ADVANCED HYDROLOGY: CE 610 A

COURSE PROJECT

A REPORT ON HYDROLOGIC MODELLING OF DISCHARGE FROM NEELESWAWRAM CATCHMENT IN PERIYAR RIVER

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DEPARTMENT OF CIVIL ENGINEERING
HYDRAULIC AND WATER RESOURCES ENGINEERING

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Introduction

Periyar is the longest river and the river with the largest discharge potential in the Indian state of Kerala. It is one of the few perennial rivers in the region and provides drinking water for several major towns. The Periyar basin spreads over an area of 5,398 square kilometres (2,084 sq mi), most of it in central Kerala.
Out of 5398 km^2 of catchment, 318 km^2 belongs to the neeleswaram catchment.

Neeleswaram catchment

Located in the north east side of Kerala neeleswaram catchment has periyar river flowing between the landmass which cuts the catchment in two side and drain into the Arabian sea. The width of the river ranges from 150m to 390m across the catchment.
Soils of the Periyar river basin fall within 6 broad categories.

1) lateritic soil
2) hydromorphic soil
3) brown hydromorphic soil
4) riverine alluvium
5) coastal alluvium
6) forest loam

Catchment is endowed with rich natural resources and is noted for its majestic forts, ravishing rivers, hills, green valley. Industrial area is not present in the neeleswaram catchment, it is much affected by the human intervention, lesser part of the catchment is residential, the upper part of the catchment is mainly hills and wide vegetation on it and the soil type on the river is 100% silt ranging with a depth of upto 2m varying over the chainage.

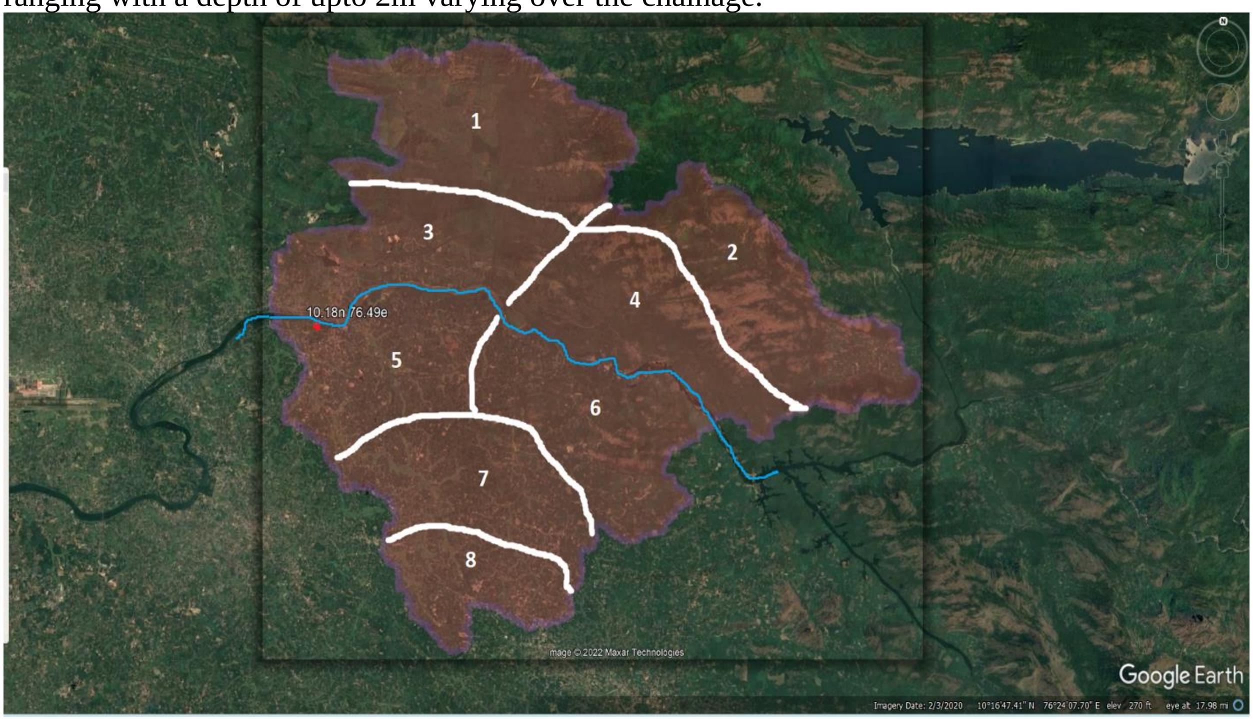
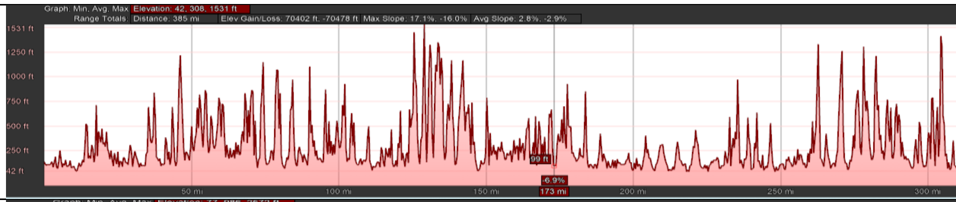
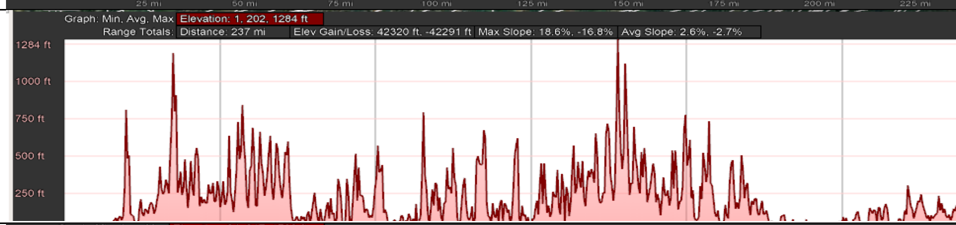
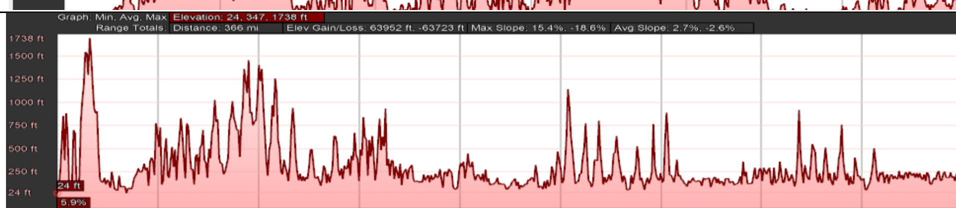
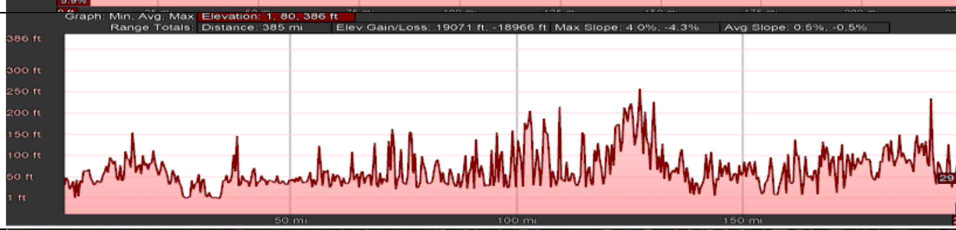
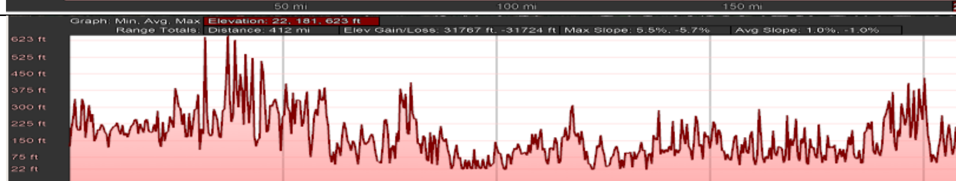
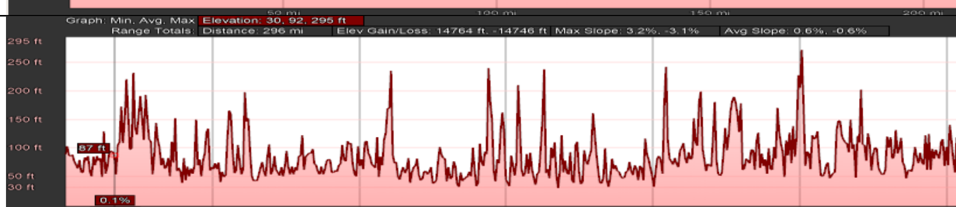
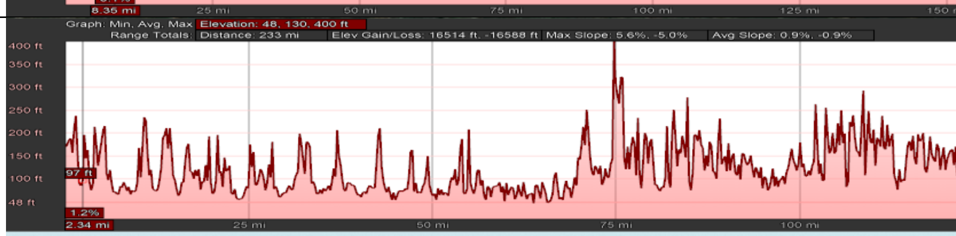


Figure I Neelshwaram catchment

Topography :The catchment has hills ranging upto 2700t. in the upper part, to show variation of elevation catchment is divided into 8 areas of land and elevation is calculated from google earth.

