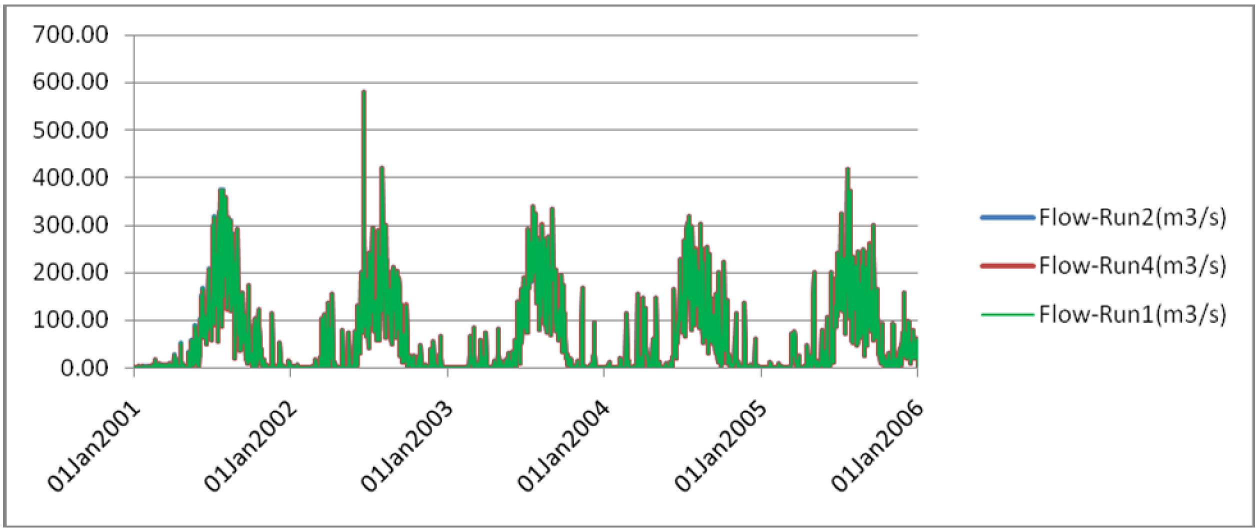


Figure 23: Cummulative total flow of the watershed at the outlet

As the hytogrph of the simulated result shows much of the precipitation that falls in the watershed is changed in to direct runoff. The physical characteristics of the watershed in addtion to the soil and land cover condition has also significant contribution(see table 3 below).

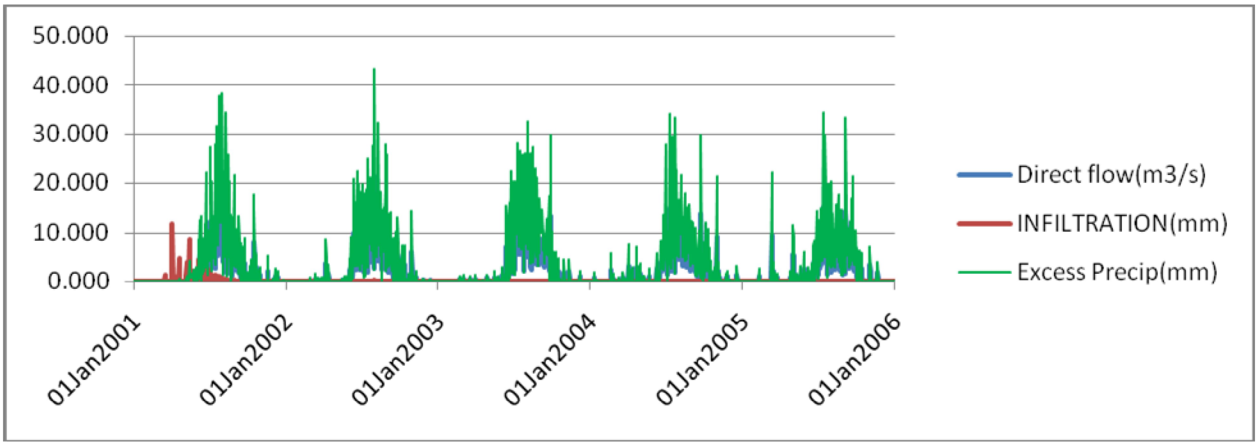


Figure 24: Part of the rainfall contributing for direct preciptation

Table 2: Table shows the objective function of the optimal trial value

Measured	Simulated	Observed	Difference	% difference
Volume (MM)	6084.84	3949.92	2134.92	54.05
Peak Flow (M3/S)	578.9	256.9	322	125.3
Time of Peak	20Jun2002, 00:00	06Aug2001, 00:00		
Time of Center of Mass	08Aug2003, 06:58	04Sep2003, 09:15		

Table 3: Physical characteristics of watershed

WS_Name	Area	CN	S	Ia
W420	48361458.11	68	119.5294	23.90588
W460	62999.94	67	125.1045	25.0209
W470	55762176.72	67	125.1045	25.0209
W480	68215495.37	67.321	123.2968	24.65937
W500	206043277.9	67.292	123.4594	24.69189
W610	93709800.43	67.215	123.8918	24.77837
W630	73002550.99	70	108.8571	21.77143
W690	166699799.4	62.905	149.7835	29.9567
W720	386567063.5	68.955	114.3562	22.87123
W790	250213491.1	67	125.1045	25.0209

The data of each simulation run is stored in the HEC-DSS data storage system and it makes ease of data retrieving system when needed. The data of the model is also easily processed in the Microsoft Excel software by using DSS excel add-in.

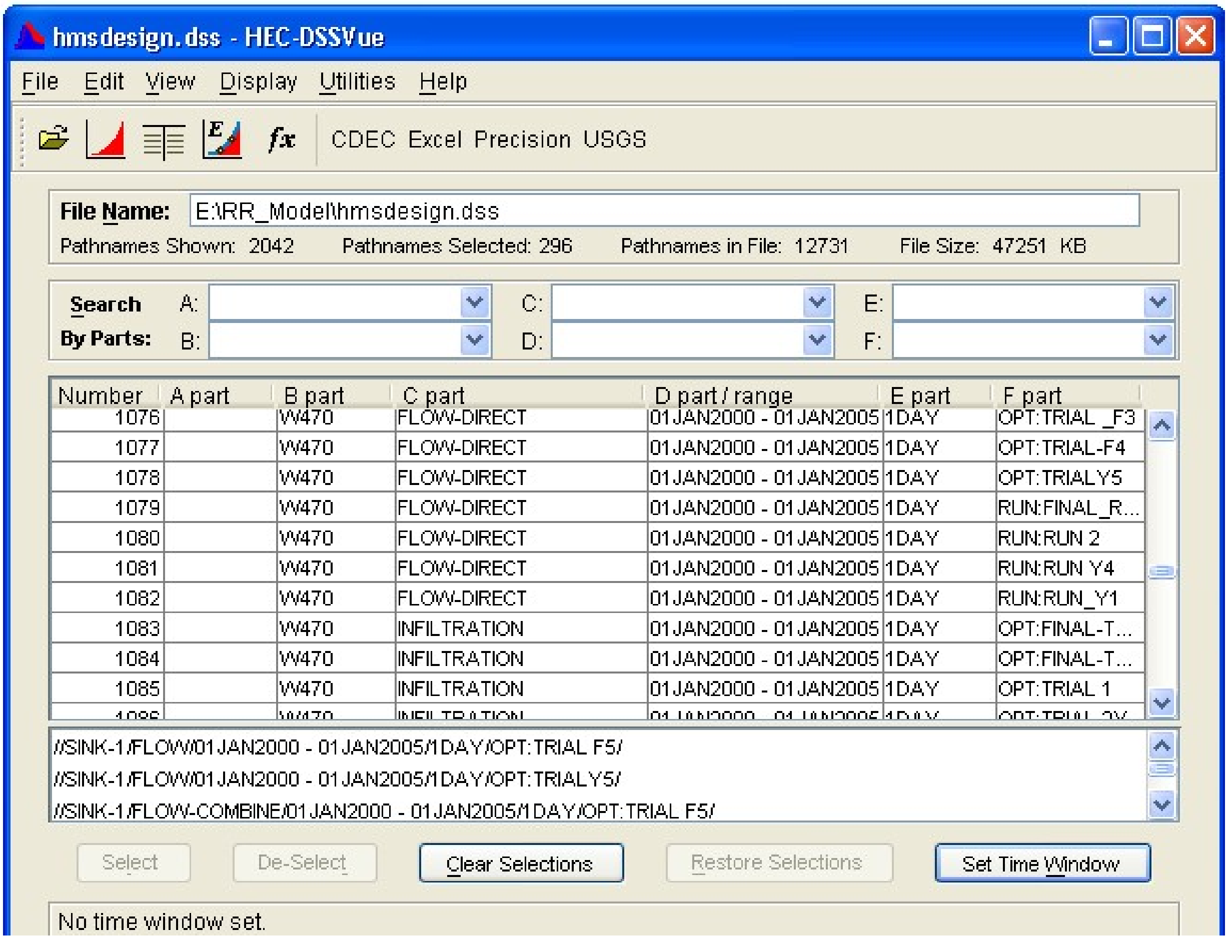


Figure 25: DSS data storage of the simulation run

From the simulation run results (as the figures below) it concluded that in all subbasins much of the rainfall on the area is chached to direct runoff. This causes downstream flooding and water scarcety and erosin problem on the upper part of the watershed .

