Continuous Rainfall-Runoff Simulation below Red Butte Creek Including Snowmelt

Salt Lake City, Utah

Term Project, CEE-6440, 2016Fall

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Abstract:

This project describes a case study of continuous rainfall-runoff modeling in part of Red Butte Creek watershed, Salt Lake City, Utah using ArcGIS and the Hydrologic Engineering Center – Hydrologic Modeling System (HEC-HMS) version 4.1 to estimate runoff in the red butte creek. ArcGIS tools are used to process a DEM to delineate watershed, stream network, and extract other watershed parameter and characteristic that could be used as input for many hydrological models. In this study, a continuous soil moisture accounting (SMA) and temperature index (Degree-day) snowmelt methods were used to simulate the long-term relationship between rainfall, interception, surface storage, infiltration, snowmelt, runoff, ground water percolation and evapotranspiration. Simple canopy, simple surface, Muskingum, Clark Unit hydrograph, recession, and Priestley Taylor were used for canopy, surface, routing, transform, base flow, and evapotranspiration methods respectively. The objective of this project is to evaluate the performance and potentiality of the HMS with the SMA and temperature index algorithms on a small part of red butte creek. The SMA and temperature index algorithms in HEC-HMS was calibrated using 1-year streamflow data from Feb 2014 to Feb 2015. Sensitivity analysis of model parameters has been conducted. ATI-Melt rate function and maximum infiltration rate were found to be most sensitive parameters within snowmelt and SMA methods for this watershed, respectively. Statistical evaluation was conducted to determine the performance of the HEC-HMS model and found to be Nash-Sutcliffe Efficiency EFC = 0.796. Overall, the temperature index and SMA procedure in the HEC-HMS conceptual model performed satisfactorily and can be used for long-term runoff modeling in the red butte creek.

Keyword – Continuous Hydrologic simulation; ArcGIS; HEC-HMS; SMA; Temperature Index, Sensitivity Analysis; Nash-Sutcliffe Efficiency

1. Objective:

Event based simulation model does not account the soil moisture variation with time. The soil moisture variation contributes important role in rainfall-runoff generation process. In addition, the event based simulation does not account evapotranspiration. In mountainous area, precipitation is occurring in both rain and snow form based on the elevation and air temperature. Within the simulation model if precipitation occurring as snow is taken equivalent to rain it causes big differences in the runoff generation amount. The reason behind this is that the liquid water come from snow is lesser than the rain amount. In general, peak flow in the mountainous area happened in the month of May to April due to snowmelt results variation in peak flow. Therefore, in order to take an account to the evapotranspiration losses and snow factor especially in the mountainous area long term simulation with appropriate snowmelt method must be use within the model. In this study case as term project, continuous rainfall-runoff modeling has been performed in a part of Red Butte Creek using HEC-HMS 4.1. The objective of this continuous simulation is to evaluate the performance of temperature index (snowmelt) and soil moisture accounting method in the HEC-HMS.

2. Introduction:

2.1 Tools:

ArcGIS: is used to combine information with location. GIS software tool is an important tool for civil and environmental engineers to use in their work. It is used to view spatial data, create layered maps, and perform spatial analysis. It can be used to store geographic data, make maps and analyze spatial data. GIS includes a set of comprehensive tools for working with the geographic data.

Snowmelt is an important water resources to many aspects of hydrology, including water supply, HEC-HMS: The Hydrologic Modeling System (HEC-HMS) is one of the mostly used tool developed by U.S. Army Corps of Engineers Hydrologic Center (HEC), designed to simulate rainfall runoff processes. HEC-HMS is a numerical model that includes a large set of methods to simulate watershed, channel, and water-control structure behavior, thus predicting flow, stage, and timing.

2.2 Temperature Index (Degree-Day) method:

Snowmelt is an important water resources to many aspects of hydrology, including water supply, flood control and erosion. Because of its significant contribution to the hydrological cycle, it is important to simulate snow runoff by using hydrological models [1]. Physically model are based on mass-energy balance and have physical meaning. Conceptual models are mainly based on mass conservation in association with simplified representation of momentum and energy equation [2]. In general, a temperature index or degree-day approach, and includes a conceptual representation of the cold energy stored in the snowpack [3]. The temperature index method is based on direct relationship between snow melt and air temperature. This model is commonly used than physically based models because of four main reasons: a) availability of air temperature data b) easy interpolation and forecasting possibilities of air temperature c) good performance d) computational simplicity [4]. The most important advantage of a temperature index approach is that snowmelt amount can be calculated using only average daily air temperatures, which is the most easily measured and widely available meteorological variable. This is the main reason for using temperature index approach for snowmelt runoff model in this study. The main disadvantages of temperature index models is that it does not take into account diurnal variations in meltwater flux and surface freezing [5]. In general, temperature index model works as below is shown in fig 1.

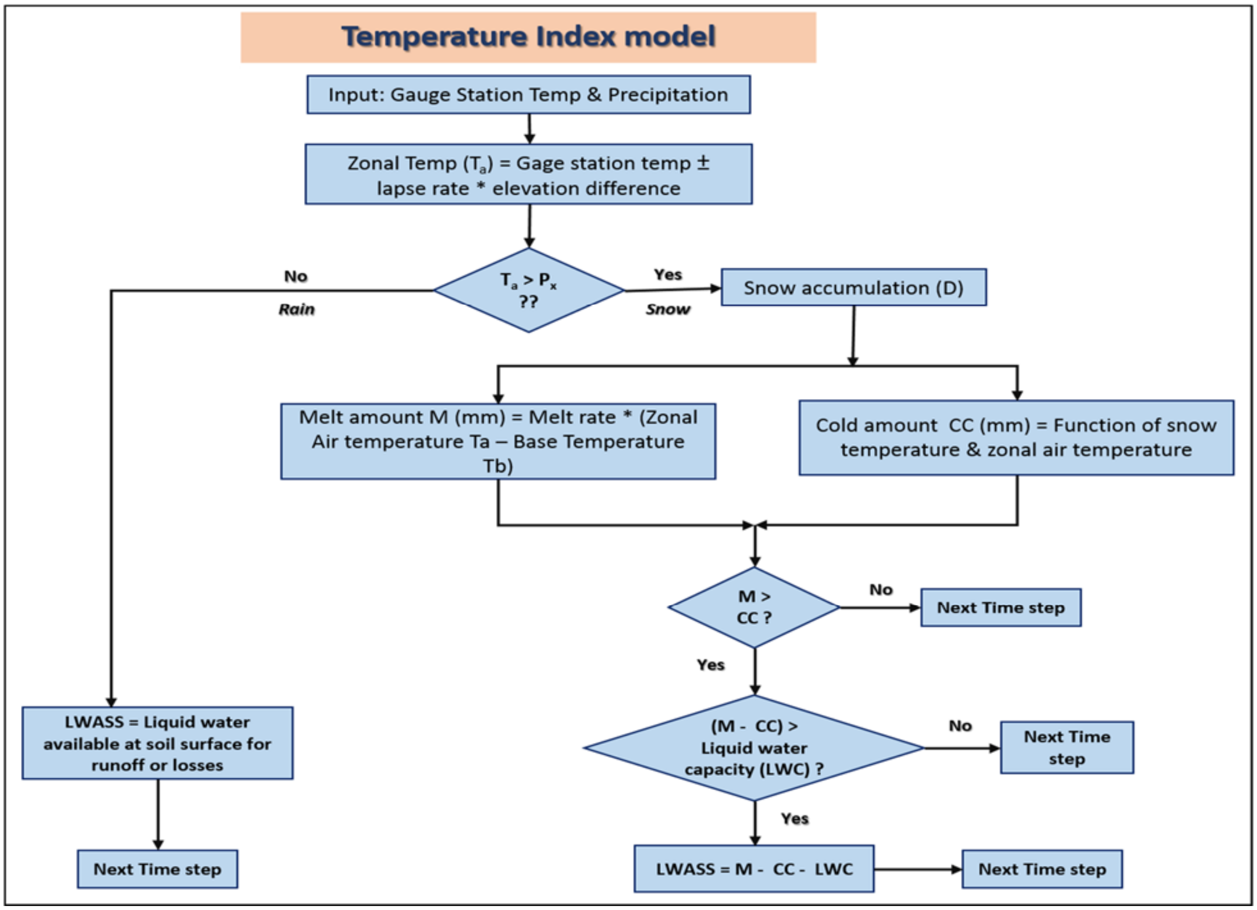


Fig1: Fig showing general flow chart of temperature index model.

Each subbasin is broken into a number of elevation band in temperature index model. One elevation band may be used to represent a subbasin with very little terrain. Subbasin with large elevation variations should use multiple elevation band [3]. Each subbasin must have a specified lapse rate and each temperature time-series gage must have an elevation specified for it. The temperature for each elevation band is computed using the temperature recorded in the time-series, the elevation of the time-series gage, the lapse rate for the subbasin, and the elevation of the band. The adjusted temperature for each elevation band is computed by adding a correction to the specified time-series, computed as the lapse rate multiplied by the band elevation minus the time-series elevation [3]. The Px temperature is used to discriminate between precipitation falling as rain or snow. When the air temperature is less than the specified Px temperature, any precipitation is assumed to be snow. When the air temperature is above the specified temperature, any precipitation is assumed to be rain and contributes as Liquid Water available at Soil Surface either for runoff or loss. This discrimination temperature is usually 1-2 degrees above freezing [3].

Melt amount calculation is performed based on the zonal air temperature and base temperature at each time step. If the air temperature is less than the base temperature, then the amount of melt is assumed to be zero. Typically, the base temperature should be 0 ^{0}C [3]. Similarly, cold amount calculation is performed based on the zonal air temperature and snowpack temperature. Liquid Water Capacity (LWC) is the amount of melted water that must accumulate in the snowpack before liquid water becomes available at the soil surface for infiltration or runoff. Typically, the maximum liquid water held in the snowpack is on the order of 3%-5% of the snow water equivalent, although it can be higher. If there is no cold amount and melt amount is greater than LWC then excess water will be available for LWASS [3].

2.3 Soil Moisture Accounting Loss Method:

The soil moisture accounting loss method uses five layers (canopy, surface, soil profile, groundwater1, and groundwater2) to represent the dynamics of water movement in the soil shown in fig 2 [3]. It should be used in conjunction with a canopy method and a surface method.