Region in map	Variation of Elevation	RANGE OF ELEVATION
1		42ft-1531ft
2		77ft-2672ft
3		1.2ft-1284ft
4		24ft-1738ft
5		1.8ft-3868ft
6		22.18ft-623ft
7		30ft-285ft
8		48ft-400ft

HYDROLOGIC SIGNATURE

Hydrologic signatures of the catchment are quantitative metrics that describe statistical or dynamic properties of discharge.

Hydrologic signature considered in this report are precipitation ,evapotranspiration and discharge (outflow).

To take count of these hydrologic signature at various time scale, we have a large data set for neeleswaram catchment.

How the required data is a acquired from the field?

- Precipitation: Rainfall data is obtained from the raingauges at all grid points across the catchment. After receiving the grid point rainfall data a single average value of whole catchment is calculated, which can be done by various methods, i.e. Thiessen polygon method, Arithmetic mean method or the isoheytal method depending upon the topography of the catchment.

- Discharge : The hydrological boundaries of the catchment are assumed to correspond to the topographic watershed boundaries, therefore value of the discharge produced by the catchment is calculated by the discharge recorded between the upstream measurement site of the catchment and the last point where the water leaves the catchment. The methods that can be used to find discharge are volumetric gauging, float gauging, current metering etc. The choice of method used is dependent on the characteristics of the stream and application of it.

- Potential Evapotranspiration : Different approaches used to measure the potential evapotranspiration(PET) can be direct or indirect methods. Water budgeting technique, indirect meteorological measurement are indirect methods and direct methods includes pan evaporation, lysimeter or direct soil water measurements etc. In India, direct methods of PET across locations are cost prohibited and using an indirect method using meteorological data remains a better alternative.

DATA SET CONSIDERED IN THIS REPORT

- Precipitation: 30 years (1981-2010) catchment average precipitation value in millimeter per day.
- Discharge : 30 years(1981-2010) at the coordinate 10.18°N 76.49°E in millimeter per day.
- Potential evapotranspiration : 30 years (1981-2010) provided as monthly average in millimeter but equally distributed over the month.

The hydrologic signatures of the catchment at various time scales are as follows:

1. Annual timescale
   The Budyko’s curve is plotted for the annual timescale, this curve describes the theoretical energy and water limits on the catchment.

Water balance equation:
$P = Q + E$
where precipitation(P), discharge (Q) and actual evapotranspiration(E) are the annual average values. And E/P VS Ep/P is plotted.

Code file: Budyko.m

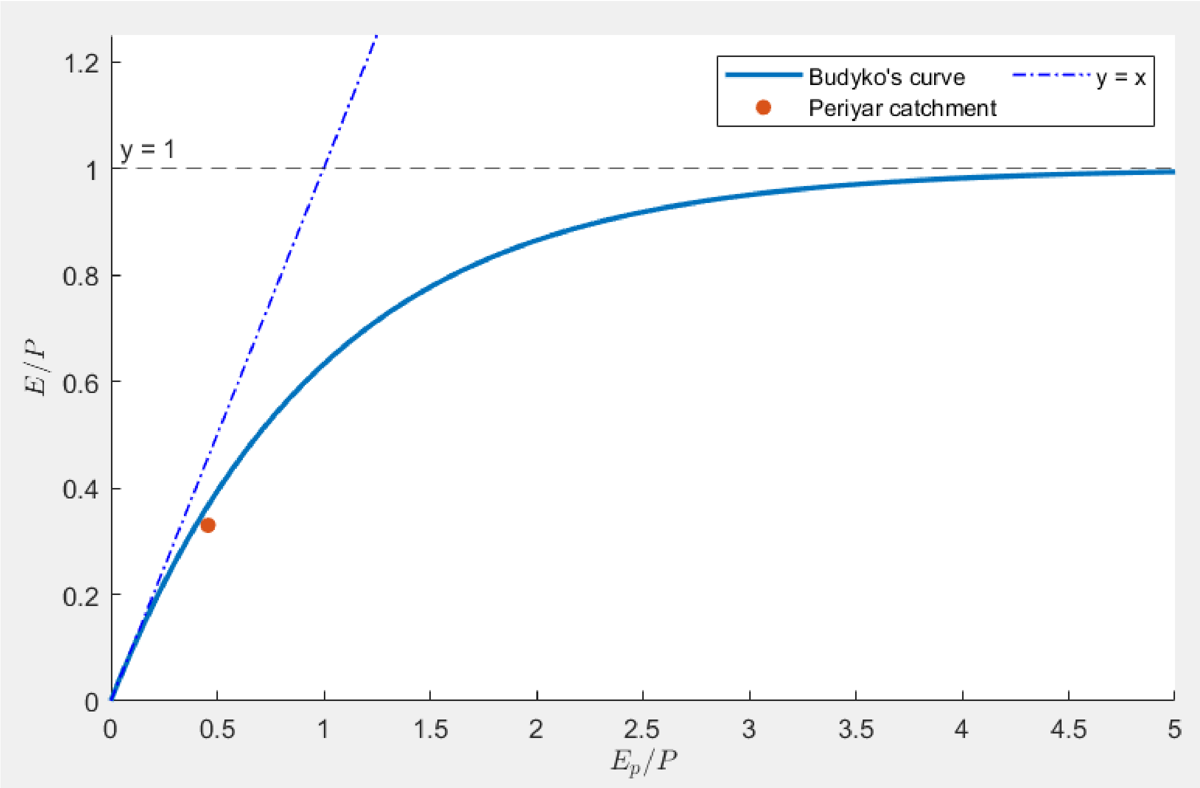


Figure II Budyko's Curve

$$Aridity\ Index\ = \frac{Ep}{P}$$

Envelope in the graph is the maximum value E/P can take at a given aridity index, and The Budyko's curve is a result of optimization of water use by the ecosystem which acts as a reference condition for different catchment.
Inference:
Ep/P = PET , P= Precipitation
Here, we get
Aridity Index = 0.4585
E/P = 0.3299

Aridity index lesser than one, i.e. Ep < P implies that catchment has more rainfall than that can be evaporated by the PET
Therefore, Neeleswaram catchment is energy limited.

2. Seasonal Timescale

The Regime curve is plotted for the given monthly values, it shows the overall pattern of the catchment signatures throughout the year.

Code file: Manipulation.m

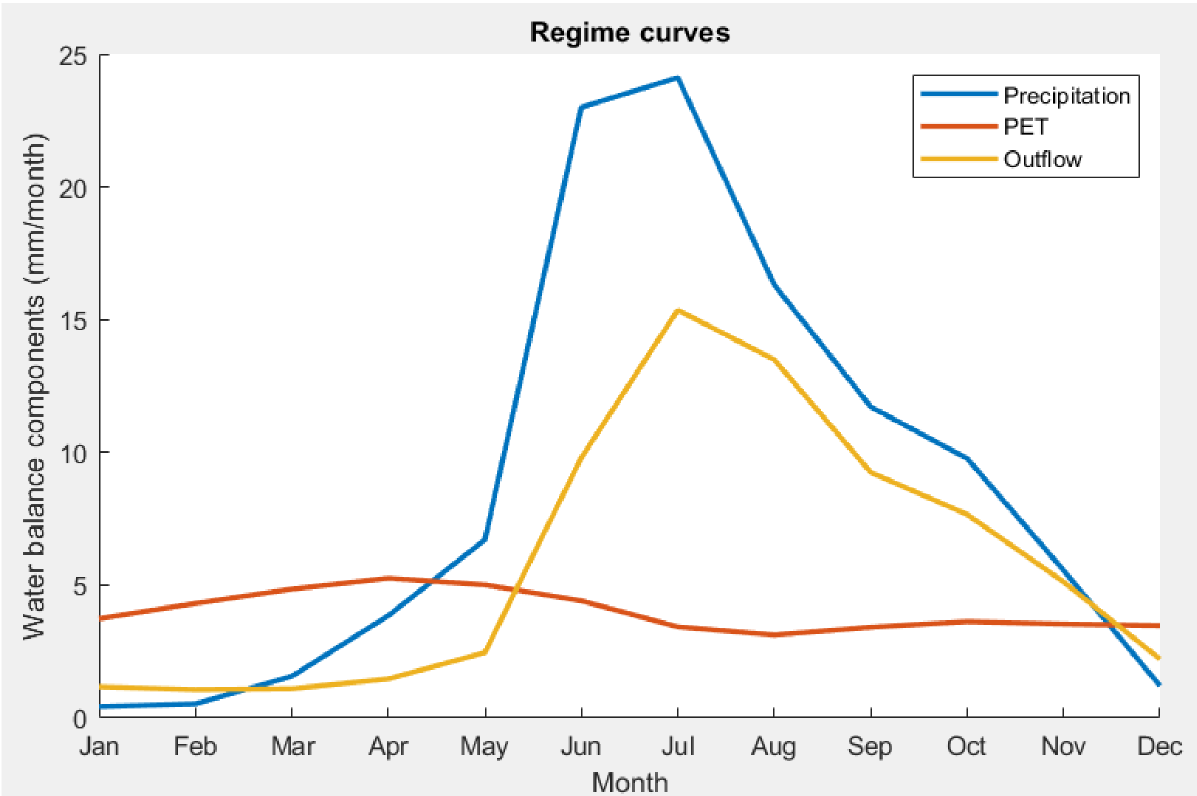


Figure III Regime curves at seasonal timescale

Inference:
Seasonality: Precipitation curve being highly varying with peak value at July and minimum at the
end points. Shows that the Neeleswaram catchment has high seasonality.

Phase: PET is less varying and hence it is hard to say whether the precipitation and potential evapotranspiration are in which phase, but the peak value of precipitation is in July and PET has values near its lower value and while PET is maximum the observed precipitation was near lower side. Therefore the catchment is out of phase, also in budyko's curve the catchment lies under the curve which supports the above argument.

