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EFFECTS OF IMPERVIOUSNESS ON FAMILY BIOTIC INDEX VALUES IN THE SOUTHERN APPALACHIAN HEADWATERS AND RESULTING EXTENSION EDUCATION

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EFFECTS OF IMPERVIOUSNESS ON FAMILY BIOTIC INDEX VALUES IN THE SOUTHERN APPALACHIAN HEADWATERS AND RESULTING EXTENSION EDUCATION

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ABSTRACT

This dissertation offers a starting point for determining thresholds of anthropogenic impacts to sustain biological integrity in headwater streams and offers examples of successful Extension education outreach efforts to educate stakeholders about vital connections between the landscape and surface waters. The following research and succeeding education efforts reported in this dissertation seek to understand water quality impairment and variability in headwater streams, inform thresholds to maintain biological integrity of these areas, and extend scientifically based information through the Extension Service. Understanding effects from changes in the catchments can ameliorate future impacts, prioritize preservation efforts and inform restoration trajectories. Although a variety of stakeholders have preserved and passively managed unimpaired stream systems, others have attempted to enhance or restore streams with limited success. Without consideration of the effect of the surrounding landscape on surface headwater streams, preservation and restoration efforts may not maintain biological integrity of these overlooked, but vital, resources.

DEDICATION

For my loving children,

I hope we enjoy playing in the clean water for a very long time.

Thanks "J."

ACKNOWLEDGMENTS

I am grateful for the support of my family, friends and colleagues that fostered the following explorations. Without the support of my thoughtful parents, enthusiastic sister, cherished friends, extraordinary children and thoughtful, yet patient, committee, I would have been unable to complete these projects and contributions. I am very appreciative of the kindness and support during this process.

Many esteemed and respectable colleagues from Clemson University, The North Carolina Arboretum, University of North Carolina Asheville, North Carolina State University and funding agencies that include the Pigeon River Fund, NC Division of Water Quality, Division of Water Resources, USDA and the Environmental Protection Agency were integral to the success of this interdisciplinary project.

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CHAPTER ONE

INTRODUCTION

Clear, cool headwater streams in the mountains of North Carolina are inextricably linked to the surrounding landscape. Trickling perennial streams drain precipitation from their catchment and are capable of sustaining excellent water quality to support rich aquatic biodiversity that feeds and beneficially contributes to the stream network below. However, headwater ecosystems may be easily compromised by even seemingly insignificant anthropogenic impacts. Although the NC Mountains contain some of the highest headwater streams densities in the nation, they remain very susceptible to changes in the catchments that sustain them. Small headwater streams were not mapped until recently, and are now known to be ubiquitous. However, impacts from historic and current land use may threaten the rich biodiversity found in few other places in the world.

This dissertation is provided as a collection of research papers, in publication form, that underpin correlations between anthropogenic impacts and levels of degradation in headwater streams (chapter 2 and 3); evaluate Extension education efforts directed at increasing awareness about techniques and practices to preserve or improve water quality in streams (chapter 4) and documents how low impact development demonstration practices have supported water quality education (chapter 5).

Existing research on the complex and highly variable macroinvertebrate response to anthropogenic interventions indicate wide variability across a variety land uses. There is agreement that impervious surface area negatively affects water quality. However, these thresholds are coarsely defined and only a small amount of imperviousness (less than 5 to 10%) may substantially degrade surface waters. This research supports defining more detailed, regional thresholds to aid in policy, planning and design to meet the goals of the US Clean Water Act "to restore, and maintain the chemical, physical, and biological integrity of the Nation's waters."

Summary

The beginning chapters (2 and 3) develop an understanding of biological integrity threshold based on models and techniques readily available and actively used by stakeholders involved with preserving or enhancing water quality. Chapter 2 reports on a procedure that may be useful to establish water quality bioclassification thresholds for headwater catchments, which were also rated for legacy impacts from historic land use. The procedure links a hydrologic model (TR-55) to a modified benthic macroinvertebrate collection technique (chapter 2). Many natural resource, design and engineering professionals use the TR-55 guidance to determine curve numbers (CN), which can measure imperviousness in small catchments (<25 miles^2) by incorporating soil and land use characteristics into a single value. Biological assessments of streams were based on benthic macroinvertebrates sampled from three adjacent riffle habitats in each stream using a kick-net. Each macroinvertebrate was identified to the family taxonomic level and assigned a Hilsenhoff Family Biotic Index value (FBI). Water quality in each catchment was rated with a composite FBI value and formed five bioclassification categories that ranged from Excellent to Fairly Poor.

Catchment CN values (n=179) ranged from 55 to 89 and results from a quadratic regression was used to model the relationship between the bioclassification values (inverse metric) and CN, which is a measure of imperviousness and hydrologic soil group (r^2=0.78). Some variation was found across bioclassification categories when the Coefficient of Variation (CV) of each group was compared, indicating that the family level bioassessment was a consistent method across the CN gradient.

Variables consisting of macroinvertebrate metrics (taxa richness, FBI, EPT and Percent EPT) and legacy land use were modeled in Chapter 3 using multivariate statistical procedures. EPT is a water quality metric based on the number of the most sensitive macroinvertebrate families Ephemeroptera (E), Plechoptera (P) and Trichoptera (T). Principal Component Analysis (PCA) explained all but three percent of the variability within the first two components to evaluate CN (land use) gradients. In addition to findings that suggest some variability in the CV across FBI bioclassifications (Chapter 2), the CV was plotted across other macroinvertebrate metrics and illustrated an increase in the variability of EPT and Percent EPT as CN values increased, suggesting EPT deteriorated as a stable metric when imperviousness increased. FBI classifications were further investigated by visually comparing a clustering method with FBI ratings to visually inspect if the FBI ratings were consistent with clusters.

Much attention has focused on increasing awareness in hopes that behavior change will improve water quality. Chapter 4 results indicated an increase in awareness about techniques and practices associated with Low Impact Development (LID) after participating in a one-day LID workshop. Additional education efforts are highlighted in Chapter 5 that illustrates how demonstration projects and underlying research can supplement direct and indirect regional education efforts. Education involves increasing awareness about impacts to stream systems and amelioration efforts. Demonstration sites can illustrate different techniques and direct and indirect education may increase awareness that leads to improved water quality.

Extension professionals have educated stakeholders about water quality improvement, particularly at the site scale. The educational program is based on the investigations into the effects of impervious land cover on receiving headwater stream systems in the Southern Appalachian Mountains of North Carolina and methods to ameliorate impacts from impervious surface area.

CHAPTER TWO

EFFECTS OF IMPERVIOUSNESS ON FAMILY BIOTIC INDEX VALUES IN THE SOUTHERN APPALACHIAN HEADWATERS

This chapter was written for journal publication.

ABSTRACT

Many studies support strong relationships between increased impervious cover and declining biological integrity of surface waters. Biological integrity is often evaluated using multimetric indices that consider the pollution tolerance of macroinvertebrates This study suggests a method for predicting the biological integrity of first-order streams that drain small catchments based on curve numbers. A curve number represents hydrologic soils series information and the land use based on impervious cover. This method employs a runoff model, called TR-55, for small catchments and is used by professionals involved with land use decisions. Curve numbers were strongly correlated with a single habitat, rapid assessment biological index that relies on identification to the family level using Hilsenhoff's biologic index to pollution tolerance. Both indices use higher values to represent increased imperviousness and increasing organic pollution in stream. Breakpoints for biological integrity were found given different ratings based on curve numbers. Although not intended as strict breakpoints, sites in the study area with curve numbers less than 70 represented good or higher water quality ratings. Sites with curve numbers exceeding 70 did not meet the threshold for maintaining biological integrity. This rapid biological assessment method may guide land management decisions by suggesting a quantifiable method with bioclassification thresholds to preserve or restore biological integrity of surface water systems. Additionally, these gradients can inform prioritization goals for preservation and restoration opportunities.

INTRODUCTION

More than half of the nations' Total Maximum Daily Load (TMDL) listed stream impairments are due to nonpoint pollution (Furtak & Menchu, 2009). Stormwater from impervious areas is a leading contributor to stream impairment because of alterations to natural hydrologic regimes and nutrient flows (Barbour & Faulkner, 1999). Schueler's impervious cover model conceptually illustrates increased stream degradation as a result of increased impervious area in a catchment, and is often expressed as a percent of the cover in the catchment (Schueler et al., 2009). Several studies suggest strong correlations between increasing urbanization and the decline of macroinvertebrate health, a surrogate for biological integrity (Christina M. Cianfrani et al., 2006; Roy et al., 2003; Stepenuck et al., 2002; Waite et al., 2008). Although much literature exists for percent imperviousness as a predictor of stream health, it may not serve as a sole predictor (Booth et al., 2004; Roy, et al., 2003), particularly at the lower range of the impervious gradient (Karr & Chu, 2000).

The impervious gradient of land uses may be defined better using curve numbers to represent small catchments. CN are useful because they take into account impervious cover of land uses based on the hydrologic soil group (HSG) they occupy. HSG groupings are referred to as A, B, C or D and A is generally the most absorbent, while D is saturated and has a higher relative curve number for the same land use designation (or imperviousness). All HSG are represented by a single curve number when the entire catchment is entirely impervious. Catchments can contain different land uses and soil groups. CN for each of these combinations are assigned and weighted based on area to produce a composite CN (TR–55, 2009).

Many researchers have successfully demonstrated that gradients of imperviousness may be variable at the lesser end of imperviousness, but quickly collapse into degraded water quality at certain thresholds (Collins et al., 2008; Cuffney et al., 2005). These gradients may be suitable for predicting stream health as a result of urbanization and are well suited for coarse risk assessments using GIS tools based on models (Bryce et al., 1999). Other studies have focused on the influences of landscape patterns (Alberti et al.) and composition and width of riparian buffers on stream health (McBride & Booth, 2005). While the vast majority of the studies rely on rapid bioassement protocols that utilize macroinvertebrate identification to the genus and even species level (Barbour & Faulkner, 1999), some evidence supports using family level methods that take less time. Family level identification may be useful for contrasting many sites along land use gradients, but may compromise bioassement accuracy and incorrectly assess water quality ratings (Hilsenhoff, 1988; Lenat & Resh, 2001). Family identification is not intended as a substitution for species level identification, but degraded streams may have agreement between family and species level identification (Pond et al., 2009).

Abundant literature underpins the importance of headwater streams (Cushing & Allan, 2001; Hauer & Lamberti, 2006). Myer has categorized headwater stream system function. She calls attention to the rich biodiversity of headwater streams and cautions that anthropogenic changes in the headwaters may threaten “the biological integrity of entire river networks” (Meyer et al., 2007, p 99). In the Southern Appalachians, headwater streams represent more than half of the stream systems length, and without protective regulatory policies, may be difficult to protect (Nadeau & Rains, 2007) or restore. Without a quantifiable method that correlates anthropogenic impacts and biological integrity, anthropogenic impacts may continue to destabilize biological integrity.

This study advances a methodology originally suggested by Bruton (2004) that links anthropogenic impacts and biological integrity. A correlation between curve numbers (index of imperviousness and soil series) and family level bioassesment was explored for the Southern Appalachian Mountains in North Carolina. Bioclassification thresholds were generated from a quadratic regression and may be used by regulators and design professionals to further refine preservation and restoration prioritizations for headwater streams. These thresholds can inform design, planning and natural resource professionals’ decisions to minimize impacts to biological integrity in headwater stream systems and support trajectory targets for using Low Impact Development methods (Perrin et al., 2009).

METHODS

Catchment Selection

Small catchments (n=179) were selected based on a gradient of land uses and hydrologic soil series in the mountainous region of Western North Carolina. All catchments contained perennial, headwater streams with intact riffle habitat and enough base flow to support the sampling protocol. Catchment selection was based on differing land uses and hydrologic soil groupings. Catchment selection was further influenced by accessibility and ownership. Land uses ranged from second growth hardwood forests to urban areas with high impervious cover. Catchments were categorized by curve numbers based on the Curve Number Methodology (TR–55, 2009). The CN is determined by overlaying land use on the hydrologic soil series. Land uses with greater impervious cover and less absorptive soils have higher CN.

The catchment size ranged from 5.7 to 2416.2 acres, with a mean of 229 acres. Seven HUC (11 digit) watersheds were represented and elevations of the headwater catchments approximately ranged from 1,310 to 5,020 with mostly steeper stream slopes ranging from two to 40% (mean=20.64%). Catchments were also categorized into stable or unstable depending on subjective assessments of prior land disturbance, or legacy impact (Maloney et al., 2008). Stable catchments included sites without recent anthropogenic disturbances, yet trails, roads, and limited development may have occurred. National and state forests and parks without recent development are examples of stable sites. Unstable sites could also have low imperviousness, but more likely experienced recent or sustained disturbance. Catchment stability was further explored by evaluating bioclassification values in stable and unstable catchments.

Curve Number Determination

Many environmental gradients exist throughout the study region in the mountains of North Carolina due to climate, geologic, soils and anthropogenic impacts. Although interactions from these gradients were not part of this study, the curve numbers produced a single value that distills some of the variability of environmental gradients to a single integer. Each catchment was characterized by a curve number using the TR-55 Curve

Number Methodology (TR–55, 2009). This method uses the hydrologic soil unit and the percent imperviousness of the land cover to predict discharge. Each hydrologic soil series has a distinct relationship with imperviousness to determine a curve number. Although often used by stormwater modelers and incorporated into stormwater routing programs (Smart, 2010), the discharge prediction capabilities are notably coarse (Fennessey et al., 2001).

Catchments for the sites were calculated by producing a polygon of the watershed in ESRI ArcView (Environmental Systems Research Instititute) using heads up digitizing based on USGS 7.5 minute quadrangle maps that were digitally available. Each catchment polygon was subdivided based on the hydrologic soil series available from the Soil Survey Geographic Database (SSURGO), where soil series were classified into HSG (A, B, C or D), and a curve number was assigned based on the land use in the TR-55 methodology. Sites with differing soil series and land cover were combined to create a single, weighted composite curve number that represented a single integer for the entire catchment. Site stability was assessed by using land use and cover. Forested sites with no anthropogenic impacts such as trails or unimproved gravel roads were classified as stable sites. Although these sites may have contained features not visible, they were assumed to contain less than five percent impervious cover. No impervious cover estimates were made for rock outcrops or cliff faces in the study area.

Curve numbers are often used by natural resource managers, hydrologists, and design professionals to determine runoff for an area of interest. Recently, low-impact development has gained popularity as a method to improve water quality by mimicking natural hydrologic flows (Perrin, et al., 2009). The hydrologic and stormwater routing models rely on curve numbers to predict discharge from a specified storm event based on land use and HSG. Curve numbers can also be applied to the proposed landscape intervention and designers can use LID techniques to mimic the predevelopment hydrology (Prince George's County (Md.) Dept. of Environmental Resources, 2000).

Macroinvertebrate Sampling

Macroinvertebrates are a useful indicator of water quality and stream health. These organisms are abundant in most streams and respond quickly to environmental stresses. For example, species like stoneflies are less likely to persist in polluted environments, while midges are more tolerant to pollution. A variety of bioassessment techniques capture information about stream health based on pollution tolerances of certain families, genera or species of macroinvertebrates. However, inadequate sampling methodologies prevented bioclassification of North Carolina headwater streams until a modified Qual-4 method was employed (Fleek, 2009). This method collects macroinvertebrates from multiple habitats.

In order to classify stream health, a modification of the Hilsenhoff Family Biotic Index (Hilsenhoff, 1987) as described by Bruton (2004) was employed. This modification relied on riffles as the single habitat for sampling and comparison (Barbour & Faulkner, 1999). Collections from single habitat (riffles) may be interchangeable with multiple habitat sampling (Rehn et al., 2007). Sites were sampled during the months of March thru early June of 2004, 2005, 2006 and 2007 and sites higher in elevation were generally sampled later in the spring. Sampling teams were staffed by AmeriCorps members, agency staff, and faculty from land grant institutions in the southeastern United States. Team members were trained to collect using the modified method, which consisted of placing a 1,000 micron net downstream of each riffle. Substrate at headwater stream riffles were then vigorously scratched with a 14 prong garden rake until one square meter per riffle was disturbed for one-minute. Only the stream riffle was disturbed and the stream bank and edges were avoided to the greatest extent possible. Two adjacent upstream riffles were sampled in the same manner until three square meters were disturbed for each sampling location. Several sampling locations consisted of a single long riffle and up to three contiguous square meters were sampled. Although sites were preselected, any sampling sites with backwater conditions or low baseflow discharge were not sampled and other catchments with like characteristics were substituted.

The contents of the net were rinsed with distilled water or water upstream of the riffle into a screened bucket. Macroinvertebrate samples with large amounts of captured detritus were cleaned in the field with careful attention to retain attached organisms. This procedure was repeated on riffles upstream of the previously sampled riffle until three collections were obtained in the sampling location of interest. Up to three riffles were combined into one sample that was treated with 95% ethanol immediately in the field, sealed in plastic bags and labeled with the site name, date and names of those collecting samples. Location information was recorded using a subscription based, backpack GPS receiver (Trimble AG-132 GPS Receiver) and ArcPad (Environmental Systems Research Instititute). Other non-insects, such as crawfish and salamanders, were noted and discarded. Occasionally, samples were field picked and identified, but all macroinvertebrate organisms were identified to the family level at Clemson University's Stream Laboratory. Reference collections were maintained for the last three years of the study period.

