Project Title

An efficient forecast of hydrologic response for water resources management

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May 2019

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Acknowledgements

First and foremost, I would like to thank every person involved in helping the study. This project is supported by NM WRRI-New Mexico Water Resources Research Institute grant. The Dept. of Geography also deserves due appreciation for providing support to the investigator. I would like to thank all the members of my dissertation committee, specifically Dr. Hatim Geli, Dept. of Animal and Range Science for sharing his knowledge. I would like to extend special gratitude to Dr. Philip King, Dept. of Civil Engineering, New Mexico State University for his assistance with valuable advice that greatly improved the shape of the research. Eventually, I would like to give special thanks to my advisor Dr. Christopher Brown for his support and inspiration.

Executive Summary

The hydrologic models are input and output of water system simulated and predicted through hydrological parameters. The hydrologic models have been using around the world, and are now being considered as one of the essential tools for water resource management. Although the sophistication of hydrologic model has been improved in recent times, nonetheless the models are still yet to be considered unbiased and complete in delineating spatially distributed hydrologic process. These models are distinct in terms of their characteristics and compatibility. Two hydrologic models were simulated for a watershed in order to get the flow, flow peak and time of flow peak. WMS was the basic software in the study. In this investigation, WMS supported hydrologic model HEC-HMS was employed to simulate two rainfall- runoff models. The HEC-HMS supports the methods exponential loss rate, SCS curve number and Green Ampt infiltration function for calculating precipitation loss. The widely used SCS curve number (CN) method was deployed in one model. Snyder's unit hydrograph was used in another model to compare with SCS curve number method in the study. And model's outputs are analyzed considering different literature and past research. The methodical dissimilarities were discussed briefly. Models and their results are compared in order to identify the key factors for the better estimation of the hydrologic response. Two models have given two different flood peak, time to peak and time of concentration. The Snyder lag has come 1.65 while SCS lag was 2.84. So, it is anticipated that the larger watershed should create the larger differences. Recognizing the fact that the different hydrological models' outcomes varied, it can be stated conclusively that choosing the appropriate model for a certain study is significant whereas efficient flow estimation is to be achieved.

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Chapter 1 – Background and Problem Statement

1.1 Introduction:

Water and river prehistorically means lifelines to people of the arid and semi-arid Southwest. Because drainages have been main orienting features of daily life by providing places of drinking water, farming, hunting, gathering and even practicing rituals [1]. But according to history, the region has experienced drought periodically coming back to the area that has affected the water resources [1]. Reduction in precipitation, snowpack, droughts along with warmer and drier springs have caused water supply in Rio Grande River to decrease. The increasing dependency on water resources to meet the water demand due to recent population growth has also been observed [2]. Water demand already exceeds the supply in New Mexico except wet years [1]. So, water security has become a biggest issue here. Climate change is anticipated to aggravate water condition in arid southwest of U.S. Exploitation of water resources has made water resources management increasingly important to the society. The effects in terms of hydrologic responses need to be modeled and assessed efficiently simply not just because of its important socio-economic value but also to ensure improved management of water resources.

These hydrologic response models have been developed and using around the world, and are now being considered as one of the essential tools for water resource management [3]. Although the sophistication of hydrologic model has been improved in recent times, nonetheless the models are still yet to be considered unbiased and complete in delineating spatially distributed hydrologic process. These models are distinct in terms of their characteristics and compatibility [3]. The general inputs, which are required by the different models are precipitation, temperature, soil properties, topography, and vegetation cover [3]. An appropriate model should produce output closest to reality with less complexity. Assuming the differences in responses from different models for a certain watershed, research scope is being created like what would be the differences, which come from two different models in terms of flow, peak discharge, time to peak, time of concentration etc. for a certain watershed under same climatic condition.

1.2 Objective

The main intention of the work is to pursue knowledge over the couple of models for hydrologic analysis, and to analyze their outputs for a watershed. The objective of the study is to gather knowledge over a few rainfall-runoff models and to determine if models' outputs vary for same hydrologic inputs and study area. The study will also develop reasoning for having the similarities and the differences of outputs from two different models.

