# ABSTRACT

Title of dissertation: QUANTIFICATION OF THE EFFECTIVENESS OF AGRICULTURAL RIPARIAN BUFFERS TO PROTECT STREAM HEALTH IN MARYLAND'S COASTAL PLAIN AND PIEDMONT REGIONS.

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This research quantified the effectiveness of agricultural riparian buffers to protect stream health in Maryland's Coastal Plain and Piedmont physiographic regions. Easily-obtainable data were used to develop scientific guidance for buffer management strategies. Three data sets were used: the 1998 University of Maryland Agricultural Buffer Survey, the 1996 Smithsonian Environmental Research Center Water Quality Survey, and the 1995-1997 Maryland Biological Stream Survey. Collectively, these data were used to represent baseflow water quality and landscape conditions in agricultural catchments. A set of landscape characteristics describing the agricultural riparian landscape was developed, from which a classification system for agricultural riparian landscapes was developed. The Agricultural Riparian Classification System can identify a subset of sites for targeted research. Additionally, the distribution of agricultural riparian buffers was characterized. Although over 70%

of sites were buffered, because the statewide average buffer width was approximately 49 meters, almost 50% of buffers could not be detected by remotely sensed data with a resolution of 30 meters. Models were developed to predict measures of stream health at a site. Buffers acted differently on instream nitrate concentration, fish IBI (FIBI), benthic IBI (BIBI), and instream physical habitat (PHI). All models indicated that nitrate source terms overshadowed any on-site buffer effects and that Confined Animal Feeding Operations and pastures acted as point sources, overwhelming non-point-source effects. Therefore, livestock best managements practices are critical for the reduction of nitrate to streams. FIBI, BIBI and PHI in the Piedmont region were unaffected by buffer presence, but BIBI and PHI in the Coastal Plain were affected by buffer presence, type and width. Regression tree modeling was able to delineate a range of minimum effective buffer width between 22-38 meters. All measures of stream health in Piedmont systems were controlled by hydrology and geomorphology. Therefore, insofar as buffers can mediate hydrologic effects on flow conditions in a stream, they may indirectly affect FIBI, and BIBI and PHI in Piedmont systems. Because FIBI was not directly affected by buffer presence, use of FIBI to measure success of buffer installation or restoration would give false results.

# QUANTIFICATION OF THE EFFECTIVENESS OF AGRICULTURAL RIPARIAN BUFFERS TO PROTECT STREAM HEALTH IN MARYLAND'S COASTAL PLAIN AND PIEDMONT REGIONS

by

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# DEDICATION

For Daddy.

Now you’ll have to address me as Dr. Honey.

And Gary

We had, perhaps, the perfect mentor-student relationship,

and I hope to continue as your professional associate and friend.

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# CHAPTER 1

# INTRODUCTION AND LITERATURE REVIEW

## BACKGROUND

Habitat is being altered throughout the world at an alarming rate. Natural regimes are altered by anthropogenic modifications to landscapes. Human-induced changes often alter aquatic environments by changing the amounts and distribution of water, sediment, and nutrients released from the modified landscapes. These changes in turn create responses in physical, chemical, and biological processes in streams and rivers that are ultimately manifest in the biotic community (Imhof et al., 1996).

In 1983, concern about worsening water quality in the Chesapeake Bay led to the formation of the Chesapeake Bay Program (CBP), a multi-jurisdictional cooperative effort to restore the nation's largest estuary. The Chesapeake Executive Council set restoration of the Bay's "living resources" as a primary goal in 1987. To achieve that goal, it called for a number of actions to improve water quality, including a 40 percent reduction in the amount of nitrogen and phosphorus entering the Bay (Alliance for the Chesapeake Bay, 1993).

Recognition that human alteration of the landscape causes diffuse and significant sources of water pollution has achieved widespread acceptance over the past decade. Accordingly, the general approach to watershed protection has shifted from a focus on point-source pollution control to non-point-source (NPS) pollution control. These efforts emphasize implementation of Best Management Practices (BMPs) for pollution reduction.

Agricultural is a significant contributor of NPS nitrogen to the Chesapeake Bay (EPA, 1983). Agricultural riparian buffers are considered important components of these management efforts because of the limitations of other best management practices for NPS pollution control and because they are generally recognized for their abilities to reduce NPS pollution and stabilize stream systems (Chesapeake Bay Program, 1996). Riparian forest buffers (RFB) were singled out in part for their nutrient reduction capabilities, but also because they were reminiscent of the natural landscape in which the stream channel and stream ecosystems of the Bay watershed had evolved.

There are several programmatic indications of the trust in agricultural riparian buffers to mitigate pollution in the Chesapeake Bay watershed. In 1994 the Executive Council issued Directive 94-1, a set of goals and actions to increase the focus on riparian stewardship and to enhance efforts to conserve and restore riparian forest buffers (Alliance for the Chesapeake Bay, 1996). In October 1996, the Executive Council of the CBP established a goal of restoring riparian forest buffers on 2010 miles of streams in the Chesapeake Bay watershed by 2010 (Chesapeake Bay Program, 1999). The Conservation Reserve Program (CRP) and its enhancement, the Conservation Reserve Enhancement Program (CREP), were established in Maryland to provide enhanced incentive funds to farmers who restore wetlands and stream buffers on environmentally sensitive lands (Chesapeake Bay Program, 1999). In May of 2002, the CBP published nutrient reduction estimates for various management plans in the Chesapeake Bay watershed. One plan estimated reduction of 62 million pounds of nitrogen per year through "maximum participation" in current voluntary pollution reduction programs (Blankenship, 2002). Projected implementation and effectiveness of agricultural riparian buffers was a major portion of this pollution reduction estimate.

## GOAL OF THE STUDY

The goal of this study is to determine the effectiveness of agricultural riparian buffers to mitigate the effect of agricultural pollution on physical, chemical and biological measures of stream health, using easily- obtainable data. There are numerous government-sponsored data sets that contain a vast amount of information, and can possibly be exploited to answer questions beyond the original scope of the survey. The Maryland Biological Stream Survey data is a prime example: it is a large environmental data set that contains information on riparian settings in Maryland.

## GENERAL BENEFITS OF RIPARIAN BUFFERS

Widespread recognition of riparian areas as unique ecosystems can be traced to the late 1970s. Riparian ecosystems were identified by Ewel (1978) as having two essential characteristics: laterally flowing water that rises and falls at least once within a growing season and a high degree of connectedness with other ecosystems. Since that time, riparian buffers have received much attention for their role in stream ecosystem function, including their capacity to mitigate NPS pollution. Streamside forests are extremely complex ecosystems that help provide optimum food and habitat for stream communities (Vannote et al., 1980; Naiman et al., 1988; Gregory et al., 1991; Naiman and Decamps, 1997; Correll, 2000; Stewart et al., 2000). Whereas energy and material are exchanged between terrestrial and aquatic ecosystems via meteorological, geologic, and biological vectors, the riparian zone forms a permeable, but influential, boundary that serves as a vector interceptor and moderator of sediments, allochthonous nutrients, temperature and bank erosion (Likens and Bormann, 1974). The riparian buffer vegetation impacts stream health in all areas of description – physical, chemical and biological (Correll, 1996; Tabacchi et al., 1998). Because forested riparian buffers serve as a primary source of nutrients to low-order streams, it can perhaps be said that riparian forest buffers are the single most critical element of these ecosystems. The energy flow that drives these ecosystems is derived from and mediated by the land-based vegetation of the riparian forest buffer. Leaf-fall and woody debris provide the basis of the food chain in the form of detritus. Canopy characteristics can have a strong influence on shredders and detritivores by altering the quality and abundance of detrital inputs (Egglishaw, 1964; Molles, 1982; Corkum, 1992). Overhanging vegetation mediates the amount of sunlight energy reaching the stream, thereby mitigating thermal impacts and limiting growth of instream vegetation. Branches, roots and other tree parts that fall into the stream channel provide shelter for instream inhabitants, retain sediment, and contribute to the maintenance of habitat diversity through the development of riffles and pools.