In a energy limited catchment the evapotranspiration will follow potential evapotranspiration curve and thus discharge will be roughly the difference between precipitation and potential evapotranspiration.

3. Daily Timescale

The precipitation flow duration curve(PDC) and flow duration curve(FDC) are plotted on daily scale. These curves shows number of days for which the flow or precipitation is more than the threshold value.
Y axis = P&Q   values in millimeter per day
X axis = probability of exceedance (n/N)
Where n = no. of days the flow is maximum than the value itself
N = total number of days

Code file: Manipulaion.m

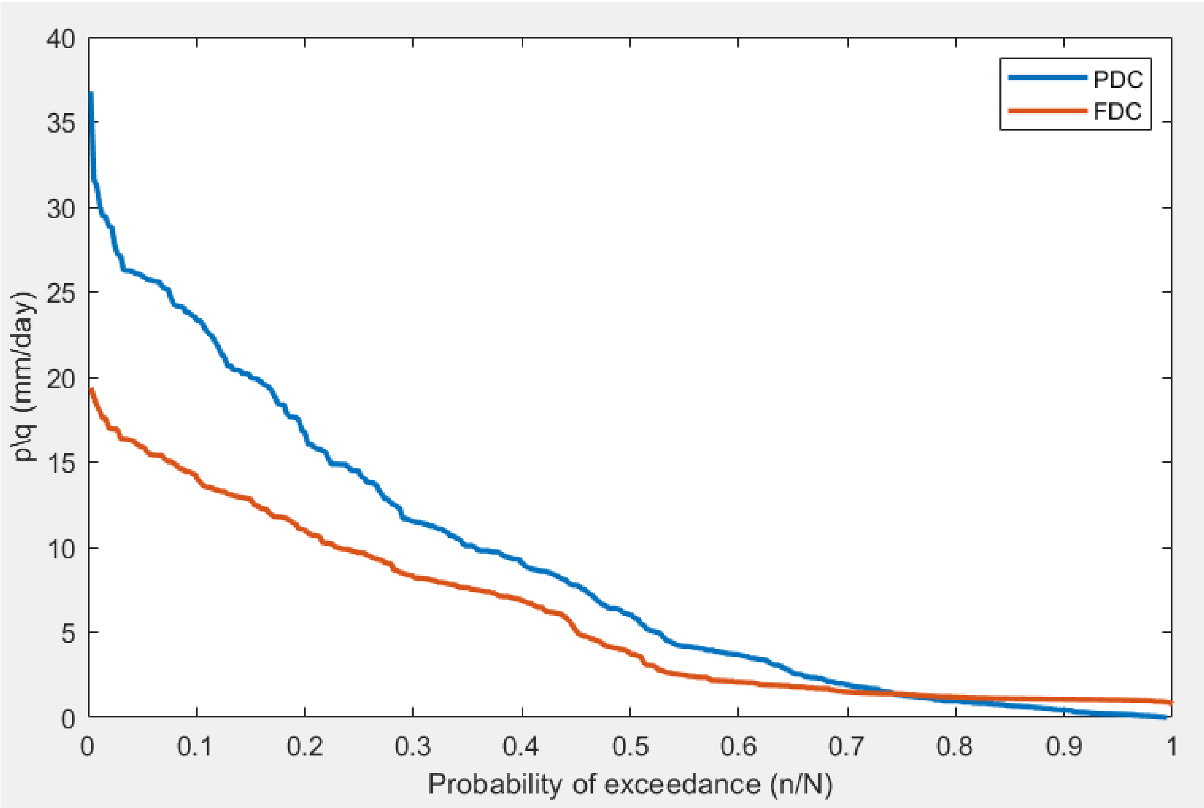


Figure IV Duration curves

Inference:
PDC shows high variability spanning over the timeline, also it has higher peaks
FDC has lower variability than the PDC and it has very little variation is most of the time as it is flat when the probability of exceedance is higher.

The reason for FDC being less variable can be the changing situation of the catchment reservoir and streams. In a capacity survey under Bureau of Indian Standards in 1995 and 2007, was said that 47% storage reduction was seen in span of 45years. In view of the possible loss of active storage volume of dams through sedimentation and its consequential adverse impact discharge variability.

HYDROLOGIC MODELLING

It is the characterization of real hydrologic signature by the use of mathematical model and doing computer simulations for the desired modelled output which then can be helpful in determine the particular catchment properties and the influences of various parameters. The best performance model can also be used to generate future yields or scenario modelling.

Till now we have discussed the hydrologic signature based on the data provided and observed the phase of catchment, seasonality, regime curves etc. but to know the catchment characteristics ,properties and to analyze the change in properties of the catchment or the introduction of new parameters will influence the discharge(drainage from catchment) out of the catchment. We have to simulate the modelled outflow using the precipitation and potential evapotranspiration , while changing the various parameter or introducing the new parameters with or without changing combinations.

Therefore parameters will be based on the actual catchment properties whose value can be used from the known data or by trial and error for the best match of modelled and actual outflow.

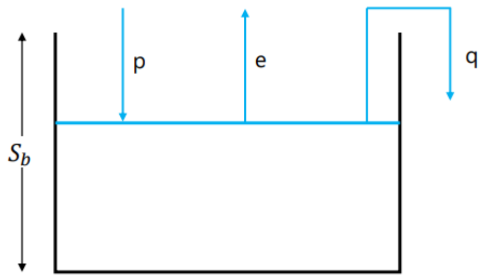
The final flow time series(modelled outflow) will be from the best combinations of parameter considered in the model. The best fit/performance will be checked by Nash-Sutcliffe efficiency (NSE).

NSE : Nash-Sutcliffe efficiency ranges from one to negative infinity; a value of one indicates a perfect fit, while a value of zero indicates that a mean value would have produced the same level of accuracy.

$$NSE = 1 - \left(\frac{\sum_{i=1}^{n}(Y_i^{obs} - Y_i^{sim})^2}{\sum_{i=1}^{n}(Y_i^{obs} - Y_i^{mean})^2}\right)$$

Model 1: Monthly water balance model of monthly averaged data for 30 years.

Monthly water balance model



Bucket storage capacity S_b [mm]

Precipitation rate p [mm/day]

Evapotranspiration rate e [mm/day]

Runoff rate q [mm/day]

Model equations

$$\frac{dS}{dt} = p - e - q$$ Mass balance

$$e = e_p \frac{S}{S_b}$$ Evaporation depends linearly on soil moisture

$$q = \begin{cases} p & if\ S = S_b \\ 0 & if\ S < S_b \end{cases}$$ Overflow bucket model

1. $$e_t = e_{p_t} \frac{S_{t-1}}{S_b}$$
2. $$S_{temp} = S_{t-1} + p_t - e_t$$
3. $$q_t = \begin{cases} 0 & if\ \ S_{temp} < S_b \\ S_{temp} - S_b & if\ S_{temp} > S_b \end{cases}$$
4. $$S_t = S_{t-1} + p_t - e_t - q_t$$

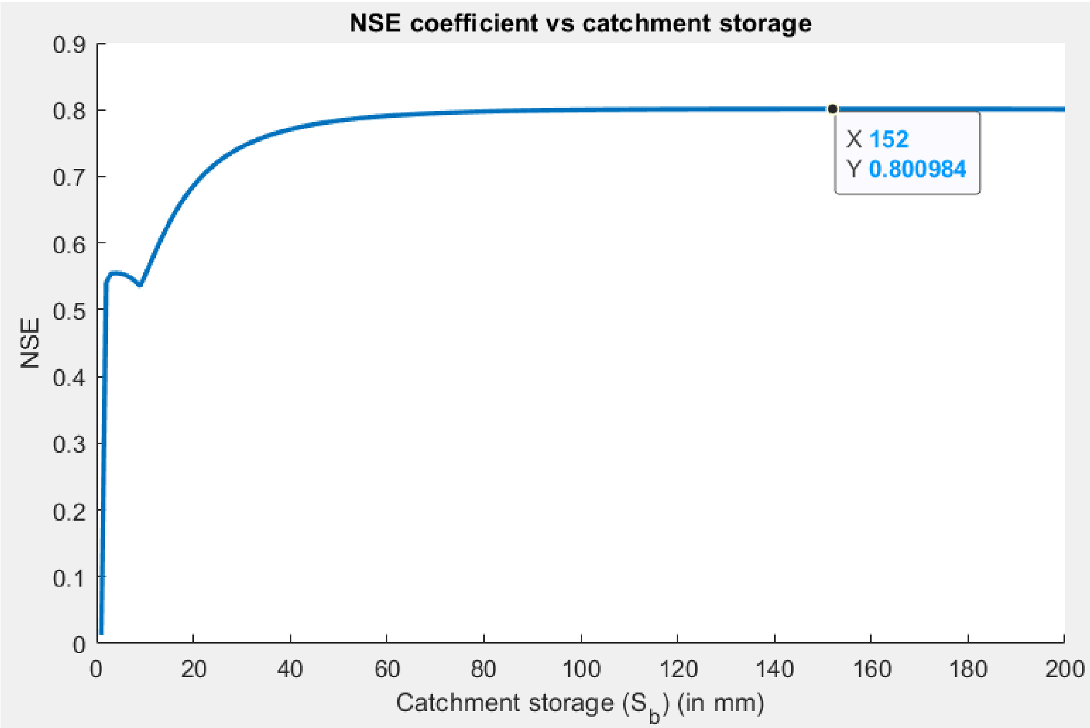
1. $$e_t = \min(e_{p_t} \frac{S_{t-1}}{S_b}, S_{t-1})$$
2. $$S_{temp} = S_{t-1} + p_t - e_t$$
3. $$q_t = \begin{cases} 0 & if\ \ S_{temp} < S_b \\ S_{temp} - S_b & if\ S_{temp} > S_b \end{cases}$$
4. $$S_t = S_{t-1} + p_t - e_t - q_t$$

For both above monthly models, result remains the same as shown below,

Only parameter is maximum storage capacity.