The overall objectives of the investigation are:

1. To estimate peak flow, runoff volume, time to peak and time of concentration through rainfall-runoff models.
2. To identify the similarities and dissimilarities of outputs i.e. peak flow, runoff comparing two models.

CHAPTER 2 – STUDY AREA AND RATIONALE OF THE STUDY

2.1 Study Area

The study concerns with the southern New Mexico, the area is located at around 25 miles north of the Texas boarder in the Rio Grande Valley in South-central New Mexico. The area is arid by nature, characterized by light and variable precipitation with low relative humidity.

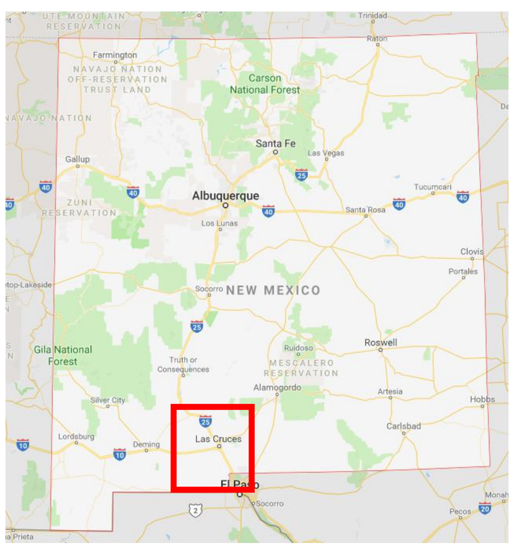

Fig 1. The study area: Rio Grande Valley in South-central New Mexico (*Source: Google map*)

Plentiful sunshine, up to 80 percent of possible sunshine covers the area. The annual average precipitation is estimated as 8-9 inch, which is not enough to produce dryland crops but enough to produce forage on nearby grazing lands [4]. General flood is not quite common in New Mexico, however sometimes heavy thunderstorms can cause more than a few inches of rainfall in a small area. Tropical hurricane rarely causes heavy rainfall in this region. Local flash floods appear occasionally from these heavy rain in the rough surface landscape with light vegetation cover. Potential evapotranspiration is much higher than average annual precipitation in this area [4]. The data for the analysis was downloaded from web services, which includes USGS National Elevation Data (NED), US National Land Cover Database, World Imagery and Ssurgo Soil Type. The watershed was delineated within a basin of arid region of South-central of New Mexico.

2.2 Literature Review and the rationale of the study

Water availability is significant to the people of the arid and semi-arid Southwest. Water security which certainly triggers food security has been one of the largest global problems that strongly affects the arid and semiarid regions. The amount of precipitation is expected to decrease by 20% or even more in arid and semi-arid areas over the next century. Impending water-shortage crisis is approaching to the Southwest in 2019 [5]. The overall water stress is continuously increasing.

Water has been one of the vital resources of the New Mexico State with increasing demand due to State's rapidly growing population that is projected to increase by 85% in the next fifty years [1]. The consequential larger economy in addition to interstate stream compact delivery obligation will make the resource acutely scarce. Because the flows from two major rivers— the Rio Grande and the Pecos of New Mexico are barely capable to meet both existing needs and interstate stream compact delivery obligations. The agriculture has been remaining the major water uses for a long time, but this sector is now being confronted competition from expanding urban demand. These circumstances tend to aggravate the scenario which will cause an increased economic value for water in the coming years [6]. Therefore, water quantity dynamic must be assessed and estimated efficiently for the proper water resources management.

