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Long-term Water Balance of an Inland River Basin in an Arid Area, North-Western China

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Abstract

China, like many other countries in the region suffers from the water scarcity and problems of desertification and land degradation. One of the most useful approaches to deal with such a problem in the region is water balance study and analysis of different components involved to get an overview of the water supply and demand of the region so that engineers and policy makers can use that in their decision. Different hydrologic models have been developed for different conditions e.g. catchment size and data availability. Hydrologic Modeling System (HEC-HMS) among them is capable to simulate different catchment sizes with well detailed information as well as limited data availability. Geographic Information System (GIS) is also used as a useful tool to delineate sub-basins and extract terrain and physical characteristics of the region and associate them to the hydrologic model. Long term water balance for years between 1963 and 2001 was studied at Shiyang River basin, an inland catchment in Gansu province in western part of China. Calibration for the model could not be applied because of immense data limitation, though the model computes a fairly good estimation of water volume of the region which was applied in water balance equation. The hydrologic components e.g. water supply and demand of the region was determined and the trend of changes of the components were also presented for the study period. The study shows a good cooperation between GIS and HEC-HMS to apply for water balance study and gives a good estimation of component values despite limited data.

Keywords
Geographic Information System (GIS), Hydrologic Modeling System (HEC-HMS), Arid Zone, Water Balance.

Table of Contents

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List of Figures

List of Tables

Abbreviations, Acronyms, and Symbols

AMSL	Average Mean Sea Level
CN	Curve Number
DEM	Digital Elevation Model
ESRI	Environmental Systems Research Institute
GIS	Geographic Information System
HEC-(HMS)	Hydrologic Engineering Center- (Hydrologic Modeling System)
MP	Master Plan
NASA	National Aeronautics and Space Administration, USA
NCAR	National Center for Atmospheric Research, USA
NGA	National Geospatial Intelligence Agency, USA
NRCS	Natural Resources Conservation Service, USA
RDA	Research Data Archive
SCS	Soil Conservation System
STRM	The Shuttle Radar Topography Mission

Chapter 1 – Introduction

1.1 Introduction to the Oasis Project

This study is being done considering a much bigger project called "Oasis-hydrosphere-desert Interaction Influencing Overall Economical Development". To make it short in this paper is called Oasis project. The Oasis project was a study for three catchments in north-western part of China, Gansu province. The project was led by cooperation of a number of major Chinese and European Institutes, universities and agencies, including water resources department of Lund University, Sweden. Aim of the study was to develop an overall master plan (MP). The MP is used for decision making and analyzing the scenarios in arid and semi-arid areas, for the region with the close interaction between oasis stability and ecological environment and human activities. The project supports were mainly provided by local and regional and national government. Many actions such as data collection, field investigation, discussion, meeting and information spreading were done by actively participation of government agencies. Available data including economy, society, hydrology, ecology, environment and water resources utilization, collected through field survey in the Hexi Corridor in September 2003. All data were compiled and presented in GIS format. (Technical Part of Final Report, 2005 & SWMOI, 2006) All initial data and information to conduct the water balance study provided from the available materials and papers issued for the Oasis project or related subjects.

1.2. Study Area

1.2.1. The Gansu Province and Shiyang River Basin

Gansu province, long and narrow in shape, is located in North-West of China (see Fig.1). It is bordered by Mongolia to the North, Inner Mongolia to the northeast, Níngxia and Shaanxi to the east and southeast, Sichuan to the south, Qinghai to the west and Xinjiang autonomous region in the northwest. The area of this province is around 454’400 km^2 and the estimated population in 2005 was around 26 million (with the growth rate of 6.02%) of which 1.4 million live in Capital city of Lanzhou. This region has been a passage from upper Huang He region (Yellow River) to western China. This long corridor is also known for the Silk Road to India and Persia and as a way through which Marco Polo entered to China (Encyclopedia Britannica, 2008 & IPNA, 2008).

Figure 1 Gansu Province Location (Google Earth, 2008)

Gansu province is mostly special loess topography in the middle and in the east part, and green land in northwest as well as the Gobi Desert which spreads intermittently. Climate in this area is temperate monsoonal with characteristics of continental climate. 9^{o} C is the mean temperature, while in the hottest month, July, the temperature is $20\text{-}24^{o}$ C and for the coldest month in January, is -12^{o} to 2^{o} C. The precipitation is increasing from west to east. Mean annual precipitation is estimated 50-500 mm.

1.2.2. Shiyang River Basin

There are three inland rivers in the Hexi Corridor, among them Shiyang River and its catchment are the project's interest area. Shiyang River has eight tributaries namely, the Dajing, Gulang, Huangyang, Zamu, Jinta, Xiying, Dongda and Xida rivers, from east to west respectively (See Fig 2). Shiyang river basin, with an area of 41'600 km^2 is a part of Gansu province, located between 101.68^{o} – 104.27^{o} E and 36.48^{o} – 39.45^{o} N. The river sources are based on precipitation in form of rain and snow mostly in Qilian Mountains. The average annual runoff of the river is about 15.75×10^{8} m^{3}. The river passes through three different hydrological and ecological conditions, called three different zones. It starts at zone one, a very frigid, semiarid and humid area, in north at the Qilian Mountains. Here in this zone, the elevation differs from 2000 to 5000 AMSL and precipitation and potential evaporation are estimated about 300-600 mm and 700-1200 mm respectively, with a drought index (DI—the ratio of potential evaporation to precipitation) of 1–4. The river flows to the arid and cool area, zone 2, passes through corridor with elevation of 1500-2000 AMSL and DI of 4–15. Zone 3 is in the desert to the north, in the warm and arid part of the catchment. The elevation here is between 1300 and 1500 with the annual precipitation and potential evaporation of >150 mm and 2000-2600 mm respectively and with DI of 15–25. This area in the Hexi Corridor has the most critical water shortage and therefore is a very important area in the Gansu region for sustainable water management research and studies (Dahlgren, S., et. al, 2007; Kang, S., et al, 2004).

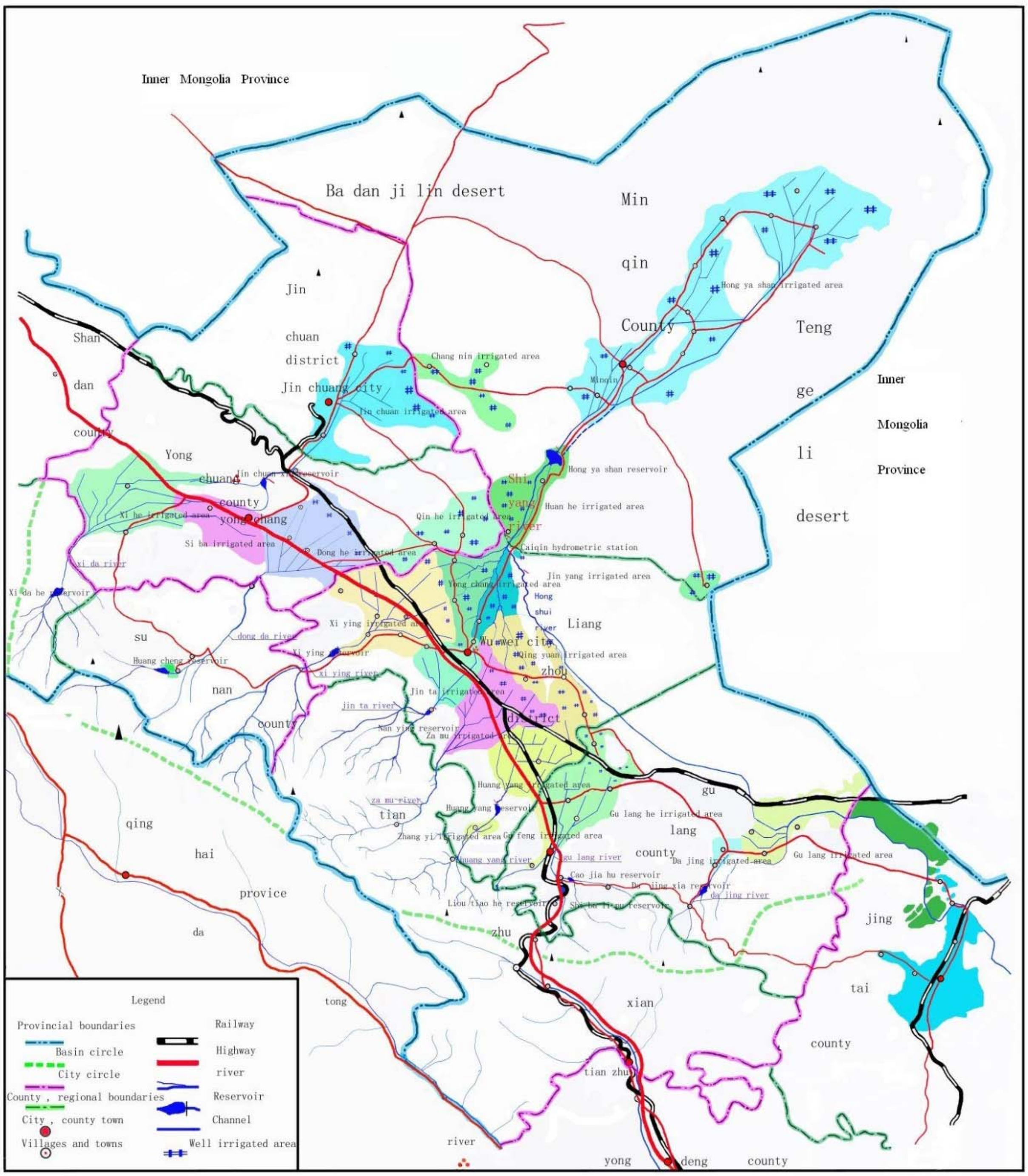

Figure 2 Shiyang River Basin (Gansu Province Water Resources Department, Shiyang River Basin Management Bureau)

The tree different zones are also distinguished by differences in landscapes and vegetation. The first region in the Qilian Mountains has bush and grassland crisscross, and mountain forest and meadow on the slopes. The second region is recognizable as low mountains and hills comprising low grassland and dry grassland vegetation; and finally the third region is formed of Corridor plain on south of Badanjilin and Tenggeli desert with desert vegetation. The soil structure in Qilian Mountain area is formed of alpine frigid desert, alpine meadow, sub-alpine meadow, mountain gray-cinnamonic, mountain black soil and mountain chestnut soil, while the zonal soils are sierozem, grey desert soil and grey-brown desert soil as well as saline, meadow and marshy soil which are distributed in some small area, forms the soil structure of the oasis plain and desert areas to the north (Kang, S., et al, 2004).

The current condition of 8 tributaries in the Shiyang river basin is as following (see Figure 2). Xida and Donga are two rivers of western part of the basin which do not reach the main river. Donga River supplies irrigation demands while Xida besides irrigation and agriculture demands supplies municipal, industrial and hydropower demands downstream the reservoir on the dam. There are five other rivers in the central part of the basin. All of them have been regulated and have connection with the Shiyang River. Among them Gulang River has three tributaries, Liutiao, Shibalibao, Caojiahu, with reservoir on each. The last tributary of Shiyang River is Dajing River which is not connected to the main river anymore (Research Notes, WEAP 21).

There are 23 reservoirs in the Shiyang River Basin. 8 medium sized with total capacity of 450 Mm^3. 86% of water use in this area is for irrigation, 5.7% for industrial demands and 3.9% is for urban and rural water demands. Estimated annual water use and renewable water resources are almost the same and annually is 2’850 Mm^3 (Research Notes, WEAP 21).

1.3 Statement of the Problem

The problems in the Shiyang river basin are the common problems in arid and semi arid area. Water shortage and limited ware resources especially for a region whose water use for agriculture is about 86% can severely affect the sustainable development of the region. Kang, S., et. al. (2004) mentioned a “serious loss of vegetation, gradual soil salinization and desertification” because of some inappropriate human activities related to water and its management. Supply of water by nature is not in humans’ control and water demand is increasing; therefore the water management is the most important effort to support the very fast increasing economy in China. In Hexi corridor, Shiyang river basin’s agriculture and industry grows and demands water management to deal with such a water shortage (Kang, S., et al, 2004). Water Balance is a good way to approach the problems associated to the region.

1.3.1 Objectives

The objective of this project is to study the water balance of the Shiyang river basin for the whole region as well as tributary sub-basins. To provide spatial data and using those in a hydrologic model i.e. HEC-HMS, applying GIS was intended to investigate and practice to find out convenience of using GIS as a tool in association to a hydrologic model. Finally, to figure out the trends of changing in the water balance components in the region according to the available and simulated data to get an overview of water supply and demand in the region during the study period in different parts of the basin.

1.3.2 Scope of Study

According to the objectives of the study three scopes were defined to reach the goals, listed below.

- To prepare inputs for the hydrologic model; for this part the focus is mainly to use ArcGIS as the tool and do all spatial related data preparation i.e. watershed characteristics.
- To apply the hydrologic model, using available and prepared data, making model calibration and validation against historical data.
- To analyze the results to calculate and present the water balance components of the basin and its sub-basins and to use the graphs of the average value of the results to find out the trend of changes of water balance components of the region during the period of study.

Chapter 2 Methodology

2.1 Water Balance Concept

2.1.1 General Approach in Water Balance

According to the definition presented by US Army Corps of Engineers (1980), "a water balance is the systematic presentation of data on the supply and use of water within a geographic region for a specific period of time". In the other word, water balance is used to identify the water sources and water uses, in a geographical region during a specific period of time. The water balance study could provide information of the water availability and uses over a time for a region. Also water balance could be used to determine how well a region equipped to collect adequate data; based on that, it is possible to judge how well the region has been managed in supply and use.

Hydrologic system is a complex system. Changing in one factor makes other factor to be modified. To improve knowledge of such a system, implementation of water balance seems very much useful to identify water conservation and its impact on the supply and demands. Regarding the mentioned fact therefore, water balance study is an unavoidable part of water resources assessment such as impact of dam/reservoir diversion work, well production, deforestation and any development in any other resources.

The supply and use's components of water balance are essential to be known for each study depending on the availability of data as well as the study's objections. In general, the supply components of water balance are precipitation, stream flow, surface storage (including reservoir, lakes, etc.), groundwater (water entering the study area from another basin), Return flow (water discharged to a stream or aquifer after use) and Saline water (brackish ground or surface water or ocean water, used primarily as a source for cooling water). Agriculture, Municipality and industrials, water right (legal entitlements to the withdraw water), In-stream flow (the required amount of flow in a natural stream to maintain acceptable condition for fish and wildlife, navigation, recreation, hydroelectric power generation, water quality, salinity, repulsion and downstream users), Natural depletion (evaporation / evapotranspiration / seepage) are the supply components of water balance. The above definition is a general one that could be change according to every specific area and condition. For example, for a water balance study in a catchment, hydrological data such as infiltration, precipitation and evaporation are used (R. J. Hayes, et. al., 1980).

2.1.2 Water Balance Boundaries

Hydrological system is a unique system in the global scale; though the water balance could be done in much smaller scales by dividing the interested area. To identify each catchment it is essential to identify the hydrological boundaries.

All or part of a ground water basin, a reservoir or lake or all or part of a river basin could be a study area considering water balance. For instance, for a single river study, the water balance should be applied for the whole watershed of that river. A fact which must be taken into consideration is that the institutional boundaries affect the hydrological boundaries, since they are essential for water management and official actions. The common institutional boundaries could be metropolitan statistical area, county, water irrigation district as well as city or town. Water balance study could be done in different type of period i.e. several years, single years as well as part of a year which is dependent on the scope of study. For example several years period could be useful for extended period of drought or assessment effect of long-term use of water in an area (R. J. Hayes, et. al., 1980).

2.1.3 Water Balance Equation

Mathematical definition of water balance as equations helps to present data systematically by which any possible deficiency would be obvious. Water balance equation depends upon a system and the purpose of study. Water balance equation for a stream system without intermediate storage would be:

Downstream flow = upstream flow + local inflow – depletions – withdrawals ± S

In which:
Downstream flow is available flow to supply the very last part of stream which is defined for water balance.
Upstream flow is the incoming flow to the system out of water balance boundaries.
Local inflow is flow back to the system from agriculture runoff, municipal sewage treatment.
Depletion is natural losses through evaporation or seepage in canals and rivers
Withdrawal is agricultural, municipal and industrial demands

Since different variety of data type in sources and accuracy are used, it is expected not to have precise accounting of supply or a complete description of surface or ground water system. The imprecise result could be consequent of oversight in identifying all inputs, over estimation of some output, use of average and constant percentage without considering seasonal and climatic variation factor, inability to account for complex interaction among hydrological factors such as surface and ground ware and finally estimation and assumption which are essential to define boundaries (R. J. Hayes, et. al., 1980).

In a region such as Shiyang river basin, considering a poorly gauged region, for long term water balance study simply can use the following equation;

$Q= P- E$

In which Q is runoff, P is precipitation and E is Evaporation (A. Sokolov, et. al., 1974).

2.1.4 Determination of Principal Water Balance Components

For most cases, there are not enough available data. In such cases, to develop the require data, hand computation or computer simulation models can be used. Required data to apply the water balance study for a watershed system are discussed in this part. Hydrologic data and climate data are the main needed data. Hydrologic data could include flow data which normally is collected at the different gages at specific places such as outlet a reservoir or a watershed outlet. Climate data includes evaporation and precipitation data. The characteristics of the watershed are also important such as infiltration rate of the soil. As before mentioned, each region has its own condition, with different data availability, data accuracy etc, which make each project unique.
An important part of the water balance study is summarizing and presentation of results. In fact the way of presenting data is what makes the whole study practical and ready for decision making .The summarization and presentation of data and result could be in different format such as aerial photographs, satellite taken data and also tables and charts. For instance aerial photographs could be used for showing the location of study field and the boundaries (R. J. Hayes, et. al., 1980).

2.2 Hydrological Modeling

Modeling is a simplified and practical way of engineering analyses which is both efficient and can be accurate. Modeling help engineers to reproduce the real condition in mathematical way. With using available information of the study area and combining them and using physical laws into a system, engineers can predict the future occurrence which is possible to make decisions based on them. Among all models, hydrologic modeling, regarding movement of water, attempts to have and explanation of movement of water over time and space, considering hydrological cycle component such as infiltration and evaporation. Figure 3 shows schematic of hydrologic cycle.

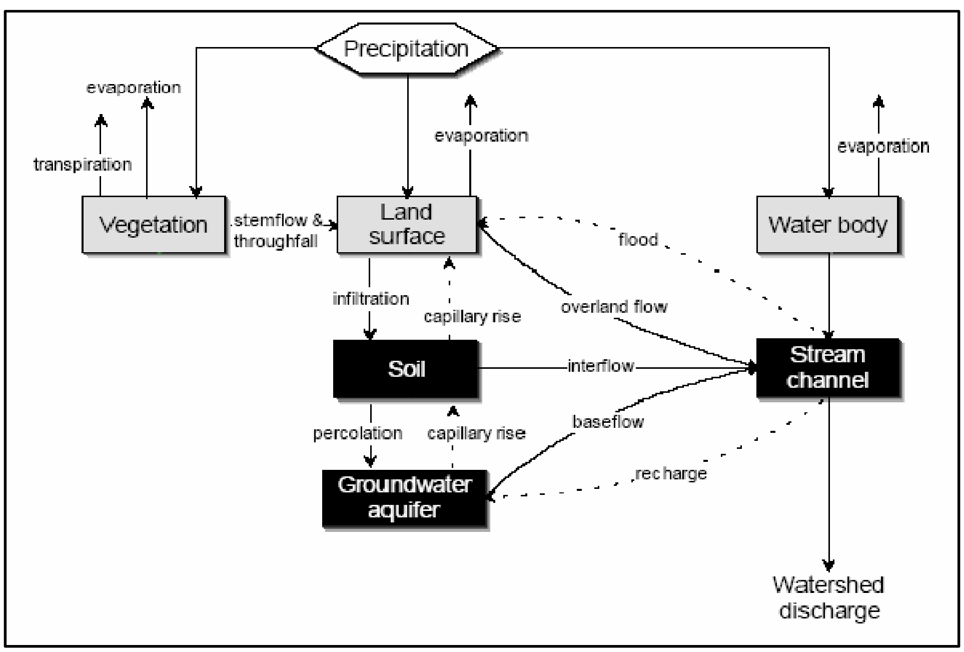

Figure 3 Schematic of Hydrologic Cycle (HEC-HMS, 2000)

Water comes to the land and inland water body from atmosphere. It goes to the soil, in different layers through infiltration to form or contribute in sub-surface run off in higher level or in ground water in deeper layers of the soil. The water can come back to the system by pumping for agriculture use, or can flows to the rivers as perennial streams. The water in the surface can move back to the atmosphere through evapotranspiration; evaporation directly from the soil surface and water bodies or transpired by the plants and vegetations. The water which has already neither infiltrated nor evaporated would flow as surface runoff and form or contribute small and then bigger streams and rivers (see Figure 3).

