Environmental Sciences and Engineering

Hydrology Assignment 2

Group 21

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Contents

1 Introduction

The consequences of big floods on houses, infrastructure and lands can be huge. For example during summer 2021, the costs of the several floods across Switzerland reached hundreds of millions Swiss francs (Kirchhof, 2021b). To avoid damages, it is necessary to be able to have reliable models that could predict the river level rise from a given precipitation scenario.
The approach we will use in this assignment is the instantaneous unit hydrograph (IUH) approach. It is used because it is a "simple linear model that can be therefore used to derive the hydrograph resulting from any amount of excess rainfall" (Mays, 2010).
We will therefore assume three different hydrographs: one for the watershed surface runoff, a second one for the subsurface flow of the watershed and a third one for the river part until it reach the analysis point. With this we will be able to estimate effect of a precipitation over a timeline on our focus point.

2 Curve Number (CN) method

To be able to use the unit hydrograph method, we have to determine infiltration and runoff rates depending on the precipitation scenario. Therefore the curve number (CN) method will be used. A CN number is related to different land uses. Then, for a watershed, an area-average composite CN can be computed. In our case, the area-average CN is 86.7 and given by the equation below.

$$CN_{average} = \sum \frac{CN_i * A_i}{A_{total}} \Rightarrow 98 \times 0.5 + 71 * 40 + 61 * 0.1 = 86.7 \tag{1}$$

From this CN we can get, through the given equations 2 and 3, a potential maximum retention S of 38.96 and an initial abstraction value I_a of

$$S = 25.4 \times (\frac{1000}{CN} - 10) \Rightarrow S = 38.964 \tag{2}$$

$$I_a = 0.2 \times S \Rightarrow I_a = 7.793 \tag{3}$$

To be able to use the rainfall-runoff relation (see equation 4), we have to compute the cumulative rainfall values "J" of the three analysed events.

$$\frac{I}{S} = \frac{J_e}{1 - J_e} \quad \text{with} \quad J = I_a + J_e + I \tag{4}$$

And then, from equation 4, we can extract the cumulative effective precipitation 'Je' and the cumulative infiltration 'I' by the equations 5.

$$J_e = \frac{(J - I_a)^2}{J - I_a + S} \quad \& \quad I = J - I_a - J_e \tag{5}$$

By a simplified derivation of the cumulative values we can get the intensities of infiltration and effective precipitation. And this gives us the result show in the figure 1.

