A STATISTICAL MODEL FOR ESTIMATING MEAN ANNUAL AND MEAN MONTHLY FLOWS AT UNGAGED LOCATIONS

A Thesis

by

ZUBIN ROHINTON SUKHESWALLA

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

December 2003

Major Subject: Civil Engineering

A STATISTICAL MODEL FOR ESTIMATING MEAN ANNUAL AND MEAN MONTHLY FLOWS AT UNGAGED LOCATIONS

A Thesis

by

ZUBIN ROHINTON SUKHESWALLA

Submitted to Texas A&M University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Approved as to style and content by:

Francisco Olivera (Chair of Committee)	Anthony Cahill (Member)
Raghavan Srinivasan (Member)	Paul Roschke (Head of Department)

December 2003

Major Subject: Civil Engineering

ABSTRACT

A Statistical Model for Estimating Mean Annual and Mean Monthly Flows at Ungaged Locations. (December 2003)

Zubin Rohinton Sukheswalla, B.E., Bombay University, India

Chair of Advisory Committee: Dr. Francisco Olivera

Prediction of flow is necessary for planning and management of water resources. The objective of this study is to estimate mean annual flows for the USA and mean monthly flows for the rivers of central Texas based on the precipitation and their watershed characteristics. Flow varies largely with topographic and climatic parameters and hence generalization of runoff models is difficult. This model aims at providing a prediction at ungaged locations with very few parameters that are easily available and measurable. Scatter in predicted data will be seen at the annual and monthly time scale in the range selected for each data. This model will work on annual and monthly means to reduce the scatter and produce better estimates.

To Mom, Dad and Farzeen

ACKNOWLEDGMENTS

I am deeply indebted to my advisor, Dr. Olivera for having given me a chance to work with him. He has been a source of inspiration and motivation to me all along. He has guided me at every step and opened my eyes to a world of knowledge. His encouragement and experience have made the journey smooth. His insights and constant pursuance have been a driving force in this research.

I would like to thank my parents for supporting me during my times of need and helping me in every walk of my life. My mother, the smartest woman I have ever known, has had the greatest effect on my life. She is the best teacher and guide a son could ever wish for. My father, my greatest critic, has been a stalwart support and the only person I look up to for an unbiased and truthful opinion of my accomplishments. Without him I could have never come so far.

I am highly grateful to Farzeen, my fiancé, for sticking with me and being there for me when I needed someone to talk to. Her hard working attitude has been a constant source of motivation for me to do better. She has been the most important addition to my life and this thesis is dedicated to my parents and to her.

Lastly, my research group has been a constant help to me. I thank Rajeev Raina, Milver Valenzuela, and Srikanth Koka for all their help and assistance.

TABLE OF CONTENTS

CHAPTER Page

LIST OF FIGURES

LIST OF TABLES

CHAPTER I

INTRODUCTION

Rain is a very important and necessary event for all living beings. Humans, however, require water for more than just daily essential chores. Water forms an integral part of the socio-economic structure.

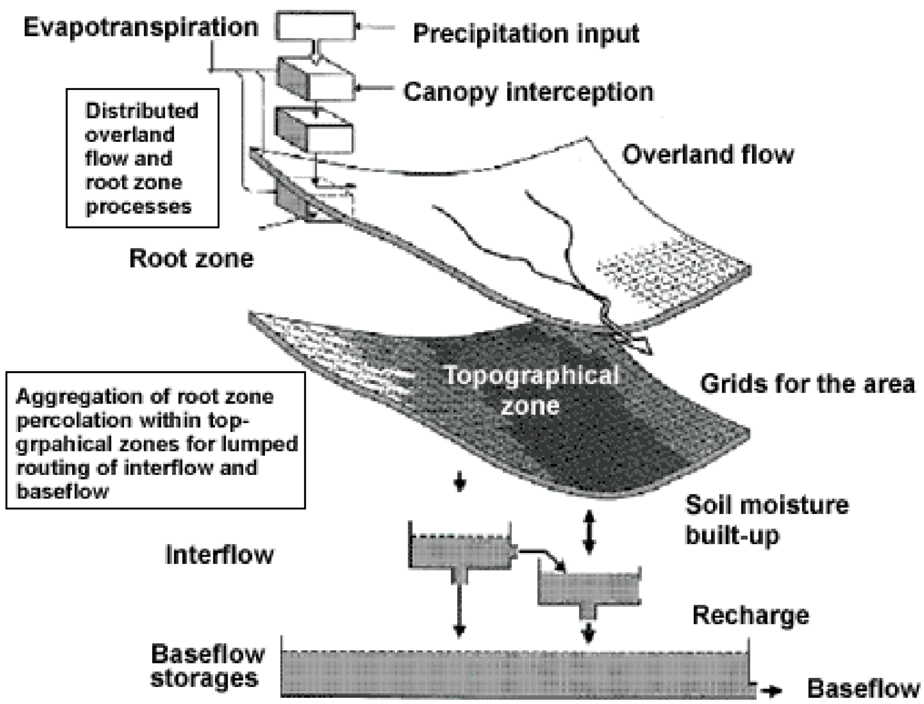

Figure 1. Hydrological Water Balance Model (Narula, 2003)

Figure 1 refers to the natural process of creation of flow due to rain. A major part of the rain is lost by evaporation back into the atmosphere. The remaining infiltrates to form ground water. If the soil gets saturated and cannot take any more infiltration then it overflows and this overflow becomes surface water or runoff. Surface water also has its

---

The model journal is *The ASCE Journal of Water Resources Planning and Management.*

sources in ground water, which sometimes makes it way back into streams or seas due to the geology of the area. Some ground water never joins surface water again if it gets trapped in perched aquifers. The contribution of surface water to our daily needs cannot be understated. The quantification of surface water based on the contribution that precipitation makes to it is very useful for planning, management and preservation of this resource. Therefore, the quantification and estimation of surface water based solely on precipitation and the geography of the drainage area is the objective of this study.

The amount of flow at any point depends on the meteorological, topographical and hydrogeological characteristics of that region. Figure 2 is quite similar to Figure 1; only more in detail about the vertical and lateral processes that occur during the creation of flow.

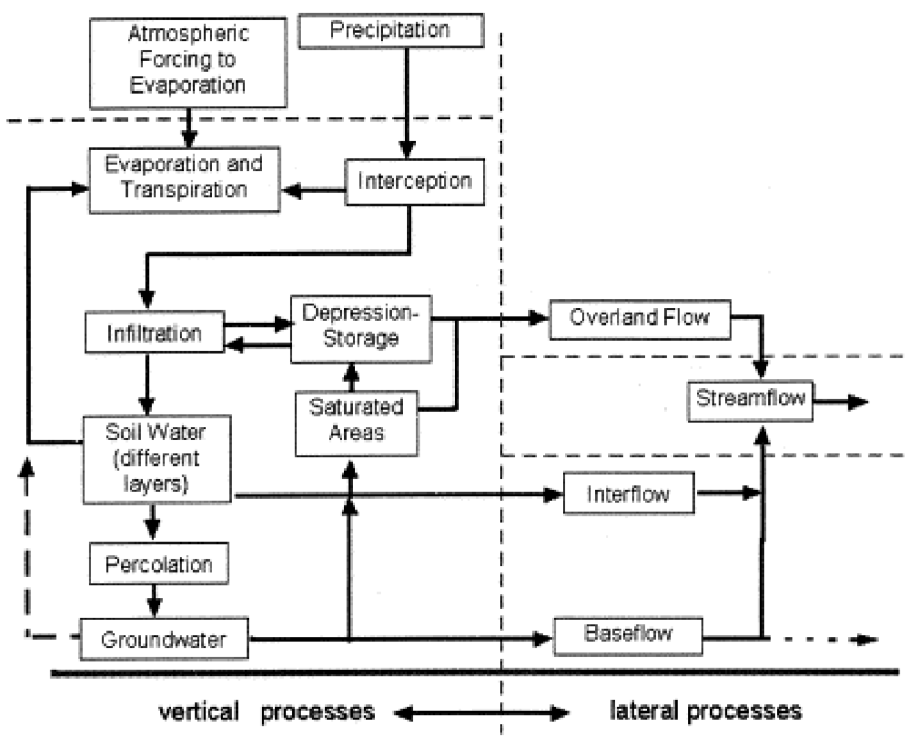

Figure 2. Lateral and Vertical Hydrological Processes (Becker *et al.*, 1999)

The streamflow at any point is the cumulative sum of overland flow, interflow and base flow (Becker *et al.,* 1999). Overland flow is caused by lateral flow from depression storage. Interflow is caused by lateral flow from soil water as it vertically percolates through different soil layers. Base flow is the lateral flow of ground water that joins the streamflow due to the geology of the area (Becker and Braun*.,* 1999*)*.

Flow is dependent on physical processes like precipitation, evapotranspiration, groundwater inflow and ground water outflow. These are the primary processes of physically-based water balance models.

Physically-based models do not apply to monthly and annual time scales because they overlook the distribution of precipitation over time. Statistical models constitute an alternative variable. The statistical model will have a dependent variable and independent parameter(s). The dependent variable will be flow and the independent parameters will be precipitation and watershed characteristics. The watershed characteristics will be average slope, average curve number, area, and regulated area of the watershed. The statistical model will take the following form:

$$\mathbf{Q = \boldsymbol{f}(P, S, CN, A, RA)}$$

where, Q $[L^3T^{-1}]$ = Flow, P $[LT^{-1}]$ = Precipitation, S = Slope, CN = Curve Number, A $[L^2]$ = Area, and RA = Regulated Area

The precipitation is the only parameter varying with time whereas slope, curve number, area and regulated area are constants for each watershed.

CHAPTER II

LITERATURE REVIEW

Traditionally, hydrological models have been modelled as physically-based or conceptual depending on the complexity and extent of completeness of the structure of the model (Beven, 1989; Refsgaard *et al.*, 1989; Bergstrom, 1990; Refsgaard, 1996,1998). In physically-based water balance models, all the physical phenomena like precipitation, evapotranspiration, ground water inflow, ground water outflow and storage need to be quantified and modeled. This form of modeling is data intensive like the Colorado's Decision Support Systems' (CDSS) (StateWB model 2001). Models are further classified into lumped or distributed, based on basin terrain (Bergstrom and Graham, 1998). A statistical model derives an empirical relationship between flow, precipitation and any other parameters that are included in the model. The relationship is derived based on observed data for all the dependent and independent parameters in the model. The best relationship is identified using suitable statistical parameters.

Becker and Braun (1999), and Wolock and McCabe (1999) stated that large scale modeling of streamflow could be done efficiently using simple models. These models maybe lumped or distributed as the case maybe. Distributed models require high resolutions for efficient modeling like the MIKE SHE model (Ewen *et al.*, 1999) and the TOPMODEL (Beven *et al.*, 1994). However, for large scales such high resolution is not always available. Also, distributed models are generally not practical and efficient for large-scale modeling (Becker and Braun., 1999). Becker and Pfützner (1987) even say that statistical lumped models that fulfill large scale modeling requirements of resolution and computation time are better.

There have been studies performed on the Niger basin (Olivera *et al.*, 1995) using statistical models that aim at determining the runoff fraction for the basin by comparing mean annual precipitation and mean annual flow in the basin. Other studies with similar objectives have been carried out for the San Antonio-Nueces basin of Texas by Saunders and Maidment (1995) and for the Souss basin of Morocco by Olivera (1995). Results of such researches focus on trends in a particular basin. Studies that aim at developing a general relationship between precipitation and flow for numerous watersheds on a multi-watershed scale are not well represented. This study will try to find a statistical relationship between flow, precipitation, and watershed parameters (like slope, curve number, area of watershed and regulated area of the watershed). Each of these parameters affects the flow in a stream in their own respective way. A related study conducted to evaluate the water balance model performance for the conterminous US showed that the central region of USA provided uncertain runoff estimates (Hay and McCabe, 2002). Hay's study employs a monthly time scale and 44 stations nationwide. The results motivated this study for a statistical relationship for the conterminous USA and the Region 12. This study, however, will use 838 flow stations for the conterminous USA and 56 flow stations for Region 12. Hay and McCabe (2002) also evaluated the performance of the model based on variation in each of the parameters. It was revealed that some parameters did not drastically affect the model for large changes in their values. The analysis of this study shall also include a similar investigation into the sensitivity of the model parameters. Another study conducted by Wurbs (1999) evaluated the performance of different hydrologic models for watersheds in Texas. This study dealt with comparing the author's ratio-based model with more complex hydrologic models like the Soil Water Assessment Tool (SWAT). In the above study, the results produced by the ratio-based approach adopted were very similar to those produced by the other models. This study draws inspiration from Wurbs' (1999) work and deals with further investigation into the estimation of flows at ungaged locations using a similar model. A study conducted for the state of Idaho by Hortness and Berenbrock (2001) of the US Geological Survey (USGS) estimated monthly and annual streamflow statistics at ungaged sites in Idaho. The study used precipitation as the only variable parameter in the regression equation. The other parameters were watershed characteristics that are constant for each watershed. The study linearized a non-linear form of equation for its estimation of streamflow statistics. This study shall also linearize a non-linear form of statistical equation with precipitation as the only variable parameter besides watershed characteristics for the conterminous USA. This study shall also supply a non-linear form of statistical equation with the same parameters as the linear form.

Modeling strategies can be debated forever if the aim of the modeling is forgotten (Bergström and Graham, 1998). General opinion is that physically-based models are better than statistical models because of the exact theoretical representation of physical phenomena, and hence requiring less calibration or tuning of parameters (Bergström and Graham, 1998). Statistical models on the other hand, are practical when a compromise needs to occur between the model's data demands and obstacles in operational application of the data (Bergström and Graham, 1998). A strategy needs to chosen that is appropriate for the problem being solved (Refsgaard, 1998).

We will use a statistical model because work done previously suggest that the annual and monthly time scales are best represented by them due to the lack of data for high resolutions.

CHAPTER III

METHODOLOGY

A. Precipitation and Flow Data

The flow and precipitation datasets were available with two basic files namely,

i. Geographic Location File

ii. Value File

The geographic location file is necessary to know the position of the gaging and recording stations and to spatially represent them. The value file is used in the latter half of the project when all the parameters are ready for computation purposes. It should also be noted that each of the stations has a unique StationID so that later on we can relate the location file and value file.

The flow data was available in daily, monthly and annual format. Hence, the monthly flow dataset was readily available and did not require much formatting to make it ready for use. The flow stations with too small or too large drainage areas were discarded. Exceptionally large watersheds will not be included due to the large time of concentration. Small drainage areas will not be included for reasons of inaccuracy in delineation. The flow data distribution can be seen in Figure 3. Figure 4 shows the area (in sq. miles) per flow station in each hydrologic region of USA.

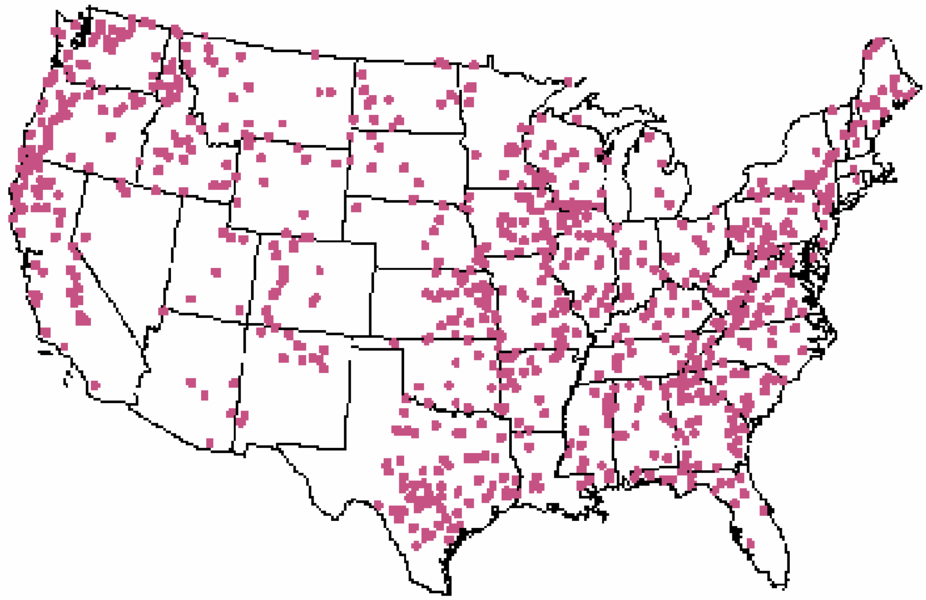

Figure 3. Distribution of Flow Stations

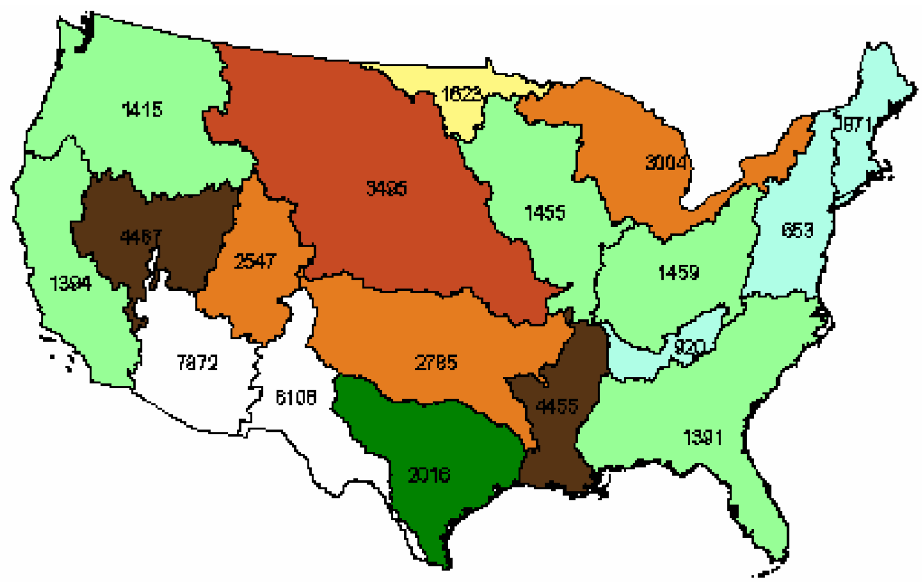

Figure 4. Area per Flow Station for Hydrologic Regions of USA

The precipitation value file obtained from the United States Historical Climatology Network (USHCN, 2003) was available in a daily format. Figure 5 shows the distribution of precipitation over USA. Figure 6 shows the area per flow station in each hydrologic region of USA.

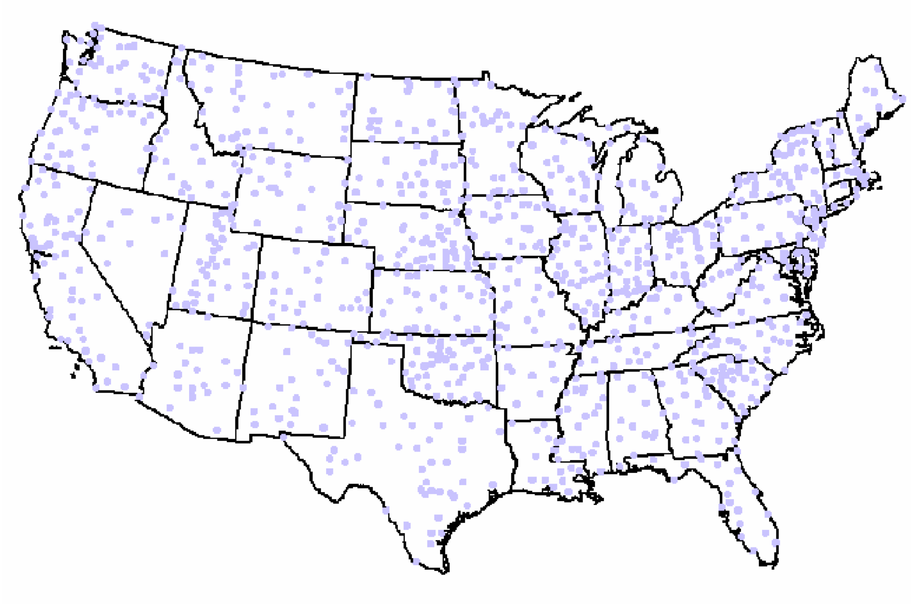

Figure 5. Distribution of Precipitation Stations

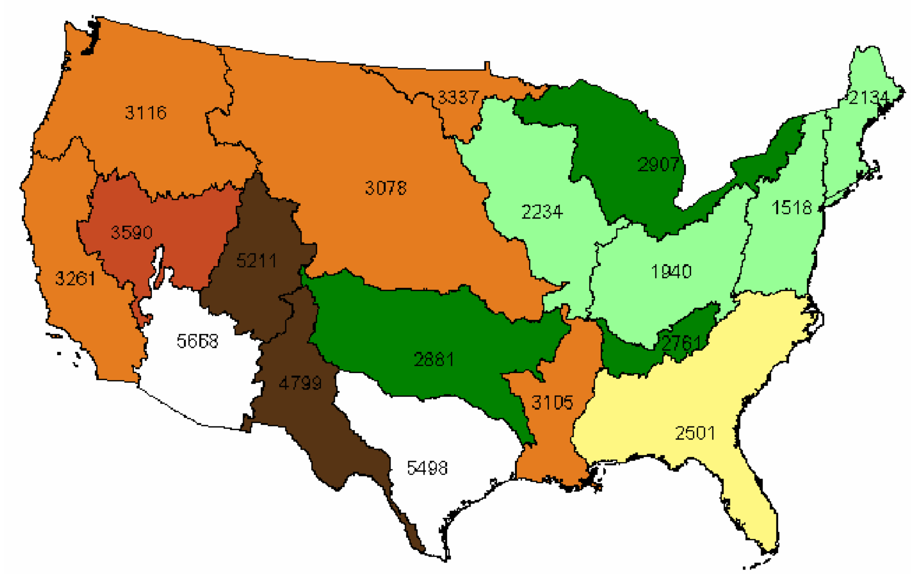

Figure 6. Area per Precipitation Station for Hydrologic Regions of USA

B. Spatial Analysis

B1. Delineation of Stream Network

A Digital Elevation Model (DEM) was used to model the geography of the study area. A DEM is a grid of square cells where each cell represents the elevation value at that location. The size of each cell determines the resolution of the DEM. Larger the cell coarser the resolution. For large areas like the conterminous USA coarser resolutions are preferred over finer resolutions due to lower computational times and availability issues. The elevation value for each cell is an average over all the elevations inside the cell. The assumption here is that for the extent of the study area this approximation is not a cause of a significant error. The user ultimately needs to make a decision regarding the resolution to be adopted for the DEM for the study area under consideration. In this study, a 500-meter DEM was used.

The projection of the DEM should be noted so that henceforth all spatial representation is in the same projection. Therefore, the geographic locations files will be imported into a GIS and reprojected. The Digital Elevation Model (DEM) was filled using the *fill* command in Arc Info Workstation 8.2. The *fill* command is an automatic method to fill all depressions that are caused in the elevation surface due to interpolation errors between surface values (Refer Figure 7).

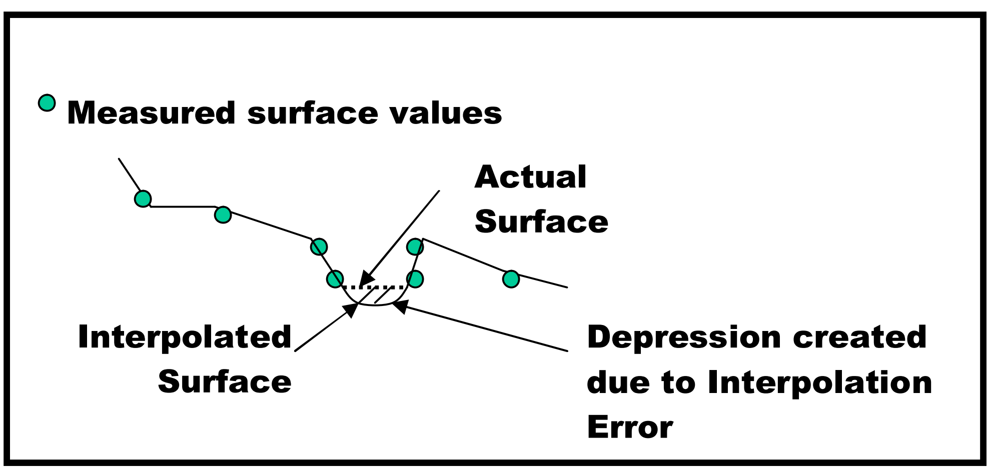

Figure 7. Creation of Interpolated Depressions

However, depressions can also be a feature of the landscape. The four major depressions of USA are Salt Lake, Death Valley, Salton Sea and Saline Valley. The latitudes and longitudes of the lowest elevation in these inland depressions were available at the aforementioned source. The grid cells with these latitudes and longitudes were then identified on the DEM grid. These four grid cells were allotted a *NODATA* cell value. A *NODATA* value means the absence of data. In this case its physical meaning is a sinkhole. A sinkhole is defined as one that is unplugged and drains infinitely. Now, when the DEM is filled all the other depressions are filled except for the depressions that have been specifically isolated.

After the DEM is filled, it is ready for use to create a stream network. Firstly, the flow direction grid is created using the *flowdirection* command in ArcInfo Workstation 8.2. The flow direction grid is one where each cell is assigned a value based on the direction in which it drains. Secondly, the flow accumulation grid is created using the *flowaccumulation* command. The flow accumulation grid is one where each cell is assigned a value based on the area that drains into it. A cell value in the flow accumulation grid is the number of cells that drain into each cell. The stream network is created using a threshold value. A threshold value is a condition on the flow accumulation grid. A threshold value means that only those cells in the flow accumulation grid with cell values higher than the threshold value will be selected for viewing purposes. The threshold value is at the discretion of the user. A high threshold value means that a stream network with only major streams will be viewed. This is generally preferred for studies with large study areas since small streams create unnecessary clutter in the view. A threshold value of zero will create a stream network that shows all the streams big or small that drain the study area.

B2. Selection of Flow Stations based on drainage area criteria

The flow stations with too small or too large drainage areas will be discarded to ensure that these watersheds do not cause inaccuracies (viz., extremely large time of concentration, and inaccuracy in detailing respectively) in the study's results. Exceptionally large watersheds will not be included due to the large time of concentration within them. Considering an average flow velocity of 0.3 m/s, for example, the time of concentration for watersheds greater than 50,000 sq. km. was found to be large enough to affect the monthly time scale. This means that on a monthly time scale a significant part of the precipitation in one month could reach the flow station in the next month. For this reason, large drainage areas were defined as those with 50,000 sq. km. or more area. Also, small drainage areas are defined as those that have less than 250 sq. km. of drainage area. Considering the DEM resolution of 500m, 250 sq. km. is only 1000 cells, which is too small. Because of the large scale of this project, the 500m resolution DEM was used although 30m DEMs are available for the whole country. The selection of the flow stations based on the drainage area resulted in the number of flow stations dropping from 1614 to 1230, a 23.8% drop.

B3. Selective Snapping of Flow Stations

Snapping is the process of correcting the location of a flow station so that it coincides with the delineated stream. In this study, the snapping is automated based on a condition. The flow station will be snapped to the stream network grid cell within a radius defined by the user with the highest drainage area. This method has been devised to make sure that the flow stations fall directly on the stream network. The radius of this method is incremented in steps of one cell size of the stream network. The first radius used is the cell size and the last radius used is ten times the cell size. The drainage areas of the grid cell to which the flow stations are snapped will be then compared to the documented drainage area ($D.A._{doc}$) of the flow station. The documented drainage area is available at the USGS website for all USGS gaging stations. If the new drainage area ($D.A._{obs}$) is within ± 5% of $D.A._{doc}$ then it is assumed that the flow station has been snapped successfully. Figure 8 presents the snapping procedure.

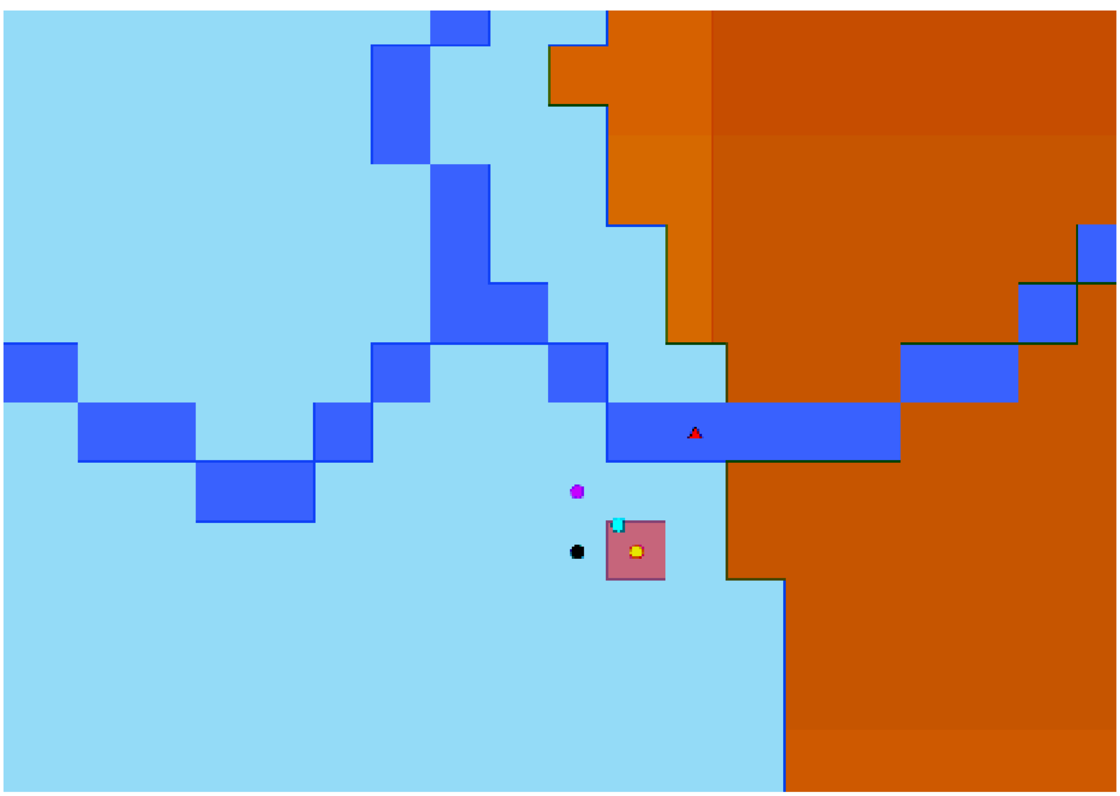

Figure 8. Progressive Snapping

The criterion has been devised in a way to optimize capturing of all possible flow stations as they are progressively snapped and transit to greater than 105% of $D.A._{doc}$. The assumption here is that all the flow stations will at some snapping distance appear in the selection range and get selected. There are a few exceptions when flow stations jump the selection range from under -5% to over +5%.

ArcInfo Workstation is the snapping environment. Arc Macro Language (AML), shown below, is used iteratively as a number of steps and commands are involved in preparing the existent data after snapping.

```
grid
flwgr500 = snappour(flwalbgr500,fac,500)
one500 = flwgr500 / flwgr500
fac500 = one500 * fac
flow500 = gridpoint(fac500,value)
flwstn500 = gridpoint(flwalbgr500,value)
&return
```

The above AML is for a snapping distance of 500 meters. The value 500 can be replaced by any snapping distance the user chooses. The *flowalbgr500* is the grid created out of the flow stations that have made it to the 500-meter snapping radius. The ArcInfo command used is *snappour*. *Snappour* works in a manner that it snaps the grid cell under consideration to the grid cell with the highest user defined variable within a variable. The variable is in the form of the *value* of another grid. In this case, a grid is created out of all the flow stations that passed through the drainage area selection criterion. The grid is created using the *Theme/Convert to Grid* menu tab after the *Spatial Analyst* is loaded from the *File/Extensions* menu tab in ArcView GIS 3.2. The cells in this grid will be snapped by the snapping command. The variable grid is the flow accumulation grid. The first radius of snapping (snapping distance) is 500m. The syntax of the *snappour* is:

OutputGrid=snappour(*GridToBeSnapped*,*ValueGrid*, S*nappingDistance*)

The snappour command is carried out at the G*rid:* prompt in ArcInfo Workstation. The prompt can be changed form A*rc:* to *Grid:* by typing *grid* at the *Arc:* prompt. Now, the flow stations (represented by the grid cells) have been snapped to some location within the snapping radius where the flow accumulation is the greatest. Since the flow accumulation grid and the output grid are two different layers, we need to transfer the new flow accumulation value underneath each snapped flow station to the flow station. For this, a few steps are carried out in Arc Macro Language (AML) and finally a point shapefile is created from the grid using the command *gridpoint*. The flow accumulation transferred to the flow stations is the new drainage area in cell units. $D.A._{obs}$ can be found by multiplying the flow accumulation value in cell units by the cell area (500*500 m^2.).

Now, this point shapefile is analyzed to see if the $D.A._{obs}$ is within 5% of $D.A._{doc}$. As described before, the flow stations with $D.A._{obs}$ > 105% of $D.A._{doc}$ will be removed from the flow station shapefile. Also, those stations with $D.A._{obs}$ within ± 5% of $D.A._{doc}$ will be selected and kept aside. The stations with $D.A._{obs}$ < 95% of $D.A._{doc}$ will be selected and those flow stations will be used in the next snapping iteration. The next iteration will have its radius incremented to twice the cell size. This process will be carried on until the number of flow stations that make it through the selection criteria is very less or all the stations are greater than 105% of $D.A._{doc}$. The limit in this study was a snapping distance of 5000m. Finally, all the flow stations that made it through were gathered together and a flow station shapefile was created. This flow station shapefile was used henceforth in all the analysis in the rest of the study.

The snapping of flow stations was an important step in the development of the data. After the selection procedure, the number of stations dropped from 1230 to 865, a 29.67% drop (a 46.41% drop from the original number of flow stations). The snapping summary is as shown in Table 1.

Table 1. Results of Snapping

Snap Distance	Total No. of Stations	No. of Stations Selected	No. of Stations Dropped	% Selected
0	1230	377	89	30.65
500	764	307	91	40.18
1000	366	72	28	19.67
1500	266	44	30	16.54
2000	192	25	21	13.02
2500	146	15	18	10.27
3000	113	8	17	7.08
3500	88	6	17	6.82
4000	65	6	5	9.23
4500	54	2	52	3.70
5000	41	3	3	7.32

B4. Delineation of Watersheds

The flow stations are now converted to a grid. This grid is used as an input to the *watershed* command. The syntax for the *watershed* command is:

OutputGrid = watershed (*FlowdirectionGrid*, *FlowStationsGrid*)

The watersheds can be converted to polygons using *Theme/Convert to Shapefile* option in ArcView 3.2. The watersheds of USA are shown in Figure 9.

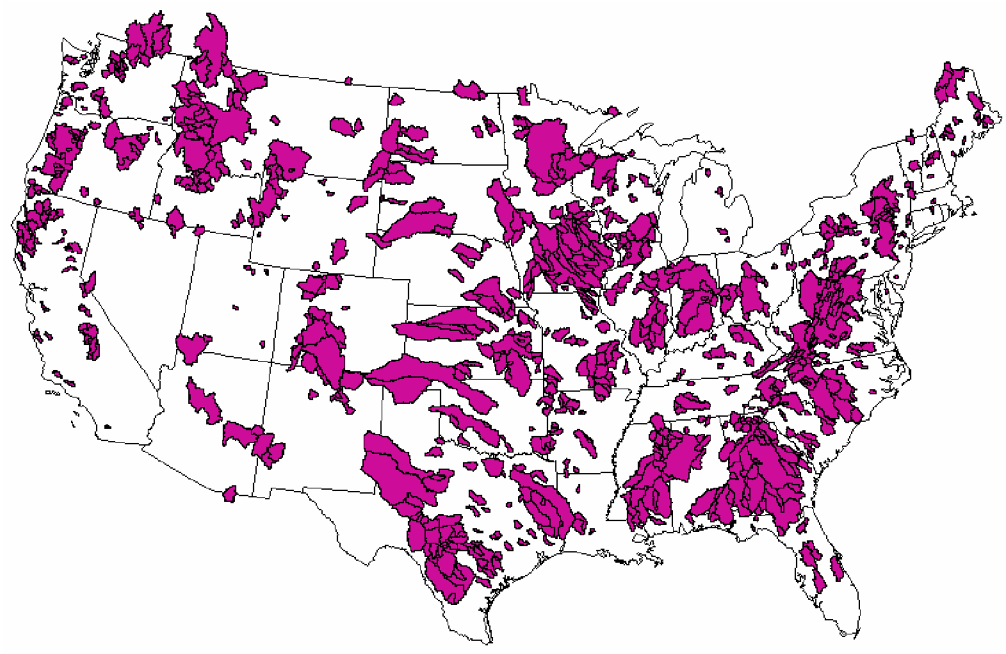

Figure 9. Delineated Watersheds of USA

The watershed grid created will have a few spurious single-celled areas. These single-celled areas are created during the watershed creation process. A closer look at these areas will reveal that they share the same ID with one of its neighboring watersheds. This means that it is in reality a disjoint or broken part of a neighboring watershed. Such spurious single celled watersheds can be combined with their parent watershed using *View/Geoprocessing Wizard/Dissolve Polygons* in ArcView 3.2. The Geoprocessing Wizard can be loaded from *File/Extensions/Geoprocessing Wizard*. After this step, the extensive properties of the watershed like area and perimeter need to be updated. This can be done using the extension *CRWR Vector/Update Feature Geometry*.

B5. Nested Watershed Criterion

In a nested watershed feature, the larger outer watershed polygon engulfs the smaller inner polygons. However, the areas are computed as per the individual polygons for each of the flow stations. Hence, the most downstream flow station should have the cumulative area of all the upstream flow stations plus the area between itself and these stations. This fact is correctly represented in the DEM Drainage Areas but when it comes to the polygons this consideration is lacking. For this reason, the polygon areas of downstream outlets in a watershed need to be corrected manually, since the flow stations that are nested and in the watershed being considered need to be identified from the view and then corrected accordingly in the attribute table. This problem of nested watersheds appeared in 208 watersheds. This meant that 208 corrections needed to be done manually before the study could continue. However, this problem of entering data manually was foreseen to occur in another case when the precipitation dataset came into the picture. Hence, this portion of work was temporarily shelved until the stage in which the precipitation stations were also included in the project. After that, both the problems can be solved simultaneously saving time and effort. The shelving of the job at this stage did not affect the process of converting the precipitation stations into theissen polygons and in the calculation of weighted precipitation for the watersheds for each time step.

B6. Creation of Theissen Polygons of Precipitation Stations

Precipitation varies over time as well as space. It is therefore intuitive to create surfaces out of precipitation data. Precipitation data used in this study is in the form of point values in space. Therefore creation of a surface to fill up all the gaps between any two given points can be done by interpolation or by simply assigning proximity neighborhoods. In this study, the latter method is adopted due to its simplicity. Also, large areas with a few point values will have interpolated values that may not be anymore accurate than values produced by neighborhood functions. One of such neighborhood functions is defined by Theissen polygons. Theissen polygons are defined on the basis of the closest neighborhood.

The precipitation stations are viewed in ArcView using the *Theme/Add Event Theme* option. Alber's Equal-Area Conic is the projection of the DEM and the precipitation dataset is projected in this projection using the *CRWR Vector/Project*.

The precipitation data is available over a number of years. A few precipitation stations will be newer than the others and hence will have a smaller time series. Therefore, for every year in the time scale, the Theissen polygons will change if the number of precipitation stations having data for that time changes. Therefore, Theissen polygons will have to be created for each year. The Theissen polygons can be created using *CRWR Vector/Theissen Polygons*. Once the Theissen polygons are created, the precipitation station data can be transferred to them using the *Tables/Join* menu tab when the tables are active in ArcView 3.2 As a result a new shapefile is created which shares the same extent as the DEM. The attribute table of this file is as shown in Figure 10.

Shape	State	Station_id	Station_na	Lat	Long	Start_yr	End_yr	No__of_yrs
Point	AL	11084	BREWTON 3SSE	31.07	-87.05	1928	1996	69
Point	AL	12813	FAIRHOPE 2NE	30.55	-87.89	1948	1996	49
Point	AL	13511	GREENSBORO	32.71	-87.59	1890	1996	107
Point	AL	13816	HIGHLAND HOME	31.95	-86.32	1948	1996	49
Point	AL	15749	MUSCLE SHOALS FAA	34.76	-87.62	1940	1996	57
Point	AL	17157	ST BERNARD	34.17	-86.82	1930	1996	67
Point	AL	17304	SCOTTSBORO	34.69	-86.05	1927	1996	70
Point	AL	17366	SELMA	32.42	-87.00	1930	1996	67
Point	AL	18024	TALLADEGA	33.44	-86.10	1891	1996	106
Point	AL	18178	THOMASVILLE	31.92	-87.74	1930	1996	67
Point	AL	18323	TROY	31.79	-85.95	1930	1996	67
Point	AL	18438	UNION SPRINGS 9S	32.02	-85.75	1948	1996	49
Point	AL	18469	VALLEY HEAD	34.57	-85.62	1948	1996	49
Point	AZ	20080	AJO	32.37	-112.87	1914	1996	83
Point	AZ	21026	BUCKEYE	33.39	-112.59	1893	1996	104
Point	AZ	21614	CHILDS	34.36	-111.70	1915	1996	82
Point	AZ	23160	FORT VALLEY	35.27	-111.74	1909	1996	88
Point	AZ	24089	HOLBROOK	34.91	-110.17	1893	1996	104
Point	AZ	24849	LEES FERRY	36.87	-111.60	1916	1996	81
Point	AZ	25467	MESA	33.42	-111.80	1896	1996	101
Point	AZ	25512	MIAMI	33.41	-110.89	1914	1996	83
Point	AZ	26250	PARKER 6NE	34.22	-114.22	1893	1996	104

Figure 10. Location file of Precipitation Stations

Stationid	Yr	Prcpt (in.)	Nodata	Sample_days
11084	1964	76.95	0	366
11084	1929	78.50	0	304
11084	1930	58.34	0	365
11084	1931	40.12	0	365
11084	1932	51.93	0	366
11084	1933	55.97	0	365
11084	1934	60.15	0	365
11084	1935	57.95	0	365
11084	1936	65.93	0	366
11084	1937	63.50	0	365
11084	1938	37.54	0	365
11084	1939	77.52	0	365
11084	1940	69.12	0	366
11084	1941	49.71	0	365
11084	1942	64.48	1	365

Figure 11. Data File of Precipitation Stations

The Data File of the precipitation stations is then added as a table in ArcView. This table is shown in Figure 11. The attributes of the projected shapefile are joined to the data file using the *Tables/Join* with the *Stationid* as the key attribute. This new table will now have the precipitation stations with the year of precipitation, precipitation depth and lat-long fields including other attributes like name of station, state, etc. as shown in Figure 12.

Shape	Stationid	Station name	State	Lat	Long	Yr	Prcpt (in.)	Sample_days	Nodata	Start yr	End yr	No. of yrs
Point	11084	BREWTON 3SSE	AL	31.07	-87.05	1928	53.27	244	1	1928	1996	69
Point	11084	BREWTON 3SSE	AL	31.07	-87.05	1929	78.50	304	0	1928	1996	69
Point	11084	BREWTON 3SSE	AL	31.07	-87.05	1930	58.34	365	0	1928	1996	69
Point	11084	BREWTON 3SSE	AL	31.07	-87.05	1931	40.12	365	0	1928	1996	69
Point	11084	BREWTON 3SSE	AL	31.07	-87.05	1932	51.93	366	0	1928	1996	69
Point	11084	BREWTON 3SSE	AL	31.07	-87.05	1933	55.97	365	0	1928	1996	69
Point	11084	BREWTON 3SSE	AL	31.07	-87.05	1934	60.15	365	0	1928	1996	69
Point	11084	BREWTON 3SSE	AL	31.07	-87.05	1935	57.95	365	0	1928	1996	69
Point	11084	BREWTON 3SSE	AL	31.07	-87.05	1936	65.93	366	0	1928	1996	69
Point	11084	BREWTON 3SSE	AL	31.07	-87.05	1937	63.50	365	0	1928	1996	69
Point	11084	BREWTON 3SSE	AL	31.07	-87.05	1938	37.54	365	0	1928	1996	69
Point	11084	BREWTON 3SSE	AL	31.07	-87.05	1939	77.52	365	0	1928	1996	69
Point	11084	BREWTON 3SSE	AL	31.07	-87.05	1940	69.12	366	0	1928	1996	69
Point	11084	BREWTON 3SSE	AL	31.07	-87.05	1941	49.71	365	0	1928	1996	69
Point	11084	BREWTON 3SSE	AL	31.07	-87.05	1942	64.48	365	1	1928	1996	69

Figure 12. Merged Location and Data Files of the Precipitation stations

This table is then once again brought into the view using the *View/Add Event Theme* option. Then the precipitation stations for each year are queried using the Query tool in *Theme/Properties/Definition*. The selected stations are then converted to a separate shapefile by using the *Theme/Convert to Shapefile* option in the theme view. This process is continued for all the years. Thus, if the range of years for the entire precipitation Data File is say *n*, then the number of projected shapefiles created are also *n*.

Now, we have precipitation shapefiles for a range of years. There are cases when, say 1959, may have stations A, B, C, D, E & F, but 1960 might have only A, C, D, E, & F.

Therefore the Theissen polygons shapefile created from the file for the year 1959 will have 6 polygons whereas for 1960 there will be only 5 polygons.

So theissen polygons can be created from each year's precipitation station shapefile using *CRWR Vector/Theissen Polygons*. The ID value for the theissen polygons is the *StationID* of the precipitation station. The attributes of the Theissen polygon shapefile looks like as shown in Figure 13. The *Area* is in m^2.

Shape	Stationid	Area	Prcnt_tot
Polygon	11084	12212482424.1691	0.10322431322406
Polygon	12813	45767253691.5449	0.38684136168019
Polygon	13511	13308475944.1054	0.11248804638363
Polygon	13816	6853891804.82783	0.05793156951163
Polygon	15749	8378158881.44915	0.07081522548668
Polygon	17157	12794791962.1518	0.10814620379916
Polygon	17304	6119698026.05043	0.05172589846496
Polygon	17366	8887600257.11400	0.07512120803015
Polygon	18024	13733591323.1868	0.11608127514110
Polygon	18178	12967120297.0407	0.10960278513947
Polygon	18323	6651727483.90061	0.05622280363904
Polygon	18438	9030420648.25919	0.07632837757016
Polygon	18469	6302296700.11699	0.05326928842218
Polygon	20080	56950067828.0356	0.48136254656780

Figure 13. Attribute Table of Theissen Polygons

C. Watershed Parameters

C1. Transfer of Precipitation to watersheds

The transfer of precipitation values to flow stations is carried out by transferring the precipitation from the Theissen polygons to the watershed polygons that drain into the flow stations. The watersheds and the theissen polygons are two different two-dimensional layers and hence a watershed may be influenced by many theissen polygons. The precipitation is transferred to the watersheds using *CRWR Vector/Poly to Poly*

Property Transfer. The target polygon shapefile is the watershed shapefile. The source file is the theissen shapefile for a year. Each set of theissen polygons (for each year) is used to transfer the values to the watershed polygons. The watershed polygons will therefore have precipitation values transferred to it for each year. The watershed polygon's modified attribute table is as shown in Figure 14.

Shape	Grid_code	Sum_area	Prcpt1948
Polygon	1047000	909249984.0000	37.17
Polygon	1048000	1265500032.0000	37.17
Polygon	1052500	397500000.0000	24.19
Polygon	1055000	247500000.0000	37.17
Polygon	1060000	354500000.0000	37.61
Polygon	1064500	982249984.0000	22.46
Polygon	1074500	282000000.0000	22.46
Polygon	1075000	200500000.0000	22.46
Polygon	1076500	1107250048.0000	29.47
Polygon	1086000	367750016.0000	38.69
Polygon	1119500	316000000.0000	36.26

Figure 14. Watershed Polygon Table after First Transfer of Precipitation Data from Theissen Polygon

The *Grid_code* attribute, obtained from the flow stations grid, is the StationID of the respective flow station that is the outlet to each watershed polygon. This process is repeated for all the years and the same watershed attribute table is continuously updated. The watershed attribute table will begin looking like shown in Figure 15 as more and more years are added.

Shape	Grid_code	Sum_area	Prcpt1948	Prcpt1949	Prcpt1950
Polygon	1047000	909249984.0000	37.17	30.74	43.09
Polygon	1048000	1265500032.0000	37.17	30.74	43.09
Polygon	1052500	397500000.0000	24.19	41.35	45.80
Polygon	1055000	247500000.0000	37.17	30.74	43.09
Polygon	1060000	354500000.0000	37.61	32.17	38.70
Polygon	1064500	982249984.0000	22.46	33.08	35.45
Polygon	1074500	282000000.0000	22.46	33.08	35.45
Polygon	1075000	200500000.0000	22.46	33.08	35.45
Polygon	1076500	1107250048.0000	29.47	32.10	33.84
Polygon	1086000	367750016.0000	38.69	35.42	39.85
Polygon	1119500	316000000.0000	36.26	31.41	32.03

Figure 15. Watershed Polygon Table after Multiple Transfers of Precipitation Data from Theissen Polygons

The precipitation in the watersheds needs a correction for nested watersheds. This is when the area of the nested watersheds is corrected too. The corrections are carried out manually. The watershed table as shown in Figure 16 will have one column of the areas achieved from dissolving the spurious single celled polygons as explained before. It will also have *n* columns for *n* years of precipitation. This table is exported in comma delimited text format and reopened in Excel.

The *Data/Text to Columns* feature of Excel is used to get the table back in a database format. The table is then sorted in an ascending *Grid_code* arrangement. Simultaneously, an ArcView 3.2 view window is kept open with the watershed shapefile in the view. Each watershed from the Excel document is identified in the view and its area is recalculated by identifying all nested watersheds within it. The area will be the sum of all the nested watersheds within the parent watershed.

The precipitation on the other hand is calculated by weighing the precipitation. The weights are the ratios of each nested watershed's corrected area to the area of the parent watershed. As can be seen in Figure 16, the outer polygon nests all the other smaller polygons inside it. Therefore Victoria, TX, has the drainage area of all the flow stations that drain polygons 1 to 9 plus the area of polygon number 10.

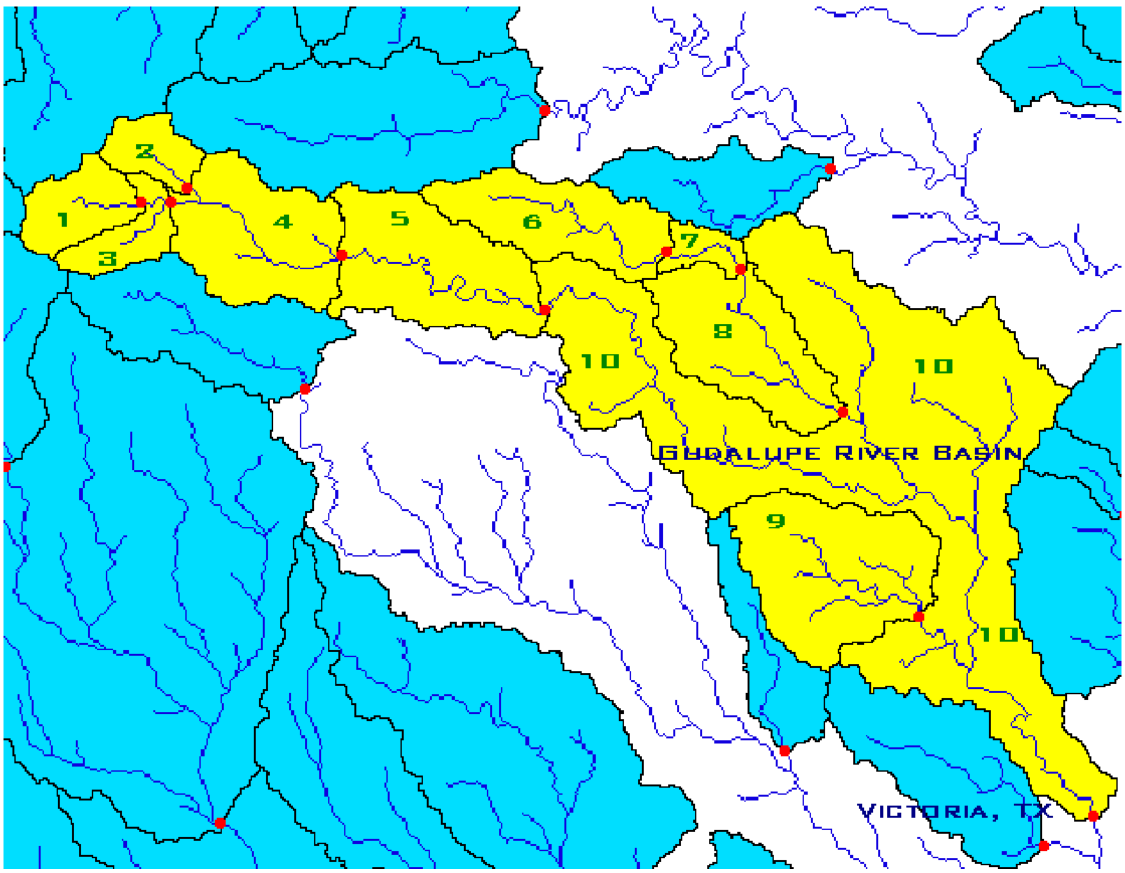

Figure 16. Sub-basins of the Guadalupe River Basin

Shown in Figure 17 are the precipitation stations in purple and the thick black lines that intersect the view are the theissen polygons created with the precipitation stations as inputs.