Hydrologic models which are used for water resources planning are ways to have a better understanding of the physical process of the components of the system interacting all together. Hydrologic models can be used to analyze water movement in a catchment and to forecast flooding. It can also be used to estimate hydropower potentials. By means of hydrologic models, analyzing the surface runoff can be conducted. That would be analyzing the response of surface run off in the whole system to changes in climate or land use as well as changes because of construction dams and reservoirs. To observe groundwater in order to support that the water table does not drop. They could also use the outputs for hydraulics models to investigate sediment and pollutant transport. Also models provide user-specified events, which may never happen, but would be very important for decision making such as probable flood or drought. Hydrological models can be classified to lumped and distributed parameterization considering spatial input resolution variation. While distributed models need high resolution spatial variation, the lumped models does not need so. As a matter of fact, GIS would be a great tool to prepare data for the model such as Digital Elevation Model (DEM) as grid data of elevations. The Hydrologic models can also be classified to events and continuous models. While the events models consider only one rainfall event, the continuous model consider the catchment events over a period of time. Since Shiyang river basin is a large basin and the rainfall events does not happen all over the basin at the same time, the Hydrologic model of Shiyang, modeling by HEC HMS is continuous (S. Gourdji al. et., 2005).

2.2.1 HEC Hydrological Modeling System

The model uses in the study is “the Hydrologic Modeling System” (HMS). It has been designed and developed by U.S Army Corps of Engineers Hydrologic Engineering Center’s (HEC). “The Hydrologic Modeling System is designed to simulate the precipitation-runoff processes of dendritic watershed systems” (HEC-HMS, 2006). Capability of modeling wide range of geographical areas including large river basin make this model to be applicable for the Shiyang River Basin. The HMS is capable of representing variety of watersheds by subdividing the hydrological system to the smaller and manageable pieces. Regarding the goals of the study and specific condition of the catchment, different mathematical model called Methods are predicted. By having enough information of the catchment considering different methods, any of them can be used to represent the mass or energy flux. Four main components of HEC-HMS are:

- A system for storing and managing large amount data
- Analytical models capability of calculating overflow and channel routing
- An Advanced graphic display showing the hydrologic system and its components
- A tool for displaying and reporting output

2.2.2 HMS Inputs

The first step is to use the available spatial and hydrological information. To do so, knowing the necessary input data and the system of using data seems important. In the following section a brief description of preparing input data to model the watershed is discussed.

Data Storage System (DSS)

Data Storage System (DSS) is a file format which is used to store various types of data including times series data (precipitation, discharge) over time and other types of data such as unit hydrograph. Each set of data has six same information fields as header which defines a name for project or basin or etc, location, data parameter, starting data of data set, time interval, and a user description. This system provides capability to store large amount of data as time series or other types in a single and simple file (HEC, 2005).This file also can be produced easily by Microsoft Excel. Army Corps of engineers has developed an extension for Microsoft Excel, HEC-DSS Microsoft Excel data exchange Add-in. The Add-in is a visual basic based application used to store and retrieve data set in irregular intervals (HEC-DSS, 2003).

HMS Input Files

HEC-HMS needs three groups of input data to build up the model. The first set of inputs is for basin model which deal with the simulation of runoff. The second one is meteorological model defining the characteristics of precipitation in any form. The last one is called Control Specification which specifies the starting and ending date of the model as well as interval of input data. Some certain terrain features needs to be introduced to the model, terrain characteristics of the basin and the streams are important. Sub-basins and hydrologic parameters such as slope, length, etc. should be identified. Connectivity of segments defines which element is up or downstream. The basin model has been introduced to simulate the sub-basins, by calculating the water losses through infiltration considering soil properties, delivering water trough channels and finally calculate the excess overflow. For the above mentioned calculations, several other models, called methods, are involve (see Table 1). Regarding the available data, and specific condition, each could be applied. Meteorological model uses the several other methods to deal with precipitation, evaporation as well as snowmelt. Different available methods are used, based on the type of available data, to introduce evaporation, precipitation, and snowmelt to the model (see Table 2). Finally, control specification defines the exact time of starting and ending of the simulation as well as calculation time intervals (HEC-HMS, 2006).

In this study, SCS curve number (SCS) method is used for loss rate and gage weight method is used to introduce precipitation to the model. These methods are further discussed in the next chapters.

Table 1 HMS Model Parameter Methods (HEC-HMS, 2006)

Hydrologic Element	Calculation Type	Method
Sub-basin	Loss Rate	Deficit and constant rate (DC)
		Exponential
		Green and Ampt
		Gridded DC
		Gridded SCS CN
		Gridded SMA
		Initial and constant rate
		SCS curve number (CN)
		Soil moisture accounting (SMA)
	Transform	Clark s UH
		Kinematic wave
		ModClark
		SCS UH
		Snyder s UH
		User-specified s-graph
		User-specified unit hydrograph (UH)
	Base-flow	Bounded recession
		Constant monthly
		Linear reservoir
		Recession
Reach	Routing	Kinematic wave
		Lag
		Modified Puls
		Muskingum

Table 2 Precipitation Methods (HEC-HMS, 2006)

Precipitation Methods	Description
Frequency storm	Used to develop a precipitation event where depths for various durations within the storm have a consistent exceedance probability.
Gage weights	User specified weights applied to precipitation gages.
Gridded precipitation	Allows the use of gridded precipitation products, such as NEXRAD radar
Inverse distance	Calculates sub-basin average precipitation by applying an inverse distance squared weighting with gages.
SCS storm	Applies a user specified SCS time distribution to a 24-hour total storm depth.
Specified hyetograph	Applies a user defined hyetograph to a specifiedsub-basin element.
Standard project storm	Uses a time distribution to an index precipitation depth

2.2.3 Modeling Outputs

Simulation is being run based on the defined control specification(s). The simulation(s) compute the outlet flow of the sub-basins, all stream junctions and reaches. The results of the simulation are available in the form of graphs and tables. Results are tabulated at global summary tables which tabulated all hydrologic elements and also it is possible to see each element individually as either graphs or tables (HEC-HMS, 2006)

2.3 Implementation of Geographic Information System (GIS)

2.3.1 Arc GIS

“A geographic information system (GIS) integrates hardware, software, and data for capturing, managing, analyzing, and displaying all forms of geographically referenced information” (ESRI, 2009). GIS is a very practical tool regarding spatial and also temporal analysis in many fields of studies such as water resources management. GIS is capable of storing high amount of data over geographical area. Its being practical is more considered because of capability of GIS in spatial operation on different sets of data and linking all of them together. GIS uses two type of information, the first one is Spatial Information describing location and shapes and the second one is Descriptive Information relating features (Chen H., et. al., 2004). The GIS software used in this project is ArcGIS Developed by ESRI. The capability of ArcGIS is to use data as input, manipulate and prepare data as output compatible with HEC-HMS which is one of the advantages of using this tool.

2.3.2 Arc-Hydro

Center of Research for Water Resources, University of Texas, Austin, in collaboration with several universities (Consortium of Universities for the Advancement of Hydrological Sciences) and ESRI developed mapping software specifically for water resources. The software called Arc GIS Hydro Data Model or in short Arc-Hydro and work based on Arc GIS software. Describing geospatial and temporal data of landscape and available water resources features, is the main purpose of arc hydro data model. This data model target tree main issues. The first one is hydro description which describes the principle water resources feature in an area. The second one is describing the connection of different feature and tracing the water movement in that field. The third one is time pattern of flow and features' water quality (Arc-Hydro, 2001).

Arc hydro is capable to analyze topography information such as DEM data, to trace the water from the higher level point to the lower one, and finally is capable to determine the flow lines inside and on the border of a watershed in a hydrological system. This is the capability which is being used in this study to delineate the watershed and prepare available data for hydrological simulation as well as water balance study.

2.3.3 HEC Geo-HMS

The advances in GIS and its ability to manipulating data and perform spatial analysis to develop the hydrologic models has made it a necessary tool for engineers and hydrologist. Since using GIS, efficiently needs enough knowledge and experiences, the US army Corps of engineers, Hydrologic Engineering Center, developed a Geo-Spatial Hydrologic Modeling Extension for the Arc-GIS for limited experienced engineers and hydrologist. The extension provides users with interface, menu, tools, bottoms to generate hydrologic inputs for directly use of Hydrologic Modeling System, HEC-HMS (Geo-HMS, 2003).

Geo-HMS has capability to create the background map containing the stream alignments and sub-basin boundaries, which provides users with sub-basin delineation and manipulation's tool; for instance it is possible to delineate sub-basins by supplying point data set as desired outlets. It also creates lumped basin model which contains hydrologic elements and their connectivity to represent the water movement through the sub-basins. Creating a grid-cell parameter file and distributed basin model are also of its capabilities. It also can generate the table of physical characteristics of watersheds and streams as well as having the ability to analysis the DEM data. Computing the CN value of sub-basin is also possible with Geo-HMS along with generating the meteorological model and control specification (Geo-HMS, 2003).

Chapter 3 Data Preparation

Before starting to run the simulation, and study the water balance of the Shiyang River basin, it is necessary to collect all necessary information and data. In this chapter, preparation of terrain data and hydrologic data is being discussed. The available data and data taken from some data bases through the net are untreated and therefore they must be manipulated and organized in order to make them ready as input data for HEM-HMS model.

The main and initial step for the hydrological model is description of the landscape and streams of the study area. Digital Elevation model (DEM) is used as raw data. Arc-GIS and Arc-Hydro give a description of the landscape, delineate the watershed boundaries, and define the stream lines and rivers of the region. The characteristics of the soil, focus on infiltration rate, are being represented by SCS Curve number method. Preparation of Curve Number values for the region also is being done by means of Arc-GIS and Geo-HMS with DEM data and soil type data as input. Finally the meteorological data, precipitation, evaporation and runoff values should be manipulated and organized in a way that can be used in HEC-HMS. All meteorological data are taken from the Oasis project.

3.1 Digital Elevation Model (DEM) Processing

The presentation of elevation of the Earth's surface is vital for so many of research projects. Digital Elevation Model (DEM) is digitally recorded surfaces' elevation by satellite technology. For this project, DEM data was the primary data needed which will be explained and discussed later on this paper. The DEM data was provided from USGS website on free public domain. The data is obtained through a project by NASA called "The Shuttle Radar Topography Mission (SRTM)". The SRTM has provided over 80% of the whole globe with DEM resolution of 90 m in equator at the mosaic of 5° × 5°. The project was an international project spearheaded by the National Geospatial-Intelligence Agency (NGA) and the National Aeronautics and Space Administration (NASA). Then NASA released the second version of SRTM digital topographic data known as finished data version. The DEM data used in this project is the 3rd version of SRTM. This is an improvement of the previous version, especially in filling No-Data area which was in the 2nd version (A. Jarvis, et. al, 2006). The SRTM data is available as 3 arc second (approx. 90m resolution) DEMs. The vertical error of the DEM's is reported to be less than 16m (NASA, 2006; CGIAR, 2006).

Automated watershed delineation was conducted for the raw DEM data in order to find the River basin borders and the result was clipped by the Gansu province border. The final Shiyang River basin boundaries were assigned (See Figure 4).

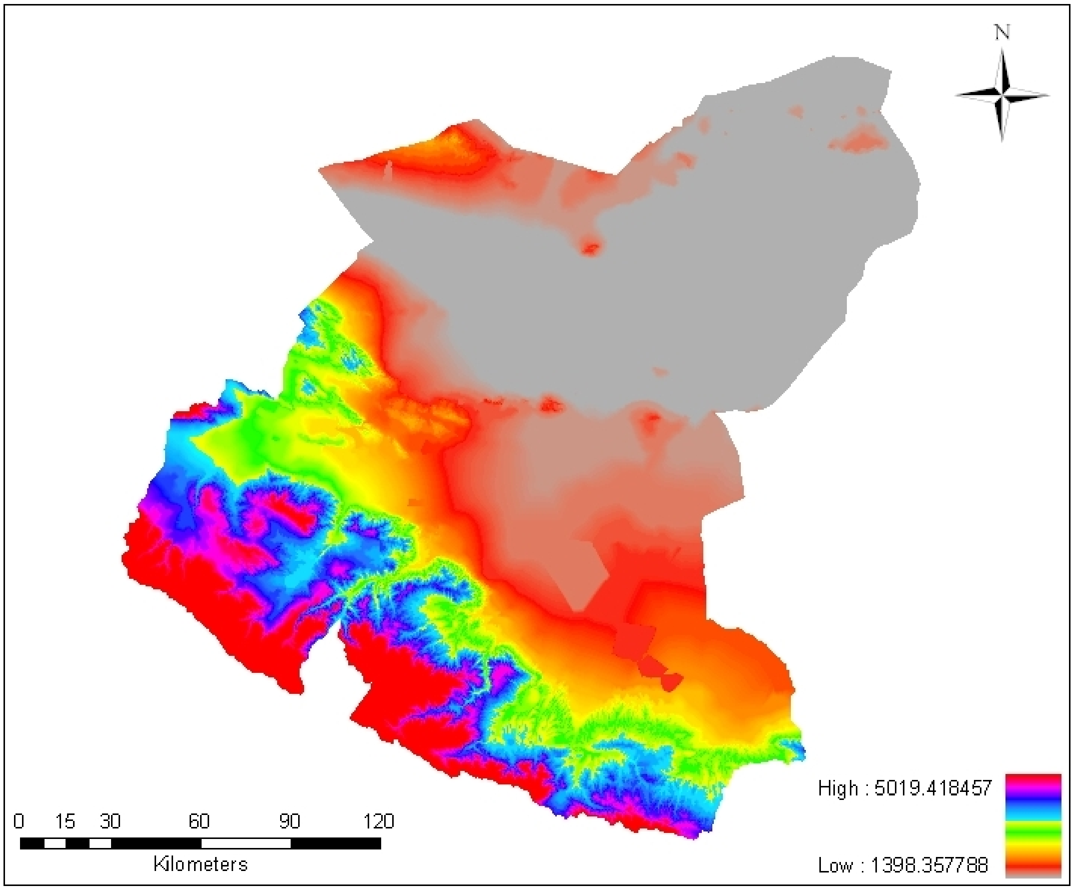

Figure 4 Shiyang River Basin DEM Data Map

3.2. Catchment Processing

The primary focus on the data preparation is the terrain processing. Raw DEM data is clipped to the Shiyang river basin and now is ready to be processed. The aim is to identify the drainage pattern of the Shiyang river basin as well as basin and sub-basin's boundaries. This process is done by means of Arc Hydro and Geo-HMS tools in the Arc GIS environment. The Geo-HMS at the end makes the files format readable for HMS model.

The first step in terrain processing is watershed delineation and stream extraction. This is done based on the physical fact that water moves from the higher level to the lower. Regarding this fact Arc Hydro tool uses DEM data recognizing each cell elevation and makes the water move through higher to lower one. The receiving cells joined together and constitute the streams in the catchment (Chen H., et. al., 2004). The details of processing are discussed in the following lines.

Watershed Delineation

The first step for watershed delineation is to use 'DEM Reconditioning' function. This function imposes the already known streams in the region to the DEM layer. This is done by AGREE method developed in Center for Research in Water Resources at the University of Texas at Austin. This method defines lower elevation for the stream vector layer than the lowest elevation in the DEM raster layer. It makes an agreement with the stream delineation and the real observes streams on the final layer called Agree-DEM (see Figure 5a).

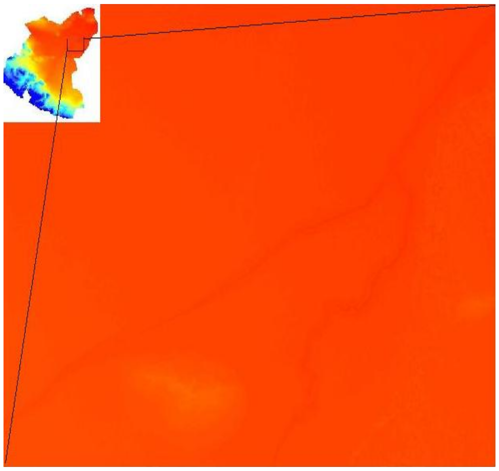

Figure 5a Agree DEM

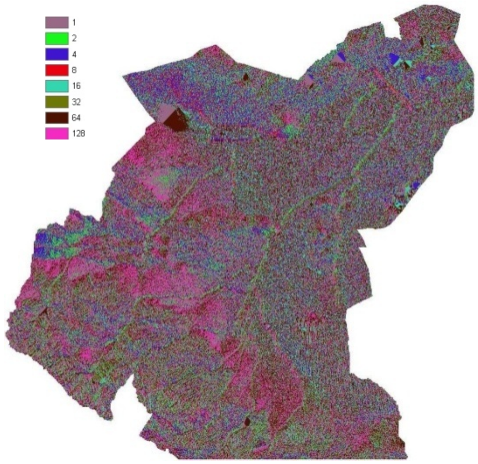

Figure 5b Flow Direction

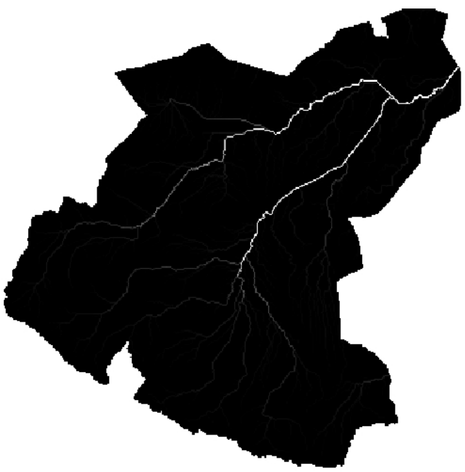

Figure 5c Flow Accumulation

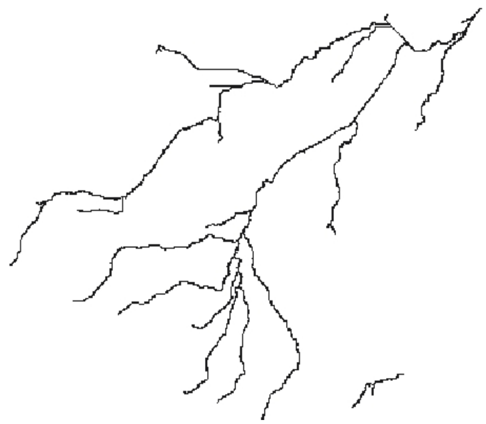

Figure 5d Stream Delineation

Figure 5e Segment Definition

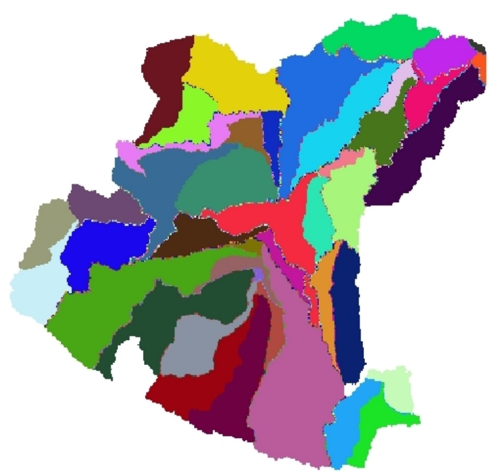

Figure 5f Catchment Delineation

The next step is called Fill Sink. This function is like automatic correction of some possible errors in DEM data. In some cases some cells have the lower elevation that their surrounded cells which make them as a sink and water cannot flow out from those cells, and that would turn to a problem for watershed delineation. Fill Sink will fill this problem by fill up them.

The next function is ‘Flow Direction” and assigns each cell’s direction where water flows to. It assigns values 1, 2, 4, 16, 32, 64 & 128 for the main directions from East to North-East respectively (see Figure 5b). Flow direction grid is used for the ‘Flow Accumulation’ function to show how many cells upstream flows to each cell (see Figure 5c). The result grid layer is necessary for stream definition. By defining a threshold for stream, the cell with values more than the threshold is defined as a part of stream. The value of each cell is in Flow Accumulation layer is compared with the give threshold. Different values were tried and the result streams were compared with the real stream vector layer and the decision was made about applying threshold value. The result is a raster layer with value one for stream’s cells and No-Data for the rest (see Figure 5d).

The next function is ‘Stream Segmentation’ and assign unique values for each segment of river which could be either a head segment or as a segment between two segment junctions (see Figure 5e). At this part everything is ready to delineate the sub-catchment of Shiyang River basin. Based on each stream segment generated at the last part, sub-basin grid layer is generated. The cells participating in each segment get the same value as the sub-basin value (see Figure 5f). The last part of using Arc-hydro is converting raster data to vector data as some of inputs for Geo-HMS. Catchment polygon, Adjoin catchment polygon as well as drainage line layer are created and added to the data folder (Arc-Hydro, 2007).

3.3 Curve Number Grid

The soil losses or abstraction is an important part of calculation of overland flow. In fact the rainfall can freely overflow unless it is not trapped. The rainfall is trapped either by interception by vegetation, or infiltration to the soil or even stored in the soil surface. Rainfall runoff or direct runoff therefore is the amount of water which is remaining on the surface (chow et al. 1988). Therefore having information of losses process is important for data preparation. There are different methods provided for HMS model showing in table 1. Among them Soil Conversation Method (SCS) (Now the Natural Resources Conservation Service, NRCS) is used to calculate the amount of losses. This method uses Curve Number methodology for losses calculation (HEC-HMS, 2006).