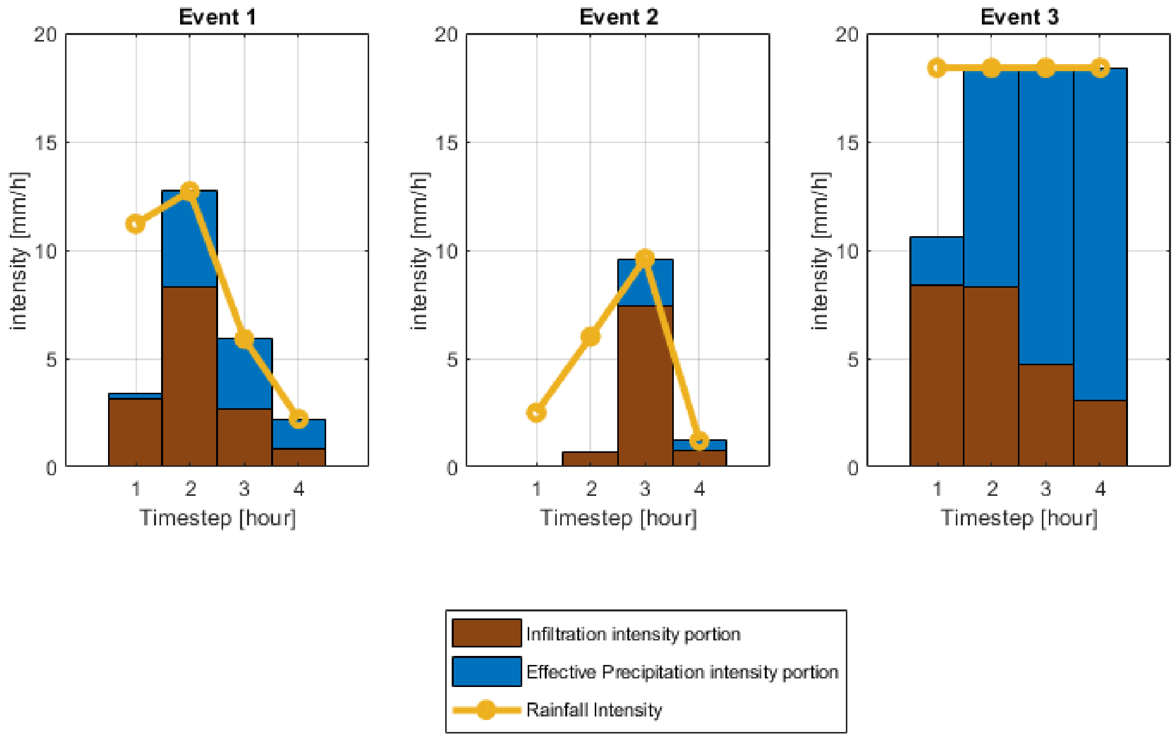


Figure 1: Portion of infiltration intensity and effective precipitation to the total precipitation of the 3 given events.

We can already observe how the distribution of the precipitation into infiltration and effective precipitation differs between the events. In our case, the total effective precipitation occurring during the 3 events have big differences as we can see in figure 2 but this is mainly due to the precipitation intensity.

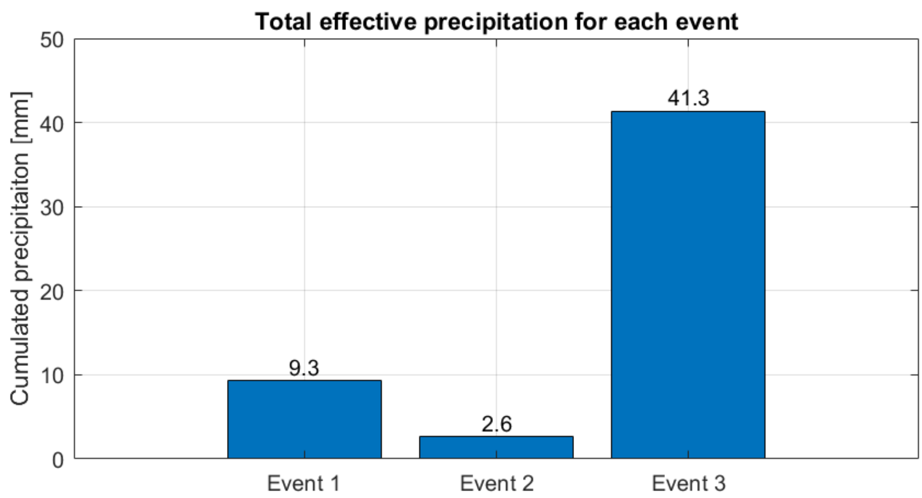


Figure 2: Total effective precipitation accumulated over the 4 hour interval of each event.

3 Discharge at a watershed and at a channel outlet

First the watershed unit hydrograph of our situation is based to have a gamma distribution and the channel unit hydrograph is based on an inverse Gaussian distribution.
With a discretization interval dt, here of 0.1 hour, the result of watershed IUH and channel IUH can be visualised in the graph below.

