WATER RESOURCES RESEARCH INSTITUTE

ACHIEVING NEW MILESTONES FOR STORMWATER RUNOFF REDUCTIONS IN BLACK CREEK WATERSHED

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1. Executive Summary

The Black Creek Watershed Association (BCWA) works on disconnecting impervious surfaces from the creek system through retrofits and education. BCWA is a partnership of citizens, neighborhoods, and local government organizations and agencies formed ten years ago and coordinated by the Water Resources Research Institute at NC State University. They assessed the causes of Black Creek's impairment and developed a watershed restoration and action plan in 2009. The watershed assessment conducted during the planning process (2009) identified excessive stormwater runoff volumes and velocity as the main impairing factors, with polluted runoff, particularly nutrients and toxins, as secondary factors. Much of the stormflow during rain events runs off of the impervious surfaces like parking lots and arrives from culverts and pipes that drain straight into the creek while bypassing riparian buffers. Restoring the biological health of the watershed requires broad scale implementation of stormwater practices to disconnect existing impervious cover from the creek system and allow stormwater to infiltrate.

This EPA319 project built on the momentum from the many previous retrofit projects successfully implemented at schools and in neighborhoods, facing towards a new audience of private landowners of large parcels that include business, non-profit, and municipal sites. The project also included retrofitting and monitoring previously permitted bioretention (rain garden) areas to determine possibility for increasing infiltration, and monitoring and modeling headwater tributary hydrology to better understand potential impacts of impervious surfaces disconnection scenarios.

Businesses and private institutions were successfully engaged through direct contact, providing information about the watershed effort and asking their interests in participating in retrofit and monitoring projects. We enjoyed a high positive response rate from those approached for projects and in-kind effort, and negative responses the few times when donations were requested. Site constraints prevented us from installing bioretention at a coastal Federal Credit Union branch. We instead partnered with Harvest Church, located in highly impervious upper East Fork to install bioretention areas, bioswales, and permeable walkways. Three commercial/office sites participated in retrofits to increase and monitor stormwater storage in bioretention cells, included Advance Auto, Discount Tire, and the Accreditation Commission for Health Care. Veolia/Kruger, Inc. sponsored an employee service stream clean-up event, and Fortnight Brewing Company and Water Resources Research Institute sponsored a "Black Creek Backyard Safari" educational field tour.

The continuation of retrofit efforts at public and residential sites had mixed results. While the BCWA prioritized retrofits at North Cary Park, various constraints prevented a project there. A constructed wetland was installed at the nearby Robert J. Godbold Park instead. High interest from homeowners in residential projects that we call "Rainscapes" continued by word of mouth, resulting in several site visits and advice, two conservation plantings, and one rain garden that we installed. We sought to implement 1-2 more rain gardens with willing homeowners in the last quarter of the project but were unable to identify a contractor to do so. Capacity for affordable professional installation of rain gardens continues to present challenges in this area.

Regarding monitoring efforts, two bioretention cells were retrofitted with an upturned elbow at the underdrain outlet and monitored. The research found that retrofitting existing bioretention in Black Creek watershed can reduce the volume of runoff discharged from bioretention to the creek by up to 50% when recommended soil media is used. Streamflow monitoring in the main stem of Black Creek and in two headwater tributaries coupled with modeling were conducted to estimate the reductions of stormwater volume and peak flow with various retrofit scenarios. Results find disconnecting ~30 acres of impervious cover in the high priority Upper East Fork would reduce effective impervious cover to 31% from the current 42%, and reduce 700,000 gallons of stormwater reaching Black Creek from a 1 inch storm. This subcatchment that drains part of downtown Cary including the Town of Cary municipal campus and the Harvest Church site, is a high priority for retrofits.

Private and school interest in participating in stormwater retrofits and support activities is high in this watershed, meaning opportunities for continuing retrofits should be plentiful. While implementing this project, we identified an elementary school in the high priority East Fork headwaters interested in partnering, and were approached by a homeowners association for partnering on residential retrofits. Finding local capacity, including contractors for installation and funding, are the limiting factors in continued restoration of the watershed. Landowner and volunteer interest in participating continues to drive restoration of the popular Black Creek watershed forward.

2. List of figures

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Abbreviations:

Accreditation Commission for Health Care (ACHC)
Advanced Auto (AAuto
Black Creek Watershed Association (BCWA)
Best Management Practices (BMPs)
Bioretention cell (BRC)
Discount Tire (DT)
Environmental Protection Agency (EPA)
Fiscal Year (FY)
Geographical information systems (GIS)
Internal water storage (IWS)
Nitrate (NO2)
North Carolina Division of Water Resources (NCDWR)
NC State University (NCSU) Department of Biological and Agricultural Engineering (BAE)
Orthophosphate (ortho-P)
Total ammoniacal nitrogen (TAN)
Total Kjeldahl nitrogen (TKN)
Total Maximum Daily Load (TMDL)
Total phosphorus (TP)
Total suspended sediments (TSS)
Water Resources Research Institute (WRRI)

4. Introduction/Background

The Black Creek Watershed Association (BCWA) is a partnership of citizens, neighborhoods, and local government organizations and agencies that was formed and has been coordinated by NC State University since 2006. They initially assessed the causes of Black Creek's impairment, and developed a watershed restoration and action plan (2009) to improve the stream system's health that was accepted by EPA as an alternative to a Total Maximum Daily Load (TMDL). The Black Creek watershed, about 3.3 mi2 in area, is in the northern section of the Town of Cary. The creek discharges to Lake Crabtree, in the Crabtree Creek subwatershed of the Neuse River Basin. The watershed is typical of a developed Piedmont watershed with hilly terrain, low-high density residential subdivisions, schools, town parks, and supporting commercial and office properties. The Town's popular Black Creek Greenway runs adjacent to most of Black Creek and connects to Umstead State Park, Crabtree County Park, and City of Raleigh greenways. Hence many people are familiar with the creek system through use of the greenway.

Highly urbanized, the watershed is nearing build-out with a combination of high density residential, commercial, and institutional development. Classified C, NSW (nutrient supporting watershed), Black Creek has been on the EPA Clean Water Act Section 303(d) list since 1998 with impairment for aquatic life and potential sources listed as urban runoff/storm sewer. Like many suburban Piedmont watersheds, most of it was built out before stormwater regulations such as the Neuse Rules and EPA Phase Two were in effect. The watershed assessment conducted as part of the Black Creek Watershed planning process (2009) identified excessive stormwater runoff volumes and velocity as the main impairing factors. Much of the stormflow during rain events arrives from culverts and pipes that drain straight into the creek or its tributaries bypassing the riparian buffers, resulting in increased pollutants and erosion. The assessment also found high levels of fecal coliform bacteria, and high turbidity and nutrients during targeted stormflow monitoring. While the riparian buffers in this watershed are mainly intact, many stormwater conveyances connect directly from downspouts and parking lots to the creek system bypassing opportunities to infiltrate stormwater. A GIS study conducted by a BCWA member characterized 23% of the watershed land as impervious cover that is untreated by stormwater management practices (though overall impervious cover is closer to 30%). Restoring the biological health of the watershed requires broad scale implementation of stormwater retrofit practices to disconnect this impervious cover from the creek system and allow stormwater to infiltrate and evaporate. In the years of 2009- 2013 we successfully created and implemented a residential retrofit campaign and schoolyard retrofits, resulting in multiple schoolyard retrofits and multiple residential scale retrofits that we called "rainscapes". This FY12 EPA319 project continued the

Figure 1: Black Creek after storm event

efforts of the Water Resources Research Institute, NC State University, the Town of Cary, and the BCWA in disconnecting impervious cover and restoring the creek back to health. For this effort, we turned to new target audiences of private organizations and Town of Cary Parks to increase awareness of our efforts and broaden our reach across the watershed.

5. Purpose and Goals

Goals seek to continue implementing the watershed plan and measuring improvements.
The grant allowed the BCWA and project team to build on the successes, momentum, and tools created to continue working towards delisting of Black Creek. Specific goals included:

- Continue Black Creek restoration by engaging the commercial development community, with education, a commercial site retrofit demonstration BMP, and improving infiltration of existing permitted bioretention
- Create a sponsorship and recognition program for Black Creek donors and partners
- Continue Black Creek restoration by installing retrofit BMPs on public land
- Continue Black Creek restoration by installing at least one more residential BMP to keep our foot in the door with residents
- Expand flow monitoring to a high priority headwater tributary. Use GIS and hydrologic data sets to more precisely determine the retrofit targets needed to move the stream system to a natural flow regime that has less erosive flows, and thus will lead to improved biologic community.

6. Deliverables

Periodic meetings of the BCWA to plan outreach and education activities, provide guidance on site selections, and BMP designs

- The BCWA met six times over the course of the grant to provide guidance on all aspects of the grant.
- They also were engaged electronically in between meetings via individual and small group emails.
- An online survey was provided to BCWA members to learn preferences for an educational field tour.

Figure 2: Black Creek Backyard Safari

Regular outreach and engagement with BCWA and community: periodic electronic or printed newsletters to inform community of efforts and recruit participants, BCWA website updated regularly, with access to maps, reports and educational materials; social media updates.

Activities included:

- A new BCWA website rolled out in August 2015 at go.ncsu.edu/blackcreek
- Two newsletters called "the Black Creek Watershed Wire" were published and distributed to members of the Black Creek Watershed database.
- Black Creek listserve communications: Informal email updates were provided in lieu of the newsletters on a regular basis. The Black Creek watershed audience is extremely comfortable with electronic communications, so the listserve and Facebook page continue to serve as the main lines of communication. Invitations to workshops and volunteer service events were sent by email. BCWA members frequently used the listserve to share about issues and proposed development that affect the watershed.
- BCWA Facebook page: All events and occasional informational posts were made on the FB page. We experimented with sponsoring a Facebook event to see if that would increase registration to the event and followers. It did not appear to increase registrations, it did direct traffic to the BCWA Facebook page and resulted in increased awareness of the BCWA, and a few additional "likes".
- A new tabletop banner was designed and created to bring to events.
- Town of Cary Arbor Day: A BCWA display was set up at a booth in March 2016. An Enviroscape was used to engage the youth and adults who stopped by the booth.

Core steering committee of business/institutional stakeholders convened and meets regularly; Outreach/engagement plan for business/institutional stakeholders developed and implemented, including a public recognition event for sponsors and partners.

- Individual phone calls and emails to business owners, including members of Rotary and the Cary Chamber of Commerce were made to explore the idea of a steering committee. It was determined impractical to convene a steering committee of business stakeholders given the small size of the watershed.
- An outreach/engagement plan for business/institutional stakeholders was developed by the BCWA early in the grant period. The main objectives included increased knowledge about BCWA, stormwater effects and solutions among businesses and institutions in the watershed.
- A fact sheet targeting businesses was created to raise awareness of our efforts and entice them to get involved.

- A small number of BCWA members agreed to provide 1-2 businesses with fact sheets targeted for institutional education and engagement. The businesses reached were located within shopping centers so they did not have authority for onsite landscape changes. This effort may have raised awareness of our group but did not result in partnerships.
- We approached businesses to ask them to partner with us on the bioretention monitoring project, and provided the same fact sheets. All of the businesses approached agreed to participate, including Accreditation Commission for Health Care (ACHC), Discount Tire, and Advance Auto.
- Organizations who partnered on or sponsored Black Creek efforts were recognized via social media (Facebook page), in event printed materials, the website, and via emails to the listserve.

Sponsorship program developed and launched, with donations from sponsors received.

Sponsorships were sought individually from organizations specifically to fund Big Sweep and a field tour event, Black Creek Backyard Safari. Harris Teeter, Walmart, Café Carolina, WRRI, and Fortnight Brewing Company were approached for in-kind or financial sponsorships. Contributions received include:

- WRRI provided lunch for the Black Creek Backyard Safari
- Fortnight Brewing Company gift/tour certificates to include in tour packets
- Kruger/Veolia, who have an office in the watershed, sponsored Big Sweep for Black Creek in April 2016 as an employee service day. They provided breakfast and lunch to volunteers who conducted the clean-up. The employee who organizes service events learned about BCWA through a colleague who lives in the watershed and participated in our Backyard Safari. It's not surprising that we're finding sponsorships are more likely acquired through networking and connections than cold calls.

Figure 3: Veolia/Kruger employees celebrate a successful Big Sweep with BCWA

3 annual stream clean-ups

Big Sweep for Black Creek events were held in October 2013, September 2014, and April 2016. A stream clean-up scheduled for October 2015 had to be canceled due to a tropical storm. Each time the clean-up removes trash from ~3 miles of the stream and greenway.

We partnered with the Town of Cary on each Big Sweep, as we scheduled the clean-ups on the same day the Town held their Big Sweep events. Town of Cary staff provided refreshments and give-aways, gloves and bags, and picked up the trash and recycling after it had been collected by our volunteers. Kruger/Veolia, who have an office in the watershed, sponsored the April 2016 Big Sweep.

Two stormwater retro-fits on public properties.

Northwoods Elementary School Cistern

A 450 gallon cistern and a pump were installed in the community garden at Northwoods Elementary school. Our Wake County Extension partner Mitch Woodward and a PTA parent installed the cistern and pump, with Northwoods Elementary PTA contributing funds to install a gutter on the trailer classroom where the cistern is located. The school installed educational signs to accompany the cistern, and teachers, students, and PTA members use it regularly.

Location: Latitude 35°47'45.08"N , Longitude 78°47'25.06"W

Size of treatment area: 560 sq. ft. rooftop

Size of cistern: 450 gallons

Pollutant removal/water captured: 5850 gallons captured annually (assuming 25% of barrel used each week). 12 pounds N removed from stormwater runoff annually.

Figure 4: Northwoods Elementary School cistern (left and right) and school garden (right)

Robert J. Godbold Park wetland:

A wetland was installed to treat a parking lot at this Town of Cary public park. The wetland was located at the site of an undersized and underperforming dry detention basin. Town of Cary Public Utilities did the excavation themselves, while volunteers were organized, including four Green Hope High School students and WRRI employees, to install the wetland plants.

Figure 5: Godbold Park wetland during fall planting (left) and the following spring (right)

Location: 35.80062” N, 78.791285"W

Size of treatment area: .79 acre of parking lot

Size of wetland: 1,200 square feet

Pollutant removal:

Table 1: Pollutant removals from Godbold Park wetland

	Load before BMP (lbs/yr)	Load after BMP (lbs/yr)	Load Reduction (lbs/yr)
BOD	40	15	25
COD	696	348	348
TSS	1,785	402	1,384
LEAD	2	1	1
COPPER	0	U	U
ZINC	3	2	1
TDS	4,787	U	U
TN	10	8	2
TKN	14	U	U
DP	0	U	U
TP	1	1	1
CADMIUM	0	U	U

U = Removal Efficiency for the particular BMP and constituent unavailable.

Methodology is EPA Region 5 Model based on the manual "Pollutants Controlled Calculation and Documentation for Section 319 Watersheds Training Manual".

Storm Peak flow from the 1 yr. 24 hr. storm (2.88 inches) is reduced from predevelopment rate

Pre-Development 1.46 cfs
Post Development 2.29 cfs
Original Design 1.03 cfs
Retrofit Design 0.6 cfs

One stormwater retro-fit on a business or institutional property, to treat a large parking lot or rooftop (example: grocery store, strip mall, or church parking lot)

Harvest Church retrofits: A series of BMPs were constructed at this site in the headwaters of the East Fork of Black Creek, including two bioretention areas, a grassed bioswale, and permeable walkways that replaced previously impervious walkways.

Location: Latitude "N, Longitude "W

Size of treatment area: 5,250 sf

Size of permeable paved walkway: 1300 sf of impervious surface removed and 1,500 sf of PICP installed.

Figure 6: Harvest Church permeable walkways and bioretention

Pollutant removal: See table below, calculated using Jordan Lake model.

Table 2: Stormwater pollutant and volume reductions for Harvest Church

Practice	Area in square feet	Total N reduction lbs/ac/yr	Total P reduction lbs/ac/yr	Vol reduction cf/yr
Bioretention area 1	1600	4.1	0.7	2,011
Bioretention area 2	1250	4.1	0.7	1,573
Bioswale area	2500	4.1	0.7	3,145
Totals	**5350**	**12.3**	**2.1**	**6,729**

1 residential rain garden

The Morris rain garden was designed and constructed in the Silverton neighborhood of the watershed. This is the first residential rain garden built in this neighborhood.

Location: 35°49'41.99"N, 78°46'31.35" W

Size of treatment area: 1000 square feet

Size of raingarden: 150 square feet

Pollutant removal: .20 lbs nitrogen per year

At least 3 bioretention underdrains will be retrofit as IWS zones to increase infiltration.

Three existing permitted bioretention areas were identified and initially included in the study and retrofit plan. One of these bioretention areas was eventually determined as not monitorable. Two bioretention areas, at Advanced Auto and Discount Tire, were retrofitted with internal water storage (IWS) zones.

Three bioretention cell hydrologically monitored pre- and post-retrofit to determine increased infiltration/reduced outflow from this procedure.

Done, with two bioretention cells monitored pre- and post-retrofit to determine increased infiltration/reduced flow. Methods and results are included in the “Methods and Execution” section of this report, with the full report with data and references included as an appendix.

Stormwater retrofit BMP atlas of potential projects updated to include additional potential sites

The Black Creek watershed stormwater retrofit BMP atlas was updated with additional sites identified by the project team and BCWA volunteers. Sites that were implemented were marked as such, and a BCWA volunteer converted the atlas to a format that allowed creation of a GIS layer of existing and potential BMPs in the watershed.

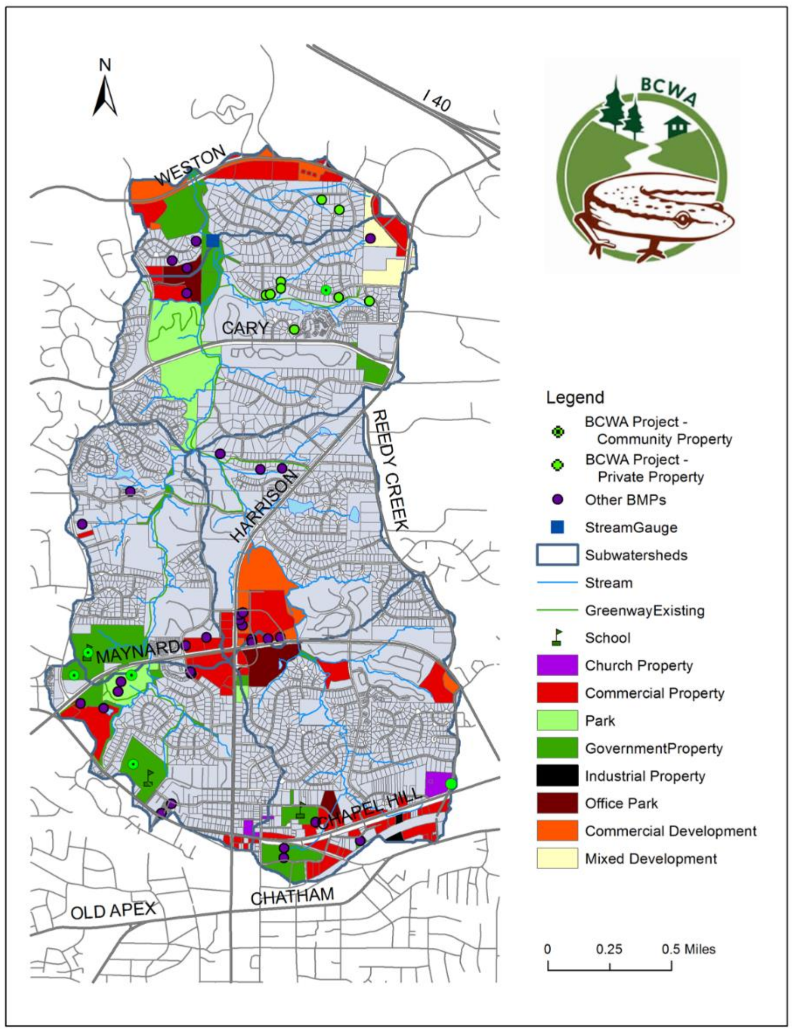


Figure 7: Watershed map with best management practices

Additional projects anticipated depending on amount leveraged by sponsorships.

Some in-kind sponsorships were acquired. Additional activities occurred, some related and some not related to the sponsorships. There activities are listed here:

- **Northwoods Elementary 5th grade service event:** We worked with the Northwoods Elementary PTA to help prepare for and plan a service event to uplift their rain garden in spring 2015. This included educating parents about rain garden maintenance.

- **Black Creek Backyard Safari**: An educational public field tour was held in October 2015. Sixteen people, including 3 middle school children, walked a greenway and learned about Black Creek and its aquatic inhabitants, stormwater impacts, and solutions for reducing stormwater running into the creek. Five volunteers from BCWA and the NCDWR served as guest hosts while they explained how the Northwoods Elementary School rain garden and cistern worked, what was happening in the Godbold Park wetland and a raingarden along a private greenway, and shared samples of macro-invertebrates and a salamander caught in the creek. An educational sign was created and installed at the greenway rain garden for the event, and will remain there to educate homeowners about rain gardens. As a result of the event, additional community members were subscribed to the Black Creek listserve, and a new introduction was made by a participant to a business whose employees actively use the greenway.
- **"Rain Gardens Need Love, too" service events:** This effort educated about the importance and "how to" of long-term, regular maintenance of installed stormwater projects. Two service events to install mulch and plants at the West Cary Middle School parking lot bioretention were planned, one with a high school group and BCWA volunteers, and one with school staff and PTA members. As school administration and parents have turned over since the 2010 installation, the events brought them up to speed on the purpose and care of the bioretention areas. The school was provided with an updated maintenance schedule. They pledged to "uplift" the additional bioretention areas on their own. Posts about the event raised awareness about the need for rain garden maintenance, resulting in a PTA member from a different school cheering the event and stating that they will do something similar at their school's bioretention area in 2017.

7. Methodology and Execution

Public retrofits

Northwoods Elementary School: Given a previous partnership with Northwoods Elementary School, they were familiar with the watershed restoration effort and eager to install a rainwater harvesting cistern in their community garden. The PTA provided cost sharing in the form of having a gutter installed on a trailer adjacent to their community garden. Wake County Extension Agent Mitch Woodward installed the cistern with help from a PTA parent. The PTA also added multiple spigots for collecting rainwater with multiple watering cans. A teacher commented that the kids love and look forward to watering the garden using the cistern. This project has provided multiple benefits of reducing runoff, providing water conservation opportunities, and increasing awareness of students, parents, and the public about rain water harvesting. Most recently,


Figure 8: Students at Northwoods Elementary

the school's community garden was featured on a news story, with the cistern shown throughout the footage:

http://abc11.com/education/school-gardens-giving-back-to-community/1495522/

Town of Cary park sites:

Figure 9: North Cary Park bioretention concept design

First try- North Cary Park: The BCWA was interested in a project at North Cary Park for educational purposes, so we decided with initial support from the Town to pursue design of a bioretention area to treat the parking lot runoff currently not being treated. The site was surveyed, and a design was completed. Town of Cary staff liaisons with stormwater and Parks and Recreation met with others in Town of Cary Public Works and Utilities to see if they could provide equipment and excavation cost sharing and plan a construction date. Unfortunately, they decided not to support the project at that site at all, due to the expense of having to move a utility pole, concerns about structural integrity of soils down slope of the rain garden, and ultimately because the Town has decided not to add BMPs that are not required by regulation to their maintenance schedule.

Robert J Godbold Park wetland: A wetland was designed and installed collaboratively with the Town of Cary at the Town's Robert V. Godbold Park. After a design was created, an on-site meeting was held to discuss the project. NCSU staff developed a list of tasks and proposed a division between the Town of Cary and NCSU. Town of Cary agreed to provide excavation services, while NCSU provided a requested soil survey, design services, and plants. The wetland was constructed during summer, 2014, with a volunteer planting event held in September. WRRI and Town of Cary Staff, Kris Bass Engineering, and four students from Green Hope High School AP Environment Class installed 223 plants. Plants included soft rush, fox sedge, lizard tail, pickerel weed, duck potato, Virginia sweetspire (around rip rap), American beauty berry (around rip rap), and swamp milkweed, which was requested by Town of Cary citizens to provide habitat for monarchs.

Private retrofits

The first business approached, Coastal Federal Credit Union (CFCU), was excited to work with us at their Harrison Ave branch. A bioretention design was created in the only place that was not impacted by utilities. Our contact suggested they would consider taking on the cost of required tree removal. However, after presenting the plan to our CFCU contact he informed us that he thought Town of Cary had a sidewalk planned adjacent to the area that may impact it. After many discussions with TOC Transportation staff, it was determined that the future sidewalk project would likely negatively impact a bioretention area, so the project did not move forward.

Figure 10: Harvest Church bioswale & permeable walkway

The second organization approached was Harvest Church, as we identified the site was located in the upper East Fork of Black Creek which is a high priority area for reducing runoff. A new parish was getting formed, and as their immediate focus was on improving the church grounds they were eager to work with us. A team of graduate students at NCSU BAE proposed a site plan which included bioretention, permeable pavement, and a cistern to treat rooftop runoff, and bioswales to treat parking lot runoff. Church leaders chose not to implement the bioswales in the front of the church lot, due to concerns that it would reduce play area for children. They also chose not to install a cistern due to aesthetic concerns. Bioswales were instead behind the church, to treat runoff from a building that houses classrooms in the back of the church lot (see Figure 10). The final results included multiple practices throughout the site.

Business/institutional campaign

We originally envisioned working with businesses and other private institutions by forming a subcommittee to guide these efforts and partnering with the Town of Cary to implement them by advertising opportunities to learn more and get involved. Given the small size of the watershed and difficulty reaching a wide swath of businesses through an organization like the Cary Chamber of Commerce or Rotaries in a small area, this method was abandoned. The Town was also not interested in partnering on such a campaign.

The more successful method for engaging businesses/institutions was to approach them individually with a specific project or action in mind. Businesses that were approached by BCWA members with fact sheets, with the purpose of follow up "site evaluations", were unresponsive. When we approached businesses with specific actions or projects that we could directly partner on, we received 100% positive responses (not including sponsorships). We approached businesses to ask them to partner with us on the bioretention monitoring project, they received the same fact sheets when they were initially approached. All of the businesses approached agreed to participate, including Accreditation Commission for Health Care (ACHC), Discount Tire, and Advance Auto.

We referred to our stormwater project atlas to identify private business/institutional sites that could provide water quality benefits. We first approached Coastal Federal Credit Union to work with them on installing a stormwater retrofit at their branch office in the watershed. They were eager to work with us, and we were pleased to have a private partner. However, utility and planned sidewalk improvement constraints ultimately prevented us from installing a retrofit at the branch. We then approached Harvest Church, which provided a much better opportunity to reduce runoff given their location in the headwaters and large size of their parcel. They too were eager to work with us, so we focused on a series of retrofits on the site.

Some sponsorships associated with specific events were received, so this part of the campaign was modestly successful. We learned that national corporations with a local presence were not productive targets, while small local organizations and those with whom we made connections through the BCWA network were more willing sponsors.

Organizations who partnered on or sponsored Black Creek efforts were recognized via social media (Facebook page), in event printed materials, the website, and via emails to the listserve.

Residential rain garden:

Four site visits to residential sites were conducted to assess for rain garden opportunities. Sites were identified by word of mouth among the BCWA. One homeowner hired a landscape professional to implement a rain garden design we provided. Due to the high cost quoted for the rain garden by the professional (his backyard has a steep grade, requiring retention walls, the cost quoted was >$4,000) the homeowner chose to implement conservation plantings and not the rain garden. The owner commented that erosive flows in his backyard had decreased as a result of the project. Another homeowner thought he may design and install one himself, though he, too, ended up going the easier route of planting natives. A Buckhurst West HOA property (playground) was visited on their request. Ideas for a rain garden and native plantings were provided to the Board, as well as the fact sheet series on rainscapes and ideas for native plantings that would help intercept runoff and reduce erosion.

Figure 11: Morris rain garden after planting

A residential rain garden site in the Buckhurst West neighborhood was selected and design began, then the homeowner moved away. A second site, a BCWA member's home in the Silverton neighborhood was then selected. Design and successful implementation of the Morris rain garden followed. An attempt at constructing a second rain garden that was identified and designed in the final months of the project was made. We were not able to find a contractor who was able to construct it within the time and budget constraints of our grant, however. One contractor responded with an extremely high quote, and another was affordable but unable to fit it into his crew's schedule. A third did not respond to our request. Finding affordable turn-key installation of residential rain gardens may be a concern for our next project.

Bioretention retrofits and monitoring

Site Descriptions

Three bioretention cells (BRCs) located in the Black Creek Watershed in Cary, NC were identified for monitoring and retrofit. Located at an Advance Auto Parts, Discount Tire, and the Accreditation Commission for Health Care, the three BRCs will henceforth be referred to as AAuto, DT, and ACHC, respectively. All were chosen due to their conventional design featuring non-elevated underdrains. Due to an unforeseen error during initial construction, ACHC was determined to not be monitorable. Multiple attempts to repair the BRC were not successful and a proper fix was deemed too costly. The remainder of this report will focus on AAuto and DT.

Table 3: Characteristics of the two bioretention cells examined

Attribute	Advance Auto	Discount Tire
Latitude	35.803277	35.803236
Longitude	-78.779720	-78.780596
Surface area (ac)	0.04	0.03
Drainage area (ac)	1.08	1.37
Hydraulic loading (unitless)	25.3	41.5
Watershed imperviousness (%)	84%	60%
Watershed land use	Commercial	Commercial
Media depth (ft)	3	Varies
Storage depth (in)	12	6.6

Figure 12: Advance Auto (left) and Discount Tire (right)

Methods

<u>Monitoring</u>

At the DT BRC, runoff entered the cell via a riprapped channel connected to an asphalt parking lot and through two connected downspouts (8-inch and 3-inch). Runoff exited the DT BRC via a single 6-inch underdrain and through bypass overflow occurring at the outlet structure. To effectively monitor the five flow locations, a compound weir was installed to capture higher flow from the parking lot and contracted v-notch weirs were installed at the remaining locations. Water depth at each weir was monitored on 2-minute intervals with Onset® HOBO® U20 Water Level Data Loggers. Water levels were subsequently converted to flow measurements using the weir equation. Data were processed and analyzed using Hoboware ® Pro software.

At the AAuto BRC, watershed runoff was routed through a junction box into the BRC via a 15-inch RCP. An ISCO 720 area velocity meter was installed on the bottom of the inlet pipe to collect flow data using the known dimensions of the inlet pipe. AAuto was drained by two 4-inch underdrains connected to an outlet structure. A compound weir was installed in the outlet structure and an ISCO 730 bubbler module measured water depths. All flow data was collected on 2-minute intervals. Rainfall data was also monitored with a manual rain gauge and a recording, tipping bucket. Flow and rainfall data were processed and analyzed using ISCO Flowlink ® software.