3.3.1 Soil Conservation System (SCS) Curve Numbers

Soil Conservation Service (SCS) runoff curve number method is most commonly used method for estimating rainfall excess (Handbook of Hydrology, 1992). The SCS Curve Number is used to characterize the runoff properties of a region (sub-basin) for its particular land use and soil infiltration characteristics. The CN value is between 30 and 100. The high values show that the region does not retain water so much and most of the rainfall turns to overland flow, while low values correspond to high ability of retaining water and therefore high losses rate and low overland flow for the region.

The SCS runoff equation:

$$Q = \frac{(P-I_\alpha)^2}{(P-I_\alpha)+S} \qquad \text{(eq. 1)}$$

Where: Q = runoff
P = Rainfall
S = Potential maximum retention after runoff begins
I_α = Initial abstraction

According to the Handbook of Hydrology (1992), Initial abstraction is "all losses before run off begin". Water retained in the surface depressions, water intercepted by vegetation, and evaporation and infiltration constitute the initial abstraction.
$I\alpha$ as an empirical equation is:

$$I_a = 0.2\,S \qquad \text{(eq. 2)}$$

To get an equation independent from initial abstraction value, substituting eq.2 into eq.1 gives:

$$Q = \frac{(P-0.2S)^2}{P+0.8S} \qquad \text{(eq. 3)}$$

$$S = \frac{1000}{CN} - 10 \qquad \text{(eq. 4)}$$

Where S is parameter related to the soil and land cover condition. The value CN is for different land uses affiliated to the soil type which is determined in the table of SCS Runoff Curve Numbers and also the classification of different soil types are explained and are available at Chapter 5 of Handbook of Hydrology (Handbook of Hydrology, 1992). The SCS's soil type classification is in four groups A, B, C & D. where, as a short description group A is constitute of deep sand, deep loess and aggregated silts. Group B made up of shallow loess and sandy loam while clay loams, shallow sandy loam, soil low in organic content and soils usually high in clay are know as group C and finally group D is assigned to the soils that swell significantly when wet as well as to the heavy plastic clays and certain saline soils (McCuen, 2004). See also appendix 1 for more information on SCS curve number tables and the soil types.

3.3.2 Curve Numbers (CN)

The curve number (CN) values for each sub-basin result from the land use and soil type information. To deal with the huge amount of data in the field of study, Arc-GIS is used as a tool to calculate CN value for each cell in the region and Geo-HMS is used to find out the average CN value for each sub-basin in the Shiyang river basin.

3.2.2.1 Land Use Data

Land use information is on GIS format and should be processed to get ready and merge with the soil type data. The available land uses are in 25 classes. They are reclassified to the very same classes with the same categorization in the SCS Runoff Curve tables for each (see table 3, Figure 6 & 7).Then regarding the available information of the area, the decision is made if each categorization is in either Poor, Fair, or Good condition according to the Tables of SCS runoff Curve Numbers (see Appendix 2).

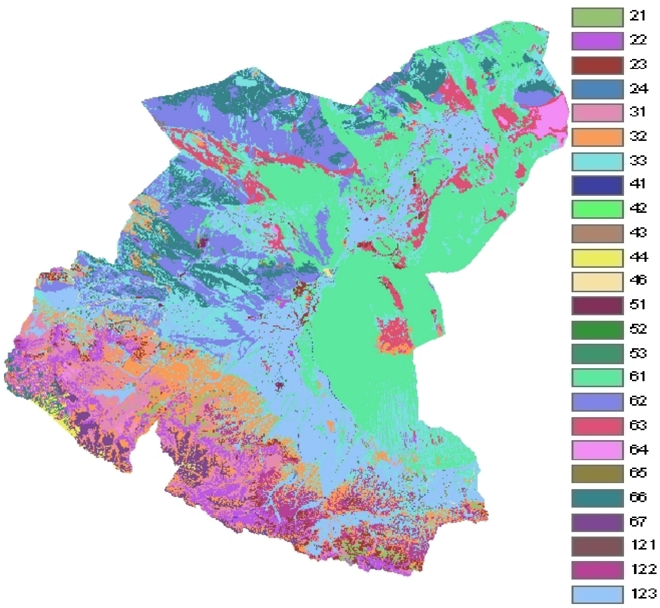

Figure 6 the Initial Land Use Classification

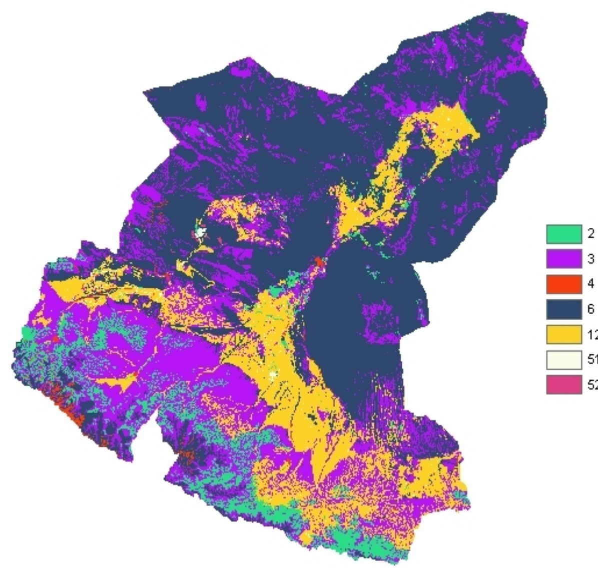

Figure 7 the Classified Land Used Classification

Table 3Original and Reclassified Land Use Table

Old Value	Description	New Values
21	Woodland	2
24	Spares Woodland	
22	Close Shrub land	
23	Other woods(Orchard, Tea plantation)	31
31	Meadow (fc > 50%)	
32	Meadow (20% < fc < 50%)	
33	Meadow (5% < fc < 20%)	33
41	River and Canal	4
42	Lake	
43	Reservoir	
44	Snow and Ice	
46	Beach land	

51	Urban and Built-up Land	51
52	Rural Residential Area	52
53	Airport, Industrial area, Oil Fiel	
61	Desert	6
62	Gobi	
63	Saline-Alkali Soil	
64	Wetland	
65	Bare Soil	
66	Bare rock and Gravel	
67	Barren	
121	Dry Farm land (Mountainous Region)	12
122	Dry Farm land (Hill Region)	
123	Dry Farm land (Plain Region)	

3.2.2.2 Land Soil Type Data

Soil type data was not available for the region in the primary data. Therefore the task was to find some information about either the soil type or infiltration rate or any other information to make decision about soil types of the region. G. Yexin et. al. (2006) had a research on the region and had provided the geomorphic feature of the Shiyang river basin (see Figure 8). According to the map the region has divided into 5 main part base on which is possible to get the soil type of the region.

The first region is called Mid-High Mountain mostly located in the south and partly in North and North-East of the Basin. The Mantoushan hill, Hongyashan hill in the middle of the basin, and North hill are mainly constitute of red sand stone, schist, gneiss, migmatite and metamorphic rock. Crushing stones are covered the surface bedrock (G. Yexin, et. al., 2006). Regarding the Mention criteria for the soil type, group A is suitable for this part. The second part is called Low Mountain and hill on the map (see Figure 8). This part is itself also made of 3 zones. In north of Qilian which is made of fold and fault block, lithology is mostly loess or clayey loam. The second part is located in the middle of Shiyang river basin in hill and Low Mountains. The structure of this region is mainly red sandstone, schist, metamorphic rock and migmetite, and the last part is located in the north in hills which made up of schist, marble and sandstone. Thus the soil type of this region is A & C. C for the second zone and the others are assigned with soil type of A (G. Yexin, et. al., 2006). Alluvial fan is the third part in the basin which is located in the north of Qilian Mountain. This area is mainly covered by sand gravel and cobble of Quaternary. Therefore the soil type would be chosen as A. The forth part is a plain region. This part is also divided to two regions. Sand, gravel and cobble covered with clayey loam in south and in the north covered by clayey loam and silt loam. The decision was to assign group B for north and group C for south region of this part. Finally, group A was assigned for desert area since this region consists of medium-fine sand. The coverage of surface is sand and dunes (G. Yexin, et. al., 2006). The whole region then categorized to three soil type i.e. A, B and C (see Figure 9).

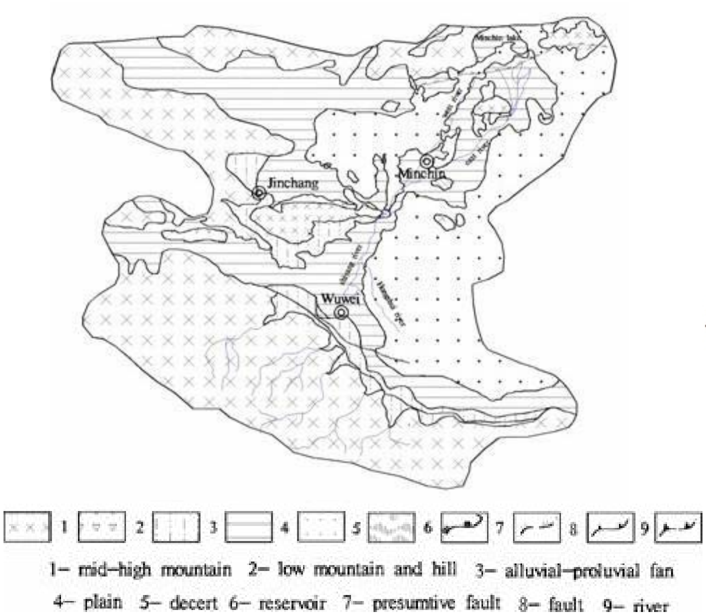

Figure 8 the Geomorphic Feature of Shiyang River Basin (G. Yexin, et. al., 2006)

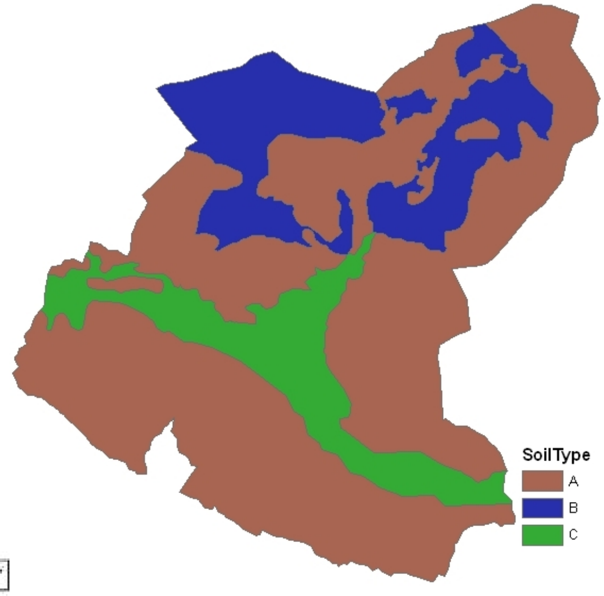

Figure 9 Made Up Soil Type Regions for Shiyang River Basin

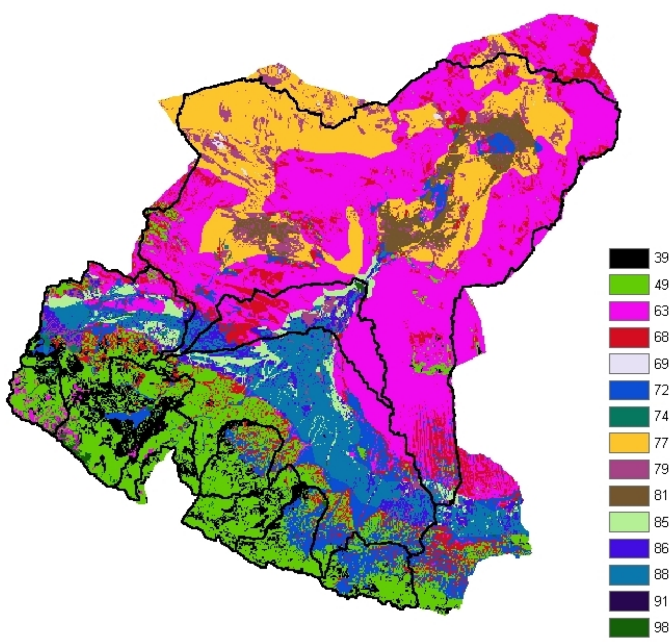

Figure 10 Curve Number Grid Values

The required sets data to generate the CN grid are ready now. By joining attribute of land use and soil type there is a final layer for soils in which each cell has its own values for both soil type and land use class. The value of each class affiliated with specific soil type is set in a Look-up table that Geo-HMS use to calculate the CN value for each cell (see Table4). The final is a grid set of data consisting CN values which is used by Geo-HMS again to calculate the average value of each sub-basin and convert that to a compatible format for HMS model (see Figure 10).

Table 4 Look-Up Table

DESCRIPTION	Value	A	B	C	D
Wood Shrub	2	49	68	79	84
Meadow(High)	31	39	61	74	80
Meadow(Mid)	32	49	69	79	84
Meadow(Low)	33	68	79	86	89
Water	4	98	98	98	98
Urban	51	68	79	86	89
Industrial	52	81	88	91	93
Desert	6	63	77	85	88
Dry Farmland	12	72	81	88	91

3.4 Comprehensive Model

To use all available data in a comprehensive system the model needs to use a tool to gather all components such as DEM of the area, land use and soil information in the form of CN grid, stream networks and sub-basins. For this project HEC-GeoHMS as an extension of Arc-GIS is being used and the result would be a model representative of physical description of the region compatible to HEC-HMS. GeoHMS needs all available or manipulated data discussed in the last part to generate the model. DEM data, all data result from geospatial processing, CN grid, and stream layer are necessary input data for GeoHMS.

At the beginning, the project area must be defined by assigning the outlet of the whole catchment. The next step is to merge sub-basins or define some interest points as outlet of new sub-basin and make the final sub-basins in a way that would be useful for the whole study. One of criteria used to make the final sub-basin is using the observation stations as outlet so that make it easier to compare the results with the observed data. The other one was the regenerate the sub-basin of 8 tributaries of Shiyang Rivers (see Figure 11a & 11b).

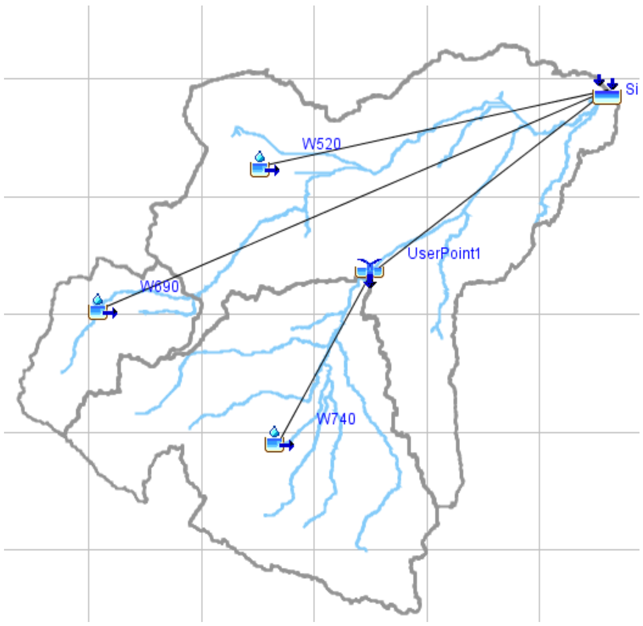

Figure 11a Final Sub-basin & Schematic of Catchment in HMS Model (Basin Model 1)

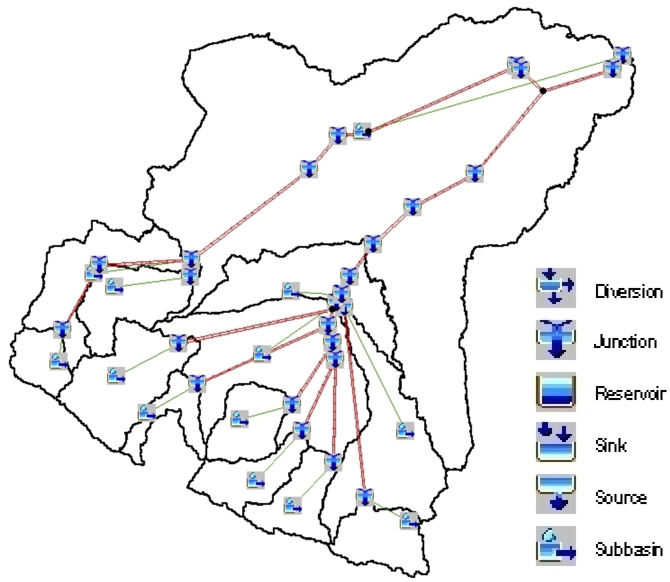

Figure 11b Final Sub-basin & Schematic of Catchment in HMS Model (Basin Model 2)

As figure 11a shows, the model 1was produced mainly based on the most downstream observed flow stations at Hongyashan reservoir to calculate and present the water usage of the upstream of that region which contribute the main water demand of the Shiyang river basin. The second model showing in figure 2 was generated to study water balance of the sub basins upstream of the Hongyashan reservoir.

The next step is to extract the basin Characteristics. Rivers' length, River's slope, sub-basins' slope and area as well as longest flow path of each sub-basin, centroid point and its elevation, and centroidal flow path are the characteristics being extracted and populated in attribute tables of each element. Then the methods which are supposed to be used in HMS are assigned for each model, though it is possible to choose the methods in HEC-HMS as well. SCS for loss method is being used. Transform method and Base-flow type as well as Route method are not chosen for the project, since the model is being defined in the simplest way because of availability of data and considering the long term study of the region. The next step is to assign names (ID attribute) for the river segments and sub-basins. It is done automatically by the program. CN grid now is being used by Geo-HMS to compute the average curve number of each sub basins. The next steps are selecting unit as SI and checking data to verify all inputs as well as making a GIS representation of how the features look line in the HMS environment showing all sub-basins and hydrologic elements and their connectivity (see Figure 11a & 11b).The final step is to convert the comprehensive model so that it is compatible with HEC-HMS.

3.5. Meteorological Data

3.5.1. Precipitation

The available data for precipitation needs some changes in the format and some other calculation so that they can be used in the HMS model. HMS model uses daily format in the simulation, since the available precipitation data is in monthly data for 40 stations and the simulation is for the long term period the decision was made to downscale the monthly available data to daily, though that would be one of the shortfalls of the simulation. Precipitation data is available for 41 stations all over the basin with different density of distribution (see Figure12). However, data is not available in an even period for all stations (see Figure 13). The daily distribution of rainfall could affect the amount of water which either percolates through the soil or contributes in the surface runoff. To downscale the data the only available sets of daily data in the Shiyang river basin was used. With applying this method that is possible to make a new data set as close to the reality as possible, though the reproduction of the daily data is not the reality, however that is the best could be done with the data availability. There are two stations available for the downscaling, Station number 52681 and 52787 located at longitude and latitude 38° 38`, 103° 05` and 37° 12`, 102° 52` and elevation 1367 and 3044 m AMSL respectively. The data from these two stations picked from CISL research data archive (RDA) website. The CISL RDA "is managed by the Data support section of the computational and information system laboratory at the national center for atmospheric research (NCAR) in Boulder, Colorado" at USA. (http://dss.ucar.edu/). In order to choose stations for each of 52681 and 52787 stations, two criteria was followed. The closer in distance, more adaptability, which is shows in figure 12. It also tried to take a look at elevation of different stations. By using the available DEM data, stations above 1600 m AMSL were chosen for station 52787 with elevation 3044 m AMSL and chosen stations for 52681 were in lower elevations.

Because of not having precipitation data for the same period for all station, the simulations were decided to be done in two main periods i.e. 1963 to 1985 and 1985 to 2001. The logic behind this is that during the first period only 15 of stations can represent the precipitation while during the second and latest period all 40 precipitation stations are being used. Therefore in first period the resolution of data is less than the second period.

The other process with is done on the precipitation data was to find out the weighting of each stations for each sub-basin by applying Thiessen Polygon. Thiessen Polygon method is actually used to make a polygon based on each point and as the result any location inside the polygon is closer to the associated point than to the other points (ArcGIS help, 2005). Using ArcGIS as a tool helps to make the layer of Thiessen Polygon and overlay it on the top of sub-basin layer. Then it is possible to compute the percentage of association of each station in sub-basin and use a weighting factor in HMS model while generating meteorological method (see Figure13). The table of percentage of the association of stations in each sub-basin is available in appendix 3.