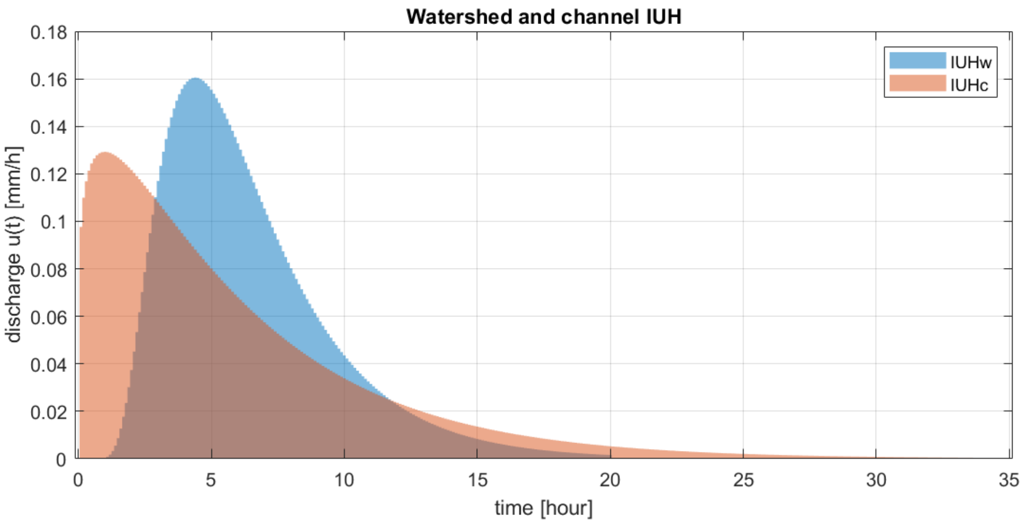


Figure 3: Discretized watershed and channel IUH based on the given distribution pattern.

Since a unit hydrograph is the direct runoff hydrograph resulting from one unit (here 1 mm) of constant intensity uniform rainfall, the area under the curve should be equal to 1. Therefore it is important to take a long enough time interval for the computation to be as close as necessary to 1. Here we decided to fix the limit to 95%. S

	IUHw	IUHc
Time interval computation [h]	35	20
Area	0.99504	0.99547

Table 1: Area under the curve with the time interval over wich the IUH was computed to reach this area.

From the previously computed effective precipitation and the two unit hydrographs, we are able to compute convolution to find the watershed outlet discharges and the channel outlet discharges. The first discrete convolution, between the effective precipitation and the watershed IUH, returns the catchment hydrograph (named here Qw) at the outlet point. This hydrograph is convolved with the channel IUH, and returns the channel outlet hydrograph. This two steps and the resulting hydrographs can be observed in the figure 4.

