1 Introduction

River streamflow data contain important information both about stormwater runoff and groundwater baseflow. Stormwater runoff generally consists of direct overland flow (surface runoff normally conveyed by sewer systems and other directly-connected impervious areas) and interflow (subsurface flow that is near the surface and may not be directly related with any large-scale groundwater aquifers). The partitioning of stormwater runoff between overland flow and interflow is a complicated art, currently under research in water resources engineering. In general terms, the greater the amount of impervious surface in a watershed, the greater the partition of surface runoff. Groundwater baseflow is the component of the river flow resulting from direct discharge of groundwater into the stream. The baseflow component is what keeps water flowing in the river when there has been no rainfall for a long time. Generally, the baseflow component decays exponentially until the next storm event, during which the groundwater will be somewhat recharged, raising the baseflow component of the flow hydrograph.

Figure 1 shows a schematic of a typical flow measurement at a streamflow gauging station and an interpretation of the flow in terms of identified major storms and groundwater baseflow. The storm runoff volume is the area between the recorded streamflow record and the groundwater baseflow component. Thus, in order to use streamflow data to measure stormwater runoff, we require an estimate of the start and end of the storm as well as the contribution to the river flow by groundwater.

There are many ways to identify storms in river flow data. One attribute clear from the figure is that the river flow suddenly increases at the start of the storm, reaches a peak, and then gradually returns to the baseflow condition. The slope of the streamflow record can be used to help identify the storm start and end dates—this will be part of the challenge problem for this assignment. The simplest model for the baseflow contribution is to connect the start and end flow rates of the storm by a straight line (dotted line in Figure 1).

Once an automated method to identify individual storms is defined, the statistics of all storms in the period of record can be analyzed, including duration, peak river flow rate, total runoff volume, etc. These provide important information about flood flows in the river, and can often be related to watershed attributes, such as contributing area and channel length within the watershed. In this assignment, we will explore these calculations for a major flood that occurred on the Brazos River in 1998 and for the complete flow record for water year 1999.
Figure 1: Schematic of the flow $Q$ in a river as a function of time $t$. The figure also identifies the groundwater baseflow component and the signature of typical storms.

2 River Flow Data

Refer to the previous assignment using USGS river flow data to download data from

- http://waterdata.usgs.gov/nwis

You will need to download the daily surface water data for three gauges on the Brazos River:

1. 08096500 Brazos River at Waco, TX
2. 08108700 Brazos River at SH 21 near Bryan, TX
3. 08114000 Brazos River at Richmond, TX

For the basic assignment, you will need all data from 01-Oct-1998 to 30-Sep-1999. This is the data for water year 1999.

When you navigate to the webpage for each gauge where the data type and time span can be selected, notice the drop-down list titled “Available data for this site” near the top of the page. Use this list to also download the site map. The site map provides the Latitude and Longitude of each gauging station, as well as the contributing drainage area and the elevation of the gauge. Use the site location data to map each gauge along with the Brazos river in Google Earth. Use the contributing drainage area for the calculations outlined below.
3 Assignment

3.1 First Steps

Use the read_usgs.m function provided for the previous programming assignment to read in the flow data at each gauge. Plot the data for water year 1999 for each gauge in a stacked plot (use SUBPLOT in Matlab) using the same vertical axis for each plot, similarly to Figure 2. The major storm occurring in October 1998 is a famous “perfect storm” over Texas. You can read more about this storm event by Googling “October 1998 Central Texas Floods.” While the flooding was much greater in other Texas watersheds, this storm represents one of the largest recorded at the Brazos River near Bryan, TX, gauge in its entire period of record.

3.2 Numerical Calculations

Perform each of the following exercises and summarize the results in the report detailed in the next section.

1. For each gauge over the full water year 1999, create the following series of graphs. These should be contained on a single portrait page using SUBPLOT similarly to the figure already created of the streamflow data.
(a) At the top, plot the measured flow rate using an appropriate vertical axis so that the flows are clearly visible.

(b) Next, plot the slope of the measured flow data using forward differences for the first data point in the period of record, central differences for the central data points, and a backward difference for the last data point in the period of record. You may explore higher-order finite differences, but pay attention to the resolution of the data before employing a finite difference formula that use several data points spanning a long time period in the estimator. Be sure to label the correct units on your plots.

(c) Using the slope data, identify the days on which a peak of the flow occurs (slope changes from positive to negative). Plot these peak flow data in the third graph using an appropriate symbol. Using the Matlab `HOLD ON` command, also plot a straight line representing the annual average flow rate.

(d) Finally, use the trapezoidal rule to compute the cumulative discharge volume (in cubic miles) of the river as a function of time. That is, for each day in the time series, integrate the flow data up to that day and plot the total volume. Be sure to convert your units (seconds and days) so that you obtain an accurate volume. What was the total annual runoff? If this value resulted from a constant flow rate, how does that flow rate compare with the average flow rate plotted in the previous plot?

2. For the October, 1998, storm, perform the following analyses at each gauge.

   (a) From the river flow data and the slopes of the flow computed in the previous section, identify the start date and end date of the runoff signature resulting from the storm occurring October 16-18, 1998. Because it takes a long time for the rainfall to make its way through the watershed, the start and stop dates at each gauge will be different.

   (b) Estimate the total stormwater runoff volume at each gauge by integrating the flow rate between the start and stop times identified above for this storm and subtracting the baseflow contribution.

   (c) Plot the stormwater runoff volume and groundwater baseflow volume versus watershed contributing area for each gauge (this should be a single plot with three data points for each line). How would you interpret the trend?

3.3 Data Reporting

The results of this programming assignment will be reported in the form of a technical memorandum from your engineering consulting firm to the Federal Emergency Management Agency (FEMA), the entity responsible for flood mapping in the United States. The report should describe each of the gauges used in the analysis, including a location map showing all three gauges together with the trace of the Brazos River. The introduction may also include the plot of the flow rate at each gauge created under “First Steps” above.

The main body of the technical report will include the flow analysis figures created for each gauge, including estimates of the flow slope, peak flows, and cumulative discharge. Discuss the attributes of each gauge and compare and contrast the numerical results for each analysis among the
three gauges (e.g., are typical slopes of the streamflow hydrograph of similar or different magnitude at each gauge, and how do they vary going downstream?).

The final section of the technical memorandum should discuss your analysis of the October storm. In particular, discuss the trends in the flow/drainage area figure and how it should be interpreted. Also discuss to what extent the groundwater baseflow increased at each gauge as a result of the storm and the total duration of the flood passage.

4 Challenge Problem

In the above assignment, you analyzed a single storm (task 2) by identifying the storm start and stop times by hand. For the challenge problem, derive an objective, automated storm start and stop identification algorithm applicable to the Brazos River at SH 21 near Bryan, TX. To do this, you should use the complete flow record (not just water year 1999) at that gauge. Once your computer program can find the start and stop times of all storms in the period of record, use your program to calculate the average runoff volume, standard deviation of runoff volume, and to plot a histogram of runoff volume for all storms. Do not forget to subtract the baseflow component of the streamflow measurement for each storm. Include this analysis as a separate section of your technical report and compare the results for the October storm with the average and standard deviation of storm runoff volume for this gauge. How extreme of an event was this October storm based on these data?