Streamside vegetation also contributes to channel stability and shape by holding bank sediment and reducing erosion during periods of high flow (Ormerod et al., 1993). Offstream riparian vegetation provides additional vegetation that increases the organic content and infiltration capacity of the soil, thereby contributing to denitrifying conditions that reduce nitrogen inputs in groundwater moving to the stream (Lowrance et al., 1984, 1997; Correll, 1996; Barling and Moore, 1994). This offstream vegetation also serves to filter and slow sediment and surface flow moving toward the stream (Osborne and Kovacic, 1993). Thus riparian buffers serve to mediate the energy- and mass- flow interactions between small streams and the extended landscape systems of which they are a part. Careful management of riparian area therefore offers a strategy for buffering streams from a variety of land use impacts while still allowing land use to continue over the broader landscape.

## ENVIRONMENTAL CONTROLS ON INSTREAM NITRATE CONCENTRATION

In a seminal paper on watershed hydrology, Hynes (1975) stated that the behavior of aquatic ecosystems and associated hydrologic characteristics are derived primarily from the basin they drain. The physical and chemical characteristics of a stream are controlled by physical watershed characteristics and the interaction of precipitation, surface runoff, and groundwater with this matrix of watershed characteristics (Larsen et al., 1986; Hughes and Larsen, 1988; McMahon and Harned, 1998). Numerous studies have indicated that land use/cover can play an important role in determining stream water quality. Despite uncertainties in measuring and predicting the effects of agricultural land use, it is clear that agriculture has played an important role in the recent increases in nutrient delivery to coastal waters and the consequent acceleration of eutrophication.

Agriculture is considered a major source of nutrient discharge from the watershed of the Chesapeake Bay (EPA, 1983; Alliance for the Chesapeake Bay, 1993). Numerous studies have shown that watersheds with greater proportions of agriculture discharge greater amounts of nitrate-nitrogen in their surface streams (Loehr, 1974; Dillon and Kirchner, 1975; Hill, 1978; Omernik et al., 1981; Beaulac and Teckhow, 1982; US EPA, 1990; Correll, 1983; Peterjohn and Correll, 1984; Roberts and Marsh, 1987; Haith and Shoemaker, 1987; Osborne and Wiley, 1988; Neill, 1989; Correll et al., 1992; Nearing et al., 1993; Tim et al., 1995; Hunsaker and Levine, 1995; Bohlke and Denver, 1995; Taraba et al., 1996; Freifelder et al., 1998; USGS, 1999).

Beyond the effect of general agricultural land use, several researchers have found that row-crop agriculture is an important predictor of chemistry variables in groundwater (Correll et al., 1992) and receiving streams (Correll et al., 1994; Richards et al., 1996; Taraba et al., 1996; Jordan et al., 1997a, b, c). In particular, Taraba et al. (1996) found nitrate-nitrogen in discharge water from agricultural watersheds in Kentucky to be linearly related to percent row crops. Jordan et al. (1993, 1997c) found dramatic differences in watershed discharges related to the proportion of cropland. By their estimation, in Coastal Plain settings, cropland discharged 20 kg N /ha/yr, pasture discharged 5.8 kg N /ha/yr and forest discharges 1.4 kg N /ha/yr. In contrast, they found discharges of phosphorus were not correlated with land use. Modeling work performed by Gburek and Folmar (1999) demonstrated that baseflow nitrate concentration could be accurately modeled as a function of agricultural land use categories. Based on a one-time sampling of baseflow in an agricultural watershed of the Valley and Ridge Province, they modeled nitrate suing a multiple linear regression equation as

$$NO_3\text{-}N\ (mg/l) = [(1.0)(\%\ forest) + (8.0)(\%\ rotation) + (20.0)(\%\ corn) + (10.0)(\%\ pasture) + (30.0)(\%\ animals)] / 100 \qquad (1.1)$$

A relatively small number of researchers found streamwater discharge of nitrate to be poorly correlated with cropland. Lowrance and Leonard (1988) found that nitrate was not correlated to percent of spring-planted row crops, but correlated with land in winter wheat, which is fertilized in late fall or early winter. Jordan and Weller (1996) reported that for larger drainage basins (0.2 - 1.3 x $10^5$ $km^2$), nitrate was poorly correlated with cropland, but highly correlated with a finer analysis considering anthropogenic input of nitrogen from atmospheric deposition, fertilizer application, and nitrogen-fixing crops.

Agricultural practices may also contribute to differences in nitrate-nitrogen discharge from agricultural watersheds. Weil et al. (1990) found significantly higher nitrate-nitrogen in groundwater under irrigated Coastal Plain soils treated with poultry manure than under unmanured fields. Angle et al. (1993) found that soil nitrate concentrations were consistently lower under no-tillage fields compared to conventional tillage. These results indicated that the use of no-tillage cultivation might reduce nitrate leaching beyond the crop root zone.

Physiographic setting has also been shown to affect differences in nitrate-nitrogen discharge from agricultural watersheds McMahon and Lloyd (1995) found that streams in Coastal Plain agricultural basins had higher nitrogen and phosphorus concentrations than non-Coastal Plain agricultural basins. However, fields and planted acreages were larger, and absolute amounts of fertilizers used were larger. In a later study, McMahon and Harned (1998) reported that agricultural basins in the Coastal Plain with medium drained soils had the highest nitrogen and phosphorus concentrations. Jordan et al. (1997a) also found dramatic differences in watershed discharges related to both land use and location within the Coastal Plain.

Concern about worsening water quality in our Nation's waters has prompted considerable research on the ability of buffers to mitigate the effects of agricultural NPS pollution. Two papers focused on the ability of riparian buffers to reduce nitrate in groundwater flowing laterally through the buffer spearheaded these efforts. Peterjohn and Correll (1984) and Lowrance et al. (1984) identified agricultural riparian buffers as critical areas in stream ecosystems, able to retain as much as 90 percent of the nitrate-nitrogen in upland groundwater moving into the forest from an upland agricultural field. This early work did not determine the mechanisms for this reduction. Since that time, the significance of temperate riparian forests as nitrate removal areas, and therefore as barriers to the efficient export of nitrate to the adjacent stream, has been well documented (Lowrance et al., 1984, 1997; Peterjohn and Correll, 1984; Gilliam and Skaggs, 1988; Groffman and Teidje, 1989; Correll, 1991;

Correll et al., 1992; Groffman et al., 1993; Haycock and Pinay, 1993; Jordan et al., 1993, 1997 a, b, c; Pinay et al., 1993, 1993; Fennessy and Cronk, 1997; Snyder et al., 1998; Creed and Band, 1998). The vast majority of research reported in the literature has been conducted on Coastal Plain riparian forests, which are typically located on well-drained uplands above poorly drained riparian forests (Jordan et al., 1993).

These studies were typically conducted in conditions where shallow aquicludes forced groundwater to flow laterally through forest soils. Under these conditions, riparian forests acted as nutrient sinks, retaining 70 to 90 percent of the total nitrogen inputs, which entered mainly as nitrate in subsurface discharges from adjacent cropland (Jordan et al., 1997a). The mechanisms of nitrogen removal by riparian forests were not completely understood, but much of the nitrogen removal was believed to be due to denitrification, since these forests demonstrated denitrifying conditions, and nutrient retention has been shown to be primarily a belowground process.

Riparian effectiveness to reduce nitrate in groundwater has been found to reflect both temporal and physical factors. Groffman and Tiedje (1989) documented differences in excess of a factor of 10 in the rates of denitrification in riparian soils. During brief periods in the spring and autumn, daily rates of denitrification exceeded 0.5 kg N/ha/d. Annual denitrification rates ranged from less than 1 kg N/ha/yr in well-drained sandy soils to over 40 kg N/ha/yr in poorly drained clay loam soils. Bohlke and Denver (1995) found reduced effectiveness of riparian forests on dissolved nitrate in Coastal Plain watersheds where groundwater flow followed relatively deep flow paths before converging and discharging rapidly upward to the stream.

## MODELS TO PREDICT INSTREAM NITRATE IN AGRICULTURAL AREAS

Whereas these studies used an empirical approach to delineate buffer function, another approach to investigate the effect of riparian buffers on water quality has been to develop a physically explicit model. Models allow researchers to test their knowledge about the behavior and functioning of environmental systems. Phillips (1989) generated a physically explicit Riparian Buffer Delineation Equation to predict buffer widths for removal of 90 percent of nitrate from runoff typical of 50 acres of row crops. This model predicted effective widths from 5 to 93m, based on soils and other conditions. The Riparian Ecosystem Management Model (REMM) is another physically explicit riparian model that has been in development and testing for many years (Lowrance and Shirmohammadi, 1985; Inamdar et al., 1999, 1999; Lowrance et al., 2000). This model quantifies groundwater nitrate reductions by riparian buffers under varying site conditions. Both of these models are extremely data intensive and are limited to field scale effects on groundwater passing through a riparian buffer.