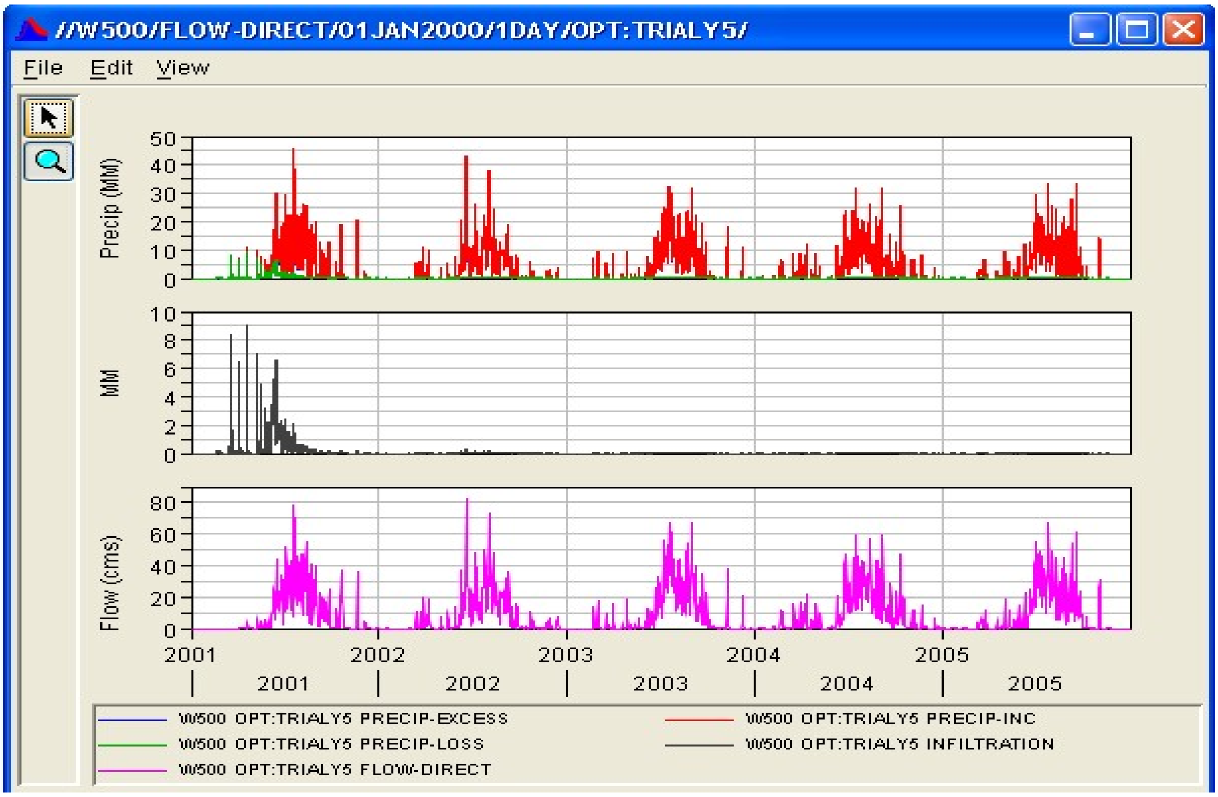


Figure 26: Simulated result of subbasin W500

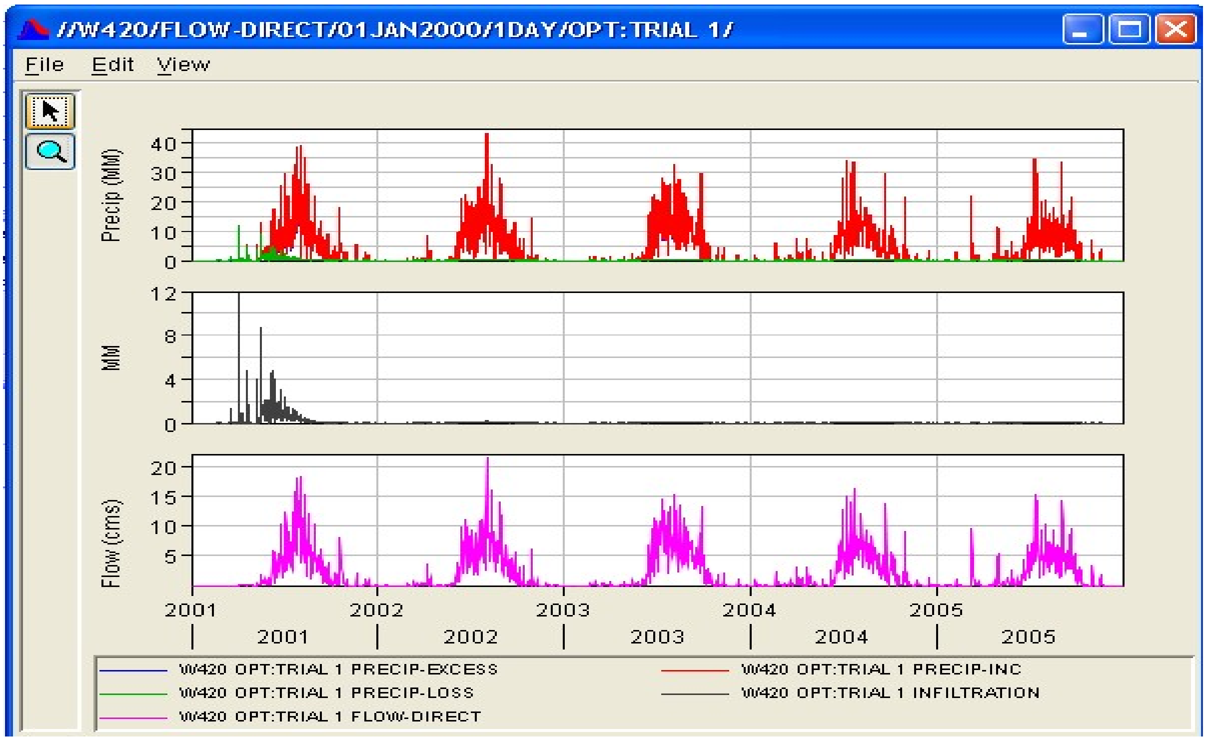


Figure 27: Simulated result of Subbasin420

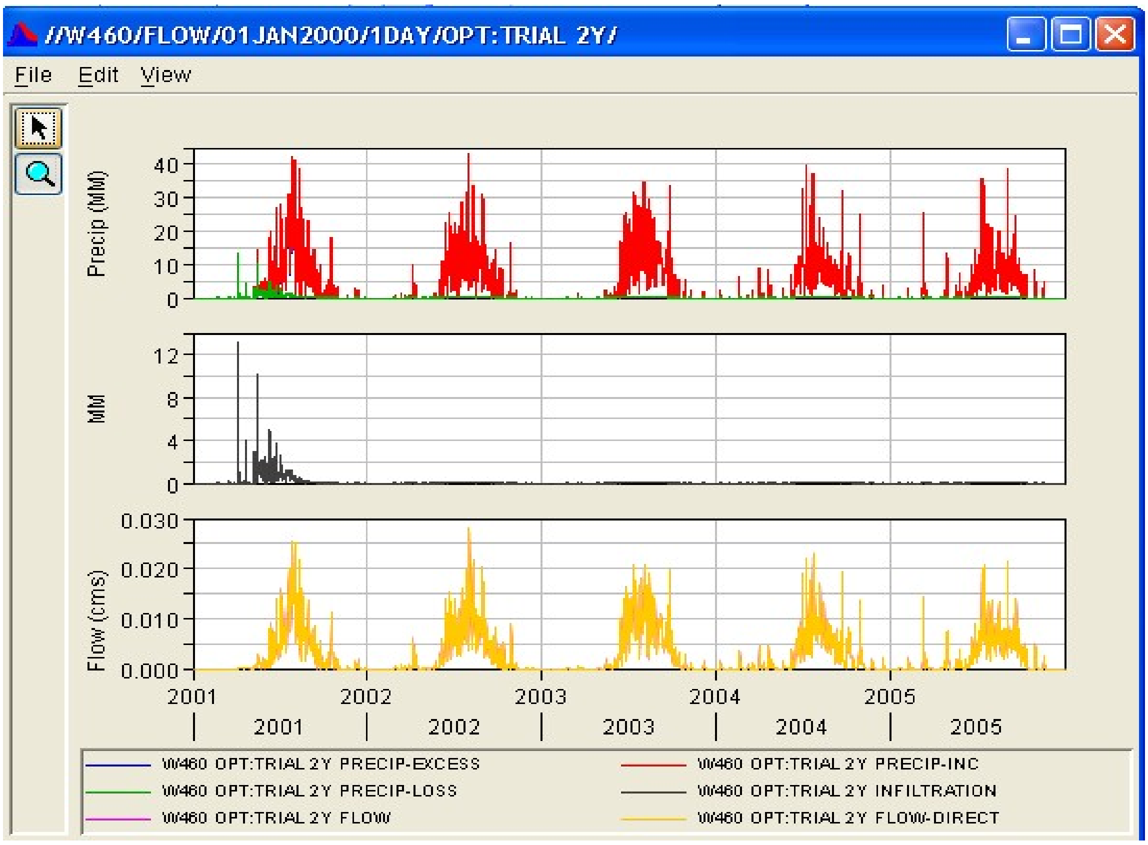


Figure 28: Simulation Result of Subbasin460

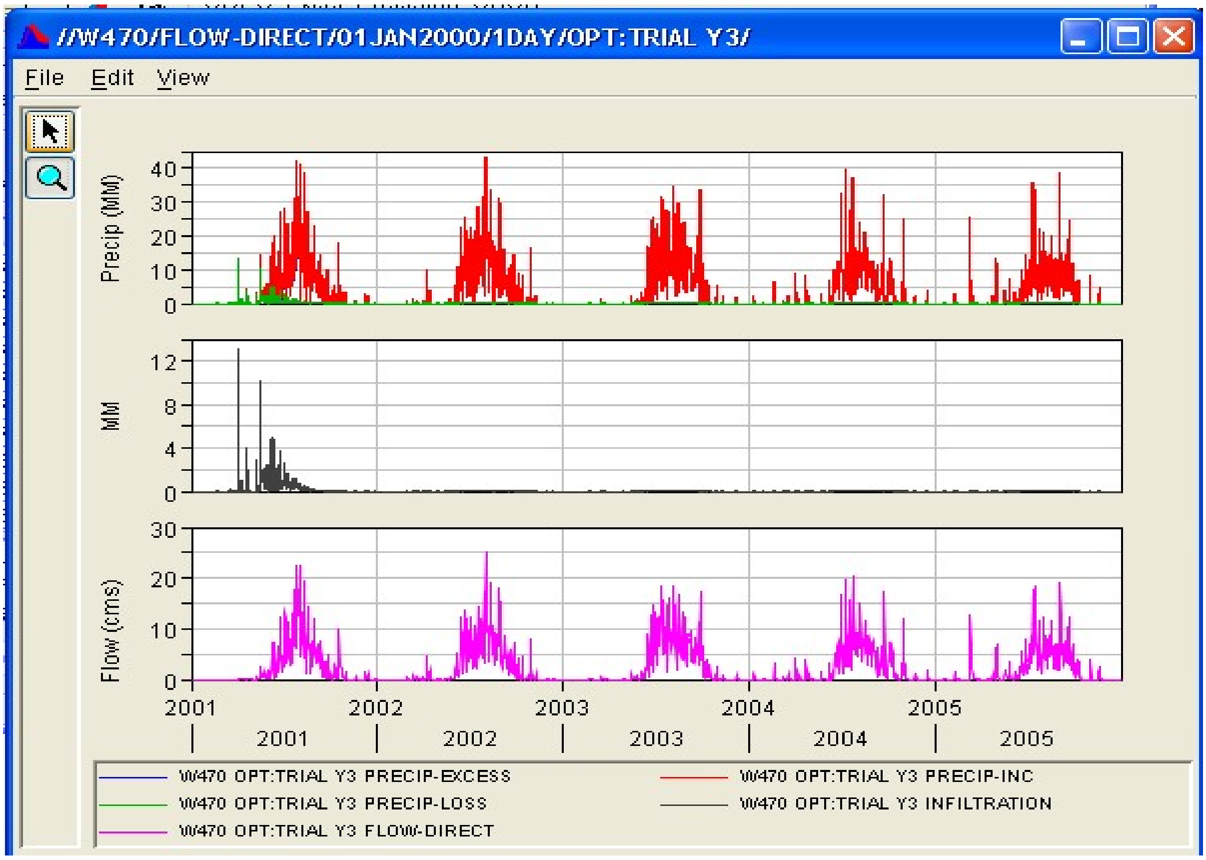


Figure 29: Simulated result of Subbasin 470

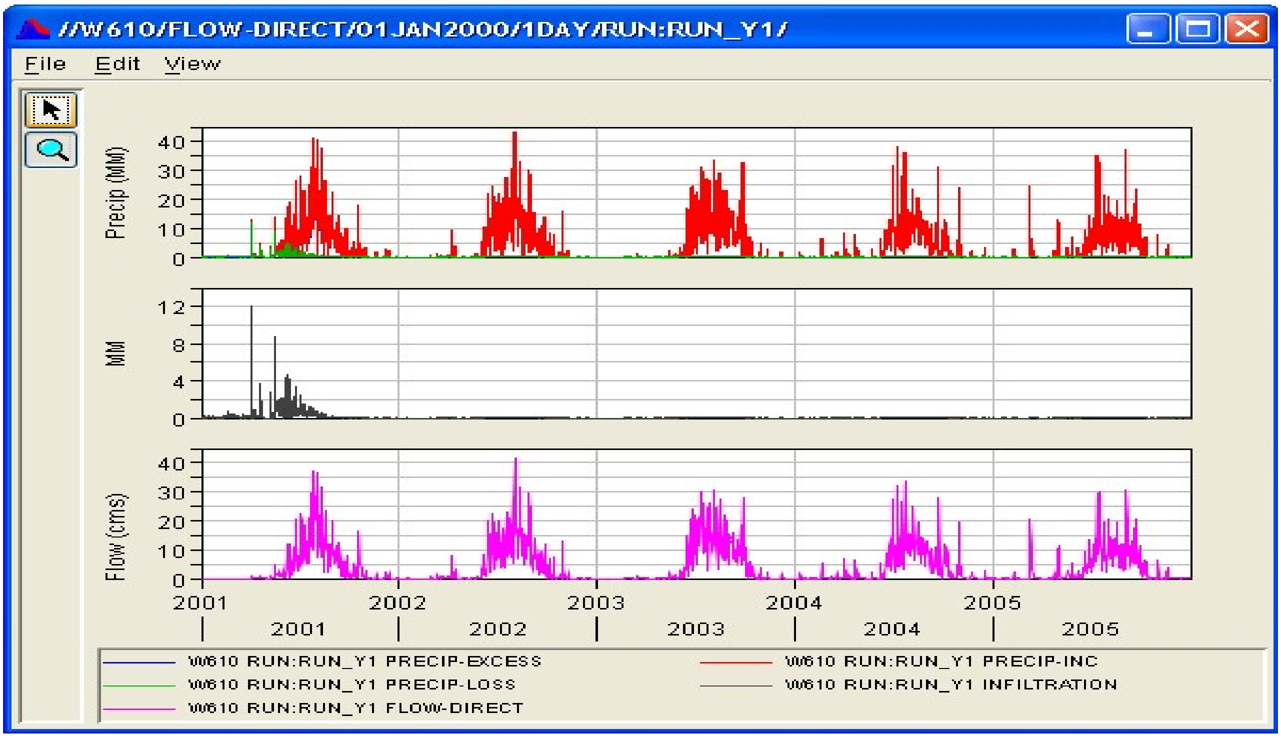


Figure 30: Simulated Result of Subbasin 610

The model result indicates that whenever there is incremental precipitation there is an increase in direct runoff where as at the beginning of the rain there is high initial loss/ abstraction. This is possibly due to high infiltration at the beginning of precipitation. Evapotranspiration affects precipitation in such a way that it decreases its amount as and has an inverse relationship.

Most of the subbasins provide more or less similar results in that the direct runoff and base flow concentrated only during the wet season especially for June to September. The effect of evapotranspiration negatively affects runoff and base flow. For more understanding it is advisable to see most of the results at the annex.

5.1 Optimization Trials

Parameter estimation is the process of adapting a general model to a specific watershed. Some parameters can be estimated directly from field measurements. For example, the area that must be entered for a subbasin element can be measured directly in the field using standard surveying procedures or from maps developed through surveying. Other parameters can be estimated indirectly from field measurements. In this case, the field measurement does not result in a value that can be input directly to the program. However, the field measurement can provide a strong recommendation for a parameter in the program based on previous experience. For example, measurements of soil texture are highly correlated with parameters such as hydraulic conductivity. Finally, there are parameters that can only be estimated by comparing computed to observed results such as observed stream flow. Even for parameters of the first two types, there is often enough uncertainty in the true parameter value to require some adjustment of the estimates in order for the model to closely follow the observed stream flow.

The quantitative measure of the goodness-of-fit between the computed from the model and the observed flow is called the objective function. An objective function measures the degree of variation between computed and observed hydrographs. It is equal to zero if the hydrographs are exactly identical. The key to automated parameter estimation is a search method for adjusting parameters to minimize the objective function value and find optimal parameter values. A minimum objective function is obtained when the parameter values best able to reproduce the observed hydrograph are found. Constraints are set to insure that unreasonable parameter values are not used.

Optimization trials are one of the three different components that can compute: simulation runs, optimization trials, and analyses. Each trial is based on a simulation run. The run provides the basic framework of a basin model, meteorological model, and control specifications within which parameters are estimated. A variety of graphs and tables are available from the *Watershed Explorer* for evaluating the quality of the estimation.

The iterative parameter estimation procedure used by the program is often called optimization. Initial values for all parameters are required at the start of the optimization trial window. A hydrograph is computed at a target element by computing all of the upstream elements. The target must have an observed hydrograph for the time period over which the objective function will be evaluated. Only parameters for upstream elements can be estimated. The value of the objective function is computed at the target element using the computed and observed hydrographs. Parameter values are adjusted by the search method and the hydrograph and objective function for the target element are recomputed. This process is repeated until the value of the objective function is sufficiently small, or the maximum number of iterations is exceeded can be viewed after the optimization trial is complete.

6. Conclusions and recommendations

This research work has attempted to carry out by the integration of HEC-HMS with GIS based estimation of rainfall-runoff potential for Gumara watershed. Optimization trial of the model was conducted using a basin model generated by the ArcGIS extension of HEC-GeoHMS and five years of observed rainfall/runoff data. Within the watershed the model was found to be most sensitive to rainfall input and curve numbers. Rainfall-runoff data collected during the 2001 to 2005 daily rainfall data were used to test the parameterized hydrology model against an observed daily runoff record. Comparison of the predicted hydrograph with the observed hydrograph indicated daily runoff volume reasonably well but under predicted some storm events, including the annual depth.

