SWAT PROJECT OF GRAND RIVER BASIN AT MARSHVILLE

SWAT Model build-up and Calibration

DETERMISNISTIC HYDROLOGICAL MODELLING

PROJECT 3 REPORT

Group Members

Pardeep Kaur (107663)

Ashmeet Singh (1115556)

Abstract

The aim of this Project is to build-up and calibrate SWAT model of Grand River basin at Marshville. The SWAT model is build-up by following the instructions given in the class and in the assignment. This project also includes the validation of the SWAT model by using monthly streamflow measurements and analyse the impact of climate change scenario. Climate change analysis is done by selecting the climate data from WETechData for mid century (2050's:2035-2064) and end century (2085's:2070-2099) period, which focused on impacts on streamflow and other water balance components. The focus of this project is on the hydrology part of the SWAT model. Statists RSR, NSE, PBIAS are used for comparison and decision making for the further process. For calibration time period (1983-1987) has been selected and parameters are adjusted to get the best calibrated values. The range of parameters is taken into consideration while calibrating the SWAT model. For validation, time period of 1988-1993 has been selected and best calibrated values from calibration ae used for validation of the SWAT model. The results of the calibration were in very good range whereas for validation the range varied from satisfactory to very good range. The spatio-temporal analysis and climate Analysis also been considered and performed by selection climate scenarios.

CONTENTS

INTRODUCTION

The SWAT (Soil and Water Assessment Tool) model is a river basin, or watershed, scale model, which was developed to predict the impact of land management practices on water, sediment, and agricultural chemical yields in watersheds. The model is physically based and computationally efficient which used readily available inputs and enables users to study long-term impacts which was developed by developed by the United States Department of Agriculture - Agricultural Research Services (USDA – ARS). The SWAT model can be used for various watershed and water quality modeling studies. SWAT can be used to simulate a single watershed or multiple hydrologically connected models. Every watershed is first divided into subbasins and then into hydrologic response units (HRUs) based on the land use and soil distributions. SWAT uses a two-level disaggregation scheme; a preliminary sub basin identification is carried out based on topographic criteria, followed by further discretization using land use and soil type considerations.

SWAT model is used to run hydrological models to get water balance ratios like: stream flow-precipitation ratio, base flow-total flow ratio, ET-precipitation ratio etc. It has various components like weather, surface runoff, evapotranspiration, nutrient & pesticide loading etc. The objective of such a model is to predict the long-term impacts in large basins of management and timing of agricultural practices within a year.

This project includes the use of SWAT model to build-up runoff simulation model for Grand River Basin at Marshville station then calibration and validation. This project focuses on the simulation of runoff and then follow the procedure of manual calibration of 12 given parameters in the project's instructions. Calibrated model has been used to depict spaciotemporal changes at sub-watershed scale in various components of water budget (e.g precipitation, water yield).

For climate analysis

Project Objectives

1. Build-up a SWAT model for Grand river Basin at Marsville station by following instructions given below.
    - Make sure you select the watershed outlet point at the Marsville streamflow gauging station. In fact, the watershed boundary has been provided in such a way that the whole watershed outlet would be at vicinity of the gauging station.
    - After initial setup, copy and replace the SWAT2012.mdb in your project folder from the SWAT_DATA_BASE. The database contains any updates that were needed to be made
    - During HRU delineation, use 0-2, 2-5, 5-999 under slope classification and a threshold value of 5% each for land use, soil and slope.
    - Use WGEN_US First Order for weather generator during weather inputs section
    - Use a warm-up period of 3 years (1980-1882) should be used when simulating hydrology.

2. Simulate a baseline model and compare observed and simulated flow at outlet of the watershed. Investigate statistics and temporal time series plots. Make sure you use the data from 1983 to 1993 both for calibration and validation purposes. Change the parameters only within reasonable limits or range or physical meaning.

3. Use an iterative process of manual calibration where you use expert judgment in selecting the parameter that would help satisfy calibration criteria (such as achieving a "very good" rating)

4. Make sure there are no warning messages appear in the hydrology part of the "swatcheck" and also your calibration quantitative statistics are significantly improved. Use several performance measures (e.g. R2, NSE and PBIAS) and evaluation criteria paper (Moriasi et al., 2015) to evaluate your model performance. Also, the temporal time series hydrographs of observed and simulated needs to be close to each other.

5. Use the calibrated model to depict spatiotemporal changes at sub-watershed scale in various components of water budget (e.g. precipitation, water yield, etc)

6. Select one climate model from WETechData (http://www.2w2e.com/) (Ashraf Vaghefi et al., 2017) and one scenario (RCP 8.5), and assess the impacts on streamflow and other water balance components for mid-century (2050's: 2035-2064) and end-century (2085's: 2070-2099) period. You can present climate change results on monthly and annual time scales. The

1.SWAT Model build-up of Grand river basin at Marshville

The SWAT model is build-up by following steps:

<u>Step1Project setup:</u>

The ArcSWAT ArcGIS extension a graphical user interface is used for the SWAT (Soil and Water Assessment Tool) model. The first step in using ArcSWAT is to set up a project so that necessary folders and databases are created to store all the data.

<u>Step2 Adding data:</u>

- In the Automatic watershed delineation, DEM(digital elevation model) for the Grand river basin is added into the ArcSWAT which can be seen from (figure.1)and after adding DEM, watershed looks like (figure.2).
- In the Stream Definition, DEM based flow direction and accumulation is completed (figure 1).
- Then whole watershed is delineated by selecting outlet at Marshville station, polygon feature class with subbasins is added to the map document (figure.3). In the topographic report 25 subbasins with low and high elevation data can be seen.
- The final step in watershed delineation is to generate parameters/attributes for all the sub-basins.