A landscape approach to wetland function has been suggested in order to make reasonable decisions about how any particular wetland might affect water quality parameters on a broader scale (Whigham et al., 1998) and, in fact, several studies predicting water quality from landscape and riparian buffer characteristics have been conducted. This landscape approach has indicated that location within the watershed appears to play a key role in riparian effectiveness. Riparian areas that border uplands appear to be more important for nitrogen processing and retention of large sediment particles (Whigham et al., 1998). Although Osborne and Wiley (1988) found riparian areas to be important areas for nitrate processing, they cautioned that although riparian forests in the lower part of watershed can limit nutrient inputs from immediate surrounding areas, they have no effect on mitigating inputs from upstream.

In many studies, nutrient concentration in streams was more strongly related to catchment-wide land use and geology than riparian corridor characteristics (Omernik, 1976; Omernik et al., 1981; Osborne and Wiley, 1988; Close and Davies-Colley, 1990; Hunsaker and Levine, 1995; Richards et al., 1996; Herlihy and Kaufman, 2000). Some studies attributed their results to the use of low-resolution land use/land cover data (Richards et al., 1996). Most recently, however, the Mid-Atlantic Remote Sensing Atlantic Coast (RESAC) Program and the University of Maryland performed a study to identify and assess riparian forest buffers in Montgomery County, Maryland, using extremely high-resolution remotely sensed (RS) data (resolution of 4 meters). The extent of riparian buffer coverage was compared with watershed water quality. Even at this level of resolution, the relationship between water quality and watershed riparian buffer became significantly different only at an alpha of 0.20 (Zinecker et al., 2001).

In other studies, riparian characteristics explained more variation in water chemistry parameters than whole watershed data, indicating that some water quality parameters can be modified by local riparian conditions (Osborne and Kovacic, 1993; Johnson et al., 1990; Tufford et al., 1998). Tufford et al. (1998) conducted a Geographic Information System (GIS) study in which buffer zones of set widths were constructed around the streams and land use/land cover were related to pollution levels in stream.  Land use within a 150-m zone around the stream was the best predictor of nitrate-nitrogen concentrations in the stream, with $R^2$ values from 0.25 - 0.63.  Basnyat et al. (1999) conducted a similar study, but instead of using set boundary widths for the riparian zone, they identified "contributing zones" using GIS tools and RS data. Models were then constructed and evaluated at three scales: basin scale, contributing-zone scale, and stream buffer/riparian zone scale.  Regression results at the stream buffer scale suggested that water quality was highest when passive land uses, such as forests and grasslands are located adjacent to streams.

Several models have been developed to evaluate water quality effects of alternative watershed land use and management strategies.  The advent of GIS methods has allowed water quality models to be coupled with landscape information to provide a means for describing variable conditions throughout a watershed.  The hydrologic submodels of existing distributed watershed models such as the Hydrological Simulation Program - Fortran (HSPF) (Johansen et al., 1983) and the Soil and Water Assessment Tool) (SWAT) (Arnold et al., 1998) are conceptually based and not physically based.  These models all require intensive site-specific parameter calibration.  Nikolaidis et al. (1993) developed the Nutrient Transport and Transformation Model (NTT-Watershed), a physically based model used to design riparian buffers for NPS pollution control.  Heng and Nikolaidis (1998) simulated nitrogen dynamics in a predominantly forested watershed.  Osmond et al. (1997) developed WATERSHEDSS, a prototype GIS-assisted model to aid in the management of predominantly agricultural watersheds.  Perry et al. (1999) used the “SPANS” model to determine the water quality impact of different riparian forest management scenarios in a highly agricultural watershed. Riparian effects were modeled by extrapolating field-scale measurements on riparian forest buffer capacity to the watershed scale. While providing results, all of these models assume linear relationships between forces acting at the local and watershed scales, are highly technical, and data-intensive.

The differences in conclusions from empirical studies indicate that the influences of landscape factors on streams are complex and probably operate at both site (field scale) and watershed scales. Most studies have focused on reducing sediment and water-borne pollutant loads under controlled field-plot experiments. However, the water quality impact of riparian buffers clearly depends on their location and interaction with other watershed elements as well as on their physical characteristics (Vandervalk and Jolly, 1992; Whigham et al., 1998). The degree of pollution reduction can be expected from the installation of buffers remains unclear; in fact, no research has been done to demonstrate the change of in-stream levels of pollutants in response to conversion of riparian land from crops to buffers (Dosskey, 2000).

There are now over 700 publications on the water quality functions of riparian buffers (Correll, 2000) and yet the cumulative effectiveness of riparian buffers in reducing NPS pollution in agricultural watersheds has not been fully established. The problem is twofold. Most research is performed on small areas, at the field or site scale, where as management decisions are made at the watershed scale or larger. Secondly, most research is concerned with the effect of buffers on nitrate in groundwater nitrate, whereas most management problems are concerned with levels of instream nitrate.

## ENVIRONMENTAL CONTROLS ON INSTREAM COMMUNITIES – FISH AND MACROINVERTEBRATES

Living resources, not nutrients, are not the final concern in the management of ecosystems. Current management strategies are incorporating results of biological assessments into decision-making. Rapid bioassessment techniques that qualify the health of instream communities are being used to assess water conditions and impacts of stream restoration efforts and land use decisions. Therefore, understanding controls in the instream communities that are used to assess stream conditions is critical to properly assess their usefulness as a guidance criterion for management decisions.

Significant questions exist concerning the scale of the primary regulating mechanism(s) for instream communities. By the late 1990s, the importance of large-scale land use and catchment characteristics as determinants of stream assemblages was recognized. Johnson and Gage (1997) suggested that upland structure and land uses beyond the riparian zone are the primary regulators of instream community structure and processes. Richards et al. (1996) suggested that the influence of landscape cover characteristics throughout the basin might be as important as riparian vegetation for understanding stream ecosystems.

Several studies have sought to identify the predominant environmental factors that control stream macroinvertebrate communities (Richards et al., 1993, 1996, 1997;

Collier, 1995; Bunn et al., 1999; Lammert and Allan, 1999) and fish communities (Frenzel and Swanson, 1996; Hall et al., 1996). There is considerable evidence to suggest that both the quality and quantity of available habitat affect the structure and composition of resident biological communities (Maddock, 1999). Several studies demonstrated strong associations between agricultural land use and alterations in stream habitats that cause compositional changes to stream communities (Lenat, 1984; Corkum, 1989, 1990; Quinn and Hickey, 1990**;** Roth et al., 1998; Allan et al., 1997). Several studies have sought to distinguish the relative effects of riparian influence versus the extended landscape. The influence of stream buffer regions on stream habitats and biota has been shown to vary significantly and does not always follow distinct trends (Johnson and Gage, 1997).

Aquatic communities are affected by geologic, geomorphic, hydrologic and riparian conditions, but the relations are aquatic community dependent. Several studies have shown that fish and macroinvertebrates appear to respond differently to landscape and habitat variables (Lammert and Allan, 1999; Fitzpatrick et al., 2000; Herlihy and Kaufman, 2000). Plafkin et al. (1989) suggested that macroinvertebrates are indicative of local habitat conditions while fish reflect conditions over broader spatial areas because of their relative mobility and longevity. The mobility of fish and their possible linkage into larger metapopulations may reduce their sensitivity to the variability of stream habitat (Schlosser and Angermeier, 1995). Thus it might be expected that indexes based on macroinvertebrates give somewhat different indications of stream condition than indexes based on fish.

Lammert and Allan (1999) related biotic condition to patterns of land use and channel structure for 18 sites in an agricultural watershed in Michigan. They used multiple linear regression to add instream habitat variables to land use variables in order to explain variation in biotic integrity scores. Fish showed a stronger relationship to flow variability and immediate land use, while macroinvertebrates correlated most strongly with dominant substrate. Their results suggested that riparian land use and instream habitat were not independent variables, supporting the hypothesis of Frissell et al. (1986) that the regional configuration of a watershed constrains the local structure.

