RWater Module 6

Assessment of Urbanization Effect on Streamflow using Flow Duration Curve

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Learning Goals

During the process of landuse change, when a forest, agricultural or open grassland area is converted into highways, streets, parking lots, sidewalks, and buildings, the ground can no more absorb rain water in the same quantity it was "used to" do earlier. Rather, majority portion of the rain quickly routes to the nearby stream in the form of surface runoff. These result into the three major attributes of urbanization effects on streamflow: (i) higher peak discharge and overall rise in total volume of water in the stream, (ii) more frequent high flow condition or flash flooding under similar rainfall condition compared to a non-urban context, (iii) increased surface runoff contribution into the stream along with decreased groundwater flow. However, these attributes are often difficult to understand simply by looking into the long term streamflow hydrograph, especially for places where rate of urbanization is gradual. Analyzing a Flow Duration Curve (FDC) can be very helpful in this regard. After completing this module, students will be able to:

i. draw FDC for any location using the USGS streamflow data in RWater
ii. understand the change in streamflow pattern being caused by this ongoing process of urbanization, simply by analyzing the FDC of that location.

Flow Duration Curve (FDC)

A Flow Duration Curve (FDC) illustrates the percentage of time, or probability, that flow in a stream will equal or exceed a particular value. The FDC analysis is a method involving the frequency of historical flow data over a specified period. Figure 1 shows an example of a flow duration curve where the daily mean flows during 1/1/1986 to 1/1/2003 equals or exceeds 14 cfs 60% of the time. Typically, low flows (flow during prolonged dry spells or when there is hardly any rainfall) are exceeded majority of the time, while high flows, such as those resulting in floods, are supposed to be barely exceeded.

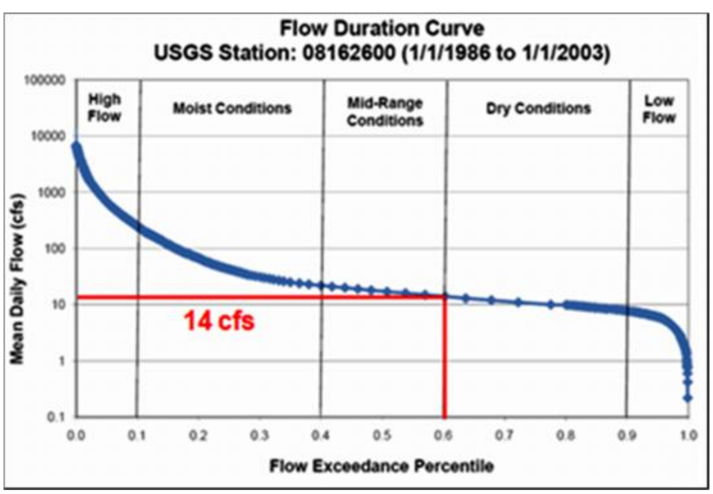

Figure 1. Source: http://www.crwr.utexas.edu

A common way to look at the FDC is by dividing it into five zones (as illustrated in Figure 1), representing high flows (0-10%), moist conditions (10-40%), mid-range flows (40-60%), dry conditions (60-90%), and low flows (90-100%). These zones, especially the high (10%) and low flow (90%) thresholds, work as the general indicator of altered hydrologic conditions of the stream because of urbanization.

Assessing Changes in Streamflow from FDC

The major attributes of urbanization effects, such as (i) higher peak discharge, (ii) more frequent 'High Flow' conditions, and (iii) increased surface runoff with decreased groundwater contribution, can most often be difficult to detect simply by comparing hydrographs for two non-overlapping time periods. On the contrary, FDC analysis is formulated in a way that comparing two FDCs, being constructed over two different time periods, can provide a useful means for understanding the change in the magnitude of streamflow values under altered land use conditions.

Shape of two FDCs for the same watershed but constructed for two separate periods can be different due to the variations in the meteorological conditions, such as rainfall, and changes in watershed's geophysical characteristics, such as the landuse type. However, variations in meteorological conditions take place over a fairly long time; hence its effect on an FDC's shape is insignificant. In this way, change in the shape of an FDC can be attributed mostly to the landuse changes. Compared to a similar watershed that has not undergone development, the FDC of an urbanized watershed tends to have higher "High Flows", representing more frequent extreme conditions, being coupled with lower "Low Flows", representing less groundwater contribution. We are going to validate these conceptualizations based on some real-time scenarios as described below.