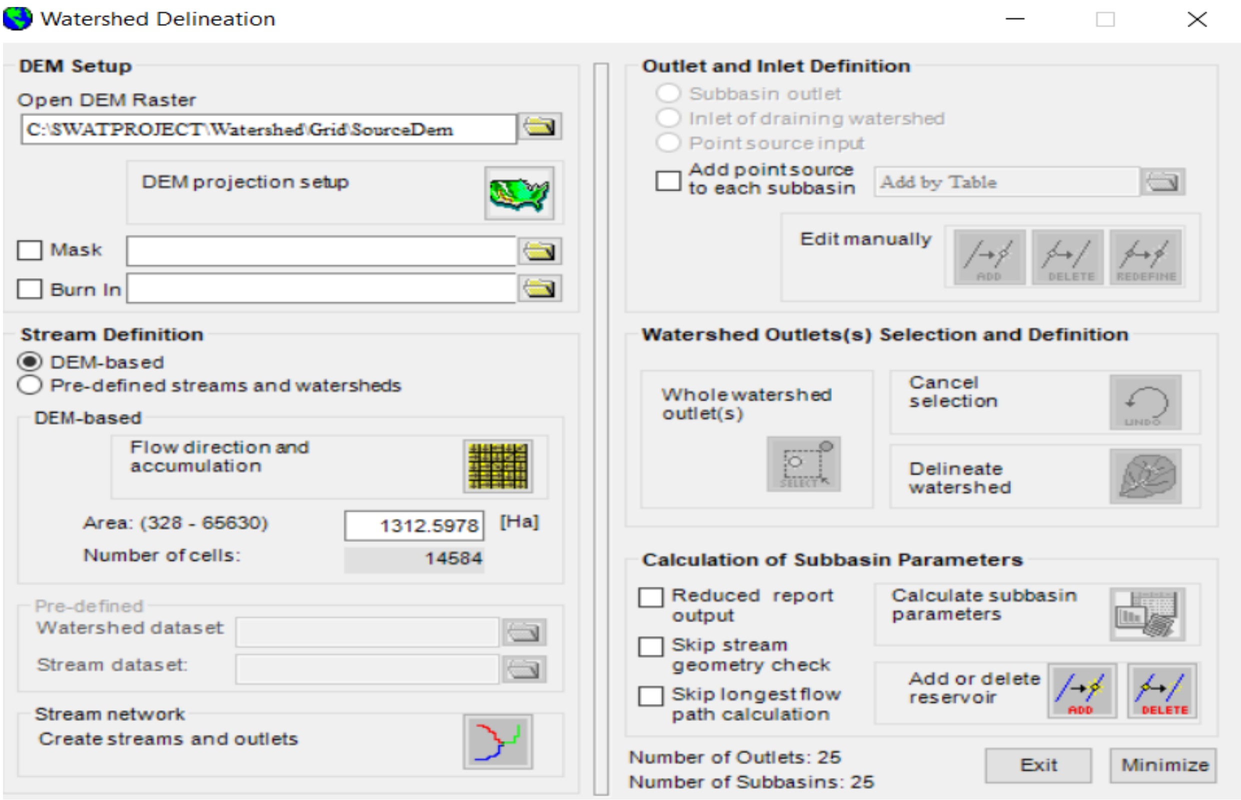


Figure.1

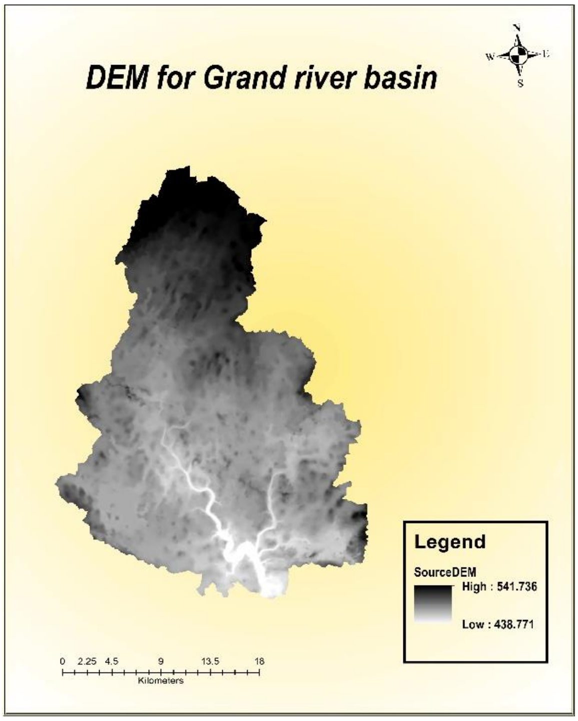


Figure.2

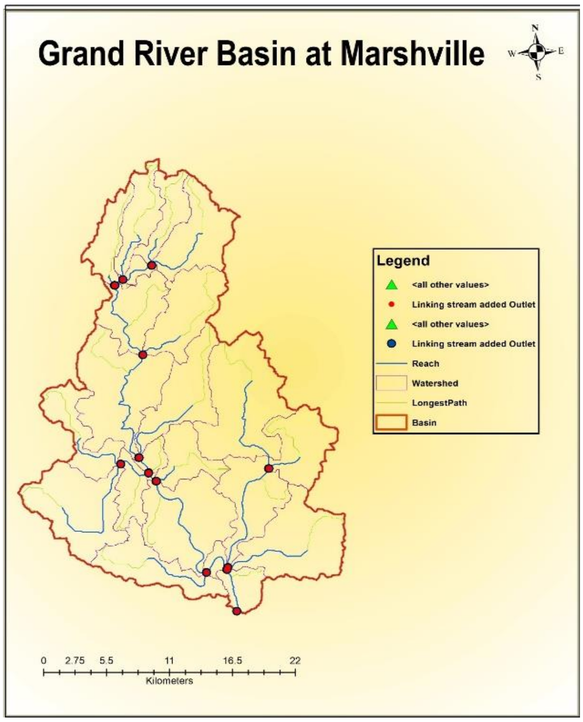


Figure.3

Step 3 HRU Analysis:

After watershed delineation, the next step is to create HRUs by using land use, soil and elevation (slope) information. In HRU Analaysis Land use, Soil and Slope classifictaion is added. For land use distribution in Grand river basin, land use is classified into10 categories (table.1).

Number	**Land use**	
1	Agricultural Land-Row Crops	AGRR
2	Forest-Mixed	FRST
3	Forest-Deciduous	FRSD
4	Forest-Evergreen	FRSE
5	Wetlands-Non-Forested	WETN
6	Pasture	PAST
7	Range-Grasses	RNGE
8	Residential-High Density	URHD
9	Water	WATR
10	Barren	BARR

