RWater Module 5
Hydrograph Analysis to Study the Effect of Urbanization on Streamlow
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Learning Goals

Urbanization refers to the concentration of human populations into discrete areas, leading to transformation of land for residential, commercial and transportation purposes. Such changes in landuse result into unprecedented changes in ecosystems and environmental processes. From the previous modules, we have come to know that flow pattern in a stream can be affected by any of the three major factors: climatic, geographic as well as human induced changes. Urbanization falls into the 'human factor' category. After completing this module, students will be able to:

i. see the trend of landuse change in Las Vegas, Nevada, the fastest growing city in the United States over the past two decades

ii. visualize the possible changes in streamflow for a small watershed in the same area, being caused by this ongoing process of urbanization

Visualizing Urbanization Trend in an Area: Example of Las Vegas

The Landsat program is a NASA enterprise for acquisition of satellite imagery of the Earth surface. Following are the true-color Landsat satellite images for Las Vegas, being obtained from http://landsatlook.usgs.gov/, over a period from 1984 to 2014. As these images suggest, Las Vegas has been experiencing rapid urbanization since 1984. In these images, buildings and paved areas appear in gray shades, the clearest example are the sites adjacent to the famous 'Vegas Strip' along the center diagonal and McCarran International Airport near the bottom center of each image. Grass-covered land, such as parks and golf courses, appears in green.

A video clip showing these ongoing changes can be played from the Google Earth Engine by clicking in the following link: https://earthengine.google.org/#intro/LasVegas. Run in slow motion for best visualization.
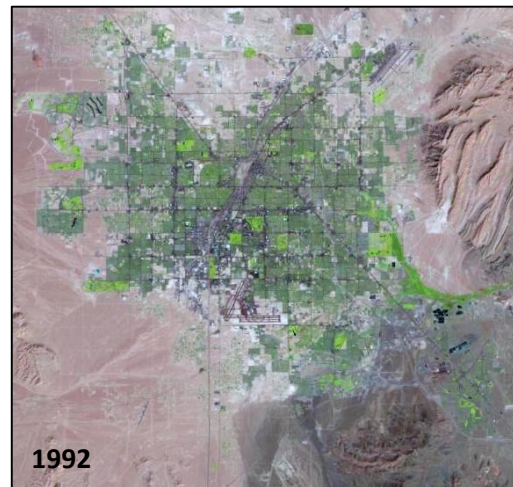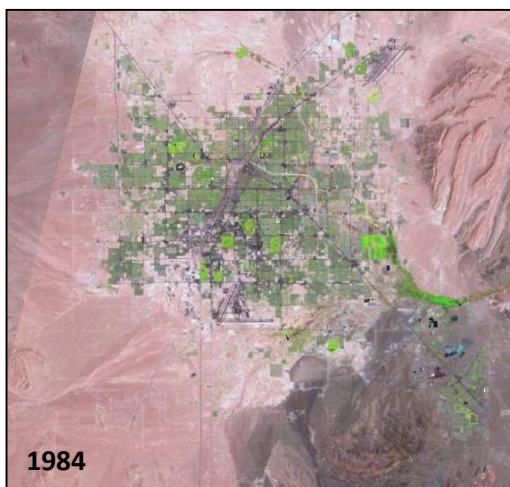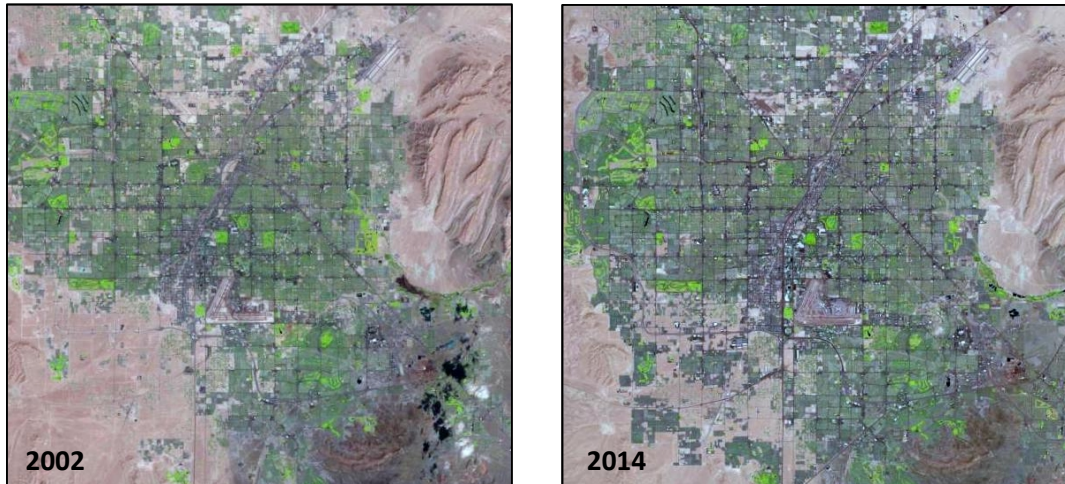
Changes in Streamflow with Urbanization

