Rock Creek Watershed

Stormwater Runoff Analysis

i-Tree Hydro Report

Stormwater modeling case study presented at the 17th Annual EPA Region 6 Stormwater Conference

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By Eric Kuehler[1] and Patti Erwin[2]

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[1] Technology Transfer Specialist, USDA Forest Service, Athens, GA
Contact information: ekuehler@fs.fed.us ; 706-559-4268
[2] Urban and Community Forestry Coordinator, Arkansas Forestry Commission, Fayetteville, AR
Contact information: patti.erwin@arkansas.gov ; 479-442-4963

Figure 1 Rock Creek watershed in western Little Rock, AR. USGS stream flow gaging station #07263580 (red dot in lower, right-hand corner of image) is the outfall for the watershed located at 36th Street. It reported hourly flow data in 2006.

Introduction

Rock Creek watershed is located in western Little Rock, AR and extends into Pulaski County. Prior to development, it was heavily forested with a mixture of pine and deciduous forest cover. This forest system, with its tree canopy cover to intercept and slow rainfall, ground cover to slow runoff velocity, and permeable soils to infiltrate stormwater and filter its pollutants, provided limited stormwater runoff and high water quality. With development, tree canopy was removed, permeable soils were compacted to support impermeable structures (i.e. roads, parking lots, buildings, etc.), and exposed ground cover was generally replaced with high maintenance lawns. This developed system increases stormwater runoff volume and velocity as well as pollutant loading to Rock Creek, the Arkansas River, and eventually the Gulf of Mexico. Increased stormwater volume and velocity contributes to soil erosion which increases suspended solids in the creek and can negatively impact the stream bed as well as the necessary fauna that maintains stream health. Pollution loading also impacts fish and other biota in the creek and downstream resulting in potential human health issues for those who harvest fish from the creek or river.

The stream outfall for the 54 km^2 Rock Creek watershed was monitored hourly in 2006 by the United States Geological Survey (USGS) using a gauging station located at 36th Street in Little Rock. This is an important watershed because many of its headwaters have become surrounded by development as urbanization expands westward from Little Rock and into the surrounding county. Understanding how urbanization and its interaction with natural resources impacts stormwater runoff in such a developing watershed can better steer stormwater management decisions. The purpose of this modeling project is to estimate the benefits of increased urban tree canopy cover (TC) and reduced directly connected impervious area (DCIA) on stream water quantity and quality in the Rock Creek Watershed.

Methodology

The USDA Forest Service urban hydrology simulation model, i-Tree Hydro[3], was used to estimate water quantity and quality for the Rock Creek watershed in its current condition (base case) and for various theoretical conditions (alternative case) such as increased TC and/or reduced DCIA. The Hydro model uses various data sets such as land cover percentages, meteorological and stream flow data, and elevation models to calibrate the watershed stream flow model with actual stream flow data.

Meteorological and streamflow discharge data were obtained from the Little Rock National Airport and United States Geological Survey's National Water Information System (NWIS), respectively. Topographic Indices (TI) were also used by i-Tree Hydro to estimate storm flow velocities. These three data sets were obtained through the i-Tree Hydro Graphic User Interface (GUI).

The boundary of the Rock Creek watershed was determined using the Watershed Assessment, Tracking and Environmental Results System[4] (WATER) provided by the Environmental Protection Agency (EPA) through Google Earth (Figure 1). Using the boundary layer for the watershed, land cover classification

[3] http://www.itreetools.org/hydro/index.php

[4] http://www2.epa.gov/waterdata/waters-watershed-assessment-tracking-environmental-results-system

for the entire watershed was estimated through photo interpretation of 200 random points within the boundary using i-Tree Canopy[5]. Eleven land cover classes were estimated (Table 1). This classification of land cover provided the current condition or base case from which all other management scenarios were compared.

Table 1 Rock Creek watershed land cover classification through photo interpretation using i-Tree Canopy.

Cover Class	# of Random Points	% Cover (+/- SE)
Deciduous tree canopy over permeable surface cover	48	24.0 (3.0)
Deciduous tree canopy over impervious surface cover	5	2.5 (1.1)
Evergreen tree canopy over permeable surface cover	19	9.5 (2.1)
Evergreen tree canopy over impervious surface cover	1	0.5 (0.5)
Short, deciduous vegetation	3	1.5 (0.9)
Short, evergreen vegetation	5	2.5 (1.1)
Herbaceous vegetation	48	24.0 (3.0)
Bare soil	5	2.5 (1.1)
Impervious surfaces that drain directly to receiving waters via pipes	33	16.5 (2.6)
Impervious surfaces that drain to permeable surface cover	29	14.5 (2.5)
Open water	4	2.0 (1.0)

For this case study, we compared current conditions with two alternative management treatments:

1. Increase tree canopy cover incrementally over the entire watershed (from 32% to 42%) with 33% of the increased canopy cover growing over impervious surface cover
2. Reduce directly connected impervious areas incrementally by up to 30% (from 50% to 35%) watershed-wide while assuming that disconnection will be discharged over pervious surfaces and thus not increase flooding.