Table.1

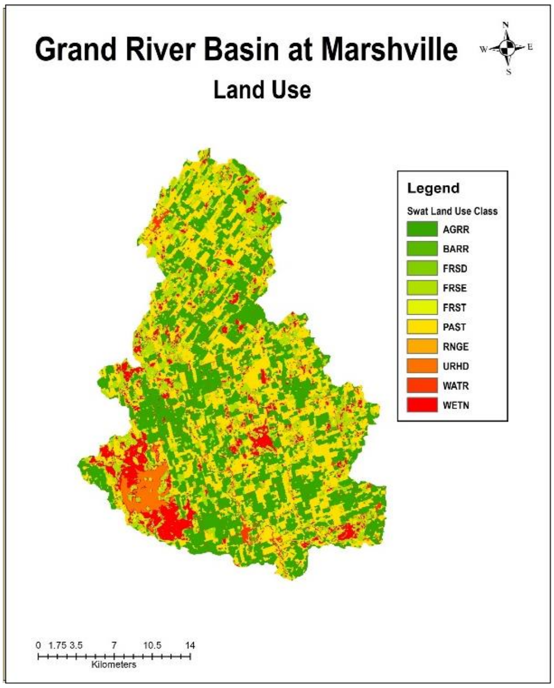


Figure.4

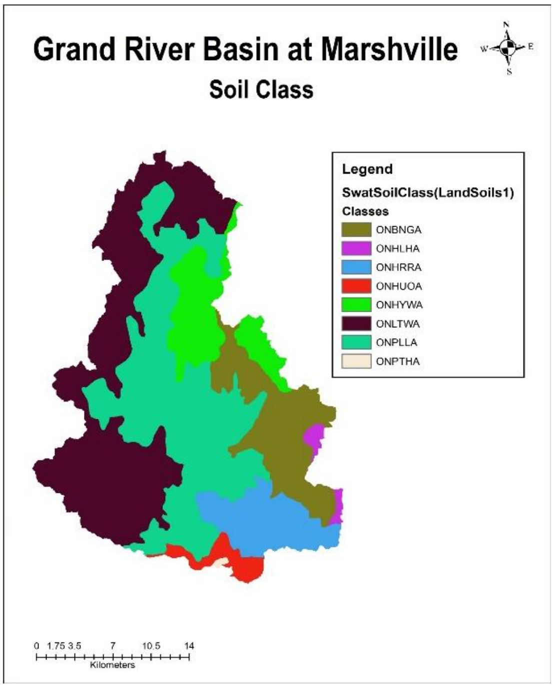


Figure.5

Soil is classified into 8 categories(figure.5) and slope is classified into 3classes 0-2,2-5,5-9999 as per the requirement of the project instructions (figure.6). 5% of HRU threshold is used for land use percentage, soil class percentage and slope class percentage definition (figure.7). After HRU analysis whole watershed is divided into 25 subbasins and 359 HRUs by considering land use and slope classification.

Watershed	Area (ha)	Area(acres)	Km2
Grand river basin	65629.98	162174.96	656.30

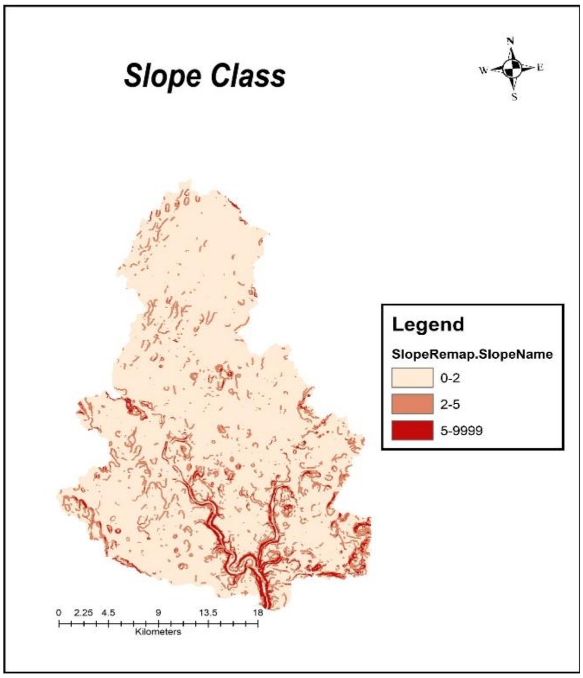


Figure.6

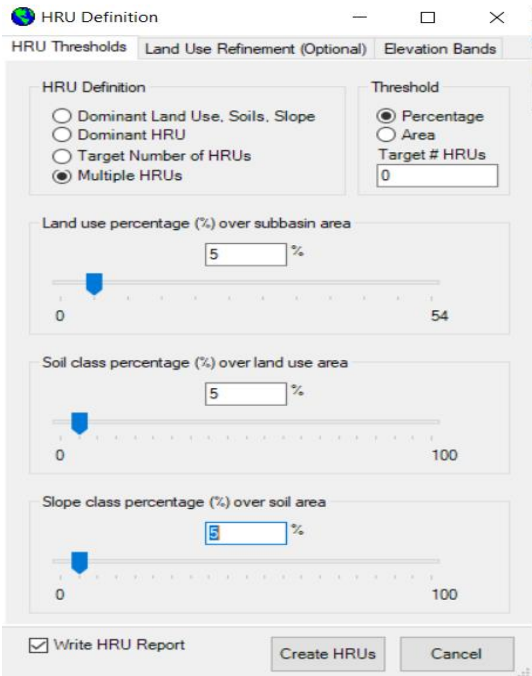


Figure.7

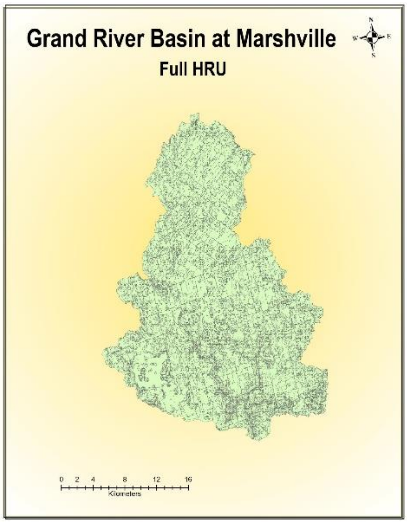
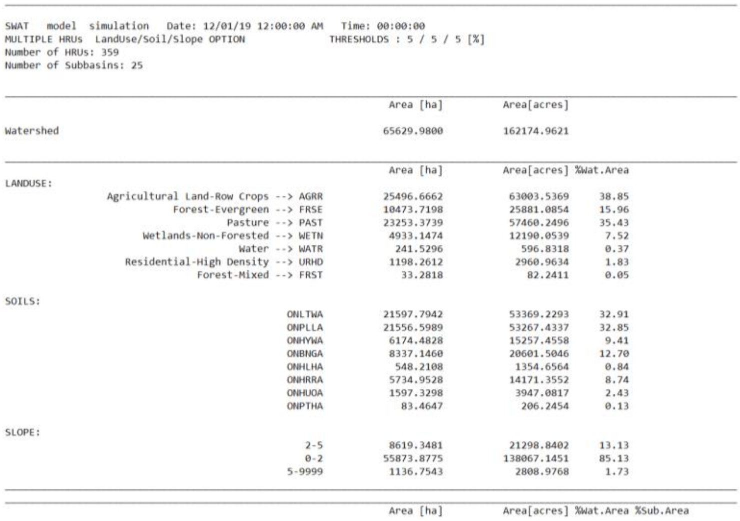