FDC Analysis: Example for Chicago Area, Illinois

In this part of the module, we will consider two adjacent locations near the Chicago city area; one of which is a fast-growing suburb, the other one is mostly agricultural and has not been into much development. Here, our task is to compare FDCs between a past and a more recent time frame for both of these watersheds and thereby detect the attributes of possible effects of urbanization on streamflow, if there is any. The gage stations we will be taking here as examples are the USGS 05551700 and USGS 05568800, which are the outlets for the watersheds called respectively the Blackberry Creek near Yorkville and the Indian Creek near Wyoming. Click on http://goo.gl/cLNpiA to see these example watersheds as well as the gage stations in a customized Google map. You can change the Google basemap and zoom-in to get some idea about the current landuse conditions therein.

Followed by downloading of streamflow data, FDCs can be drawn directly in RWater without any sort of data pre-processing. Each step of the RWater script is associated with relevant explanations (lines with # sign).

```
### 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' and 'hydroTSM' into RWater
library(waterData)
library(hydroTSM)

##########################
#Example for Blackberry Creek#
##########################
### STEP 3
### Downloading streamflow data directly from USGS for station 05551700
    # importDVs is the function that calls the data from USGS website
    # "00060" and "00003" indicates 'Streamflow' and 'Mean Daily Data' respectively
    # Here, we will download mean daily streamflow data for two different periods
    # Provide a range of date within sdate and edate in YYYY-MM-DD format
    # Save the downloaded data with a name 'blackberry1' and 'blackberry2'

blackberry1<-importDVs("05551700", code="00060", stat="00003",
                       sdate="1971-01-01", edate="1990-12-31")
blackberry2<-importDVs("05551700", code="00060", stat="00003",
                       sdate="1991-01-01", edate="2010-12-31")

### Plotting the Flow Duration Curve
    # Y axis will be in log scale
    # We are defining 90% exceedance as the Low Flow threshold (lQ.thr=0.9)
    # 10% exceedance is taken as the High Flow threshold (hQ.thr=0.1)
    # 90% and 10% exceedance threshold flow values are shown on the plot by writing "thr.shw=TRUE"

### STEP 4
    # Write "par(mfrow=c(1,2))" so that the Plot window gets divided in a '1row x 2columns' space
    # Now, two FDCs can be shown in two adjacent plots
par(mfrow=c(1,2))

### STEP 5
    # FDC for 1971-1990 [from the data table 'blackberry1']
fdc(blackberry1$val, lQ.thr=0.9, hQ.thr=0.1, plot=TRUE, log="y",
    main= "Flow Duration Curve", xlab="% Time flow equalled or exceeded",
    ylab="Streamflow [cfs]", ylim=c(1,10000), yat=c(0.1, 1, 10, 100, 1000, 10000),
    col="red", pch=21, lwd=500,
    lty=3, cex=0.4, cex.axis=1.2, cex.lab=1.2, leg.txt="1971-1990",
    leg.cex=1, leg.pos="topright", verbose=TRUE, thr.shw=TRUE, new=T)
grid(nx = NULL, ny = NULL, col = "lightgray", lty =21, lwd=0.5, equilogs = TRUE)

### STEP 6
    # FDC for 1991-2010 [from the data table 'blackberry2']
fdc(blackberry2$val, lQ.thr=0.9, hQ.thr=0.1, plot=TRUE, log="y",
    main= "Flow Duration Curve", xlab="% Time flow equalled or exceeded",
    ylab="Streamflow [cfs]", ylim=c(1,10000), yat=c(1, 10, 100, 1000, 10000),
    col="dark violet", pch=21, lwd=500,
    lty=1, cex=0.4, cex.axis=1.2, cex.lab=1.2, leg.txt="1991-2010",
    leg.cex=1, leg.pos="topright", verbose=TRUE, thr.shw=TRUE, new=T)
grid(nx = NULL, ny = NULL, col = "lightgray", lty =21, lwd=0.5, equilogs = TRUE)
```