Other studies have documented influences other than land use that show significant effects on instream biotic communities. Fish assemblages have been found to be affected by hydrology and hydraulics (Poff and Allan, 1995), stream order (Osborne et al., 1992), riparian grazing (Armour et al., 1991; Wohl and Carline, 1996), percent cropland in the watershed (Frenzel and Swanson, 1996), riparian characteristics (Fitzpatrick et al., 2000), and nutrients (Miltner and Rankin, 1998). The benthic macroinvertebrate community has been shown to be affected by riparian grazing (Armour et al., 1991; Wohl and Carline, 1996), stream width ((Richards et al., 1996), nutrients (Miltner and Rankin, 1998), and past land use (Harding et al., 1998). Measures of these environmental determinates are often not included in a readily available GIS data sets that focus on land use.

Most recently, a cooperative feasibility study was conducted in 2001 with the US Environmental Protection Agency (EPA) Mid-Atlantic integrated assessment team, Maryland Department of Natural Resources (Power Plant Research Program, Watershed Management and Analysis Division) and Versar, Inc., of Columbia, Maryland. The goal was to develop improved methods for targeting riparian buffer restoration in the Mid-Atlantic. This study used Maryland Biological Stream Survey (MBSS) data from the Patapsco river basin, which is a largely urban area. They found fish Index of Biotic Integrity (IBI) to be significantly related to urban land use, with more variation being explained as the scale of focus was increased from local to riparian to catchment. In contrast, the benthic IBI was found to be strongly affected by local conditions, including riparian buffer width. For a sub-population of sites with greater than 50 percent agricultural land use, there was a 55 percent reduction in the likelihood of a poor or very poor benthic IBI if riparian buffer width was increased from 0 to 30m (Southerland et al., 2002).

## MODELS TO PREDICT INSTREAM COMMUNITIES – FISH

Studies seeking to determine the scale of critical influence on fish communities have shown mixed results. Several studies have shown that watershed land use was a more important determinate for fish communities than the riparian zone (Steedman, 1988; Gregory et al., 1991; Taylor et al., 1993; D'Angelo et al., 1997; Roth et al., 1998; Allan et al., 1997; Lammert and Allan, 1999; Southerland et al., 2002). Roth et al. (1998) found that regional land use was the primary determinant of local habitat and fish communities, able to overwhelm the ability of local riparian vegetation to support high-quality habitat and biotic communities. Correlations were strongest at the catchment scale ($R^2$ = 0.50 for fish IBI vs. percent agriculture, $R^2$ = 0.76 for habitat index vs. percent agriculture), and tended to become weak and non-significant at local scales. Allan et al. (1997) found that extent of agricultural land at the subcatchment scale was the single best predictor of local stream conditions in a highly agricultural watershed in Michigan, with local riparian vegetation a weak secondary predictor of habitat quality and biotic integrity. In contrast, a set of studies by Goldstein et al. (1996) in Minnesota and North Dakota found fish to be more related to aquatic habitat, riparian, and hydrologic conditions than to watershed agricultural land. Steedman (1988) reported that biotic integrity of Ontario streams was related to the proportion of stream channel length with riparian forest coverage. Fitzpatrick et al. (2000) examined correlations among stream biological quality, watershed and riparian land cover, and hydrological characteristics for 25 agricultural streams in Wisconsin. Several spatial scales were found to influence fish communities, but local riparian conditions appeared to be more important than watershed land cover. Lammert and Allan (1999) also found that land use immediate to the stream was more predictive of fish IBI than regional land use, but was less important than instream habitat variables in explaining the variability observed in fish assemblages. Stewart et al. (2000) correlated habitat, fish and macroinvertebrate data for 38 2nd- and 3rd-order warmwater streams in Wisconsin. They found that fish density was positively correlated to the average length of riparian corridors that were greater than 30m in width ($R = 0.42$, $P < .009$), implying that a longer, more continuous, wider riparian corridor is beneficial for fish density in the stream. Herlihy and Kaufman (2000) examined relationships between indicators of instream ecological conditions (chemistry, benthos, and fish) with indicators of local reach riparian condition, watershed condition, and natural drivers (size, elevation, and slope). Multiple regression models showed the fish community to have very weak or no relationship to either watershed or riparian indicators.

Wichert and Rapport (1998) performed the only temporal study. In this study they examined the effects of improved agricultural practices and riparian vegetation on stream habitat and fish community structure over 43 years. Water quality data showed that levels of critical substances in the three study watersheds never reached levels harmful to fish life, but degraded habitat and fish communities. Their findings showed that effects of agricultural BMPs were mixed with effects of riparian vegetation in short term studies, and that changes in fish communities are evident only over long periods of comparison.

## MODELS TO PREDICT INSTREAM COMMUNITIES – MACROINVERTEBRATES

The current interest in the use of fish IBI as a criterion to judge stream restoration or land use management decisions make it of critical interest. Empirical studies have consistently shown that benthic macroinvertebrate communities are strongly influenced by local conditions. D'Angelo et al. (1997) found that local factors had the greatest influence on the invertebrate community, and Richards et al. (1996) suggested that land use features, such as riparian buffers, have strong local influences on stream habitats. Aguiar et al. (2002) also found that riparian features had greater influence than other environmental characteristics on the composition of macroinvertebrate assemblages. Lammert and Allen (1999) found local instream habitat variables to be superior to land use in predicting biotic integrity for macroinvertebrates. Fitzpatrick et al. (2002) examined correlations among stream biological quality, watershed and riparian land cover, and hydrological characteristics for 25 agricultural streams in Wisconsin. They found that, in contrast to fish, benthic communities were influenced more by instream habitat, riparian width and baseflow. They found no significant correlation between measures of macroinvertebrate community and percent of watershed area in row crops. In the study conducted by Stewart et al. (2000) on 38 2nd- and 3rd-order warmwater streams in Wisconsin, agricultural land use located in the 10m to 30m buffer zone was found to be more influential on the macroinvertebrate community than agricultural land use located farther away from the stream. Although Herlihy and Kaufman (2000) found the benthic IBI to be more strongly associated with watershed than riparian conditions for the overall data set, the subset of upland sites showed a stronger correlation between IBI and riparian conditions.

## THE STATE OF RIPARIAN RESTORATION GUIDANCE - PLACEMENT AND WIDTH

Upland vegetated buffers are widely recognized as being necessary to protect wetlands, streams and other aquatic resources, and stream buffer width guidance has been available as far back as the late 1980s (Budd et al., 1987). However, because riparian buffers perform multiple functions, no single recommendation for sizing and management of buffers for practical performance criteria has been found to be suitable for all cases (FISRWG, 1998).

In general, narrower buffer widths are considered adequate for chemical and physical functions, while wider buffers are considered necessary for adequate protection of the biological components of stream ecosystems (Brazier and Brown, 1973; Hewlett and Fortson, 1982; Large and Petts, 1992; Osborne and Kovacic, 1993; Castelle et al., 1994; Haycock and Muscutt, 1995; Alliance for the Chesapeake Bay, 1996). Published width recommendations range from a few meters for temperature control to several hundred meters for recreation (Hewlett and Fortson, 1982; Castelle et al., 1994). At least 15 to 30 meters are believed to be necessary to protect wetland and streams under most conditions (Castelle et al., 1994). Stream buffers less than 50 meters wide can be important for defining elements of stream habitat such as woody debris and shoreline protection (Budd et al., 1987). Buffer width recommendations also depend on the size of the stream, ranging from less than 10 meters for small ditches and streams to greater than 50 meters for large rivers (Haycock and Muscutt, 1995). Adequate widths to provide water quality protection through nutrient reduction are widely variable, ranging from 20 meters (Haycock and Muscutt, 1995) to 90 meters (Castelle et al., 1994). If ecological objectives are to be incorporated into riparian buffer guidance, meeting the minimum area needs of a species, guild, or community is especially important. The minimum area is the amount of habitat required to support the expected or appropriate use and can vary greatly across species and seasons (FISRWG, 1998). However, most width guidance values for "species diversity" do not indicate if the species are terrestrial or aquatic. Finally, riparian influence might be expected to vary with stream order (Vannote et al., 1980; Alliance for the Chesapeake Bay, 1996), which will influence width and placement recommendations.