Initial water storage in the catchment is equal to the maximum storage capacity.

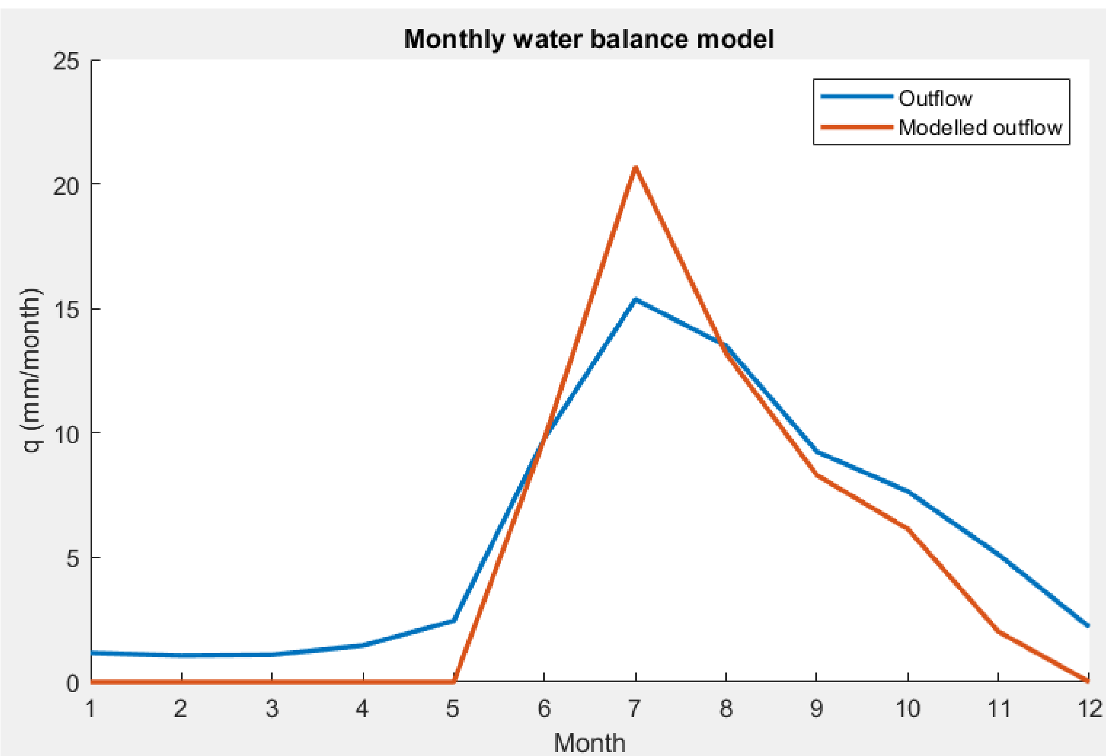
Code File: M_monthy.m



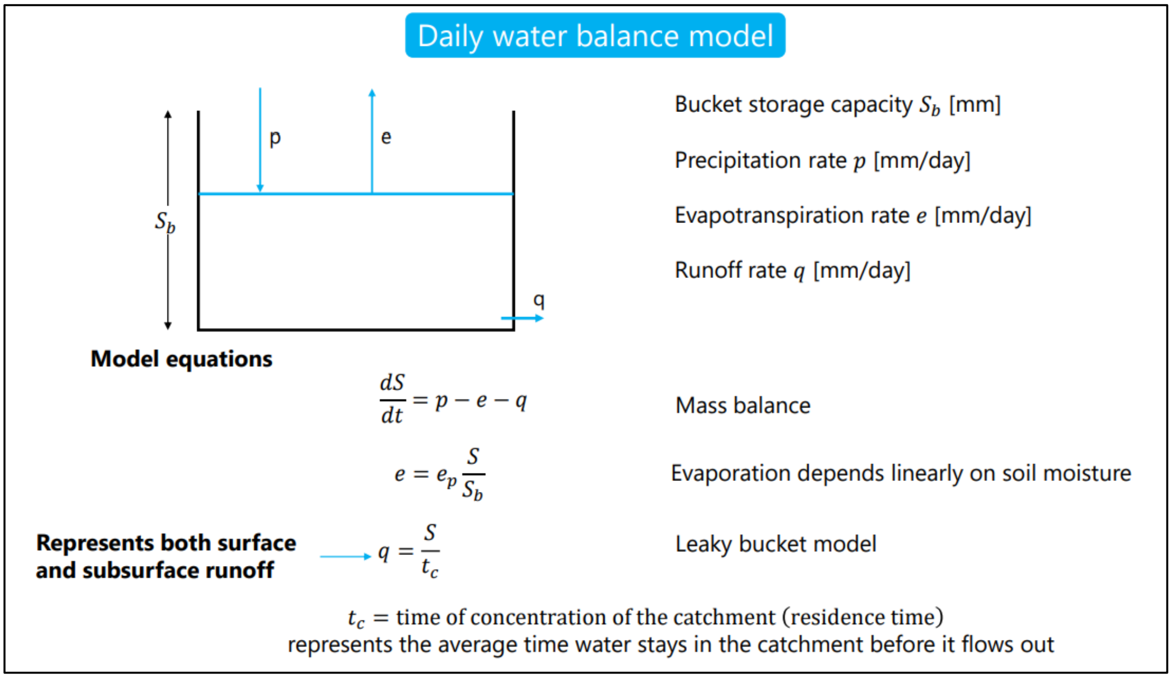
Outcomes:

- Max. NSE = 0.8010 ;
- Minimum optimum catchment storage = 152 mm (modelled)

Monthly water balance model plotted with S_b = 152 mm



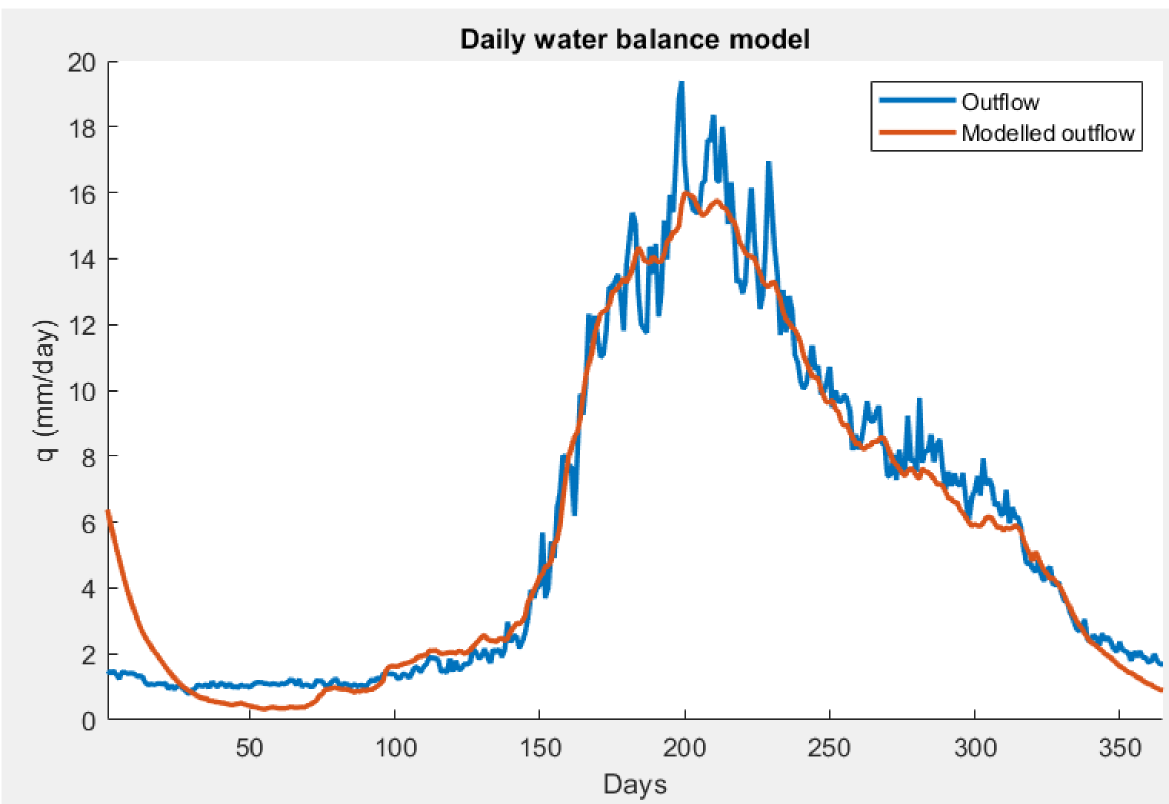
Model 2: Discretized daily water balance model for daily averaged values of 30years.



Assumption -1 initial water storage in the catchment is equal to the maximum capacity.

