RWater Module 6
Flow Duration Curve Analysis to Study the Effect of Land Use Change on Streamflow
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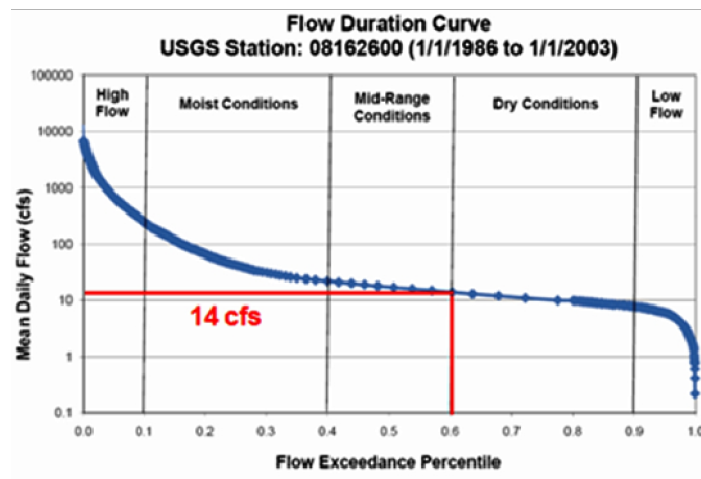Lyles School of Civil Engineering, Purdue University

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

Effects of urbanization on streamflow 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 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 can be less significant. 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.

- Similarly, in a watershed where agriculture has been intensified over time with associated depletion of forest and grassland, both high and low flow can increase, leading towards overall increase in total volume of water (yield) in the stream. We are going to validate some of these perceptions based on actual gauge station data as described below.

FDC Analysis: Example for Chicago city, 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.

- Load the script for this module from your working directory.
- Select certain segments of the script and run in steps as shown below.
- **Make changes only in the portion with "XXXX" or as directed**
- Relevant explanations associated with each step are also provided here. These explanatory notes are only for building user's perception over the code.

```
### 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 packages into RWater
library(waterData)
library(hydroTSM)

### STEP 3
### Downloading streamflow data directly from USGS for station 05551700
### Here, we will download daily streamflow data for two different periods
### We will save the two datasets as 'blackberry1' and 'blackberry2'

blackberry1<-importDVs("XXXX",
        code="00060", stat="00003",
        sdate="YYYY-MM-DD",
        edate="YYYY-MM-DD")
blackberry2<-importDVs("XXXX",
        code="00060", stat="00003",
        sdate="YYYY-MM-DD",
        edate="YYYY-MM-DD")
```

A package is a collection of R functions to serve specific analysis purpose. Package names are case sensitive (**waterData**, **hydroTSM**: **D**, **TSM** are capital letters)

In this example, replace **XXXX** with **05551700**.

importDVs is the function name which pulls the data from USGS website (case sensitive: **D** and **V** are capital letters)

"00060" and "00003" indicates 'Streamflow' and 'Mean Daily Data' respectively

Provide a range of date within **sdate** and **edate** in YYYY-MM-DD format. In this example, use 1971-01-01 to 1990-12-31 for 'blacberry1' and 1991-01-01 to 2010-12-31 for 'blackberry2' respectively

Click on 'blackberry1' or 'blackberry2' (upper right). You will see that streamflow values are listed in the right column (column header name is **val**)

```
### STEP 4
### Plotting the Flow Duration Curve
par(mfrow=c(1,2))

### FDC for 1971-1990
[from the dataframe 'blackberry1']
fdc(XXXX,
    lQ.thr=0.9, hQ.thr=0.1,
    plot=TRUE, log="y",
    main= "Blackberry Creek FDC (1971-1990)",
    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="???",
    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)
```

Option of creating a multi-paneled plotting window (see Appendix for details). Here, we will have two figures in the Plots window

Replace **XXXX** with **blackberry1$val**. This will command RWater to plot the streamflow values from the **val** column of the 'blackberry1' dataframe

Use 10000 as the maximum limit of the Y axis (**ylim**)

Specify Y axis tick marks as shown here (**yat**)

