Using GIS for Prioritization in Subwatershed Restoration

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November 28, 2011

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Introduction:

The United States was founded in rural living. The 1790 census estimated that a mere 5.1% of Americans lived in urban areas (USCB nd). A trend toward urban living, however, has steadily increased throughout U.S. history until in 1920, the balance tipped and the census indicated that more citizens lived in urban than rural areas (USCB nd). That trend has since continued. By 2004, an estimated 80% of the population in the United States was living in urban and suburban areas (Auch et al 2004). While providing many benefits, this trend toward urbanization has come at a cost to water quality. In addition to reducing important components of natural systems, such as forests and vegetation, urban and suburban growth replaces much of these components with impermeable or impervious surfaces, such as roads, parking lots, and rooftops. Impervious surfaces not only reduce the benefits, such as absorption and filtration, of these natural components, they reverse it. With increased urbanization has come degraded water quality.

Funding for watershed restoration is limited. It is important to prioritize by need and implement projects that will maximize results. Geographic Information Systems (GIS) can be used throughout the watershed restoration process. It is used to determine and document mapping characteristics of the subwatershed, such as watershed boundaries, hydrology, and monitoring locations.. It is useful for analysis, such as determining subwatershed strengths and weaknesses, as well as potential restoration areas. It can track progress at all levels. It also effectively communicates this information to and educates stakeholders and decision makers. This study explores ways in which GIS can be used to prioritize and maximize watershed management efforts.

Watersheds and Development:

The natural water cycle is affected by several factors, such as vegetation and slopes, and processes, such as precipitation and evaporation (Figure 1). Of particular interest is the process of infiltration. Infiltration helps supply water to trees and plants, as well as replenish groundwater. Groundwater then supplies streams and lakes. Development interferes with this cycle. To a certain extent, natural systems can absorb these disruptions. At some point, however, the impact of these disruptions, regardless of the type of development, accumulates and is discernibly negative.

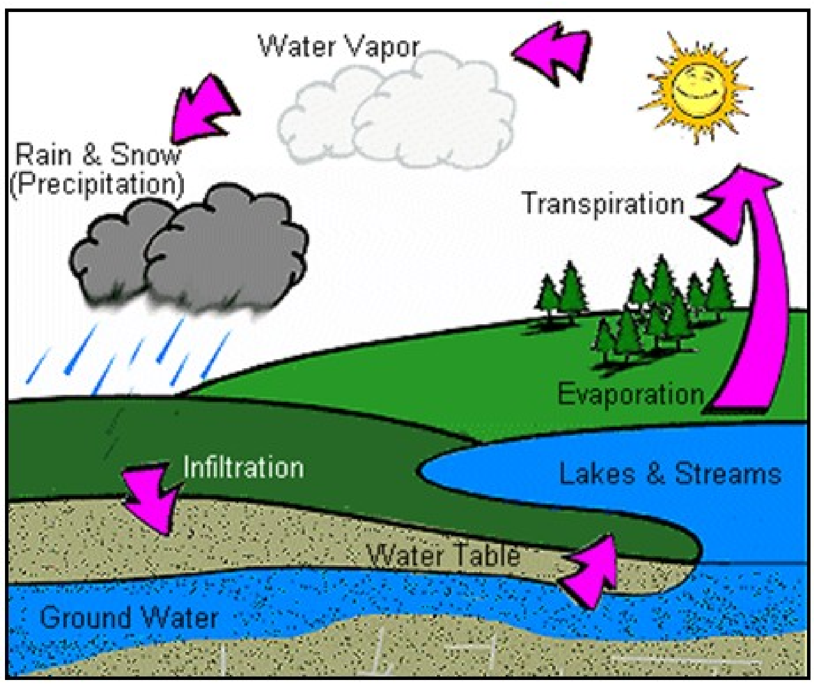

Figure 1: Introduction (Watersheds and Development) - Natural Water Cycle (WIDNR nd)

As areas urbanize, mature vegetation is removed and replaced with impervious surfaces, such as roads and buildings (Figure 2). Evapotranspiration and soil infiltration decrease. Stormwater runoff is forced across these impervious surfaces and downstream with increased volume and velocity.

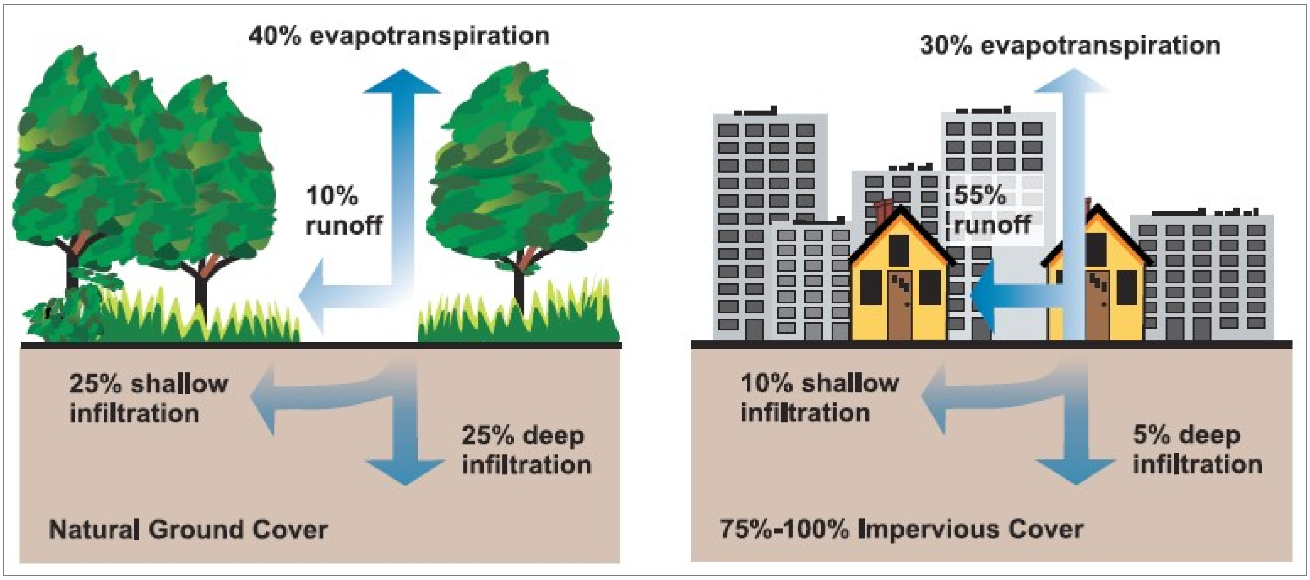

Figure 2: Introduction (Watersheds and Development) - Impact of Impervious Surfaces on the Water Cycle. Urban development increases impervious surfaces (e.g., roads, parking lots, rooftops) and subsequent runoff. (USEPA 2003)

In an attempt to control the increased stormwater volume and velocity, municipalities began to engineer infrastructure to handle runoff. These channels, inlets, pipes, and culverts act as a man-made extension of the natural stream system (Figure 3 and Figure 4). The intent of this legacy infrastructure was to collect and funnel stormwater downstream as quickly and efficiently as possible (Szpir 2007).

Figure 3: Introduction (Watersheds and Development) - Stormwater Outlet. Legacy infrastructure increases stormwater volume and velocity. (Schuler 2005)

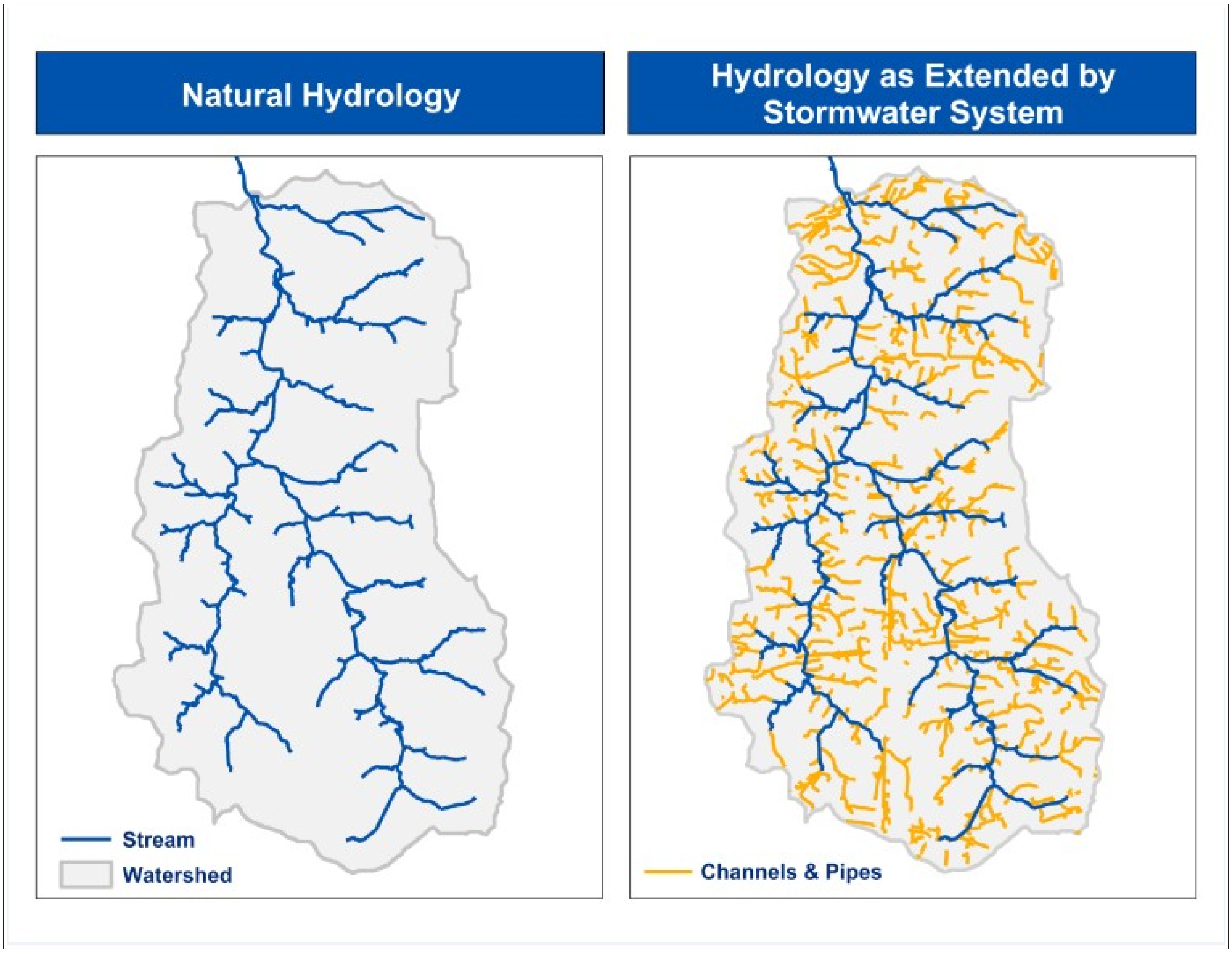

Figure 4: Introduction (Watersheds and Development) - Stormwater System. Stormwater systems play a significant role in watershed drainage patterns. (Data Source: Black Creek Watershed Association)

Subwatershed Health and Restoration:

Over time, the relationship between impervious cover and stream health became increasingly apparent. As impervious cover increases, stream health decreases. The Impervious Cover Model (ICM) provides a generalization of this relationship (Figure 5). As little as 10% impervious cover negatively impacts stream health. Beyond 25%, stream health is degraded and beyond 60%, it is considered to be drainage (Schueler et al 2009).