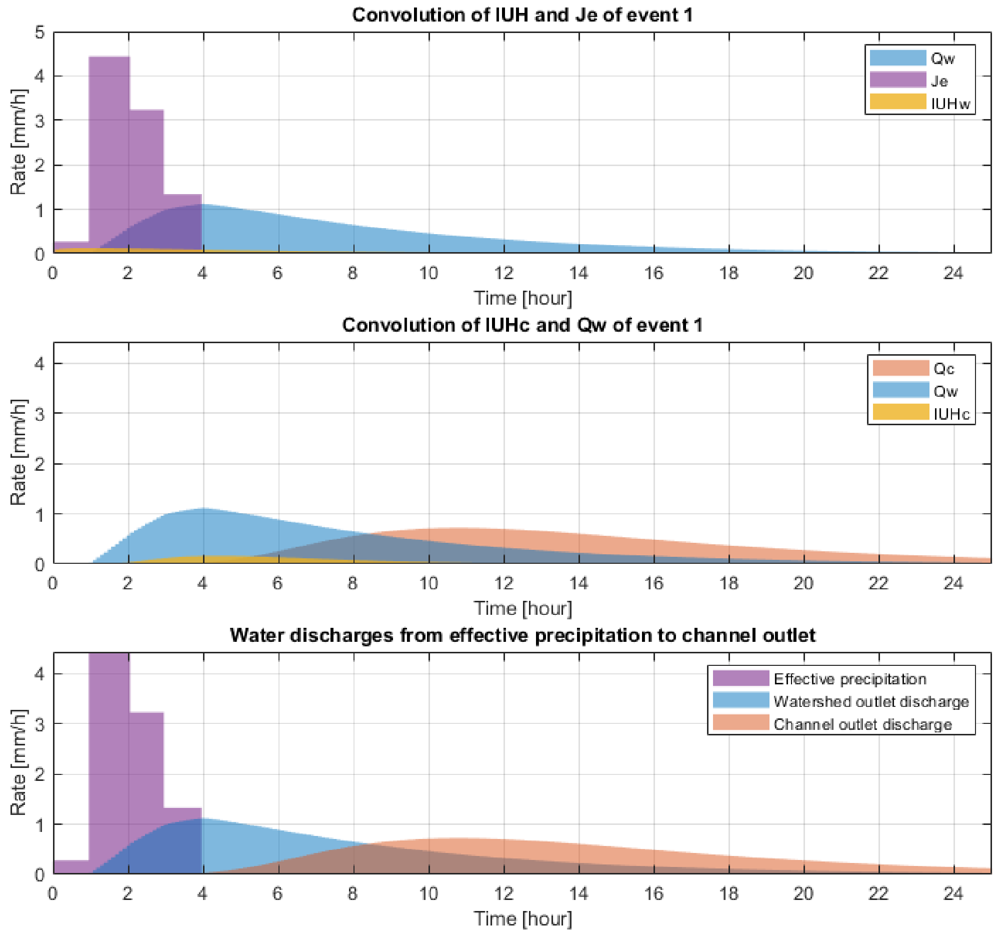
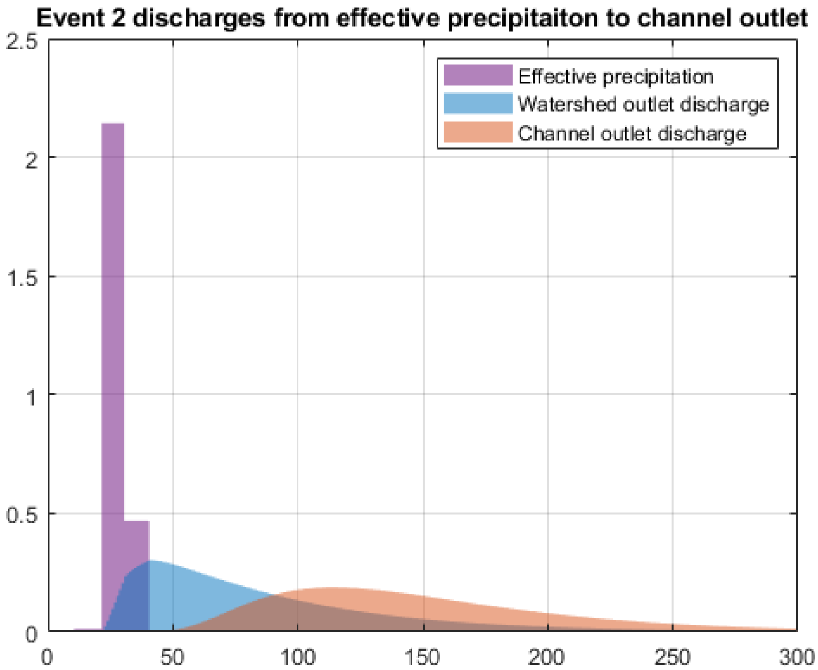
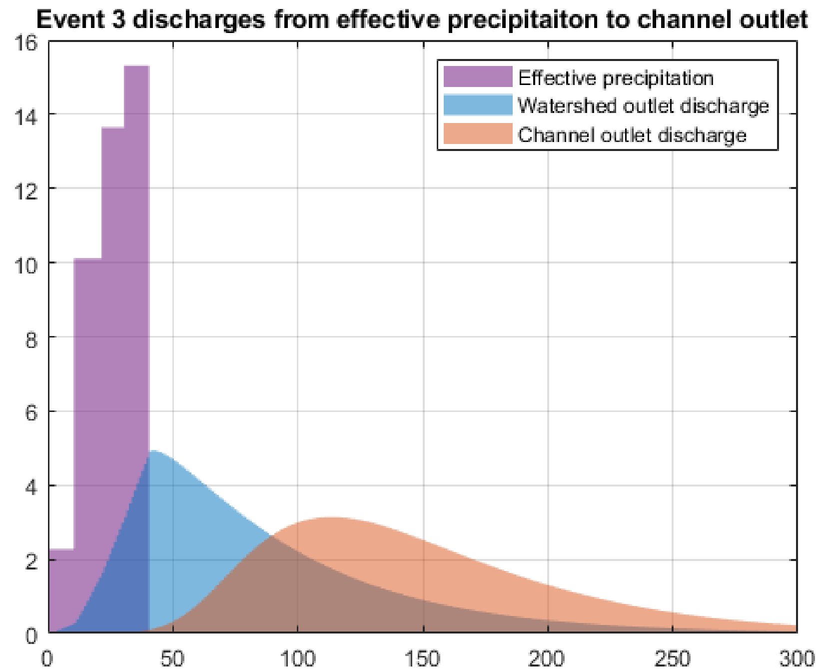


Figure 4: First subfigure on top shows the result of the first convolution between effective precipitation Je and the watershed unit hydrograph IUHw. The second subfigure, in the middle, shows the resulting hydrograph Qw of the convolution between the resulting hydrograph Qw from previous step with the channel unit hydrograph IUHc. To finally, in the bottom subfigure, have a summary of the resulting discharges.

