ASSESSING THE CHANGE IN RUNOFF RESPONSE IN A DEVELOPING SE PIEDMONT WATERSHED THROUGH THE UNIT HYDROGRAPH, UNIT IMPULSE RESPONSE, AND MANN-KENDAL STATISTICAL TREND TEST APPROACHES

V. Gagrani[1], J. Karl[2], and C. J. Allan[1]

UNC CHARLOTTE

1.Department of Geography and Earth Sciences, University of North Carolina at Charlotte, Charlotte, NC 28223, United States. Vgagrani@uncc.edu and cjallan@uncc.edu
2. Permitting and Mitigation Administrator, Charlotte Mecklenburg Stormwater Services, Charlotte, NC 28202, United States. jkarl@ci.charlotte.nc.us

Charlotte-Mecklenburg STORM WATER Services

Introduction

In this study, the change of runoff hydrology in five developing SE Piedmont sub-watersheds (10% to 54% conversion of forest/farmland to suburban development) with a combination of engineered SCMs and stream restoration to meet the stormwater control requirements within a drinking water supply watershed was assessed. Three different analytical approaches, the Mann-Kendall statistical trend test, the unit hydrograph comparison, and unit impulse response were applied owing to the absence of a true reference watershed, ongoing land cover alterations, a short predevelopment period, stream restoration construction and engineered SCMs installation.

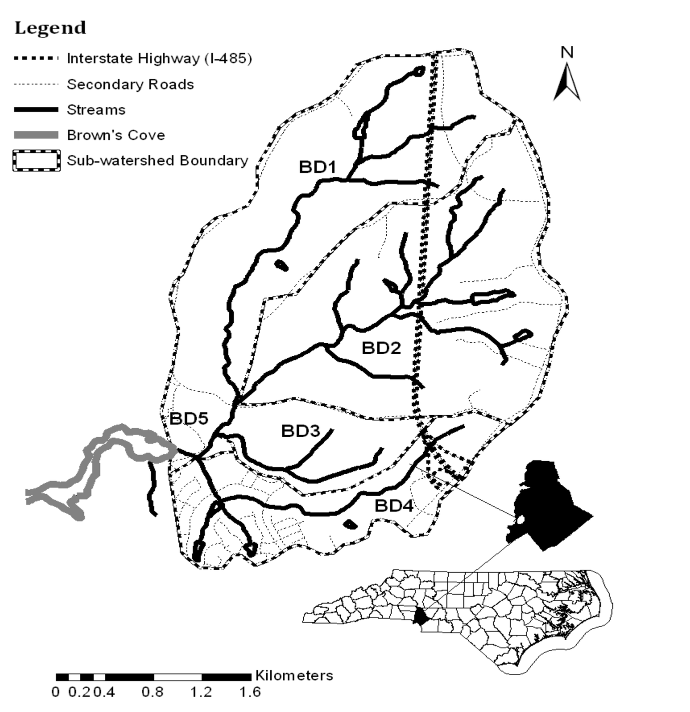

Figure 1: Locations of the BD1, BD2, BD3, BD4, and BD5 sub-watersheds in the Beaverdam Creek (BDC) watershed

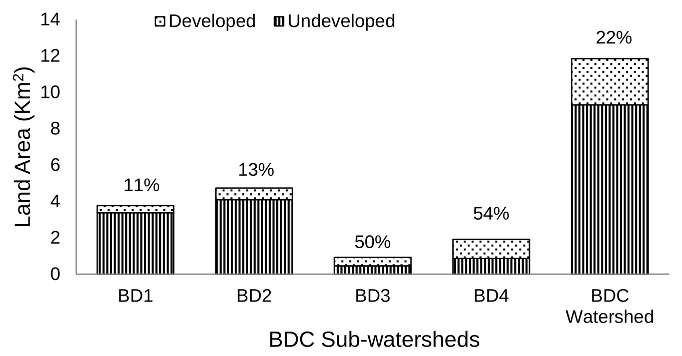

Figure 2: Drainage area of the BDC sub-watersheds and percent land development

BDC sub-watersheds	BD1		BD2		BD3		BD4		BDC watershed	
Drainage Area (km²)	3.78		4.74		0.93		1.92		11.85	
Years	2003	2010	2003	2010	2003	2010	2003	2010	2003	2010
Forest	61.00	50.32	60.30	46.96	86.10	36.29	42.80	21.07	61.32	45.15
Low density residential (≤12% built upon area)	31.88	31.88	31.38	31.38	11.80	11.80	48.70	16.11	31.54	26.26
High density residential (≥12% built upon area)	0.00	0.00	0.00	0.00	0.00	44.01	0.00	50.73	0.00	11.67
Transportation(I-485)	5.80	5.80	5.00	5.00	1.70	1.70	7.80	7.80	5.25	5.25
Institution	0.00	0.00	0.70	1.14	0.00	5.80	0.00	0.00	0.28	0.91
Airport	0.00	10.68	0.00	7.76	0.00	0.00	0.00	0.00	0.00	6.51
Commercial	0.02	0.02	0.02	4.16	0.00	0.00	0.00	3.59	0.01	2.25
Industrial	0.80	0.80	1.70	2.70	0.00	0.00	0.00	0.00	0.94	1.34
Water	0.50	0.50	0.90	0.90	0.40	0.40	0.70	0.70	0.66	0.66