Ten different treatment combinations were analyzed through i-Tree Hydro. Holding DCIA constant at 50%, we looked at the effects that tree canopy cover changes had on stormwater quantity and quality. Tree canopy cover treatments included 32%, 35%, 38%, and 42% TC. Holding TC constant at 32%, we analyzed the effects that reduced disconnection had on stormwater runoff. DCIA treatments included 50%, 45%, 40%, and 35%. To observe the cumulative effects of TC and DCIA, we also analyzed several combinations of these treatments that included 35% tree canopy with 45% DCIA (35TC45DC), 38% TC with 40% DCIA (38TC40DC), and 42% TC with 35% DCIA (42TC35DC).

In i-Tree Hydro, all land cover percentages must sum to 100. As tree canopy percentage increased, other land cover class percentages were decreased. To assess the stormwater effects from increased

[5] http://www.itreetools.org/canopy/index.php

tree canopy, calculations were made to determine how impervious and herbaceous land cover would change with increasing tree canopy cover percentages (Table 2). In our scenarios, we assumed that as tree canopy cover increased, one-third of that canopy would cover impervious surfaces and two-thirds would cover herbaceous surfaces. All other land cover was held constant.

Table 2 2006 Land cover percentage changes due to growing tree canopy over impervious and herbaceous cover for the Rock Creek watershed. It was assumed that 1/3 of the tree canopy would cover impervious surfaces and 2/3 of the canopy would cover herbaceous surfaces. All other land cover percentages used by i-Tree Hydro were unchanged from the base case.

Condition	% Tree Canopy	% Impervious	% Impervious under TC	% Herbaceous
Current (Base case)	32	30	13	27
35% TC	35	29	15	25
38% TC	38	28	16	23
42% TC	42	26	18	21

The i-Tree Hydro model allows the user to calibrate the modeled streamflow with actual streamflow data. Even though the meteorological data was not collected in the watershed (located over 10 km away in east Little Rock), we were able to calibrate the discharge volume for the watershed for 2006 to within 2% of actual discharge volume using the i-Tree Hydro auto-calibration function (hourly calibration interval) (Figure 2).

Results

For 2006, the Little Rock National Airport recorded 1132 mm of rainfall. The majority of the rainfall fell during the spring (32% for April through June) and autumn (33% for October through December) while the least percentage of rainfall fell during the summer (15% for July through September). The winter months (January through March) accounted for 21% of the total rainfall for the year.