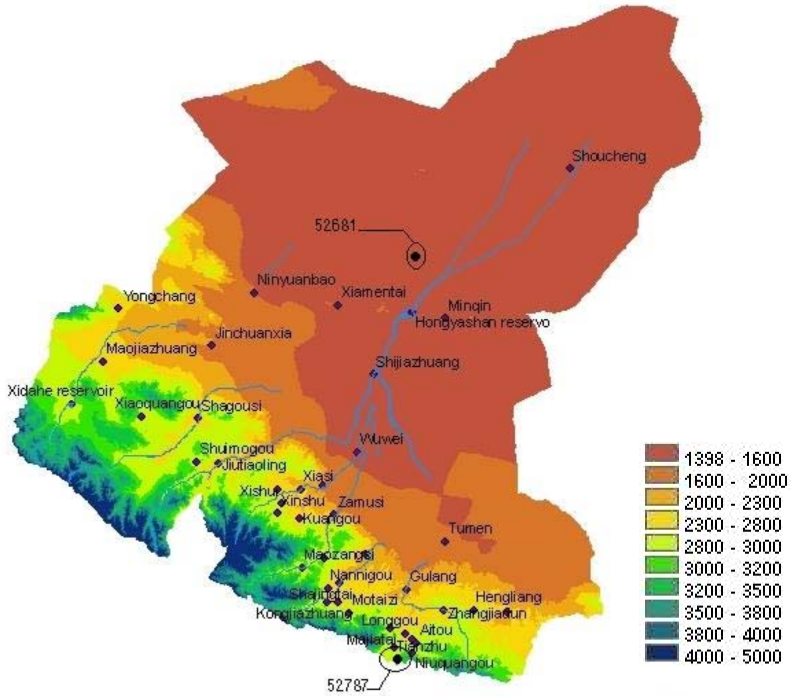

Figure 12 Locations of Precipitation Stations on the Basin Topographcal Map

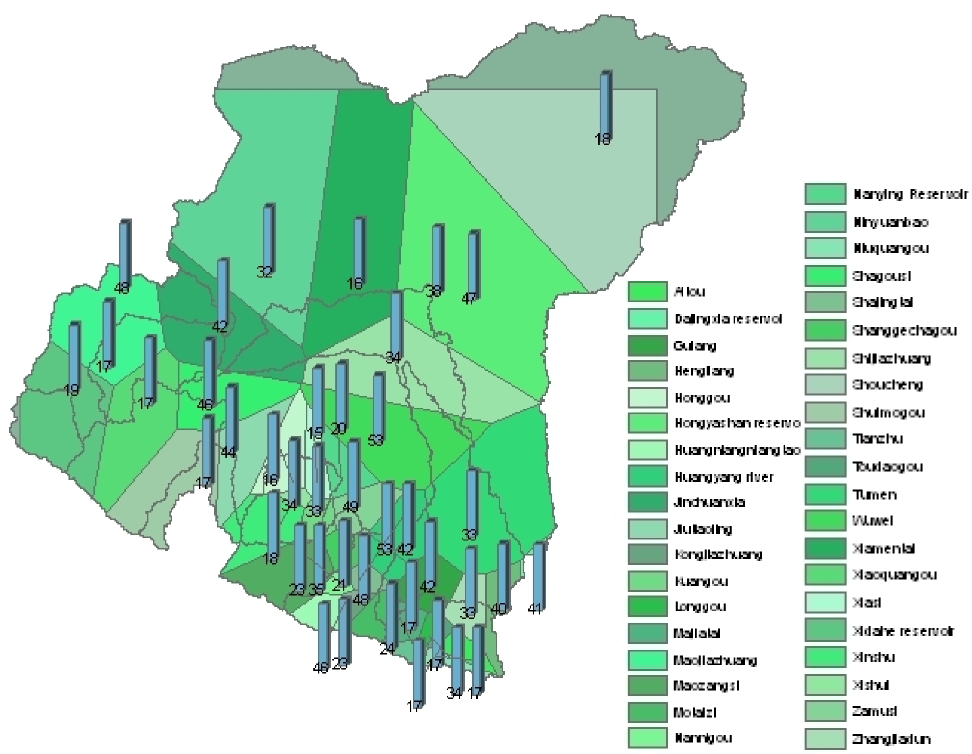

Figure 13a Thiessen Polygons for Precipitation & Sub-basin Overlaid Map and period Time of Available Years Data for Each Precipitation Station. (1985-2001)

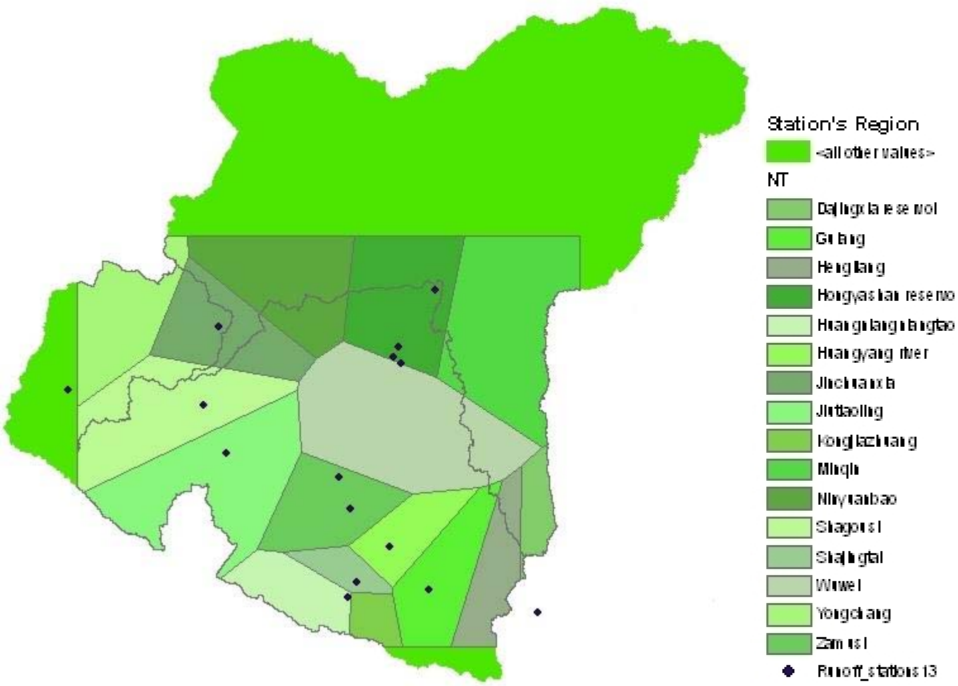

Figure 13bThiessen Polygons for Precipitation & Sub-basin Overlaid Map (1963-1985)

3.5.2. Evaporation

Among three available evaporation methods in HMS model, the Monthly Average is being used to calculate the potential evapotranspiration in each sub-basin and calculate the Aridity Index and its changes during the period of study.

Evaporation data is available for 7 stations in monthly scale. The Evaporation data used in the HMS model is in the monthly scale then the average Evaporation of each sub-basin is used. To calculate the value for each sub-basin, the closet and therefore more effective station to the sub-basin is considered. To compute the weight of stations for each sub-basin the method used for precipitation, Thiessen Polygon Method is used for both Basin Model 1 and 2 (see Fig 14a & 14b).

Applying Thiessen Polygon in ArcGIS for this reason results in a polygon layer containing smaller polygons constitute each sub-basin. In fact the area of each region is as the weight of the association station. The average evaporation over each sub-basin is computed and applied in the HMS model (see Appendix 3).

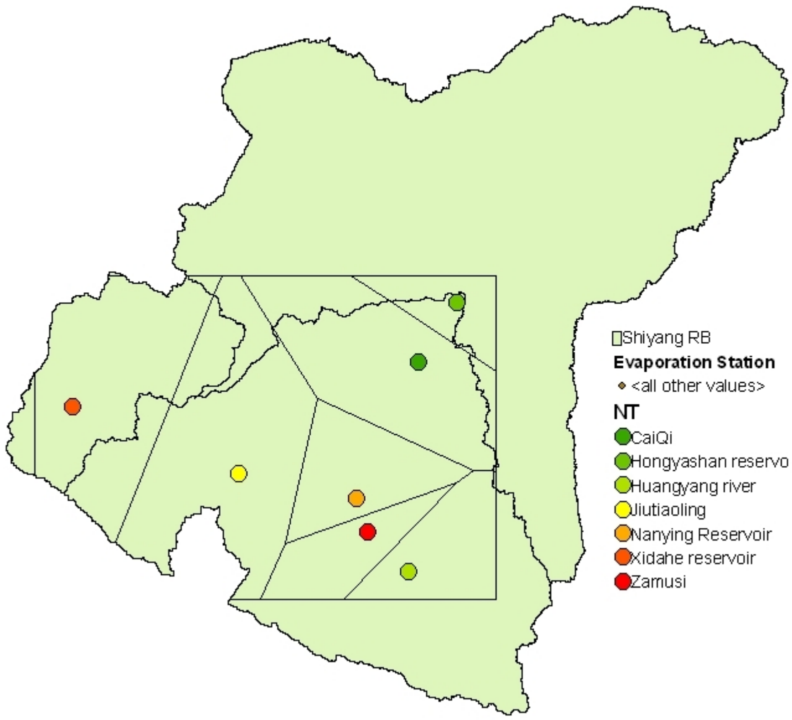

Figure 14aThiessen Polygons for Evaporation & Sub-basin Overlaid Map (Basin Model 1)

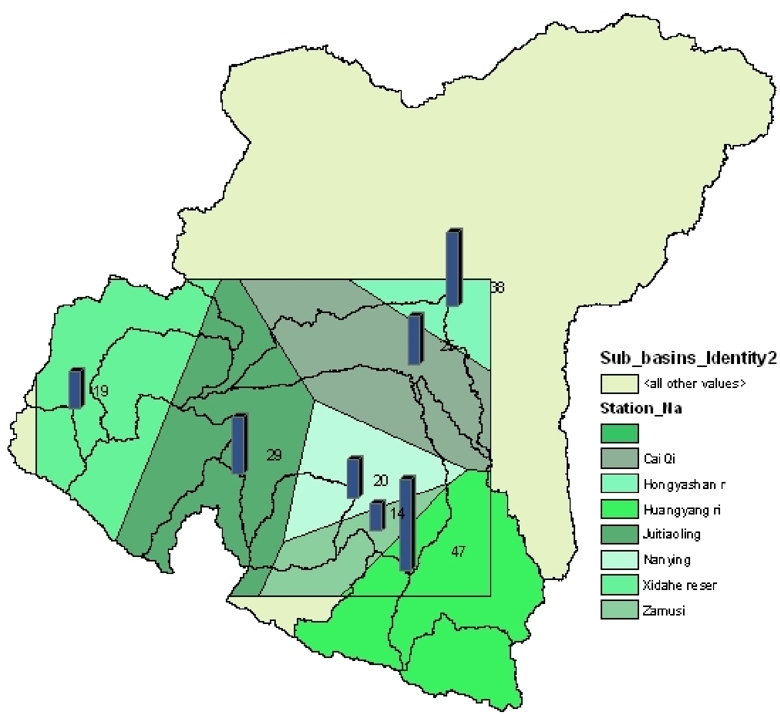

Figure 14b Thiessen Polygons for Evaporation & Sub-basin Overlaid Map and period Time of Available Years Data for Each Evaporation Station. (Basin Model 2)

Chapter 4 – Modeling Approach

In this chapter, it is been trying to discuss the steps needed from beginning to run the hydrologic simulations. First, a short description of the basin model and hydrologic model in the HEC-HMS and the methods applied for them is presented. In continue, input data including the prepared information by GIS, modeling procedure as well as the output results of the simulation are presented in a comprehensive modeling approach.

4.1 Models' Description

4.1.1 Basin Model

Defining the sub-basin model is a way of physical description of a watershed. The physical properties of the Shiyang River basin are defined in different components etc. Loss method, Transform method, Base Flow method and Routing method by which different properties of the basin are discussed and defined for the HMS model. In fact the basin model is to convert the meteorological data into stream flow in the watershed. For the basin model, hydrologic elements are the representative of the actual basin's components such as watershed catchment, rivers and confluence (HEC-HMS, 2006). The basin models have already been created by means of ArcGIS tool, HEC-GeoHMS and imported to the HMS model. The imported models have some characteristics while there are some other information missing and must be defined for the models. Loss method is the one used in this project model. Regarding long term study and limitation with availability of data, it has been tried to make the model as simple as possible. To do so, each basin model is defined only with loss method and therefore the losses of transform and routing method are not consider; along with base flow constitutes a part of main runoff and therefore are calculate as a part of uses water in each sub-basin.

One of two ways of producing inflow in the HMS model is sub-basin as a hydrologic element. Model generates outflow out of sub-basin at the outlet by having meteorological data and base flow subtracting from losses and thus transform the excess to the outlet. For this project the SCS Curve Number method is used to calculate the actual infiltration. The CN value of each sub-basin has already been calculated by ArcGIS and GeoHMS and has been imported to the HMS model. Besides the CN values, there is an option for initial abstraction which is left blank so that the model calculate it automatically as 0.2 time the potential retention, this value itself is calculated from the curve number. This value is also can be modified during calibration process (HEC-HMS, 2006).

4.1.2 Metrological Model

The other main component of the HMS model is meteorological model. As a matter of fact, this is to prepare the meteorological boundary of the model. The boundaries are precipitation and potential evapotranspiration. Model calculates the overflow, meaning calculating the amount of water on the soil surface. Based on atmospheric condition, meteorological model can compute the potential evapotranspiration. Meteorological Model contains three main components with which user can define Precipitation, Evaporation as well as the snowmelt to the model (HEC-HMS, 2006).

4.1.2.1 Precipitation Method

For the precipitation model, there are seven different methods available. Since this project contains sub-basin, it is necessary for the model to define precipitation and should use one of the available models. A hyetograph, which is a correct time step for rainfall in each sub-basin, is generated by precipitation method (HEC-HMS, 2006).

4.1.2.2 Evaporation Method

There are three methods available in the HMS model to define evaporation for the sub-basins. Among Priestley Taylor, Gridded Priestley and Monthly average, the latest was picked up due to the available data. This method is considered the observed data by Pan Measurement method or/ and any other modern method. The value of evaporation are used in monthly average format of each sub-basin and used to compute the potential evaporation of the region (HEC-HMS, 2006).

4.2 The Comprehensive Hydrological Method

The HMS model needs all models and time series as well as bunch of control specification to run the simulation successfully. Depends on available data regarding precipitation and observed run off different basin models, meteorological model and control specifications can be defined for the HMS model. Following discusses different components used in the HMS model for different simulation run.

4.2.1. HMS Inputs

The main components which are used as HMS inputs are Basin model, meteorological model, control specification as well as time series i.e. precipitation and observed data. The basin model as explained before was made in GIS format and converted to HMS files. Two basin models were made and used for simulation. Two main basin models were generated. One was divided to three main sub-basins i.e. W520, W690, W740 considering the upstream of Shiyang Reservoir (see Figure 11a). W740 represents the sub-basin upstream the Hongyashan Reservoir where itself is sub-divided to 6 main sub-basins i.e. Dongda, Xiying, Jinta, Zamu, Haungyang and Gulang. The main aim was to study the water balance of the sub-basin based on the observed data on the main spot of the region which is the Shiyang Reservoir. Because of the less availability of observed data and considering the long term water balance the model was tried to be as simple as possible. Regarding this fact, only sub-basin model was considered. In this case the model uses the precipitation through the meteorological model and applied the loss method to calculate the infiltration based on the soil information to calculate the possible runoff.

The second basin model was also generated, dividing the Shiyang River Basin to 13 sub-basins (see Figure 11b). Since the simulations consider only sub-basin as presenting the region, to simulate each stage, the basin model needs some modification. To do so, for the sub-basin with inflow from the upstream, the modification was made so that the observed data at the outlet of upstream sub-basin are used as inflow to the sub-basin. Therefore for each modification, SINKs were defined to produce inflow to the sub-basins with observed inflow at each station (see Figure 15a & 15b).

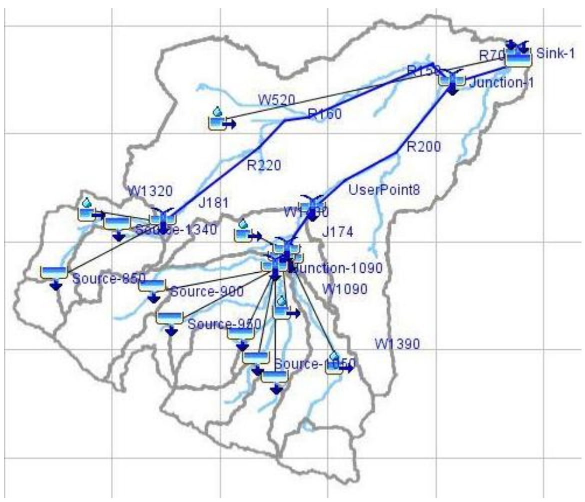

Figure 15a Schematic of Modification of the Second Basin Model (Modification 1)

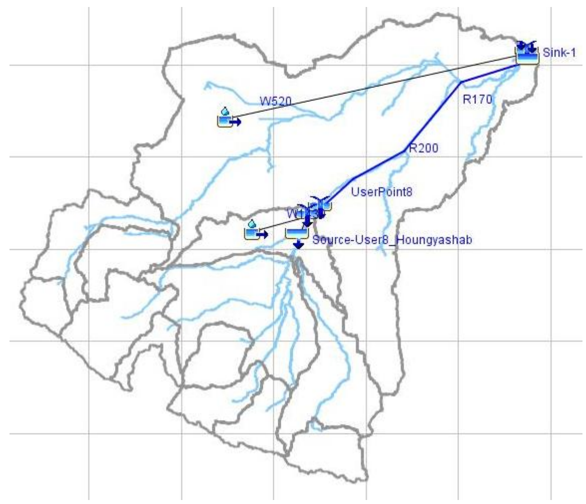

Figure 15b Schematic of Modification the Second basin Model (Modification 2)

In meteorological method, Gage weight method for precipitation and monthly average for evaporation was chosen. Precipitation stations were defined for each sub-basin and gage weight's values, calculated by Thiessen method, were allocated to the associated station. To complete the meteorological model, the average evaporation of each sub-basin was allocated as well. The last step was to define control specification. Control specifications were defined yearly from years 1963 to 2001. Years 1963 to 1985 were chosen since the 15 stations have data on the same period, but in order to use all available data from all stations another period was defined for simulation between years 1985 and 2001, hereupon the values of this period are closer to reality compare to the first period of simulation (see Appendix 3).

4.2.2. Modeling Procedure (Hydrologic Simulation)

Hydrological simulations were made based on input i.e. basin models, hydrological model and control specification. The simulation was run for each year (each control specification) and each basin model. For the first basin model with three sub-basins, the simulations were done simply by the available basin model and then the results were used to study the water balance. While for the second basin model simulation were done from upstream, down to the outlet of the catchment. The simulation first was done for all catchments upstream and then for the downstream catchments, the model modified in a way so that the outflow of the upstream sub-basin was allocated as the observed data at outlet point. As a result the available expected run-off of each sub-basin could be calculated separately. And this modification was continued through the water flow down the Shiyang River basin.

4.2.3. Modeling Procedure (Calibration)

There is a general idea of input parameters to the model. That results in an estimation of output values. To make the results as precise as possible, normally a processed calibration applies. In calibration process, modeler tries to fit the simulated values to observed values of the same events. While doing this, the input parameters modified and the claim is that calibrated values are much closer to reality compared to the un-calibrated ones. The process of calibration in this project could not be applied. Most of the observed data in the region were after using water in irrigation through drainage systems. That means that simulated runoff could not be fit with the observed values.