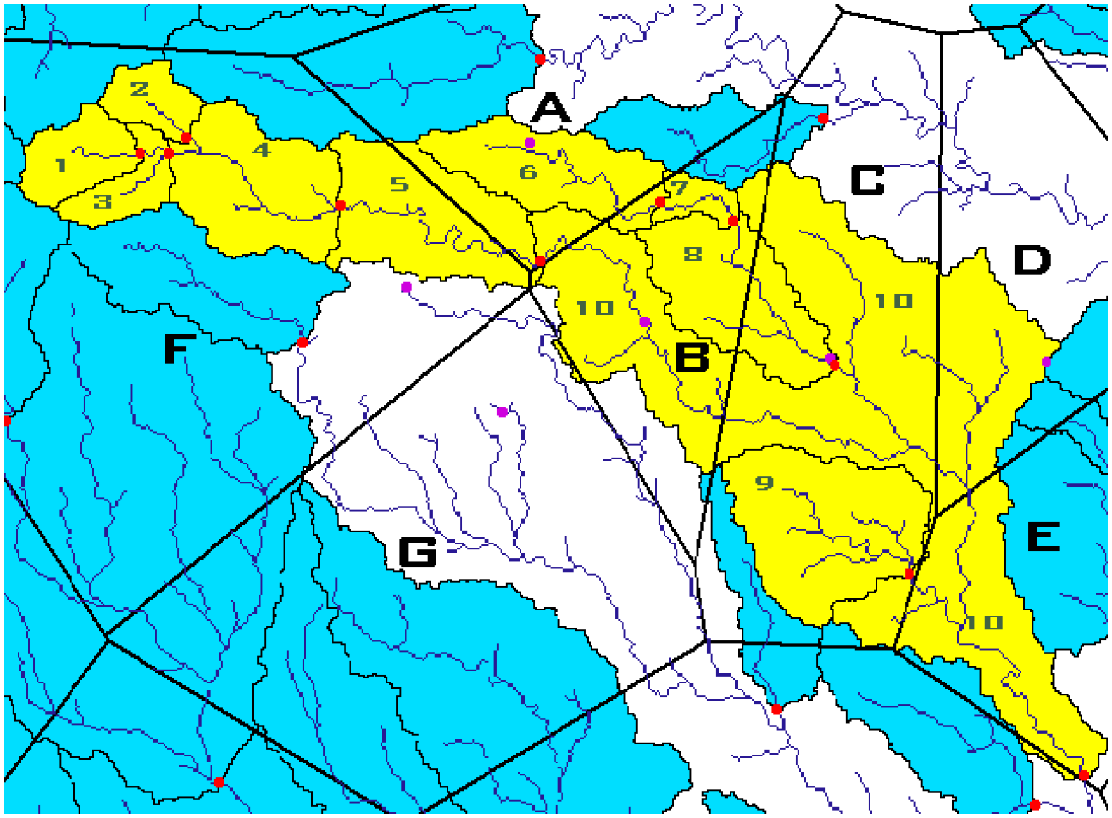

Figure 17. Extent of Theissen Polygons Over the Guadalupe Basin

Hence, if the precipitation in polygon F is, say 50 inches, and in polygon A, 45 inches, then the weighted precipitation of polygon 5 will be given by: -

$$P_5 = \{[50*(2A_5/3) + 45*(1A_5/3)]/A_5\} \quad \text{where, } A_5 = \text{Area of polygon 5}$$

$$P_5 = 48 \text{ in.}$$

C2. Transfer of Slope, Curve Number and Area

Slope directly affects the amount of flow (runoff) obtained at the watershed outlet. Lower the average slope of the watershed, lesser is the flow obtained at the outlet due to higher losses because of higher travel time through the watershed. The slope will be derived from the filled digital elevation model and then the average slope for each watershed will be calculated based on the watershed shapefile.

Curve number is a measure of the permeability. Curve number is a measure from 1 to 100 where the lower limit represents the most physically permeable soil and the upper limit represents the least physically permeable soil. Therefore, lower the curve number lesser is the flow obtained at the outlet. The same can be done for calculating the Average Curve Number for each watershed from the Blackland Research Labs Curve Number Grid.

Area of the watershed is a physical parameter that varies inversely with flow. The watershed with larger area will mean that the precipitation has more time to infiltrate before it reaches the outlet of the watershed. Area is used as the fourth parameter in the empirical relationship.

The average slope is calculated using *CRWR Raster/Average Grid Value over Polygon.* The same menu tab can be used for calculating the average curve number for each watershed polygon from the Curve Number grid. The average slope and curve number values are then joined to the watershed table using the *Join* tool.

C3. Calculation of Regulated Area

Regulated area of the watershed can be defined as the ratio of the cumulative sum of the drainage areas upstream water bodies present in a watershed to the area of the watershed. This parameter needs to be included to take into account the effect of human intervention on the flow in a watershed during wet and dry seasons. To calculate regulated area, we will first need to overlay the water body shapefile over the watershed shapefile. Once this is done, we can calculate the regulated area of the watershed.

To calculate the regulated area, we first need to overlay the waterbody shapefile above the watershed shapefile. This can be done using *Intersect/Geoprocessing Wizard.* Once this is done, we can calculate the regulated area of the watershed. It must be noted that if the stream encounters two or more water bodies serially then the upstream drainage area for that combination is the drainage area of the outlet of the water body which comes last in the series in the downstream direction of the stream. The upstream drainage areas are calculated for each outlet of the waterbody. The next step is to sum them and divide this sum by the drainage area of the outlet of the watershed that contains this waterbody. It must be noted that each of the sub basins will also have a regulated area value if it contains a water body in it. This regulated area is the sub basin's own value and in this case it does not arithmetically add up with the other regulated areas to give the final regulated area for the parent watershed.

C4. Precipitation Correction

A correction will be carried out at this stage on the precipitation values. This requires a multi-annual average precipitation grid (Daly *et al.*, 1994) for the study area. A ratio shall be applied to the precipitation values based on the values in the Daly precipitation grid to each precipitation station. The ratio shall be defined as the average of the precipitation grid values over each watershed to the grid value at the location of the precipitation station. This correction takes into account the areal variability of precipitation over the watershed by providing better precipitation values for each station.

The precipitation in the watershed table is corrected by applying a ratio derived from the Daly precipitation grid. The numerator of the ratio is the average precipitation grid value over each watershed. The precipitation grid is averaged over the watersheds using the *CRWR Raster/Average Grid Value over Polygons* option. In this way the watershed table will contain a new field with average precipitation grid value over each polygon.

$$\overline{\overline{P}}_{station} = \left[\frac{\overline{\overline{P}}_{Daly}}{P_{Daly}} \right] * P_{station} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.1$$

The denominator of the ratio is the precipitation grid value at the point where the precipitation station lies. This value is obtained by converting the precipitation stations to a grid and then combining this grid with the 5000m Daly precipitation grid. This is done using *CRWR Raster/Combine Grids*. This step will create a new grid with a table that has four fields, two from each grid. This table is important because each precipitation station will have a corresponding value from the precipitation grid. The transfer of the calculated value to the watershed table requires creation of a shapefile from the intersection of the watersheds with the theissen polygons. This is done using *View/Geoprocessing Wizard/Intersect*. The new shapefile will have fields for WatershedIDs (Flow Station IDs), Precipitation Station IDs, Percentage of Theissen Polygon areas affecting each watershed and other fields unimportant from the current operation’s perspective. The precipitation Station IDs are used to join the precipitation grid values to the intersected table using the *Join* tool. The average precipitation field obtained for the numerator of the correction ratio is also joined to this table using the watershed IDs. A new field is created to calculate the ratio by going to *Table/Start Editing*. Then after going to *Edit/Add Field* the new field name is selected and the required decimal accuracy is specified. After the new field is created the ratio is calculated for each record in the intersected table using the *Field Calculator* tool in *Field/Calculate*. The ratio will be the average precipitation grid value field (numerator) divided by the precipitation grid value at the location of the precipitation station field (denominator). Another field is then created to account for the weight each ratio has on the final correction figure. This is because each watershed maybe affected by different theissen polygons and hence the percentage of each theissen polygon affecting each watershed must be known to weight the individual ratios. These weights were provided in the form of percentage of area during the watershed-theissen polygon intersection carried out before. The new field will therefore be the product of the individual ratios with the percentage field. After this, the intersected table will be stopped from further editing by going to *Table/Stop Editing*. This new field will give the individual weighted ratios which need to be summarized by sum for each watershed. This can be done by selecting the watershedID header in the table and then by using the *Field/Summarize* option. Once inside the *Summary Table Definition* window the header for the field with individual weighted ratios is selected and *Sum* is selected for the summarize operation to be performed. A new table is then created with the WatershedID and the precipitation correction ratio for each watershed.

This ratio can then be multiplied with all the precipitation values in the watershed table to get the corrected precipitation for each time step. However, if the precipitation grid used is of a single year or a month then the corrected precipitation calculated from it can only be used for that year or month respectively. In such a case, the entire process described above will be repeated for precipitation correction for all the months.

C5. Unit Changes and Data Conformity

Once the precipitation correction is carried out for all the time steps, the next step is to make sure that all the derived data that will be used in further analysis will be compatible with each other. The units of flow and precipitation are changed from *cfs* and *inches/yr* (or *inches/mth*) respectively to *mm/yr* (or *mm/mth*).

The flow is converted from *cfs* to *mm/yr* by dividing the flow by the area of the watershed (m^2) and multiplying by *918732.533721*. If the flow needs to be converted to *mm/mth* then the numeric value above is divided by 365 and multiplied by the number of days in the month. The precipitation is converted from *inches/yr* to *mm/yr* by multiplying by *25.4*. The slope (mm/mm), curve number and regulated area (m^2/m^2) are dimensionless parameters. Area is in square meters (m^2).

The watershed table is now ready for analysis. For the annual analysis, the table will be summarized for annual mean and for the monthly analysis it will be summarized for monthly mean. The table is imported to Excel for all statistical and graphical analysis. Exporting of ArcView 3.2 tables can be done by selecting the target table and then by selecting the *File/Export* menu tab.

D. Analysis of Mean Annual Flow for USA

A range of 1948 to 1988 was selected since the precipitation station data was available without gaps for this range. The number of flow stations for this range decreased from 865 to 838.

D1. Analysis of mean annual flow based on hydrologic regions of USA

1. Mean annual flow versus mean annual precipitation

The exported file is sorted in ascending order with the Hydrologic Unit Code as the sorting criteria in Excel.

Table 2. Hydrologic Regions of USA

Region 01	New England	Region 11	Arkansas-White-Red
Region 02	Mid-Atlantic	Region 12	Texas-Gulf
Region 03	South Atlantic-Gulf	Region 13	Rio Grande
Region 04	Great Lakes	Region 14	Upper Colorado
Region 05	Ohio	Region 15	Lower Colorado
Region 06	Tennessee	Region 16	Great Basin
Region 07	Upper Mississippi	Region 17	Pacific Northwest
Region 08	Lower Mississippi	Region 18	California
Region 09	Souris-Red-Rainy	Region 19	Alaska
Region 10	Missouri	Region 20	Hawaii
	Region 21	Caribbean	

Graphs will be created for the first 18 regions of conterminous USA. The 21 hydrologic regions of USA are shown in Table 2. The mean annual precipitation of all the stations in a region will be plotted against the corresponding mean annual flow. The graphs for regions 1-18 can be viewed in Appendix A (Figures A-1 to A-18). A summary of the R^2 values for the regions are presented in Table 3.

Table 3. Summary of Annual Flow Versus

Precipitation per Hydrologic Region of USA

Region No.	Sampling Size	Best R^2
1	24	7.00E-06
2	64	0.4166
3	115	0.4191
4	15	0.8345
5	65	0.5309
6	25	0.7302
7	93	0.7709
8	13	0.3264
9	9	0.0091
10	84	0.7754
11	59	0.7346
12	69	0.8774
13	5	0.0179
14	17	0.0141
15	8	0.0155
16	8	0.6543
17	113	0.5076
18	52	0.6335

The graphs showed a lot of scatter for all regions except for Regions 4, 6, 7, 10, 11, and 12. Region 4 and 6, however, had only 15 and 25 stations respectively and their results are not as reliable as in the other regions. Regions 7, 10, 11 and 12 have good sampling sizes ranging from 59 to 93; and, Region 12 (Texas-Gulf) had the least scatter with a R^2 of 0.8774. Regions 17 and 18 have good sampling sizes but produce relatively low R^2 values. Also the plots show more runoff than precipitation. This can be explained because Region 17 and 18 have mountainous terrain and hence the precipitation at higher elevations is not captured by gauging stations present at lower altitudes (Wolock and McCabe, 1999). A map of the R^2 values over the 18 hydrologic regions can be seen in Figure 18.

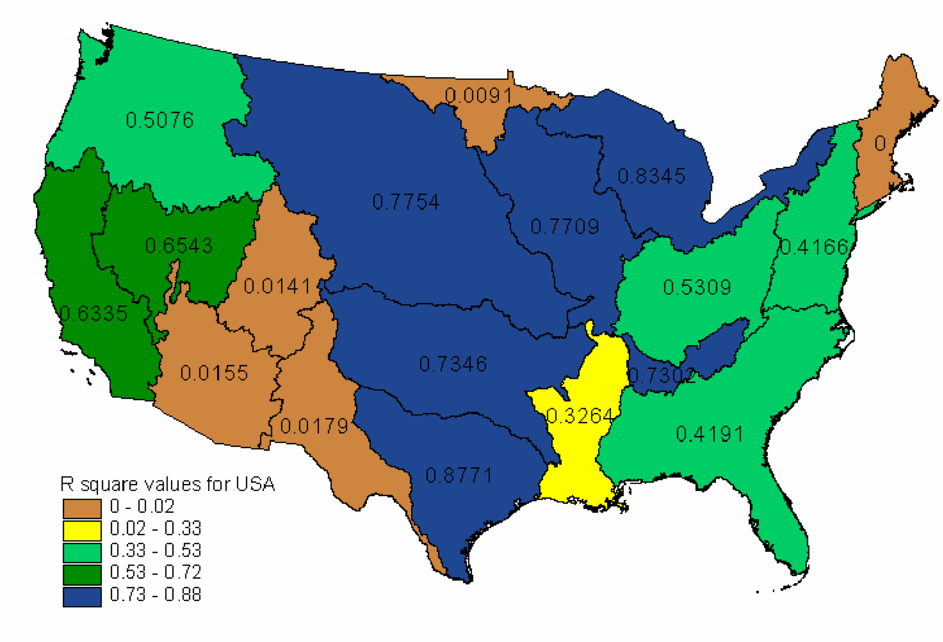

Figure 18. R^2 values for the 18 Hydrologic Regions of USA

At this stage the flow stations were divided into blocks based on their drainage areas. The runoff versus precipitation graphs were recreated for each of these blocks. The frequency distribution showed that only 46 flow stations had drainage areas in the range of 15,000 - 50,000 sq. km. The results are presented in Appendix A (Figures A-19 to A-27). It is seen that a general trend of runoff greater than precipitation is found in all the graphs.

2. Ratio of flow to precipitation versus slope and curve number

A new column will be created in the watershed table. The cells of this column will have a ratio of the flow to the precipitation (both mean annual) for each of the selected flow stations in USA. This column will be plotted against the slope for each of the 18 regions. Another set of graphs will be created based on region where the ratio is plotted against the curve number. These graphs are available for viewing in Appendix A (Figures A-28 to A-65).

The results of the slope set depicted the theoretical relationship of slope with flow i.e., higher the slope more was the flow for a given precipitation. However, in flatter areas of the country (Regions 3, 7, 10, 11, and 12) the slope had no definable relationship with the amount of flow produced with change in precipitation. As can be seen in Figure 19, region 12 is the flattest region of the country and there is no direct relationship between flow and slope for this region.

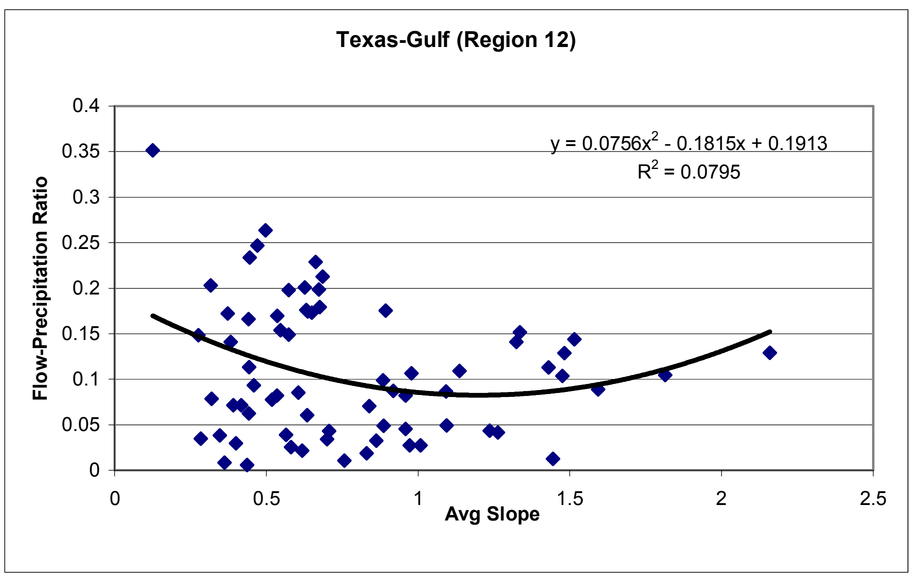

Figure 19. Flow-Precipitation Ratio versus Average Slope for Region 12

The curve number set of plots was inconclusive in regards to finding a relationship between curve number and flow.

3. Calculation of regression coefficients

The watershed table will be now used to carry out multiple linear regressions using the data available. The mean annual flow will be regressed against precipitation, slope and curve number. A non-linear form of equation suggested by Wurbs (1999) shall be converted to its linear form by applying natural Logarithm to both sides of the equation thereby rendering it linear. The non-linear form suggested is:

$$Q = aF_1^{a_2}.F_2^{a_3}.F_3^{a_4}.....F_{(n-1)}^{a_n} \text{ .... } 3.2$$

where, Q is the flow (dependent variable),

F_i are the independent variables, and

a_i are constants (or regression coefficients)

This form can be converted to a linear form like shown below:

$$LnQ = Ln(a_1F_1^{a_2}.F_2^{a_3}.F_3^{a_4}.....F_{(n-1)}^{a_n}) \text{ ....} 3.3$$

$$LnQ = Ln(a_1) + a_2.Ln(F_1) + a_3.Ln(F_2) + ... + a_nLn(F_{(n-1)}) \text{ .... } 3.4$$

If the non-linear form has an exponential term like, $e^{(a_5.F_4)}$ then its linear form will be $a_5.F_4$. Therefore, if there are *n* independent variables then there will be 2^n arrangements. The number of arrangements will decrease in the linear form if there are variables that have zero values in the data. Such a variable (for e.g. F_4) can only take on the form of $a_5.F_4$ and not $a_5.Ln(F_4)$. This is because the logarithm of zero is undefined.

A set of linear regressions was carried out with precipitation, slope and curve number as the only independent parameters. A new set was then created with area added as another independent parameter. The sensitivity of the model to the area was observed. The R^2 values of the provided by the regression algorithm in Excel were used to choose the best equation. As can be seen in Table 4, the simple linear form shown in Equation 3.5 had the highest R^2 value.

$$Q_{est} = a_1 + a_2.P + a_3.S + a_4.CN \quad \text{.....................................} \quad 3.5$$

In the second case, seen in Table 5, with area as an extra parameter the same linear form had the highest R^2 value. The form is shown below:-

$$Q_{est} = a_1 + a_2.P + a_3.S + a_4.CN + a_5.A \quad \text{................................} \quad 3.6$$

However, the change in R^2 value was negligible considering another parameter was added to the linear regression. The R^2 value changed from 0.6995 for equation 3.5 to 0.7001 for equation 3.6.

Table 4 Regression Equations without Area as a Parameter

Equation	R^2 value	Rankings
R = 0.733 * P + 67.9797 * S - 6.7764 * C	0.6696	
R = 0.78596 * P + 80.198 * S + 2.1979 * C - 688.837	0.6995	# 1
LogR = 0.0011 * P + 0.0973 * S + 0.0171 * C	0.5695	
LogR = 0.000994 * P + 0.0777 * S + 0.0027 * C + 1.1024	0.6242	# 2
LogR = 0.00099 * P + 0.0799 * S + 0.7017 * LogC	0.6215	
LogR = 0.00099 * P + 0.0769 * S + 0.2899 * LogC + 0.7595	0.6234	# 3
LogR = 0.0011 * P + 0.6518 * LogS + 0.0196 * C	0.4769	
LogR = 0.00098 * P + 0.4877 * LogS + 0.0009 * C + 1.3871	0.5699	
LogR = 0.00098 * P + 0.5193 * LogS + 0.7912 * LogC	0.5623	
LogR = 0.00099 * P + 0.4809 * LogS - 0.0117 * LogC + 1.4694	0.5697	
LogR = 1.012 * LogP + 0.0555 * S - 0.0104 * C	0.5108	
LogR = 1.7883 * LogP + 0.0822 * S - 0.00044 * C - 3.0181	0.6388	
LogR = 1.6755 * LogP + 0.07005 * S - 1.4736 * LogC	0.6157	
LogR = 1.7918 * LogP + 0.0816 * S - 0.1558 * LogC - 2.7726	0.6390	
LogR = 1.0584 * LogP + 0.3595 * LogS - 0.0109 * C	0.4790	
LogR = 1.7546 * LogP + 0.5169 * LogS - 0.0022 * C - 2.6422	0.5804	
LogR = 1.6767 * LnP + 0.4564 * LnS - 1.403 * LnC	0.5693	
LogR = 1.7606 * LnP + 0.5123 * LnS - 0.455 * LnC - 1.9801	0.5816	

Table 5. Regression Equations with Area as a Parameter

Equation	R^2 value	Rank
R = 0.7811 * P + 79.7932 * S + 2.1593 * C - 1.6815E-09 * A - 674.6686	0.7001	# 1
LogR = 0.000973 * P + 0.07598 * S + 0.00258 * C - 7.27286E-12 * A + 1.16365	0.6324	# 4
LogR = 0.00096 * P + 0.07452 * S + 0.00263 * C - 0.1015 * LogA + 2.0829	0.6347	# 2
LogR = 0.000973 * P + 0.07522 * S + 0.2739 * LogC - 7.3204E-12 * A + 0.8388	0.6317	# 5
LogR = 0.0009602 * P + 0.0738 * S + 0.2858* LogC - 0.102 * LogA + 1.7452	0.6340	# 3
LogR = 0.000958 * P + 0.4739 * LogS + 0.000715 * C - 7.2156E-12 * A + 1.4482	0.5778	# 7
LogR = 0.000944 * P + 0.4623 * LogS + 0.000755 * C - 0.10346 * LogA + 2.3858	0.5807	# 6
LogR = 0.000959 * P + 0.4675 * LogS - 0.03134 * LogC - 7.253E-12 * A + 1.5529	0.5777	N/A
LogR = 0.000945 * P + 0.4562 * LogS - 0.0208 * LogC - 0.1038 * LogA + 2.4767	0.5805	N/A
LogR = 1.7518 * LogP + 0.0804 * S - 0.000541 * C - 7.08354E-12 * A - 2.87442	0.6465	N/A
LogR = 1.7293 * LogP + 0.07889 * S - 0.00044 * C - 0.09947 * LogA - 1.92144	0.6489	N/A
LogR = 1.755 * LogP + 0.07988 * S - 0.1621 * LogC - 7.0826E-12 * A - 2.6234	0.6467	N/A
LogR = 1.7325 * LogP + 0.07842 * S - 0.1452 * LogC - 0.0993 * LogA - 1.6962	0.6491	N/A
LogR = 1.7172 * LogP + 0.5028 * LogS - 0.00237 * C - 7.0322E-12 * A - 2.4969	0.5880	N/A
LogR = 1.7231 * LogP + 0.4987 * LogS - 0.4645 * LogC - 7.0111E-12 * A - 1.8259	0.5891	N/A
LogR = 1.6985 * LogP + 0.4871 * LogS - 0.4484 * LogC - 0.1010 * LogA - 0.8775	0.5919	N/A

E. Analysis of Mean Monthly Flow for Region 12 (Texas-Gulf)

Analysis of annual mean charts revealed that Region 12 had the least scatter and the best R^2 value amongst all the 18 regions. It was decided that the study should be scaled down to the monthly scale for Region 12 so that it can be studied in more detail. The procedure explained in this section was adopted for each of the 12 months. This includes 12 sets of regression equations (both linear and non-linear form) one for each of the 12 months. The data for each flow station was taken on a monthly time scale and then 12 means, one for each month, were calculated for each station. These means were the flow and precipitation data used in further analysis. The flow and precipitation were monthly means for each station. A range of 28 years was selected from 1968 to 1995. The number of flow stations dropped from 69 to 56 for this range. 69 is the total number of flow stations available for Region 12 with historical data for the range of 1948-1988.

E1. Linear Method

The linear method used in this study is a linear model of a non-linear prototype. Rainfall-runoff relationships are non-linear in form (Wurbs, 1999). To make it linear will require a linearizing operation. Natural Logarithm was applied to both sides of the non-linear form to convert it to a linear form. As evident, the linear form will have different coefficients from the non-linear form.

Linear regression will be done for each of the linearized forms and the best equation will be with the least Standard Error of Estimate (SEE). Standard Error of Estimate is defined in Equation 3.7.

$$SEE = SD\sqrt{(1-R^2)} \quad \text{...} \quad 3.7$$

1. Based on calculation of linear regression coefficients

Linear regression coefficients are calculated for all the 12 months for all the stations in Region 12. These coefficients are calculated in Excel using the *Tools/Data Analysis/Regression*. The Data Analysis option is not preloaded into Excel by default when it opens and has to be loaded manually using the *Tools/Add-Ins/Analysis ToolPak* option. The regression tool in Excel is only a linear regression tool and the coefficients produced by this algorithm cannot be used for non-linear forms of equations.

These regression coefficients will then be used for estimation of flow for each of the flow stations. The estimated flow will then be plotted against the observed flow.

The regression equations are calculated for each of the linear conversions of the non-linear forms. Regulated area is added to the list of independent parameters. The mean flows per month are now regressed against the respective mean precipitation, slope, curve number, area, and regulated area. There will be 2^5 (=32) different non-linear equations. The number of linearized equations will be reduced due to the Logarithm situation (Log_{10} (0) is undefined). In this case, the regulated area for some stations was zero and hence the number of different linearized equations dropped to 16 (=2^4). These 16 linear forms were evaluated by regression for each of the 12 months and the best equation was selected for each of the 12 months using the SEE statistic in equation 3.4. The estimated flow was calculated using the best form of equation. For each of the 12 months, the estimated flow was plotted against the observed flow.

It was observed that the least Standard Error of Estimate of 0.62 for the linear model was for the month of April. Table 6 has the SEE arranged in an ascending order.

Table 6. Standard Error of Estimate
table for Linear Model

Month	SEE
April	0.619811
May	0.633459
June	0.675045
October	0.686352
March	0.759441
February	0.759733
December	0.768646
September	0.792207
November	0.818877
January	0.825102
August	0.951035
July	1.111472

Table 7 presents the best equations of each month as per the linear model.

Table 7. Linear Regression Equations for all Months

January	LnR = 3.05*LnP + 1.54*S + 2.74*LnCN - 0.107*LnA + 0.243*RA - 20.42
February	LnR = 3.54 * LnP + 1.04 * S + 3.6 * LnCN - 0.32 * LnA + 0.597 * RA - 21.2
March	LnR = 3.17*LnP + 1.24*S + 0.972*LnCN + 0.045*LnA – 0.365*RA - 16.61
April	LnR = 4.22*LnP + 0.54*S + 0.644*LnCN - 0.298*LnA + 0.965*RA - 12.68
May	LnR = 4.74*LnP + 0.37*S - 0.216*LnA + 0.98*RA - 15.69
June	LnR = 3.74*LnP + 0.48*S + 2.16*LnCN - 0.34*LnA + 1.28*RA - 16.81
July	LnR = 3.65*LnP + 0.98*S + 3.03*LnCN - 0.419*LnA + 2.03*RA - 18.31
August	LnR = 0.045*P + 1.067*S + 0.026*CN - 0.327*LnA + 2.23*RA + 2.61
September	LnR = 0.056*P + 1.29*S + 0.003*CN – 4.266E-11*A – 0.68*RA - 4.84
October	LnR = 3.68*LnP + 0.71*S + 0.009*CN + 3.91E-11*A – 1.33*RA - 15.5
November	LnR = 2.42*LnP + 0.61*S + 0.009*LnCN - 0.324*LnA + 1.075*RA - 2.52
December	LnR = 2.92*LnP + 1.46*S + 0.035*LnCN - 0.061*LnA – 0.284*RA – 11.81

The predicted flow was plotted against the observed flow for each of the months. The results can be seen in Appendix B (Figures B-1 to B-12).

2. Statistical Analysis

For each month an annual time series of predicted flow was created for each of the stations based on the linear regression coefficients for that month. These annual flows were averaged for each month. These averages were compared and plotted against the averages from the observed flows for that month. The same procedure was adopted to compare and plot Standard Deviation values of the predicted and observed flows.

The plots of mean predicted v/s mean observed flows for all the months were scattered around the 45^0 line. The results can be viewed in Appendix B (Figures B-13 to B-24). The months of July (Figure B-19), August (Figure B-20), and September (Figure B-21) have a large amount of scatter unbalanced to one side of the 45^0 line. July and August are the worst months but September seems to be doing better than it actually is. This is due to the fact that the linear regression coefficients were calculated directly on averaged flow values as per month whereas the statistical graphs were created by averaging each of the datasets after the linear coefficients were applied to the data. In short, taking a Logarithm of a mean value (first case) is not the same as taking the mean of Logarithmic values (second case).

The plots of Standard Deviation values of predicted flows against observed flows were inconclusive in showing any relationship. These plots can be viewed in Appendix B (Figures B-25 to B-36).

3. Zonal Analysis

Hypothetical zones were created for the estimated flow data. The confidence parameter was denoted as α (alpha). Alpha was used to develop a zone around the predicted data and then see how many observed data points fell in the interval. This same step was carried out for a number of intervals. The procedure will be clearer with the illustration shown in Figure 20. The interval created between alpha =2 and alpha = 0.5 (1/2) is called Zone 2 and the region between alpha = 3 and alpha = 0.333 (1/3) is Zone 3 and so on. Obviously, Zone 3 also includes Zone 2 as part of it. In Figure 20 the points falling in the interval created between alpha = 2 and alpha = 0.5 are better estimates than the ones in the interval created by alpha = 3 and 0.333 and so on.

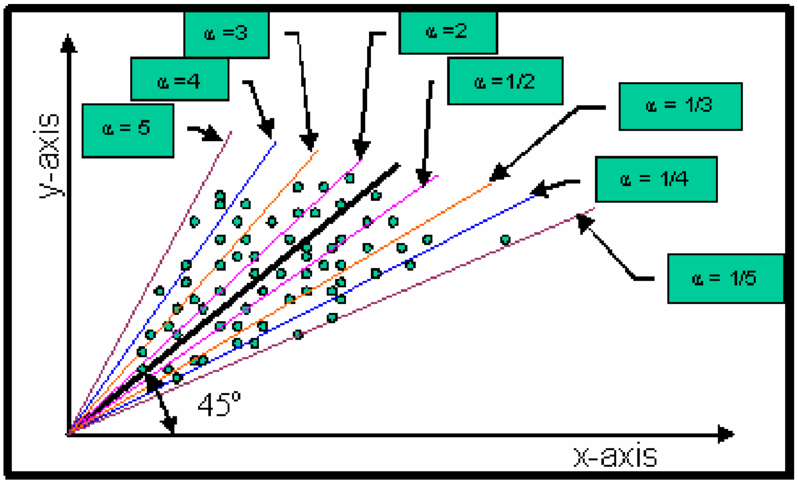

Figure 20. Illustration of Zones

The zonal analysis method was carried out for 7 zones. The results are split in to Tables 8, 9, and 10.

Table 8. Zonal Analysis for Zones 1.33 and 1.5

Month	Zone 1.33			Zone 1.5		
	In	Out	Total	In	Out	Total
January	28	44	72	34	38	72
February	24	48	72	39	33	72
March	30	42	72	39	33	72
April	18	54	72	30	42	72
May	19	53	72	23	49	72
June	18	54	72	23	49	72
July	14	58	72	25	47	72
August	21	51	72	29	43	72
September	25	47	72	33	39	72
October	26	46	72	35	37	72
November	26	46	72	35	37	72
December	23	49	72	33	39	72
Average	23	49		32	41	

Table 9. Zonal Analysis for Zones 2, 3, and 4

Month	Zone 2			Zone 3			Zone 4		
	In	Out	Total	In	Out	Total	In	Out	Total
January	50	22	72	64	8	72	69	3	72
February	57	15	72	63	9	72	70	2	72
March	51	21	72	64	8	72	65	7	72

Month	Zone 2			Zone 3			Zone 4		
	In	Out	Total	In	Out	Total	In	Out	Total
April	53	19	72	60	12	72	64	8	72
May	33	39	72	54	18	72	57	15	72
June	37	35	72	50	22	72	54	18	72
July	39	33	72	53	19	72	61	11	72
August	45	27	72	56	16	72	61	11	72
September	49	23	72	62	10	72	66	6	72
October	56	16	72	64	8	72	67	5	72
November	53	19	72	63	9	72	64	8	72
December	48	24	72	64	8	72	71	1	72
Average	48	24		60	12		64	7.9	

Table 10. Zonal Analysis for Zones 5, 6, and 7

Month	alpha = 5			alpha = 6			alpha = 7		
	In	Out	Total	In	Out	Total	In	Out	Total
January	71	1	72	71	1	72	72	0	72
February	70	2	72	71	1	72	71	1	72
March	68	4	72	70	2	72	70	2	72
April	66	6	72	67	5	72	68	4	72
May	59	13	72	62	10	72	65	7	72
June	58	14	72	62	10	72	64	8	72
July	64	8	72	65	7	72	67	5	72
August	64	8	72	67	5	72	68	4	72
September	67	5	72	69	3	72	70	2	72
October	70	2	72	70	2	72	71	1	72
November	68	4	72	70	2	72	70	2	72
December	72	0	72	72	0	72	72	0	72
Average	66	5.6		68	4		69	3	

In table 8 it is seen that the months of January, February and March are the best months; however more than 60% of the values fall outside the zones. In Table 9 there is a large increase in the number of stations falling within zone 3 from zone 2 for a majority of the months. Zone 4 includes a majority of the stations for all of the months except May and June. All the remaining stations for each of the months are scattered and fall in higher zones. December followed by January is the most compact month since 71 (of 72) and 69 (of 72) stations are within Zone 4 when the Zone 4 average is only 64.

E2. Non-Linear Method

The non-linear method was used to portray the rainfall-runoff relationship in another way. It was used to compare the differences a non-linear form had from its linearized counterpart. The equation is theoretically more realistic in its portrayal of the rainfall-runoff relationship (Wurbs, 1999); however, whether in reality it was really superior to its linearized counterpart needed justification.

In order that a fair comparison could be made, the non-linear model was similar to the linear model with respect to the independent parameters, time scale and data used. The non-linear model coefficients for each month were calculated by non-linear regressions. As previously mentioned, Excel does not support non-linear regression in its *Data Analysis/Regression* option; however, *Solver* in Excel does have the capability of providing regression coefficients if the model is set up in an appropriate manner. *Solver* is not loaded by default when Excel starts. Just like the *Analysis ToolPak*, it needs to be loaded manually by going to *Tools/Add-Ins* and checking the *Solver Add-in* option. Once it is loaded, it can be selected from *Tools/Solver*.

Solver is an optimization algorithm. Functions may have global minimums and maximums as well as local minimums and maximums. If the seed value falls between a local maximum and local minimum then solver will converge to either of these two values depending on whether solver is set up to maximize or minimize the objective function. The converged value in such a case is a local maximum or minimum and not the global maximum or minimum. Since the location of global values is unknown using different seed values iteratively may solve this problem.

Solver is used to calculate non-linear regression coefficients. Solver was run for 16 different non-linear equations for each of the 12 months. Solver is set up to minimize the sum of squared errors by changing the coefficients of the independent parameters. This step is repeated with different seed values for the coefficients to take care of the problem of global and local values. Of the 16 different non-linear forms, the one with the least Sum of Squared Errors (SSE) is considered the best equation for that month. This same procedure is carried out for all the months. The Root Mean Squared Error (RMSE) is the standard statistic generally used but in this case it will not make any difference if the SSE is used in its place because the number of observations for all the months is the same. It was observed that the least Sum of Squared Errors (SSE) of 1269.5 for the non-linear model was for the month of September. Table 11 has the SSE arranged in an ascending order. The non-linear regression equations for each month are presented in Table 12.

Table 11. Sum of Squared Errors table for Non-Linear model

Month	SEE
September	1269.501
November	1322.227
January	1686.485
February	1802.16
August	1858.371
December	1912.128
July	1952.46
April	2377.996
October	2411.764
March	2904.825
June	3975.693
May	4335.635

Table 12. Non-Linear Regression Equations for all Months

January	$R = P^{2.108} . A^{0.112} . e^{(0.467*S + 0.022*CN - 0.344*RA - 10.16)}$
February	$R = P^{2.54} . CN^{2.14} . A^{0.125} . e^{(0.398*S - 0638*RA - 19.56)}$
March	$R = P^{2.21} . A^{0.142} . e^{(0.335*S + 0.023*CN - 0.31*RA – 11.26)}$
April	$R = P^{3.31} . A^{0.144} . e^{(0.267*S + 0.004*CN - 0.178*RA - 15.07)}$
May	$R = P^{3.59} . A^{0.11} . e^{(0.169*S - 0.015*RA - 16.65)}$
June	$R = P^{2.97} . CN^{2.93} . A^{0.07} . e^{(0.543*S – 0.204*RA – 24.84)}$
July	$R = e^{(0.038*P + 0.78 * S + 0.49 * RA -14.09)} . CN^{2.43} . A^{0.13}$
August	$R = e^{(0.045*P + 0.38*RA – 8.66)} . S^{0.737} . CN^{0.424} .A^{0.276}$
September	$R = e^{(0.056*P + 1.29*S + 0.003*CN + 4.27E-11*A – 0.68*RA – 4.84)}$
October	$R = P^{2.92} . A^{0.15} . e^{(0.42*S + 0.012 * CN - 1.16*RA – 14.93)}$
November	$R = P^{2.07} . A^{0.04} . e^{(0.39*S + 0.027*CN – 0.45*RA -9.39)}$
December	$R = P^{1.81} . A^{0.03} . e^{(0.48*S + 0.036*CN – 0.51*RA -8.15)}$

The predicted flow was plotted against the observed flow for each of the months. The results can be seen in Appendix B (Figures B-37 to B-48). An interesting observation is that the month of September (Figure B-45) does just as bad for the non-linear model as for the linear model; however its SSE statistic for the non-linear model is the best from all the months. When the predicted flows are plotted against the observed flows for both the models it can be seen that the non-linear model does better than the linear model in most of the months.

Statistical Analysis

The plots of mean predicted flow v/s mean observed flow showed over-prediction for all the months except May and November. May had a distinct under-prediction while November was the only month that was evenly balanced around the 45^0 line. The standard deviation plots also showed a high standard deviation of the predicted data than the standard deviation of the observed data.

An ACF = 0 means that there is no correlation and an ACF = -1 (or 1) means perfect correlation. An ACF = 0.3 has an inverse, shifted profile of ACF= -0.3 and hence it does not say much in terms of which is better. The ACF plots showed that the predicted and observed values were mainly in the region of -0.4 to 0.4, which means that the predicted and observed values have a very low degree of correlation within themselves.

The plots of mean predicted flow v/s mean observed flow, in Appendix B (Figures B-49 to Figures B-60), showed over-prediction for all the months except May (Figure B-53) and November (Figure B-59). May had a distinct under-prediction while November was the only month that was evenly balanced around the 45^0 line. The standard deviation plots, in Appendix B (Figures B-61 to B-72) also showed a high standard deviation of the predicted data than the standard deviation of the observed data.

An ACF = 0 means that there is no correlation and an ACF = -1 (or 1) means perfect correlation. An ACF = 0.3 has an inverse, shifted profile of ACF= -0.3 and hence it does not say much in terms of which is better. The ACF plots in Appendix B (Figures B-73 to B-84) showed that the predicted and observed values were mainly in the region of -0.4 to 0.4, which means that the predicted and observed values have a very low degree of correlation within themselves.

F. Analysis of Mean Monthly Flow time-series for Region 12 (Texas-Gulf)

In this analysis, a monthly time series was used for Region 12. Linear and non-linear models were developed for this method. A watershed constant was included in the non-linear model instead of the watershed parameters. The performances of these models were evaluated.

In this method a mean monthly time series for each flow station was created for the observed values and a time-series of predicted values was obtained by regression. The sum of squared errors (SSE) estimate was used in deciding the best regression equation for each flow station.

F1. Linear Method

The form with the least sum of squared errors is the best linear form for Region 12. It must be noted here that the linear regressions are carried out for each of the stations individually. Therefore, each station will have its own best linear equation.

The linear regressions were carried out with different seed values in order that the objective function was minimized to the global minimum and not to a local minimum. Since the linear regressions need to be carried out for each of the stations a Visual Basic macro in Excel was developed to automate the regression procedure for each of the stations. The macro used *Solver* as the linear regressor. The macro evaluated each linear form of equation multiple times with different seed values. Of all the multiple iterations the calculated coefficients that gave the least sum of squared errors were selected as the best coefficients for that linear form. This procedure was repeated by the macro for all the other linear form of equations for that station. The best linear form was the one with the least sum of squared errors of all the linear forms of equations.

The prediction of mean flow is carried out on two different premises. The first is where the standard five independent parameters are used; namely, precipitation, slope, curve number, area, and regulated area. The second is wherein the previous month's predicted flow was added as the sixth parameter. This parameter was added after the regression was carried out with the first premise. It was observed that predicted flow was closely related to the observed flow in the graphs created for the first premise. The macro created for the first premise was slightly modified to evaluate the extra parameter in the second premise.

1. Based on precipitation and watershed parameters

Linear regressions were carried out with precipitation and watershed parameters (slope, curve number, area, and regulated area) as the independent parameters. When the best linear form was determined, it was applied to estimate a monthly time series for each of the stations. The estimated time series was plotted against the observed time series for the stations. There was a distinct, yet indefinite, relationship between the observed values and the estimated values. The results showed that all the data points were over-predicted showing that the model calibration was unsuccessful. The results can be viewed in Appendix C (Figures C-1 and C-2).

2. Based on precipitation, watershed parameters and previous month's prediction

Since the five parameters did not yield good results it was decided to add a sixth parameter, the previous month's prediction, as one of the independent parameters in the regression. The macro was altered for inclusion of the new independent parameter. The estimated time series was plotted against the observed time series for a few stations to observe the change from before.

This new model was very sensitive to slight changes in seed values and became unstable very easily if the combination of seed values made the first month's prediction large. It required a lot of calibration and the ranges of the seed values were narrowed to attain stability. The predicted statistics were plotted against the observed statistics and there was no improvement in the plots considering that a sixth parameter was included in the model. These plots are presented in Appendix C (Figures C-3 and C-4).

F2. Non-Linear Method

The non-linear method follows the exact same procedure as the linear method. The visual basic macro is slightly modified to include the new forms of non-linear equations. Besides using the original five parameters and the addition of the previous month's prediction as the sixth parameter, a watershed constant substitutes the watershed parameters and the non-linear method is applied to precipitation and the watershed constant. In this new case, there is only one independent parameter.

The previous month's prediction is also added to create another case for the non-linear model to execute on. The first month of each time series will not have any previous month's prediction. Hence in this case the first month's observed flow is used in place where the previous month's prediction fits in. The non-linear model will calculate the predicted flow from this value besides precipitation and watershed parameters or watershed constant as the case maybe. The first month's predicted value is used in the second month's non-linear regression and so on till the end of the monthly time series.

1. Prediction of mean monthly flow based on watershed parameters

Based on precipitation and watershed parameters

The macro was slightly modified to apply the non-linear model to precipitation and the watershed parameters. The non-linear model required a new set of seed values during the calibration process. Sum of squared errors was the objective function to be minimized. The predicted statistics plotted against the observed statistics revealed that it performed better than the linear model. These plots are presented in Appendix C (Figures C-5 and C-6). The results showed that nearly all the data points were under-predicted. This observation was different from the observation seen in the linear model which had over-prediction.

Based on precipitation, watershed parameters and previous month's prediction

In this case, the macro was modified to include the previous month's prediction. This was done to compare the performance of the linear method with the performance of the non-linear method with the six-parameter model. The new non-linear model performed better than its linear counterpart but it failed to have any marked improvement over the five parameter non-linear model. The non-linear model with the sixth parameter also had high under-prediction as can be seen in Appendix C (Figures C-7 and C-8).

2. Prediction of mean monthly flow based on watershed constant

In this section, the non-linear model was slightly modified to substitute a watershed constant instead of the watershed parameters. The watershed parameters are constant and hence it is logical to substitute a watershed constant instead of them. Also, this watershed constant is used only with precipitation as the only independent parameter. Later on the previous month's prediction is added to see if its inclusion affects the model in any way.

<u>Theory behind watershed constant</u>

The watershed constant is a simplification of a number of watershed parameters that are constant over time. Area, slope, curve number, regulated area are a few of the watershed parameters that can be considered to be constant for a watershed over a short period of time.

The non-linear form with precipitation and watershed parameters is:

$$Q = a_1 P^{a_2} .S^{a_3} .CN^{a_4} .A^{a_5} .RA^{a_6} \text{ .... 3.8}$$

The watershed constant is substituted for the terms of S, CN, A and RA like shown below:

$$Q = a\ P^b \text{ .... 3.9}$$

where, a is the watershed constant and is given as:-

$$a = a_1 .S^{a_3} .CN^{a_4} .A^{a_5} .RA^{a_6}$$

and, $b = a_2$

<u>Based on watershed constant, and mean monthly precipitation</u>

Equation 3.8 is used in this estimation routine. The macro was modified accordingly to consider only two possible non-linear variations of this non-linear form. This method produced SSEs a little greater than the five-parameter model used before. It made the process of calibration very easy with only one coefficient seed value to calibrate instead of four. The results of the watershed constant model were quite better to those obtained in the five parameter non-linear model. The statistical values of mean and standard deviation showed much less under-prediction with scatter below the 45^0 line. This process not only increased processing time and efficiency but also gave good results. The results can be viewed in Appendix C (Figures C-9 and C-10).

Based on watershed constant, mean monthly precipitation and previous month's prediction

The previous month's prediction is added to equation 3.8. The new non-linear form is like below:

$$Q_i = a\ P^b Q_{i-1}^c\ ,\ \ where\, i > 1 \qquad \text{3.10}$$

The macro was modified to include all four permutations of this non-linear form.

The watershed constant along with the previous month's prediction was a simpler alternative to the six parameter non-linear model. The statistical values of mean and standard deviation showed much lesser under-prediction than the six parameter non-linear model. The statistical results, in Appendix C (Figures C-11 and C-12), were encouraging since it was a smarter option over the six-parameter non-linear model. When these results are compared to the model described in Section (III).(F).(F2).(2).(ii) above it can be clearly seen that the additional parameter made the model unstable when it should have improved the results.

The variation of a, b, and c with respect to slope, curve number and area of the watershed is presented in Appendix C (Figures C-13 to C-21). No well-defined relationship is seen in any of these plots.

CHAPTER IV

DATA REVIEW

A. Data Requirements

The data needed for this project and their sources are:

i. Monthly Flow Dataset: US Geological Survey (USGS)

ii. Precipitation Dataset: US Historical Climatological Network (USHCN)

iii. 500m Digital Elevation Model: Source USGS

iv. SCS Curve Number Dataset: Blacklands Research Laboratories, Temple, Texas

v. Inland Water body Shapefile: National Atlas of USA, USGS (2003)

vi. Precipitation Grid: Daly (1994)

B. Precipitation Data

NOTE: This dataset is a part of a larger dataset consisting of maximum and minimum temperatures, precipitation, snowfall and snowfall depth for all the stations.

Purpose: Developed to help in detection of regional climatic change.

Source: Easterling, D. (2003). United States Historical Climatological Network (USHCN)

Website: http://lwf.ncdc.noaa.gov/oa/climate/research/ushcn/ushcn.html#LOGO

Dataset range period: 1900-1996

Form of Raw data: Tab delimited format

Type of Spatial Data: Point Feature Dataset

Total number of Regions in dataset: 48 (contiguous states of U.S.A)

Total number of precipitation stations: 1211

Attributes of each station:

1. StnID – a 6 digit unique number
2. Data Indicator field: Indicates the type of data[2] with month and year
3. Number of days in month specified in Field 2

4-35. Precipitation values for each day of the month and year specified in Field 2. NODATA values are represented by –999.

C. Flow Data

Source: Slack *et al.* (1993)

Website: http://water.usgs.gov/pubs/wri/wri934076/1st_page.html

Form of Raw data: Table format

Type of Spatial Data: Point Feature Dataset

Total number of regions in dataset: 21

Total number of regions in conterminous U.S.A.: 18 (excluding Alaska, Hawaii, and the Carribean)

Total number of flow stations: 1614

Data considered for each flow station:

1. Yrs – the number of years of acceptable data
2. StnID – a 8 digit unique number
3. Station name - Complete station name including state name
4. D.A. – drainage area in sq. miles

[2] *Maximum and minimum temperatures, precipitation, snowfall and snowfall depth*

5. Latitude – Latitude of station in northing
6. Longitude – Longitude of station in westings

D. United States 500m Digital Elevation Model (DEM)

Source: U.S. Geological Survey, "500m DEM." USGS – Metadata for GCIP Reference data Set (GREDS)

Prepared by the Global Energy and Water Cycle Experiment (GEWEX) for its Continental-Scale International Project (GCIP) Reference Data Set (GREDS)

Website: http://nsdi.usgs.gov/nsdi/wais/water/gcip.HTML

Purpose: To support the global change research community.

Method of Data Collection:

DEM data is derived by USGS using DLG (Digital Line Graph contours) hypsographic and hydrographic data.

Data Records:

The DEM file is organized into 3 record types: A, B & C.

Type A record contains general information like name, boundaries, minimum and maximum elevations, number of B type records and projection parameters. Each DEM has only one type A record.

Type B record contains elevation profiles. Each profile has a type B record.

Type C record contains statistics about the accuracy of the data.

Data Characteristics:

Type of Spatial Data: Grid

Data Type: Floating Point

Projection Details:

Projection: Albers

Units: meters

Spheroid: GRS1980

1st Standard Parallel: 29 30 0.000

2nd Standard Parallel: 45 30 0.000

Central Meridian: -96 00 0.000

Latitude of Projection's Origin: 23 00 0.000

False Easting (meters): 0

False Northing (meters): 0

Cell/Pixel size: 500m

Grid size: Number of Rows: 6996

Number of Columns: 12232

Vertical Elevation: meters (whole integer values only)

NOTE: The Data Accuracy and Data Verification information is referenced from the 500-meter DEM metadata.

Data Accuracy:

The vertical accuracy of the DEM is described using the vertical Root Mean Square Statistic (RMSE). A selection criterion is an RMSE of one-half of a contour or better.

The horizontal accuracy of the DEM is mathematically described using the UTM meters.

Data Verification:

- Identification of maximum and minimum values of elevations and comparison with the maximum and minimum values of the most accurate available contours or spot elevation map products. The maximum and minimum grid points must be within the tolerance levels of the contours or spot elevation values.
- Verification of all below sea level elevations with the best available map product of the area and if it is not available then adjusting it with the surrounding terrain.

E. 5000m Precipitation Grid

Source: Daly, C., Neilson, R.P., and Phillips, D.L. (1994) "A Statistical Model for Mapping Climatological Precipitation over Mountainous Terrain." *Journal of Applied Meteorology*, 33, pp. 140-158.

Data Characteristics:

Type of Data: Spatial (Raster)

Data Type: Integer

Time Scale: Monthly Mean (One grid for each month)

Grid Resolution: 5000m

Grid Extent: Texas

Grid Projection Details

Projection: Albers

Units: meters

Spheroid: GRS 1980

1st Standard Parallel: 27 25 0.000

2nd Standard Parallel: 37 55 0.000

Central Meridian: -100 00 0.000

Latitude of Projection's Origin: 31 10 0.000

False Easting (meters): 1000000.00000

False Northing (meters): 1000000.00000

F. Curve Number

Source: 250m Curve Number Dataset, Blackland Research Labs at *Texas A&M University*.

Data Characteristics:

Type of Data: Spatial (Raster)

Data Type: Integer

Grid Resolution: 250m

Grid Extent: Conterminous USA

Grid Projection Details

Projection: Albers

Spheroid: Clarke 1866

1st Standard Parallel: 29 30 0.000

2nd Standard Parallel: 45 30 0.000

Central Meridian: -96 00 0.000

Latitude of Projection's Origin: 23 00 0.000

False Easting (meters): 0

False Northing (meters): 0

G. Water bodies of USA

Source: U.S. Geological Survey (2002). "Streams and Waterbodies of the United States."

Data and Metadata Website: http://www.nationalatlas.gov/hydrom.html

Purpose: These data are intended for geographic display and analysis at the national level, and for large regional areas.

Available Formats: Shapefile, and

Spatial Data Transfer Standard (SDTS)

Map Scale: 1:2,000,000

CHAPTER V

CONCLUSION

Flow was estimated from five independent parameters at different time scales. The annual scale was adopted for the entire conterminous USA while the monthly scale was used for Region 12 (Texas-Gulf). It was observed that on the annual scale Region 12 performed the best. Region 12 displayed the least scatter and was the most coherent. The R^2 value of 0.8774 was far better than the other regions of USA. On the annual scale it was observed that the area of the watershed hardly improved the prediction of flow considering that a whole new parameter was added to improve prediction. It was observed that slope had a very strong effect on the amount of flow produced; the effect of curve number was undeterminable.

The monthly scale was adopted for Region 12. The monthly scale was applied in two formats. One format was where the flow was predicted for each month. In this case each station has only one value per month. Flow was predicted first using a linear model and then using a non-linear model. It was observed that the non-linear model performed better than the linear model justifying that rainfall-runoff relationships are non-linear in form (Wurbs, 1999). The month of April performed the best in the linear model whereas the month of September performed the best in the non-linear model. The sum of squared errors (SSE) statistic was used to determine the best month for the non-linear model. When the R^2 values of the months were compared for the non-linear model it turned out that April was the best month in the non-linear model too. This result was more in line with the result of the linear model. This showed that the SSE method is not the right statistic for determining the best month. This is because for the dataset is bivariate i.e., each time interval has two measurements, precipitation and flow. The SSE statistic can be applied only to univariate data. The SSE method can be used to decide the best non-linear form of all the 16 non-linear forms for each of the months. It cannot be used to deduce the best month of the 12 months. Univariate data is that which has only one measurement for each time step. The R^2 statistic can be used to compare the months because it can be used on bivariate data. This explains why R^2 is the appropriate statistic for determining the best month for the non-linear model.

The second format of applying the monthly time scale was where the monthly time series was predicted for each station using a linear model and a non-linear model. The non-linear model proved to better than the linear model because of lower SSEs. Calibration for both these types of models was carried out. The non-linear model had four formats; with and without the previous month's prediction as an extra parameter and with and without the watershed constant. It was seen that the models with the watershed constant were easier to calibrate in terms of computer downtime and number of seed values to initialize. Also, the non-linear model with the watershed constant performed exceedingly well than its five parameter equivalent. The previous month's prediction was a very unstable parameter and it made all the models that it was included in unstable.

In conclusion, Region 12 performed very well on the annual time scale; however at the monthly time scale the predicted values for the monthly time series models (both linear and non-linear) were too high and irregular. For Region 12, the mean flow per month model performed well in estimation of mean flows for some months, particularly April. The non-linear model performed better than the linear model.

It is recommended that evapotranspiration be included as a parameter in the model. As per the results obtained it can be suggested that curve number and regulated area be excluded from the model as their effects were uncharacteristic and undefined. Another valuable comment would be to include watersheds with drainage areas of less than 10,000 sq. km. only in the study. This condition might eliminate errors caused by inclusion of large drainage areas.

REFERENCES

Becker, A., and Braun, P. (1999). “Disaggregation, aggregation and spatial scaling in hydrological modeling.” *Journal of Hydrology*, 217, 239-252.

Becker, A., and Pfützner, B. (1987). “EGMO-system approach and sub-routines for river basin modeling.” *Acta hydrophysica 31*, 125-141.

Bergstöm, S. (1990). “Principles and confidence in hydrological modelling.” *Nordic Hydrology 22*, 123-136.

Bergström, S., and Graham, L.P. (1998). “On the scale problem in hydrological modeling.” *Journal of Hydrology 211 (1-4)*, 253-265.

Beven, K. (1989). “Changing ideas in hydrology-The case of physically-based models.” *Journal of Hydrology 105*, 157-172.

Beven, K.J., Quinn, P.F., Romanowicz, R., Freer, J., Fisher, J., and Lamp, R. (1994). “TOPMODEL.” *Computer Models of Watershed Hydrology,* V.P. Singh, ed., Water Resources Publications, Highlands Ranch, Colorado.