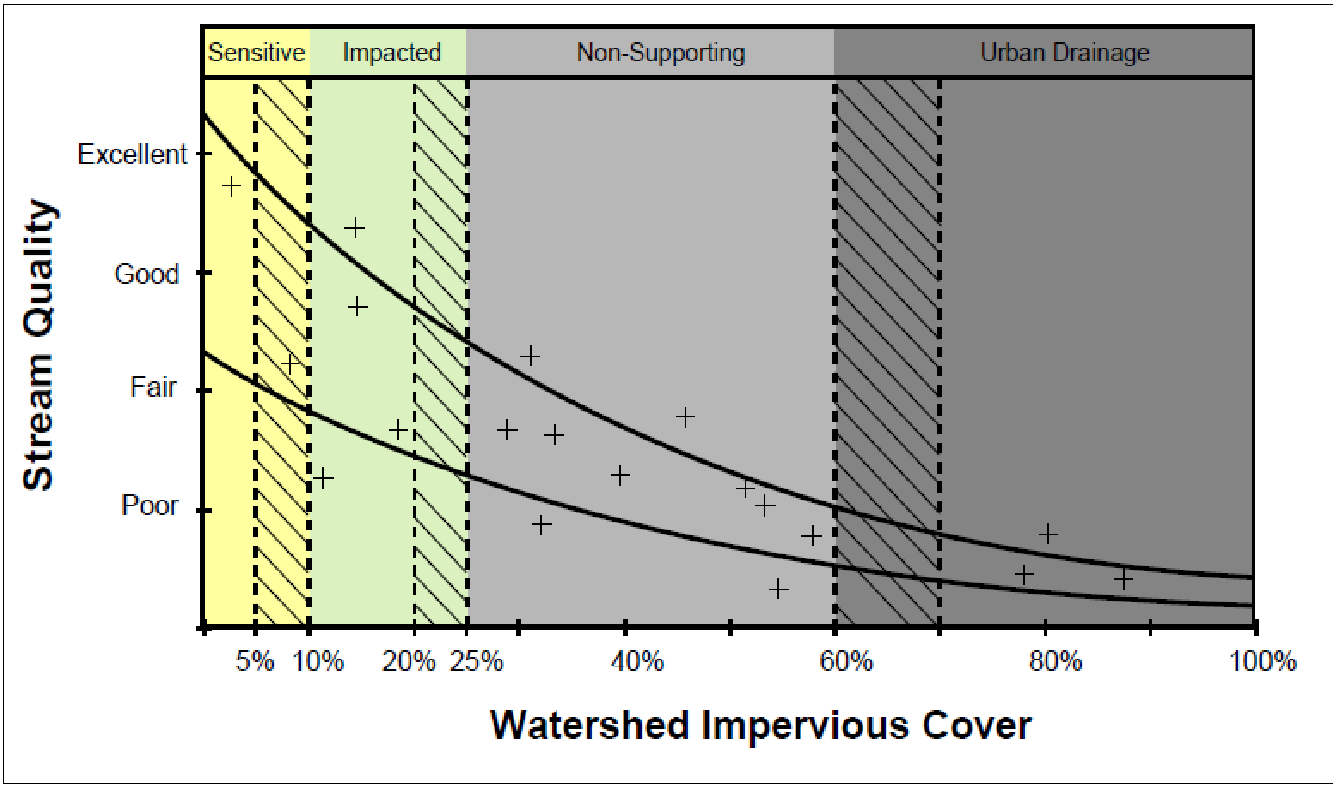

Figure 5: Introduction (Subwatershed Health and Restoration) - Impervious Cover Model (ICM). The ICM provides a generalization of the relationship between impervious cover levels and stream health. (Schueler et al 2009)

Legacy stormwater infrastructure does, to an extent, control local flooding. Unfortunately, it also has several unintended consequences as well. According to the Center for Watershed Protection (CWP), the effects of urbanization include changes to stream hydrology, physical alteration of the stream corridor, stream habitat degradation, declining water quality, and loss of aquatic diversity (Schueler 2005).

Similar to the concept of legacy stormwater infrastructure is the concept of effective impervious surfaces. In essence, effective impervious surfaces are those that are “directly connected to stream channels” (USEPA 2010). For example, if stormwater moves from an impervious surface, such as a road, through an inlet and into a stormwater pipe, even though the stormwater pipe is technically underground and the ground above it could be pervious or natural, the stormwater is still traveling across an impervious surface. It is not being absorbed or filtered. It is not slowing in velocity. In effect, the impervious surface has been extended. Subwatersheds with higher amounts of effective impervious surfaces are of higher priority for restoration.

In many areas, legacy stormwater practices are evolving from funneling stormwater downstream to retaining and handling it onsite through Best Management Practices (BMPs), such as wet ponds**,** and Low Impact Development (LID) practices, such as bioretention (Figure 6 and Figure 7). Isolating, retaining, and handling precipitation onsite through BMPs and LID practices more closely mimics the natural water cycle, allowing for reduced volume, increased absorption, reduced velocity, and increased infiltration..

Figure 6: Introduction (Subwatershed Health and Restoration) - Stormwater Wet Pond. Best Management Practices (BMPs) can isolate, retain, and handle larger subsets of stormwater runoff. (Schueler et al 2007)

Figure 7: Introduction (Subwatershed Health and Restoration) - Bioretention. Smaller BMPs and LID practices, such as bioretention or rain gardens, can be implemented for a cumulative effect. (Schueler et al 2007)

Though BMPs are increasingly a requirement for new development, issues created by legacy stormwater practices remain. Because retrofitting legacy stormwater infrastructure is more complex and expensive, it is unrealistic to retrofit entire stormwater systems. Some retrofits, however, are often needed to restore the health of impaired waterways.

The positive impacts associated with BMPs can also be realized through stormwater retrofits. Stormwater retrofits interrupt, capture, and handle subsets of runoff onsite, in effect "disconnecting" areas of effective impervious cover. Similar to how human activity extended natural hydrology with the incorporation of legacy stormwater infrastructure, stormwater retrofits can reduce or "disconnect" portions of this extended hydrology (CBSTP 2010).

The CWP has developed and documented a comprehensive and multidisciplinary approach in their Urban Subwatershed Restoration series. Per the CWP and for the purpose of this study, urban refers to any subwatershed with greater than 10% impervious cover, subwatershed refers to smaller watersheds usually five to ten square miles in size, and restoration refers to using a variety of practices to improve stream health (Schueler 2005). The CWP series provides strategies and processes, as well as guidance regarding effectiveness and generalized costs. It is apparent in reviewing their ten-part series how complicated and involved subwatershed restoration can become. The CWP groups subwatershed restoration practices into several categories: stormwater retrofits, stream repair, riparian management, discharge prevention, watershed forestry, pollution source control, and municipal practices (Schueler

2005). All are important components for consideration for potential incorporation into restoration efforts.

Stormwater retrofits can largely be divided into two categories (Figure 8). Storage stormwater retrofits are generally larger projects (such as retention ponds), located on public land, effective, moderately priced, and accommodate larger drainage areas (Schueler 2005). Onsite stormwater retrofits are generally smaller projects (such as a rain garden), located on individual properties, provide recharge and water quality benefits, more costly, and along with several similar projects, provide a cumulative benefit (Schueler 2005). GIS can help set stormwater retrofit targets and identify sites for restoration.

Storage Retrofits	On-site Retrofits
Serve 5 to 500 acres	Serve 0.1 to 5 acres
Generally constructed on public land	Generally constructed on private land
May need dozens in a subwatershed	May need hundreds in subwatershed
Assessed at subwatershed scale	Assessed at catchment/neighborhood scale
Moderate cost per impervious acre treated	High cost per impervious acre treated
Impractical in ultra urban areas	Practical in ultra urban areas
Permitting can be extensive	Few permits are needed
Can provide all stormwater targets	Only provide recharge and water quality
Public construction	Public delivery
Utilize ED, wet pond, and wetlands	Rely on bioretention, filtering, infiltration, swales and other treatment practices

Figure 8: Introduction (Subwatershed Health and Restoration) - Stormwater Retrofit Types. The Center for Watershed Protection divides stormwater retrofits into two categories, Storage Retrofits and Onsite Retrofits. (Schueler et al 2007)

Scope of this Study:

The focus of this study is on how GIS analysis can be used to prioritize and maximize watershed management efforts. The scope has been narrowed to urban subwatersheds, negatively impacted by development and subsequent stormwater. The analysis has also been narrowed to the prioritization of subwatersheds, establishment of a restoration target, and identification of potential restoration sites. Restoration efforts of a local stream have been incorporated to help further explore and demonstrate these concepts.

Study Area – Black Creek – Cary, NC:

The study area, Black Creek, is a 3.3 square mile subwatershed located in Cary, just outside of Raleigh, North Carolina (Figure 9). It could be considered "typical" of many suburban watersheds. Much of the subwatershed has been developed. It is largely comprised of residential neighborhoods, retail space, corporate offices, schools, and parks. Though current regulations require new development to implement BMPs, much of the Black Creek subwatershed was built out with legacy stormwater practices. A popular, recreational greenway accompanies much of the stream's main stem. The stream eventually flows into Lake Crabtree, a man-made flood-control lake and sound buffer for the regional airport.

In 1998, Black Creek was placed on the federal 303(d) list indicating that the stream health was impaired ("fair bioclassification") and that a plan of action (Total Maximum Daily Load (TMDL)) was required for restoration to its intended usage standard ("aquatic life") (NCDWQ-IR 2010). Waterways are assigned standards based on expected usage. The "aquatic life" standard indicates that the stream "shall be suitable for aquatic life propagation and maintenance of biological integrity, wildlife, secondary recreation, and agriculture" (NCDWQ-UM 2010).

In 2004 and 2005, a new apartment complex and office building were built along the edge of Lake Crabtree. Several area residents, greenway users, and park visitors objected to the development plans as submitted to the Town of Cary and urged to have them altered (Puente et al 2006). Because of the apparent local interest and the impaired state of the stream, the North Carolina State Watershed Education for Communities and Officials (WECO) organized the Black Creek Watershed Association (BCWA) in 2006 (WECO 2009). Largely funded through grants, the BCWA is now a collaborative effort between WECO, North Carolina State University (NCSU), the Town of Cary, Lake Crabtree Park, local neighborhood homeowners associations, and interested individuals.

Given the level and age of the development, it is not a surprise that the stream health assessment indicates stormwater-related degradation – both through the increased volume and accumulation of toxic organic chemicals from impervious surfaces and cars (WECO 2009). Though the riparian corridor is reasonably intact along the greenway, many of the associated benefits have been bypassed by legacy stormwater infrastructure.