Parameters: Sb, t_c

Code File: M_daily.m



Outcomes:

- Max. NSE = 0.9602 ;
- Minimum optimum catchment storage = 134 mm;
- T_c = 21 days

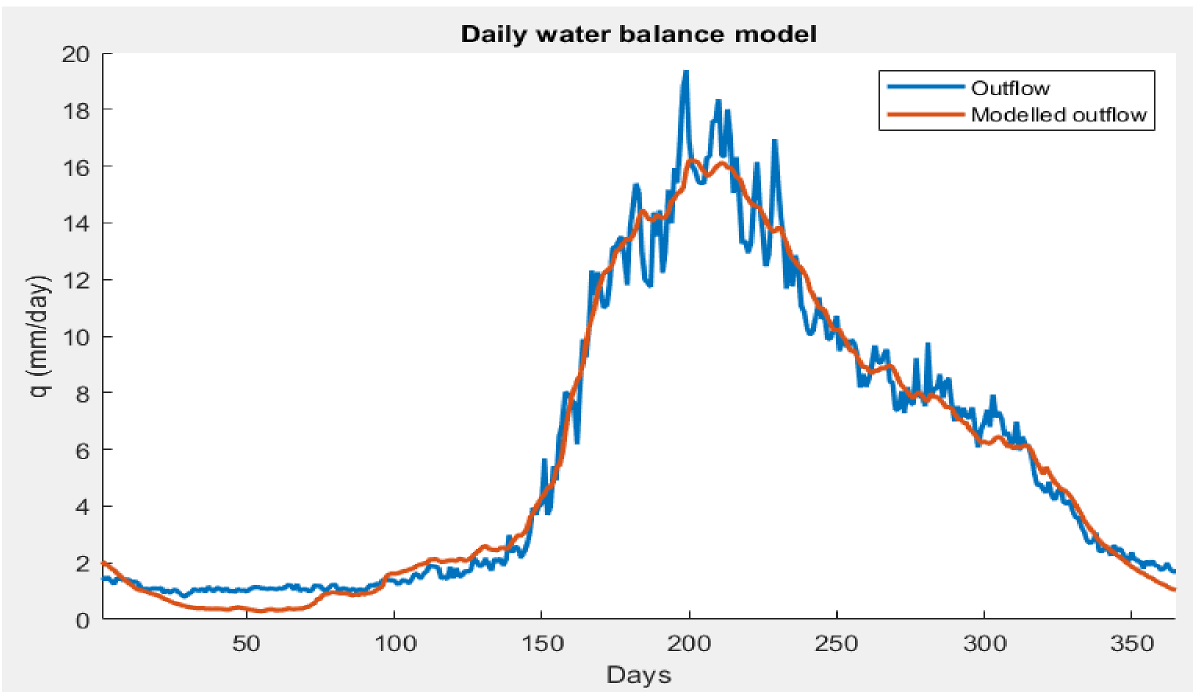
In this model the initial discharge was higher and then is decreases and becomes a best fit.

The sudden initial discharge is maybe because of already stored water in the catchment so that as the rainfall happens the discharge is generated but to eliminate the initial hike in discharge value, we can take the initial storage capacity as a parameter in next model and check.

Assumption -2 initial water storage in the catchment is not equal to the maximum capacity.

Parameters: Sb, t_c, $S_{initial}$ (initial storage)

Code File: M_daily3a.m



Outcomes:

- Max. NSE = 0.9763;
- Minimum optimum catchment storage = 161 mm;
- t_c = 23 days;
- Best Initial storage = 47 mm

The assumption made was right the initial hike in the discharge is reduced we got a more perfect fit for the curve. Now that the initial stored water is optimum and its less than the maximum capacity now more water will store (plus the optimum max storage cap. Is also increased) and the lag time is increased because of decrement of surface flow(the fastest).

Because this data is average 30 years the influence of parameter might have particularly decreased so now, we take data of single year.

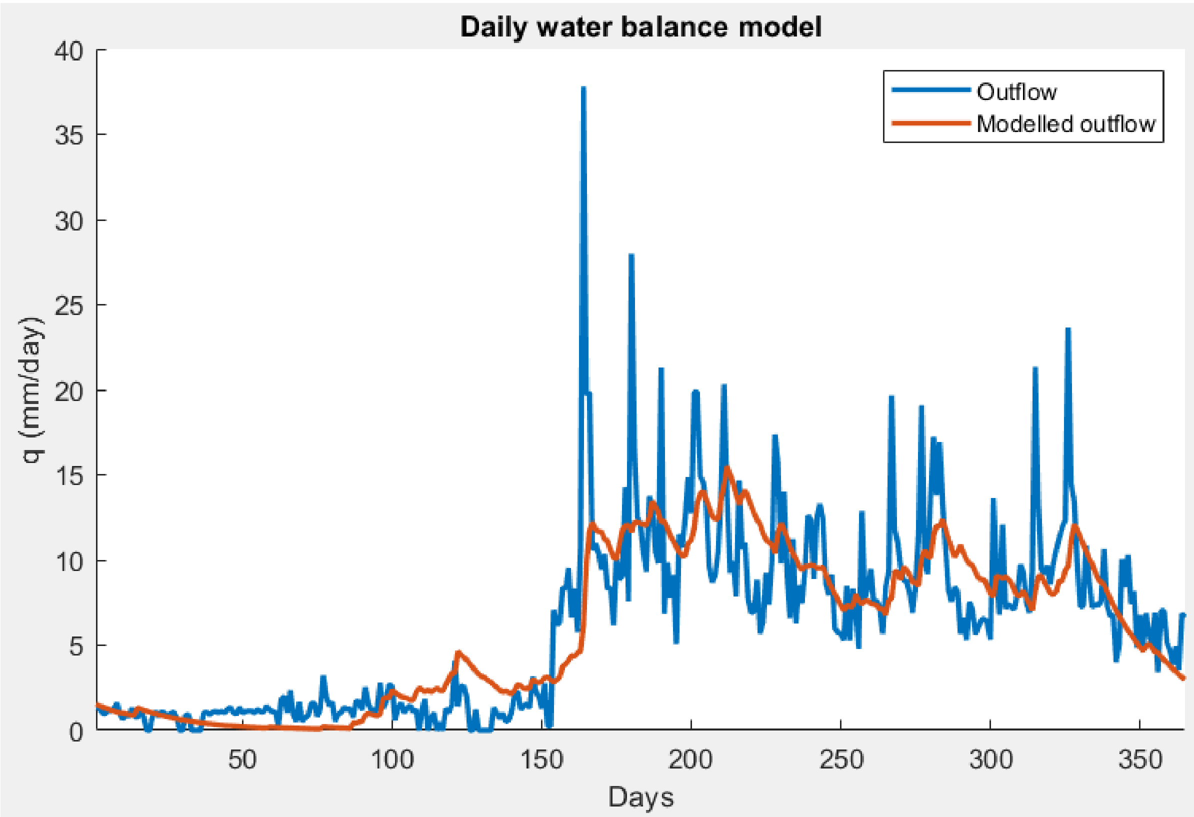
Model 3 Discretized daily water balance model for the year 2010

Assumptions -1 leaky bucket is considered (no overflow happens)

Only discharge is from the leaky bucket which represent both surface and sub-surface flow.

Parameters: Sb, $S_{initial}$, t_c

Code File: M_daily3a10.m



Outcomes:

- Max. NSE = 0.6206;
- Minimum optimum catchment storage = 199 mm;
- t_c = 32 days
- Best Initial storage = 49 mm

In this model, the optimum max catchment storage is increased because the catchment is holding whole runoff with increased lag time as the major outflow is underground.

And our NSE is reduced as rainfall has major peak which creates a lot of surface runoff which is not taken into consideration in this model.

In next model we have taken the overflow and leaky bucket both.

Assumptions -2 Bucket overflow + leaky bucket was considered

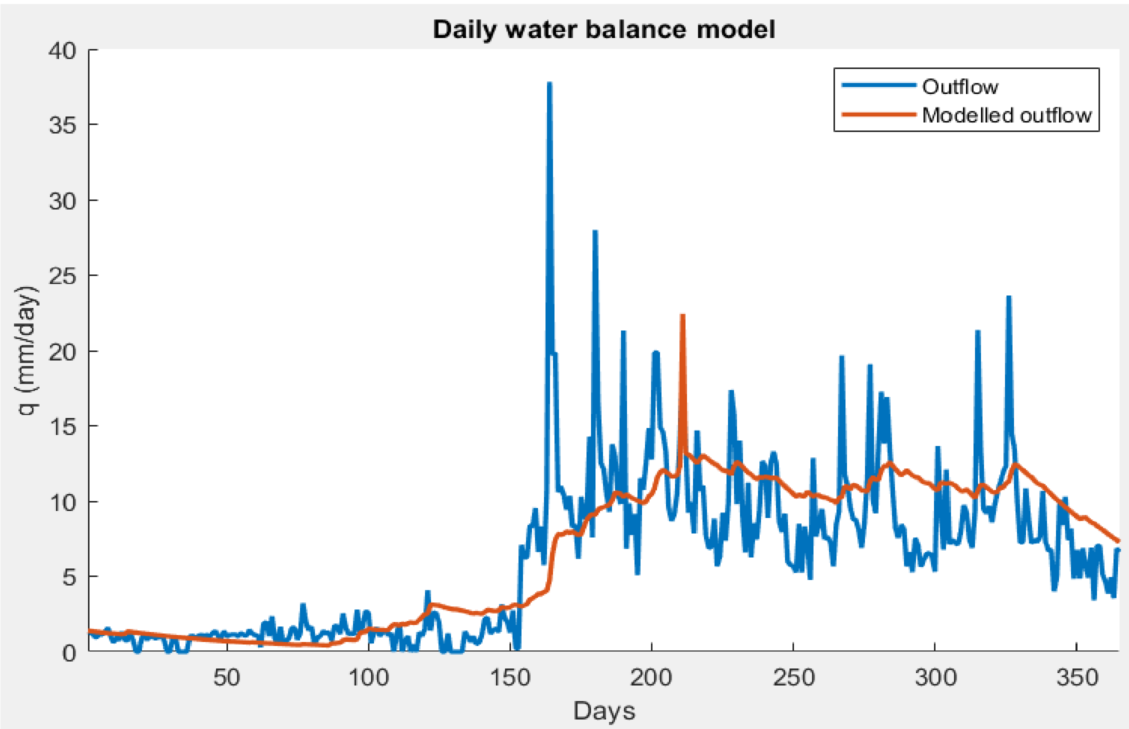
$Leaky\ discharge = \frac{S}{t_c},$

$Overflow\ discharge\ = \begin{cases} p, & S > Sb \\ 0, & S \geq 0 \end{cases} \}$

Therefore, total discharge model = $\frac{S}{t_c}$ + $\begin{cases} p, & S > Sb \\ 0, & S \geq 0 \end{cases} \}$

Parameters : Sb, t_c, $S_{initial}$

Code File: M_daily3b.m



Outcomes:

- Max. NSE = 0.5488;
- Minimum optimum catchment storage = 937 mm;
- t_c = 71 days;
- Best Initial storage = 99 mm

The change we made in this model has resulted in wring as we got less NSE value, and increase in lag time too, maybe because we considered the overflowing water as discharge because it was huge in quantity but its not the best fit. we see high maximum catchment storage(937mm) which means the discharge reaching stream is mainly from the leaky part because initial storage was 99 and maximum storage is found to be 937 so at end of the year whole rainfall which has to be overflown is stored in the catchment. Hence it satisfy the increment in lag time.
Now in next model we will consider leaky plus overflowing bucket but wont consider the overflown surface water I n runoff.

