Sources of Stream Discharge in the North East and North West Branches of the Anacostia Watershed

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Problem

Land use is often used to predict the amount of runoff occurring in watersheds. It is often assumed, from studies of small watersheds, that the amount of impervious surfaces will be proportional to the amount of runoff, and most methods of predicting runoff assume a 1:1 relationship between the two. This study aims at testing the relationship between impervious surfaces and runoff in a large, urbanized watershed by employing hydrograph separation procedures.

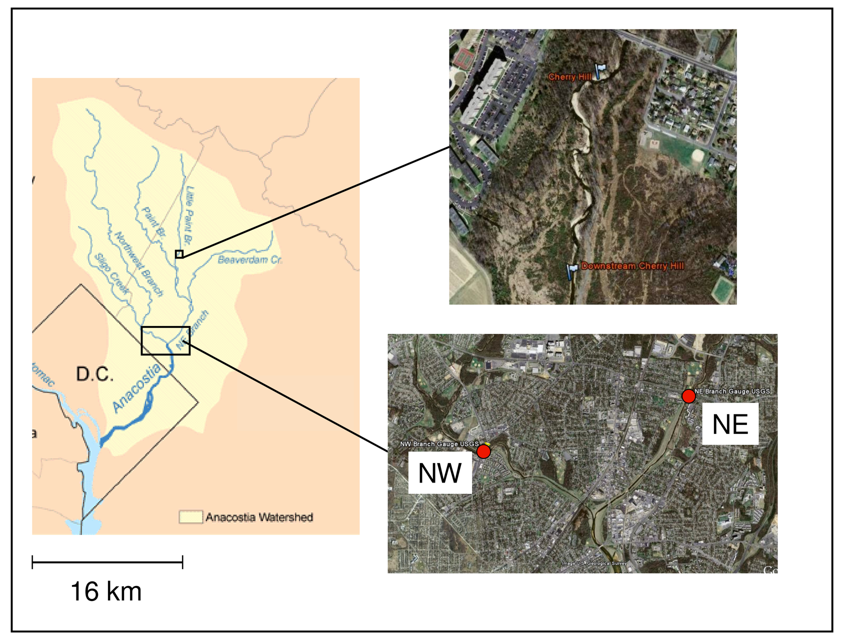
Hypotheses

1. Electrical conductivity can be used to separate hydrographs into event water (direct precipitation and overland flow) and pre-event water (groundwater) components in urban watersheds.

2. The amount of event water discharge in the stream is directly proportional to the amount of impervious surfaces found within the sub-watershed.

3. At each watershed location the proportion of event water discharge should be similar for different storm events because it reflects the amount of impervious surfaces, which remain constant. The runoff ratio, therefore, does not change due to differences in storm intensity or storm duration.

Study Sites



This map of the Anacostia Watershed shows the location of the NE and NW Branch gauges. Note the heavy amount of urbanization near the gauges and presence of an intact floodplain near the headwaters. (Images taken from Google Earth).

Methods

Event water is considered to be any water that is not previously stored in the system prior to the storm event. In this study it is a combination of direct precipitation and overland flow runoff. Pre event water is considered to be any water that has been stored in the watershed prior to the storm event. In this study it is considered to be the baseflow, or groundwater runoff. Field measurements of overland flow and precipitation samples were collected from the Cherry Hill site on two separate storm events in order to compare the conductivities of overland flow runoff and precipitation.

USGS stream gauges track conductivity and gauge height, with a correlation to discharge.

Baseflow Characterization: Electrical conductivity of groundwater discharge, or pre-event water, is assumed to be the baseflow electrical conductivity prior to the storm event and is measured in the channel prior to the storm events by two gauges. The conductivity is an average of baseflow conductivities over a twenty four hour period prior to the storm event.

Rainwater Conductivity Data: Electrical conductivity of event water is measured and recorded by the NADP in Beltsville, MD located within the NE Branch of the Anacostia River. In addition to the data obtained from the NADP, rainwater samples were collected and tested for their electrical conductivities.

Methods

To perform the hydrograph separations at each site, two mass balance equations from Ladouche et al., 2001 were employed.