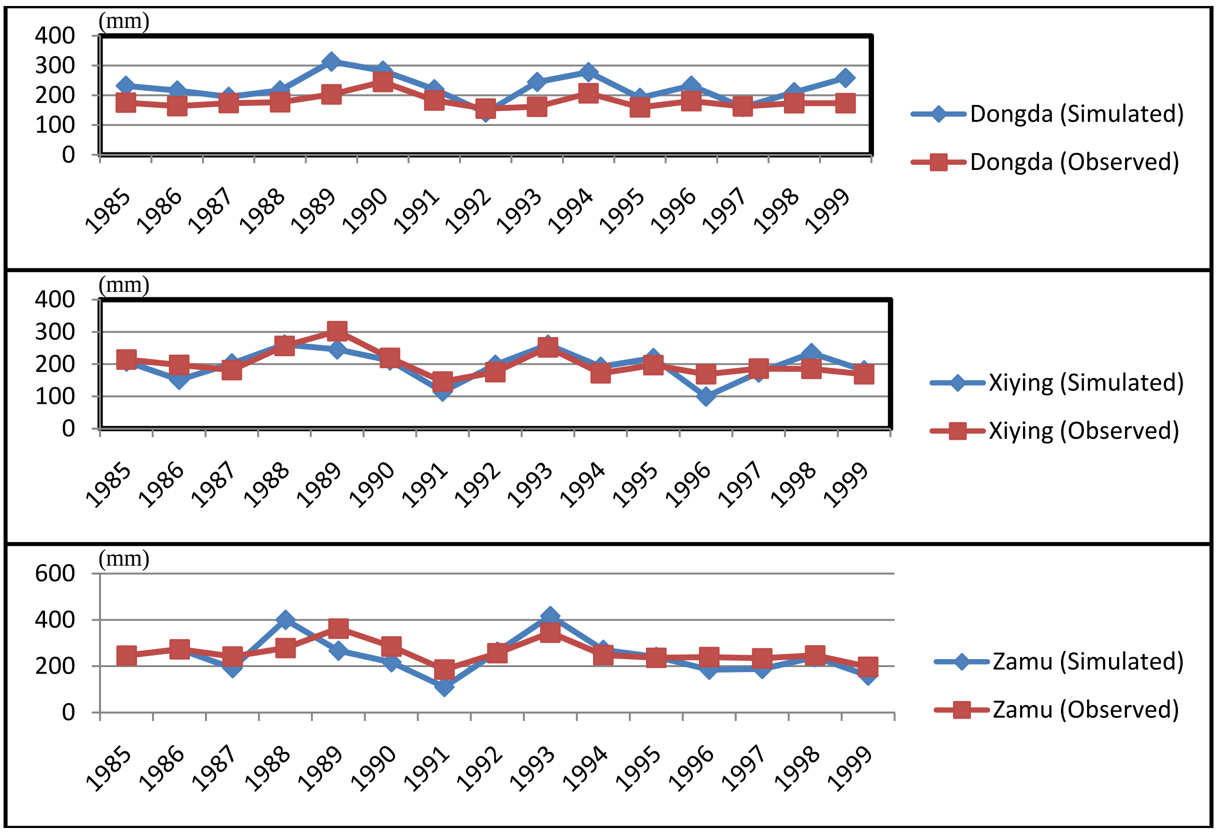

Figure 16 Observed and Calibrated Average Volume of Runoff Comparison

Table 5 Volume Percentage Error

Period		W900(Dongda)			W950(Xiying)			W1050(Zamu)		
		Simulated	Observed	Error%	Simulated	Observed	Error%	Simulated	Observed	Error%
1985	1986	231,96	175,2	32,4	207,52	214,18	3,109534	246,13	246	0,052846
1986	1987	215,86	163,48	32,04	150,98	197,53	23,56604	273,17	272,94	0,084268
1987	1988	195,08	173,63	12,35	201,94	181,72	11,12701	191,54	241,89	20,81525
1988	1989	216,47	176,53	22,63	260,79	256,46	1,688372	399,97	278,66	43,53334
1989	1990	313,35	203,15	54,25	245,45	302	18,72517	267	362,67	26,37935
1990	1991	282,82	245,07	15,4	211,21	219,17	3,631884	217,33	285,34	23,83472
1991	1992	220,36	182,43	20,79	114,33	145,95	21,66495	110,08	185,56	40,67687
1992	1993	141,98	155,03	8,418	197,8	175,4	12,77081	262,29	256,45	2,277247
1993	1994	244,63	161,32	51,64	259,99	252,03	3,158354	416,53	344,81	20,79986
1994	1995	277,69	206,62	34,4	191,59	171,82	11,50623	270,31	248,31	8,859893
1995	1996	191,33	159,52	19,94	218,48	197,01	10,89792	239,83	236,61	1,360889
1996	1997	232,09	180,42	28,64	99,06	168,62	41,25252	184,87	239,43	22,78745
1997	1998	160,3	162,61	1,421	173,35	185,96	6,781028	188,15	234,25	19,67983
1998	1999	210,3	173,34	21,32	234,01	185,33	26,26666	239,2	246,97	3,146131
1999	2000	258,48	173,57	48,92	180,48	168,57	7,065314	159,4	197,36	19,23389
Average		226,2	179,5	27,0	196,5	201,5	13,5	244,4	258,5	16,9

In details, the problem is that there are only three sub-basins (i.e. Dongda, Xiying and Zamu) in which there is not any reservoir and therefore the observed data could be used for calibration; though the calibration would be locally and not cover the whole region. Another problem is that the data are not actual daily data for precipitation and they have been downscaling to daily so that they could be used in the model. Besides, the observed data are in mean monthly values so the fitness for the simulated and observed data is not possible in this sense. Therefore to deal with mentioned problems, the automated calibration in the model is used only to check the precision of the model results. The automated calibration method called percent volume method was used for the 3 sub-basins. The values of calibration for CN were calibrated for each year and the average CN values was used to compare with the actual or initial value of CN. In the other word, the model is run for each year during the study period; automated calibration gives a modified CN values for each sub basin, and finally the average CN values is used for final calibration. The percentage error here is defined as difference of the volumetric simulated values based on the average CN and observed volume of water at the outlet of each sub basin (see Table 5). The percentage error for W900 (Dongda), W950 (‘Xiying) and W1050 (Zamu) are 27%, 13.5% and 16.9% respectively, (see Figure 16).

Regarding the comparison done above and average available errors and lack of any observed data to calibrate the model, the decision was made to accept the initial values of CN as well as runoff estimation by simulation though the result would be rough the average trend of changes during the period time is trustable. Of course the values of CN were close enough to real values since they are based on real soil information of the region discussed in previous chapters.

4.2.4. HMS Outputs

All basin model, meteorological model and control specification together constitute the simulation run and thereafter the results are graphically and in the form of tables available. The results are available for each control specification (each year in this case) separately. Each run includes one basin and one meteorological model and therefore the results are also computed for all basin models' components. Generally, available results for sub-basin are:

1- Summary table including the Peak discharge, total precipitation, total loss, total excess, total base flow and discharge.
2- Separately graphs and tables of all hydrological component used and computed by the simulation i.e. outflow, precipitation, cumulative precipitation, potential evapotranspiration, excess precipitation, precipitation loss, direct runoff and base flow.

In this case, the computed data were also affected by the availability of data and simplification of the simulation. The important output data used were for sub-basin. Precipitation over each sub-basin, loss through infiltration, and run off from each sub-basin were used for study the water balance of the region. In this case, we have precipitation and loss (infiltrated) data as input, and the result is the amount of runoff. The amount of runoff from the regulated observed data at the end of each sub-basin gives the amount of water which has been use by human activities and therefore be evaporated.

Precipitation – Loss = runoff

Simulated Run off – observed Runoff = evaporation

The potential evapotranspiration was also use to find out the trend of aridity index during simulations years. The whole calculation and presentation of results are discussed in Chapter 5.

Chapter 5 – Results and Conclusion

5.1 Results and Discussions

In this chapter the results from the simulation are presented in two time periods i.e. 1963-1985 and 1985-2001 and also the whole period is analyzed as an average value over the whole catchment. As mentioned before, simulations were made mainly based on the two basin models to use the simulation results for water balance study of the region. Simulations based on the first basin model were for the sub-basin upstream the Hongyashan Reservoir (see Figure 11a & 15a) and simulation based on the second one focuses on the main tributary's catchments in the Shiyang River basin (see Figure 11b & 15b). All results and discussion, of course, is limited with the availability and accuracy of the data.

5.1.1 Basin Model 1

To analyze the water balance of the region, first the water balance of the Hongyashan Reservoir was studied (W740). The model produces the precipitation over the basin and also takes the losses out of the system through infiltration into consideration. The result is simulated run-off at the outlet of each sub-basin. Simulation was made based on the available precipitation data on different stations over the basin. Data was available from 1963 to 1985 for some stations and from 1985 to 2001 data was available for all stations (see Table 5). In this part, the simulation was run for two different periods mentioned above. For each period, Thiessen polygon method used to introduce the precipitation weights of each station. Observed data at the outlet of the Hongyashan reservoir were used to calculate consumed water inside the sub-basin during the years of simulation. According to the simulation the average precipitation over the sub-basin was 292.4 mm while the average precipitation during years 1963 to 1985 was 283.1 mm and 282.3mm during years 1985 and 2001. It should be mentioned again that resolution of precipitation station used in the earlier period was less than the latest one. The Evaporation was calculated from the main water balance equation considering long term period. The result was 167.1 mm, 196.9 and 179.6 for period of 63-85, 85-2001 and 63-2001 respectively. The total loss of the region is also computed with the average of 96.3 mm over the region (see Table 6).

In sub-basin W740, for which observed data is available, the precipitation trend for year 1962-1985 is increasing, while the runoff (observed runoff) from the Hongyashan Reservoir is decreasing. The result has a growing trend of evaporation. The trend lines in this study are defined as the best fit line in the graphs as a linear equation. For this area, where there are agricultural fields, results show an increasing trend in water use during year 1963 to1985 although the increasing trend of evaporation is bigger than the one of the precipitation. Of course these changes in water use can also involve some changes in land-use as well. In this project the simulations were run assuming the land-uses are the same during the simulation period. In order to get better results it is of course recommended to run different simulation taking land-use changes into consideration as well, for further research in this region.

The water balance components' trend during years 1985 to 2001 is a bit different. The precipitation trend and observed runoff both are decreasing. The graphs show an increasing trend for evaporation thus the same results can be made for the period 1985 to 2001 considering water consumption and land use changes in the region (see Figures 17a & 17b).

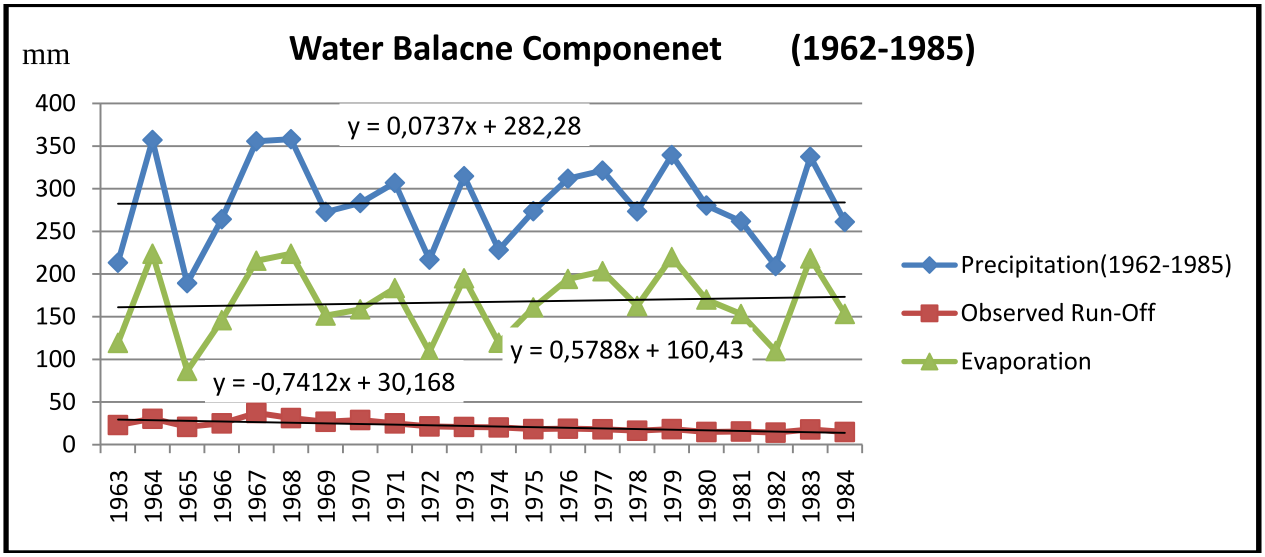

Figure 17a Water Balance Component for sub-basin W740 (1962-1985)

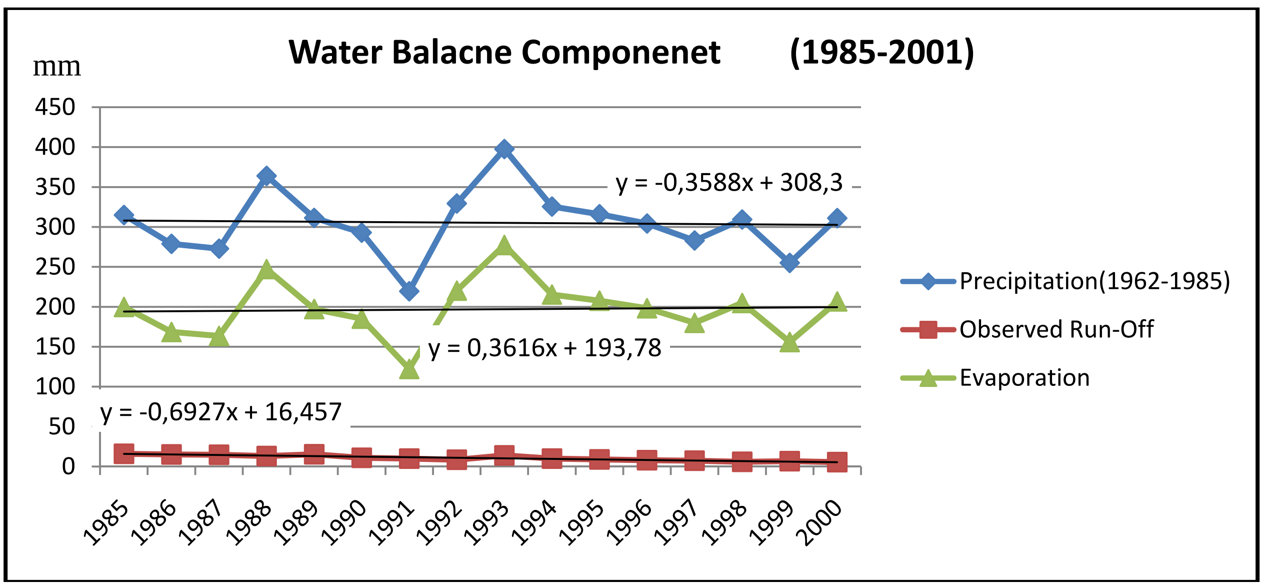

Figure 17b Water Balance Component for sub-basin W740 (1985-2001)

The trend of aridity shows the same trend as water balance components' trend for W740. An increasing trend in precipitation during the first period ends to developing the aridity index which shows less aridity conditions (see Figure 18).

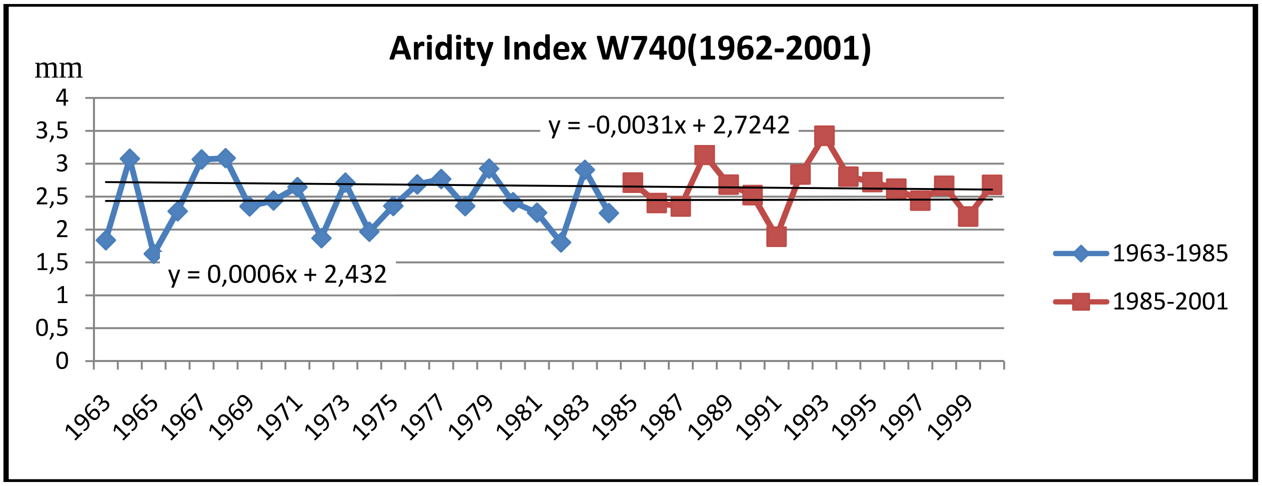

Figure 18 Aridity Index for Sub-basin W740 (1963-1985)

The runoff from the other two sub-basins (W520& W690) was computed by the model, considering the precipitation and water loss in each sub-basin. Since there is no flow from these two sub-basins to the outlet of the catchment, therefore this conclusion is made that all precipitation excess is evaporated. According to the results the average precipitation, runoff and evaporation in sub-basins W520 is 145.4 mm, 81.7 and 81.7 mm respectively over the area of sub-basin and these values for W620 are 246,2 mm, 160,7 mm and81,7 mm respectively (see table 6). Table 6 shows all water balance component values for three sub-basins for different periods. The volumetric values are also available.

For the other two sub-basins there is not any observed station and therefore data, since there is no flow throughout the basin (for more details and water balance of some upstream sub-basin the second model and simulation based on that was conducted and will be discussed further). That is because all the precipitated water is being evaporated and therefore there is no water in the reaches anymore (see Figure 12). According to the simulation the average precipitation over the sub-basin W690 with the area of 3274.4 Km^2 is 212.6 mm during years 1963 and 1985. The average for the years 1985 to 2001 is 292.4 mm and for the whole period is 264.2 mm. These values for the sub-basin W520 is 123.9, 174.9 and 145.4 mm respectively. The trend of precipitation over the Shiyang River Basin is changing in two different periods of studies. The trend shows decreasing in precipitation during years 1963 to 1985 while the simulation for the period 1985 to 2001 shows an increasing trend in precipitation overlay (see Figure 19 and Table 6).

Table 6 Water Balance Component of Shiyang River Basin (First Basin Model)

Name & Unit	Area(Km^2)	Year	Precipitation	Runoff (Sim)	Runoff (Obs)	Evaporation	Loss
W690 (mm)	3274.4 9.27%	1963-1985	212.6	131.2	0.0	63.4	81.4
		1985-2001	292.4	201.3	0.0	106.9	91.1
		1962-2001	246.2	160.7	0.0	81.7	85.5

W690(10^3m^3)		1963-1985	696107.7	429604.3	0.0	207491.3	266503.4
		1985-2001	957317.9	659077.4	0.0	350060.0	298240.5
		1962-2001	806090.9	526224.5	0.0	267520.2	279866.4
W520 (mm)	18275 51.74%	1963-1985	123.9	63.4	0.0	63.4	60.5
		1985-2001	174.9	106.9	0.0	106.9	68.0
		1962-2001	145.4	81.7	0.0	81.7	63.7
W520(10^3m^3)		1963-1985	2264322.3	1158045.2	0.0	1158045.2	1106277.1
		1985-2001	3196948.5	1953746.0	0.0	1953746.0	1243202.6
		1962-2001	2657007.1	1493077.1	0.0	1493077.1	1163929.9
W740 (mm)	13766 38.98%	1963-1985	283.1	188.7	21.6	167.1	95.2
		1985-2001	305.3	207.4	10.6	196.9	97.8
		1962-2001	292.4	196.6	17.0	179.6	96.3
W740(10^3m^3)		1963-1985	3897530.0	2598000.9	297952.6	2300048.3	1310141.5
		1985-2001	4202097.3	2855378.1	145489.4	2709888.7	1345953.4
		1962-2001	4025768.9	2706370.2	233757.5	2472612.7	1325220.2
Catchment(mm)	35315.4	1963-1985	194.2	118.5	8.4	103.8	76.0
		1985-2001	236.6	154.8	4.1	142.0	81.8
		1962-2001	212.1	133.8	6.6	119.9	78.4
Catchment(10^3m^3)		1963-1985	6857960.1	4185650.3	297952.6	3665584.8	2682922.0
		1985-2001	8356363.8	5468201.5	145489.4	5013694.7	2887396.5
		1962-2001	7488866.9	4725671.9	233757.5	4233210.0	2769016.6

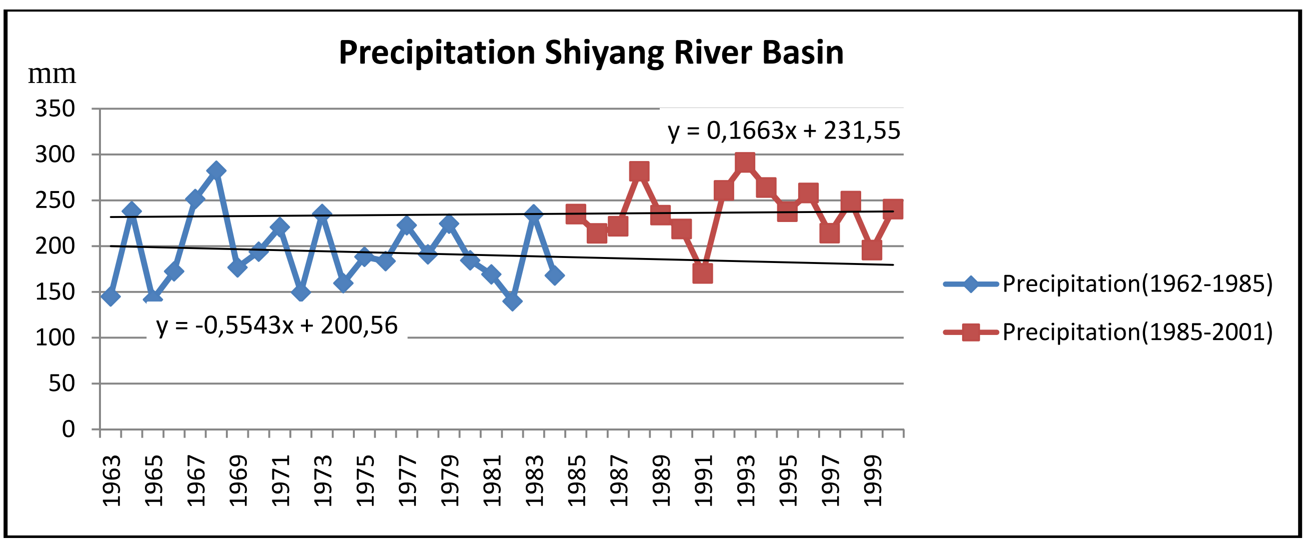

Figure 19 Average Precipitations over Shiyang River Basin (19623-1985)

The Analyzing of the precipitation over the three main sub-basins in the initial simulation shows the same trend for the sub-basin W520 which has 51.77% of the basin's area while in the other two sub-basins precipitation trend is decreasing during year 1985 to 2001. The trend for W690 with 9.2% of the area shows decreasing and W740 with 38.98% of the basin's areas shows increasing in the precipitation during years 1963 and 2001 (See Figure 20).