The Family Biotic Index (FBI) was calculated for each sample using published family tolerance values, primarily from Hilsenhoff (Cummins et al., 2005; Hilsenhoff, 1988). Missing family tolerance values were determined from other published sources (Cummins, et al., 2005). Abundance values (e.g. one, three, or 10) were applied for rare, common or abundant families where one or two specimens were rare; three to nine specimens were common; and ten and more were rated as abundant specimens. The FBI is equal to the sum of the multiplication of tolerance values and abundance values for each family, then divided by the sum of all abundance values as expressed below:

Equation 1: FBI Value. (Bruton, 2004).

$$FBI = (1/N) \text{ Sum } (TV_i)\ (n_i)$$

Where TV_i = $_i$th taxa's tolerance value (0 to 10)
N_i = $_i$th taxa's abundance value
(1 if 1 or 2 organisms; 3 if 3 to 9 organisms; 10 if more than 10 organisms)
N = sum of all abundance values

Variation in the FBI ratings was determined by using the coefficient of variation (CV) in the five categories. The coefficient of variation is useful for describing variation across classes (Ott & Longnecker, 2001).

Data Analyses

Two variables were used to develop a relationship between land use and the biotic integrity of streams as represented by benthic macroinvertebrates. The independent variable was the curve number of each sampling location and the dependent variable was the FBI value. Neither variable was normally distributed. Variables were plotted and fit with a spline to approximate best fit (Ott & Longnecker, 2001). FBI was log transformed to satisfy assumptions of normally distributed residuals (McGarigal et al., 2000) by xx rejecting the null hypothesis of the Shapiro-Wilk test that data is from the normal distribution. The coefficient of variation was also examined on metrics (total richness, EPT's and percentage EPT's) used to describe macroinvertebrates (Barbour & Faulkner, 1999; Hauer & Lamberti, 2006). These metrics were then plotted by the bioclassification ratings from the FBI values, such as "excellent" or "fair." Lastly, curve numbers were analyzed with one-way analysis of variance (ANOVA) to assess differences in means of stable and unstable catchments that were subjectively assigned based on disturbance.

RESULTS

The calculated curve numbers in the study ranged from 55 in undisturbed, forested areas with higher infiltration soils to a maximum curve number of 89 in urban sites with high impervious areas. Overall, the mean curve number was 60 and the majority of sites (n=122) were represented by curve numbers ranging from 55 to 59. The remaining sites (n=57) had CN that ranged from 60 to 89.

The bioclassification values overall ranged from 2.1 indicating "excellent" water quality to 7.5 indicating a "fairly poor" rating. Scores above 7.5 that indicate "poor" water quality were not found in this study. Collectively, the sites (n=179) were rated "very good" with a mean of 3.76 and standard deviation (SD) of 1.21. An enumeration of CN wtih accompanying FBI mean values for each rating is shown in Table 1.

Table 1: Family Biotic Index (FBI) Rating mean values by CN

Curve Number (CN)	n	Excellent	Very good	Good	Fair	Fairly poor
55	25	3	.	.	.	.
56	28	2.98	3.62	.	.	.
57	24	2.94	3.69	.	.	.
58	15	2.9	4.11	.	.	.
59	30	3.03	3.93	.	.	.
60	8	3.28	4.05	4.81	.	.
61	4	.	4.09	.	.	.
62	5	.	3.98	5.06	.	.
63	6	.	3.81	4.92	.	.
64	1	.	.	.	5.54	.
65	3	.	4.5	4.74	.	.
66	2	.	.	5.14	.	.
67	3	.	.	4.65	5.78	.
68	3	.	.	.	5.86	6.67
69	3	.	.	5.36	5.86	.
70	2	.	.	.	6.31	.
71	3	.	.	5.2	6.06	6.68
72	1	.	.	.	.	6.55
73	1	.	.	.	6	.
74	2	.	.	.	5.89	.
75	4	.	.	.	5.96	6.65
76	1	.	.	.	6.23	.
77	1	.	.	.	.	7.05
79	1	.	.	.	6.17	.
84	1	.	.	.	.	7.5
87	1	.	.	.	.	6.95
89	1	.	.	.	.	6.67

More than half the sites were classified as stable sites (n=89) using land use criteria. The mean curve number, reported as an integer, in stable sites was approximately 57 (56.83) with a SD of 1.56. The mean of FBI bioclassification value was 2.98 with a SD of 0.28. This bioclassification rating was “excellent.” Among the 89 stable sites, all but five sites were rated with an “excellent” FBI score.

The remaining, less stable sites (n=90) had a mean curve number higher than stable sites of approximately 64 (63.84) with a SD of 7.48. Mean FBI bioclassification values was 4.53 with a SD of 1.30. This bioclassification rating is considered “good.” However, 27 of the less stable catchments were ranked “excellent,” using the FBI score.

A polynomial model fit the family biotic index using curve number values as the predictor. Because FBI values increased initially, then leveled, a polynomial model was chosen to best represent the data (Garson, 2010; Ott & Longnecker, 2001). The model indicated that CN explains variance in the FBI values. As CN increased, FBI became more degraded (r^2=.78, p<.0001).

The predicted quadratic equation for the fit was:

Equation 2: Polynomial Model of lnFBI by CN

$$LnFBI = -5.45067 + (0.17317*CN) + (-0.00101*(CN^2))$$

Where:
FBI=Family Biotic Index
CN=Curve Number

Thresholds of the FBI rating as they relate to curve numbers were determined and enumerated in Table 2. Differences in the coefficient of variation, as percentages, are enumerated in Table 3. A one-way ANOVA indicated that the stable and less stable sites were different ($p<.0001$).

Figure 1: Scatterplot with polynomial model fit of lnFBI Values by Curve Number with Prediction Bands

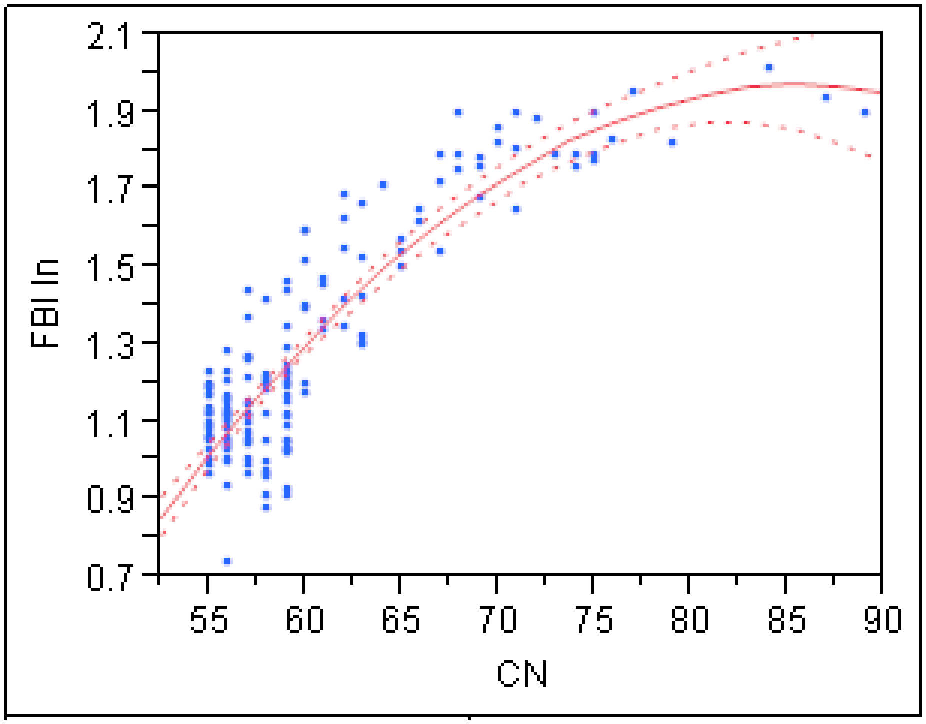

Table 2: FBI Rating with Corresponding Curve Number Ranges with CN of 69 or less indicating Good, Very Good and Excellent FBI Rating

FBI Rating	CN Min	CN Max
Excellent	55	59
Very good	60	64
Good	65	69
Fair	70	75
Fairly poor	76	89

Table 3: Coefficient of Variation (CV) of FBI rating indicating slightly decreasing variability as the stream quality degrades.

	Excellent	Very good	Good	Fair	Fairly poor
Std Dev	0.268948	0.297648	0.290532	0.224771	0.316496
Mean	2.988518	3.90273	4.961598	5.959505	6.839188
CV	9.0%	7.6%	5.9%	3.8%	4.6%

DISCUSSION AND CONCLUSIONS

This study follows the literature supporting Schuler's meta analysis and the reformulated impervious cover model that illustrates impacts to stream health from increased imperviousness across a variety of physiographic regions (Schueler, et al., 2009). In the North Carolina mountain physiographic region, biocriteria were established to assess headwater streams in North Carolina and illustrated that as imperviousness increased, stream health deteriorated (Fleek, 2009). Although Schueler cautions against solely predicting stream health with imperviousness or land use, this study explained variability of FBI using curve numbers.

The resulting prediction capability and thresholds of biological impairment by CN can quantitatively guide design and planning decisions. Often, stakeholders with limited time and resources may prefer finer resolution studies, but these can be resource intensive and may not be commissioned. This coarser method may be useful for supporting preservation and restoration prioritization efforts. For example, LID often relies on preserving higher infiltration areas of the site and achieving predevelopment hydrological conditions through design and planning. With specific CN ranges, professionals would be able to predict water quality based on design outcomes. Although the CN thresholds might differ in other physiographic regions, this method could provide a litmus test for site designers to preserve biological integrity. Limitations of this study include not extrapolating outside the study area; lack of randomly selected sampling sites and the lack of higher CN sites (higher imperviousness).

Data collection for this study was based on convenience sampling to represent a wide land use gradient and HSG. Few, highly impervious catchments (higher CN) were available to sample, but were largely nonexistent due to anthropogenic modifications. Despite efforts to locate perennial streams in these catchments, extant streams were culverted or daylighted at a confluence with backwater. Additionally, a severe drought early in the study limited viable higher CN sites because baseflow was insufficient for sampling. Despite the ability of the model to predict FBI at the higher CN ranges, the threshold for maintaining biological integrity was below 70, where the model prediction capabilities were robust.

In this study, the FBI was useful for comparing many catchments with varying land uses. This is consistent with using family level data to examine coarse differences across a wide land use gradient (Lenat & Resh, 2001) since no accepted, rapid bioassesment protocols existed in North Carolina prior to the design phase of this study. Most traditional sampling methodologies were not suitable for headwater stream bioclassification until North Carolina Division of Water Quality (DWQ) adopted a modified Qual-4 method to bioclassify headwater streams to meet regulatory and policy goals (*Standard operating procedures for benthic macroinvertebrates*). This method collects macroinvertebrates from a variety of habitats and uses the NCBI for bioclassification (Lenat, 1993). The technical memorandum included findings on impacts of different land uses on headwater streams in the mountains (Fleek, 2009). This study employed a single habitat collection method (from riffles) for catchment comparison.

Both variables in this study are composed of indices of the stream health and land use. Although they are course assessments, they may be useful as a screening tool for more rigorous investigations (Hilsenhoff, 1988). Although this study relied on rapid assessment techniques, family level identification is often not used for bioclassification studies. Most studies rely instead on identification to the genus or species level and utilize specific tolerance values for those organisms to rate bioclassification. This process can provide enhanced resolution, but requires additional resources. Lenant found that FBI rating may be best for up to three classes to rate water quality (Lenat & Resh, 2001). Additional research contrasting different levels of identification, specifically at lower impervious areas, would inform the literature.

This study provided course thresholds to inform land use decisions made by design, planning and natural resource professionals prioritizing restoration or enhancement opportunities in small catchments. The curve number methodology uses hydrologic soil classifications that is based on soil series information, which includes slope and infiltration information. Curve numbers may provide greater resolution than impervious cover because infiltration of soils by land use is incorporated in the curve number. For example, a curve number describing the same land use might vary depending on soil series and therefore give rise to more precision than impervious cover estimates. Although imperfect, the TR-55 methodology is widely used by regulatory, design and planning professionals to determine discharge from runoff on small catchments (Fennessey, et al., 2001). Recently, practitioners using low-impact development techniques have relied on this method to mimic pre-development hydrologic regimes

(Perrin, et al., 2009; Prince George's County (Md.) Dept. of Environmental Resources, 2000).

Neither impervious cover nor curve numbers solely predict stream health. Methods that account for variability from riparian buffer composition or intactness should be considered (Christina M. Cianfrani et al., 2006; Lovell & Sullivan, 2006; Wenger, 1999) to enhance prediction capabilities. Future refinements to this study may include the exploration of variation within stable sites. Both the reformulated impervious cover model (Schueler, et al., 2009) and research by Karr (Karr & Chu, 2000), suggested increased variation at the lower range of imperviousness. Our study also exhibited slightly decreasing coefficients of variation as degradation increased. Further evaluation of this variance should be explored to inform preservation and restoration efforts.

The correlation between higher curve numbers and degraded water quality can inform land use decisions, particularly as it relates to Low Impact Development, which strives to mimic predevelopment hydrology. Using coarse thresholds, as illustrated in this study, can guide the enhancement or preservation of stream quality with quantitative methods. The very rapid assessment method could be recalculated for other regions to inform prediction tools for prioritization of protection, enhancement or restoration of catchments.

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APPENDICES

APPENDIX A

Curve Number (CN)	Family Biotic Index (FBI) Rating
55	2.85
55	2.62
55	2.78
55	3.29
55	3.05
55	3.07
55	2.73
55	3.09
55	3.31
55	3.21
55	2.85
55	3.28
55	2.87
55	2.98
55	3.24
55	2.93
55	2.94
55	2.91
55	2.68
55	3.00
55	2.89
55	2.91
55	3.43
55	2.98
55	3.11
56	2.09
56	3.04
56	2.88
56	2.55
56	2.78
56	3.18
56	3.16
56	2.95
56	2.71
56	3.04
56	3.01
56	3.42

Curve Number (CN)	Family Biotic Index (FBI) Rating
56	3.33
56	3.12
56	2.86
56	2.73
56	2.81
56	3.05
56	3.10
56	3.42
56	3.62
56	3.06
56	2.82
56	3.01
56	3.07
56	3.21
56	3.00
56	3.10
57	3.56
57	3.53
57	3.36
57	3.02
57	3.03
57	2.63
57	3.13
57	3.15
57	2.69
57	2.84
57	2.88
57	2.73
57	2.98
57	3.93
57	3.56
57	3.52
57	2.63
57	3.07
57	3.07
57	2.93
57	2.87

Curve Number (CN)	Family Biotic Index (FBI) Rating
57	3.55
57	4.21
57	2.99
58	2.85
58	3.07
58	3.39
58	3.35
58	3.31
58	4.11
58	3.33
58	2.70
58	2.41
58	3.26
58	2.63
58	2.60
58	2.59
58	2.48
58	2.65
59	3.21
59	4.21
59	3.62
59	3.34
59	2.80
59	2.79
59	3.63
59	3.47
59	3.30
59	3.43
59	3.35
59	3.85
59	3.15
59	3.28
59	2.86
59	2.85
59	2.48
59	2.78
59	2.98
59	2.81
59	3.38

Curve Number (CN)	Family Biotic Index (FBI) Rating
59	3.28
59	3.16
59	3.04
59	3.07
59	2.76
59	2.49
59	2.52
59	3.15
59	4.33
60	4.57
60	4.02
60	3.24
60	4.92
60	3.29
60	3.31
60	4.07
60	4.94
61	4.36
61	3.81
61	4.29
61	3.89
62	5.40
62	5.10
62	4.69
62	3.83
62	4.12
63	3.69
63	3.76
63	3.65
63	4.15
63	5.27
63	4.58
64	5.54
65	4.50
65	4.66
65	4.82
66	5.05
66	5.22
67	6.00

Curve Number (CN)	Family Biotic Index (FBI) Rating
67	5.56
67	4.65
68	5.96
68	6.67
68	5.76
69	5.36
69	5.78
69	5.93
70	6.18
70	6.44
71	5.20
71	6.68
71	6.06
72	6.55
73	6.00
74	6.00
74	5.79
75	6.00
75	6.00
75	5.87
75	6.65
76	6.23
77	7.05
79	6.17
84	7.50
87	6.95
89	6.67

CHAPTER THREE

EXPLORATORY ANALYSIS OF LAND USE GRADIENTS ON MACROINVERTEBRATES METRICS

This chapter was written for journal publication.

ABSTRACT

Assessments of the biological integrity of the nation's surface waters underpin preservation and restoration activities that have yet to achieved the intent of the decades old Clean Water Act. Benthic macroinvertebrates can be rated on an index based on family level identification in order to determine water quality conditions across a gradient of land uses. As impervious cover (IC) increases, assemblages of pollution tolerant macroinvertebrates become more prevalent. IC can also be estimated based on a weighted index of land use and hydrologic soil group to approximate runoff from small watersheds. This estimation results in a curve number (CN) that has previously explained variability in the family benthic index (FBI) as IC increases. In this study, several multivariate methods explore variability of land use gradients on macroinvertebrates. Principal component analysis, clustering and correspondence models explained variation in macroinvertebrate metrics across a gradient of curve numbers (land uses). Principal Component Analysis (PCA) explains variability across multiple macroinvertebrate family level identification metrics as CN increased.