Water quality samples were also collected at AAuto using ISCO 6712 automated samplers. Composite water quality samples were taken at the inlet and outlet on a flow-weighted event basis, triggered by measurements taken from the area velocity meter and bubbler module, respectively. Per U.S. EPA (2002) standards, a minimum of five aliquots was required for a sample to be representative of the storm event. Events producing precipitation between 0.2-2.0 inches and with antecedent dry conditions of at least 6 hours were sampled, provided outflow was generated. Samples were chilled on ice and transported to a U.S. EPA certified laboratory within 24 hours of event conclusion. Laboratory analysis was performed for total Kjeldahl nitrogen (TKN), nitrate and nitrite ($NO_{2,3}$-N), total Ammoniacal nitrogen (TAN), total phosphorus (TP), orthophosphate (ortho-P), and total suspended sediments (TSS). Organic nitrogen (ON) was calculated as the difference between TKN and TAN. Particle bound phosphorus (PBP) was calculated as the difference between TP and ortho-P. Total nitrogen (TN) was calculated as the sum of TKN and $NO_{2,3}$-N.

Discount Tire

Following the installation of monitoring equipment, the pre-retrofit period at the DT BRC began in June 2014. During the pre-retrofit period (late April 2014 – early November 2015), 91 storm events were observed.

In early November 2015, an upturned elbow was installed to elevate the underdrain of the DT BRC. The upturned elbow was installed by attaching a 90-degree PVC elbow joined with an approximately 2 ft section of schedule 40 PVC to the existing underdrain (Appendix E). The new elevated underdrain was encapsulated within the existing weir box for continued monitoring. The elevated underdrain would force infiltrated runoff to be stored within the newly created 2 ft internal water storage (IWS) zone where it would exfiltrate into the in situ soil or exit through the elevated underdrain as infiltrating runoff exceeded storage capacity.

The post-retrofit monitoring period ended in August 2016. A total of 51 storm events were recorded during the period.

Advance Auto

The retrofit period for the AAuto BRC began in June 2014. A shallow 4-inch IWS zone was created by elevating the existing underdrains via the installation of an elevated weir. By setting the crest of the weir 4-inches above the invert of the underdrains, infiltrated runoff was forced to pond internally within the AAuto BRC. During the retrofit period (June 2014 – October 2015), 90 storm events were observed.
In early November 2015, the elevated weir was removed and the pre-retrofit period began. The outlet weir was installed at the downstream end of the outlet structure to reinstate the original function of the AAuto BRC. A total of 41 events were recorded during the pre-retrofit monitoring period (November 2015 – early June 2016).

Statistical Analysis

Hydrology and water quality data were analyzed using R (R Core Team, 2016) to compare pre-retrofit and post-retrofit runoff volumes and influent and effluent concentrations. F-tests were performed to examine pre and post-retrofit hydrology data variances. When sample variances were not significantly different, a paired t-test was performed. Otherwise, a Welch Two Sample t-test was performed. Water quality data was tested for normality using the Shapiro-Wilk and Anderson-Darling tests. Due to a lack of normality and censored water quality data, pre and post-retrofit water quality data were tested for significant differences using the Wilcoxon signed rank test (Helsel, 1990).

Results and Discussion

A complete summary of hydrology and water quality data can be found in the full in the Appendices A-C.

Rainfall

Due to the two BRCs being located at adjacent developments, rainfall data was shared between the two sites. During the 28-month monitoring period, 143 events were recorded, totaling 104 inches of rain (normalized to 45 inches per year); normal annual precipitation for the monitored area is 43 inches (State Climate Office of North Carolina, 2016).

Median rainfall during the pre-retrofit period was 0.47 inches while median rainfall during the post-retrofit period was 0.52 inches. No statistically significant differences existed between rainfall during the pre and post-retrofit monitoring periods.

Volume Reduction

Volume reduction for the BRCs was examined using Davis' (2008) exported runoff fraction:

$$f_{V24} = \frac{V_{out-24}}{V_{in}} \quad (1)$$

where V_{out-24} is volume leaving the BRC within 24 hours of a storm and V_{in} is the volume of runoff entering the BRC. The target ratio for Low Impact Development is $f_{V24} < 0.33$ (Davis, 2008).
During the pre-retrofit period, median f_{V24} values for the two BRCs were 34% and 36% (AAuto and DT). The pre-retrofit compliance values fall below median values reported during a study of six BRCs in Maryland and North Carolina by Li et al. (2009); however, during the post-retrofit period, target f_{V24} compliance improved significantly for both retrofits (*p*<0.001) with median f_{V24} values of 15% and 1% for DT and AAuto, respectively. Probabilities of exceeding the target f_{V24} value decreased with both retrofits; at DT, the likelihood of exceeding the target f_{V24} value decreased by approximately 20% post-retrofit while exceedance probability at AAuto decreased by 40% (Appendix D).
Overall runoff exported from AAuto to the watershed was significantly reduced (p<0.001) through the use of the 4-inch IWS. While exported runoff was also reduced at DT with the 2-foot IWS, differences between monitoring periods were not statistically different. These results ran contrary to initial predictions of greater runoff reduction with a greater IWS depth due to increased storage. Theoretical storage post-retrofit would allow 24 and 4 inches of ponding for DT and AAuto, respectively; however, median observed inter-event storage of 6.4 inches was much less than expected for DT. Median observed storage for AAuto was 5.6 inches.

Impaired hydrologic function has been previously observed at BRCs that have clogged soil media (Brown and Hunt, 2012, 2011a; Hatt et al., 2007) and was suspected at DT due to 29% of observed events (n = 143) generating overflow. This conclusion was supported by a particle size distribution analysis of the soil media within both BRCs and the native soil (Table 2). The North Carolina Department of Environmental Quality recommends BRC soil media to consist of 85-88% sand and 8-12% fines (N.C. DEQ, 2007); clay and silt levels in the soil media at DT were 63% higher than recommended and resulted in a calculated saturated hydraulic conductivity rate of 0.64 inches per hour (Saxton and Rawls, 2009).

Table 4: Particle size distribution of DT and AAuto soil medias

	Discount Tire	Advance Auto	Native Soil
% Sand	25%	86%	54%
% Silt	62%	9%	40%
% Clay	13%	5%	6%

Observed data were used to create a model to predict runoff discharged from the two BRCs. Through the incorporation of their respective IWS zones, while recognizing the previously discussed media constituents, DT will reduce annual runoff volumes discharged to the Black Creek watershed by 1% (4,175 gal) while AAuto will reduce annual runoff volumes by 50% (245,800 gal).

Peak Flow Reductions

Previous research has shown successful peak flow mitigation by BRCs, with peak flow reductions of 65-90+% observed in previous studies (Dietz and Clausen, 2005; Hatt et al., 2009; Hunt et al., 2008; Lucke and Nichols, 2015). Another metric for BRC hydrologic evaluation proposed by Davis (2008) is the peak runoff rate ratio,

$$R_{Peak} = \frac{q_{peak-out}}{q_{peak-in}} \tag{2}$$

where q is the peak runoff rate during a storm event. Davis (2008) also recommended the 0.33 ratio threshold for compliance with LID goals. While retrofitting with IWS did not make a statistically significant improvement to peak runoff reduction, DT met the compliance threshold for 76% of observed events during both monitoring periods while AAuto met the threshold for 90% and 100% of observed events during pre and post-retrofit periods, respectively.

Water Quality

While not the focus of this research, the authors feel it noteworthy to share the results of water quality analysis through the use of the 4-inch IWS at AAuto. Previous research has shown mixed results with using IWS zones to foster denitrification and reduce $NO_{2,3}$-N loads (Brown and Hunt, 2011b; Kim et al., 2003; Li et al., 2014; Passeport et al., 2009). The desire to promote the removal of $NO_{2,3}$-N is driven by the frequency in which conventionally drained BRCs export $NO_{2,3}$-N (Hatt et al., 2009; Hsieh and Davis, 2005; Hunt et al., 2008, 2006).

The use of a shallow 4-inch IWS at AAuto did not significantly impact $NO_{2,3}$-N removal. Median reduction to event mean concentrations (EMCs) decreased from 40% to 33% after installing the 4-inch IWS zone. The export of $NO_{2,3}$-N was observed during 5 of 19 (26%) of events.

Synthesis and Recommendations

The following conclusions and recommendations are synthesized from this research:

- Retrofitting BRCs in the Black Creek Watershed with an upturned elbow at the underdrain outlet can reduce the volume of runoff discharged to the receiving watershed from BRCs by up to 50%, as seen at AAuto.

- The degree of volume reduction is greatly impacted by soil media and associated hydraulic conductivity. Better hydrologic performance was observed when recommended soil media was used at AAuto.

- It is recommended that BRCs within the Black Creek Watershed be retrofitted to include IWS zones by following the methodology listed in this research; however, infiltration tests should be performed on BRC soil media to inspect for clogging. Proper maintenance and media replenishment should greatly increase volume reduction associated with retrofits.
- Increased removal of $NO_{2,3,}$-N via the inclusion of a shallow IWS zone is not supported by this research; however, deeper IWS may provide the necessary anaerobic conditions to foster denitrification.

Please see appendix for references and data specific to the bioretention monitoring effort.

Hydrology Monitoring and modeling Summary

See appendix with Final Report for methods, execution, and results of the hydrology monitoring and modeling effort.

The overall objective of the hydrological component of the project was to quantify potential peak flow reductions from the implementation of a downspout disconnection campaign for effective impervious cover reduction in targeted subwatersheds within the Black Creek watershed (Wake County near Cary, NC). High peak flows typified by urban stormwater runoff – as documented historically in the main stem of Black Creek – have led to severe bank erosion, downed trees along streamsides, impaired water quality due to sediment loads, and a potential degradation of macroinvertebrate habitat. The disconnection campaign being implemented by the Black Creek Watershed Association (BCWA) is based on the concept that stormwater volumes in urban watersheds can be reduced by disconnecting impervious (hard and non-draining) surfaces such as rooftops, parking lots, and driveways, and thus reducing historically high peak flows and resulting downstream impacts. By allowing stormwater to be drained naturally into the soil rather than routed directly to creeks via curbs and pipes, the stormwater flows are dampened, energy is dissipated, the erosion potential along the banks of Black Creek is minimized, downstream sediment loads are potentially reduced, and macroinvertebrate habitats are either preserved or allowed to be restored.

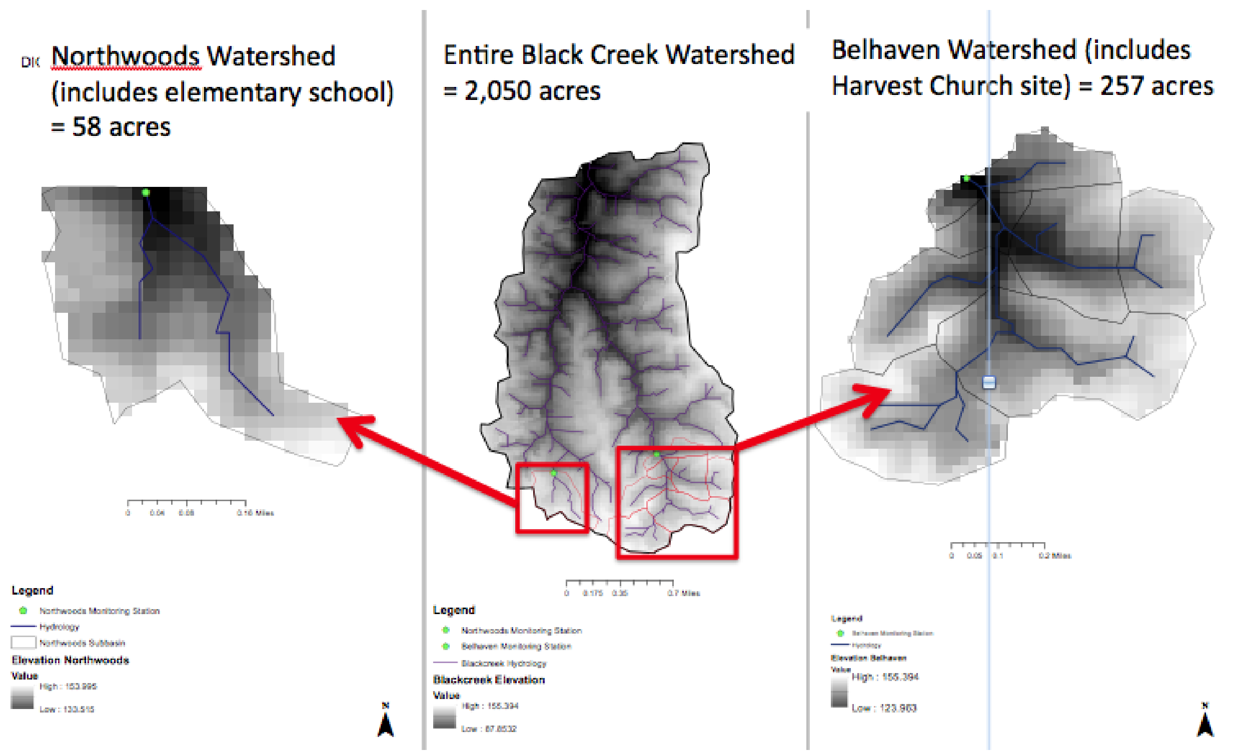


Figure 13: Digital Elevation Model produced by GIS of Upper headwater tributary drainage areas studied

The hydrological component of the project continued flow data collection at a monitoring station in the main stem of Black Creek (2,050 acres), along with two additional monitoring stations installed in headwater tributaries within the outhern part of the watershed where stormwater reduction practices are planned (East Fork, Belhaven Rd. culvert, 257 acres, and West Fork, Northwoods Rd. culvert, 58 acres). Streamflow monitoring and watershed modeling efforts were conducted to gain an accurate estimate of the scope of retrofit projects that would be necessary to achieve stormwater volume and peak flow reduction in the larger Black Creek. The continuation of hydrologic data collection has led to an improved understanding of stormflow in the urban Black Creek watershed, as well as the potential for runoff reduction over time due to stormwater management practice retrofit efforts.

Streamflow monitoring was conducted over the course of 2.5 years during 2014-2016; however, due to quality assurance/control and instrumentation issues, only 10 months of data from Nov. 2015 to Aug. 2016 were used for analyses. Monitoring efforts were coupled with watershed model simulations to determine stormwater volume and peak flow reductions under given effective impervious cover scenarios in a smaller first-order watershed that contains Northwoods Elementary School (upper West Fork) and a larger third-order watershed that is comprised of residential and commercial development (upper East Fork) including Harvest Church. Monitoring results provided a watershed characterization of streamflows given certain rainfall events while also allowing for the calibration of the watershed model for the tributaries under estimated existing impervious cover conditions. Using measurements of rainfall and streamflow data, runoff coefficients – or the percentage of rainfall that becomes runoff – were determined for the main stem of Black Creek and also the smaller East Fork watershed. Although highly variable due to storm event characteristics, seasonality, and antecedent moisture conditions (e.g. number of days since previous rainfall), the average runoff coefficient over the monitoring period for Black Creek was 0.20 (or 20% of the rainfall was seen as stream flow), which is considered to be lower than average percentage for urban watersheds. This percentage of rainfall as runoff is considerably less than that measured during the 2010-2012 monitoring period, when the average runoff coefficient was 0.30. Overall, the average calculated runoff coefficient for all storms measured between 2010-2016 was 0.26. In the headwaters of Black Creek, the average runoff coefficient in the monitoring period for the East Fork watershed was 0.16 (or 16% of the rainfall was seen as stream flow). In contrast, the West Fork headwater stream draining Northwoods Elementary School had negligible runoff coefficient values, which is expected given that this specific watershed is comprised of very little impervious cover. For comparison, as previously monitored during 2010-2012, the 84-acre Wessex subwatershed exhibited a runoff coefficient of 0.57, an extremely high percentage of rainfall as runoff even for an urban watershed.

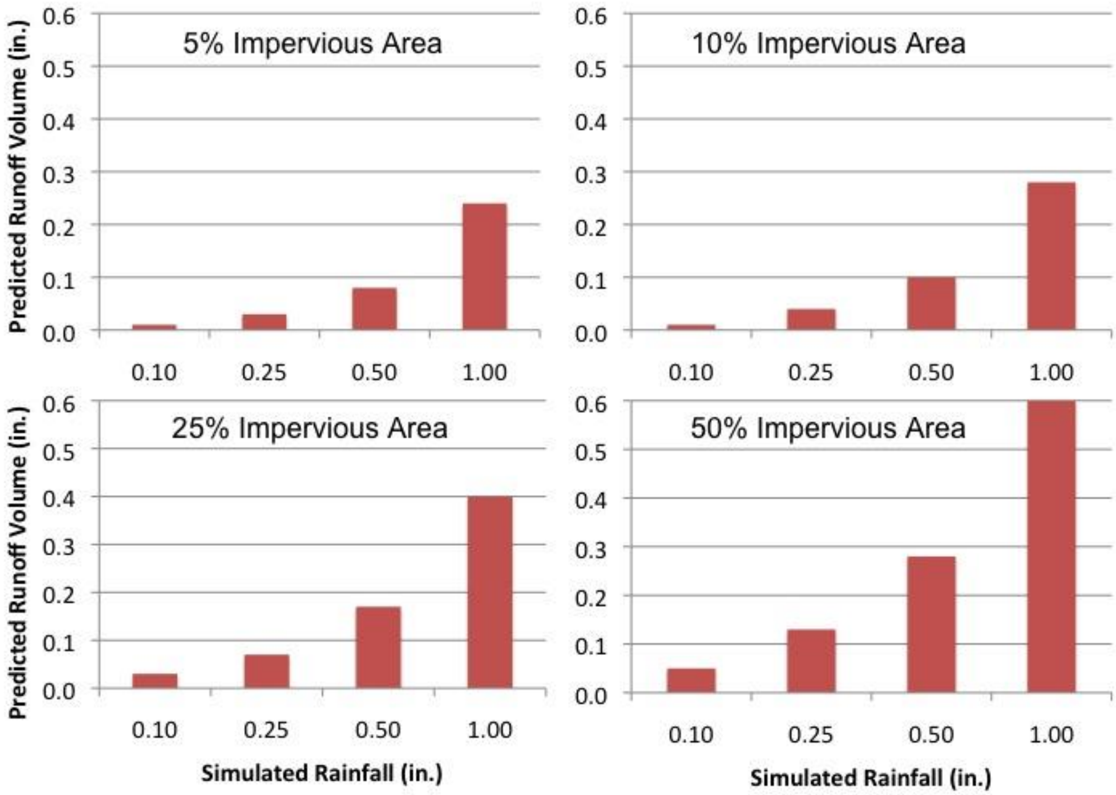


Figure 14: Runoff volume (in.) for varying effective impervious cover percentages in the Belhaven (Upper East) tributary for four simulated storm event scenarios

Simulation results from watershed models indicated that if the downspout disconnection campaign led to a removal of 10.4 acres (or revert back from the current 41% IC to the 1999 scenario at 23.1% IC) of effective impervious cover within the 58 acre subwatershed, then peak flow would be reduced from 7.1 cfs to 5.0 cfs, and ~236,000 gallons of stormwater would be kept from the Northwoods tributary and thus Black Creek from a one-inch storm. If a more aggressive campaign were to reduce the effective impervious cover to 10% (or disconnect ~18 acres of the 24 acres of IC), then the peak flow would be reduced from 7.1 cfs to 3.4 cfs and ~425,000 gallons of water would be kept from flowing to the West Fork tributary and to Black Creek from a one-inch storm. In addition, if residential areas in the upper East Fork neighborhoods would implement the downspout disconnection program to remove 30.6 acres (or revert back from the current 42.4% IC to the 1999 scenario, with 30.5% IC) of effective impervious cover within the 257 acre subwatershed, then peak flow would be reduced from 81.3 cfs to 65.4 cfs, and ~700,000 gallons of stormwater would be kept from the East Fork tributary and thus Black Creek from a one-inch storm. If a more aggressive campaign were to reduce the effective impervious cover to 10% (or disconnect ~83 acres of the 109 acres of IC), then the peak flow would be reduced from 81.3 cfs to ~38 cfs and ~2.2 million gallons of water would be kept from flowing into the East Fork and eventually to Black Creek from a one-inch storm.

These efforts would significantly reduce overall peak flows as well as the potential for bank erosion, water quality impairment, and macroinvertebrate habitat degradation. The watershed modeling exercise provided estimates based on the simulated conversion of effective impervious cover to forested and/or grassed landscapes based on expected hydrologic processes, thus possibly over-predicting volume reduction. As a result, stormwater reduction could be further limited by the actual design and as-built capacities of individual stormwater control measures within each watershed.

Table 5: Impervious cover scenarios in Northwoods watershed for one inch storm

% IC (northwoods)	Peak Flow (cfs)	Runoff Coefficient	Volume generated (gal)	Volume Reduced (gal)
41	7.1	0.49	771,671	0
32.5	6.1	0.42	661,432	110,239
23.1	5.0	0.34	535,445	236,226
10	3.4	0.22	346,464	425,207
5	2.9	0.18	283,471	488,200

Table 6: Impervious cover scenarios in Upper East Fork watershed for one inch storm

% IC (B	Peak Flow (cfs)	Runoff Coefficient	Volume generated (gal)	Volume Reduced (gal)
42.4	81.3	0.50	3,489,083	0
32.9	68.7	0.42	2,930,830	558,253
30.5	65.4	0.40	2,791,266	697,817
10	37.9	0.22	1,535,196	1,953,887
5	31.2	0.18	1,256,070	2,233,013

Since the 257-acre Upper East Fork subwatershed encompasses approximately 12.5% of the total 2,050-acre land area of the Black Creek watershed land area, HEC-HMS simulation results based on existing topography, soils, and land use/land cover, along with scenarios of reduced effective impervious cover, provided guidance as to how much stormwater flow and volume may be reduced from a given storm event before entering Black Creek. Conversely, based on monitoring and modeling results, the 58-acre subwatershed, in which Northwoods Elementary School is located, would benefit somewhat from downspout disconnection retrofit efforts, but flows from this area appear to be relatively negligible based on our measurements and data analyses.

The results from this work do not give direct indication of specific water quality benefits; however, it is expected that the significant reduction of overall peak flows would reduce the potential for bank erosion, water quality impairment including sediment loading, and the degradation of aquatic habitat. Furthermore, simulations were not conducted for highly impervious areas such commercial or major roadway land uses. Simulation results do reveal how much impervious cover area reduction would be required to achieve effective downspout disconnection for water quantity management based on rainfall and subsequent discharge at the residential/neighborhood subwatershed scale. Further work must be conducted to determine any hydrographic benefits at the larger Black Creek watershed scale, with efforts to expand monitoring and modeling to other subwatersheds with different land uses, stormwater infrastructure, and impervious cover percentages.

8. Outputs and results

See section 4 “Deliverables” and “methods” for a complete and detailed explanation of all results, Deliverables are listed here also. Any changes in the expected results are listed here.

1. Periodic meetings of the BCWA to plan outreach and education activities, provide guidance on site selections, and BMP designs- *completed.*
2. Regular outreach and engagement with BCWA and community: periodic electronic or printed newsletters to inform community of efforts and recruit participants, BCWA website updated regularly, with access to maps, reports and educational materials; social media updates.- *completed*
3. Core steering committee of business/institutional stakeholders convened and meets regularly- *Not formed, individual contacts made instead.*
4. Outreach/engagement plan for business/institutional stakeholders developed and implemented, in including a public recognition event for sponsors and partners- *completed, though in lieu of a public recognition event, sponsors and partners were recognized in event materials, and online venues.*
5. Sponsorship program developed and launched, with donations from sponsors received- *some small donations received.*
6. 3 annual stream clean-ups- *completed.*
7. Two stormwater retro-fits on public properties. *The Northwoods Elementary School cistern and the Robert J. Godbold Park stormwater wetland were installed.*
8. 1 stormwater retro-fit on a business or institutional property, to treat a large parking lot or rooftop- *the Harvest Church bioretention areas, bioswales, and permeable paved walkways were installed.*
9. 1 residential rain garden- *completed. In addition, two conservation plantings were installed by homeowners to replace turf.*
10. At least 3 bioretention underdrains will be retrofit as IWS zones to increase infiltration.

    Two bioretention underdrains were retrofitted, due to an unforeseen problem with the third bioretention.

11. 3 bioretention cells will by hydrologically monitored pre- and post-retrofit to determine the increased infiltration / reduced outflow from this simple retrofit.- *Two bioretention cells*

were monitored. A third bioretention intended for the study was determined as unmonitorable.

12. Stormwater retrofit BMP atlas of potential projects updated to include additional potential sites.- *completed.*
13. Additional projects anticipated depending on amount leveraged by sponsorships. *Additional activities were conducted, including a field tour called the Black Creek Backyard Safari, a 5th grade service learning event, and service event called 'Rain gardens need love too". We also tried to get an additional residential rain garden installed near the end of the grant after cost savings were realized on the Harvest Church project, but were unable to find a contractor who could install it in the time period requested.*
14. Mandatory DWQ/EPA reporting requirements – *completed.*

9. Outcomes and Conclusions

The methods used were successful in increasing awareness of the Black Creek watershed and solutions among our targeted audiences of private businesses and institutions. We learned that our originally proposed method of broadly advertising a business engagement campaign to recruit participants at various levels was not suitable for such a small watershed. Instead, we turned to individual contacts and specific requests to partner on projects. Participation was welcomed by each private business or institution that we directly approached with a specific project request. The first organization we approached for a retrofit, Coastal Federal Credit Union, was excited to work with us. Much time was spent surveying and designing a bioretention retrofit, but the site constraints of utility locations, and a proposed widening of the adjacent road created too much uncertainty for us to go forward with the project.

The second organization approached, Harvest Church, was an eager and willing partner. They saw the value of participating, and the multiple benefits of protecting creation while improving their property. Churches may provide ideal partnerships, though only one other is located in the watershed.

The idea of seeking sponsorships was also an effort that required hands-on, direct requests. Large national corporations with a local presence were an unfruitful target. Local businesses with some networking connection to the BCWA were more amenable, though in-kind rather than cash sponsorships were the result of these contacts. This highlights the importance of the strategy of providing hands-on service and networking events in the watershed to introduce new people to the BCWA and provide opportunities to get involved. As an example, we connected with Kruger/Veolia through participation of a former employee on our Black Creek Backyard Safari.

While we were successful in completing two public stormwater retrofits, we faced an unforeseen limitation due to a policy of the Town to not take on any BMP retrofits that will add to their maintenance load, which means that no retrofit BMPs can be installed on Town property. This highlights the necessity to continue working with Wake County Schools and private landowners on future retrofits to keep restoration momentum moving forward.

The research on adding internal water storage zones provides evidence that simple retrofits to add an upturned elbow in existing permitted bioretention areas may be a cost-effective retrofit to reduce stormwater runoff volumes reaching the creek.

We also found that finding a contractor for residential rain gardens is getting more difficult and more expensive. It could be that the economy is getting better so they are able to charge more, also it appears that contractors we've used for small projects in the past are in more demand and are focusing on larger projects. Hence, while we had hoped to construct 1-2 more rain gardens near the end of the grant period, we were unable to find a contractor who could do it within our budget and time constraint. There may be a niche open for small companies to install residential rain gardens and small retrofits. With the exception of the municipality, we continue to experience positive responses when approaching people for partnering on stormwater projects. The limiting factors for retrofitting this watershed include site constraints such as utility locations, and capacity to implement retrofits, including local contractors who have the skills and desire to undertake them. High landowner willingness to participate is a positive attribute in this watershed- this willingness and strong volunteer participation on the Black Creek Watershed Association drives the continued restoration efforts forward.

10. Budget

	Federal request	**Matching funds**
Budgeted in contract	$201,738	$139,109
Actual expenditures	$196,008.07	$146,585.62
Difference	$5,729.93	-$7,476.62

11. References

Center for Watershed Protection. 2010. Impervious Cover TMDL Field Survey & Analysis Report. University of Connecticut

Horvath, Elena. 2011. Using GIS for Prioritization in Subwatershed Restoration. Submitted to The Pennsylvania State University for Master in Geographic Information System. November 28, 2011

NC Division of Water Quality. Basinwide Planning Program: Neuse River Basinwide Water Quality Plan – Chapter Two. 2009.

NC State University. Less rain down the drain: Disconnecting stormwater systems to restore Black Creek. EPA319 Grant Final Report. April 2013.

NC State University. Black Creek Watershed Assessment, Monitoring, & Planning. EPA319 Grant Final Report & Watershed Plan. June 2009

Black Creek Watershed Association website contains all reports, meeting summaries, maps, technical presentations of the Black Creek Watershed Association: www.go.ncsu.edu/blackcreek

12. Appendices

Newsletter
Business fact sheet
Bioretention retrofit monitoring report
Hydrology monitoring and modeling report

BCWA

THE BLACK CREEK WATERSHED WIRE

News from Black Creek Watershed, Cary, NC March 2015

Visit the project website at www.ncsu.edu/WECO/blackcreek

Moving forward in the creek

Fourteen people met for a Black Creek Watershed Association winter dinner meeting January 14 at Cary Town Hall in the new Water Resources Department's conference room. They discussed current stormwater control projects, monitoring efforts in the creek, and decided YES, we DO want to keep working together to improve Black Creek, by putting together a new grant proposal to continue work beyond 2015. Their ideas for the future are included in this newsletter, along with the summary of their discussion.

Black Creek highlights

Updates about current projects funded by the EPA grant included the following:

Godbold Park Wetland: Kris Bass of Kris Bass Engineering designed a wetland retrofit of an underperforming dry detention basin that received drainage from the upper parking lot. Town of Cary Public Works provided excavation services, and Town of Cary, Water Resources Research Institute (WRRI) staff, Green Hope High School students, and Bass planted the wetland. A BCWA member asked if an educational sign would be installed. The Town may have a similar sign elsewhere that could be adapted for the Godbold Park site. Christy will work with Charles Brown on the design and installation of a sign.

Godbold Park wetland planting day

Harvest Church Project: Located in the East Fork headwaters of the Black Creek watershed, on the corner of Reedy Creek Rd. and Chapel Hill Road, much overland and piped stormwater flow from this site flows directly into a highly eroded manmade culvert. A new congregation is managing this previously developed site. Church leaders are happy to partner on improvements to the site, to help freshen the grounds and help the creek.

We identified several opportunities for reducing and treating stormwater runoff, including a regenerative stormwater conveyance (see definition below) at the piped outfall, rain gardens/bioretention, permeable walkways, and bioswales. Based on the Church's preferences to improve their

(Continued on page 2)

Next Gathering:

BCWA tour and picnic in late spring! Keep an eye on the BCWA listserve for information! Participants will help plan a fall event to appreciate our project partners.

Membership in the BCWA is open to all with an interest in improving the creek its tributaries.

To subscribe to the BCWA listserve, contact Christy Christy_perrin@ncsu.edu with your email address.