Daly, C., Neilson, R.P., and Phillips, D.L. (1994) “A Statistical Model for Mapping Climatological Precipitation over Mountainous Terrain.” *Journal of Applied Meteorology*, 33, pp. 140-158.

Easterling, D. (2003). United States Historical Climatological Network (USHCN) http://lwf.ncdc.noaa.gov/oa/climate/research/ushcn/ushcn.html#LOGO

Ewen, J., Sloan, W.T., Kilsby, C.G., and O'Connell, P.E. (1999). "UP modeling system for large scale hydrology: deriving large scale physically-based parameters for the Arkansas-Red River basin." *Hydrology and Earth Sciences System 3.1*, 125-136.

Hay, L.E., and McCabe, G.J. (2002). "Spatial variability in water-balance model performance in the conterminous United States." *Journal of the American Water Resources Association*, AWRA Paper 00086.

Hortness, J.E., and Berenbrock, C. (2001). "Estimating monthly and annual streamflow statistics at ungaged sites in Idaho." *Water-Resources Investigations Report 01-4093*, Boise - Idaho. http://idaho.usgs.gov/PDF/wri014093/4093.pdf

Narula, K.K. (2003). *teri* Water Programme, Internet Website http://www.teriin.org/waterprogram/thrust.htm

Nash, J.E., and Sutcliffe, J.V. (1970). "River forecasting through conceptual models – Part I: A discussion of principles." *Journal of Hydrology 10*, 282-290.

Olivera, F. (1995). "Water balance of the Souss Basin." University of Texas at Austin and United Nations Food and Agricultural Organization. http://civil.ce.utexas.edu/prof/maidment/olivera/morocco/report.htm

Olivera, F., McKinney, D.C., Maidment, D.R., Zichuan, Y., and Reed, S. (1995). "Mean-annual water balance of the Niger River, West Africa." *Proc., UNESCO Symposium on Runoff Computations for Water Projects, Oct. 30 - Nov. 3, 1995*, St. Petersburg, Russia.http://www.ce.utexas.edu/prof/olivera/nig_stdy.htm/nigstdy.htm.

Refsgaard, J.C. (1996). "Terminology, modeling protocol and classification of hydrological model codes." M.B. Abbott, J.C. Refsgaard, eds, *Distributed hydrological modelling*. Kluwer Academic Publishers, Dordrecht, pp. 17-39.

Refsgaard, J.C. (1998). "Conceptual versus physically-based hydrological models: Which models to be used for BALTEX purposes?" Proceedings of the 2nd Study Conference on BALTEX, Rügen, Germany, 25-29 May, 180-184.

Refsgaard, J.C., Alley., W.M., and Vuglinsky, V.S. (1989) "Methodology for distinguishing between man's influence and climate effects on the hydrological cycle." IHP-III Project 6.3, Technical Documents in Hydrology, UNESCO, Paris.

Saunders, W.K., and Maidment, D.R. (1995). "Grid-based watershed and stream network delineation for the San Antonio-Nueces Coastal Basin." *Proc., Texas Water '95, August 14-18, 1995*, San Antonio, Texas. http://www.ce.utexas.edu/prof/maidment/GISHYDRO/saunders/method.pdf

Slack, J. R., Lumb, A. M., and Landwehr, J. M (1993). "Hydro-Climatic Data Network (HCDN): Streamflow data set, 1874 – 1988." U.S. Geological Survey Water-Resources Investigations Report 93-4076.

StateWB (April 2001), *Colorado's decision support systems*, Documentation http://cdss.state.co.us/manuals/statewb/statewbgui_1_0.doc

Wolock, D. M., and McCabe, G. J (1999). "Explaining spatial variability in mean annual runoff in the conterminous United States." *Climate Research Vol. 11*, 149-159.

Wurbs, R.A. (1999). "Comparative evaluation of methods for distributing naturalized streamflows from gaged to ungaged Site." Technical Report No. 179, Texas Water Resources Institute, 8, College Station, Texas.