Great effort has been put forward to come up with better description of the hydro-system of the watershed with relatively more precise estimation. Furthermore, this study has also proposed mechanism of water yield estimation for the proposed development project in the watershed. As a result, the total available water in the system, hence water resource potential, can be explained based on results from this study work. Therefore, the objectives of this study have been achieved.

The research is conducted using semi-distributed hydrologic modeling which needs a lot of data. However, data scarcity and incompleteness made the calibration difficult to fit the calculated and observed values. Therefore, modeling should always be supplemented with available relevant data sources.

The simulation studies carried out in this research work are within time span of 2001 up to 2005. This was originally constrained with the available dataset that can be obtained. However, wider time span of analysis can enhance the reliability on the results and accuracy of the results.

Generally it has been demonstrated that GIS & remote sensing techniques can provide significant information and analytical capability to water resource assessment of a certain basin. Hence, further studies on this subbasin could make use of this versatile tool to update the hydrologic description of the area

Limitations

One of the major challenges faced while conducting this research work is the difficulty to obtaining satellite image products. Some of the digital imageries are very large in size and most of them are acquired through the internet. Consequently, the limitation of band width was a major constraint in obtaining the datasets. Therefore, this thesis work was limited to using dataset which are possible to acquire though the available bandwidth limit. However, superior results can be obtained if imageries with higher resolution and good spatial accuracy can be used.

Furthermore, because this study is carried out with incomplete data sources, the study should have supported with detail field survey to supplement the incomplete information.

This research has made use of SRTM data to extract watershed physical parameters. One of the major limitations to process SRTM data is the corruption of water utility ArcGIS extensions Such as ApFramework and HEC–GeoHMS. To alleviate this problem, modification on these extensions is vital to process the data properly.

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ANNEXES

Table 4: Hydrologic soil groups derived from soil properties

(Modified from USDA (1986) and NEH-4 (1997) lookup tables)

HSG	USDA soil texture class	Soil content	%	Property
A	1, 2, 3	Sand, loamy sand or sandy loam types of soils	4.69	Low runoff potential and high infiltration rates even when thoroughly wetted; consist chiefly of deep, well to excessively drained sands or gravels
B	4, 5, 6	Silt loam, loam, or silt	8.41	Moderate infiltration rate and consist of soils chiefly with moderately fine to moderately coarse textures
C	7	Sandy clay loam	3.98	Low infiltration rates when thoroughly wetted and consist chiefly of soils with moderately fine to fine structure.
D	8, 9, 10, 11, 12	Clay loam, silty clay loam, sandy clay, silty clay or clay	5.78	Highest runoff potential, very low infiltration rates when thoroughly wetted and consist chiefly of clay soils
0	0	Water bodies	11.59	N/A
-1	13	Permanent ice/snow	65.55	N/A

Table 5: Definition of Hydrologic soil Groups

Hydrologic Soil Group	Soil Group Characteristics
A	Soils having high infiltration rates, even when thoroughly wetted and consisting chiefly of deep, well to excessively-drained sands or gravels. These soils have a high rate of water transmission.
B	Soils having moderate infiltration rates when thoroughly wetted and consisting chiefly of moderately deep to deep, moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission.
C	Soils having slow infiltration rates when thoroughly wetted and consisting chiefly of soils with a layer that impedes downward movement of water, or soils with moderately fine to fine texture. These soils have a slow rate of water transmission.
D	Soils having very slow infiltration rates when thoroughly wetted and consisting chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface, and shallow soils over nearly impervious material. These soils have a very slow rate of water transmission.