Like us on Facebook for updates and photos: www.facebook.com/blackcreekwatershed

Inside this issue:

Black Creek Happenings, continued

entrance by reducing flooding there, the current grant will focus on retrofitting this entranceway with bioretention, permeable walkways, and a bioswale this spring.

A regenerative stormwater conveyance (RSC) is a restoration practice for eroded stormwater outfalls. An RSC utilizes a series of shallow aquatic pools, grade controls, native vegetation and underlying sand and beds to treat, detain, and convey storm flow in a non-erosive manner (definition from state of West Virginia).

Coastal Federal Credit Union bioretention: A bioretention (rain garden) retrofit will divert runoff from the front parking lot into what is currently a raised grassy area that fronts Harrison Avenue. Jon Page, NCSU Dept BAE, is designing this and the Harvest Church retrofits.

Residential rain garden: We will work with a BCWA member to install a rain garden in Silverton this spring.

Stream Flow Monitoring:

Dan Hitchcock explained that monitoring has been ongoing in the Black Creek mainstem for 5 years now. We have five years of solid data, including rainfall data from the UGSG rainfall gauge at Lake Crabtree. He can look at individual storms and characterize how much rainfall ends up in Black Creek. In general, Black Creek is very flashy. Two additional flow sensors were installed in upper headwater streams in Northwoods and at the tributary that crosses Belhaven Drive. These sensors have collected stream flow data since July 2014, to provide information about headwater drainage areas.

We sought to concentrate our stormwater retrofits, including the bioretention upfits, in these areas. The amount of impervious surface being disconnected and stormwater treated at Harvest Church and the Credit Union will be too small to measure instream impacts at the flow monitoring sites. We will have to use the data in a modeling effort to learn more about how retrofitting efforts may impact the stream. A couple of hydrology models include HEC-HMS and Hydrocad. Delineating the upper wetlands is the tough part, since there is so much grey (manmade) infrastructure in the headwaters.

Question (Q): Why does the runoff seem worse recently?

Response (R): Last year's rainfall was 10-12 inches higher than normal!

Q: Do cisterns make an appreciable difference for runoff?

R: If there are enough of them, strategically placed where needed, and they are regularly used.

One of the Beechtree pond outfalls after rain (*Amin Davis)*

Beechtree dam discussion

The Beechtree Homeowners Association has a committee to evaluate and recommend maintenance options for their two ponds and dams. Would installing several rain gardens reduce the stress and maintenance requirements on the dams?

R: Since rain gardens are designed to treat and infiltrate rain from the common 1 inch storm, and are designed to overflow during large events, they would not help the dams during the types of events that could damage them. While we notice the big rain events more, 90% of our storms are <1 inch so rain gardens would still be helpful for capturing and treating most of the rainfall we receive.

Future projects ideas from BCWA:

Participants said **YES** to plugging away to improve Black Creek after the current grant ends in Dec. 2015, and provided ideas:

- Continue retrofits at Harvest Church– great site!
- Residential rain gardens with Beechtree HOA
- Kingswood Elementary School (with PTA)
- Boundary Lane Apartments (worked with TOC Phoenix Project– possible tie-in to TOC programs)
- Northwoods Elementary School bioretention
- Town Center Area Plan– talk with TOC
- Black Creek Greenway improvements– talk with TOC about seeking retrofit opportunities
- Macrobenthic invertebrate monitoring (last done in 2008)

Help with grant proposals and seeking sponsors is needed to keep this community-driven Black Creek effort going! The next EPA 319 grant proposal is due in late May. Email Christy at christy_perrin@ncsu.edu about opportunities to participate.

Eyes on erosion

BCWA members from Silverton and Beechtree are working to reduce sedimentation from a construction site that drains to Silverton's lake. Their efforts have included speaking to Town of Cary and Town of Morrisville staff, viewing the site and practices with the developer, and researching options to improve the situation. Thanks for keeping your eyes out on erosion in Black Creek and neighboring watersheds. Remember that you can always call Town of Cary Water Resource Department (919) 469-4030 to report any unusual looking sedimentation in streams.

January BCWA Meeting Particpants

Liz Adams, Silverton
Kris Bass, Kris Bass Engineering
Colleen Bockhan, Lake Crabtree County Park
Charles Brown, TOC Water Resources Dept.
Susan Davenport, Winchase/Beechtree
Nora Deamer, NC Division of Water Resources
Paul Eppers, Beechtree
John Fear, Water Resources Research Institute
Dan Hitchcock, Clemson University
Eric Kulz, Beechtree and TOC Water Resources Dept.
Karen Kulz,Beechtree
Jon Page, NCSU Dept. Biological and Agricultural Engineering
Christy Perrin, Water Resources Research Institute
Leigh Williams, Buckhurst West and Northwoods Elementary PTA

North Carolina Watershed Stewardship Network

Join the NC Watershed Stewardship Network!

The NCWSN will connect professional and volunteer stewards across NC. We aim to provide online and in-person networking and skill-building opportunities. Send your email address to Christy to join the listserve and learn about new opportunities as they roll out!

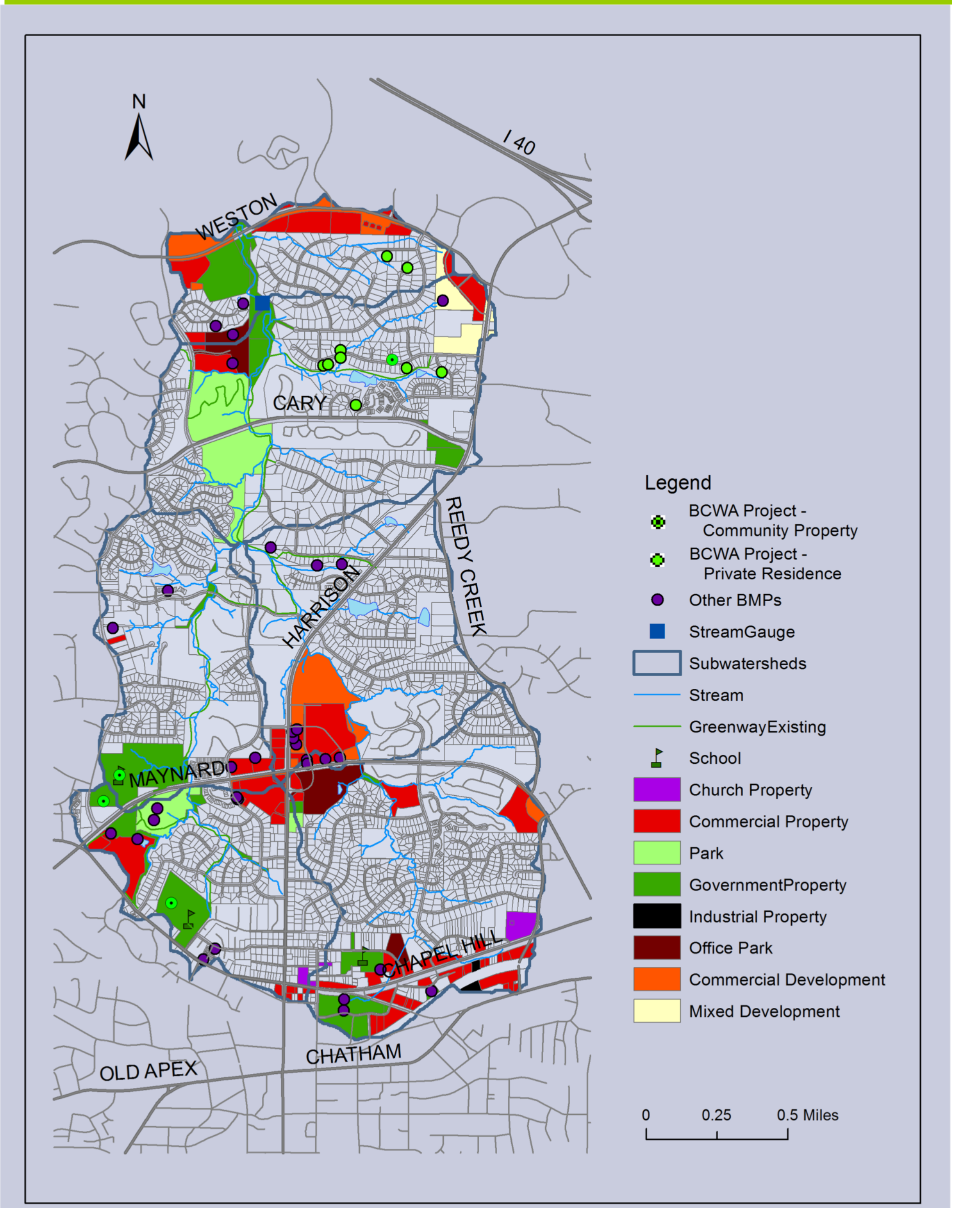
Www.ncwatershednetwork.org

WRRI

Phone: 919-513-1152
christy_perrin@ncsu.edu
www.ncsu.edu/wrri

NC STATE UNIVERSITY

Black Creek Watershed



● BMPs are Best Management Practices, techniques to treat/reduce stormwater runoff

Become a Black Creek Champion!

For businesses, institutions, apartments & shopping centers

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Black Creek Watershed Association

Water Resources Research Institute of UNC

With Funding from the US Environmental Protection Agency

Black Creek Champions

Too much storm water runoff has damaged Black Creek and its greenway, but reducing runoff and pollution can help restore this important community resource.

Who are the champions?

Your neighbors have been working together to improve water quality in Black Creek for the aquatic animals who depend on it and the community residents who enjoy it.

They have been Installing rain gardens and cisterns to capture runoff, and using landscape techniques that reduce pollution.

Rain gardens, cisterns, & downspout disconnects reduce runoff

Residents, schools, and homeowners associations like Beechtree and Wessex have been eager to enjoy the benefits of prettier landscapes while improving the community. Photos are of completed projects.

What are the benefits?

The majority of nearby residents surveyed want to see Black Creek improved. Supporting Black Creek shows you care about the community.

Runoff reduction projects such as rain gardens can add beauty to your property while also providing habitat to birds, amphibians, butterflies, and other beneficial insects. Easy actions like using asphalt-based rather than coal tar-based parking lot sealant reduces harmful pollution.

How can I get involved?

1. **Visit www.ncsu.edu/WECO/rainscaping** for landscape techniques
2. **Request a site visit** from NCSU professionals to identify ways to reduce storm water runoff and pollution from your property.
3. **Pledge** to make a change that reduces runoff and then show us that you've implemented it by summer 2015.
4. One or more business or institutional properties will qualify for **FREE** design and installation to be a community demonstration project.
5. **And/or donate funds** to support the watershed restoration effort.

Enjoy publicity via the Black Creek listserve, web media, and a framed certificate of appreciation.

Send an email to Christy_perrin@ncsu.edu to schedule a site visit today!

www.ncsu.edu/WECO/blackcreek

Creating Internal Waters Storage Zones in Bioretention Retrofits in Black Creek Watershed:
Report by Jeffery Johnson, NCSU Department of Biological and Agricultural Engineering

Site Descriptions

Three bioretention cells (BRCs) located in the Black Creek Watershed in Cary, NC were identified for monitoring and retrofit. Located at an Advance Auto Parts, Discount Tire, and the Accreditation Commission for Health Care, the three BRCs will henceforth be referred to as AAuto, DT, and ACHC, respectively. All were chosen due to their conventional design featuring non-elevated underdrains. Due to an unforeseen error during initial construction, ACHC was determined to not be monitorable. Multiple attempts to repair the BRC were not successful and a proper fix was deemed too costly. The remainder of this report will focus on AAuto and DT.

Table 1. Characteristics of three bioretention cells examined in Cary, NC.

Attribute	Advance Auto	Discount Tire
Latitude	35.803277	35.803236
Longitude	-78.779720	-78.780596
Surface area (ac)	0.04	0.03
Drainage area (ac)	1.08	1.37
Hydraulic loading (unitless)	25.3	41.5
Watershed imperviousness (%)	84%	60%
Watershed land use	Commercial	Commercial
Media depth (ft)	3	Varies
Storage depth (in)	12	6.6


Figure 1. Advance Auto (left) and Discount Tire (right).

Methods

Monitoring

At the DT BRC, runoff entered the cell via a riprapped channel connected to an asphalt parking lot and through two connected downspouts (8-inch and 3-inch). Runoff exited the DT BRC via a single 6-inch underdrain and through bypass overflow occurring at the outlet structure. To effectively monitor the five flow locations, a compound weir was installed to capture higher flow from the parking lot and contracted v-notch weirs were installed at the remaining locations. Water depth at each weir was monitored on 2-minute intervals with Onset® HOBO® U20 Water Level Data Loggers. Water levels were subsequently converted to flow measurements using the weir equation. Data were processed and analyzed using Hoboware ® Pro software.

At the AAuto BRC, watershed runoff was routed through a junction box into the BRC via a 15-inch RCP. An ISCO 720 area velocity meter was installed on the bottom of the inlet pipe to collect flow data using the known dimensions of the inlet pipe. AAuto was drained by two 4-inch underdrains connected to an outlet structure. A compound weir was installed in the outlet structure and an ISCO 730 bubbler module measured water depths. All flow data was collected on 2-minute intervals. Rainfall data was also monitored with a manual rain gauge and a recording, tipping bucket. Flow and rainfall data were processed and analyzed using ISCO Flowlink ® software.

Water quality samples were also collected at AAuto using ISCO 6712 automated samplers. Composite water quality samples were taken at the inlet and outlet on a flow-weighted event basis, triggered by measurements taken from the area velocity meter and bubbler module, respectively. Per U.S. EPA (2002) standards, a minimum of five aliquots was required for a sample to be representative of the storm event. Events producing precipitation between 0.2-2.0 inches and with antecedent dry conditions of at least 6 hours were sampled, provided outflow was generated. Samples were chilled on ice and transported to a U.S. EPA certified laboratory within 24 hours of event conclusion. Laboratory analysis was performed for total Kjeldahl nitrogen (TKN), nitrate and nitrite ($NO_{2,3}$-N), total Ammoniacal nitrogen (TAN), total phosphorus (TP), orthophosphate (ortho-P), and total suspended sediments (TSS). Organic nitrogen (ON) was calculated as the difference between TKN and TAN. Particle bound phosphorus (PBP) was calculated as the difference between TP and ortho-P. Total nitrogen (TN) was calculated as the sum of TKN and $NO_{2,3}$-N.

Discount Tire

Following the installation of monitoring equipment, the pre-retrofit period at the DT BRC began in June 2014. During the pre-retrofit period (late April 2014 – early November 2015), 91 storm events were observed.

In early November 2015, an upturned elbow was installed to elevate the underdrain of the DT BRC. The upturned elbow was installed by attaching a 90-degree PVC elbow joined with an approximately 2 ft section of schedule 40 PVC to the existing underdrain (Appendix E). The new elevated underdrain was encapsulated within the existing weir box for continued monitoring. The elevated underdrain would force infiltrated runoff to be stored within the newly created 2 ft internal water storage (IWS) zone where it would exfiltrate into the in situ soil or exit through the elevated underdrain as infiltrating runoff exceeded storage capacity.

The post-retrofit monitoring period ended in August 2016. A total of 51 storm events were recorded during the period.

Advance Auto

The retrofit period for the AAuto BRC began in June 2014. A shallow 4-inch IWS zone was created by elevating the existing underdrains via the installation of an elevated weir. By setting the crest of the weir 4-inches above the invert of the underdrains, infiltrated runoff was forced to pond internally within the AAuto BRC. During the retrofit period (June 2014 – October 2015), 90 storm events were observed.

In early November 2015, the elevated weir was removed and the pre-retrofit period began. The outlet weir was installed at the downstream end of the outlet structure to reinstate the original function of the AAuto BRC. A total of 41 events were recorded during the pre-retrofit monitoring period (November 2015 – early June 2016).

Statistical Analysis

Hydrology and water quality data were analyzed using R (R Core Team, 2016) to compare pre-retrofit and post-retrofit runoff volumes and influent and effluent concentrations. F-tests were performed to examine pre and post-retrofit hydrology data variances. When sample variances were not significantly different, a paired t-test was performed. Otherwise, a Welch Two Sample t-test was performed. Water quality data was tested for normality using the Shapiro-Wilk and Anderson-Darling tests. Due to a lack of normality and censored water quality data, pre and post-retrofit water quality data were tested for significant differences using the Wilcoxon signed rank test (Helsel, 1990).

Results and Discussion

A complete summary of hydrology and water quality data can be found in Appendices A-C.

Rainfall

Due to the two BRCs being located at adjacent developments, rainfall data was shared between the two sites. During the 28-month monitoring period, 143 events were recorded, totaling 104 inches of rain (normalized to 45 inches per year); normal annual precipitation for the monitored area is 43 inches (State Climate Office of North Carolina, 2016).

Median rainfall during the pre-retrofit period was 0.47 inches while median rainfall during the post-retrofit period was 0.52 inches. No statistically significant differences existed between rainfall during the pre and post-retrofit monitoring periods.

Volume Reduction

Volume reduction for the BRCs was examined using Davis' (2008) exported runoff fraction:

$$f_{V24} = \frac{V_{out-24}}{V_{in}} \quad (1)$$

where V_{out-24} is volume leaving the BRC within 24 hours of a storm and V_{in} is the volume of runoff entering the BRC. The target ratio for Low Impact Development is $f_{V24} < 0.33$ (Davis, 2008).

During the pre-retrofit period, median f_{V24} values for the two BRCs were 34% and 36% (AAuto and DT). The pre-retrofit compliance values fall below median values reported during a study of six BRCs in Maryland and North Carolina by Li et al. (2009); however, during the post-retrofit period, target f_{V24} compliance improved significantly for both retrofits (p<0.001) with median f_{V24} values of 15% and 1% for DT and AAuto, respectively. Probabilities of exceeding the target f_{V24} value decreased with both retrofits; at DT, the likelihood of exceeding the target f_{V24} value decreased by approximately 20% post-retrofit while exceedance probability at AAuto decreased by 40% (Appendix D).

Overall runoff exported from AAuto to the watershed was significantly reduced ($p<0.001$) through the use of the 4-inch IWS. While exported runoff was also reduced at DT with the 2-foot IWS, differences between monitoring periods were not statistically different. These results ran contrary to initial predictions of greater runoff reduction with a greater IWS depth due to increased storage. Theoretical storage post-retrofit would allow 24 and 4 inches of ponding for DT and AAuto, respectively; however, median observed inter-event storage of 6.4 inches was much less than expected for DT. Median observed storage for AAuto was 5.6 inches.

Impaired hydrologic function has been previously observed at BRCs that have clogged soil media (Brown and Hunt, 2012, 2011a; Hatt et al., 2007) and was suspected at DT due to 29% of observed events (n = 143) generating overflow. This conclusion was supported by a particle size distribution analysis of the soil media within both BRCs and the native soil (Table 2). The North Carolina Department of Environmental Quality recommends BRC soil media to consist of 85-88% sand and 8-12% fines (N.C. DEQ, 2007); clay and silt levels in the soil media at DT were 63% higher than recommended and resulted in a calculated saturated hydraulic conductivity rate of 0.64 inches per hour (Saxton and Rawls, 2009).

Table 2. Particle size distribution of DT and AAuto soil medias.

	Discount Tire	Advance Auto	Native Soil
% Sand	25%	86%	54%
% Silt	62%	9%	40%
% Clay	13%	5%	6%

Observed data were used to create a model to predict runoff discharged from the two BRCs. Through the incorporation of their respective IWS zones, while recognizing the previously discussed media constituents, DT will reduce annual runoff volumes discharged to the Black Creek watershed by 1% (4,175 gal) while AAuto will reduce annual runoff volumes by 50% (245,800 gal).

Peak Flow Reductions

Previous research has shown successful peak flow mitigation by BRCs, with peak flow reductions of 65-90+% observed in previous studies (Dietz and Clausen, 2005; Hatt et al., 2009; Hunt et al., 2008; Lucke and Nichols, 2015). Another metric for BRC hydrologic evaluation proposed by Davis (2008) is the peak runoff rate ratio,

$$R_{Peak} = \frac{q_{peak-out}}{q_{peak-in}} \quad (2)$$

where q is the peak runoff rate during a storm event. Davis (2008) also recommended the 0.33 ratio threshold for compliance with LID goals. While retrofitting with IWS did not make a statistically significant improvement to peak runoff reduction, DT met the compliance threshold for 76% of observed events during both monitoring periods while AAuto met the threshold for 90% and 100% of observed events during pre and post-retrofit periods, respectively.

Water Quality

While not the focus of this research, the authors feel it noteworthy to share the results of water quality analysis through the use of the 4-inch IWS at AAuto. Previous research has shown mixed results with using IWS zones to foster denitrification and reduce $NO_{2,3}$-N loads (Brown and Hunt, 2011b; Kim et al., 2003; Li et al., 2014; Passeport et al., 2009). The desire to promote the removal of $NO_{2,3}$-N is driven by the frequency in which conventionally drained BRCs export $NO_{2,3}$-N (Hatt et al., 2009; Hsieh and Davis, 2005; Hunt et al., 2008, 2006).

The use of a shallow 4-inch IWS at AAuto did not significantly impact $NO_{2,3}$-N removal. Median reduction to event mean concentrations (EMCs) decreased from 40% to 33% after installing the 4-inch IWS zone. The export of $NO_{2,3}$-N was observed during 5 of 19 (26%) of events.

Synthesis and Recommendations

The following conclusions and recommendations are synthesized from this research:

- Retrofitting BRCs in the Black Creek Watershed with an upturned elbow at the underdrain outlet can reduce the volume of runoff discharged to the receiving watershed from BRCs by up to 50%, as seen at AAuto.
- The degree of volume reduction is greatly impacted by soil media and associated hydraulic conductivity. Better hydrologic performance was observed when recommended soil media was used at AAuto.
- It is recommended that BRCs within the Black Creek Watershed be retrofitted to include IWS zones by following the methodology listed in this research; however, infiltration tests should be performed on BRC soil media to inspect for clogging. Proper maintenance and media replenishment should greatly increase volume reduction associated with retrofits.

- Increased removal of $NO_{2,3,}$-N via the inclusion of a shallow IWS zone is not supported by this research; however, deeper IWS may provide the necessary anaerobic conditions to foster denitrification.

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Appendix A – AAuto Hydrology Data

Table 1. AAuto Pre-Retrofit Data

Storm Date	Rainfall (in.)	ADP	Peak Q In (cfs)	Volume In (cf)	Peak Q Out (cfs)	Rp	Volume Out (cf)	fV	Storage Vol (cf)	Volume Reduction	Peak Q Reduction
1-Nov-2015	2.40	5	0.76	9944.1	0.077	0.101	4464.7	0.45	2507.8	55.1%	89.9%
7-Nov-2015	0.39	6	0.35	951.1	0.055	0.158	780.3	0.82	297.6	18.0%	84.2%
9-Nov-2015	1.45	2	0.95	7626.7	0.059	0.062	3556.6	0.47	359.9	53.4%	93.8%
19-Nov-2015	1.10	10	1.72	6715.4	0.089	0.051	2652.7	0.40	511.9	60.5%	94.9%
29-Nov-2015	0.96	10	0.24	6369.0	0.037	0.150	1163.3	0.18	773.1	81.7%	85.0%
2-Dec-2015	0.10	3	0.26	109.9	0.000	0.000	0.0	0.00	109.9	100.0%	100.0%
17-Dec-2015	1.13	15	0.88	3478.1	0.058	0.066	1947.9	0.56	571.6	44.0%	93.4%
22-Dec-2015	2.23	5	4.96	6847.8	0.121	0.024	6316.2	0.92	915.2	7.8%	97.6%
28-Dec-2015	0.14	6	0.14	668.9	0.014	0.104	88.5	0.13	186.7	86.8%	89.6%
30-Dec-2015	1.55	2	1.67	8169.5	0.074	0.044	4724.1	0.58	574.5	42.2%	95.6%
9-Jan-2016	0.23	10	0.23	977.5	0.023	0.101	194.1	0.20	349.5	80.1%	89.9%
15-Jan-2016	0.46	6	0.20	999.8	0.037	0.188	454.6	0.45	522.5	54.5%	81.2%
24-Jan-2016	0.71	7	0.04	2039.7	0.028	0.659	346.2	0.17	280.6	83.0%	34.1%
25-Jan-2016	0.29	1	0.04	631.9	0.017	0.457	186.8	0.30	9.2	70.4%	54.3%
3-Feb-2016	1.54	9	1.27	3079.3	0.067	0.053	3343.2	1.09	959.9	-8.6%	94.7%
8-Feb-2016	0.17	5		156.3	0.019	0.000	73.3	0.47	0.0	53.1%	
16-Feb-2016	1.03	1	1.17	9553.9	0.072	0.062	2491.4	0.26	0.0	73.9%	93.8%
22-Feb-2016	0.51	6	0.05	1350.8	0.029	0.606	604.3	0.45	250.0	55.3%	39.4%
24-Feb-2016	0.68	2	1.24	2505.9	0.039	0.031	1487.4	0.59	406.7	40.6%	96.9%
2-Mar-2016	0.14	7	0.06	496.8	0.010	0.169	45.2	0.09	245.8	90.9%	83.1%
3-Mar-2016	0.18	1	0.02	215.4	0.015	0.642	114.1	0.53	142.1	47.0%	35.8%
13-Mar-2016	0.2	10	1.12	604.8	0.000	0.000	0.0	0.00	604.8	100.0%	100.0%
14-Mar-2016	0.97	1	1.66	6261.2	0.083	0.050	2162.5	0.35	631.5	65.5%	95.0%
26-Mar-2016	0.93	12	0.29	2713.8	0.040	0.138	1240.6	0.46	392.5	54.3%	86.2%
2-Apr-2016	0.18	7	0.32	459.4	0.005	0.017	22.7	0.05	345.7	95.1%	98.3%
12-Apr-2016	0.66	10	0.36	2830.0	0.034	0.094	734.0	0.26	415.6	74.1%	90.6%
22-Apr-2016	1.7	10	0.75	4967.8	0.008	0.011	2629.0	0.53	647.0	47.1%	98.9%
28-Apr-2016	1.1	6	2.52	2935.1	0.060	0.024	1810.7	0.62	573.1	38.3%	97.6%
1-May-2016	0.18	3	0.57	621.8	0.010	0.018	33.8	0.05	588.0	94.6%	98.2%
2-May-2016	0.95	1	2.15	3572.1	0.032	0.015	1623.2	0.45	666.2	54.6%	98.5%
5-May-2016	1.57	3	1.30	5608.2	0.037	0.028	2849.3	0.51	1868.5	49.2%	97.2%

12-May-2016	0.23	7	0.40	818.6	0.010	0.026	57.6	0.07	466.4	93.0%	97.4%
17-May-2016	0.11	5	0.11	291.2	0.000	0.000	0.0	0.00	291.2	100.0%	100.0%
18-May-2016	0.14	1	0.18	639.2	0.014	0.079	59.0	0.09	461.0	90.8%	92.1%
19-May-2016	0.15	1	0.26	477.7	0.004	0.016	29.5	0.06	379.8	93.8%	98.4%
21-May-2016	0.31	2	0.82	808.7	0.015	0.019	96.2	0.12	790.6	88.1%	98.1%
22-May-2016	0.13	1	0.31	574.5	0.007	0.024	21.9	0.04	558.3	96.2%	97.6%
29-May-2016	0.98	7	2.15	3036.9	0.040	0.018	1008.7	0.33	581.8	66.8%	98.2%
30-May-2016	0.12	1	0.20	338.4	0.007	0.037	24.6	0.07	300.8	92.7%	96.3%
5-Jun-2016	0.52	6	1.28	2740.3	0.027	0.021	1224.9	0.45	536.9	55.3%	97.9%
5-Jun-2016	1	0	1.33	1441.7	0.041	0.031	406.2	0.28	1145.7	71.8%	96.9%
Mean	0.72	5.20	0.86	2795.84	0.03	0.11	1245.59	34%	541.96	66.1%	89.0%
Median	0.52	5.00	0.48	1441.73	0.03	0.04	604.34	33%	466.44	66.8%	95.3%
Std. Dev.	0.61	3.73	0.95	2825.61	0.03	0.17	1539.20	26%	459.19	26.1%	17.2%

Table 2. AAuto Post-Retrofit Hydrology Data

Storm Date	Rainfall (in.)	ADP (days)	Peak Q In (cfs)	Volume In (cf)	Peak Q Out (cfs)	Rp	Volume Out (cf)	fV	Storage Vol (cf)	Volume Reduction	Peak Q Reduction
10-Jun-2014	1.02	4	2.78	2818.25	0.019	0.01	114.2	0.041	1974.5	95.9%	99.3%
11-Jun-2014	1.29	1	5.39	4071.62	0.045	0.01	518.8	0.127	1984.5	87.3%	99.2%
12-Jun-2014	0.38	1	1.60	586.46	0.003	0.00	13.5	0.023	586.5	97.7%	99.8%
19-Jun-2014	0.23	7	1.35	36.43	0.000	0.00	0.0	0.000	396.3	100.0%	100.0%
20-Jun-2014	0.41	1	1.21	698.82	0.000	0.00	0.0	0.000	698.8	100.0%	100.0%
21-Jun-2014	1.25	1	4.48	5286.49	0.044	0.01	455.3	0.086	3120.2	91.4%	99.0%
27-Jun-2014	0.94	6	1.83	3681.71	0.018	0.01	152.2	0.041	2368.5	95.9%	99.0%
10-Jul-2014	0.87	13	1.14	1828.37	0.007	0.01	36.2	0.020	1613.3	98.0%	99.4%
15-Jul-2014	2.99	5	5.38	9571.49	0.200	0.04	1165.9	0.122	3549.2	87.8%	96.3%
20-Jul-2014	0.12	5	0.15	69.10	0.000	0.00	0.0	0.000	473.1	100.0%	100.0%
21-Jul-2014	0.77	1	0.99	2202.78	0.007	0.01	52.0	0.024	1500.2	97.6%	99.3%
22-Jul-2014	0.11	1	0.31	131.93	0.000	0.00	0.0	0.000	131.9	100.0%	100.0%
24-Jul-2014	0.16	2	0.17	137.18	0.000	0.00	0.0	0.000	137.2	100.0%	100.0%
27-Jul-2014	0.36	3	1.79	977.99	0.000	0.00	0.0	0.000	978.0	100.0%	100.0%
1-Aug-2014	0.46	5	0.58	1703.45	0.000	0.00	0.0	0.000	1496.8	100.0%	100.0%
2-Aug-2014	0.45	1	0.58	1115.95	0.000	0.00	0.0	0.000	1116.0	100.0%	100.0%
9-Aug-2014	1.5	7	0.55	4247.62	0.007	0.01	145.3	0.034	3357.8	96.6%	98.7%
11-Aug-2014	0.3	2	0.29	880.96	0.000	0.00	0.0	0.000	881.0	100.0%	100.0%
12-Aug-2014	2.62	1	5.57	8854.71	0.157	0.03	888.8	0.100	3113.9	90.0%	97.2%
18-Aug-2014	0.88	6	1.71	2067.00	0.007	0.00	56.3	0.027	1956.3	97.3%	99.6%
5-Sep-2014	0.23	1	0.28	450.31	0.000	0.00	0.0	0.000	450.3	100.0%	100.0%
8-Sep-2014	0.98	21	0.31	4947.13	0.000	0.00	0.0	0.000	4947.1	100.0%	100.0%
23-Sep-2014	3.06	2	1.69	7957.53	0.037	0.02	628.8	0.079	887.4	92.1%	97.8%
10-Oct-2014	1.11	17	0.87	2917.37	0.013	0.01	112.9	0.039	999.7	96.1%	98.6%
11-Oct-2014	0.25	1	1.01	307.13	0.001	0.00	2.4	0.008	653.8	99.2%	99.9%
15-Oct-2014	0.36	4	0.26	821.53	0.002	0.01	38.3	0.047	410.8	95.3%	99.4%
29-Oct-2014	0.12	14	0.13	164.13	0.000	0.00	0.0	0.000	164.1	100.0%	100.0%
1-Nov-2014	0.54	3	0.18	1452.67	0.000	0.00	0.5	0.000	167.0	100.0%	99.9%
6-Nov-2014	0.2	5	0.10	162.73	0.000	0.00	0.0	0.000	162.7	100.0%	100.0%
17-Nov-2014	0.37	11	0.37	853.72	0.000	0.00	0.0	0.000	853.7	100.0%	100.0%
23-Nov-2014	0.47	6	0.54	355.23	0.001	0.00	8.0	0.022	355.2	97.8%	99.8%
25-Nov-2014	1.46	2	2.19	4723.28	0.030	0.01	629.6	0.133	55.5	86.7%	98.6%