Qt = Qa + Qb

QtCt = QaCa + QbCb

Analysis of Error

Uncertainty equation for hydrograph separation results from Genereux, 1998

$$W_{f_1} = \left\{ \left[\frac{C_2 - C_S}{(C_2 - C_1)^2} W_{C_1} \right]^2 + \left[\frac{C_S - C_1}{(C_2 - C_1)^2} W_{C_2} \right]^2 + \left[\frac{-1}{(C_2 - C_1)} W_{C_S} \right]^2 \right\}^{1/2}$$

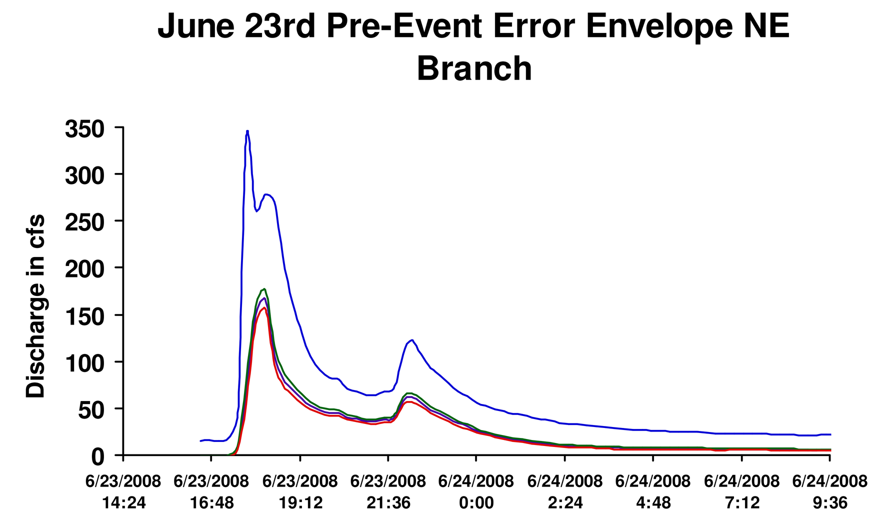


Figure 1: This diagram shows three separations that were performed for each storm hydrograph using average end-member compositions and values that were ± one standard deviation from the mean. This provides upper and lower bounds to the hydrograph separation results and is a graphical representation of the error equation shown above.

Results

1. Comparison of Overland Flow Conductivity to Precipitation Conductivity

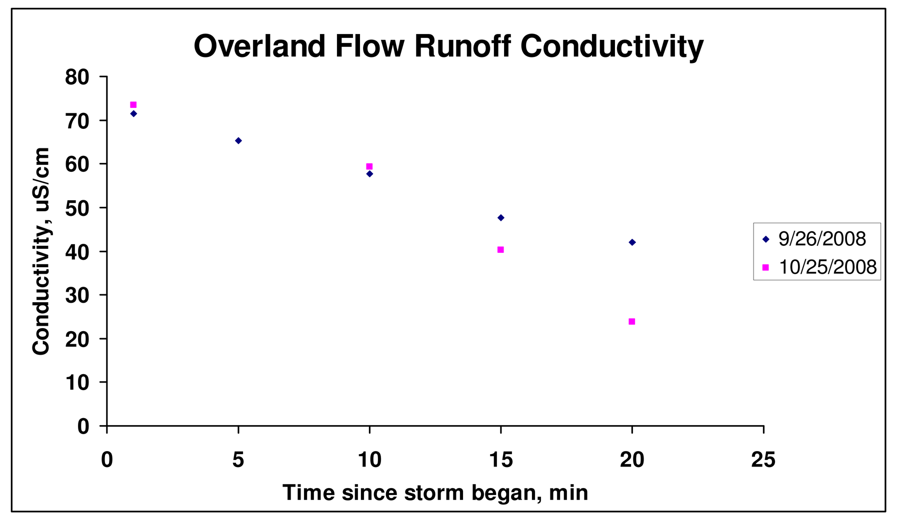


Figure 2: Overland flow runoff conductivity decreases rapidly after the onset of precipitation, and eventually dip below the conductivity of the precipitation. The conductivity of precipitation for the 9/26 and 10/25 storm events were 52.7 ± 0.3 µS/cm and 41.6 ± 0.3 µS/cm, respectively.