Figure.8 Watershed



SWAT model simulation Date: 12/01/19 12:00:00 AM Time: 00:00:00
MULTIPLE HRUs LandUse/Soil/Slope OPTION THRESHOLDS : 5 / 5 / 5 [%]
Number of HRUs: 359
Number of Subbasins: 25

	Area [ha]	Area[acres]	%Wat.Area
Watershed	65629.9800	162174.9621	
LANDUSE:			
Agricultural Land-Row Crops --> AGRR	25496.6662	63003.5369	38.85
Forest-Evergreen --> FRSE	10473.7198	25881.0854	15.96
Pasture --> PAST	23253.3739	57460.2496	35.43
Wetlands-Non-Forested --> WETN	4933.1474	12190.0539	7.52
Water --> WATR	241.5296	596.8318	0.37
Residential-High Density --> URHD	1198.2612	2960.9634	1.83
Forest-Mixed --> FRST	33.2818	82.2411	0.05
SOILS:			
ONLTWA	21597.7942	53369.2293	32.91
ONPLLA	21556.5989	53267.4337	32.85
ONHYWA	6174.4828	15257.4558	9.41
ONBNGA	8337.1460	20601.5046	12.70
ONHLHA	548.2108	1354.6564	0.84
ONHRRA	5734.9528	14171.3552	8.74
ONHUOA	1597.3298	3947.0817	2.43
ONPTHA	83.4647	206.2454	0.13
SLOPE:			
2-5	8619.3481	21298.8402	13.13
0-2	55873.8775	138067.1451	85.13
5-9999	1136.7543	2808.9768	1.73

Area [ha] Area[acres] %Wat.Area %Sub.Area

Figure.9:Final HRU distribution report

Full HRU is showm in figure 8 and report for final HRU disrtibution is shown in fig.9

<u>Step 4: Weather data</u>

In weather station option WGEN_US_FirstOrder weather genertair is used to generate weather data and then given rainfall (PCP_Stations) and Temperature data(TMP_Stations) is used for further weather classification.

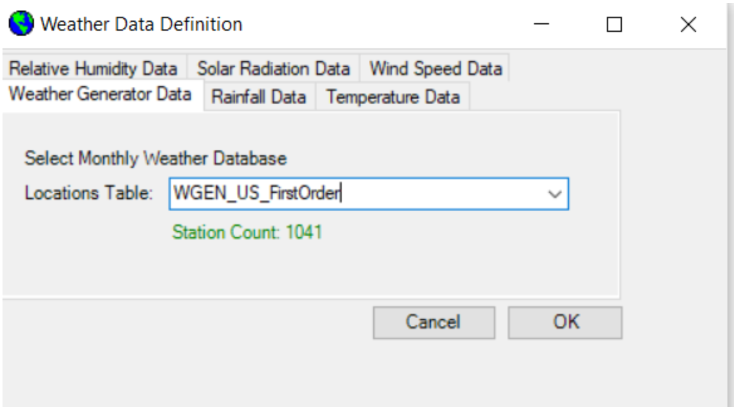


Figure.10

Then iput files are created by option write input tables and then model is ready run.

<u>Step 5: Run Model</u>

In SWAT simulation model is set to run for 10 year simulation period. 3 year of warmup period (1980-1982) is used for this projet, model had been run for 10 year of simulation period (1983-1993).

2.SWAT Model calibration and Validation

Several calibration techniques have been developed for SWAT, including manual calibration procedures and automated procedures using the shuffled complex evolution method and other common methods. In this project manual calibration procedure is used where all parameters are adjusted one at a time and results are observed for each one.

Model calibration is the process in which base model is adjusted so that model predictions better represent the real-world processes and conditions. When performing of the model, model parameters are adjusted to increase accuracy and to reduce the model prediction uncertainty. Calibration is performed by carefully selecting the model parameters values and adjusting them within the suitable range. A general list of parameters that are shown to be sensitive for cold-climate regions such as Ontario has been used for calibration (table.2).

Then results for runoff are compared with the observed data by using various statistics R2, NSE, and PBIAS. A very good rating is selected for these statistics for the model performance A iterative process of model calibration has been followed in this SWAT project.

Parameters	File	Default value	Range Tested
CN2	mgt	Variable	-10% to + 10%
AWC	sol	Variable	-10% to +10%
ESCO	bsn	0.95	0.6 to 0.95
OV_N	hru	0.14 cropland	0.1 to 0.14 for cropland
Alpha_BF	gw	0.048	0.01 to 0.10
GW_DELAY	gw	31	20 to 60
GW_QMN	gw	1000	1000 to 2500
SFTMP	bsn	1	-2 to 2
SMTMP	bsn	0.5	-2 to 2
SMFMX	bsn	4.5	2 to 8
SMFMN	bsn	4.5	2 to 8
TIMP	bsn	1	0 to 1

Table.2:Model parameters for Calibration.

Validation is the procedure to find the accuracy of calibrated model by using best calibrated parameter values in a new modelling situation, but accuracy can vary according to the modelling goals.

In this project calibration and validation processes are done by considering two different time plots. Calibration is done for Calibration was done for the first five-year period i.e. from 1983-1987 and 1980-1982 was chosen as the warm up period. Validation for the calibrated values was done for the period of 1988-1993. To compare the results RSR, PBIAS and NSE statistics are used. Qualitative ratings suggested by (Moriasi et al,2015)

Table 4. General performance ratings for recommended statistics for a monthly time step.

Performance Rating	RSR	NSE	PBIAS (%)		
			Streamflow	Sediment	N, P
Very good	$0.00 \leq RSR \leq 0.50$	$0.75 < NSE \leq 1.00$	$PBIAS < \pm10$	$PBIAS < \pm15$	$PBIAS < \pm25$
Good	$0.50 < RSR \leq 0.60$	$0.65 < NSE \leq 0.75$	$\pm10 \leq PBIAS < \pm15$	$\pm15 \leq PBIAS < \pm30$	$\pm25 \leq PBIAS < \pm40$
Satisfactory	$0.60 < RSR \leq 0.70$	$0.50 < NSE \leq 0.65$	$\pm15 \leq PBIAS < \pm25$	$\pm30 \leq PBIAS < \pm55$	$\pm40 \leq PBIAS < \pm70$
Unsatisfactory	$RSR > 0.70$	$NSE \leq 0.50$	$PBIAS \geq \pm25$	$PBIAS \geq \pm55$	$PBIAS \geq \pm70$

3.Spatio-Temporal Analysis

Calibrated model is used to depict spatio-temporal changes at sub-watershed scale in various components of water budget (precipitation, water yield etc). Spatial and temporal scales are intrinsic to the simulation of model response variables, and these scales must be considered in developing a C/V strategy. Spatial and temporal scales affect many aspects of H/WQ modeling, including selection of an appropriate model and selection and allocation of C/V comparison data also establishment of the appropriate model assessment criteria and targets.