Macroinvertebrates were collected from catchments in the mountains of North Carolina that represent a gradient of land uses characterized by TR 55 curve numbers. Increasing CN values are generally associated with greater imperviousness. FBI is an inverse metric that uses greater values to indicate poorer water quality based on macroinvertebrates tolerance to pollution. Subsets of the land use CN gradients were also examined with PCA. Although PCA explains much of the variability of metrics along the different CNs, increased variability occurred in EPT and percent EPT as catchment CN increased according to the coefficient of variation. EPT is a count of macroinvertebrate families Ephemeroptera (E), Plechoptera (P) and Trichoptera (T) that are most sensitive to pollution. Low counts indicate poor water quality. However, the variability explained

by PCA, which follows other research, suggested increasing variation in lower CN sites and decreasing variability at degraded sites. Lastly, FBI classifications were visually compared with a k-means cluster method based on multiple macroinvertebrate metrics. Cluster groups were compared with FBI rating classifications using correspondence analysis to visually inspect for agreement. Correspondence analysis compared subjective measurements of legacy land use with FBI rating classifications. These multivariate explorations explain variance in multiple metrics across land use gradients and supported the use of CN classifications for land management decisions. These complex relationships may be useful for preservation and restoration strategies to improve or protect biological integrity of headwater streams.

INTRODUCTION

Benthic macroinvertebrates are often used to rate the quality of these surface water networks for research and regulatory purposes. Several metrics provide reliable information about the health of a stream based on macroinvertebrate community composition. Common metrics include taxa richness, EPT's richness and percent EPT's (Barbour & Faulkner, 1999; Hauer & Lamberti, 2006). EPT is a water quality metric that uses the count of the most sensitive macroinvertebrate families Ephemeroptera (E), Plechoptera (P) and Trichoptera (T). In addition to these metrics, a Hilsenhoff family benthic index (FBI) is useful for comparing sampling sites across a gradient (Lenat & Resh, 2001). When greater resolution or follow-up investigations are required, species level identification can inform metrics and bioclassifications (Hilsenhoff, 1988).

Little disagreement appears to remain about degradation of receiving aquatic systems due to increased impervious cover (Schueler et al., 2009). Meaningful correlations between land use and bioclassification are reported in the literature (Fleek, 2009; Schueler, et al., 2009). Fleek reported correlations between poor assemblages of macroinvertebrates and increased imperviousness across North Carolina headwater streams. He found greater variation within bioassessment metrics in the less impervious land cover (2009). Forested and other less impervious land cover has shown greater variability than land uses with increasing imperviousness (Calabria, 2010; Fleek, 2009; Schueler, et al., 2009). Fleek compared metrics using coefficient of variation of metrics and found increasing variation as imperviousness decreased (2009). He also reported only slight changes in the coefficient of variation for bioassement values (2009), indicating that the bioassement had little variation across a land use gradient. In other words, the rating criteria varied little across the entire land use gradient. At a national scale, Schueler and others compiled similar data in a meta analysis and also found support for increased degradation as imperviousness increases (Schueler, et al., 2009). They also posit greater variation in less impervious systems and less variation with increased imperviousness (Schueler, et al., 2009).

Land use gradients can be represented by a CN, which takes into account imperviousness and soil type. The TR-55 methodology assigns higher curve number values as imperviousness increases CNs range from 38 to 98 (TR–55, 2009), depending on land use and soil classification. Soil series are typically classified into four hydrologic soil groups (HSG) based on surface and subsurface infiltration capacity. Four HSG (A, B, C and D) range from faster draining (A) to a slower draining (D) group. Dual HSG assignments are possible if the water table is within two feet of the surface and can be drained to greater than two feet depth (Hoeft et al., 2007). Each land use and HSG are assigned a curve number and then weighted by area to determine a composite CN for the catchment. This method is intended for watersheds less than 25 square miles. Although the TR-55 may lack resolution (Fennessey et al., 2001), it is often used to model stormwater runoff from landscape interventions associated with Low Impact Development (Perrin et al., 2009).

Curve numbers are independent of macroinvertebrate metrics and FBI, but can be used to predict stream health. In a previous study, a polynomial regression explained more than 77% of variance between CN and FBI (Calabria, 2010). While this regression informed site scale interventions, particularly as it relates to Low Impact Development (LID), it did not utilize other macroinvertebrate metrics such as EPT, percent EPT, and taxa richness. Multivariate statistics can explore complex relationships between macroinvertebrate assemblages and land use, stream morphology and other environmental gradients (Booth et al., 2004; Lear et al., 2009; McBride & Booth, 2005).

METHODS

This study explored FBI and other metrics across a CN (land use) gradient in the Southern Appalachians of North Carolina to determine if variability could be explained using multivariate statistics. A previous analysis of these data used a regression model (r^2=.78, $p<.0001$) to explain variability of ln FBI by CN (Calabria, 2010). This study explained similar variability using the first component in the PCA, which was the "water quality" vector comprised of several metrics (taxa richness, percent EPT, EPT and FBI) instead of the lnFBI in the previous analysis.

In addition to coefficient of variation across CN groups, multivariate statistical methods, such as PCA, clustering and correspondence analysis, support explorations about macroinvertebrate responses to a land use gradient as quantified by curve numbers. Clustering with the k-means clustering method lends support to the FBI ratings. Resulting clusters were visually compared with FBI classification using correspondence analysis. FBI classifications were examined for consistency across land use gradients with coefficient of variation that also compared macroinvertebrate metrics. Legacy land use was also explored using correspondence analysis to visually assess subjective decision criteria because historic land use may influence the current macroinvertebrate assemblages (Maloney et al., 2008).

This study utilized macroinvertebrate data from headwater catchments in the Southern Appalachians of North Carolina that spanned a variety of land uses (Calabria, 2010; Calabria et al., 2009). Macroinvertebrates were collected and classified using the Hilsenhoff FBI. A polynomial model explained variability in the “water quality” vector with land use data represented by CN, which are a single integer that describes imperviousness and soil conditions of small catchments (TR–55, 2009).

Coefficients of Variation

Coefficients of variation were determined for Family Biotic Index (FBI), taxa richness, EPT richness and EPT percentage across categories of CN that were classified by the FBI rating. Three categories of CN were derived for this study. The categories are based on Lenat’s suggestion that three categories are sufficient for comparing sites when using family level classifications (Lenat, 1993). Coefficient of Variation is standard deviation divided by the mean Smaller, similar resulting values indicate consistency across the categories that were compared (Ott & Longnecker, 2001).

Principal Component Analysis

Metrics were analyzed with multivariate methods. Principal Component Analysis is a useful data reduction method that distills multiple variables into components (vectors) that describe collective variation (Manly, 2005). Components have negative and positive eigenvectors from the underlying variables and can be named for the variables with the highest eignevectors (McGarigal et al., 2000). If much of the variance is explained with the first two components, they can be plotted to aid in visualizing the data. Influence from the underlying variables can also be displayed in a ray plot. In this study, PCA was run on the entire gradient of curve numbers.

Because of cautions raised when using PCA across an entire gradient (Manly, 2005), PCA was run on three CN categories (superior, good, poor). CN and the metrics (taxa richness, EPT's richness, percent EPT and FBI) failed to satisfy assumptions of normality.

Cluster Analysis

Cluster analysis consists of grouping the most similar data points together for additional data explorations. Although cluster analysis has many methods to group data, k-means was used to compare clusters with FBI classifications of CN. No outlier screening was performed because valuable data may have been lost if not used in the analysis (McGarigal, et al., 2000). This method allows the user to assign the number of clusters. Five clusters were fit into this model, which is the same as the number of FBI value categories (excellent, very good, good, fair, fairly poor) to assess fit with correspondence analysis.

Correspondence Analysis

Contingency tables and correspondence analysis compare ordinal or categorical data using the Chi Square goodness-of-fit test to determine if variables are related by examining responses across categories (de Vaus, 2002; Ott & Longnecker, 2001). The correspondence analysis display the categories of the variables. Similarity may be inferred if plotted data points are in similar quadrants based only on distances along horizontal and vertical axes ("Electronic statistics textbook," 2010). The plot was visually compared with all FBI value categories (excellent, very good, good, fair, and fairly poor) and with cluster groups from the k-means method. These five CN classes were also compared to legacy land use. The FBI scores were determined using a modified Hilsenhoff method (Bruton, 2004; Hilsenhoff, 1988). Hilsenhoff’s original family biotic index method categorizes stream health using categories across a range from “excellent” to “very poor” and the method was developed to rate streams for organic pollution (Hilsenhoff, 1988).

Hilsenhoff's categories were used in the cluster analysis and aggregated into three categories to compare the CV based on Lenat's suggestion of limiting comparisons to three groups when using family level identification (Lenat & Resh, 2001). CNs less than 65 were grouped together and represented "excellent" and "very good" FBI scores to form the category "superior" (n=138) . CNs between 65 and 69 represented "good" (n=15) and CN above 69 were rated "fair or poor" and categorized as "poor" (n=26). Three CN classes were based on the regression between FBI scores and CN (Calabria, 2010) from the TR-55 model that characterizes runoff based on imperviousness and soil classifications (TR–55, 2009). Culverting, filling and lack of baseflow precluded collecting macroinvertebrates from catchments with very higher CNs. The subjective stability classification was based on legacy land uses, which were ranked "stable" or "less stable" based on field visits and aerial photography interpretation (Calabria, 2010; Calabria, et al., 2009; TR–55). Despite relatively low CNs, sites with single family, low density residential use and development of trails and roads for recreation were rated "less stable."

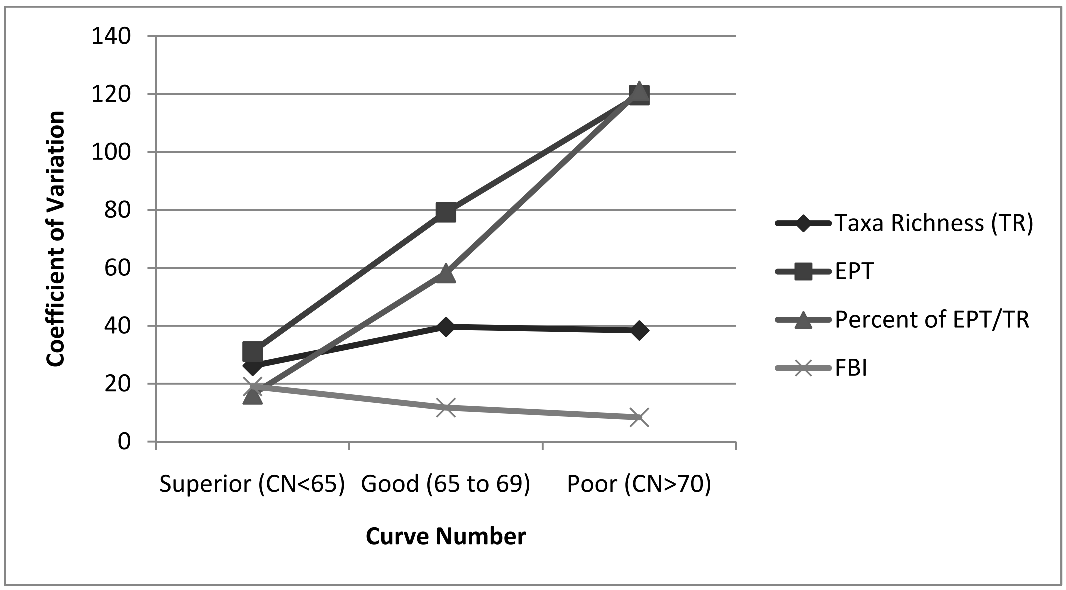
RESULTS

This study explored variability in several different ways using CV, PCA and cluster analysis verified with correspondences analysis. Contrary to most studies, the CV of the three CN groups (superior, good, and poor). indicated variability at higher CN (higher IC), yet the PCA supported increased variability at the lower CN (low or no IC) when exploring the CN gradient. The CN explained variability in the first principal component and was similar to a regression model that explained used CN to explain similar variability in lnFBI almost (Calabria, 2010). The cluster analysis grouped sites into distinct clusters that were mostly indicative of the water quality ratings for all five categories (excellent, very good, good, fair, and fairly poor) based on a correspondence analysis of the categorical data.

Coefficients of Variation

Coefficient of variation for the FBI, followed by taxa richness, were the most static metrics examined across three curve number categories (Figure 1) and were consistent with similar coefficient of variation scores across five FBI classifications (Calabria, 2010). EPT and percent EPT showed increasing variation as a CNs increased (Figure 1).

Figure 1: Coefficient of Variation by Curve Number Group



PCA explained variance of multiple metrics across the entire CN gradients (Table 2), and the subsets (superior, good and poor) of these data (Table 3) based on stream health. The curve number and FBI classifications with cluster membership are shown in Appendix A.

Principal Component Analysis on Entire Gradient

The first component form the PCA explained more than 88% of the variation from benthic macroinvertebrate metrics and FBI across the entire CN gradient (Table 1). The second component explained more than 8% of the variation. Only highly correlated variables (taxa richness, EPT richness, percent EPT's and the family biotic index) from the entire CN gradient were included. The first principal component and was positively correlated to taxa richness, EPT richness and percent EPT's and it was negatively correlated with FBI, which is an inverse metric. The second principal component was positively correlated with taxa richness and was negatively correlated with percent EPT's.

Table 1: PCA Percentages across Entire Gradient

	Variance explained on Entire FBI Gradient
PC 1	88.44
PC 2	8.43
PC1+PC2	96.87

Principal Component Analysis on Gradient Subsets

In addition to the entire land use gradient, PCA modeled each subset of the CN classification (superior, good, and poor), as shown in Table 2. In each of the three classifications, both principal components explained at least 87% of the variance as shown in (Table 2).

Table 2: PCA Cumulative Percentages by Curve Number Category

	Variance explained on “Superior” FBI	Variance explained on “Good” FBI	Variance explained on “Poor” FBI
PC 1	70.73	76.51	66.82
PC 2	19.93	16.89	20.35
PC1+PC2	90.66	93.40	87.17

As shown in Table 3, the first principal component has eigenvectors represented evenly by all metrics and the inverse of FBI, except for the “poor” category. The second principal component behaves differently; it has eigenvectors from taxa richness and the inverse of percent EPT for the entire gradient and the “superior” classification. In the “good” category, all metrics eigenvectors load slightly less evenly with the first principal component, but the second principal component was primarily loaded by FBI instead of percent EPT's, whereas taxa richness loaded the second component. In the “poor” category, EPT's and percent EPT's had stronger eigenvectors than taxa richness and the inverse of FBI in the first principal component. The second principal component of the “poor” category had the highest eigenvector from the taxa richness variable.

Table 3: Eigenvectors of principal component one and two on Entire Gradient and Subsets. Parenthesis denoted negative values.

Entire Gradient		**Comp. 1**	**Comp. 2**
	Eigenvectors		
	Taxa Richness	0.49	0.65
	EPT's	0.52	0.30
	Percent EPT's	0.49	(0.61)
	FBI	(0.50)	0.35
Superior			
	Eigenvectors		
	Taxa Richness	0.49	0.63
	EPT's	0.57	0.24
	Percent EPT's	0.44	(0.67)
	FBI	(0.49)	0.31
Good			
	Eigenvectors		
	Taxa Richness	0.47	0.63
	EPT's	0.55	0.18
	Percent EPT's	0.54	(0.14)
	FBI	(0.43)	0.74
Poor			
	Eigenvectors		
	Taxa Richness	0.34	0.91
	EPT's	0.58	(0.02)
	Percent EPT's	0.57	(0.24)
	FBI	(0.47)	0.34

The loading plot illustrates how the variables load on the principal components in Figure 2. Vectors of each variable are plotted on the first and second component. If vectors clump together or are exactly opposite this suggests that one variable offers little more information than the adjacent variable. The vectors of the loading plot indicate positive or negative loading from underlying variables (JMP, 2009).

A plot of the first and second principal components was useful for aggregating catchments based on the variables and was coded by the family biotic index classifications in Figure 3. Although some of the variables were highly correlated, they may suggest different information. The plot illustrates that the first component on the horizontal axis showed a gradient of water quality since it is had similar correlations with underlying variables. The second component illustrates a decreasing intensity as water quality degraded. Because the first component illustrates water quality, it was plotted against CN (Figure 4). It accounts for the nearly the same variability (r^2=.77, p<.0001) as the polynomial regression model of FBI by CN (r^2=.78, p<.0001) where both polynomial regressions were significant (Calabria, 2010).

Figure 2: Loading Plot of Principal Components illustrating negative loading from the FBI (inverse metric) and positive loading from other variables that are common macroinvertebrate metrics.

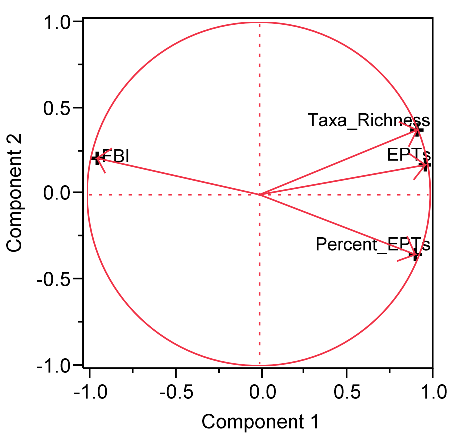


Figure 3: Plot of Principal Component 2 by Component 1, coded by FBI rating classification. The first components consisted of macroinvertbrate metrics and is a general “water quality” index,

whereas the second component consisted of taxa richness and Percent EPT's and represented "diversity" and shows less variability in "fairly poor" FBI classification.