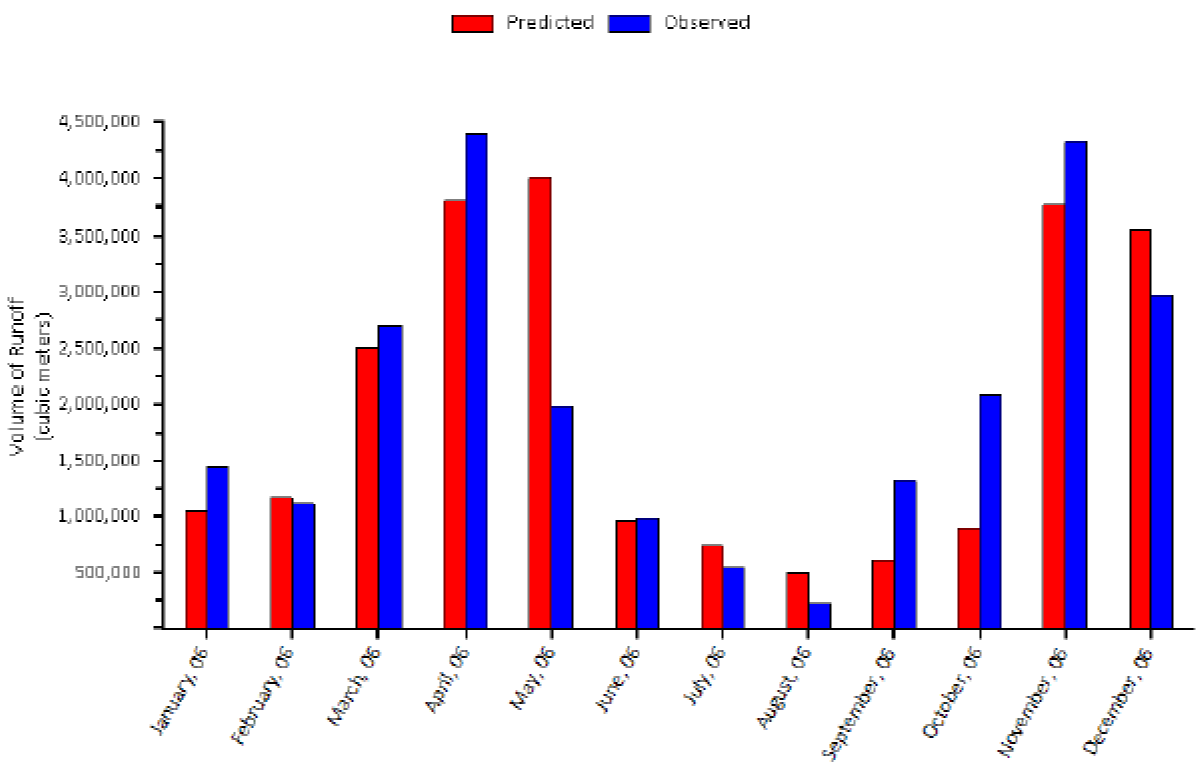

Figure 2 i-Tree Hydro calibration results for 2006 stream discharge data obtained from the Rock Creek gaging station and 2006 weather data collected at Little Rock National Airport in east Little Rock. Predicted streamflow (red columns) over the year was predicted to be 2% lower than observed stream discharge (blue columns).

Tree canopy results

Keeping DCIA constant at 50% and increasing TC incrementally from the estimated 32% to 35%, 38%, and 42%, i-Tree Hydro estimated that total streamflow volume would be decreased by 97.4, 113.4, and 126.3 million gallons annually, respectively, or 1.6%, 1.8%, and 2.0%, respectively (Table 3). Overland impervious flow would be reduced by 4.7 and 18.2 million gallons if TC were increased to 38% and 42%, respectively, however, overland flow would be essentially unchanged when increasing TC from 32% to 35%. Stream base flow would also be reduced by approximately 2% with increasing canopy cover.

Using national event mean concentration (EMC) data, i-Tree Hydro estimated pollutant loading for the watershed. For Rock Creek, overall pollutant loading was shown to be reduced annually by 0.2%, 0.8%, and 2.5% when TC was increased to 35%, 38%, and 42%, respectively. Because these estimates are derived from national averages it is advised to use these values to show trends only. More detailed monitoring of the stream would be suggested to get more accurate pollutant loading results.

Table 3 Rock Creek total annual streamflow, overland impervious flow, and base flow in millions of gallons as modeled by i-Tree Hydro for the base case (32% tree cover) and for increased tree canopy cover while holding directly connected impervious area constant at 50%.

%TC	Total annual flow (million gal.)	% change	Overland impervious Flow (million gal.)	% change	Base flow (million gal.)	% change
32	6216	-	748.5	-	5401.8	-
35	6119	-1.6	748.6	0	5305.7	-1.8
38	6103	-1.8	743.8	-0.6	5294.7	-2.0
42	6090	-2.0	730.3	-2.4	5295.4	-2.0

Directly connected impervious area results

Keeping TC constant at 32% and incrementally decreasing the percentage of DCIA from the base case of 50% to 45%, 40%, and 35%, i-Tree Hydro estimated that total, annual streamflow would initially decrease by 19.6 million gallons (0.3%) at 45% DCIA, but then increase by 33.8 and 88.1 million gallons (0.5% and 1.4%) at 40% and 35% DCIA, respectively (Table 4). Overland impervious flow showed tremendous decreases annually ranging from 74.8 to 224.5 million gallons (10% - 30% reduction) as DCIA decreased. We assumed that the end of these directly connected structures would flow over pervious land cover before reaching the creek thus increasing soil infiltration of stormwater. Because of this increased infiltration, i-Tree Hydro estimated that annual stream base flow volume would increase by 54.0, 179.8, and 306.7 million gallons for 45%, 40%, and 35% DCIA, respectively. This would be an increase of 1.0%, 3.3%, and 5.7%, respectively.