9-Dec-2014	0.41	14		1016.72	0.000	0.00	0.4	0.000	1016.7	100.0%	100.0%
16-Dec-2014	0.3	7	0.57	720.45	0.000	0.00	0.0	0.000	720.4	100.0%	100.0%
22-Dec-2014	0.49	6	0.17	710.40	0.000	0.00	0.0	0.000	692.0	100.0%	100.0%
23-Dec-2014	2.05	1	4.58	6874.42	0.031	0.01	999.5	0.145	2598.1	85.5%	99.3%
29-Dec-2014	0.5	6	0.17	1227.55	0.001	0.01	8.5	0.007	767.8	99.3%	99.5%
4-Jan-2015	0.2	6	0.23	431.04	0.000	0.00	0.0	0.000	431.0	100.0%	100.0%
12-Jan-2015	1.39	8	1.72	2665.69	0.016	0.01	214.8	0.081	917.7	91.9%	99.1%
18-Jan-2015	0.59	6	0.25	909.33	0.000	0.00	1.7	0.002	702.3	99.8%	99.9%
23-Jan-2015	0.69	5	0.09	1472.58	0.000	0.00	0.9	0.001	620.1	99.9%	99.9%
26-Jan-2015	0.31	3	0.08	439.41	0.000	0.00	0.0	0.000	439.41	100.0%	100.0%
2-Feb-2015	0.56	7		891.61	0.000	0.00	0.7	0.001	891.61	99.9%	100.0%
9-Feb-2015	0.5	7	0.15	1307.74	0.000	0.00	0.0	0.000	1307.7	100.0%	100.0%
17-Feb-2015	0.21	8	0.08	373.42	0.000	0.00	0.0	0.000	373.4	100.0%	100.0%
18-Feb-2015	0.2	1	0.04	431.46	0.000	0.00	0.0	0.000	431.5	100.0%	100.0%
26-Feb-2015	0.38	8	0.23	1150.16	0.000	0.00	0.5	0.000	873.9	100.0%	100.0%
27-Feb-2015	0.28	1	0.04	374.40	0.006	0.17	55.8	0.149	165.0	85.1%	83.4%
1-Mar-2015	0.27	2	0.07	1548.50	0.017	0.23	632.3	0.408	422.8	59.2%	76.6%
5-Mar-2015	0.99	4	0.41	3330.35	0.051	0.13	1466.0	0.440	802.0	56.0%	87.4%
11-Mar-2015	0.06	6	0.13	175.40	0.000	0.00	0.0	0.000	175.4	100.0%	100.0%
14-Mar-2015	0.42	3	0.31	1053.07	0.011	0.04	88.9	0.084	910.8	91.6%	96.4%
19-Mar-2015	0.65	5	0.11	1742.50	0.020	0.18	477.6	0.274	553.8	72.6%	81.7%
26-Mar-2015	0.22	7	0.44	424.59	0.000	0.00	0.0	0.000	424.6	100.0%	100.0%
27-Mar-2015	0.14	1	0.10	250.75	0.000	0.00	0.0	0.000	250.7	100.0%	100.0%
30-Mar-2015	0.22	3	0.08	266.63	0.000	0.00	0.0	0.000	266.6	100.0%	100.0%
9-Apr-2015	0.5	10	0.57	1268.23	0.018	0.03	287.2	0.226	903.8	77.4%	96.9%
9-Apr-2015	0.22	0	1.05	491.25	0.000	0.00	0.0	0.000	491.3	100.0%	100.0%
14-Apr-2015	0.4	5	0.84	1297.75	0.009	0.01	84.8	0.065	1207.4	93.5%	98.9%
15-Apr-2015	0.36	1	0.12	1138.77	0.015	0.12	305.9	0.269	316.8	73.1%	87.9%
19-Apr-2015	0.75	4	0.80	2597.13	0.035	0.04	921.9	0.355	880.9	64.5%	95.6%
20-Apr-2015	0.48	1	1.03	1118.81	0.015	0.01	418.2	0.374	256.8	62.6%	98.5%
25-Apr-2015	0.3	5	0.14	1262.27	0.002	0.02	11.6	0.009	1114.7	99.1%	98.3%
30-Apr-2015	0.93	5	2.13	3080.29	0.033	0.02	847.3	0.275	1377.3	72.5%	98.5%
10-May-2015	0.46	10	0.91	2873.65	0.008	0.01	74.5	0.026	1853.4	97.4%	99.1%
21-May-2015	0.18	11	0.82	629.56	0.000	0.00	0.0	0.000	629.6	100.0%	100.0%
1-Jun-2015	0.34	11	0.04	1081.73	0.000	0.00	0.0	0.000	1081.7	100.0%	100.0%
2-Jun-2015	0.13	1	0.21	532.00	0.000	0.00	0.0	0.000	532.0	100.0%	100.0%

4-Jun-2015	0.1	2		131.93	0.000	0.00	0.0	0.000	131.9	100.0%	100.0%
9-Jun-2015	0.42	5	1.07	1067.10	0.003	0.00	13.0	0.012	1010.5	98.8%	99.8%
17-Jun-2015	0.54	8	1.46	1192.00	0.034	0.02	144.9	0.122	1108.9	87.8%	97.7%
18-Jun-2015	3.02	1	5.10	10435.88	0.641	0.13	4256.7	0.408	3199.5	59.2%	87.4%
20-Jun-2015	0.12	2	0.46	370.66	0.000	0.00	0.0	0.000	370.7	100.0%	100.0%
27-Jun-2015	1.73	7	1.68	6009.32	0.078	0.05	2100.8	0.350	2154.0	65.0%	95.3%
3-Jul-2015	0.23	6	0.58	656.93	0.000	0.00	0.0	0.000	656.9	100.0%	100.0%
5-Jul-2015	0.26	2	0.76	923.70	0.000	0.00	0.1	0.000	920.6	100.0%	100.0%
8-Jul-2015	0.59	3	1.72	1159.94	0.051	0.03	450.2	0.388	1159.9	61.2%	97.0%
13-Jul-2015	1.47	5	1.97	4431.87	0.057	0.03	1808.0	0.408	2021.9	59.2%	97.1%
23-Jul-2015	0.51	10	1.48	2253.39	0.051	0.03	676.6	0.300	1897.4	70.0%	96.5%
6-Aug-2015	0.13	14	0.29	179.92	0.000	0.00	0.0	0.000	179.9	100.0%	100.0%
11-Aug-2015	0.32	5	0.28	1097.89	0.000	0.00	0.0	0.000	1097.9	100.0%	100.0%
18-Aug-2015	0.22	7	0.92	413.55	0.000	0.00	0.0	0.000	413.5	100.0%	100.0%
19-Aug-2015	0.97	1	2.74	5172.91	0.100	0.04	1189.9	0.230	2387.7	77.0%	96.4%
19-Aug-2015	0.17	0	0.36	644.42	0.000	0.00	0.0	0.000	644.4	100.0%	100.0%
31-Aug-2015	0.76	12	0.68	1596.99	0.044	0.07	328.2	0.206	1006.6	79.4%	93.4%
5-Sep-2015	0.3	5	0.62	677.27	0.000	0.00	0.0	0.000	677.3	100.0%	100.0%
9-Sep-2015	0.29	4	1.35	796.91	0.001	0.00	5.5	0.007	772.3	99.3%	99.9%
24-Sep-2015	3.2	15	1.23	10573.55	0.059	0.05	4046.6	0.383	934.3	61.7%	95.2%
27-Oct-2015	0.5	17	0.20	3306.36	0.013	0.07	125.3	0.038	1486.9	96.2%	93.2%
28-Oct-2015	0.43	1	0.82	5283.97	0.018	0.02	437.1	0.083	1486.9	91.7%	97.8%
Mean	0.66	5.34	1.04	2017.97	0.02	2%	305.56	8%	1051.81	92.1%	98.0%
Median	0.42	5.00	0.58	1106.92	0.00	0%	3.95	1%	863.80	99.3%	99.9%
Std. Dev.	0.69	4.40	1.29	2381.98	0.07	4%	714.59	13%	900.02	12.7%	4.2%

Appendix B – Discount Tire Hydrology Data

Table 1. DT Pre-Retrofit Hydrology Data

Storm Date	Rainfall (in.)	Vol In (cf)	Qp In (cfs)	Storage (cf)	Vol Out (cf)	Qp Out (cfs)	RO Out (in.)	fv	Rp	Volume Reduction	Qp Reduction
4/25/14	0.29	553.8	0.22	44.46	33.8	0.01	0.0068	0.0611	0.05	76.6%	92%
4/29/14	1.15	2723.3	0.82	190.36	977.4	0.08	0.1965	0.3589	0.10	80.8%	93%
5/15/14	3.65	11051.0	1.91	188.69	5734.1	0.64	1.1530	0.5189	0.33	77.8%	96%
6/9/14	1.03	1851.1	1.68	501.89	870.3	0.12	0.1750	0.4701	0.07	84.8%	97%
6/11/14	1.29	1989.2	2.83	1090.39	1868.9	1.20	0.3758	0.9395	0.42	90.5%	95%
6/12/14	0.38	831.1	1.15	130.46	247.0	0.04	0.0497	0.2972	0.03	90.9%	95%
6/13/14	0.20	431.3	0.08	237.80	2.9	0.00	0.0006	0.0066	0.03	78.7%	94%
6/19/14	0.23	404.0	0.88	246.08	66.2	0.05	0.0133	0.1639	0.05	76.0%	94%
6/20/14	0.41	1084.7	1.00	120.60	204.2	0.06	0.0411	0.1883	0.06	82.1%	89%
6/21/14	1.27	2448.7	1.78	540.67	1667.0	0.82	0.3352	0.6808	0.46	86.2%	95%
6/27/14	0.94	1780.0	1.66	547.92	953.9	0.38	0.1918	0.5359	0.23	99.7%	99%
7/10/14	0.87	1851.1	0.71	85.92	546.2	0.10	0.1098	0.2951	0.14	82.4%	90%
7/15/14	2.99	5630.6	1.94	252.22	4650.9	1.16	0.9352	0.8260	0.60	98.0%	95%
7/20/14	0.12	226.2	0.04	8.54	0.1	0.00	0.0000	0.0002	0.00	95.7%	90%
7/21/14	0.77	2125.1	0.68	284.52	659.4	0.09	0.1326	0.3103	0.13	87.2%	96%
7/22/14	0.11	309.3	0.10	47.55	9.3	0.01	0.0019	0.0301	0.07	90.2%	90%
7/24/14	0.16	422.9	0.15	2.15	32.7	0.02	0.0066	0.0772	0.14	98.2%	96%
7/27/14	0.36	822.1	1.08	328.23	183.6	0.05	0.0369	0.2233	0.05	89.2%	91%
8/1/14	0.56	1467.2	0.27	133.07	249.6	0.03	0.0502	0.1702	0.12	97.1%	94%
8/2/14	0.87	614.0	0.09	2.69	13.5	0.00	0.0027	0.0219	0.04	87.6%	93%
8/9/14	1.50	6811.1	0.36	137.14	1227.5	0.04	0.2468	0.1802	0.11	76.6%	95%
8/11/14	0.30	1019.7	0.12	1.70	42.4	0.01	0.0085	0.0416	0.07	97.7%	96%
8/12/14	2.62	5815.1	1.96	138.59	5191.9	1.79	1.0440	0.8928	0.91	94.0%	92%
8/18/14	0.90	1664.0	1.23	579.96	604.5	0.07	0.1216	0.3633	0.06	99.4%	99%
9/4/14	0.23	671.4	0.15	93.69	22.5	0.01	0.0045	0.0335	0.04	88.5%	91%
9/8/14	0.99	4605.4	0.17	5.74	444.7	0.02	0.0894	0.0966	0.11	83.7%	94%
9/13/14	0.11	528.2	0.20	79.55	2.9	0.00	0.0006	0.0055	0.01	87.7%	97%
9/23/14	1.95	6651.0	0.55	4.43	1804.3	0.32	0.3628	0.2713	0.59	87.4%	93%
10/10/14	1.11	2441.5	0.91	425.95	642.0	0.06	0.1291	0.2629	0.07	92.3%	94%
10/11/14	0.38	973.1	0.72	375.29	195.5	0.03	0.0393	0.2009	0.04	99.4%	98%
10/14/14	0.58	1363.4	0.47	85.55	290.4	0.04	0.0584	0.2130	0.08	93.9%	93%

10/15/14	0.66	2015.9	0.25	42.07	258.9	0.02	0.0521	0.1284	0.07	95.8%	96%
10/29/14	0.13	276.0	0.12	73.65	1.4	0.00	0.0003	0.0052	0.01	51.2%	88%
11/1/14	0.54	1762.8	0.26	103.26	185.0	0.02	0.0372	0.1049	0.08	42.2%	94%
11/6/14	0.20	526.1	0.31	253.12	37.9	0.01	0.0076	0.0721	0.04	28.0%	72%
11/17/14	0.37	580.7	0.28	26.05	304.5	0.04	0.0612	0.5244	0.13	42.3%	69%
11/23/14	0.48	619.8	0.45	4.02	406.5	0.03	0.0817	0.6558	0.07	56.9%	89%
11/25/14	1.46	4623.4	0.20	1.49	4346.8	0.56	0.8741	0.9402	2.75	34.7%	84%
12/6/14	0.17	95.3	0.07	0.24	29.7	0.01	0.0060	0.3115	0.18	48.9%	92%
12/8/14	0.12	53.0	0.03	1.86	12.5	0.02	0.0025	0.2348	0.79	10.1%	69%
12/9/14	0.41	431.3	0.05	0.09	286.1	0.02	0.0575	0.6633	0.35	49.8%	91%
12/16/14	0.30	457.6	0.27	102.75	218.7	0.03	0.0440	0.4780	0.12	37.7%	81%
12/22/14	0.49	417.8	0.12	13.78	308.1	0.03	0.0620	0.7374	0.25	49.2%	82.9%
12/23/14	2.05	8636.7	0.61	110.95	6002.0	1.47	1.2069	0.6949	2.40	41.1%	74.5%
12/29/14	0.50	467.8	0.08	0.62	472.0	0.03	0.0949	1.0091	0.34	30.1%	54.2%
1/4/15	0.20	271.5	0.17	0.00	171.9	0.02	0.0346	0.6332	0.10	59.4%	78.0%
1/12/15	1.39	2630.4	0.25	48.21	1725.5	0.27	0.3470	0.6560	1.09	75.7%	80.0%
1/18/15	0.59	680.3	0.12	2.85	412.7	0.02	0.0830	0.6067	0.19	16.9%	65.3%
1/23/15	0.69	500.7	0.05	1.06	347.9	0.02	0.0700	0.6949	0.29	13.7%	74.0%
1/26/15	0.31	219.0	0.05	2.88	174.0	0.02	0.0350	0.7947	0.50	33.3%	50.8%
2/2/15	0.43	1453.4	0.21	4.39	548.0	0.03	0.1102	0.3770	0.13	45.5%	75.7%
2/9/15	0.50	340.1	0.08	52.05	164.9	0.02	0.0332	0.4849	0.24	55.5%	68.8%
3/1/15	0.80	3325.8	0.15	4.22	924.6	0.03	0.1859	0.2780	0.22	79.5%	37.0%
3/5/15	0.99	1080.9	0.17	72.10	972.9	0.06	0.1956	0.9001	0.37	35.7%	90.2%
3/14/15	0.42	206.9	0.09	0.12	202.9	0.03	0.0408	0.9810	0.29	51.6%	91.5%
3/19/15	0.64	501.6	0.04	0.00	385.0	0.02	0.0774	0.7676	0.55	-23.0%	87.9%
3/26/15	0.22	173.8	0.14	62.99	104.9	0.04	0.0211	0.6034	0.26	44.5%	93.8%
3/27/15	0.14	78.3	0.05	7.30	41.6	0.02	0.0084	0.5317	0.35	49.0%	43.3%
3/30/15	0.22	430.8	0.02	7.84	108.8	0.02	0.0219	0.2524	0.71	59.1%	90.6%
4/9/15	0.23	188.7	0.44	138.62	99.8	0.03	0.0201	0.5290	0.07	79.1%	88.2%
4/9/15	0.50	453.2	0.17	0.00	365.5	0.05	0.0735	0.8065	0.27	80.4%	89.3%
4/14/15	0.40	464.2	0.50	29.98	247.2	0.05	0.0497	0.5325	0.09	97.0%	96.2%
4/19/15	0.74	2433.4	0.19	0.69	496.6	0.03	0.0999	0.2041	0.13	97.5%	96.2%
4/20/15	0.33	259.5	0.36	0.00	162.7	0.02	0.0327	0.6272	0.07	91.4%	89.8%
4/25/15	0.30	129.5	0.02	2.31	80.7	0.01	0.0162	0.6229	0.64	70.4%	92.0%
4/30/15	0.56	447.7	0.54	275.61	431.9	0.09	0.0869	0.9649	0.17	78.2%	91.9%

5/1/15	0.35	829.2	0.04	0.01	130.7	0.01	0.0263	0.1577	0.34	70.5%	91.3%
5/10/15	0.45	200.3	0.26	89.41	97.7	0.03	0.0196	0.4879	0.10	75.1%	89.3%
5/21/15	0.18	155.2	0.22	96.16	36.7	0.03	0.0074	0.2367	0.13	63.1%	77.9%
6/9/15	0.42	311.7	0.40	32.16	197.1	0.06	0.0396	0.6325	0.14	67.6%	87.7%
6/17/15	0.54	461.6	0.45	174.63	304.3	0.08	0.0612	0.6592	0.19	60.0%	61.0%
6/18/15	3.01	7977.6	2.19	0.00	8594.9	1.98	1.7283	1.0774	0.91	17.7%	82.6%
6/20/15	0.11	480.8	0.29	117.87	16.4	0.01	0.0033	0.0340	0.04	45.2%	79.5%
6/26/15	1.74	5302.4	1.05	0.00	1808.1	0.14	0.3636	0.3410	0.14	54.1%	78.4%
7/3/15	0.23	863.3	0.31	135.63	35.3	0.01	0.0071	0.0408	0.04	29.1%	81.5%
7/5/15	0.26	1028.7	0.43	174.83	142.9	0.05	0.0287	0.1389	0.11	62.9%	87.1%
7/8/15	0.59	1066.6	0.95	555.45	584.0	0.13	0.1174	0.5476	0.14	46.9%	73.0%
7/13/15	1.47	3177.3	1.03	232.76	1700.5	0.64	0.3419	0.5352	0.63	46.9%	73.0%
7/21/15	0.52	530.9	0.81	358.32	103.8	0.04	0.0209	0.1955	0.05	46.9%	73.0%
7/23/15	0.51	1135.3	0.78	346.53	615.5	0.13	0.1238	0.5422	0.16	46.9%	73.0%
8/6/15	0.14	249.5	0.25	158.77	1.6	0.00	0.0003	0.0065	0.01	46.9%	73.0%
8/11/15	0.32	617.0	0.17	78.81	14.6	0.01	0.0029	0.0237	0.04	46.9%	73.0%
8/18/15	0.22	386.0	0.54	272.81	19.3	0.02	0.0039	0.0500	0.03	46.9%	73.0%
8/19/15	0.17	363.6	0.14	92.96	30.1	0.02	0.0061	0.0829	0.12	46.9%	73.0%
8/19/15	0.97	1584.0	1.23	553.69	1399.2	0.57	0.2814	0.8834	0.46	46.9%	73.0%
8/31/15	0.76	1586.3	0.51	223.38	358.6	0.04	0.0721	0.2261	0.08	46.9%	73.0%
9/5/15	0.30	610.2	0.48	320.32	91.9	0.04	0.0185	0.1506	0.09	46.9%	73.0%
9/9/15	0.11	533.3	0.59	380.57	369.5	0.11	0.0743	0.6928	0.18	46.9%	73.0%
10/10/15	0.27	662.1	0.09	13.43	26.3	0.01	0.0053	0.0397	0.08	46.9%	73.0%
10/27/15	0.93	2483.0	0.51	4.18	1261.1	0.06	0.2536	0.5079	0.11	46.9%	73.0%
11/1/15	2.42	6457.3	0.44	5.46	5456.3	0.11	1.0972	0.8450	0.26	46.9%	73.0%
Mean	0.70	1620.30	0.52	140.41	811.83	0.16	0.16	41%	28%	64%	84%
Median	0.48	662.07	0.28	79.55	249.65	0.03	0.05	36%	13%	63%	89%
Standard Dev	0.70	2130.75	0.57	186.14	1541.28	0.37	0.31	30%	44%	26%	13%

Table 2. DT Post-Retrofit Hydrology Data

Storm Date	Rainfall (in.)	Vol In (cf)	Qp In (cfs)	Storage (cf)	Vol Out (cf)	Qp Out (cfs)	fV	Rp	Vol Reduction	Qp Reduction
11/7/15	0.39	1278.20	0.41	804.49	189.86	0.0433	0.1485	0.1067	85.1%	89.3%
11/11/15	1.45	5023.64	0.49	451.45	1498.79	0.0456	0.2983	0.0935	70.2%	90.6%
11/19/2015	1.09	3176.18	0.72	1293.92	1399.73	0.0701	0.4407	0.0980	55.9%	90.2%
11/29/2015	0.96	702.92	0.05	248.30	348.72	0.0201	0.4961	0.4435	50.4%	55.6%
12/2/15	0.10	40.11	0.03	40.11	0.00	0.0000	0.0000	0.0000	100.0%	100.0%
12/17/2015	1.13	1249.36	0.32	665.45	727.53	0.0413	0.5823	0.1280	41.8%	87.2%
12/22/2015	2.23	7423.33	0.89	1133.48	4066.02	0.6867	0.5477	0.7725	45.2%	22.7%
12/28/2015	0.20	1085.33	0.05	1085.33	0.00	0.0000	0.0000	0.0000	100.0%	100.0%
12/30/2015	1.55	4681.69	0.82	747.25	2348.17	0.2438	0.5016	0.2975	49.8%	70.2%
1/9/16	0.23	1078.38	0.18	1078.38	0.00	0.0000	0.0000	0.0000	100.0%	100.0%
1/16/16	0.46	1442.69	0.15	1070.56	74.53	0.0140	0.0517	0.0915	94.8%	90.8%
1/17/16	0.12	464.52	0.05	464.52	0.00	0.0000	0.0000	0.0000	100.0%	100.0%
2/3/16	1.54	5594.12	0.86	1586.57	2028.03	0.4368	0.3625	0.5094	63.7%	49.1%
2/8/16	0.17	494.04	0.09	494.04	0.00	0.0000	0.0000	0.0000	100.0%	100.0%
3/13/16	0.20	362.03	0.51	362.03	0.00	0.0000	0.0000	0.0000	100.0%	100.0%
3/14/16	0.97	1772.23	1.43	771.28	1622.16	0.8234	0.9153	0.5773	8.5%	42.3%
3/26/16	0.93	2699.85	0.32	989.37	353.49	0.0233	0.1309	0.0738	86.9%	92.6%
4/2/16	0.18	559.94	0.22	559.94	0.00	0.0000	0.0000	0.0000	100.0%	100.0%
4/12/16	0.66	2235.56	0.23	1115.87	196.47	0.0173	0.0879	0.0740	91.2%	92.6%
4/22/16	1.59	4076.69	1.16	1660.99	2911.76	0.7124	0.7142	0.6118	28.6%	38.8%
4/28/16	1.10	2317.61	1.19	1086.54	2020.37	1.1058	0.8717	0.9275	12.8%	7.2%
5/1/16	0.18	549.66	0.23	549.66	0.00	0.0000	0.0000	0.0000	100.0%	100.0%
5/3/16	0.51	1125.17	1.05	501.70	681.55	0.1885	0.6057	0.1799	39.4%	82.0%
5/5/16	1.57	3881.47	0.67	973.29	2184.24	0.4528	0.5627	0.6732	43.7%	32.7%
5/12/16	0.23	618.82	0.21	618.82	0.00	0.0000	0.0000	0.0000	100.0%	100.0%
5/18/16	0.15	456.28	0.06	456.28	0.00	0.0000	0.0000	0.0000	100.0%	100.0%
5/19/16	0.15	649.60	0.09	649.60	0.00	0.0000	0.0000	0.0000	100.0%	100.0%
5/21/16	0.31	720.30	0.38	603.94	32.41	0.0218	0.0450	0.0575	95.5%	94.3%
5/22/16	0.13	334.61	0.08	334.61	0.00	0.0000	0.0000	0.0000	100.0%	100.0%
5/29/16	0.98	2158.79	0.89	1105.23	625.38	0.0680	0.2897	0.0761	71.0%	92.4%
5/30/16	0.12	404.96	0.05	404.96	0.00	0.0000	0.0000	0.0000	100.0%	100.0%

6/5/16	0.52	1114.99	0.75	953.46	174.80	0.0500	0.1568	0.0670	84.3%	93.3%
6/5/16	0.58	1480.88	0.76	416.91	375.97	0.0423	0.2539	0.0556	74.6%	94.4%
6/6/16	0.42	1294.14	0.37	296.00	259.73	0.0398	0.2007	0.1085	79.9%	89.2%
6/15/16	1.19	1256.28	0.70	1043.14	240.55	0.0622	0.1915	0.0894	80.9%	91.1%
6/23/16	0.20	356.05	0.24	356.05	0.00	0.0000	0.0000	0.0000	100.0%	100.0%
6/23/16	0.59	1409.67	0.76	713.38	199.67	0.0353	0.1416	0.0464	85.8%	95.4%
6/28/16	1.42	3263.71	0.80	913.56	1705.31	0.5107	0.5225	0.6378	47.7%	36.2%
6/29/16	0.60	1344.60	0.48	752.40	362.53	0.0646	0.2696	0.1351	73.0%	86.5%
7/3/16	0.89	1750.20	0.95	1154.27	1098.31	0.3842	0.6275	0.4046	37.2%	59.5%
7/5/16	0.60	1253.31	0.52	1042.14	327.39	0.0663	0.2612	0.1279	73.9%	87.2%
7/8/16	0.38	679.49	0.81	538.96	57.18	0.0291	0.0842	0.0358	91.6%	96.4%
7/15/16	1.09	1863.36	1.11	1685.63	1474.93	0.5832	0.7915	0.5277	20.8%	47.2%
7/16/16	6.17	10916.05	1.97	1103.54	12011.90	1.8438	1.1004	0.9351	-10.0%	6.5%
7/26/16	0.50	949.42	0.62	949.42	0.00	0.0000	0.0000	0.0000	100.0%	100.0%
7/31/16	0.20	392.92	0.09	392.92	0.00	0.0000	0.0000	0.0000	100.0%	100.0%
8/2/16	0.45	1059.41	0.67	921.93	12.07	0.0104	0.0114	0.0154	98.9%	98.5%
8/4/16	1.82	3280.28	0.82	1679.21	3004.37	0.7929	0.9159	0.9633	8.4%	3.7%
8/5/16	0.14	349.21	0.13	212.17	9.93	0.0087	0.0284	0.0642	97.2%	93.6%
8/8/16	0.62	1166.48	0.87	659.38	286.23	0.0413	0.2454	0.0473	75.5%	95.3%
8/20/16	0.18	277.24	0.19	277.24	0.00	0.0000	0.0000	0.0000	100.0%	100.0%
Mean	0.79	1845.41	0.54	783.72	880.59	0.19	26%	20%	74%	80%
Median	0.52	1249.36	0.49	747.25	199.67	0.04	15%	7%	85%	93%
Standard Dev	0.94	2014.88	0.42	398.45	1858.79	0.36	31%	28%	31%	28%

Appendix C – AAuto Water Quality Data

Table 1. AAuto Influent and Effluent EMCs (mg/L).