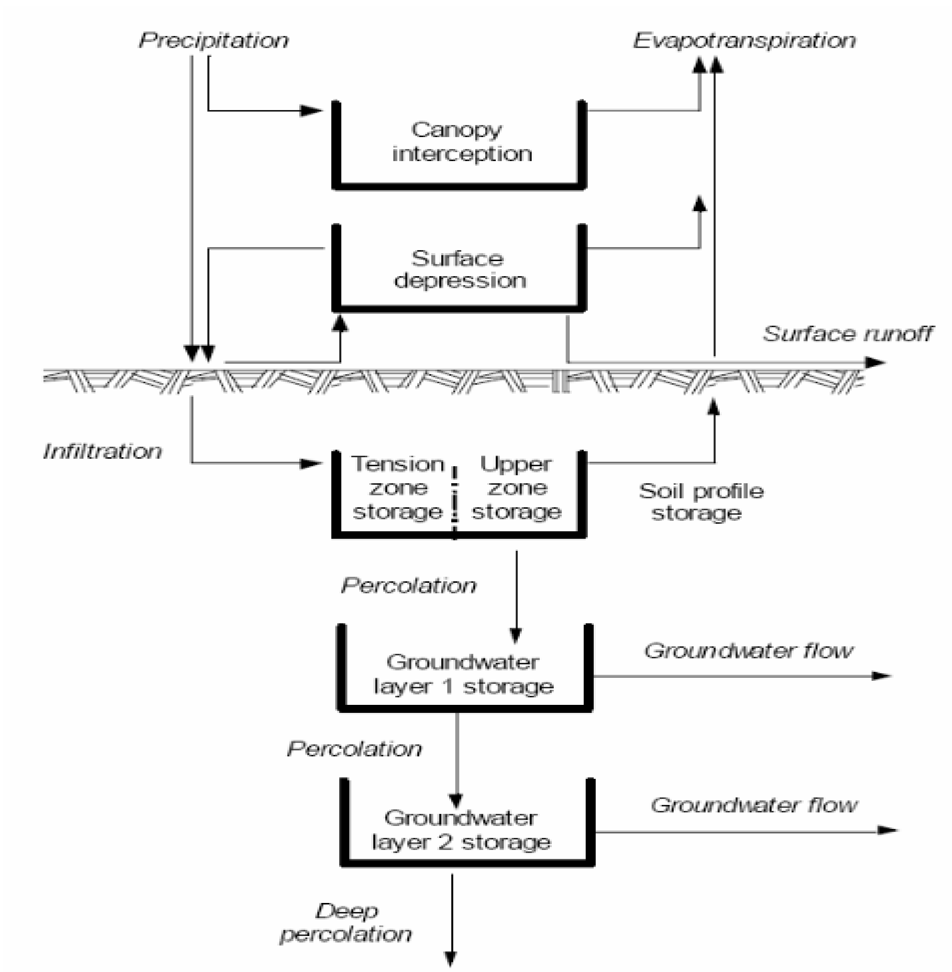


Fig2: Fig showing dynamic of soil water movement in SMA

Water reach to the surface (Through fall) is calculated by deducting canopy storage capacity from precipitation. The soil layer will dry out between precipitation events as the canopy extract soil water. There will be no soil water extraction unless a canopy method is selected. Canopy interception is computed identically for the pervious and impervious parts of the subbasin. Precipitation that cannot be infiltrated is allocated to depression storage. Overflow from depression storage becomes surface runoff. No infiltration or depression-storage losses are deducted from precipitation onto impervious surfaces. Runoff from impervious surface has no second chance to infiltrate. Water is removed from canopy storage only by evaporation. Water is removed from depression storage by evaporation and infiltration. The maximum rate at which water can be absorbed into the soil termed as maximum infiltration rate. Maximum infiltration rate varies with the water content of the soil. The soil moisture accounting module assumes that the maximum infiltration rate decreases linearly with increasing water content [6]. The soil profile is subdivided into tension storage and gravity storage. Tension storage specifies the amount of water storage in the soil profile that does not drain under the effect of gravity and only removed by evapotranspiration. Groundwater layers are not designed to represent aquifer processes; they are intended to be used for representing shallow interflow processes [3]. The actual percolation rate between two adjacent layers depends on a user-specified maximum percolation rate, and is a function of current storage in the two adjacent layers. Lateral outflow from the groundwater layers can be routed to the stream as base flow [3].

13 parameters are required to characterize the canopy, surface, soil, groundwater1, and groundwater2 layers and run the simulation.

Maximum Canopy storage (Inches)
Maximum Surface storage (Inches)
Impervious surface area (%)
Maximum infiltration rate (Inches/Hour)
Maximum soil percolation rate
Total soil profile storage (Inches)
Soil tension storage (Inches)
Groundwater-1 (GW-1) storage (Inches)
GW-1 maximum percolation rate (Inches/Hour)
GW-1 storage coefficient (Hour)
Groundwater -2 (GW-2) storage (Inches)
GW-2 maximum percolation rate (Inches/Hour)
GW-2 storage coefficient (Hour)

The GW-2 percolation rate is an extremely conceptual parameter and thus determined during model calibration. The value of maximum soil percolation rate taken as equivalent to the GW-1 maximum percolation rate [7]. Parameter required for SMA method were determined using following tool and sources shown in Table 1.

Table 1: Table showing list of tool and data sources used to determine SMA parameters.

Parameter	Tool	Data Source
Maximum Canopy Storage	ArcGIS	NLCD 2011
Maximum Surface Storage	ArcGIS	SSURGO
Impervious percent (%)	ArcGIS	NLCD 2011
Maximum soil storage (Porosity)	ArcGIS	SSURGO
Maximum tension storage	ArcGIS	SSURGO
Maximum soil infiltration rate	ArcGIS	SSURGO
Maximum percolation rate	ArcGIS	SSURGO
GW1 maximum percolation rate	ArcGIS	SSURGO
GW1 maximum Storage	Excel	Recession Limb analysis
GW 1 Coefficient	Excel	Recession Limb analysis
GW2 Maximum percolation rate	HEC-HMS	Model Calibration
GW2 maximum Storage	Excel	Recession Limb analysis
GW 2 Coefficient	Excel	Recession Limb analysis

2.4 Study Area and Data acquisition:

The present study was conducted in a small part of Red Butte Creek (RBC) between the Red Butte Reservoir and Red Butte Cottoms Grove Basic Aquatic (RB_CG_BA) station, Salt Lake City, Utah (Fig 3). The study area upstream to the RB_CG_BA gauging and CUWCD station on the RBC, comprised of 2.66 km^2. At many location upstream and downstream of RBC reservoir Iutah (Innovative Urban Transitions and Aridregion Hydro-sustainabilit) has monitoring aquatic and climatic sites. Green Infrastructure climatic (GIRF_C) station data located at downstream of red butte reservoir were used in this study such as precipitation, air temperature, snow depth, net long and short wave radiation. Central Utah Water Conservancy District (CUWCD) operating release discharge data from red butte reservoir at every 15 min time-step. Red Butte Cottams Grove Basic Aquatic (RB_CG_BA) at downstream near GIRF_C has discharge data calculated based on elevation discharge relationship.

Red Butte Creek (RBC) watershed is 18.8 km^2 with elevations between 1500 and 2400 m. Average annual streamflow ranges from 0.058 m^3/s to 0.416 m^3/s. Red Butte Creek originates in the mountains of northeastern Salt Lake County, and Red Butte Canyon is a Research Natural Area managed by the U.S. Forest Service. Red Butte Reservoir, initially built to supply water to Fort Douglas, is currently used as a habitat for June sucker fish that are transported to other watersheds in the Wasatch Front [8]. The RBC basin is dominated by four distinct plant communities – riparian, grass-forb, oak-maple, and coniferous [9]. Soils in the basin are classified as Moll soils and consist of well drained soils that are formed in colluvium and alluvium derived from mixed sedimentary rocks [10]. There is little profile development, and most soils consists of a layer of dark – to reddish- brown, cobbly silt loam or cobbly loamy sand overlaying bedrock.

Depth of soils is irregular, varying from 50cm on south-facing slopes to as much as 150 cm on north facing slopes. Soils are neutral to moderately alkaline (PH 6.1 to 8.4), and the deeper horizons have 55-80 percent coarse fragments that, in the more alkaline soils, are coated with lime [10].

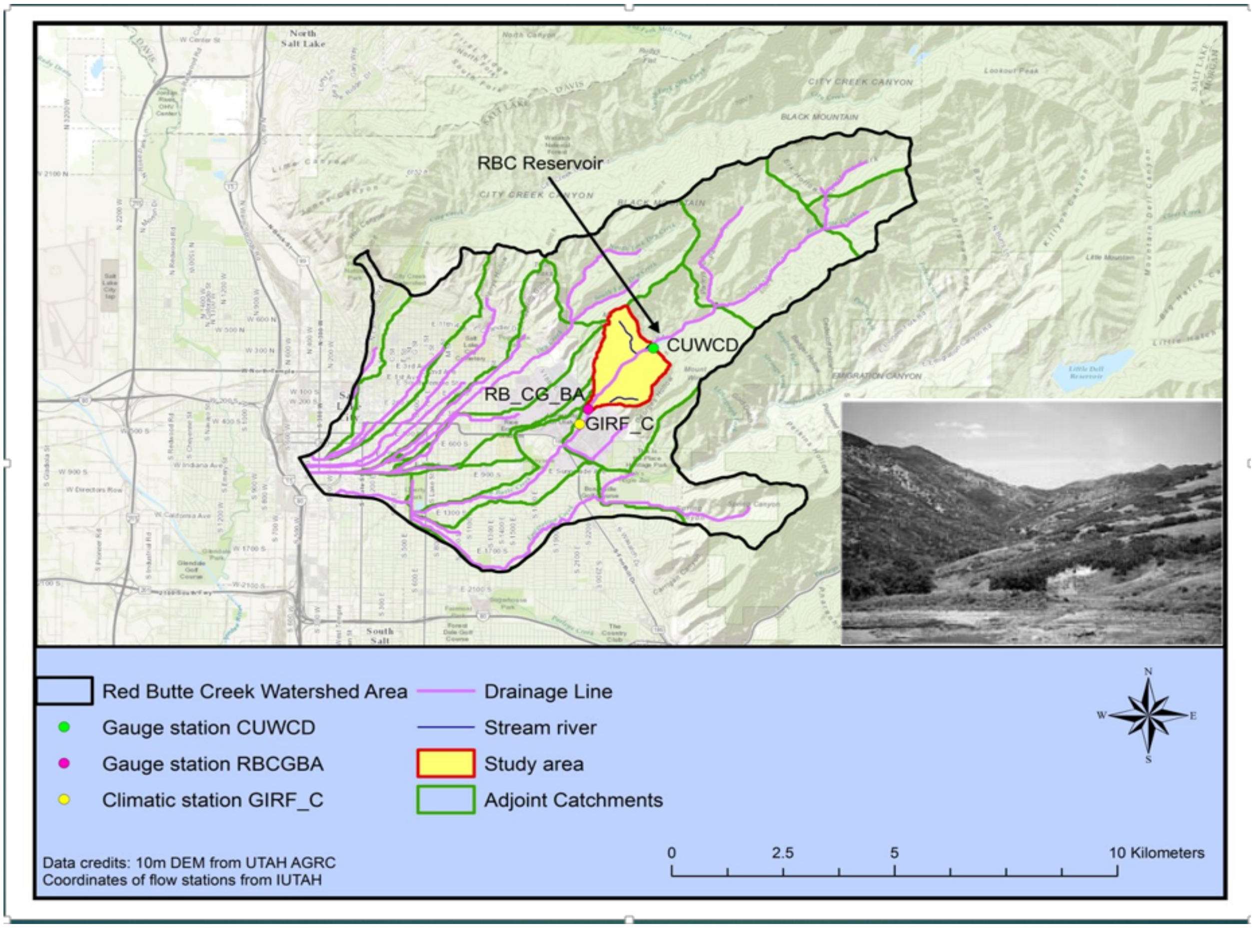


Fig3: Fig showing Study area between red butte reservoir and red butte cottoms grove basic aquatic station

To implement the HEC-HMS model in the study area, spatial data such as digital elevation model (DEM), soil map and land use land cover map are required in order to define the catchment boundary and the various physiological characteristics of the study area. 10 meter resolution DEM, stream network and coordinates of stations were obtained from http://data.iutahepscor.org/mdf/Data/Red_Butte/. Land use land cover map of the area was obtained National Land Cover Database 2011 (NLCD 2011) http://nationalmap.gov/index.html. The land use land cover has been classified into 5 classes: Develop; Forest; Shrubland; Planted/Cultivated; and Wetlands for this study area. Soil information of the study area was obtained from Natural Resources Conservation service (USDA) https://gdg.sc.egov.usda.gov/ . Meteorological data such as precipitation, air temperature, snow depth, net long and short wave radiation, and discharges data for a simulation period of Feb 2014 to Feb 2015 at daily interval were obtained from Iutah site http://data.iutahepscor.org/tsa/.