Write 1971-1990 within **leg.txt**

See Appendix for all other syntax (example: xlab, lty, lwd etc.)

```
### FDC for 1991-2010 [from the dataframe 'blackberry2']
fdc(XXXX,
    lQ.thr=0.9, hQ.thr=0.1,
    plot=TRUE, log="y",
    main= "Blackberry Creek FDC (1991-2010)",
    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="???",
    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)
```

> Similarly, replace **XXXX** with **blackberry2$val**. This will command RWater to plot the streamflow values from the **val** column of the 'blackberry2' dataframe
>
> Write 1991-2010 within **leg.txt**

Ok! You have successfully created two FDCs for the Blackberry Creek. Click on the 'Zoom' button in the Plot window for more clear illustration.
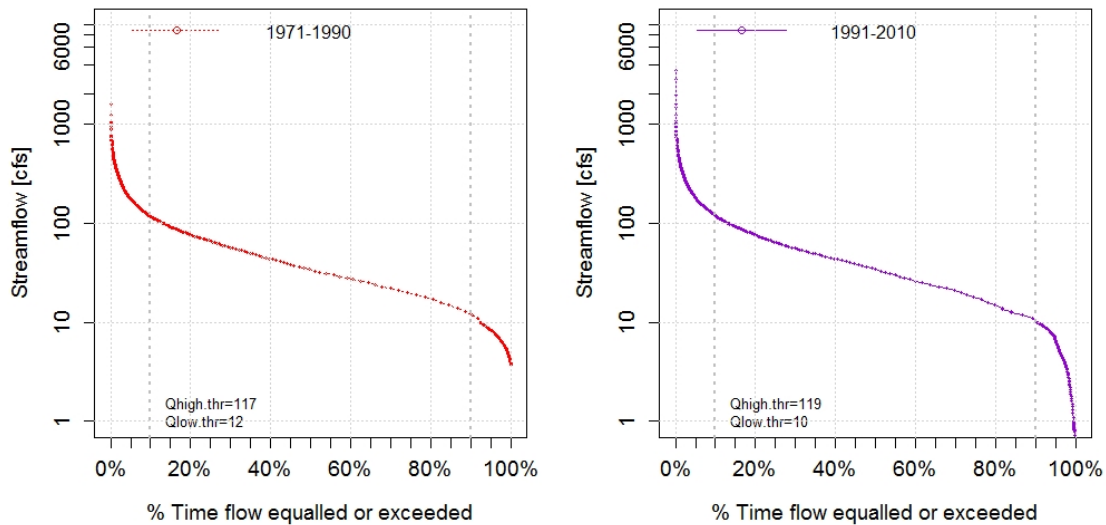

Figure 2: FDC Analysis for Blackberry Creek, IL

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 5
### Downloading streamflow data directly from USGS for station 05568800
### Comparison between 1971-1985 and 1996-2010
### Save the downloaded data with a name 'indiancreek1' and 'indiancreek2'

indiancreek1<-importDVs("XXXX", code="00060", stat="00003",
                        sdate="YYYY-MM-DD", edate="YYYY-MM-DD")
indiancreek2<-importDVs("XXXX", code="00060", stat="00003",
                        sdate="YYYY-MM-DD", edate="YYYY-MM-DD")


### Divide the plot window to display two figures
par(mfrow=c(1,2))

# FDC for 1971-1985 [from the dataframe 'indiancreek1']
fdc(XXXX,
    lQ.thr=0.9, hQ.thr=0.1,
    plot=TRUE, log="y",
    main= "Indian Creek FDC (1971-1985)",
    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="XXXX",
    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)

# FDC for 1996-2010 [from the dataframe 'indiancreek2']
fdc(XXXX,
    lQ.thr=0.9,hQ.thr=0.1,
    plot=TRUE, log="y",
    main= "Indian Creek FDC (1996-2010)",
```