In areas of little development such as agricultural or forests, a hydrograph will rise slowly during the rainfall and gradually decrease as well. This is due to the increased infiltration of the rain water into the soil, less runoff, and increased interception by vegetation. In urban areas, impervious surfaces (highways, streets, parking lots, sidewalks, and buildings) now 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 (see Figure 1 below). As a result, peak discharge goes high, meaning more water in the stream. Also, time between the peak rainfall and peak discharge (called lag time) decreases drastically, that is, a hydrograph tends to peak quickly and drop quickly as well which we generally call "Flash Flooding". This phenomenon has also been discussed in Module 4 using a hypothetical example of surface imperviousness.
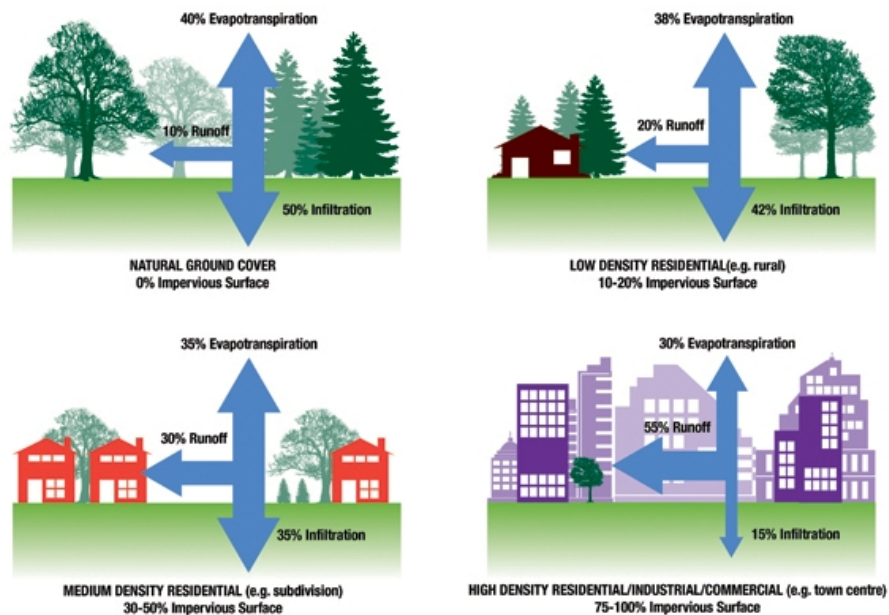

Figure 1. Source: Arnold and Gibbons (1996), APA Journal

Now, in order to understand the urbanization effect from a real-time situation we are going to download the streamflow data at a particular USGS gage station (USGS 09419700) in the Las Vegas city area and compare between a past and a more recent time frame (1971-1980 and 2001-2010, respectively). The station we will be studying here as an example is the USGS 09419700, which is the outlet for the watershed called Las Vegas Wash near Pabco Road. Click on http://goo.gl/Y5lYZZ to see the watershed as well as the gage station in a customized Google map.