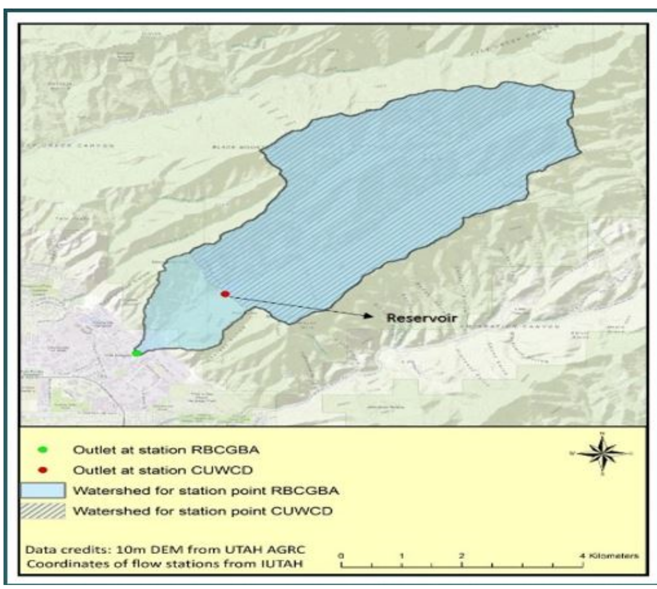
3. Methodology:

3.1 Study Area Development

Before delineating watershed boundary, the raw DEM was pre-processed so that a well-defined watershed and river network could be delineated. All the terrain processing require including DEM reconditioning to delineate the watershed were done using HEC-GeoHMS 10.1 in ArcGIS 10.3. The processes require to perform before delineating watershed is mention below.

a. Dem Reconditioning
b. Fill Sinks
c. Flow direction
d. Flow accumulation
e. Stream Definition
f. Stream Segmentation
g. Catchment Grid Delineation
h. Catchment Polygon Processing
i. Drainage Line Processing
j. Adjoint Catchment Processing

Actual study area covers upstream area from RB_CG_BA gauging station and to the CUWCD station on the RBC. It is necessary to isolate the watershed boundary of RB_CG_BA beyond that point (CUWCD). Two watershed were delineated at outlets RB_CG_BA and CUWCD (Fig4a). Finally, the study area was developed by editing the RB_CG_BA watershed through the intersection line of two watershed using HEC-GeoHMS 10.1 in ArcGIS 10.3 shown in Fig 4b. The study area is converted into the shapefile and made ready to extract the all the SMA parameters. All the processes described above in shown in fig 5.



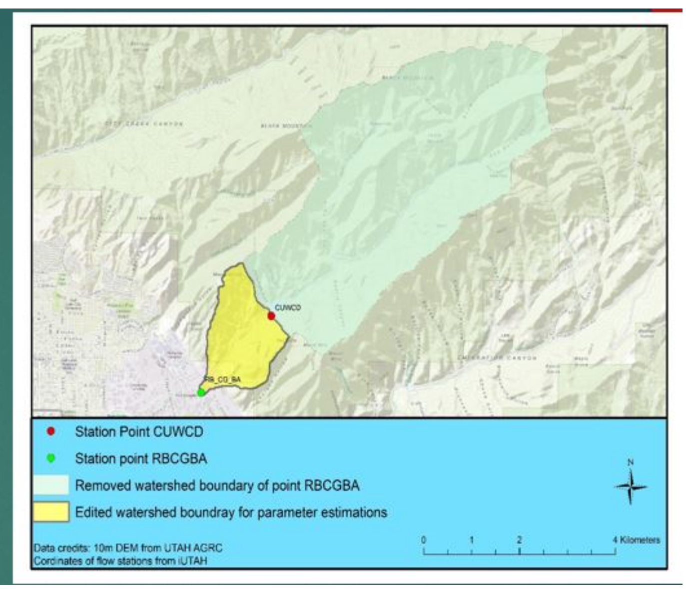


Fig4a: Fig showing watershed boundary for two outlet Points RB_CG_BA and CUWCD

Fig4b: Fig showing edited study area for parameters estimation

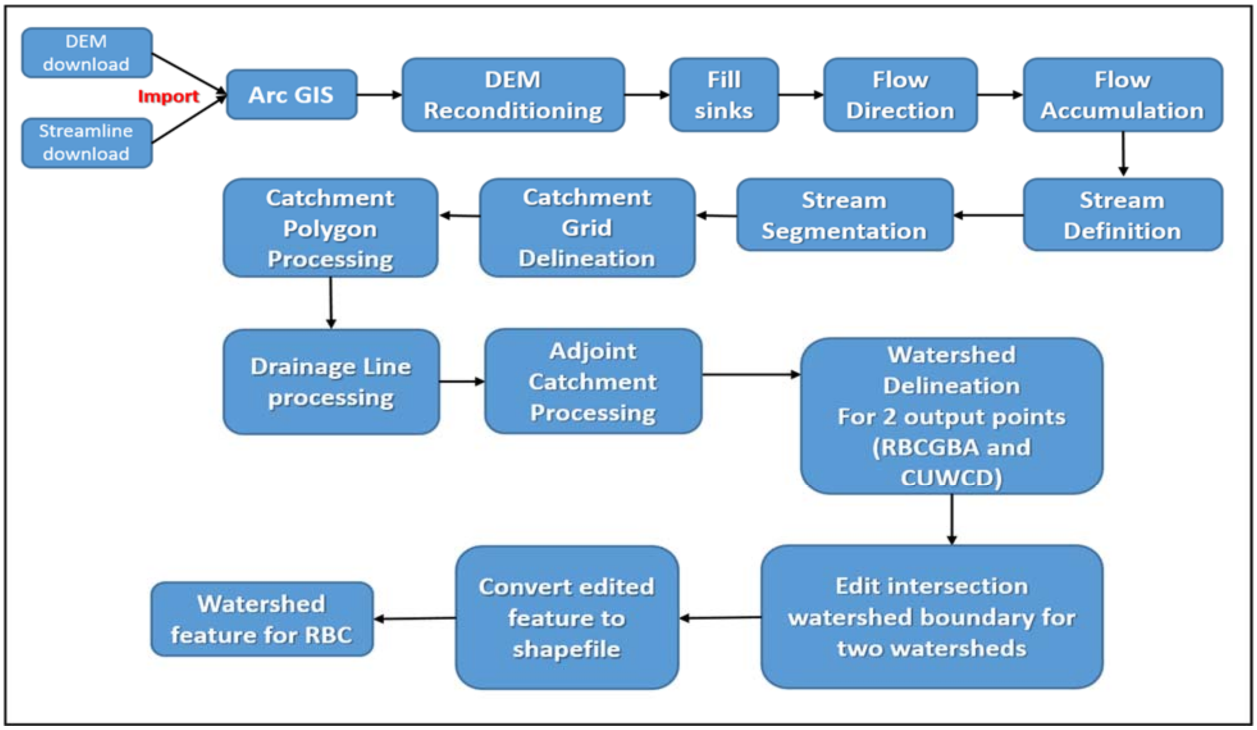


Fig 5: Fig showing all processes required to develop the model for extraction of SMA parameters

3.2 Temperature Index (Snowmelt) Parameters estimation:

There are many parameter in temperature index method that their values need to assume for particular watershed and should determine through calibration work. Important parameter values assigned in this model is shown in table2, 3, and 4.

Table 2: Table showing important parameter values assign in the model for temperature index method

Temperature Index	
Met Name:	**Met 1_For_RB_CG_BA**
*PX Temperature (F)	34
*Base Temperature (F)	32
*Wet Meltrate (IN/DEG F-DAY)	0.12
Rain Rate Limit (IN/DAY)	0.40
ATI-Meltrate Coefficient:	0.98
*ATI-Meltrate Function:	Table 1_RB_CG_BA
Meltrate Pattern:	--None--
Cold Limit (IN/DAY)	0.5
ATI-Coldrate Coefficient:	0.5
ATI-Coldrate Function:	Table 1_RB_CG_BA
Water Capacity (%)	4
Groundmelt Method:	Constant Value
Groundmelt (IN/DAY)	0

Table 3: Table showing important parameter Assign in the model

ATI (DEG F-DAY)	Meltrate (IN/DEG F-DAY)
0.0	0.015
150.0	0.040
500.0	0.120

Table 4: Table showing important parameter assign in the model

ATI (DEG F-DAY)	Coldrate (IN/DEG F-DAY)
0.0	0.02
500.0	0.02
1000.0	0.02

Px temperature is assigned to 34 ^{0}F as earlier said its value ranges from 1-2 ^{0}C above freezing. The default value was assign for base temperature as 32 ^{0}F which is the maximum temperature of snowpack. The wet melt rate is the melt rate which is used when precipitation rate falling as rain is greater than rain rate limit [3]. According to Engineer Research and Development Center (EDRC) the value of wet melt rate is generally in the range of 0.05 – 0.15 in/^{0}F-day [11]. The EDRC also suggest to set higher value of wet melt rate. The wet melt rate value in the model was assumed to be 0.12 in/^{0}F-day. When precipitation (rain) rate is less than rain rate limit dry melt rate comes under the function/will be activated [3]. Dry melt rate will work based on the values assigned through pair data manager within HEC-HMS shown in the table 3 above [3]. The value shown in the table 3 is recommended value by EDRC [11]. ATI (DEG F-DAY) in the table 3 above represent average zonal/air temperature per day. Rain rate limit is the limit which discriminates the dry melt and wet melt. The default value of rain limit 0 Inches/day is used if no value is entered, meaning that even a trace of precipitation results in the use of the wet melt rate [3]. The rain rate limit was assumed to be 0.4 Inches/day for this watershed. ATI-Melt rate coefficient is a coefficient which updates the dry melt rate within table 3. The default value (0.98) [3] of ATI-Melt rate coefficient was assigned in this model.

Similarly, when precipitation rate falling as snow is greater than specified cold limit the temperature of snowpack is assumed to be air temperature taking an account that maximum snowpack temperature is 0 ^{0}C [3]. Precipitation (Snow) rate is less than cold limit the snowpack temperature will be updated based on the ATI-Cold rate coefficient. In this model, cold limit was assumed to be 0.5 Inches/day. The recommended value of ATI-Cold rate coefficient by ERDC [11] is 0.2 – 0.5, and the value assigned in this model was 0.5. The cold rate will be updated based on the snowpack temperature. The value of table 4 was assigned through pair data manager within HEC-HMS and recommended by ERDC [11]. ATI (DEG F-DAY) in table 4 represent snowpack temperature and corresponding cold rate values on the right side column. Anderson (1973) suggests cold rate values ranging from 0.015 to 0.028 Inches/^{0}F –day with a reasonable value of 0.02 inches/^{0}F –day [11]. He states that the cold rate should vary throughout the year with the minimum occurring in the summer time, moving in exactly the opposite manner of the melt factor throughout the year. This means that the maximum value of cold rate should occur during midwinter and the minimum value in midsummer. Although cold rate values varies throughout the year because of being unknown about relationship between snowpack temperature and the cold rate, ERDC recommended (Table -4) values were used in this model.