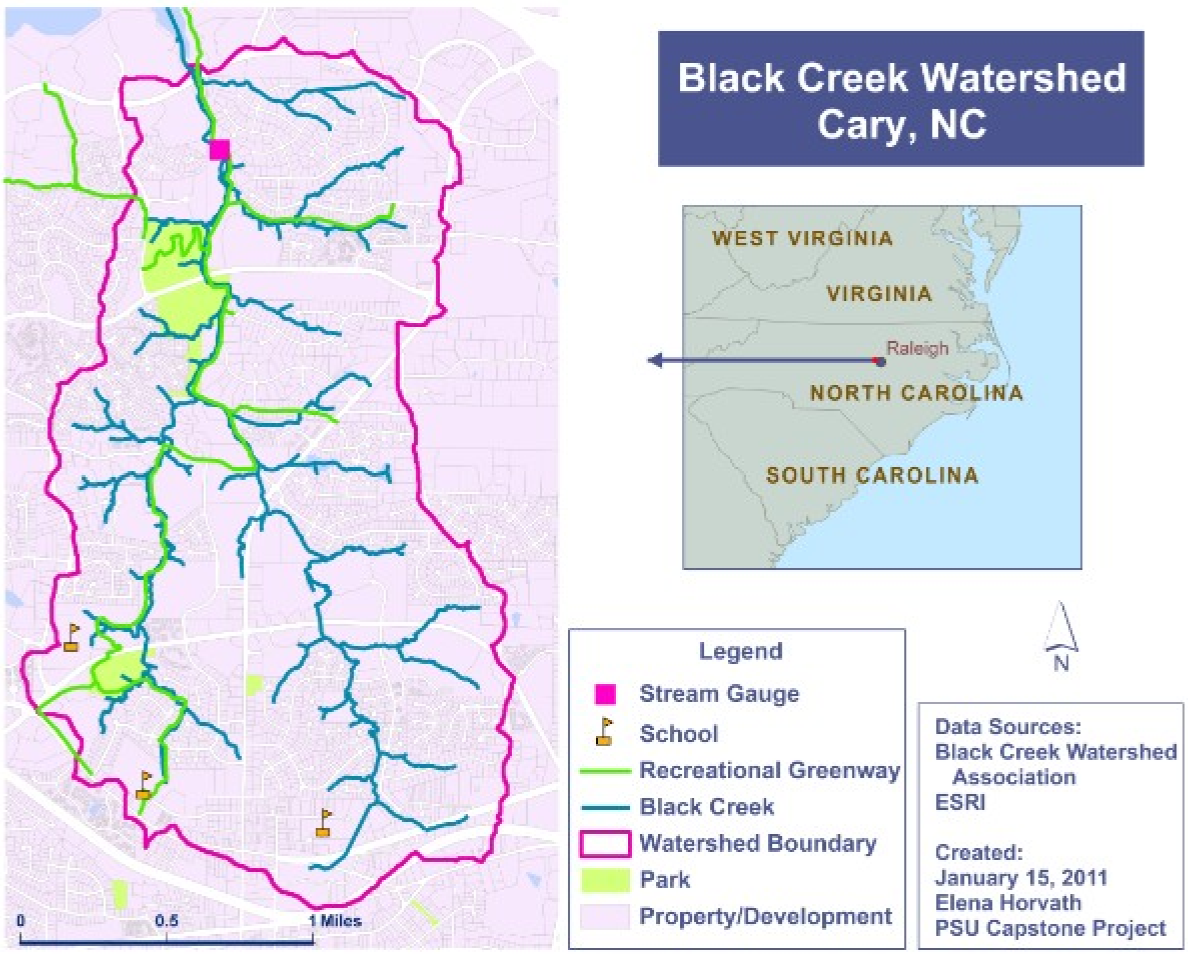

Figure 9: Introduction (Study Area) - Black Creek Watershed in Cary, NC. Typical of many suburban watersheds across the country, the health of Black Creek has been negatively impacted by development.

Through WECO's leadership and work with BCWA participants, a watershed management plan was developed and accepted in lieu of a TMDL by the State of North Carolina (WECO 2010). The goals of the association primarily include education and restoring the health of the stream, targeting measurable progress by 2014 and removal from the 303(d) list by 2018 (WECO 2010).

Work to date by the association has included studying and documenting the stream's health, walking the entire stream and updating the stream's current hydrology, organizing several educational presentations, installing a monitoring gage and pet waste stations along the greenway, providing several hands-on volunteer projects, such as a stream condition assessment and litter sweeps, and the implementing two rain gardens at a local school. The association is also working with a local homeowners association to teach residents how to implement individual stormwater reduction efforts on personal property. Though commitment and participation continues to be strong, as with many watersheds, more retrofits will be required to restore the health of Black Creek.

Objectives and Deliverables:

This study will approach the use of GIS in subwatershed restoration conceptually, as well as specifically for Black Creek.

Objective 1 – Prioritize subwatersheds: Among the first steps in subwatershed restoration is to determine where to focus efforts. This is largely done through testing for the federally-mandated 303(d) Impaired Waters list. Black Creek is on this list and is, therefore, to be restored. However, the practice of comparing, trending, and prioritizing subwatersheds within a larger watershed or municipality can help maximize results.

1. Concept: Impervious cover typically results in degraded water quality and, therefore, can be used for a general evaluation
2. Consideration: When and how the subwatershed was developed makes a difference
3. Alternative Concept: Prioritize legacy development and location within the watershed

Objective 2 - Develop the Stormwater Retrofit Goal: Once the subwatersheds have been prioritized, focus is narrowed to the individual subwatershed level. Once a cause has been established through a health assessment, measurable targets need to be set. When stormwater runoff is the primary indicator, stormwater retrofits will likely need to be incorporated. These retrofits reduce stormwater volume by disconnecting or isolating, retaining, and handling subsets of runoff.

1. Concept: Restoration goals are typically set with pollutant-specific TMDLs
2. Consideration: When stormwater is the primary indicator, the issue is more related to the volume and an array of pollutants, not a specific pollutant
3. Alternative Concept: Focus on disconnecting runoff (CWP et al 2010) and prioritizing legacy stormwater infrastructure

Objective 3 – Identify and Prioritize Restoration Areas: Once targets have been set, focus is further narrowed to within the subwatershed and where potential restorations might be located.

1. Concept: The restoration goal (e.g., water quality or benthic diversity) guides efforts. Local knowledge, aerial photography & contour maps can identify potential restoration areas.
2. Consideration: Maximize results by incorporating more into the prioritization process
3. Alternative Concept: Prioritize based on “target rich” legacy stormwater infrastructure, the state of the variable-width riparian corridor, and the drainage acreage that would be disconnected

Methodology and Results:

Objective 1 – Prioritize Subwatersheds (Methodology and Results):

When considering on which subwatershed to focus restoration efforts and funding, such as at a river-level watershed or within a municipality, several steps can be taken for prioritization.

Step 1) Determine subwatersheds boundaries

Though it is a single subwatershed, the Black Creek subwatershed was used to demonstrate this step (Figure 10).

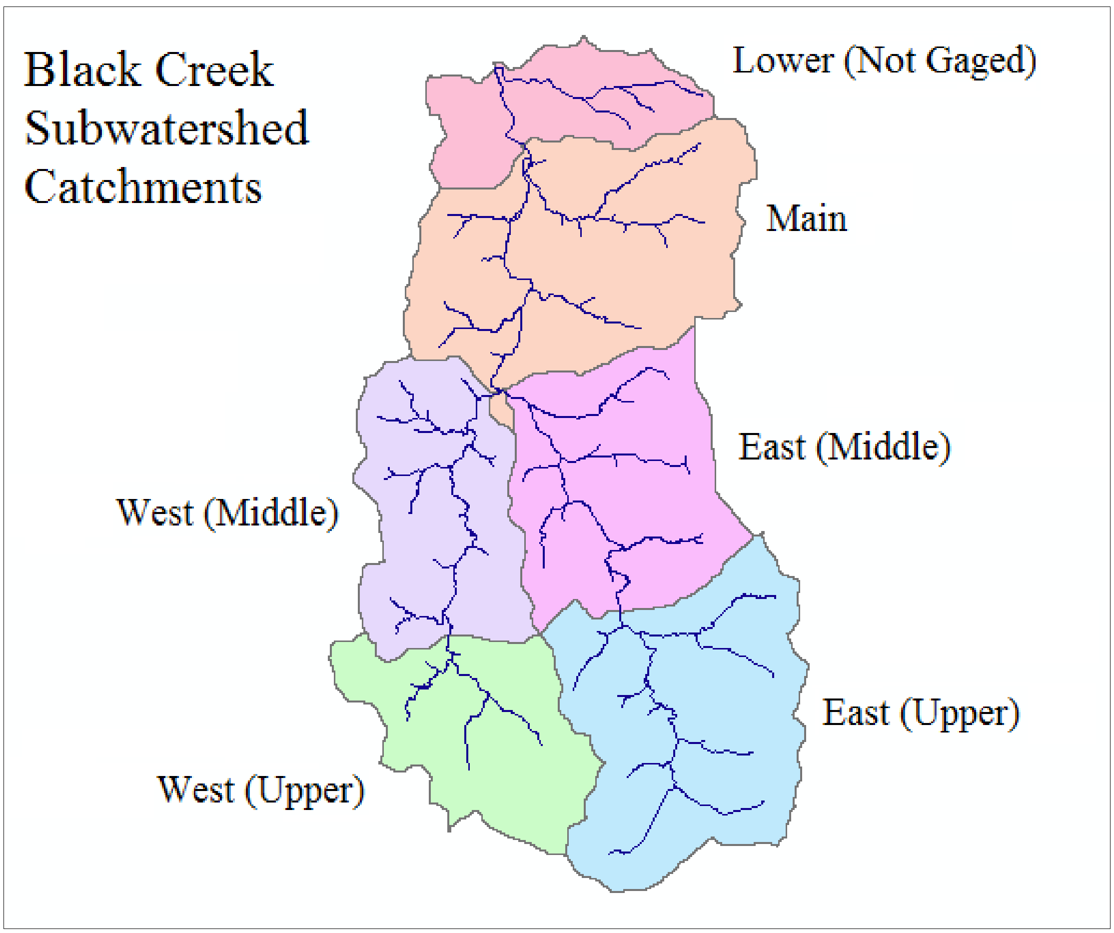

Figure 10: Objective 1 (Subwatershed Prioritization) - Subwatersheds. Building on work already completed by the BCWA, six subwatershed catchments were compiled for use in this project.

Step 2) Establish a delineation point between legacy (funnel downstream) and current (handle onsite) stormwater practices

In this case, the Black Creek watershed is located completely within the Town of Cary. The Town's stormwater plan is largely influenced by two major sets of regulations. First, the Neuse Basin Rules were established by the State of North Carolina and became effective in 1998 (NNSWS nd). In addition to the associated rules, Cary was also among a few towns within the watershed selected to implement a "model" stormwater plan.

Second, the federally mandated Clean Water Act also covers Black Creek. The Clean Water Act (CWA) of 1972 required point-source discharges, such as those by industry, municipalities (e.g., sewage), and other applicable facilities, into navigable U.S. waters to do so under a National Pollutant Discharge Elimination System (NPDES) permit (USEPA 2008). In 1987, a significant update was made to the CWA to establish the stormwater program. Phase I went into effect in 1990 for medium and large (serving >100,000) municipalities, certain industrial sites, and large (>5 acres) construction sites (USEPA 2008). Phase II regulations were issued in 1999 and went into effect in 2003 for remaining municipalities in "urbanized" areas, additional industrial sites, and medium-sized (1-5 acres) construction sites (USEPA 2008). Cary is a Phase II municipality.

Since the majority of the Cary's stormwater regulations shifted with the implementation of the Neuse Basin Rules, 1998 was established as the delineation point between legacy and current stormwater practices for Black Creek.

Step 3) Collect or create impervious cover data sets

A 1999 impervious surfaces layer, available from the Town of Cary, was used as the legacy impervious surfaces layer. The subwatershed was extracted by mask and overlaid with the catchments layer in ArcGIS (Figure 11).