Cover type	Quality of cover	Soil Group			
		A	B	C	D
NATURAL COVERS					
Grass, Annual or perennial	Poor	0.16	0.09	0.06	0.04
	Fair	0.31	0.16	0.09	0.07
	Good	0.41	0.22	0.12	0.09
Meadows-Area with seasonally high water table, principal vegetation is sod-forming grass	Poor	0.20	0.11	0.06	0.05
	Fair	0.30	0.15	0.09	0.07
	Good	0.50	0.24	0.17	0.14
Chaparral, Broadleaf (Manzanita and scrub oak)	Poor	0.28	0.15	0.09	0.06
	Fair	0.40	0.20	0.12	0.08
	Good	0.49	0.25	0.14	0.10
Open brush-Soft wood shrubs, buckwheat, Sage, etc	Poor	0.21	0.11	0.07	0.05
	Fair	0.34	0.18	0.11	0.07
	Good	0.39	0.20	0.12	0.08
Woodland-Coniferous or broadleaf trees predominate. (Canopy density is at least 50%)	Poor	0.35	0.18	0.11	0.07
	Fair	0.44	0.22	0.13	0.09
	Good	0.53	0.26	0.15	0.11
Woodland-Grass (Coniferous or broadleaf trees with canopy density from 20 to 50 %)	Poor	0.25	0.13	0.08	0.06
	Fair	0.36	0.18	0.11	0.08
	Good	0.47	0.24	0.14	0.09
URBAN COVERS					
Residential or commercial(lawn, shrubs, etc)	Good	0.48	0.25	0.16	0.12
Open space: Grass cover<50%	Poor	0.26	0.09	0.06	0.04
Grass cover 50-75%	Fair	0.31	0.16	0.09	0.07
Grass cover>75%	Good	0.41	0.22	0.12	0.09
AGRICULTURAL COVERS					
Fallow	Poor	0.16	0.09	0.06	0.04
(Land plowed but not tilled or seeded)	Fair	0.31	0.16	0.09	0.07
Pasture, dry land(Annual grasses)	Good	0.41	0.22	0.12	0.09
Pasture, Irrigated(legumes and perennial grass	Poor	0.24	0.12	0.07	0.05
	Fair	0.36	0.18	0.11	0.08

Table 6: SCS Curve number look up table

Table 7: NRCS runoff number for selected agricultural land use

Cover Description			Curve number for hydrologic soil group			
Cover type	Treatment	Hydrologic condition	A	B	C	D
Fallow	Bare soil	-----	77	86	91	94
	Crop residue cover(CR)	Poor	76	85	90	93
		Good	74	83	88	90
Row crop	Straight row(SR)	Poor	72	81	88	91
		Good	67	78	85	89
	SR+CR	Poor	71	80	87	90
		Good	64	75	82	85
	Contour(C)	Poor	70	79	84	88
		Good	65	75	82	86
	C+ CR	Poor	69	78	83	87
		Good	64	74	81	85
	Contour and terraced(C&T)	Poor	66	74	80	82
		Good	62	71	78	81
	C&T+CR	Poor	65	73	79	81
		Good	61	70	77	80
Small grain	SR	Poor	65	76	84	88
		Good	63	75	83	87
	SR+CR	Poor	64	75	83	86
		Good	60	72	80	84
	C	Poor	63	74	82	85
		Good	61	73	81	84
	C+CR	Poor	62	73	81	84
		Good	60	72	80	83
	C&T	Poor	61	72	79	82
		Good	59	70	78	81
	C&T+CR	Poor	60	71	78	81
		Good	58	69	77	80
Closed-|Seeded or broadcast legumes or rotation meadow	SR	Poor	66	77	85	89
		Good	58	72	81	85
	C	Poor	64	75	83	85
		Good	55	69	78	83
	C&R	Poor	63	73	80	83
		Good	51	67	76	80

1 Average runoff condition and I_a=0.2S.
2 Crop residue cover applies only if residue is on at least 5% of the surface throughout the year.
3 Hydraulic condition is based on combination factors that affect infiltration and runoff, including (a) density and canopy of vegetative areas, (b) amount of year-round cover, (c) amount of grass or closeseeded legumes, (d) percent of residue cover on the land surface (good ≥20%), and (e) degree of surface roughness.
Poor: factors impair infiltration and tend to increase runoff.
Good: factors encourage average and better than average infiltration and tend to decrease runoff.

Table 8: NRCS runoff curve number for other agricultural land use

Cover Description		Curve number for hydrologic soil group			
Cover type	Hydrologic condition	A	B	C	D
Pasture, grass land, or range-continuous forage for grazing	Poor	68	79	86	89
	Fair	49	69	79	84
	Good	39	61	74	80
Meadow – Continous grass, protected from grazing and generally mowed for hay	----	30	58	71	78
Brush- Bush –weed-grass mixture with brush the major element	Poor	48	67	77	83
	Fair	35	56	70	77
	Good	30	48	65	73
Woods= Grass combination (Orchard or tree farm)	Poor	57	73	82	86
	Fair	43	65	76	82
	Good	32	58	72	79
Woods	Poor	45	66	77	83
	Fair	36	60	73	79
	Good	30	55	70	77
Farmsteads- buildings, lanes, driveways, and surrounding lots	----	59	74	82	86

1 Average runoff condition and I_a=0.2S.
2 Poor: <50% ground cover or heavily grazed with no mulch.
Fair: 50% to 75% ground cover and not heavily grazed.
Good: >75% ground cover and lightly or only occasionally grazed.
3 Poor: <50% ground cover.
Fair: 50% to 75% ground cover.
Good: >75% ground cover.
4 Actual curve number is less than 30%; use CN=30 for runoff computations.
5 CN’s shown were computed for areas with 50% woods and 50% grass (pasture) cover. Other combinations of conditions may be computed
from the CN’s for woods and pasture.
6 Poor: forest litter, small trees, and brush are destroyed by heavy grazing or regular burning.
Fair: woods are grazed, but not burned, and some forest litter covers the soil.
Good: woods are protected from grazing, and litter and brush adequately cover the soil.

Table 9: Monthly rainfall data

		DebreTar	BahirDar	Wereta	Mekane Eyesus	Dera Hamusit	Wanzaye	Amed Ber	Arb Gebeye	Gassay
2001	Jan	0	0	188.3	0	0	0	0	0	0
	Feb	1.3	1.2	324	4.7	0	0	0.3	0.1	1.3
	Mar	17.2	1.9	270.7	52.2	0	0	9.4	13.4	17.2
	Apr	24	24.2	118.6	79.3	34.3	7	15.2	42.2	24
	May	77.4	56.6	67.9	58.8	52.7	75.8	31.7	86.7	77.4
	Jun	191.2	250.5	26.5	260.5	149.5	142.6	289.6	243.4	191.2
	Jul	433.7	340.6	6.5	357	418.4	649.2	384.1	356.1	433.7
	Aug	410	422.1	373.5	401.9	510.9	260.9	329.1	505.2	410
	Sep	154.8	142.8	121	64.9	160.3	150.4	81	179.1	154.8
	Oct	45.6	93	156.4	73.6	84.4	33	92.8	63.5	45.6
	Nov	4.5	12.5	24.1	0	0	0	33.2	25.1	4.5
	Dec	7.2	16.9	0	12.1	4.1	0	4.2	16.1	7.2
2002	Jan	0.4	0	0	3.8	0	0	0.3	0.4	0.4
	Feb	1	1.2	0	1.2	0	0	0	1	1
	Mar	60.2	8.5	0	52.1	6.4	0	8.7	60.2	60.2
	Apr	45.1	16.2	18.7	34.5	23.1	29.2	13	45.1	45.1
	May	47.2	2.9	22.8	5.8	5.2	0	8.4	47.2	47.2
	Jun	203.3	327.2	164.1	191.1	165.8	162.5	220.1	203.3	203.3
	Jul	256.6	415	327.3	344.3	271.73	310.4	274.5	256.6	256.6
	Aug	313.4	405	335.4	362.8	495.8	400.2	292.6	313.4	313.4
	Sep	132.8	155.2	115.2	207.1	199.4	210.3	135.1	132.8	132.8
	Oct	2.9	18.1	13.5	14.6	77.2	54.8	16.4	2.9	2.9
	Nov	16.9	0.5	0	3.2	10.4	0	6.9	16.9	16.9
	Dec	18.8	1	0	3.6	0	0	5.9	18.8	18.8
2003	Jan	0	0	0	0	0	0	0	0	0
	Feb	13.9	0.6	0	16.5	0	0	7.9	13.9	13.9
	Mar	24.1	0.3	0	76.8	3.2	0	23.4	24.1	24.1
	Apr	28.1	0	2.6	6.3	0	0	28.1	28.1	28.1
	May	10.4	1.2	0	10.7	12.4	2.2	10.4	10.4	10.4
	Jun	86.2	239.8	154	168.6	58.7	214.8	86.2	86.2	86.2
	Jul	435.7	506.2	298.4	349.2	450.8	402.9	435.7	435.7	435.7
	Aug	324.8	451.1	334.4	316.4	368.6	347.8	324.8	324.8	324.8
	Sep	231.3	188.6	292.9	237.2	414.4	306.5	231.3	231.3	231.3
	Oct	16.7	74.2	9.5	16.5	130.3	0	16.7	16.7	16.7
	Nov	33.3	5.5	6.3	3.7	0	1.2	33.3	33.3	33.3
	Dec	14.8	5.7	5.2	20.7	0	0	14.8	14.8	14.8
2004	Jan	0.5	8.7	1.3	5.2	0.1	0	1	0.5	0.5
	Feb	37.6	20.5	5.9	8.3	0	0	10.6	37.6	37.6
	Mar	33.7	5.7	6.7	11.2	7	0	10.3	33.7	33.7
	Apr	75.5	45.6	37.5	57.7	16.6	24.5	55.9	75.5	75.5
	May	19.1	1.8	3.2	23.2	8.9	0	22.1	19.1	19.1
	Jun	141	166.7	163.1	132.2	1.8	117.9	120.2	141	131.2
	Jul	333.7	488.3	332.1	415.1	257.8	378.8	322	333.7	309.5
	Aug	295.2	297.9	320.2	194.2	456.4	262.4	312.8	295.2	232.4
	Sept	120.8	163.3	132.5	103.1	174.3	211.1	175.3	120.8	109.8
	Oct	85.8	93.2	55.6	44.7	157.5	87.2	114.6	85.8	43.1
	Nov	42.5	4.1	29.5	22.3	35.7	9.8	15.5	42.5	33.6
	Dec	12.7	0	0	2.4	12.6	0	3.5	12.7	6.5
2005	JAN	1.3	0.7	0	3.9	0	0	1.1	1.3	3.8
	feb	0	9.3	0	3.6	0	0	0	0	0
	MAR	34.1	85.9	26.7	56.6	26.7	27.8	19.5	34.1	34.1
	Apr	10.3	10.5	0	12.9	0	0	0	10.3	10.3
	MAY	56.3	74.9	37.9	35.8	50.2	54.7	48.2	56.3	56.3

	JUN	206.4	159.4	145.7	115.8	3.8	56.4	77.5	206.4	206.4
	JUL	433.6	493.6	241.8	320.2	147.8	261	402	433.6	433.6
	AUG	294	217.8	304.6	257.1	304.6	271.6	288	294	294
	SEP	216.2	278.3	231.3	230.7	282.6	291.1	216.2	216.2	216.2
	OCT	5	53.1	44.6	39.8	44.6	39.9	5	46	5
	NOV	29.7	7.7	28.4	7.7	28.4	28.4	29.7	173.8	29.7
	DEC	0	0	0	0	0	0	0	344.3	0