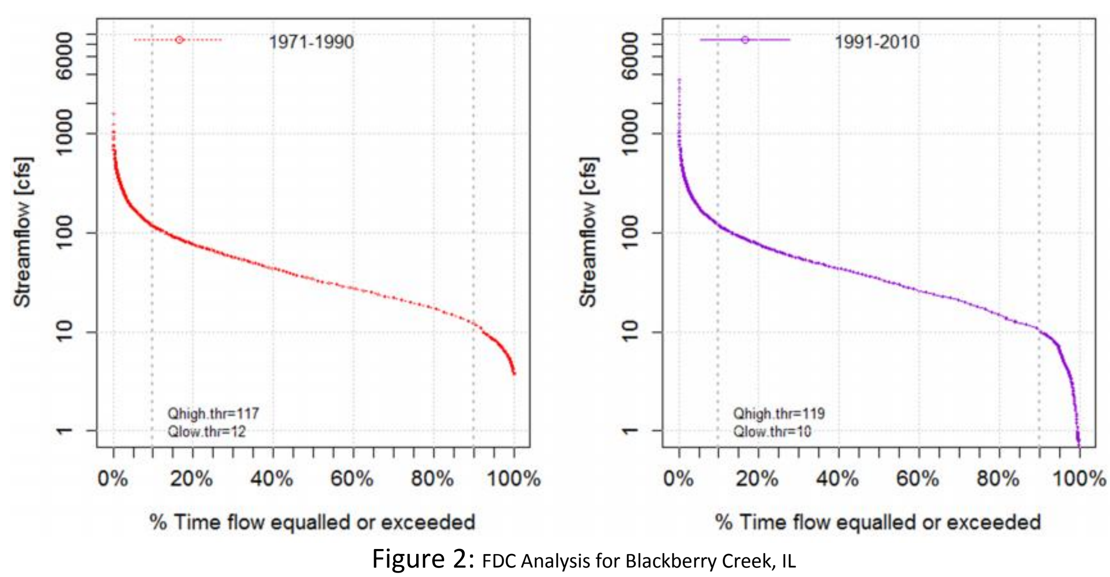

Figure 2: FDC Analysis for Blackberry Creek, IL

The two plots which you have just created show the FDC of the Blackberry Creek in a pre-development and post-development stage. Now, read the plots carefully and comment on the following statements just by stating TRUE or FALSE:

(i) The daily mean flows during 1971-1990 equals or exceeds 50 cfs 10% of the time **TRUE/ FALSE**

(ii) The daily mean flows during 1991-2010 equals or exceeds 10 cfs 90% of the time **TRUE/ FALSE**

(iii) As seen from Figure 2, highest peak discharge values in the blackberry creek during 1971-1990 barely crossed over 1000 cfs, whereas, for the period 1991-2010, flow values in a range of 1000-2000 cfs has become relatively frequent compared to the past. **TRUE/ FALSE**

(iv) Also, the stream has been recently exhibiting higher peaks around 4000 cfs which never occurred during 1971-1990. **TRUE/ FALSE**

(v) In low flow condition, the minimum flow values were in scale of 5 cfs during 1971-1990, which is seen to have been lowered close to nil in recent times. **TRUE/ FALSE**

(vi) These changes between the two FDCs are due to less surface runoff and more groundwater contribution in the streamflow. **TRUE/ FALSE**

(vii) The FDC analysis does not show any trace of ongoing urbanization in this location. **TRUE/ FALSE**