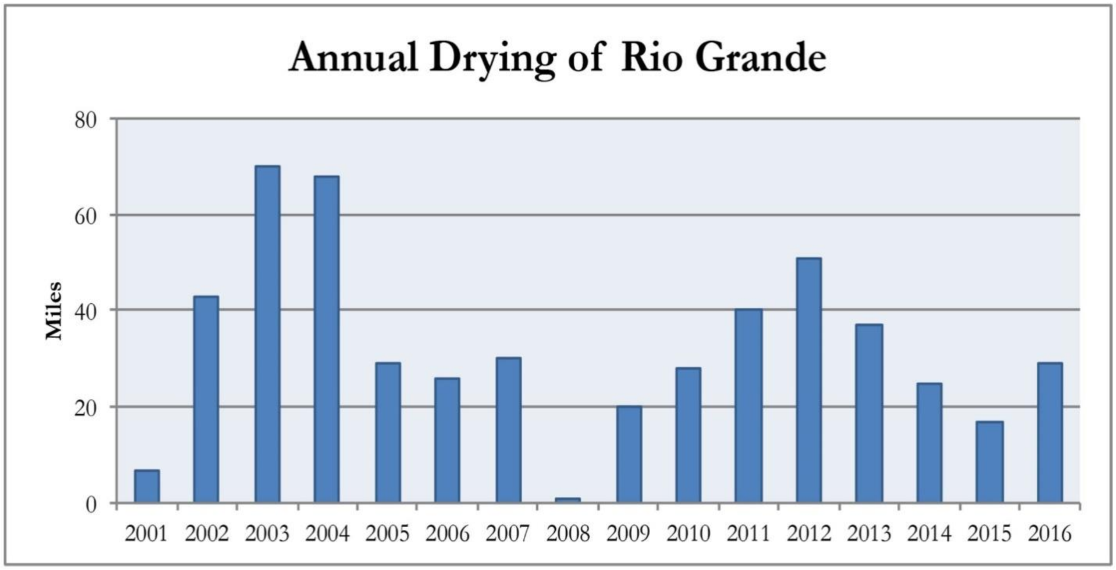

Fig 2. River drying along the Rio Grande in central New Mexico 2001-2016 (Source: Report, Rethinking the Rio, Web report at http://www.rethinkingtherio.org/problem)

Hydrologic models are dedicated to simulate the water cycle of a landscape. Rainfall-runoff models are the ideal way of examining hydrologic processes. These models are used for quantitative analysis, storm hydrograph analysis, flood forecasting of watershed, in responses to precipitation, surface water runoff, etc. [7]. Various models with different applications for different watersheds ranging from small to large have been developed and used for hydrologic analyses. The models can be used for both gauged and ungauged watersheds, and predicting climate change effect. Water flow of the study area will be evaluated in this report through estimating discharge (cubic-meter/s) at outlets of the watershed. These models are distinct in terms of their characteristics and compatibility [3]. So, different tools to simulate hydrological models may give different stream flows and sediment values. Anticipating these differences resulted from different hydrologic models for the same watershed, the study comes to investigate if two models' responses are varied for a certain watershed. The study explores the reasoning of the variation and also attempts to identify the key factors for the better estimation of the hydrologic response.

CHAPTER 3: METHODS AND DATE TO BE DEPLOYED

The hydrologic models are input and output of water system, this system is simulated and predicted through hydrological parameters. The general process of a hydrological model includes:

1) The input data that includes climatic and hydrologic parameters

2) Hydrologic model set up through mathematical equations which represent the process of transformation of rainfall into flow or runoff.

3) To produce the output data or result as runoff hydrographs [8].

3.1 Hydrologic Model Setup

The Watershed Modeling System (WMS) is a water modeling software application that uses to simulate watershed. It includes various tools to program basic and advanced delineations, calculations, and modeling. It supports HEC-1, HEC-RAS, HEC-HMS, TR-20, TR-55, Rational, MODRAT, HSPF, GSSHA, and so on. WMS was the basic software which has been used for the study [8]. In this investigation, WSM software supported hydrologic model HEC-HMS was employed for two rainfall- runoff model.