			TKN		NO23		TAN		TN		ON		TP		OrthoP		PBP		TSS	
onfig	Date	Rainfall (in)	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out
Conv	12/18/15	1.130	0.140	0.140	0.251	0.173	0.140	0.014	0.391	0.313	0.000	0.126	0.028	0.021	0.009	0.003	0.019	0.018	11.300	1.25
Conv	4/13/16	0.660	0.639	0.140	0.347	0.289	0.138	0.018	0.986	0.429	0.502	0.122	0.051	0.015	0.003	0.003	0.048	0.012	4.560	1.25
Conv	5/4/16	0.950	0.283	0.140	0.427	0.086	0.138	0.013	0.710	0.226	0.145	0.127	0.035	0.024	0.029	0.012	0.006	0.012	2.840	1.25
Conv	5/13/16	0.230	0.588	0.140	0.604	0.654	0.381	0.034	1.192	0.794	0.207	0.106	0.031	0.018	0.006	0.003	0.025	0.015	3.740	1.25
Conv	5/18/16	0.250	1.118	0.140	0.638	0.569	0.271	0.017	1.756	0.709	0.847	0.123	0.064	0.013	0.018	0.003	0.046	0.010	16.540	1.25
Conv	6/7/16	1.000	0.518	0.140	0.113	0.036	0.014	0.022	0.631	0.176	0.504	0.118	0.031	0.014	0.012	0.003	0.019	0.011	4.280	1.25
Mean		**0.703**	**0.548**	**0.140**	**0.397**	**0.301**	**0.180**	**0.020**	**0.944**	**0.441**	**0.368**	**0.120**	**0.040**	**0.017**	**0.013**	**0.005**	**0.027**	**0.013**	**7.210**	**1.25**
Median		**0.805**	**0.553**	**0.140**	**0.387**	**0.231**	**0.139**	**0.017**	**0.848**	**0.371**	**0.355**	**0.123**	**0.033**	**0.016**	**0.010**	**0.003**	**0.022**	**0.012**	**4.420**	**1.25**
Std. Dev.		**0.390**	**0.338**	**0.000**	**0.203**	**0.257**	**0.127**	**0.008**	**0.486**	**0.257**	**0.309**	**0.008**	**0.014**	**0.004**	**0.009**	**0.004**	**0.016**	**0.003**	**5.487**	**0.00**
IWS	6/10/14	1.020	0.730	0.389	0.161	0.316	0.252	0.114	0.891	0.705	0.478	0.275	0.112	0.056	0.054	0.022	0.058	0.034	40.840	4.21
IWS	7/11/14	0.870	0.776	0.307	0.316	0.329	0.098	0.033	1.092	0.637	0.678	0.274	0.048	0.031	0.003	0.003	0.045	0.028	40.480	5.23
IWS	8/19/14	0.880	0.347	0.140	0.173	0.128	0.140	0.033	0.520	0.268	0.207	0.107	0.020	0.018	0.007	0.003	0.013	0.015	13.080	1.25
IWS	1/16/15	1.390	0.140	0.140	0.077	0.065	0.034	0.018	0.217	0.205	0.106	0.122	0.067	0.052	0.025	0.025	0.042	0.027	15.220	5.07
IWS	3/16/15	0.420	0.386	0.140	0.180	0.105	0.180	0.067	0.566	0.245	0.206	0.073	0.030	0.005	0.003	0.003	0.027	0.002	14.210	1.25
IWS	4/16/15	0.360	0.373	0.140	0.202	0.133	0.153	0.027	0.575	0.273	0.220	0.113	0.021	0.011	0.012	0.003	0.009	0.008	4.190	1.25
IWS	4/20/15	0.750	0.740		0.266		0.274		1.006		0.466		0.046		0.003		0.043		5.410	
IWS	4/21/15	0.480	0.356	0.140	0.219	0.212	0.170	0.087	0.574	0.352	0.186	0.053	0.028	0.016	0.013	0.003	0.015	0.013	3.050	1.25
IWS	4/27/15	0.300	0.792		0.513		0.311		1.305		0.481		0.079		0.003		0.076		6.350	
IWS	6/18/15	0.540	1.868	0.489	0.442	0.454	0.639	0.158	2.310	0.943	1.229	0.331	0.207	0.065	0.038	0.011	0.169	0.054	69.210	6.78
IWS	8/12/15	0.320	1.365		0.467		0.197		1.832		1.167		0.068		0.009		0.059		19.600	
IWS	8/20/15	0.970	0.140	0.298	0.114	0.137	0.151	0.068	0.254	0.435	-0.011	0.230	0.055	0.039	0.023	0.022	0.033	0.017	14.870	4.20
IWS	10/29/15	0.930	0.394	0.140	0.189	0.093	0.176	0.052	0.583	0.233	0.218	0.088	0.040	0.026	0.013	0.021	0.027	0.006	8.300	1.25
Mean		**0.7**	**0.65**	**0.23**	**0.26**	**0.20**	**0.21**	**0.07**	**0.90**	**0.43**	**0.43**	**0.17**	**0.06**	**0.03**	**0.02**	**0.01**	**0.05**	**0.02**	**19.6**	**3.2**
Median		**0.8**	**0.39**	**0.14**	**0.20**	**0.13**	**0.18**	**0.06**	**0.58**	**0.31**	**0.22**	**0.12**	**0.05**	**0.03**	**0.01**	**0.01**	**0.04**	**0.02**	**14.2**	**2.7**
Std. Dev.		**0.3**	**0.50**	**0.13**	**0.14**	**0.13**	**0.15**	**0.04**	**0.61**	**0.25**	**0.39**	**0.10**	**0.05**	**0.02**	**0.02**	**0.01**	**0.04**	**0.02**	**19.3**	**2.1**

Appendix D – Probability Plots

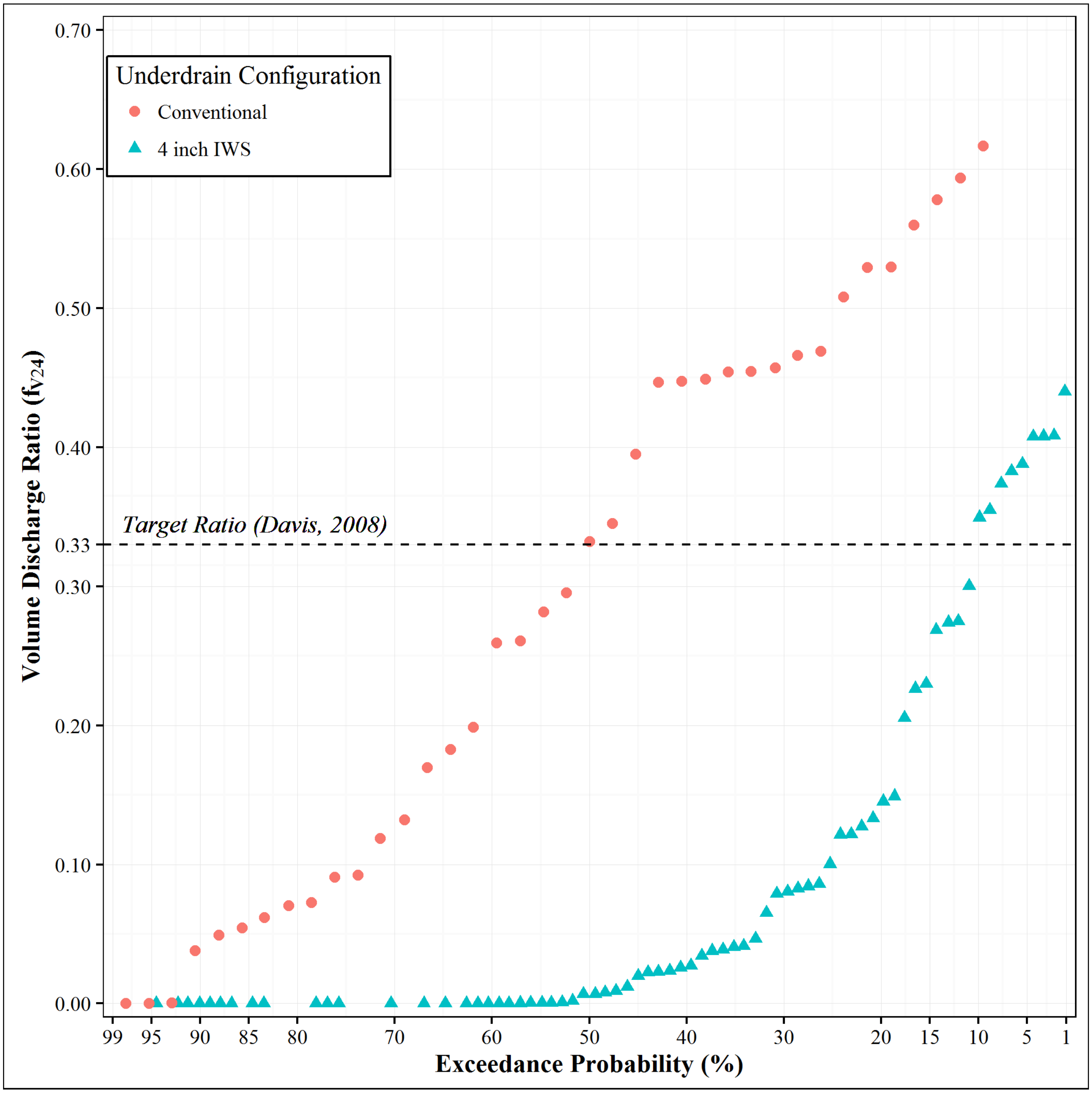

Figure 1. Advance Auto volume discharge ratio exceedance probability plot.

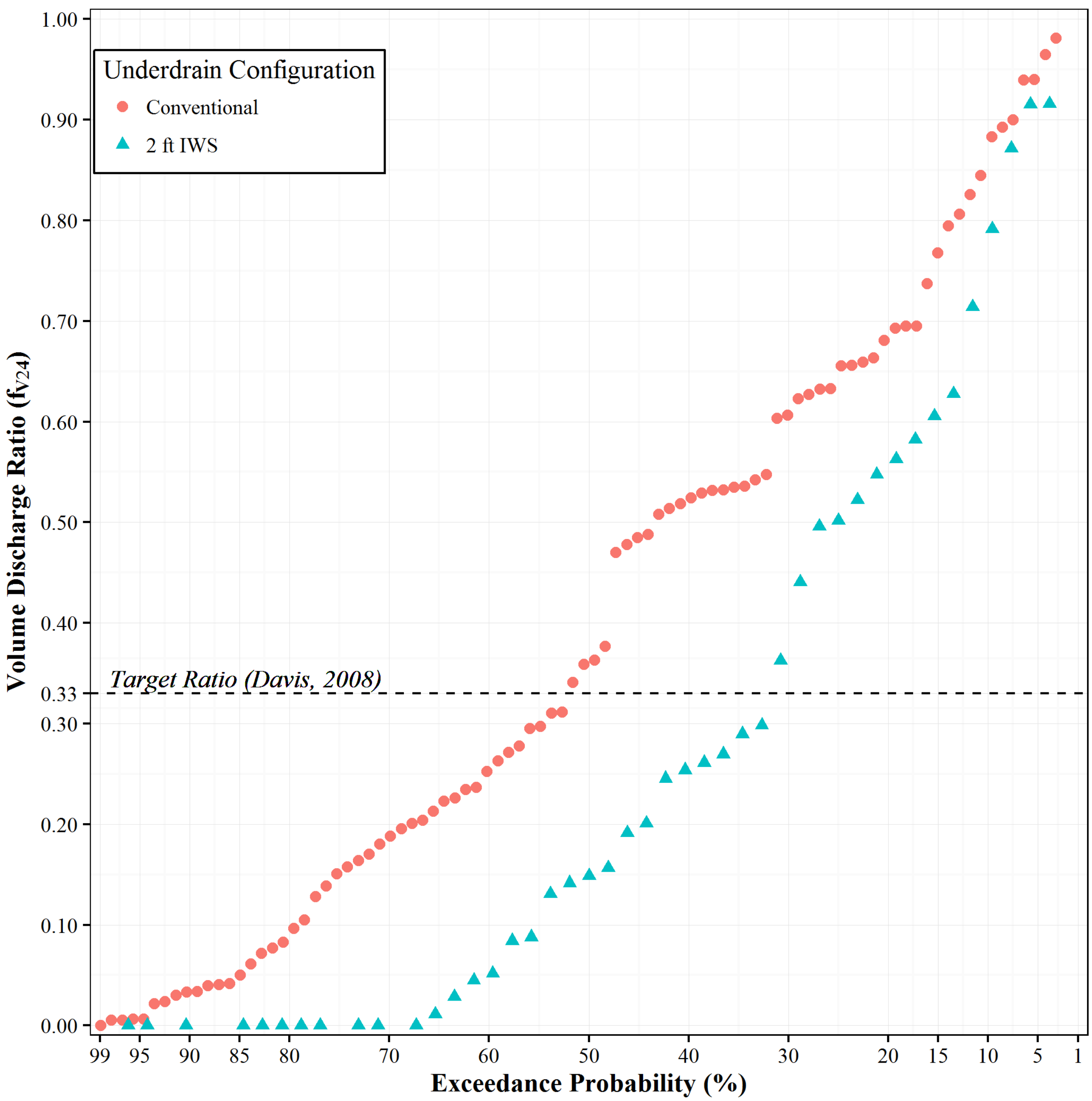

Figure 2. Discount Tire volume discharge ratio exceedance probability plot.

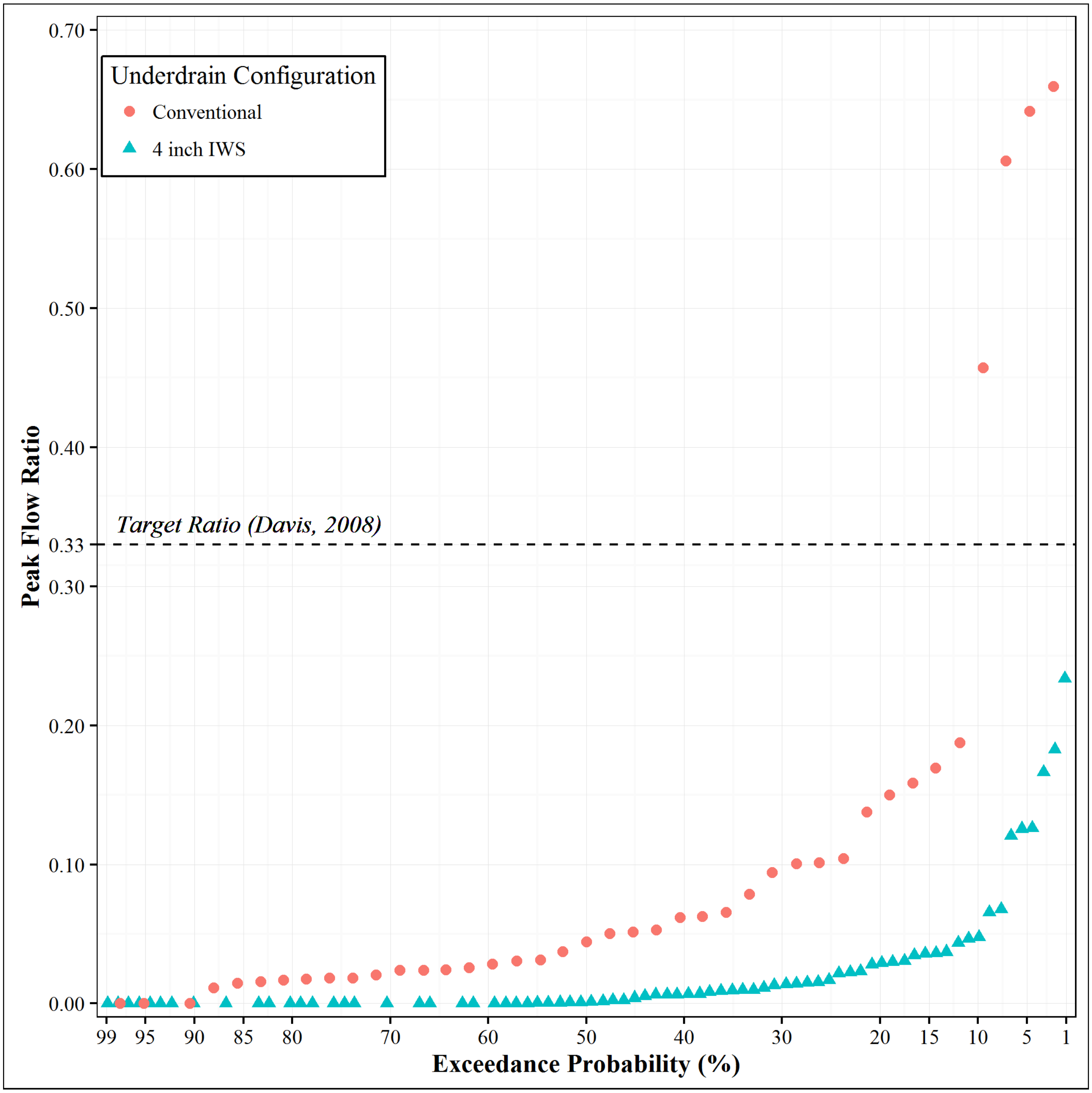

Figure 3. Advance Auto peak discharge ratio exceedance probability plot.

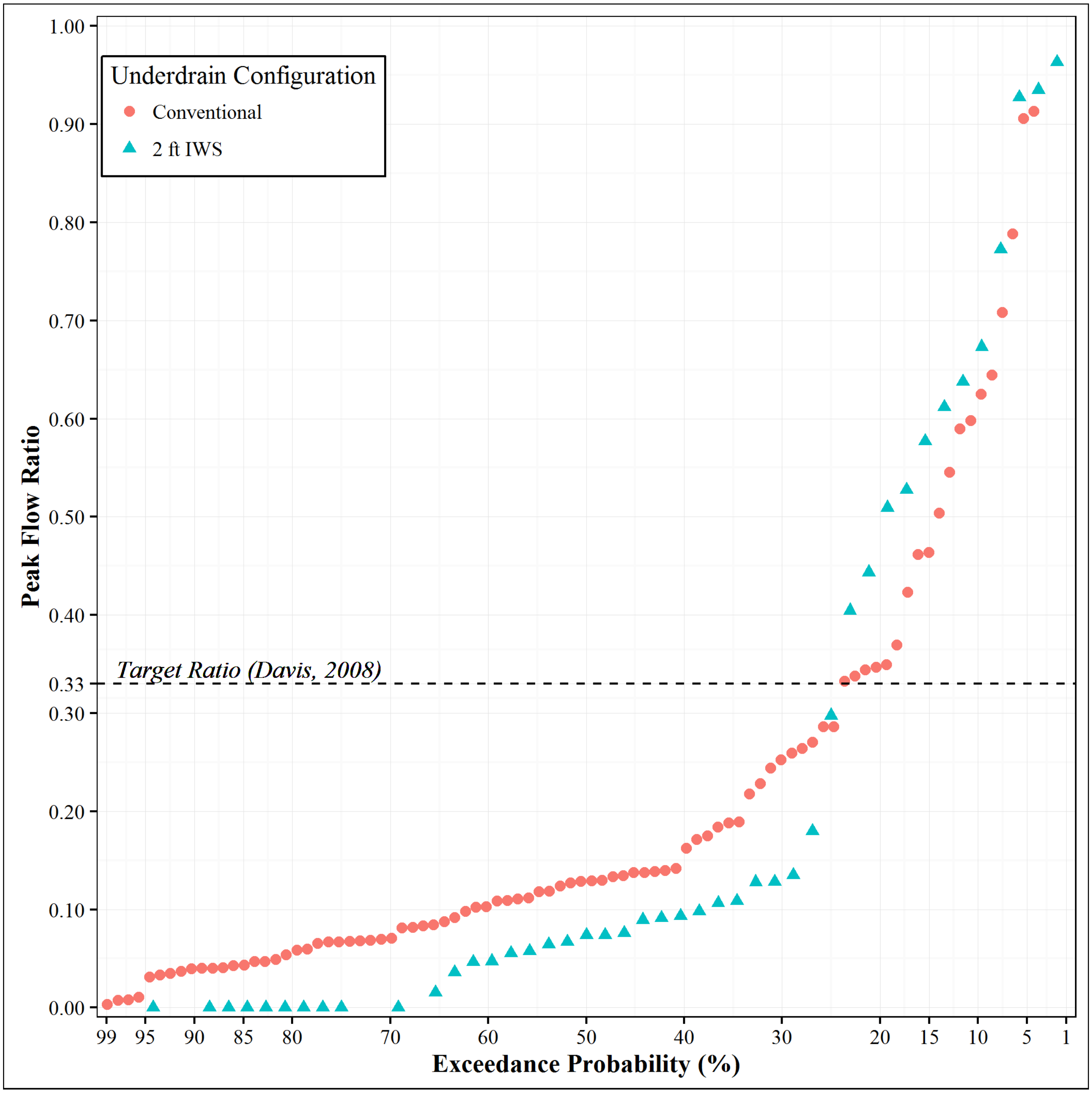

Figure 4. Discount Tire peak discharge ratio exceedance probability plot.

Appendix E – AAuto Water Quality Plots

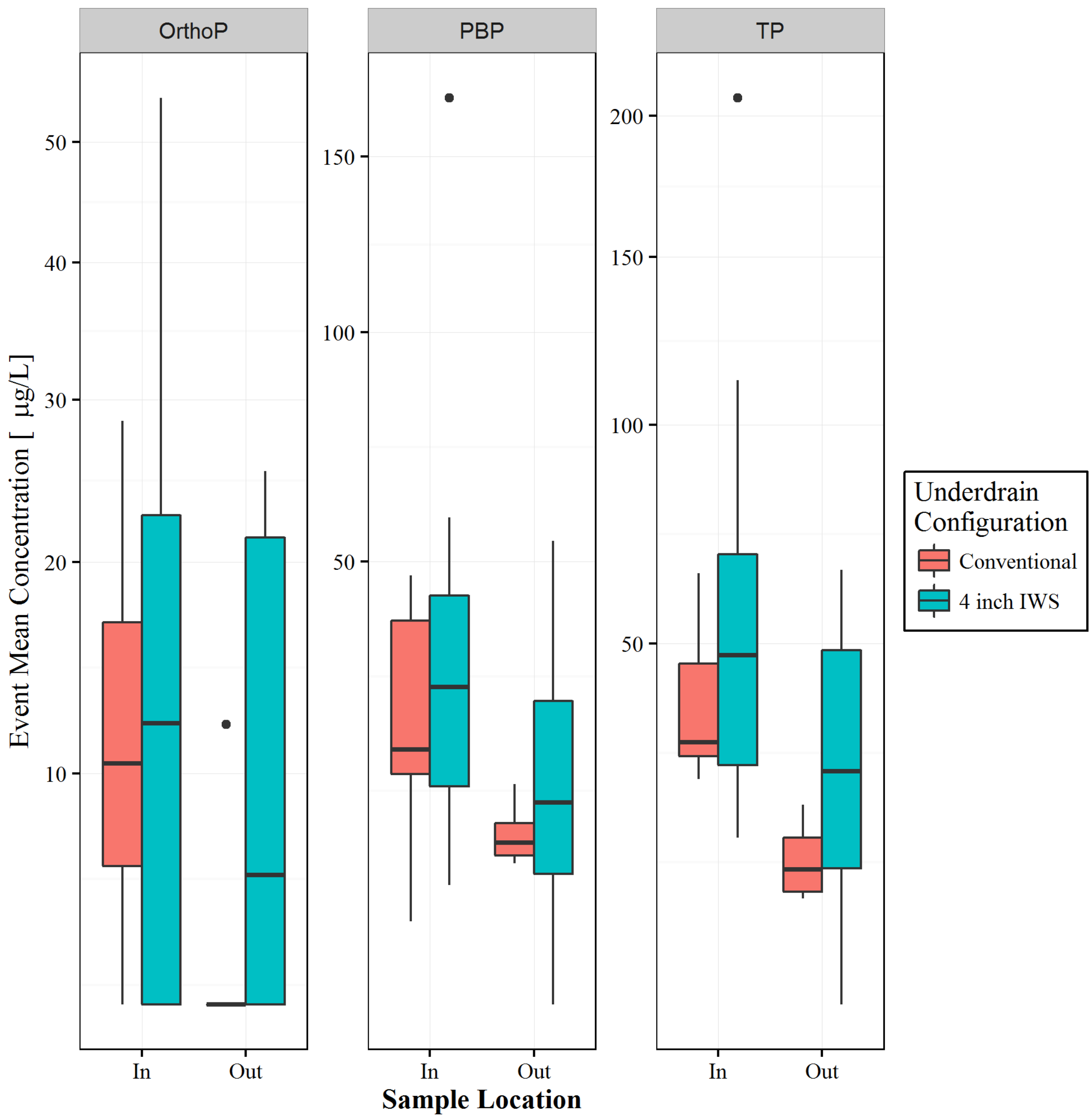

Figure 1. Phosphorus species EMCs at AAuto.

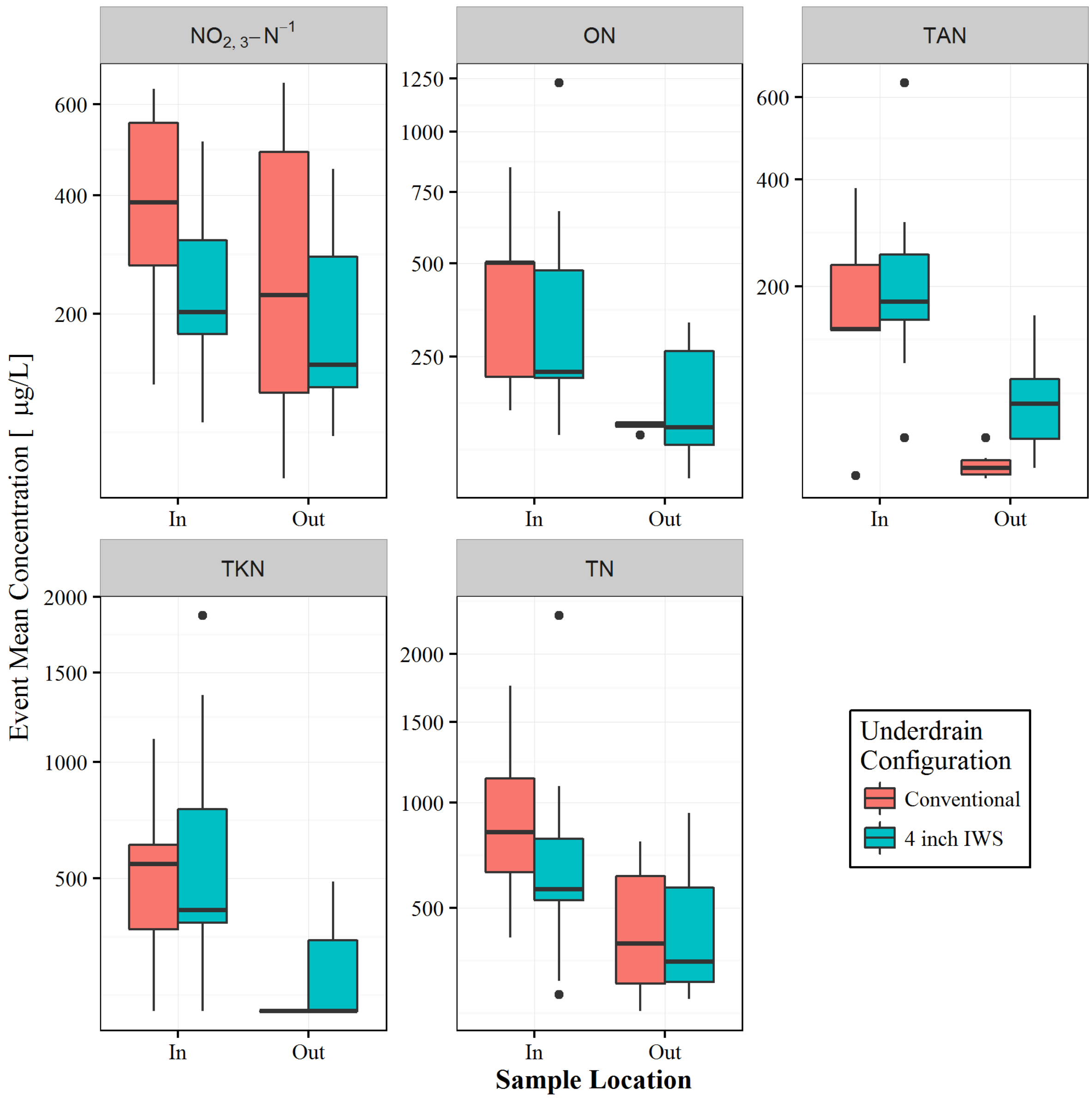

Figure 2. Nitrogen species EMCs at AAuto.

Appendix F – Site Photos

Figure 1. Weir box located at DT 3 inch inlet from roof.

Figure 2. Inlet apron from 15-inch RCP at AAuto with sample box.

Figure 3. Compound weir installed to monitor parking lot runoff at DT.

Figure 4. ISCO 6712 automatic samplers used for water quality monitoring at AAuto.

Figure 5. Pre-retrofit underdrain entrance to DT outlet structure.

Figure 6. Post-retrofit elevated underdrain at DT using a simple upturned elbow.

Project: Achieving New Milestones for Stormwater Runoff Reductions in Black Creek Watershed (cooperative agreement)

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Prepared for: Christy Perrin, Water Resources Research Institute and the Black Creek Watershed Association (BCWA)

Date: September 27, 2016

Executive Summary

The overall objective of the hydrological component of the project was to quantify potential peak flow reductions from the implementation of a downspout disconnection campaign for effective impervious cover reduction in targeted subwatersheds within the Black Creek watershed (Wake County near Cary, NC). High peak flows typified by urban stormwater runoff – as documented historically in the main stem of Black Creek – have led to severe bank erosion, downed trees along streamsides, impaired water quality due to sediment loads, and a potential degradation of macroinvertebrate habitat. The disconnection campaign being implemented by the Black Creek Watershed Association (BCWA) is based on the concept that stormwater volumes in urban watersheds can be reduced by disconnecting impervious (hard and non-draining) surfaces such as rooftops, parking lots, and driveways, and thus reducing historically high peak flows and resulting downstream impacts. By allowing stormwater to be drained naturally into the soil rather than routed directly to creeks via curbs and pipes, the stormwater flows are dampened, energy is dissipated, the erosion potential along the banks of Black Creek is minimized, downstream sediment loads are potentially reduced, and macroinvertebrate habitats are either preserved or allowed to be restored.

The hydrological component of the project continued flow data collection at a monitoring station in the main stem of Black Creek (2,050 acres), along with two additional monitoring stations installed in headwater tributaries within the southern part of the watershed where stormwater reduction practices are planned (East Fork, Belhaven Rd. culvert, 257 acres, and West Fork, Northwoods Rd. culvert, 58 acres). Streamflow monitoring and watershed modeling efforts were conducted to gain an accurate estimate of the scope of retrofit projects that would be necessary to achieve stormwater volume and peak flow reduction in the larger Black Creek. The continuation of hydrologic data collection has led to an improved understanding of stormflow in the urban Black Creek watershed, as well as the potential for runoff reduction over time due to stormwater management practice retrofit efforts.

Streamflow monitoring was conducted over the course of 2.5 years during 2014-2016; however, due to quality assurance/control and instrumentation issues, only 10 months of data from Nov. 2015 to Aug. 2016 were used for analyses. Monitoring efforts were coupled with watershed model simulations to determine stormwater volume and peak flow reductions under given effective impervious cover scenarios in a smaller first-order watershed that contains Northwoods Elementary School (upper West Fork) and a larger third-order watershed that is comprised of residential and commercial development (upper East Fork) including Harvest Church. Monitoring results provided a watershed characterization of streamflows given certain rainfall events while also allowing for the calibration of the watershed model for the tributaries

under estimated existing impervious cover conditions. Using measurements of rainfall and streamflow data, runoff coefficients – or the percentage of rainfall that becomes runoff – were determined for the main stem of Black Creek and also the smaller East Fork watershed. Although highly variable due to storm event characteristics, seasonality, and antecedent moisture conditions (e.g. number of days since previous rainfall), the average runoff coefficient over the monitoring period for Black Creek was 0.20 (or 20% of the rainfall was seen as stream flow), which is considered to be lower than average percentage for urban watersheds. This percentage of rainfall as runoff is considerably less than that measured during the 2010-2012 monitoring period, when the average runoff coefficient was 0.30. Overall, the average calculated runoff coefficient for all storms measured between 2010-2016 was 0.26. In the headwaters of Black Creek, the average runoff coefficient in the monitoring period for the East Fork watershed was 0.16 (or 16% of the rainfall was seen as stream flow). In contrast, the West Fork headwater stream draining Northwoods Elementary School had negligible runoff coefficient values, which is expected given that this specific watershed is comprised of very little impervious cover. For comparison, as previously monitored during 2010-2012, the 84-acre Wessex subwatershed exhibited a runoff coefficient of 0.57, an extremely high percentage of rainfall as runoff even for an urban watershed.