Let us now perform another FDC comparison for a very nearby watershed called Indian Creek. The steps which we will be following are similar as they were for the Blackberry Creek.

```
##########################
#Example for Indian Creek#
##########################
### STEP 7
### Downloading streamflow data directly from USGS for station 05568800
    # Here as well, we will download mean daily streamflow data for two different periods
    # Provide a range of date within sdate and edate in YYYY-MM-DD format
    # Save the downloaded data with a name 'indiancreek1' and 'indiancreek2'
indiancreek1<-importDVs("05568800", code="00060", stat="00003",
                        sdate="1971-01-01", edate="1985-12-31")
indiancreek2<-importDVs("05568800", code="00060", stat="00003",
                        sdate="1996-01-01", edate="2010-12-31")

### Plotting the Flow Duration Curve
### STEP 8
    # Write "par(mfrow=c(1,2))" so that the Plot window gets divided in a '1row x 2columns' space
    # Now, two FDCs can be shown in two adjacent plots
par(mfrow=c(1,2))

### STEP 9
    # FDC for 1971-1985 [from the data table 'indiancreek1']
fdc(indiancreek1$val, lQ.thr=0.9, hQ.thr=0.1, plot=TRUE, log="y",
    main= "Flow Duration Curve", xlab="% Time flow equalled or exceeded",
    ylab="Streamflow [cfs]", ylim=c(0,10000), yat=c(1, 10, 100, 1000, 10000),
    col="red", pch=21, lwd=500,
    lty=3, cex=0.4, cex.axis=1.2, cex.lab=1.2, leg.txt="1971-1985",
    leg.cex=1, leg.pos="topright", verbose=TRUE, thr.shw=TRUE, new=T)
grid(nx = NULL, ny = NULL, col = "lightgray", lty =21, lwd=0.5, equilogs = TRUE)

### STEP 10
    # FDC for 1996-2010 [from the data table 'indiancreek2']
fdc(indiancreek2$val, lQ.thr=0.9, hQ.thr=0.1, plot=TRUE, log="y",
    main= "Flow Duration Curve", xlab="% Time flow equalled or exceeded",
    ylab="Streamflow [cfs]", ylim=c(0,10000), yat=c(1, 10, 100, 1000, 10000),
    col="dark violet", pch=21, lwd=500,
    lty=1, cex=0.4, cex.axis=1.2, cex.lab=1.2, leg.txt="1996-2010",
    leg.cex=1, leg.pos="topright", verbose=TRUE, thr.shw=TRUE, new=T)
grid(nx = NULL, ny = NULL, col = "lightgray", lty =21, lwd=0.5, equilogs = TRUE)
```

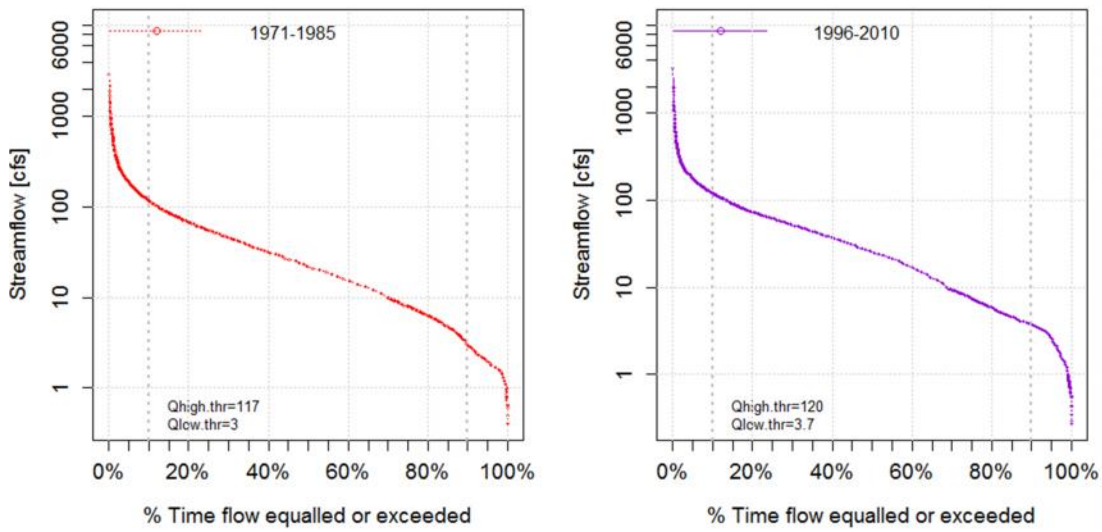

Figure 3: FDC Analysis for Indian Creek, IL

From these FDCs, do you think landuse is significantly changing for Indian Creek? Why or Why not?