Table 4 Rock Creek total annual streamflow, overland impervious flow, and base flow in millions of gallons as modeled by i-Tree Hydro for the base case (50% Directly Connected Impervious Area) and for decreased DCIA while holding tree canopy cover constant at 32%.

%DCIA	Total annual flow (million gal.)	% change	Overland impervious Flow (million gal.)	% change	Base flow (million gal.)	% change
50	6216	-	748.5	-	5401.8	-
45	6197	-0.3	673.6	-10.0	5455.8	+1.0
40	6250	+0.5	598.8	-20.0	5581.6	+3.3
35	6304	+1.4	523.9	-30.0	5708.4	+5.7

By decreasing the volume of stormwater that is flowing over impervious surfaces (and depositing directly into Rock Creek) and allowing it to infiltrate onto permeable surface cover, we would expect pollutant loading to the creek to be reduced. Hydro estimated that annual pollutant loads could be reduced by 9.0%, 17.9%, and 26.8% at 45%, 40%, and 35% DCIA, respectively. This makes sense as more of the stormwater runoff is allowed to percolate through the soil and thus pollutants would be filtered.

TC and DCIA combination results

Running various scenarios with increasing TC and decreasing DCIA can help us see the cumulative effect that these systems have on stormwater runoff quantity and quality. Compared to the base case (32TC50DC) total annual stream flow was reduced by 43.8 million gallons for 35TC45DC but increased by 34.8 million gallons for 42TC35DC (Table 5). Overland, impervious flow showed a steady reduction as TC increased and DCIA decreased. Hydro estimated a reduction of 74.7 (10.0%), 153.5 (20.5%), and 237.3 (31.7%) million gallons of stormwater runoff for 35TC45DC, 38TC40DC, and 42TC35DC, respectively. Base flow, however, was estimated to increase by 30.0 (0.6%), 143.9 (2.7%), and 266.9 (4.9%) million gallons for 35TC45DC, 38TC40DC, and 42TC35DC, respectively.

Table 5 Rock Creek total annual streamflow, overland impervious flow, and base flow in millions of gallons as modeled by i-Tree Hydro for the base case (32% Tree Canopy cover and 50% Directly Connected Impervious Area) and for various combinations of tree cover and directly connected impervious area percentages

Treatment	% TC	% DCIA	Total annual flow (million gal.)	% change	Overland impervious Flow (million gal.)	% change	Base flow (million gal.)	% change
32TC50DC	32	50	6216.2	-	748.5	-	5401.8	-
35TC45DC	35	45	6172.4	-0.7	673.8	-10.0	5431.8	+0.6
38TC40DC	38	40	6209.6	-0.1	595.0	-20.5	5545.7	+2.7
42TC35DC	42	35	6251.0	+0.6	511.2	-31.7	5668.7	+4.94

By increasing TC and decreasing DCIA concurrently, stormwater runoff pollution loading was shown to decrease by greater amounts than if TC were increased or DCIA were decreased alone (Figure 3). Hydro estimated that annual pollutant loads could be reduced by 9.0%, 18.5%, and 28.5% for 35TC45DC, 38TC40DC, and 42TC35DC, respectively, compared to the base case (Table 6). This demonstrates the cumulative effect that increasing tree canopy has in combination with disconnecting stormwater drains that empty directly into receiving waters.