Streamflow data can be downloaded directly by following the script. In addition, two pre-processed rainfall datasets for both time frames are required for this module.

- 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 a specific package into RWater
library(waterData)

### STEP 3
### Downloading streamflow data directly from USGS
### Save the downloaded data by giving it a name such as 'vegasflow71.80'

vegasflow71.80<-importDVs("XXXX",
        code="00060", stat="00003",
        sdate="YYYY-MM-DD",
        edate="YYYY-MM-DD")
vegasflow01.10<-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**: **D** is capital letter)

In this example, replace **XXXX** with **09419700**.

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 2009-01-01 and 2010-12-31 respectively

You are saving the downloaded dataframes by giving them specific names such as **vegasflow71.80**.

Click on 'vegasflow71.80' or 'vegasflow01.10' (upper right). You will see that streamflow values are listed in the right column (column header name is **val**)

Provide generic names to the dataframes. It is important to know which columns (more specifically, which data) within your downloaded dataframe you need to use for different analyses. Also, R language is very case sensitive. You need to be careful in reusing the names of your dataframes to avoid possible errors.

For this module, we need to use rainfall data for the particular watershed. The required data has already been obtained from the weather station at the McCarran International Airport, Nevada. You need to upload that data in your RWater working directory. To know how to set up a working directory, please refer to previous modules.

```
### STEP 4
### Two rainfall datasets for the two periods (1971-1980 and 2001-2010)
### File names are 'vegasrain71.80' and 'vegasrain01.10' respectively

### Caution: The following file path will be different in your case
vegasrain71.80=read.csv("/home/mygeohub/put your user name here/put the name
of your working directory/vegasrain71.80.csv",
          header = TRUE,
          stringsAsFactors = FALSE)
vegasrain01.10=read.csv("/home/mygeohub/put your user name here/put the name
of your working directory/vegasrain01.10.csv",
          header = TRUE,
          stringsAsFactors = FALSE)
```

Load the given rainfall dataset from your working directory. Use your own RWater **username** and the **name of your current working directory** to load the data

stringsAsFactors is case sensitive (**A** and **F** are capital letters). See Appendix for the meaning of the function

Click on 'vegasrain71.80' or 'vegasrain01.10' in the workspace (upper right). You will see two columns: one is date and the other one is the rainfall value in mm)

```
### To enable the subset function, 'date' has to be a character
class(vegasrain71.80$Date)
class(vegasrain01.10$Date)


### STEP 5
### Split the plot window in two rows
par(mfrow=c(2,1))
```

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

```
### STEP 6
### We will plot rainfall hyetograph in a reverse Y axis
### We can modify the maximum limit of the X and Y axes, line color as well
as the title of the graph etc.
par(mar=c(5, 4, 4, 8) + 0.1)
barplot(vegasrain71.80$Rainfall.mm.,vegasrain71.80$Date,
        space = c(0,1),width = 0.5,ylim=rev(c(0,120)),
        xlab="Days in year 1971-1980", ylab="Rainfall(mm)",
        main="Las Vegas Wash at Pabco Rd, NV (1971-1980)",
        axes=TRUE,las=1,xaxt="n",col="blue", border="blue")
par(new=T)
plot(vegasflow71.80$val,type="l",pch=21, col="red",
        lty=12,lwd=1.5,yaxt="n", ylim=c(0,3000),
        xlab="",ylab="",axes=T)
axis(side=4)
mtext("Streamflow(cfs)",side=4, cex.lab=1,las=3,line=3, col="black")
legend(2000,3500,"Streamflow", col = "red", lwd=1.5, lty=12, bty="n")
legend(2000,3000,"Rainfall", col = "blue", lwd=7, lty=1, bty="n")
border=c("black")
```