Issues of scale (both spatial and temporal) may influence the appropriate use of observed comparison data for a given modeling application. If different scales between observed comparison data and model output variables must be used, these constraints must be resolved, either by upscaling (aggregating data from smaller scale to represent a larger scale) or downscaling.

Climate Analysis

In 21st century climate change is recognized as the major environmental problem facing by globe. Estimation of impacts of climate change at both global and regional scale has become a attraction for researchers. Future climate change is projected to have significant impacts on water resources availability in many parts of the world.

Impact assessment require climate at various spatial and temporal scales. GCMs are typical sources of future climate data. The increase in temperature, variations in precipitation, and changes in the frequency of extreme events increase the probability of flood occurrences and change the total and seasonal water supply.

For the climate projection scenario, GCM 1 climate model and scenario 4 (RCP 8.5) was adopted from WETechData (Ashraf Vaghefi et al., 2017) to assess the impacts on streamflow and other water balance components for mid-century (2050’s:2035-2064) and end-century (2085’s:2070-2099) period.

Calibration

Instructions for calibration:

- Calibration was done for the first five-year period i.e. from 1983-87
- 1980-1982 was chosen as the warm up period.
- Based on the sensitivity analysis- CN2, SMTMP, TIMP and OV_N were the most sensitive parameters.
- Manual calibration of all the factors was done separately to get the best fit values for each and every parameter (Table.3).

Parameters	File	Default Value	Range Tested
CN2	Mgt	Variable	-10% to +10%
AWC	Sol	Variable	-10% to +10%
ESCO	Bsn	0.95	0.6 to 0.95
OV_N	Hru	0.14	0.1 to 0.14
Alpha_BF	Gw	0.048	0.01 to 0.10
GW_DELAY	Gw	31	20 to 60
GW_QMN	Gw	1000	1000 to 2500
SFTMP	Bsn	1	-2 to 2
SMTMP	Bsn	0.5	-2 to 2
SMFMX	Bsn	4.5	2 to 8
SMFMN	Bsn	4.5	2 to 8
TIMP	bsn	1	0 to 1

Table.3

Calibration Results:

Based on the sensitivity analysis- CN2, SMTMP, TIMP and OV_N were the most sensitive parameters. Best calibrated values are shown in table.4, those manually calibrated values are selected for the model validation for different time period. Those values are selected by comparing the output of model and observed data with the help of RSR, PBIAS and NSE. For these statistics very good rating is achieved for calibrated values.

Parameter best Calibrated values

Parameter	Definition	Calibrated Value	Range
CN2	Curve Number	2.30%	-10% to +10%
AWC	Available water capacity of soil layer	2%	-10% to +10%
ESCO	Soil evap compensation factor	0.85	0.6 to 0.95
OV_N	Manning’s value	0.10	0.1 to 0.14
Alpha_BF	Baseflow Alpha Factor	0.068	0.01 to 0.10
GW_DELAY	Delay time	25	20 to 60
GW_QMN	Threshold depth of water	1490	1000 to 2500
SFTMP	Snowfall Temperature (℃)	-0.43	-2 to 2
SMTMP	Snow melt base temperature (℃)	0.70	-2 to 2
SMFMX	Melt Factor (June 21)	2.80	2 to 8
SMFMN	Melt Factor (Dec 21)	4.30	2 to 8
TIMP	Snow pack temp lag factor	0.50	0 to 1

Table.4

For comparison RSR, NSE, PBIAS statistics are used for calibration results(Table.5). For all the parameters very good rating is achieved for these statistics to select the best calibrated values. To check the underprediction and overprediction of model PBIAS has been used. Percent bias (PBIAS) measures the average tendency of the simulated data to be larger or smaller than their observed values.

The optimal value of PBIAS is 0.0, with low-magnitude values indicating accurate model simulation. Positive values indicate model underestimation bias, and negative values indicate model overestimation bias

$$PBIAS = \frac{C}{D}(100)$$

$$C = \sum_{I=1}^{n}(o - s)$$

$$D = \sum_{i=1}^{n} o$$

For this project PBIAS =-7.1 is achieve which is in very good rating and a graph to represent the results is made(graph.2).

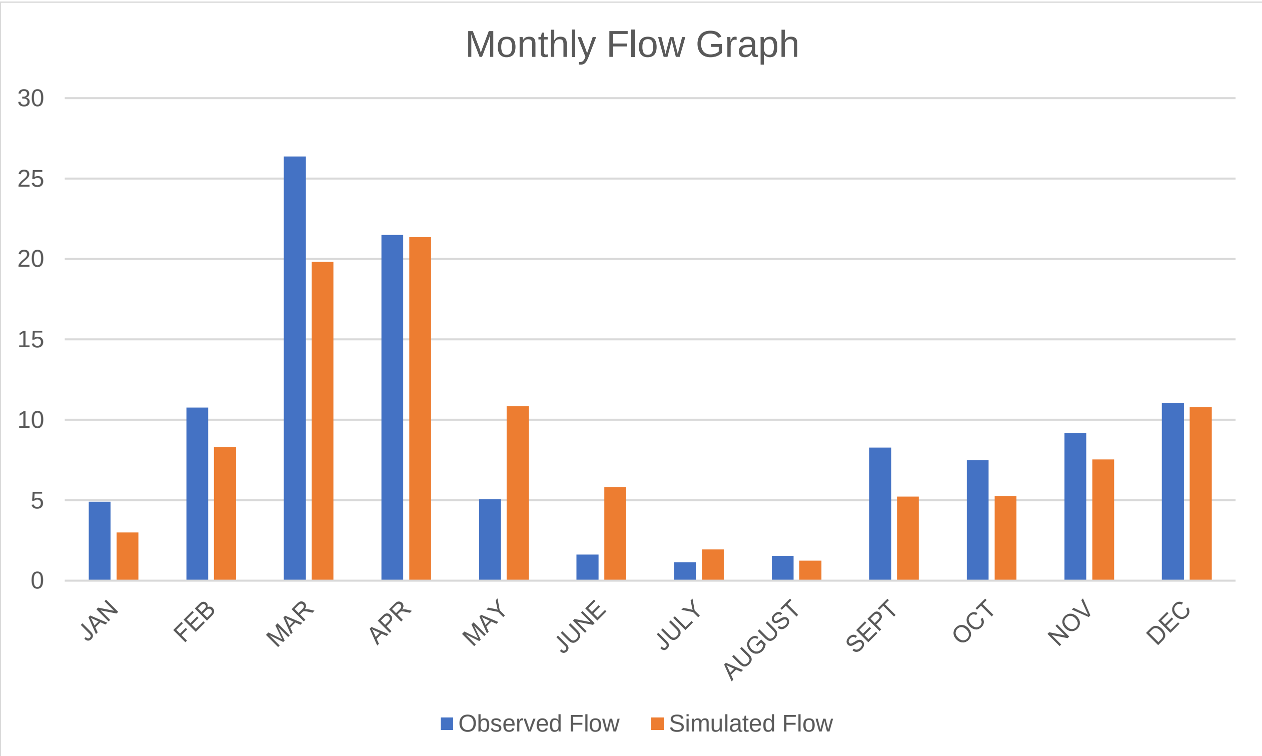
Statistics for comparison

RSR	0.47	Very good
NSE	0.78	Very good
PBIAS (%)	-7.1	Very good

Table.5:

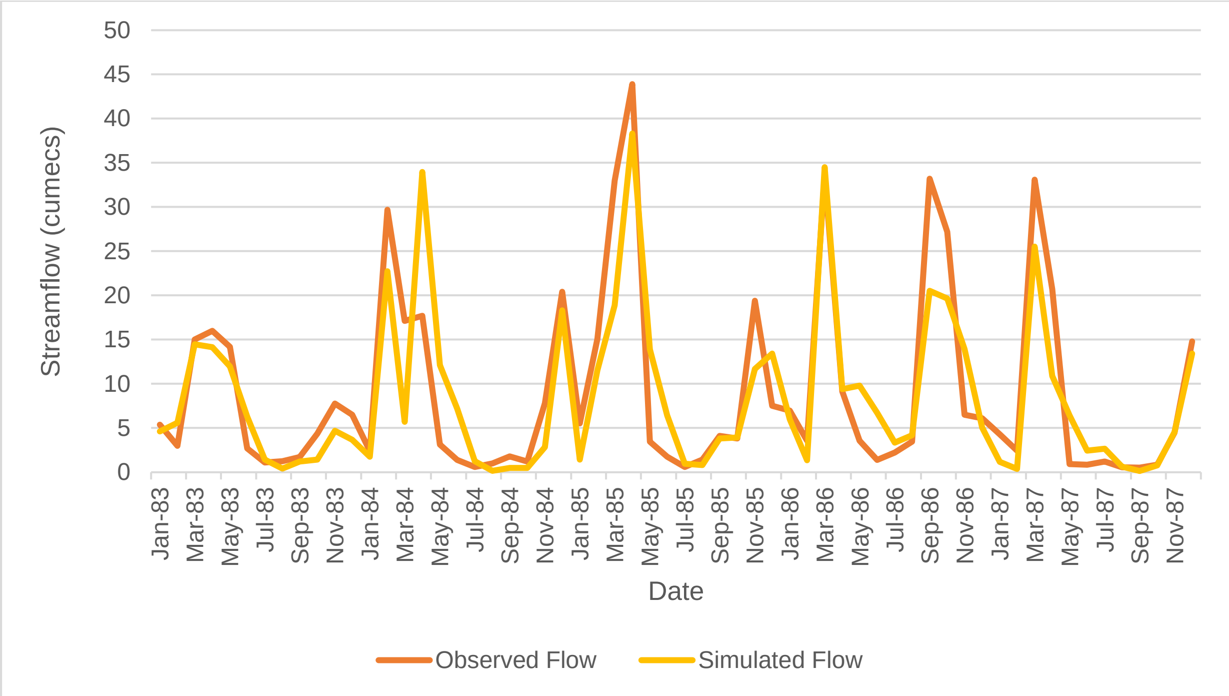
Table 4. General performance ratings for recommended statistics for a monthly time step.

Performance Rating	RSR	NSE	PBIAS (%) Streamflow	PBIAS (%) Sediment	PBIAS (%) N, P
Very good	$0.00 \leq RSR \leq 0.50$	$0.75 < NSE \leq 1.00$	$PBIAS < \pm10$	$PBIAS < \pm15$	$PBIAS < \pm25$
Good	$0.50 < RSR \leq 0.60$	$0.65 < NSE \leq 0.75$	$\pm10 \leq PBIAS < \pm15$	$\pm15 \leq PBIAS < \pm30$	$\pm25 \leq PBIAS < \pm40$
Satisfactory	$0.60 < RSR \leq 0.70$	$0.50 < NSE \leq 0.65$	$\pm15 \leq PBIAS < \pm25$	$\pm30 \leq PBIAS < \pm55$	$\pm40 \leq PBIAS < \pm70$
Unsatisfactory	$RSR > 0.70$	$NSE \leq 0.50$	$PBIAS \geq \pm25$	$PBIAS \geq \pm55$	$PBIAS \geq \pm70$



Graph.1

Observed/ Simulated flow (1983-1987)



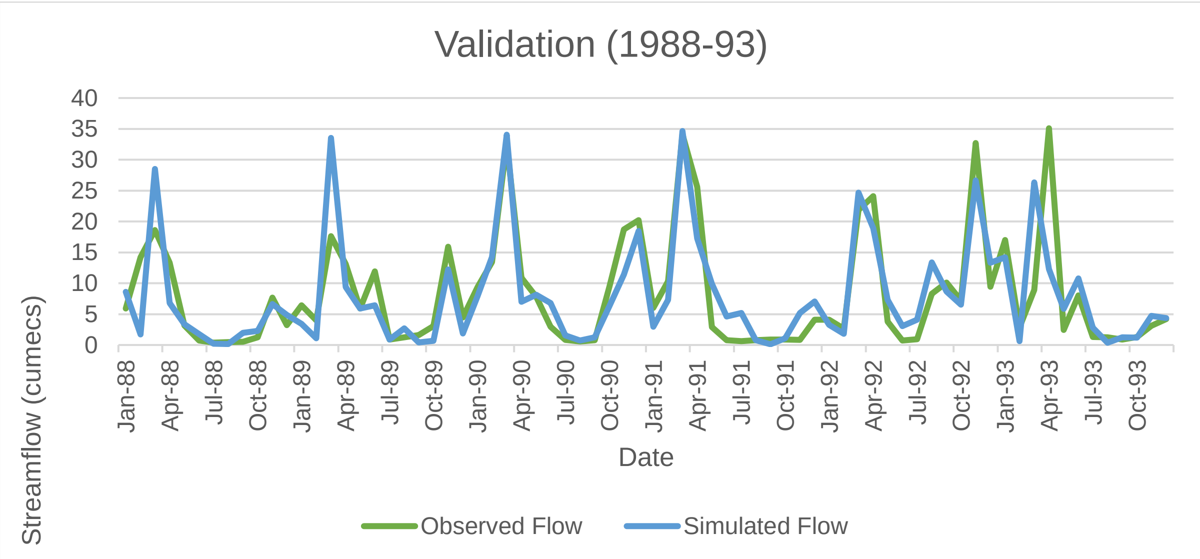
Graph.2

Validation

- Validation for the calibrated values was done for the period of 1988-1993.
- General performance ratings for **RSR** was coming under "good rating", **NSE** under "satisfactory rating" and **PBIAS** under "very good rating".