B		420	460	480	500	610	630	690	702	790
C	DATE	PRECIP-INC	PRECIP-INC	PRECIP-INC	PRECIP-INC	PRECIP-INC	PRECIP-INC	PRECIP-INC	PRECIP-INC	PRECIP-INC
E										
F		GAGE	GAGE	GAGE	GAGE	GAGE	GAGE	GAGE	GAGE	GAGE
Units		MM	MM	MM	MM	MM	MM	MM	MM	MM
Type		PER-CUM	PER-CUM	PER-CUM	PER-CUM	PER-CUM	PER-CUM	PER-CUM	PER-CUM	PER-CUM
1	31Dec2000									
2	01Jan2001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3	02Jan2001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
4	03Jan2001	0.000	0.000	4.580	0.000	0.100	0.000	0.000	0.000	0.000
5	04Jan2001	0.000	0.000	6.290	0.000	0.140	0.000	0.000	0.000	0.000
6	05Jan2001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
7	06Jan2001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
8	07Jan2001	0.000	0.000	10.470	0.000	0.230	0.000	0.000	0.000	0.000
9	08Jan2001	0.000	0.000	2.250	0.000	0.050	0.000	0.000	0.000	0.000
10	09Jan2001	0.000	0.000	1.390	0.000	0.030	0.000	0.000	0.000	0.000
11	10Jan2001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
12	11Jan2001	0.000	0.000	0.450	0.000	0.010	0.000	0.000	0.000	0.000
13	12Jan2001	0.000	0.000	2.290	0.000	0.050	0.000	0.000	0.000	0.000
14	13Jan2001	0.000	0.000	10.870	0.000	0.230	0.000	0.000	0.000	0.000
15	14Jan2001	0.000	0.000	1.350	0.000	0.030	0.000	0.000	0.000	0.000
16	15Jan2001	0.000	0.000	1.260	0.000	0.030	0.000	0.000	0.000	0.000
17	16Jan2001	0.000	0.000	0.540	0.000	0.010	0.000	0.000	0.000	0.000
18	17Jan2001	0.000	0.000	2.110	0.000	0.050	0.000	0.000	0.000	0.000
19	18Jan2001	0.000	0.000	2.970	0.000	0.060	0.000	0.000	0.000	0.000
20	19Jan2001	0.000	0.000	1.930	0.000	0.040	0.000	0.000	0.000	0.000
21	20Jan2001	0.000	0.000	0.580	0.000	0.010	0.000	0.000	0.000	0.000
22	21Jan2001	0.000	0.000	13.980	0.000	0.300	0.000	0.000	0.000	0.000
23	22Jan2001	0.000	0.000	7.950	0.000	0.170	0.000	0.000	0.000	0.000
24	23Jan2001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
25	24Jan2001	0.000	0.000	3.150	0.000	0.070	0.000	0.000	0.000	0.000
26	25Jan2001	0.000	0.000	3.190	0.000	0.070	0.000	0.000	0.000	0.000
27	26Jan2001	0.000	0.000	0.940	0.000	0.020	0.000	0.000	0.000	0.000
28	27Jan2001	0.000	0.000	0.760	0.000	0.020	0.000	0.000	0.000	0.000
29	28Jan2001	0.000	0.000	1.710	0.000	0.040	0.000	0.000	0.000	0.000
30	29Jan2001	0.000	0.000	3.590	0.000	0.080	0.000	0.000	0.000	0.000
31	30Jan2001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
32	31Jan2001	0.000	0.000	3.150	0.000	0.070	0.000	0.000	0.000	0.000
33	01Feb2001	0.000	0.000	1.530	0.000	0.030	0.000	0.000	0.000	0.000
34	02Feb2001	0.000	0.000	2.520	0.000	0.050	0.000	0.000	0.000	0.000
35	03Feb2001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

36	04Feb2001	0.000	0.000	1.030	0.000	0.020	0.000	0.000	0.000	0.000
37	05Feb2001	0.000	0.000	6.560	0.000	0.140	0.000	0.000	0.000	0.000
38	06Feb2001	0.000	0.000	0.360	0.000	0.010	0.000	0.000	0.000	0.000
39	07Feb2001	0.000	0.000	0.580	0.000	0.010	0.000	0.000	0.000	0.000
40	08Feb2001	0.000	0.000	2.200	0.000	0.050	0.000	0.000	0.000	0.000
41	09Feb2001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
42	10Feb2001	0.000	0.000	3.280	0.000	0.070	0.000	0.650	0.210	0.440
43	11Feb2001	0.000	0.000	8.720	0.000	0.190	0.000	0.090	0.030	0.060
44	12Feb2001	0.000	0.000	0.810	0.000	0.020	0.000	0.000	0.000	0.000
45	13Feb2001	0.000	0.000	5.080	0.000	0.110	0.000	0.000	0.000	0.000
46	14Feb2001	0.000	0.000	9.210	0.000	0.200	0.000	0.000	0.000	0.000
47	15Feb2001	0.000	0.000	8.400	0.000	0.180	0.000	0.000	0.000	0.000
48	16Feb2001	0.000	0.000	4.270	0.000	0.090	0.000	0.000	0.000	0.000
49	17Feb2001	0.000	0.000	1.350	0.000	0.030	0.000	0.000	0.000	0.000
50	18Feb2001	0.000	0.000	12.130	0.000	0.260	0.000	0.000	0.000	0.000
51	19Feb2001	0.000	0.000	3.730	0.210	0.080	0.000	0.010	0.460	0.000
52	20Feb2001	0.000	0.000	33.030	0.000	0.710	0.000	0.000	0.000	0.000
53	21Feb2001	0.090	0.100	2.210	0.010	0.140	0.060	0.000	0.000	0.000
54	22Feb2001	0.090	0.100	11.290	0.010	0.340	0.060	0.000	0.000	0.000
55	23Feb2001	0.090	0.100	2.750	0.040	0.150	0.060	0.790	0.330	0.540
56	24Feb2001	0.090	0.100	4.910	0.010	0.200	0.060	0.000	0.000	0.000
57	25Feb2001	0.040	0.000	2.520	0.170	0.060	0.000	0.000	0.010	0.000
58	26Feb2001	0.000	0.000	7.190	0.210	0.160	0.000	0.530	0.630	0.360
59	27Feb2001	0.000	0.000	7.010	0.000	0.150	0.040	0.050	0.000	0.070
60	28Feb2001	0.000	0.000	4.940	0.000	0.110	0.000	0.000	0.000	0.000
61	01Mar2001	0.000	0.000	14.830	0.040	0.320	0.000	0.000	0.080	0.000
62	02Mar2001	0.000	0.000	2.830	0.000	0.060	0.000	0.000	0.000	0.000
63	03Mar2001	0.000	0.000	4.490	0.000	0.100	0.000	0.000	0.000	0.000
64	04Mar2001	0.000	0.000	1.390	0.000	0.030	0.000	0.000	0.000	0.000
65	05Mar2001	0.000	0.000	2.340	0.000	0.050	0.000	0.000	0.000	0.000
66	06Mar2001	0.000	0.000	7.140	0.000	0.150	0.000	0.000	0.000	0.000
67	07Mar2001	0.000	0.000	3.640	0.000	0.080	0.000	0.000	0.000	0.000
68	08Mar2001	0.000	0.000	7.680	0.000	0.170	0.000	0.000	0.000	0.000
69	09Mar2001	0.000	0.000	5.260	0.000	0.110	0.000	0.000	0.000	0.000
70	10Mar2001	0.000	0.000	1.800	0.000	0.040	0.000	0.000	0.000	0.000

71	11Mar2001	0.000	0.000	1.350	0.000	0.030	1.250	1.530	0.060	1.900
72	12Mar2001	0.000	0.000	4.090	0.000	0.090	0.000	0.000	0.000	0.000
73	13Mar2001	0.000	0.000	6.700	0.000	0.140	0.000	0.000	0.000	0.000
74	14Mar2001	0.000	0.000	1.260	0.000	0.030	0.000	0.650	0.210	0.440
75	15Mar2001	0.000	0.000	0.000	0.530	0.000	0.000	1.550	1.650	1.040
76	16Mar2001	0.060	0.070	2.060	0.000	0.110	1.560	4.570	0.950	4.150
77	17Mar2001	0.190	0.170	8.270	0.820	0.350	2.870	4.330	1.830	4.840
78	18Mar2001	1.310	0.100	0.310	8.330	0.350	0.190	11.140	10.930	7.580
79	19Mar2001	0.090	0.100	0.050	0.010	0.100	0.320	0.330	0.020	0.410
80	20Mar2001	0.040	0.000	0.000	1.630	0.010	0.000	6.160	5.140	4.150
81	21Mar2001	0.090	0.100	2.750	0.010	0.150	0.060	0.000	0.000	0.000
82	22Mar2001	0.000	0.000	8.130	0.000	0.180	0.000	0.000	0.000	0.000
83	23Mar2001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
84	24Mar2001	0.000	0.000	4.180	0.000	0.090	0.000	0.000	0.000	0.000
85	25Mar2001	0.000	0.000	13.480	0.000	0.290	0.000	0.000	0.000	0.000
86	26Mar2001	0.000	0.000	1.350	0.000	0.030	0.000	0.000	0.000	0.000
87	27Mar2001	0.000	0.000	0.850	0.000	0.020	0.000	0.000	0.000	0.000
88	28Mar2001	0.090	0.100	7.240	0.150	0.250	0.100	0.060	0.310	0.070
89	29Mar2001	0.000	0.000	0.900	0.000	0.020	0.000	0.000	0.000	0.000
90	30Mar2001	0.000	0.000	2.700	0.000	0.060	0.000	0.000	0.000	0.000
91	31Mar2001	0.000	0.000	1.390	0.000	0.030	0.000	0.000	0.000	0.000
92	01Apr2001	0.000	0.000	5.170	0.000	0.110	0.000	0.000	0.000	0.000
93	02Apr2001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
94	03Apr2001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
95	04Apr2001	11.900	13.170	7.210	6.750	12.770	7.590	15.270	12.950	10.780
96	05Apr2001	0.090	0.100	5.040	0.430	0.200	0.060	0.190	0.990	0.120
97	06Apr2001	0.000	0.000	0.000	0.110	0.010	9.490	13.090	1.160	15.410
98	07Apr2001	0.000	0.000	0.000	0.040	0.000	0.000	1.490	0.560	1.010
99	08Apr2001	0.000	0.000	2.250	0.000	0.050	0.000	0.000	0.000	0.000
100	09Apr2001	0.980	1.130	0.620	0.160	1.090	1.660	9.210	2.810	6.980
101	10Apr2001	0.000	0.000	8.000	0.140	0.170	0.090	0.290	0.370	0.250
102	11Apr2001	0.000	0.000	1.260	0.000	0.030	0.000	0.000	0.000	0.000
103	12Apr2001	0.090	0.100	0.050	0.010	0.100	0.060	0.000	0.000	0.000
104	13Apr2001	0.090	0.100	5.000	0.010	0.200	0.060	0.000	0.000	0.000
105	14Apr2001	0.000	0.000	1.570	0.000	0.030	0.000	0.000	0.000	0.000