Table1: Land use changes from 2003 to 2011 in the BDC sub-watersheds

Methodology: Research Approaches

Average Unit Hydrograph Approach
The unit hydrographs for the stable pre development period (July 2003 to March 2005/ April 2004 for the BD4) and for the post development period (March 2008 to December 2010) were developed .

Unit Impulse Response
The unit impulse response is a instantaneous runoff response change from an actively urbanizing watershed resulting from an input of a single impulse of known amplitude and duration of precipitation (unit storm event) (Farahmand et al. 2007). For the study sub-watersheds, the auto regressive with an exogenous variable or ARX rainfall-runoff time series models were developed by using 30 or more days of continuous 15-minute rainfall-runoff time series from the pre and post development periods.

Mann-Kendal Non-parametric Trend Detection Test
The trends in precipitation, baseflow, and quickflow time series for the five study watersheds were assessed with the rank-based Mann-Kendall (MK) non-parametric test (Mann 1945 and Kendall 1975).

Results: Unit Hydrograph, Unit Impulse Response, and Mann Kendal Trend Test Approaches

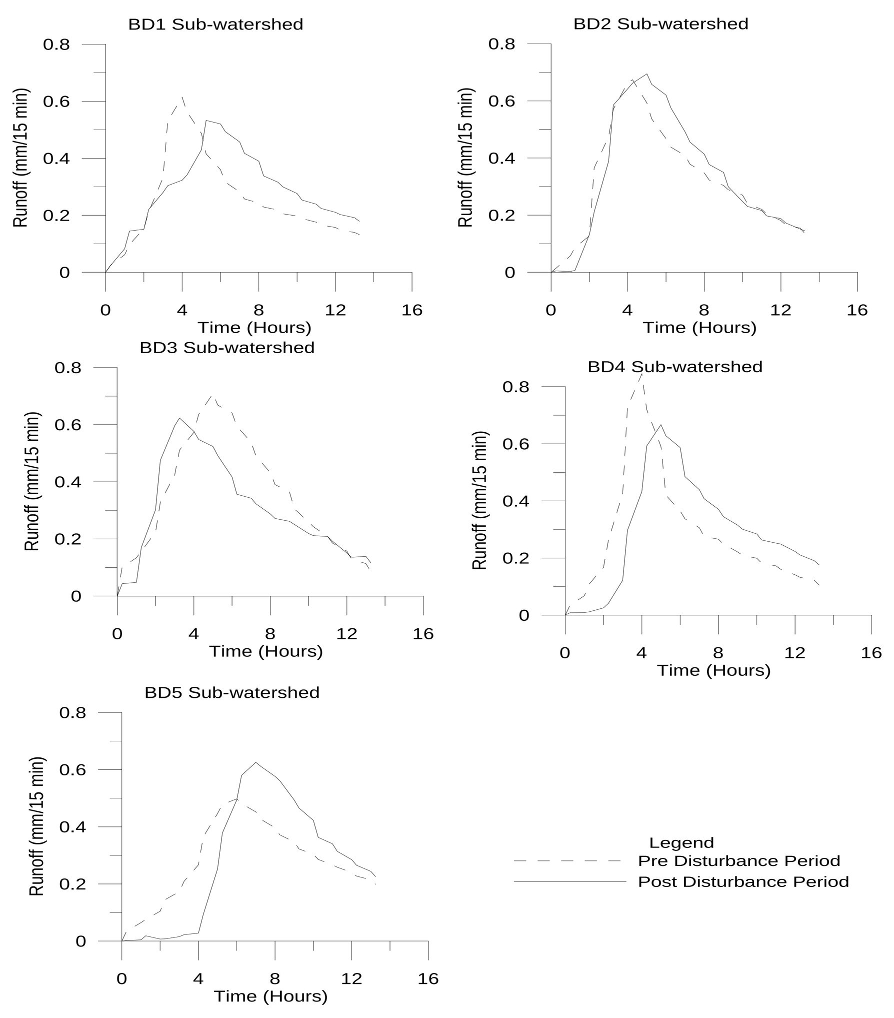

Figure 3: Pre and post land development average unit hydrographs of the BDC sub-watersheds