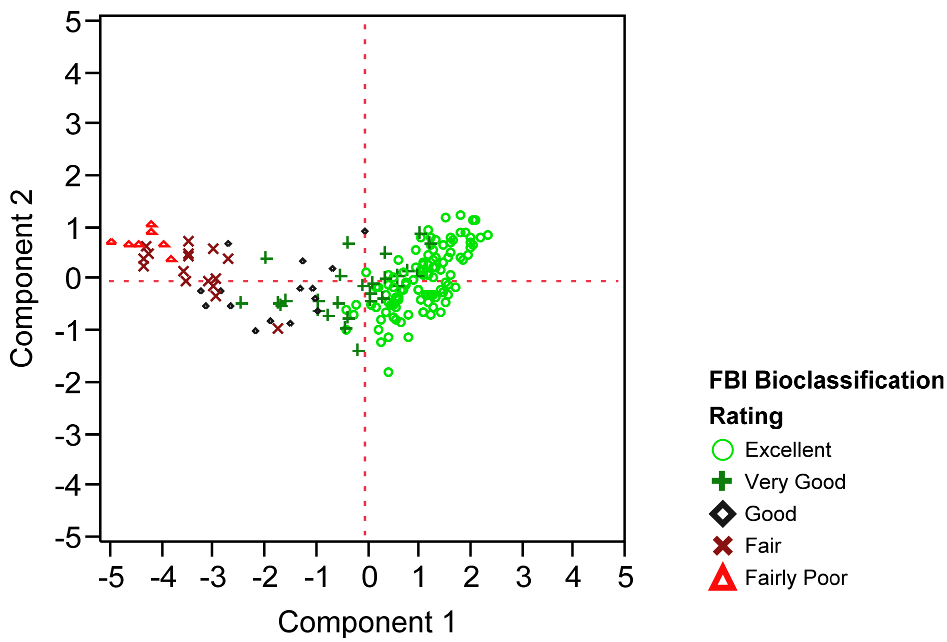
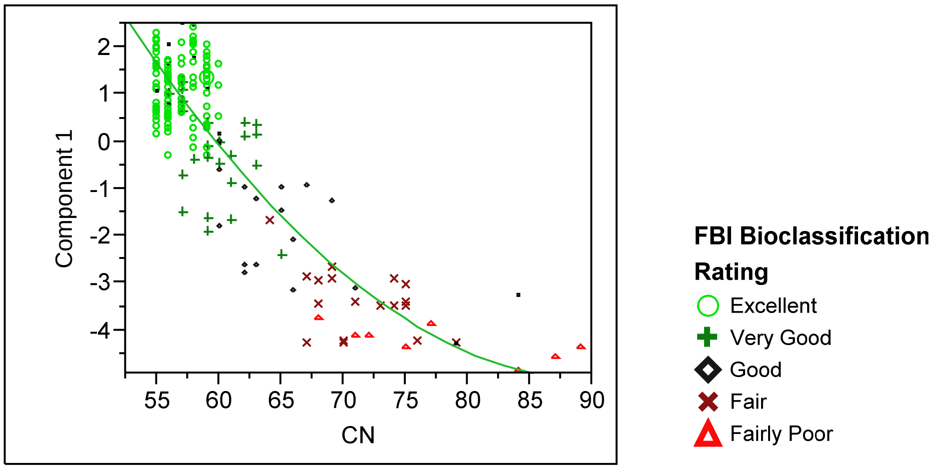


Figure 4: Polynomial Regression of Component 1 by Curve Number, coded by FBI rating classification illustrates reduction in “water quality” as CN increases.



Component 1 = 38.050824 - 0.9491335*CN + 0.0052211*CN^2
R^2=.77
P<.0001

The loading plots for each classification (superior, good and poor) are illustrated below (Figures 5-7). The vectors in the loading plots for the subsets echo the vectors from the loading plot across the entire gradient, with the exception on the Percent EPT in the “superior” category that suggests this variable contributes to the loading in higher water quality sites.

Figure 5: Loading Plot for “Superior” CN classification

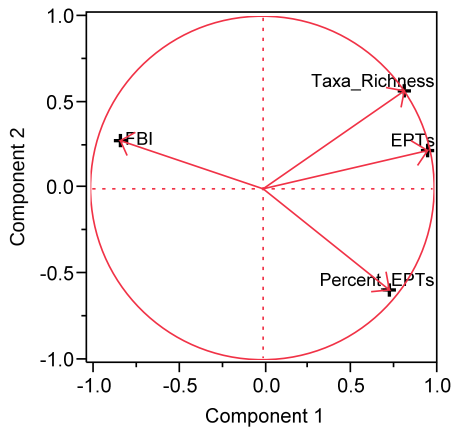


Figure 6: Loading Plots for “Good” CN classification

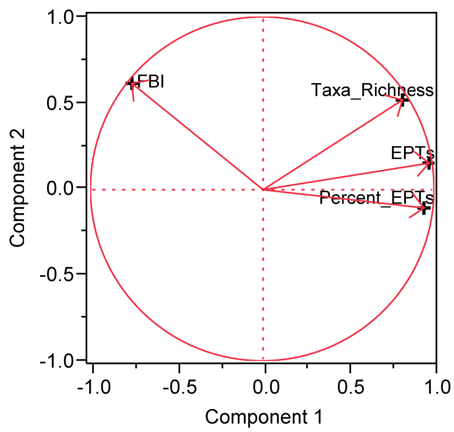
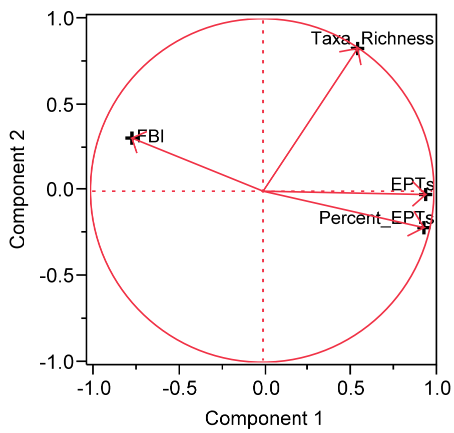


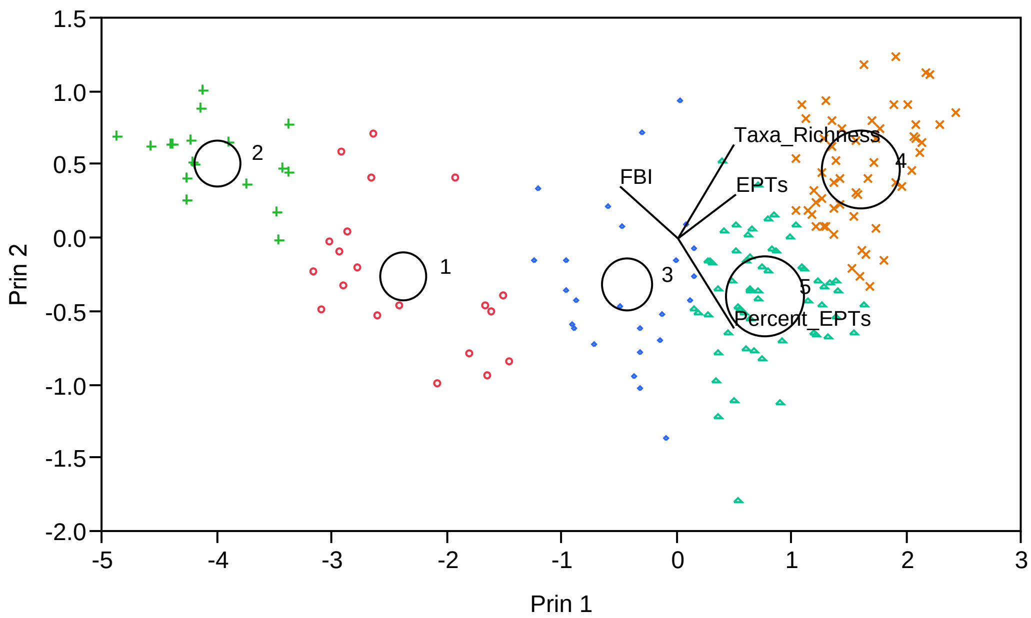
Figure 7: Loading Plots for “Poor” CN classification



Clustering

The cluster analysis (Figure 8) illustrates the clustering as coded by cluster membership. The symbols and colors illustrate the five FBI categories, which are particularly dispersed throughout the clusters that represent good and fair water quality. The clusters to the right of the graph are "excellent" and degrade to "fairly good" on the left side of the graph. This pattern is the same in the principle component plot in Figure 3. The vector plot also indicated the loading from is a result of the metrics and is centered on the origin. The circles are located in the center of the clusters and numbered for identification. Their sizes vary with the number of points in the cluster (JMP, 2009).

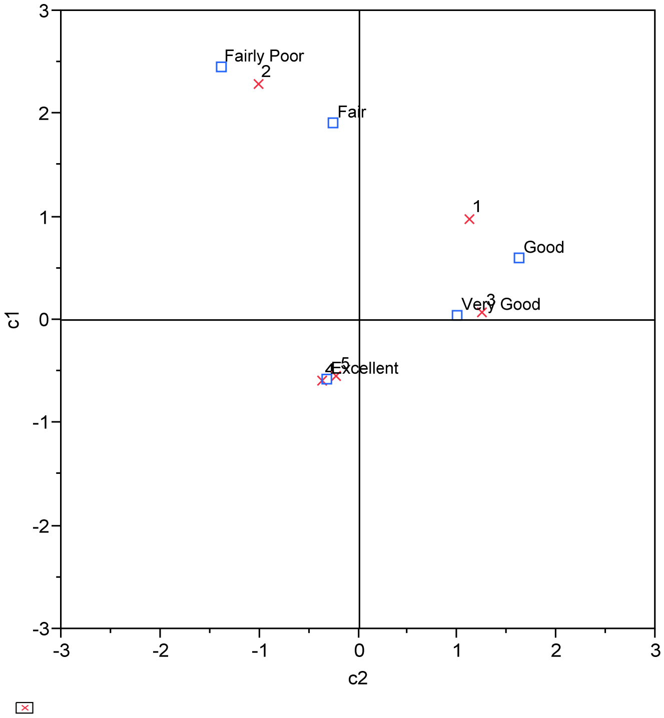
Figure 8: K-means clustering coded by cluster (not FBI classification) where the circles proportionally indicate number of items in a cluster and centers indicate origin of each cluster (JMP, 2009). Note the clusters generally follow the "water quality" gradient found in principal component one. Vector loading variables are centered on the origin.



Correspondence Analysis

Correspondence analysis of the clustering method (Figure 9) associated FBI categories with clusters. It associated two clusters (4 and 5) with the "excellent" category, one cluster (3) with "very good." Correspondence analysis of the clustering method revealed less agreement with the remaining clusters (1 and 2) and poorer water quality conditions. With the exception of the excellent cluster, the plot indicated the clusters are not associated with each other.

Figure 9: Correspondence Analysis of k-means clusters and FBI Ratings illustrating two clusters (4 and 5) are associated with "excellent" water quality category and are not strongly associated with other clusters or water quality categories.

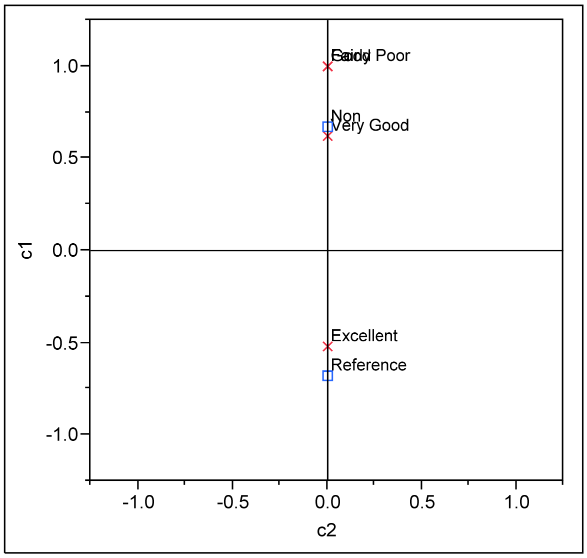


K means clusters

FBI Bioclassification Rating

Catchments were rated as "stable" and "less stable" based on perceived historic land use when macroinvertebrate collections were made and the aerial photography was used to prepare CNs. Correspondence analyses (Figure 10) associated "stable" legacy land use with "excellent" FBI categories, whereas all the remaining categories were associated with the “less stable” condition. Aerial interpretation relied heavily on tree cover, size and placement of roads and structures.

Figure 10: Correspondence Analysis of legacy land use and FBI ratings



FBI Bioclassification Rating

Reference

DISCUSSION

The effects of land-use on headwater streams systems and family level identification were illuminated by analyzing macroinvertebrate metrics with PCA, cluster and correspondence analysis. Metrics in the study consisted of taxa richness, EPT's, percentage EPT's and the FBI. CN was independent of these metrics.

Coefficient of Variation

Three CN categories were compared using coefficient of variation across the entire land use gradient. Although Schueler’s impervious cover model suggests wide variation in less impervious systems (Schueler, et al., 2009), this study had only one occurrence of a low CN (64) that received a rating of “fair.” This combination of low CN with a “fair” rating indicates that while variability has been described as wide ranging in systems without IC, as Schueler indicated, it was uncommon in this study.

The coefficient of variation (CV) was useful for comparing differences across groups to further probe the variability issue raised by Schueler. Both the FBI and taxa richness had lower and more consistent CV values than EPT's or percentage EPT's across the CN groups. The CV of FBI remained fairly static across CN groups and gives rise to its use as a stable metric for classifying stream health across an entire CN gradient. This study suggests increased variability in the degraded systems, not the sites with better water quality. Contrary to this study, CV for species level bioassessments in headwater streams was consistent across different land uses (Fleek, 2009).

In this study, the EPT and percent EPT had lower CVs when CN increased (as imperviousness increased), possibly attributed to the decline of pollution sensitive EPT's in degraded streams. EPT's are highly sensitive to pollution, and the infrequent occurrence of EPT‘s in higher CN catchments may have contributed greater variability. Additionally, the lack of higher CN sites also influenced the CV. Because the CV is the standard deviation divided by the mean, classifications with outliers can more easily distort this proportion. All EPT's and CN data were used in these analyses and no outliers were discarded, which may be a limitation (Ott & Longnecker, 2001). Overall, while data points with higher CN would be useful to understanding the entire land use gradient, they are not necessary to inform the threshold between good and fair, which is the breakpoint for maintaining biological integrity (Calabria, 2010).

Principal Component Analysis

PCA explained variability across the entire land use gradient and subsets of the data based on the three CN groups (superior, good, poor). The plot of first and second components (Figure 3) was useful for visualizing and interpreting the distribution of the data along the first and second principal components. The data points were coded by the FBI classification and the first component functions as a "water quality" vector, while the second component functions as a "richness" vector. The first component (water quality) component was plotted against CN (Figure 4) and the model explained the same variability as the polynomial regression of lnFBI by CN (Calabria, 2010). The model in this study (PC 1 by CN) suggests that the additional metrics, while they are useful for other purposes, did not add explain additional variability and supports the lnFBI by CN regression model.

The second component (richness) suggested a similar pattern of variance described both by Fleek and Schueler (Fleek, 2009; Schueler, et al., 2009). Although this pattern is dissimilar from the CV in this study, the PC 2 (Figure 3) indicates reduced variability in the higher CN (increased IC) sites and greater variability in the lower CN sites with excellent water quality ratings. Variance in the second component may be attributed to the reduced taxa richness and percent EPT in the poorer water quality sites.

Overall, the first and second components explained almost all the variability across the full gradient of CN (Table 2). All the eignevectors (metrics and FBI) evenly loaded on the first principal component. This trend was also evident in the CN subset analyses to a lesser extent (Table 3). This finding illustrated the benefit of using a combination of metrics to describe sources of variability in the data. Within the CN subset, at least 87% of the variance was explained by the first and second principal components. Percent EPT was a useful metric across the entire land use gradient and in the CN groups rated “superior.” However, in the CN groups with “good” and “poor” FBI rating, percent EPT's did not heavily influence the component and is less useful in more degraded CN groups because of EPT intolerance to pollution and resulting scarcity of those macroinvertebrates in poor water quality. As with the coefficient of variation, the EPT’s and percent EPT's, shifted in the loading plots (Figure 5, 6 and 7) and became less relevant as CN increased. This may also explain the reduction in the ability of the PCA to explain as much variance when CNs increased. Although these results may have limited application to other physiographic areas, the methods helped explained variability in this study.