APPENDIX A

Graphs of analysis for the conterminous USA

A. Graphs of Mean Annual Flow based on hydrologic regions of USA

A1. Mean Annual Flow versus Mean Annual Precipitation

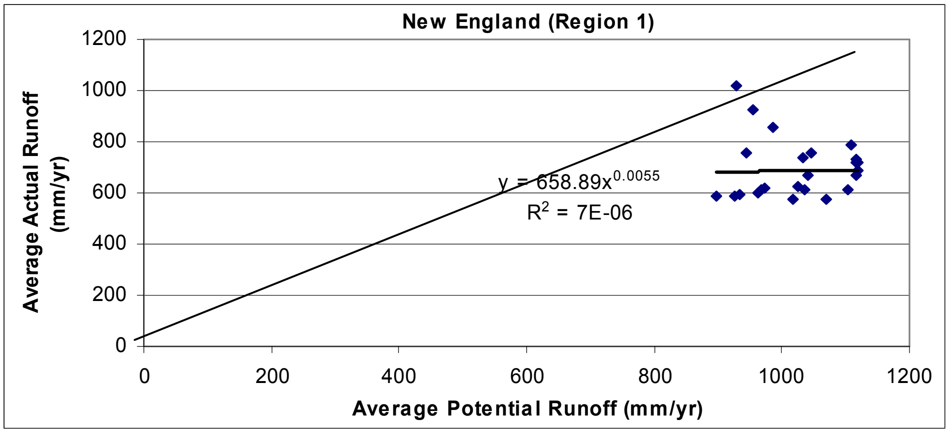

Figure A - 1

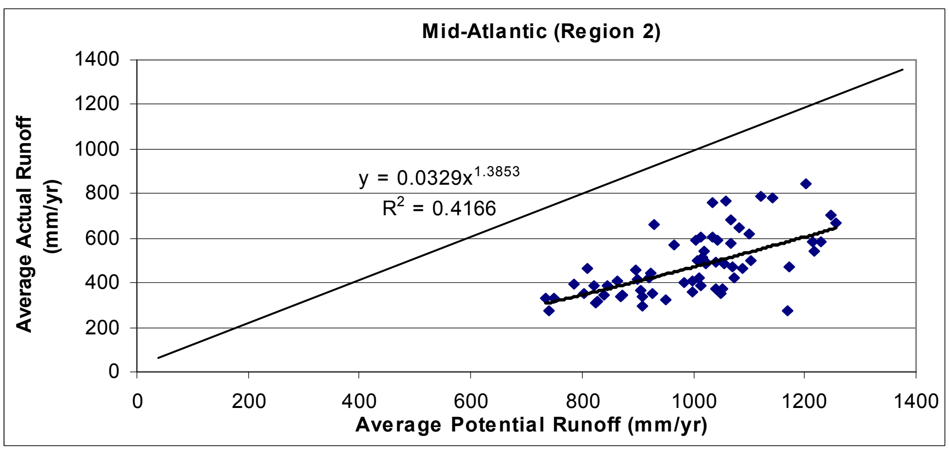

Figure A - 2

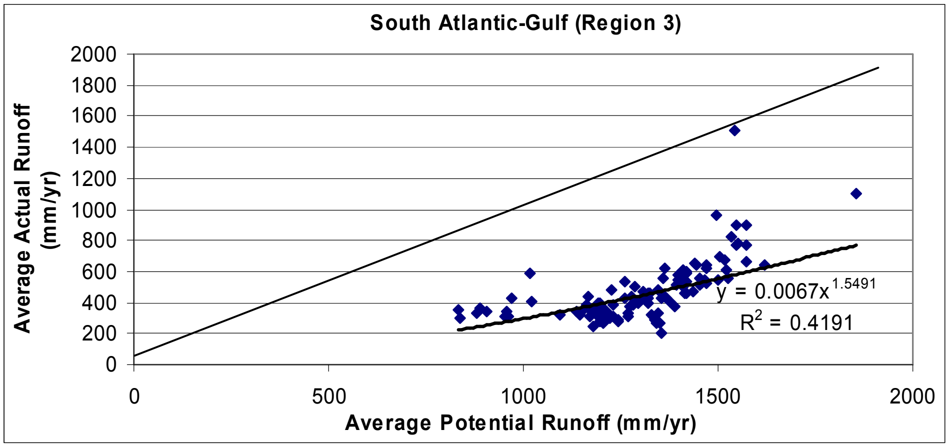

Figure A - 3

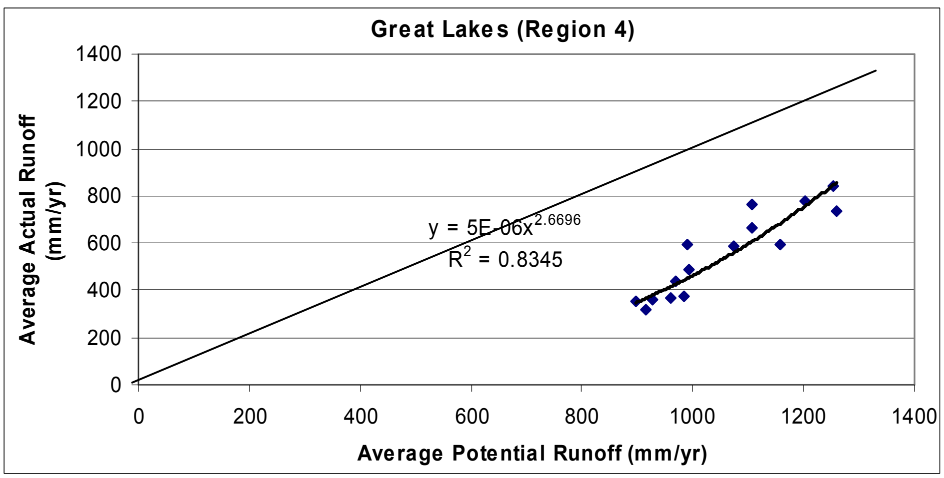

Figure A - 4

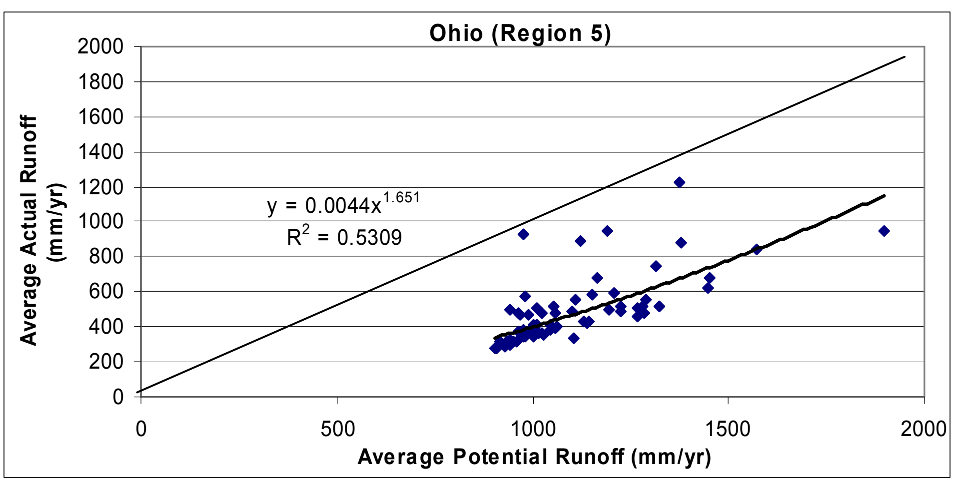

Figure A - 5

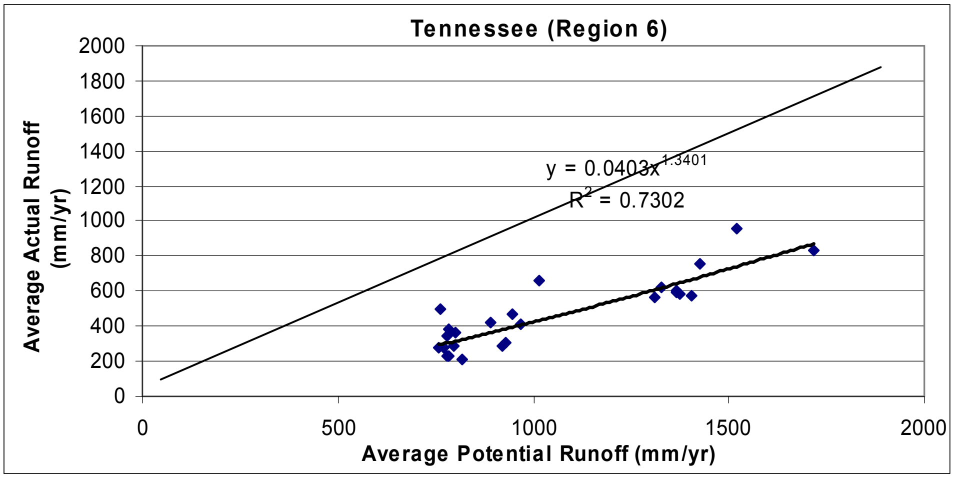

Figure A - 6

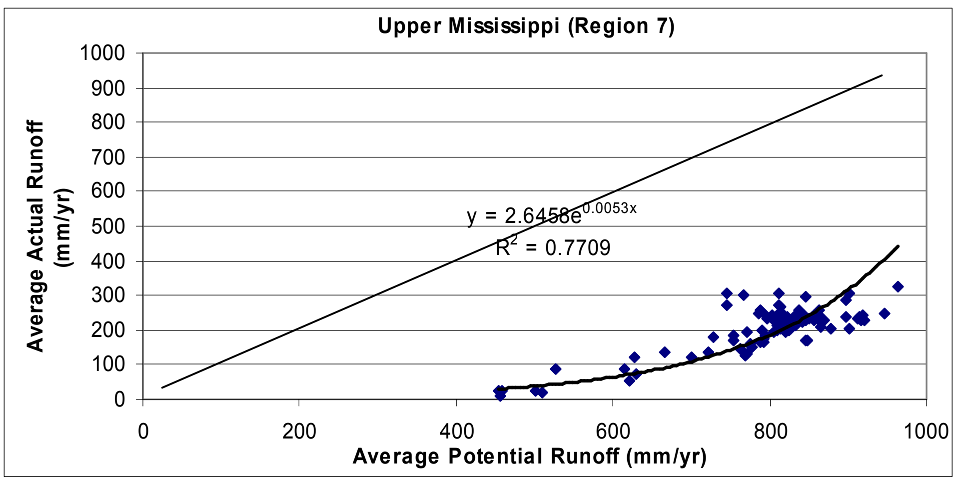

Figure A - 7

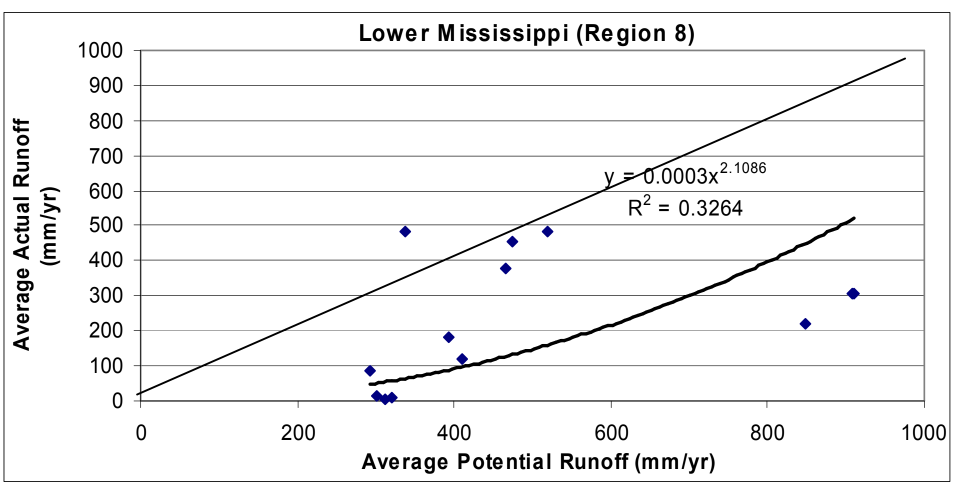

Figure A - 8

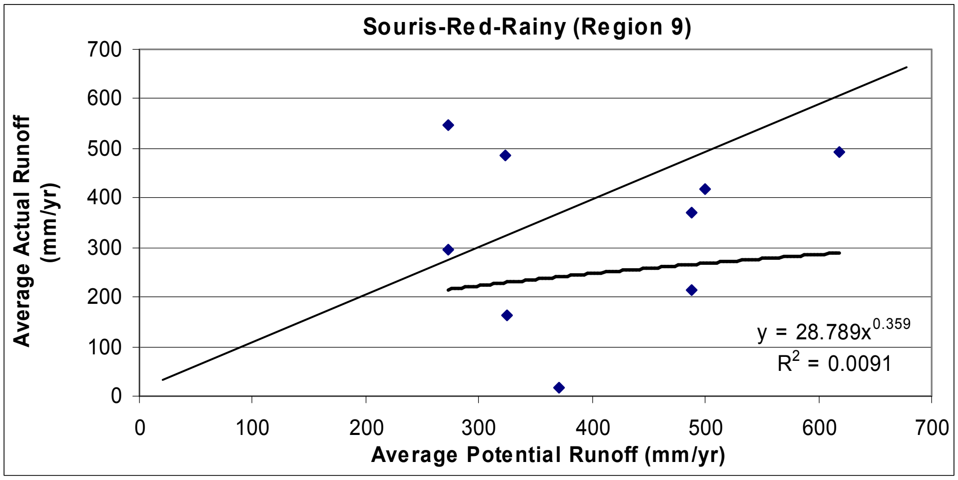

Figure A - 9

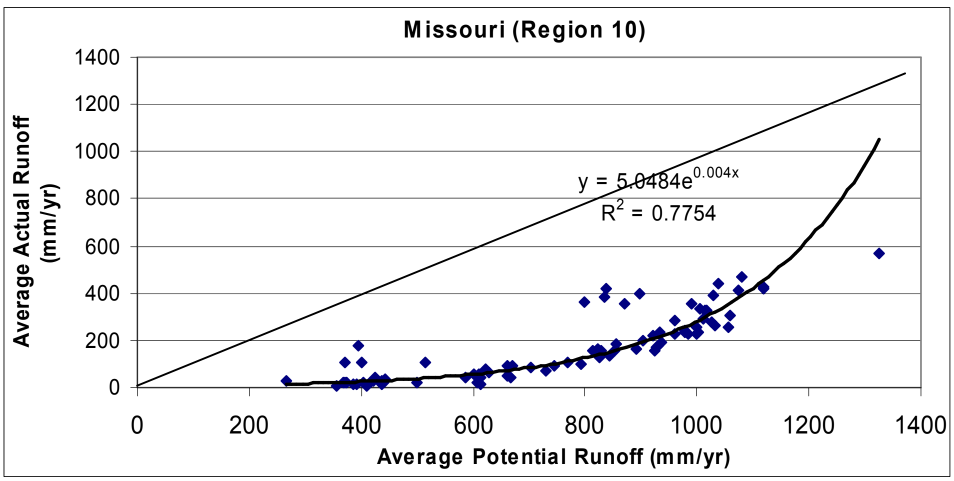

Figure A - 10

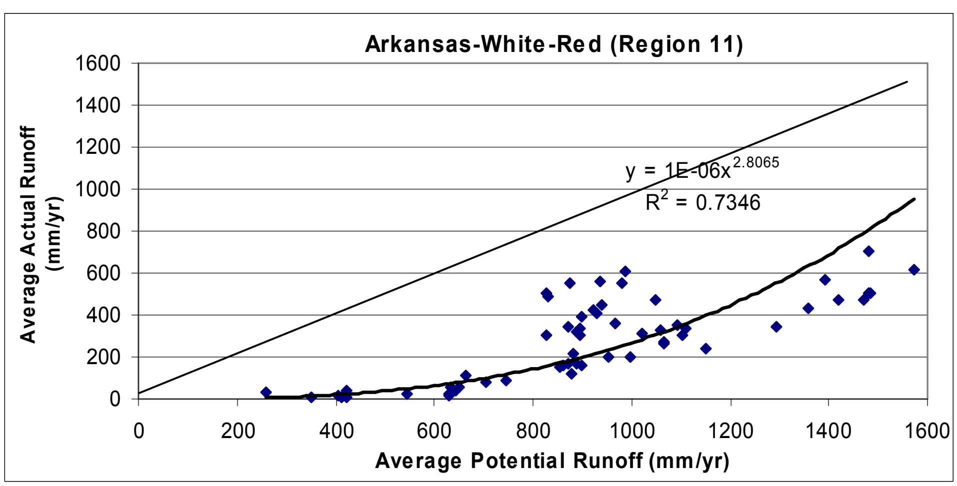

Figure A - 11

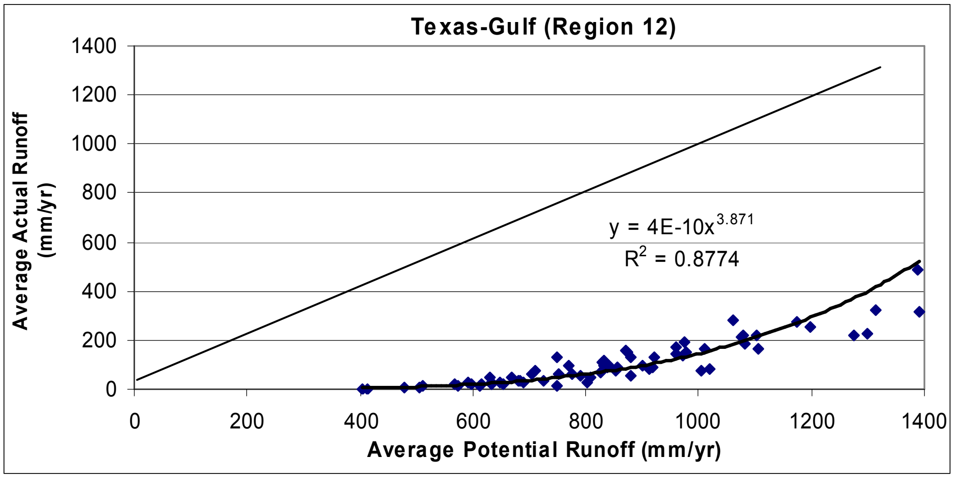

Figure A - 12

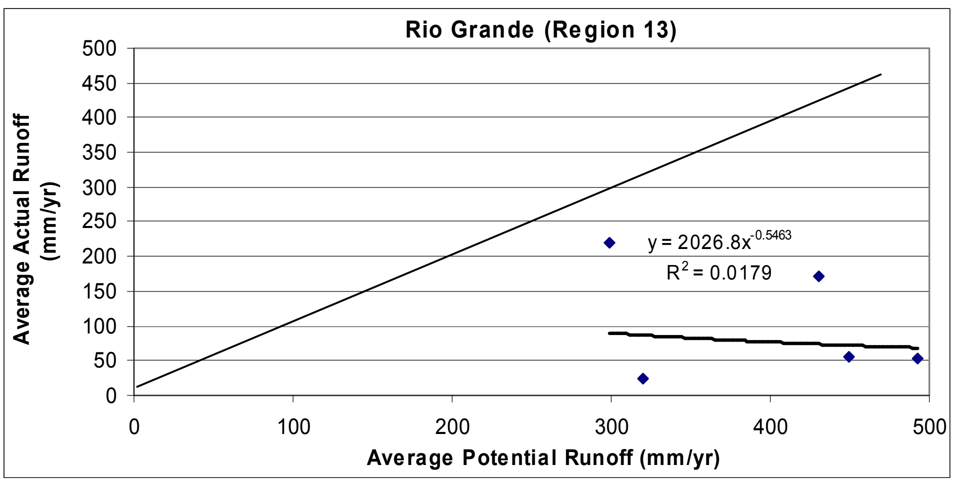

Figure A - 13

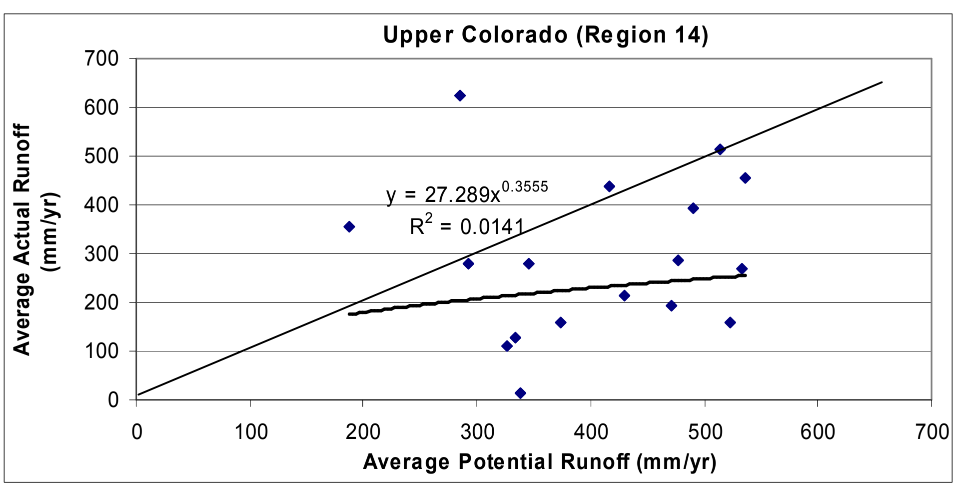

Figure A - 14

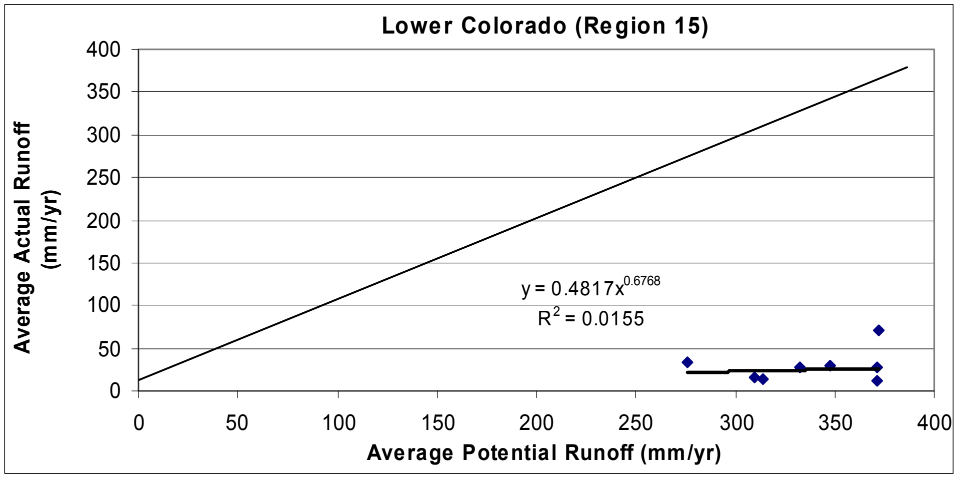

Figure A - 15

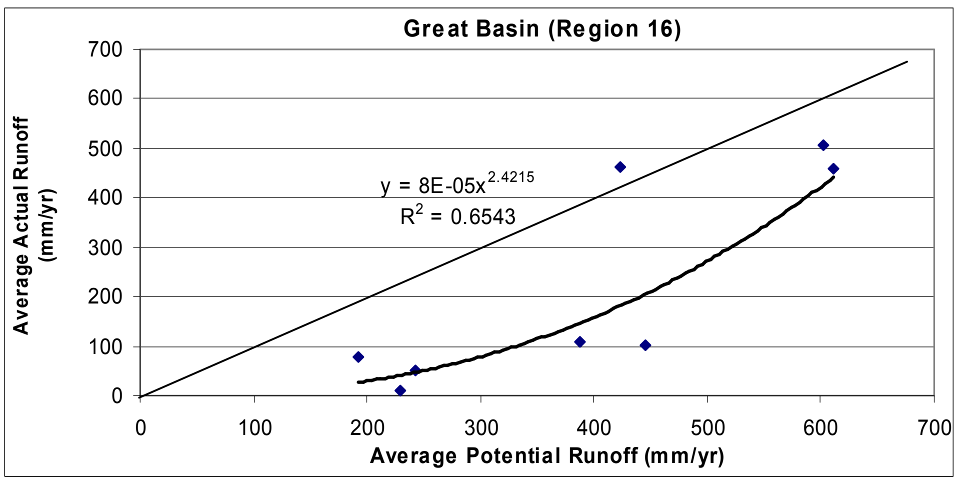

Figure A - 16

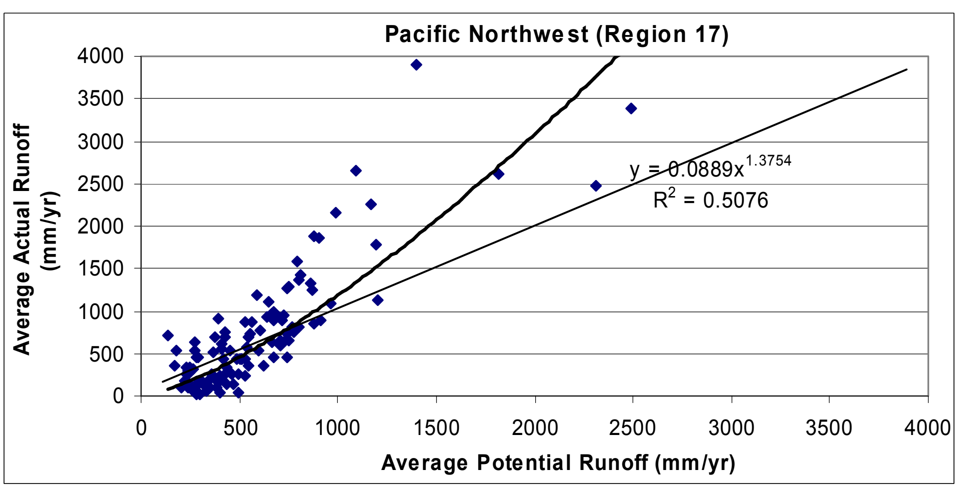

Figure A - 17

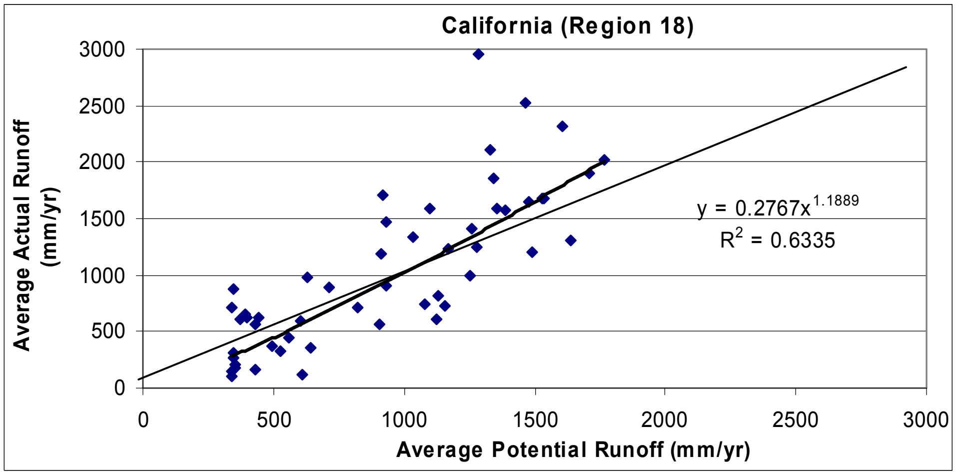

Figure A - 18

A2. Flow versus Precipitation Graphs based on Drainage area

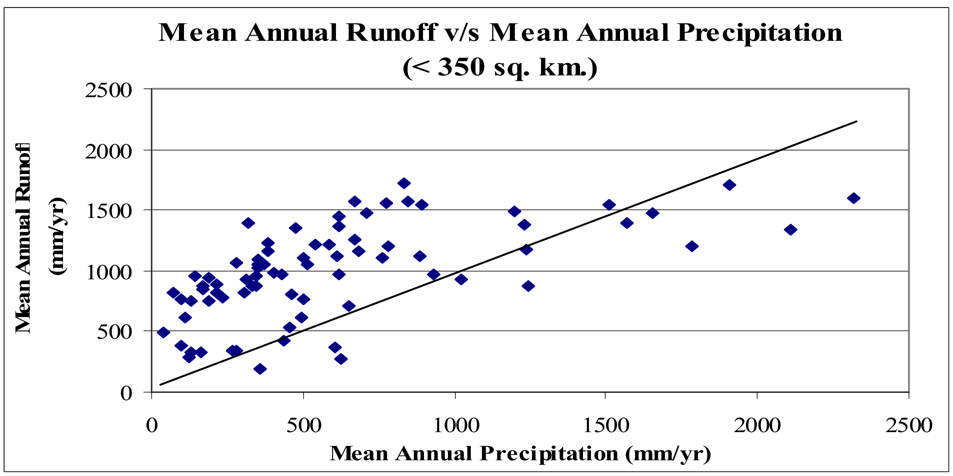

Figure A - 19

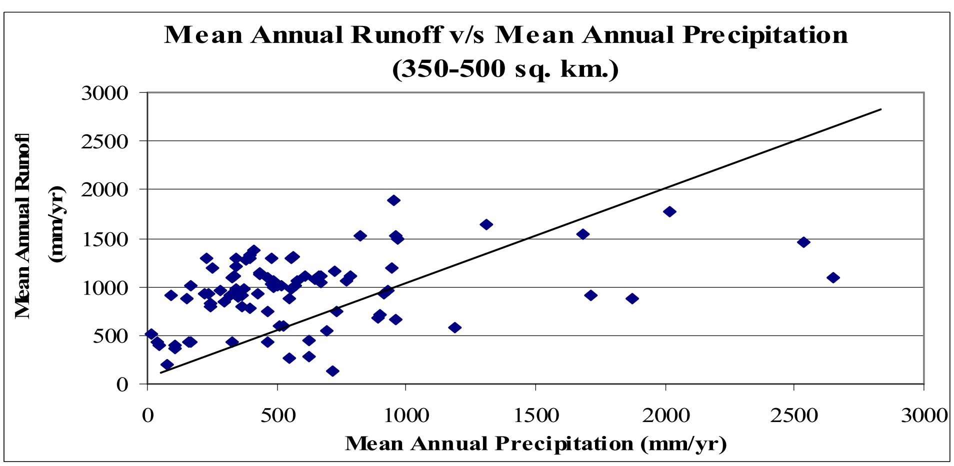

Figure A - 20

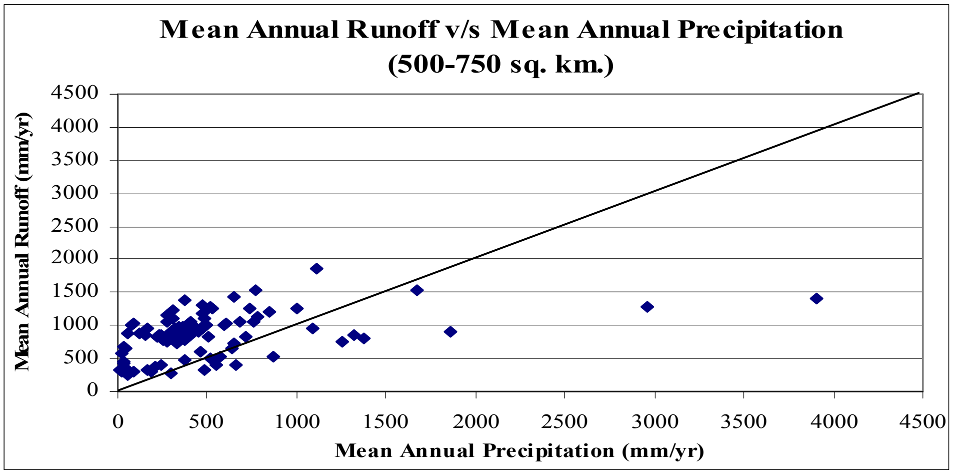

Figure A - 21

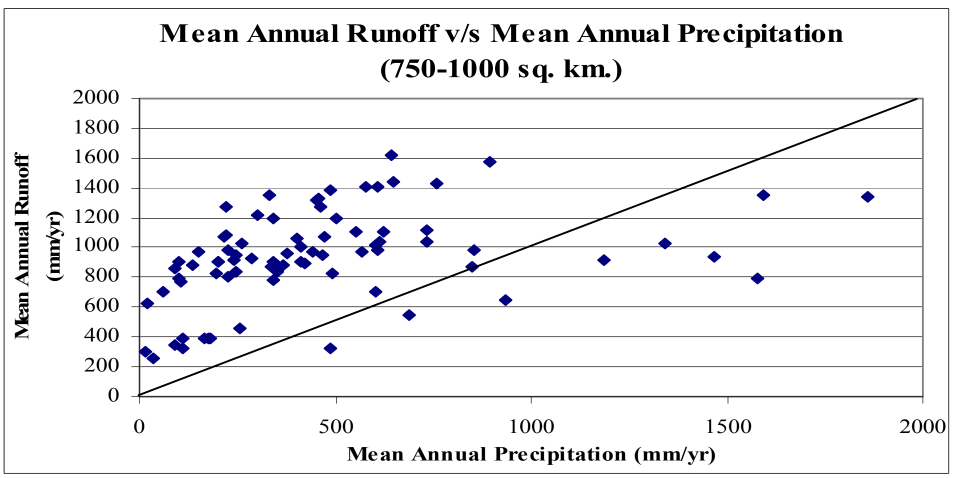

Figure A - 22

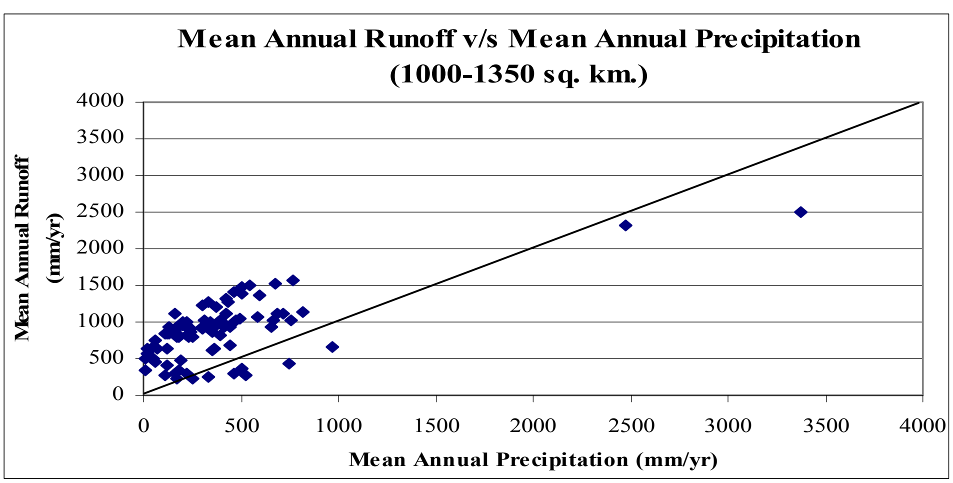

Figure A - 23

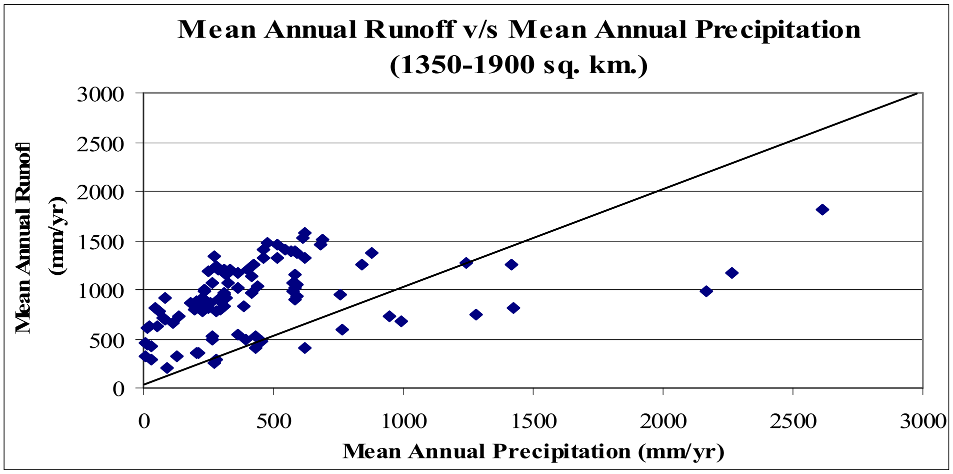

Figure A - 24

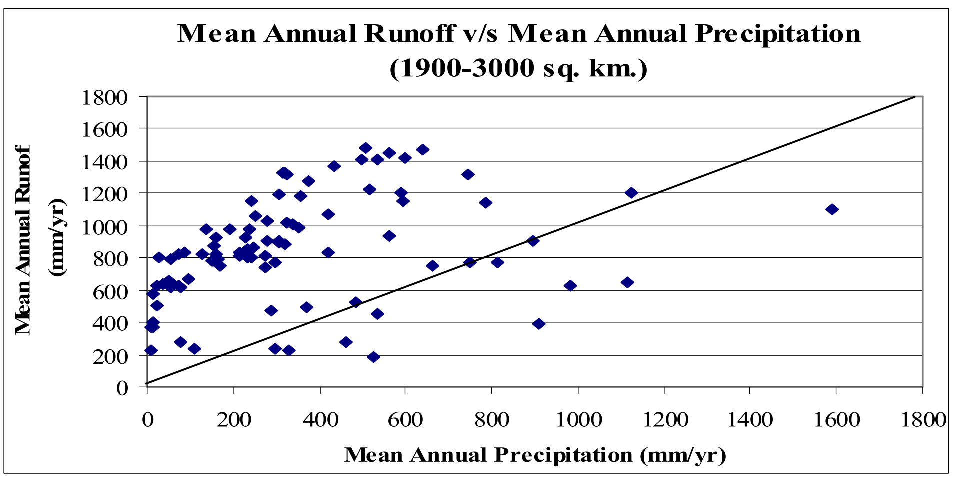

Figure A - 25

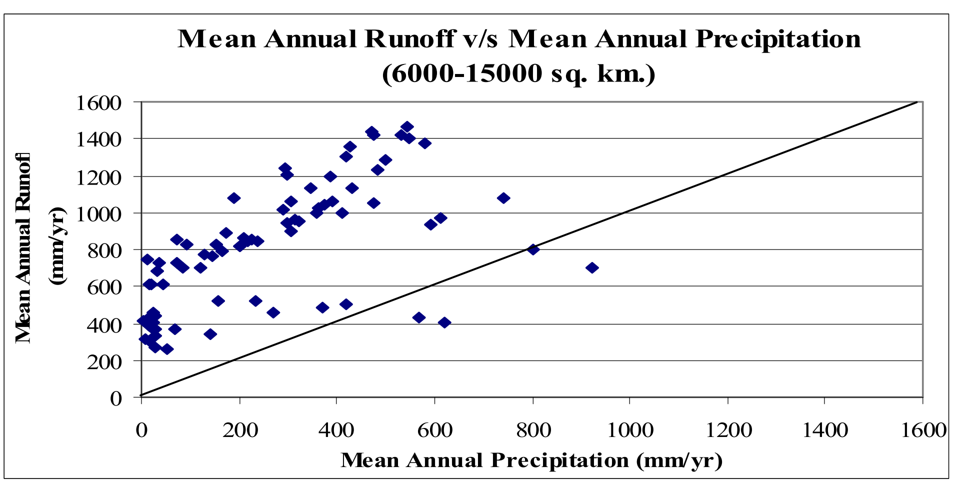

Figure A - 26

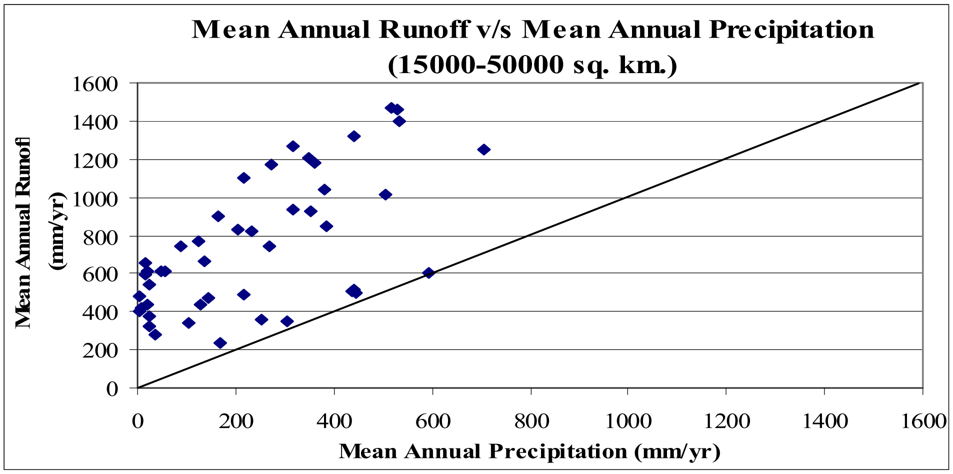

Figure A - 27

A3. Ratio of Flow to Precipitation versus Slope and Curve Number

1. Ratio of Flow to Precipitation versus Slope

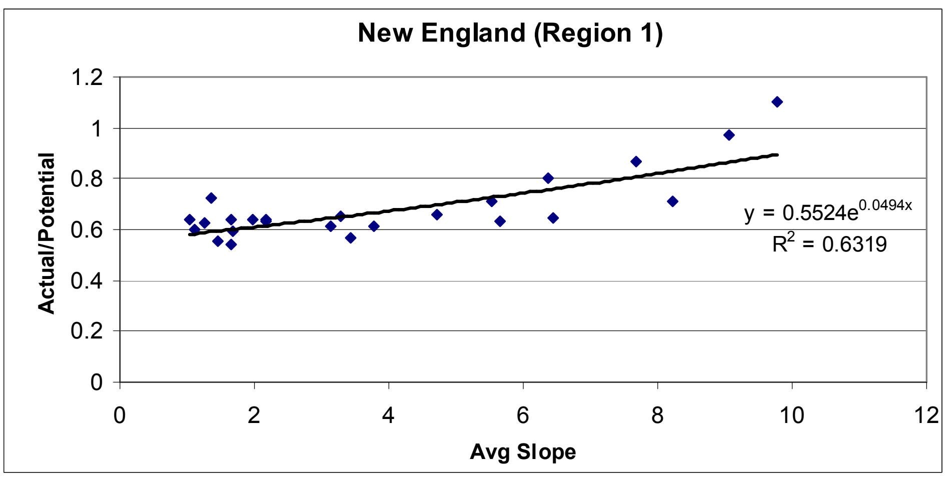

Figure A - 28

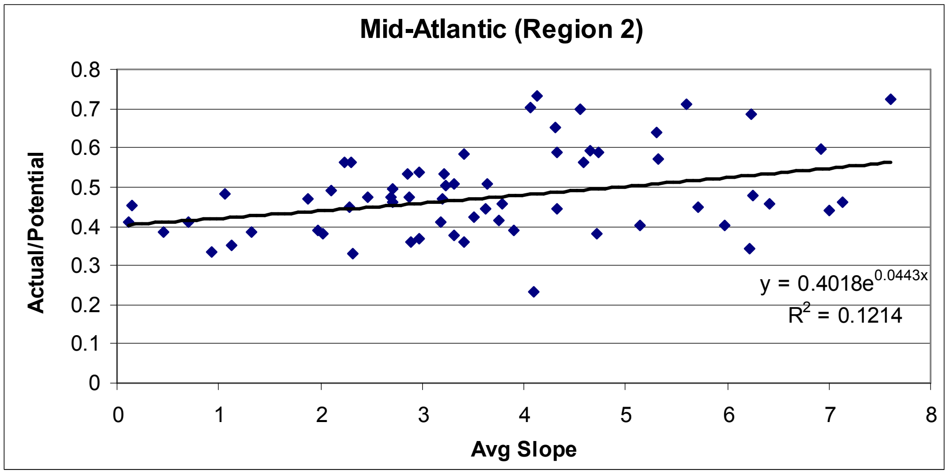

Figure A - 29

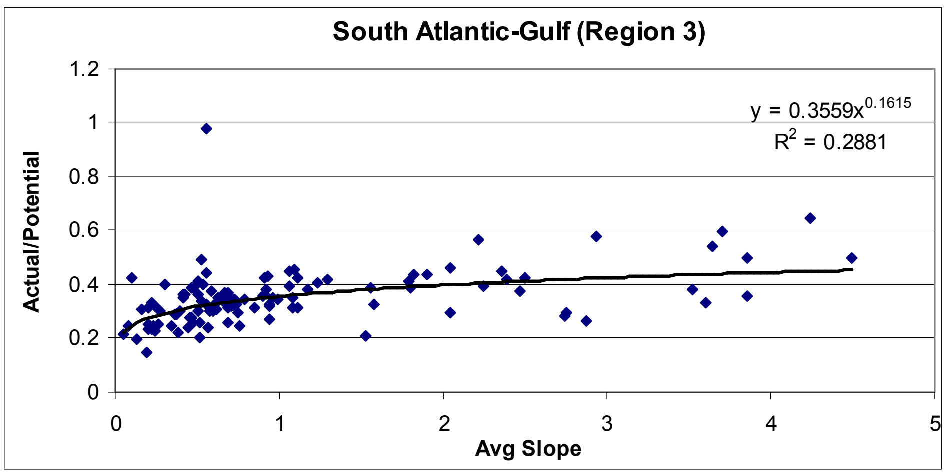

Figure A - 30

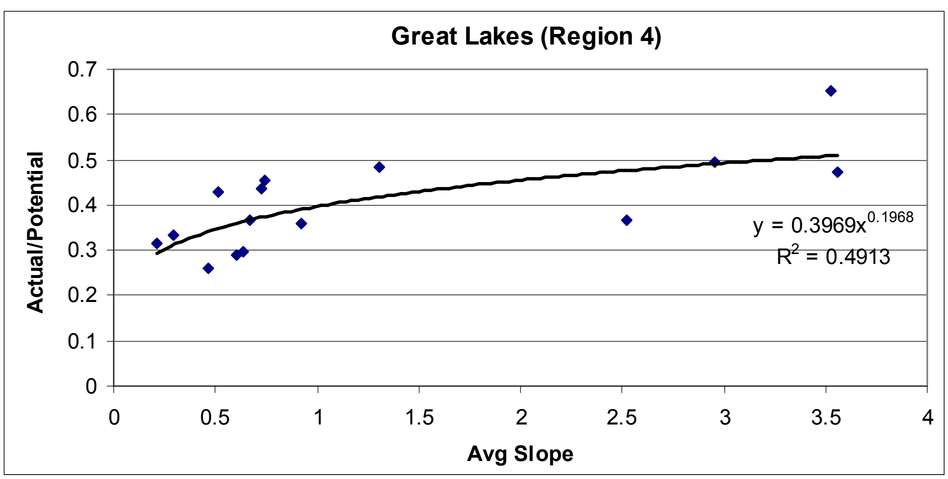

Figure A - 31

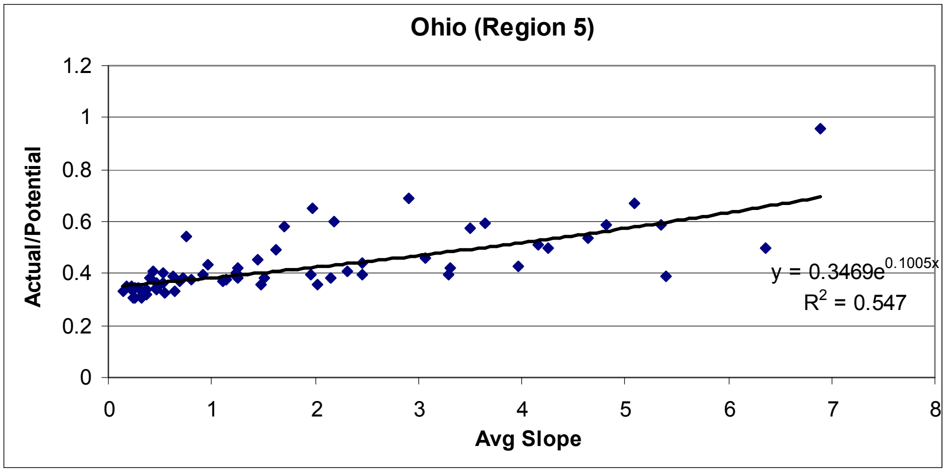

Figure A - 32

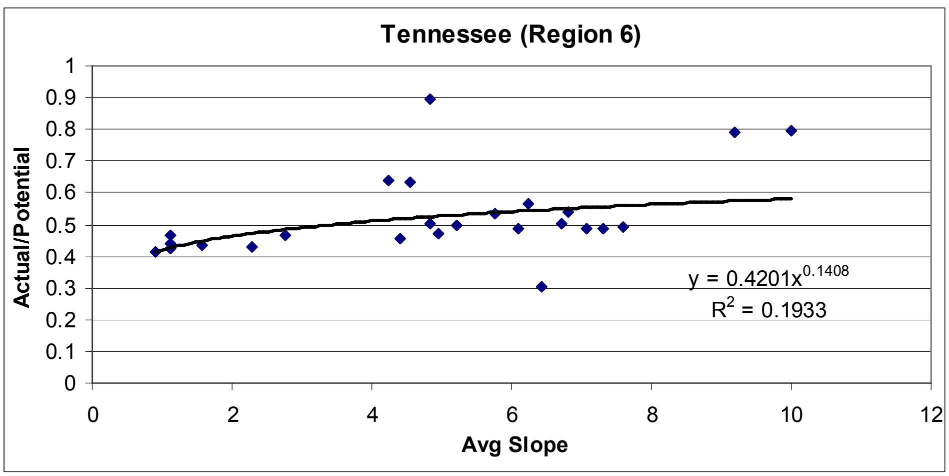

Figure A - 33

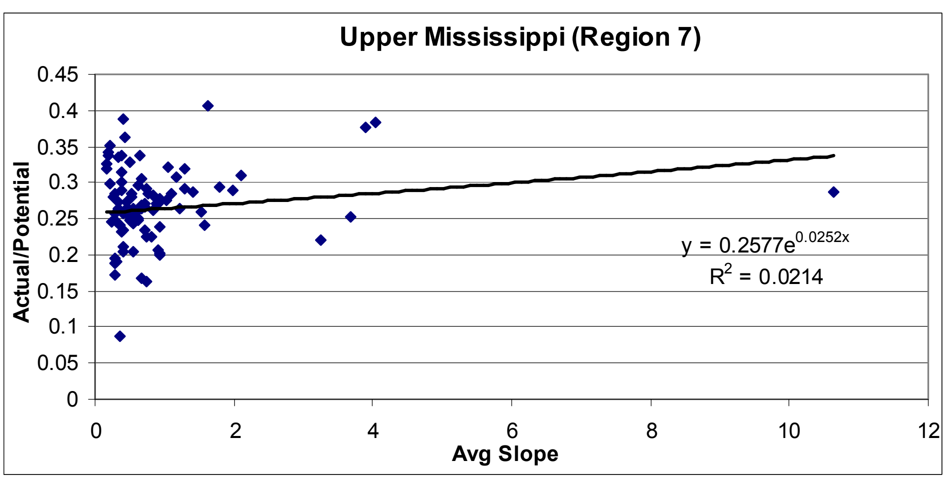

Figure A - 34

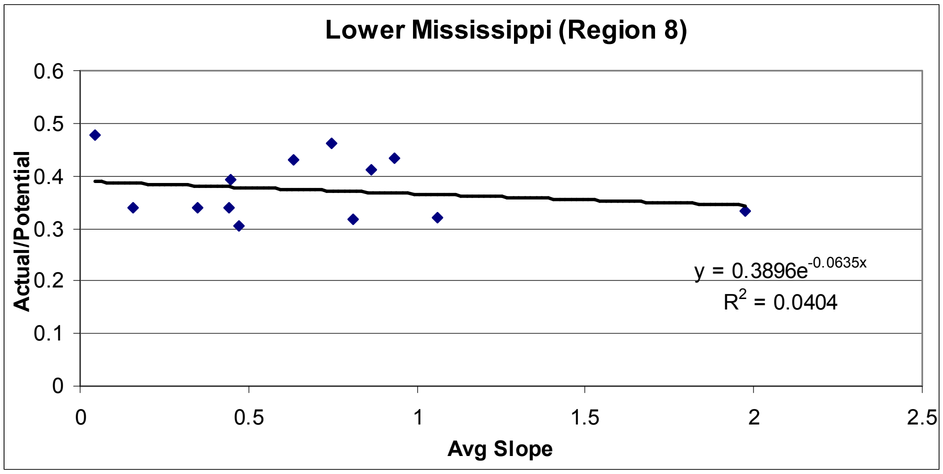

Figure A - 35

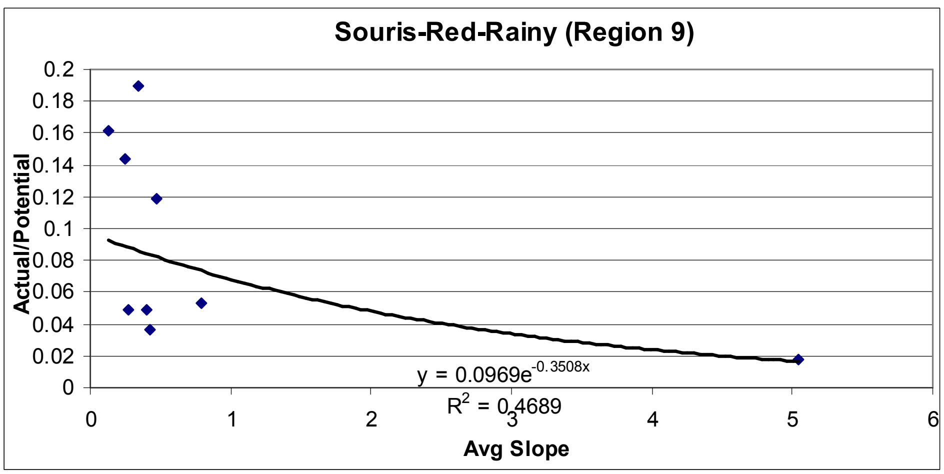

Figure A - 36

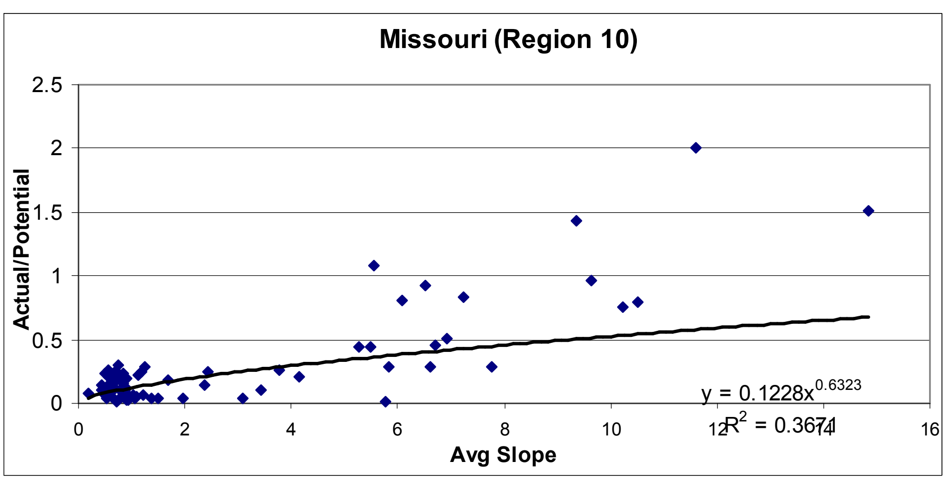

Figure A - 37

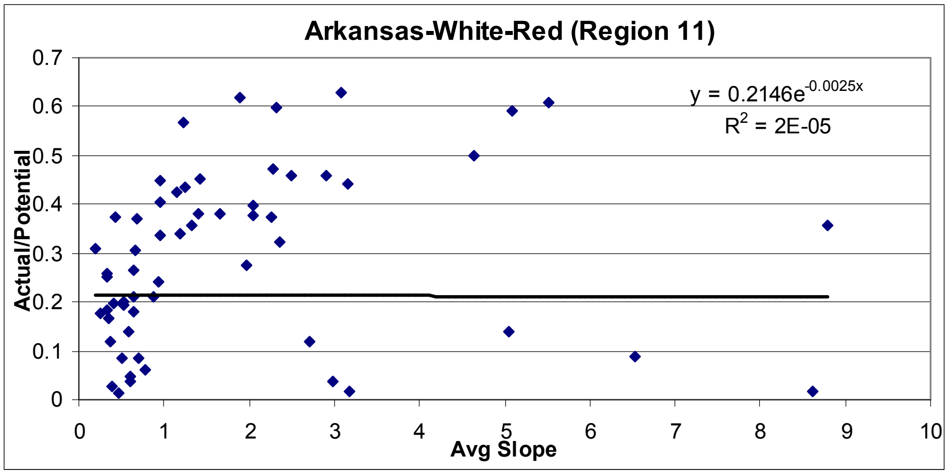

Figure A - 38

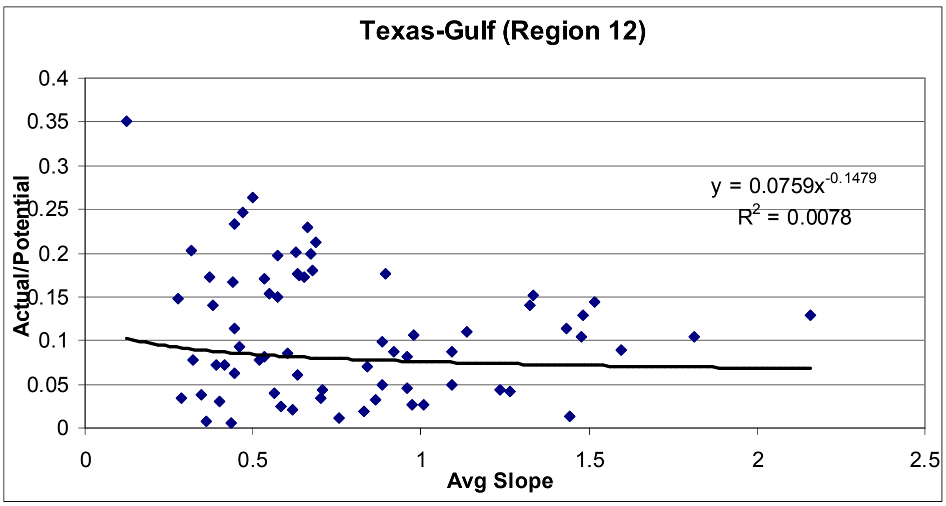

Figure A - 39

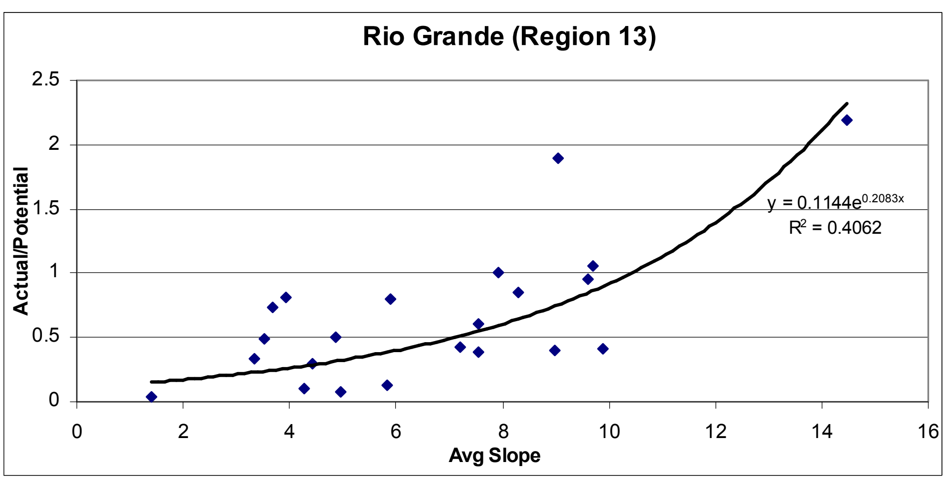

Figure A - 40

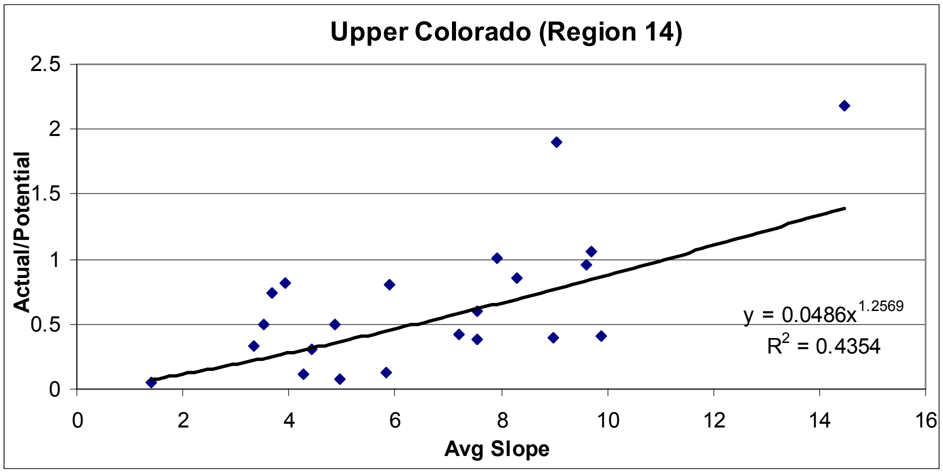

Figure A - 41

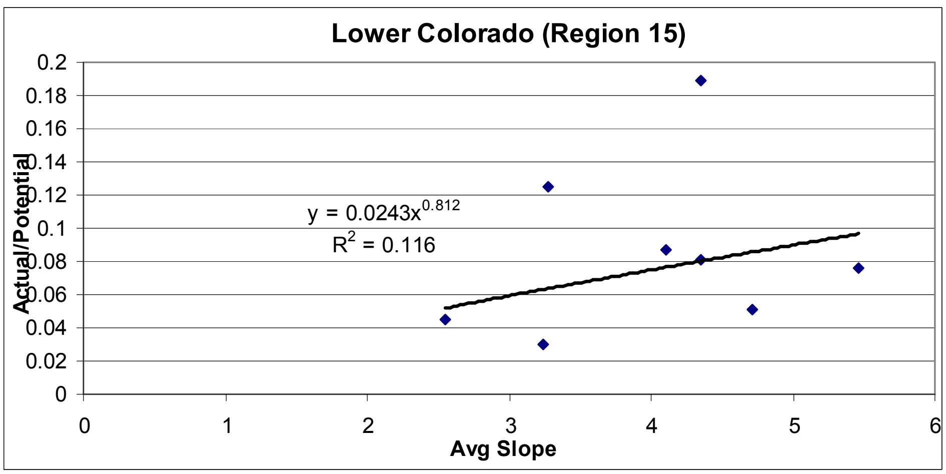

Figure A - 42

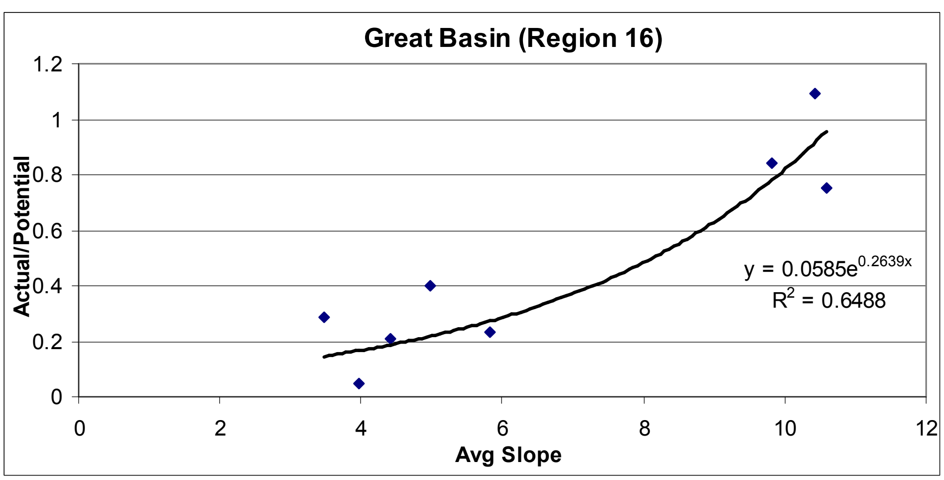

Figure A - 43

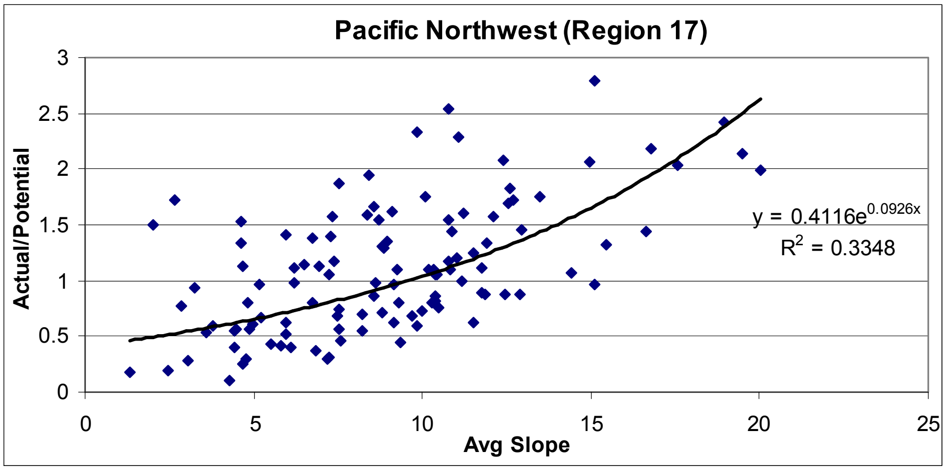

Figure A - 44

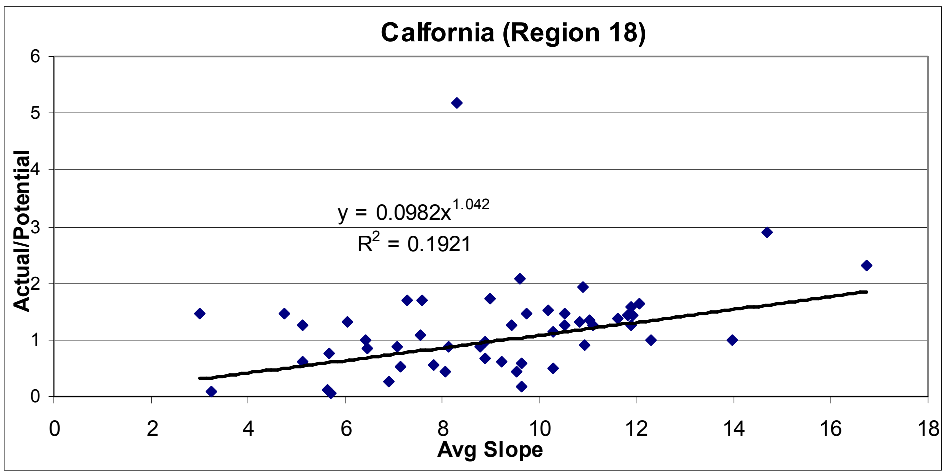

Figure A - 45

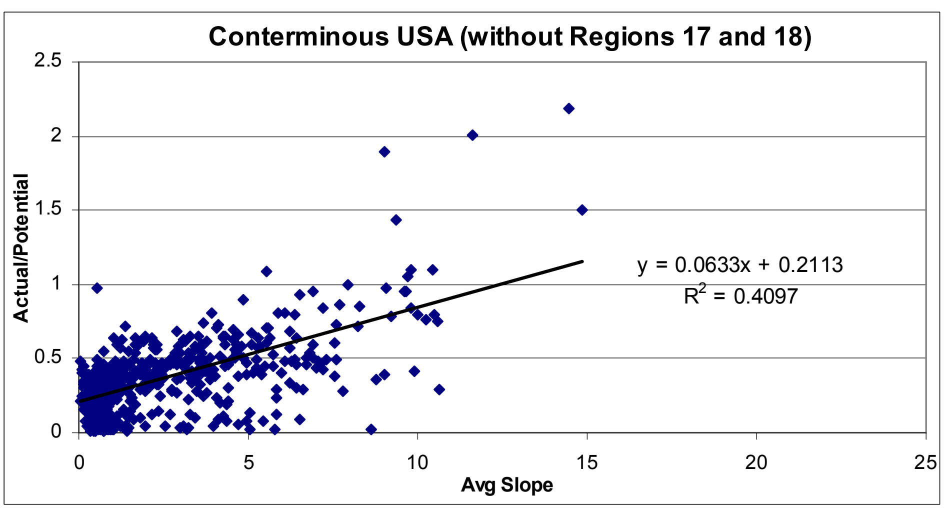

Figure A - 46

2. Ratio of Flow to Precipitation versus Curve Number

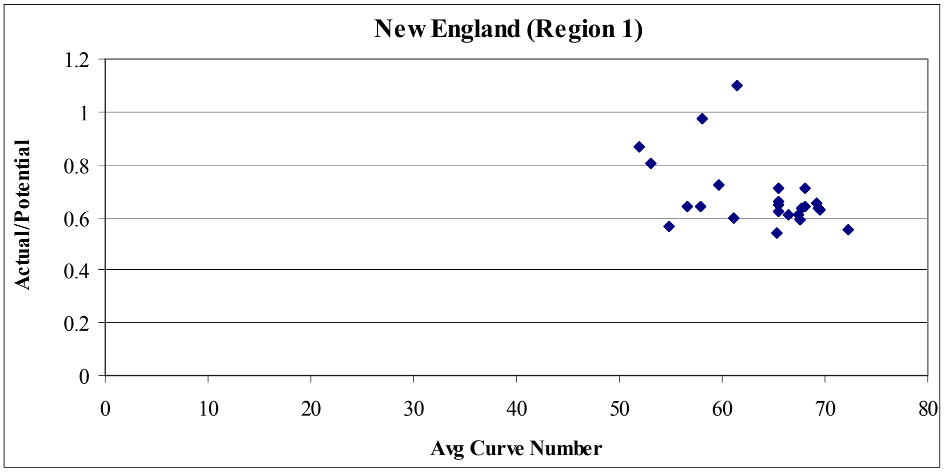

Figure A - 47

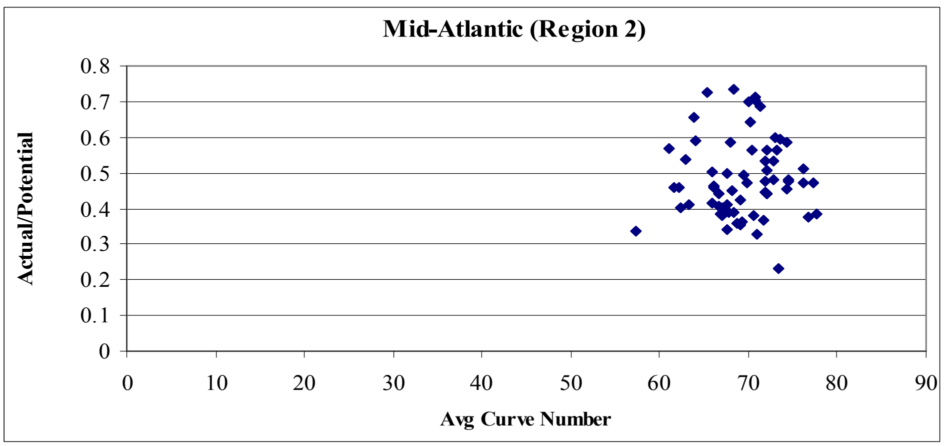

Figure A - 48

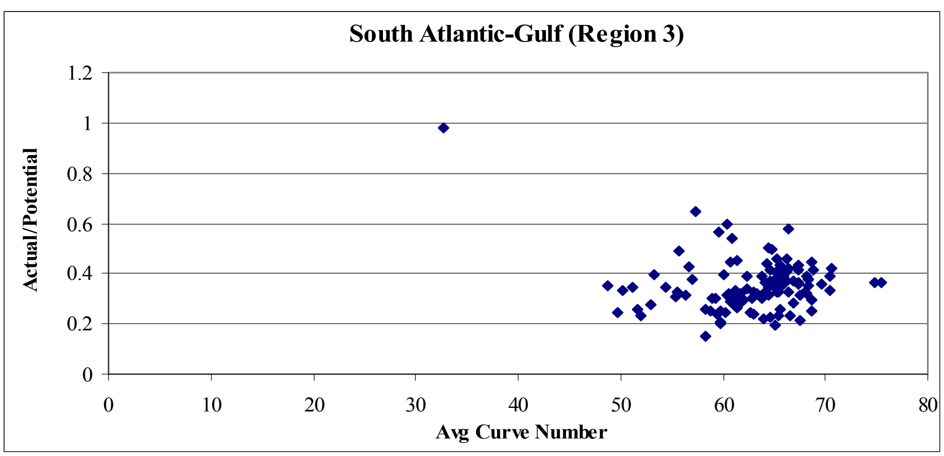

Figure A - 49

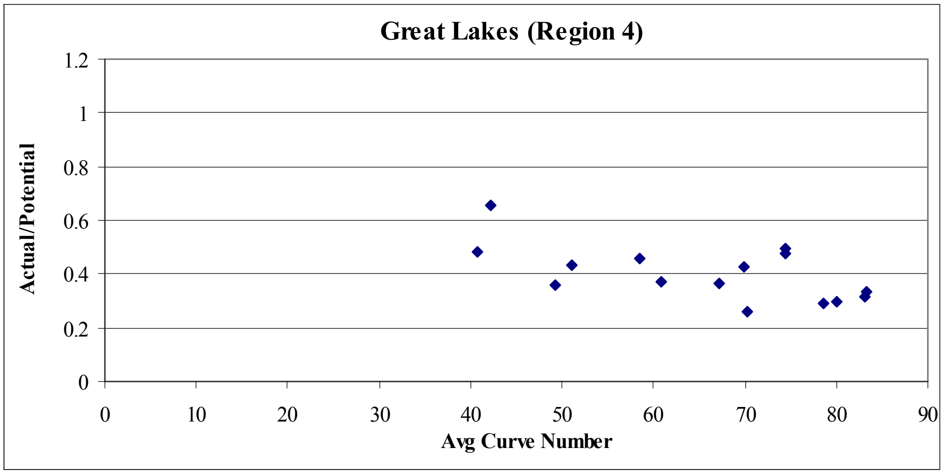

Figure A - 50

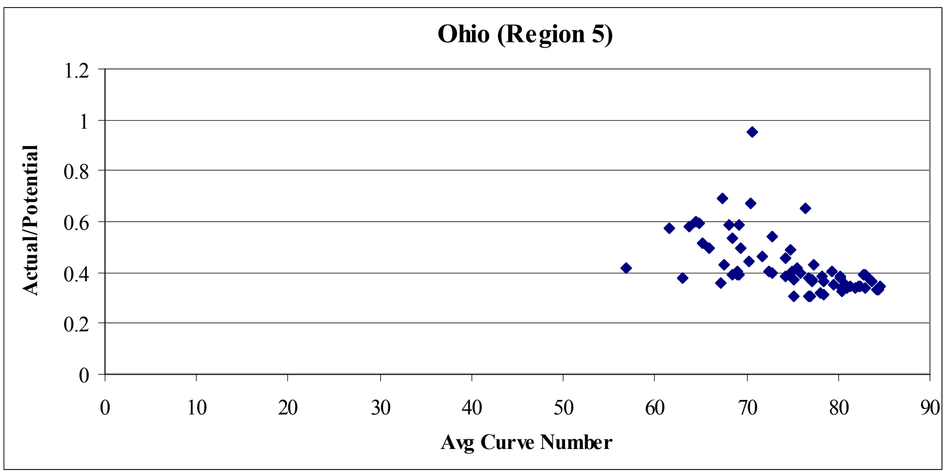

Figure A - 51

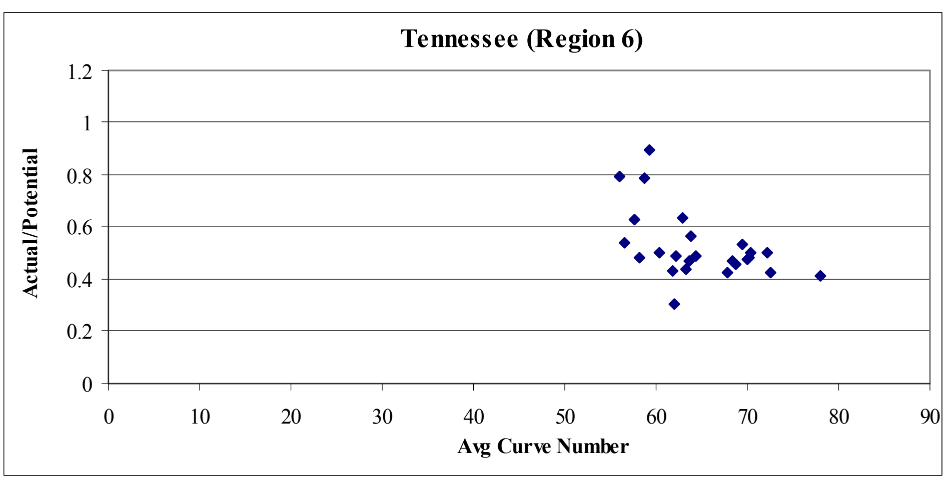

Figure A - 52

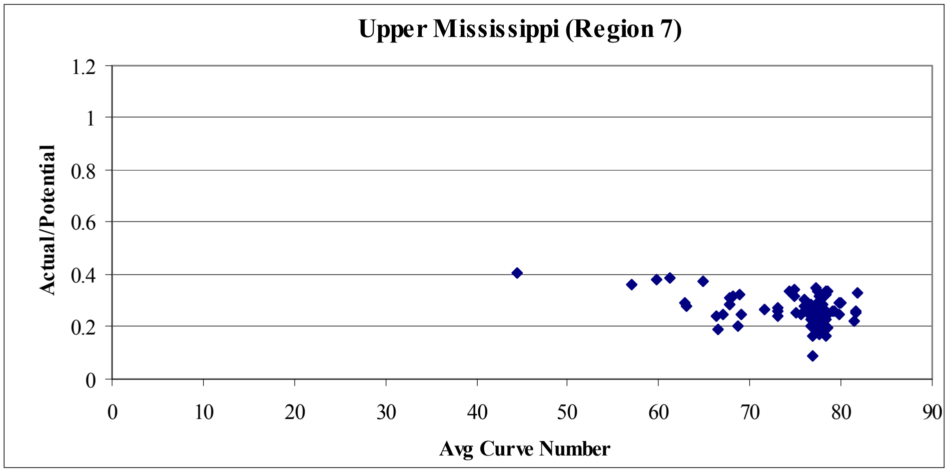

Figure A - 53

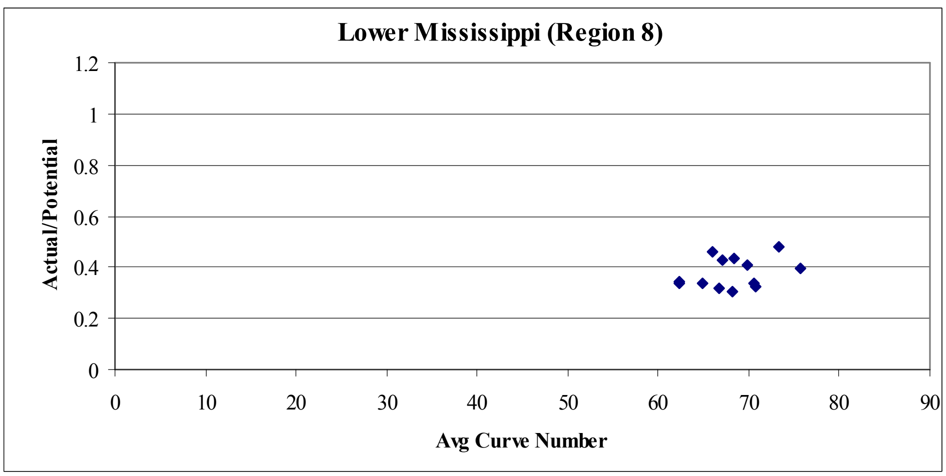

Figure A - 54

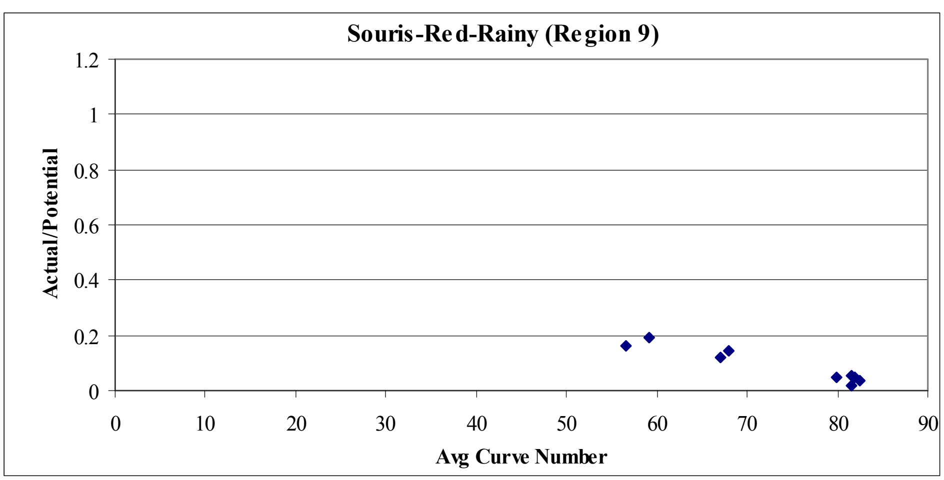

Figure A - 55

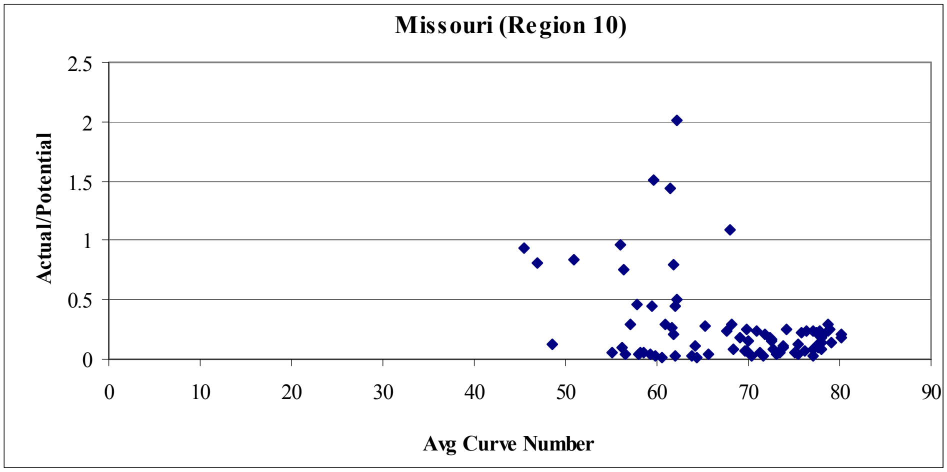

Figure A - 56

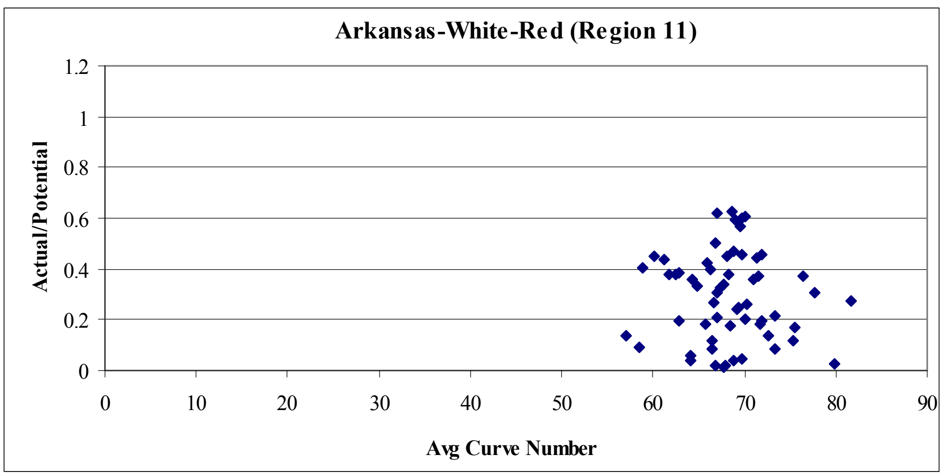

Figure A - 57

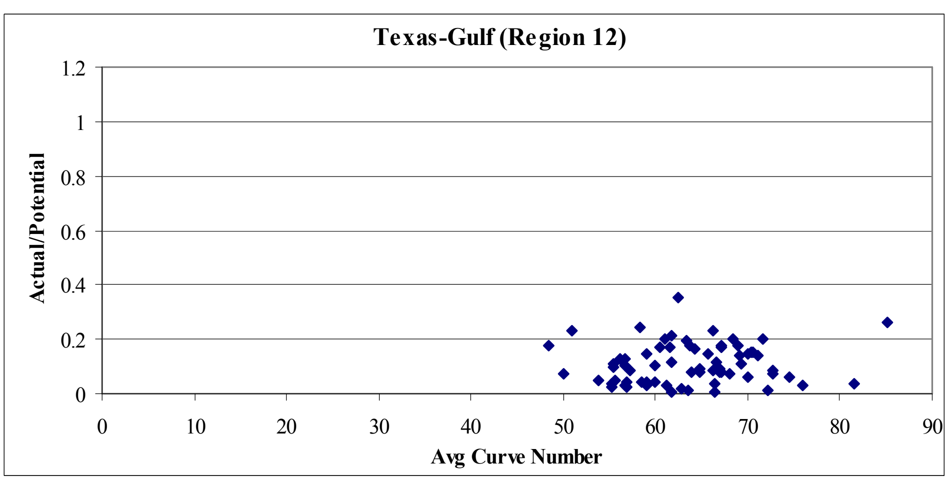

Figure A - 58

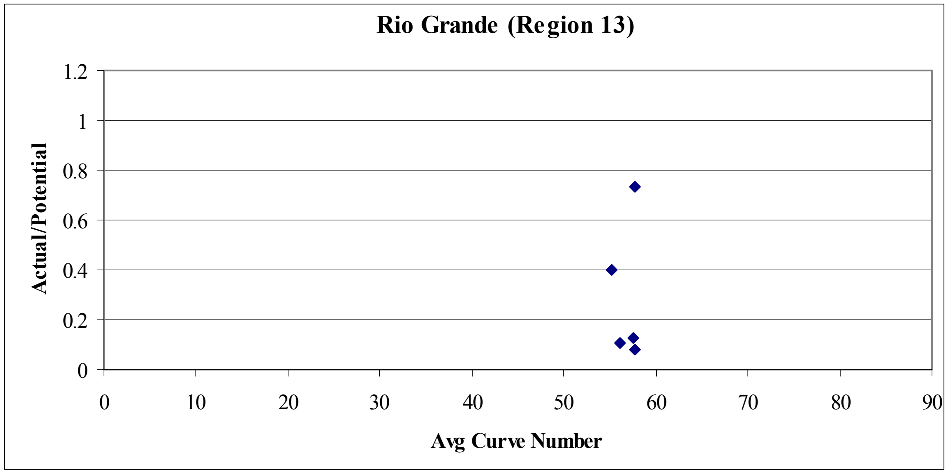

Figure A - 59

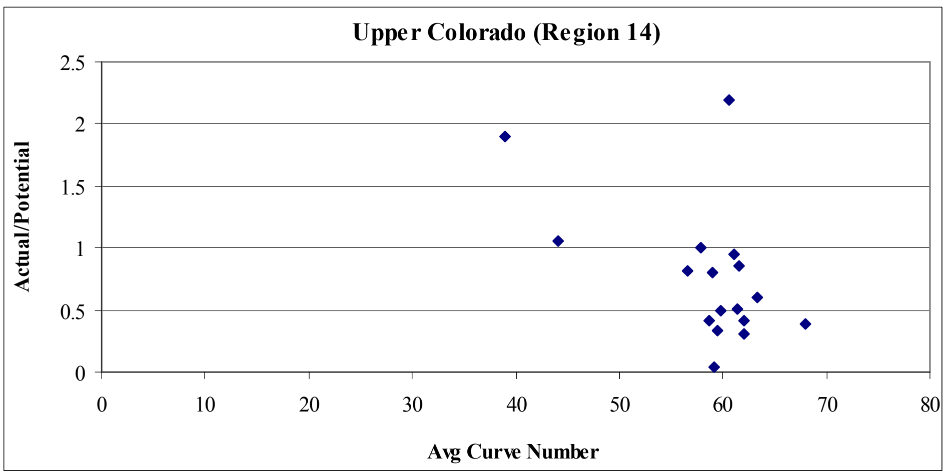

Figure A - 60

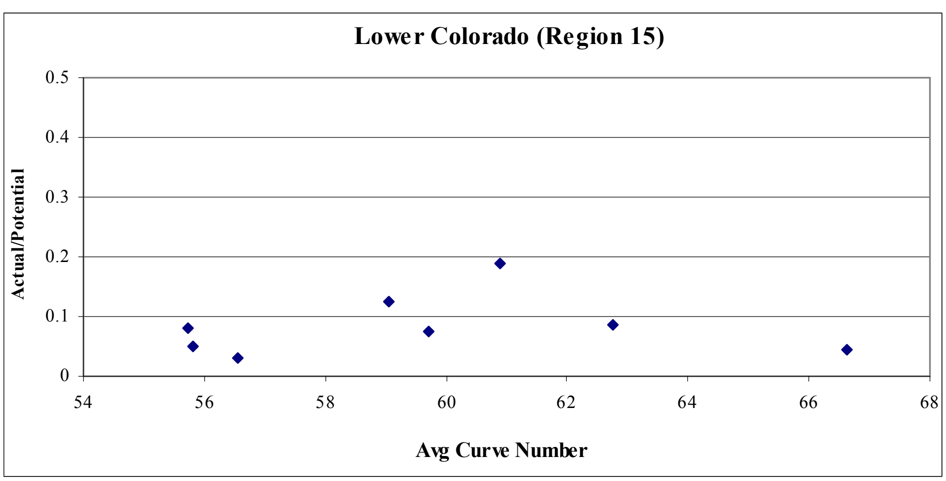

Figure A - 61

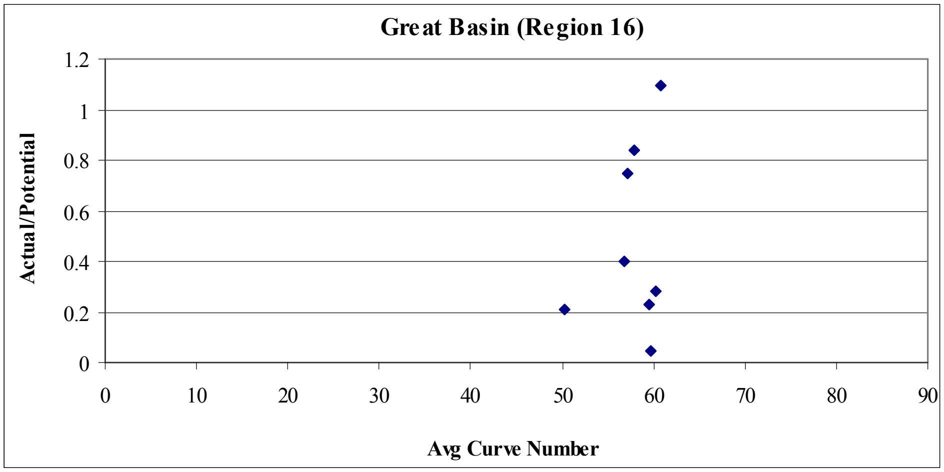

Figure A - 62

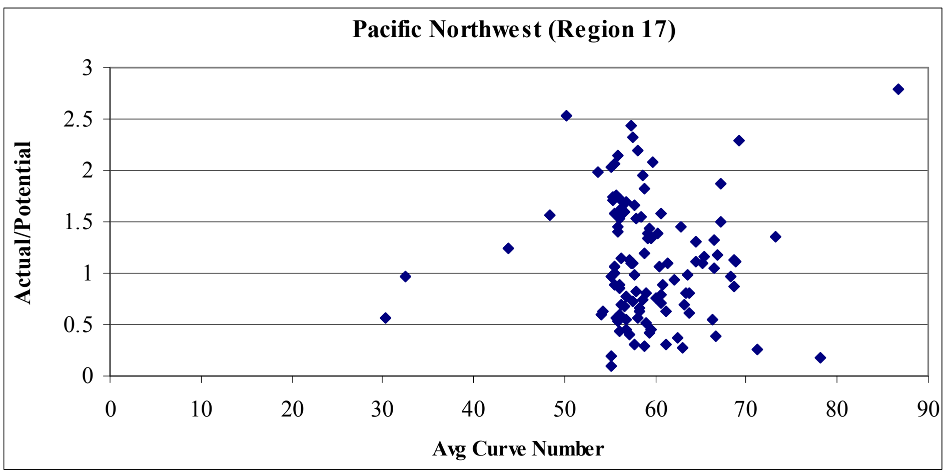

Figure A - 63

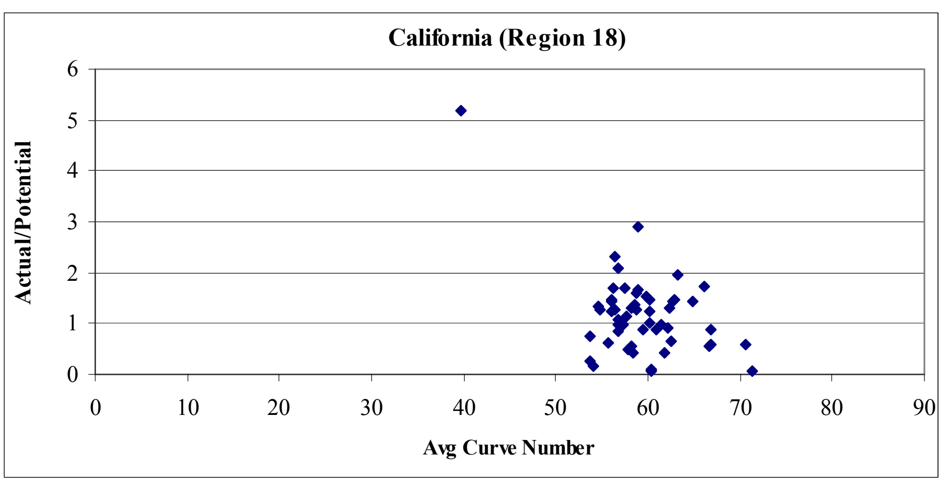

Figure A - 64

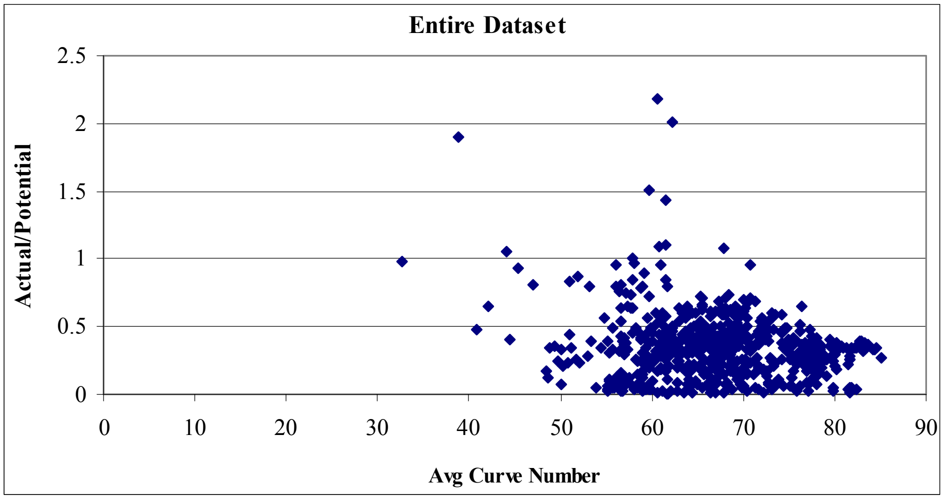
Entire Dataset
2.5
2
1.5
1
0.5
0
Actual/Potential
0
10
20
30
40
50
60
70
80
90
Avg Curve Number

Figure A - 65

APPENDIX B

Graphs of analysis for mean flow for Region 12 (Texas-Gulf)