In this segment we are plotting the **rainfall** data from 1971-1980

In this segment we are plotting the **streamflow** data from 1971-1980

```
barplot(vegasrain01.10$Rainfall.mm.,vegasrain01.10$Date,
        space = c(0,1),width = 0.5,ylim=rev(c(0,120)),
        xlab="Days in year 2001-2010", ylab="Rainfall(mm)",
        main="Las Vegas Wash at Pabco Rd, NV (2001-2010)",
        axes=TRUE,las=1,xaxt="n",
        col="blue", border="blue")
par(new=T)
plot(vegasflow01.10$val,type="l",pch=21, col="red",
     lty=12,lwd=1.5,yaxt="n", ylim=c(0,3000),
     xlab="",ylab="",axes=T)
axis(side=4)
mtext("Streamflow(cfs)",side=4, cex.lab=1,las=3,line=3, col="black")
legend(2000,3500,"Streamflow", col = "red", lwd=1.5, lty=12, bty="n")
legend(2000,3000,"Rainfall", col = "blue", lwd=7, lty=1, bty="n")
border=c("black")
```

It is important to understand the expressions or syntax in a programming tool such as RWater.

- There can be many columns in one dataframe, each of them holding different sets of values. By writing **vegasflow01.10$val** you are referring to the particular column named as **val** (that stores the streamflow values) within the **vegasflow01.10** dataframe.

- par(new=T) will allow plotting a new graph over the previous graph. In the above example, rainfall bar diagram is plotted first and then streamflow hydrograph is plotted in the same space.

- You can get more information about other expressions/commands such as ylim, xlab, lty etc. in the RWater syntax (see appendix).

- The example scripts in this module can be easily reused for any other USGS gage locations, simply by making appropriate changes based on your judgment.
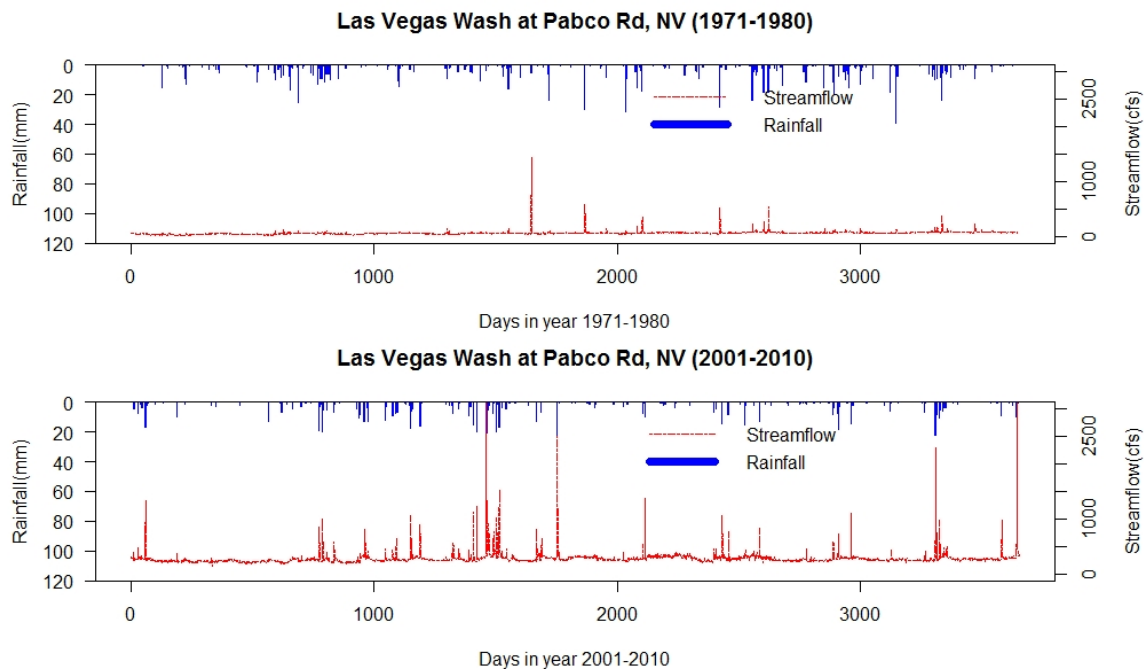