Cluster and Correspondence Analysis

Five clusters were specified for the k-means method using macroinvertebrate metrics (EPT, percent EPT and taxa richness) and FBI values. The clusters followed the “water quality” vector and supported the FBI classifications. Correspondence analysis suggested stronger association between the excellent water quality classification and clusters four and five. The “very good” category was closely associated with cluster three. The remaining clusters (1 and 2) did not associate closely with the remaining three FBI ratings (good, fair, and fairly poor); however, the plot does indicate dissimilarity between the categories. This finding indicates the clusters, although composed of a combination of water quality ratings, were not associated with each other and supported the coarse water quality classification for the three CN groups.

Although outside of the scope of this study, legacy land use may be responsible for some of the remaining variation (Maloney, et al., 2008). No sites in this study were characterized as reference sites because most sites were severely impacted by clear cutting for timber within the past century. Subsequent reforestation efforts by the WPA and CCC helped reduce erosion and fostered habitat improvement. Other legacy land use variability may have been introduced from two severe hurricanes and one tropical depression during the fall of 2004, which was followed by a severe drought for the first two of the four years in the study. Nonetheless, the separation in the correspondence analysis indicated that both the “excellent” sites and stable sites were not similar to the other classifications and less stable sites. Most of the stable sites are in public ownership and may not have experienced land use change. Variability in the stable and excellent sites has yet to be explained. Explorations of environmental factors such as elevation, slope, stream gradient, geology and watershed characteristics may have an effect on macroinvertebrate assemblages and occurrences.

CONCLUSION

This study explored the suitability of family level identification and variability of macroinvertebrates' response to CN gradients. PCA offered support for the inclusion of many metrics to explain variance across land-use gradients. Use of PCA indicated that percent EPT may be less useful in higher CN catchments. Coefficient of variation and cluster analysis supported FBI classifications across CN gradients. The findings of this study give rise to the use of coarse comparisons of sites with different CN to support the restoration or preservation of biological integrity.

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APPENDIX A

Catchments (n=179) by Legacy Land Use, CN Category, FBI Category, and Cluster ID

Legacy Land Use	CN Category (3)	FBI Category (5)	CN	Cluster ID	n
Stable	Excellent	Superior	55	1	10
Stable	Excellent	Superior	55	2	12
Stable	Excellent	Superior	55	3	3
Stable	Excellent	Superior	56	1	4
Stable	Excellent	Superior	56	2	13
Stable	Excellent	Superior	57	1	6
Stable	Excellent	Superior	57	2	7
Stable	Excellent	Superior	58	1	8
Stable	Excellent	Superior	58	2	2
Stable	Excellent	Superior	59	1	6
Stable	Excellent	Superior	59	2	9
Stable	Excellent	Superior	59	3	2
Stable	Excellent	Superior	60	1	1
Stable	Excellent	Superior	60	2	1
Stable	Very Good	Superior	57	1	2
Stable	Very Good	Superior	57	2	2
Stable	Very Good	Superior	59	2	1
Less Stable	Excellent	Superior	56	2	5
Less Stable	Excellent	Superior	56	3	5
Less Stable	Excellent	Superior	57	2	4
Less Stable	Excellent	Superior	58	3	4
Less Stable	Excellent	Superior	59	1	2
Less Stable	Excellent	Superior	59	2	3
Less Stable	Excellent	Superior	59	3	3
Less Stable	Excellent	Superior	60	2	1
Less Stable	Very Good	Superior	56	2	1
Less Stable	Very Good	Superior	57	2	1
Less Stable	Very Good	Superior	57	3	1
Less Stable	Very Good	Superior	57	4	1
Less Stable	Very Good	Superior	58	3	1
Less Stable	Very Good	Superior	59	3	2
Less Stable	Very Good	Superior	59	4	2
Less Stable	Very Good	Superior	60	3	2
Less Stable	Very Good	Superior	61	3	3
Less Stable	Very Good	Superior	61	4	1
Less Stable	Very Good	Superior	62	2	1

Legacy Land Use	CN Category (3)	FBI Category (5)	CN	Cluster ID	n
Less Stable	Very Good	Superior	62	3	1
Less Stable	Very Good	Superior	63	3	4
Less Stable	Very Good	Good	65	4	1
Less Stable	Good	Superior	60	3	2
Less Stable	Good	Superior	60	4	1
Less Stable	Good	Superior	62	3	1
Less Stable	Good	Superior	62	4	2
Less Stable	Good	Superior	63	4	2
Less Stable	Good	Good	65	3	1
Less Stable	Good	Good	65	4	1
Less Stable	Good	Good	66	4	2
Less Stable	Good	Good	67	3	1
Less Stable	Good	Good	69	4	1
Less Stable	Good	Poor	71	4	1
Less Stable	Fair	Superior	64	4	1
Less Stable	Fair	Good	67	4	1
Less Stable	Fair	Good	67	5	1
Less Stable	Fair	Good	68	4	1
Less Stable	Fair	Good	68	5	1
Less Stable	Fair	Good	69	4	2
Less Stable	Fair	Poor	70	5	2
Less Stable	Fair	Poor	71	5	1
Less Stable	Fair	Poor	73	5	1
Less Stable	Fair	Poor	74	4	1
Less Stable	Fair	Poor	74	5	1
Less Stable	Fair	Poor	75	4	1
Less Stable	Fair	Poor	75	5	2
Less Stable	Fair	Poor	76	5	1
Less Stable	Fair	Poor	79	5	1
Less Stable	Fairly Poor	Good	68	5	1
Less Stable	Fairly Poor	Poor	71	5	1
Less Stable	Fairly Poor	Poor	72	5	1
Less Stable	Fairly Poor	Poor	75	5	1
Less Stable	Fairly Poor	Poor	77	5	1
Less Stable	Fairly Poor	Poor	84	5	1
Less Stable	Fairly Poor	Poor	87	5	1
Less Stable	Fairly Poor	Poor	89	5	1

CHAPTER FOUR

EVALUATING CHANGES IN AWARENESS AND SATISFACTION IN THREE LOW IMPACT DEVELOPMENT WORKSHOPS

This chapter was written for journal publication.

ABSTRACT

Despite efforts to treat harmful stormwater runoff from untreated impervious areas, over half of the reported TMDL impairments to surface water are caused by nonpoint pollution sources. One of these sources is stormwater, which impairs thousands of receiving waters nationally. One method to reduce impairment is called Low Impact Development (LID) and it relies on conservation planning and integrating treatment practices that mimic predevelopment hydrology. An approach used by the North Carolina State University (NCSU) Cooperative Extension Service was to increase stakeholders' awareness about treating stormwater using LID. Several introductory LID workshops were held as part of an educational outreach effort for those involved with planning, design, implementation and maintenance. Increasing awareness is only one component of encouraging behavior change. Several models suggest other components and conditions necessary to change and sustain behavior change, but are outside of the scope of this project. This study investigated participants' change in familiarity and awareness with LID themes and topics as a result of the workshops. Traditional lecture style workshops were based on the *Low Impact Development (LID): A Guidebook for North Carolina*, published by NCSU Cooperative Extension and other research based information to improve water quality through LID techniques and practices. Results from 1) pre- and post-questionnaires and 2) satisfaction surveys illustrated an increase in respondents' awareness and familiarity with LID modules ($p<.001$) and topics ($p<.035$). Participants also reported satisfaction with material, relevancy, format and presenters in all modules. This increase in awareness is a necessary, but not sufficient, step for behavior change to reduce water quality impairment.

INTRODUCTION

Stormwater is the result of runoff from impervious surfaces. When it enters streams or other waters, it is often classified as nonpoint source pollution and, combined with other nonpoint sources, constitutes more than half of the recorded impairments of surface waters in the United States (Furtak & Menchu, 2009). Combining conservation planning techniques with routing of stormwater through a variety of structural practices can ameliorate stormwater impacts to receiving waters. This approach is often referred to as Low Impact Development (LID).

LID relies on ecologically based design principles to minimize site impacts and recommends treating stormwater through a series of interconnected treatment practices to slow, treat and cool stormwater before it enters surface waters (Prince George's County (Md.) Dept. of Environmental Resources, 2000a, 2000b). LID techniques and practices improve water quality by preserving sensitive areas of the site and promoting the design, construction and monitoring of appropriate interventions to mimic predevelopment nutrient and hydrological cycles (Perrin et al., 2009). LID techniques strive to meet predevelopment hydrological cycles by relying on site inventory and analyses to guide suitable preservation and development areas, which follow ecological planning techniques from the past several decades (Ndubisi, 2002). At the site scale, biological processes help transform or sequester excess nutrients, sediment and heavy metals that negatively affect water quality.

Municipalities and other local governments in North Carolina are located in a geologically diverse environment composed of coastal, piedmont and mountainous areas with varied environmental conditions. Historic land use has modified much of the environment and caused impairments to surface water systems. NCSU published *Low Impact Development (LID): A Guidebook for North Carolina* and accompanying curricula highlight appropriate LID design, construction and maintenance techniques to suit these diverse settings. These efforts complement the intent of the 2007 NPDES Phase II rules ("Stormwater unit: NPDES Phase II Stormwater Program," 2009) adopted by several North Carolina municipalities to improve water quality. The LID Guidebook and curricula respond to these diverse environmental settings by suggesting appropriate techniques based on local conditions. However, cultural barriers may preclude some LID practices. For example, a LID practice known as stormwater wetlands contain a permanent pool of water that encourages anerobic conditions, which often transforms nitrogen to reduce nutrient loading in surface waters (Line et al., 2008). While this is beneficial for treating runoff, many landowners have historically drained wetlands to increase arable land and reduce mosquito habitat. Although integrating LID techniques and practices is beneficial to improving water quality, their novelty may be an impediment to their adoption.

Several behavior models suggest necessary steps for overcoming impediments. Although behavior models indicate other components are necessary to change behavior, they agree that without a change in awareness or knowledge, no change in attitude or behavior will likely occur (Ajzen, 1991; Ajzen & Fishbein, 1973; Kollmuss & Agyeman, 2002; Smith, 1982; Stern et al., 1999). Behavior change has been encouraged by national Extension programs for almost a century using demonstration projects.

Although demonstration projects involve experiential learning pedagogy, traditional classroom lectures and emerging web-based programs have demonstrated an ability to increase awareness as well (Brain et al.; Johnson et al.; Ray). Educational events that take place as classroom lectures may be more successful if presenters can first connect with the participants at their current level of understanding of the topics (Smith, 2002). Also, the presenters should try to accommodate the variety of learning styles across participants (Johnson, et al., 2008). As Kolb mentions, different occupations may be surrogates for different learning styles (Kolb & Kolb, 2005; Kolb & Kolb, 2009). The presenter's challenge is to convey information to a wide variety of audiences to meet predefined educational objectives, as well as, evaluating and reporting on the program's effectiveness (Arnold, 2002; Weerts, 2005).

This study focused on using questionnaires to evaluate if any change occured in the participants' awareness as a result of the three piloted introductory LID workshops. A secondary evaluation component explored differences in participants' satisfaction of workshops across time to detect any change in satisfaction as a result of refining the agenda based on respondent feedback. Although these refinements may threaten internal validity (Creswell, 2003), these refinements were incorporated into later workshops and a web-based curricula, which is available to web users. This format support calls among Extension professionals to expand Extension's web-based presence (Ray, 2007). Additionally, the curricula was made available to Extension professionals to download and adapt for their region when replicating the introductory training. The results of this study were disseminated to grantors and captured in Extension reporting.

METHODS

Workshop Description

Three workshops were held across the state of North Carolina during the fall of 2009 to promote the Low Impact Development guidebook and curricula published by NCSU. NCSU Cooperative Extension offered workshops to introduce participants to LID components centered on planning, policy, design, implementation and maintenance, which accompany most of the guidebook chapters. One-day LID workshops were held initially in the coastal, then the Piedmont and lastly the mountain region of North Carolina, content was modified to reflect specific environmental conditions for each physiographic area, which may threaten internal validity (Creswell, 2003). The workshops were held in Barco, Pittsboro and Asheville, NC. The lecture format workshops introduced LID concepts supported by the guidebook. Additional information conveyed introductory information about LID marketing, maintenance and monitoring, *Green Building* and *HealthyBuilt Homes* certification and local case studies. Workshop participants received a binder of materials complete with an agenda, copies of presentations, and both printed and digital copies of the Guidebook.

The workshop agenda broadly covered policy, design, construction and maintenance topics. Although the same content was presented at each workshop, the agenda (Table 1) was modified based on questionnaire and survey analyses, comments from the participants and the presenter's availability. All the presenters were knowledgeable in one or more phases of LID. The chronologically ordered phases include regional planning, conceptual site planning, design development and implementation. The implementation phase includes the preparation of construction documents, bidding, construction administration and annual maintenance reporting (Harris et al., 1998).

Table 1: Agenda for Third and Final Workshop

NC Low Impact Development and Green Building Workshop: Showcasing the 2009 NC Low Impact Development Guidebook
Welcome and Introductions
Introduction to NC LID Guidebook and Low Impact Development
Green Building* and *HealthyBuilt Homes
Decentralized Wastewater and LID
Marketing LID
Government Planning and Regulatory Strategies
Lunch Break
LID Site Assessment and Design
LID Construction
Stormwater Best Management Practices
LID Maintenance and Monitoring
Local Case Studies

Workshop announcements were sent to water quality list serves across the state, previous attendees of NCSU water quality trainings and several local newspapers and newletters. Local Extension offices also posted information on websites and circulated announcements to their constituents that include industry, professional and trade groups.

Educational Effectiveness Approach

Program effectiveness was measured with quasi experimental, mixed mode, one group pre-and post questionnaire (Creswell, 2003) to assess any changes in familiarity and awareness of LID techniques and practices (Calabria et al., 2010). A separate satisfaction survey was administered during the workshops. North Carolina Extension Evaluation foms were modified for this workshop (Jayaratne, 2009).

Pre- and Post-Experimental Design

Participants self enrolled in the workshops and voluntarily responded to the request for pre- and post- questionnaires. These studies were reviewed by the Internal Review Board at NCSU and were exempted from the Protection of Human Subjects Act ("Protection of human subjects," 2005).

Questionnaire Development

Nearly identical pre-and post-questionnaires measured familiarity with underlying LID principles, experience with LID project phases and limited demographic information. LID principles were introduced in the workshop modules and consisted of marketing, planning, design, construction, maintenance and wastewater topics. Participants experience with LID phases was requested to determine how often a respondent performs LID planning, design, construction and/or maintenance activities for specific sites in a year prior to the workshop.

The pre- and post-questionnaires followed published guidelines and principles on design, format and content (Converse, 1987; Dillman, 2007; Rea & Parker, 2005). These design methods sought to ease the respondents' ability to answer questions correctly while minimizing measurement error (Dillman, 2007). Specific components of the questionnaires included an introduction that indicated the sponsor, objectives and goals and the "significance of the results" (Rea & Parker, 1997, p 30). Other introductory components included the selection reason, confidentiality statement, surveyor contact information, time commitment, and gratefulness to the respondent (Dillman, 2007, p 162). The initial introductory question was an easy to answer question. The following questions were grouped with clearly labeled section headings that asked how much respondents agreed or disagreed with the following questions (Converse & Presser, 1986; Dillman, 2007; Rea & Parker, 2005). Questions were based on a five-point Likert scale posed in short question banks determine familiarity and agreement with statements (Dillman, 2007). Open ended, venting questions were presented at the end of the questionnaire and survey to capture additional respondent input (Rea & Parker, 1997, p 36 & 43).

Mixed Mode Deployment

Respondents were offered pre- and post- questionnaires and a satisfaction survey. Questionnaires were distributed to potential respondents either by paper during the day of the workshop, or online one week prior to the workshop. Paper copies were useful for capturing respondents who did not register prior to the workshop. Although these modes were mixed, this procedure maximized the number of possible respondents (Dillman & Christian, 2007; Kaplowitz et al., 2004) and likely did not diminish response rates (Porter & Whitcomb, 2007). All post- testing questionnaires were offered within one day of the workshop as a web-based questionnaire. At least three reminders were sent for both pre- and post-testing to maximize response rates (Dillman, 2007). The moderator reminded the respondents at each workshop about the benefit of the research and how their feedback would inform the curricula and summary information would be reported to grantors to document any change in awareness, presumably as a result of the workshop. Respondent fatigue (Dillman, 2007) was minimized by administering questionnaires on separate days and in different modes, except for walk-ins the day of the workshop.

Satisfaction Survey

Satisfaction surveys were distributed at the beginning of the workshops and moderators reminded participants to complete the paper surveys after each presentation. The survey mimicked the agenda for each workshop because the order of presentations was different at each workshop. Surveys were collected at the workshop conclusion. A 5-point Likert scale was used by the respondents to self report their satisfaction with each presenter's material, relevancy and format for each module. Comments were encouraged by adding a comment field after each question bank.

Statistical Analyses

Wilcoxon Signed Rank tests and contingency tables were used to determine if any differences occurred between the for the pre- and post-questionnaires. Contingency tables explored differences across demographic variables and experience level with LID phases. A serpertate analysis on the satisfaction survey relied an analysis of variance (ANOVA) with post hoc Tukey-Kramer HSD tests to determine any differences in respondents' satisfaction across workshop locations.