The maximum liquid water capacity (LWC) specifies the amount of melted water that must accumulate in the snowpack before liquid water becomes available at the soil surface for infiltration or runoff [3]. Typically, the maximum liquid water held in the snowpack is on the order of 3% - 5% of snow water equivalent (SWE), although it can be higher. The value of LWC was assigned to be 4%. Heat from the warm ground will cause the bottom of the snowpack to melt. In general, ground melt is small in quantity [3]. The ground melt in this simulation is assumed to be zero.

As earlier said, the temperature for each elevation band is computed using the temperature recorded in the time-series, the elevation of the time-series gage, the lapse rate for the subbasin, and the elevation of the band. Study area (sub-basin) is divided into 10 elevation band with each band covering 10% of total sub-basin area. For each elevation band, HMS requires the percent area, representative elevation [3]. To determine the representation elevation of each band, a cumulative area-elevation curve was developed using ArcGIS and DEM of watershed. The cumulative area-elevation curve of study area is shown in Fig 6. The median elevations of each elevation band were determined corresponding to 5, 15, 25, 35, 45, 55, 65, 75, 85, and 95% of cumulative area % as representative elevation of each band. The representative elevation of each band is shown in table 5.

Table 5: Table showing representative elevation of 10 elevation band.

Elevation band	1	2	3	4	5	6	7	8	9	10
Percent of sub basin 1	10 (0-10) %	10 (10-20) %	10 (20-30) %	10 (30-40) %	10 (40-50) %	10 (50-60) %	10 (60-70) %	10 (70-80) %	10 (80-90) %	10 (90-100) %
median elevation (feet)	5019.6852	5167.323	5269.02904	5351.05004	5436.35188	5531.49624	5649.60648	5784.12092	5961.28628	6233.596

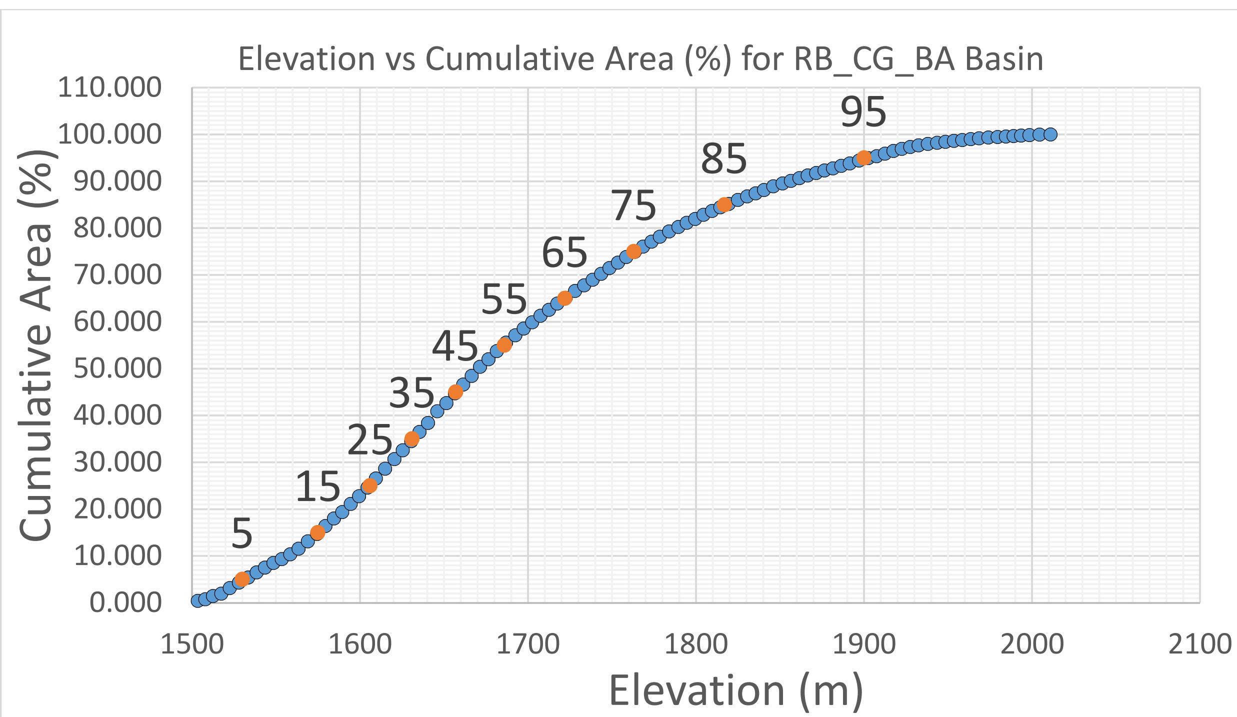


Fig 6: Fig showing cumulative area % verses elevation (m) of study area.

3.3 Soil Moisture Accounting (SMA) parameters estimation:

3.3.1 Percentage Impervious:

Impervious percent raster data for Red Butte Creek was downloaded from NLCD 2011 site. The impervious raster data was clip for study area and zonal statistics was performed to get watershed average impervious percent value.

3.3.2 Maximum canopy storage:

Land use raster data was clipped for study area. Value field contains National Land Cover Dataset (NLCD) classes. A new field was created. The canopy interception values were assigned under newly created field based on best judgement according to NLCD values shown in table 6 [12].

Table 6: Table showing canopy interception values for different types of vegetation.

Type of vegetation	Canopy interception	
	in.	mm.
General vegetation	0.05	1.27
Grasses and Deciduous Trees	0.08	2.032
Trees and Coniferous trees	0.1	2.540

Unfortunately, ArcGIS is unable to convert one raster directly into another raster based on a different field. So, in order to create the canopy interception raster, first point feature was created and then convert it into a raster. Zonal statistic was performed to get average watershed canopy storage value [12]. The impervious cover and land use map of study area were shown in Fig 7a and Fig 7b respectively.

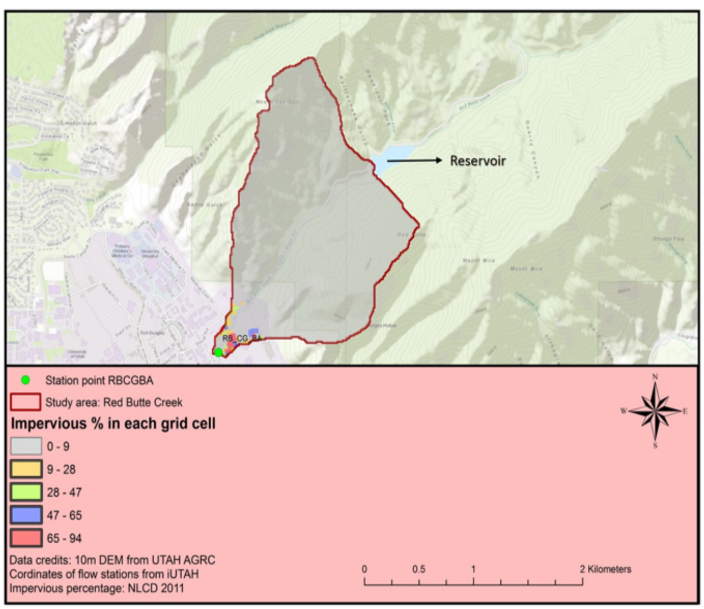


Fig 7a: Fig showing impervious cover map Of study area

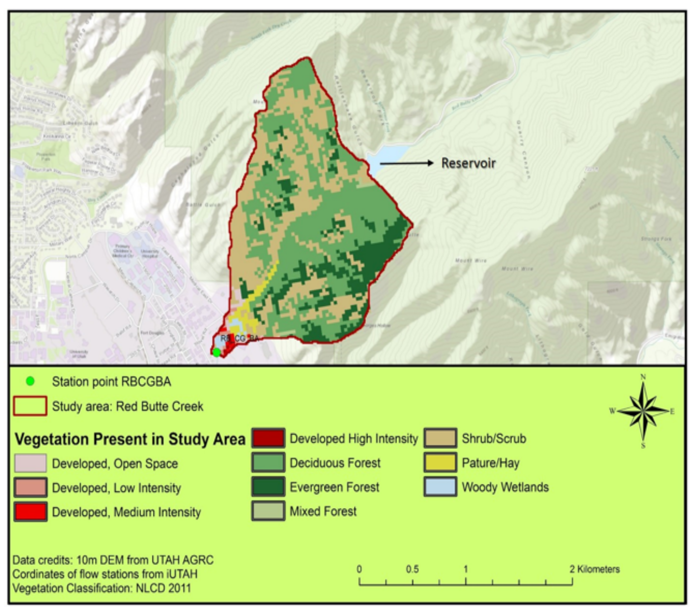


Fig 7b: Fig showing land use cover of study area

3.3.3 Max Soil Infiltration, Max Soil Storage, Soil Tension Storage, Max Soil Percolation and Max depression storage estimation using SSURGO data.

The procedure to determine SMA 5-parameters mentioned above is a long process. The procedure to determine above parameter are described step-wise in the ***appendix A*** below or reader can also refer to [12]. It should be noted that hydraulic conductivity value is in um/s and soil depth in cm according to SSURGO metadata [13]. Soil data organization map by SSURGO was shown in Fig 8. After determining SMA 5-parameters mentioned above, as earlier said the value of maximum soil percolation rate taken as equivalent to the GW-1 maximum percolation rate. The GW-2 percolation rate is an extremely conceptual parameter and thus determined during model calibration.

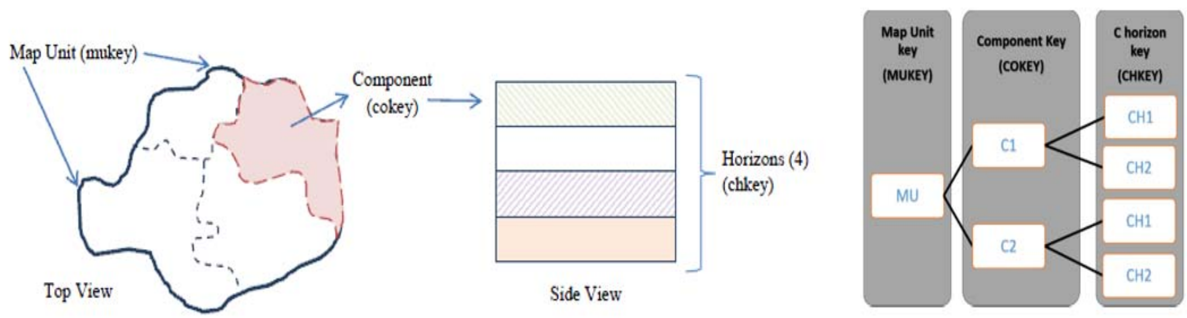


Figure 8. Fig showing Soil data map by organized by SSRUGO

3.3.4 GW-1 and GW-2 storage and storage coefficient estimation using streamflow data by regression analysis:

Stream convey stored water from different sources: stream channels, surface soil (interflow), and groundwater. Recession limb of hydrograph includes contribution from surface, subsurface, and groundwater storages. In SMA, GW-1 storage and storage coefficient parameters are represented by subsurface storage whereas GW-2 parameters are represented by groundwater storage [12].