Three comprehensive sources of stream/riparian guidance have been published. The U.S. EPA authored a multi-year synthesis of current expertise on stream corridor restoration and published the results as a guidebook entitled “Stream Corridor Restoration; Principles, Processes, and Practices” (FISRWG, 1998). The United States Department of Agriculture (USDA) Forest Service published the “Chesapeake Bay Riparian Handbook: a Guide for Establishing and Maintaining Riparian Forest Buffers” (Palone and Todd, 1997). The Maryland Department of Natural Resources (DNR) published a guidance manual on their website entitled “Riparian Forest Buffers: Function and Design for Protection and Enhancement of Water Resources” (Maryland DNR website, 2002). However, all of these publications failed to provide quantitative guidance for the functions and processes of riparian buffers in different settings. Rather, general guidelines for buffer widths of 100 to 300 feet were suggested.

Agricultural systems management and restoration have traditionally focused on site-level strategies (Imhof et al., 1996). Specific guidance for riparian restoration and management has typically been established by political acceptability and not necessarily scientific merit (Castelle et al., 1994; FISRWG, 1998), and often does not incorporate concepts of landscape ecology or clear ecological objectives. Resource agencies are most often responsible for setting buffer size requirements or guidelines.

Buffers are a voluntary BMP, and width recommendations are driven by the buffer function of interest to the funding agency. For example, USDA funds the CREP program in Maryland, and is primarily concerned with the reduction of nutrients in surface water. There are basically two systems for establishment of buffer width guidance - fixed width and variable width buffer systems. Variable width buffer systems have a stronger scientific base, as they consider a combination of buffer sizing criteria, such as functional value, adjacent land use intensity and other site-specific conditions. Unfortunately, variable-with buffer systems require greater expenditure of resources and higher level of training for agency staff, while offering less predictability for land use planning.

## RIPARIAN CLASSIFICATION SYSTEMS

Because physical variation in riparian areas may aid or prevent the interception and transformation of pollutants (Cirmo and McDonnell, 1997; Weller et al., 1998), understanding the underlying natural variation in riparian buffer landscapes can augment interpretation of the impact of land use patterns on aquatic conditions. As the plenary speaker for the American Water Resources Association International Conference on Riparian Ecology and Management in Multi-Use Watersheds, held in Portland, Oregon, in August 2000, Dr. David Correll of the Smithsonian Environmental Research Center stated that "one of the most urgent needs in riparian research is to develop and utilize an adequate system of classification for riparian buffers" (Correll, 2000). Without a comprehensive description of site geology, vegetation, hydrology, and soils, research findings are hard to generalize or extrapolate to other sites (Correll, 2000). Additionally, riparian characteristics that can be readily examined using a GIS format can be combined with land-use and soil maps in order to determine what riparian management alternatives might contribute to decreasing nonpoint source pollution impacts on surface waters (Delong and Brusven, 1991).

A few studies have developed procedures for classifying riparian areas. Most riparian classification systems focus on a few selected attributes of riparian areas, such as hydric soil or hydrophilic plant associations (Dick-Peddie and Hubbard, 1977; Brown et al., 1979; Norton et al., 1980, 1981; Batchelor, 1982; Winward, 1984; Youngblood et al., 1985; Curry and Slater, 1986; Szaro and Patton, 1986; Kovalchik, 1987; Baker, 1989; Padgett et al., 1989; Kovalchik and Chitwood, 1990; Petersen et al., 1992; Durkin et al., 1996; Girard et al., 1997; Alpert and Kagan, 1998; Lyon and Sagers, 1998; Arbuckle et al., 1999). Although these perspectives adequately characterized the terrestrial plant communities, they have provided little understanding of the wide array of ecological processes and communities associated with the land-water interface (Gregory et al., 1991). Additionally, most of these were developed for management agencies such as USDA, US Department of Wildlife, US Bureau of Land Management, and the National Forest System (Cowardin et al., 1979; Youngblood et al., 1985; Pierce and Johnson, 1986; Kovalchik, 1987; Padgett et al., 1989). Therefore, many of these systems were developed for specific settings in the western United States (Colorado, Idaho, Kansas, Montana, Nevada, New Mexico, Oregon, Utah and Wyoming).

Very few systems have expanded the focus of the classification system to include the landscape setting. Kovalchik and Chitwood (1990) added geomorphology to a floristic classification system they had developed in 1987. This resulted in a system that classified riparian sites by location in the landscape (such as a mountainous landform), in the stream system (ex: first-order watershed), by gradient, elevation, fluvial surface (such as v-shaped floodplain), and soil type. Delong and Brusven (1991) developed a classification system that identified riparian characteristics using discrete categorical units to identify agricultural areas prone to erosion. Most recently, Quinn et al. (2000) developed a landscape classification system for large-scale riparian settings in New Zealand. They used a subjective knowledge-based approach to develop classes that reflected similarities in morphology, riparian functions, human uses, and likely riparian management options.

An applicable classification system could enhance efforts to elucidate buffer effectiveness by providing a technique to reduce error in modeling efforts, with subsequently clearer guidance for buffer restoration (placement and width.)

## MARYLAND'S AGRICULTURAL RIPARIAN BUFFERS – AVAILABLE INFORMATION

There are currently no studies in the primary literature describing the state of riparian buffers in Maryland. Current estimates of buffer extent, location, distribution and type are largely based on surveys conducted using RS data (Chesapeake Bay Program, 1996; 1999). As part of the Chesapeake Bay Riparian Forest Buffer

Initiative, a riparian forest buffer inventory was completed for the Bay watershed in 1997. The inventory used the EPA's Environmental Monitoring Assessment Program land cover data (1989-1991) and included an accuracy assessment protocol using aerial photography to verify its reliability. This GIS technology was used to assess the status of riparian areas and to provide a baseline for information on riparian forest buffers in the watershed for state and federal agencies. Maryland was determined to have 26,966 stream km (16,756 miles), with 12,926 stream km (8,032 miles) possessing 30.5 meter (100-foot) buffers on both sides, 14,565 stream km (9050 miles) possessing 30.5 meter (100-foot) buffers on one side, and 12,402 stream km (7706 miles) possessing less than 30.5 meter (100-foot) buffers on one side (Chesapeake Bay Program, 1999).

These remote-sensing studies were used to delineate the extent of riparian buffers, but the resolution of the image (30 m) is greater than the width of many buffers. LandSat earth-orbiting satellites have provided images tailored to resource assessment since 1982. In landscape-level analysis studies, the 30-meter ground resolution has been shown to provide approximately 81 percent accuracy (Hewitt, 1990). However, when the resource to be analyzed is small compared to the pixel size (e.g. narrow stream channels or riparian zones) space data cannot provide accurate information on the resource (Muller et al., 1993). The Mid-Atlantic RESAC Program and the University of Maryland performed a study to identify and assess riparian forest buffers in certain subwatersheds of Montgomery County, Maryland, using high-resolution (4 m) RS data (Zinecker et al., 2002). Whereas the resolution of these data was sufficient for adequate representation of riparian buffers, this imagery was available only for the metropolitan corridor between Washington and Baltimore.

Pollution reduction estimates are dependent upon accurate estimates of buffer extent and watershed-scale impact on nutrient reduction. In 1999, the University of Maryland, the Maryland Agricultural Cooperative Extension Service and the Forestry Division of Maryland's Department of Natural Resources conducted a study entitled "Environmental Benefits and Costs of a Voluntary Riparian Forest Buffer Program". This research sought to provide guidance for voluntary incentive programs in Maryland by determining the water-quality benefit of agricultural RFBs and the level of incentive necessary for the implementation of RFBs in different areas of the state. Due to the lack of adequately accurate information, a fieldwork-based survey of agricultural riparian buffers in Maryland's Chesapeake Bay watershed was conducted as part of this project. This research provided the first extensive, ground-truthed attempt to describe a large set of agricultural riparian buffers, the surrounding land, and to a lesser extent, the land and streams within the buffers.