The pre- and post-test analyzed self reported changes in awareness before and after the workshop. Databases with respondents' answers from the pre- and post-questionnaires were matched using two unique identification fields. Mismatched information was excluded from this analysis using listwise deletion. Any case with missing information in any variable was omitted from the entire analysis. Additionally, all personally identifiable information and comments were removed before analysis. The respondents who participated in the workshop were considered as a dependant sample and nonparametric analyses using the Wilcoxon Sum Rank and Sign Tests analyzed direction and magnitude of change in the ordinal values (de Vaus, 2002; Ott & Longnecker, 2001). Reverse coding was not performed on several questions because the test indicates direction. Contingency tables were visually examined to compare workshop locations, various demographic variables and frequency with LID phases to inform future research. Respondents who reported at least monthly and quarterly involvement in any phase of LID (planning, design, construction, maintenance) were categorized as experienced for this study. The remaining respondents were categorized as inexperienced. Several demographic variables were tested for association with experience and workshop location by (Pearson) chi square and visually screened for differences in row and column percentages. Fisher's Exact Test was used for any table limited to two categories in both rows and columns (de Vaus, 2002; Garson, 2009).

Satisfaction surveys were coded and descriptive statistics for different workshop modules and locations were compared to determine satisfaction. Satisfaction of each module in each workshop location was tested using the oneway ANOVA testing of the means. If at least one satisfaction score (mean) was significantly different, then post hoc analyses with Tukey-Kramer HSD were run to determine significant differences of means across workshop locations. Differences across time could be tested to determine if refinements to the later workshops were more or less satisfactory to respondents.

RESULTS

All three workshops had a combined total of 137 people who registered or walked in the day of the workshop. Paper or online modes resulted in 122 completed pre- and post-questionnaires with 57 matched questionnaires after listwise deletion, which were used for analysis. Of the deleted surveys, very few questionnaires (n=2) were terminated early, resulting in minimum breakoff (Peytchev, 2009). A total of 100 paper satisfaction surveys were collected at the conclusion of the three workshops and resulted in 66 completed questionnaires after listwise deletion, which were used for analysis.

Respondents of the pre- and post-questionnaires reported a significant increase in familiarity ($p < 0.001$) and awareness ($p < 0.035$) with LID modules and topics, presumably as a result of attending the one day workshop. Additionally, responses from the satisfaction survey administered during the workshops revealed that respondents were satisfied with the material, relevancy, format and presenters on a scale ranging from very dissatisfied to very satisfied.

Pre and Post

Workshop modules and topics introduced underlying principles of LID to improve water quality, the guidebook, and the certification programs of the North Carolina *HealthyBuilt Homes*. Changes in awareness were evaluated using the Wilcoxon Signed Ranks and Sum test (JMP, 2009). The respondents showed significant increases in familiarity across every workshop module with Z scores ranging from -6.321 to -4.959 ($p<.001$) as shown in Table2:

Table 2: Wilcoxon Sign Ranked Z scores for familiarity of modules based on changes before and after workshops

Wilcoxon Signed Ranks Test **Familiarity with Module**	**Z Score**
How to Market Low Impact Development?	-6.321[a] *
The 2009 North Carolina Low Impact Development Guidebook?	-5.848[a] *
How to maintain and monitor Low Impact Development features?	-5.763[a] *
Government Planning and Regulatory Strategies to implement Low Impact Development?	-5.376[a] *
Examples of Low Impact Development in your Region?	-5.276[a] *
Construction of Low Impact Development projects?	-5.190[a] *
Underlying principles of Low Impact Development?	-5.100[a] *
Green Building and NC HealthyBuilt Homes?	-4.959[a] *

a. Based on negative ranks.
* $p<.001$

Respondents also showed a significant increase in familiarity with workshop topics as shown by the Wilcoxon Sign Ranks Test Z scores in Table 3. All but two of the topics showed significant increases in awareness ($p<.01$).

Table 3: Wilcoxon Sign Ranked Z scores for familiarity of topics based agreement or disagreement with statements on changes before and after workshops

Wilcoxon Signed Ranks Test **Topics (planning, policy, design, implementation and maintenance)**	**Z Score**
Slowing, treating and cooling stormwater is beneficial to protecting water sources for human consumption.	-3.928[a] *
Combined sewer and stormwater pipes sometimes overflow, but Low Impact Development (LID) features or practices can minimize the number of times per year this happens.	-3.661[a] *
Local watersheds with more than one quarter imperviousness, such as parking lots and rooftops, are likely to degrade the receiving streams.	-3.084[a] **
Low Impact Development (LID) features or practices can treat pollutants for the majority of storm events.	-2.772[a] **
One underlying approach of Low Impact Development (LID) is to mimic the way water would runoff or infiltrate before development occurs.	-4.388[a] *
Low Impact Development (LID) planning and practices can offset downstream impacts when changing land use from a forest to parking areas.	-3.332[a] *
Low Impact Development (LID) features or practices should require an operation and maintenance plan after a development is turned over to a property owner's association.	-3.072[a] **
Traditional planning ordinances can hinder Low Impact Development in a community.	-2.624[a] **
LID can be encouraged by municipalities that use incentives such as expedited plan reviews.	-3.869[a] *
Low Impact Development (LID) features or practices are difficult to integrate into redevelopment projects.	-2.108[b] ***
The NC HealthyBuilt Homes Program is advantageous because it increases marketability.	-5.736[a] *
LID offers economic benefits to all constituents including developers, municipalities, and homeowners.	-5.040[a] *
Soil is the best treatment plant for wastewater.	-5.453[a] *
The use of onsite wastewater systems is increasing in North Carolina.	-3.123[a] **

a. Based on negative ranks.
b. Based on positive ranks (in lieu of reverse coding)
* $p<.001$
** $p<.01$
*** $p<.035$

Demographics of the pre-and post- questionnaire respondents illustrated that 56% identified their income as primarily through public sources and 34% indicated they were female. The average age was 43 years with an age range of more than 40 years. Attendance was highest in the mountains, which was also the last workshop. The coast had the lowest proportion of total attendance at 18%, the central, or piedmont, workshop attracted 35% of the participants, while the mountains represented 52%.

Across all workshops, half the respondents reported little or no experience in any LID phases. These respondents were classified as inexperienced and reported yearly or no involvement with planning, designing, constructing or maintaining LID projects. Of the remaining respondents, approximately 40% reported quarterly or monthly involvement with any LID phase and were categorized as having experience with LID for the purposes of this study as shown in the Table 4: Experience with LID. These summary data were explored and showed no dependency between gender, private or public income source, or workshop location when compared with LID experience using contingency tables based on the chi square goodness of fit test.

Table 4: Experience with LID

LID Phase	Inexperienced (% of Total)	Experienced (% of Total)
Planning	59.81%	40.19%
Designing Practices	60.20%	39.80%
Constructing practices	61.73%	38.27%
Maintaining practices	59.77%	40.23%

Satisfaction

Responses from all the satisfaction surveys were reduced through listwise deletion to yield a total of 66 respondents classified by location. Respondents reported satisfaction (mean=4.21, SD=0.13) on a five point scale with the workshops' material, relevancy, format and presenters, as shown in greater detail in Table 5: Respondent Satisfaction by Module. The respondents were consistent and rated the Stormwater Best Management Practices Overview presentation the highest, which also had the least standard deviation. Although respondents ranked LID Construction the least satisfactory, with some of the largest standard deviation, they expressed satisfaction with the module.

Table 5: Respondent Satisfaction by Module

Module	Material	SD	Relevancy	SD	Format	SD	Speaker	SD
Introduction to NC LID Guidebook and LID	4.21	0.41	4.23	0.42	4.14	0.58	4.14	0.6
Green Building and Healthy Built Homes	4.06	0.78	4.08	0.81	4.08	0.66	4.15	0.81
Decentralized Wastewater and LID	4.2	0.71	4.12	0.75	4.27	0.65	4.24	0.84
Marketing LID	4.2	0.64	4.29	0.65	4.2	0.66	4.32	0.71
Government Planning and Regulatory Strategies	4.15	0.59	4.32	0.64	4.18	0.55	4.17	0.62
LID Site Assessment and Design	4.21	0.67	4.27	0.62	4.18	0.68	4.2	0.71
LID Construction	3.97	0.68	4.05	0.69	3.97	0.7	3.91	0.78
Stormwater BMP	4.39	0.55	4.48	0.53	4.38	0.55	4.47	0.53
LID Maintenance and Monitoring	4.21	0.6	4.32	0.61	4.2	0.64	4.29	0.67
Case Studies	4.29	0.63	4.41	0.74	4.29	0.7	4.21	0.73

Analyses of the means of the combined satisfaction by module indicated the last two workshops improved over the first workshop. Two modules improved significantly between the first workshop held at the coast and the last two workshops, the *Green Building* and *HealthyBuilt Homes* and Decentralized Wastewater and LID ($p<.001$). Additionally, no coastal modules were rated significantly higher than the later two workshops.

DISCUSSION

This educational effort responded well to agency requests from EPA and USDA to increase awareness about preserving or restoring water quality using a LID approach. These workshops attracted stakeholders in the public and private sector who self-reported greater awareness and familiarity with LID strategies and techniques to improve water quality after attending the workshop. Anecdotally, many of the participants' comments supported the data analysis that indicated increased familiarity and awareness. Some comments also suggested intentions to make behavioral change by integrating LID into their area of expertise. Many behavior change models call for increased awareness prior to a change in attitude or behavior.

Since these workshops were pilots for the web-based curricula, data analyses and comments guided refinements to the curricula. Improvements between the first and last two workshops consisted of adjusting the agenda order to clarify LID context by addressing the larger scale components first, such as existing problems, policy and planning components. Then, site scale information was presented later in the day. Feedback also suggested the need to provide additional photographs of treatment practices in different settings to demonstrate the adaptability of practices to the geographic region and catchment area they treat. Several comments indicated the introductory material presented in the workshop was beneficial and more information on specifics of constructing these practices was requested. This information bolstered data analyses that indicated the introductory workshop was useful as it points to the next step in the progression of learning about specific features such as construction, maintenance and monitoring methods of stormwater treatment practices.

The satisfaction surveys were beneficial for reporting purposes and collecting comments. However, the responses contained little change in standard deviation across the module evaluation components that consisted of material, relevancy, format and presenter. The homogenous responses may anecdotally suggest that little consideration was actually given to each metric and that future satisfaction surveys may want to minimize respondents' effort by only asking if they were satisfied with the particular module. Although respondents were not asked to complete all three instruments on the same day, the questionnaires and survey were kept as short as possible to minimize respondent fatigue. The design of the questionnaire included specific sections, or question banks that prefaced sections with both ranges of answers to diminish measurement error from leading questions. Some questions were inserted to break the respondents pattern of consistently answering in agreement or disagreement. This method violated Dillman's 15th principle of "asking respondents to say yes in order to meet no" and resulted in the only questions without significant increases in awareness. These were not reported on in this study.

Although the results suggest respondents were satisfied with workshops, some anecdotal comments indicated otherwise. The importance of disseminating scientific based research cannot be underestimated. For instance, extolling the benefits of stormwater wetlands to treat stormwater in the coastal plain was met with marked skepticism because many of the wetland areas were historically drained for agriculture and development, to limit suitable mosquito habitat, and increase arable acreage. The workshop presenters were able to cite a study supporting a claim that stormwater wetlands can reduce mosquito populations if properly constructed and maintained because these areas foster mosquito predators (Hunt et al., 2005). Without knowledgeable presenters, the audience may be less receptive to new research based information. In limited cases, presenters attempted to address questions outside of their expertise and several resulting comments in the questionnaires highlighted some respondents' sensitivity toward non-expert opinions. These comments suggest future presenters of the curricula should indicate they do not know the answer but will follow-up with answers from contacted experts.

Limitations to these findings include concerns about not having a representative sample to extrapolate results from this study to a larger population because a random sample was not used. Also, respondents self reported familiarity and the loss of viable data due to list wise deletion methods may have influenced findings. The pre- and post- response rate was 75% and the satisfaction survey was nearly 92%. These rates were reduced after listwise deletion and reduced degrees of freedom. Future research opportunities include testing to see if a single, "retrospective post/pre" questionnaire administered at the end of the workshop (Garton et al., 2007) is different from bracketing the sections of educational workshops with pre- and post-questionnaires. Additional research may also include follow-up questionnaires to determine any change in behavior and potential barriers to implementing LID.

CONCLUSION

Lecture format, single day workshops increased awareness by extending research-based information about LID in three geologically diverse areas of North Carolina. These introductory workshops increased participants' awareness about themes ($p<.001$) and topics ($p<.035$) related to mimicking natural hydrologic cycles to restore surface water quality to meet LID goals and objectives. Participants reported satisfaction with material, relevancy, format and presenters. Results and feedback from both studies guided refinements to the curricula, which is now available to extension professionals in a digital format to adapt for their stakeholders.

ACKNOWLEDGMENTS

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NCSU has developed a LID Guidebook and subsequent education curricula; both funded by the Environmental Protection Agency Clean Water Act Section 319 program to address stormwater impacts in North Carolina and is housed at:

http://www.ces.ncsu.edu/depts/agecon/WECO/ncsulid/

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APPENDICES

APPENDIX A

Pre Questionnaire

Pre-Workshop Evaluation

General Information and Instructions

You are receiving this questionnaire because you may have registered for one of the LID Cirricula Workshops at the Currituck County Extension Office on Sept 23rd, Central Carolina Community College on Oct 15th, or the NC Arboretum, Asheville on Oct 26th.

Your response is confidential and used for evaluation purposes by NCSU's Cooperative Extension Program and its grantors. We would like to match your responses before and after the workshop through your birth month and last two digits of your mobile phone number to discern any changes in your responses before and after the workshop. Information you provide is confidential, no personally identifiable information will be released or retained, and only summarized responses will be distributed to meet grant deliverables. Grantors have generously contributed resources for the educational events you plan to attend and are curious about their investment in your education.

Your confidential answers will help us understand what you may or may not have learned about Low Impact Development. Should you have any questions, please contact Carter Cone at 828 665 2492 or Deb Paxton, NCSU IRB Administrator at 919-515-7515. You must be 18 or over to complete this survey.

Please take a moment to complete this short questionnaire about your knowledge of Low Impact Development PRIOR to attending the conference. NCSU will email a follow-up questionnaire after the conference that we hope you will also complete; however your participation is voluntary.

The questionnaire should take less than 15 minutes to complete. Thank you for your feedback, Cooperative Extension is always looking for ways to serve you better.

1. Which LID Curricula Workshop are you attending?

- ◯ Currituck County Extension Office on Sept 23rd, 2009
- ◯ Central Carolina Community College on Oct 15th, 2009
- ◯ NC Arboretum, Asheville on Oct 26th, 2009

2. Are you taking this questionnaire before or after the workshop?

- ◯ Before
- ◯ After

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Pre-Workshop Evaluation

12. Could you please share the zip code of your primary residence?

ZIP/Postal Code:

Please take a moment to write any suggestions that you may have about the LID Curricula Workshop.

NC Low Impact Development Guidebook
http://www.ncsu.edu/WECO/lid

We appreciate you taking time to respond to this questionnaire.

Pre-Workshop Evaluation

3. We would like to match your responses before and after the workshop through your birth month and last two digits of your mobile phone number to discern any changes in your responses before and after the workshop. Information you provide is confidential and no personally identifiable information will be retained.

- ○ January
- ○ February
- ○ March
- ○ April
- ○ May
- ○ June
- ○ July
- ○ August
- ○ September
- ○ October
- ○ November
- ○ December

4. Last 2 digits of your mobile phone (or two easy to remember numbers):

Your Familiarity and Involvement with Low Impact Development (LID)

5. Please check each dot to indicate your familiarity about the following topics prior to attending the workshop.

How familiar are you with:

	Very Unfamiliar	Unfamiliar	Neither Familiar nor Unfamiliar	Familiar	Very Familiar
The 2009 North Carolina Low Impact Development Guidebook?	○	○	○	○	○
Underlying principles of Low Impact Development?	○	○	○	○	○
Construction of Low Impact Development projects?	○	○	○	○	○
Government Planning and Regulatory Strategies to implement Low Impact Development?	○	○	○	○	○
How to maintain and monitor Low Impact Development features?	○	○	○	○	○
How to Market Low Impact Development?	○	○	○	○	○
Green Building and NC HealthyBuilt Homes?	○	○	○	○	○
Examples of Low Impact Development in your Region?	○	○	○	○	○

Pre-Workshop Evaluation

6. Your involvement with Low Impact Development (LID)

Please indicate how often you may or may not be involved with the following components for different sites:

	Never	Sometimes (at least 1 or 2 times per Year)	Frequently (at least 1 or 2 times per Quarter)	Often (at least 1 or 2 times per Month)
Low Impact Development Planning?	○	○	○	○
Designing Low Impact Development practices?	○	○	○	○
Constructing Low Impact Development practices?	○	○	○	○
Maintaining Low Impact Development practices?	○	○	○	○

Your Opinion about Low Impact Development

7. Some folks agree or disagree with the following statements.

We are interested in hearing about whether you agree or disagree with the statements below:

	Strongly Disagree	Disagree	Neither Agree or Disagree	Agree	Strongly Agree
One underlying approach of Low Impact Development (LID) is to mimic the way water would runoff or infiltrate before development occurs.	○	○	○	○	○
Slowing, treating and cooling stormwater is beneficial to protecting water sources for human consumption.	○	○	○	○	○
Low Impact Development (LID) planning and practices can offset downstream impacts when changing land use from a forest to parking areas.	○	○	○	○	○
Local watersheds with more than one quarter imperviousness, such as parking lots and rooftops, are likely to degrade the receiving streams.	○	○	○	○	○
Low Impact Development (LID) features or practices can treat pollutants for the majority of storm events.	○	○	○	○	○
The cost of installing Low Impact Development (LID) measures is usually much more than draining water to the nearest detention basin.	○	○	○	○	○
Using a rain barrel for irrigation can significantly reduce runoff from the site	○	○	○	○	○
Managing Low Impact Development (LID) features throughout a development is more difficult than managing a regional detention area.	○	○	○	○	○
Low Impact Development (LID) features or practices are difficult to integrate into redevelopment projects.	○	○	○	○	○

Pre-Workshop Evaluation

8. Some folks agree or disagree with the following statements.

We are interested in hearing about whether you agree or disagree with the statements below:

	Strongly Disagree	Disagree	Neither Agree or Disagree	Agree	Strongly Agree
Combined sewer and stormwater pipes sometimes overflow, but Low Impact Development (LID) features or practices can minimize the number of times per year this happens.	◯	◯	◯	◯	◯
Low Impact Development (LID) features or practices should require an operation and maintenance plan after a development is turned over to a property owner's association.	◯	◯	◯	◯	◯
The NC HealthyBuilt Homes Program is advantageous because it increases marketability.	◯	◯	◯	◯	◯
LID offers economic benefits to all constituents including developers, municipalities, and homeowners.	◯	◯	◯	◯	◯
LID construction and conventional construction have slight differences.	◯	◯	◯	◯	◯
Plan reviews for LID is the same process as traditional plan reviews.	◯	◯	◯	◯	◯
Traditional planning ordinances can hinder Low Impact Development in a community.	◯	◯	◯	◯	◯
LID can be encouraged by municipalities that use incentives such as expedited plan reviews.	◯	◯	◯	◯	◯
The use of onsite wastewater systems is increasing in North Carolina.	◯	◯	◯	◯	◯
Soil is the best treatment plant for wastewater.	◯	◯	◯	◯	◯

You are almost finished, would you please tell us a little about yourself?