Though legacy development will be prioritized because of its "target rich" nature (i.e., greater benefits if retrofitted), current development does impact the subwatershed and, therefore, is also considered in the prioritization. The current impervious cover data set was created by hand digitizing updates to the 1999 Impervious Surfaces layer with ArcGIS using publicly available 2010 orthophotography for Wake County (Figure 11). The accuracy is sufficient for prioritization purposes; however, should additional analysis be considered, the accuracy should be verified as appropriate beforehand.

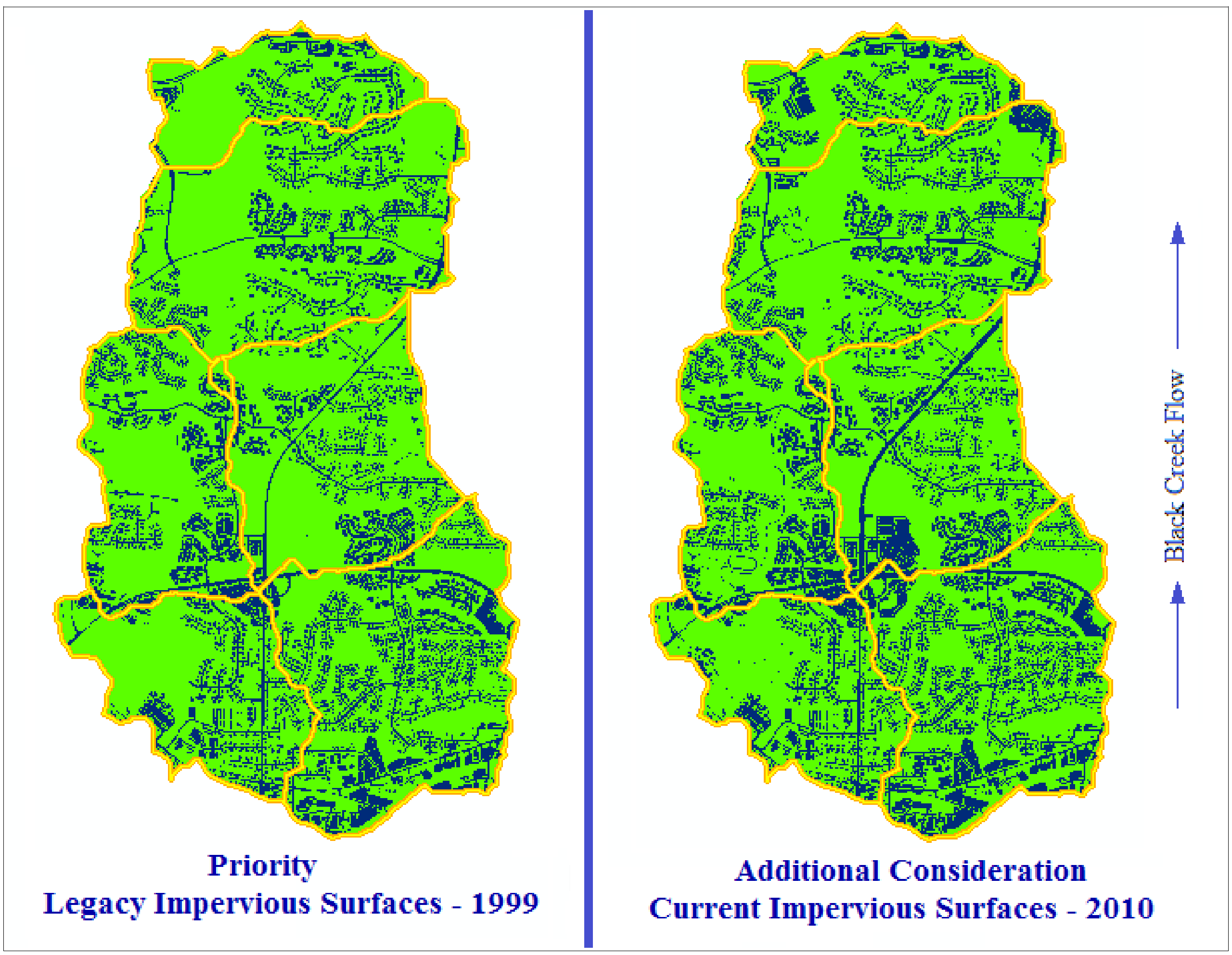

Figure 11: Objective 1 (Subwatershed Prioritization) - Impervious Surfaces.

Step 4) Prioritize impervious cover

The impervious cover analysis was completed in ArcGIS. Each year's impervious surface layer was converted to raster and reclassified into impervious (90) and pervious/no data (0). Each year's reclassed raster was then extracted by individual catchment with the analysis mask. The resulting raster cell counts were then summarized as applicable and used to calculate the impervious cover percentages. These percentages were then categorized according to the ICM (Figure 12).

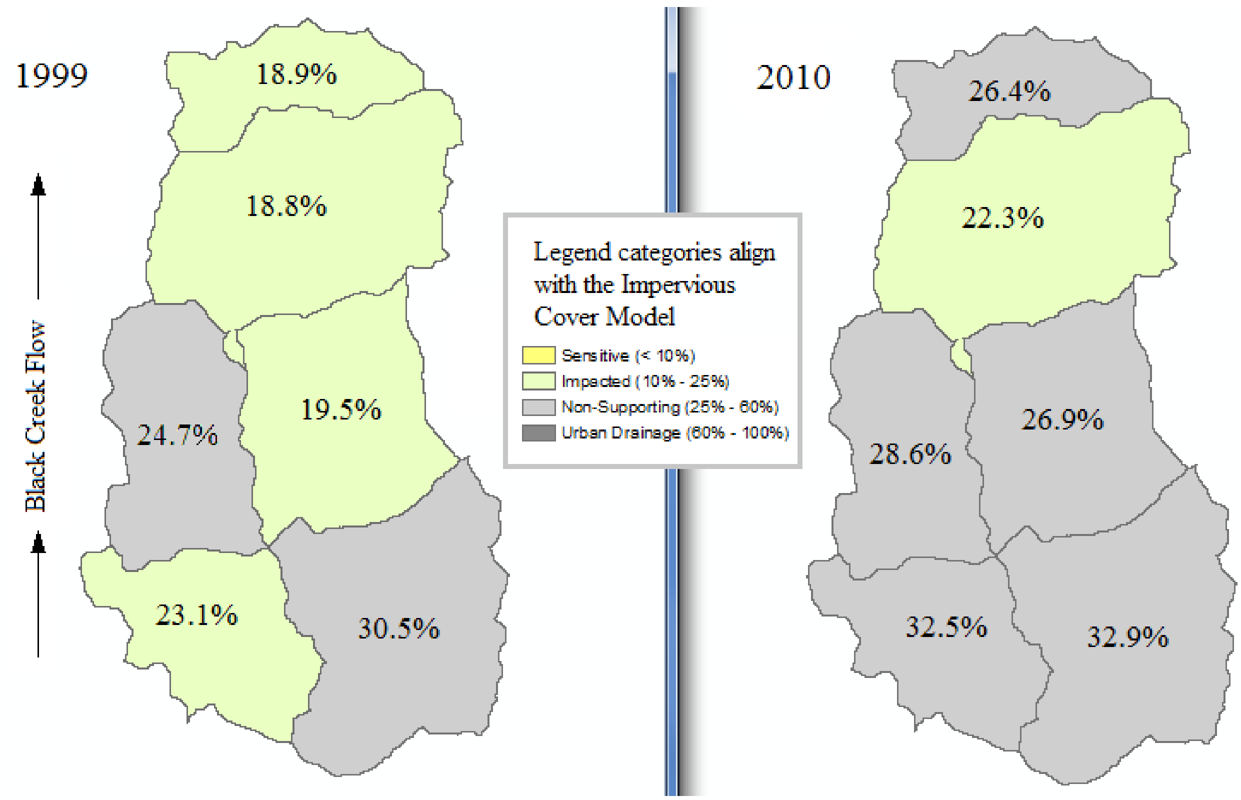

Figure 12: Objective 1 (Subwatershed Prioritization) - Impervious Surface Percentages. In eleven years, three more Black Creek catchments moved into the Non-Supporting (25%-60%) category of the ICM

Step 5) Prioritize location

In general, the further upstream a subwatershed is in the watershed, the more it benefits the watershed as a whole, and the higher its subsequent prioritization. For example, the benefits of a complete restoration of lower subwatersheds would only benefit that those subwatersheds and downstream watersheds. Restoration efforts in upper subwatersheds benefit middle and lower subwatersheds as well (Figure 13).

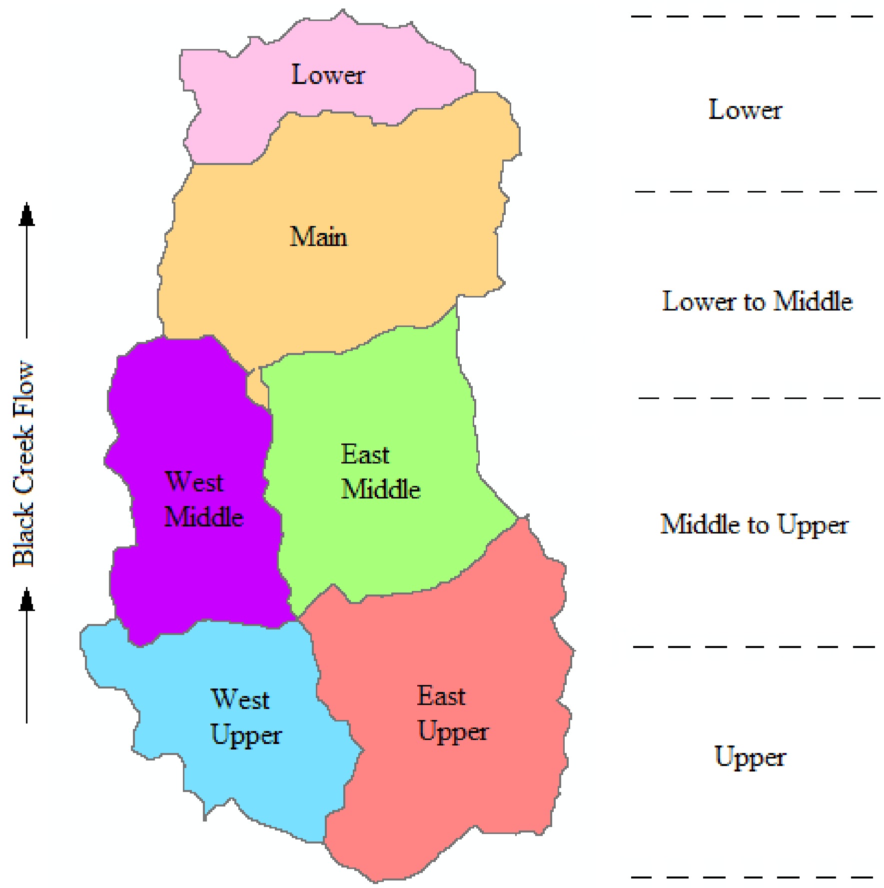

Figure 13: Objective 1 (Subwatershed Prioritization) - Subwatershed Location.

Step 6) Prioritize subwatersheds

The final step in prioritizing subwatersheds was to compile the results (Figure 14).