A. Graphs of predicted flow with linear method

A1. Based on linear regression coefficients

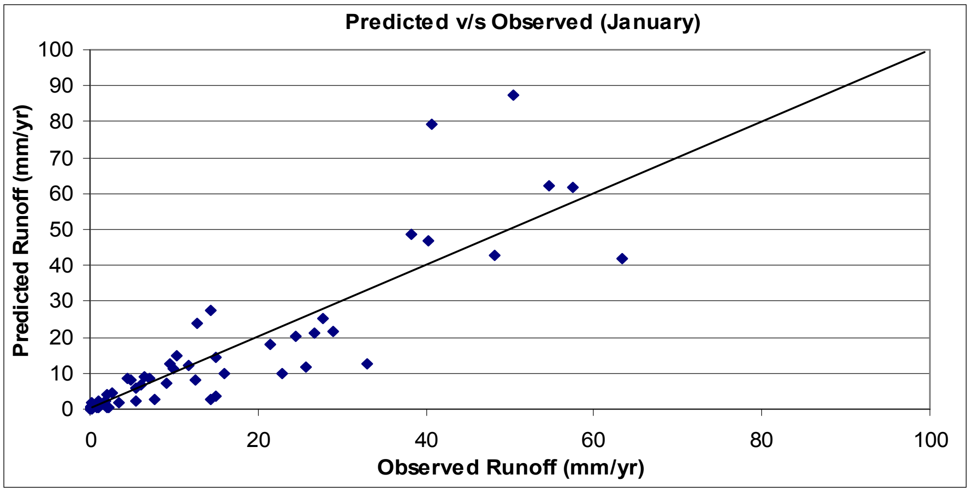

Figure B - 1

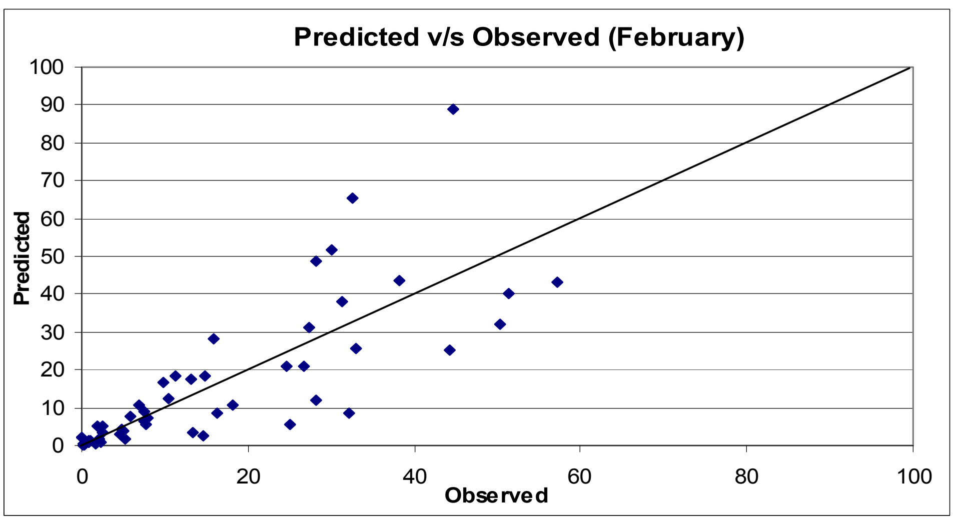

Figure B - 2

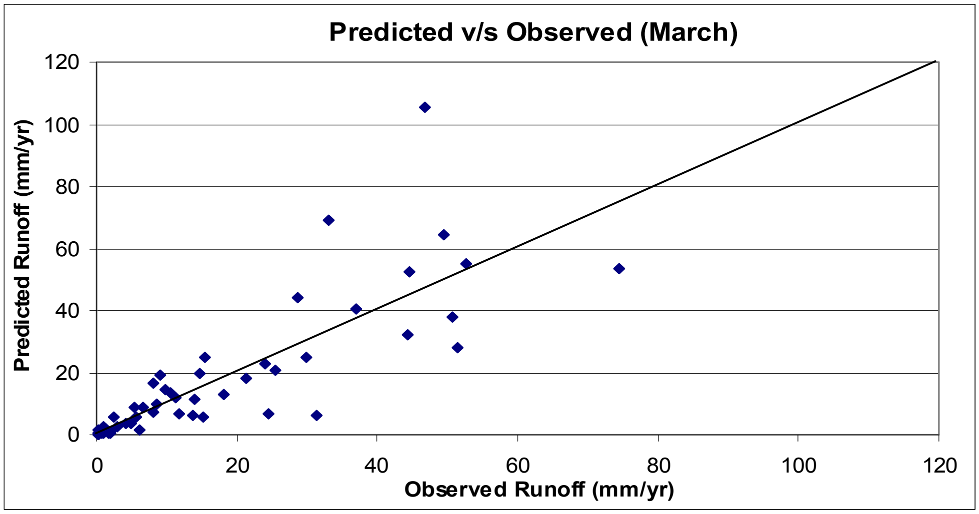

Figure B - 3

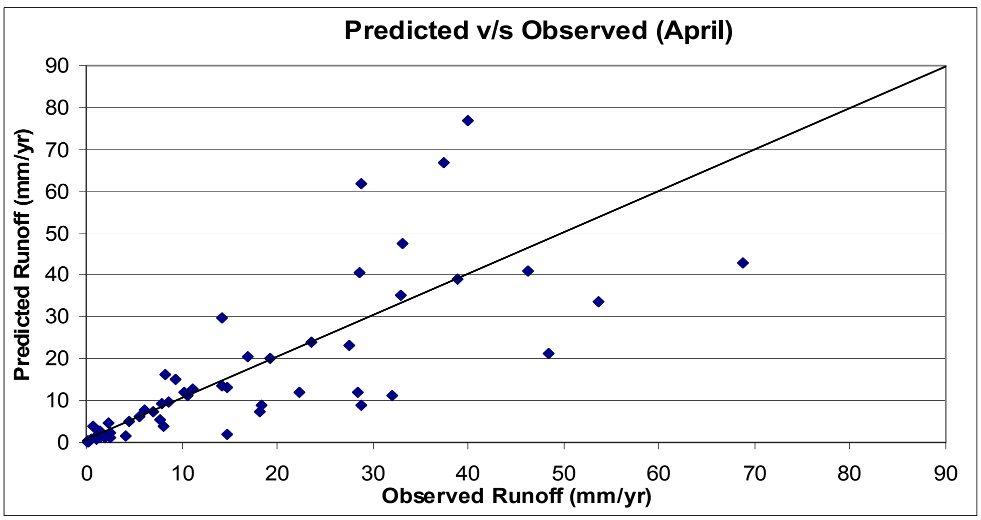

Figure B - 4

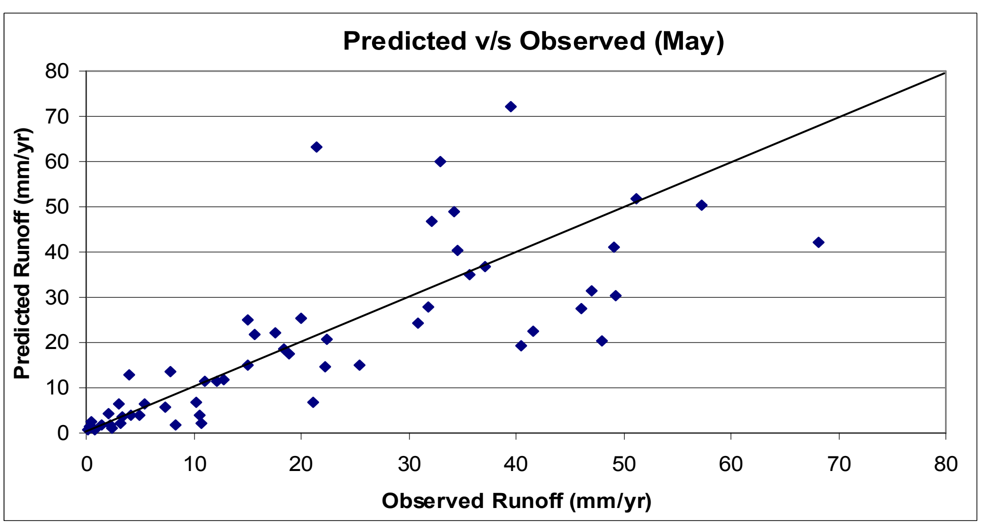

Figure B - 5

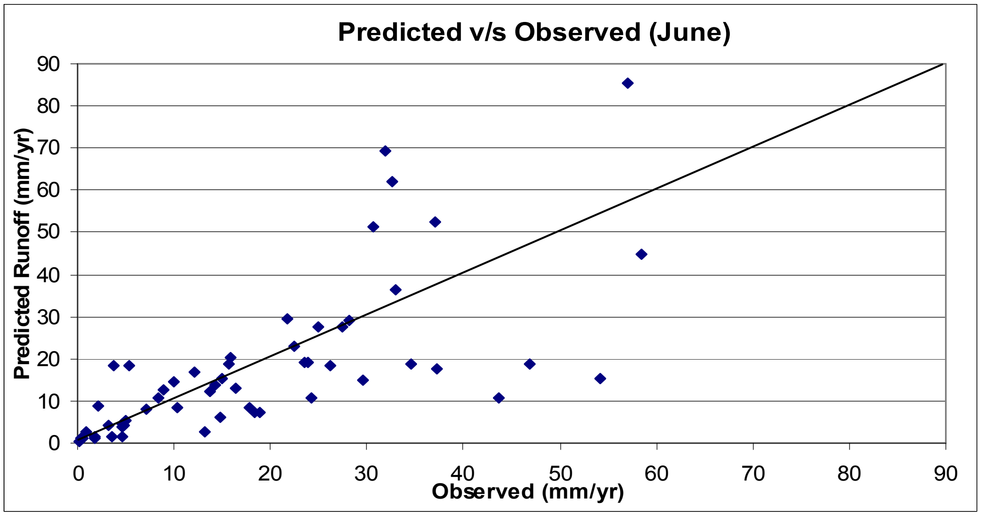

Figure B - 6

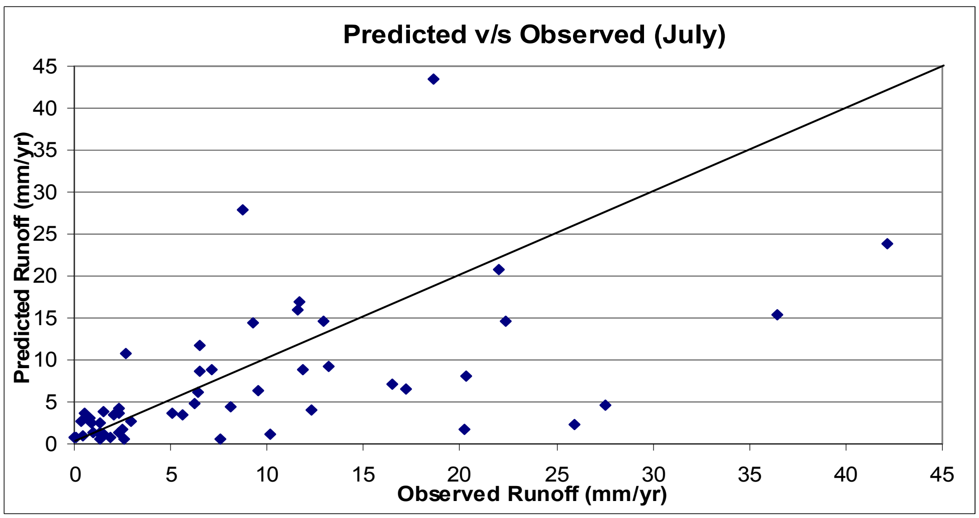

Figure B - 7

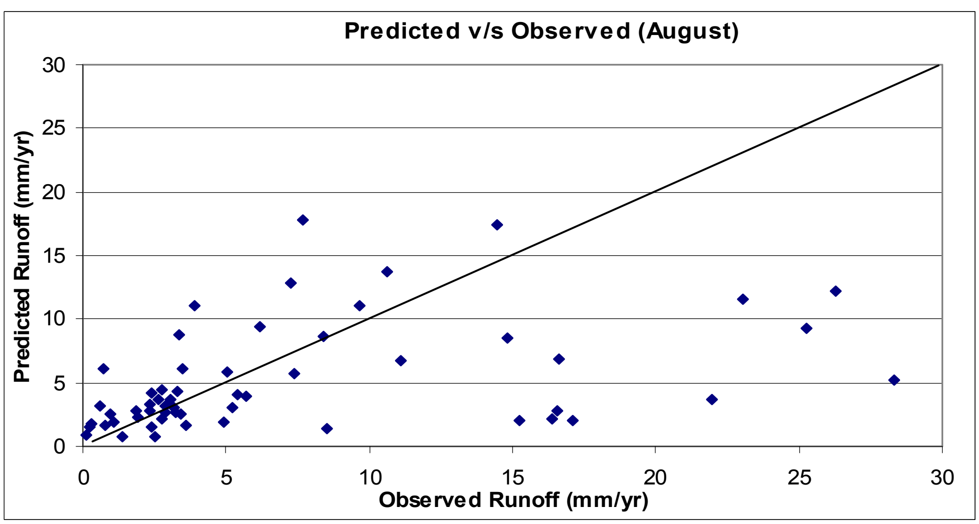

Figure B - 8

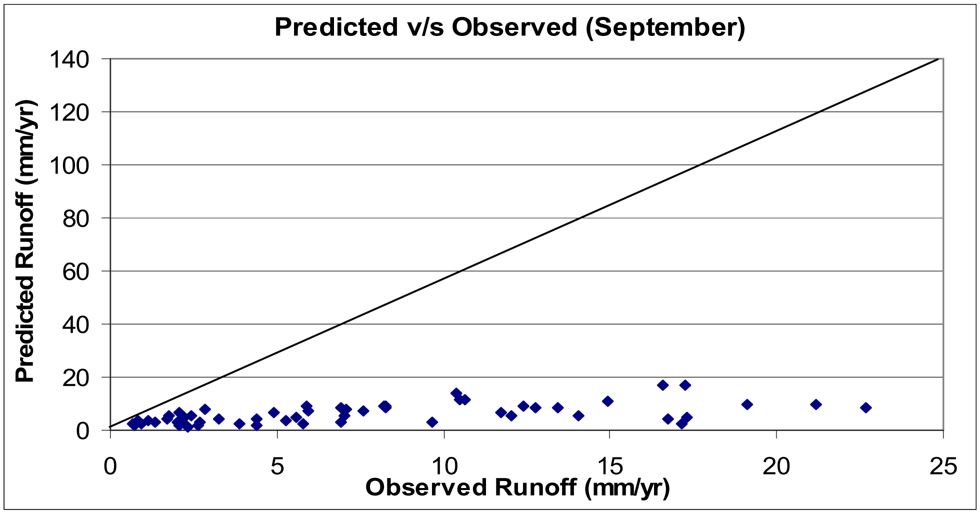

Figure B - 9

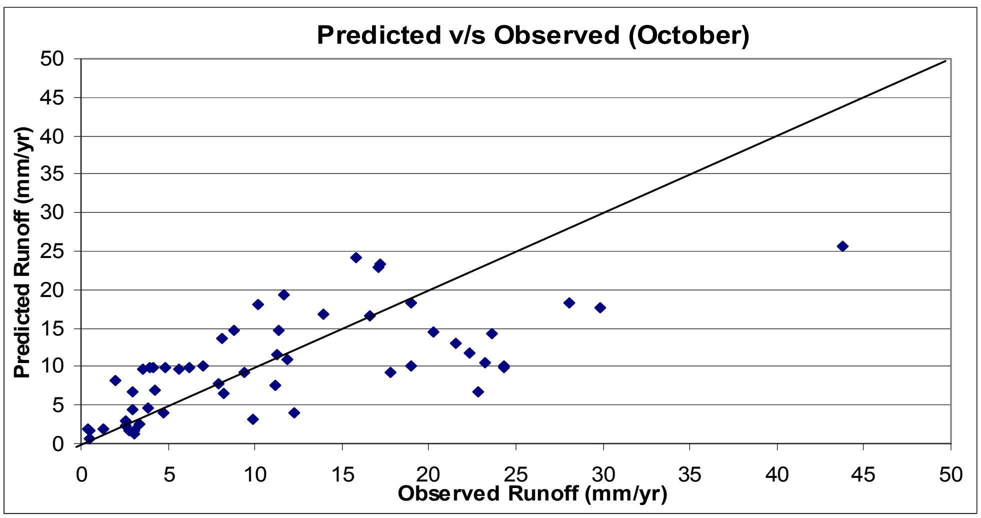

Figure B - 10

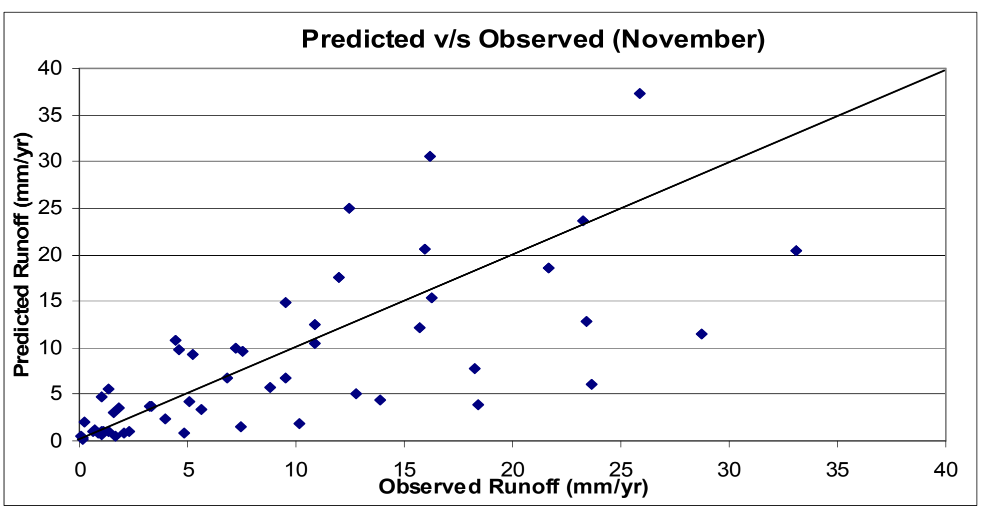

Figure B - 11

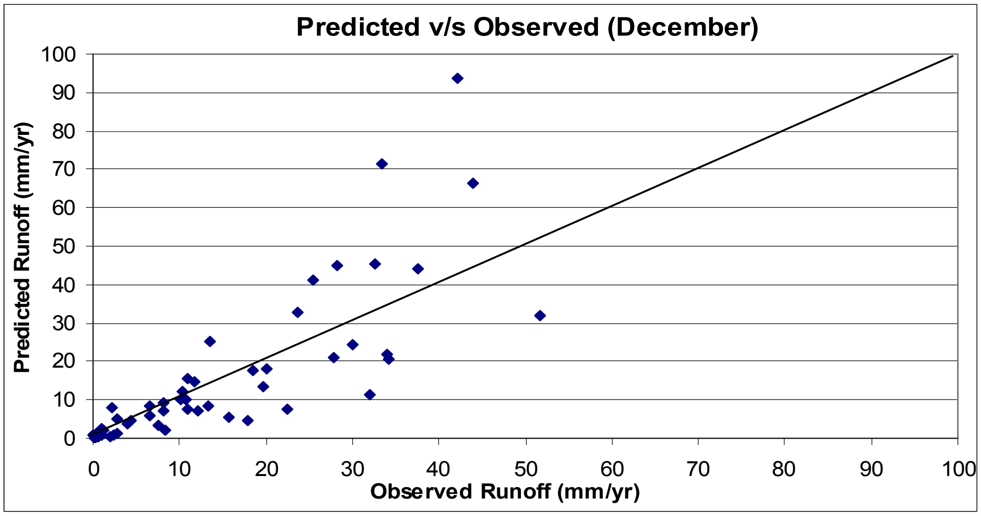

Figure B - 12

A2. Statistical Analysis

1. Mean

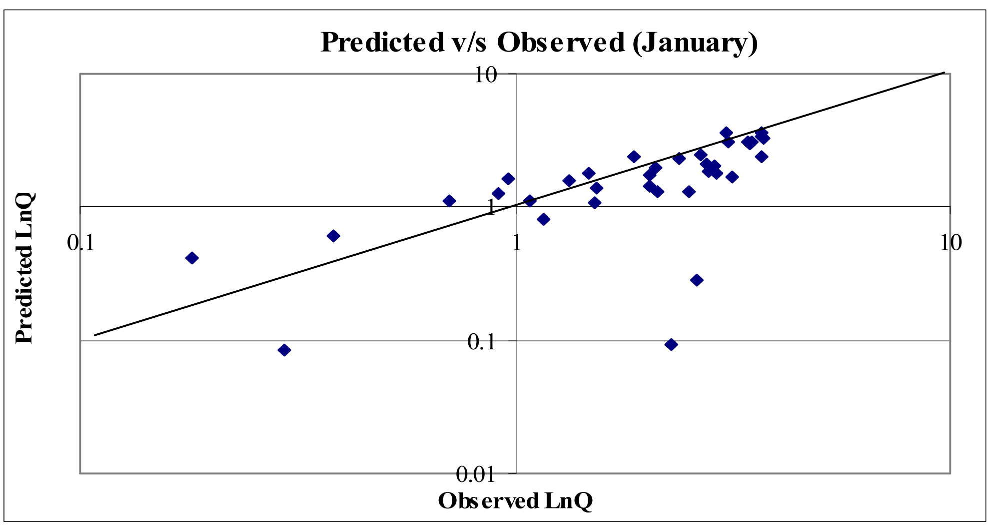

Figure B - 13

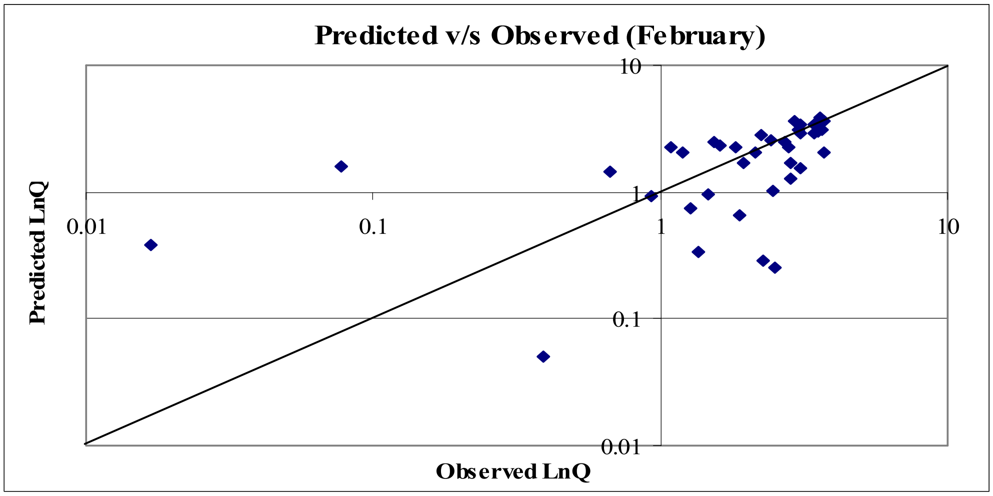

Figure B - 14

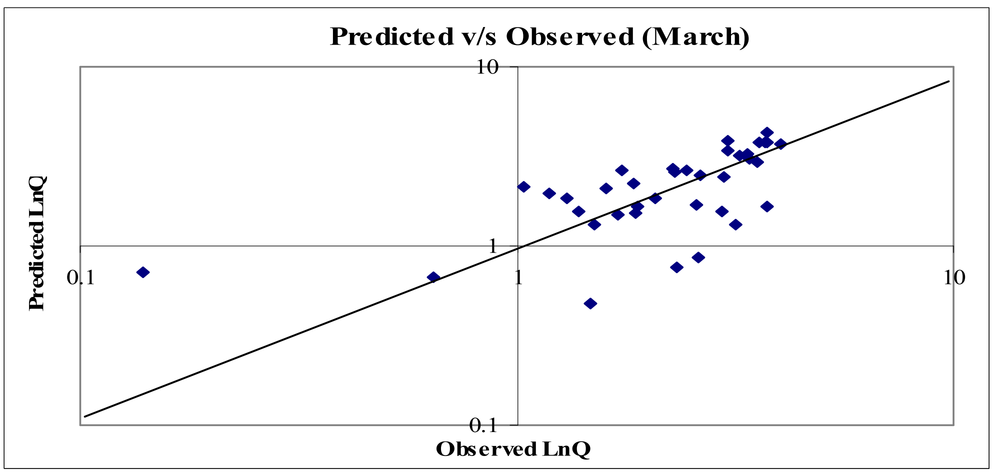

Figure B - 15

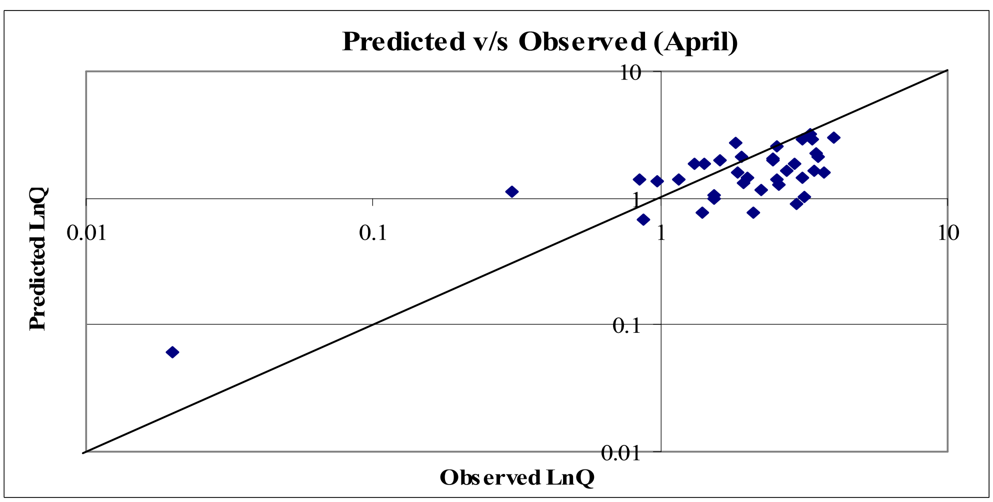

Figure B - 16

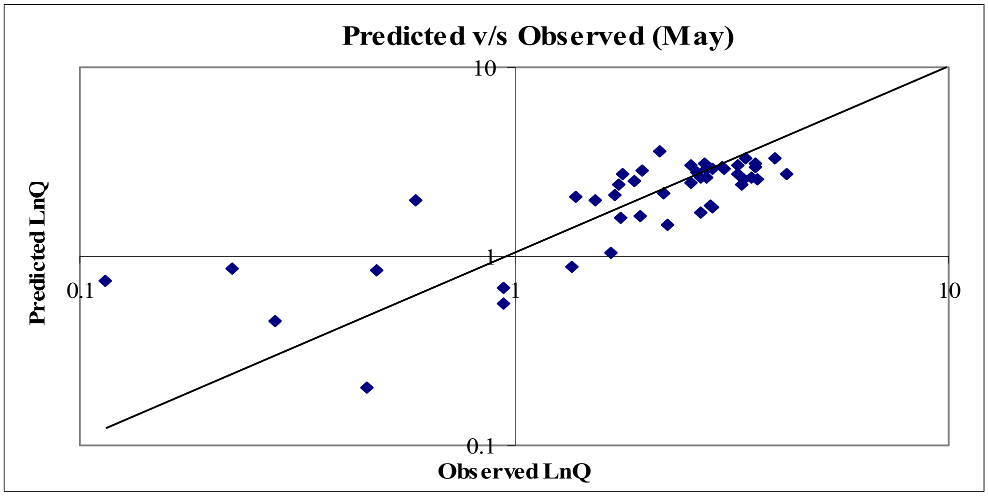

Figure B - 17

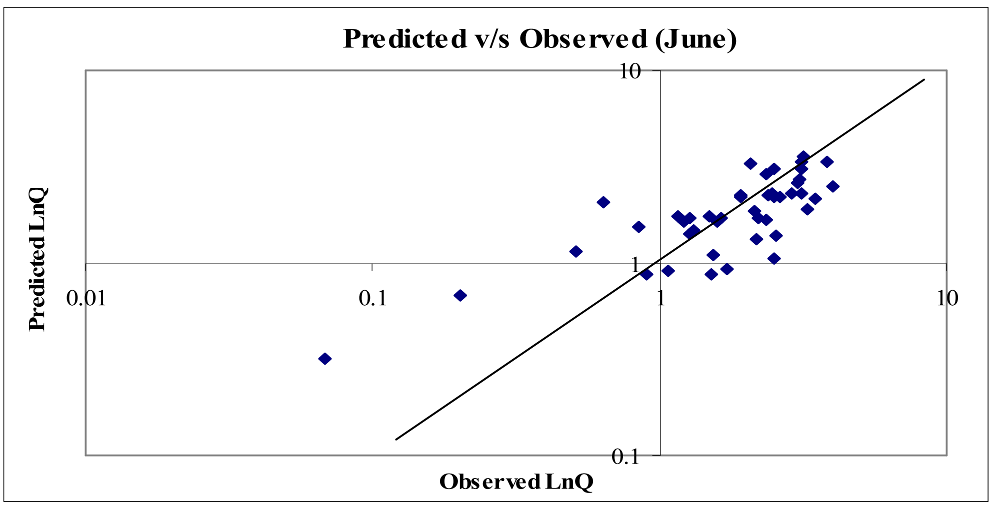

Figure B - 18

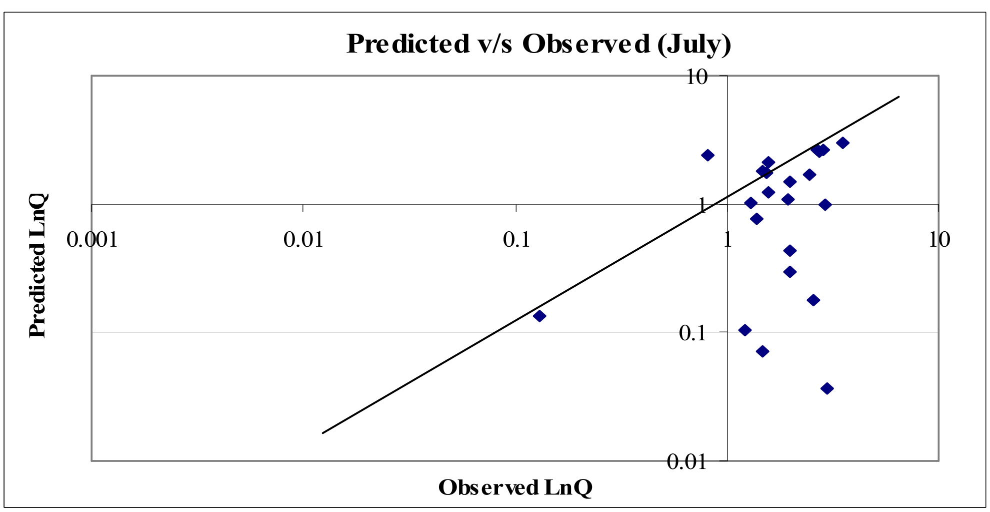

Figure B - 19

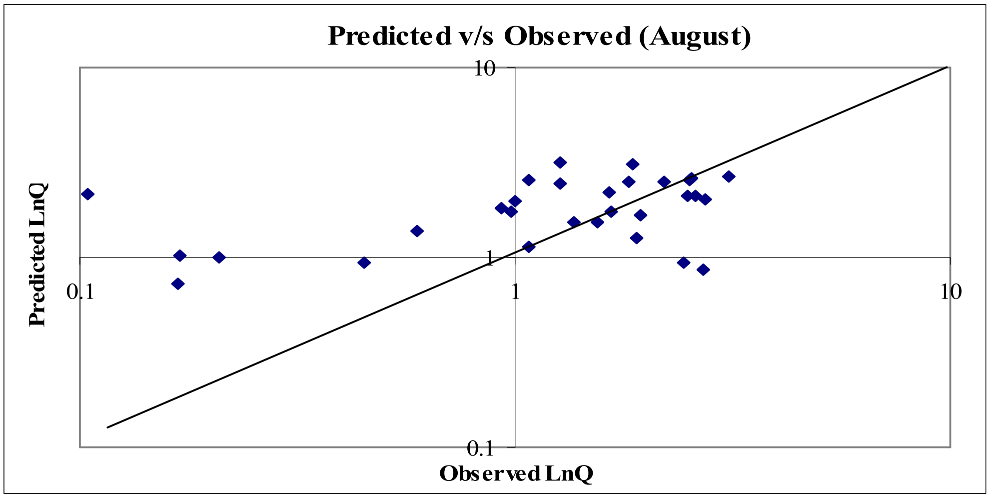

Figure B - 20

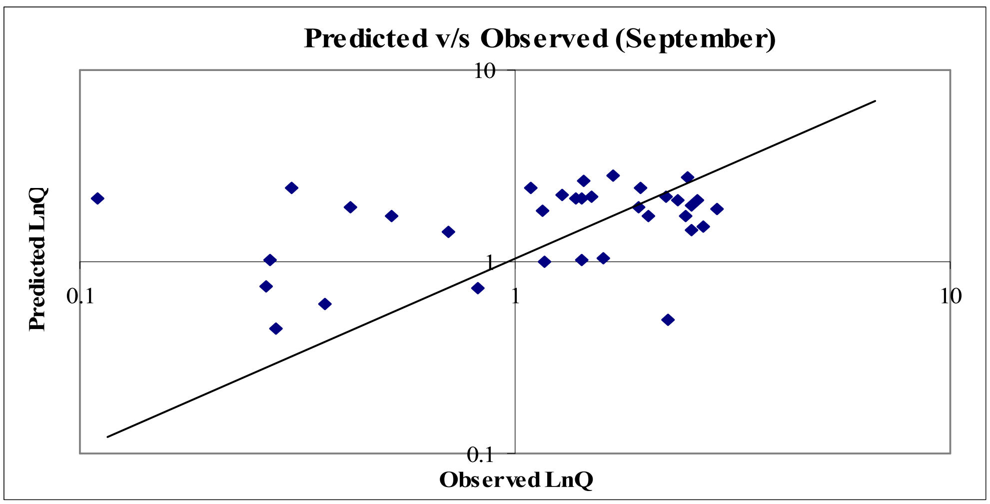

Figure B - 21

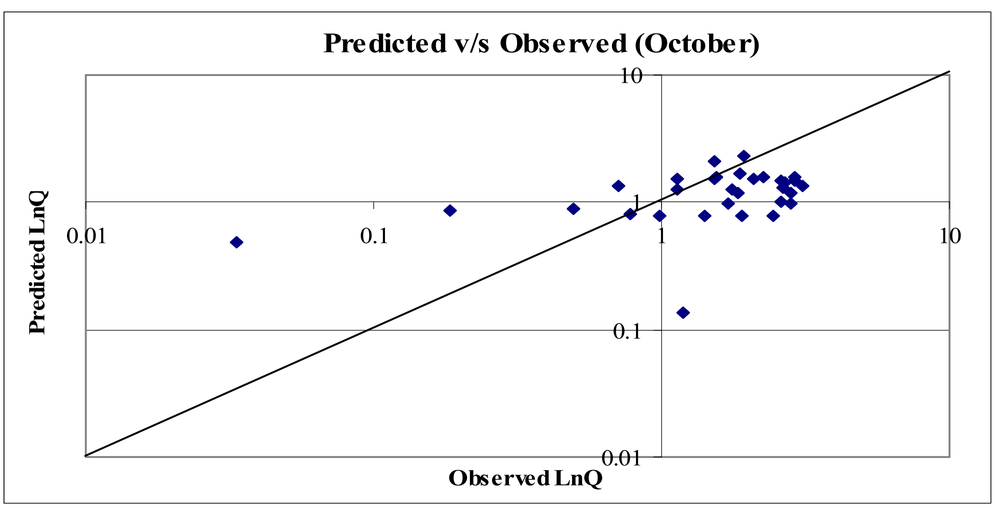

Figure B - 22

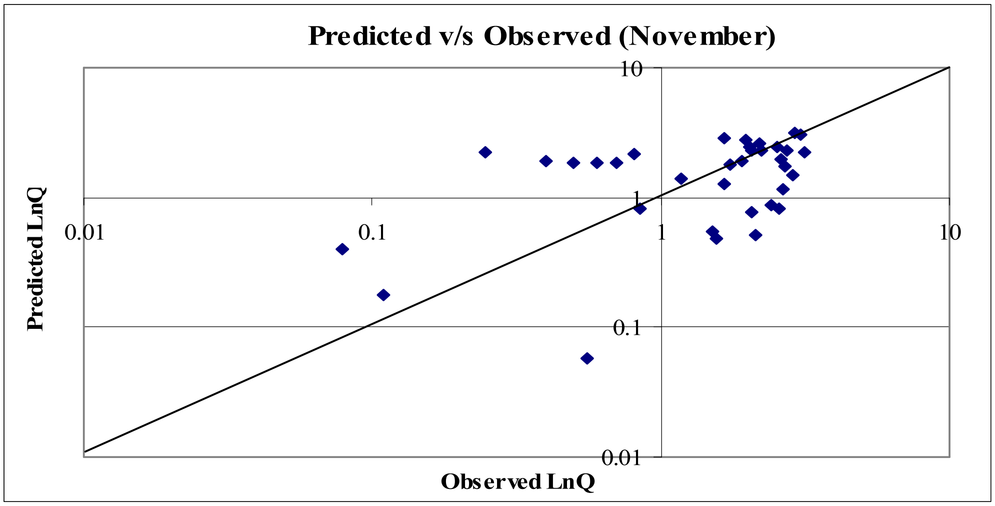

Figure B - 23

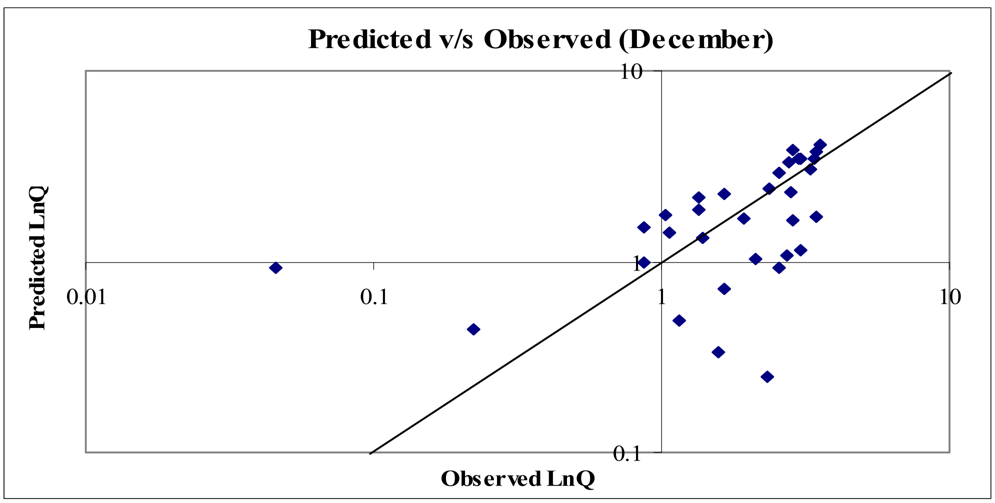

Figure B - 24

2. Standard Deviation

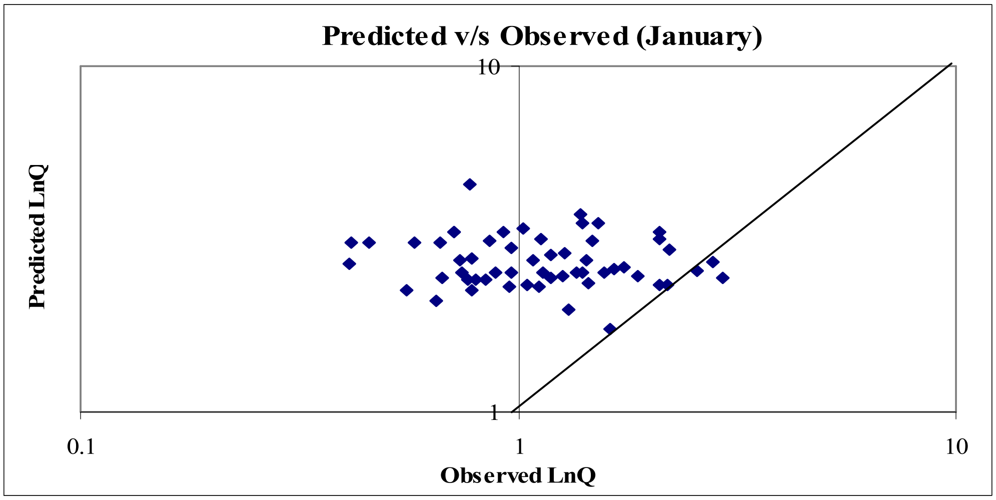

Figure B - 25

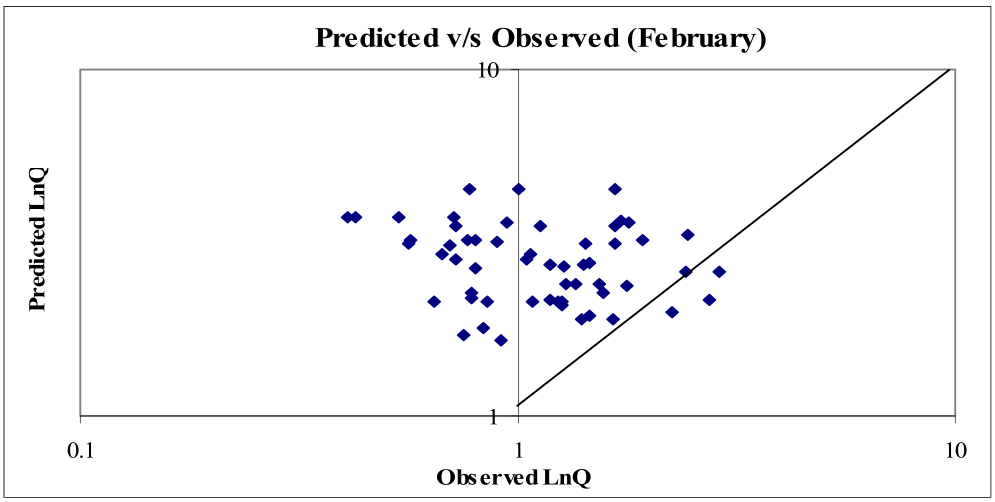

Figure B - 26

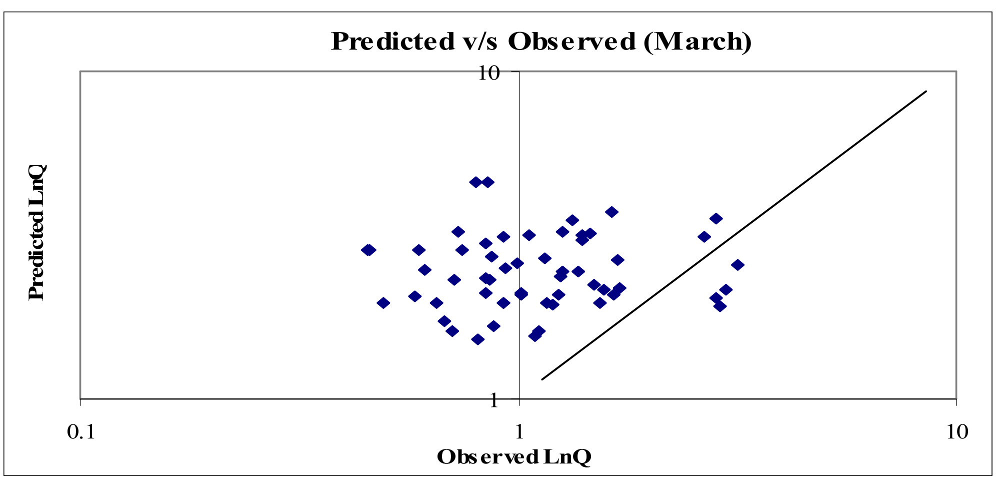

Figure B - 27

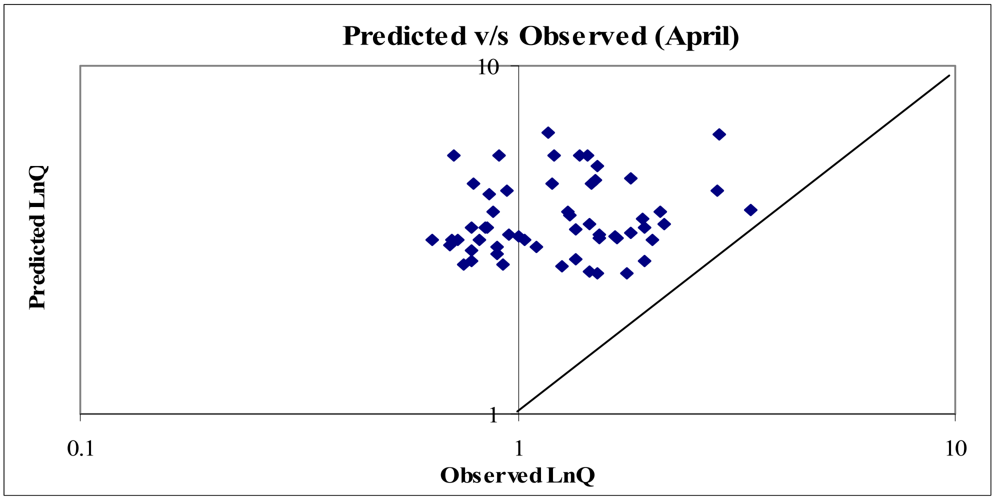

Figure B - 28

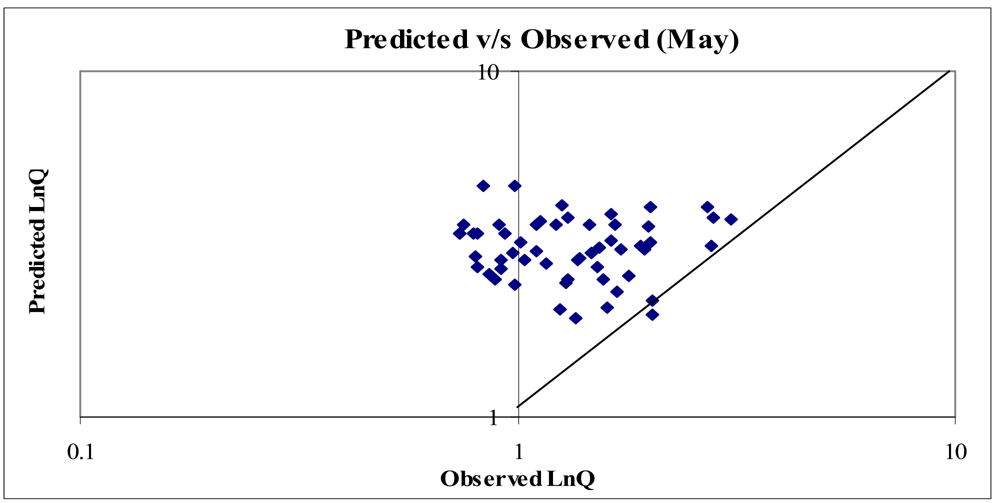

Figure B - 29

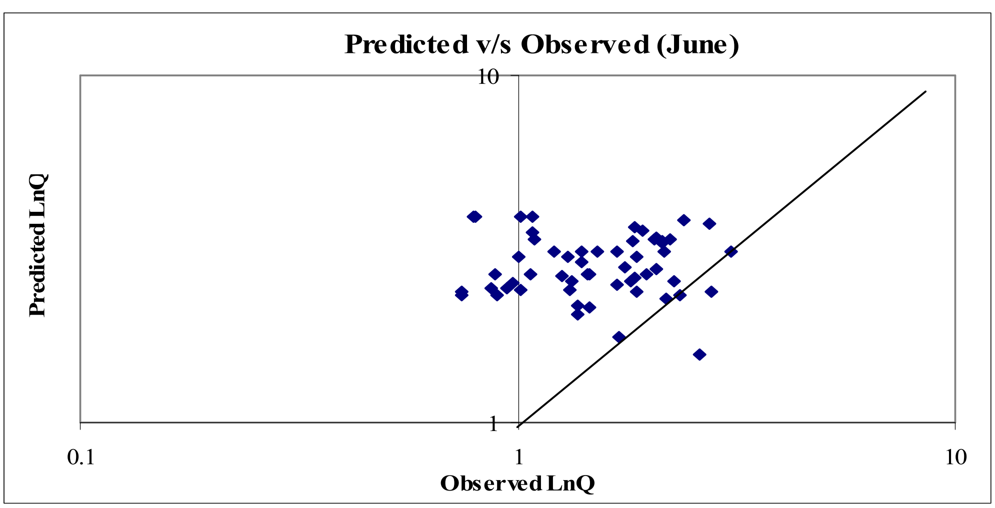

Figure B - 30

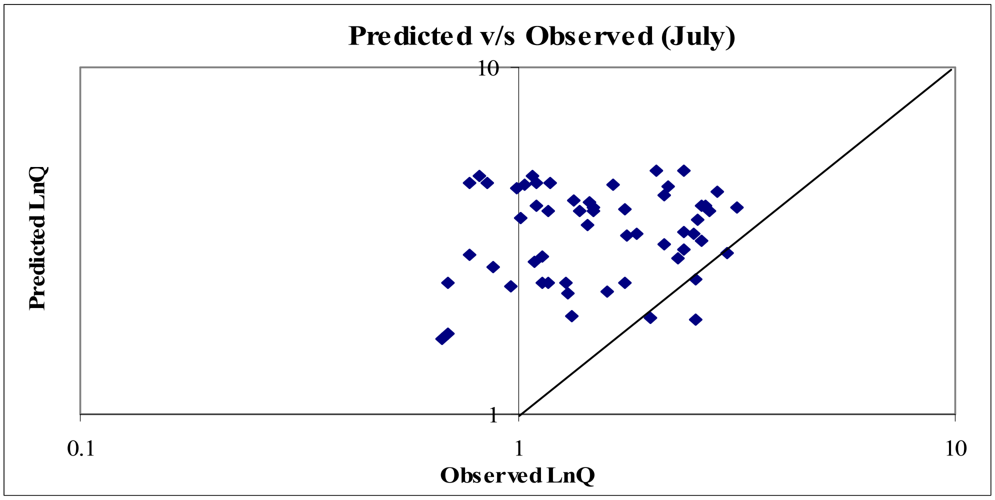

Figure B - 31

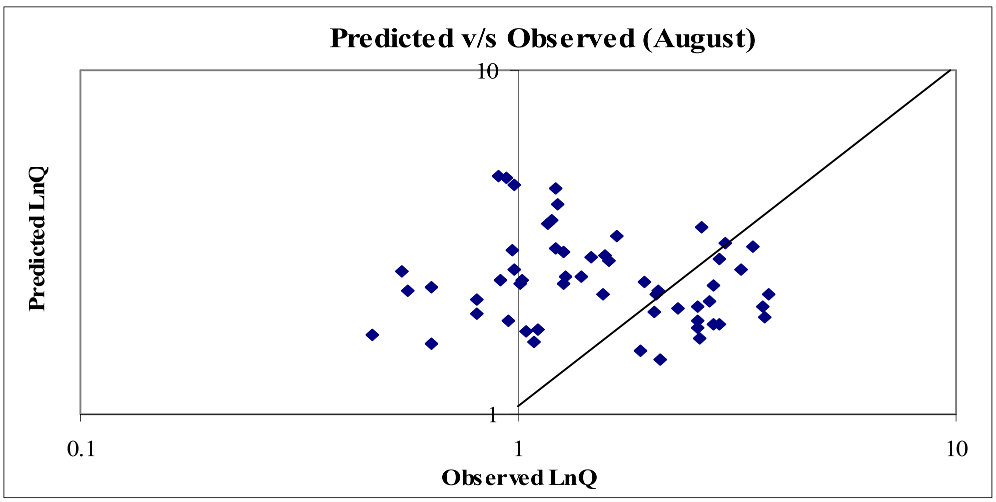

Figure B - 32

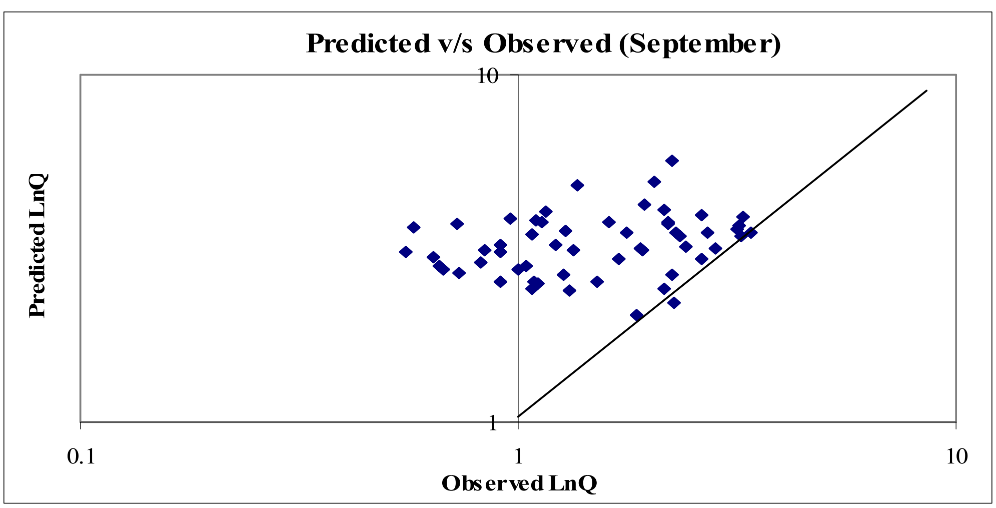

Figure B - 33

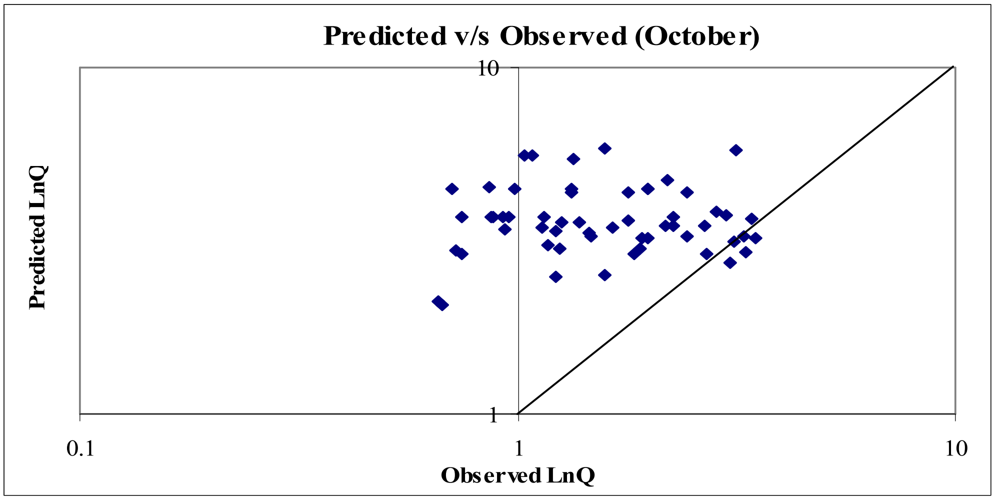

Figure B - 34

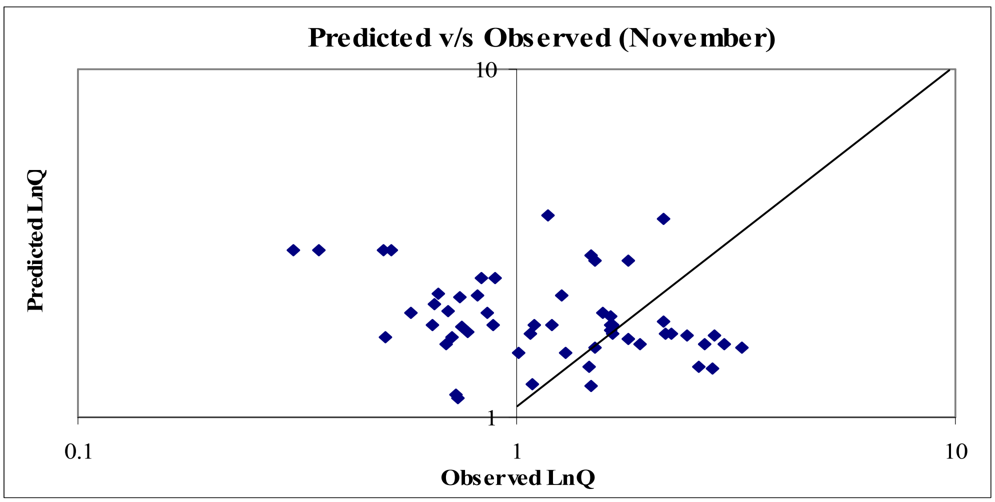

Figure B - 35

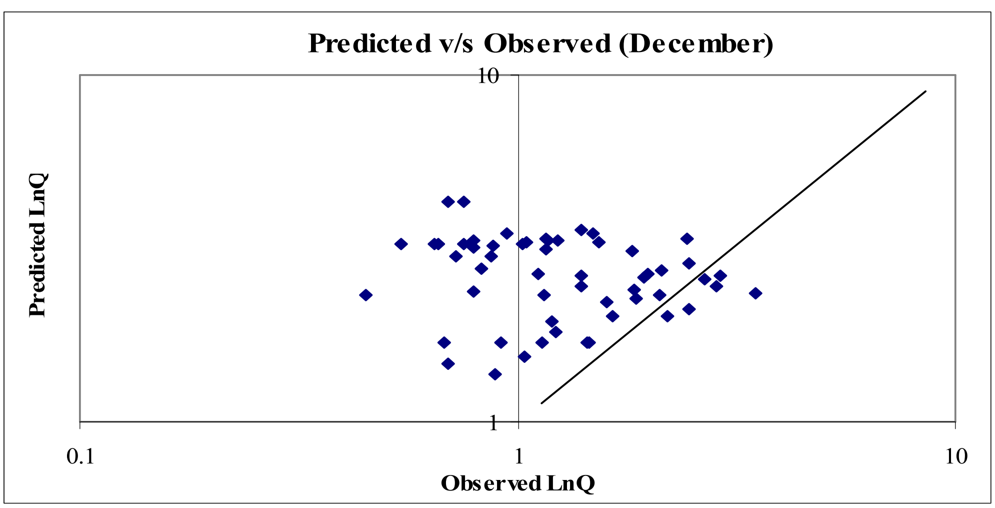

Figure B - 36

B. Graphs of predicted flow based on non-linear method

B1. Based on non-linear regression coefficients

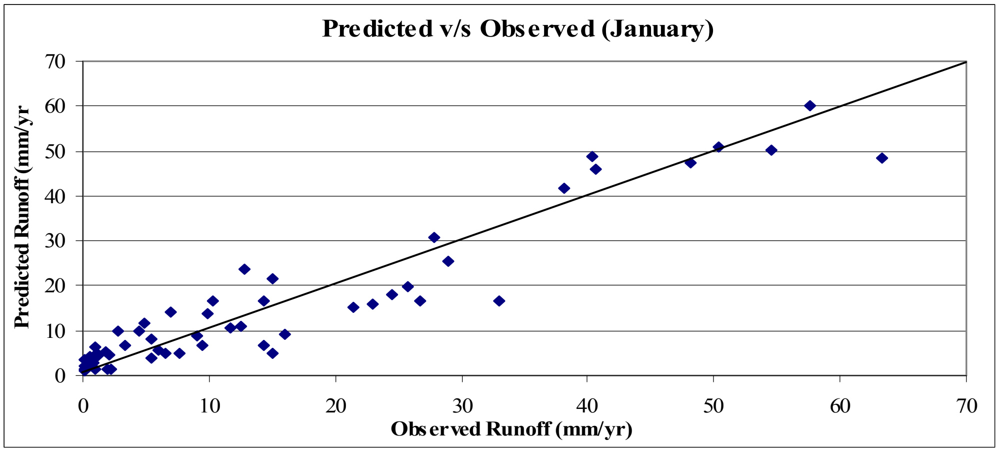

Figure B - 37

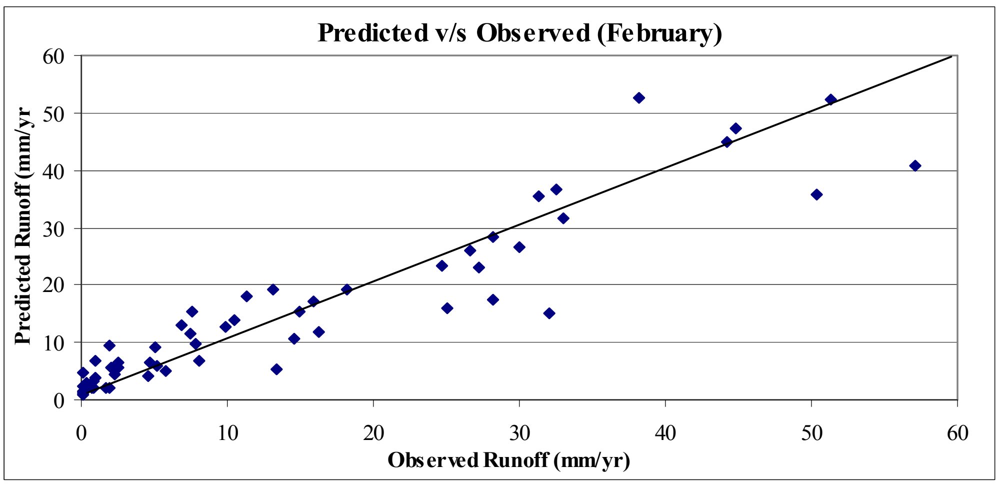

Figure B - 38

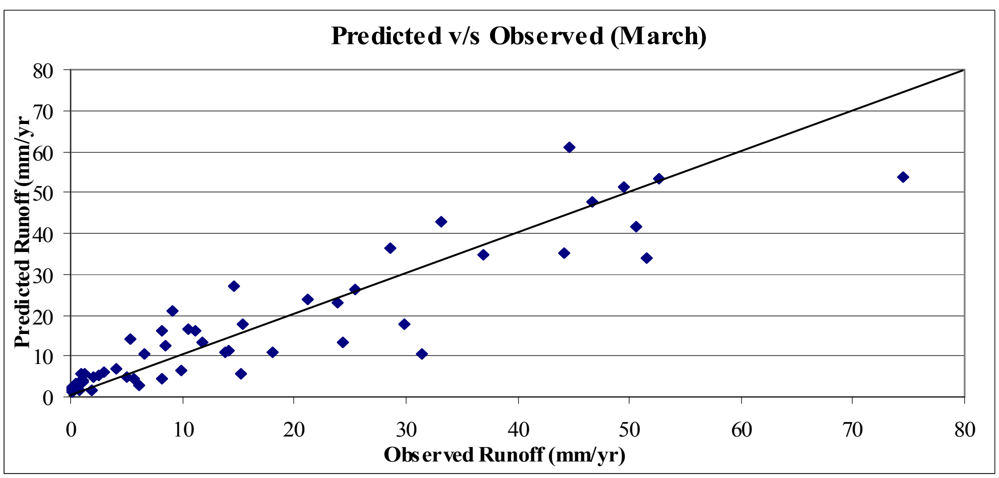

Figure B - 39

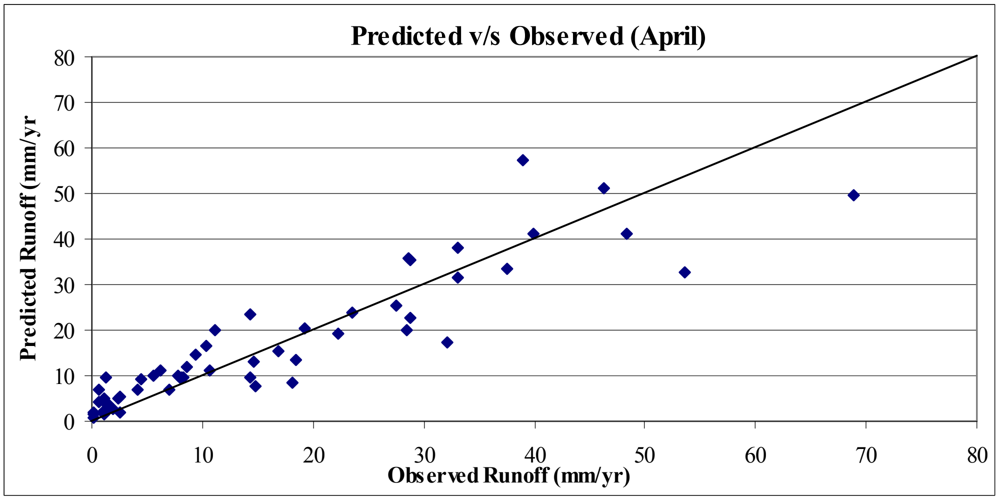

Figure B - 40

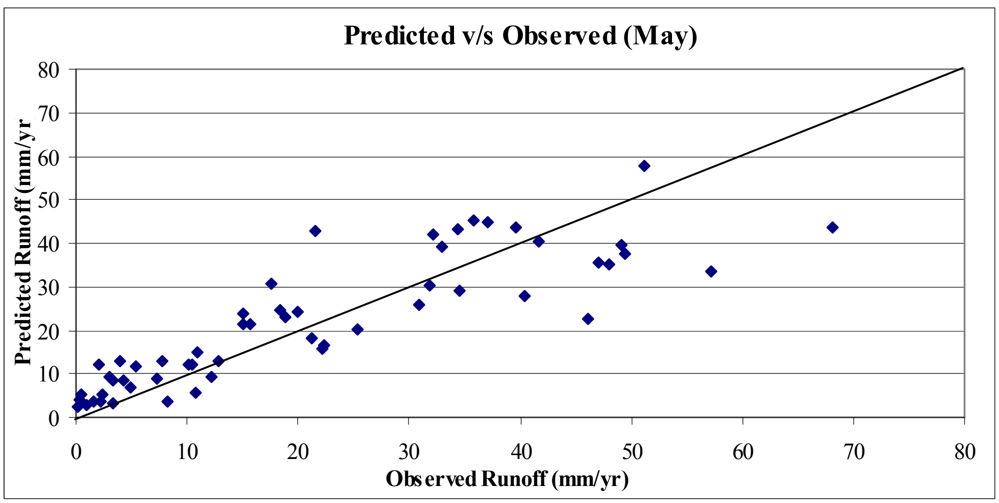

Figure B - 41

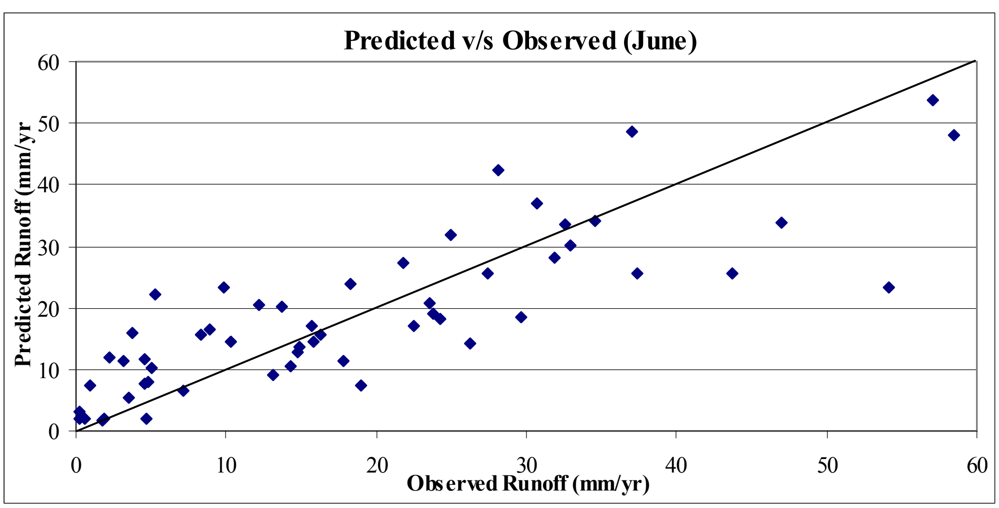

Figure B - 42

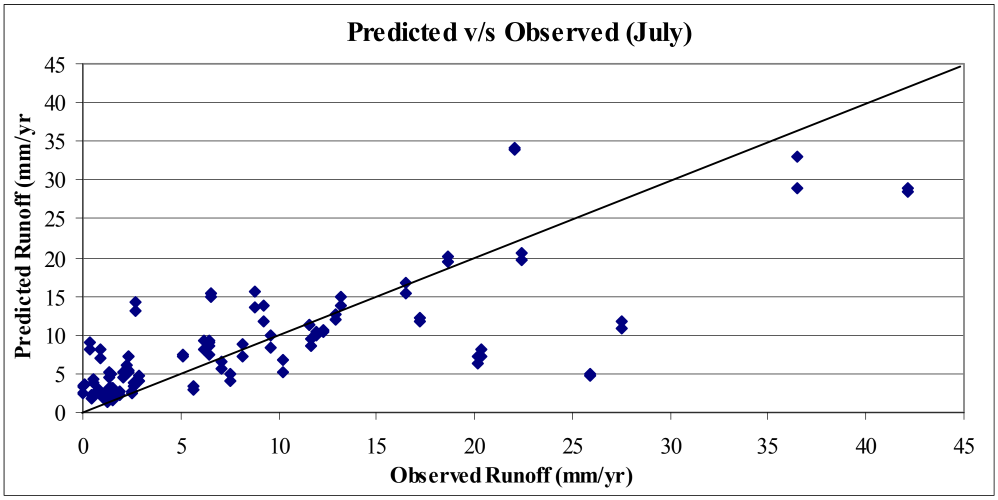

Figure B - 43

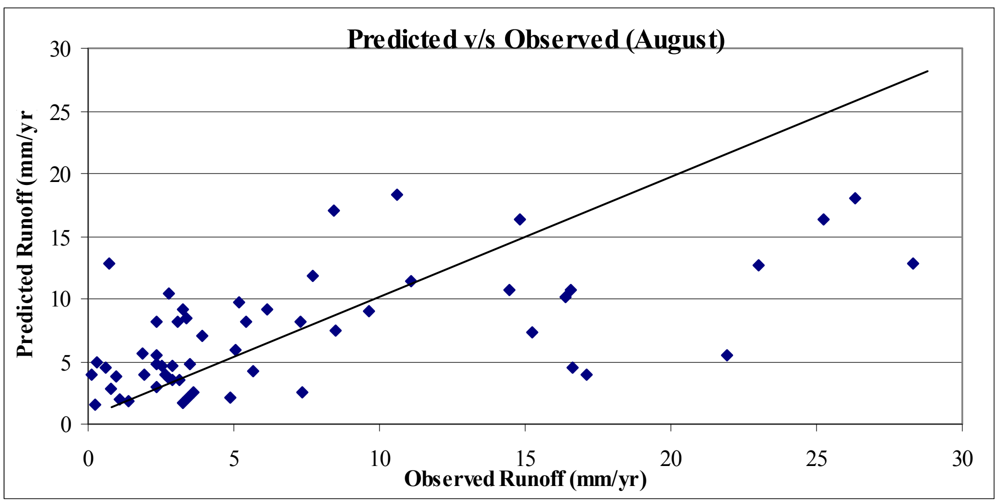

Figure B - 44

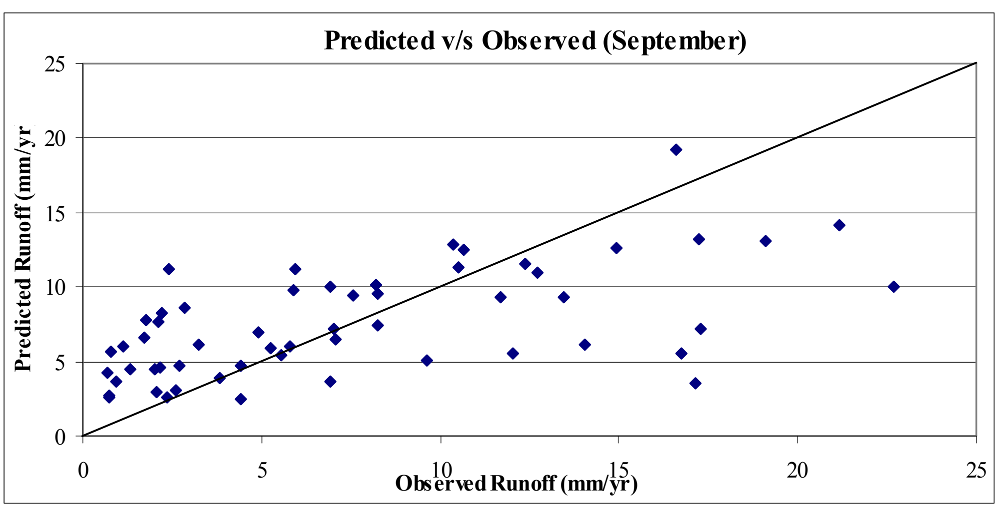

Figure B - 45

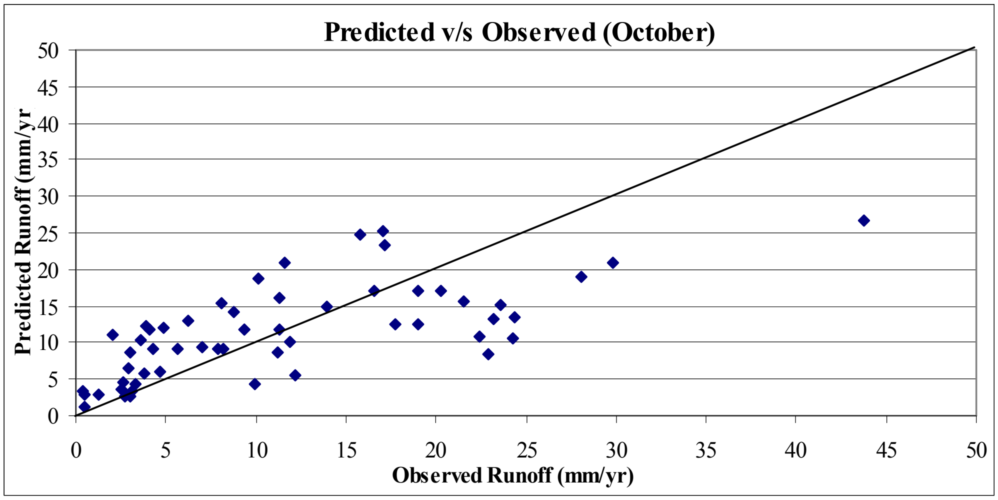

Figure B - 46

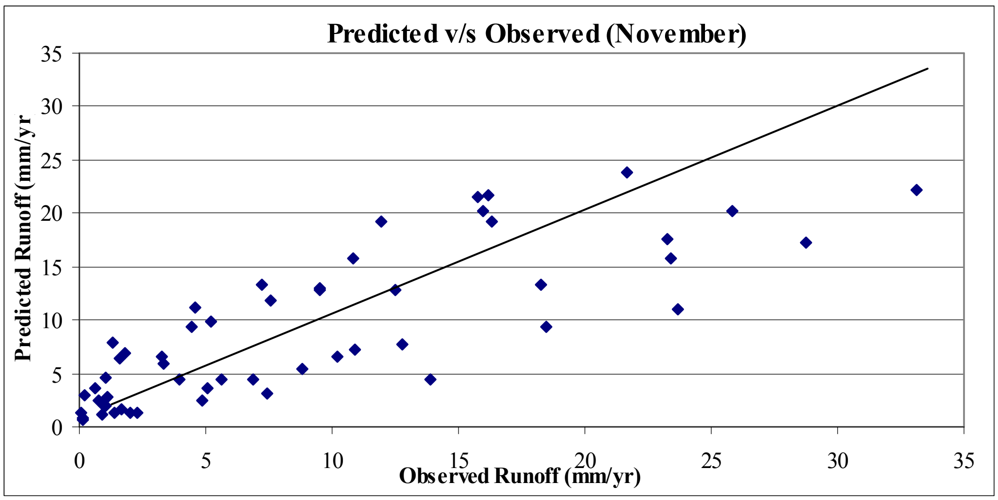

Figure B - 47

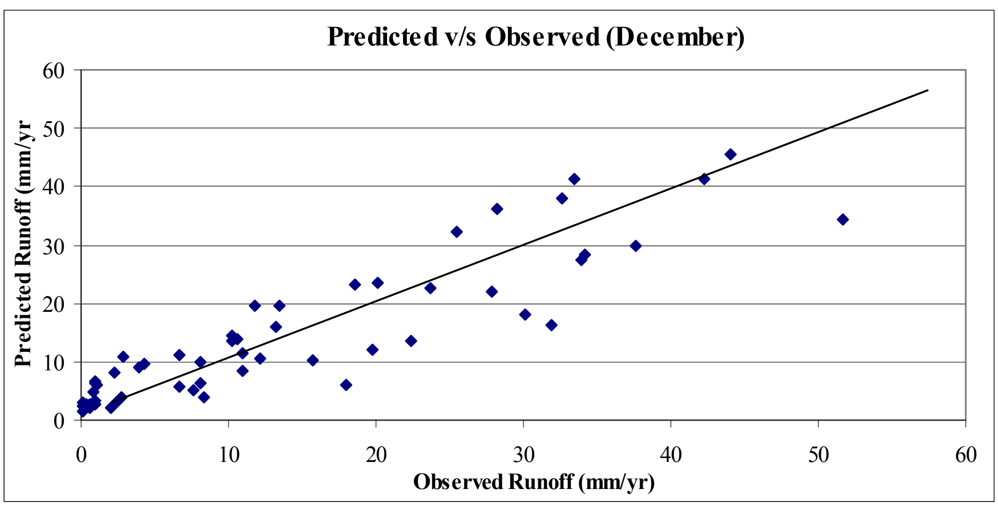

Figure B - 48

B2. Statistical Analysis

1. Mean

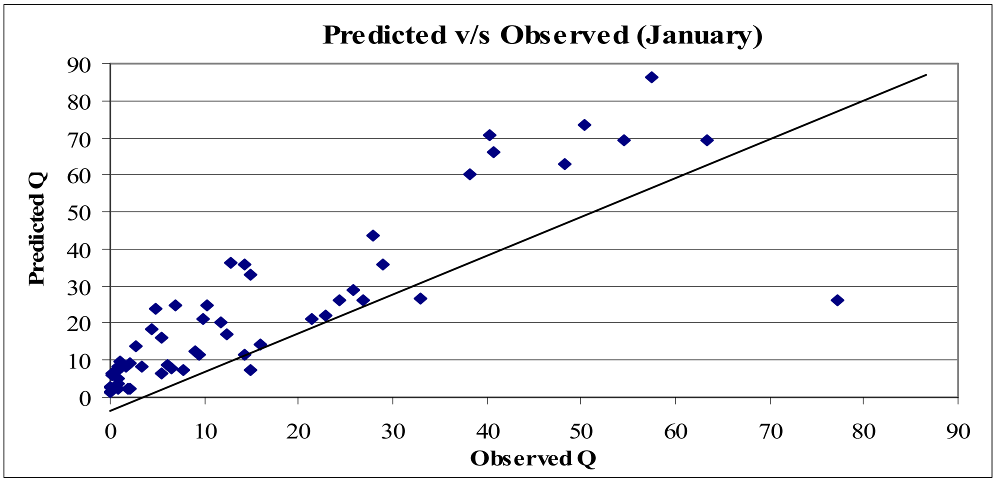

Figure B - 49

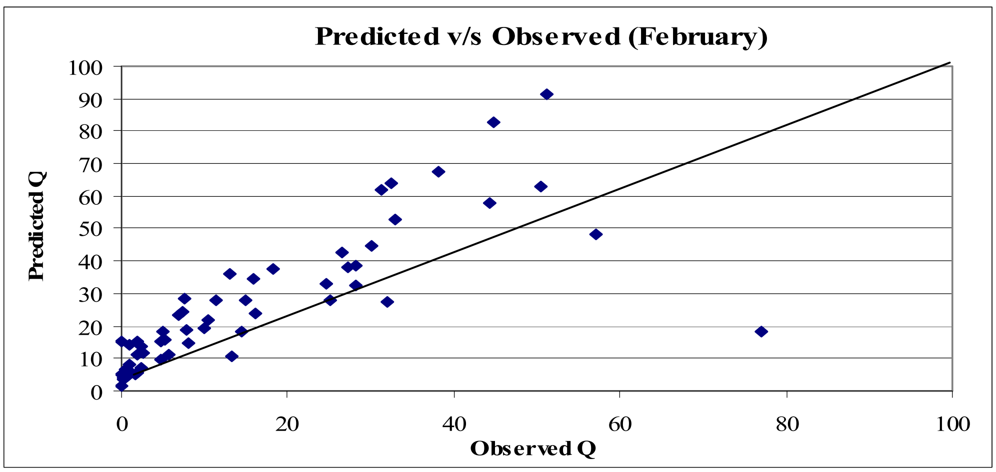

Figure B - 50

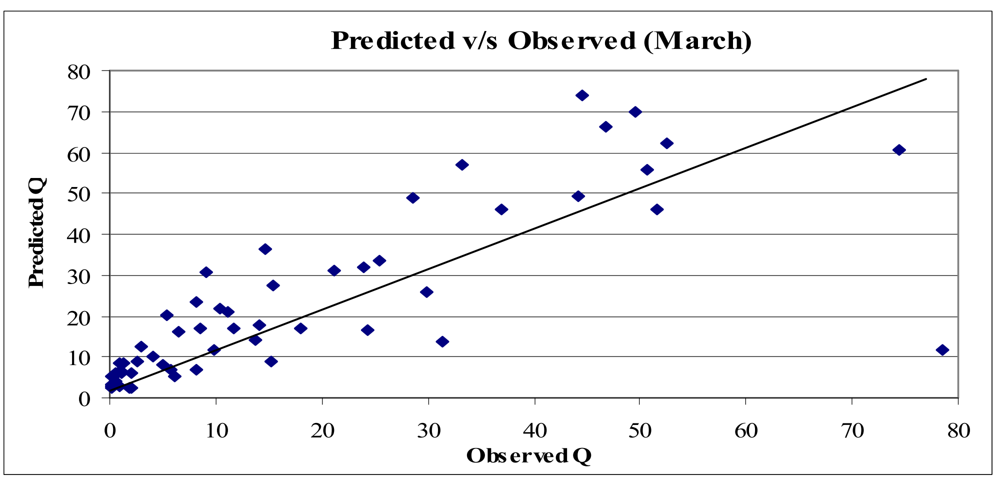

Figure B - 51

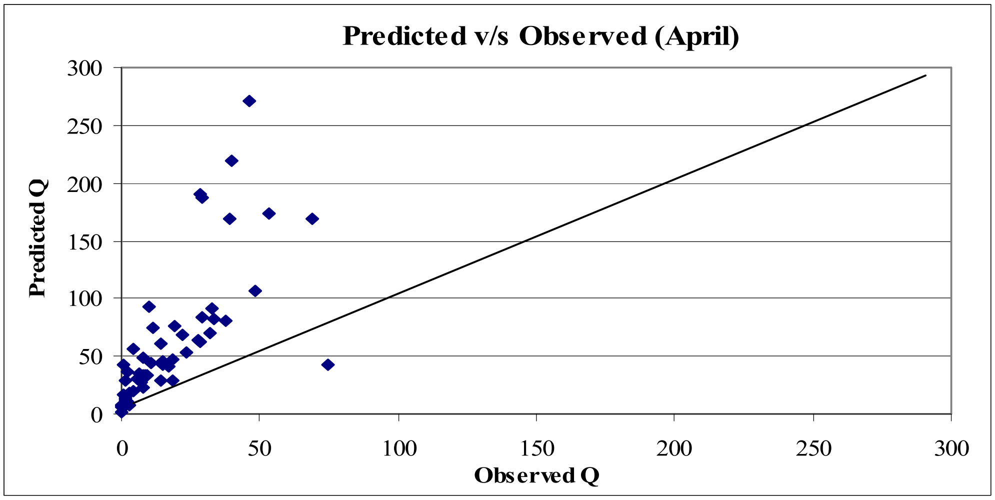

Figure B - 52

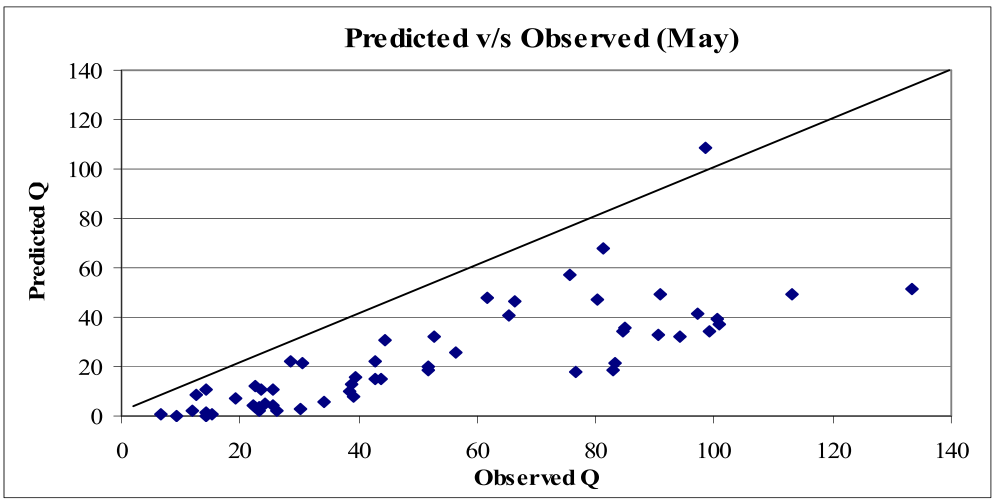

Figure B - 53

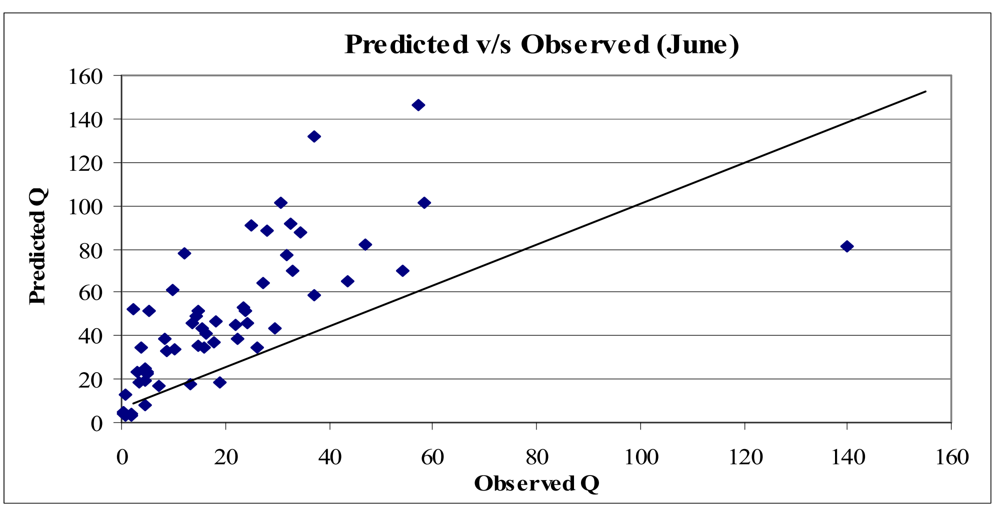

Figure B - 54

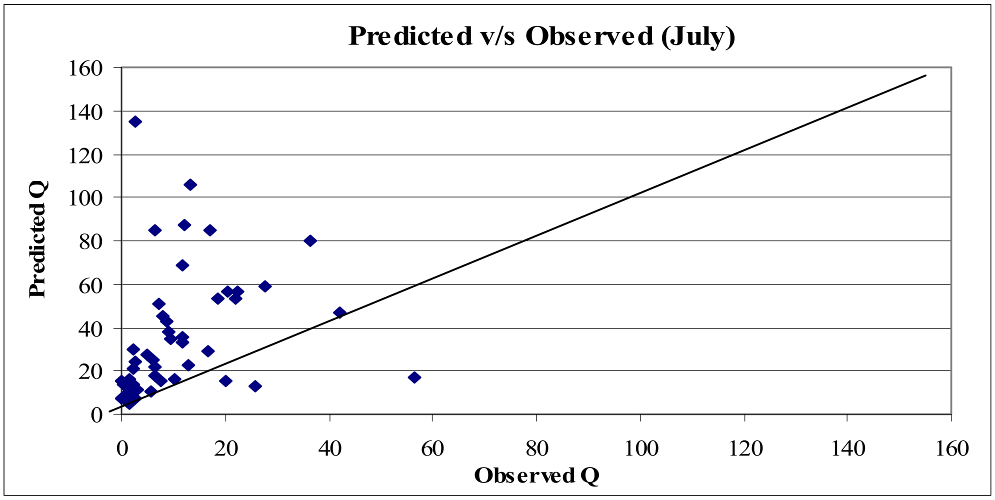

Figure B - 55

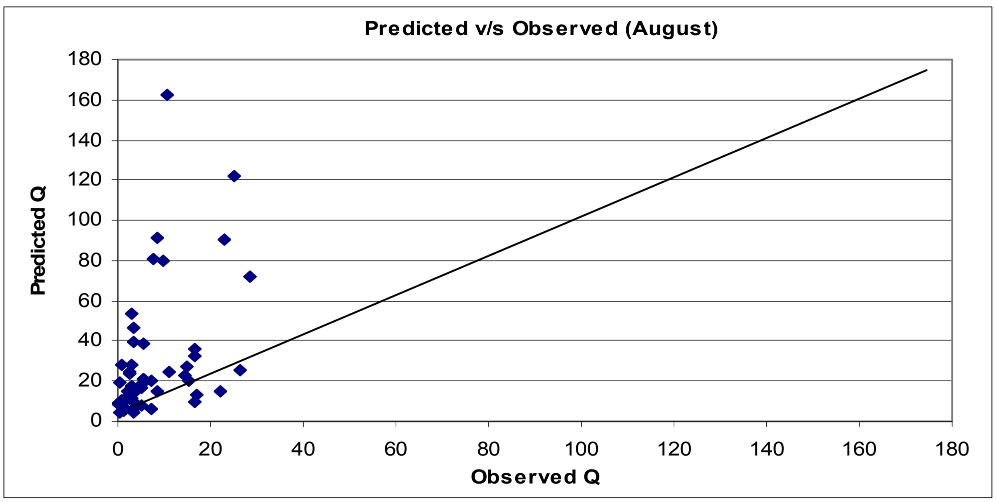

Figure B - 56

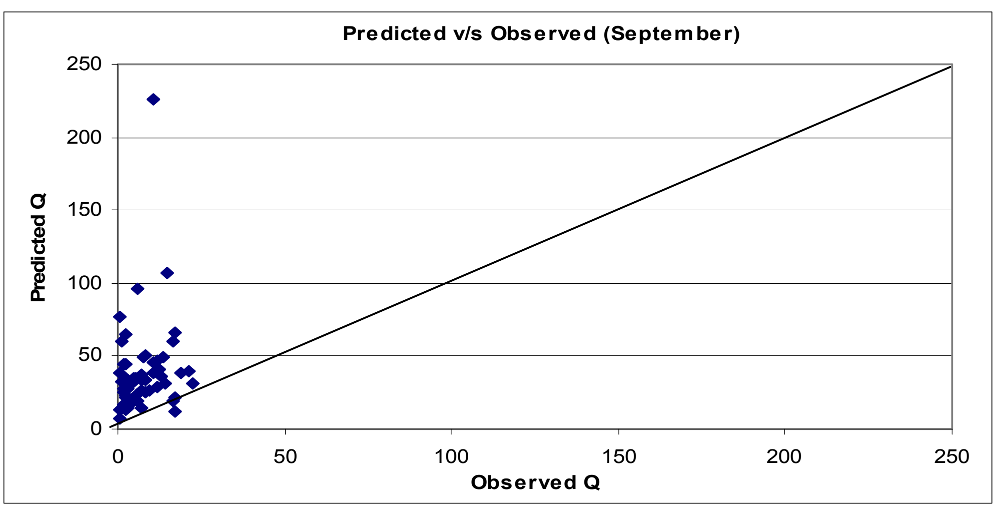

Figure B - 57

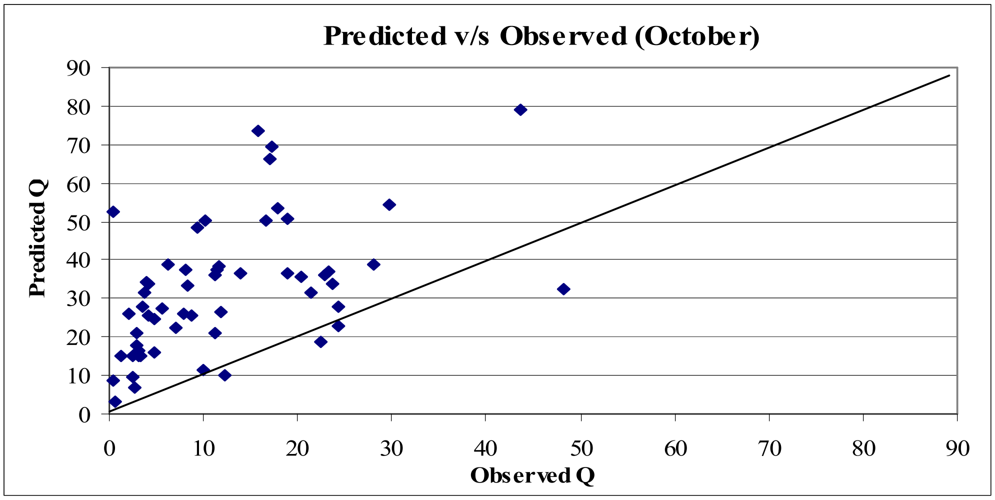

Figure B - 58

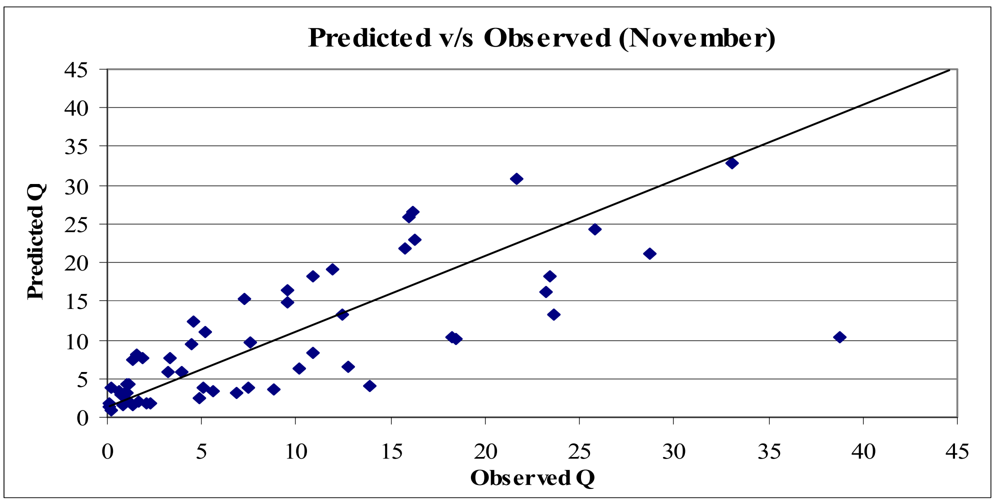

Figure B - 59

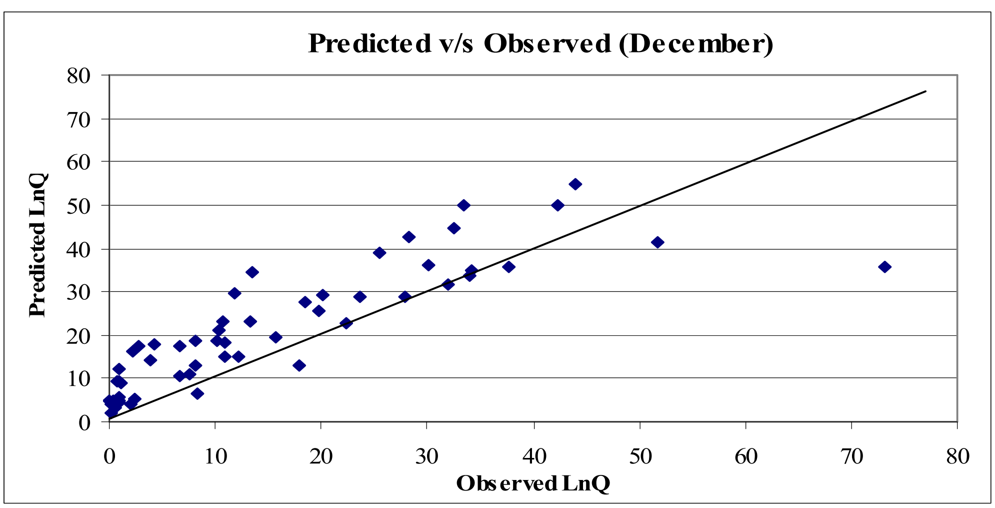

Figure B - 60

2. Standard Deviation

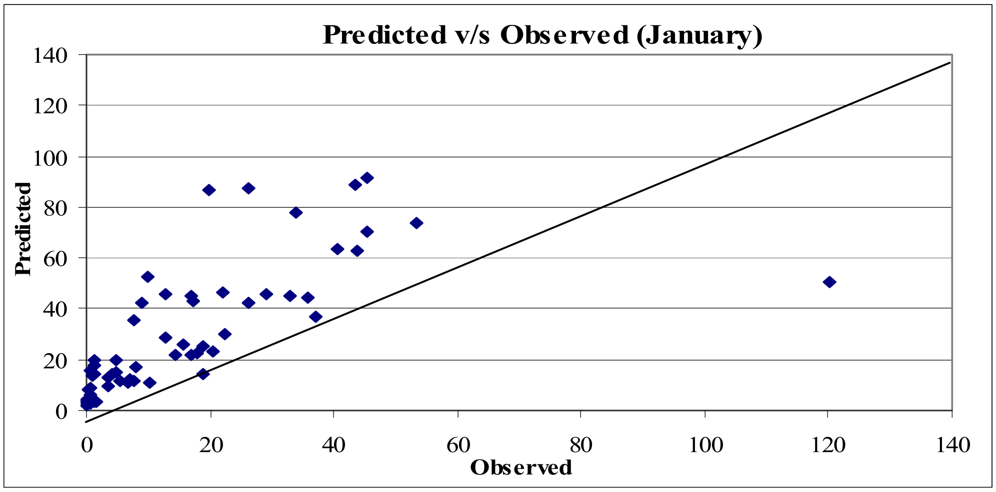

Figure B - 61

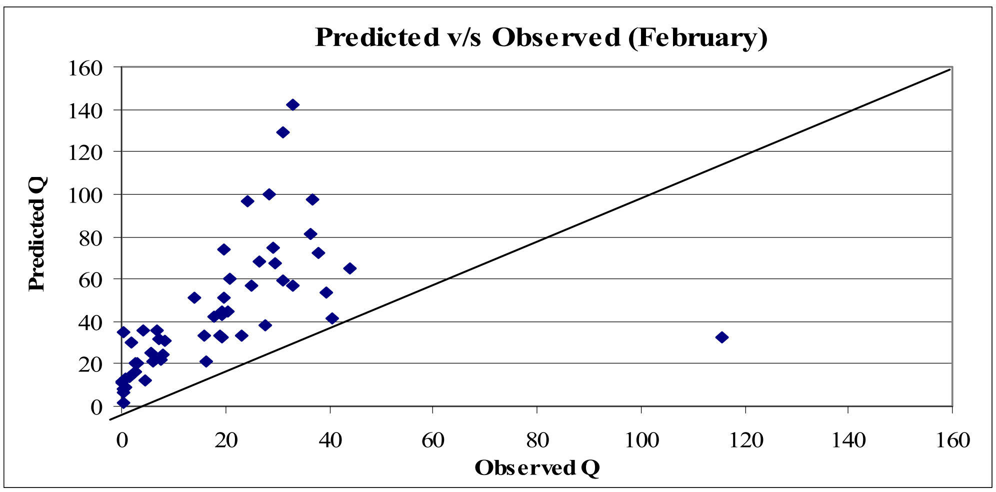

Figure B - 62

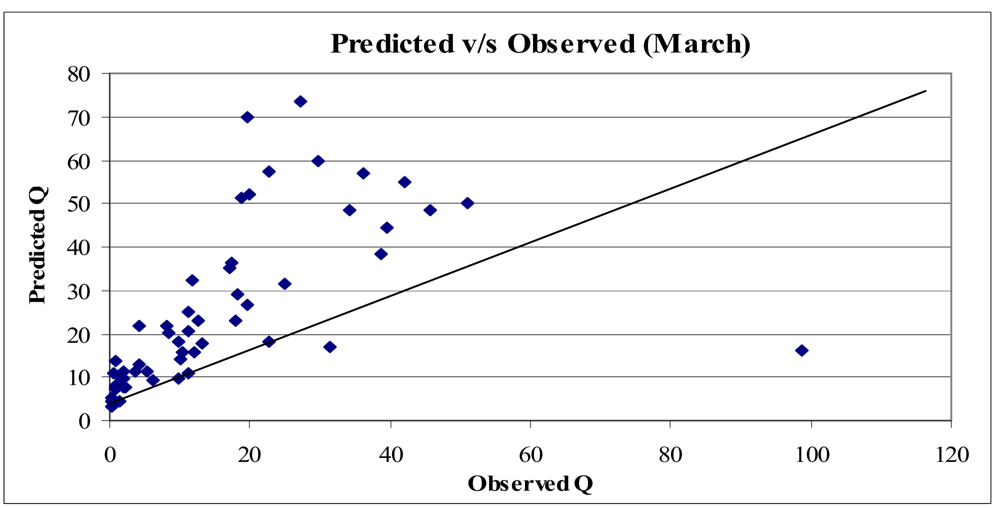

Figure B - 63

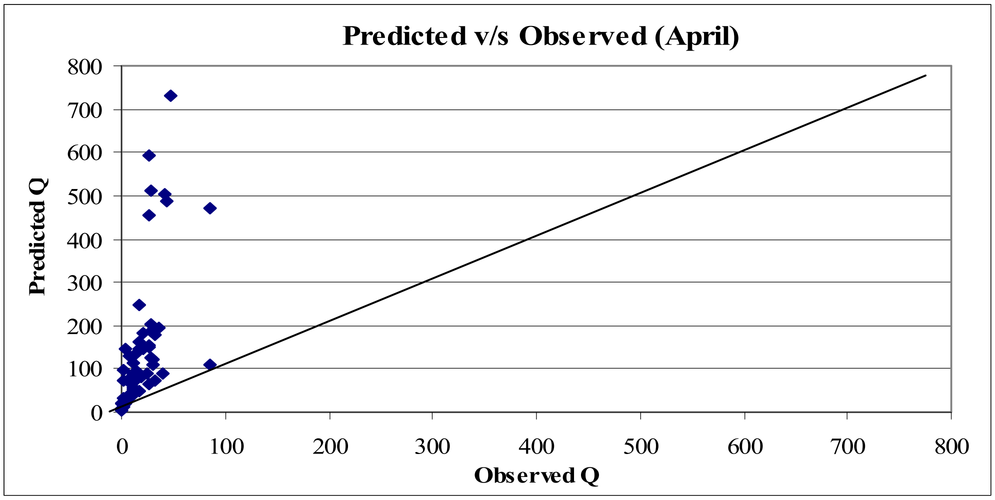