106	15Apr2001	0.000	0.000	0.490	0.000	0.010	0.000	0.000	0.000	0.000
107	16Apr2001	0.000	0.000	5.980	0.000	0.130	0.000	0.000	0.000	0.000
108	17Apr2001	0.000	0.000	4.580	0.000	0.100	0.000	0.000	0.000	0.000
109	18Apr2001	0.170	0.200	0.110	0.010	0.190	0.110	0.480	0.160	0.330
110	19Apr2001	0.090	0.100	1.720	0.190	0.130	0.060	1.840	0.980	1.250
111	20Apr2001	5.340	4.400	4.650	10.800	4.610	10.350	12.590	10.610	14.000
112	21Apr2001	0.000	0.000	1.350	0.000	0.030	0.000	0.000	0.000	0.000
113	22Apr2001	2.010	2.330	4.740	0.170	2.320	1.290	0.010	0.090	0.060
114	23Apr2001	0.090	0.100	0.050	0.010	0.100	0.060	0.000	0.000	0.000
115	24Apr2001	0.000	0.000	3.010	0.000	0.070	0.040	0.050	0.000	0.070
116	25Apr2001	0.000	0.000	0.990	0.000	0.020	0.000	1.440	0.460	0.980
117	26Apr2001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
118	27Apr2001	0.090	0.100	0.050	0.010	0.100	0.060	2.140	0.690	1.450
119	28Apr2001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
120	29Apr2001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
121	30Apr2001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
122	01May2001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
123	02May2001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
124	03May2001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
125	04May2001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
126	05May2001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
127	06May2001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
128	07May2001	0.090	0.100	0.050	0.010	0.100	0.190	0.160	0.010	0.210
129	08May2001	1.640	1.500	0.830	2.180	1.510	2.130	3.320	2.130	3.160
130	09May2001	5.090	3.500	5.430	9.760	3.870	3.370	5.730	3.960	4.920
131	10May2001	0.550	0.630	4.030	0.580	0.690	1.330	1.400	1.290	1.630
132	11May2001	0.000	0.000	9.660	1.210	0.210	0.000	1.920	3.230	1.270
133	12May2001	0.000	0.000	0.000	0.180	0.000	0.000	0.010	0.390	0.000
134	13May2001	0.060	0.070	0.040	0.000	0.060	0.480	0.550	0.020	0.680
135	14May2001	0.090	0.100	0.050	0.010	0.100	0.060	0.000	0.000	0.000
136	15May2001	12.800	14.300	7.830	7.760	13.850	8.790	6.770	12.640	5.410
137	16May2001	8.770	10.130	5.540	4.950	9.750	6.310	2.150	9.510	2.070
138	17May2001	1.660	1.430	5.870	3.830	1.580	1.150	0.510	4.400	0.580
139	18May2001	3.190	3.700	2.020	0.560	3.560	2.040	0.110	0.790	0.150
140	19May2001	1.390	1.570	0.860	0.290	1.510	0.870	0.010	0.070	0.040

SINK-1	SINK-1	SINK-1	SINK-1	SINK-1	SINK-1	SINK-1	SINK-1	SINK-1	SINK-1	SINK-1	SINK-1	SINK-1	SINK-1	SINK-1	SINK-1	SINK-1	SINK-1	SINK-1	SINK-1	SINK-1	SINK-1	SINK-1
FLOW	FLOW	FLOW	FLOW	FLOW	FLOW	FLOW	FLOW	FLOW-COMBINE	FLOW-COMBINE	FLOW-COMBINE	FLOW-COMBINE	FLOW-COMBINE	FLOW-COMBINE	FLOW-COMBINE	FLOW-COMBINE	FLOW-OBSERVED	FLOW-RESIDUAL	FLOW-RESIDUAL	FLOW-RESIDUAL	FLOW-RESIDUAL	FLOW-RESIDUAL	FLOW-RESIDUAL
OPT:TRIAL 1	OPT:TRIAL 2Y	OPT:TRIAL Y3	OPT:TRIAL Y4	OPT:TRIALY5	RUN:RUN 2	RUN:RUN Y4	RUN:RUN _Y1	OPT:TRIAL 1	OPT:TRIAL 2Y	OPT:TRIAL Y3	OPT:TRIAL Y4	OPT:TRIALY5	RUN:RUN 2	RUN:RUN Y4	RUN:RUN_Y1	OPT:TRIAL 1	OPT:TRIAL 1	OPT:TRIAL 2Y	OPT:TRIAL Y3	OPT:TRIAL Y4	OPT:TRIALY5	RUN:RUN_Y1
M3/S	M3/S	M3/S	M3/S	M3/S	M3/S	M3/S	M3/S	M3/S	M3/S	M3/S	M3/S	M3/S	M3/S	M3/S	M3/S	M3/S	M3/S	M3/S	M3/S	M3/S	M3/S	M3/S
INST-VAL	INST-VAL	INST-VAL	INST-VAL	INST-VAL	INST-VAL	INST-VAL	INST-VAL	INST-VAL	INST-VAL	INST-VAL	INST-VAL	INST-VAL	INST-VAL	INST-VAL	INST-VAL	INST-VAL	INST-VAL	INST-VAL	INST-VAL	INST-VAL	INST-VAL	INST-VAL
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.00	0.00	0.00	0.00	0.00	1.3
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.00	0.00	0.00	0.00	0.00	1.2
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.00	0.00	0.00	0.00	0.00	1.1
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.9	-3.95	-3.95	-3.95	-3.95	-3.95	-3.0
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.9	-3.93	-3.93	-3.93	-3.93	-3.93	-3.0
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.9	-3.87	-3.87	-3.87	-3.87	-3.87	-3.1
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.9	-3.85	-3.85	-3.85	-3.85	-3.85	-3.1
0.36	0.34	0.36	0.00	0.31	0.36	0.31	0.36	0.36	0.34	0.36	0.00	0.31	0.36	0.31	0.36	3.8	-3.44	-3.46	-3.44	-3.80	-3.49	-3.1
0.29	0.28	0.29	0.00	0.26	0.29	0.26	0.29	0.29	0.28	0.29	0.00	0.26	0.29	0.26	0.29	3.8	-3.49	-3.50	-3.49	-3.78	-3.52	-3.2
0.21	0.21	0.21	0.00	0.19	0.21	0.19	0.21	0.21	0.21	0.21	0.00	0.19	0.21	0.19	0.21	3.7	-3.51	-3.51	-3.51	-3.72	-3.53	-3.2
0.05	0.05	0.05	0.00	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.00	0.05	0.05	0.05	0.05	3.7	-3.60	-3.60	-3.60	-3.66	-3.61	-3.1
0.06	0.06	0.06	0.00	0.05	0.06	0.05	0.06	0.06	0.06	0.06	0.00	0.05	0.06	0.05	0.06	3.6	-3.58	-3.58	-3.58	-3.64	-3.59	-3.2
0.28	0.27	0.28	0.00	0.24	0.28	0.24	0.28	0.28	0.27	0.28	0.00	0.24	0.28	0.24	0.28	3.5	-3.23	-3.24	-3.23	-3.51	-3.27	-3.1
1.78	1.76	1.78	0.00	1.58	1.78	1.58	1.78	1.78	1.76	1.78	0.00	1.58	1.78	1.58	1.78	3.1	-1.30	-1.32	-1.30	-3.08	-1.50	-1.9
0.75	0.74	0.75	0.00	0.67	0.75	0.67	0.75	0.75	0.74	0.75	0.00	0.67	0.75	0.67	0.75	3.1	-2.39	-2.40	-2.39	-3.14	-2.47	-2.4
0.42	0.41	0.42	0.00	0.37	0.42	0.37	0.42	0.42	0.41	0.42	0.00	0.37	0.42	0.37	0.42	3.4	-2.97	-2.98	-2.97	-3.39	-3.02	-2.8
0.21	0.21	0.21	0.00	0.19	0.21	0.19	0.21	0.21	0.21	0.21	0.00	0.19	0.21	0.19	0.21	3.4	-3.17	-3.17	-3.17	-3.38	-3.19	-3.0
0.49	0.49	0.49	0.01	0.44	0.49	0.44	0.49	0.49	0.49	0.49	0.01	0.44	0.49	0.44	0.49	3.4	-2.88	-2.89	-2.88	-3.36	-2.93	-2.8
0.79	0.78	0.79	0.08	0.71	0.79	0.71	0.79	0.79	0.78	0.79	0.08	0.71	0.79	0.71	0.79	3.4	-2.58	-2.59	-2.58	-3.29	-2.66	-2.6
0.66	0.65	0.66	0.11	0.59	0.66	0.59	0.66	0.66	0.65	0.66	0.11	0.59	0.66	0.59	0.66	3.3	-2.63	-2.63	-2.63	-3.18	-2.69	-2.6
0.30	0.30	0.30	0.06	0.27	0.30	0.27	0.30	0.30	0.30	0.30	0.06	0.27	0.30	0.27	0.30	2.8	-2.47	-2.47	-2.47	-2.71	-2.50	-2.3
3.81	3.79	3.81	1.42	3.46	3.81	3.46	3.81	3.81	3.79	3.81	1.42	3.46	3.81	3.46	3.81	2.7	1.12	1.10	1.12	-1.27	0.77	0.5
3.49	3.48	3.49	1.69	3.19	3.49	3.19	3.49	3.49	3.48	3.49	1.69	3.19	3.49	3.19	3.49	2.7	0.81	0.79	0.81	-0.99	0.51	0.4
0.89	0.88	0.89	0.44	0.81	0.89	0.81	0.89	0.89	0.88	0.89	0.44	0.81	0.89	0.81	0.89	2.6	-1.75	-1.75	-1.75	-2.20	-1.83	-1.7