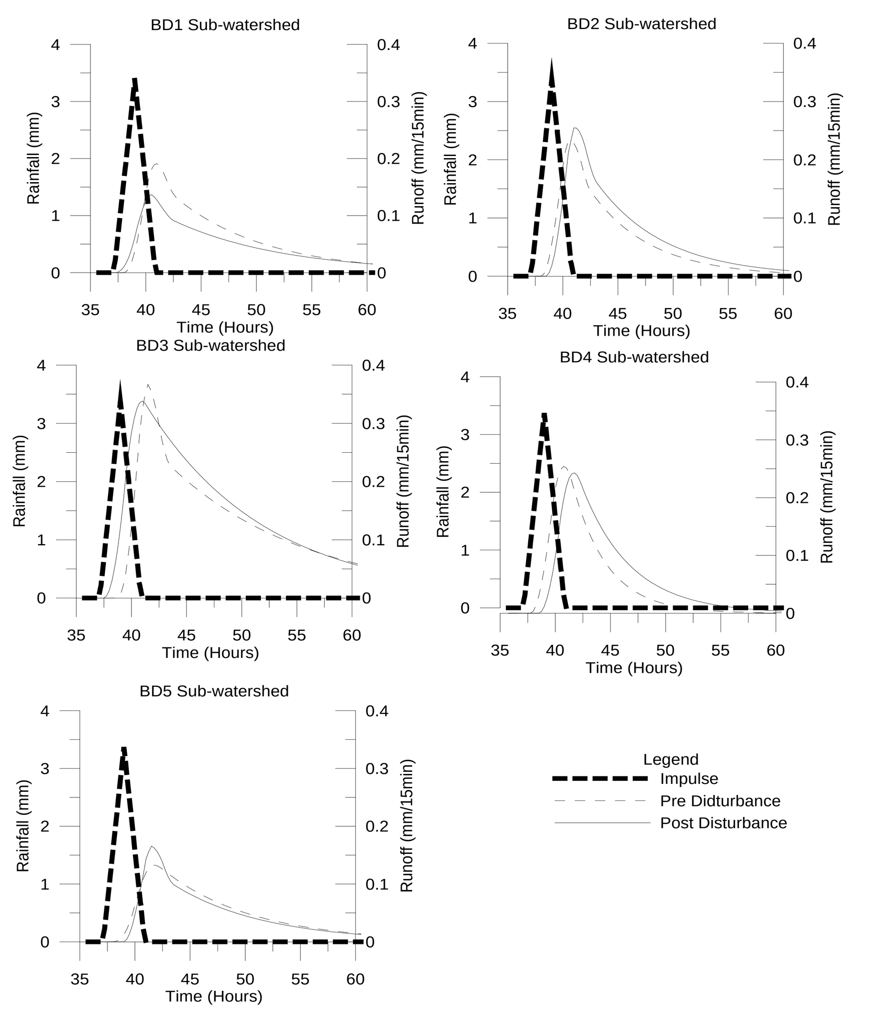

Figure 4: Pre and post land development unit impulse response hydrographs of the BDC sub-watersheds