Simulation results from watershed models indicated that if the downspout disconnection campaign led to a removal of 10.4 acres (or revert back from the current 41% IC to the 1999 scenario at 23.1% IC) of effective impervious cover within the 58 acre subwatershed, then peak flow would be reduced from 7.1 cfs to 5.0 cfs, and ~236,000 gallons of stormwater would be kept from the Northwoods tributary and thus Black Creek from a one-inch storm. However, if a more aggressive campaign were to reduce the effective impervious cover to 10% (or disconnect ~18 acres of the 24 acres of IC), then the peak flow would be reduced from 7.1 cfs to 3.4 cfs and ~425,000 gallons of water would be kept from flowing to the West Fork tributary and to Black Creek from a one-inch storm. In addition, if residential areas in the upper East Fork neighborhoods would implement the downspout disconnection program to remove 30.6 acres (or revert back from the current 42.4% IC to the 1999 scenario, with 30.5% IC) of effective impervious cover within the 257 acre subwatershed, then peak flow would be reduced from 81.3 cfs to 65.4 cfs, and ~700,000 gallons of stormwater would be kept from the East Fork tributary and thus Black Creek from a one-inch storm. However, if a more aggressive campaign were to reduce the effective impervious cover to 10% (or disconnect ~83 acres of the 109 acres of IC), then the peak flow would be reduced from 81.3 cfs to ~38 cfs and ~2.2 million gallons of water would be kept from flowing into the East Fork and eventually to Black Creek from a one-inch storm.

These efforts would significantly reduce overall peak flows as well as the potential for bank erosion, water quality impairment, and macroinvertebrate habitat degradation. The watershed modeling exercise provided estimates based on the simulated conversion of effective impervious cover to forested and/or grassed landscapes based on expected hydrologic processes, thus possibly over-predicting volume reduction. As a result, stormwater reduction could be further limited by the actual design and as-built capacities of individual stormwater control measures within each watershed.

Since the 257-acre Upper East Fork subwatershed encompasses approximately 12.5% of the total 2,050-acre land area of the Black Creek watershed land area, HEC-HMS simulation results based on existing topography, soils, and land use/land cover, along with scenarios of reduced effective impervious cover, provided guidance as to how much stormwater flow and volume may be reduced from a given storm event before entering Black Creek. Conversely, based on monitoring and modeling results, the 58-acre subwatershed, in which Northwoods Elementary School is located, would benefit somewhat from downspout disconnection retrofit efforts, but flows from this area appear to be relatively negligible based on our measurements and data analyses.

The results from this work do not give direct indication of specific water quality benefits; however, it is expected that the significant reduction of overall peak flows would reduce the potential for bank erosion, water quality impairment including sediment loading, and the degradation of aquatic habitat. Furthermore, simulations were not conducted for highly impervious areas such commercial or major roadway land uses. Simulation results do reveal how much impervious cover area reduction would be required to achieve effective downspout disconnection for water quantity management based on rainfall and subsequent discharge at the residential/neighborhood subwatershed scale. Further work must be conducted to determine any hydrographic benefits at the larger Black Creek watershed scale, with efforts to expand monitoring and modeling to other subwatersheds with different land uses, stormwater infrastructure, and impervious cover percentages.

Methods

Specific tasks for this component of the project to support the downspout disconnection program in the Black Creek watershed were performed to answer the following questions:

1. What are the rainfall-runoff relationships in terms of streamflow in the Black Creek watershed and in smaller residential/commercial subwatersheds in the headwaters of the East and West Forks?

2. How much can we reduce peak flows in the headwater streams using retrofitted stormwater practices that disconnect impervious surface cover from influencing watershed flows?

3. How much reduction in stormwater volume can be achieved using these disconnection practices in the upper subwatersheds?

<u>Watershed Descriptions</u>

Black Creek - Main Stem

The Black Creek watershed (Figures 1 and 2) is approximately 2,050 acres (~3.2 mi^2) and is highly urbanized (33% impervious cover) as it drains a large portion of the commercial area of the Town of Cary as well as several residential neighborhoods and local commercial areas.

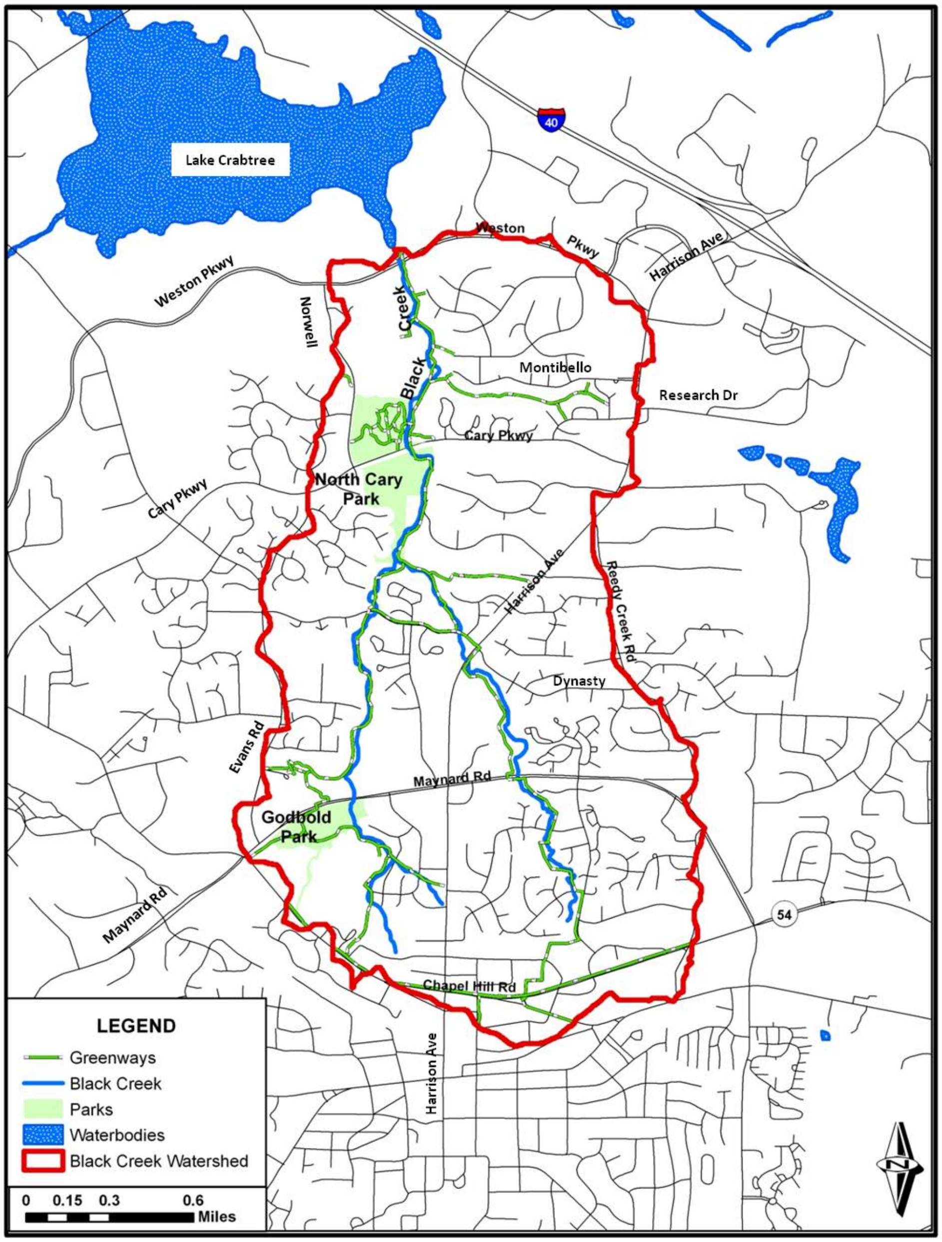


Figure 1. The 2,050-acre Black Creek watershed delineated in red (credit: Elena Horvath).

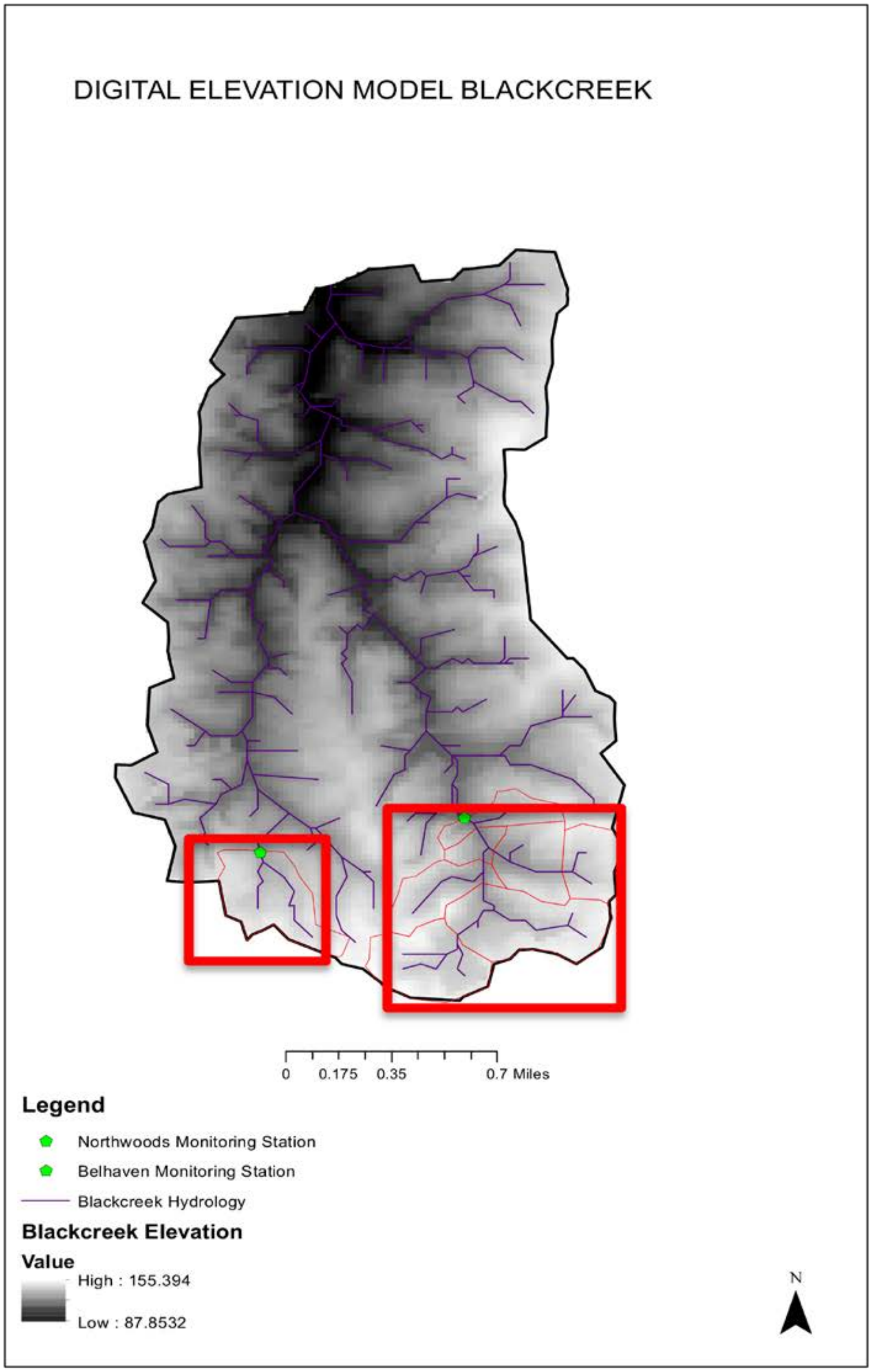


Figure 2. The 2,050-acre Black Creek watershed represented as a digital elevation model (DEM). The representative East Fork (right) and West Fork (left) subwatershed areas are highlighted in red in the southern area of the main stem watershed with green dots showing monitoring station locations.

East Fork Subwatershed

The subwatershed that drains a good portion of the upper East Fork (Figure 3) is approximately 257 acres and includes Sorrell Rd., Reedy Creek Rd., Gregory Dr. and Kingswood Dr. east of N. Harrison Ave. and north of Chapel Hill Rd. The subwatershed includes residential and commercial development. This subwatershed eventually drains directly to the main stem of Black Creek joining the West Fork well downstream of Maynard Dr. near North Cary Park.

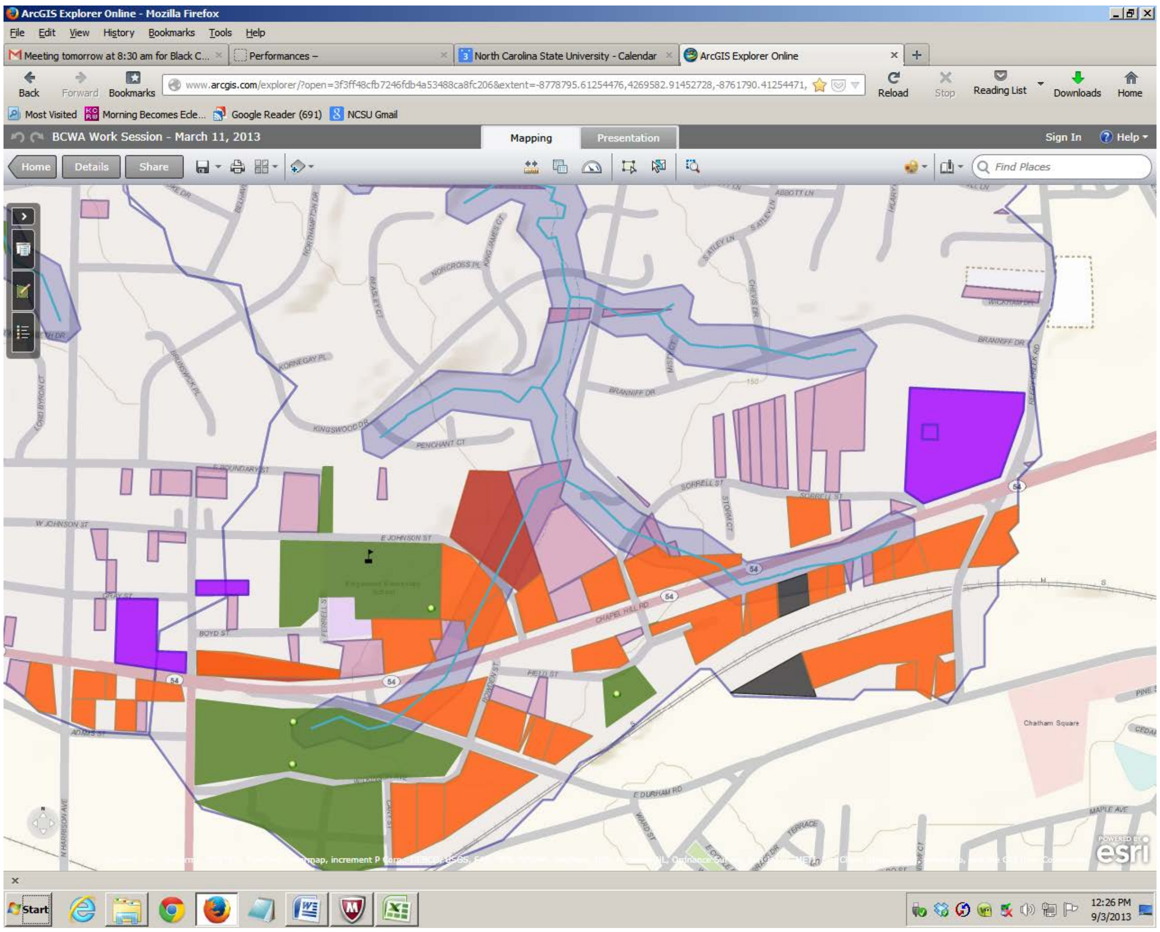


Figure 3. East Fork subwatershed with permitted BMPs (green dots), completed disconnection retrofits (yellow dots), public property (green areas), commercial property (orange areas), vacant parcels (pink areas), and churches (purple areas) (credit: Black Creek Watershed Association).

Based on recommendations by WRRI and the BCWA, the subwatershed above Belhaven Rd. was targeted for monitoring and modeling efforts because stakeholders in these drainage areas were willing to participate in the downspout disconnection campaign, including Harvest Church (Figure 3 right side in purple).

West Fork Subwatershed

The subwatershed that drains a small portion of the West Fork (Figure 4) is approximately 58 acres and includes Northwoods Rd., and W. Boundary St. west of N. Harrison Ave. and north of Chapel Hill Rd. The subwatershed includes mostly residential development and a school. This subwatershed eventually drains directly to the main stem of Black Creek joining the East Fork well downstream of Maynard Dr. near North Cary Park.

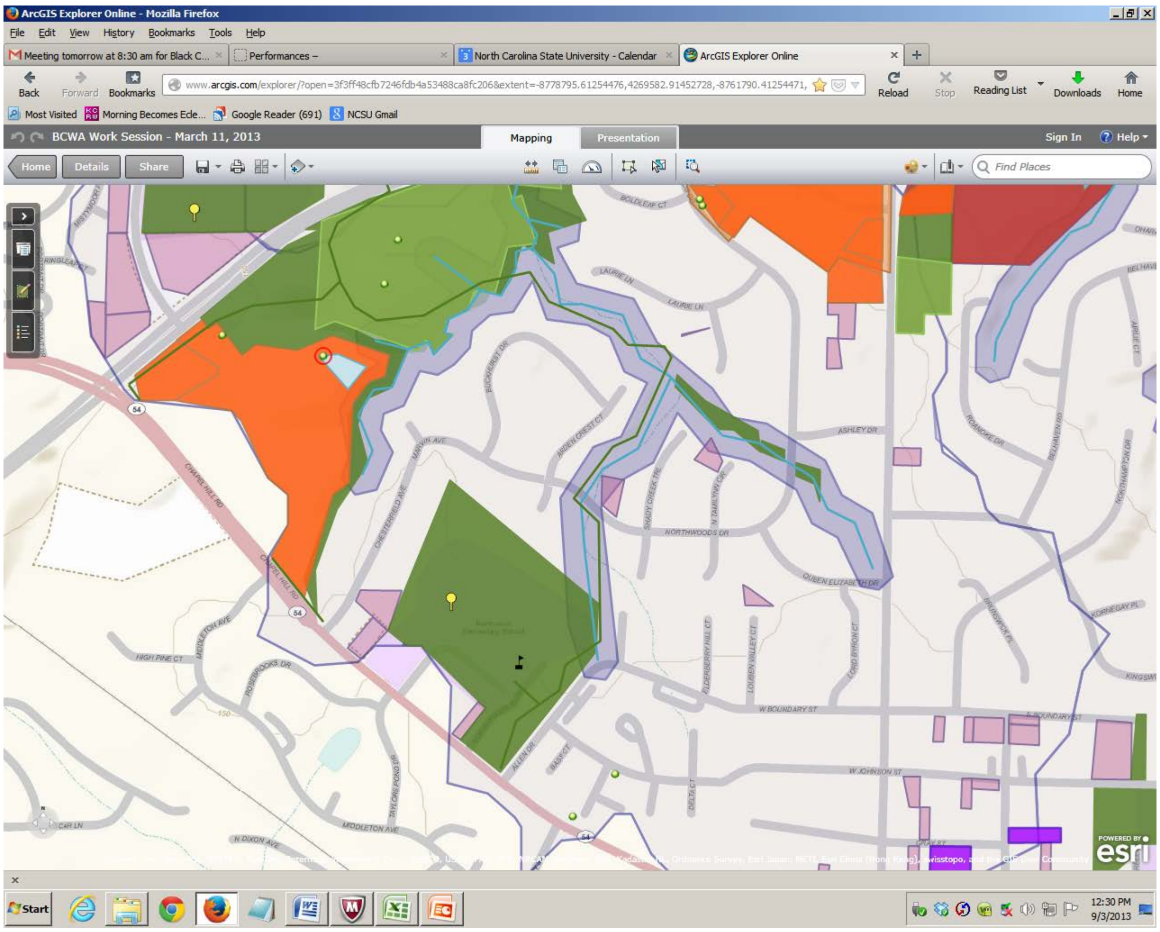


Figure 4. West Fork subwatershed with permitted BMPs (green dots), completed disconnection retrofits (yellow dots), public property (green areas), commercial property (orange areas), vacant parcels (pink areas), and churches (purple areas) (credit: Black Creek Watershed Association).

Based on recommendations by WRRI and the BCWA, the Northwoods Elementary School (Figure 4 center in green) drainage area was targeted for monitoring and modeling efforts because stakeholders in these drainage areas were willing to participate in the downspout disconnection campaign.

<u>Monitoring</u>

Rainfall was collected online from the USGS weather station located near Lake Crabtree, which can be found at the following website: (http://waterdata.usgs.gov/nc/nwis/uv/?site_no=355020078465645&PARAmeter_cd=00045)

At the Black Creek main stem station, streamflow monitoring was originally conducted using an existing Isco® 6812 automated sampler that logged stream stage (level) data collected by an Isco® 720 submerged probe with a pressure transducer. The sensor experienced failure during the course of monitoring and was replaced by a Solinst® Levelogger Gold™ pressure transducer for measuring stream stage as compensated for barometric pressure using data from a simultaneously recording Solinst® Barologger™ sensor. The water level sensor was mounted in a vented well attached to the streambank and was capable of storing data internally. For culvert water level measurements, Solinst® sensors were mounted to the pipe channel bottoms far enough into the pipe to minimize turbulent flow. Data from culvert water level sensors were also barometrically compensated. All data were downloaded quarterly, and levels were adjusted accordingly based on respective offsets based on the height at which sensors were positioned above the channel bottom.

Stream surveys (with A. Jayakaran, Clemson University) were conducted at the Black Creek main stem monitoring station to determine slope and channel dimensions to be used in the equation to calculate flows. Pipe culvert slopes were also determined via survey efforts.

Manning's equation was used to determine velocity from stream stage (level) data and surveyed stream dimensions as follows:

$$V = \frac{1.49}{n} R^{2/3} S^{1/2}$$

where V = velocity (ft/sec), n = Manning's coefficient (unitless, n = 0.05 for these streams as Piedmont creeks with course material, including some boulders), R = hydraulic radius (ft) calculated from depth (see below), and S = slope (unitless, 0.0024 used for the Wessex watershed and 0.0051 for Black Creek).

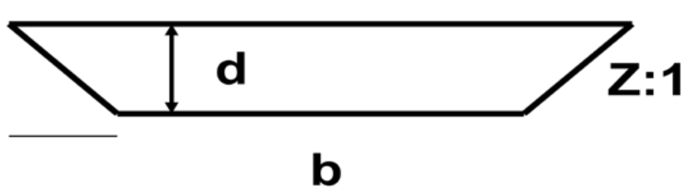


Figure 5. Dimensions for trapezoidal stream channel calculations used to determine hydraulic radius and cross-sectional area from stage data to be used in Manning's velocity (above) and flow equations (see below), where d = depth (water level), b = bottom channel width (28.0 ft for Black Creek), and Z = side slope (1.0 used for Black Creek).

Hydraulic radius (R in ft) is determined as follows (see Figure 4):

$$R = \frac{bd + Zd^2}{b + 2d\sqrt{Z^2 + 1}}$$

Cross-sectional area (A in ft^2) was determined using the trapezoidal equation based on water level in the stream and surveyed stream dimensions as follows (see Figure 5):

$$A = bd + Zd^2$$

For piped culverts at the headwater stream monitoring locations (East Fork at Belhaven Rd., pipe diameter 10 ft., West Fork at Northwoods Rd., pipe diameter 4 ft.), circular pipe calculations were performed using water level depth (stage) data.

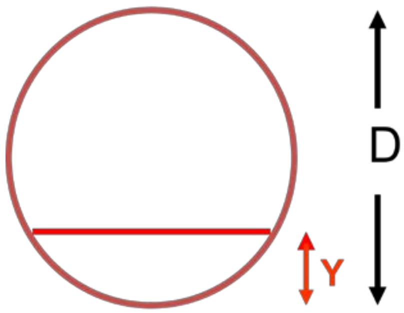


Figure 6. Dimensions for circular pipe calculations used to determine hydraulic radius and cross-sectional area from stage data to be used in velocity and flow equations (see above), where Y = depth (water level, ft), and D = diameter (ft).

Cross-sectional flow area (A in ft^2) and hydraulic radius (R in ft) were calculated using the following respectively:

$$A = \frac{D^2}{8}(\theta - \sin\theta)$$

$$R = \frac{D}{4}\left(1 - \frac{\sin\theta}{\theta}\right)$$

Where theta (θ) is determined as follows for pipes less than half full:

$$\theta = 2\ \tan^{-1}\left[\frac{\sqrt{\left(\frac{D}{2}\right)^2 - \left(\frac{D}{2} - Y\right)^2}}{\frac{D}{2} - Y}\right]$$

Instantaneous flow rates were derived from the continuity equation as follows:

$$Q = VA$$

where Q = flow (ft^3/sec or cfs), V = Manning's velocity (ft/sec) and A = cross-sectional area (ft^2).

Because both upper watershed monitoring stations were located at double barrel (two pipe) culverts, flow through each pipe was calculated separately, where flow was calculated for the ungaged pipe using level data corrected for offset invert elevations from its respective gaged pipe, then the flows were summed to give total culvert flow. By integration of the area under the hydrograph curve, the stormwater volume for each rainfall event greater than 0.2 in. was determined. By dividing stormwater volume (ft^3) by watershed area (as ft^2 converted from acres), an equivalent depth of flow for each storm was determined (inches converted from ft).

Runoff coefficients (unitless)– or the percentage of effective depth of rainfall (inches) that was generated as stormflow (depth in inches) – were calculated for each storm above 0.2 in. of rainfall for comparison between storms, across the watershed, and between subwatersheds.

Modeling

The rainfall and streamflow data were incorporated into watershed models along with topography and land cover data to assess the predictability of runoff reduction as related to urban stormwater management practice installations within the Black Creek watershed. The modeling effort was conducted to better characterize potential benefits from the practices that will be proposed for implementation.

A watershed model - the U.S. Corps of Engineer's HEC-HMS model - was used to predict streamflows at both the East and West Fork tributary stations, as both were considered to be target subwatersheds for stormwater retrofits via downspout disconnection. HEC-HMS was selected because of its availability at no cost as well as its popularity with stormwater management decision-making professionals. To simulate streamflows for storm events based on a given equivalent depth of rainfall, each model incorporated watershed characteristics (topography, land use/land cover, soils) as well as varied impervious cover percentages based on downspout disconnection scenarios. Simulate runs included varying scenarios of impervious cover percentages as a range that represents both growth (50%) and reduction (5, 10, and 25%) as compared to analyses performed by Horvath (Figure 7) that indicate 1999 impervious cover percentages of 23.1% and 30.5% for upper West and East Fork drainage areas respectively, and 2010 impervious cover percentages of 32.5% and 32.9% for upper West and East Fork drainage areas, respectively. Interestingly, between this span of years, the upper West Fork transitioned from an "impacted" watershed to a "non-supporting" level based on impervious cover percentage. Lastly, aerial imagery from 2015 was used to determine most current impervious cover percentages of 41.0% and 42.4% for upper West and East Fork drainage areas, respectively (both remain "non-supoorting).

Watershed characteristics to be used as inputs to HEC-HMS were generated by the ArcHydro® tool in ArcGIS™ Version 10.0 (Esri, Redlands, CA). The model was calibrated using 2012 watershed information, and these results were compared to runoff coefficients and peak flow rates derived from observed data.

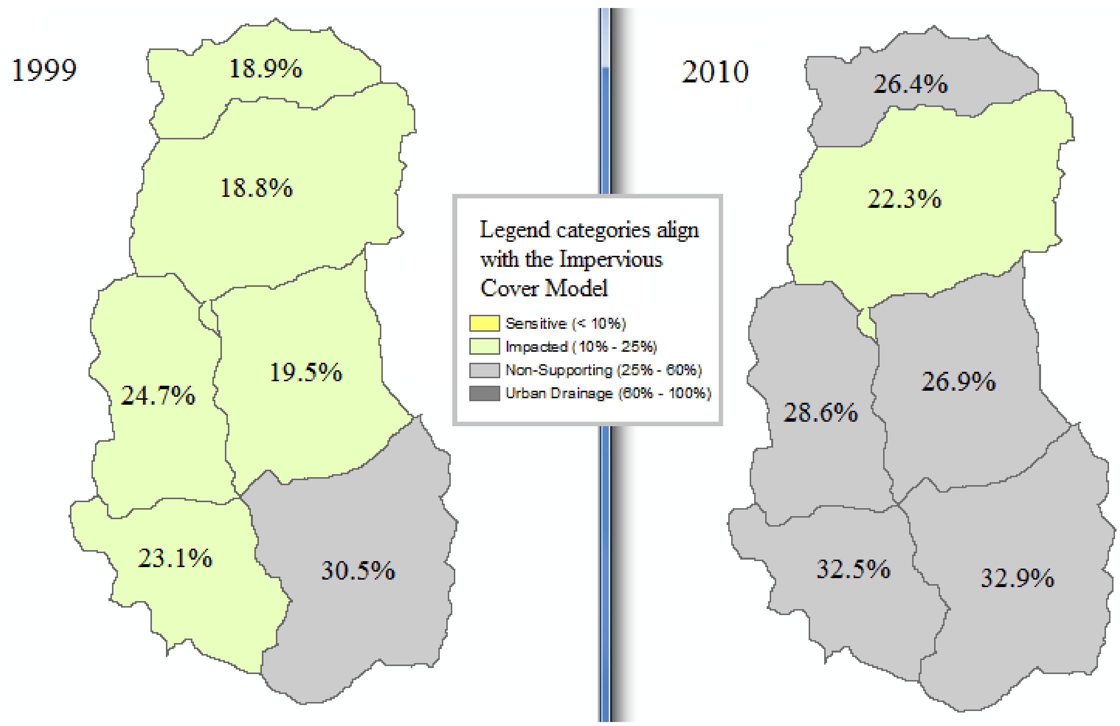


Figure 7. Comparison of effective impervious cover percentages between 1999 and 2010 for the Black Creek Watershed. These data analyses served as criteria for simulation scenarios, along with proposed stormwater management measures as part of the watershed-based plan (credit: Elena Horvath).

Results and Discussion

Monitoring results for the Black Creek main stem station and the upper East and West Fork tributaries are summarized below. For the modeling component of the project, simulations were performed for the upper two tributaries of the East and West Forks of Black Creek based on plans for stormwater retrofits in those target areas; it is assumed that flow predictions for given retrofit scenarios in this subwatershed can be scaled up to the larger Black Creek watershed to provide estimates of load reductions in terms of reduced peak flow and stormwater volumes.