The only other data set that currently includes extensive, ground-truthed information on Maryland buffers is the Maryland Biological Stream Survey (MBSS). The MBSS has gained national attention in recent years because of the comprehensive, spatially intense nature of the program. Since 1994, the Maryland Department of Natural Resources (DNR) has conducted the MBSS, a comprehensive program to assess the status of biological resources in Maryland’s streams. This annual survey examines the water quality, physical habitat, and biological conditions in first through third order, non-tidal streams (Klauda et al., 1998). Although buffer characterization is not the primary purpose of the survey, the MBSS includes limited site-specific, ground-truthed information on riparian buffers. The results of the 1995-1997 sampling provide the following statewide statistics about Maryland buffers; about 59 percent of all stream miles have forested riparian buffers, 14 percent are buffered by vegetation other than forest, such as abandoned cropland or lawns, 27 percent of all stream miles in the state are unbuffered, and about 40 percent of the forested stream miles have buffers greater than 50 meters wide (Boward et al., 1999).

## MBSS 1995-1997 DATA

Data from the 1995-1997 sampling round have been made publicly available on the Maryland DNR website as Microsoft Excel files. The Guide to Using 1995-1997 Maryland Biological Stream Survey Data contains an explanation of the 1995-1997 sampling design and an overview of laboratory and field methods (Mercurio et al., 1999). More detailed information on methods may be found in the MBSS sampling manual (Kazyak, 1997). The guide describes the contents of each data set. Variables listed in each of the data sets are defined and additional information is provided to assist users in interpreting and analyzing MBSS data.

Approximately 300 75-meter stream segments were sampled each year, with biological, chemical, and physical parameters measured at each segment using standardized methods. Biological measurements included abundance and health of fish, and composition of benthic macroinvertebrate communities. Chemical measurements included pH, acid-neutralizing capacity (ANC), sulfate, nitrate-nitrogen, conductance, dissolved oxygen and dissolved organic carbon (DOC). Numerous physical habitat measurements were assessed including flow, stream gradient, maximum depth, thalweg depth, wetted width, temperature, the number of root wads and woody debris, embeddedness, instream habitat, epifaunal substrate, pool and riffle quality, bank stability, channel flow status, shading, and riparian buffer type and width. The presence of storm drains, effluent discharges, and beaver ponds were also recorded. The aesthetic value and remoteness of each site were quantified based on evidence of human activity at each site. Regional land cover data were used to characterize catchment land uses.

Several indicators of the biological health of the stream sampled were developed from the data collected. A fish IBI and a benthic IBI (Roth et al., 1998; Stribling et al., 1998) were used to assess the condition of both the fish and benthic macroinvertebrate communities by comparing the species assemblages found at each site to minimally impacted reference sites found throughout the state. IBI scores used for the 1995-1997 MBSS are the mean of several individual metric scores and range from 1 (very poor) to 5 (good). A reference-based Physical Habitat Index (PHI) was also developed as a means of summarizing a variety of important habitat metrics (Hall et al., 1999), such as instream habitat, diversity of velocity and depth, and embeddedness.

Klauda et al. (1998) reported the preliminary results of the 1995-1997 MBSS, and concluded that degradation of physical habitat is the primary threat to Maryland's freshwater streams. Several reports documenting MBSS results for specific river basins are available. The results of the first three years (1995-1997) of sampling were summarized for the general public in “From the Mountains to the Sea: the State of Maryland’s Freshwater Streams” (Boward et al., 1999). The survey assessed stream conditions as deviation from minimally impacted expectations and identified likely sources of degradation by delineating basic relationships between biological conditions and anthropogenic stresses. Roth et al. (1999, 1999) developed two technical versions of the 1995-1997 data analysis in "State of the Streams: 1995-1997 Maryland Biological Stream Survey Results" and “Relative and cumulative impacts of stressors on streams: 1995-1997 MBSS results”. Basic comparisons were made between the biological and physical habitat indices and riparian and land use/land cover data at the state- and basin-wide scales. Fish and benthic IBI scores were found to increase slightly with riparian width, but these increases were not significant. Very weak correlations were found between certain measures of the benthic community and measures of instream nitrate. Fish and benthic IBI scores were sensitive to the degree of watershed urbanization, but were less able to detect effects of agriculture at the watershed scale. Limited multiple regression analysis was also performed using each of the IBIs as the response variable and seven pre-determined "stressors" as indicator variables. Width of riparian vegetation at the site was not found to be a significant factor for explaining variation in fish IBI. In contrast, benthic IBI increased significantly with PHI and riparian buffer width.

## SUMMARY OF LITERATURE FINDINGS AND RESEARCH NEEDS

Many riparian functions are well established, but the degree to which riparian buffers can contribute to reduction of pollutant levels in agricultural streams remains to be quantified (Fennessy and Cronk, 1997; Dosskey, 2000). An examination of the effect of agricultural buffers at the watershed scale has not been done in Maryland. Such an analysis requires a trustworthy description of buffers, water quality, and the stream communities in primarily agricultural watersheds. Whereas Roth et al. (1995) looked at riparian effect on water quality and instream communities in Maryland, no work has been done focusing on riparian effect in agricultural settings. In addition, the current body of literature has clearly established that buffer effectiveness varies due to placement and landscape characteristics. Therefore, Maryland policymakers are still without guidance to predict or quantify the effect of riparian buffer management at the watershed-level. Current topics of interest are nutrients, driven by CBP goals, and stream communities, driven by popularity of bioassessment techniques.

Thus, existing work has established a strong framework for the general environmental drivers in these systems. However, the effectiveness of riparian buffers in any particular setting has not been clearly shown. The general approach used to predict buffer effect on instream measures of stream health has been empirical analysis of a data set with or without a spatial component, such as GIS information. This research will construct empirical models as well, because the scale of the question is large.  Easily-obtainable and readily-available data will be used, to establish a protocol that can be used by management agencies.  In particular, buffer effectiveness models will be based on MBSS data, which are publicly-available information based on a rapid assessment technique, and contain ground-truthed information on buffers.

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# CHAPTER 2 –

# CHARACTERIZATION OF AGRICULTURAL RIPARIAN BUFFER LANDSCAPES IN THE COASTAL PLAIN AND PIEDMONT PHYSIOGRAPHIC REGIONS OF MARYLAND


## ABSTRACT

This paper presents the characterization of riparian buffers in agricultural settings within the stream channel, buffer, and adjacent agricultural field on both sides of the stream. The survey was designed to use "easily available data" - fieldwork followed a rapid assessment approach and other landscape data were obtained from publicly available documents and web-based files. The results indicated that almost all sites (93.2%) had some type of buffer and most buffers were forested. Most grass buffers were in the Piedmont physiographic region. Most unbuffered sites were associated with Piedmont pastures where animals had access to the stream, and demonstrated high streambank erosion. Buffers were as prevalent and as wide on the Eastern Shore as the western shore. Buffer width was widely variable. Although the statewide average buffer width for all buffer types was approximately 49 meters, almost 50% of buffers may not be detected by remotely sensed (RS) data with a resolution of 30 meters. This problem was more pronounced in the Piedmont. These

results present the first comprehensive structural characterization of Maryland's Coastal Plain and Piedmont agricultural riparian buffers and their landscapes.

## INTRODUCTION

In 1983, concern about worsening water quality in the Chesapeake Bay led to the formation of the Chesapeake Bay Program (CBP), a multi-jurisdictional cooperative effort to restore the nation's largest estuary. The Chesapeake Executive Council set restoration of the Bay's "living resources" as a primary goal in 1987. To achieve that goal, it called for a number of actions to improve water quality, including a 40% reduction in the amount of nitrogen and phosphorus entering the Bay (Alliance for the Chesapeake Bay, 1996a). Efforts to implement these actions focused first on coastal tributaries of the Bay. By 1994, however, attention had expanded to the complete watershed, with the development of a set of goals and actions to increase the focus on riparian stewardship and to enhance efforts to conserve and restore riparian forest buffers (Alliance for the Chesapeake Bay, 1996b). Riparian forest buffers (RFB) were singled out in part for their nutrient reduction capabilities, but also because they are reminiscent of the natural landscape in which the stream channel and stream ecosystems of the Bay watershed had evolved.