Results for Validation

To Validate the SWAT model of Grand river basin, validation period was selected from 1988-1993. After model run results are compared and numerical aid is used for comparison. As statistics were showing very good rating for calibrated values but for validation RSR, NSE, and RSR showed good rating ,NSE was in satisfactory range and PBIAS was in very good range. As a result, calibration and validation period affects the output of the model and thus for very good rating calibrated valued for 1983-1987 cannot be used for different validation period (1988-1993).



Graph.3

Statistics for Comparison

RSR	0.59	Good
NSE	0.65	Satisfactory
PBIAS (%)	-1.3	Very good

Spatio Temporal Analysis

The water budget analysis for the initial model and the calibrated model didn't vary much as the readings were quite similar. Precipitation value remained the same for both the models. The evapotranspiration and transpiration numbers were around 503 mm for the initial uncalibrated model whereas it was around 540 mm for the calibrated model. Thus ET/Transpiration witnessed an increase in value though by not much big of a factor. Surface runoff varied between 226 mm for the initial model to 217 mm for the calibrated model. Thus, not big of a change. The recharge to the deep aquifer remained same from 12mm for the uncalibrated model to 11 mm for the calibrated one. Same is the case for PET value for the initial model i.e. 769 mm and 766 mm of calibrated model. The value for the return flow of water witnessed the most significant change compared to other water budget factors i.e. return flow for water in the initial uncalibrated model remained 218 mm and for the calibrated model it changed to 176 mm. Setting aside these factors and considering the water balance ratios for both these models, it can be found that the ratios (Streamflow/Precip, Baseflow/Total Flow, Surface Runoff/Total Flow, Perc/ Precip, Deep Recharge/Precip and ET/Precipitation) remained almost consistent for both the models.

