RWater Module 4
Effect of Watershed Characteristics on Runoff Generation and Streamflow Response

Adnan Rajib and Venkatesh Merwade
Lyles School of Civil Engineering, Purdue University

Learning Goals

The physical properties of an area influence the flow of water in the streams. These properties may be associated with natural and human factors. This module demonstrates few hypothetical examples through which students will be able to:

i. recognize some of the major physical properties of a watershed (watershed characteristics)
ii. explain how these properties effect runoff generation and streamflow response

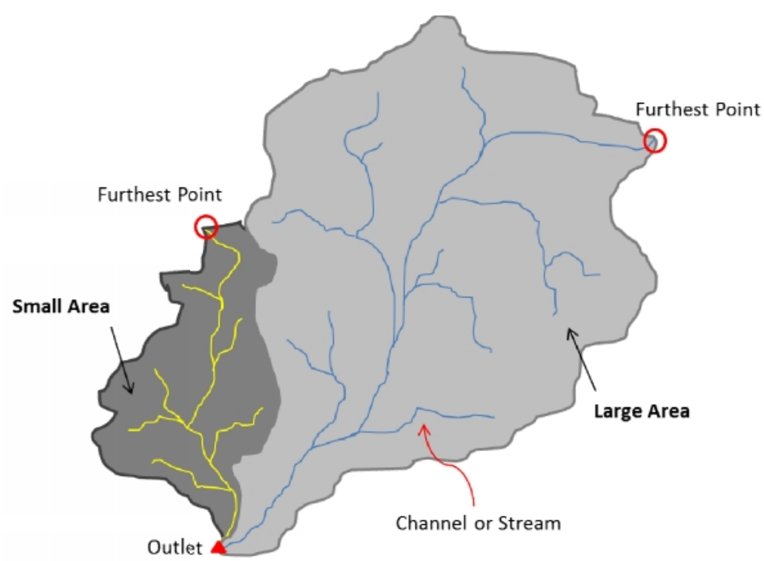
Physical Properties of Watersheds and their Effect on Streamflow

Some of the major physical properties of a watershed (also known as the watershed characteristics) that can effect streamflow are as follows:

1. drainage area or watershed size
2. stream density
3. surface imperviousness
4. land slope
5. soil moisture condition etc.

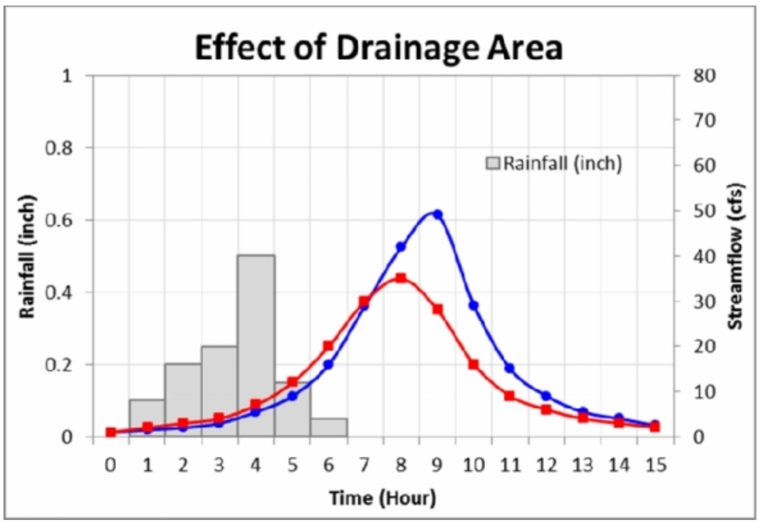
Drainage Area

By definition, there is always an associated area of land within a watershed boundary, which drains all the rainwater through channels/streams towards the lowest point. This drainage area is often referred as the watershed size. Now, consider two adjacent watersheds as shown in the following figure, one being larger than the other.