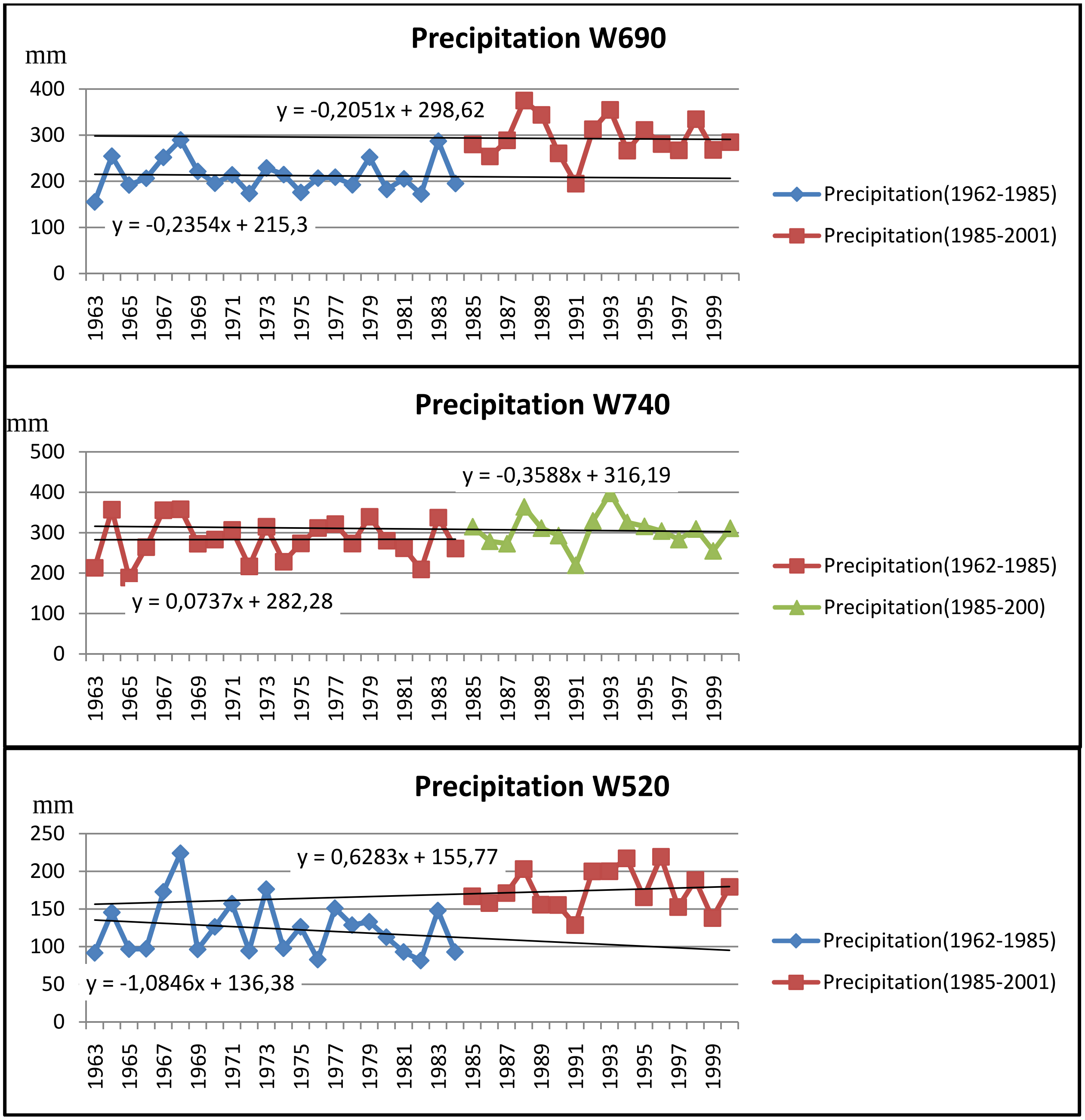

Figure 20 Average Precipitation in Sub-basins W520, W690 & W740

The Aridity Index over these two sub-basins also shows the same fact over both W520 and W690 (see Figure 21).

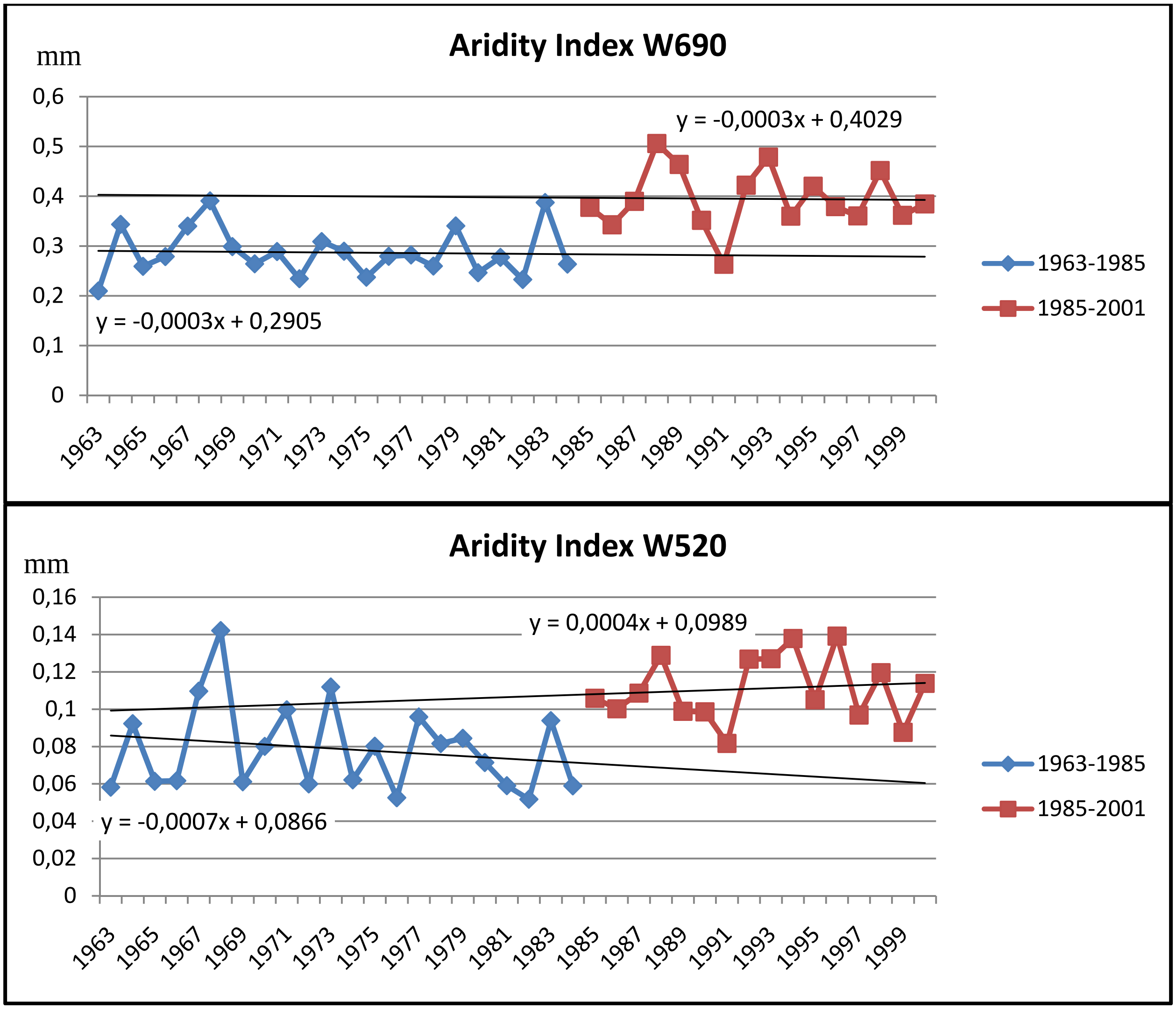

Figure 21 Aridity Index of W520 & 690 (1963-2001)

5.1.2. Basin Model 2

Water balance for the second basin model considers more details of the area. In the second basin model, the whole catchment is divided to 13 sub-basins; among them are seven up stream sub-basins of the main tributaries of Shiyang river basin (see Figure 11b).
Five sub-basins i.e. Dongda, Xiying, Jinta, Zamu and Huangyang flow to sub-basin W1090. W1090 along with the other sub-basins 1390 constitutes the water to the Hongyashan reservoir. Sub-basin Gulang flows to W1390 and therefore constitutes partly of flow to the Honyashan Reservoir.

The other upstream sub-basin Xida, W1340 and W1320 to the western part of the catchment are not affected the Shiyang river since there is not flow from that part to the main river anymore. Therefore that part is also been studied separately. Gulang sub-basin has 482.35 mm precipitation, 69.31 mm of runoff and 276.27 mm evaporation. The runoff has been collected at Gulang station at the outlet of this sub-basin. The precipitation during year 1985 to 2001 has been declined. The amount of water at the out flow of the sub-basin as well as evapotransipiration throughout the sub-basin at years between 1989 and 2001 shows an increasing trend (see Figure 22).

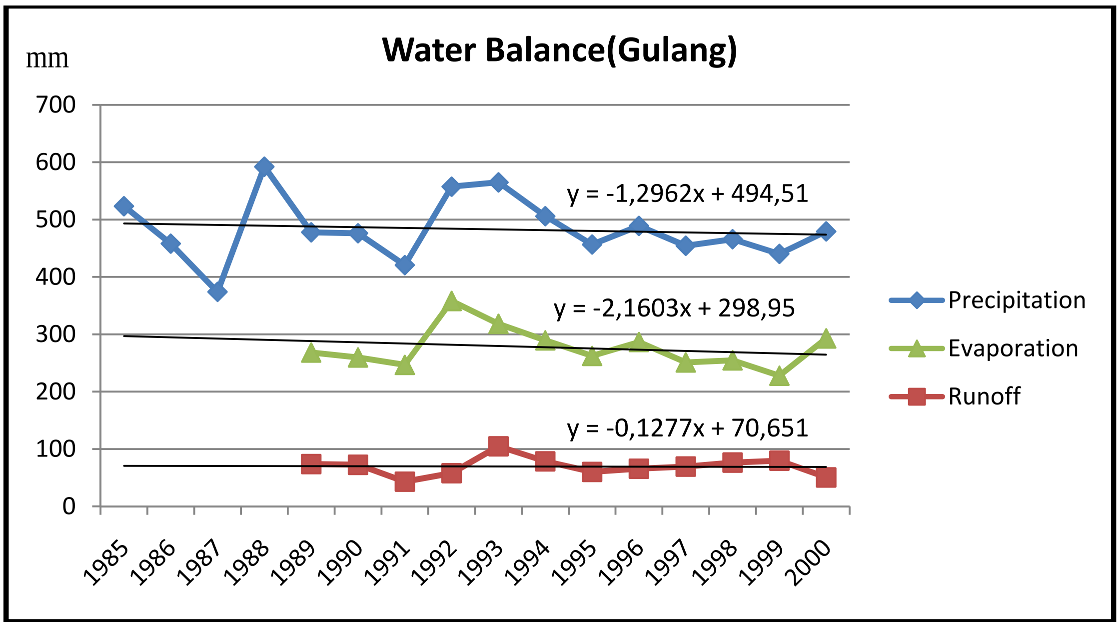

Figure 22 Water Balance Components of W1150 (1985-2001)

The trend for the Hongyang sub-basin is a bit different. While the precipitation in the sub-basin and runoff at the outlet has been decreasing, the amount of precipitation shows an increasing trend which shows the usage of water in this region has been developed. Having Hongyang reservoir in the sub-basin can justify the changes in water use and then increasing in evaporation in this area. The average precipitation in this sub-basin is482.65 mm, 183.17mm of evaporation and observed data at the outlet of Hongyang reservoir during years 1980 and 2001 is 153.59 mm (see Figure 23).

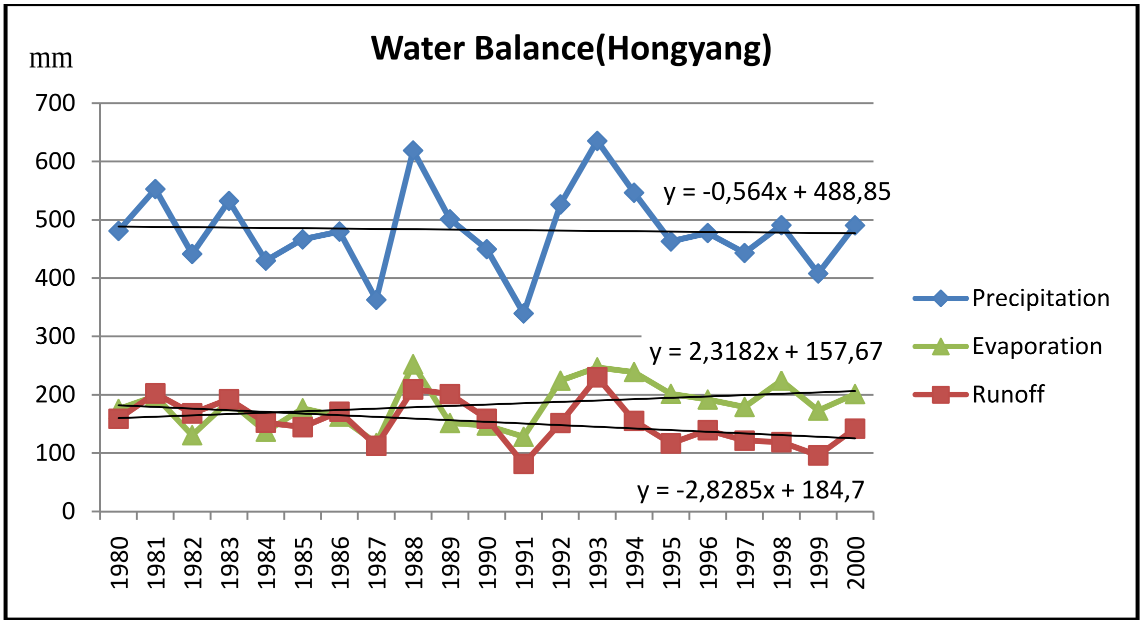

Figure 23 Water Balance Components of W1100 (1980-2001)

Precipitation in Zamu sub-basin is 393.7 mm and an average runoff 267.19 at the outlet, Zamusi station. The trends of precipitation and runoff during years 1980 to 2001 shows increasing in precipitation while decreasing in runoff, which shows and improvement of water use and therefore evaporation in this region (see Figure 24).

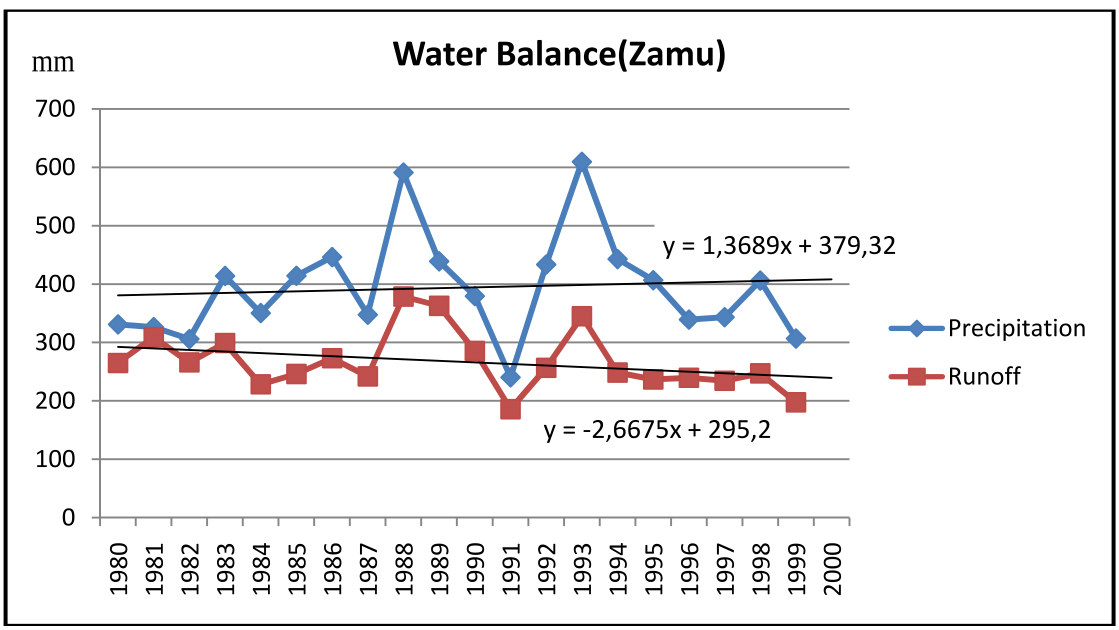

Figure 24 Water Balance Components of W1050 (1980-2001)

Water balance study in Jinta sub-basin shows an increasing trend in precipitation while runoff from the basin has been decreasing however the trend of changes is not considerable. Those results in increasing evaporation and therefore amount of water used in this sub-basin during years 1985 to 2001(see Figure 25).

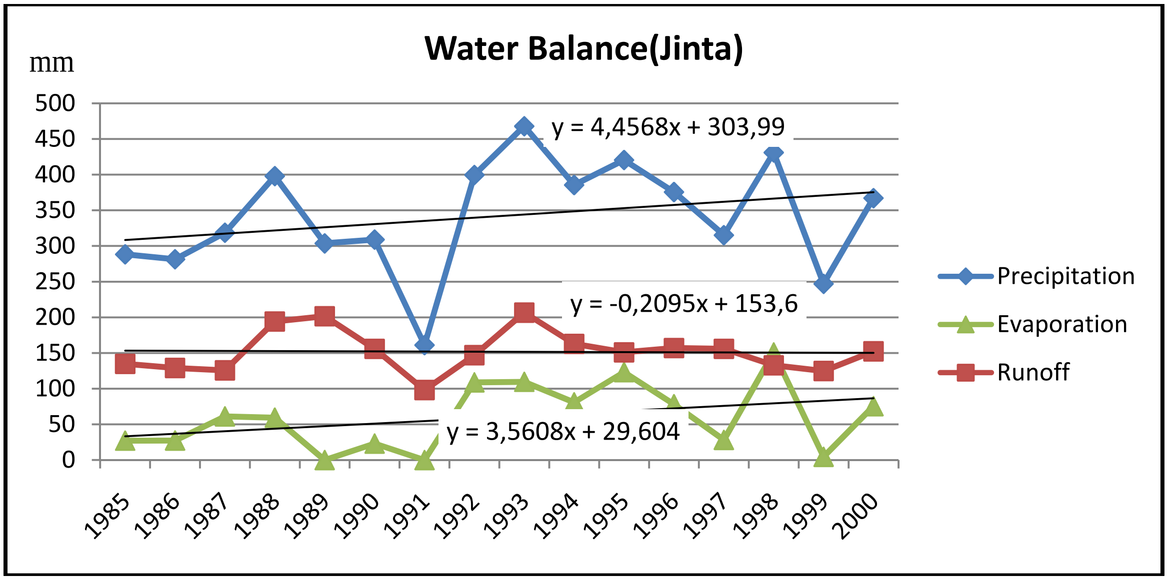

Figure 25 Water Balance Components of W1000 (1985-2001)

Changing in Xiying and Dongda sub-basins, shows a decreasing trend in both precipitation and runoff from the outlets (see Figure 26).