### Background

Although there is general agreement on the qualitative benefits of riparian buffers, attempts to quantitatively relate riparian information, watershed information, aquatic conditions and water quality have met with mixed success and very few

studies have been conducted at the watershed scale (Gregory et al., 1991; Whigham et al., 1988; Osborne and Wiley, 1988; Wissmar and Beschta, 1998; Tufford et al., 1998; Perry et al., 1999). Because physical variation in riparian areas may aid or prevent the interception and transformation of pollutants (Hill, 1996; Weller et al., 1998), understanding the underlying natural variation in riparian buffer landscapes can augment interpretation of the impact of land use patterns on aquatic conditions. Without a comprehensive description of site geology, vegetation, hydrology, and soils, research findings are hard to generalize or extrapolate to other sites (Correll, 2000).
Riparian systems have received much attention for their role in stream ecosystem function and for their capacity to mitigate non-point-source (NPS) pollution (Lowrance et al., 1984, 1997; Correll, 1996; Barling and Moore, 1994). Streamside forests are complex ecosystems that help provide optimum food and habitat for stream communities. They can be effective in removing excess nutrients and sediment from surface runoff and shallow groundwater and shading streams to optimize light and temperature conditions for aquatic plants and animals. Streamside forests also ameliorate the effects of some pesticides and directly provide dissolved and particulate organic food needed to maintain high biological productivity and diversity in the adjoining stream (Maryland DNR website, 2002).

In 1998, the University of Maryland, Maryland Cooperative Extension, and the Forestry Division of Maryland's Department of Natural Resources joined together to conduct a fieldwork-based survey of agricultural riparian buffers in Maryland's Chesapeake Bay watershed. This survey provided the first extensive, ground-truthed data set describing a large set of agricultural riparian buffers, the surrounding land,

and to a lesser extent, the land and streams within the buffers. Because agencies are typically restricted to "rapid assessment"-type surveys, this survey described these landscapes using "easily obtainable" data. Field surveys were designed to take less than one hour per site, and map and other landscape data were obtained from publicly-available documents and web-based files. Therefore, the methodology used in the survey can be reproduced and the results expanded by state agencies.

The purpose of this paper is to present the characterization of riparian buffers and their agricultural settings within the Coastal Plain and Piedmont physiographic regions of Maryland. These results are of theoretical use to scientists investigating the functional role of buffers in water quality protection, as well as practical use to the agencies that administer the effort to establish riparian forest buffers in Maryland. The research also provides information of value to field staff that provide farmers with information about riparian forest buffers and cost-share programs that promote them. While these results are specific to Maryland, the general findings are of use to other locations throughout the United States where the establishment of forest buffers is considered as a water quality measure and remotely sensed data are used to conduct buffer surveys.

**Objectives**

1. To develop a set of easily obtainable landscape characteristics that can describe the agricultural riparian landscape.
2. To characterize agricultural riparian landscapes in the Coastal Plain and Piedmont physiographic regions of Maryland in terms of land use, buffer characterization

(distribution, vegetation type, width), topography, surface hydrology, groundwater hydrology and channel morphology.

3. To identify correlations among structural measures of riparian landscape characteristics.
4. To evaluate the usefulness of remotely sensed data for riparian buffer surveys.

## METHODS

### Overall summary of methods

The agricultural riparian landscape was conceptualized as the stream channel, buffer, and adjacent agricultural field (Figure 1). Characterization of this landscape was performed at 209 sites in eight Maryland watersheds. Two scales of data were considered. Information about the site's contributing watershed provided insight about cumulative hydrologic impacts and sources of agricultural NPS pollution. These data were developed from publicly available Geographic Information System (GIS) files. Site characterization provided ground-truthed information about the local riparian landscape below the resolution of RS data. These data were obtained through on-site surveys.

### Sample site selection

A sample frame of streams and surrounding properties was developed to characterize riparian landscapes of the Maryland Chesapeake Bay watershed. The survey sample design (Cochran, 1977) required that all watersheds be predominantly agricultural, with minimum urban development. Watersheds were selected from the

Coastal Plain and Piedmont physiographic regions. Maryland's Appalachian Plateau was not sampled due to fiscal constraints. Because buffers are agricultural Best Management Practices (Novotny and Olem, 1994), they are voluntary measures implemented by the landowner, and their presence, width, and type are functions of agricultural culture as well as environmental conditions. The Eastern Shore of the Chesapeake Bay has a distinct and unique agricultural community. Therefore, the sampling scheme was stratified by physiographic region and "shore" (i.e., "Eastern" and western shores of the Chesapeake Bay) to reflect both physical and cultural influences. The Pocomoke was deliberately included due to interest in *Pfisteria piscicida* impacts (Burkholder and Glasgow (1997). Figure 2 shows the locations of the eight watersheds that were selected.

**Figure 1. Schematic of the agricultural riparian landscape as defined for the 1998 University of Maryland Agricultural Riparian Buffer Survey.**

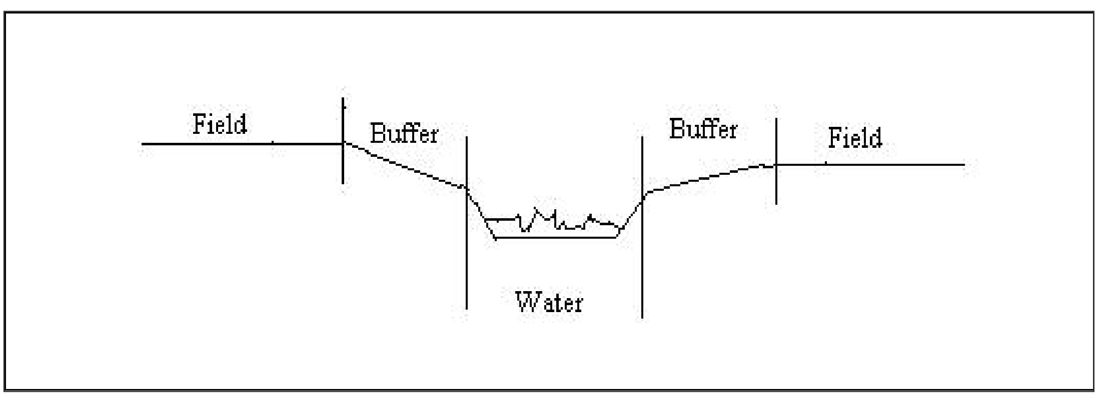
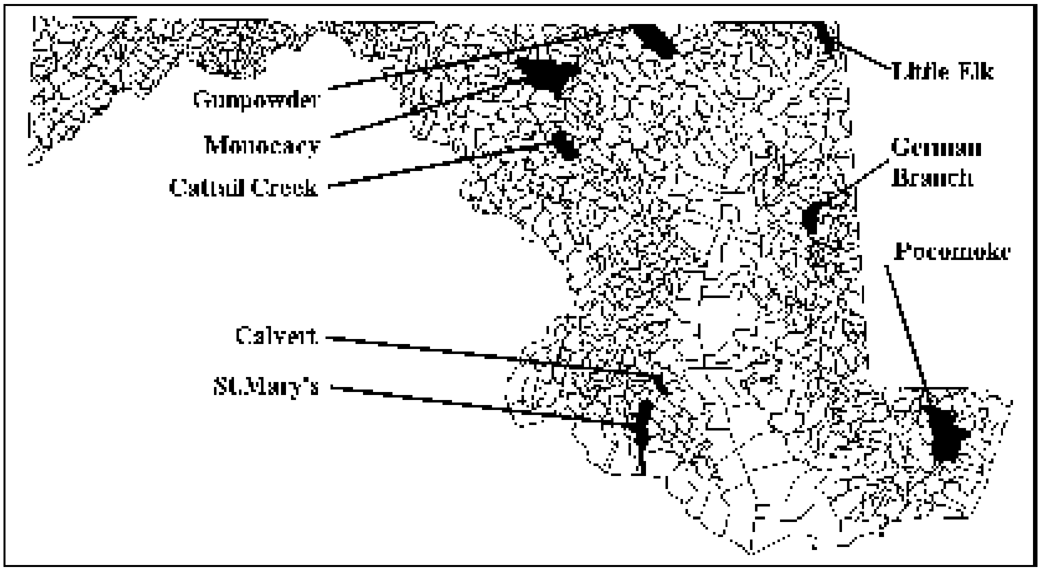


**Figure 2.** **Map of the University of Maryland 1998 Agricultural Riparian Buffer Survey sample watershed locations superimposed over 16-digit Hydrologic Unit Code watersheds as defined by USGS.**




A total of 207 sites were surveyed. Maryland's Department of Natural Resources PropertyView database lists all property owners. PropertyView was parsed to identify agricultural property owners adjacent to blue-line streams. Properties were drawn randomly without replacement from the database. An original list and a replacement list of the same size were drawn at the same time; field workers were instructed to make all reasonable attempts to contact properties on the first list before starting on the replacement list. All sites were in some type of agricultural or forested land use and located on one or both sides of a stream or ditch. Figures 3 a-h present the forested area and research site locations for each of the sampled watersheds. The boundaries of each sample watershed were determined by aggregating all 16-digit hydrologic unit areas that contained at least one survey site in that stream system. Figures are not shown to scale - see Figure 2 for an appreciation of the variation in size of the watersheds (25.2 ha - 218.3 ha). Site locations are approximate and unlabelled to preserve confidentiality of site owners.