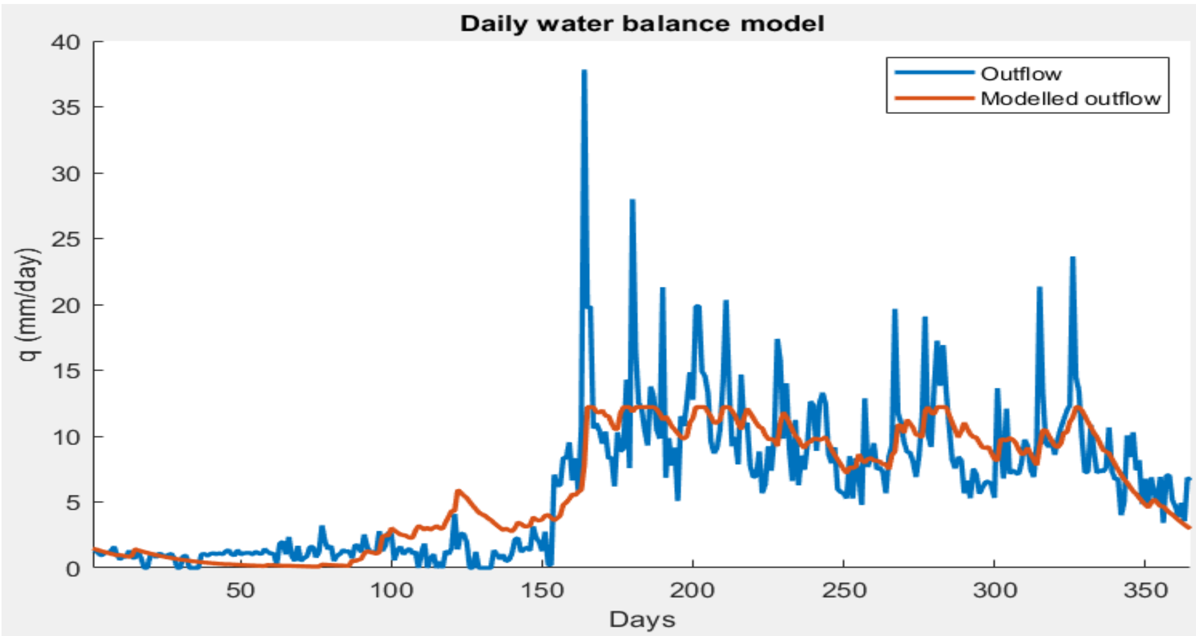
Assumptions -3 Bucket overflow + leaky bucket was considered but overflow was not taking part in modelled outflow

Total discharge model = $\frac{s}{t_c} + \begin{cases} p, & S > Sb \\ 0, & S \geq 0 \end{cases}\}$

q = s/tc, but stemp cannot be greater than sb

Parameters : Sb, t_c, $S_{initial}$

Code File: M_daily3bw.m

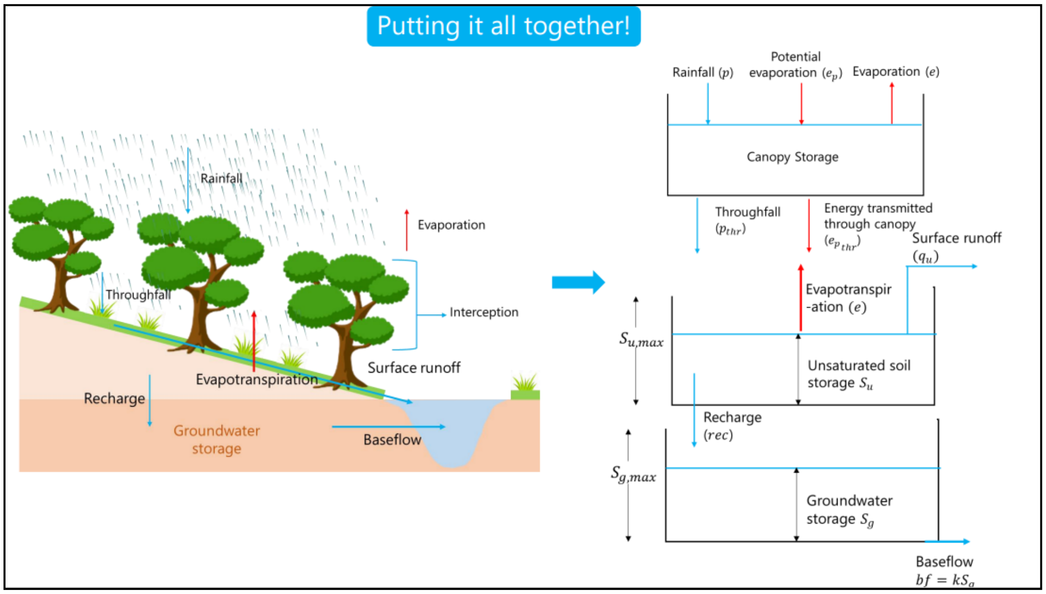


Outcomes:

- Max. NSE = 0.6517;
- Minimum optimum catchment storage = 305 mm;
- t_c = 25 days;
- Best Initial storage = 37 mm

This model has shown a good NSE value, in this model the bucket is over flowing but the overflown water is not joining the stream for generating discharge, this can happen due to human interferences, there are many walls like structures seen from maps that are like walls built across the river (a short wall up to the level of river) which can create a stable storage in the river and it will interfere the discharge values, as river will be storing a temporary storage on it but would not allow that discharge joining the stream. We didn't find any evidence or study regarding this short wall, but there are short walls (weirs) created on river near villages so that river didn't dry up in a particular region up to certain level.

Model 4 Conceptual Modelling for Daily averaged data (2010)

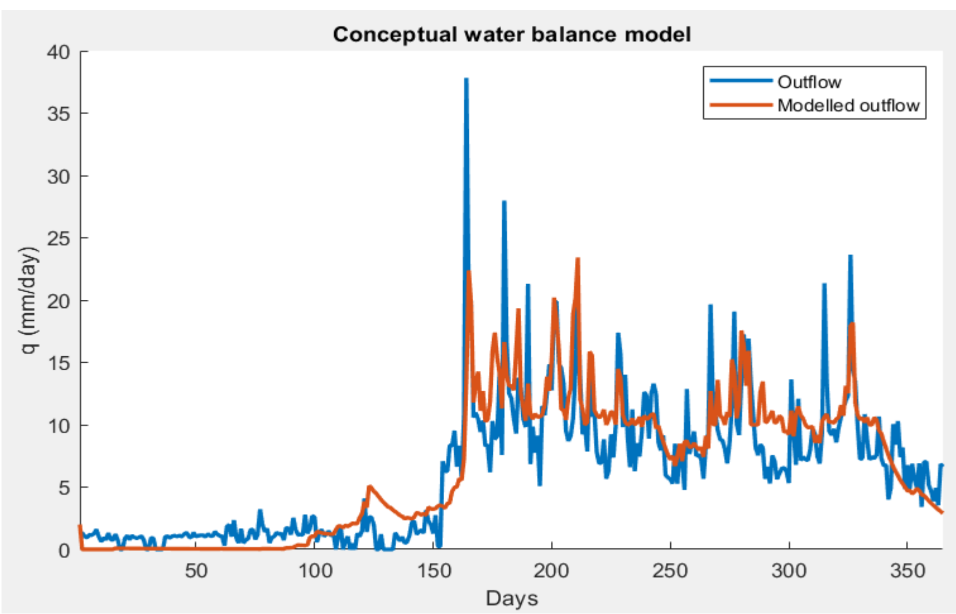


Assummed parameter,

- Canopy storage, S_c = 1 mm
- Initial canopy storage, Sct_1 = 1 mm
- Initial unsaturated soil storage, Sut_1 = 2 mm
- Initial groundwater storage, Sgt_1 = 2 mm

In conceptual modelling we are using 3 bucket system for canopy, unsaturated and ground water zone, and as the catchment has a lot of vegetation and hilly terrain because of more parameter in this modelling we have kept assumed canopy storage at 1 mm and as the catchment has a less construction the seepage, infiltration will be effective.