Figure B - 64

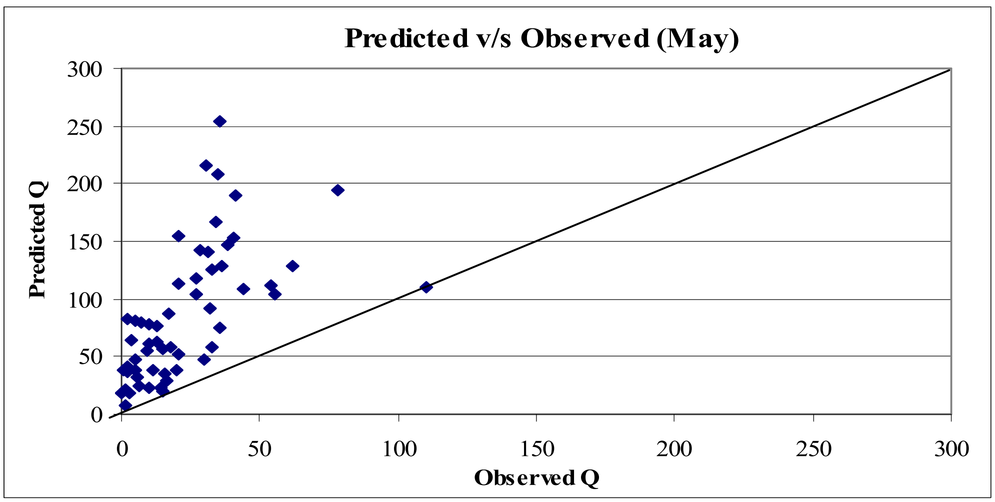

Figure B - 65

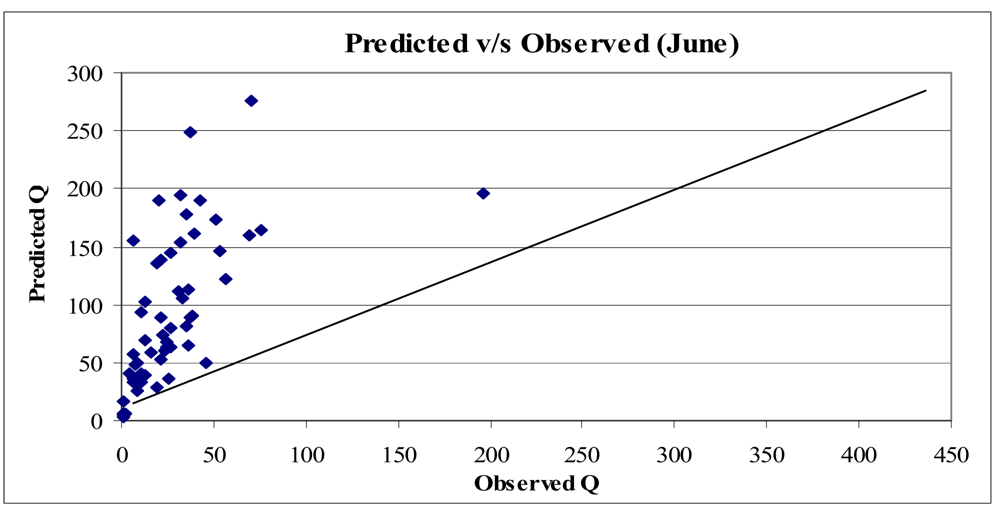

Figure B - 66

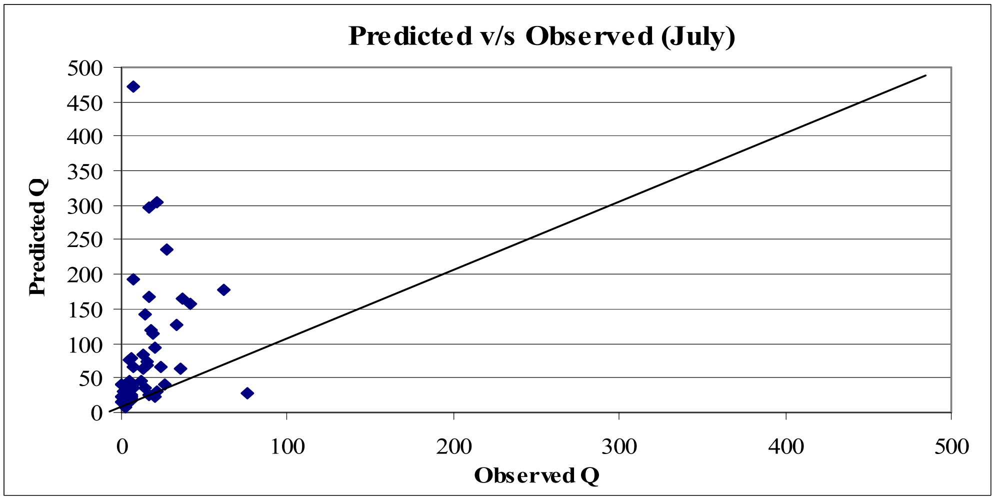

Figure B - 67

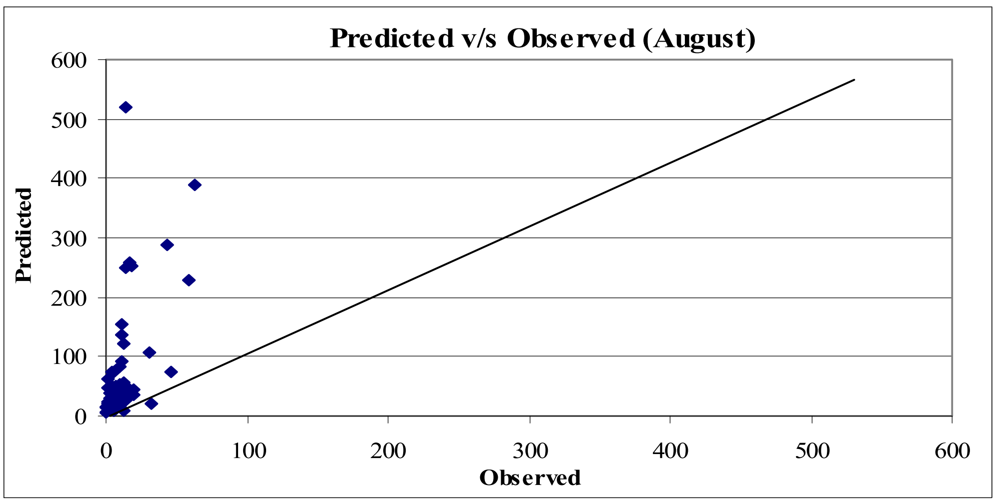

Figure B - 68

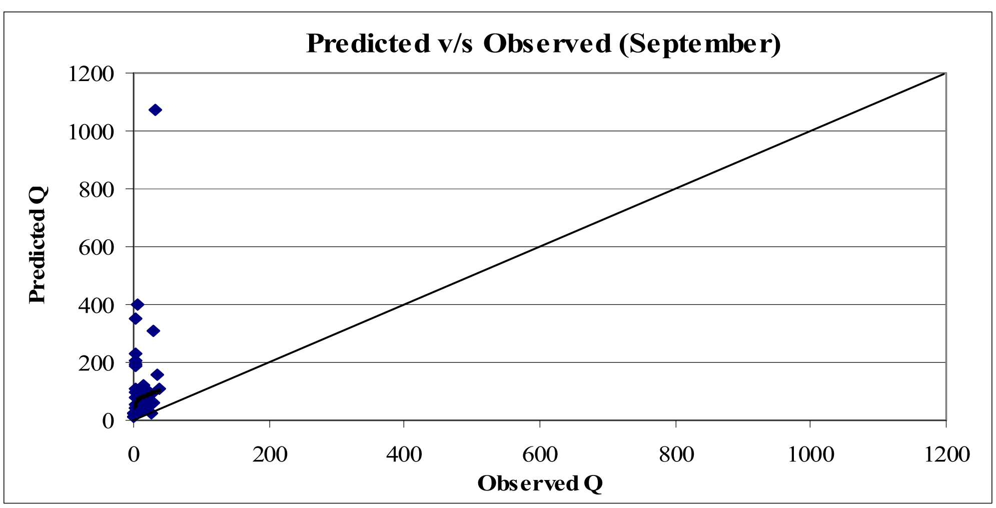

Figure B - 69

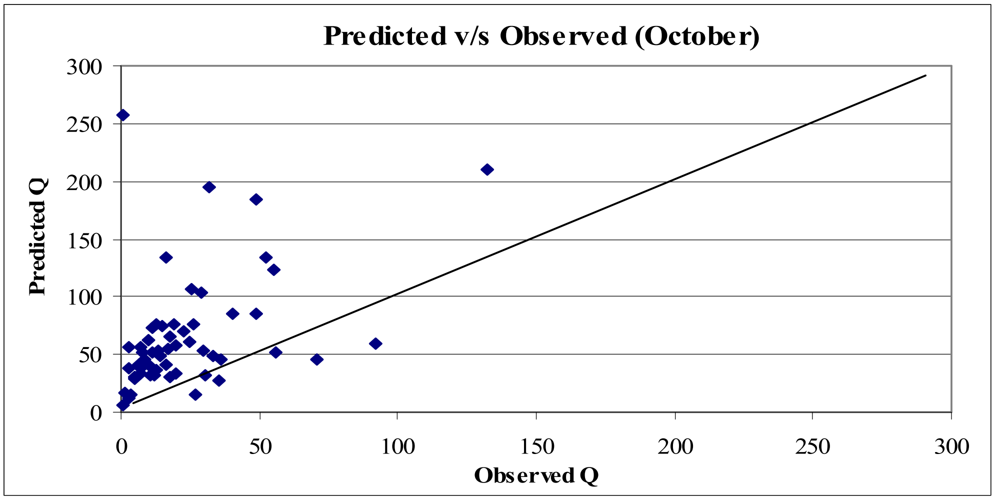

Figure B - 70

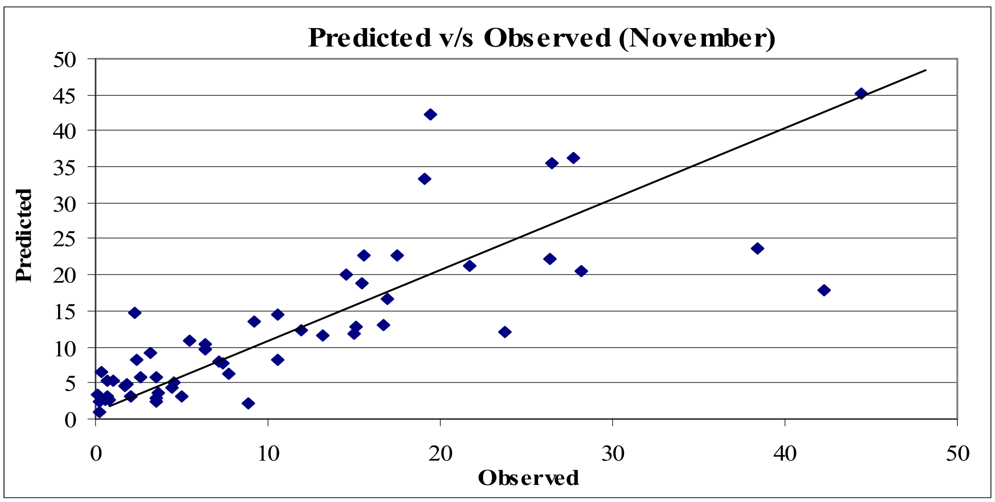

Figure B - 71

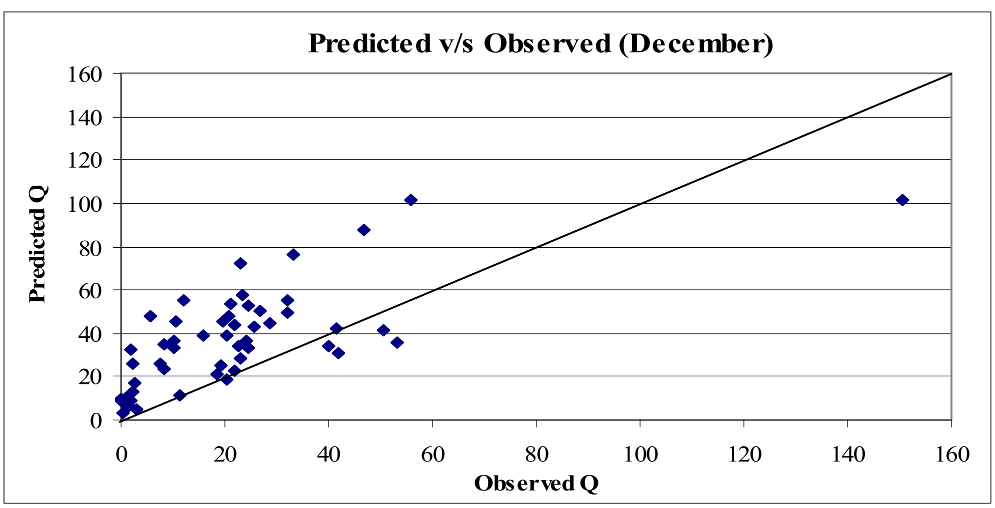

Figure B - 72

3. Autocorrelation

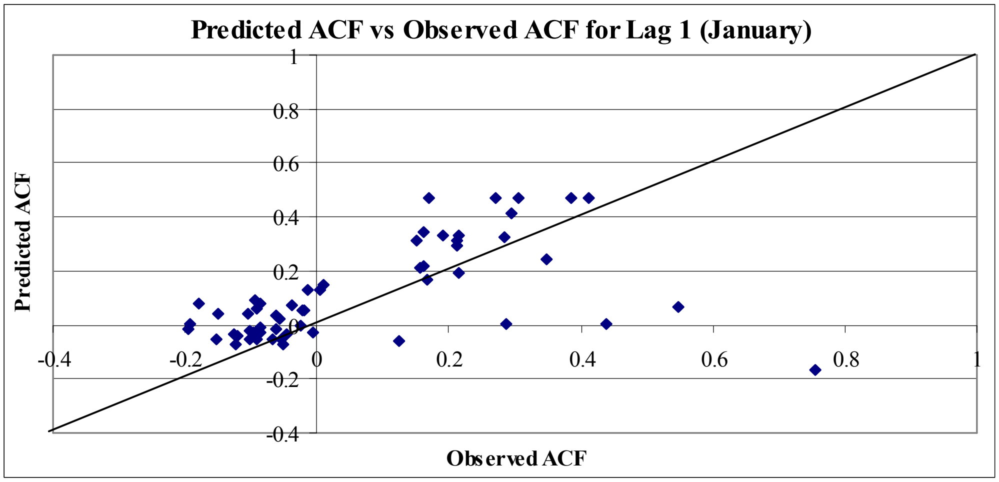

Figure B - 73

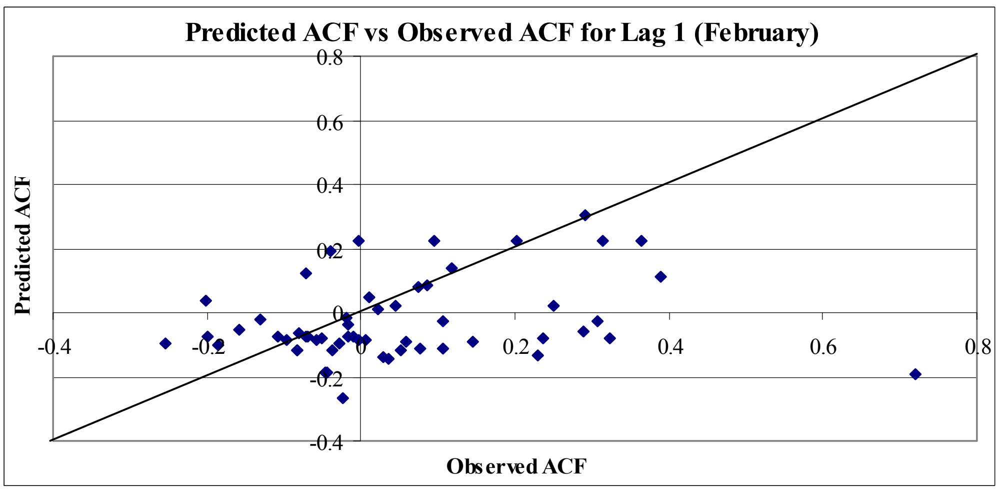

Figure B - 74

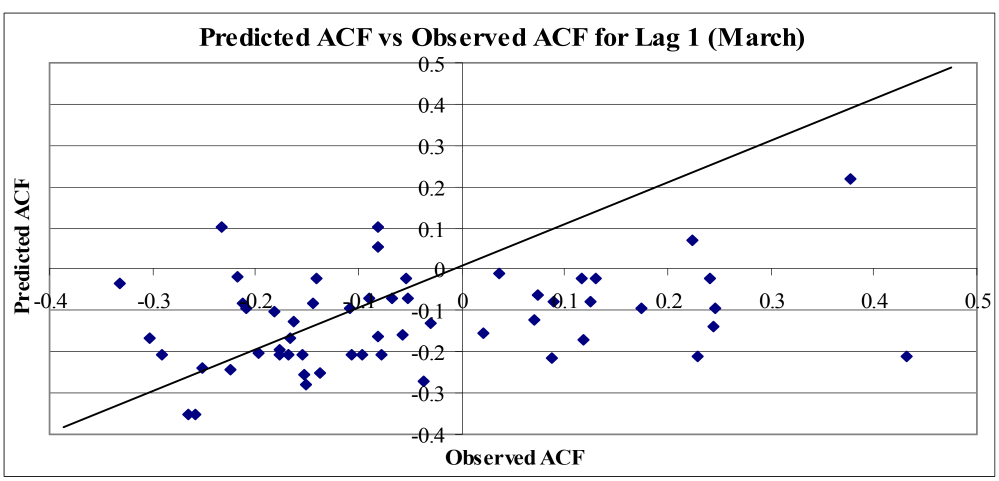

Figure B - 75

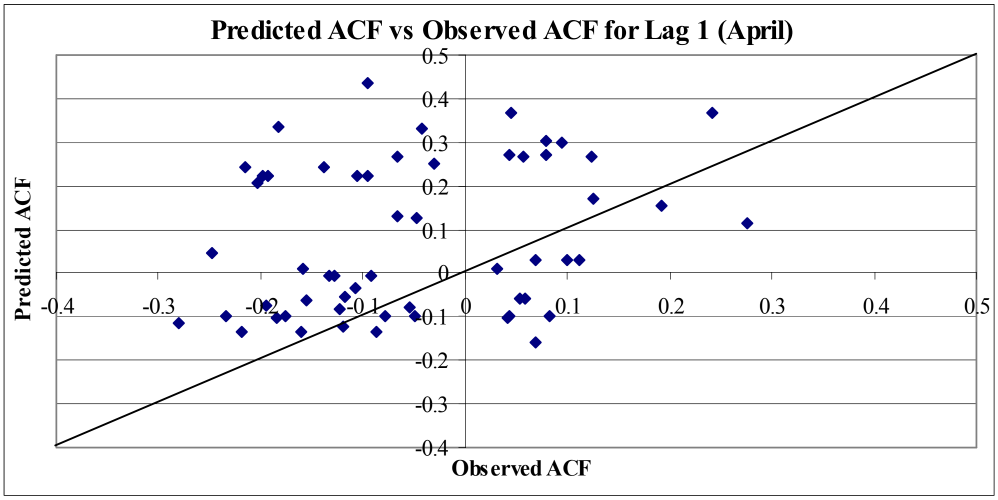

Figure B - 76

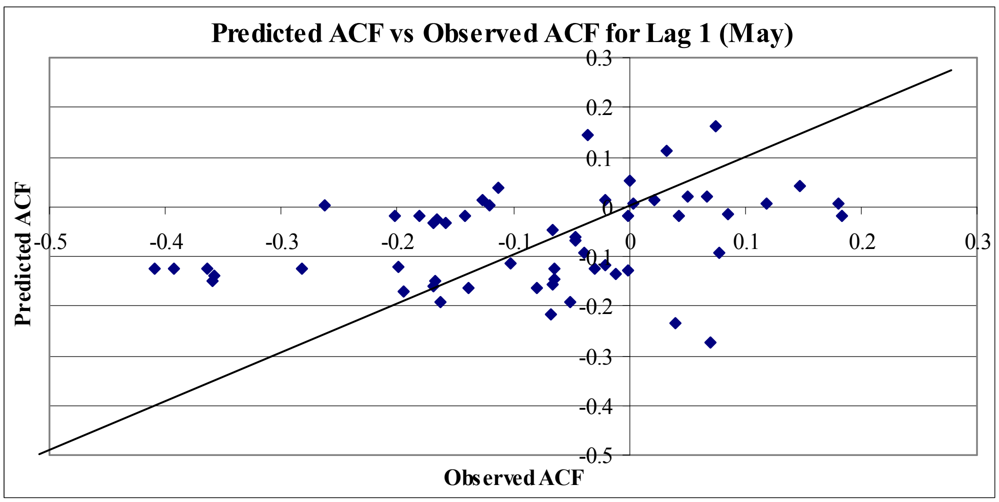

Figure B - 77

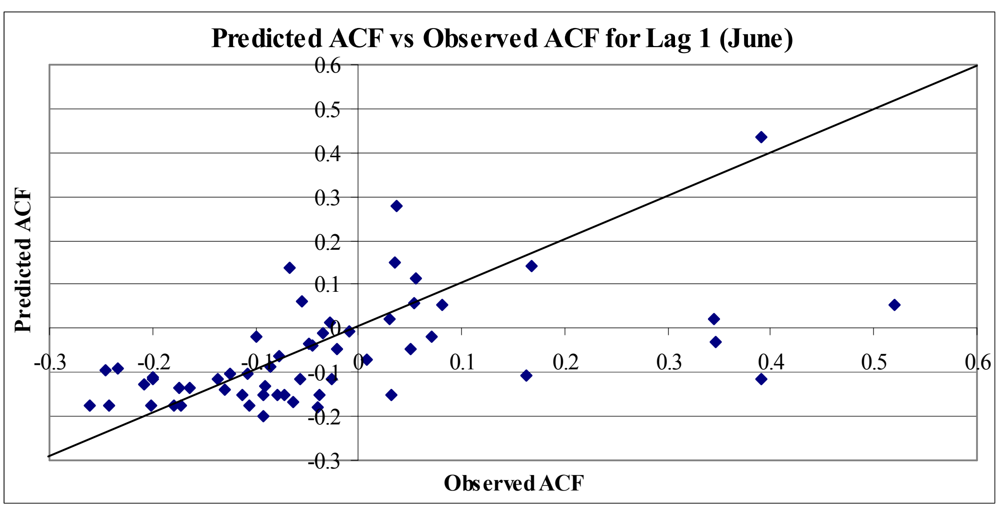

Figure B - 78

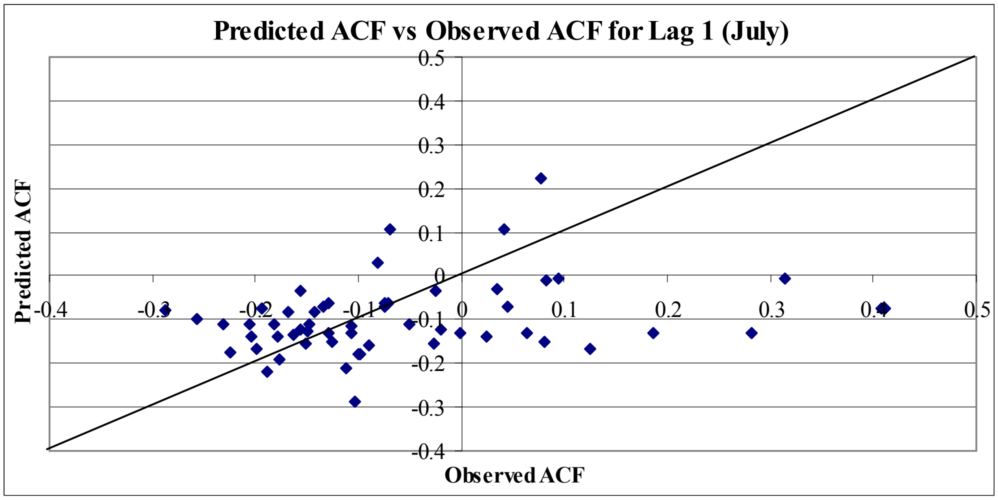

Figure B - 79

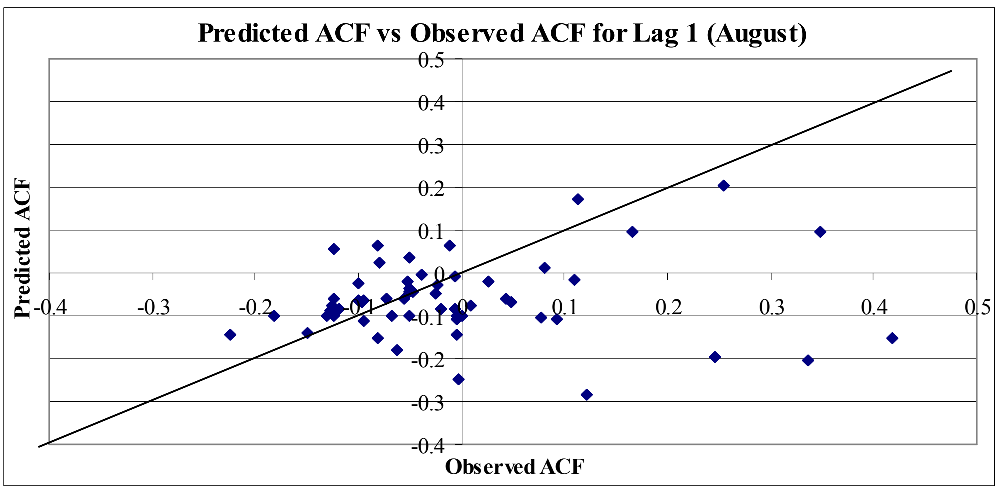

Figure B - 80

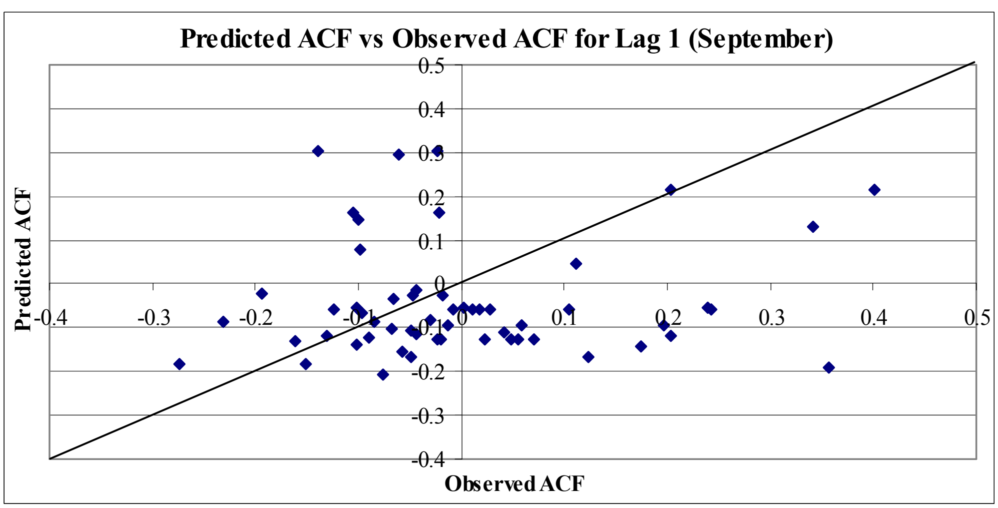

Figure B - 81

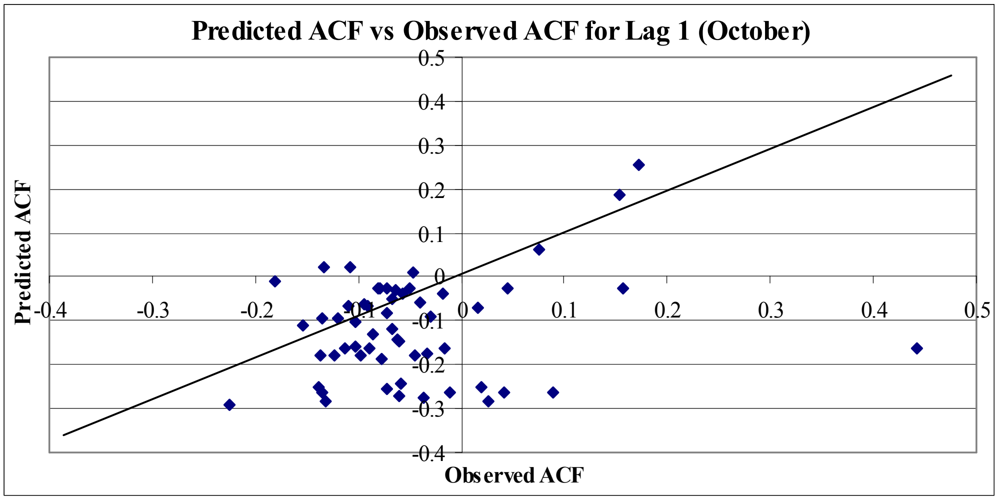

Figure B - 82

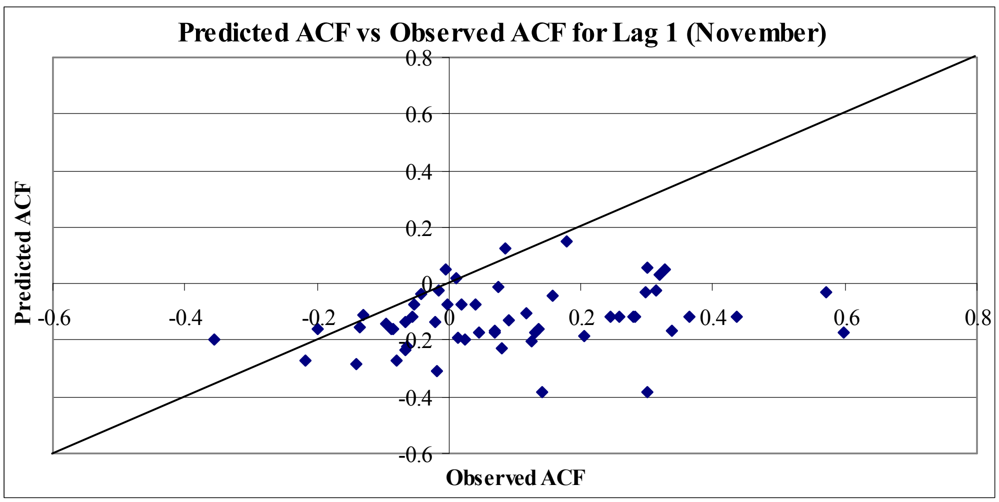

Figure B - 83

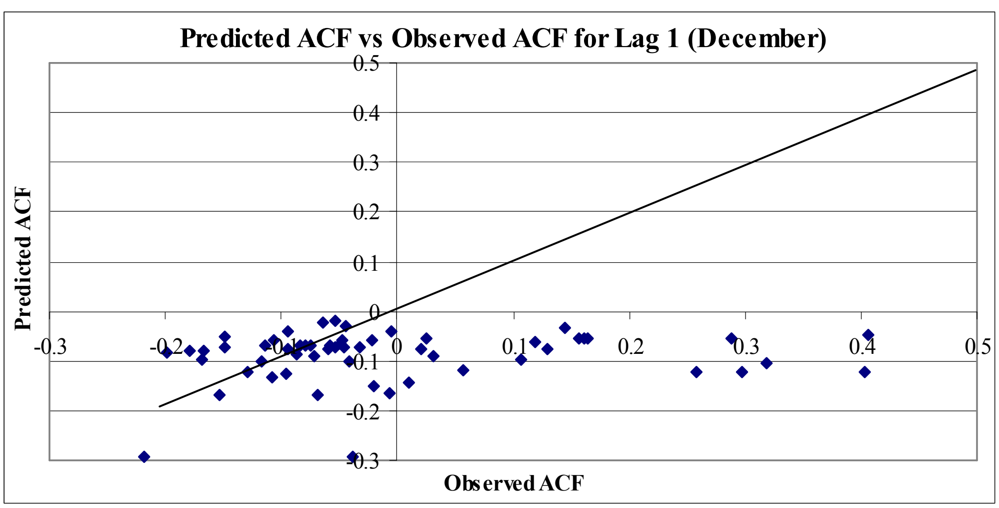

Figure B - 84

APPENDIX C

Analysis for mean monthly flow time-series for Region 12 (Texas-Gulf)

A. Graphs of predicted flow with linear method

A1. Based on precipitation and watershed parameters

1. Mean

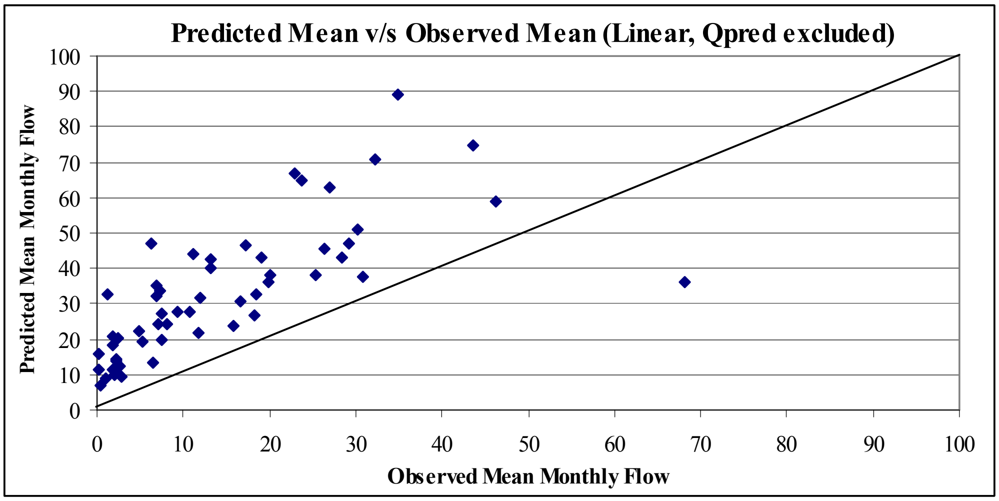

Figure C - 1

2. Standard Deviation

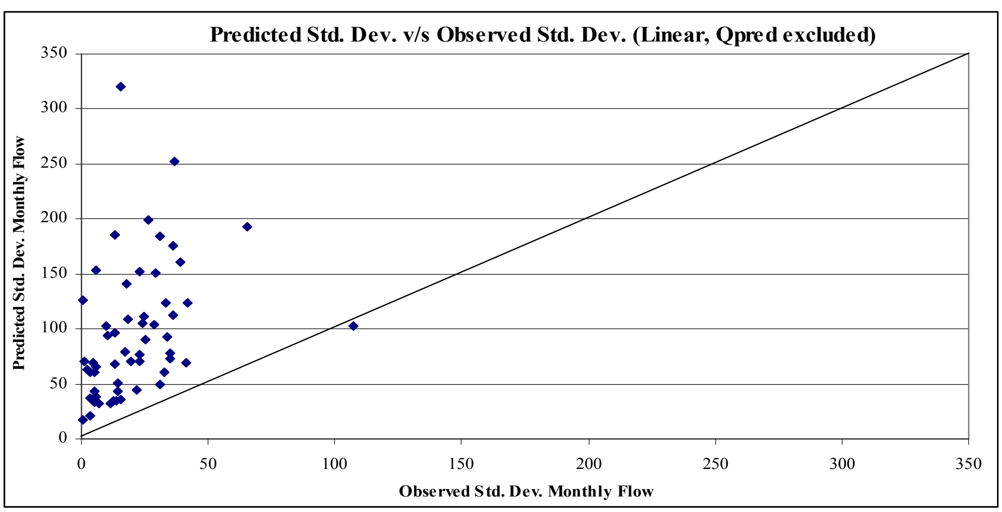

Figure C - 2

A2. Based on precipitation, watershed parameters and previous month's prediction

1. Mean

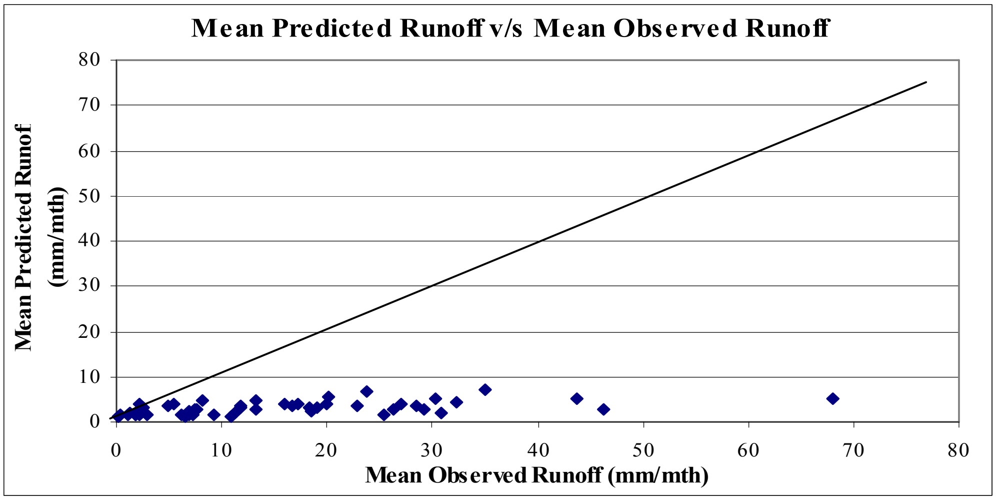

Figure C - 3

2. Standard Deviation

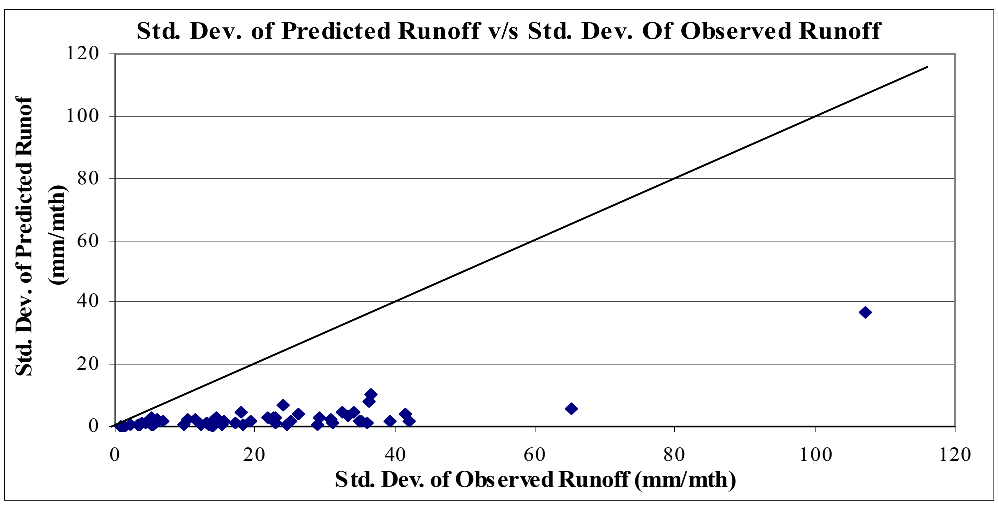

Figure C - 4

B. Graphs of predicted flow with non-linear method without watershed constant

B1. Based on precipitation and watershed parameters

1. Mean

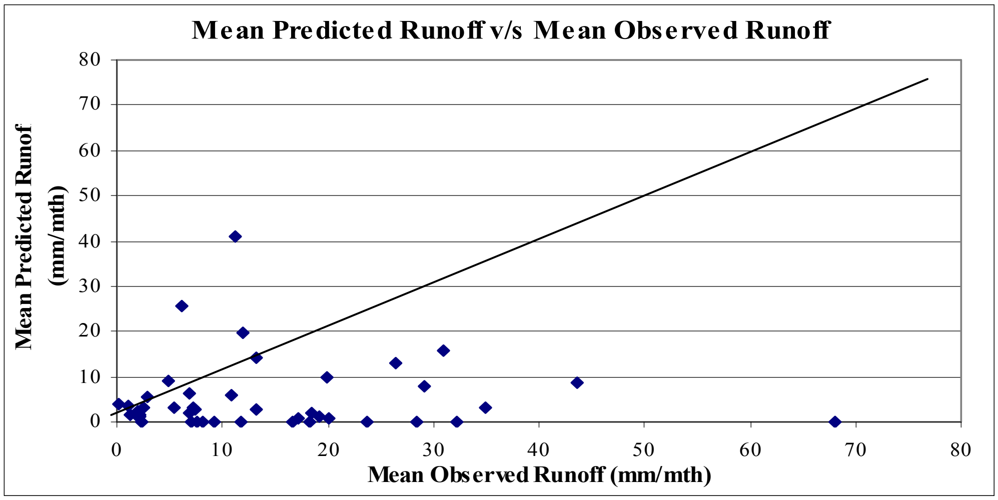

Figure C - 5

2. Standard Deviation

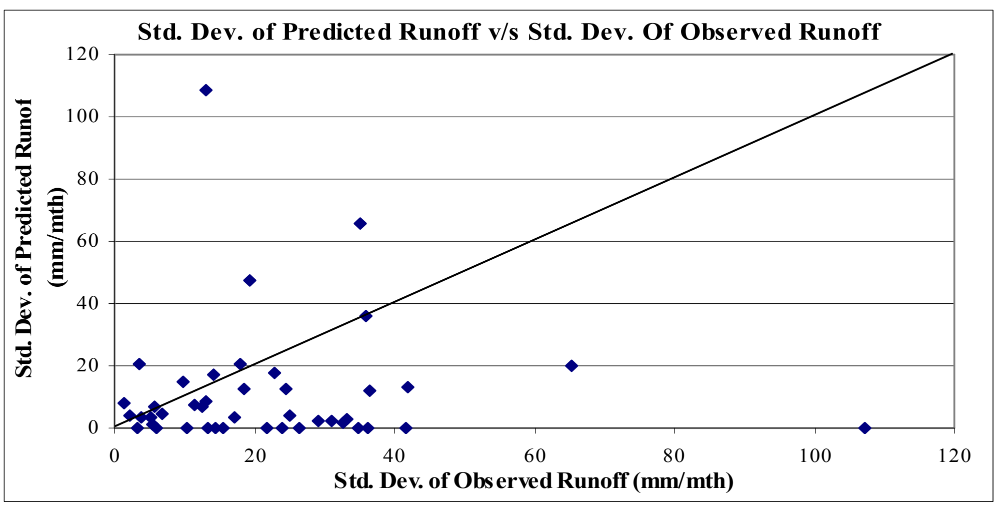

Figure C - 6

B2. Based on precipitation, watershed parameters and previous month's prediction

1. Mean

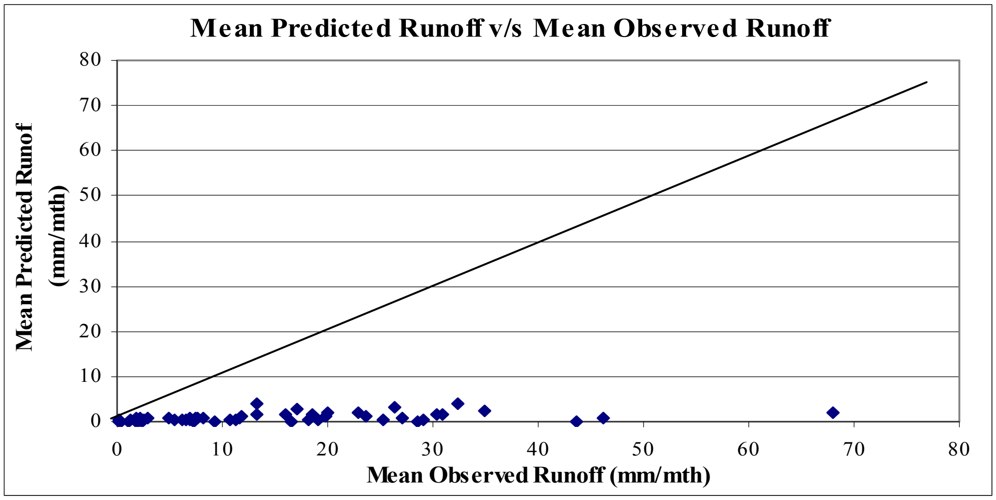

Figure C - 7

2. Standard Deviation

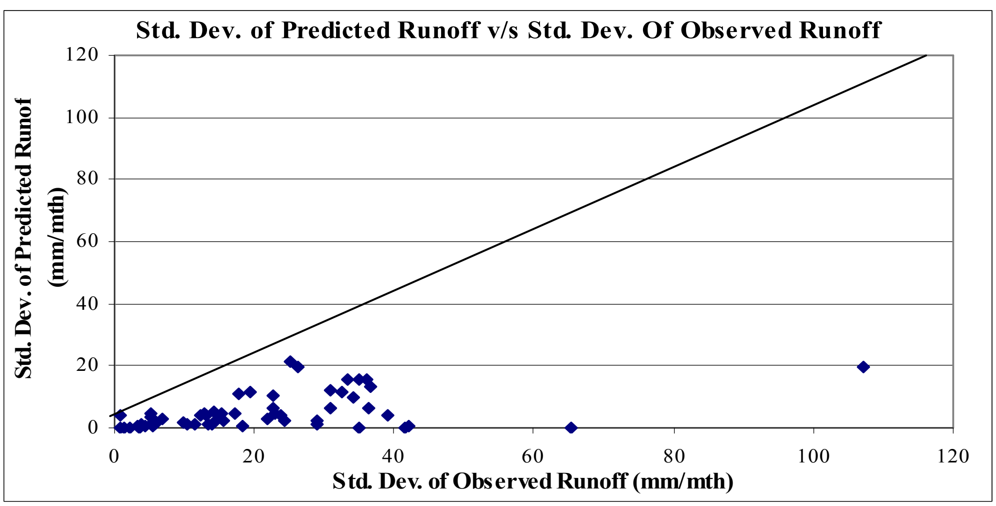

Figure C - 8

C. Graphs of predicted flow with non-linear method with watershed constant

C1. Based on precipitation and watershed constant

1. Mean

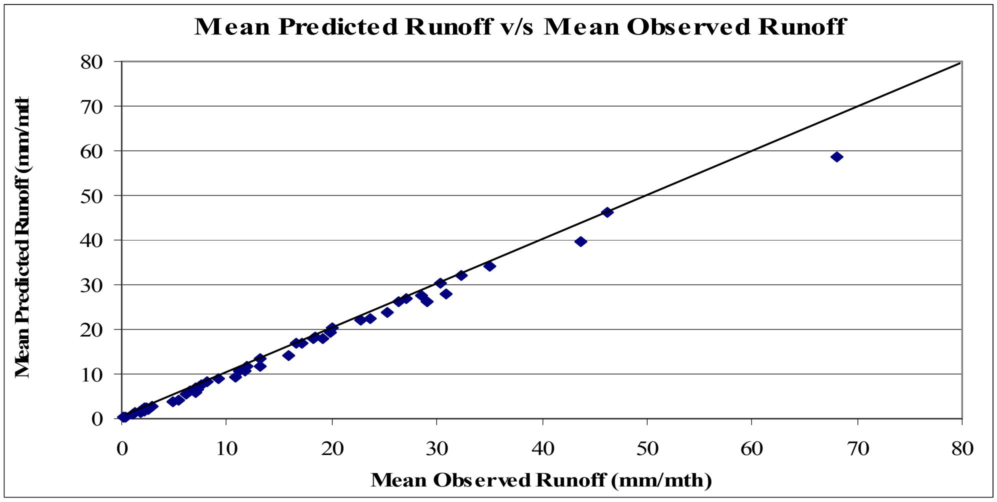

Figure C - 9

2. Standard Deviation

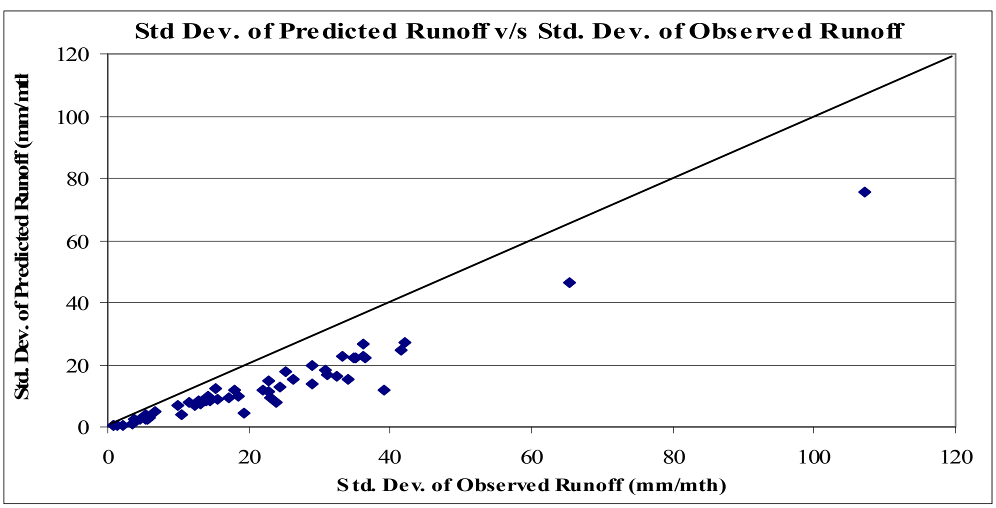

Figure C - 10

C2. Based on precipitation, previous month's prediction, and watershed constant

1. Mean

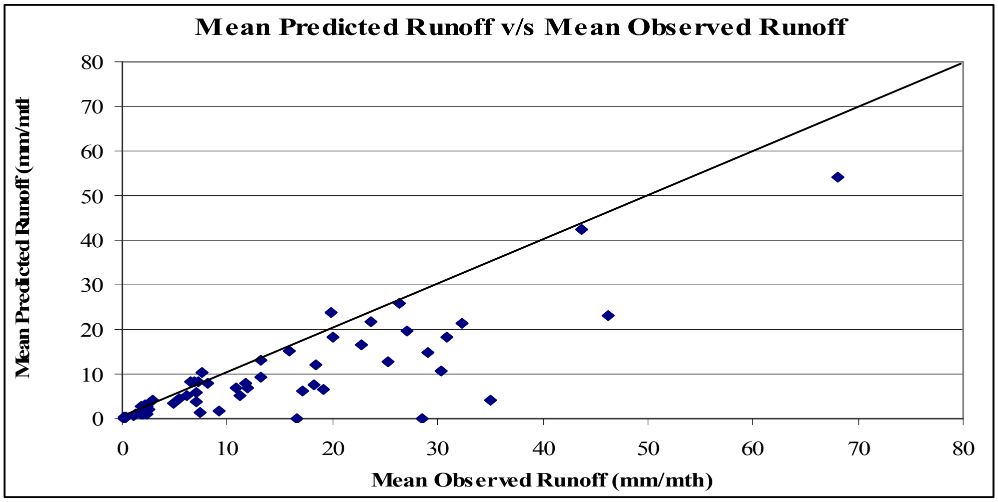

Figure C - 11

2. Standard Deviation

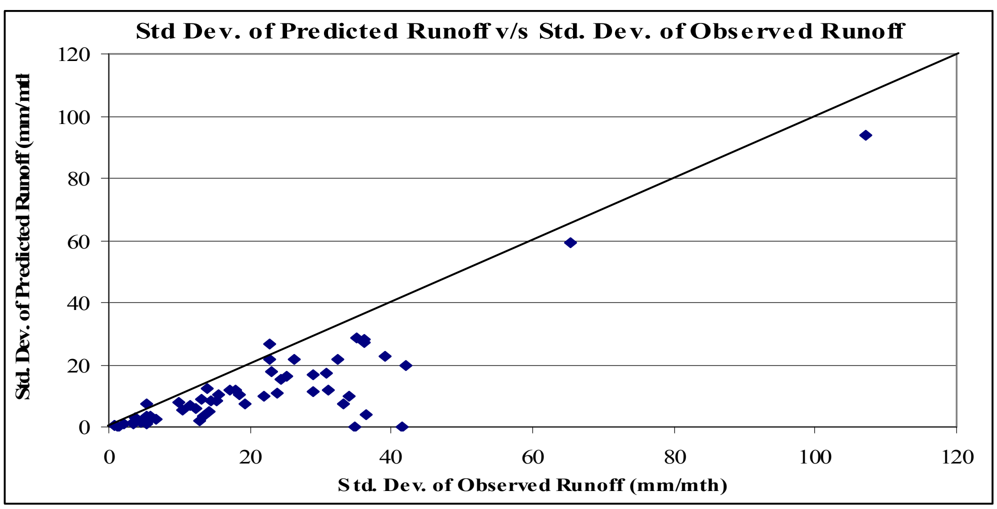

Figure C - 12

C3. Relationship of a, b, and c values with respect to slope, curve number and watershed area.

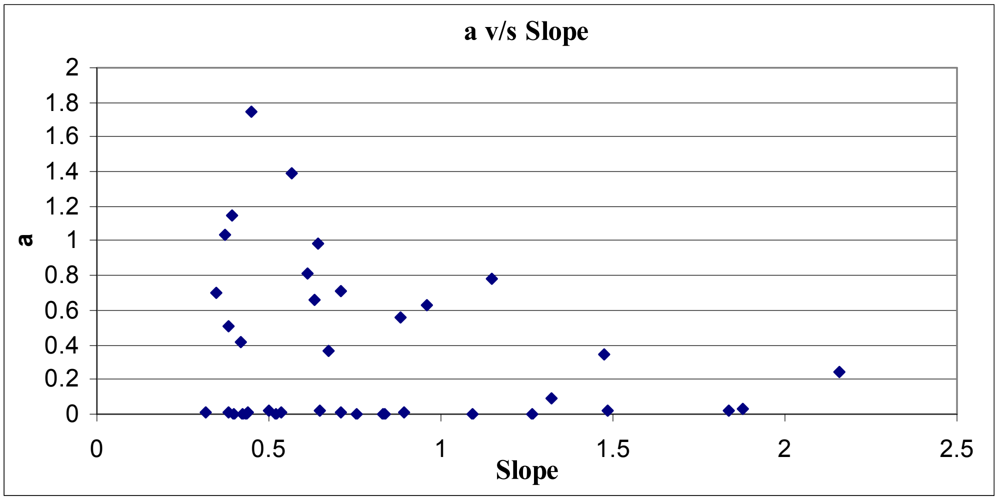

Figure C - 13

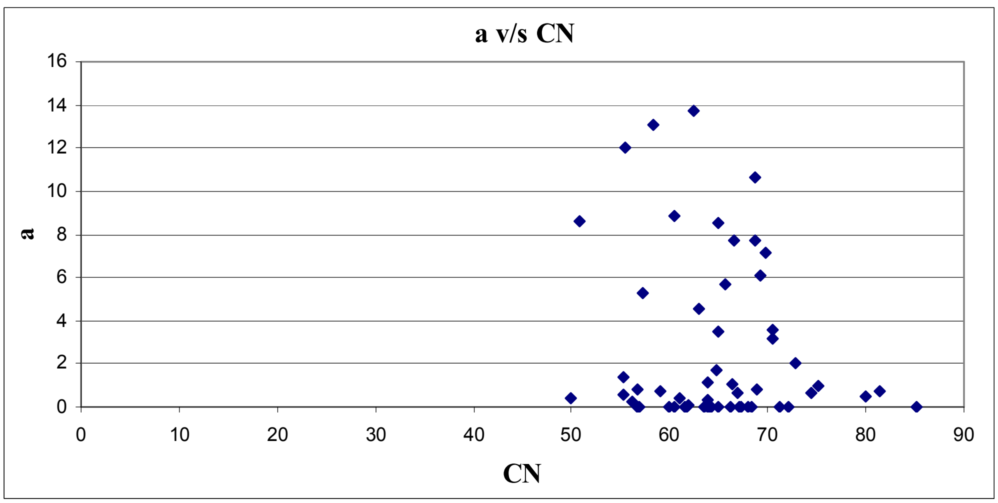

Figure C - 14

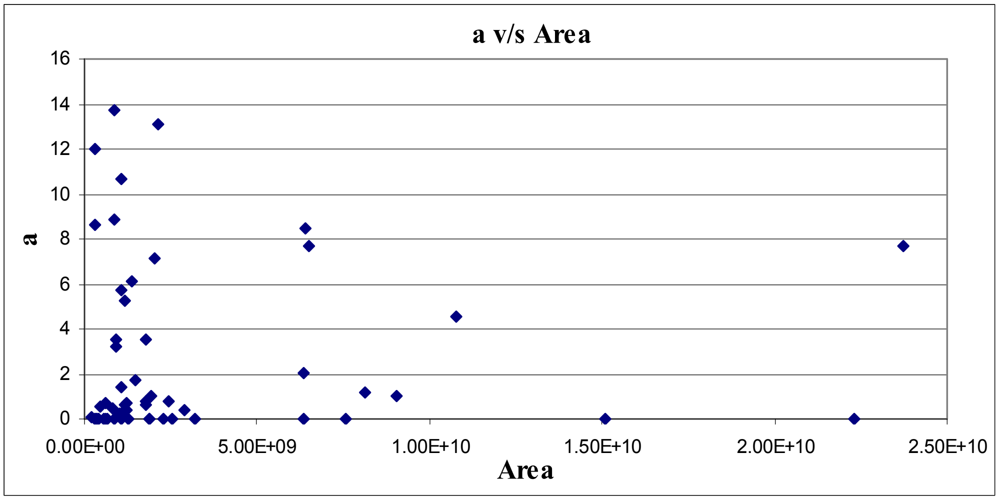

Figure C - 15

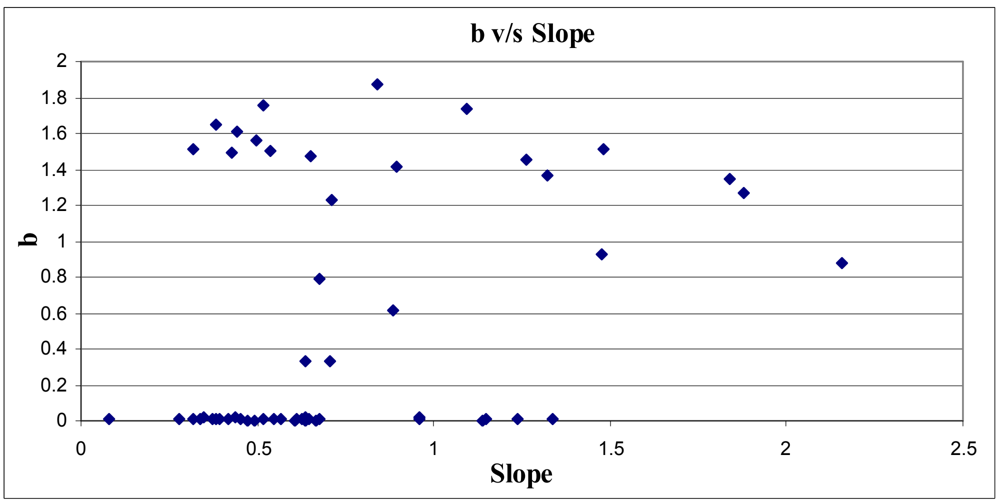

Figure C - 16

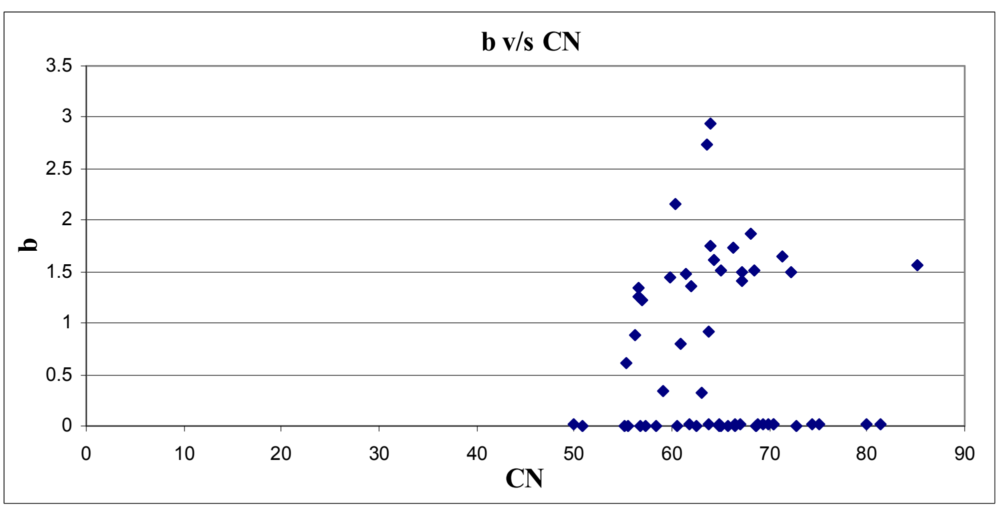

Figure C - 17

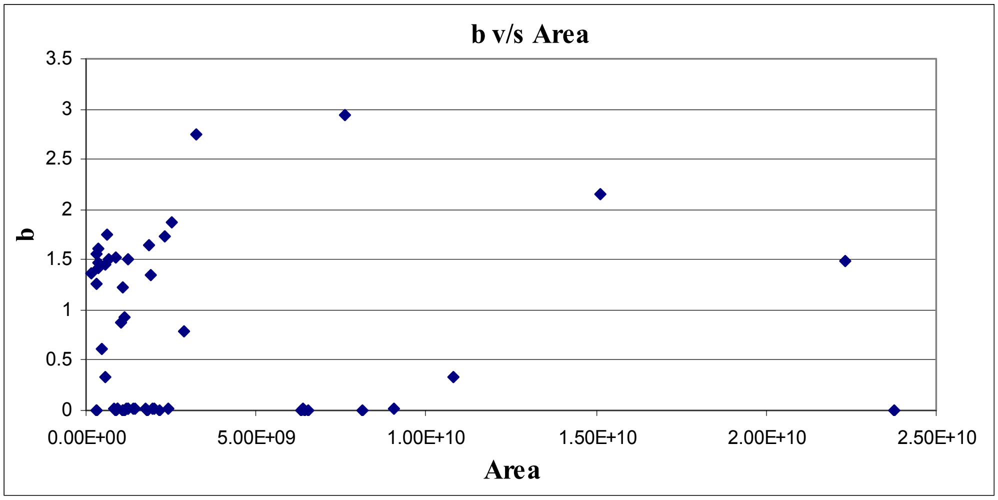

Figure C - 18

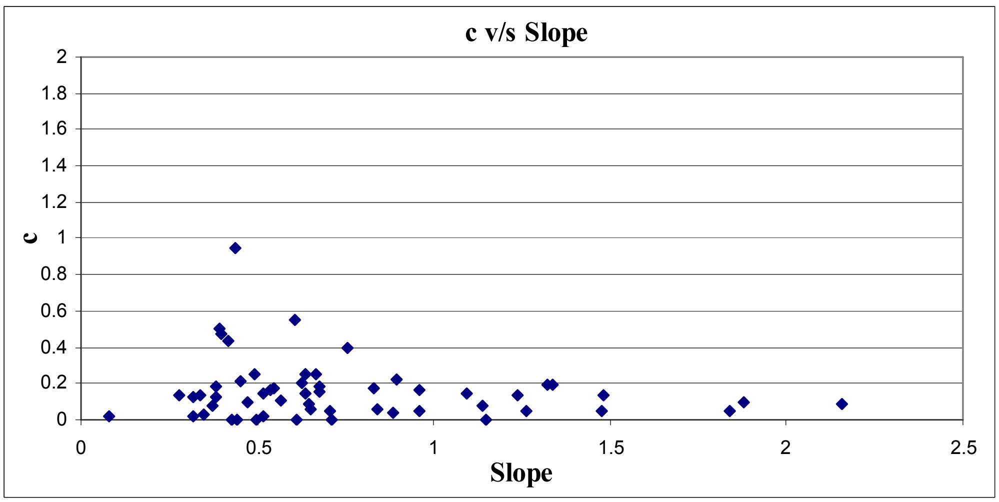

Figure C - 19

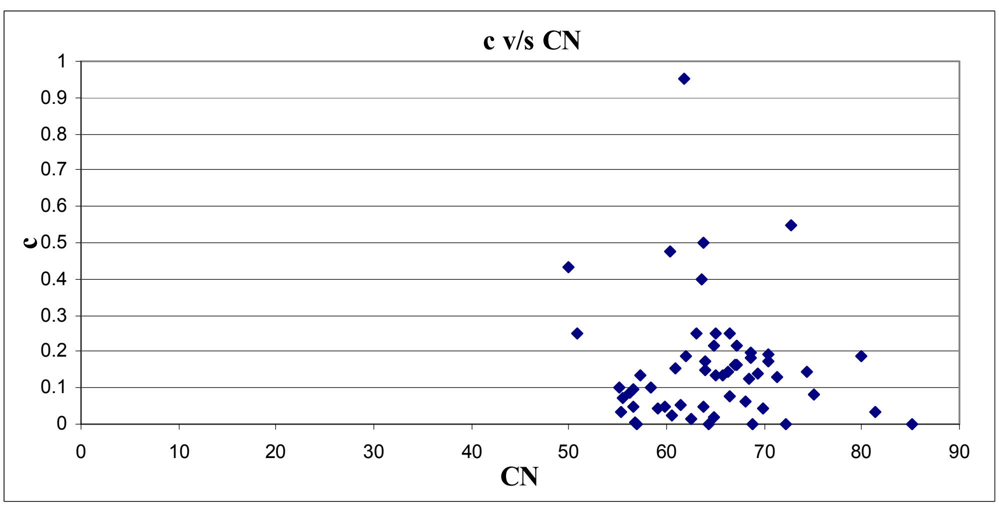

Figure C - 20

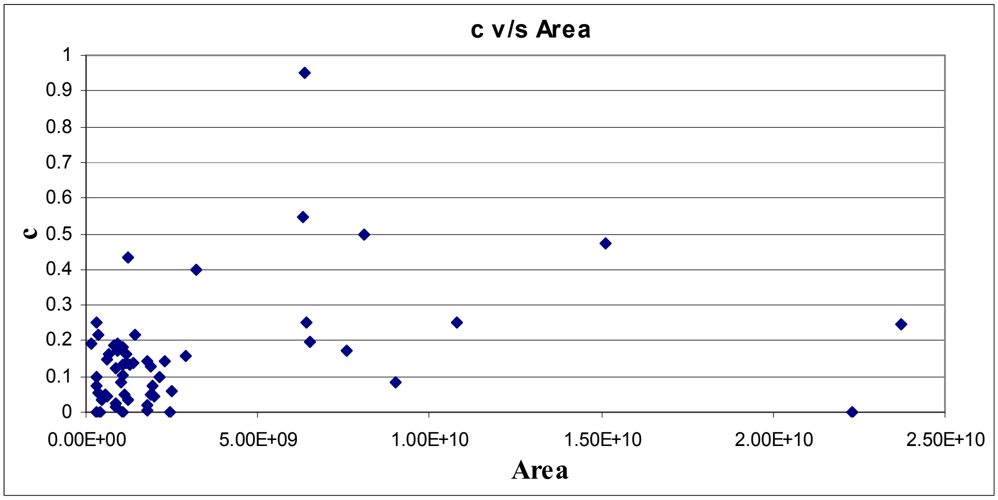
c v/s Area
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
c
0.00E+00
5.00E+09
1.00E+10
1.50E+10
2.00E+10
2.50E+10
Area

Figure C - 21

APPENDIX D

Flow Station Data

StationID	Cataloging Unit	Runoff (mm/yr)	Precipitation (mm/yr)	Slope	Curve Number	Area (km^2)
1010000	1010001	600.67	963.88	1.26	65.46	3336.00
1010500	1010001	611.54	968.98	2.18	69.75	6671.75
1011500	1010001	586.54	896.57	3.29	69.14	1370.50
1014000	1010001	593.29	932.73	2.17	69.07	14495.75
1021500	1050002	717.36	1117.47	1.03	57.96	1186.75
1022500	1050002	755.14	1044.78	1.36	59.74	583.00
1023000	1050002	666.76	1040.56	1.67	68.1	365.75