From the same steps as for event shown in the figure 4, the event 2 and event 3 were computed with the same unit hydrographs but with the respective precipitation. The result are shown below in figure 5a and 5b.



(a) Results for event 2



(b) Results for event 3

Figure 5: Watershed and channel hydrographs resulting from the effective precipitation of the event.

Finally, from the resulting hydrograph we can find the maximal discharge that the watershed and channel outlet are subjected to. The results for the three events analysed are given in the table 2.

	event 1	event 2	event 3
Watershed outlet maximum discharge [mm/h]	1.12	0.30	4.932
Time of appearance [hour]	4.1	4.1	4.2
Channel outlet maximum discharge [mm/h]	0.72	0.19	3.14
Time of appearance [hour]	10.9	11.4	11.3

Table 2: Maximal discharges observed and their time of appearance.

4 Discharge from surface and subsurface contributions at a watershed outlet

Now we will focus on a longer time period of precipitation data. With the watershed IUH of the previous part we will compute the resulting discharge hydrograph for the watershed outlet. But this time, we will also suppose a subsurface flow by introducing his respective unit hydrograph.
But first, in this part, the effective precipitation is assumed to be $0.3 \times J(t)$ and the infiltration rate to be $0.1 \times J(t)$.
Then,the surface discharge hydrograph is computed through a discrete convolution between the effective precipitation and the watershed IUH.
And then, the same way, the subsurface discharge hydrograph is obtained by the convolution of the subsurface IUH with the infiltration intensities. Therefore we have to compute first the subsurface IUH. As for the surface watershed, it is based on a gamma distribution. The result can be seen in figure 6.

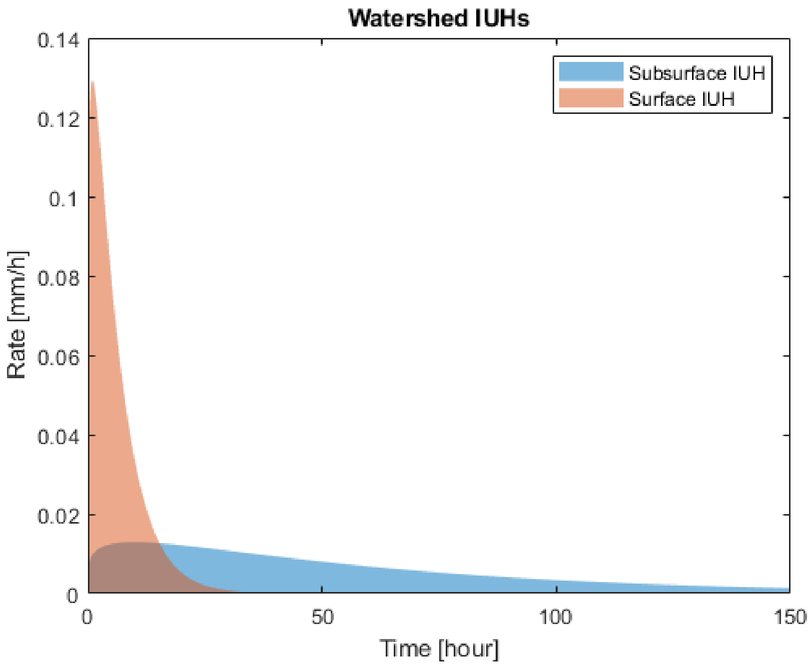


Figure 6: Watersheds unit hydrographs.