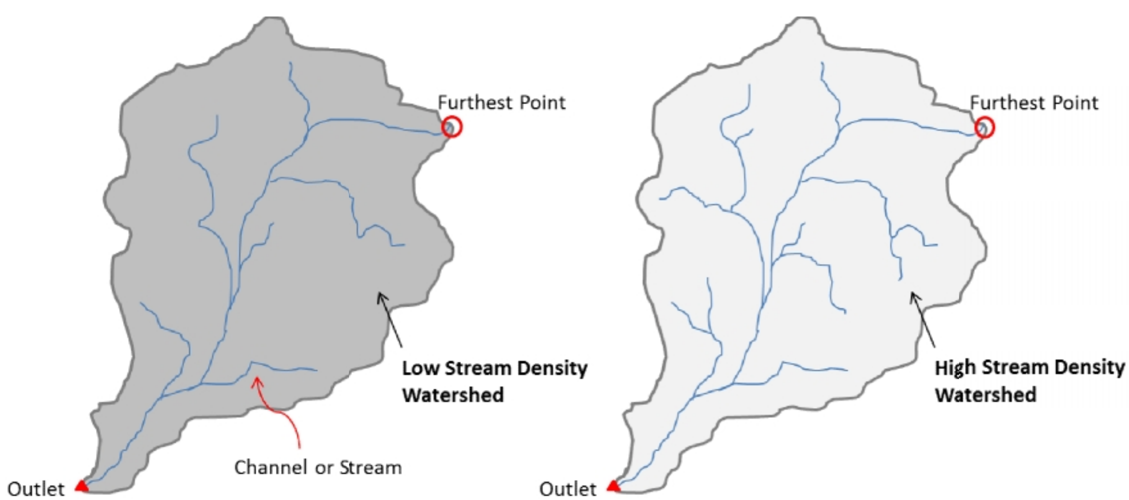
- If same amount of rain falls in a uniform manner over both the watersheds, the larger one produces more runoff volume. All other properties being same, a drainage area that is twice as large can generate twice as much runoff volume than a smaller one.
- In addition, runoff traveling from the most upstream point of the larger watershed will travel a longer path, and therefore take longer to reach the outlet than runoff traveling from the farthest point in the smaller watershed.

These two factors cause the larger watershed to produce higher peak discharge, also time between the peak rainfall and peak discharge (called lag time) goes longer. The following figure shows the streamflow hydrograph for both the aforementioned watersheds in response to a rainfall event. Identify which one of the hydrographs represents the larger watershed and the smaller watershed respectively.



Drainage Density

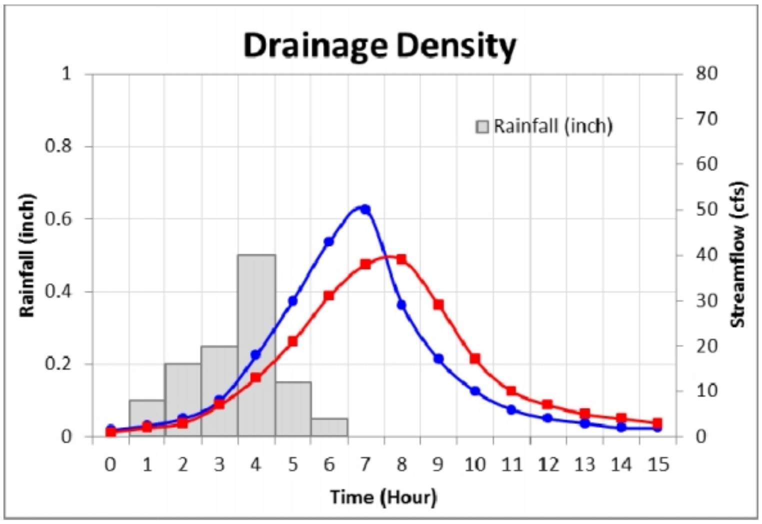
Drainage Density (also known as Stream Density) is the length of all channel tributaries within the watershed divided by total watershed area.