9. Please tell us about yourself

What is your age in years?

[ ]

10. Please indicate your gender below

◯ Male

◯ Female

11. Do you receive your income primarily through a private or public entity?

◯ Private

◯ Public

APPENDIX B

Post Questionnaire

Post-Workshop Evaluation

9. Please take a moment to write any suggestions that you may have about the LID Curricula Workshop.

NC Low Impact Development Guidebook
http://www.ncsu.edu/WECO/lid

We appreciate you taking time to respond to this questionnaire.

Post-Workshop Evaluation

General Information and Instructions

You are receiving this questionnaire because you may have attended one of the LID Cirricula Workshops at the Currituck County Extension Office on Sept 23rd, Central Carolina Community College on Oct 15th, or the NC Arboretum, Asheville on Oct 26th.

Your response is confidential and used for evaluation purposes by NCSU's Cooperative Extension Program and its grantors. We would like to match your responses before and after the workshop through your birth month and last two digits of your mobile phone number to discern any changes in your responses before and after the workshop. Information you provide is confidential, no personally identifiable information will be released or retained, and only summarized responses will be distributed to meet grant deliverables. Grantors have generously contributed resources for the educational events you plan to attend and are curious about their investment in your education.

Your confidential answers will help us understand what you may or may not understand about Low Impact Development. Should you have any questions, please contact Carter Cone at 828 665 2492 or Deb Paxton, NCSU IRB Administrator at 919-515-7515. You must be 18 or over to complete this survey.

Please take a moment to complete this short questionnaire about your knowledge of Low Impact Development AFTER attending the workshop. Your participation is voluntary.

The questionnaire should take less than 12 minutes to complete. Thank you for your feedback, Cooperative Extension is always looking for ways to serve you better.

1. Which LID Curricula Workshop are you attending?

- ◯ Currituck County Extension Office on Sept 23rd, 2009
- ◯ Central Carolina Community College on Oct 15th, 2009
- ◯ NC Arboretum, Asheville on Oct 26th, 2009

2. Are you taking this questionnaire before or after the workshop?

- ◯ Before
- ◯ After

Page 1

Post-Workshop Evaluation

3. We would like to match your responses before and after the workshop through your birth month and last two digits of your mobile phone number to discern any changes in your responses before and after the workshop. Information you provide is confidential and no personally identifiable information will be retained.

○ January	○ May	○ September
○ February	○ June	○ October
○ March	○ July	○ November
○ April	○ August	○ December

4. Last 2 digits of your mobile phone (or two easy to remember numbers):

Your Familiarity and Involvement with Low Impact Development (LID)

5. Please check each dot to indicate your familiarity about the following topics after attending the workshop.

How familiar are you with:

	Very Unfamiliar	Unfamiliar	Neither Familiar nor Unfamiliar	Familiar	Very Familiar
The 2009 North Carolina Low Impact Development Guidebook?	○	○	○	○	○
Underlying principles of Low Impact Development?	○	○	○	○	○
Construction of Low Impact Development projects?	○	○	○	○	○
Government Planning and Regulatory Strategies to implement Low Impact Development?	○	○	○	○	○
How to maintain and monitor Low Impact Development features?	○	○	○	○	○
How to Market Low Impact Development?	○	○	○	○	○
Green Building and NC HealthyBuilt Homes?	○	○	○	○	○
Examples of Low Impact Development in your Region?	○	○	○	○	○

Your Opinion about Low Impact Development

Post-Workshop Evaluation

6. Some folks agree or disagree with the following statements.

We are interested in hearing about whether you agree or disagree with the statements below:

	Strongly Disagree	Disagree	Neither Agree or Disagree	Agree	Strongly Agree
One underlying approach of Low Impact Development (LID) is to mimic the way water would runoff or infiltrate before development occurs.	◯	◯	◯	◯	◯
Slowing, treating and cooling stormwater is beneficial to protecting water sources for human consumption.	◯	◯	◯	◯	◯
Low Impact Development (LID) planning and practices can offset downstream impacts when changing land use from a forest to parking areas.	◯	◯	◯	◯	◯
Local watersheds with more than one quarter imperviousness, such as parking lots and rooftops, are likely to degrade the receiving streams.	◯	◯	◯	◯	◯
Low Impact Development (LID) features or practices can treat pollutants for the majority of storm events.	◯	◯	◯	◯	◯
The cost of installing Low Impact Development (LID) measures is usually much more than draining water to the nearest detention basin.	◯	◯	◯	◯	◯
Using a rain barrel for irrigation can significantly reduce runoff from the site	◯	◯	◯	◯	◯
Managing Low Impact Development (LID) features throughout a development is more difficult than managing a regional detention area.	◯	◯	◯	◯	◯
Low Impact Development (LID) features or practices are difficult to integrate into redevelopment projects.	◯	◯	◯	◯	◯

Post-Workshop Evaluation

7. Some folks agree or disagree with the following statements.

We are interested in hearing about whether you agree or disagree with the statements below:

	Strongly Disagree	Disagree	Neither Agree or Disagree	Agree	Strongly Agree
Combined sewer and stormwater pipes sometimes overflow, but Low Impact Development (LID) features or practices can minimize the number of times per year this happens.	○	○	○	○	○
Low Impact Development (LID) features or practices should require an operation and maintenance plan after a development is turned over to a property owner's association.	○	○	○	○	○
The NC HealthyBuilt Homes Program is advantageous because it increases marketability.	○	○	○	○	○
LID offers economic benefits to all constituents including developers, municipalities, and homeowners.	○	○	○	○	○
LID construction and conventional construction have slight differences.	○	○	○	○	○
Plan reviews for LID is the same process as traditional plan reviews.	○	○	○	○	○
Traditional planning ordinances can hinder Low Impact Development in a community.	○	○	○	○	○
LID can be encouraged by municipalities that use incentives such as expedited plan reviews.	○	○	○	○	○
The use of onsite wastewater systems is increasing in North Carolina.	○	○	○	○	○
Soil is the best treatment plant for wastewater.	○	○	○	○	○

You are almost finished, would you please tell us a little about yourself?

8. Could you please share the zip code of your primary residence?

ZIP/Postal Code: [ ]

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APPENDIX C

Satisfaction Survey

NC State University A&T State University COOPERATIVE EXTENSION
Empowering People · Providing Solutions

LID WORKSHOP
October 26, 2009
Asheville, North Carolina
Module Evaluation

Information collected from the module evaluation is confidential and used for purposes of internal evaluation analysis and grant reporting by NC Cooperative Extension Service; we are always looking for ways to serve you better. Please take a moment to complete this short survey. It will help us know how we're doing, and how we can better serve your needs.

Directions:
A. Please circle the appropriate number to indicate your opinion about the following topics **after** viewing each module presentation. Circle only one answer.
B. Please include any additional comments you have about the presentation.

MODULE 1: Introduction to NC LID Guidebook and Low Impact Development

A. *SATISFACTION SURVEY*

How satisfied or dissatisfied were you with:	Very Disappointed	Disappointed	Neutral	Satisfied	Very Satisfied
1) The material that was presented in this module?	1	2	3	4	5
2) The relevancy of the material?	1	2	3	4	5
3) The format in which the information was presented?	1	2	3	4	5
4) The way that information was conveyed by the speaker?	1	2	3	4	5

B. *ADDITIONAL COMMENTS*

MODULE 2: Green Building and HealthyBuilt Home

A. *SATISFACTION SURVEY*

How satisfied or dissatisfied were you with:	Very Disappointed	Disappointed	Neutral	Satisfied	Very Satisfied
1) The material that was presented in this module?	1	2	3	4	5
2) The relevancy of the material?	1	2	3	4	5
3) The format in which the information was presented?	1	2	3	4	5
4) The way that information was conveyed by the speaker?	1	2	3	4	5

B. *ADDITIONAL COMMENTS*

MODULE 3: Decentralized Wastewater and LID

A. *SATISFACTION SURVEY*

How satisfied or dissatisfied were you with:	Very Disappointed	Disappointed	Neutral	Satisfied	Very Satisfied
1) The material that was presented in this module?	1	2	3	4	5
2) The relevancy of the material?	1	2	3	4	5
3) The format in which the information was presented?	1	2	3	4	5
4) The way that information was conveyed by the speaker?	1	2	3	4	5

B. *ADDITIONAL COMMENTS*

MODULE 4: Marketing LID

A. *SATISFACTION SURVEY*

How satisfied or dissatisfied were you with:	Very Disappointed	Disappointed	Neutral	Satisfied	Very Satisfied
1) The material that was presented in this module?	1	2	3	4	5
2) The relevancy of the material?	1	2	3	4	5
3) The format in which the information was presented?	1	2	3	4	5
4) The way that information was conveyed by the speaker?	1	2	3	4	5

B. *ADDITIONAL COMMENTS*

MODULE 5: Government Planning and Regulatory Strategies

A. *SATISFACTION SURVEY*

How satisfied or dissatisfied were you with:	Very Disappointed	Disappointed	Neutral	Satisfied	Very Satisfied
1) The material that was presented in this module?	1	2	3	4	5
2) The relevancy of the material?	1	2	3	4	5
3) The format in which the information was presented?	1	2	3	4	5
4) The way that information was conveyed by the speaker?	1	2	3	4	5

B. *ADDITIONAL COMMENTS*

PLEASE TURN PAGE OVER

MODULE 6: LID Site Assessment and Design

A. *SATISFACTION SURVEY*

How satisfied or dissatisfied were you with:	Very Disappointed	Disappointed	Neutral	Satisfied	Very Satisfied
1) The material that was presented in this module?	1	2	3	4	5
2) The relevancy of the material?	1	2	3	4	5
3) The format in which the information was presented?	1	2	3	4	5
4) The way that information was conveyed by the speaker?	1	2	3	4	5

B. *ADDITIONAL COMMENTS*

MODULE 7: LID Construction

A. *SATISFACTION SURVEY*

How satisfied or dissatisfied were you with:	Very Disappointed	Disappointed	Neutral	Satisfied	Very Satisfied
1) The material that was presented in this module?	1	2	3	4	5
2) The relevancy of the material?	1	2	3	4	5
3) The format in which the information was presented?	1	2	3	4	5
4) The way that information was conveyed by the speaker?	1	2	3	4	5

B. *ADDITIONAL COMMENTS*

MODULE 8: Stormwater Best Management Practices (BMPs)

A. *SATISFACTION SURVEY*

How satisfied or dissatisfied were you with:	Very Disappointed	Disappointed	Neutral	Satisfied	Very Satisfied
1) The material that was presented in this module?	1	2	3	4	5
2) The relevancy of the material?	1	2	3	4	5
3) The format in which the information was presented?	1	2	3	4	5
4) The way that information was conveyed by the speaker?	1	2	3	4	5

B. *ADDITIONAL COMMENTS*

MODULE 9: LID Maintenance and Monitoring

A. *SATISFACTION SURVEY*

How satisfied or dissatisfied were you with:	Very Disappointed	Disappointed	Neutral	Satisfied	Very Satisfied
1) The material that was presented in this module?	1	2	3	4	5
2) The relevancy of the material?	1	2	3	4	5
3) The format in which the information was presented?	1	2	3	4	5
4) The way that information was conveyed by the speaker?	1	2	3	4	5

B. *ADDITIONAL COMMENTS*

MODULE 10: Case Studies

A. *SATISFACTION SURVEY*

How satisfied or dissatisfied were you with:	Very Disappointed	Disappointed	Neutral	Satisfied	Very Satisfied
1) The material that was presented in this module?	1	2	3	4	5
2) The relevancy of the material?	1	2	3	4	5
3) The format in which the information was presented?	1	2	3	4	5
4) The way that information was conveyed by the speaker?	1	2	3	4	5

B. *ADDITIONAL COMMENTS*

CHAPTER FIVE

LOW IMPACT DEVELOPMENT DEMONSTRATION AND EDUCATION IN WESTERN NORTH CAROLINA, USA

This chapter was written for journal publicatio

Low Impact Development Demonstration and Education in Western North Carolina, USA

Retour sur 10 ans d'expérience en démonstration et en formation sur le développement à impact réduit (LID) dans l'ouest de la Caroline du Nord (USA)

Calabria, J*

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Hosted by:
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RÉSUMÉ

Pendant les dix dernières années, le centre de formation de la French Broad, de l'Université d'Etat de la Caroline du Nord (NCSU), a proposé des formations sur des projets de démonstration (financés par des fonds externes) visant la promotion des savoir-faire en matière d'amélioration de la qualité de l'eau. Les thèmes de formation sont centrés sur le traitement des eaux de ruissellement et sur les méthodes de préservation et d'amélioration du linéaire des cours d'eau, elles-mêmes basées sur des configurations et des dimensions existantes en condition naturelle. Est proposée et discutée dans cet article une vision d'ensemble des sites de démonstration et des sujets de formation de façon à ce que cette information puisse servir à d'autres institutions régionales qui cherchent elles aussi à transmettre des savoir-faire, résultant d'expériences scientifiques, sur le thème du dimensionnement et de la mise en place du développement à faible impact (LID). Sont documentées en particulier les prises de conscience des problèmes faisant suite aux séances de formation. D'autres projets de recherches sont revus pour illustrer les progrès tangibles, sur la perception du public, résultants des travaux de recherche et de formation du centre de la French Broad pour améliorer la qualité de l'eau, et maintenir santé, sécurité et bien-être du public.

Translated by François Birgand, Ph.D.

ABSTRACT

During the past decade, the French Broad River Watershed Training Center of North Carolina State University has offered educational opportunities surrounding externally funded demonstration projects. Our goal was to extend research-based information to improve water quality. Educational themes centered on stormwater runoff treatment and addressed conservation planning and stream enhancement that relied on natural channel design methods. An overview of the demonstration sites and accompanying educational components are discussed below. Demonstration sites are useful because they inform other regional education efforts, which seek to extend scientifically based information about the design and implementation of low impact development. Other education and research components are briefly reviewed to illustrate additional, tangible benefits the French Broad Training Center has offered the public to improve water quality and sustain the health, safety and welfare of the public.

KEYWORDS

Education, Interpretation, Low Impact Development, Sustainability, Water Quality

1 INTRODUCTION

Education outreach is necessary to increase awareness about preserving or improving water quality. Surface water quality in North Carolina has been degraded by land use conversion from formerly forested and agricultural areas to increasingly impervious suburban and urban land uses. Increased change in volume and rate of stormwater runoff has disrupted the natural hydrological cycle and untreated stormwater often flows directly into surface waters. In order to reverse this trend, the French Broad River Watershed Training Center (FBTC) has offered educational programming across a variety of disciplines to improve water quality.

Education takes the form of field days, workshops and conferences that are done in combination with the implementation or monitoring of integrated management practices. The educational outreach is wide ranging and has offered workshops and conferences from conservation planning at a watershed scale to the site-specific integration of stormwater treatment practices and stream enhancement using natural channel design techniques. Furthermore, many of these techniques and practices demonstrate the concept of low impact development (LID), which attempt to mimic natural nutrient and hydrologic cycles that occurred prior to land use change and development (Perrin et al., 2009). Demonstration sites and accompanying educational outreach are critical to increasing awareness about improving water quality.

2 PROJECT DESCRIPTION

The (FBTC) is a collaborative effort between two entities within the University of North Carolina System, the North Carolina State University (NCSU) and The North Carolina Arboretum (TNCA). The FBTC has worked with a variety of stakeholders in Western North Carolina to attract external funding to implement integrated management practices for demonstration and education purposes.