An important difference to note is the time interval in which the hydrograph has an effect. This is mainly due to a very slow flow through the subsurface. Therefore a rain on a certain day has an effect on the total discharge even 6 days after it.
This difference can be very well visualized on a monthly scale with the portion of the total discharge which comes from the surface and the portion that comes from the subsurface flow. An example with the month of November can be observed in the figure 7.

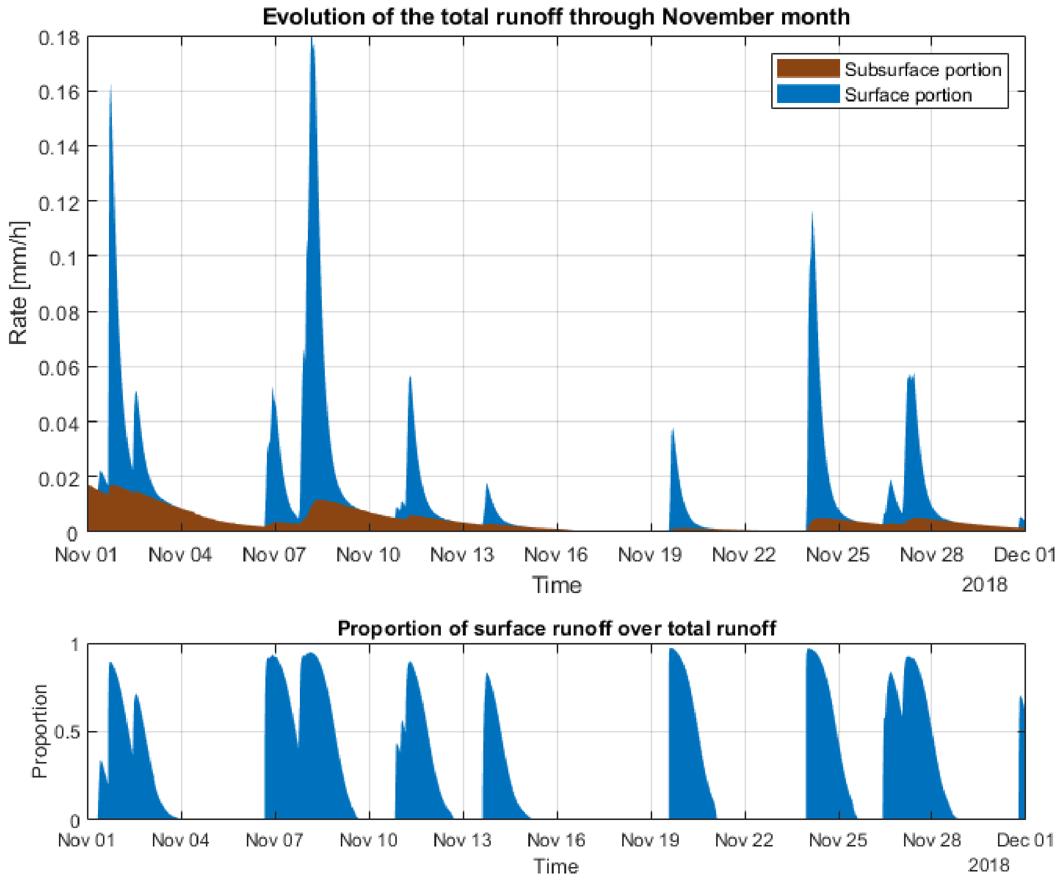


Figure 7: The portions of surface and subsurface discharge in the total watershed outlet discharge in the top figure. And the ratio of the subsurface discharge to the total discharge in the bottom figure.

Finally, to better understand the part of extremes total discharges, we computed, as asked, the fraction of the year where the total discharge was higher than 0.2 mm/h and the fraction where the discharge was lower than 0.002 mm/h. The result can be observed in figure 8.

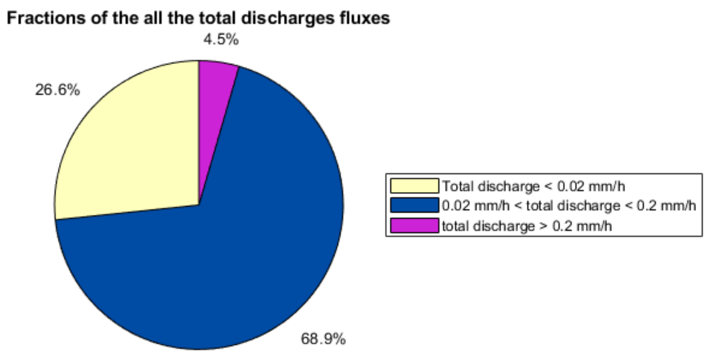


Figure 8: Fractions of extreme discharge rate of the year.