Code File: M_concept1.m



Outcomes:

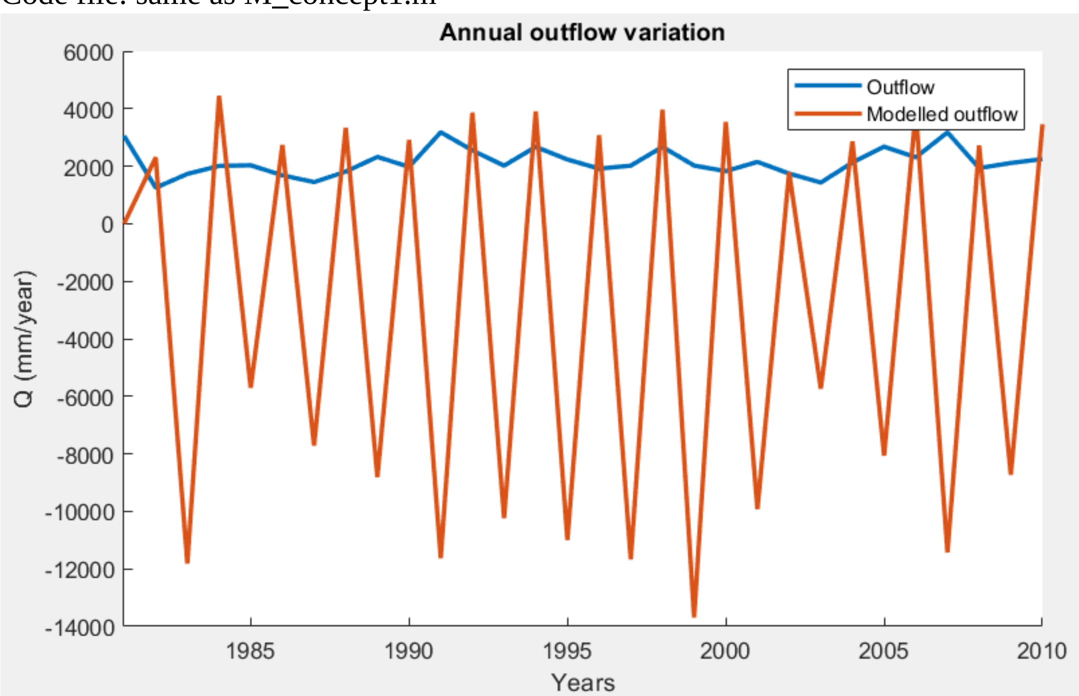
- Constant for baseflow, k = 1
- Constant for recharging water, ks = 40
- Maximum storage of unsaturated soil, S_u = 610 mm
- Maximum storage of unsaturated groundwater, S_g = 10 mm
- Alpha = 1.7
- Beta = 3
- Max. NSE = 0.7264

Because of hilly region the value of beta(contributes to surface runoff) is more than the alpha(contributed to recharge) as surface will be higher at hills. We got a higher ks value which implies there is large portion of precipitation contributing to recharge and hence we got less unsaturated ground water capcity, also the catchment had initial unsaturated soil storage as 2mm but maximum storage capacity iterated is 610 mm which is filled by rainfall and we can see the initialy we have discharge as zero for upto 100 days. (we tried with the increasing the initial Su value but further discharge was affected by it.

Hence we can say

Conceptual model (Model 4) is found to be the best model.

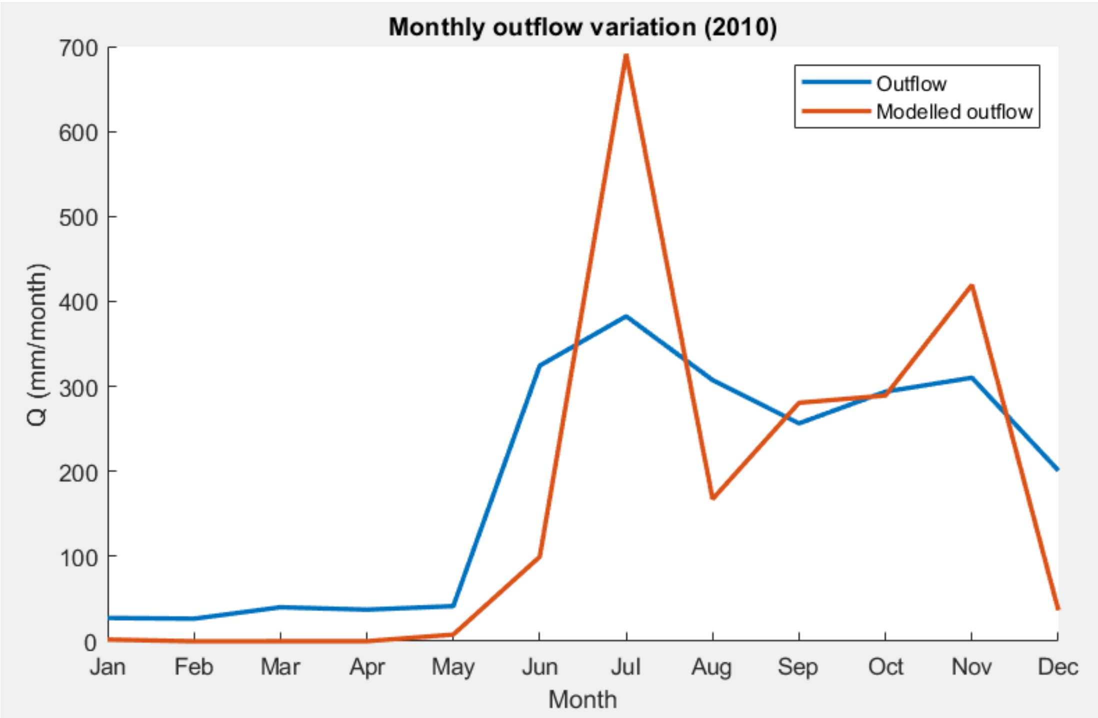
a. Observed and modelled annual flow time-series
   Data of precipitation used is the cumulative precipitation and PET in a year to give us 30 values per each that we used in the best model(conceptual model).
   Code file: same as M_concept1.m



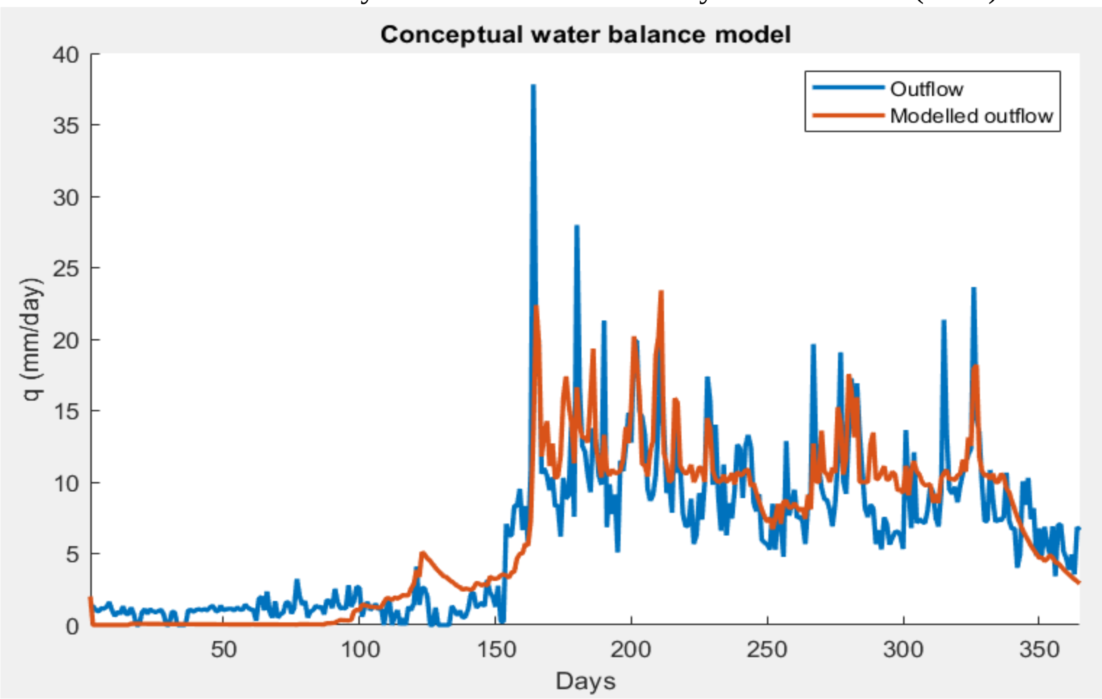
The modelled outflow graph we received is highly varying as the model was optimized for discrete daily values.

b. Observed and Modelled monthly flow time-series

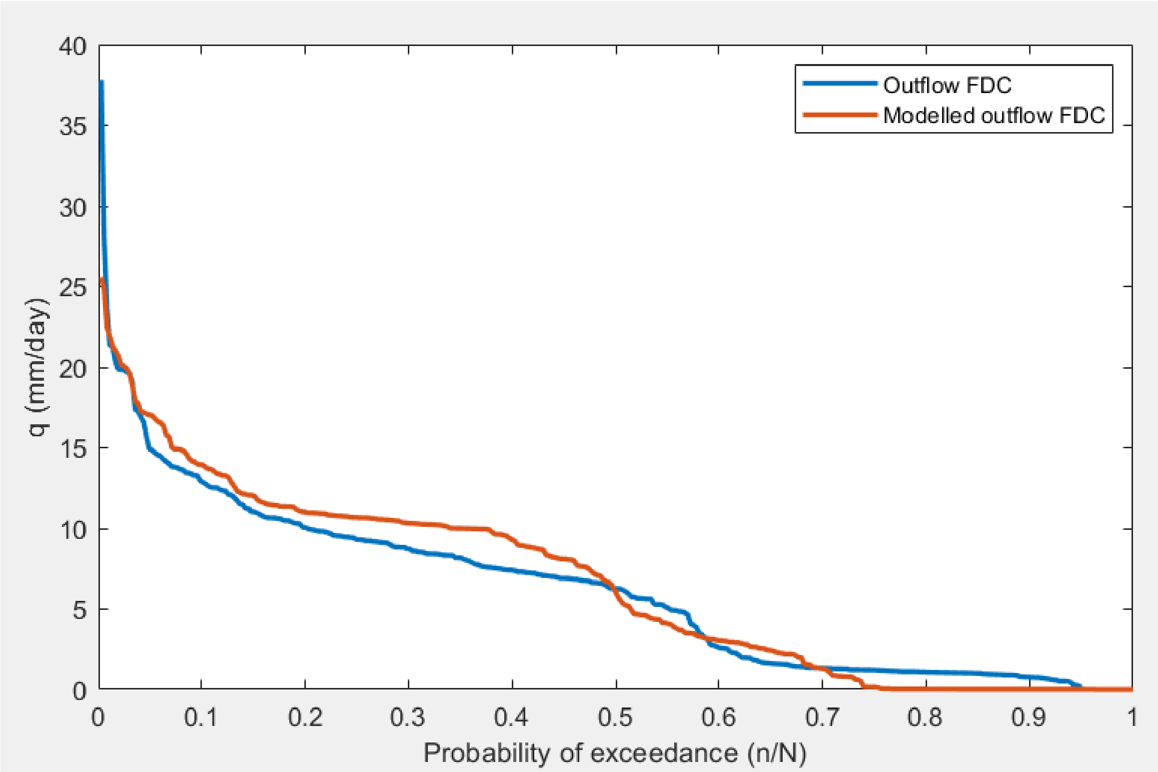
Data used is months of 2010, so we got 12 values for precipitation and PET to generate discharge values.
Code file: same as M_concept1.m



c. Observed and modelled daily flow time-series for one year of the data. (2010)