2.1 Demonstration Sites

The FBTC has implemented a variety of projects across Western North Carolina to improve water quality. Over two dozen demonstration projects are located at the North Carolina Arboretum in the Bent Creek Experimental Forest as shown in Figure 1. These different practices illustrate low-impact development practices to slow, treat and cool stormwater. Generally, low-impact development treats stormwater with a variety of different practices (Perrin, et al., 2009). These practices treat stormwater by fostering natural interactions between bacteria, plant roots and high infiltration soil to transform, sequester and treat stormwater to benefit the health, safety and welfare of the public. The combination of these techniques and practices is generally referred to as LID where natural resource analyses and planning guides development suitability (Ndubisi, 2002) and retrofit opportunities. These strategies help reverse negative impacts through planning and the implementation of appropriate structural and non-structural practices to treat stormwater and wastewater close to its source.

Two areas at TNCA are particularly noteworthy examples of integrated management practices to demonstrate LID techniques and practices to improve water quality through natural processes to slow, treat and cool stormwater runoff from impervious surfaces. These sites were developed according to the North Carolina Arboretum Master Plan. After the site inventory phase was completed, careful analysis informed the planning and design process to reconcile a variety of goals, which included making LID demonstration a primary focus. On both sites, stormwater is treated by multiple practices in series. These different practices sequester, transform or treat constituents like sediment, nutrients, heavy metals, and bacteria. Stormwater runoff flows through multiple practices prior to leaving the site through evapotranspiration, infiltration or runoff. By mimicking natural, hydrologic and nutrient cycles, many other benefits can be realized that offset impacts from impervious surfaces. In addition to contributing to a diverse landscape setting and enhancing education outreach opportunities, these practices enhance habitat potential. A corresponding website reports on FBTC demonstration projects and education activities through a list serve. It also includes project descriptions as shown in Figure 2.

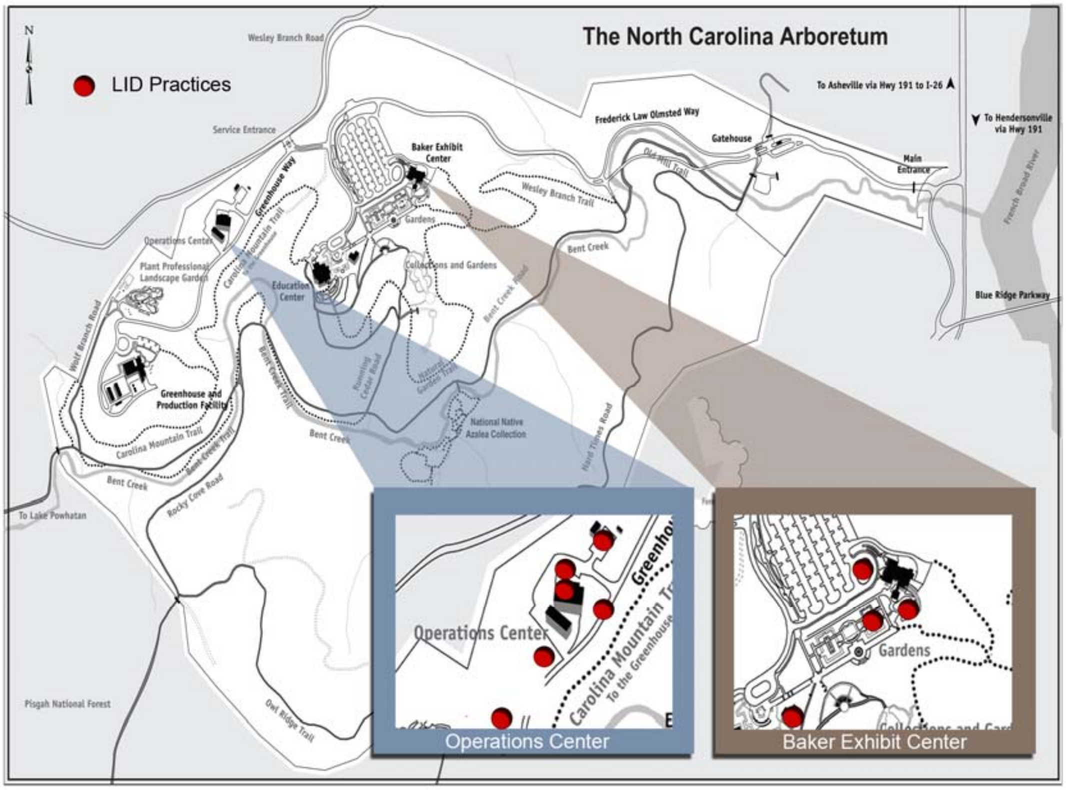

FIGURE 1: Demonstration projects on 175 hectare campus (Credit: Megan Mailloux)

The website includes project descriptions georeferenced with a .kmz file to allow users to navigate across sites and has linked project descriptions, like the image below (http://www.bae.ncsu.edu/programs/extension/wqg/frenchbroad/, accessed Oct 2, 2009):

STORMWATER BMP

The Baker Exhibit Center Rain Garden
The North Carolina Arboretum
Asheville, North Carolina

This feature is prominently located at the North Carolina Arboretum's gateway for visitors, the Baker Exhibit Center. The rain garden captures water from the Baker Center events lawn and portions of the building and parking area. The events lawn was designed as a primary treatment with water infiltrating through the turf, Stalite media, and into perforated pipes that drain into the rain garden at the arrival area. In the rain garden, stormwater receives a second treatment as the water is slowed, cooled, and treated with natural processes in the plants and soil. Education and direct interpretation of this highly visible site is accomplished through workshops, conferences, tours and indirect signage.

FIGURE 2: Example Project Description (Credit: Megan Mailloux)

2.1.1 Low Impact Development Demonstration at the Baker Exhibit Center

The Baker Exhibit Center is the gateway and arrival area for the over 230,000 annual visitors. This project is located on a hilltop and features several cisterns, rain gardens, turf reinforced swales, and a converted sediment basin that slows, treats and cools stormwater. Several of these features drain from one to another and maximize stormwater treatment because different features treat different constituents. For example, rain gardens may sequester sediment and heavy metals, but stormwater wetlands are more efficient at treating nutrients. Additional benefits of storing water include using it for supplemental irrigation. At this site, harvested water can be used for craft demonstrations that include dye making because rain water is preferred to treated water.

2.1.2 Low Impact Development Demonstration at the Operations Center

The second comprehensive LID site is located at the Operations Center and was the pilot example for the Triangle J. Certified building in the University System of North Carolina. The Operations Center houses all of the necessary functions to manage the 176 hectare (434 acres) campus. In addition to geothermal heat wells, solar boosters, and passive solar design, the building features a modest vegetated roof. The site has additional features where stormwater flows through at least two of the following practices before draining into a level spreader. Permeable parking, rain garden, stormwater wetland pockets, and turf reinforced vegetated swales work together to treat stormwater prior to draining into a jurisdictional wetlands that feeds Bent Creek, a trout stream and well used recreational area.

2.2 Integrated Management Practices Evaluation

Several demonstration projects are being evaluated to determine hydrologic budgets, changes in constituent loading and plant species trials. Although many of the practices were constructed for demonstration, components of these practices were constructed differently to optimize efficiency and test leaching of different materials, such as substrates and compost mixes for structural soils. Findings from some of the comparison and efficiency studies have informed design refinements to improve these practices. Local post construction evaluation studies concluded that LID practices can effectively treat stormwater (Cates et al., 2009; Line et al., 2008). Also, indigenous plants are currently trialed in these different features and will be evaluated for survivability. These projects and accompanying research, which is described in more detail below, underpin direct and indirect stakeholder education efforts to increase their awareness about treating water quality.

3 EDUCATION

Without awareness of water quality issues, many degraded streams may remain impaired and not comply with state and federal rules that seek to improve surface waters. Suitable interdisciplinary efforts can improve water quality. Once landowners and the public are aware, they can request that consultants, contractors and maintenance professionals employ the latest scientifically based information. The FBTC has offered education events to raise awareness about water quality issues and also offered research based information to help plan, design and construct low impact development features to meet stakeholder requests.

Educational efforts seek to increase awareness and offer solutions to improve water quality. At the site scale, interpretation of these features includes direct and indirect educational efforts based on the demonstration models practiced by land grant institutions for almost a century. Direct education consists of a variety of educational formats such as presentations and field tours. Indirect education utilizes other formats, such as signage, to communicate concepts and the project history to participants.

3.1 Direct Education

A variety of direct educational opportunities have occurred over the past decade and generally consist of tours, field days, workshops and conferences. During 2009, over 1,600 participants took part in educational offerings, totaling approximately 4,600 contact hours. The chart below describes participants across the different education modes in Figure 3.

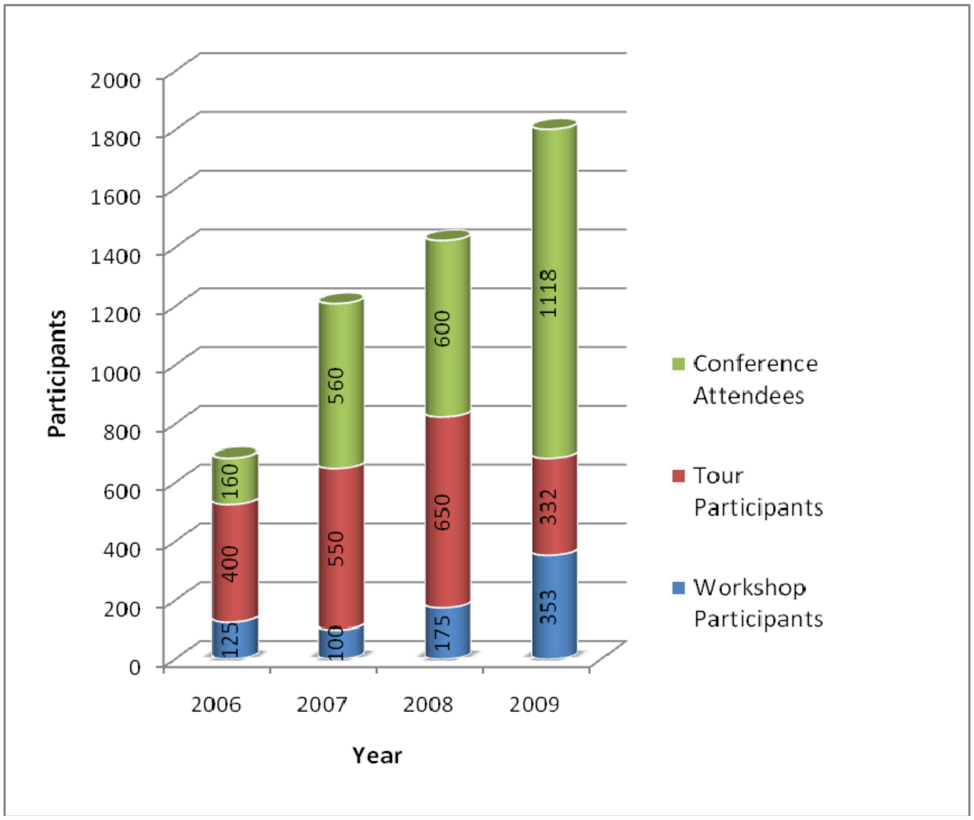

Figure 3: Number of participants by educational mode (Credit: Carter Cone)

Tours and field days generally center around the structural best management practices located at The North Carolina Arboretum and are tailored for specific audiences. For example, field days demonstrating sediment and erosion control technologies and practices cater to audiences that included grading contractors as shown in Figure 4, while other field days target the green industry professionals. Workshops are longer than field days and involve class work and field trips after lunch to reinforce concepts learned during class. Examples of workshop topics include rain garden design and construction, aggressive exotic vegetation removal and monitoring of structural best management practices. Several conferences have also been held at the North Carolina Arboretum. These conferences last several days and include training on low-impact design, conservation, land stewardship and management (Cone et al., 2009).

Figure 4: Typical field tour by Carter Cone

3.1.1 Evaluating Education

Evaluating the effectiveness of educational events is helpful to reporting participant satisfaction and changes in knowledge to grantors and other stakeholders concerned with the quality the educational events. This information also identifies needs for future educational efforts. The FBTC has used several types of the evaluations to document change in awareness or knowledge as a result of education trainings. The most common evaluation captures the participants' opinion of the course material or content, appropriateness of material, quality of the speakers, facility, etc. Occasionally, pre-and post-questionnaires are administered to ascertain changes in the respondents' awareness or knowledge, presumably due to the educational event. A pre-test is given before the educational event, then directly afterward, a post test is given. Appropriate statistical tests, such as the Wilcoxon Signed Rank Tests, are used to determine the direction and magnitude of change in awareness (de Vaus, 2002; Ott & Longnecker, 2001). These evaluations of educational outreach demonstrate improvements in awareness and also documented that respondents were satisfied with the educational experience (Calabria et al., 2010).

3.2 Indirect Education

Indirect education consists of permanent signage, brochures and fact sheets. One example of interpretive signage illustrates the construction sequences of rain gardens or stormwater wetlands to help the viewer understand the various steps that occurred in the construction process at that particular site. Several interpretive signs are mounted adjacent to these features and reference consistent photo points over time, like the Baker Exhibit Center Rain Garden sign as shown in Figure 5. The interpretive panel overlooks the rain garden and illustrates the rough grading, backfilling with suitable structural soil, planting and monitoring components (Figure 6).

Figure 5: Interpretive signage installation at the Baker Exhibit Center

Figure 6: Interpretive signage (Credit: John Bubany)

4 RESEARCH

The FBTC has worked with other partners to extend research-based information regarding bioengineering, monitoring of stormwater practices and further refined impervious cover impacts to aquatic systems in the Southern Appalachian Mountains within North Carolina, USA.

4.1 Bioengineering

Live stakes are a bioengineering method to stabilize stream banks in the dormant season following enhancement or restoration activities that usually include disturbance through rough grading. Live stakes are generally used because they are easier to harvest, install and more resistant to eroding than bare root or container plantings. The French Broad Training Center partnered with NCSU's Horticulture Department to conduct survivability studies and concluded that a popularly suggested species, Black Willow (*Salix nigra)*, performed poorly compared to other species, such as Silky Dogwood (*Cornus amomum*) and Ninebark (*Physocarpus opulifolius*) (Calabria et al., 2006). Although black willow was commonly specified for bioengineering, several engineers, landscape architects and biologists are now specifying Silky Dogwood, Ninebark and other plants to increase survivability and biodiversity. Local nurseries and plant suppliers are able to harvest and supply these materials, which contributes to their profit since the dormant season, when this plant material is harvested, is traditionally a less demanding time in the industry.

4.2 Impervious Cover Impacts

Several research projects suggest that imperviousness of catchments affects aquatic systems in headwater stream systems. A polynomial model of imperviousness by a stream health index explained much of the variability, which is supported by other studies such as the revised impervious cover model and the urban intensity index (Cuffney et al., 2005; Schueler et al., 2009). These data are specific to headwater catchments in the southern Appalachians and can be used by regulatory and design professionals to inform guidance on mitigating impervious area impacts (Calabria et al., 2009).

5 DISCUSSION

The contributions of FBTC are evident in a variety of ways, which include contributions of scientifically based information to many professionals, regulators, natural resource managers and landowners to improve water quality, particularly at a site scale. This interdisciplinary approach has reached a wide-ranging audience to address the complex issues associated with improving water quality. The program's effectiveness may rest on educating a broad audience. If homeowners, landowners, developers and regulators are not aware of techniques and practices to preserve and improve water quality; they will unlikely commission or compel planners, design professionals, engineers and contractors to design and implement these practices. Alternatively, professionals should be educated to meet these requests. The education process may be more successful if clients, land and home owners, developers and regulators begin to ask those who can design, implement and design (landscape architects, engineers) to meet those requests. Anecdotally, past workshops that offered education to broad audiences with different skill sets and professions may be less effective than educating audiences from similar disciplines, unless the diverse professional group can interact and form cross disciplinary ties. Either way, audiences have been generally pleased with the relevancy and delivery of the material. Respondents who attended educational events have reported their satisfaction with educational events and data analysis shows significant increases in awareness about concepts and resources related to water quality (Calabria, et al., 2010).

In addition to the interpretation of these practices, results from monitoring has led to design refinements and also expanded the marketability of indigenous plants to improve water quality treatment. Without the remarkable efforts of the staff of the FBTC and The North Carolina Arboretum; and external funding from local sources such as the Pigeon River Fund, state sources such as North Carolina Department of Environment and Natural Resources' Division of Water Resources and federal sources like the Environmental Protection Agency, United States Department of Agriculture and AmeriCorps program, it is unlikely that a decade of Low Impact Development practices and accompanying education programs would have increased the awareness of as many participants.

6 CONCLUSION

The success of the FBTC results from conveying research-based information to a variety of disciplines by interpreting demonstration projects to improve water quality. These diverse audiences include natural resource managers, engineers, design professionals, land and homeowners and property associations, realtors, regulatory and municipal and agency staff. Education outreach is necessary to increase awareness about preserving or improving water quality in Western North Carolina. The educational opportunities surrounding these demonstration projects have increased the awareness of participants and broadened their understanding of LID.

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