	Legacy (1999) Impervious Surface Percentage					
Points (Categories)	**East Upper**	**West Upper**	**East Middle**	**West Middle**	**Main**	**Lower**
0 (Sensitive (<10%))						
5 (Impacted (10-25%))		23%	20%		19%	19%
10 (Non-Supporting (25-60%))	31%			25%		
15 (Urban Drainage (60-100%))						
Legacy/1999 Point Subtotal	10	5	5	10	5	5
Adjustment for Current/2010 *	0	1	1	1	0	1
Impervious Surface Subtotal	**10**	**6**	**6**	**11**	**5**	**6**

* Adjustment for Current/2010 – Though legacy development is weighted more heavily for prioritization, current development also has an impact. One point was added to the subtotal if the impervious cover percentage in 2010 resulted in an ICM category shift upward (i.e., from Impacted to Non-Supporting)

	Subwatershed Location					
Points (Categories)	**East Upper**	**West Upper**	**East Middle**	**West Middle**	**Main**	**Lower**
0 (Lower)						X
5 (Lower to Middle)					X	
10 (Middle to Upper)			X	X		
15 (Upper)	X	X				
Subwatershed Location Subtotal	**15**	**15**	**10**	**10**	**5**	**0**

	Subwatershed Prioritization Summary					
Impervious Surface Subtotal	10	6	6	11	5	6
Subwatershed Location Subtotal	15	15	10	10	5	0
Point Totals	25	21	16	21	10	6
Priority	**1**	**2**	**3**	**2**	**4**	**5**

Figure 14: Objective 1 (Subwatershed Prioritization) - Summary. Each subwatershed (catchment) was categorized and, if applicable, adjusted, resulting in point subtotals. These subtotals were then summarized into a point total and each subwatershed (catchment) was given a priority rank within the watershed (subwatershed).

Objective 2 – Develop the Stormwater Goal (Methodology and Results):

Once the subwatersheds have been prioritized, restoration focus can be narrowed to a single subwatershed, such as Black Creek. When stormwater is the primary indicator of degradation, targets based on reducing or disconnecting runoff, as was done with Eagleville Brook, and prioritizing legacy development may be more effective than traditional pollutant-specific TMDLs.

In the case of Eagleville Brook, located in Mansfield, CT, an impervious cover TMDL was developed. Progress will initially be measured through disconnects in impervious cover and TMDL progress will ultimately be measured through improvements in aquatic life (CTDEP 2007).

In similar restoration efforts, it seems common for several potential restoration sites identified during the desktop analysis to eventually be eliminated during the site visit phase. For example, in the case Eagleville Brook, the GIS estimate was reduced by 51 acres or 23.6% since this land was “already disconnected and should not be considered 'effective'” (CTDEP 2010). This GIS estimation “error” may at least partially been a result of considering of both legacy and current development. In addition to legacy impervious cover being a “target-rich” environment for restoration, focusing on legacy development should also improve the accuracy of the stormwater goal and desktop analysis, as well as the efficiency of the field assessment phase.

In setting a retrofit target in this study, an approach similar to that used to set Eagleville Brook's impervious cover target was applied. However, in line with the assertion that legacy impervious cover is of higher priority than current impervious cover, legacy impervious cover estimates have been used in determining the stormwater disconnection target. Figure 15 provides a visual demonstration of this concept.

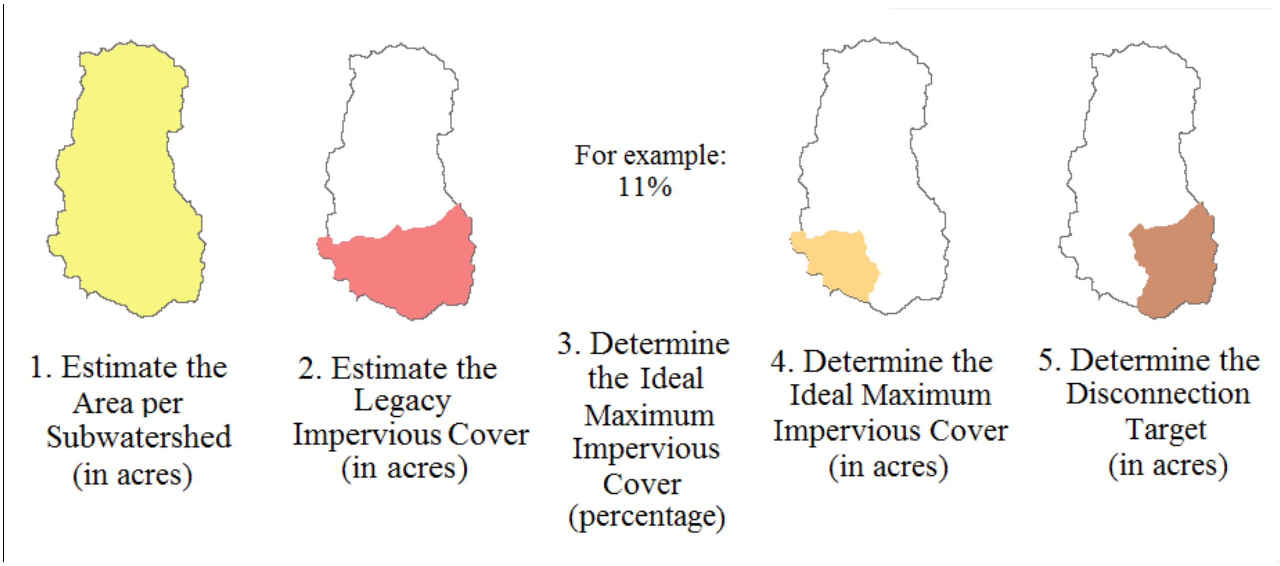

Figure 15: Objective 2 (Stormwater Goal) - Concept Visualization. This visualization is for demonstration purposes only. Impervious cover estimates in steps 2, 4, and 5 would be distributed throughout the subwatershed.

Step 1) Estimate the area per catchment (acres)

Using ArcGIS, the subwatershed area was calculated.

Step 2) Estimate the legacy impervious cover (acres)

Again, using ArcGIS, the legacy impervious cover was calculated.

Step 3) Determine the ideal maximum impervious cover (percentage)

In the case of Eagleville Brook, an Impervious Cover TMDL target of 11% was set based on an integrated aggregate of point and non-point sources, as well as the margin of safety (CTDEP 2007). In line with the Eagleville Brook example and the ICM estimation of 10% as the delineation between Sensitive and Impacted stream quality, 11% was also used for this study.

Step 4) Determine the ideal maximum impervious cover (acres)

The ideal maximum impervious cover acreage was calculated by multiplying the area per subwatershed (step 1) by the ideal maximum impervious cover percentage (step 3).

Step 5) Determine the disconnection target (acres)

The disconnection target was calculated by subtracting the ideal maximum impervious cover (step 4) from the legacy impervious cover estimate (step 2).

Step 6) Revise the disconnection target (as applicable)

In the case of Black Creek, the Town of Cary maintains and made available a copy of their BMP map. It contained point data for the BMPs that they are tracking, plus project number, type, location, owner, contact, and inspection information.

Using ArcGIS, BMPs located within the Black Creek subwatershed were selected. Additional fields were added to the attribute table to indicate in which catchment the BMPs were located (Subwatrshd), the associated drainage area (DrainAcre), and the type (legacy or current) of development (Developmnt). The details of the BCWA bioretention project at West Cary Middle School were also added to the local copy of the attribute table for future reference by the BCWA.

Drainage areas (Spatial Analyst Watersheds) were created using the BMP database points. These drainage areas were then compared to the legacy and current development layers. As was to be expected, most were associated with current development; however 12 acres of drainage area in the East Upper (Town Hall) and West Upper (West Cary Middle School) catchments were associated with legacy development. This disconnected legacy acreage was subtracted, resulting in a revised disconnection target.

Figure 16 summarizes the results for Black Creek.

Step		Black Creek (acres)
1	**Total Subwatershed Area**	2217.89
2	**Legacy Impervious Cover**	508.86
3	**Ideal Max Impervious Cover (11% * Step 1)** [1]	243.97
4	**Disconnection Target (Step 2 – Step 3)**	264.89

Ideal Max Impervious Cover [1] - As determined by the ICM and a 1% margin of error

		Existing Retrofits
5	**Legacy Disconnections** [2]	12.01
6	**Revised Disconnection Target (Step 4 – Step 5)**	252.88

Legacy Disconnections [2] - As determined through the BMP database kept by the Town of Cary

Figure 16: Objective 2 (Stormwater Goal) - Black Creek Results. Overall, the disconnection target is 264.89 acres or 11.94% of the watershed. Existing BMPs within legacy development reduced the Disconnection Target by 12 acres.

Objective 3 – Identify and Prioritize Restoration Areas (Methodology and Results):

Once the retrofit target is set, focus can further be narrowed to within the subwatershed. Potential retrofit opportunities can be prioritized based on “target rich” legacy development, the state of a variable-width riparian corridor, and the drainage acreage that would be disconnected.

Step 1) Identify high level subwatershed goals

The CWP identifies several high level subwatershed restoration goals including improvements in water quality, biology, physical/hydrology, and community usage (Schueler 2005). Though more than one goal might be set and potential sites might meet multiple subwatershed goals, it is important to identify and ensure coverage for each subwatershed goal. For example, habitat restoration could require specific types of vegetation that might not be required to restore water quality.

In the case of Black Creek, the focus is on the generalized restoration of the stream's aquatic health and the associated benefits to community usage.

Step 2) Prioritize catchments

In the first objective, subwatersheds were prioritized based on impervious cover, particularly resulting from legacy development, and location within the watershed. In this step, selected subwatersheds can further be prioritized by catchment using additional layers. The layers collected and created to prioritize Black Creek's catchments were as follows:

a) Catchment Location
b) Impervious Cover
c) Riparian Corridor
d) Stormwater Outfalls

Results were evaluated by layer, then summarized by catchment.

Step 2a) Collect or create needed data sets

Existing Data Sets: While completing the health assessment of the subwatershed and the development of the watershed plan, the BCWA collected and created several data sets. These include Hydrology (including updated GPS verification of stream detail), Land Use and Land Cover (plus orthophotos, DEM, 5 & 10 ft contours, soils), Municipal (greenway, parcels, parks, sewer, water, roads, schools), Research (monitoring gauges & collection sites, watershed & subwatershed boundaries), and Stormwater System (updated/confirmed survey data).

In addition to the data sets available through the BCWA, several data sets have already been completed for this project. These include the catchment boundaries (Figure 10), impervious cover (Figure 11 and Figure 12), and catchment location (Figure 13).

Simplified Variable-Width Riparian Buffer: A riparian buffer is the area immediately adjacent to the stream. Conserving these areas or restoring them to a more natural state of vegetation allows for protection through the mitigation, absorption, and filtration of surface flow, as well as stream channel and habitat stabilization and protection (Cappiella et al 2005). Two-dimensional regulated buffers, such as the required 100 feet in Cary, lend themselves well to comprehension, adherence, and enforcement. However, other factors, such as slope and soil type, also impact the effectiveness of a riparian corridor and are worth consideration in individualized restoration efforts. A simplified variable width buffer was created with ArcGIS for Black Creek (Figure 17).