1030500	1020003	626.84	1025.65	1.01	66.46	3630.50
1031500	1020004	736.07	1033.96	2.39	68.03	757.00
1035000	1020005	612.71	1035.29	1.67	67.62	764.50
1038000	1050003	610.45	1103.05	1.45	72.22	381.75
1047000	1030003	732.83	1115.4	4.71	65.52	909.25
1048000	1030003	685.08	1120.08	3.62	67.4	1265.50
1052500	1040001	786.06	1107.97	5.54	65.48	397.50
1060000	1060001	668.32	1116.04	1.11	61.19	354.50
1064500	1060002	855.41	985.17	7.68	51.89	982.25
1074500	1070001	1019.64	927.67	9.78	61.52	282.00
1075000	1070001	926.85	954.83	9.07	53.21	482.50
1076500	1070001	757.47	945.14	6.37	50.92	1589.75
1086000	1070003	574.68	1016.28	3.43	54.8	367.75
1119500	1100002	621.09	972.2	1.97	56.6	316.00
1144000	1080105	588.35	926.38	5.65	67.69	1804.00
1176000	1080204	576.49	1069.05	1.65	65.29	385.00
1321000	2020002	756.8	1033.04	4.13	68.42	1246.50
1329000	2020003	766.45	1058.04	6.84	65.3	375.25
1329500	2020003	567.18	966.51	4.73	69.58	970.50
1334500	2020003	660.33	928.66	5.59	70.81	1290.75
1350000	2020005	683.71	1066.2	6.71	70.28	596.50
1372500	2020008	502.17	1018.78	2.11	69.47	469.50
1373500	2020008	488.19	1054.43	2.7	66.01	482.25
1379500	2030103	585.87	1214.63	1.07	72.75	263.75
1387500	2030103	669.57	1254.82	2.86	72.75	321.00
1411500	2040206	499.14	1102.27	0.11	74.29	294.50
1413500	2040102	647.77	1083.4	6.93	73.09	421.50
1420500	2040102	785.9	1122.41	4.55	70.02	616.25
1421000	2040102	783.73	1143.29	6.24	71.47	2009.50
1423000	2040101	602.05	1013.35	4.65	73.7	869.25
1426500	2040101	587.81	1042.62	4.6	72.55	1544.50
1437000	2040104	846.7	1202.75	3.52	70.82	573.50
1443500	2040105	543.1	1216.11	2.29	71.92	315.00
1463500	2040105	704.96	1248.6	2.3	72.14	17199.25

StationID	Cataloging Unit	Runoff (mm/yr)	Precipitation (mm/yr)	Slope	Curve Number	Area (km^2)
1491000	2060005	401.99	983.92	0.11	66.63	299.75
1498500	2050101	516.55	1016.54	3.32	72.02	434.25
1503000	2050101	544.36	1018.41	3.21	71.92	5606.25
1518000	2050104	405.67	862.48	3.19	76.15	724.50
1520000	2050104	340.4	907.33	3.31	76.83	783.75
1532000	2050106	456.02	894.92	3.64	76.2	561.25
1534000	2050106	490.68	1039.69	2.75	77.3	1009.75
1539000	2050107	605.1	1033.7	3.42	74.26	704.50
1541000	2050201	620.93	1101.49	2.24	70.41	786.00
1543500	2050202	574.62	1066.33	4.03	62.9	1798.50
1555500	2050301	482.68	1021.3	3.58	69.85	414.00
1556000	2050302	474.41	1070.74	4.32	66.75	764.25
1558000	2050302	593.11	1005.64	4.32	64.06	576.00
1560000	2050303	461.94	1088.38	3.51	69.18	455.00
1562000	2050303	418.81	1073.22	3.9	68.03	1946.50
1564500	2050304	419.04	1009.31	3.75	65.89	552.50
1567000	2050304	409.62	997.05	4.27	67.8	8348.99
1568000	2050305	499.74	1006.22	3.98	67.55	512.25
1574000	2050306	389.1	1012.28	1.33	77.64	1325.75
1601500	2070002	473.09	1172.67	5.15	67	654.50
1604500	2070002	271.63	1168.02	4.09	73.44	587.00
1608500	2070001	324.93	951.45	6.23	67.64	3816.25
1610000	2070003	375.99	1041.69	4.21	70.97	8122.00
1611500	2070003	312.9	823.62	4.71	67.06	1738.00
1613000	2070004	359.8	997.7	3.55	67.04	10635.75
1614000	2070004	298.47	907	2.72	70.92	601.25
1631000	2070005	332.64	749.97	3.62	72.03	4220.25
1632000	2070006	330.22	734.29	5.72	68.19	554.25
1634000	2070006	272.47	741.92	2.97	73.1	2028.00
1639500	2070009	370.57	1052.77	1.13	69.13	269.75
1644000	2070008	337.12	868.94	1.98	67.7	886.75
1645000	2070008	352.92	1050.19	0.93	57.29	267.75
1646502	2070008	353.07	925.92	2.02	71.8	30065.00
1667500	2080103	390.44	821.31	2.88	71.86	1204.00
1668000	2080104	354.79	804.56	1.82	72.2	4155.50
1674000	2080105	318.03	827.56	0.46	66.78	641.00
2013000	2080201	363.77	905.9	6.33	62.33	425.75
2014000	2080201	423.17	920	7.13	62.24	399.75
2015700	2080201	461.79	810.41	5.32	61.14	281.50
2018000	2080201	412.82	899.77	6.42	61.56	865.00
2027800	2080203	395.69	785.25	3.24	65.91	379.25
2030500	2080203	345.07	840.14	0.71	63.25	569.50
2035000	2080205	386.57	845.14	3.79	66.83	16230.00
2046000	3010201	346.74	871.84	0.3	60.01	276.00
2047000	3010201	336.99	908.09	0.31	64.66	3542.00