2. Precipitation End-member Values

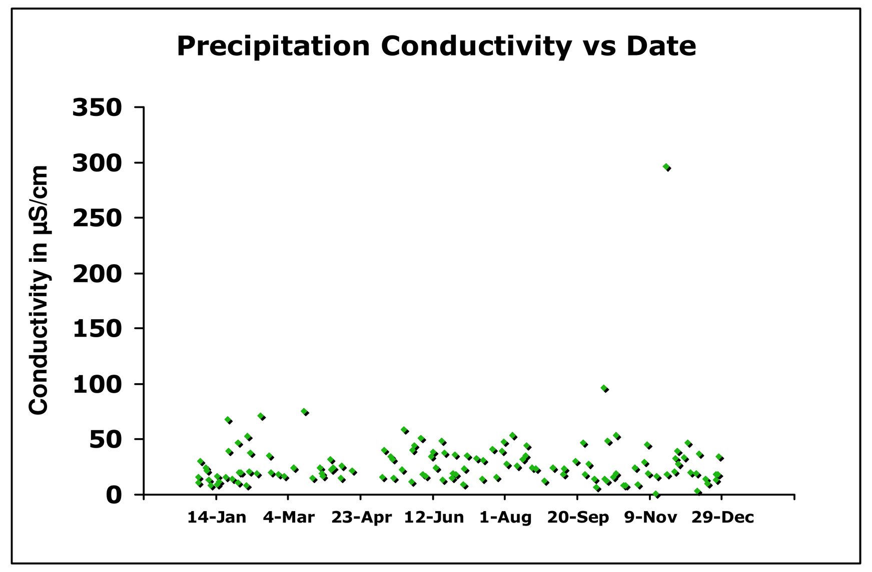


Figure 3: Seasonal variations in precipitation data from 2004 to 2008. The arithmetic mean is 25.0 µS per centimeter with a standard deviation of 12.7 µS per centimeter. These data were provided from NADP.

3. Average Conductivity Values of End-Members

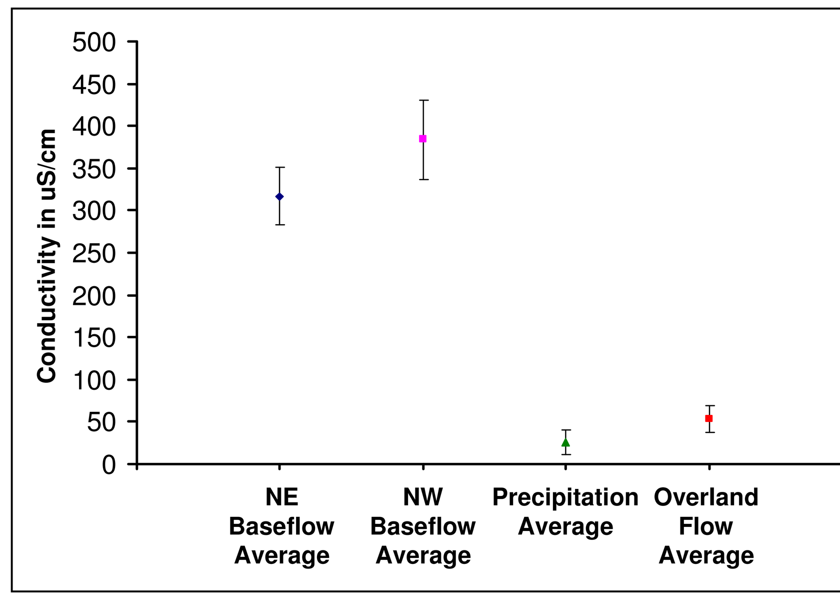


Figure 4: End-member averages and standard deviations. Precipitation and overland flow runoff data overlap, while baseflow conductivity values are distinctly higher.