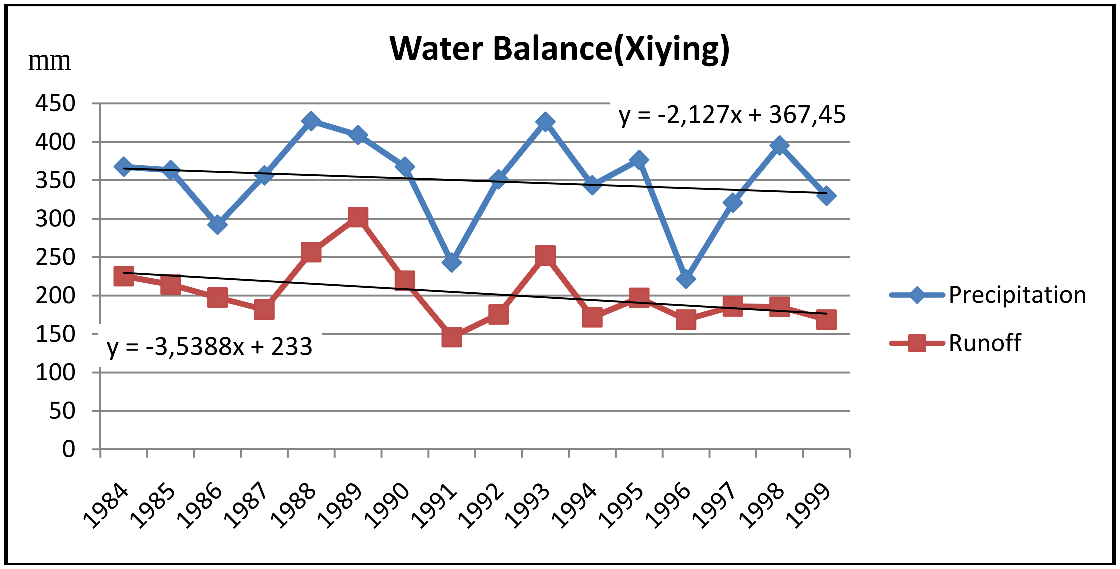

Figure 26 Water Balance Components of W950 (1984-2001)

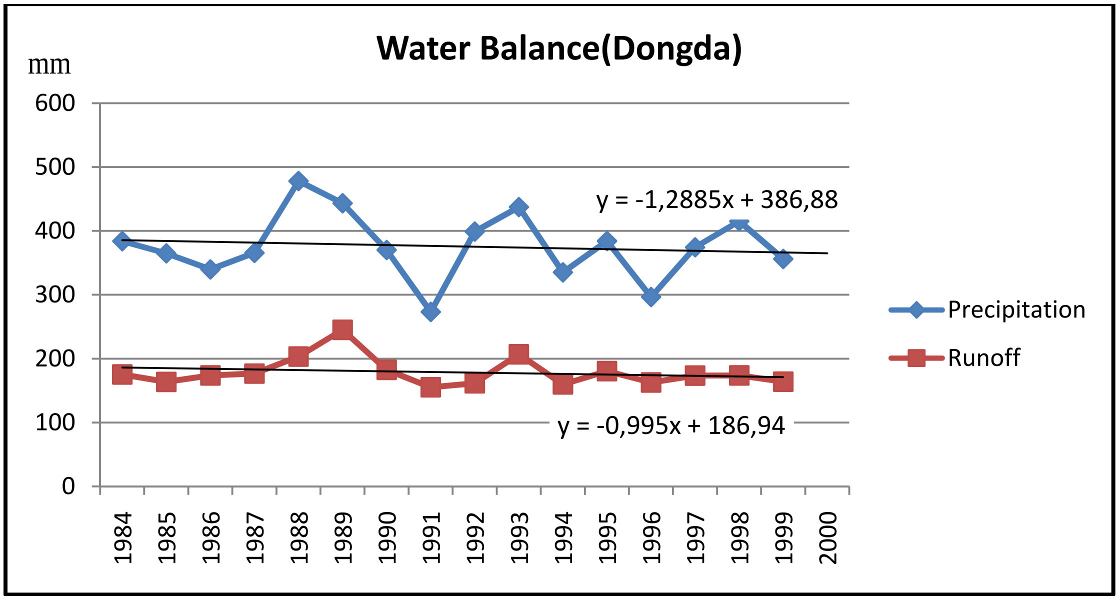

Figure 27 Water Balance Components of W900 (1984-2001)

In sub-basin W1390 and W1090 which are downstream sub-basins of the mentioned sub-basin the precipitation and runoff are decreasing during the simulation period of each sub-basin. For W1390 also the evaporation is decreasing. This area is located in the desert region and the runoff depends on the inflow to the sub-basin from upstream (i.e. Gulang and itself has an increasing in outflow) and therefore less water available less evapotranspiration (see Figure 28).While for the other one, W1090, water balance study shows increasing in evaporation and water use in the region (see Figure 29).

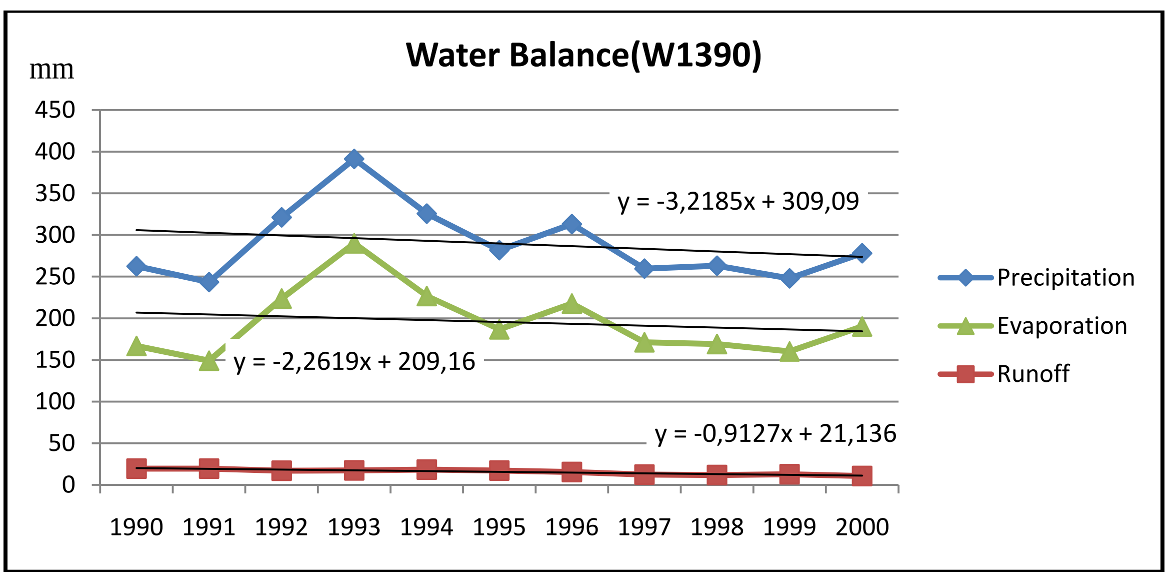

Figure 28 Water Balance Components of W1390 (1990-2001)

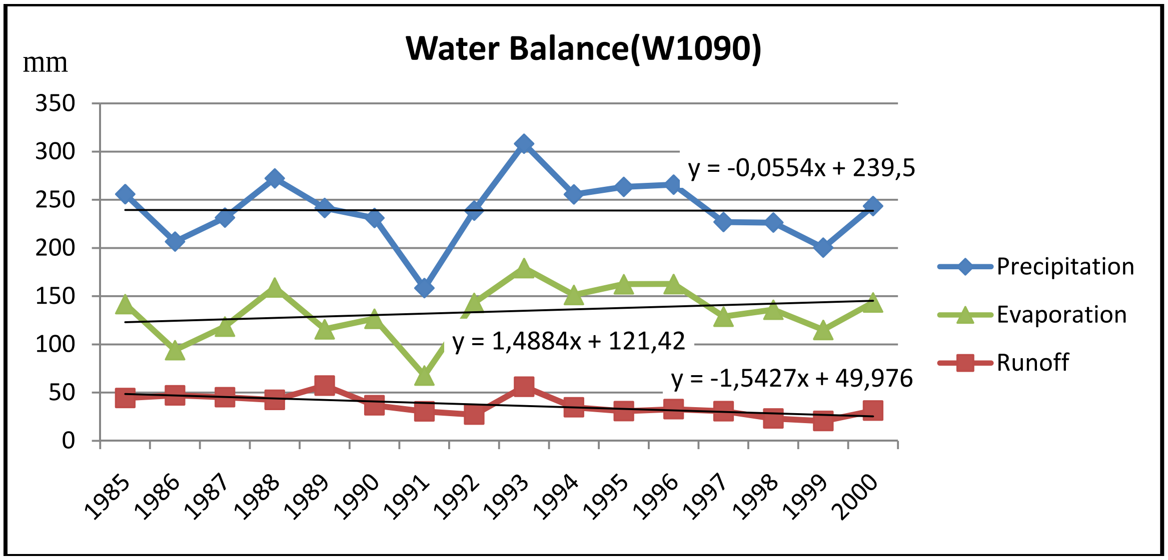

Figure 29 Water Balance Components of W1090 (1985-2001)

Incoming flow to the W1430 is decreasing since the outflow from the W1090 and 1390 is decreasing. The precipitation is also increasing during 1985 to 2000 and there is a drastically decline in outflow observation at Hongyashan reservoir and that shows a drastically increase in water usage at that region during years 1985-2001 which ends to increasing of evaporation in the region.

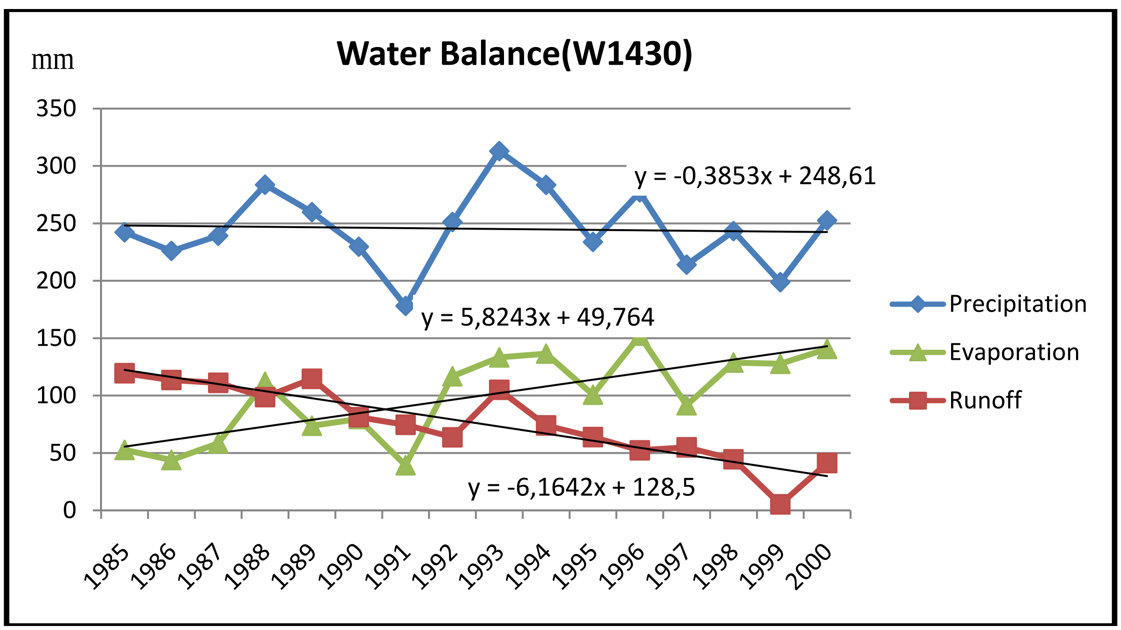

Figure 30 Water Balance Components of W1430 (1985-2001)

Trends of water balance components at Xida sub-basin is increasing for precipitation and evaporation since for the runoff is decreasing (see Figue 31). For the W1340 the precipitation is decreasing while the observed data at Jinchuanxia station shows increasing trend in runoff at the outlet. That could be because of changing in water use in the area which affects the evaporation in that region as well. But, because there is no water in the rivers in this area going downstream, this conclusion is made that all water in this region evaporated before reaching the end of sub-basin or even she Shiyang river, since downstream of these two sub-basin all is located at the desert (see Figue 32).

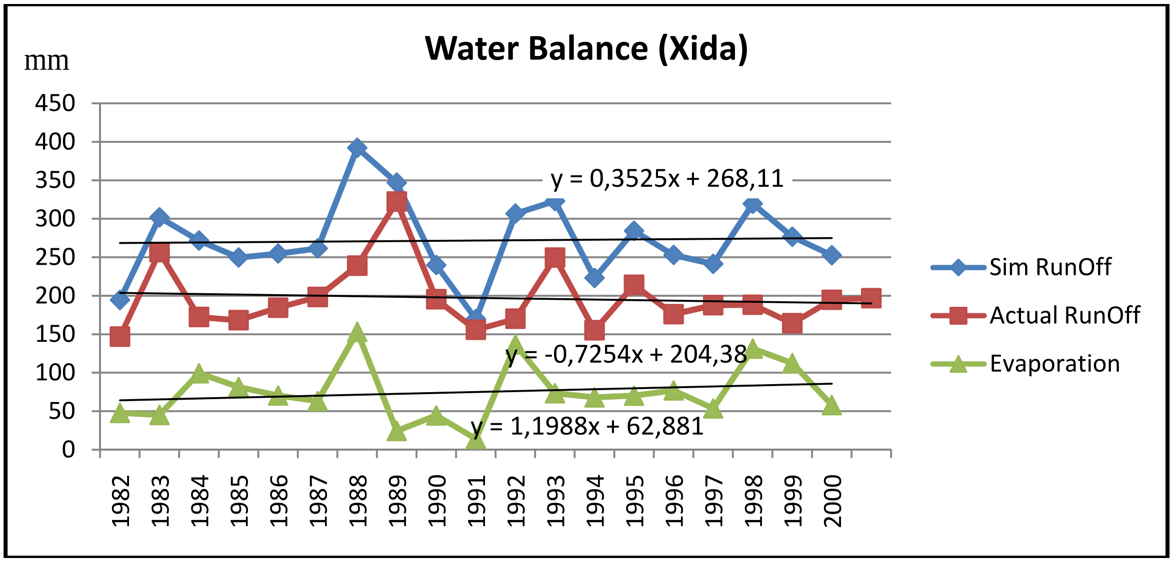

Figure 31 Water Balance Components of W850 (1982-2001)

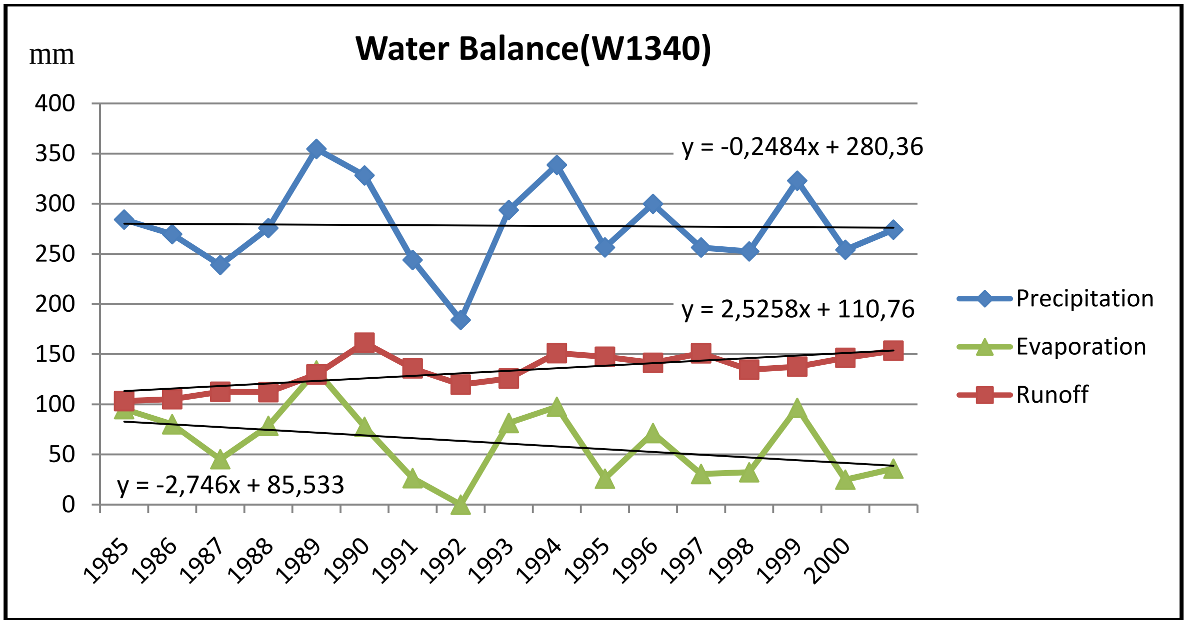

Figure 32 Water Balance Components of W1340 (1985-2001)

Table 7Water Balance Component of Shiyang River Basin (Second Basin Model)

Subbasin	Period	Area (Km^2)	Water balance Components					
			Water Depth, mm			Volume , 1000 m^3		
			Precipitation	Runoff	Evaporation	Precipitation	Runoff	Evaporation
W850	1982-2001	811	412.57	196.77	74.87	334594.27	159580	60719.57
W900	1984-2001	1614	355	163.78		572970	264341	
W950	1984-2001	1455	349.37	168.57		508333.35	245269	
W1000	1984-2001	841	341.87	151.82	59.87	287512.67	127681	50350.67
W1050	1980-2001	845.7	393.7	267.19		332952.09	225963	
W1090	1985-2001	3603.6	239.03	36.86	134.07	861368.508	132829	483134.652
W1100	1980-2001	828	482.65	153.59	183.17	399634.2	127173	151664.76
W1150	1989-2001	878	482.35	69.31	276.27	423503.3	60854	242565.06
W1320	1985-2008	1585.1						
W1340	1985-2001	1138.2	277.74	135.38	58.07	316123.668	154090	66095.274
W1390	1990-2001	2284.1	289.77	15.66	195.59	661863.657	35769	446747.119
W1430	1985-2001	1829.5	245.33	76.1	99.27	448831.235	139225	181614.465

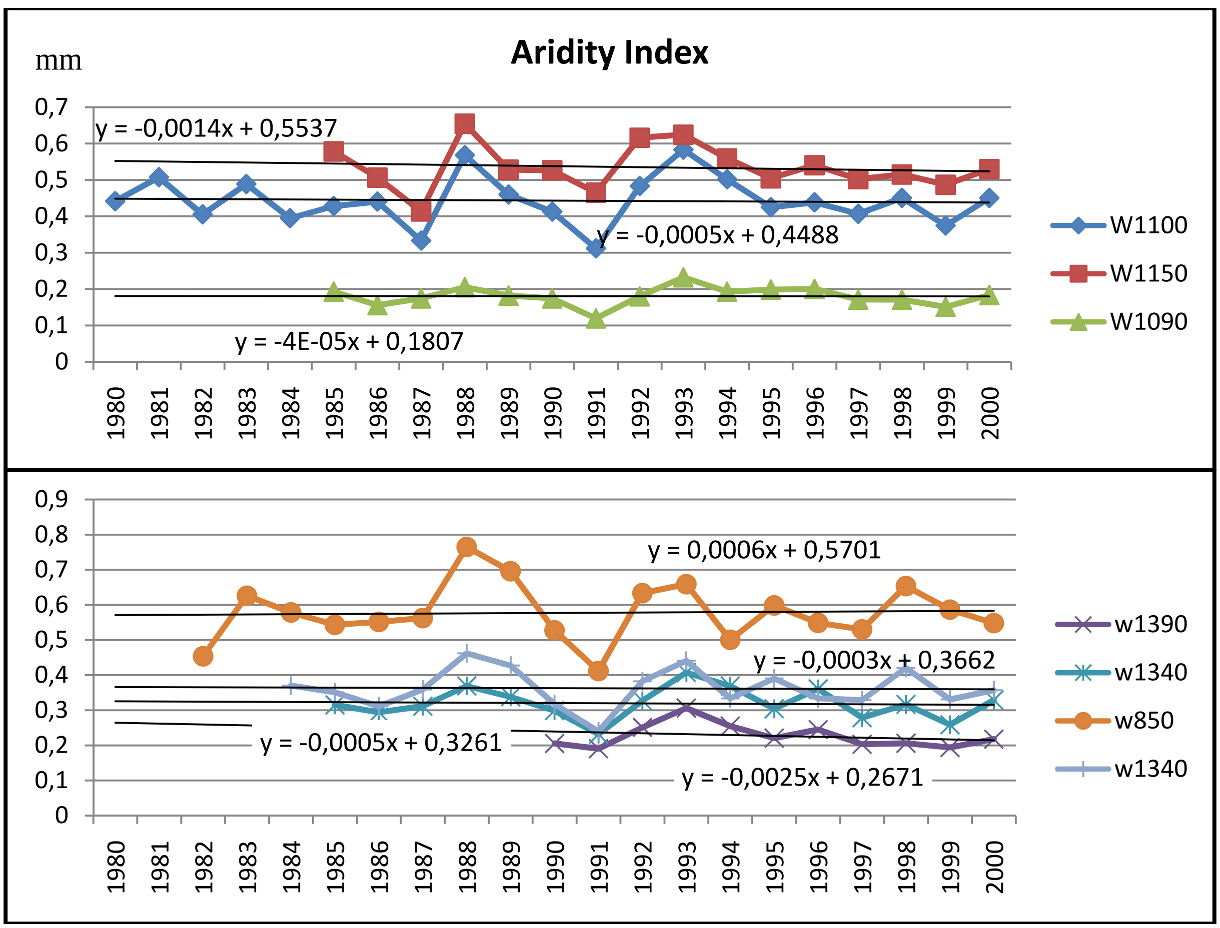

Figure 33 Aridity Index of all Sub-basins (Basin Model 2)

Table 7 shows all sub-basins constitute in the second basin model HMS simulation and their water balance components availability and computed values. Taking look at the aridity index of each sub-basin also shows that except for W850 the aridity index has been decreased for all sub-basins. This shows that during 80's and 90's the region trend has been to more aridity condition (see Figure 33).