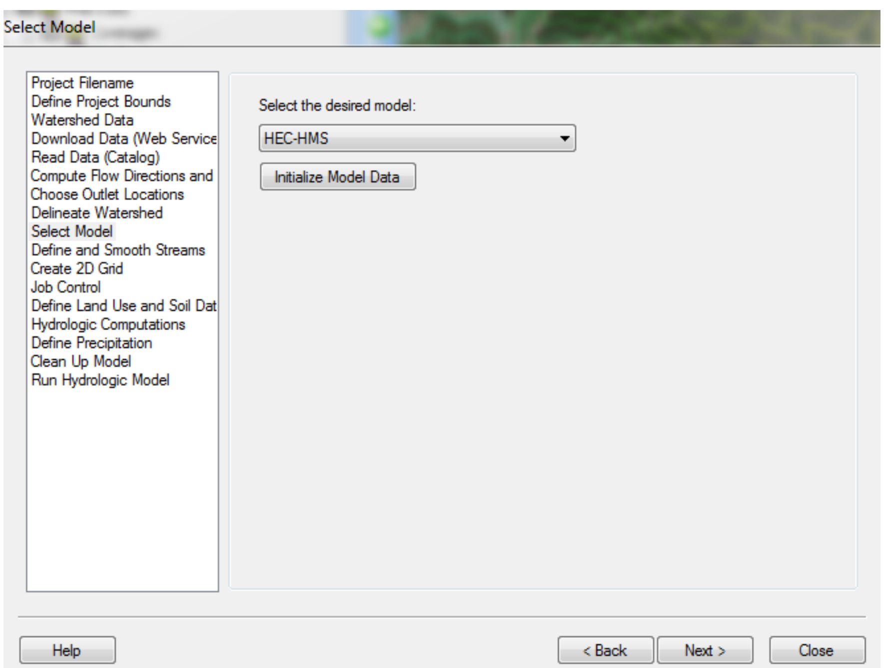

Fig 3. The dialogue box of WMS shows the steps involved

Step 1. Data collection: At the initial stage, the required datasets were identified based on the study objectives. These were collected from various sources. The required hydrologic datasets i.e. DEM, Soil land cover land use (LULC), weather data are collected, processed and used in the model. DEM data was downloaded as United States Elevation Data (NED) type from Web Services through hydrologic Modeling Wizard of WMS 10.1 with 30 m cell size. Land use and soil type data to the watershed hydrologic model are sourced from US National Land Cover Database. Temporal boundary and precipitation type '24 hours type II' at 3.13 in depth for 3 days uniformly distributed over the study area was used for the analysis.

Step 2. WMS Model (watershed delineation): Watershed delineation is one of the most commonly performed activities in hydrologic analysis. Watershed delineation is to identify watershed's boundaries on a map. This is done usually on topographic maps using info. of contour lines. An outlet is a pour point at downstream that drains its accumulated runoff through that point. Watershed delineation was performed with the systematic step by step approach in WMS taking Digital Elevation Model (DEM) and the river network. All the watershed delineation steps such as defining project boundary, filling sink, defining flow direction and accumulation, select output location were done in WMS user interfaces.