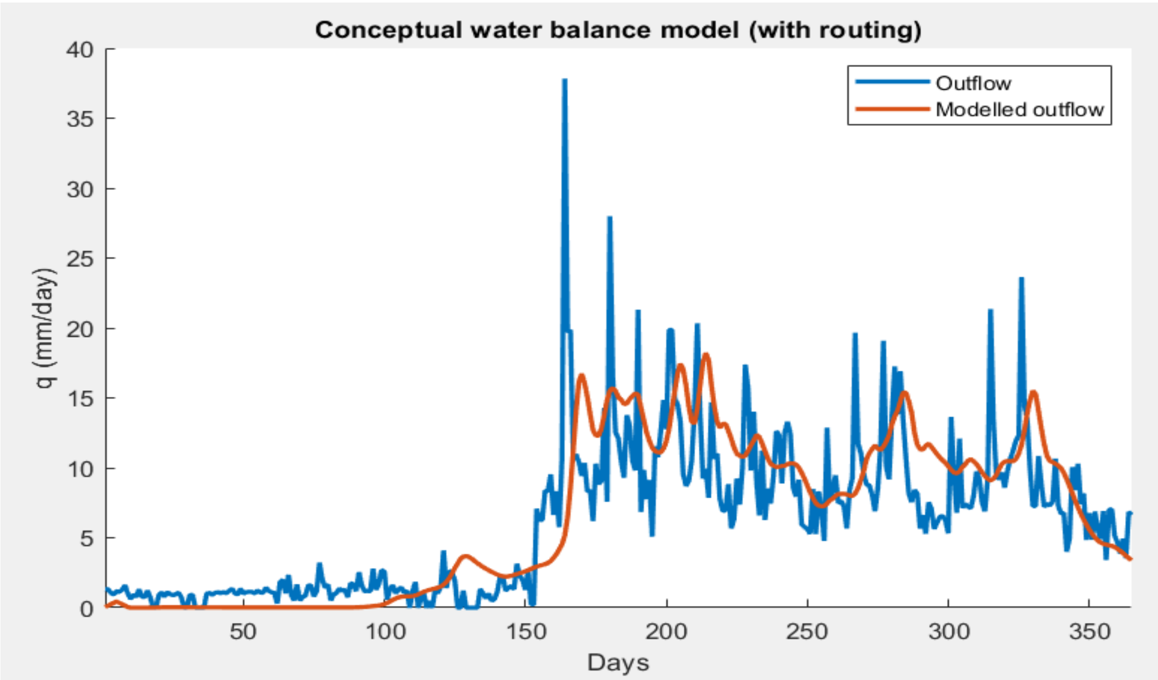


d. Observed and modelled flow duration curves(2010)
Code file: same as Manipulaion.m value of q used is from 2010 conceptual model.

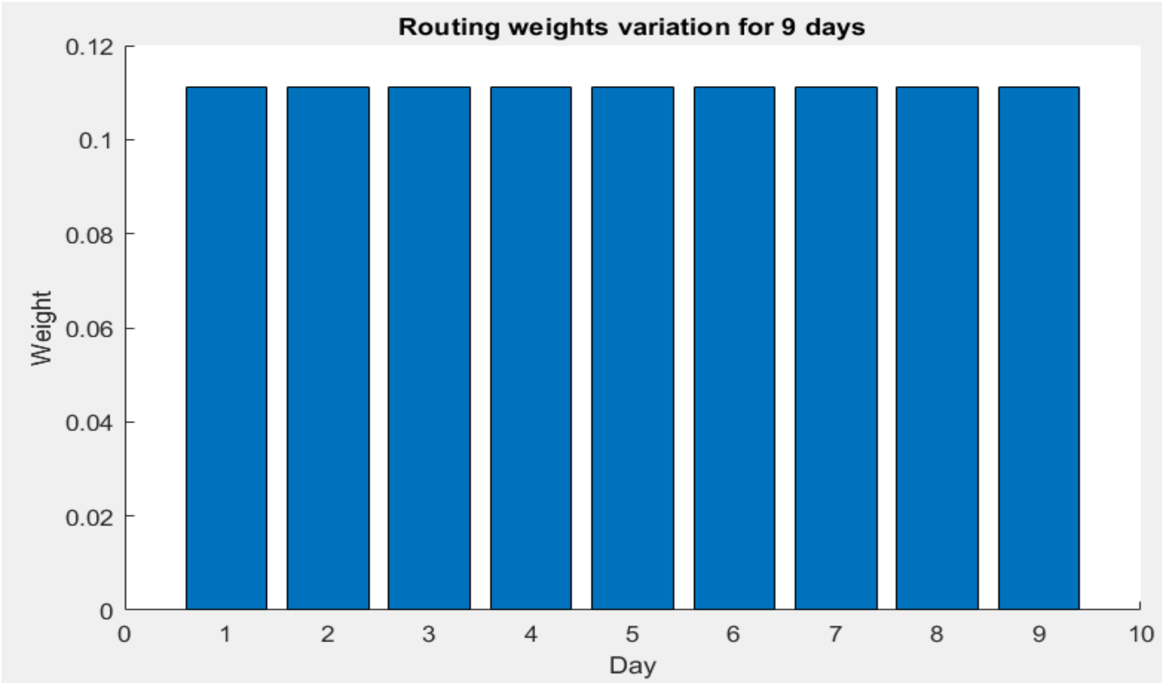


e. Observed and modelled flow time-series for a flood event from the record(2010)

We assumed triangular variation of routing weights. We found the optimum height of weight triangle for 9 days by iteration and found that equal weights gave the best result.
Code file: M_concept2.m , rout.m



Outcomes:
Max NSE : 0.8587
Optimum weights are all equal = 0.11



Discharge after routing gives us the real time discharge which is contributed by the catchment and it is highly variable from the discharge we obtained directly from bucket model, as that discharge is assumed to be vertical and instantly, but catchment is spatially varied so it affects the discharge contribution in the main stream.

After routing of the discharge obtained from conceptual modelling the model fits better than before.

CONCLUSION

Model 4 (conceptual model) performed the best for our selected catchment.

Code file: M_concept2.m

Assummed parameter,

- Canopy storage, S_c = 1 mm
- Initial canopy storage, Sct_1 = 1 mm
- Initial unsaturated soil storage, Sut_1 = 2 mm
- Initial groundwater storage, Sgt_1 = 2 mm

Outcomes:

- Constant for baseflow, k = 1
- Constant for recharging water, ks = 40
- Maximum storage of unsaturated soil, S_u = 610 mm
- Maximum storage of unsaturated groundwater, S_g = 10 mm
- Alpha = 1.7
- Beta = 3
- Max. NSE = 0.7264

After routing

Wi = 0.11 (i = 1 :9) equal weight were optimum

We get max NSE = 0.8587

In the conceptual modelling, initially the rainfall pass through the interception canopy, as the catchment as much tree cover on hills and farms , the canopy storage was assumed to be 1mm,

And then the part of rainfall and PET fall through the canopy on the surface of the ground, producing surface run off , the unsaturated soil storage was initially taken as 2mm and water holding capacity of the trees contributes to a large max storage capacity which came out to be 610mm , some part of rainfall thru is recharges in the groundwate, r and some part is evaporate and depending upon the ratio of S present by the max, capacity of unsaturated soil to the power alpha, we got alpha greater than 1 (alpha = 1.7) therofere increase in the storage increases the surface runoff and because of natural catchment recharging of ground water must be higher and we got ks =40 , beta = 3 , which implies as soon the storage of unsaturated soil increases the recharge water increases and we have k = 1 which further contributes to the base flow.

In all the total discharge contributed from the model is because of the surface flow and the base flow which is carried forward by the ground water recharging and finally reaching the stream.

The dominant hydrologic process contributing to the streamflow in neeleshwaram catchment is surface flow as the region I hilly and also the river(streams) passes through the middle of the catchment with connecting tributaries which makes it easier and faster for surface runoff to join the stream.

FUTURE SCOPE

- We have considered the rainfall data across the catchment as constant but every point on catchment has different elevation and variation in vegetation which will received different produce different discharge, therefore for that we need to divide catchment into small parts based on the topography, vegetation and geology etc. and then model them differently which will give us more complex analysis on catchment properties.
- In the conceptual modelling there can be more parameter that can be iterated as we have made assumptions for initial storages. Because those iteration were found to be time taking.
- We can use ArcGIS software to find actual elevation to do flood routing for accurate distribution of rainfall over the catchment and calculate the discharge generated plus what is been contributing to the river.