5.2 Conclusion and Recommendation

5.2.1 General

The goal of the study was to study water balance of the Shiyang river basin to have an estimation of water usage of the catchment in a long term period form 1962 to 2001. The focus on this study was on two main parts. The first part focused on using a hydro tool to prepare necessary inputs for the model. Here ArcGIS was used along with two hydro extensions which were ArcHydro and GeoHMS. The purpose was to examine the suitability of hydro tools such as what was used in this study for hydrological models. The second part focused on modeling the hydrological system of the basin using HEC-HMS. Model was applied with the minimum amount of necessary data to compare the modeled flow at each station and compare the flow with the observed data at those points. The difference would give simply the amount of water used in that area. This study, like any other models, had its own limitation, advantages and disadvantages which affected the results and final presentation of the water balance.

The study shows ArcGIS as a very good tool to prepare spatial data and make them ready to be used and modeled in the HEC-HMS. Using DEM data and easily delineation of the watershed boundaries, river reaches and all connectivity as well as physical characteristics of the catchment was the main reason of using this tool. Another advantage of using GIS is the ability of providing, managing and presenting data in a graphical format and makes it easy to report the results. Besides all mentioned above the capability of sub-basin management in a way to defines interested sub-basins in the region, compute the characteristics of each sub-basin and convert them to a format compatible with the HMS model, was the main reason that made it very suitable tool dealing with hydrologic models.

DEM resolution was very important in accuracy of watershed delineation. Regarding the size of the catchment and the steep of the soil surface resolution could be low or high to delineate accurate subbasins and streams. In the study DEM resolution was 90 m which was the highest accessible free data. The inaccuracy for subbasin delineation was mostly in downstream where the steep was quite low; but since in that area there was not any stream flowing anymore so luckily it did not affect the study at all. Besides the mention possible error for the first part using ArcGIS tool was perfectly applied.

The second part focused on modeling the system; the results were the simulated runoff from the defined points at out let of subbasins. The simulated values compared with the observed values at the points and gave an estimation of water usage in different parts of the catchment. The results showed different trends in two periods, an increasing trend of precipitation during 1962 to1985 while the precipitation trends between years 1985 to2001 was decreasing. According to the results the precipitation trends for different subbasins were different which makes sense for such a big catchment with different conditions in different places. The study showed that precipitation in upper subbasins which is mostly located in the mountain area is decreasing during the period of 1962 – 1985, while the downstream subbasins precipitation is tend to increase in the very same period. While the trend for the period 1985 – 2001 is decreasing for almost all parts of the catchment. According the study, there has been 212.1 mm of precipitation upstream the Hongyashan reservoir and 6.6 mm has been observed as flow and therefore the evaporation consider as water use here in the study has been 119.9 over the whole area of the subbasins upstream the Hongyashan reservoir. The rest is also is used in the downstream the reservoir and the flow does not continue to the out let of the basin.

The limitations in the study were basically lack of information or accuracy of available data. The input precipitation values into the model were inaccurate. Data were in monthly scale while the model needs in daily values. The problem was fixed by downscaling the available monthly data into daily values, though it was not accurate but made it possible to use the model.

The soil information used in this study was rough estimation of real soil conditions of the region, however using SCS method and applying ArcGIS made it possible to have a good estimation of soil properties to calculate water loss through infiltration.

The availability of observed data was also another limitation for the study, since the observed data were showing values at the outlets after using water by agriculture, industries and other forms of human activities. This limitation is the most critical lack of data in this study thereof it is not possible to calibrate the model.

5.2.2 Recommendations

The main problem for the study was gathering and collecting data. For further studies it is highly recommended to focuses more on gather better quality data. For each precipitation station, there is daily values; using the daily values for each stations make the result of each year based on the precipitation of the same year, while in this study the precipitation regime is the same for all over the basin in the whole period of study.

The SCS Curve number method to calculate the water loss needs to main data i.e. soil type as well as land use information. For further study, it is recommended to gather more precise data. The land use data used in the study were also assumed to be constant in the whole period of study. This is a way to deal with the lack of suitable observed data. Therefore gathering different land use data for different years along with accurate soil type information and apply them in the model would give much better result since it is not possible to calibrate the model because of the lack of suitable observed data in the region.

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Appendices

Appendix 1 SCS Curve Number Soil Type Details

Soil groups, based on the Natural Resource Conservation Service classification, are 4 groups i.e. A, B, C and D. Classification details can be checked out in ‘Urban Hydrology for Small Watersheds’ published by the Engineering Division of the Natural Resource Conservation Service, United States Department of Agriculture, Technical Release –55.

Table 1 Soil Type Classification based on Minimum Infiltration

Soil Type	Min Infiltration Rate(inch/hr)
Group A	0.3 - 0.45
Group B	0.15 - 0-30
Group C	0.05 - 0.15
Group D	0 - 0.05

Also in soil groups are defined as following (Handbook of Hydrology, 1992)

Group A is sand, loamy sand or sandy loam types of soils. It has low runoff potential and high infiltration rates even when thoroughly wetted. They consist chiefly of deep, well to excessively drained sands or gravels and have a high rate of water transmission.

Group B is silt loam or loam. It has a moderate infiltration rate when thoroughly wetted and consists chiefly or moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures.

Group C soils are sandy clay loam. They have low infiltration rates when thoroughly wetted and consist chiefly of soils with a layer that impedes downward movement of water and soils with moderately fine to fine structure.

Group D soils are clay loam, silty clay loam, sandy clay, silty clay or clay. This HSG has the highest runoff potential. They have very low infiltration rates when thoroughly wetted and consist chiefly of clay soils with high swelling potential, soils with a permanent high water table, soils with a clay pan or clay layer at or near the surface and shallow soils over nearly impervious material.

The Curve number based on land use can be seen in the' Table of Runoff Curve Numbers'.

Table of Runoff Curve Numbers (SCS, 1986)

Description of Land Use	Hydrologic Soil Group			
	A	B	C	D
Paved parking lots, roofs, driveways	98	98	98	98
Streets and Roads:				
Paved with curbs and storm sewers	98	98	98	98
Gravel	76	85	89	91
Dirt	72	82	87	89
Cultivated (Agricultural Crop) Land*:				
Without conservation treatment (no terraces)	72	81	88	91
With conservation treatment (terraces, contours)	62	71	78	81
Pasture or Range Land:				
Poor (<50% ground cover or heavily grazed)	68	79	86	89
Good (50-75% ground cover; not heavily grazed)	39	61	74	80
Meadow (grass, no grazing, mowed for hay)	30	58	71	78
Brush (good, >75% ground cover)	30	48	65	73
Woods and Forests:				
Poor (small trees/brush destroyed by over-grazing or burning)	45	66	77	83
Fair (grazing but not burned; some brush)	36	60	73	79
Good (no grazing; brush covers ground)	30	55	70	77
Open Spaces (lawns, parks, golf courses, cemeteries, etc.):				
Fair (grass covers 50-75% of area)	49	69	79	84
Good (grass covers >75% of area)	39	61	74	80
Commercial and Business Districts (85% impervious)	89	92	94	95
Industrial Districts (72% impervious)	81	88	91	93
Residential Areas:				
1/8 Acre lots, about 65% impervious	77	85	90	92
1/4 Acre lots, about 38% impervious	61	75	83	87
1/2 Acre lots, about 25% impervious	54	70	80	85
1 Acre lots, about 20% impervious	51	68	79	84

*From Chow et al. (1988).

Appendix 2 Precipitation Detail Data

The following table shows the percent of each precipitation station's association in each sub-basin. These percent values were used as HMS's input for each precipitating station's weight.

Table 2 Sub-basins and Associated Station in Percent.

NAME	Area	Area_Por_1	NT	Percent
W1000 (Jinta)	855.5	188.1	Honggou	22
		34.8	Nanying Reservoir	4
		49.6	Xishui	6
		120.4	Kuangou	14
		9.9	Maozangsi	1
		112.7	Xiasi	13
		339.9	Xinshu	40
		98.1	Shanggechagou	11
		15.6	Kuangou	2
		566.4	Maozangsi	67
		66.5	Zamusi	8
		99.1	Xinshu	12
W1090	3603.6	440.2	Shagousi	11
		244.4	Honggou	7
		82.9	Jinchuanxia	2
		242.1	Nanying Reservoir	7
		172.4	Huangyang river	5
		31.2	Kuangou	1
		502.8	Shijiazhuang	14
		264.8	Zamusi	7
		93.0	Xiasi	3
		34.7	Xinshu	1
		1003.5	Wuwei	28
		452.4	Jiutiaoling	13
		28.9	Tumen	1
W1100 (Huangyang)	831.7	73.4	Nannigou	9
		71.9	Shanggechagou	9
		123.8	Motaizi	15
		123.0	Huangyang river	15
		220.5	Huangniangniangtao	26
		48.7	Kongjiazhuang	6
		106.7	Shajingtai	13
		54.3	Maozangsi	7

W1150 (Gulang)	887.0	150.2	Aitou	17
		120.7	Majiatai	14
		90.2	Tianzhu	10
		58.2	Gulang	7
		80.2	Hengliang	9
		96.8	Niuquangou	11
		42.8	Toudaogou	5
		67.8	Longgou	8
		180.0	Zhangjiadun	19
W1320	1585.1	247.1	Jinchuanxia	16
		349.6	Maojiazhuang	22
		540.0	Yongchang	34
		0.0	Xidahe reservoir	28
W1340	1138.2	53.0	Shagousi	5
		309.4	Jinchuanxia	27
		281.6	Xiaoquangou	25
		58.7	Xidahe reservoir	5
		382.6	Maojiazhuang	33
		52.8	Yongchang	5
W1390	2284.1	38.2	Majiatai	2
		85.3	Motaizi	4
		187.9	Huangyang river	8
		107.4	Shijiazhuang	5
		302.6	Gulang	13
		160.9	Hengliang	7
		13.5	Shajingtai	1
		282.3	Wuwei	12
		108.0	Zhangjiadun	5
		989.1	Tumen	43
W1430	1829.5	2.1	Jinchuanxia	16
		6.7	Shijiazhuang	38
		285.3	Xiamentai	26
		711.6	Wuwei	2
		469.1	Hongyashan reservo	10
		28.1	Ninyuanbao	8
W520	18303.5	7122.5	Shoucheng	39
		2702.1	Minqin	15
		329.6	Yongchang	1
		160.3	Shijiazhuang	1
		2169.9	Xiamentai	12

		972.4	Tumen	5
		1450.9	Hongyashan reservo	8
		3151.7	Ninyuanbao	17
		146.0	Jinchuanxia	2
W850 (Xida)	551.1	551.1	Xidahe reservoir	100
W900 (Dongda)	1679.4	199.3	Shagousi	12
		526.4	Shuimogou	31
		760.5	Xiaoquangou	45
		193.2	Xidahe reservoir	12
W950 (Xiying)	556.1	353.4	Shuimogou	63
		47.8	Xinshu	9
		154.9	Jiutiaoling	28

Appendix 3 Evaporation Detail Data

The following table shows the percent of each Evaporation station's association in each sub-basin. These percent values were used to calculate the average evaporation over each sub-basin to be use as input in HMS for evaporation method, monthly average.

Table 3 Sub-basins and Associated Station in Percent

Sub-Basin Name	Sub-Basin Area (Km2)	Station_Portion Area	Precent	Station_Names
W1000 (Jinta)	855.5	354	41.4	Nanying
		238	27.8	Zamusi
		264	30.8	Juitiaoling
W1050 (Zamu)	845.7	744	87.9	Zamusi
		8	1.0	Huangyang ri
		94	11.1	Juitiaoling
W1090	3603.6	1126	31.2	Nanying
		267	7.4	Huangyang ri
		718	19.9	CaiQi
		339	9.4	Zamusi
		1153	32.0	Juitiaoling
W1100 (Huangyang)	831.7	816	98.1	Huangyang ri
		16	1.9	Zamusi
W1150 (Gulang)	887.0	887	100.0	Huangyang ri
W1320	1585.1	1467	92.5	Xidahe reser
		119	7.5	Juitiaoling
W1340	1138.2	301	26.4	Juitiaoling
		837	73.6	Xidahe reser
W1390	2284.1	1945	85.1	Huangyang ri
		36	1.6	Nanying
		302	13.2	CaiQi
		1	0.0	Zamusi
W1430	1829.5	173	9.5	Hongyashan r
		1450	79.3	CaiQi
		206	11.3	Juitiaoling
W520	18303.5	17181	93.9	Hongyashan r
		684	3.7	CaiQi
		400	2.2	Juitiaoling
		39	0.2	Xidahe reser

W850 (Xida)	551	551	100.0	Xidahe reser
W900 (Dongda)	1679.4	931	55.4	Juitiaoling
		748	44.6	Xidahe reser
W950 (Xiying)	556.1	556	100.0	Juitiaoling

Table 4 Monthly Average Precipitations over Each Sub-basin (Basin Model 2)

Sub-basin Names	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
W1000 (Jinta)	33.38	40.63	76.50	132.65	170.67	171.13	177.50	165.43	123.11	90.13	58.18	38.98
W1050 (Zamu)	38.84	49.18	94.93	154.07	191.27	193.78	202.73	187.72	142.05	98.67	67.03	43.99
W1090	31.07	40.95	83.97	148.25	185.74	181.23	184.16	169.02	122.80	90.83	54.45	34.70
W1100 (Huangyang)	20.66	29.72	69.63	117.13	157.93	162.78	158.71	145.31	99.47	69.62	36.74	21.49
W1150 (Gulang)	17.50	24.60	55.00	95.40	133.00	136.10	131.00	122.70	83.60	58.60	29.00	18.10
W1320	23.16	26.62	40.53	65.45	101.34	103.13	96.26	90.69	70.97	52.87	34.55	24.08
W1340	23.04	26.92	43.15	72.40	107.00	108.02	102.23	96.73	74.71	55.85	34.93	24.02
W1390	23.91	35.61	85.38	144.06	186.15	188.07	184.73	166.43	114.38	81.01	43.73	24.67
W1430	23.04	26.92	43.15	72.40	107.00	108.02	102.23	96.73	74.71	55.85	34.93	24.02
W520	28.33	42.93	109.00	176.77	226.00	234.49	232.30	204.89	140.59	98.62	56.13	29.37
W850 (Xida)	23.20	26.50	39.50	62.70	99.10	101.20	93.90	88.30	69.50	51.70	34.40	24.10
W900 (Dongda)	22.87	27.39	47.15	83.04	115.68	115.50	111.36	105.98	80.42	60.40	35.51	23.93
W950 (Xiying)	22.60	28.10	53.30	99.40	129.00	127.00	125.40	120.20	89.20	67.40	36.40	23.80

Appendix 4 Software Package

For this study 3 main soft wares were used for the modeling process and data preparation i.e. ArcGIS 9.1, HEC-HMS 3.2 and MS-Excel 2007. The hydro tools used in the study as an extension to ArcGIS are ArcHydro tools for watershed delineation and GeoHMS which prepare basin model compatible to the Hydrologic model. The model itself used is HEC-HMS 3.2. An extension to Microsoft Excel 2007, HEC-DSS Microsoft Excel, was also used to prepare time series of precipitation and runoff as DSS file format. This chapter tries to have a brief introduction of how to access the software package in the net and how to install them.

ArcHydro and HEC-GeoHMS

As a GIS tool, ArcGIS Desktop 9.1 was used in the study. ArcGIS 9.1 was published at 1995 by ESRI. The installation is simply following the procedure defined by the publisher. It is a standalone program and does not need any other complementary software to be installed. The other software HEC-HMS is also installed in the regular method defined by publisher. However for water tools, ArcHydro and HEC-GeoHMS, installation procedure is a bit more complicated.

All necessary files for ArcHydro including any information about the software and download files can be directly downloaded form the official website of its developer, Center for Research in Water Resources, at http://www.crwr.utexas.edu/giswr/hydro/ArcHOSS/index.cfm and the direct link for download the program and instruction in zip format it http://support.esri.com/index.cfm?fa=downloads.dataModels.filteredGateway&dmid=15. The official website of HEC programs also provided users by free domain access to all software developed by US Arm Corps of Engineers. (http://www.hec.usace.army.mil/). In brief the installation procedure of the public domain software, ArcHydro and HEC-GeoHMS, would be in the following steps;

1. Close all Arc Application.
2. Make sure Microsoft .NET Framework 1.1 installed on the computer, if not, it must be downloaded form Microsoft website and install on the computer. It can be downloaded form http://www.microsoft.com/Downloads/details.aspx?FamilyId=262D25E3-F589-4842-8157-034D1E7CF3A3&displaylang=en .

<u>Install the following in order:</u>

3. ApFramework (ftp://ftp.esri.com/ApFramework/)
4. Microsoft's MSXML 4 components (can be downloaded form Microsoft website)
5. XML Data Exchange (ftp://ftp.esri.com/XMLDataExchange/)
6. Arc Hydro Tools (ftp://ftp.esri.com/ArcHydro/)
7. HecGeo-HMS (ftp://ftp.esri.com/HECGeoHMS/)

The above instruction was applied for ArcGIS version 9.1 in the study. However, the procedure for other versions is the same considering the fact that each application must be downloaded compatible to the ArcGIS version. The procedure is also explained for the first time installation. In case that any water tool has been installed on the machine, all application must be uninstalled, and the directories must be checked out and any DLL file in bin directories must be unregistered and then deleted. The license for the ArcGIS also must me at least Arc-View license so that user can install and use the least tools in the programs. For following the instruction in more details, a MS word file, titled “New installation procedures for water resources applications developed by ESRI’s Professional Services (water resources group)” can be downloaded at: forums.esri.com/Attachments/30875.doc

HEC-DSS MS Excel

Hec-DSS MS Excel was used to store regular time series precipitation and runoff data. The add-on and its documentation can be downloaded from HEC website at: http://www.hec.usace.army.mil/software/hec-dss/hecdss_msexcel_addin.htm .

Installation procedure is simply as follows:

1- Download the zip file from the HEC website and unzip the file

2- Copy file “hlib42.dll” to office directory of the program files in the windows. That should be look like this: …\Program files\Microsoft office\office

3- Copy files DssExcel.xla And DssExcel.chm to the …\ Program files\Microsoft office\office\Library

4- Execute Microsoft office

5- Open a workbook open (necessary)

6- Open Tools menu ➔ Click Adds-In

7- Find “HEC-DSS MS-Excel Data Exchange” and check the box on the left

(HEC-DSS MS Excel, Data Exchange Add-In, 2003)

In order to store time series data in DSS format by means of HEC-DSS MS Excel, it is necessary to organize data in an excel sheet in a specific format. The definition of each terms are mentioned in the HEC-HMS and HEC-DSS-Vue manuals published by HEC. In the following there is a sample table of how to make and fill in the data in an excel sheet so that it can be restored by DSS MS Excel.

Reference: US Army Corps of Engineers, Hydrological Center, 2003, HEC-DSS MS Excel, Data Exchange, users’ manual.

Table 5 HEC-DSS Excel Format Sheet

Part A:		SHYANGCATCHMENT		SHYANGCATCHMENT
Part B:		Aitou		Dam of Dajingxia
Part C:		PRECIP-INC		PRECIP-INC
Part D:		01jan1984		01jan1960
Part E:		1DAY		1DAY
Part F:		OBS		OBS
Beg. Date:		1-Jan-84		1-Jan-60
Beg. Time:		1000		1000
End Date:		1-Jan-02		1-Jan-02
End Time:		2400		2400
Units:		MM		MM
Data Type:	Index	PER-CUM		PER-CUM
	1/1/1984	0.0249	1/1/1960	0.0023
	1/2/1984	0.137	1/2/1960	0.0125
	1/3/1984	0.0457	1/3/1960	0.0042
	1/4/1984	0.1536	1/4/1960	0.014
	1/5/1984	0.0872	1/5/1960	0.0079
	1/6/1984	0.0913	1/6/1960	0.0083
	1/7/1984	0.0208	1/7/1960	0.0019
	1/8/1984	0.083	1/8/1960	0.0075
	1/9/1984	0.1245	1/9/1960	0.0113
	1/10/1984	0.0415	1/10/1960	0.0038
	1/11/1984	0.2781	1/11/1960	0.0253
	1/12/1984	0.1162	1/12/1960	0.0106
	1/13/1984	0.0581	1/13/1960	0.0053
	1/14/1984	0.0457	1/14/1960	0.0042
	1/15/1984	0.0789	1/15/1960	0.0072
	1/16/1984	0.0125	1/16/1960	0.0011
	1/17/1984	0.0249	1/17/1960	0.0023
	1/18/1984	0.0706	1/18/1960	0.0064
	1/19/1984	0.0996	1/19/1960	0.0091
	1/20/1984	0.0872	1/20/1960	0.0079
	1/21/1984	0.1826	1/21/1960	0.0166
	1/22/1984	0.083	1/22/1960	0.0075
	1/23/1984	0.1494	1/23/1960	0.0136
	1/24/1984	0.0747	1/24/1960	0.0068
	1/25/1984	0.1992	1/25/1960	0.0181