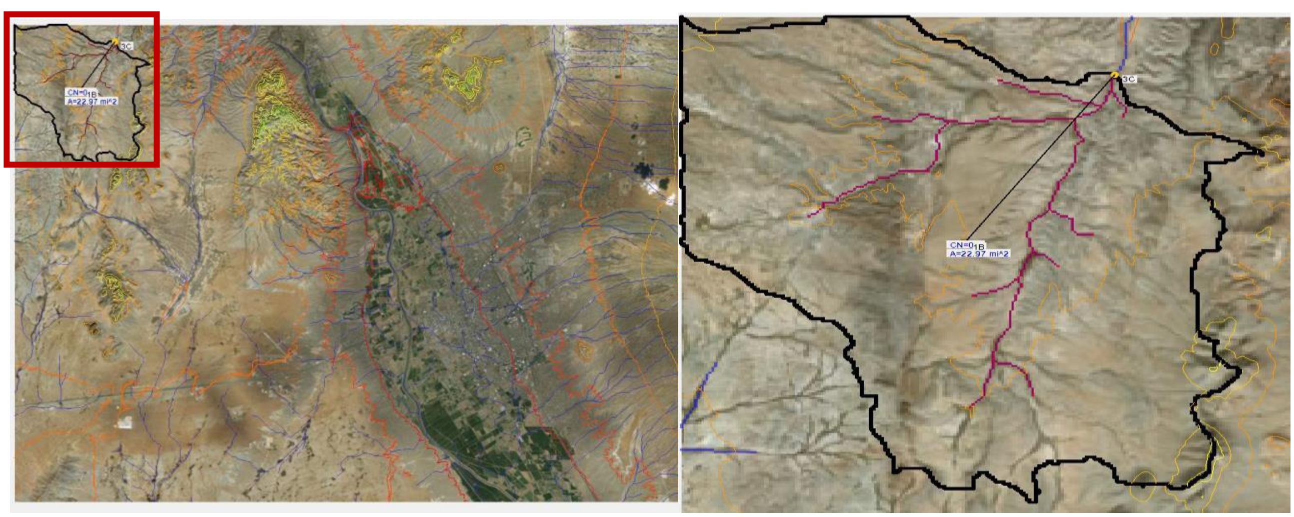

Fig 3. Delineated Watershed area 22.97 sq. - mile

Step 3. HEC-HMS analysis

The HEC-HMS model was used to simulate the hydrologic response to get surface runoff against the precipitation. The HEC-HMS supports the exponential loss rate method, SCS curve number method and Green Ampt infiltration function for calculating precipitation loss [8]. The widely used SCS curve number (CN) method was deployed in one model. The HEC-HMS model has options of using unit hydrographs like Snyder unit hydrograph, SCS dimensionless unit hydrograph etc. Snyder unit hydrograph was used to compare with SCS curve number method in the study.

The following flowchart illustrates the sequential steps involved –

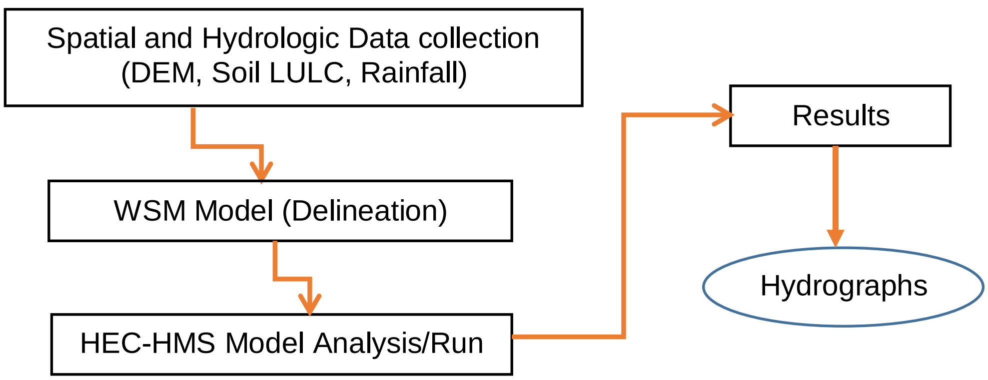

Fig 5. Conceptual flow chart of the work

3.2 SCS-CN method-

The SCS curve number method is most commonly used and efficient rainfall-runoff method for estimating the amount of runoff generated from a rainfall event in a particular area preferably in a suburban and rural area [9]. The method is designed for a single storm event, but it can be scaled to find average annual runoff values. The curve number is based on the area's hydrologic soil group, land use, treatment and hydrologic condition, and for a certain watershed whereas hydrologic characteristics of soil and design rainfall volume is known. There are two basic computation in the model, 1. Estimation of effective rainfall, and 2. Estimation of peak discharge. In addition to that the entire runoff hydrography can also be produced. When specific information on antecedent condition is not available, SCS-curve number method is widely used to estimate effective precipitation [10]. Normally the SCS model computes direct runoff with the help of the following relationship.

S = (24500/CN) – 254

Q = ((P - 0.3S) 2)/ (P + 0.7S)

CN = (Σ (CNi X Ai))/A

Where, CN = weighted curve number. CNi =

curve number from 1 to any no. N. Ai = area

with curve number CNi

A is the total area of the watershed while CN is the runoff curve number of hydrologic soil cover which is a function of soil type, land cover and antecedent moisture condition (AMC). Q is actual runoff in mm; P is total rainfall in mm; and S is the potential maximum retention of water by the soil in mm.