5 Questions

1. In Part 1, why we don't observe any effective rainfall at the beginning of event number 2?

Effective rainfall is the the rest of the substraction of initial abstraction and infiltration. At the beginning of event 2, no effective rainfall is observed because the infiltration rate that the soil can support is higher than the precipitation. We have to note also how the initial abstraction is substracted before everything else in this method (See figure 9. This has also an impact that, at the first time step, the precipitation has to be higher than the infitration rate plus the initiation abstraction to have some runoff.

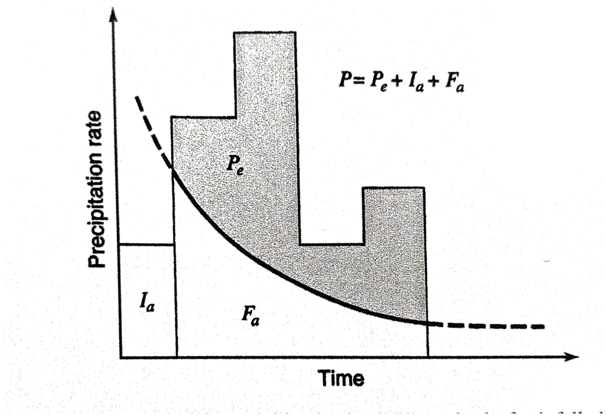


Figure 9: Rainfall runoff relationship model used by the curve number method. *Note:* Reprinted from Mays (2010). *Water resources engineering.* John Wiley & Sons.

2. In Part 2, what would happen to the discharge if the channel were twice as long? Why?

A drop of water with a similar speed would need twice the time to arrive to the end of the channel if the length is doubled. So the first effect would be a discharge peak after a longer time duration. But if the travel time is also longer, the probability of a particle to be slowed down by several factors, as friction to the river bed or diffusion, is also higher. Therefore the peak would be flatter and wider.

3. In Part 2, how could you separate the discharge that is produced by the second hour of precipitation from the discharge produced by the rest of the precipitation?

The discrete convolution algorithm is basicaly a complex sum over all the elements. It can be seen as a sum of the unit hydrographs shifted and multiplied by the effective rainfall intensities. Therefore the discharge produced by the second hour of precipitation is the unit hydrograph shifted by 1 hour and multiplied by the effective rainfall intensity of the second hour. We just have to be careful to still take into account the first hour rainfall to compute the second effective precipitation intensity. It is also possible to revert the process. Which would consist of taking out the sum of all other shifted unit hydrographs multiplied by each effective rainfall intensities.

4. In part 2 and 3 you used the IUH approach to compute the runoff response to given effective precipitation event. In the IUH approach, what happens to the runoff response occurring after a prolonged dry period? How is it different from the response during a wet period?

The response of a rainfall with the IUH approach is just the convolution of the IUH with the effective rainfall. Therefore the response is mainly in direct relation with the effective precipitation intensity. As we saw in question 1 (and figure 9), the effective precipitation is the rest of the rainfall minus the initial abstraction and infiltration rate. It depends therefore on the model used to compute the infiltration rate and initial abstraction. For example the curve number method is based on the land cover and therefore makes no initial difference on the state of the soil. But the Horton method takes a initial infiltration rate and a saturation infiltration rate. This two parameters would therefore affect the infiltration rate. In this case, if the soil is dry, the infiltration rate would be at a maximal rate at the beginning and probably higher than the precipitation intensity. It would result in no runoff until the infiltration rate is overtaken. But in reality, a very dry soil has a very bad infiltration rate at the beginning due to an initial ponding time (Kirchhof, 2021a). In the case of a very wet soil, the initial infiltration rate would already almost be the rate at saturation and therefore very probably induce a high runoff.

List of Figures

List of Tables

References

References

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