Daily streamflow data of 3 storms occurring during different months of year were selected. Storms were selected such that storms are fairly isolated; storms where the streamflow hydrograph is allowed to return to normal for a couple days before runoff from the next storm is visible. Hydrograph of streamflow for a period of selected storms at outlet RB_CG_BA were drawn on semi-logarithmic plot Fig 9.

The tail end of receding limb represents the time when groundwater is the only source contributing to streamflow, as both surface runoff & interflow have stopped. A line was projected backward from the tail-end of the receding limb having shallowest slope to the time of peak flow, maintaining the slope of that tail-end portion. A line was connected to the point at which the hydrograph begins to rise as a result of runoff. This line represent the groundwater contribution to streamflow or GW-2 parameters Fig 10.

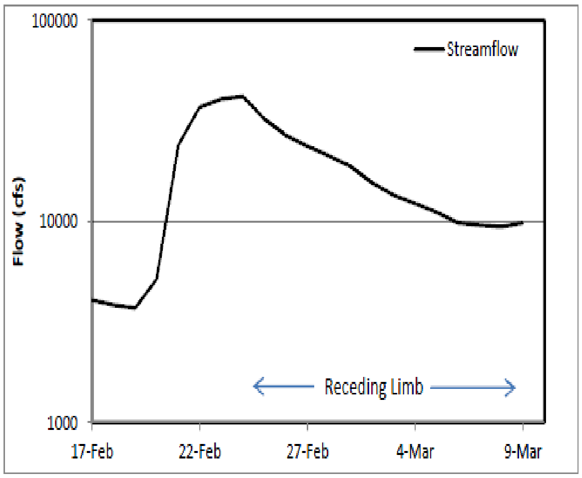


Fig 9: Fig showing streamflow hydrograph For selected storm

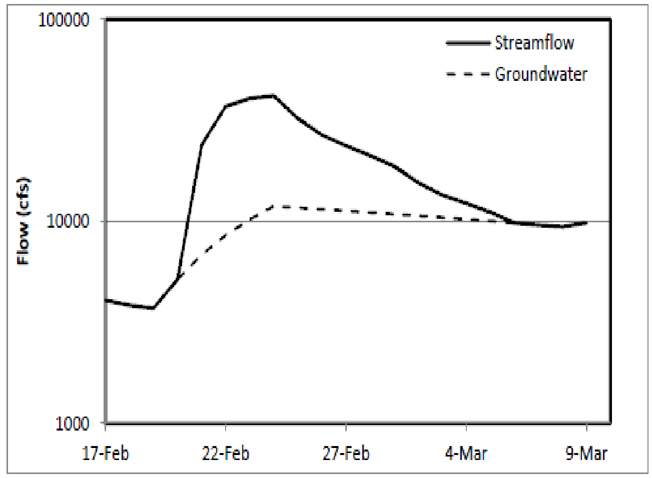


Fig10: Fig showing streamflow and groundwater contribution.

Groundwater flow was subtracted from streamflow and the result was plot on the same graph Fig 11. This line represents the contribution to streamflow from surface runoff and interflow. Again, a line was projected backward from the shallowest slope of runoff + interflow line. Using same method as used to create groundwater line, interflow line was created shown in Fig 12.

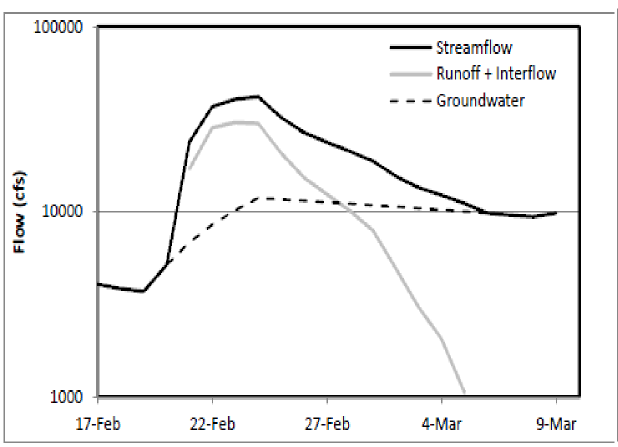


Fig11: Fig showing additionally surface runoff And interflow contribution.

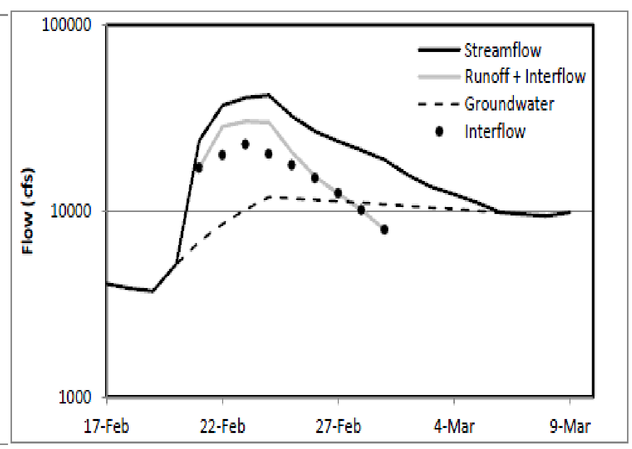


Fig 12. Fig showing additionally, Interflow contribution

The recession limb of a hydrograph, can be described by equation 1.

$Q_1 = Q_0 * Kr = Q_0 * Exp(-a * t)$………………..Eq.1

Where Q_0 is the initial streamflow, Q_1 is the streamflow at a later time t, Kr is a recession constant, and a = -In Kr. Also, Kr = Krs * Kri * Krb [14], where Krs = recession constant for surface storage, Kri = recession constant for interflow, and Krb = recession constant for base flow.

The recommended time step for streamflow regression analysis is 1 day. But due to smaller basin 6 hour time step was used in this model. Using the area of shallowest slope of the streamflow hydrograph and Equation 1 the 'a' value for each time step were calculated for groundwater 2. Average value of 'a' was calculated and then groundwater 2 recession coefficient was determine using equation 2 [12].

Recession Coefficient (Hour) = 1/a ………………Eq. 2

Using the same section of the streamflow hydrograph and equation 3 groundwater 2 storage depths were calculated for each time step and average depth of groundwater 2 storage was determined.

Storage depth $S_t = Qt / a$…………………..Eq. 3

In the similar way, groundwater 1 recession coefficient and storage depth were determined using the runoff + interflow graph. Similar process was repeated for other storms and determine the values of GW-1 and GW-2 storage and recession coefficient [12]. The GW-1 and GW-2 storage and storage (recession) coefficient for study area were determined by averaging the values obtained from the three storms.

All the parameters required for SMA method are summarized in the table 7 below.

Table 7: Table showing all the parameters required for SMA method

Parameter	Value	Tool	Data Source
Maximum Canopy Storage	0.0827 (inch)	ArcGIS	NLCD 2011
Maximum Surface Storage	0.1224 (inch)	ArcGIS	SSURGO
Impervious percent (%)	0.75 %	ArcGIS	NLCD 2011
Maximum soil storage (Porosity)	7.087 (inch)	ArcGIS	SSURGO
Maximum tension storage	5.94 (inch)	ArcGIS	SSURGO
Maximum soil infiltration rate	1.341 (inch/hour)	ArcGIS	SSURGO
Maximum percolation rate	2.372 (inch/hour)	ArcGIS	SSURGO
GW1 maximum percolation rate	2.372 (inch/hour)	ArcGIS	SSURGO
GW1 maximum Storage	0.748 (inches)	Excel	Recession Limb analysis
GW 1 Coefficient	145.7 (Hour)	Excel	Recession Limb analysis
GW2 Maximum percolation rate	2.05 (Inches/Hour)	HEC-HMS	Model Calibration
GW2 maximum Storage	0.551 (Inches)	Excel	Recession Limb analysis
GW 2 Coefficient	1405 (Hour)	Excel	Recession Limb analysis

3.4 Model development within HEC-HMS 4.1

Although most of the SMA parameters and temperature index parameter were determined using ArcGIS the simulation was run in the HEC-HMS. The HEC-HMS model was developed within the HEC-HMS manually shown in Fig 13.

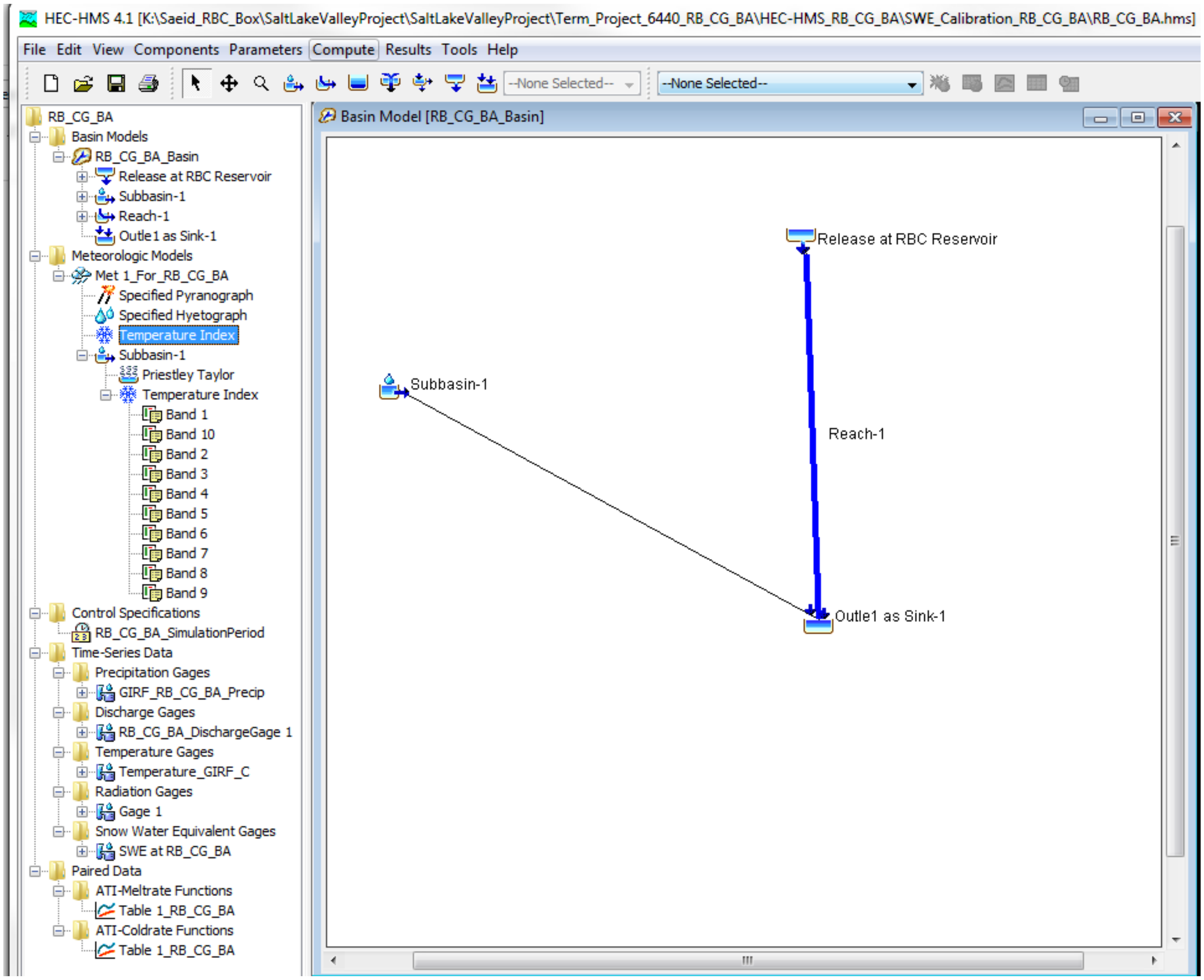


Fig 13: Fig showing HEC-HMS model manually developed within HEC-HMS 4.1

3.5 Evapotranspiration:

As earlier said Priestley Taylor method was used for evapotranspiration in this model. The Priestley Taylor method uses a simplified energy balance approach where the soil water supply is assumed to be unlimited [3]. Simplified forms of latent heat and sensible heat energy are used. The method is capable of capturing diurnal variation in potential evapotranspiration through the use of a net solar radiation. The input parameter required in the Priestley Taylor method are net radiation, air temperature, and dryness coefficient (α) [3]. Priestley and Taylor (1972) suggested a modification of the penman equation, which requires less extensive measurements [15]. According to the Priestley Taylor method actual evapotranspiration is given by equation 4.