Soils are grouped into four categories A, B, C and D based on infiltration capacity of the soil. Group A: High infiltration capacity, group B: moderately high infiltration capacity, group C: moderate infiltration capacity and group D: low infiltration capacity. Antecedent moisture condition, AMC refers the moisture content which is present in the soil before[10].

3.3 Snyder's Unit Hydrograph-

The synthetic unit hydrograph of Snyder is based on characteristics of effective rainfall duration, the peak direct runoff rate and the basin lag time. From these relationships, five characteristics are assumed for a required unit hydrograph with a given effective rainfall duration are: the peak discharge per unit of watershed area, the basin lag, the base time, and the widths, W at 50 and 75 percent of the peak discharge. The parameters were estimated by following equations (1) to (8). Lag time,

$$t_l = C_t (L * L_c)^{0.3} \quad (1)$$

Here C_t is a coefficient that varies with the variations of watershed slope and storage. According to Arora [11], the values of C_t are falling within 1.0 to 2.2. The C_t value was assumed an average 1.60 for this watershed. The lag time for the watershed is determined by the equation (1),

Storm duration, t_r

$$t_r = \frac{t_l}{5.5} \qquad (2)$$

Equation (2) represents the unit hydrograph duration or the duration of the storm. However, equation (3) can be deployed if other storm durations are to be created for the watershed, while the new storm duration t'*r*, and the corresponding basin lag time will be t'*l*.

$$t_l' = t_l + \left(\frac{t_r' - t_r}{4} \right) \qquad (3)$$

The peak discharge was obtained through equation (4):

$$Q_p' = \frac{2.78 * C_p * A}{t_l'} \qquad (4)$$

Whereas C_p is the coefficient considering flood wave and storage conditions. The C_p values are ranging from 0.3 to 0.93 as per Arora [11] with an average of 0.62 was taken for this catchment.

The base time was calculated from following equation (5):

$$t_b = 3 + 3\left(\frac{t_l'}{24} \right) \qquad (5)$$

The W_{50} and W_{75} are the time width of the hydrograph at 50% and 75% of the height of the peak flow consecutively. The unit of the peak discharge per area is cumec/sq-meter given in the equation (8) and the unit of time width is hr.

$$W_{50} = \frac{5.9}{\left(q_p'\right)^{1.08}} \qquad (6)$$

$$W_{75} = \frac{3.4}{\left(q_p'\right)^{1.08}} \qquad (7)$$

$$q_p' = \frac{Q_p'}{A} \qquad (8)$$

Snyder is believed as the first method that established a set of empirical relations among watershed characteristics, such as area (km2); length of main stream (km); and the distance from the watershed outlet to a point on the main stream nearest to the center of the area of the watershed (km). It can produce a smooth curve through seven points (Qp, tp, tb, W50 and W75) more easily with less degree of complexity [12].

Chapter 4: Results and Analysis

4.1 Results

The peak discharge 2283.8 cfs according to SCS-CN method while Snyder's method gave 2799.3 cfs. As per SCS-CN method, the time to peak was found at 15:10 hr. whereas the time to peak was 13.40 hr. from the starting point of hydrograph. The Snyder lag has come 1.65 while SCS lag was 2.84.