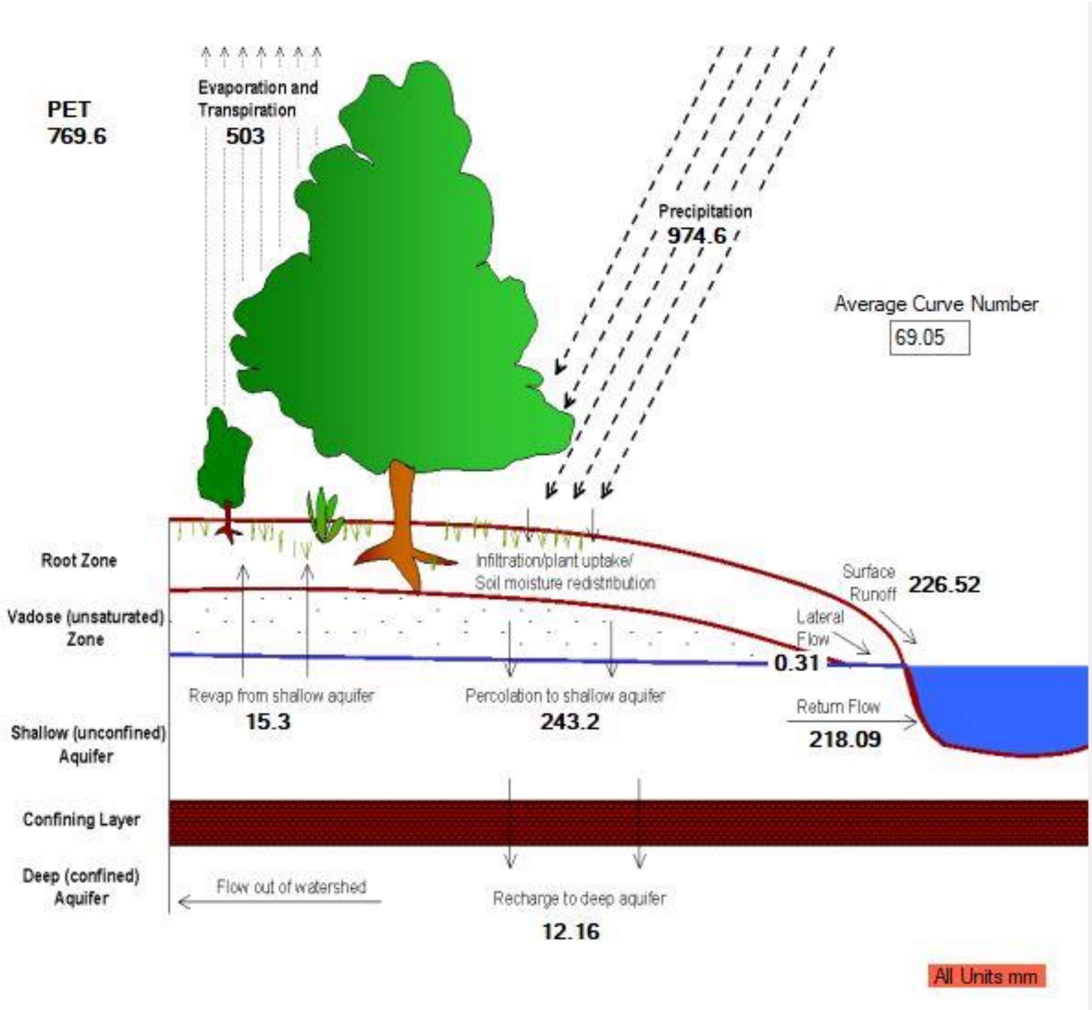


Figure.11

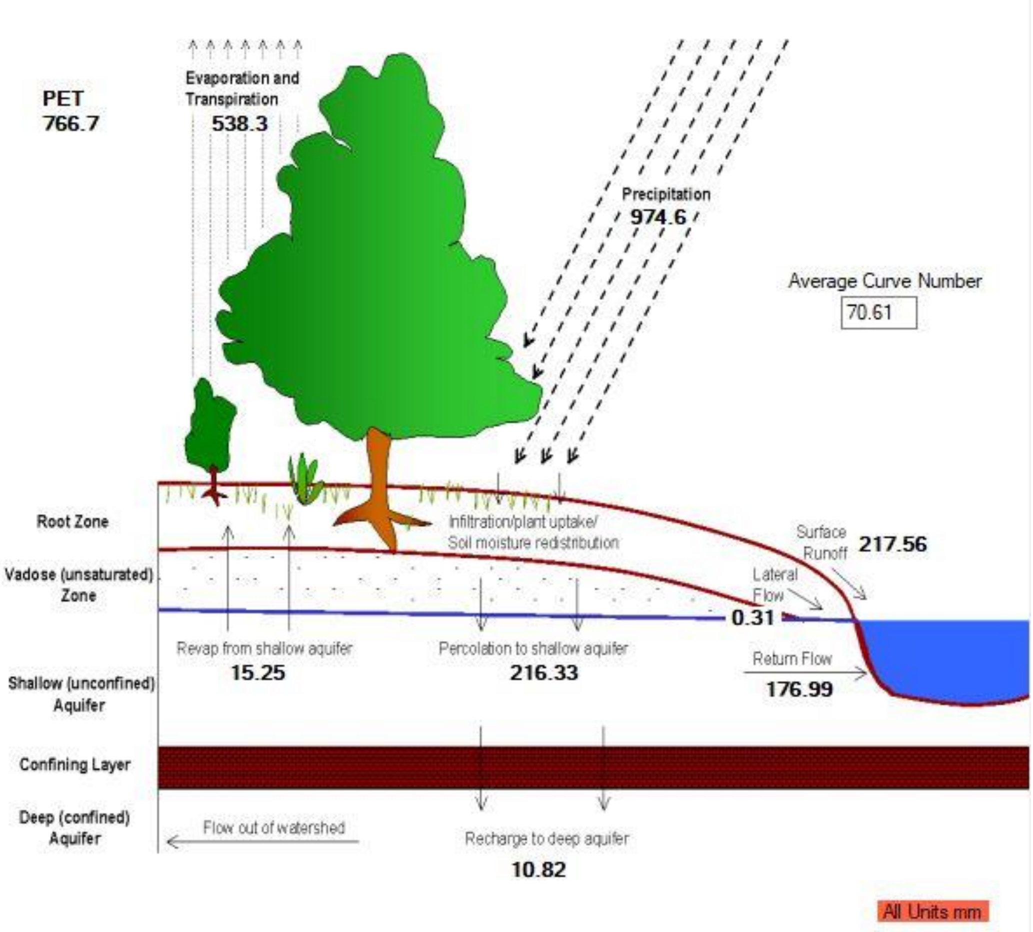


Figure.12

Results

Water Balance Ratios	Initial Model	Calibrated Model
Streamflow/Precip	0.46	0.41
Baseflow/Total Flow	0.49	0.45
Surface Runoff/ Total Flow	0.51	0.55
Perc/Precip	0.25	0.22
Deep Recharge/Precip	0.01	0.01
ET/Precipitation	0.52	0.55

Table.6

Climate Project Scenario

- For the climate projection scenario, GCM 1 climate model and scenario 4 (RCP 8.5) is adopted.
- Model was run for 3, thirty-year time periods that are:

1. Historical Period = 1953-82
2. Future Period 1 = 2035-64 (mid-century)
3. Future Period 2 = 2070-99 (end century)

For the climate projection scenario, GCM 1 climate model and scenario 4 (RCP 8.5) was adopted from WETechData (Ashraf Vaghefi et al., 2017). The model was run for 3 separate 30 year periods that are from 1953-1982 (Historical Period), 2035-2064 (Mid-Century Period) and 2070-2099 (End Century Period). Changes were made in the initial calibrated model by again changing the weather data and uploading new precipitation and temperature station files in the weather generator.

Rest all files were taken as the simulated files. For changing the initial MET files, weather data readings (temperature and precipitation) of the GCM 1 model were used to create new files according to the previous files with a different latitude, longitude and elevation values. MET files were separately made for the future period i.e. from 2005-2099 and historical period (1950-1999). These files were used to separately run the weather generator for these two time periods.

Results for climate project scenario

As weather holds an important role in determining various water parameter values. Thus when the data for the 4 time periods i.e. Historical period (1953-1982), calibrated period (1983-1987) and future periods (2035-2064, 2070-2099) was compared there were some changes found in the values of the water parameters. In the case of precipitation value, it is consistently increasing at a steady pace from 965 mm in the historical period to around 1170 mm in the future period (2070-2099).

Thus, showing a positive trend in precipitation values over the years. Furthermore, the value of ET and transpiration also kept on increasing in the time periods from 480 mm (historical period) to 575 mm (future period). Thus, indicating an increase in temperature over the years in the watershed due to the climate changes. Also, its been noticed from the numbers that there is also an increase in surface runoff from 190 mm in the historical period to 220 mm during future period as is evident from the fact that there has been an increase in precipitation over the years as well leading to an increase in runoff as well.

Moreover, due to increase in precipitation, an increase in the value groundwater recharge can also be noticed but the increase is quite less as compared to the initial value of recharge in the historical period. The values of percolation and return flow also witnessed an increase in numbers due to increasing value if precipitation. Thus, these all water parameters show a direct link with each other as if the value of one factor increases, similarly the values of other parameters also increase.

Though an increase in the values of water parameters can be witnessed over the years but the changes are not drastic. These obtained numbers/values are almost same if we look at it over the large time periods. Thus, also confirming the validity of the climate values over the years for the basin.

The climate results were compiled on monthly basins for the above four time periods and it was noticed that in the winter months (November-April), there was an increase in rain over the basin mainly in December and January. Summer months experienced comparatively less rainfall than the winter months, although these numbers were comparative to the latter months.

CLIMATE RESULTS

Parameters	**1953-82**	**1983-87**	**2035-64**	**2070-99**
Precipitation	965.50(mm)	974.60(mm)	1094.20	1168.50
ET & Transpiration	482	538.30	544.20	575.40
Surface Runoff	190.81	217.56	223.80	220.22
Recharge	14.59	10.82	16.27	18.50
Percolation	291.86	216.33	325.44	370.08
Return Flow	264.16	176.99	293.64	334.70

References

Ashraf Vaghefi, S., Abbaspour, N., Kamali, B., & Abbaspour, K. (2017). A tool kit for climate chnage analysis and pattern recognition for extreme weather conditions .

Daggupati, P., Pai, N., Ale, S., R, D.-M. K., W, Z. R., & J, J. (2015). Recommended calibration and Validation Atrategy foR Hydrologic and Water quality models. *Transactions of the ASABE*.

Moriasi, D., Gitau, M., Pai, N., & Daggpati, P. (2015). Hydrologic and Water Quality Models Performance measures and Evaluation Criteria.