A watershed with large number of tributaries has higher drainage density than a basin with very few tributary streams. The figure above shows example of two watersheds having different drainage density, assuming all other properties (area, surface imperviousness, slope etc.) to be the same.

Higher drainage density allows the watershed to drain more quickly following a rainfall event. More quickly drainage means that rain water falling onto the ground can move to the outlet faster, causing peak discharge to be higher and to occur sooner.

See the graph below. For the same rainfall event, identify which one of the hydrographs represents the high drainage density watershed and the low drainage density watershed respectively.



Surface Imperviousness

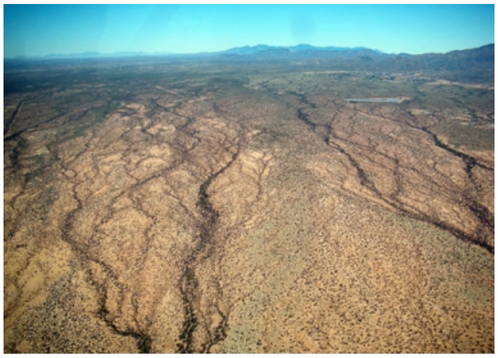
Transformation of land for residential, commercial and transportation purposes effects streamflow.

- In rural area or areas with higher proportion of agricultural fields, forests etc., the rain water falling over the ground can be absorbed by the soil in the process we call ‘infiltration’.
- Whereas, in urban areas, impervious surfaces (highways, streets, parking lots, sidewalks, and buildings) cover large areas of the ground that was “used to” absorb rain water.
- These covered surfaces no more allow rain water to infiltrate into the ground, rather majority portion of the rain quickly routes to the nearby stream in the form of surface runoff.
- As a result, peak discharge goes high, meaning more water in the stream; also, lag time decreases drastically. That is, a hydrograph tends to peak quickly and drop quickly as well which we generally call “Flash Flooding”.

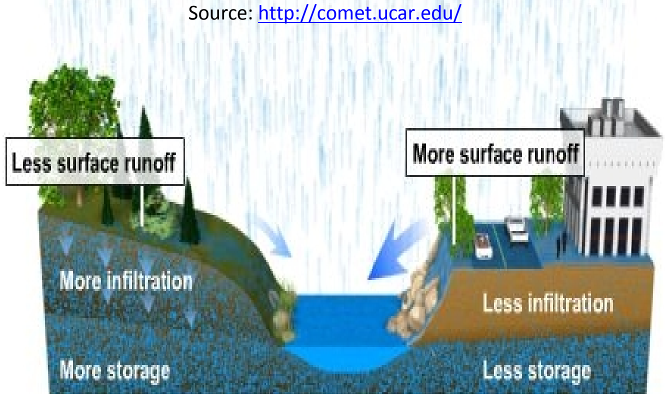
The following figure demonstrates a comparative scenario of runoff generation process between a rural and an urban condition. Read the attached graph as well. Which one of the hydrographs do you think to be more appropriate for the urban area?

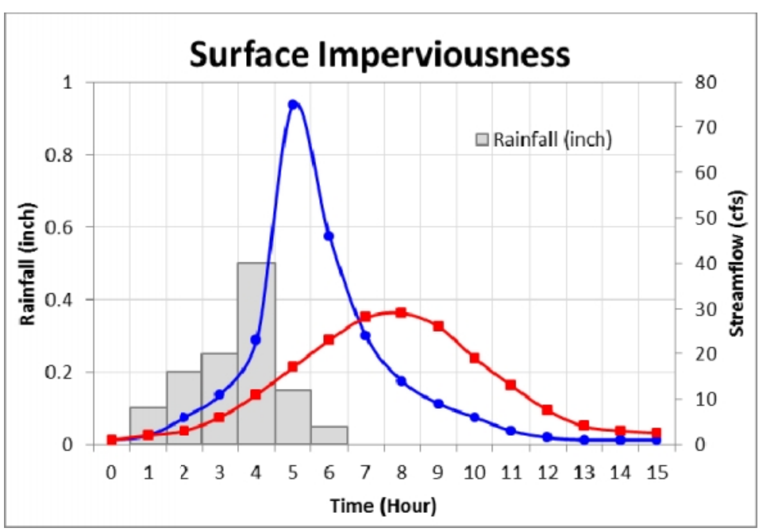
We are going to study a real-time example of urbanization effect on streamflow in Module 5.