$Ea = \alpha * (S \div (S + \gamma)) * (Rn – G)/ \lambda$…………..Eq.4

Where, λ is the latent heat of vaporization, α is a model coefficient, S is the slope of the saturation vapor density curve, γ is the psychometric constant, Rn is net radiation (sum of net short wave radiation and net long wave radiation), and G is soil heat flux. In general, for wet surface the value of α used as 1.26. The value of G can be assumed to be negligible on a daily time scale for reference evapotranspiration [15].

For the simulation of model, air temperature, net short wave and net long wave data has been obtained from the GIRF_C climatic station of Iutah site. Net radiation was calculated summing up net short wave and net long wave radiation. Dryness coefficient was assigned as default value (HEC-HMS), 1.26.

3.6 Baseflow:

Recession baseflow method have the ability to automatically reset the baseflow after each storm event and consequently used for continuous simulation [3]. The parameters need to be assign within this baseflow method were shown in Fig 14. The recession constant is the rate at which baseflow recedes between storm events. "Ratio to peak" (Ratio) is the ratio of current flow to the peak. The baseflow is reset when the value of ratio to peak falls to the specified value.

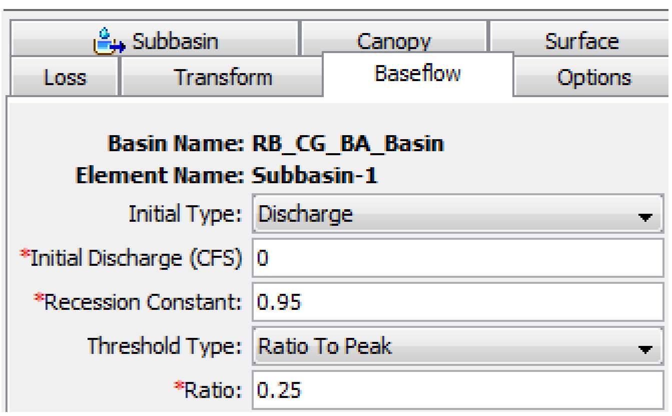


Fig 14: Fig showing parameter required for recession baseflow method.

As mention in the study area and data acquisition section earlier, study area lies between upstream area from RB_CG_BA outlet and below CUWCD station. Also, CUWCD station supplies discharge data from red butte reservoir. It was assumed that baseflow was included by the discharge data released by CUWCD station. Therefore, zero value was assigned as initial baseflow in recession baseflow method within the model. The value of recession constant and ratio to peak were assumed to be 0.95 and 0.25 in this model respectively.

3.7 Clark Unit Hydrograph:

The Clark Unit Hydrograph methods explicitly represents two critical processes of translation of excess rainfall and attenuation due to effects of storage in the sub-basin. The parameter required for the Clark UH transform method are concentration time and the storage coefficient. Time of concentration was obtained from the ArcGIS, the storage coefficient was evaluated by calibration.

3.8 Muskingum:

The Muskingum routing method uses the principle of conservation of mass to route the flow along the river reach [3]. The required parameters are Muskingum K and Muskingum X. Muskingum K is essentially travel time through the reach. It can be estimated from the knowledge of the cross section properties and flow properties. The Muskingum X is the weighting between inflow and outflow influence; it ranges from 0.0 up to 0.5 [3]. The value of Muskingum K and X were assumed to be 0.6 hour and 0.2 respectively in the model.

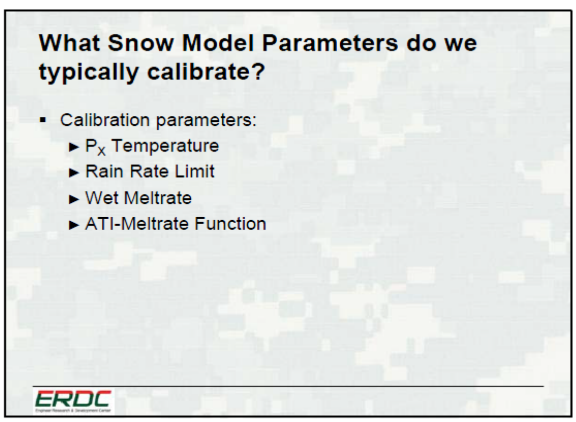
4 Model Simulation and Calibration:

Before the simulation of SMA loss method, first snow parameters was calibrated using calculated snow water equivalent (SWE) of study area. GIRF_C station only provides snow depth data. SWE was calculated as product of snow density and snow depth. Snow density is a function of many parameters such as snow temperature, wind speed, snowpack depth. Snow density was calculated using equation 5 given by Shook and Gray, 1994 [16].

$P_s = 450 - 20470 / d * [1 - e^{-d/67.3}]$………………Eq. 5

Where, Ps is mean snow density (kg/m3) corresponding to mean snow depth (d, cm). Eq.5 gives the mean density for aged, seasonal, wind-blown snow.

Model was run and then sensitivity analysis was done. Engineer Research and Development Center have suggested list of snow parameter to be calibrated shown in below.



Sensitivity analysis of four snow parameter mentioned above was performed by changing one parameter value and keeping other parameters constant. ATI-Melt rate function was found to be most sensitive parameter. ATI-Meltrate function was calibrated such that simulated and calculated SWE matches as much as possible throughout the simulation period.

After snow model parameter calibration, all the obtained SMA parameters, meteorological time-series data for simulation period of Feb2014 to Feb2015 including release discharge (CUWCD) as source were assigned within HEC-HMS model and model was run. In the similar manner sensitivity analysis of each SMA parameter was conducted. Maximum infiltration rate was found to be most sensitive parameter. Maximum infiltration rate was calibrated such that calibrated flow result matches with observed discharge at RB_CG_BA. Sum of square residual method was used as an objective function with the Nelder-Mead method as the search method for optimization.

5 Results:

In general, the temperature index and SMA method used for continuous rainfall- runoff simulation in a part of Red Butte Creek have given satisfactorily result. ATI-Melt rate function and maximum infiltration rate were found to be most sensitive parameters within snowmelt and SMA methods for this watershed, respectively. The values of calibrated snow parameter (ATI-Meltrate function) was shown in table 8, and calibrated SMA parameter (Maximum infiltration rate) was found to be 0.26 Inches/Hour. Also, calibrated results for calculated SWE and observed flow at RB_CG_BA were shown in Fig 15 and Fig 16 respectively. Nash-Sutcliffe Efficiency (EFF) and RMS error was found to be 0.796 and 0.4 CFS shown in Fig 17.

Table 8: Table showing calibrated value of snow parameter (ATI-Meltrate function)

Paired Data | Table | Graph

ATI (DEG F-DAY)	Meltrate (IN/DEG F-DAY)
0.0	0.015
10.0	0.100
50.0	0.120
500.0	0.120

Calculated SWE **Calibrated SWE**

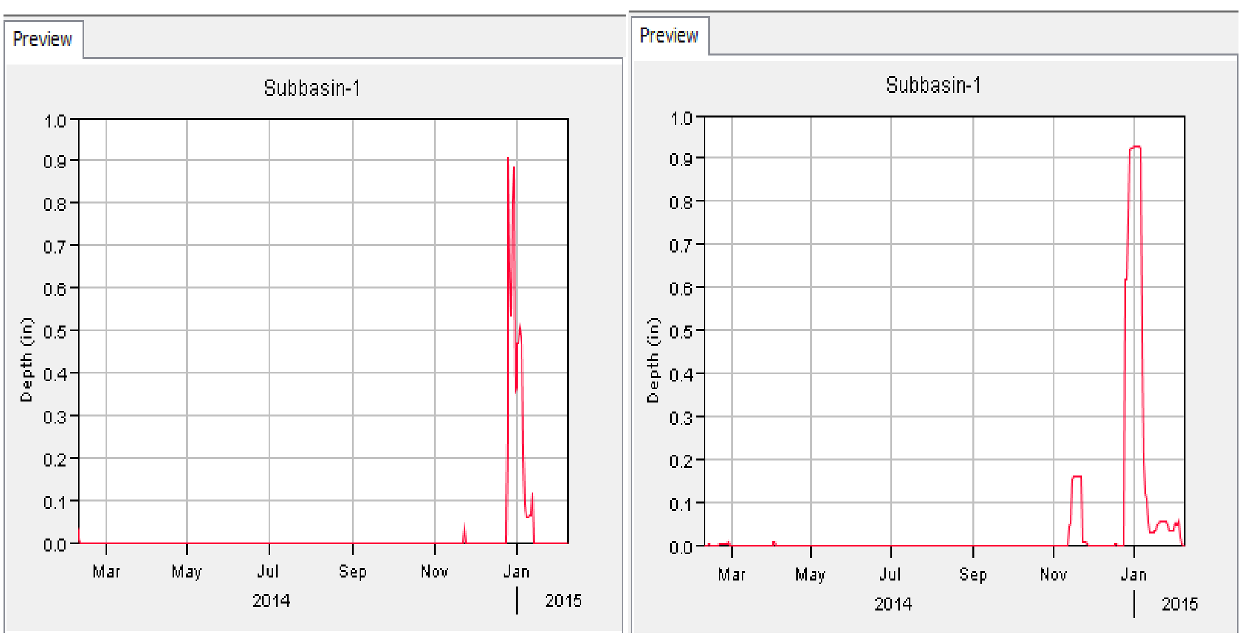


Fig 15: Fig showing calculated SWE and calibrated SWE.