Monitoring

Figures 8-10 show rainfall data collected from the USGS station as well as calculated stormwater volumes in cubic feet (cf), discharge volumes as equivalent depths normalized by watershed area (inches), and peak flows (cfs), respectively, for all storms greater than 0.2 in. (45 events) for the main stem of Black Creek and two upper tributaries between Nov. 2015 and Aug. 2016. Figures 11 and 12 show calculated runoff coefficient results based on Black Creek and the upper East Fork tributary monitoring data, respectively, over the same period and same events. Antecedent runoff conditions clearly influenced streamflow based on given rainfall depths – i.e. when a storm event occurred directly after a previous event, the resulting peak flow and stormwater volumes were very high as a response to relatively small rainfall events. Seasonality also played a factor in flow intensity and magnitude as the runoff coefficients were typically lower in the summer months except for the response from a large storm event on June 15-16.

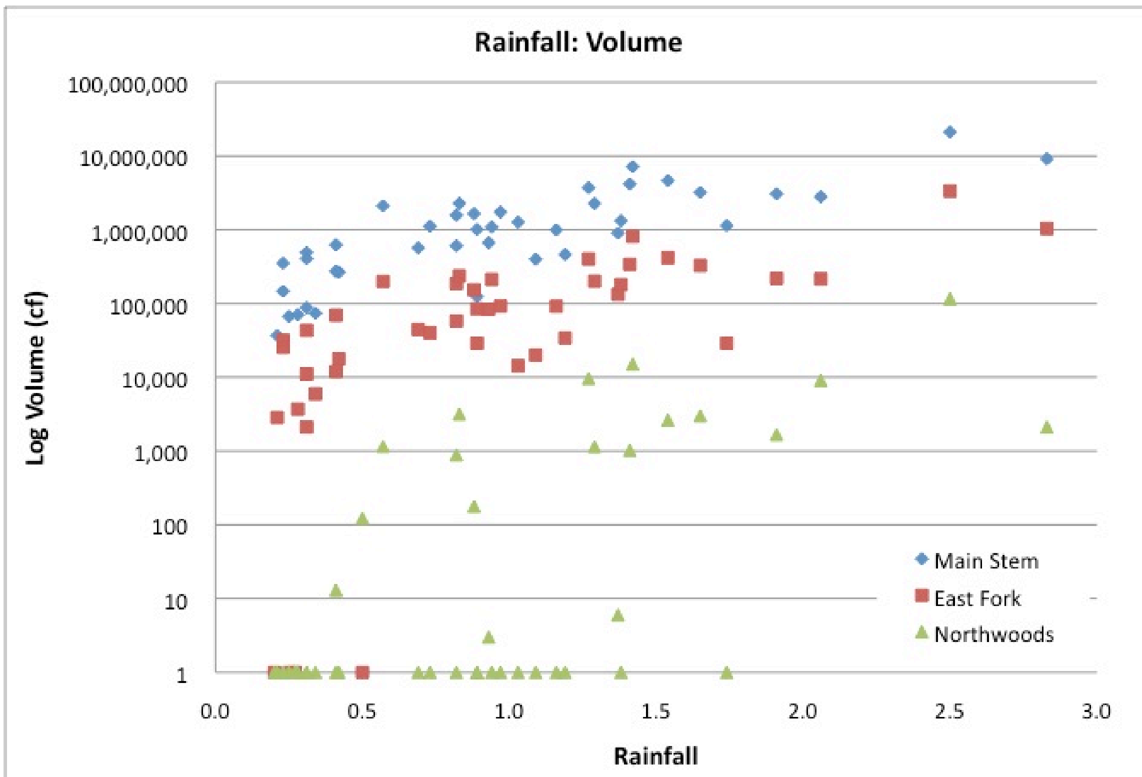


Figure 8. Watershed discharge volumes (cubic feet) per rainfall event for Black Creek main stem and the two upper subwatersheds from 53 storms during the Nov. 2015 to Aug. 2016 monitoring period. The East Fork subwatershed (257 acres) contributed significantly to main stem volumes, while volumes from the West Fork (Northwoods) subwatershed (58 acres) were barely detectable and mostly negligible, especially in summer months.

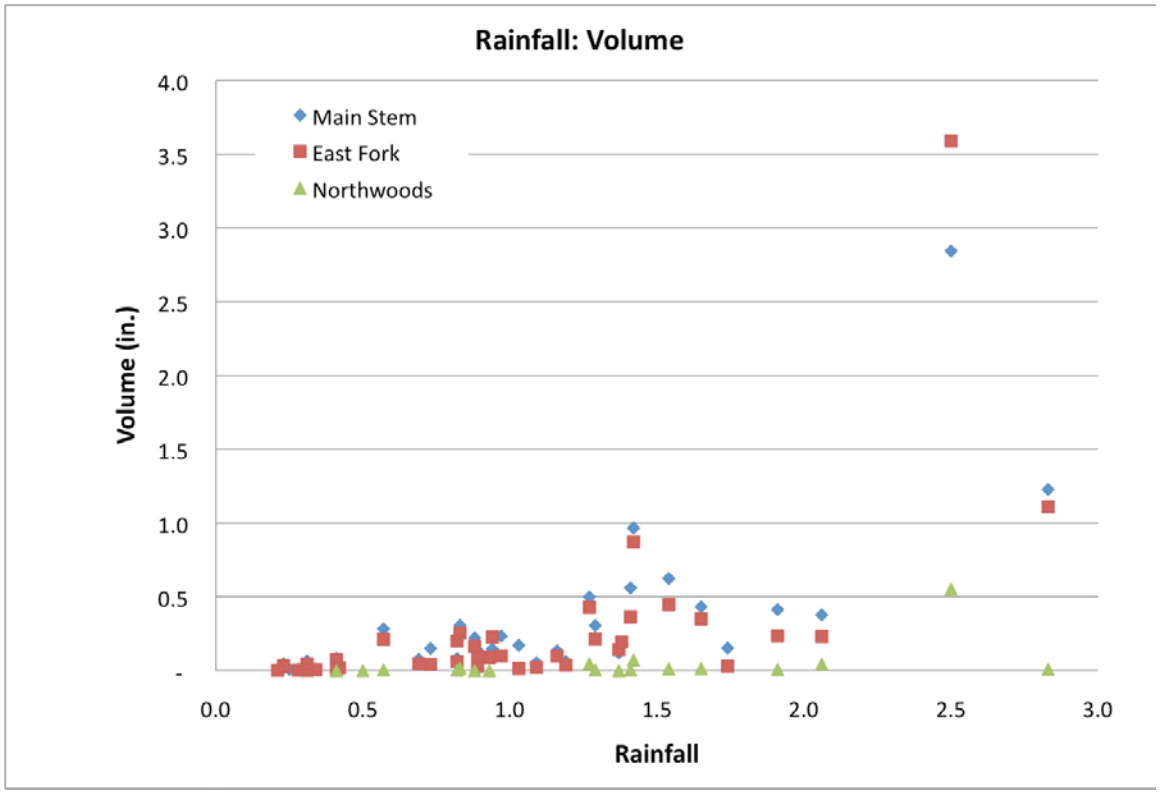


Figure 9. Watershed discharge volumes (normalized for watershed area in inches) per rainfall event for Black Creek main stem and the two upper subwatersheds from 45 storms during the Nov. 2015 to Aug. 2016 monitoring period. The East Fork subwatershed (257 acres) contributed significantly to main stem volumes, while volumes from the West Fork (Northwoods) subwatershed (58 acres) were barely detectable and mostly negligible, especially in summer months.

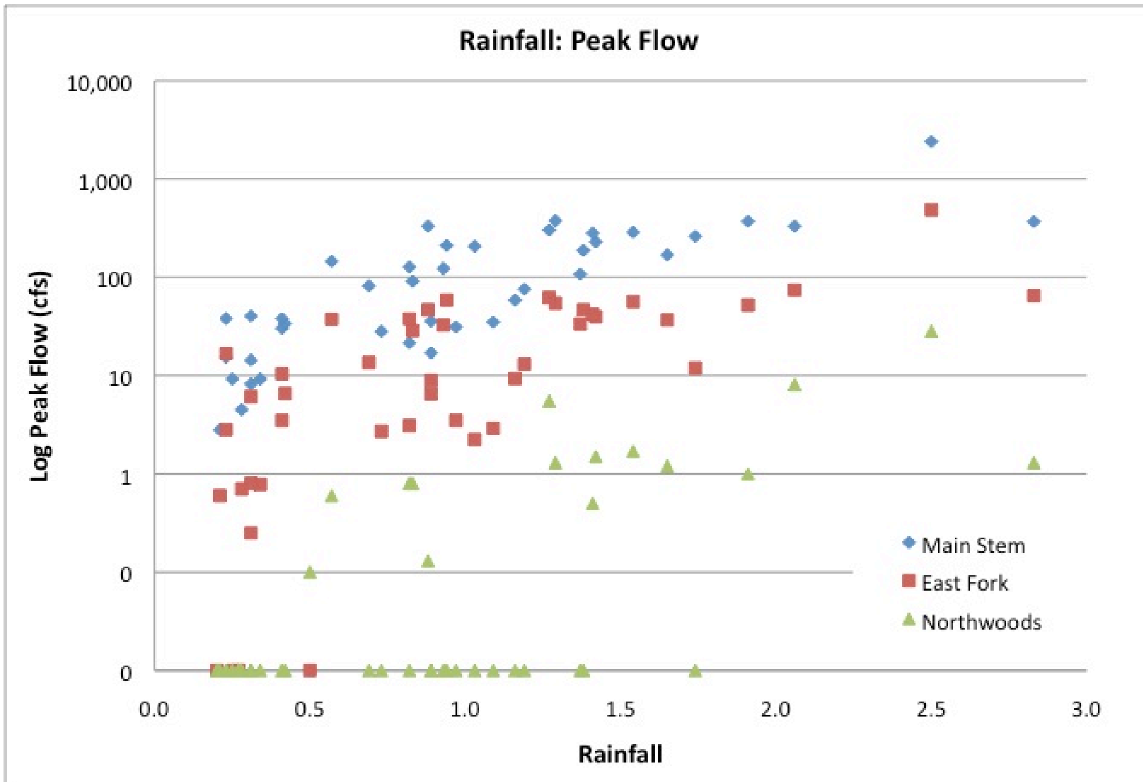


Figure 10. Watershed discharge per flows per rainfall event for Black Creek main stem and the two upper subwatersheds from 45 storms during the Nov. 2015 to Aug. 2016 monitoring period. The East Fork subwatershed (257 acres) contributed significantly to main stem flow, while flows from the West Fork (Northwoods) subwatershed (58 acres) were mostly negligible and often barely detectable, especially in summer months.

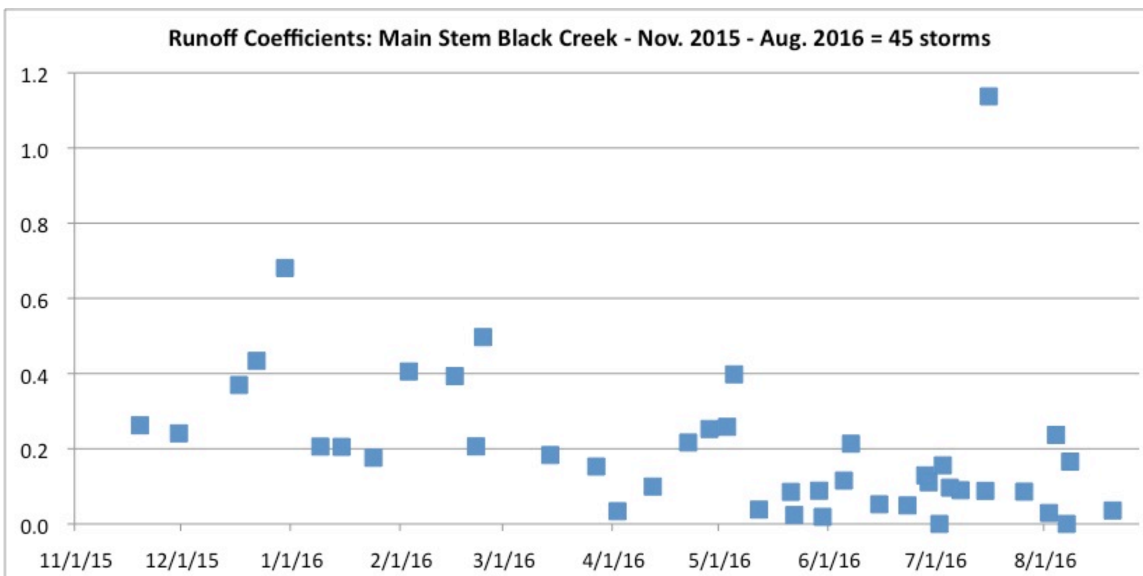


Figure 11. Runoff coefficients (ROCs)– or the percentage of rainfall generated as streamflow - calculated from the Black Creek main stem data from 45 storms during the Nov. 2015 to Aug. 2016 monitoring period. The average ROC was 0.20, indicating that one inch of rainfall would generate 0.2 in. of runoff as equivalent depth based on the watershed area (2,050 acres). Note the lower coefficients in summer months with the exception of the large June 15-16 storm event.

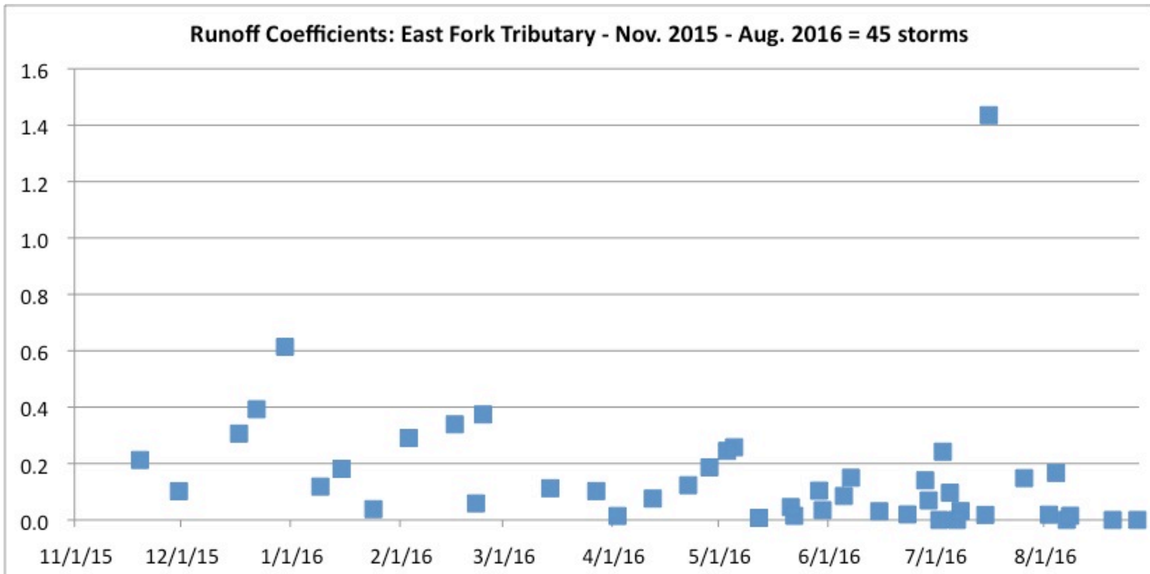


Figure 12. Runoff coefficients (ROCs)– or the percentage of rainfall generated as streamflow - calculated from the upper East Fork tributary monitoring data from 45 storms during the Nov. 2015 to Aug. 2016 period. The average ROC was 0.16, indicating that one inch of rainfall would generate 0.16 in. of runoff as equivalent depth based on the watershed area (257 acres). Note the lower coefficients in summer months with the exception of the large June 15-16 storm event.

<u>Modeling</u>

ArcHydro® Outputs

The ArcGIS™-based ArcHydro® tool was used to perform watershed analyses for both the main stem of Black Creek as well as the smaller upper tributaries. The first step was to characterize subcatchment flow routing and also to define stream networks and segments and their drainage areas (Figures 13-15). Land cover (Figures 16 and 17) and soils (Figures 18 and 19, Table 1) were identified for each of the two subcatchments and summarized by percentage area over each subcatchment. Results from this exercise provided input data for the HEC-HMS model.

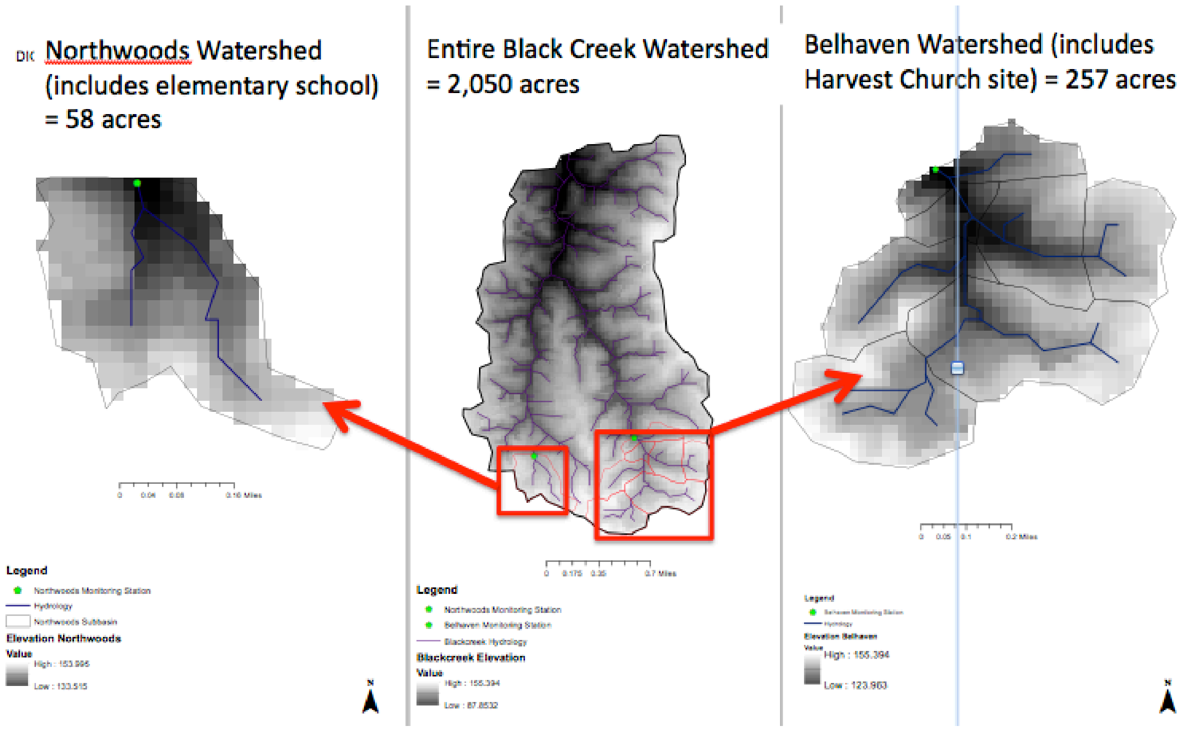


Figure 13. Digital elevation model (DEM) produced in ArcGIS™, including breakouts of the upper headwater tributary drainage areas.

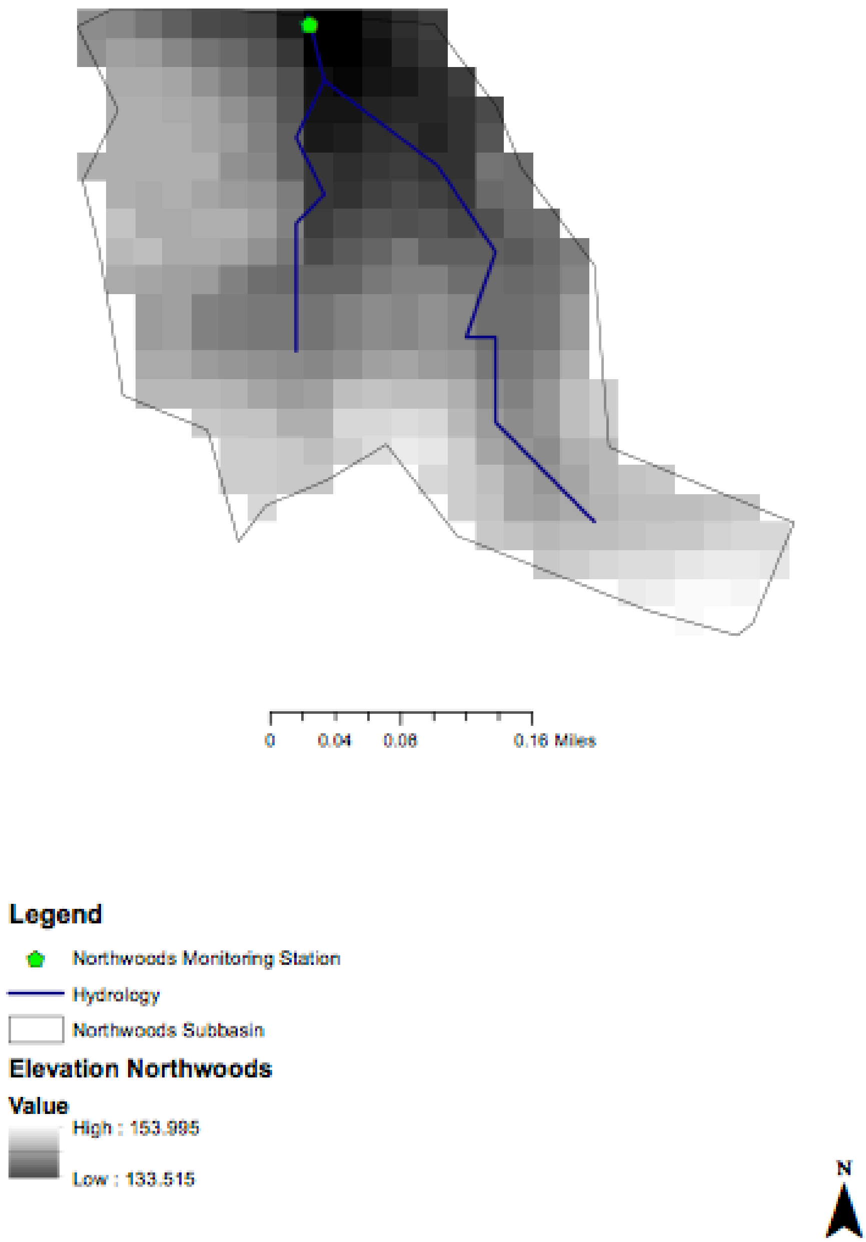
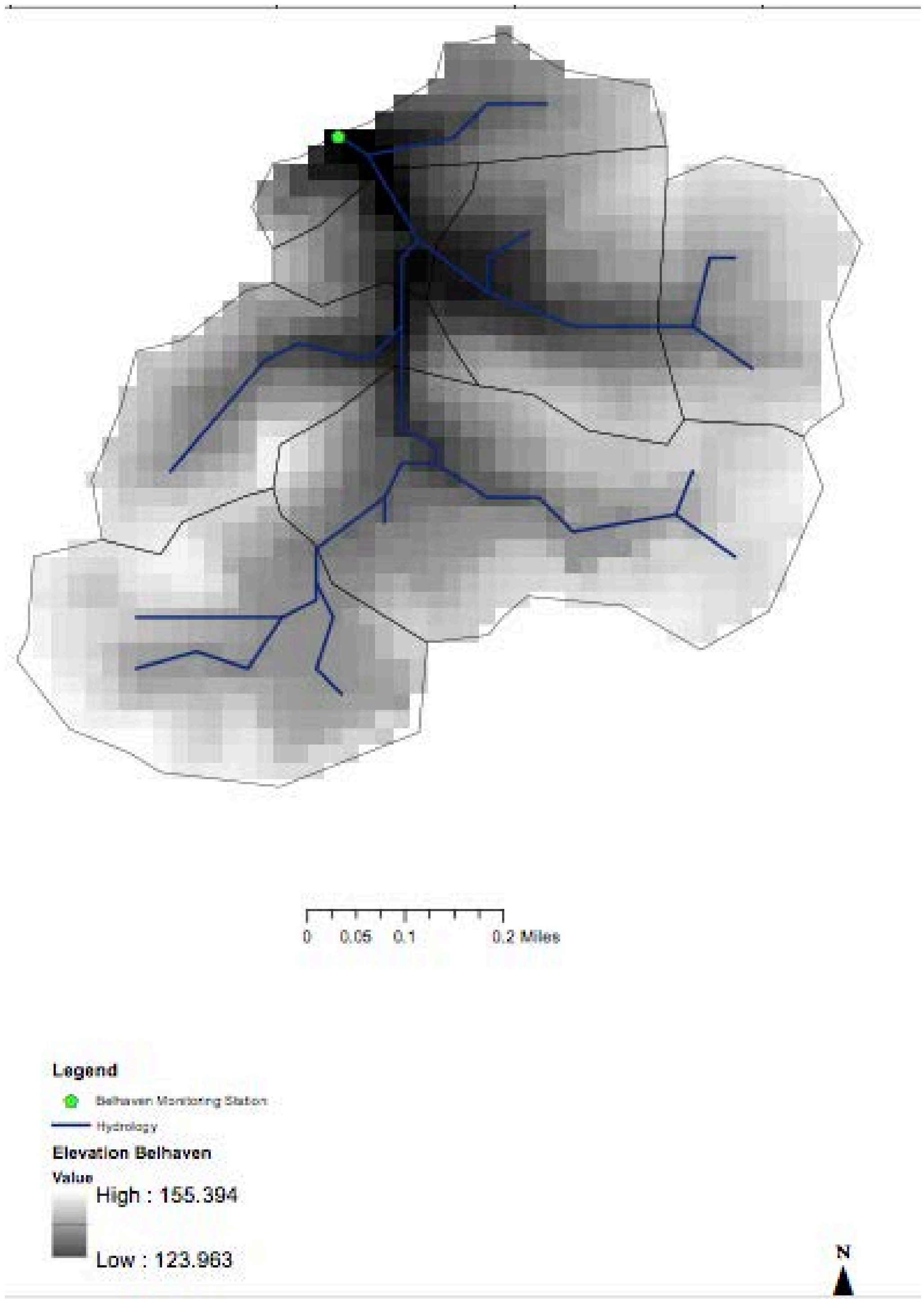


Figure 14. Digital elevation model for the upper West Fork subwatershed (58 acres) including stream network produced in ArcGIS™, as well as Northwoods Rd. culvert monitoring station (green dot).



(DEM)

Figure 15. Digital elevation model for the upper East Fork subwatershed (257 acres) including stream network produced in ArcGIS™, as well as Belhaven Rd. culvert monitoring station (green dot). Individual drainage catchments are delineated with grey lines.

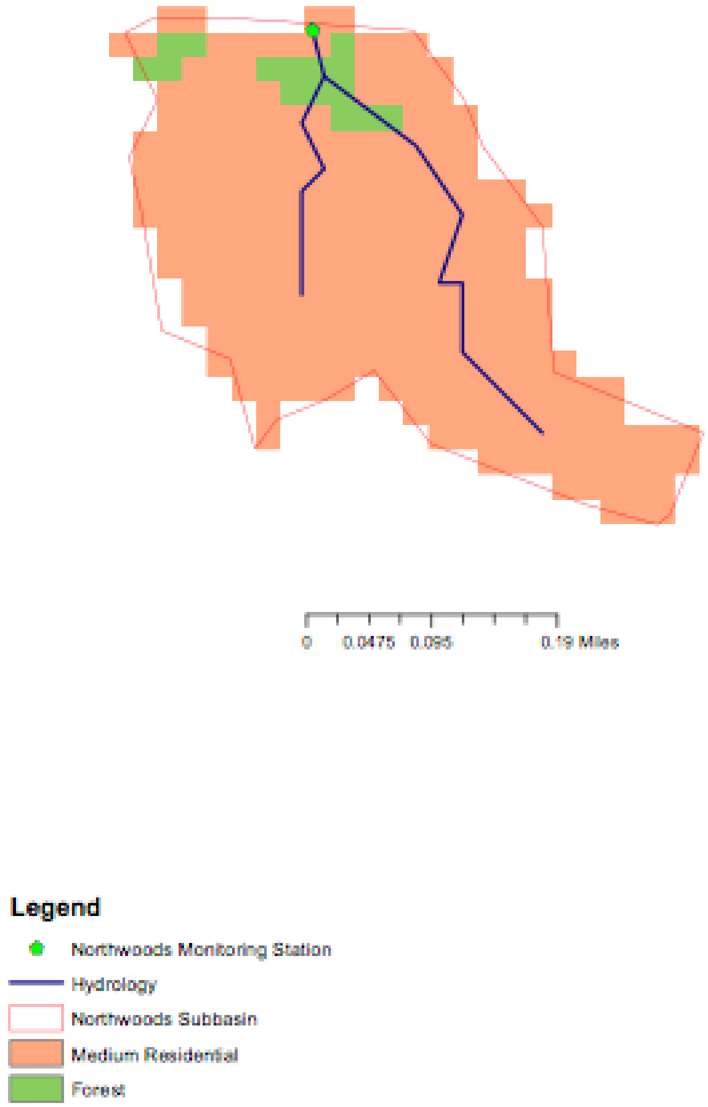


Figure 16. Land cover data for the upper West Fork subwatershed. Land cover is dominated by medium density residential (source: NLCD, 2012).