Rural Area | **Urban Area**



Source: http://comet.ucar.edu/





Land Slope

Consider two rural watersheds having equal area and drainage density. One of them is located in a hilly area and the other one is located in a flat land.

- In the hilly region, the ground is steeper and so rain water will move faster, reducing the time to reach the watershed outlet (that is, shorter lag time).
- Again, with the land sloping, rain may not fall onto the ground perpendicularly. This can affect the process of infiltration, which can thereby effect the runoff and peak discharge.

Soil Moisture Condition

Soil moisture is one of the most important factors that can effect the process of runoff generation and subsequent streamflow response. The same watershed can produce different volume of runoff depending on whether the soil underneath the ground surface is saturated or not. Consider a watershed in a rural area is having continuous rainfall. Eventually, the soil adjacent to the ground surface becomes saturated with the water which have been infiltrating. Now, if the rainfall continues further, this watershed will produce more runoff compared to what it “used to” produce in a dry condition.

You can learn about other factors and how they affect the process of runoff generation and streamflow response in advanced-level hydrology literature.

Quiz

1. If same amount of rain falls in uniformly over two watersheds, the larger watershed will produce _______ runoff volume than the smaller one.
   a. more
   b. less
   c. equal
   d. not comparable

2. For equal amount of rainfall, an urban watershed will cause peak discharge to be _______ and the lag time to be ______, compared to a rural watershed of same size, slope and drainage density.
   a. higher, shorter
   b. lower, longer
   c. lower, similar
   d. lower, shorter

Exercise

Follow the RWater script provided below. You are going to plot the streamflow hydrographs for two adjacent watersheds in Iowa for only the period of March, 2013. The watersheds are USGS 05465500 (Iowa River at Wapello, IA) and USGS 05474000 (Skunk River at Augusta, IA)

All the physical properties of these watersheds are almost similar <u>except drainage area</u>.

```
### STEP 1
### Removing previously used scripts from RWater
### Removing all previously generated datasets and plots
cat("\014")
rm(list = ls())
dev.off()

### STEP 2
### Loading two specific libraries called 'waterData' into RWater
library(waterData)

### STEP 3
### Downloading streamflow data directly from USGS

iowariver<-importDVs("05465500", code="00060", stat="00003",
                    sdate="2013-03-01", edate="2013-03-31")
skunkriver<-importDVs("05474000", code="00060", stat="00003",
                     sdate="2013-03-01", edate="2013-03-31")
```

```
### STEP 4
### Plotting the hydrographs
par(mar=c(5, 4, 4, 8) + 0.1)
plot(iowariver$val,type="l",pch=21,col="red",lty=1,lwd=2,ylim=c(0,50000),
     xlab="Days (March 2013)", ylab="Streamflow (cfs)",
axes=TRUE,las=1,xaxt="n")
par(new=T)
plot(skunkriver$val,type="l",pch=21,col="blue",lty=4,lwd=2,yaxt="n",ylim=c(0,
50000),
     xlab="",ylab="",axes=TRUE)
legend(15,50000,"USGS 05465500", col = "red", lwd=2, lty=1, bty="n")
legend(15,45000,"USGS 05474000", col = "blue", lwd=2, lty=4, bty="n")
```

Look into the plot that you have generated and identify which of the two watersheds has bigger drainage area.