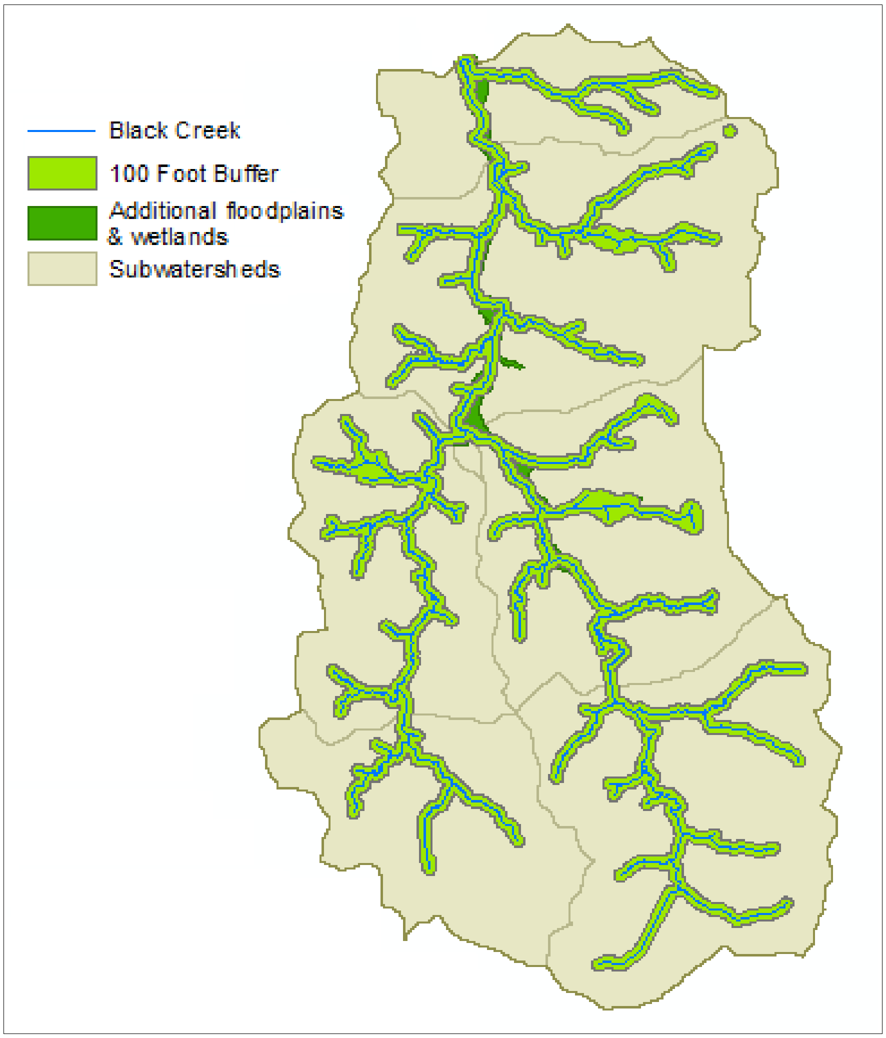

Figure 17: Objective 3 (Catchment Prioritization) - Variable-Width Riparian Buffer. A simplified variable-width buffer was created by buffering the stream by 100 feet, then extending to the edge of the floodplain, and finally extending to any adjacent wetlands.

State of the Riparian Corridor:

The variable-width riparian buffer and the National Land Cover Data from 2006 were then used to categorize and evaluate the state of the riparian corridor by catchment (Figure 18).

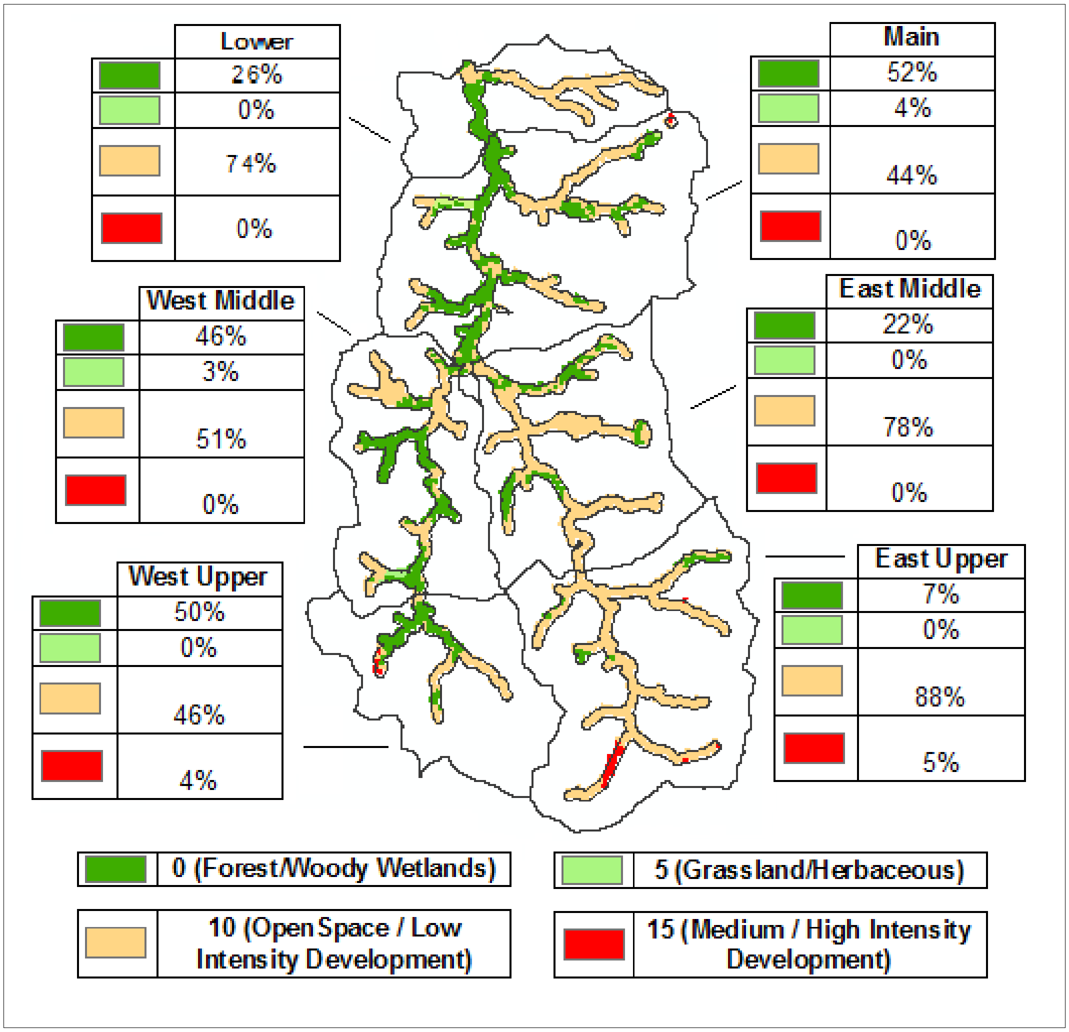

Figure 18: Objective 3 (Catchment Prioritization) - State of the Riparian Corridor. The simplified variable-width riparian buffer and the National Land Cover Data from 2006 provide insight into the state of Black Creek's riparian corridor.

Stormwater Outfalls within the Variable-Width Riparian Buffer: The Town of Cary recently completed a stormwater infrastructure audit and has made the resulting layers available to the public. Stormwater outfalls located within the variable-width buffer were selected and categorized based on their catchment and proximity to Black Creek (Figure 19).

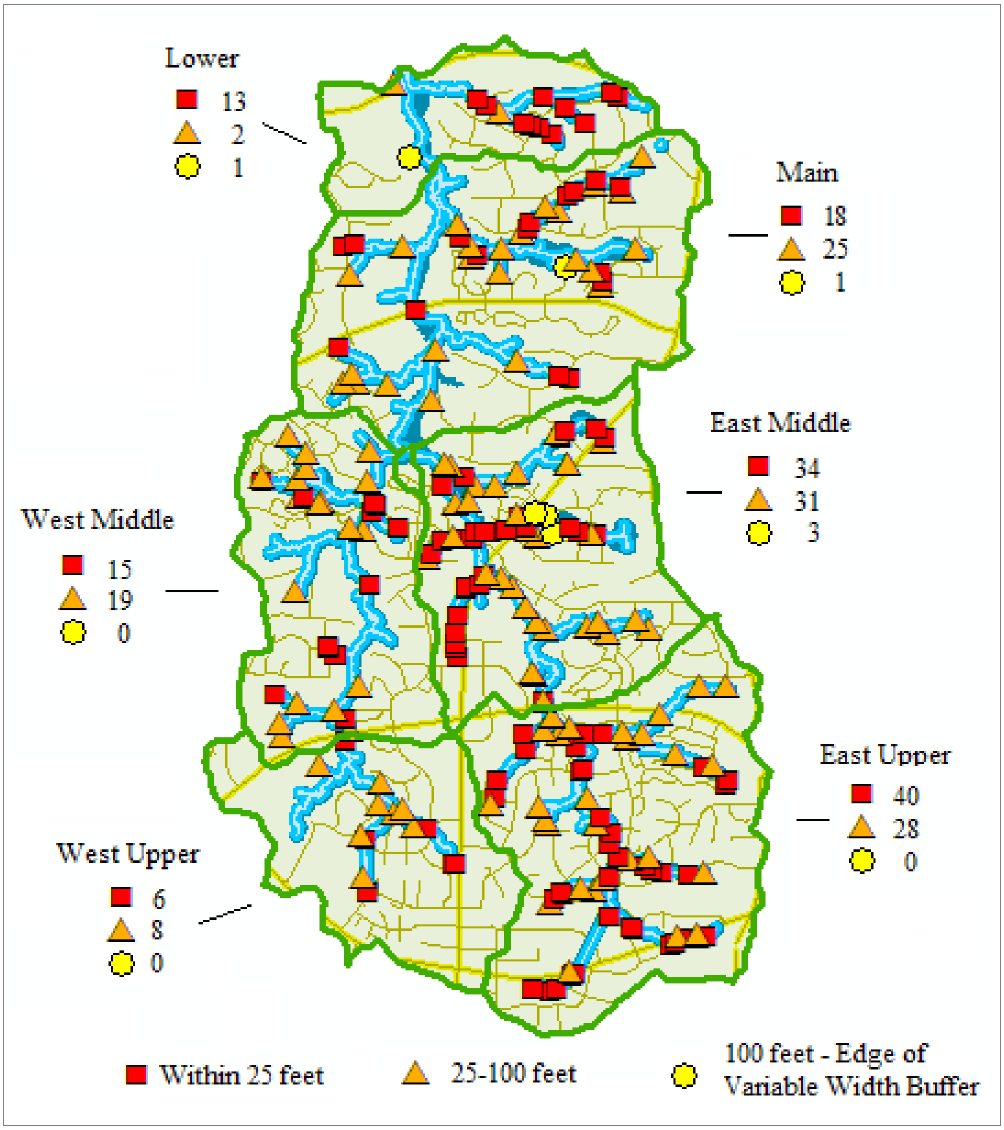

*Figure 19: Objective 3 (Catchment Prioritization) - Stormwater Outfalls.*176 stormwater outfalls are within Black Creek's variable width riparian buffer (and sub-buffer levels of 25 and 100 feet), effectively bypassing many of the intact corridor's benefits.

Step 2b) Compile results

The individualized results were compiled for an overall catchment prioritization (Figure 20).

Catchment Location: In general, upper catchments benefit lower catchments as well, so upper catchments are given higher priority.