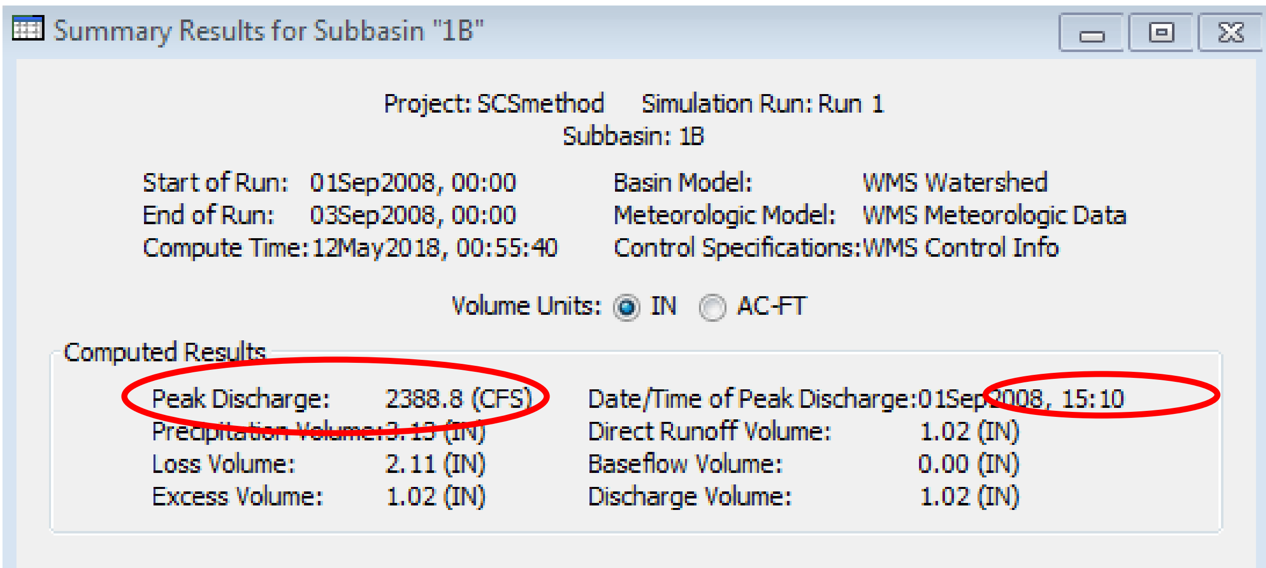

Fig 6. SCS-CN method outputs

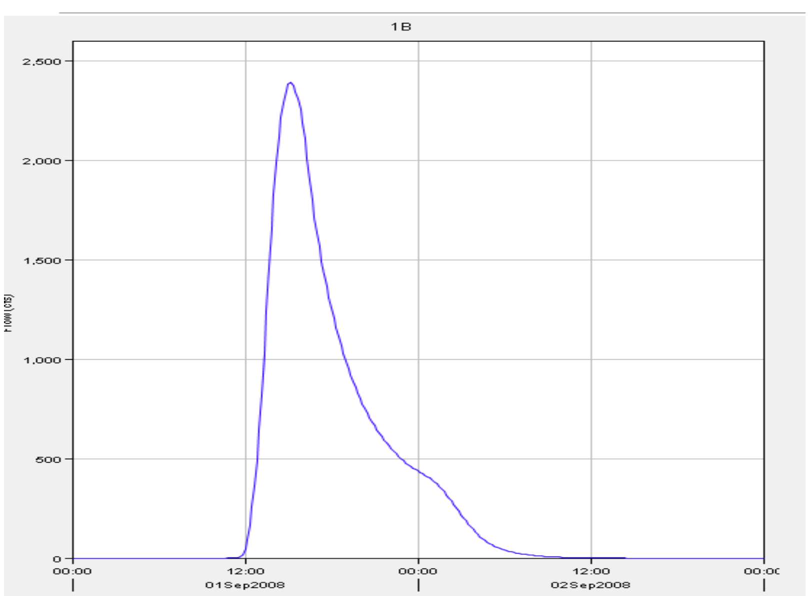

Fig 7. Hydrograph from 1st simulation (SCS-CN)