StationID	Cataloging Unit	Runoff (mm/yr)	Precipitation (mm/yr)	Slope	Curve Number	Area (km^2)
2051500	3010204	310.85	963.61	0.73	63.38	1399.00
2053800	3010101	343.64	957.67	3.86	67.37	291.50
2054500	3010101	314.95	952.37	4.81	72.59	687.25
2058400	3010101	367.83	886.86	1.79	64.62	924.50
2061500	3010101	353.44	834.38	2.5	67.24	797.00
2064000	3010102	299.31	839.34	0.9	69.57	449.00
2070000	3010103	427.54	971.91	1.55	64.3	275.50
2070500	3010103	401.52	1023.45	2.25	63.57	669.00
2074500	3010103	334.32	880.68	1.17	65.72	303.00
2083000	3020102	318.23	1145.97	0.46	61.04	1427.25
2085500	3020201	324.45	1094.73	0.75	68.6	374.00
2092500	3020204	394.95	1295.26	0.16	55.35	414.00
2102000	3030003	352.8	1154.73	0.62	61.36	3864.75
2105500	3030005	345.52	1135.75	0.58	60.4	13030.25
2107000	3030006	377.45	1202.18	0.21	60.45	1004.00
2110500	3040206	373.63	1272.86	0.12	61.23	2732.00
2116500	3040101	438.96	1168.15	2.47	66.11	5933.75
2117500	3040102	381.12	1163.85	1.58	66.38	260.00
2132000	3040202	355.02	1183.02	0.51	59.28	2692.25
2135000	3040204	385.93	1195.39	0.24	60.57	7084.75
2136000	3040205	278.97	1196.1	0.21	66.64	3094.50
2147500	3050103	342.53	1211.57	0.86	66.88	492.50
2154500	3050105	620.8	1362.67	2.61	65.27	314.25
2156500	3050106	501.11	1285.12	1.8	66.01	7204.75
2165000	3050109	532.45	1260.88	0.91	70.58	591.00
2173000	3050204	366.37	1168.33	0.69	56.39	1872.50
2173500	3050203	400.91	1196.03	0.7	50.17	1783.75
2174000	3050205	392.58	1191.53	0.23	64.73	4562.75
2175500	3050207	343.16	1191.71	0.38	61.89	891.75
2176500	3050208	307.83	1230.84	0.2	59.72	503.50
2177000	3060102	1106.14	1854.76	5.2	60.41	522.00
2192000	3060104	427.73	1366.39	1.03	63.72	3698.25
2193500	3060105	302.48	1222.36	0.75	60.27	759.00
2196000	3060107	248.18	1179.64	0.63	59.69	1398.50
2197830	3060108	329.85	1267.42	0.69	51.66	1223.25
2198000	3060108	333.79	1209.39	0.47	56.53	1666.00
2202000	3060202	308.63	1170.32	0.54	61.38	5010.75
2202500	3060202	298.69	1208.53	0.35	66.12	6964.00
2203000	3060203	289.49	1207.79	0.44	59.36	1463.50
2206500	3070103	382.51	1229.47	0.86	64.44	348.25
2213500	3070103	381.86	1280	0.83	61.96	484.75
2217500	3070101	463.51	1417.65	1.05	65.25	1070.75
2218500	3070101	433.31	1363.13	0.94	63.16	2807.00
2219500	3070101	439.39	1277.12	0.73	64.51	1147.25
2225500	3070107	306.46	1191.98	0.52	58.33	2882.25

StationID	Cataloging Unit	Runoff (mm/yr)	Precipitation (mm/yr)	Slope	Curve Number	Area (km^2)
2226000	3070106	347.47	1207.37	0.68	60.35	35399.50
2227500	3070202	281.82	1244.11	0.24	64.61	1655.75
2228000	3070201	292.72	1242.8	0.24	65.68	7519.25
2232500	3080101	286.35	1335.49	0.05	67.51	3932.75
2240000	3080102	313.56	1331.68	0.22	52.06	2999.75
2246000	3080103	396.71	1319.46	0.27	58.92	467.50
2296750	3100101	267.58	1352.46	0.18	65.14	3525.25
2313000	3100208	201.86	1354.07	0.19	58.37	4506.00
2317500	3110202	267.96	1206.31	0.39	63.96	3484.25
2320500	3110205	315.4	1269.23	0.23	57.75	20888.25
2321500	3110206	269.18	1341.3	0.17	59.77	1460.00
2324000	3110102	332.83	1346.46	0.08	49.73	951.25
2327100	3120003	667.62	1572.11	0.1	56.69	274.00
2327500	3120002	308.57	1205.89	0.45	65.64	1450.25
2329000	3120003	319.18	1330.51	0.57	60.4	2869.75
2331000	3130001	966.26	1494.15	4.2	57.29	407.50
2331600	3130001	893.48	1573.95	2.22	61.81	820.25
2333500	3130001	825.28	1532.1	3.65	60.84	377.50
2337000	3130002	472.87	1307.94	0.9	64.17	620.25
2339500	3130002	482.09	1228.19	1.06	62.58	9145.50
2341800	3130003	453.69	1317.1	1	51.18	905.25
2342500	3130003	456.76	1324.25	0.79	54.49	848.25
2347500	3130005	421.84	1302.98	0.82	63.02	4785.25
2349500	3130006	419.91	1300.33	0.89	59.17	7419.75
2350600	3130007	375.82	1387.28	0.94	61.4	505.00
2353500	3130009	425.48	1259.67	0.53	62.31	1673.25
2356000	3130008	359.26	1182.68	0.4	63.89	19526.25
2357000	3130010	303.86	1218.58	0.27	68.7	1226.75
2358000	3130011	439.97	1315.88	0.74	58.52	44712.25
2359500	3140101	1510.76	1542.59	0.55	32.73	314.50
2361000	3140201	461.03	1321.19	0.81	48.82	1833.75
2366500	3140203	533.52	1416.71	0.59	58.64	11484.00
2368000	3140103	612.56	1520.23	0.53	65.25	1692.25
2369000	3140103	771.87	1570.81	0.53	55.65	1170.25
2371500	3140301	427.56	1322.15	0.68	68.18	1264.25
2375500	3140305	542.68	1463.82	0.69	66.63	9901.75
2376500	3140106	644.22	1618.97	0.5	53.31	999.00
2379500	3150102	777.46	1550.85	3.86	64.52	335.00
2380500	3150102	767.22	1545.47	4.49	65.18	638.25
2383500	3150102	638.51	1470.76	2.01	66	2213.75
2387500	3150103	617.51	1470.21	2.39	67.08	4159.00
2389000	3150104	893.79	1545.44	2.93	66.35	288.25
2392000	3150104	691.37	1504.51	2.04	66.19	1609.00
2397500	3150105	476.07	1347.18	1.08	65.01	297.00
2398000	3150105	647.9	1440.9	2.36	61.31	508.00

StationID	Cataloging Unit	Runoff (mm/yr)	Precipitation (mm/yr)	Slope	Curve Number	Area (km^2)
2414500	3150109	550.87	1356.88	1.23	66.21	4311.25
2431000	3160101	580.75	1396.38	0.59	67.33	1659.75
2433000	3160101	608.75	1409.52	0.93	67.35	901.00
2436500	3160102	544.71	1399.57	0.48	70.49	1662.50
2437000	3160101	585.16	1419.18	0.51	69.72	5111.25
2439400	3160103	599.57	1420.34	1.12	65.6	2058.50
2440000	3160104	411.18	1375.65	0.58	63.79	414.00
2440500	3160104	510.01	1394.33	0.41	67.1	1304.75
2441000	3160104	533.38	1405.84	0.43	70.86	2508.75
2441500	3160101	547.05	1406.68	0.45	68.66	11802.00
2448000	3160108	497.53	1410.28	0.58	68.37	1972.25
2450000	3160109	646	1443.98	1.06	68.65	959.25
2456500	3160111	560.73	1453.97	1.55	65.26	2259.00
2467000	3160201	532.83	1400.93	0.92	63.6	40019.75
2467500	3160202	464.09	1412.72	0.74	65.45	1620.25
2474500	3170005	514.82	1455.07	0.62	65.05	1587.00
2479000	3170006	519.23	1469.75	0.66	65.88	17117.50
2479300	3170007	672.87	1518.44	0.56	60.7	1146.50
2486000	3180002	428.46	1355.81	0.5	67.53	8114.75
2488500	3180003	472.21	1437.01	0.61	68.68	12804.25
2489500	3180004	528.28	1456.33	0.68	65.46	16843.25
2490500	3180005	545.49	1500.92	0.5	75.46	1289.00
2492000	3180005	554.51	1526.68	0.49	74.31	3119.00
3010500	5010001	583.01	1015.96	3.51	61.55	1407.50
3011020	5010001	590.55	990.03	3.65	66.41	4146.00
3032500	5010006	583.88	1072.92	1.9	72.83	1350.00
3042000	5010007	661.92	1106.38	2.19	64.39	481.75
3049000	5010009	488.34	992.2	1.62	74.76	361.50
3069500	5020004	838.14	1253.27	5.55	70.35	1788.00
3075500	5020006	780.67	1201.91	1.97	76.48	330.25
3080000	5020006	761.16	1106	2.91	67.28	310.00
3106000	5030105	440.59	968.76	1.45	74.24	935.25
3109500	5030101	367.08	961.26	1.26	78.17	1223.00
3116000	5040001	316.98	916.03	0.67	81.32	432.25
3132000	5040002	353.71	898.67	0.91	82.72	361.75
3137000	5040003	361.58	926.17	0.76	82.88	1121.25
3144000	5040004	373.29	985.04	1.17	80.24	373.25
3161000	5050001	734.29	1259.66	4.06	63.8	505.25
3164000	5050001	592.34	1156.79	4.15	65.42	2893.75
3167000	5050001	386.87	976.99	3.29	72.8	664.25
3167500	5050001	487.31	1101.81	2.76	70.3	687.00
3170000	5050001	411.52	1009.83	2.32	69	782.25
3173000	5050002	375.29	961.53	5.4	68.39	764.25
3175500	5050002	477.95	965.58	7.47	65.98	590.25
3179000	5050002	407.17	1002.68	3.59	72.41	1001.50

StationID	Cataloging Unit	Runoff (mm/yr)	Precipitation (mm/yr)	Slope	Curve Number	Area (km^2)
3180500	5050003	683.15	1166.65	4.81	69.2	346.25
3182500	5050003	575.32	980.08	5.35	67.71	1380.50
3183500	5050003	502.23	942.23	4.65	68.59	3426.50
3186500	5050005	931.22	975.33	6.89	70.68	328.50
3193000	5050006	503.68	1010.88	4.26	70.62	21416.50
3198500	5050009	473.92	1025.41	5.78	71.72	1020.25
3202000	5090101	366.68	1016.76	1.18	67.2	1448.00
3204500	5070102	410.51	1044.61	2.46	69.13	656.75
3234500	5060002	314.8	959.26	0.54	80.32	13823.00
3237500	5090201	401.68	1061.02	1.14	76.75	976.00
3248500	5100101	434.07	1141.97	2.16	62.94	350.75
3252500	5100102	418.93	1138.33	0.61	83.58	1582.25
3253500	5100101	430.84	1129.2	1.51	72.53	8356.00
3265000	5080001	307	919.59	0.19	84.46	1249.00
3266000	5080001	316.75	918.62	0.26	84.79	1609.50
3269500	5080001	325.61	941.32	0.46	82.28	1211.75
3274000	5080002	320.45	949.08	0.46	82.73	9118.00
3275000	5080003	380.93	992.91	0.41	80.18	1325.00
3281500	5100203	514.47	1226.57	3.31	56.89	1903.75
3285000	5100205	500.9	1195.76	1.25	75.56	826.75
3298000	5140102	431.44	1131.25	0.72	83.36	375.25
3301500	5140103	488.29	1226.85	1.36	75.86	3354.75
3307000	5110001	555.47	1288.97	0.97	77.41	489.50
3310300	5110001	462.87	1269.72	0.54	77.19	917.50
3320500	5110006	510.6	1269.25	1.23	74.93	510.00
3326500	5120103	313.49	949.1	0.15	84.28	1789.00
3334500	5120107	341.13	974.43	0.23	80.73	618.00
3335500	5120108	317.88	931.96	0.23	80.02	18402.50
3339500	5120110	343.49	1004.24	0.21	81.82	1287.00
3340800	5120108	349.75	1028.01	0.37	80.98	343.75
3345500	5120112	279.9	906.33	0.25	76.7	4054.25
3346000	5120112	284.75	929.44	0.32	76.96	809.00
3351500	5120201	341.82	980.76	0.18	82.32	459.50
3360500	5120202	364.28	1025.04	0.54	79.35	12716.00
3373500	5120208	390.17	1057.32	0.69	77.12	12393.75
3374000	5120202	380.47	1043.78	0.46	80.02	27394.25
3379500	5120114	279.69	904.48	0.25	75.18	2918.75
3380500	5120115	302.83	942.61	0.36	78.14	1213.75
3381500	5120114	297.07	941.64	0.32	80.93	8065.75
3416000	5130105	618.36	1446.44	3.96	67.51	276.75
3434500	5130204	515.87	1322.55	1.23	68.92	1682.25
3436000	5130206	480.65	1286.9	0.8	75.2	483.00
3438000	5130205	515.04	1282.45	0.52	79.4	615.25
3439500	6010105	1228.64	1373.12	4.84	59.21	272.50
3448000	6010105	878.95	1378.39	4.25	63.62	1751.50

StationID	Cataloging Unit	Runoff (mm/yr)	Precipitation (mm/yr)	Slope	Curve Number	Area (km^2)
3451500	6010105	745.14	1316.14	6.23	65.71	2457.00
3453000	6010105	338.44	1107.05	6.42	62.02	424.00
3454000	6010105	515	1054.97	7.31	64.29	332.75
3465500	6010108	591.57	1207.05	7.6	62.18	2045.75
3473000	6010102	552.32	1107.64	5.22	70.42	778.25
3488000	6010101	470.04	968.05	6.1	70.24	569.75
3497300	6010201	887.12	1123.49	9.2	58.76	272.50
3500000	6010202	951.66	1896.68	6.73	60.27	368.75
3512000	6010203	945.52	1189.35	10.01	56.05	484.25
3518500	6010204	843.34	1571.44	6.8	56.61	301.50
3524000	6010205	468.41	989.92	4.63	70.07	1338.75
3528000	6010205	480.95	1057.82	4.4	68.09	3735.50
3532000	6010206	580.97	1153.16	4.83	72.12	1855.50
3540500	6010208	678.95	1452.65	2.77	63.68	1897.00
3550000	6020002	832.53	1716.02	7.08	58.19	275.00
3558000	6020003	960.91	1521.07	4.56	57.66	436.00
3574500	6030002	757.86	1424.81	5.76	69.36	809.75
3575000	6030002	578.76	1404.72	0.91	78.07	864.25
3586500	6030005	560.08	1311.29	0.66	72.55	424.75
3592500	6030006	620.83	1329.08	1.12	68.39	1693.75
3603000	6040003	582.15	1375.81	1.13	67.88	6622.25
3604000	6040004	600.13	1366.51	1.13	63.34	1144.00
3604500	6040004	592.98	1367.85	1.56	59.41	1840.75
4010500	4010101	291.84	795.64	1.96	67.15	1587.25
4025500	4010301	498.94	763.83	0.78	42.14	305.00
4033000	4020102	364.77	800.7	0.75	58.53	425.00
4071000	4030104	277.19	772.22	0.56	49.31	1743.75
4081000	4030202	279.85	759.93	0.67	60.83	667.25
4085200	4030102	233.05	784.38	0.64	79.98	343.50
4087000	4040003	225.32	778.31	0.6	78.63	1748.25
4093000	4040001	310.25	929.03	0.29	83.27	335.00
4128000	4070004	378.81	783.11	1.31	40.82	530.50
4142000	4080101	339.73	780.28	0.73	51.04	856.75
4173500	4090005	214.03	816.87	0.41	70.27	330.50
4198000	4100011	291.06	922.31	0.21	83.04	3080.00
4212000	4110004	413.77	968.37	0.52	69.97	1489.25
4221000	4130002	469.45	948.38	2.95	74.49	752.25
4221500	4130002	421.94	891.29	3.56	72.89	794.75
4293500	2010007	664.35	1016.3	4.31	63.91	1219.25
5057200	9020203	8.04	455.46	0.2	81.57	1750.50
5062500	9020108	75.15	630.25	0.47	67.09	2262.25
5064900	9020109	18.43	508.79	0.32	82.42	402.75
5066500	9020109	24.64	500.54	0.27	79.56	3178.25
5078000	9020305	119.03	627.39	0.34	59.08	1288.00
5078500	9020305	88.12	614.36	0.25	72.68	3690.75

StationID	Cataloging Unit	Runoff (mm/yr)	Precipitation (mm/yr)	Slope	Curve Number	Area (km^2)
5099300	9020313	22.59	458.77	0.4	81.87	7582.50
5099600	9020313	24.28	453.48	0.79	79.36	8483.00
5107500	9020314	85.32	527.76	0.13	56.57	3004.00
5275000	7010203	135.73	722.52	0.29	66.45	1546.75
5280000	7010204	120.83	701.23	0.28	77.59	6661.25
5286000	7010207	178.82	728.09	0.24	66.96	3523.75
5300000	7020003	53.6	621.3	0.35	76.86	2607.50
5320500	7020011	152.5	778.22	0.28	78.57	2809.50
5333500	7030001	303.5	745.44	0.57	44.37	4093.00
5336700	7030003	298.57	767.58	0.4	61.22	2265.25
5340500	7030005	270.13	745.93	0.42	61.36	16206.50
5362000	7050004	305.21	812.16	0.5	64.81	1544.00
5374000	7040004	169.93	753.1	0.74	76.71	2976.00
5376000	7040003	171.76	845.41	0.92	76.68	267.50
5379500	7040005	236.62	823.32	1.42	67.72	1671.50
5381000	7040007	273.73	810.52	0.48	78.37	1933.50
5383000	7040006	234.18	797.64	1.8	62.82	1049.00
5384000	7040008	198.9	790.69	0.89	75.09	1589.75
5385000	7040008	193.5	805.65	1.58	71.17	3215.50
5387500	7060002	220.98	827.54	0.71	76.65	1317.50
5397500	7070002	227.3	807.67	0.43	63.05	975.00
5399500	7070002	267.42	813.38	0.5	81.77	597.25
5405000	7070004	210.24	813.18	1.54	73.13	1528.75
5410490	7070006	252.11	814.42	2.11	67.84	1769.25
5412500	7060003	226.13	834.45	0.91	76.51	3886.00
5413500	7060003	216.92	822.99	1.22	76.26	694.25
5414000	7060003	243.1	832.09	1.28	76.42	376.25
5418500	7060006	240.01	841.11	0.76	76.47	3957.25
5419000	7060005	257.47	837.2	1.18	76.01	625.50
5421000	7080102	214.87	831.92	0.41	76.75	2678.00
5422000	7080103	236.5	841.81	0.53	76.36	6029.50
5430500	7090001	202.29	820.5	0.52	75.7	8712.50
5431486	7090001	225.55	822.19	0.44	77.36	509.25
5432500	7090003	235.46	857.82	1.04	77.41	708.75
5433000	7090003	231.65	860.68	1.33	76.54	568.00
5434500	7090003	244.96	859.81	1.09	77.83	2680.00
5435500	7090003	241.58	855.84	0.84	77.75	3452.25
5436500	7090004	237.58	855.3	0.94	75.88	1347.75
5440000	7090006	241.46	803.04	0.37	77.66	2853.50
5440500	7090006	185.84	754.3	0.32	77.99	306.25
5444000	7090005	242.95	793.58	0.67	77.75	366.50
5446500	7090005	232.51	819.99	0.52	76.84	25458.73
5451500	7080208	192.11	820.67	0.4	77.5	3891.25
5454500	7080209	128.68	770.95	0.67	76.28	8123.49
5455500	7080209	226.96	869.85	0.73	77.9	1506.50

StationID	Cataloging Unit	Runoff (mm/yr)	Precipitation (mm/yr)	Slope	Curve Number	Area (km^2)
5457000	7080201	174.37	792.64	0.27	77.06	1087.00
5457700	7080201	233.31	851.03	0.32	77.03	2772.75
5458000	7080201	198.04	823.62	0.4	77.19	832.25
5458500	7080201	200.73	809.49	0.44	76.27	4401.00
5459500	7080203	183.82	794.16	0.38	78.4	1319.00
5464000	7080205	203.33	814.6	0.42	77.4	13129.75
5464500	7080205	206.29	826.61	0.52	76.77	16673.00
5465500	7080209	135.93	666.57	0.54	76.87	31982.73
5470500	7080105	243.18	843	0.37	77.92	541.50
5472500	7080106	205.73	878.44	0.71	78	1882.50
5474000	7080107	209.98	864.31	0.54	78.43	11012.24
5481300	7100004	144.31	761.8	0.31	78.13	14638.75
5482500	7100006	158.35	774.1	0.33	77.83	4101.25
5484000	7100007	163.03	791.83	0.81	78.09	2561.25
5484500	7100006	165.45	787	0.4	77.91	8747.74
5486490	7100008	169.63	848.23	0.94	76.97	1311.50
5489000	7100009	202.36	902.37	0.82	81.39	983.75
5490500	7080107	124.87	769.55	0.74	78.94	36735.24
5495000	7100009	235.79	898.2	0.58	79.05	1043.75
5497000	7110002	230.78	912.63	0.61	81.62	1158.25
5498000	7110002	238.9	915.3	0.62	81.66	1001.75
5500000	7110003	226.88	916.29	0.49	79.88	1578.00
5501000	7110004	242.69	918.43	0.54	71.52	932.00
5506500	7110006	247.07	947.01	0.5	78.37	885.00
5514500	7110008	228.87	921.7	0.51	69.01	2380.25
5520500	7120001	326.26	963.89	0.2	74.39	5678.99
5525000	7120002	286.01	896.18	0.18	74.84	1744.25
5527500	7120001	307.9	901.63	0.18	75.31	13296.49
5542000	7120005	257.04	788.21	0.16	78.36	1158.50
5546500	7120006	229.41	845.98	0.63	77.73	2231.25
5555300	7130002	296.9	844.94	0.21	77.18	3079.00
5555500	7130002	195.33	771.32	0.5	78.75	3257.75
5556500	7130001	247.82	786.34	0.39	77.65	505.00
5567500	7130004	232.35	812.96	0.29	77.67	2015.50
5568000	7130004	213.11	808.61	0.48	76.97	2779.00
5569500	7130005	233.19	803.7	0.43	79.81	2764.00
5570000	7130005	236.14	811.5	0.49	80.21	4235.25
5571000	7130006	248.57	839.99	0.25	77.65	941.00
5572000	7130006	256.82	861.89	0.21	77.63	1460.75
5585000	7130010	221.09	840.94	0.44	79.2	3340.00
5592500	7140202	241.06	862.71	0.26	76.98	5104.25
5593000	7140202	225.8	855.9	0.27	75.53	7149.00
5595000	7140204	218.22	848.86	0.3	75.98	13442.75
5596000	7140106	304.64	908.13	0.34	77.43	1287.75
5597000	7140106	306.17	910.17	0.37	80.33	2004.50

StationID	Cataloging Unit	Runoff (mm/yr)	Precipitation (mm/yr)	Slope	Curve Number	Area (km^2)
6019500	10020003	119.95	409.67	5.83	60.85	1348.75
6061500	10030101	84.97	292.93	6.63	57.02	517.25
6078500	10030104	484.79	338.19	9.36	61.51	688.00
6090500	10030105	179.8	392.31	8.26	57.9	930.25
6131000	10040105	7.08	310.92	0.93	62.05	6599.75
6169500	10050015	16.41	300.74	1.09	71.31	830.00
6177500	10060002	7.68	320.78	0.9	77.1	1478.50
6186500	10070001	483.24	519.99	6.5	45.43	2642.75
6188000	10070001	453.75	473.63	9.65	56.02	1720.00
6191000	10070001	378.14	465.71	6.07	46.91	518.25
6191500	10070002	418.04	500.51	7.23	54.81	6850.25
6192500	10070002	371.04	488.05	10.23	60.79	9281.00
6209500	10070006	491.6	618.11	12.98	61.75	318.75
6214500	10070007	215.25	488.62	5.26	60.65	30683.00
6224000	10080001	547.43	272.82	11.62	62.17	490.25
6280300	10080013	486.05	322.88	14.84	59.61	802.00
6298000	10090101	295.49	272.95	5.56	67.94	504.75
6318500	10090206	163.01	324.1	6.92	62.18	320.50
6331000	10110102	15.3	370.45	0.66	73.17	2318.25
6334500	10110201	21.64	367.01	0.85	55.17	4851.25
6335500	10110203	22.59	372.08	0.92	60.81	11652.75
6337000	10110205	22.98	375.3	1.23	57.94	21240.00
6339100	10130201	36.44	444.02	0.92	68.3	533.50
6340500	10130201	27.62	436.6	0.84	70.06	6002.00
6344600	10130202	39.09	423.8	0.61	73.86	404.75
6350000	10130204	27.96	422.75	0.55	76.26	1573.00
6353000	10130205	20.1	416.11	0.61	75.52	4391.00
6354000	10130206	22.47	404.84	0.8	74.19	10401.75
6356500	10130302	13.33	393.32	1.05	59.74	3598.75
6359500	10130306	16.42	384.42	0.81	56.58	6712.50
6425500	10120111	14.74	435.45	1.49	63.83	1413.75
6426500	10120201	4.8	356.44	0.71	64.37	4179.00
6431500	10120203	106.95	401.84	3.77	61.59	439.75
6441500	10140102	18.25	438.68	0.85	59.31	7712.50
6452000	10140204	18.41	439.15	0.92	58.08	26946.50
6454500	10150002	7.09	410.19	0.74	60.62	3555.50
6464500	10150006	24.24	500.98	0.55	65.55	2801.50
6466500	10170101	66.01	629.43	0.79	73.88	1187.00
6483500	10170204	90.85	660.6	0.45	77.92	4083.00
6485500	10170203	47.69	610.9	0.47	78.06	20779.25
6600500	10230002	95.58	671.2	0.54	78.06	2313.50
6620000	10180001	106.26	514.57	4.16	61.8	3707.75
6635000	10180004	28.36	266.33	1.62	64.12	6114.75
6658500	10180010	175.64	396.2	5.48	62.05	755.25
6710500	10190002	105.79	371.59	7.78	65.36	424.25

StationID	Cataloging Unit	Runoff (mm/yr)	Precipitation (mm/yr)	Slope	Curve Number	Area (km^2)
6783500	10210005	17.3	613.35	0.75	70.34	1852.75
6791500	10210010	75.88	621.76	0.42	48.62	2013.74
6798500	10220001	56.2	601.15	0.33	56.18	5788.00
6808500	10240002	154.76	812.93	0.89	77.97	3382.50
6809500	10240003	161.26	821.52	0.88	77.98	2324.25
6810000	10240004	152.96	828.45	0.84	77.91	7255.99
6811500	10240006	129.8	826.42	0.7	72.47	2079.00
6813000	10240005	164.96	890.78	0.87	77.95	1259.75
6814000	10240007	158.72	852.55	0.77	69.11	734.75
6853800	10250016	40.72	666.03	0.56	73.51	575.00
6864500	10260006	20.54	608.08	0.54	71.65	19476.50
6868000	10260009	39.7	584.83	0.84	66.03	4970.00
6869500	10260010	43.45	612.79	0.79	70.36	7521.50
6876900	10260015	55.31	611.52	0.62	72.67	17588.75
6878000	10260008	98.86	792.99	0.59	75.38	797.25
6883000	10270206	51.79	659.7	0.18	77.05	2541.00
6884200	10270207	107.21	769.41	0.58	79.09	896.25
6884400	10270207	72.18	730.54	0.44	77.78	8349.25
6884500	10270207	83.89	703	0.68	79.69	8827.25
6885500	10270205	133.8	844.33	0.64	69.92	1055.25
6886000	10270205	89.27	743.58	0.39	78.2	23531.25
6888500	10270102	198.97	903.61	1.12	75.83	846.25
6889200	10270102	219.35	920.73	0.75	67.56	401.00
6890500	10270103	158.99	923.1	0.69	72.57	2381.25
6891500	10270104	175.08	929.76	0.75	80.16	1110.25
6892000	10270104	226.65	961.47	0.7	76.4	1024.25
6894000	10300101	284.73	961.3	0.74	78.75	493.25
6898000	10280102	183.26	855.94	0.84	80.1	1882.75
6903700	10280201	237.75	934.65	0.56	78.93	437.50
6907000	10300103	231.39	977.12	0.68	78.65	1524.25
6908000	10300104	239.02	978.78	0.58	77.09	2929.75
6910500	10300102	233.99	1001.55	0.84	77.85	1409.00
6911500	10290101	191.33	936.26	0.51	71.74	280.75
6913500	10290101	171.25	926.64	0.63	72.33	3255.50
6914000	10290101	228.55	984.33	0.51	70.84	874.25
6917000	10290103	261.37	1032.03	0.68	74.23	766.50
6917500	10290104	224.41	998.22	0.56	77.53	1038.25
6928000	10290201	253.36	999	1.18	69.88	3263.50
6933500	10290203	307.37	1060.38	1.25	66.9	7368.25
7013000	7140102	252.73	1057.41	0.93	66.37	2117.25
7016500	7140103	277.02	1025.9	0.88	73	2001.75
7018100	7140104	324.01	1017.53	1.29	68.18	1945.00
7018500	7140104	326.6	1013.61	1.15	71.9	2375.25
7019000	7140102	290.66	1012.24	1.29	62.47	9750.25
7021000	7140107	428.15	1118.95	1.15	59.77	1097.00

StationID	Cataloging Unit	Runoff (mm/yr)	Precipitation (mm/yr)	Slope	Curve Number	Area (km^2)
7029500	8010208	569.71	1326.57	0.63	67.1	3765.50
7049000	11010001	365	797.94	2.49	71.83	701.75
7050500	11010001	382.6	834.19	2.91	69.66	1367.75
7056000	11010005	419.69	837.38	4.63	66.79	2146.75
7057500	11010006	440.57	1038.45	1.15	65.96	1486.25
7061500	11010007	422.45	1118.75	2.16	62.51	1283.00
7066500	11010008	393.4	1029.16	1.4	62.91	3334.50
7067000	11010008	408.82	1074.31	1.65	57.98	4353.75
7068000	11010008	470.34	1079.03	1.34	59.05	5349.00
7069500	11010010	401.36	896.08	1.07	60.05	3026.25
7071500	11010011	336.33	1004.02	0.99	64.75	2025.50
7072000	11010011	352.85	991.06	1.04	62.94	2893.25
7074000	11010012	353.53	871.15	0.96	58.85	1195.75
7075300	11010014	549.56	873.24	3.09	68.55	386.25
7095000	11020001	35.83	257.19	5.05	56.99	840.50
7144200	11030012	89.13	745.52	0.21	75.25	3367.50
7145200	11030015	111.57	663.78	0.35	75.48	1618.50
7147070	11030017	150.39	854.88	0.25	68.51	1133.00
7147800	11030018	156.89	862.71	0.32	64.92	4856.00
7148350	11060002	38.32	642.06	0.66	64.17	2121.00
7149000	11060003	54.45	650.22	0.7	66.55	2437.25
7161000	11050003	25.7	546.34	0.61	69.78	46310.50
7167500	11070102	213.06	882.9	0.93	69.23	325.00
7172000	11070106	202.56	954.2	0.88	73.32	1119.00
7176000	11070105	163.07	898.1	0.65	71.58	16832.25
7180500	11070202	170.49	869.96	0.4	62.78	275.50
7183000	11070204	171.53	889.51	0.53	72.2	9863.25
7184000	11070205	275.27	1063.93	0.33	70.26	510.50
7186400	11070207	305.35	1103.14	0.5	81.74	607.50
7187000	11070207	312.77	1020.93	0.66	77.73	1137.75
7189000	11070208	305.43	894.94	1.18	67.75	2209.75
7195000	11110103	306.21	825.92	0.68	76.46	349.25
7196500	11110103	318.48	889.07	1.32	69.96	2420.50
7211500	11080003	7.35	411.78	3.65	67.83	7220.00
7216500	11080003	37.83	421.54	6.53	58.57	705.25
7221000	11080004	15.41	404.99	3.08	65.84	2904.75
7222500	11080005	6.05	349.86	2.08	66.89	1310.75
7229300	11090202	121.72	876.87	0.58	72.61	503.25
7234000	11100201	6.43	420.83	0.47	67.81	20499.25
7247000	11110105	363.21	968.46	2.26	68.3	528.25
7247500	11110105	353.3	1094.11	2.36	67.43	329.00
7250000	11110104	410.38	930.66	3.15	71.43	1138.75
7252000	11110201	491.17	830.07	5.09	68.96	973.00
7257000	11110202	504.35	828.43	5.67	70	718.00
7258500	11110204	346.93	870.51	2.04	66.24	626.00

StationID	Cataloging Unit	Runoff (mm/yr)	Precipitation (mm/yr)	Slope	Curve Number	Area (km^2)
7261500	11110206	444.32	940.37	2.88	68.84	1079.25
7268000	8030201	570.99	1392.41	0.51	69.85	1359.50
7289500	8060201	433.08	1358.31	0.59	66.69	3777.75
7290000	8060202	474.38	1418.45	0.48	75.14	7102.50
7290650	8060203	473.76	1472.23	0.72	70.75	1694.25
7299670	11130101	17.73	629.8	0.38	79.93	813.50
7304500	11120303	53.42	631.82	0.51	73.42	1398.00
7311500	11130203	83.09	703.36	0.37	66.49	1603.75
7311700	11130204	22.86	628.64	0.61	68.86	2428.25
7332500	11140102	201.44	997.31	0.52	70.13	1215.75
7339000	11140108	560.39	935.02	2.33	69.68	2068.25
7339500	11140109	555.87	978.81	1.23	69.51	473.25
7340000	11140109	474.98	1048.59	1.42	67.16	6813.75
7340500	11140109	610.06	986.89	1.89	67.02	963.50
7342500	11140301	267.08	1064.03	0.34	69.33	1377.50
7346000	11140306	243.54	1150.95	0.65	66.93	2300.75
7349430	11140205	336.08	896.43	0.43	71.54	599.25
7349500	11140205	327.09	1060.25	0.2	63.45	1361.00
7352000	11140208	343.24	1294.51	0.64	66.63	379.25
7363300	8040203	388.46	898.6	0.42	68.38	533.25
7363500	8040204	425.89	922.64	0.74	65.81	5446.25
7365800	8040206	336.74	1109.35	0.47	68.24	480.75
7375500	8070205	618.67	1572.63	0.45	75.67	1698.75
8010000	8080201	707.45	1480.62	0.05	73.39	347.00
8013000	8080203	503.91	1482.34	0.35	62.37	1251.00
8013500	8080203	505.25	1483.13	0.16	62.04	1925.50
8015500	8080203	502.71	1481.57	0.29	66.68	4536.00
8029500	12010005	318.39	1391.87	0.66	50.88	329.50
8030500	12010005	274.4	1174.91	0.49	66.54	24072.50
8032000	12020001	193.63	975.86	0.67	60.97	2905.25
8033500	12020003	188.58	1081.25	0.64	65.02	9317.50
8033900	12020004	254.59	1196.96	0.82	61.72	414.50
8041000	12020003	218.23	1103.53	0.64	62.98	20522.00
8041500	12020006	323.9	1312.92	0.47	58.34	2144.50
8041700	12020007	487.88	1387.75	0.08	62.43	868.50
8042800	12030101	48.83	808.25	0.63	74.44	1769.50
8055500	12030103	72.68	853.82	0.61	72.77	6338.50
8061540	12030106	279.57	1060.46	0.5	85.19	311.25
8064700	12030201	167.88	1010.89	0.44	64.26	382.25
8064800	12030201	168.95	960.07	0.65	48.48	517.00
8065800	12030202	219.56	1080.46	0.32	68.39	858.00
8066200	12030202	224.75	1297.69	0.65	61.48	371.50
8068520	12040102	163.95	1106.25	0.28	65.68	1056.75
8070000	12040103	219.55	1275.52	0.52	60.56	873.25
8080500	12050004	5.98	479.29	0.43	72.14	22307.50

StationID	Cataloging Unit	Runoff (mm/yr)	Precipitation (mm/yr)	Slope	Curve Number	Area (km^2)
8084800	12060103	24.83	647.48	0.35	81.47	1210.25
8085500	12060104	16.79	612.55	0.64	75.14	10243.00
8095000	12060204	55.61	789.64	0.84	68.05	2519.00
8095300	12060203	148.54	875.36	0.66	67.07	477.50
8101000	12070202	61.76	751.77	0.96	66.97	1189.25
8104900	12070205	131.15	747.79	0.89	67.18	336.00
8109700	12070102	77.84	1003.92	0.52	63.89	622.75
8109800	12070101	83.67	1019.46	0.53	67.23	644.25
8111700	12070104	215.84	1075.05	0.63	71.61	988.25
8126500	12090101	3.32	403.42	0.36	66.4	43919.00
8128000	12090102	22.14	567.34	0.57	55.2	1055.75
8128400	12090103	2.38	413	0.44	61.75	6362.25
8129300	12090102	11.08	510.33	0.71	56.86	1091.25
8130500	12090102	25.53	590.1	0.71	59.06	590.25
8134000	12090104	5.42	505.77	0.76	63.52	3215.50
8144500	12090109	14.62	574.91	0.58	55.22	2917.00
8146000	12090109	20.91	614.2	0.7	61.4	7747.25
8150000	12090204	33.56	684.22	0.89	53.9	4765.00
8150700	12090204	35.76	726.54	1.09	58.07	8368.50
8150800	12090204	28.75	690.67	1.26	59.88	564.75
8151500	12090204	30.88	679.46	0.96	69.81	10940.75
8152000	12090201	62.58	705.05	1.59	66.96	905.50
8153500	12090206	71.73	827.57	1.09	66.26	2311.50
8159000	12090205	91.2	855.49	0.98	69.27	793.25
8163500	12100101	143.1	960.34	0.57	69.95	273.75
8164000	12100101	137.17	972.89	0.38	71.27	2139.50
8164300	12100102	150.42	977.56	0.55	70.46	902.50
8165300	12100201	90.49	917.39	0.88	55.35	441.25
8165500	12100201	98.2	900.59	1.14	55.53	764.00
8166000	12100201	71.91	825.12	0.92	57.25	298.50
8167000	12100201	86.72	836.93	1.48	63.79	2186.50
8167500	12100201	94.97	841.41	1.48	64.94	3437.25
8171000	12100203	133.22	879.81	1.34	70.48	926.50
8171300	12100203	130.03	921.78	1.32	61.96	1104.50
8172000	12100203	156.41	872.11	0.68	68.68	2188.75
8175000	12100202	84.98	911.05	0.45	64.8	1450.50
8176500	12100204	94.29	831.45	0.63	68.63	13604.50
8177500	12100204	47.89	669.62	0.39	72.72	1292.50
8179000	12100302	119.74	832.27	1.82	58.98	1259.00
8186500	12100303	54.84	880.32	0.44	70.1	595.00
8189500	12100406	60.89	775.37	0.32	64.89	1797.25
8190000	12110101	74.19	709.07	1.84	56.64	1900.00
8190500	12110102	20.58	632.49	1.15	56.7	1776.00
8192000	12110103	27.44	633.7	1.24	57.34	4825.75
8194200	12110105	44.95	629	0.42	50	1228.25

StationID	Cataloging Unit	Runoff (mm/yr)	Precipitation (mm/yr)	Slope	Curve Number	Area (km^2)
8194500	12110105	17.69	597.98	0.4	60.4	21168.50
8195000	12110106	106.95	829.79	2.16	56.17	1040.00
8196000	12110106	98.88	768.38	1.88	56.66	312.50
8205500	12110106	13.97	749.25	0.83	63.99	8941.00
8206700	12110109	28	803.91	0.37	66.42	1931.50
8210000	12110111	18	655.04	0.39	63.81	40160.25
8276500	13020101	24.97	320.03	4.96	57.77	24782.50
8283500	13020102	219.81	299.32	6.02	57.64	1010.50
8289000	13020102	53.53	492.68	4.26	56.02	1047.00
8324000	13020202	56.49	449.43	5.85	57.52	1219.75
8378500	13060001	171.17	430.13	9	55.21	466.25
9081600	14010004	623.68	285.26	14.46	60.61	433.25
9132500	14020004	278.31	292.29	9.62	61.04	1353.25
9147500	14020006	193.65	470.74	9.88	58.74	1119.00
9165000	14030002	456.63	536.47	10.52	61.49	283.75
9223000	14040107	279.92	345.58	4.48	56.53	322.25
9239500	14050001	267.29	532.6	6.21	61.34	1525.25
9241000	14050001	515.2	514.46	7.92	57.85	559.75
9251000	14050002	158.29	523.31	4.42	62.55	8511.25
9256000	14050003	110	325.89	3.33	59.42	846.25
9278500	14060003	438.99	416.71	9.7	44.06	319.50
9299500	14060003	356.04	187.41	9.04	38.91	281.25
9304500	14050005	287.26	476.82	7.54	63.36	1942.00
9330500	14070002	129.16	333.99	7.55	67.96	274.00
9350500	14080101	157.37	374.33	7.2	62.01	5213.75
9361500	14080104	393.01	489.69	11.68	58.99	1820.25
9364500	14080104	212.41	429.59	4.11	60.75	3577.75
9378700	14080201	15.1	337.67	5.63	59.1	539.75
9384000	15020001	11.14	371.51	2.88	56.56	1929.50
9415000	15010010	15.71	309.93	4.72	55.81	13075.00
9430500	15040001	30.16	347.41	4.11	62.75	4768.75
9431500	15040002	26.91	332.9	4.35	55.59	7191.50
9444500	15040004	28.1	371.63	5.46	59.7	7261.50
9471000	15050202	14.15	314.08	2.55	66.62	3149.00
9498500	15060103	70.27	372.52	4.35	60.9	11207.00
9508500	15060203	34.46	276.02	3.27	59.04	15367.50
10128500	16020101	462.96	423.02	10.42	60.72	417.25
10174500	16030001	110.2	387.17	3.47	60.28	839.25
10296000	16050302	507.03	602.57	9.82	57.8	470.00
10308200	16050201	458.29	611.36	10.59	57.07	721.75
10312000	16050202	103.59	446.1	5.82	60.12	3676.75
10329500	16040109	76.73	193.02	4.97	56.72	454.25
10352500	16040201	51.17	242.04	4.43	50.32	569.00
10353500	16040201	11.08	228.73	3.97	61.98	2798.25
10371500	17120007	204.97	387.99	3.59	55.95	635.50

StationID	Cataloging Unit	Runoff (mm/yr)	Precipitation (mm/yr)	Slope	Curve Number	Area (km^2)
10393500	17120002	76.39	274.03	3.08	62.91	2379.25
11025500	18070304	38.78	495.3	6.43	71.39	291.50
11113001	18070102	165.73	333.42	10.3	57.91	655.25
11138500	18060008	57.03	329.76	9.63	54.01	719.75
11149900	18060005	182.6	303.12	5.12	66.92	550.25
11151300	18060005	20.94	300.06	5.7	60.41	619.25
11152000	18060005	241.39	403.03	9.64	70.65	624.00
11176400	18050004	98.02	385.48	6.91	53.66	337.50
11186001	18030001	330.21	227.4	11.49	60.17	2100.50
11187000	18030001	298.04	237.59	11.89	59.86	2516.50
11189500	18030002	89.82	204.55	7.58	58.47	1434.75
11206501	18030007	624.59	269.49	16.72	56.46	265.25
11209900	18030007	461.78	290.71	11.89	59.56	1077.00
11210500	18030007	336.29	246.84	11.6	57.99	1334.75
11213500	18030010	526.35	180.92	14.67	59	2447.50
11215000	18030010	717.07	138.71	8.31	39.73	464.50
11221700	18030008	124.58	284.43	8.05	61.83	322.50
11222000	18030012	360.27	173.1	9.6	57.64	4346.75
11226500	18040006	871.9	528.37	12.07	58.87	648.00
11264500	18040008	690.68	544.26	10.39	54.77	474.00
11266500	18040008	687.62	547.8	11.11	57.58	832.50
11274500	18040002	43.12	396.84	6.91	60.31	357.00
11342000	18020005	974.73	665.02	10.52	62.91	1109.25
11355500	18020003	329.2	431.15	5.66	53.76	413.75
11367500	18020004	933.06	643.57	4.73	56.02	913.00
11368000	18020004	990.95	670.45	9.74	55.9	1508.50
11371000	18020112	651.33	707.49	10.96	62.17	294.25
11372000	18020112	643.89	736.26	9.15	59.55	579.75
11382000	18020103	553.75	412.47	11.02	54.63	521.50
11383500	18020103	575.84	536.8	7.55	56.73	556.25
11401500	18020122	266.53	493.64	7.13	58.13	1868.75
11402000	18020122	525.91	595.26	7.06	66.89	479.00
11403000	18020122	352.14	619.54	11.48	65.35	1220.25
11413000	18020125	1093.47	960.09	10.27	57.69	666.75
11427000	18020128	850.12	874.6	9.53	61.36	871.50
11465200	18010110	728.09	741.19	6.41	57.22	435.50
11468000	18010108	601.12	706.72	6.45	56.7	801.00
11472200	18010103	898.15	713.74	5.11	58.74	412.50
11473900	18010104	765.42	601.58	9.44	56.33	1894.75
11475800	18010106	1258.84	745.09	7.29	56.28	621.50
11476500	18010106	1280.12	752.27	7.58	58.63	1382.50
11477000	18010105	923.86	701.38	9.19	59.11	7982.00
11478500	18010105	1371.53	798.36	8.99	66.15	572.00
11482500	18010102	1324.09	862.82	10.17	59.73	696.75
11497500	18010202	214.77	354.82	3.28	55.67	1362.25

StationID	Cataloging Unit	Runoff (mm/yr)	Precipitation (mm/yr)	Slope	Curve Number	Area (km^2)
11519500	18010208	362.06	549.61	8.89	62.43	1705.75
11521500	18010209	1240.3	872.13	11.83	62.71	316.00
11522500	18010210	894.88	909.89	13.97	56.78	1963.25
11523200	18010211	962.18	665.03	11.91	64.92	387.25
11525500	18010211	947.99	724.39	10.84	61.59	1889.50
11528700	18010212	662.61	749.81	8.76	59.4	1988.00
11530000	18010211	803.28	797.86	12.3	59.66	7375.25
11532500	18010101	2266.61	1166.27	10.88	63.32	1558.50
12020000	17100103	1785.61	1195.48	6.14	67.14	283.50
12027500	17100103	1125.26	1198.88	3.25	61.22	2209.75
12039500	17100102	3900.55	1396.78	15.09	86.75	686.50
12040500	17100102	3376.58	2490.25	8.98	73.26	1146.50
12048000	17110020	890.76	673.87	15.44	66.41	401.00
12134500	17110009	2616	1816.21	16.62	59.33	1406.75
12144500	17110010	2475.57	2310.05	14.41	60.38	1014.25
12186000	17110006	2652.93	1092.55	18.92	57.28	396.50
12189500	17110006	2166.08	990.95	16.78	58.3	1867.50
12303000	17010101	443.63	499.52	11.76	55.55	26513.50
12306500	17010105	435.42	528.27	10.41	57.92	1474.50
12318500	17010104	436.43	510.81	10.39	57.61	34242.25
12322000	17010104	440.42	511.52	8.57	64.15	34679.25
12354500	17010204	250.89	360.47	8.21	56.27	27040.00
12355000	17010206	742.81	424.32	10.2	55.64	1136.75
12355500	17070206	687.56	428.63	11.2	57.06	4034.50
12358500	17010207	907.04	389.38	14.05	57.53	2931.50
12359800	17010209	686.66	375.72	12.58	58.84	3050.25
12370000	17010211	621.59	406.44	9.06	57.95	1780.75
12390700	17010213	463.86	741.92	11.5	54.14	460.75
12401500	17020002	246.17	418.02	7.51	54.08	5570.75
12404500	17020002	270.92	455.27	9.86	56.06	9672.75
12413000	17010301	748.83	772.16	9.17	55.07	2324.50
12413500	17010303	763.94	766.91	11.16	56.83	3127.25
12414500	17010304	813.19	766.93	10.45	55.45	2652.75
12415000	17010304	446.6	674.27	5.2	58.15	1130.75
12442500	17020007	235.32	525.3	9.35	56.7	8934.50
12445000	17020006	145.23	470.53	7.22	58.7	18760.00
12447200	17020006	128.97	436.23	7.21	58.81	20875.25
12449500	17020008	429.89	486.63	12.91	56.05	3489.50
12449950	17020008	304.08	446.86	9.71	56.6	4664.50
12451000	17020009	1576.33	794.02	20.01	53.68	832.25
12452800	17020010	639.25	664.76	15.09	32.42	530.00
12454000	17020011	1875.61	875.56	19.5	55.78	375.00
12455000	17020011	1859.59	900.14	14.98	55.2	698.25
12457000	17020011	1423.3	813.6	13.51	43.13	1396.25
12458000	17020011	1190.21	586.25	17.56	55.17	497.75

StationID	Cataloging Unit	Runoff (mm/yr)	Precipitation (mm/yr)	Slope	Curve Number	Area (km^2)
12459000	17020011	1113.26	648.91	12.09	55.91	2434.00
12462500	17020011	865.01	562.09	10.76	58.28	3228.00
13023000	17040103	508	367.39	10.4	59.15	1166.75
13063000	17040207	166.95	389.77	5.53	56.12	866.25
13073000	17040208	127.67	323.44	4.41	66.66	1480.50
13075000	17040208	89.74	348.2	4.71	71.15	924.75
13082500	17040211	27.67	281.78	4.26	55.16	1628.75
13120500	17040218	253.92	230.65	10.83	57.38	1158.75
13139510	17040219	271.26	248.43	11.15	57.42	1621.00
13161500	17050102	110.49	276.14	6.09	57.13	1005.25
13168500	17050102	52.01	264.96	2.76	54.87	6648.75
13178000	17050108	156.86	288.58	4.43	66.19	1115.50
13185000	17050112	532.82	456.18	10.78	65.42	2155.50
13186000	17050113	434.59	413.84	10.39	66.44	1667.25
13200000	17050112	258.57	459.11	7.25	30.29	983.00
13295500	17060201	530.24	271.67	8.41	58.61	1277.25
13296500	17060201	461.28	277.9	8.58	55.27	2042.50
13298500	17060201	313.24	261.46	11	59.48	4511.75
13305000	17060204	108.62	236.68	7.59	59.55	2341.00
13306500	17060203	168.73	222.68	10.49	59.98	1340.50
13307000	17060203	167.81	236.27	9.31	62.25	16100.75
13309000	17060205	623.91	442.24	5.95	55.87	494.00
13317000	17060209	305.6	347.62	11.85	60.89	35182.50
13319000	17060104	202.45	355.42	4.49	55.77	1749.50
13331500	17060105	657.03	389.67	12.9	56.78	625.25
13334700	17060103	157.21	428.17	6.82	62.36	446.25
13336500	17060302	709.55	341.83	12.39	59.66	5103.00
13337000	17060303	877.02	345.7	10.76	50.12	3038.00
13338000	17060305	369	492.78	7.51	58.55	2225.00
13338500	17060305	323.8	526.25	3.72	77.04	3088.75
13339000	17060306	619.18	400.33	8.7	60.84	11969.75
13340000	17060306	570.23	427.85	4.64	68	13743.00
13340500	17060307	982.74	626.96	9.96	48.34	2573.75
13340600	17060307	887.61	714.33	11.51	43.8	3520.00
13342500	17060306	591.99	602.05	6.21	63.67	24174.50
13348000	17060108	112.34	612.2	1.33	78.15	336.50
14020000	17070103	603.95	371.58	9.13	56.23	346.75
14042500	17070202	265.71	345.44	2.83	56.76	311.25
14044000	17070203	180.78	351.4	6.07	58.89	1327.75
14046500	17070204	141.29	340.54	5.82	59.45	13143.25
14048000	17070204	102.39	338.7	5.28	64.54	19866.25
14101500	17070306	363.7	642.96	4.88	57.99	1099.50
14113000	17070106	448.25	559.71	4.83	58.9	3358.50
14150300	17090001	1199.41	1492.72	9.32	63.63	303.50
14154500	17090002	1002.44	1250.11	10.27	63.43	533.50

StationID	Cataloging Unit	Runoff (mm/yr)	Precipitation (mm/yr)	Slope	Curve Number	Area (km^2)
14159000	17090004	1860.53	1339.54	7.3	60.28	877.00
14178000	17090005	1677.75	1530.69	9.23	61.41	558.25
14179000	17090005	1906.15	1707	11.75	64.43	271.25
14185000	17090006	1685.31	1536.67	10.21	65.09	462.50
14185900	17090006	2319.78	1604.99	10.87	62.87	258.00
14188800	17090006	1568.22	1389.83	6.96	68.71	286.25
14208000	17090011	1306.41	1638.95	6.74	60.52	355.00
14222500	17080002	2108.02	1332.73	8.38	60.63	314.50
14232500	17080004	1469.35	933.35	12.11	55.53	827.00
14233400	17080004	1591.76	1097.96	12.93	56.14	2670.25
14245000	17080005	1234.82	1168.22	7.23	55.43	313.75
14301000	17100202	1417.14	1260.5	4.66	57.2	1750.50
14301500	17100203	2532.14	1465.51	9.16	56.05	401.50
14303600	17100203	2019.61	1768.15	6.52	56.26	452.00
14306400	17100205	1651.89	1476.05	6.21	68.75	296.25
14306500	17100205	1591.21	1357.05	7.08	65.75	837.25
14307620	17100206	1240.82	1277.03	5.15	68.34	1518.25
14307700	17100302	723.7	1156.15	9.15	58.16	386.00
14308000	17100302	820.04	1130.93	9.36	57.2	1153.75
14318000	17100301	911.76	932.4	8.62	57.66	469.00
14321000	17100303	741.9	1079.17	7.47	64.23	9425.25
14325000	17100305	1715.2	916.47	8.8	67.15	448.75
14338000	17100307	611.08	1125.03	8.22	56.81	339.00
14359000	17100308	571	908.88	5.96	61.4	5428.75
14362000	17100309	719.29	824.58	12.45	68.72	559.25
14377000	17100311	1344.06	1032.22	8.82	64.51	956.25
14377100	17100311	1187.46	913.81	9.2	59	957.50
14400000	17100312	2954.83	1287.79	11.06	69.11	700.50

VITA

Zubin Rohinton Sukheswalla was born on November 3rd, 1979 in Bombay, India. He received his Bachelor of Engineering in Civil Engineering from Bombay University, India, in July 2001. In August 2001, he started his M.S. in Civil Engineering at Texas A&M University. His research at Texas A&M University has been focused on applications of Geographical Information Systems (GIS) to hydrology. His address is 67 Bhagya Apartments, Bhardawadi Road, Andheri (W), Mumbai 400 058, India.