```
    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="XXXX",
    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)
```
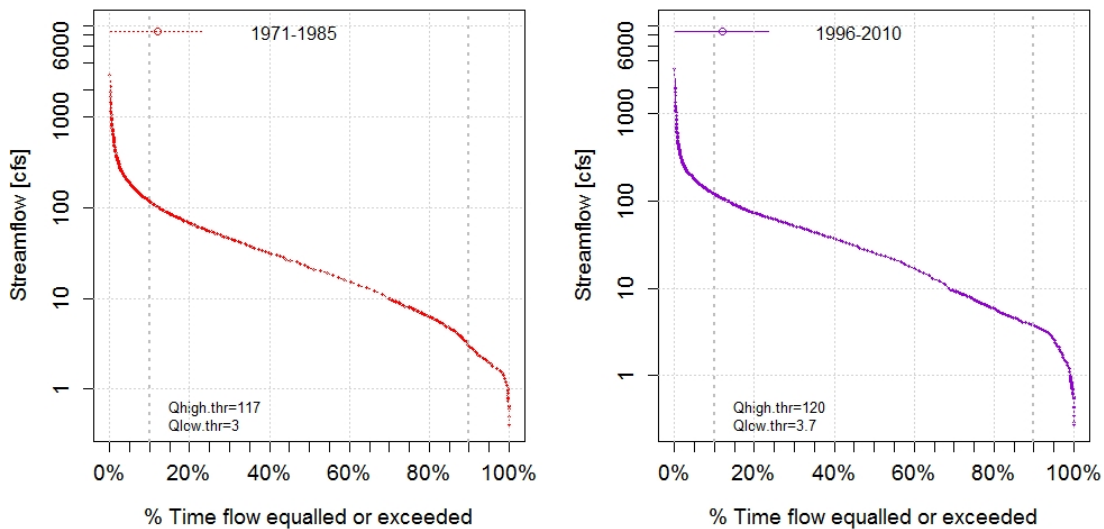

Figure 3: FDC Analysis for Indian Creek, IL

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

Verify the lessons learnt through this module by creating similar examples on your own (Complete the Exercises 1 and 2).

Exercise 1

This time the area we are concerned about is **Charlotte, North Carolina**. Here also, you will consider two nearby locations in/around the Charlotte city area; one of which is a fast-growing suburb, the other one is mostly a forest land and has not been into much development. The gage stations we will be taking here as examples are the USGS 02126000 and USGS 02146600, which are the outlets for watersheds called respectively the Rocky River near Norwood at Stanly County and the McAlpine Creek at Mecklenburg County. Click on http://goo.gl/cLNpiA to see these example watersheds as well as the gage stations in a customized Google map.

For both the watersheds, download USGS daily streamflow data for two different periods of 1971-1990 and 1991-2010.

Create your own script to plot FDCs following the example shown in this module. Which one of the locations do you think is undergoing development? Why?

Hints: ylim=c(10,100000), yat=c(10, 100, 1000,10000,100000) for Rocky River

ylim=c(0.01,10000), yat=c(0.01,0.1, 1, 10, 100, 1000,10000) for McAlpine Creek

Exercise 2

Let's go to Skunk Creek watershed near **Sioux Falls, South Dakota** (USGS 06481500). Download USGS daily streamflow data for two different periods of 1981-1990 and 2005-2014. Create your own script to plot FDCs following the example shown in this module.

Hint: ylim=c(0.01,10000), yat=c(0.01, 0.1, 1, 10, 100, 1000,10000)

You will encounter a error message while creating the FDCs. Why do you think the error has occurred? Write the following lines after Step 3 to solve this error:

```
cleanUp(skunkcreek1, task="view") ## verify the problem in your dataset
cleanUp(skunkcreek2, task="view")

skunkcreek1_fix<-cleanUp(skunkcreek1, task="fix", replace=0.1)
skunkcreek2_fix<-cleanUp(skunkcreek2, task="fix", replace=0.1)
```

Now proceed with Step 4. Use the revised dataframes **skunkcreek1_fix** and **skunkcreek1_fix** to create the FDCs. Fill out the following table based on your plot.

Duration	10% Exceedance	40% Exceedance	60% Exceedance	90% Exceedance
1981-1990	382	?	10	?
2005-2014	481	80	?	?

What can be the possible changes in land use that supports your plot?

Skunk Creek FDC (1981-1990)   Skunk Creek FDC (2005-2014)