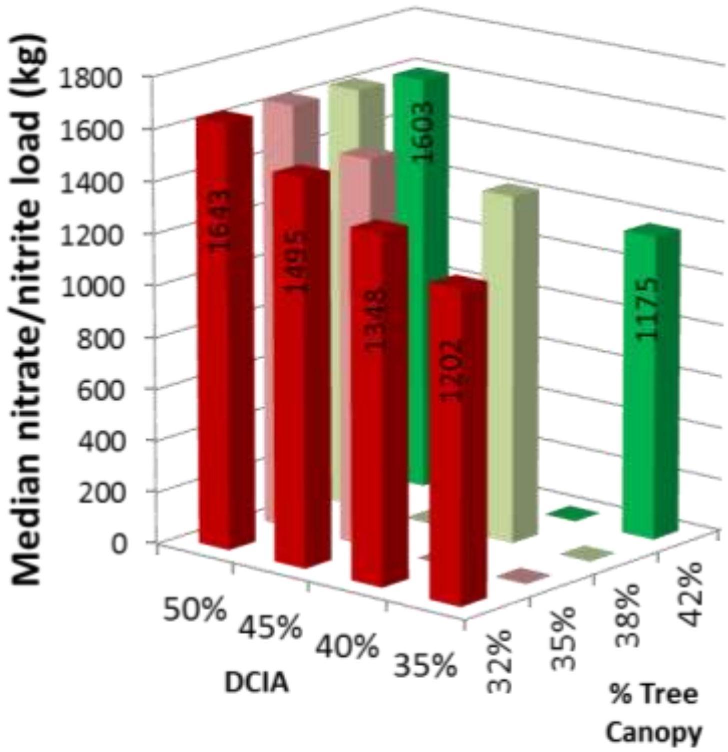

Figure 3 Annual median nitrate/nitrite pollution loading by treatment combination (% directly connected impervious area - DCIA and % tree canopy cover) as estimated by i-Tree Hydro. By increasing TC and decreasing DCIA concurrently, stormwater runoff pollution loading was shown to decrease by greater amounts than if TC were increased or DCIA were decreased alone.

Table 6 Estimated pollutant loading for Rock Creek watershed per i-Tree Hydro by tree canopy cover (TC) percentage and directly connected impervious area (DCIA) percentage. Pollution constituents include total suspended solids (TSS), chemical oxygen demand (COD), total phosphorus (TP), soluble phosphorus (Sol P), total Kjeldhal nitrogen (TKN), nitrite and nitrate (NO2_3), copper (Cu), and lead (Pb).

% TC	% DCIA	TSS (kg)	COD (kg)	TP (kg)	Sol P (kg)	TKN (kg)	NO2_3 (kg)	Cu (kg)	Pb (kg)	% change[a]
32	50	168028	137814	798.5	317.6	4532.1	1643.3	34.22	156.31	-
42	35	120138	98534	570.9	227.0	3240.4	1174.9	24.47	111.76	-28.50
32	35	122937	100831	584.2	232.3	3315.9	1202.3	25.04	114.37	-26.84
38	40	136983	112351	651.0	258.9	3694.8	1339.7	27.90	127.43	-18.48
32	40	137890	113096	655.3	260.6	3719.3	1348.5	28.08	128.28	-17.94
35	45	152791	125317	726.1	288.8	4121.2	1494.3	31.12	142.14	-9.07
32	45	152838	125355	726.3	288.9	4122.4	1494.7	31.13	142.18	-9.04
42	50	163911	134437	779.0	309.8	4421.1	1603.0	33.38	152.48	-2.45
38	50	166711	136733	792.3	315.1	4496.6	1630.4	33.95	155.09	-0.78
35	50	167760	137594	797.2	317.1	4524.9	1640.7	34.16	156.06	-0.16

[a] percent change of pollution loading compared to that of the base case (32% TC – 50% DCIA)

Conclusion

Increasing tree canopy cover over a watershed mitigates stormwater runoff and pollution loading modestly. In the Rock Creek watershed, increasing tree cover by 30% (from 32% to 42%), we could expect total stormwater runoff to be reduced by about 2% and pollution loading by 2.5%. The results from this project show that the larger contributor to reducing pollution loading is by reducing the amount of directly connected impervious area and allowing more of the stormwater runoff to infiltrate into the soil before it reaches the stream.

Tree leaves and branches intercept rainfall and retain a portion thus preventing it from reaching the ground. Tree canopy also temporarily detains rainfall and releases it slowly as throughfall thus slowing the velocity of stormwater runoff. This slowing of stormwater velocity is beneficial for stormwater management as it allows soils and stormwater BMPs to work more efficiently and not become overwhelmed. By using trees in conjunction with reduced impervious area, we could expect to reduce pollution loading. In this project i-Tree Hydro estimated that pollution loading was reduced an additional 6.2% when tree canopy cover was increased and DCIA decreased by 30% compared to decreasing DCIA by 30% alone.

Maintaining forested systems along creeks, conserving remnant forested lands, and managing the urban forest so as to minimize the negative impacts of development can help mitigate stormwater runoff volume and quality. Management strategies that increase tree canopy cover and leaf area can help to retain a portion of rainfall in the crown preventing it from running off as stormwater and slow rainfall velocity so that more runoff can soak into soil. Conserving uncompacted soil especially under tree canopy with vegetation or mulch can also help infiltrate stormwater and reduce runoff velocity.

The urban forest provides a myriad of environmental benefits that contribute to quality of life for a city's residents and visitors. Such benefits not only include stormwater runoff mitigation, but also energy conservation, urban heat island mitigation, air pollution removal, increased property values, increased human health, etc. By including urban forest management in with a city's various other managed systems (i.e. stormwater management, air quality management, electrical utility management), we could expect to reduce some of the negative consequences that come with development.