Figure 2

Let us now compare the two graphs which we have just created. Read the graphs carefully and comment on the following statements just by stating TRUE or FALSE:

  (i) No drastic changes in the streamflow between the two periods.   **TRUE/ FALSE**

  (ii) Extreme flows have become more frequent in the recent time period (2001-2010), even under the same rainfall condition. That means, for the same rainfall magnitude or intensity, this particular stream is exhibiting hike in the streamflow values compared to what it used to show in the past.   **TRUE/ FALSE**

These findings can be clarified if we split the whole time frame and re-do the plotting for a very short period of time. In this case, we will compare the streamflow values of February, 1980 and January, 2010.

```
### STEP 7
### Data only for February,1980 and January,2010 is extracted
### The new subset datasets are given appropriate names
library(xts)
vegasflowFEB1980<-subset(vegasflow71.80,
             dates>="1980-02-01"
             &dates<"1980-03-01")
vegasrainFEB1980<-subset(vegasrain71.80,
             Date>="1980-02-01"
             &Date<"1980-03-01")
vegasflowJAN2010<-subset(vegasflow01.10,
             dates>="2010-01-01"
             &dates<="2010-01-31")
vegasrainJAN2010<-subset(vegasrain01.10,
             Date>="2010-01-01"
             &Date<="2010-01-31")
```