Impervious Surfaces: In general, restoration within legacy development is likely to be more beneficial to the subwatershed as a whole, so legacy development is given higher priority.

Riparian Corridor: Land cover types were categorized (Forest-0; Grass-5; Open/Low-10; Med/High-15). Then coverage percentages within each catchment were used to create weighted averages. Forested land is already highly beneficial to the subwatershed and, therefore, a low priority to restore, so it is weighted at 0. More intensely developed land is more likely to degrade water quality, so it is given higher priority for restoration.

Stormwater Outfalls: Outfalls were categorized by their distance from the stream (25 ft-5; 100 ft-10; VWB-15). The number of outfalls within each catchment was used to create weighted averages. An adjustment was then added per 10% total outfalls (i.e., a catchment with 68 outfalls is a higher priority than a catchment with 14 outfalls).

Point Total: Category subtotals were then summarized.

Catchment Priority: The final catchment priority was then assigned based on the point totals.

Of note, none of the catchments are eliminated as a result of this analysis.

	Catchment Location					
Points (Categories)	**East Upper**	**West Upper**	**East Middle**	**West Middle**	**Main**	**Lower**
Details	See Figure 14					
Catchment Location Subtotal	**15**	**15**	**10**	**10**	**5**	**0**

	Impervious Surfaces					
Points (Categories)	**East Upper**	**West Upper**	**East Middle**	**West Middle**	**Main**	**Lower**
Details	See Figure 14					
Impervious Surface Subtotal	**10**	**6**	**6**	**6**	**5**	**6**

	State of the Riparian Corridor					
Points (Categories)	**East Upper**	**West Upper**	**East Middle**	**West Middle**	**Main**	**Lower**
0 (Forest/Woody Wetlands)	0.0	0.0	0.0	0.0	0.0	0.0
5 (Grassland/Herbaceous)	0.0	0.0	0.0	0.1	0.2	0.0
10 (OpenSpace/LowIntensityDevelopment)	8.8	4.6	7.8	5.1	4.4	7.4
15 (Medium/High Intensity Development)	0.8	0.5	0.0	0.0	0.1	0.0
Riparian Subtotal (Weighted Average)	**9.5**	**5.1**	**7.8**	**5.3**	**4.7**	**7.4**

	Stormwater Outfalls Located Within Riparian Buffer					
Points (Categories)	**East Upper**	**West Upper**	**East Middle**	**West Middle**	**Main**	**Lower**
5 (VariableWidthBuffer)	0	0	3	0	1	1
10 (100 Foot Buffer)	28	8	31	19	25	2
15 (25 Foot Buffer)	40	6	34	15	18	13
Total Outfalls per Catchment	68	14	68	34	44	16
Outfall Subtotal (Weighted Average)	12.9	12.1	12.3	12.2	11.9	13.8
Total Outfalls per Catchment	68	14	68	34	44	16
% Total Outfalls per Subwatershed*	27.9%	5.7%	27.9%	13.9%	18.0%	6.6%
Adjustment for % of Total**	2	0	2	1	1	0
Stormwater Outfall Subtotal	**14.9**	**12.1**	**14.3**	**13.2**	**12.9**	**13.8**

% Total Outfalls per Subwatershed* – There are 244 total outfalls located within the Black Creek subwatershed

Adjustment for % of Total** – To account for the total outfalls per catchment in relation to the total outfalls per subwatershed, an adjustment of 1 point per 10% of total outfalls was added to the point subtotal

	Catchment Prioritization Summary					
Categories	**East Upper**	**West Upper**	**East Middle**	**West Middle**	**Main**	**Lower**
Catchment Location	15	15	10	10	5	0
Impervious Surfaces	10	6	6	6	5	6
Riparian Corridor	9.5	5.1	7.8	5.1	4.4	7.4
Storm water Outfalls	14.9	12.1	14.3	13.2	12.9	13.8
Gaged Catchment***	1.0	1.0	1.0	1.0	1.0	0.0
Point Total	50.4	39.2	39.1	35.3	28.3	27.2
Priority	**1**	**2**	**2**	**3**	**4**	**5**

Gaged Catchment*** - BCWA has a stream gage located in the main catchment. Monitored catchments have been given an additional point in priority

Figure 20: Objective 3 (Catchment Prioritization) - Summary

3) Identify Potential Restoration Areas

The third step is to identify potential restoration areas. Many of the following ideas are based on the CWP's series on Urban Subwatershed Restoration and a review of locally available data.

The first set of results is largely focused on potential opportunities on public property (Figure 21). First, road crossings were identified. This was done using an intersection between the roads and stream layer, with a point output layer in ArcGIS. Second, government property (town, county, and state) was identified using an ownership attribute/field in the Town's CaryProperty layer. Third, government property with at least contiguous two acres within the variable-width riparian buffer and the associated stormwater outlets were identified. This was done using Select by Location (government property within the buffer), adding a new field for the area, and Calculat(ing) the Geometry (area in acres) in ArcGIS.

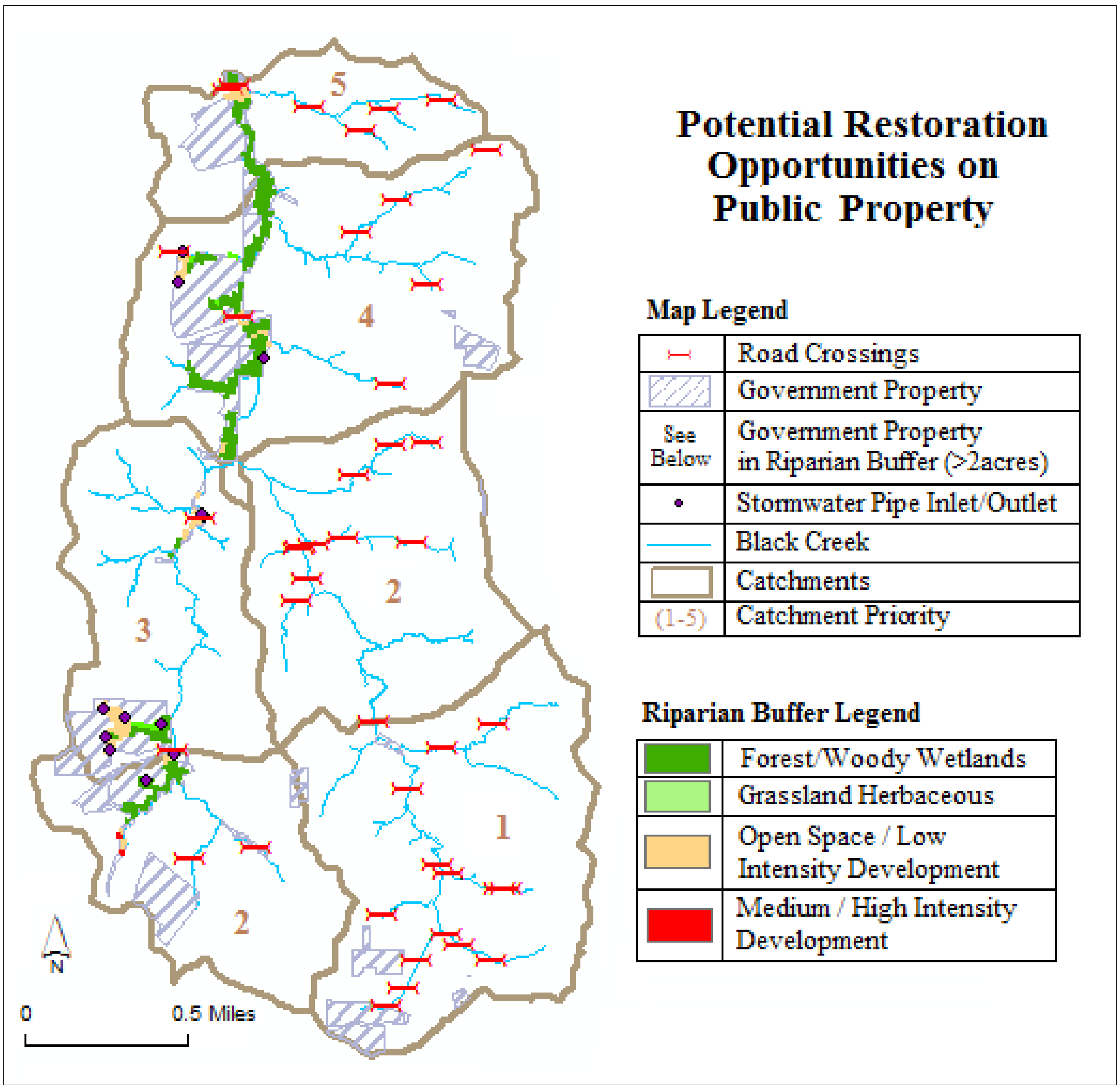

Figure 21: Objective 3 (Identify Restoration Areas) - Opportunities on Public Property.

The second set of results is focused on potential pond retrofit and educational restoration opportunities (Figure 22). First, existing ponds were identified since retrofits to ponds can provide additional stormwater storage opportunities. Second, though it would be possible to restore Black Creek's health through government-initiated stormwater outfall retrofits, a core goal of WECO, the NC State University cooperative extension that supports and facilitates the BCWA, is education. Homeowners Associations and churches can provide opportunities to educate the public on steps they can take to improve the subwatershed's health through onsite retrofits, such as disconnecting gutters and implementing rain gardens. These groups were identified using Cary's ResidentialAndNonResidential layer. Third, the percentages of legacy development were calculated for prioritization. For example, successful educational efforts in Black Creek's upper catchments with 25-68% legacy development could cumulatively provide benefit to the entire subwatershed.