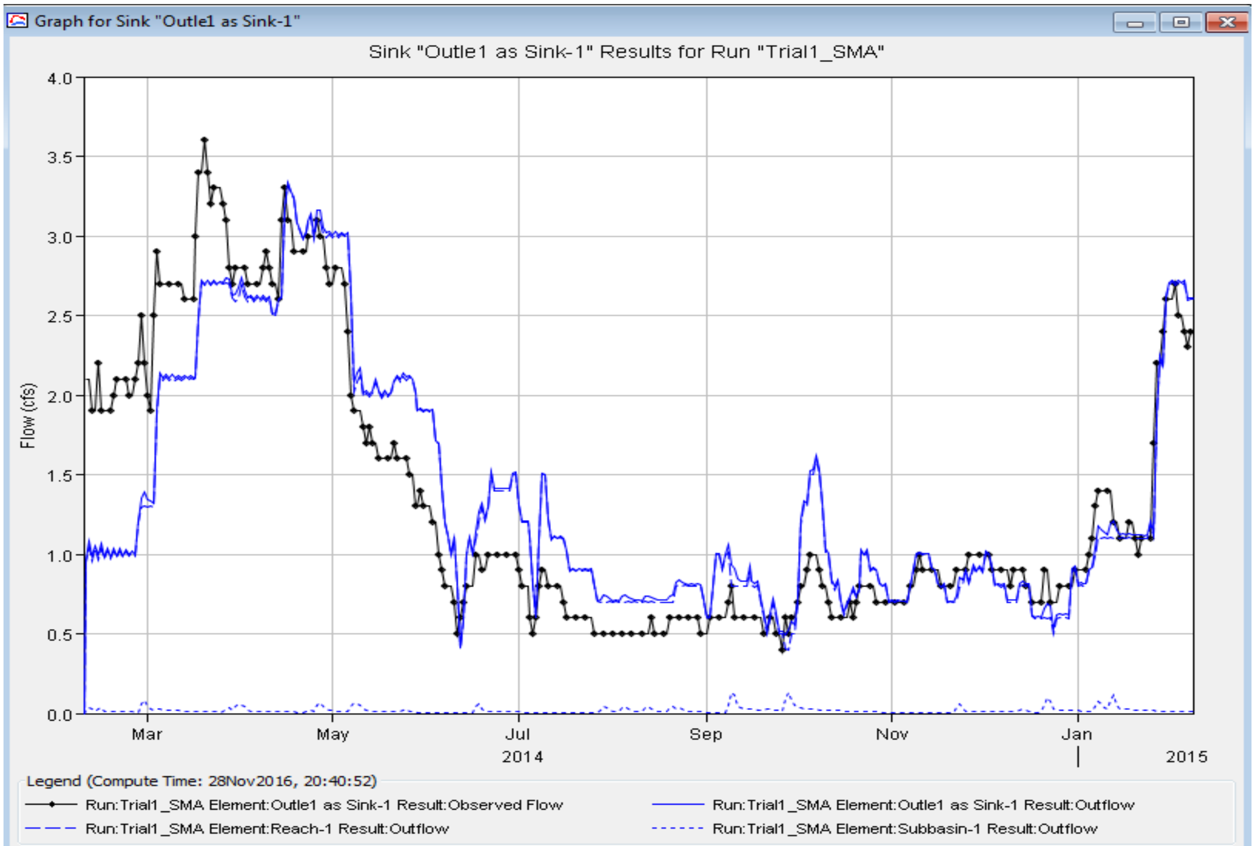


Fig 16: Fig showing calibrated and observed flow at outlet RB_CG_BA

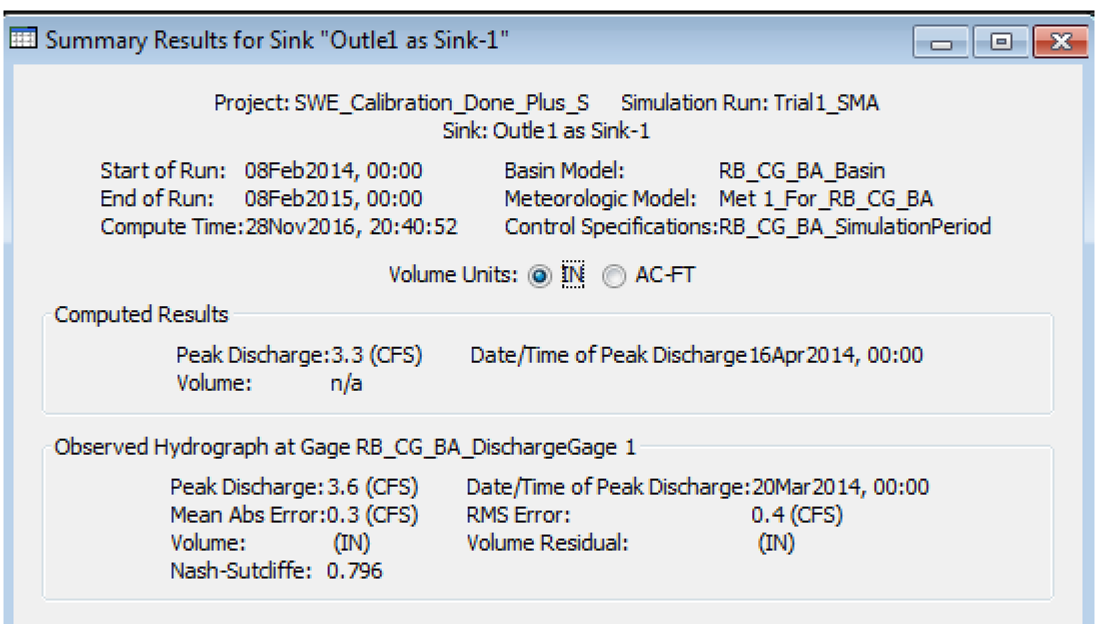


Fig 17: Fig showing the result for evaluation of simulation

6 Discussion:

The soil moisture accounting (SMA) method used for continuous rainfall-runoff modeling in a small portion of Red Butte Creek basin must be calibrated well for accurate prediction of runoff. In a continuous modeling, evapotranspiration plays an important role which is neglected with event based modeling. Simulated flow does not matches exactly throughout the year with observed flow. But it matches for the month of April, and mid of September to February month. The Nash-Sutcliffe Efficiency (EFF), (Nash and Sutcliffe, 1970) found to be one of the most widely-used criteria for indicating the overall fit of a hydrograph and the value was found to be 0.796. The value of EFF is very good according to the performance rating [17] shown in table 9. The EFF expresses the fraction of the measured stream flow variance that is reproduced by the model. During the sensitivity analysis of SMA parameters, percentage of impervious area was found to be one of the most sensitive parameter for accurate prediction of runoff at the basin outlet. Therefore, it is important to determine the percentage impervious precisely as much as possible. Model can be split into dry and wet season and then parameter can be determined seasonally in order to improve the result. Raw air temperature, net radiation data has been used because of unavailability of quality control data. Thus, in the availability of quality control data result can further be improved.

7 Conclusion:

The HEC-HMS conceptual model was successfully calibrated for Red Butte Creek basin on a continuous time scale. Sensitivity analysis of the model reveals that AIT-Meltrate function, maximum infiltration rate, and percentage impervious area are most sensitive parameters. The overall model efficiencies (EFF) given by Nash-Sutcliffe efficiency criteria is 0.796, indicating a good fit of model. Based on the overall evaluation, it could be concluded that the temperature index and SMA methods available in the HEC-HMS model can be used to model steam flow in the Red Butte Creek.

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Appendix A

Procedure to determine SMA 5-Parameters (Max. soil infiltration, soil storage, tension storage, soil infiltration, and depression storage)

Procedure to determine Max. soil infiltration, soil storage, tension storage, soil infiltration and depression storage.

- Downloaded the SSURGO data from https://gdg.sc.egov.usda.gov/
- Export chorizon table in .dbf file
- Open .dbf file in excel and save it .xlsx file.
- Delete all the columns except cokey, chkey, Ksat_r, hzdepb_r, wsatiated_r and wthirdbar_r.

Table 2. Chorizon Field Definitions

Field	Definition
chkey	Horizon ID
cokey	Component ID
ksat_r	Representative saturated hydraulic conductivity
hzdepb_r	Representative depth from soil surface to bottom of layer
wsatiated_r	Representative soil porosity
wthirdbar_r	Representative field capacity

Here, cokey and chkey represent component key and chorizon key respectively.

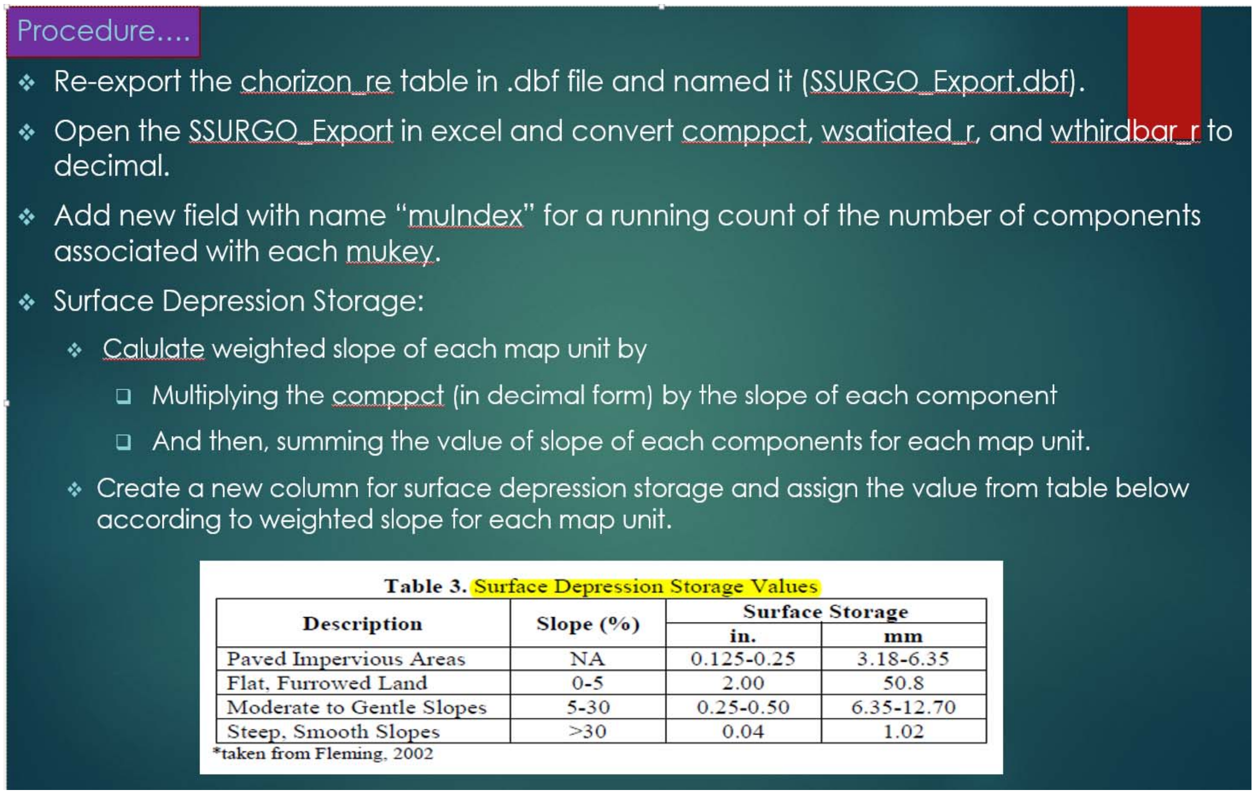
- Identified average values of "Ksat_r, wsatiated_r, wthirdbar_r" for each component.
- Identified "Ksat_r" value of topmost horizon for each component.
- Identified "hzdepb_r " value of bottommost horizon (total depth of soil profile) for each component.

Procedure….