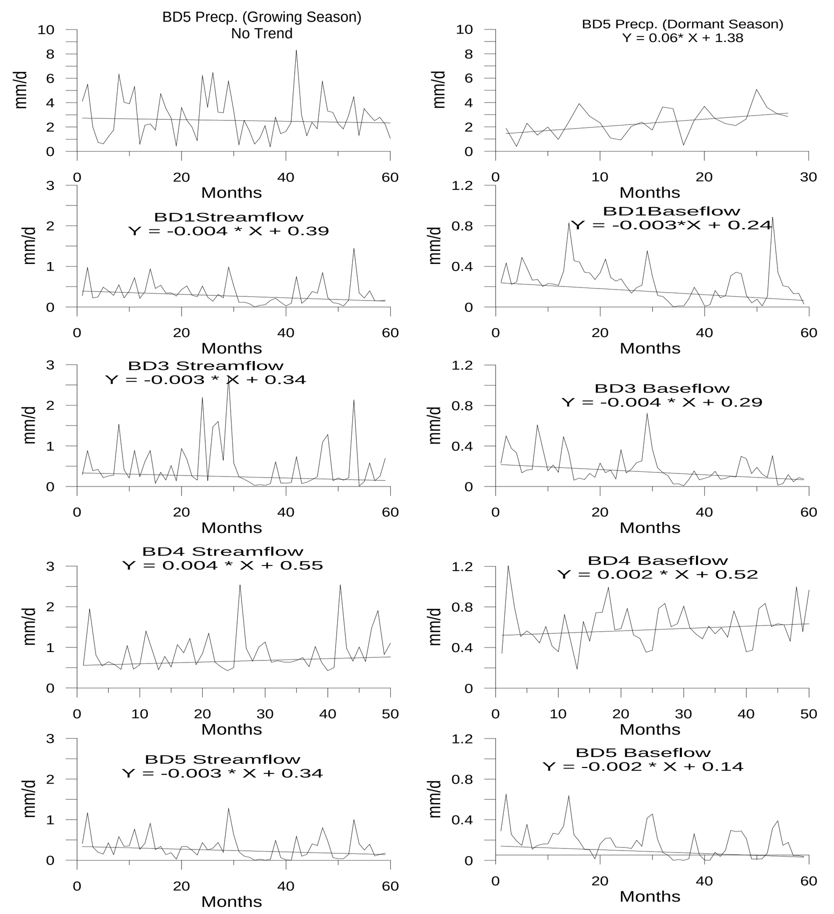

Figure 5: Mann-Kendall trend plots for the precipitation and growing season total streamflow and baseflow of the BDC sub-watersheds

- The increase in direct runoff duration and decline in direct runoff coefficient for the BD1 was attributed to the engineered SCMs installed to control the runoff from the interstate highway (I-485) and the new runway for the CDI airport in the headwater tributary of the BD1 sub-watershed (Table 2).
- The increase in infiltration rate and time to peak in the BD2 were attributed to both the construction of engineered SCMs and a major stream restoration project (Table 2).
- The slight decline in infiltration and increasing direct runoff in the BD3 were attributed to the 50% land development since 2003, whereas the decline in peakflow discharge was attributed to the stream restoration and the construction of stormwater detention basins in the developed areas (Figure 3, Table 2).
- The decline in peakflow from the BD1, BD3, and BD4 sub-watersheds were indicated from the unit hydrograph and unit impulse response analysis. The results are attributed to the engineered SCMs (figure 3 and 4, Table 2).
- The unit hydrograph and unit impulse response analysis approaches indicated a increase in peakflow discharge for the largest (BD5) sub-watershed attributed to the change in time to peak of the contributing sub-watersheds as well as to an increase in peakflow of the BD2 sub-watershed (Figure 3 and 4, Table 2).

Parameters	BDC Sub-watersheds	Change Unit Hydrograph	Change Unit Impulse Response	Mann-Kendall Analysis (For the growing season only)
Average Streamflow	BD1	NA	NA	Decreasing
	BD2	NA	NA	NT
	BD3	NA	NA	Decreasing
	BD4	NA	NA	Increasing
	BD5	NA	NA	Decreasing
Average Baseflow	BD1	NA	NA	Decreasing
	BD2	NA	NA	NT
	BD3	NA	NA	Decreasing
	BD4	NA	NA	Increasing
	BD5	NA	NA	Decreasing
Quickflow Yield	BD1	-6.20%	-4.60%	NT
	BD2	3.90%	4.20%	NT
	BD3	6%	2.30%	NT
	BD4	3.50%	4.00%	NT
	BD5	0.50%	-1.20%	NT
Peakflow	BD1	-13.2%	-28.4%	NA
	BD2	3.1%	9.5%	NA
	BD3	-12%	-7.8%	NA
	BD4	-15.8%	-4.4%	NA
	BD5	25.7%	24.8%	NA
Change Time to Peak (Hours)	BD1	0.75	0.25	NA
	BD2	0.25	-0.25	NA
	BD3	-0.75	0.75	NA
	BD4	0.75	0.25	NA
	BD5	0.75	-0.50	NA
Direct Runoff Duration (Hours)	BD1	1.1	NA	NA
	BD2	0	NA	NA
	BD3	0.34	NA	NA
	BD4	0.8	NA	NA
	BD5	0.9	NA	NA

Table 2: Comparing outputs of the Unit Hydrograph, Unit Impulse, and Mann-Kendall approaches

- The increasing trend in average streamflow for the BD4 sub-watershed was attributed to the groundwater supplemented with the delayed runoff from the engineered SCMs (Fig. 5, Table 2).
- Three of the five sub-watersheds BD1, BD3, and BD5 indicated decreasing trend in average streamflow and baseflow during the growing season (Figure 5, Table 2).
- A decline in baseflow and small increases in quickflow yield for the three out of five sub-watersheds suggest that runoff from the smaller precipitation events were captured in engineered SCMs and subsequently evaporated without contributing to the stream runoff (Figure 5 Table 2).
- The results of this study demonstrated that the unit hydrograph, unit impulse response, and Mann-Kendall trend test approaches all generally indicated similar changes in runoff response from the pre to post land development period.

Acknowledgements

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