1.19	1.19	1.19	0.68	1.09	1.19	1.09	1.19	1.19	1.19	1.19	0.68	1.09	1.19	1.09	1.19	2.6	-1.43	-1.44	-1.43	-1.94	-1.53	-1.4
1.37	1.36	1.37	0.83	1.26	1.37	1.26	1.37	1.37	1.36	1.37	0.83	1.26	1.37	1.26	1.37	2.6	-1.21	-1.21	-1.21	-1.75	-1.31	-1.2
0.67	0.67	0.67	0.41	0.62	0.67	0.62	0.67	0.67	0.67	0.67	0.41	0.62	0.67	0.62	0.67	2.5	-1.86	-1.86	-1.86	-2.11	-1.91	-1.8
0.42	0.41	0.42	0.26	0.38	0.42	0.38	0.42	0.42	0.41	0.42	0.26	0.38	0.42	0.38	0.42	2.5	-2.10	-2.10	-2.10	-2.26	-2.14	-2.0
0.69	0.68	0.69	0.44	0.63	0.69	0.63	0.69	0.69	0.68	0.69	0.44	0.63	0.69	0.63	0.69	2.5	-1.83	-1.83	-1.83	-2.07	-1.88	-1.8
1.43	1.43	1.43	0.95	1.33	1.43	1.33	1.43	1.43	1.43	1.43	0.95	1.33	1.43	1.33	1.43	2.5	-1.03	-1.03	-1.03	-1.52	-1.14	-1.1
0.39	0.38	0.39	0.25	0.36	0.39	0.36	0.39	0.39	0.38	0.39	0.25	0.36	0.39	0.36	0.39	2.4	-2.03	-2.03	-2.03	-2.16	-2.06	-2.0
1.20	1.20	1.20	0.82	1.11	1.20	1.11	1.20	1.20	1.20	1.20	0.82	1.11	1.20	1.11	1.20	2.4	-1.20	-1.21	-1.20	-1.59	-1.29	-1.2
0.88	0.88	0.88	0.61	0.82	0.88	0.82	0.88	0.88	0.88	0.88	0.61	0.82	0.88	0.82	0.88	2.4	-1.48	-1.48	-1.48	-1.75	-1.54	-1.5
1.14	1.14	1.14	0.80	1.06	1.14	1.06	1.14	1.14	1.14	1.14	0.80	1.06	1.14	1.06	1.14	2.4	-1.21	-1.21	-1.21	-1.55	-1.29	-1.2
0.30	0.30	0.30	0.21	0.28	0.30	0.28	0.30	0.30	0.30	0.30	0.21	0.28	0.30	0.28	0.30	2.3	-2.01	-2.01	-2.01	-2.10	-2.03	-2.0
0.44	0.44	0.44	0.31	0.41	0.44	0.41	0.44	0.44	0.44	0.44	0.31	0.41	0.44	0.41	0.44	2.3	-1.86	-1.86	-1.86	-1.98	-1.89	-1.8
2.60	2.60	2.60	1.90	2.42	2.60	2.42	2.60	2.60	2.60	2.60	1.90	2.42	2.60	2.42	2.60	2.3	0.35	0.34	0.35	-0.35	0.17	0.2
0.85	0.85	0.85	0.63	0.80	0.85	0.80	0.85	0.85	0.85	0.85	0.63	0.80	0.85	0.80	0.85	2.2	-1.35	-1.35	-1.35	-1.58	-1.41	-1.4
0.40	0.40	0.40	0.30	0.38	0.40	0.38	0.40	0.40	0.40	0.40	0.30	0.38	0.40	0.38	0.40	2.2	-1.79	-1.79	-1.79	-1.89	-1.82	-1.8
0.95	0.95	0.95	0.72	0.89	0.95	0.89	0.95	0.95	0.95	0.95	0.72	0.89	0.95	0.89	0.95	2.2	-1.20	-1.20	-1.20	-1.44	-1.26	-1.2
0.25	0.25	0.25	0.19	0.24	0.25	0.24	0.25	0.25	0.25	0.25	0.19	0.24	0.25	0.24	0.25	2.1	-1.89	-1.89	-1.89	-1.95	-1.91	-1.9
1.34	1.34	1.34	1.03	1.26	1.34	1.26	1.34	1.34	1.34	1.34	1.03	1.26	1.34	1.26	1.34	2.1	-0.77	-0.77	-0.77	-1.08	-0.85	-0.8
3.89	3.89	3.89	3.05	3.66	3.89	3.66	3.89	3.89	3.89	3.89	3.05	3.66	3.89	3.66	3.89	2.1	1.80	1.79	1.80	0.95	1.56	1.6
1.39	1.39	1.39	1.09	1.31	1.39	1.31	1.39	1.39	1.39	1.39	1.09	1.31	1.39	1.31	1.39	2.1	-0.66	-0.66	-0.66	-0.96	-0.75	-0.7
2.42	2.41	2.42	1.94	2.27	2.42	2.27	2.42	2.42	2.41	2.42	1.94	2.27	2.42	2.27	2.42	2.0	0.41	0.40	0.41	-0.07	0.27	0.3
4.57	4.57	4.57	3.76	4.32	4.57	4.32	4.57	4.57	4.57	4.57	3.76	4.32	4.57	4.32	4.57	2.0	2.58	2.57	2.58	1.76	2.32	2.4
4.89	4.89	4.89	4.10	4.64	4.89	4.64	4.89	4.89	4.89	4.89	4.10	4.64	4.89	4.64	4.89	2.0	2.94	2.93	2.94	2.14	2.68	2.8
3.17	3.17	3.17	2.69	3.01	3.17	3.01	3.17	3.17	3.17	3.17	2.69	3.01	3.17	3.01	3.17	1.9	1.25	1.25	1.25	0.77	1.09	1.2
1.38	1.38	1.38	1.18	1.31	1.38	1.31	1.38	1.38	1.38	1.38	1.18	1.31	1.38	1.31	1.38	1.9	-0.53	-0.53	-0.53	-0.73	-0.60	-0.6
5.84	5.83	5.84	5.06	5.56	5.84	5.56	5.84	5.84	5.83	5.84	5.06	5.56	5.84	5.56	5.84	1.9	3.93	3.93	3.93	3.16	3.66	3.8
3.33	3.32	3.33	2.91	3.17	3.33	3.17	3.33	3.33	3.32	3.33	2.91	3.17	3.33	3.17	3.33	1.9	1.46	1.46	1.46	1.04	1.30	1.4
16.58	16.57	16.58	14.88	15.90	16.58	15.90	16.58	16.58	16.57	16.58	14.88	15.90	16.58	15.90	16.58	1.9	14.72	14.71	14.72	13.02	14.04	14.4
5.66	5.66	5.66	5.10	5.43	5.66	5.43	5.66	5.66	5.66	5.66	5.10	5.43	5.66	5.43	5.66	1.8	3.84	3.83	3.84	3.27	3.61	3.7
6.77	6.77	6.77	6.20	6.53	6.77	6.53	6.77	6.77	6.77	6.77	6.20	6.53	6.77	6.53	6.77	1.8	4.96	4.96	4.96	4.39	4.71	4.9
3.17	3.17	3.17	2.91	3.06	3.17	3.06	3.17	3.17	3.17	3.17	2.91	3.06	3.17	3.06	3.17	1.8	1.39	1.39	1.39	1.14	1.28	1.4
3.16	3.16	3.16	2.92	3.05	3.16	3.05	3.16	3.16	3.16	3.16	2.92	3.05	3.16	3.05	3.16	1.7	1.43	1.42	1.43	1.19	1.32	1.4
2.09	2.09	2.09	1.94	2.02	2.09	2.02	2.09	2.09	2.09	2.09	1.94	2.02	2.09	2.02	2.09	1.7	0.36	0.36	0.36	0.21	0.29	0.3

4.14	4.13	4.14	3.85	4.00	4.14	4.00	4.14	4.14	4.13	4.14	3.85	4.00	4.14	4.00	4.14	1.7	2.41	2.41	2.41	2.12	2.28	2.4
4.68	4.68	4.68	4.36	4.53	4.68	4.53	4.68	4.68	4.68	4.68	4.36	4.53	4.68	4.53	4.68	1.7	2.99	2.99	2.99	2.68	2.84	2.9
3.74	3.74	3.74	3.50	3.62	3.74	3.62	3.74	3.74	3.74	3.74	3.50	3.62	3.74	3.62	3.74	1.6	2.09	2.09	2.09	1.85	1.97	2.0
8.58	8.58	8.58	8.07	8.33	8.58	8.33	8.58	8.58	8.58	8.58	8.07	8.33	8.58	8.33	8.58	1.6	6.95	6.94	6.95	6.43	6.70	6.9
3.79	3.78	3.79	3.57	3.68	3.79	3.68	3.79	3.79	3.78	3.79	3.57	3.68	3.79	3.68	3.79	1.6	2.18	2.18	2.18	1.96	2.07	2.1
3.19	3.19	3.19	3.02	3.11	3.19	3.11	3.19	3.19	3.19	3.19	3.02	3.11	3.19	3.11	3.19	1.6	1.60	1.60	1.60	1.42	1.51	1.6
1.54	1.54	1.54	1.46	1.50	1.54	1.50	1.54	1.54	1.54	1.54	1.46	1.50	1.54	1.50	1.54	1.6	-0.02	-0.02	-0.02	-0.11	-0.07	0.0
1.57	1.57	1.57	1.49	1.53	1.57	1.53	1.57	1.57	1.57	1.57	1.49	1.53	1.57	1.53	1.57	1.6	0.01	0.01	0.01	-0.07	-0.03	0.0
4.14	4.14	4.14	3.93	4.04	4.14	4.04	4.14	4.14	4.14	4.14	3.93	4.04	4.14	4.04	4.14	1.5	2.62	2.62	2.62	2.41	2.51	2.6
3.03	3.03	3.03	2.88	2.95	3.03	2.95	3.03	3.03	3.03	3.03	2.88	2.95	3.03	2.95	3.03	1.5	1.51	1.51	1.51	1.36	1.43	1.5
4.80	4.80	4.80	4.57	4.68	4.80	4.68	4.80	4.80	4.80	4.80	4.57	4.68	4.80	4.68	4.80	1.5	3.26	3.25	3.26	3.03	3.14	3.2
4.06	4.06	4.06	3.87	3.96	4.06	3.96	4.06	4.06	4.06	4.06	3.87	3.96	4.06	3.96	4.06	1.5	2.56	2.56	2.56	2.37	2.46	2.5
1.98	1.98	1.98	1.89	1.93	1.98	1.93	1.98	1.98	1.98	1.98	1.89	1.93	1.98	1.93	1.98	1.6	0.38	0.38	0.38	0.29	0.34	0.4
1.18	1.18	1.18	1.13	1.15	1.18	1.15	1.18	1.18	1.18	1.18	1.13	1.15	1.18	1.15	1.18	1.9	-0.74	-0.74	-0.74	-0.79	-0.77	-0.7
2.46	2.46	2.46	2.35	2.40	2.46	2.40	2.46	2.46	2.46	2.46	2.35	2.40	2.46	2.40	2.46	2.3	0.16	0.16	0.16	0.05	0.10	0.1
4.23	4.23	4.23	4.05	4.13	4.23	4.13	4.23	4.23	4.23	4.23	4.05	4.13	4.23	4.13	4.23	2.5	1.70	1.70	1.70	1.52	1.61	1.7
1.80	1.80	1.80	1.72	1.76	1.80	1.76	1.80	1.80	1.80	1.80	1.72	1.76	1.80	1.76	1.80	3.5	-1.68	-1.68	-1.68	-1.75	-1.72	-1.7
0.41	0.41	0.41	0.39	0.40	0.41	0.40	0.41	0.41	0.41	0.41	0.39	0.40	0.41	0.40	0.41	2.9	-2.49	-2.49	-2.49	-2.51	-2.50	-2.5
1.18	1.18	1.18	1.13	1.15	1.18	1.15	1.18	1.18	1.18	1.18	1.13	1.15	1.18	1.15	1.18	2.3	-1.16	-1.16	-1.16	-1.21	-1.19	-1.2
4.77	4.76	4.77	4.55	4.66	4.77	4.66	4.77	4.77	4.76	4.77	4.55	4.66	4.77	4.66	4.77	2.1	2.71	2.70	2.71	2.49	2.60	2.7
4.76	4.53	4.76	1.41	4.31	4.76	4.31	4.76	4.76	4.53	4.76	1.41	4.31	4.76	4.31	4.76	1.9	2.85	2.61	2.85	-0.51	2.39	-0.5
1.44	1.36	1.44	0.32	1.29	1.44	1.29	1.44	1.44	1.36	1.44	0.32	1.29	1.44	1.29	1.44	1.8	-0.38	-0.45	-0.38	-1.50	-0.52	-1.5
5.49	5.34	5.49	0.06	4.82	5.49	4.82	5.49	5.49	5.34	5.49	0.06	4.82	5.49	4.82	5.49	1.7	3.79	3.64	3.79	-1.63	3.12	-1.6
2.98	2.94	2.98	1.42	2.76	2.98	2.76	2.98	2.98	2.94	2.98	1.42	2.76	2.98	2.76	2.98	1.6	1.33	1.29	1.33	-0.23	1.11	-0.2
5.07	5.07	5.07	4.61	4.94	5.07	4.94	5.07	5.07	5.07	5.07	4.61	4.94	5.07	4.94	5.07	1.6	3.43	3.42	3.43	2.97	3.30	3.1
1.36	1.36	1.36	1.26	1.33	1.36	1.33	1.36	1.36	1.36	1.36	1.26	1.33	1.36	1.33	1.36	1.6	-0.28	-0.28	-0.28	-0.39	-0.31	-0.3
2.51	2.51	2.51	2.42	2.46	2.51	2.46	2.51	2.51	2.51	2.51	2.42	2.46	2.51	2.46	2.51	1.6	0.88	0.88	0.88	0.79	0.83	0.9
7.97	7.97	7.97	7.70	7.82	7.97	7.82	7.97	7.97	7.97	7.97	7.70	7.82	7.97	7.82	7.97	1.6	6.40	6.40	6.40	6.13	6.25	6.4
2.90	2.90	2.90	2.80	2.84	2.90	2.84	2.90	2.90	2.90	2.90	2.80	2.84	2.90	2.84	2.90	1.6	1.35	1.35	1.35	1.25	1.29	1.3
1.09	1.09	1.09	1.06	1.07	1.09	1.07	1.09	1.09	1.09	1.09	1.06	1.07	1.09	1.07	1.09	1.5	-0.40	-0.40	-0.40	-0.43	-0.42	-0.4
4.41	4.40	4.41	4.05	4.30	4.41	4.30	4.41	4.41	4.40	4.41	4.05	4.30	4.41	4.30	4.41	1.5	2.93	2.92	2.93	2.57	2.82	2.7
1.69	1.69	1.69	1.57	1.65	1.69	1.65	1.69	1.69	1.69	1.69	1.57	1.65	1.69	1.65	1.69	1.5	0.21	0.21	0.21	0.09	0.17	0.1
1.84	1.84	1.84	1.77	1.81	1.84	1.81	1.84	1.84	1.84	1.84	1.77	1.81	1.84	1.81	1.84	1.5	0.33	0.33	0.33	0.26	0.30	0.3
1.24	1.24	1.24	1.20	1.22	1.24	1.22	1.24	1.24	1.24	1.24	1.20	1.22	1.24	1.22	1.24	1.7	-0.48	-0.48	-0.48	-0.52	-0.51	-0.5