> Clipping a date range directly from the original streamflow and rainfall datasets
>
> We need an R package called **xts** for the sub-setting task
>
> Why is the calling structure of the date column different for rainfall and streamflow in this example (**dates** and **Date**)?

```
### STEP 8
### Plotting a segment of the whole downloaded time series

# First plot is for February,1980

par(mar=c(5, 4, 4, 8) + 0.1)
barplot(vegasrainFEB1980$Rainfall.mm.,vegasrainFEB1980$Date,
        space = c(0,1),width = 0.5,ylim=rev(c(0,100)),
        xlab="Days (Feb, 1980)", ylab="Rainfall(mm)",
        main="Las Vegas Wash at Pabco Rd, NV (February 1980)",
        axes=TRUE,las=1,xaxt="n",
        col="blue", border="blue")
par(new=T)
plot(vegasflowFEB1980$val,type="l",pch=21, col="red",
        lty=1,lwd=1.5,yaxt="n", ylim=c(0,1000),
        xlab="",ylab="",axes=T)
axis(side=4)
mtext("Streamflow(cfs)",side=4, cex.lab=1,las=3,line=3, col="black")
legend(5,1000,"Streamflow", col = "red", lwd=1.5, lty=1, bty="n")
legend(5,800,"Rainfall", col = "blue", lwd=7, lty=1, bty="n")
border=c("black")
```

```
# Second plot is for January,2010
barplot(vegasrainJAN2010$Rainfall.mm.,vegasrainJAN2010$Date,
        space = c(0,1),width = 0.5,ylim=rev(c(0,100)),
        xlab="Days (Jan, 2010)", ylab="Rainfall(mm)",
        main="Las Vegas Wash at Pabco Rd, NV (January 2010)",
        axes=TRUE,las=1,xaxt="n",
        col="blue", border="blue")
par(new=T)
plot(vegasflowJAN2010$val,type="l",pch=21, col="red",
        lty=1,lwd=1.5,yaxt="n", ylim=c(0,3000),
        xlab="",ylab="",axes=T)
axis(side=4)
mtext("Streamflow(cfs)",side=4, cex.lab=1,las=3,line=3, col="black")
legend(5,3000,"Streamflow", col = "red", lwd=1.5, lty=1, bty="n")
legend(5,2500,"Rainfall", col = "blue", lwd=7, lty=1, bty="n")
border=c("black")
```
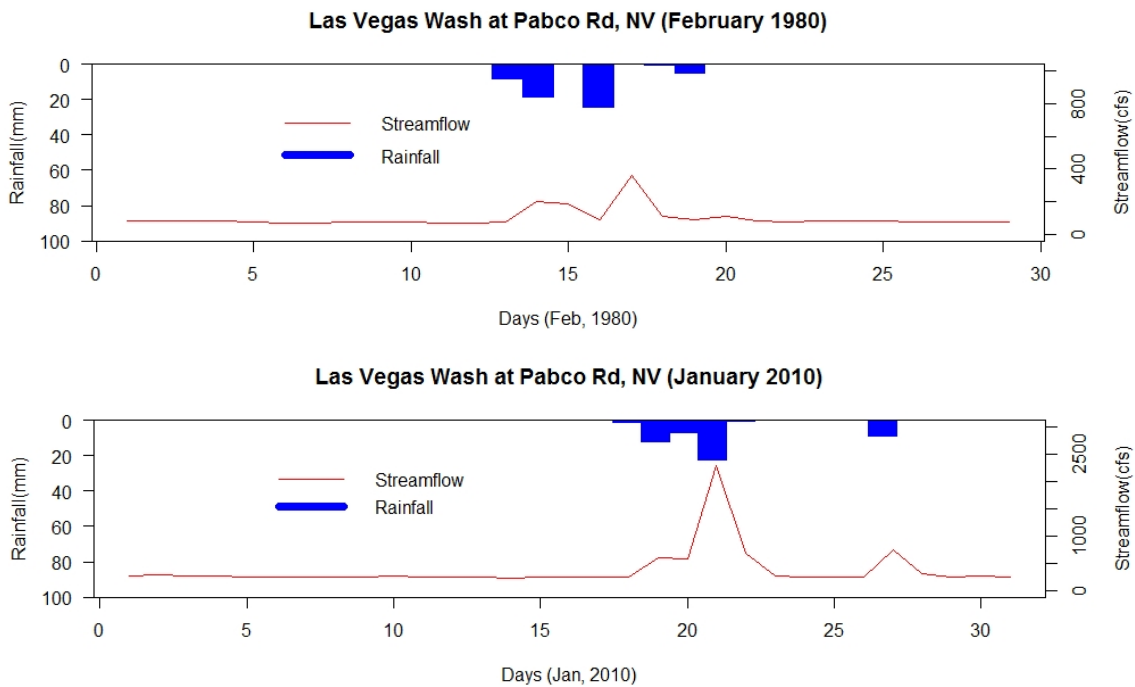

Figure 3

The two plots which you have just created show the streamflow hydrograph of the Las Vegas Wash river in a pre-development and post-development event. Note that, the rainfall pattern in these two separate events is nearly the same. However, what differences can you see in the respective streamflow response?

Quiz

1. Fill up the following table with approximate values/comments using Figure 3:

Period	Maximum Rainfall (mm)	Peak Discharge (cfs)	Slope of Rising Limb (Steep/ Mild)	Lag Time (Longer/ Shorter)
Before urbanization (FEB 1980)	25		Steep	
After urbanization (JAN 2010)	25	2500		

2. In the table above, the differences in values between the 'before-urbanization' and 'after-urbanization' period are mainly because
   a. after urbanization, an area gets covered with impervious surface
   b. rainwater cannot infiltrate into the ground
   c. majority portion of rainwater travels over the surface as 'runoff'
   d. all the above

3. From Figure 3, we can see that even when there is no rainfall, the river still has some flow in it. What component of hydrologic cycle do you think is contributing to the river? Take help from Module 1, if required.
   a. Surface runoff
   b. Evaporation
   c. Baseflow
   d. Both (a) and (c)