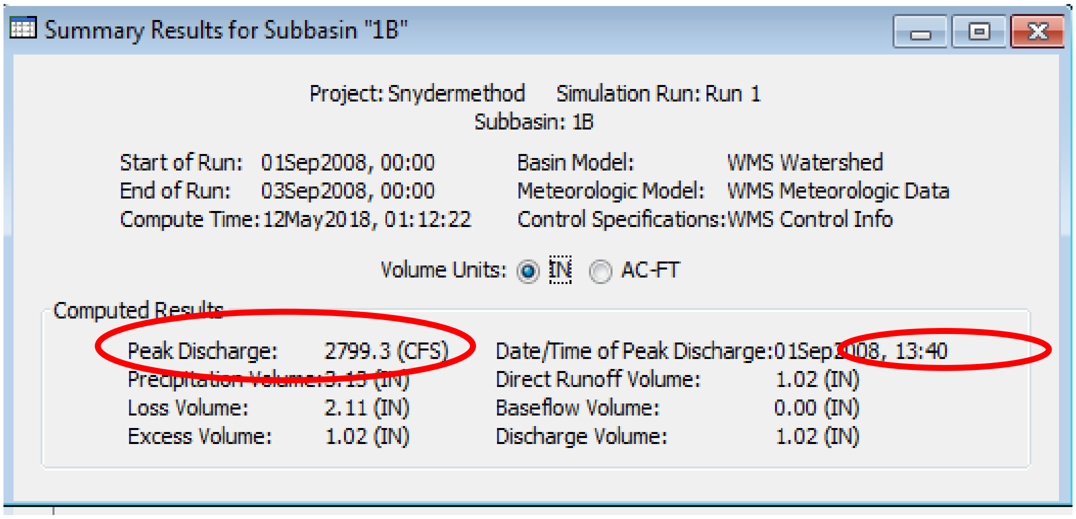

Fig 8. Snyder's method outputs

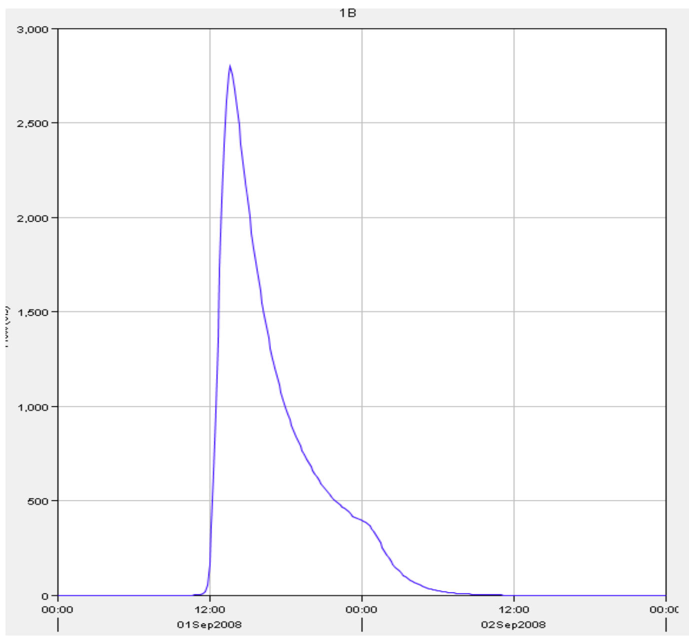

Fig 9. Hydrograph from 2nd simulation (Snyder's)

4.2 Discussion

Two models have given thought-provoking outputs differing from each other in terms of 'peak discharge', 'time to peak' and basin lag. The discharge under SCS method has come less than Snyder's method. In case of Snyder's method, the "time to peak" came 1.5 hours earlier than SCS method. The Snyder's lag was less (1.65) than SCS. A short lag time indicates high peak discharge that supports the outputs. Two models have two separate methodology to estimate flood peak and other parameters i.e. time to peak, peak flow. The methodical dissimilarities were covered in detail. Two individual method have used two different equations to estimate the lag. The larger watershed should create the larger differences. Similarly, the time of concentration was different from each other in terms of their magnitudes. As two methods' approach is different in order to estimate these parameters, so some variations reasonably can come from two separate models. Snyder's unit hydrograph follows a process that involves a certain degree of bias and error in fitting the points and adjustments [12]. In addition, there may not be area under the curve to be unity, as per prerequisite for Unit Hydrograph derivation. This might be a question about acceptability in applying in practical field.

On the other hand, SCS method is preferred for its additional morphometric parameters i.e. watershed slope and the curve number (CN), which are connected with the properties of the soil and vegetation cover for the development of peak runoff hydrograph estimating the required ordinate.

Recognizing the fact that the different hydrological models' performances varied according to their synchronization with the watershed condition, it can be stated that analyzing models' appropriateness to the study would be a significant part whereas efficient flow estimation is to be achieved.

4.3 References

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