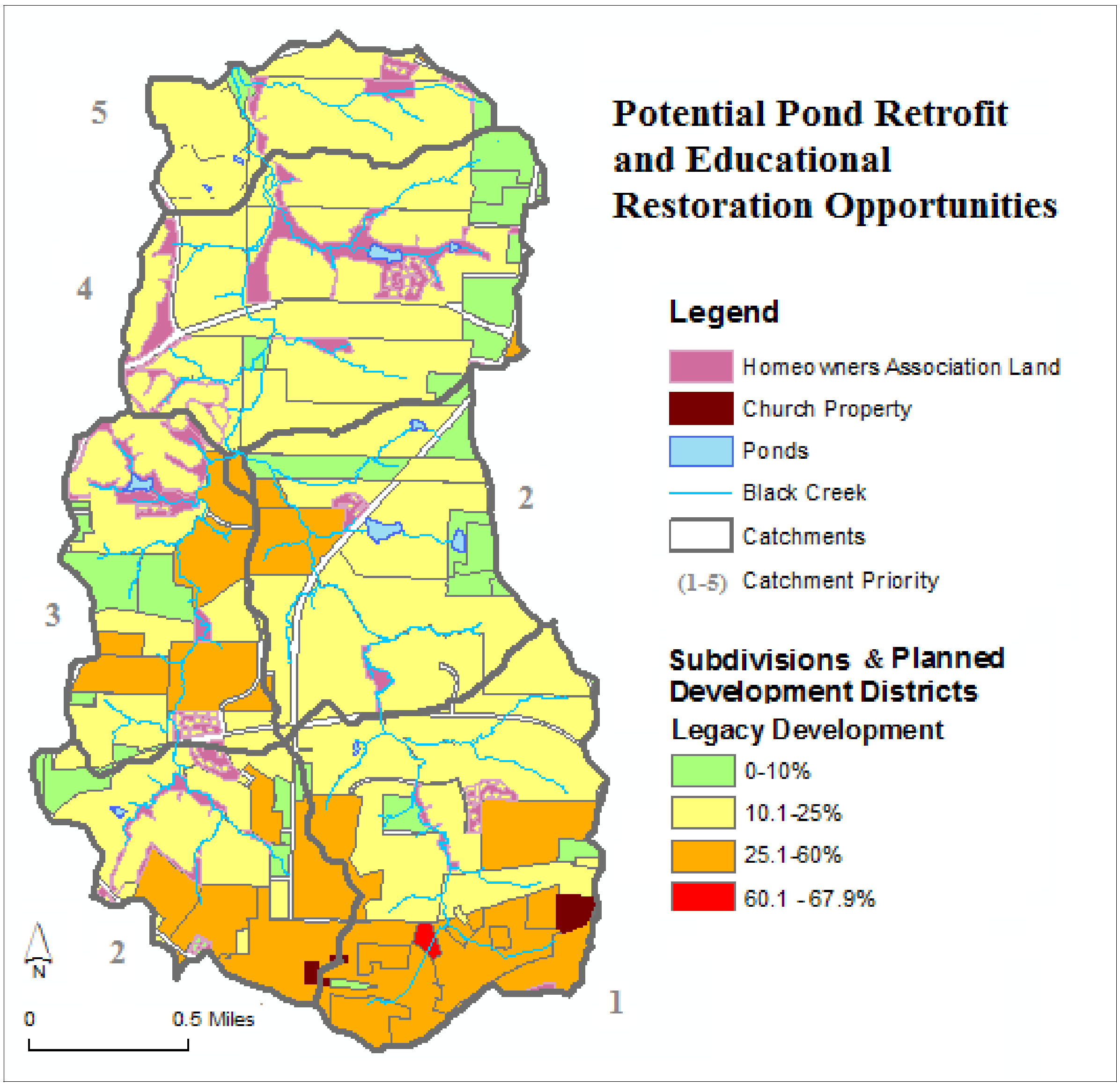

Figure 22: Objective 3 (Identify Restoration Areas) - Pond and Educational Opportunities.

Conclusion:

Next Steps:

Of note, no sites are definitively established or eliminated as a result of this analysis. At this point, the next steps include visiting potential restoration areas, determining the feasibility and location of retrofits, calculating the associated disconnection acreage, and prioritizing based on catchment priority, drainage, participant interest, and cost.

Further Study:

Though this project was both conceptual and specific in nature, there are almost always more opportunities for further study.

Variable-Width Buffers: Several models exist for the creation of variable-width buffers. In 1999, Seth Wenger released the results of his literature review. In addition to the simplified variable-width buffer created for this project, it would be of interest to include the following (Wenger 1999):

1) Base width: 100 ft (included), plus 2 feet per 1% of slope
2) Extend to edge of floodplain (included)
3) Include adjacent wetlands (included) - The corridor width is extended by the width of the wetlands, which guarantees that the entire wetland and an additional corridor is protected
4) Existing impervious surfaces in the riparian zone do not count toward the corridor width (i.e., the width is extended by the width of the impervious cover, just as for wetlands).
5) Slopes over 25% do not count toward the width

State of the Riparian Corridor: This project used NLCD with a 30m resolution from 2006. A more current land cover analysis with a finer resolution would provide a more accurate view of the riparian corridor. However, as mentioned previously, the high number of stormwater outfalls located within the riparian corridor is a more urgent priority for effective restoration.

Forestry State beyond the Riparian Buffer: Setting subwatershed forestry targets utilizing GIS analysis as outlined by the CWP would also be of interest.

Final Thoughts:

In many areas, current stormwater regulations have been in place long enough to warrant a delineation when evaluating areas based on impervious cover. This delineation can be used at multiple levels – at a high level when comparing subwatersheds within a municipality or larger watershed, at a subwatershed level when setting a restoration goal, and at a local level when identifying potential restoration sites. Implementation of this concept will differ in complexity, depending on the number of government organizations involved and the regulation history. It is not intended to replace the current 303(d) process. Such a delineation, however, should result in improved prioritization and results.

With the continued trending toward urban development, it can be expected that stormwater will increasingly be a determining factor in degraded water quality. Rather than following the traditional pollutant-TMDL methodology, impervious cover TMDLs will likely become increasingly relevant. In other words, treatment of stormwater volume and velocity issues will result in improved water quality without further isolation of specific pollutant levels. Delineating between legacy and current development will increasingly influence the accuracy of the targeted goals and site search, allowing for more effective prioritization and more efficient use of resources during the field assessment phase.

Further incorporation of other factors that influence subwatershed health, such as location, the state of the riparian corridor, and stormwater infrastructure can also help increase realized benefits.

On the other hand, it is counterproductive to overcomplicate the process. When incorporating a delineation between legacy and current development, attention must be given to ensure like-comparisons are made. For example, the nuances of the Neuse River Basin Rules might not be inherently comparable to the ordinances established by the Clean Water Act or the Town of Cary.

Subwatershed restoration is complicated and expensive. Though much of the discussion has been on subwatershed restoration, GIS has provided much of the foundation. As the availability and accuracy of data grows, innovative usage of GIS can help maximize the ecological return on investment and restoration of impacted waterways.

Acknowledgments and Contact Information:

In particular, I would like to thank Dr. Joseph Bishop (PSU) and Christy Perrin (BCWA) for their conceptual recommendations and support. I'd also like to thank Dr. Douglas Miller (PSU), Beth F. King (PSU), Patrick Beggs (BCWA), and Charles Brown (Town of Cary) for their roles and support during this phase of the project as well.

Thank you for your time. Please send any comments or questions to ekhorvath@gmail.com. I am interested in constructive feedback on the project itself, as well as similar efforts underway elsewhere.

References and Citations:

Auch, R. J. Taylor. W. Acevedo. 2004. Urban Growth in American Cities: Glimpses of U.S. Urbanization. United States Geological Survey, Denver, CO. http://pubs.usgs.gov/circ/2004/circ1252/

Cappiella, K., T. Schueler, T. Wright. 2005. *Urban Watershed Forestry Manual – Part 1: Methods for Increasing Forest Cover in a Watershed.* United States Department of Agriculture, Forest Service, Newtown Square, PA. http://www.cwp.org/documents/cat_view/69-urban-watershed-forestry-manual-series.html

CBSTP (Chesapeake Bay Stormwater Training Partnership). 2010. Impervious Disconnection. http://cbstp.org/index.php?option=com_content&view=article&id=17:archived-webcasts&catid=11&Itemid=21

CLEAR (Center for Land Use Education & Research). 2011. Riparian Corridors. College of Agriculture & Natural Resources, University of Connecticut, Haddam, CT. http://clear.uconn.edu/webinars/CLEARseries/index.htm

CTDEP (State of Connecticut Department of Environmental Protection). 2007. *A Total Maximum Daily Load Analysis for Eagleville Brook, Mansfield, CT.* http://www.ct.gov/dep/lib/dep/water/tmdl/tmdl_final/eaglevillefinal.pdf

CWP (Center for Watershed Protection), Horsley Witten Group. 2010. *Eagleville Brook Impervious Cover TMDL Field Survey and Analysis Report.* Center for Land Use Education and Research, University of Connecticut, Mansfield, CT. http://clear.uconn.edu/projects/tmdl/library/TMDL/reports/IC_TMDL_FinalTechRpt_0810.pdf

NCDWQ-IR (North Carolina Division of Water Quality). 2010. *NC 2010 Integrated Report Categories 4 and 5 Impaired Waters.* North Carolina Department of Environment and Natural Resources, Raleigh, NC. http://portal.ncdenr.org/web/wq/ps/mtu/assessment#3

NCDWQ-UM (North Carolina Division of Water Quality). 2010. *2010 Use Assessment Methodology.* North Carolina Department of Environment and Natural Resources, Raleigh, NC. http://portal.ncdenr.org/web/wq/ps/mtu/assessment#3

NNSWS (Neuse Nutrient Sensitive Waters (NSW) Strategy). nd. Accessed July 2011 at http://h2o.enr.state.nc.us/nps/neuse.htm

Puente, M., Perrin, C., and Beggs, P. Black Creek Watershed Situation Assessment. 6 Jun 2006. http://www.ces.ncsu.edu/depts/agecon/WECO/blackcreek/BC_SA_Final.pdf

Schueler, T. 2005. *Urban Subwatershed Restoration Manual No. 1: An Integrated Framework to Restore Small Urban Watersheds (Version 2.0).* Center for Watershed Protection. http://www.cwp.org/documents/cat_view/68-urban-subwatershed-restoration-manual-series.html

Schueler, T., A. Kitchell. 2005. *Urban Subwatershed Restoration Manual No. 2: Methods to Develop Restoration Plans for Small Urban Watersheds (Version 2.0).* Center for Watershed Protection. http://www.cwp.org/documents/cat_view/68-urban-subwatershed-restoration-manual-series.html

Schueler, T., D. Hirschman, M. Novotney and J. Zielinsky. 2007. *Urban Subwatershed Restoration Manual No. 3: Urban Stormwater Retrofit Practices (Version 1.0).* Center for Watershed Protection. http://www.cwp.org/documents/cat_view/68-urban-subwatershed-restoration-manual-series.html

Schueler, T., L. Fraley-McNeal, and K. Cappiella. 2009 Mar/Apr. Is Impervious Cover Still Important? Review of Recent Research. Journal of Hydrologic Engineering. 14(4): 302-315. http://cedb.asce.org/cgi/WWWdisplay.cgi?170460

Szpir, Laura. 2007. Low Impact Development (LID): A New Approach to Land Development & Stormwater Management. http://www.ces.ncsu.edu/depts/agecon/WECO/blackcreek/Cary Black Creek LID Overview 5_21_07.pdf

USCB (United States Census Bureau). nd. Table 4. Population: 1790 to 1990. http://www.census.gov/population/censusdata/table-4.pdf

USEPA (United States Environmental Protection Agency). 2003. Protecting Water Quality from Urban Runoff. EPA 841-F-03-003. http://www.epa.gov/npdes/pubs/nps_urban-facts_final.pdf

USEPA (United States Environmental Protection Agency). 2008. Archived Webcasts: Stormwater 101: The Basics. Accessed July 2011 at http://www.epa.gov/npdes/outreach_files/webcast/jul2308/114376_od/114376_od.html

USEPA (United States Environmental Protection Agency). 2010. CADDIS Volume 2: Sources, Stressors & Responses. http://www.epa.gov/caddis/ssr_urb_is2.html

WECO (Watershed Education for Communities and Officials). 2009. *Black Creek Watershed Assessment, Monitoring, & Planning: EPA319 Grant Final Report & Watershed Plan.* North Carolina State University, Raleigh, NC. http://www.ces.ncsu.edu/depts/agecon/WECO/blackcreek/documents/2009_blackcreek_319_finalReport_June10.pdf

WECO (Watershed Education for Communities and Officials). 2010. Black Creek Plan Approved by the EPA. The Black Creek Watershed Wire. North Carolina State University, Raleigh, NC. http://www.ces.ncsu.edu/depts/agecon/WECO/blackcreek/documents/2010_Mar_take2_BCWire.pdf

Wenger, S.J. 1999. A Review of the Scientific Literature on Riparian Buffer Width, Extent and Vegetation. University of Georgia, Athens, GA. http://www.rivercenter.uga.edu/service/tools/buffers/buffer_lit_review.pdf