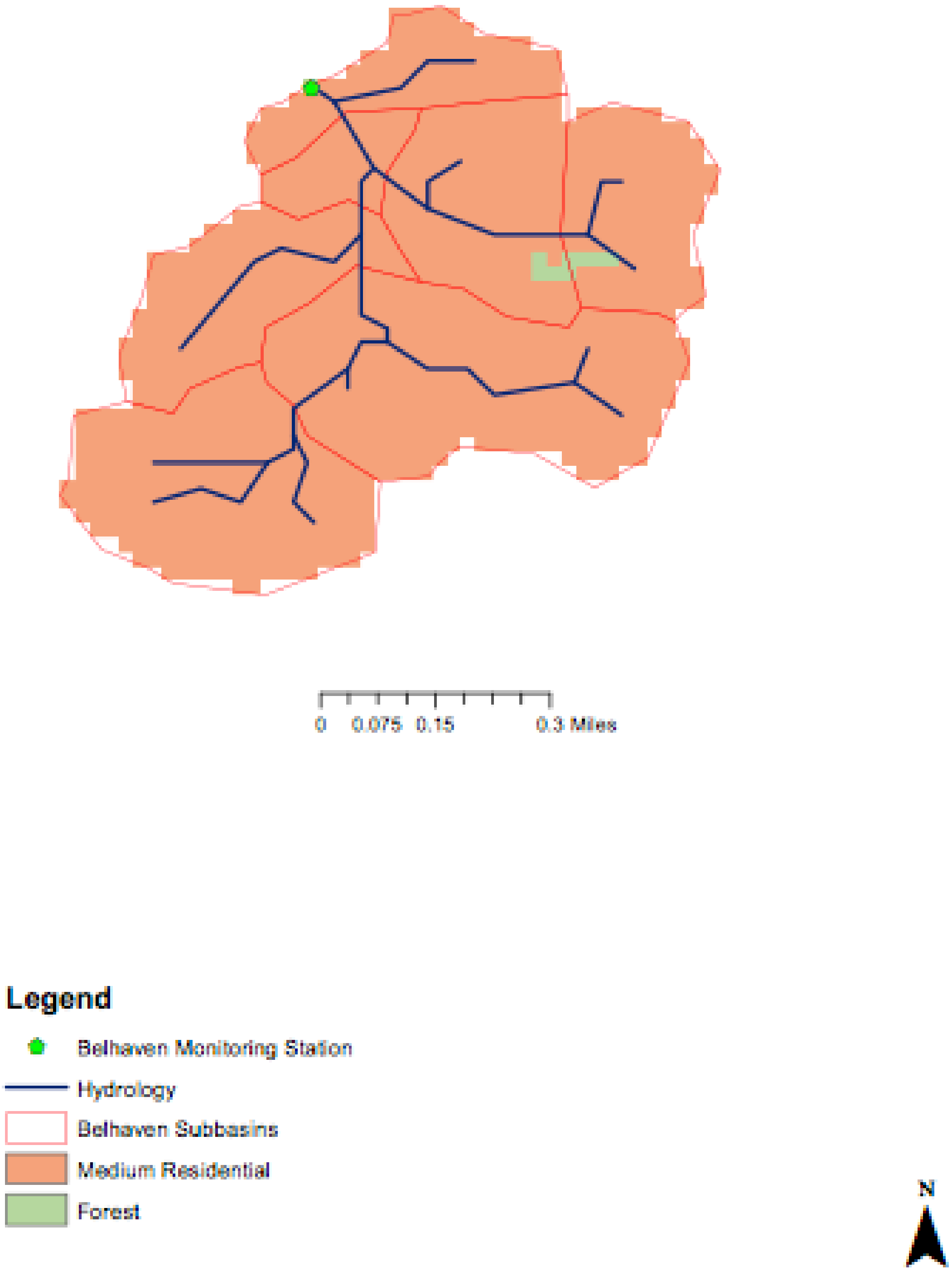
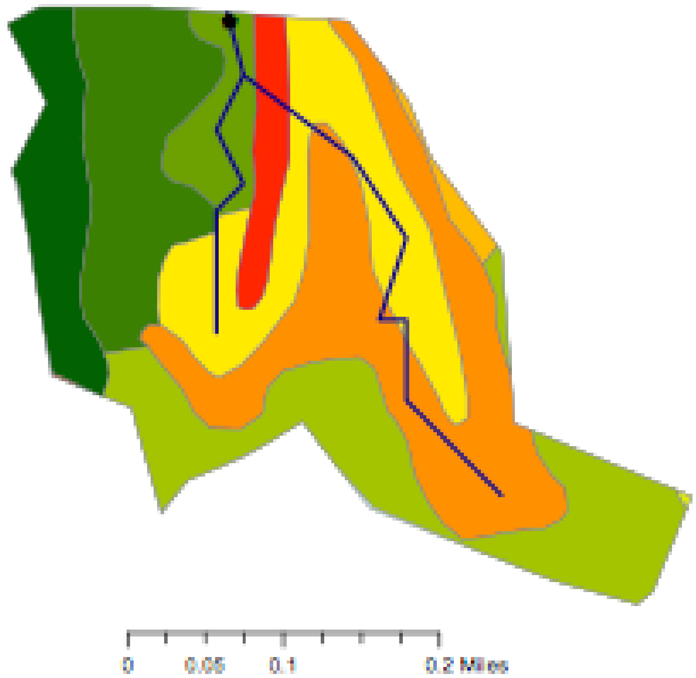
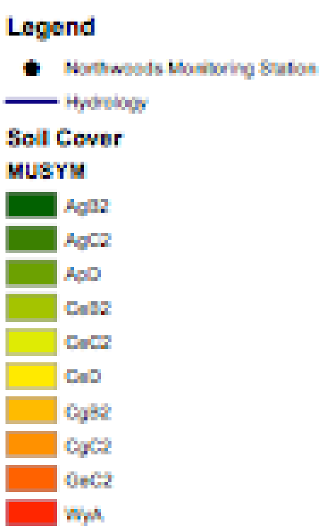


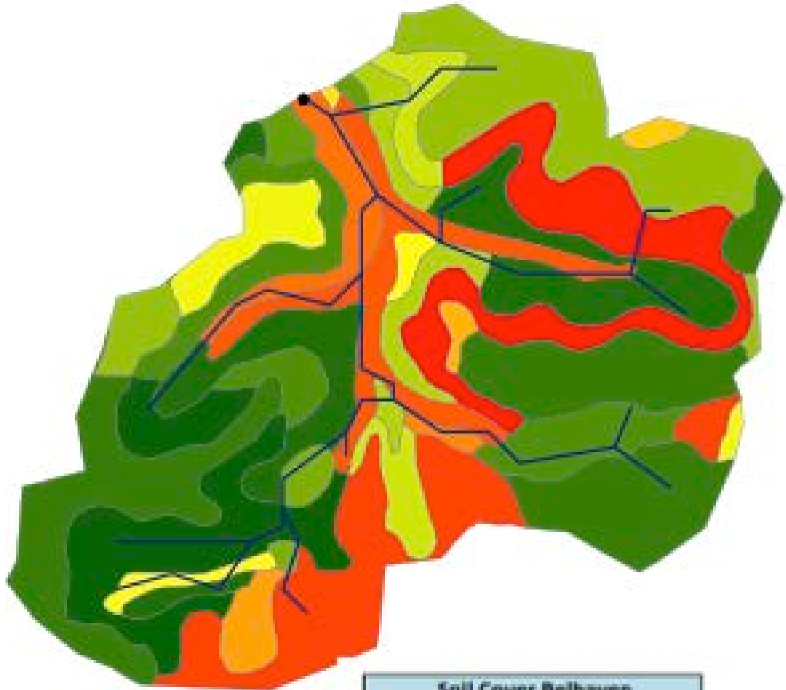
Figure 17. Land cover data for the upper East Fork subwatershed. Individual drainage catchments are delineated in red. Land cover is dominated by medium density residential (source: NLCD, 2012).

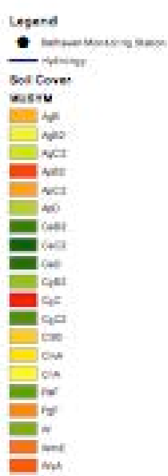




Soil Cover Northwoods	
Soil Name	Hydrologic Soil Type
AgB2	B
AgC2	B
ApD	B
CeB2	B
CeC2	B
CeD	A
CgB2	B
CgC2	B
GeC2	B
WyA	D

Figure 18. Soils data for the upper West Fork subwatershed. A soil data key can be found in Table 1 (source: USDA Web Soil Survey, 2012).





Soil Cover Belhaven	
Soil Name	Hydrologic Soil Type
AgB	B
AgC2	B
ApB2	B
ApC2	B
ApD	B
CeB2	B
CeC2	B
CeD	A
CgB2	B
CgC	B
CgC2	B
ClB3	B
CmA	D/B
CnA	C/D
PaF	B
PgF	B
WmE	B
WyA	D

Figure 19. Soils data for the upper East Fork subwatershed. A soil data key can be found in Table 1 (source: USDA Web Soil Survey, 2012).

Table 1. Soils Data Key for Upper East and West Fork Subwatersheds (USDA Web Soil Survey, 2012).

Type	Description	Hydrologic Soil Group (HSG)
AgB	Appling gravelly sandy loam, 2 to 6 percent slopes	B
AgB2	Appling gravelly sandy loam, 2 to 6 percent slopes, moderately eroded	B
AgC2	Appling gravelly sandy loam, 6 to 10 percent slopes	B
ApB2	Appling sandy loam, 2 to 6 percent slopes, moderately eroded	B
ApC2	Appling sandy loam, 6 to 10 percent slopes, moderately eroded	B
ApD	Appling sandy loam, 10 to 15 percent slopes	B
CeB2	Cecil sandy loam, 2 to 6 percent slopes, moderately eroded	B
CeC2	Cecil sandy loam, 6 to 10 percent slopes, moderately eroded	B
CeD	Cecil sandy loam, 10 to 15 percent slopes	A
CgB2	Cecil gravelly sandy loam, 2 to 6 percent slopes, moderately eroded	B
CgC	Cecil gravelly sandy loam, 6 to 10 percent slopes	B
CgC2	Cecil gravelly sandy loam, 6 to 10 percent slopes, moderately eroded	B
ClB3	Cecil clay loam, 2 to 6 percent slopes, severely eroded	B
CmA	Chewacia sandy loam, 0 to 2 percent slopes, frequently flooded	D/B
CnA	Colfax sandy loam, 0 to 3 percent slopes	C/D
GeC2	Georgeville silt loam, 6 to 10 percent, moderately eroded	B
PaF	Pacolet sandy loam, 15 to 45 percent slopes	B
PgF	Pacolet-Gullied land complex, 4 to 25 percent slopes	B
WmE	Wedowee sandy loam, 15 to 25 percent slopes	B
WyA	Worsham sandy loam, 0 to 3 percent slopes	D

HEC-HMS Inputs

The HEC-HMS watershed model (U.S. Corps of Engineers) was utilized to predict runoff volumes and peak flows for given storm events (0.1, 0.25, 0.5, and 1.0 inches of rainfall) under various percentages of impervious cover (IC = 5, 10, 25, and 50%) for both the first order Northwoods subwatershed in the West Fork and the third order East Fork subwatershed. Currently both subwatersheds have an estimated impervious cover of between 40-45%. Soils and land cover data - as previously shown - were used to populated the model, and a curve number (CN) of 72 was used to represent medium density residential land cover on moderately well-drained soils (HSG B). A standard initial abstraction of 0.2 in. was used in scenario simulations.

Calibration and Validation

The HEC-HMS tool was calibrated using a comparison of simulated flow prediction outputs and observed monitoring data. A one inch storm with 0% IC and 100% IC was simulated to ensure that the watershed area and expected discharge volume was appropriate. Successful verification was conducted for four storm event magnitudes – 0.1, 0.25, 0.5, and 1.0 in. – and with the varying impervious cover percentages to test the robustness of the model. Simulation success was indicated by the resulting runoff coefficients in range of those observed (0.10 – 0.56) and the observed peak flows for each subwatershed. Results in terms of runoff volumes and peak flows are given for the Northwoods subwatershed (Figures 20-21) and Belhaven subwatershed (Figures 22-23), respectively. Once calibration and verification were complete, the model was used to generate simulations for very specific scenarios based on past and current conditions, as well as on aggressive impervious surface cover reductions, for each subwatershed.

Assumptions

Several assumptions are incorporated into the monitoring and modeling efforts conducted in this project. These include the following:

- Watershed delineations were only as accurate as elevation data and ground-truthing information could provide. Piped flows that may contribute to overall watershed discharge may have also been overlooked and not included in analyses.

- 30-m resolution of NLCD land cover/land use data caused limitations on model performance and thus simulation results – better resolution land cover data, especially that for effective impervious cover, would be useful to improve the model and the resulting simulation scenarios

- It was assumed that 2015 data for effective impervious cover was representative of the study period, where monitoring results actually occurred over 2015-2016, the data with which the model was calibrated with data.

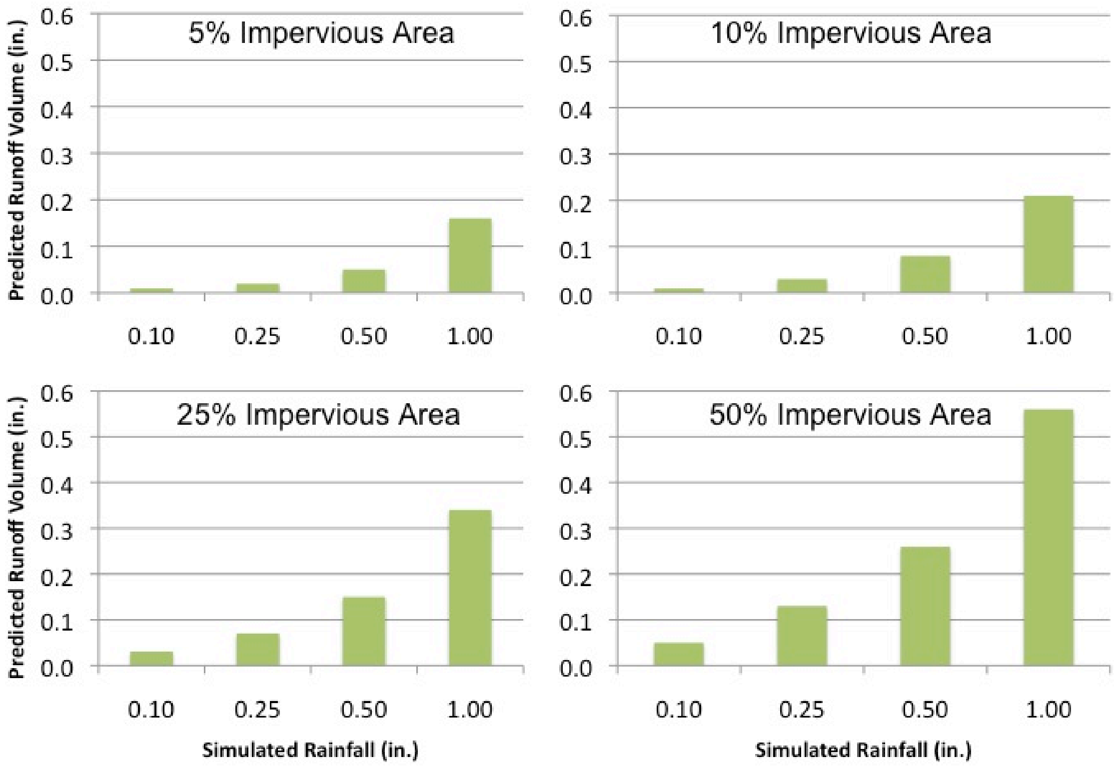


Figure 20. Simulation results in terms of runoff volume (in.) for varying effective impervious cover percentages in the Northwoods tributary for four storm event scenarios.

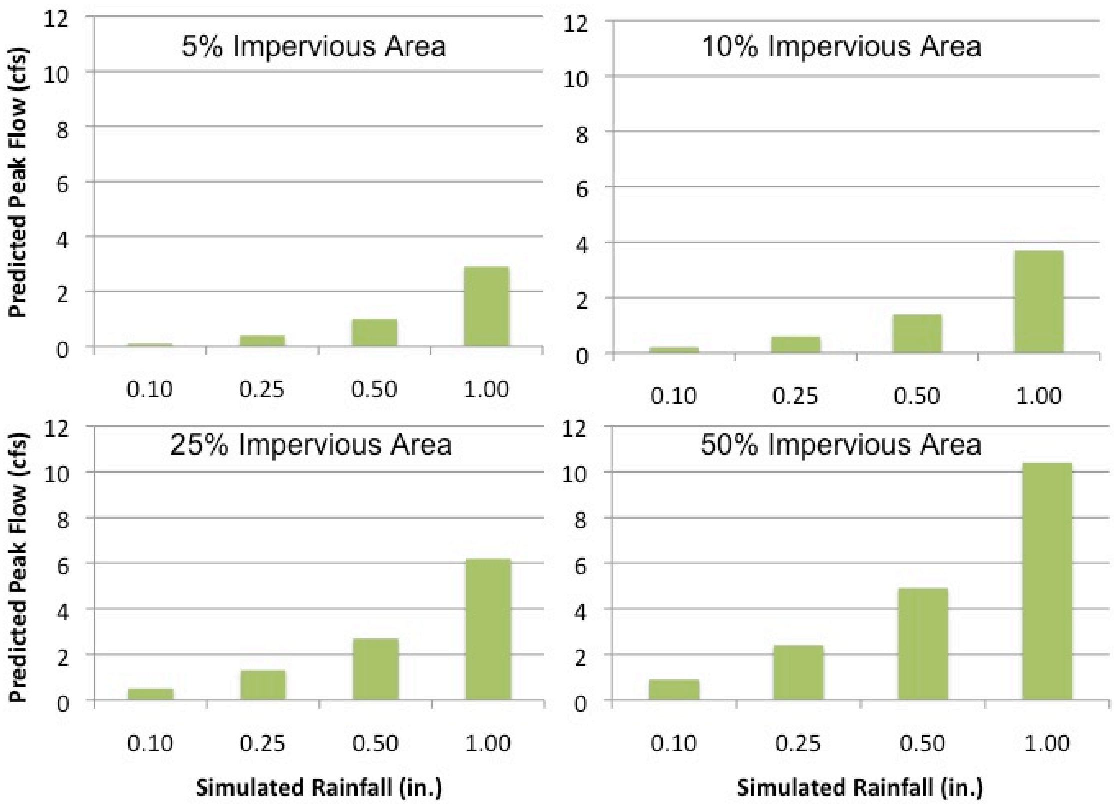


Figure 21. Simulation results in terms of peak flow rates (cfs) for varying effective impervious cover percentages in the Northwoods tributary for four storm event scenarios.

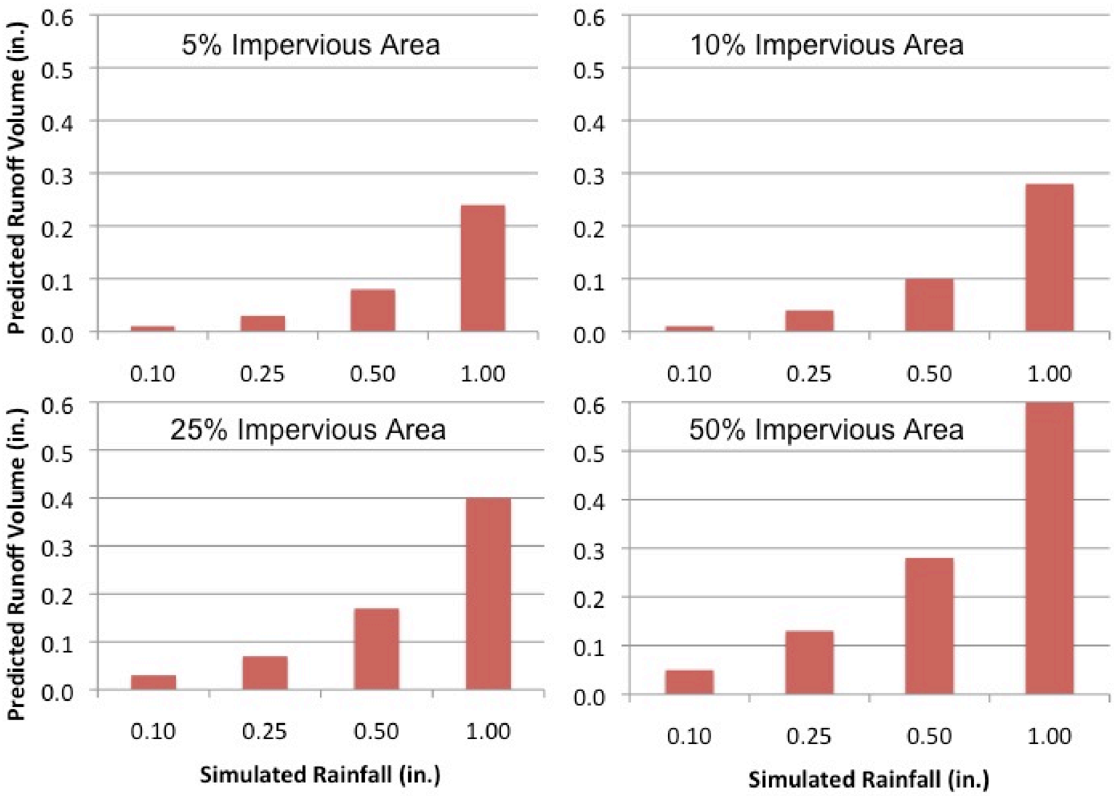


Figure 22. Simulation results in terms of runoff volume (in.) for varying effective impervious cover percentages in the Belhaven tributary for four storm event scenarios.

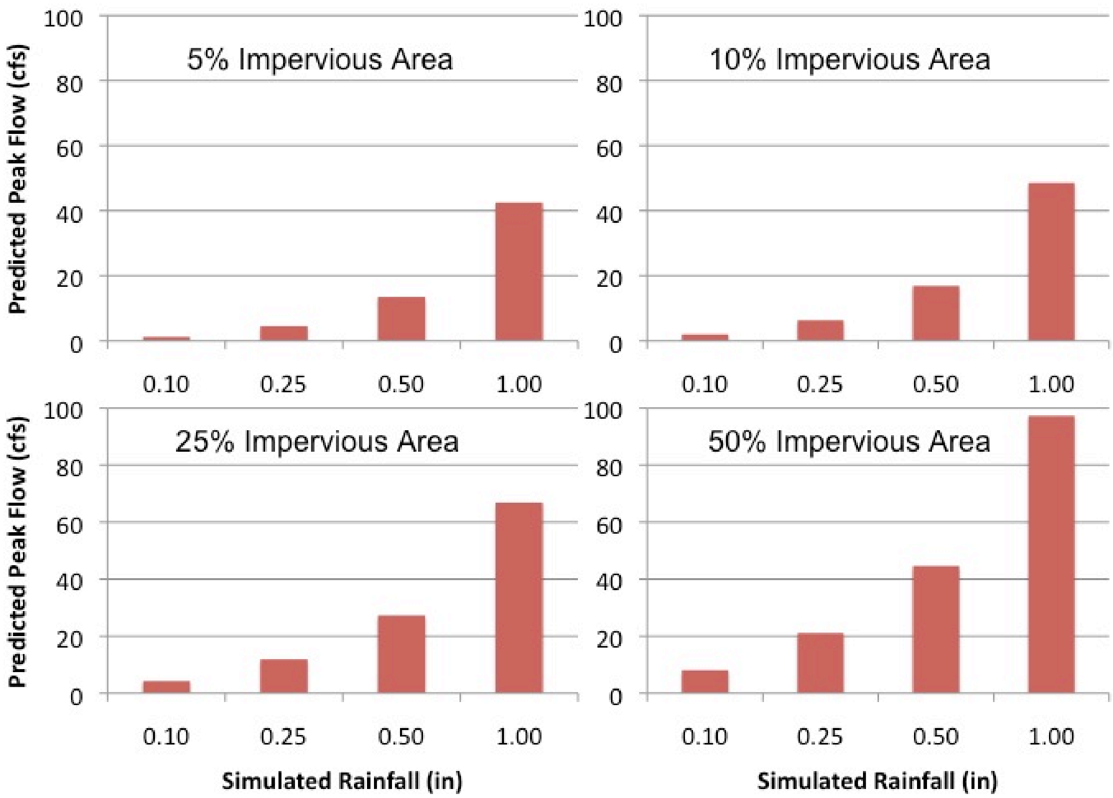


Figure 23. Simulation results in terms of peak flow rates (cfs) for varying effective impervious cover percentages in the Belhaven tributary for four simulated storm event amounts to test the range of the model and verify its robustness based on the range of monitoring results.

Simulated Scenario Results

For the West Fork Northwoods subwatershed, the following percent impervious cover scenarios were simulated: 41.0% (most current 2015 scenario), 32.5% (2010 scenario, Figure 7), and 23.1% (1999 scenario, Figure 7), as well as 10% and 5% (idealized IC reductions if a much more aggressive downspout disconnection campaign was conducted and achieved). For the Upper East Fork subwatershed, the following percent impervious cover scenarios were simulated in addition to the 5% and 10% scenarios: 42.4% (most current 2015 scenario), 32.9% (2010 scenario, Figure 7), and 30.5% (1999 scenario, Figure 7). Tables 2 and 3 summarize the results in terms of peak flow and stormwater volume reductions for a one-inch storm event based on decreasing effective impervious cover percentages within each subwatershed.

Table 2. Simulation Results by Decreasing Effective Impervious Cover Percentages in the Northwoods Watershed for a One-Inch Storm Event.

% IC	Peak Flow (cfs)	Runoff Coefficient	Volume generated (gal)	Volume Reduced (gal)

41	7.1	0.49	771,671	0
32.5	6.1	0.42	661,432	110,239
23.1	5.0	0.34	535,445	236,226
10	3.4	0.22	346,464	425,207
5	2.9	0.18	283,471	488,200

Table 3. Simulation Results by Decreasing Effective Impervious Cover Percentages in the Upper East Fork (Belhaven) Watershed for a One-Inch Storm Event.

% IC	Peak Flow (cfs)	Runoff Coefficient	Volume generated (gal)	Volume Reduced (gal)
42.4	81.3	0.50	3,489,083	0
32.9	68.7	0.42	2,930,830	558,253
30.5	65.4	0.40	2,791,266	697,817
10	37.9	0.22	1,535,196	1,953,887
5	31.2	0.18	1,256,070	2,233,013

As exhibited in Table 2, if the elementary school or residential areas in the West Fork neighborhoods would implement the downspout disconnection program to remove 10.4 acres (or revert back from the current 41% IC to the 1999 scenario at 23.1% IC) of effective impervious cover within the 58 acre subwatershed, then peak flow would be reduced from 7.1 cfs to 5.0 cfs, and ~236,000 gallons of stormwater would be kept from the Northwoods tributary and thus Black Creek from a one-inch storm. If a more aggressive campaign were to reduce the effective impervious cover to 10% (or disconnect ~18 acres of the 24 acres of IC), then the peak flow would be reduced from 7.1 cfs to 3.4 cfs and ~425,000 gallons of water would be kept from flowing to the West Fork tributary and to Black Creek from a one-inch storm.

Similarly for the East Fork subwatershed as provided in Table 3, if the Harvest Church or residential areas in these neighborhoods would implement the downspout disconnection program to remove 30.6 acres (or revert back from the current 42.4% IC to the 1999 scenario, with 30.5% IC) of effective impervious cover within the 257 acre subwatershed, then peak flow would be reduced from 81.3 cfs to 65.4 cfs, and ~700,000 gallons of stormwater would be kept from the East Fork tributary and thus Black Creek from a one-inch storm. However, if a more aggressive campaign were to reduce the effective impervious cover to 10% (or disconnect ~83 acres of the 109 acres of IC), then the peak flow would be reduced from 81.3 cfs to ~38 cfs and ~2.2 million gallons of water would be kept from flowing into the East Fork and eventually to Black Creek from a one-inch storm.

The watershed modeling exercise provided estimates based on the simulated conversion of effective impervious cover to forested and/or grassed landscapes based on expected hydrologic processes, thus possibly over-predicting volume reduction. As a result, stormwater reduction could be further limited by the actual design and as-built capacities of individual stormwater control measures within the watershed.

Conclusions

Monitoring and modeling efforts were conducted to gain an accurate estimate of the scope of retrofit projects that would be necessary to achieve stormwater volume and peak flow reduction in the larger Black Creek. The continuation of hydrologic data collection has led to an improved understanding of stormflow in the urban Black Creek watershed, as well as the potential for runoff reduction over time due to stormwater management practice retrofit efforts. Monitoring results provided a watershed characterization of streamflow given certain rainfall events where runoff coefficients – or the percentage of rainfall that becomes runoff – were determined for the main stem of Black Creek and also the smaller headwater drainage areas. The average runoff coefficient over nine months (March 2010 to February 2012) for Black Creek was 0.20 (or 20% of the rainfall was seen as stream flow), which is considered a reasonable coefficient for urban watersheds. In contrast, the average runoff coefficient for the East Fork watershed was 0.16 (or 16% of the rainfall was seen as stream flow), which is considered low for urban watersheds. Headwaters of the West Fork exhibited very little flow unless due to extreme events.

Simulation results from watershed models indicated that if the downspout disconnection campaign led to a removal of 10.4 acres (or revert back from the current 41% IC to the 1999 scenario at 23.1% IC) of effective impervious cover within the 58 acre subwatershed, then peak flow would be reduced from 7.1 cfs to 5.0 cfs, and ~236,000 gallons of stormwater would be kept from the Northwoods tributary and thus Black Creek from a one-inch storm. However, if a more aggressive campaign were to reduce the effective impervious cover to 10% (or disconnect ~18 acres of the 24 acres of IC), then the peak flow would be reduced from 7.1 cfs to 3.4 cfs and ~425,000 gallons of water would be kept from flowing to the West Fork tributary and to Black Creek from a one-inch storm. In addition, if residential areas in the upper East Fork neighborhoods would implement the downspout disconnection program to remove 30.6 acres (or revert back from the current 42.4% IC to the 1999 scenario, with 30.5% IC) of effective impervious cover within the 257 acre subwatershed, then peak flow would be reduced from 81.3 cfs to 65.4 cfs, and ~700,000 gallons of stormwater would be kept from the East Fork tributary and thus Black Creek from a one-inch storm. However, if a more aggressive campaign were to reduce the effective impervious cover to 10% (or disconnect ~83 acres of the 109 acres of IC), then the peak flow would be reduced from 81.3 cfs to ~38 cfs and ~2.2 million gallons of water would be kept from flowing into the East Fork and eventually to Black Creek from a one-inch storm.

These efforts would significantly reduce overall peak flows as well as the potential for bank erosion, water quality impairment, and macroinvertebrate habitat degradation. The watershed modeling exercise provided estimates based on the simulated conversion of effective impervious cover to forested and/or grassed landscapes based on expected hydrologic processes, thus possibly over-predicting volume reduction. As a result, stormwater reduction could be further limited by the actual design and as-built capacities of individual stormwater control measures within the watershed.

Since the 257-acre Upper East Fork subwatershed encompasses approximately 12.5% of the total 2,050-acre land area of the Black Creek watershed land area, HEC-HMS simulation results based on existing topography, soils, and land use/land cover, along with scenarios of reduced effective impervious cover, provided guidance as to how much stormwater flow and volume may be reduced from a given storm event before entering Black Creek. Conversely, based on monitoring and modeling results, the 58-acre subwatershed in which Northwoods Elementary School is located does not fit the critical for a target area for downspout disconnection retrofits in that flows from this area appear to be negligible based on our data analyses. The results do not give direct indication of water quality benefits; however, it is expected that the significant reduction of overall peak flows would reduce the potential for bank erosion, water quality impairment including sediment loading, and the degradation of aquatic habitat. Furthermore, simulations were not conducted for highly impervious areas such commercial or major roadway land uses. Simulation results do reveal how much impervious cover area reduction would be required to achieve effective downspout disconnection for water quantity management based on rainfall and subsequent discharge at the residential/neighborhood subwatershed scale. Further work must be conducted to determine any hydrographic benefits at the larger Black Creek watershed scale, with efforts to expand monitoring and modeling to other subwatersheds with different land uses, stormwater infrastructure, and impervious cover percentages.

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