4. Hydrograph Separation Results

Date of storm	Percent of Pre-event	Percent of Event
June 23rd	59.5 ± 10.8	40.5 ± 10.8
June 27th	60.2 ± 4.0	39.8 ± 4.0
July 4th	72.8 ± 6.1	27.2 ± 6.1
July 9th	51.7 ± 3.4	48.3 ± 3.4
July 13th	51.8 ± 4.1	48.2 ± 4.1
July 23rd	38.2 ± 3.3	61.8 ± 3.3
July 27th	56.8 ± 3.6	43.2 ± 3.6
August 7th	50.0 ± 3.5	50.0 ± 3.5
August 29th	82.1 ± 6.5	17.9 ± 6.5
Sept. 6th	37.9 ± 5.8	62.1 ± 5.8
Sept. 26th	47.3 ± 7.8	52.7 ± 7.8
October 25th	59.8 ± 3.5	40.2 ± 3.5

Date of storm	Percent of Pre-event	Percent of Event
June 23rd	61.7 ± 3.6	38.3 ± 3.6
June 27th	45.5 ± 3.7	54.5 ± 3.7
July 4th	74.3 ± 2.8	25.7 ± 2.8
July 9th	41.1 ± 3.1	58.9 ± 3.1
July 13th	36.9 ± 4.2	63.1 ± 4.2
July 23rd	24.8 ± 3.2	75.2 ± 3.2
July 27th	34.1 ± 3.7	65.9 ± 3.7
August 7th	49.0 ± 2.9	51.0 ± 2.9
August 29th	53.5 ± 12.8	46.5 ± 12.8
Sept. 6th	16.8 ± 3.3	83.2 ± 3.3
Sept. 26th	43.6 ± 9.0	56.4 ± 9.0
October 25th	40.0 ± 7.7	60.0 ± 7.7

Tables show the results of the hydrograph separation performed on twelve storm hydrographs. Left, NE Branch; Right, NW Branch.

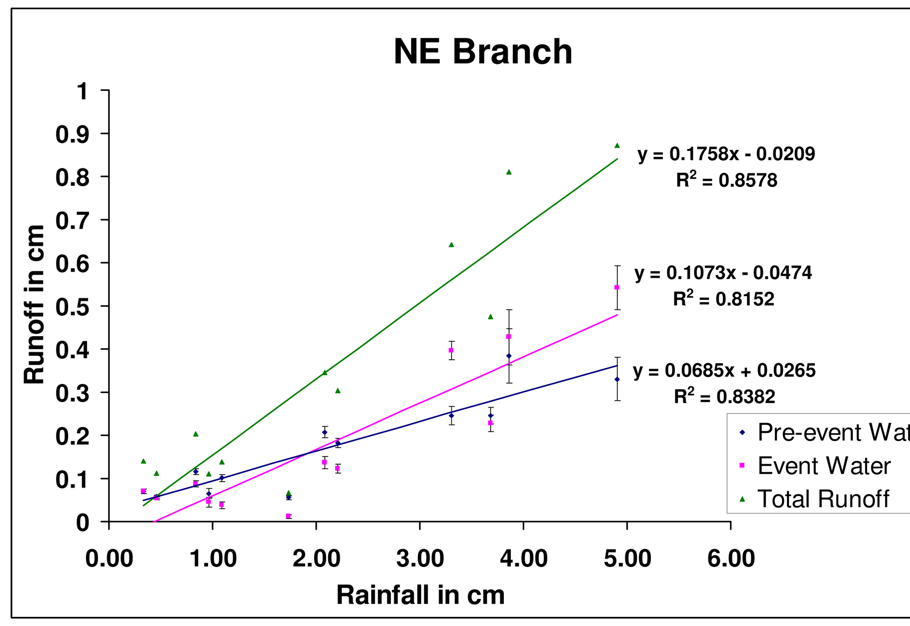


Figure 5: Relationship between rainfall and runoff for 12 storm events in the NE branch. Upper trendline shows total runoff. Overland flow runoff accounts for 61% of the total runoff, while subsurface flow accounts for 39% of total runoff.