3.12	3.12	3.12	3.02	3.06	3.12	3.06	3.12	3.12	3.12	3.12	3.02	3.06	3.12	3.06	3.12	1.9	1.20	1.20	1.20	1.10	1.14	1.2
0.85	0.85	0.85	0.82	0.83	0.85	0.83	0.85	0.85	0.85	0.85	0.82	0.83	0.85	0.83	0.85	1.9	-1.04	-1.04	-1.04	-1.07	-1.06	-1.0
0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	1.7	-1.57	-1.57	-1.57	-1.57	-1.57	-1.6
27.48	27.08	27.48	3.86	24.73	27.48	24.73	27.48	27.48	27.08	27.48	3.86	24.73	27.48	24.73	27.48	1.6	25.90	25.51	25.90	2.28	23.15	11.6
11.79	11.66	11.79	3.75	10.82	11.79	10.82	11.79	11.79	11.66	11.79	3.75	10.82	11.79	10.82	11.79	1.5	10.27	10.14	10.27	2.23	9.30	5.7
23.90	23.71	23.90	3.06	21.59	23.90	21.59	23.90	23.90	23.71	23.90	3.06	21.59	23.90	21.59	23.90	1.5	22.42	22.22	22.42	1.58	20.10	14.3
8.95	8.89	8.95	1.30	8.08	8.95	8.08	8.95	8.95	8.89	8.95	1.30	8.08	8.95	8.08	8.95	1.5	7.47	7.41	7.47	-0.18	6.60	4.6
3.15	3.13	3.15	1.49	2.94	3.15	2.94	3.15	3.15	3.13	3.15	1.49	2.94	3.15	2.94	3.15	1.5	1.68	1.66	1.68	0.02	1.47	1.1
17.61	17.51	17.61	5.58	16.03	17.61	16.03	17.61	17.61	17.51	17.61	5.58	16.03	17.61	16.03	17.61	1.4	16.20	16.11	16.20	4.17	14.63	12.1
10.19	10.16	10.19	6.04	9.59	10.19	9.59	10.19	10.19	10.16	10.19	6.04	9.59	10.19	9.59	10.19	1.3	8.87	8.83	8.87	4.71	8.26	7.4
3.14	3.14	3.14	2.24	3.00	3.14	3.00	3.14	3.14	3.14	3.14	2.24	3.00	3.14	3.00	3.14	1.3	1.88	1.87	1.88	0.97	1.74	1.6
0.73	0.73	0.73	0.52	0.70	0.73	0.70	0.73	0.73	0.73	0.73	0.52	0.70	0.73	0.70	0.73	1.3	-0.52	-0.52	-0.52	-0.73	-0.55	-0.6
2.90	2.90	2.90	2.77	2.85	2.90	2.85	2.90	2.90	2.90	2.90	2.77	2.85	2.90	2.85	2.90	1.2	1.68	1.67	1.68	1.54	1.62	1.6
1.66	1.66	1.66	1.60	1.63	1.66	1.63	1.66	1.66	1.66	1.66	1.60	1.63	1.66	1.63	1.66	1.3	0.41	0.41	0.41	0.35	0.38	0.4
0.67	0.67	0.67	0.65	0.66	0.67	0.66	0.67	0.67	0.67	0.67	0.65	0.66	0.67	0.66	0.67	1.3	-0.61	-0.61	-0.61	-0.63	-0.62	-0.6
3.47	3.47	3.47	3.36	3.41	3.47	3.41	3.47	3.47	3.47	3.47	3.36	3.41	3.47	3.41	3.47	1.4	2.06	2.06	2.06	1.95	2.00	2.0
3.49	3.49	3.49	3.39	3.44	3.49	3.44	3.49	3.49	3.49	3.49	3.39	3.44	3.49	3.44	3.49	1.4	2.10	2.10	2.10	1.99	2.04	2.1
1.88	1.87	1.88	1.24	1.78	1.88	1.78	1.88	1.88	1.87	1.88	1.24	1.78	1.88	1.78	1.88	1.3	0.54	0.54	0.54	-0.09	0.44	0.3
5.29	5.27	5.29	2.52	4.89	5.29	4.89	5.29	5.29	5.27	5.29	2.52	4.89	5.29	4.89	5.29	1.3	3.97	3.95	3.97	1.20	3.57	3.0
50.67	50.38	50.67	21.02	46.24	50.67	46.24	50.67	50.67	50.38	50.67	21.02	46.24	50.67	46.24	50.67	1.3	49.41	49.12	49.41	19.75	44.97	37.3
14.82	14.73	14.82	6.55	13.57	14.82	13.57	14.82	14.82	14.73	14.82	6.55	13.57	14.82	13.57	14.82	1.3	13.56	13.48	13.56	5.30	12.32	10.2
6.88	6.84	6.88	4.02	6.45	6.88	6.45	6.88	6.88	6.84	6.88	4.02	6.45	6.88	6.45	6.88	1.3	5.63	5.59	5.63	2.76	5.20	4.2
1.76	1.75	1.76	1.04	1.65	1.76	1.65	1.76	1.76	1.75	1.76	1.04	1.65	1.76	1.65	1.76	1.2	0.53	0.52	0.53	-0.19	0.42	0.2
2.06	2.06	2.06	1.87	2.01	2.06	2.01	2.06	2.06	2.06	2.06	1.87	2.01	2.06	2.01	2.06	1.2	0.84	0.84	0.84	0.65	0.80	0.8
4.14	4.13	4.14	2.73	3.88	4.14	3.88	4.14	4.14	4.13	4.14	2.73	3.88	4.14	3.88	4.14	1.2	2.95	2.94	2.95	1.54	2.69	2.5
1.11	1.10	1.11	0.72	1.03	1.11	1.03	1.11	1.11	1.10	1.11	0.72	1.03	1.11	1.03	1.11	1.2	-0.08	-0.08	-0.08	-0.47	-0.15	-0.2
4.86	4.84	4.86	2.75	4.48	4.86	4.48	4.86	4.86	4.84	4.86	2.75	4.48	4.86	4.48	4.86	1.2	3.67	3.66	3.67	1.56	3.29	3.0
1.34	1.33	1.34	0.75	1.23	1.34	1.23	1.34	1.34	1.33	1.34	0.75	1.23	1.34	1.23	1.34	1.2	0.19	0.18	0.19	-0.40	0.08	0.0
0.26	0.25	0.26	0.14	0.24	0.26	0.24	0.26	0.26	0.25	0.26	0.14	0.24	0.26	0.24	0.26	1.1	-0.86	-0.86	-0.86	-0.98	-0.88	-0.9
0.05	0.05	0.05	0.03	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.03	0.05	0.05	0.05	0.05	1.1	-1.03	-1.04	-1.03	-1.06	-1.04	-1.0

0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.1	-1.06	-1.06	-1.06	-1.06	-1.06	-1.1
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.1	-1.06	-1.06	-1.06	-1.06	-1.06	-1.1
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.1	-1.12	-1.12	-1.12	-1.12	-1.12	-1.1
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.2	-1.23	-1.23	-1.23	-1.23	-1.23	-1.2
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.7	-1.71	-1.71	-1.71	-1.71	-1.71	-1.7
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.7	-1.67	-1.67	-1.67	-1.67	-1.67	-1.7
0.51	0.51	0.51	0.28	0.47	0.51	0.47	0.51	0.51	0.51	0.51	0.28	0.47	0.51	0.47	0.51	1.6	-1.12	-1.12	-1.12	-1.35	-1.16	-1.2
12.68	12.63	12.68	6.26	11.63	12.68	11.63	12.68	12.68	12.63	12.68	6.26	11.63	12.68	11.63	12.68	1.6	11.12	11.07	11.12	4.69	10.07	8.7
32.19	32.04	32.19	15.35	29.60	32.19	29.60	32.19	32.19	32.04	32.19	15.35	29.60	32.19	29.60	32.19	1.7	30.48	30.34	30.48	13.65	27.90	24.1
17.51	17.45	17.51	9.86	16.25	17.51	16.25	17.51	17.51	17.45	17.51	9.86	16.25	17.51	16.25	17.51	1.8	15.73	15.67	15.73	8.07	14.46	13.0
19.42	19.37	19.42	13.11	18.24	19.42	18.24	19.42	19.42	19.37	19.42	13.11	18.24	19.42	18.24	19.42	2.1	17.35	17.30	17.35	11.05	16.17	15.4
5.89	5.88	5.89	3.87	5.52	5.89	5.52	5.89	5.89	5.88	5.89	3.87	5.52	5.89	5.52	5.89	1.7	4.17	4.16	4.17	2.15	3.80	3.6
2.76	2.76	2.76	1.80	2.57	2.76	2.57	2.76	2.76	2.76	2.76	1.80	2.57	2.76	2.57	2.76	1.7	1.05	1.04	1.05	0.09	0.86	0.8