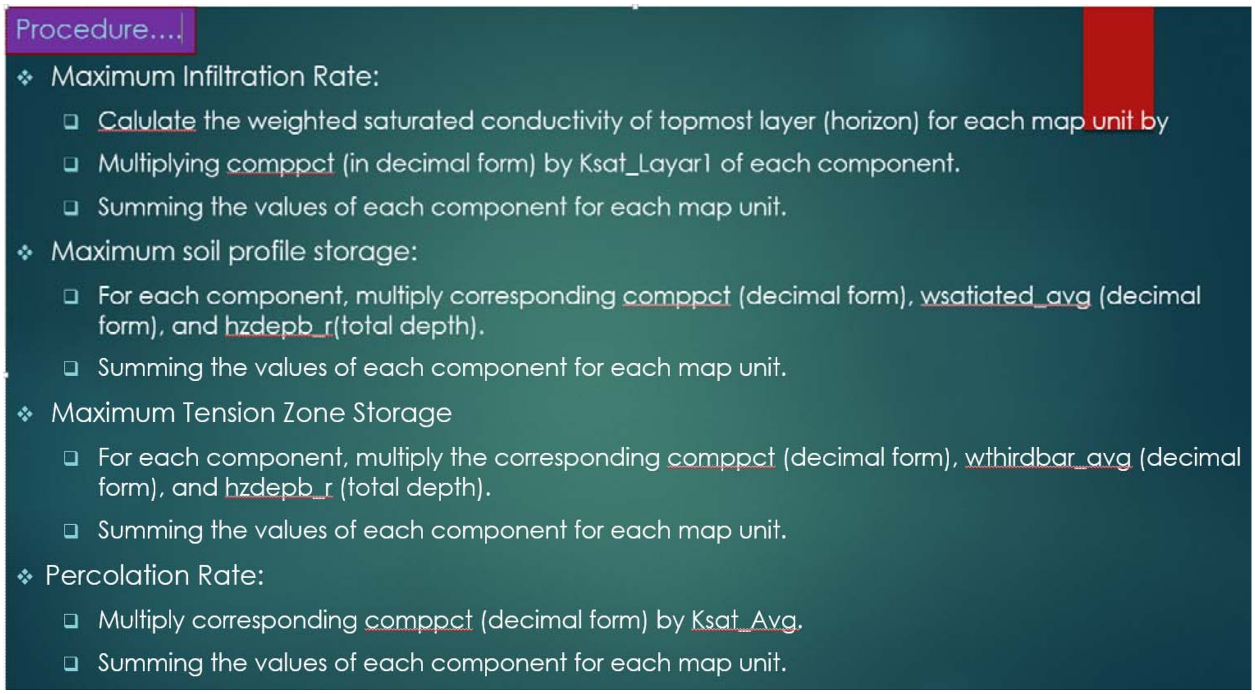
- Save the spreadsheet as .csv file (chorizon_re.csv).
- Import the .csv file (chorizon_re.csv) in ArcGIS with output table named chorizon_re.
- Open chorizon_re table and add new fields named comppct, slope, and mukey.
  - Comppct: component percent covered in map unit
  - Slope: slope of component
  - Mukey: represent map unit key
  - All these three parameter will be available in component file of a SSURGO data.
- Export the component file in .dbf file
- Open component file in excel and save it in .csv file (component.csv).
- Import component.csv file
- Join component table to chorizon_re table using cokey field.
- Using field calculator, equate chorizon_re.comppct with component.comppct_r, chorizon_re.slope with component.slope_r, and chorizon_re.mukey with component.mukey.

Once complete, remove the join

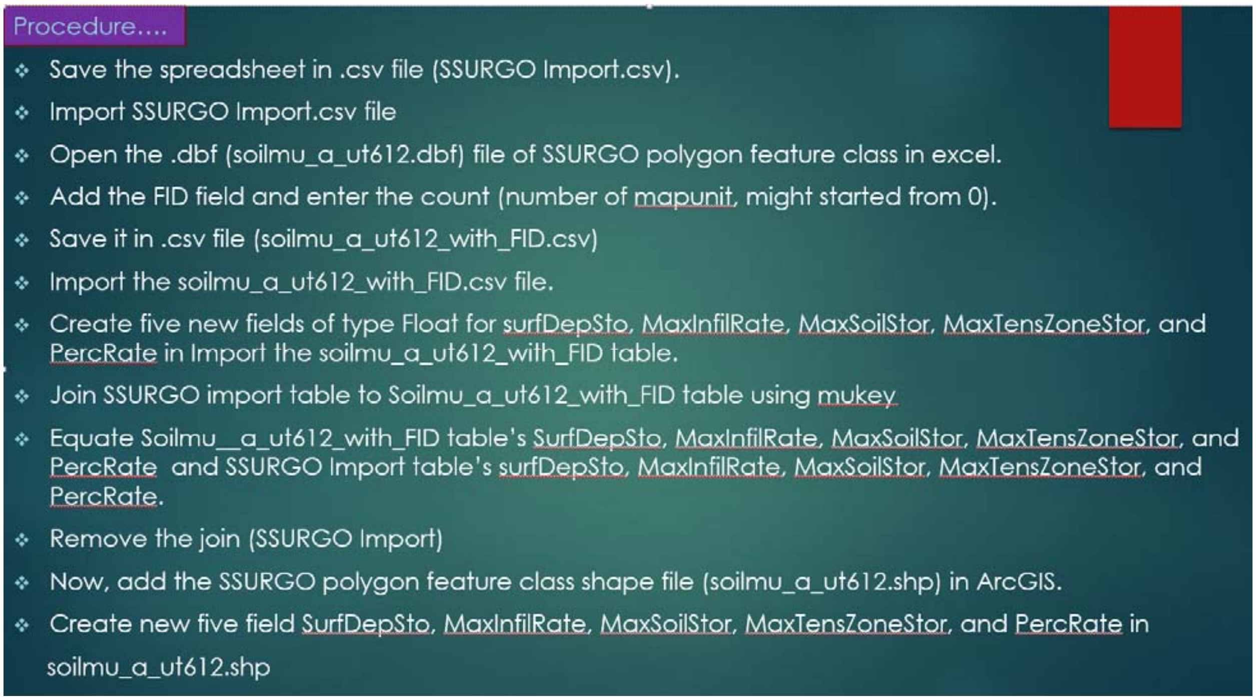
Appendix A

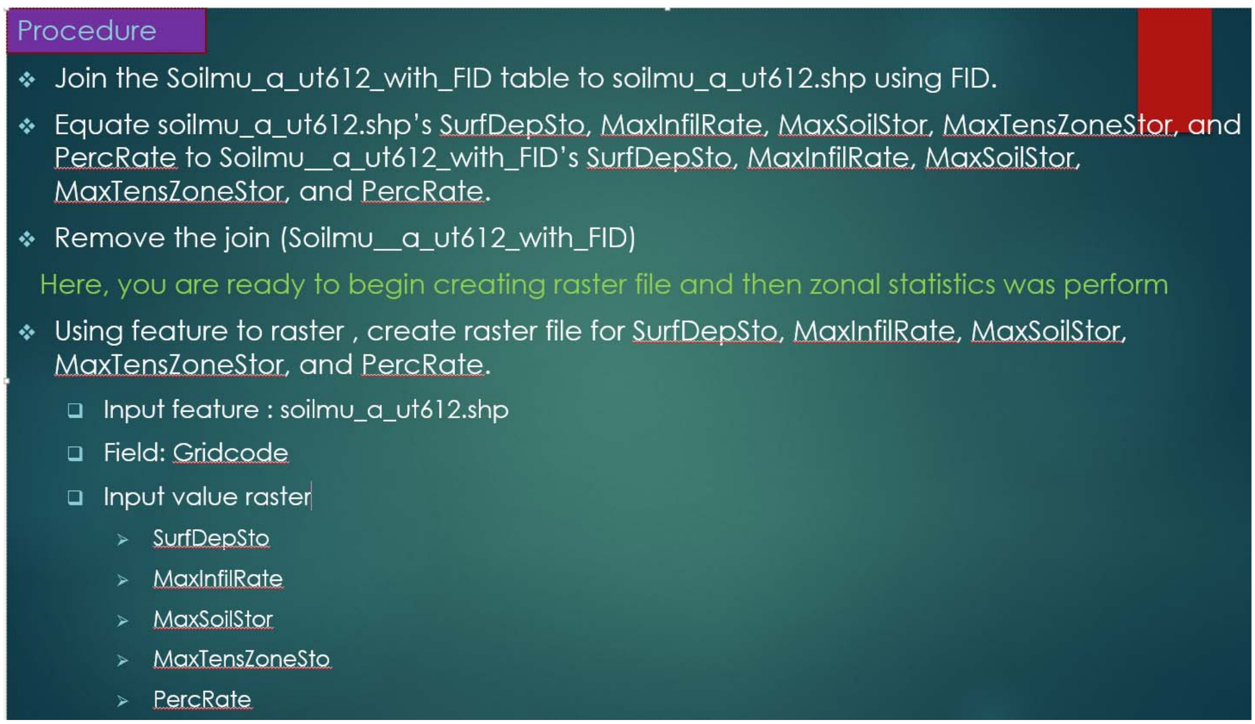


Description	Slope (%)	Surface Storage	
		in.	mm
Paved Impervious Areas	NA	0.125-0.25	3.18-6.35
Flat, Furrowed Land	0-5	2.00	50.8
Moderate to Gentle Slopes	5-30	0.25-0.50	6.35-12.70
Steep, Smooth Slopes	>30	0.04	1.02



Appendix A


Procedure….
Save the spreadsheet in .csv file (SSURGO Import.csv).
Import SSURGO Import.csv file
Open the .dbf (soilmu_a_ut612.dbf) file of SSURGO polygon feature class in excel.
Add the FID field and enter the count (number of mapunit, might started from 0).
Save it in .csv file (soilmu_a_ut612_with_FID.csv)
Import the soilmu_a_ut612_with_FID.csv file.
Create five new fields of type Float for surfDepSto, MaxInfilRate, MaxSoilStor, MaxTensZoneStor, and PercRate in Import the soilmu_a_ut612_with_FID table.
Join SSURGO import table to Soilmu_a_ut612_with_FID table using mukey
Equate Soilmu__a_ut612_with_FID table's SurfDepSto, MaxInfilRate, MaxSoilStor, MaxTensZoneStor, and PercRate and SSURGO Import table's surfDepSto, MaxInfilRate, MaxSoilStor, MaxTensZoneStor, and PercRate.
Remove the join (SSURGO Import)
Now, add the SSURGO polygon feature class shape file (soilmu_a_ut612.shp) in ArcGIS.
Create new five field SurfDepSto, MaxInfilRate, MaxSoilStor, MaxTensZoneStor, and PercRate in soilmu_a_ut612.shp


Procedure
Join the Soilmu_a_ut612_with_FID table to soilmu_a_ut612.shp using FID.
Equate soilmu_a_ut612.shp's SurfDepSto, MaxInfilRate, MaxSoilStor, MaxTensZoneStor, and PercRate to Soilmu__a_ut612_with_FID's SurfDepSto, MaxInfilRate, MaxSoilStor, MaxTensZoneStor, and PercRate.
Remove the join (Soilmu__a_ut612_with_FID)
Here, you are ready to begin creating raster file and then zonal statistics was perform
Using feature to raster , create raster file for SurfDepSto, MaxInfilRate, MaxSoilStor, MaxTensZoneStor, and PercRate.
Input feature : soilmu_a_ut612.shp
Field: Gridcode
Input value raster
SurfDepSto
MaxInfilRate
MaxSoilStor
MaxTensZoneSto
PercRate