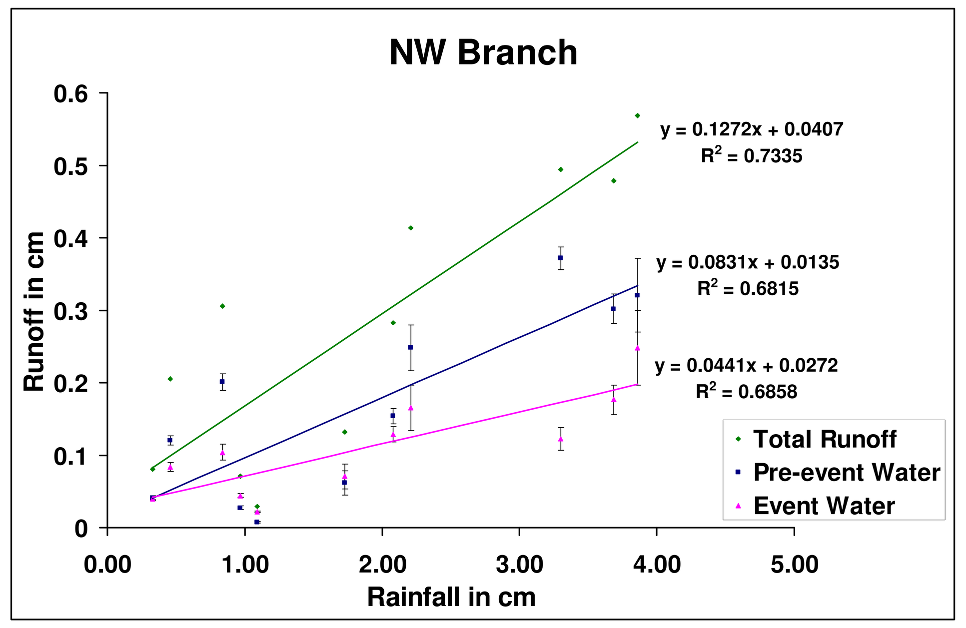


Figure 6: Relationship between rainfall and runoff for 12 storm events in the NW branch. Upper trendline shows total runoff. Overland flow runoff accounts for 35% of the total runoff, while subsurface flow accounts for 65% of total runoff.

Summary of Results

Site	Drainage Area	Percent Impervious Surfaces	Percent Total Runoff*	Percent Pre-Event Water Runoff*	Percent Event Water Runoff*
NW Branch	49.4 km^2	23	~13	~8	~5
NE Branch	72.8 km^2	26	~18	~7	~11

*Percent runoff indicates the percentage of total rainfall volume.

Discussion

Evaluation of Hypotheses

1. The assumptions for hydrograph separation analysis were met with the use of electrical conductivity as a tracer. End-member samples (precipitation and baseflow) had significantly different average conductivity values with relatively small standard deviations. Stream conductivity values fell between the end-member values and had small analytical uncertainty.

2. The amount of total runoff was not directly proportional to the amount of impervious surfaces for each site, refuting the second hypothesis.

3. The amount of pre-event for the two watersheds (as a percentage of rainfall) was similar. The amount of event water for the two watersheds were a factor of 2 different from one another, even though amounts of impervious surface in the two watersheds was similar. The event water runoff to rainfall ratios are not constant within the amount of uncertainty for all storm events, which refutes with the third hypothesis.

Conclusion

For these two large, urbanized watersheds, electrical conductivity could be used in a two-component mixing model to provide hydrograph separation analyses. Overland flow resembled the precipitation end-member, particularly for storm events longer than 20 minutes.

The amount of pre-event water in both of these watersheds was surprising large and similar for the two sites.

The amount of overland flow runoff and direction precipitation is less than anticipated. This suggests that, there are significant sites for re-infiltration and surface-groundwater mixing in these two complex watersheds. Examination of the riparian zones for both indicates extensive areas near the channels for these processes in the upper portions of both watersheds. The downstream portions of both watersheds are heavily urbanized, suggestion little infiltration or groundwater input from these sites.

These data suggest that large urban watersheds do not behave like small urban watersheds.

These results suggest that interesting interactions between surface and groundwater take place in the upper watersheds. In the future, I will examine these processes by using the Three UMD gauges in a NE Branch sub-watershed. By performing hydrograph separations on these three sites, further information about the mechanics of storm water delivery from the headwaters to the mouth of the watershed can be explored.

References

Genereux, D., 1998. Quantifying Uncertainty in Tracer-Based Hydrograph Separations: Water Resour. Res., No.4, pp. 915-919.

Ladouche, B., Probst, A., Viville, D., Idir, S., Baque, D., Loubet, M., Probst, J. L., Bariac, T., 2001. Hydrograph Separation Using Isotopic, Chemical and Hydrological Approaches: Journal of Hydrology, vol. 242, pp. 255-274.