**Figure 3. 1998 University of Maryland Agricultural Riparian Buffer Survey sampled watersheds, streams, forested areas and sample sites.**

. survey site, grey = forested area

**Figure 3a. Calvert watershed in Calvert county (2,520 ha, 10 sites)**

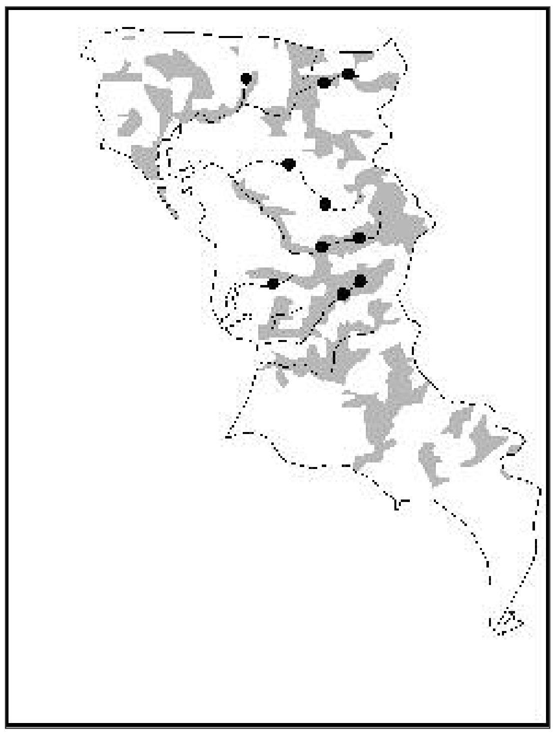


**Figure 3b. Cattail Creek watershed in Howard County (6,740 ha, 20 sites)**

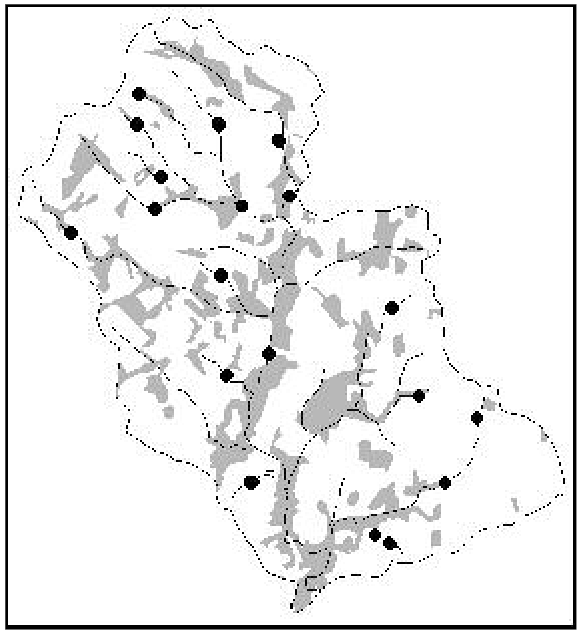


**Figure 3c. Little Elk watershed in Cecil County (5,170 ha, 13 sites)**

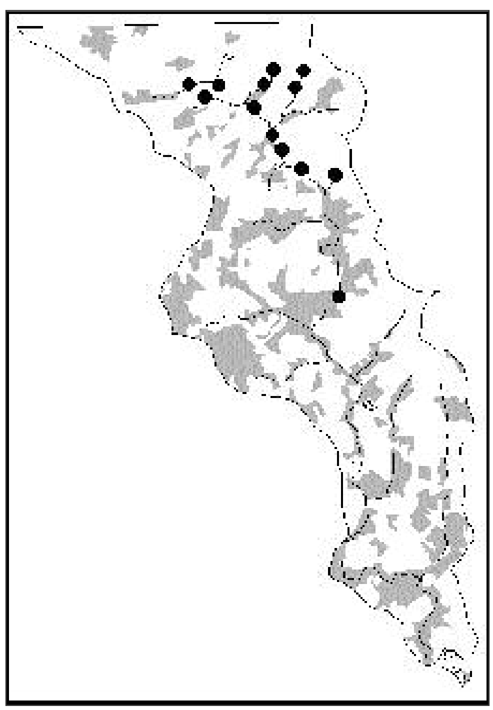


**Figure 3d. German Branch watershed in Queen Anne County (5,590 ha, 43 sites)**

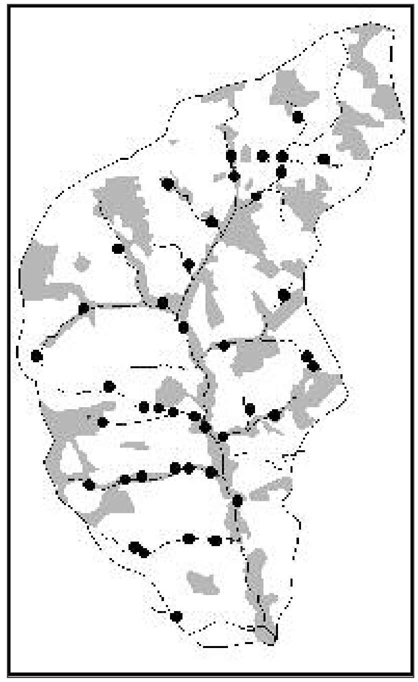


**Figure 3e. Gunpowder watershed in Baltimore County (12,880 ha, sites)**

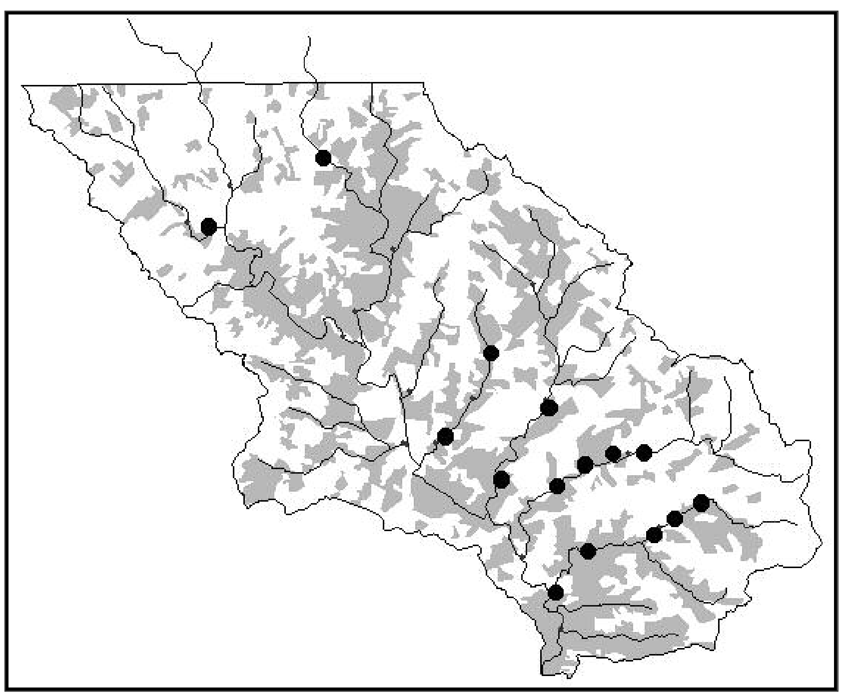


**Figure 3f. Monocacy watershed in Frederick County (21,580 ha, 36 sites)**

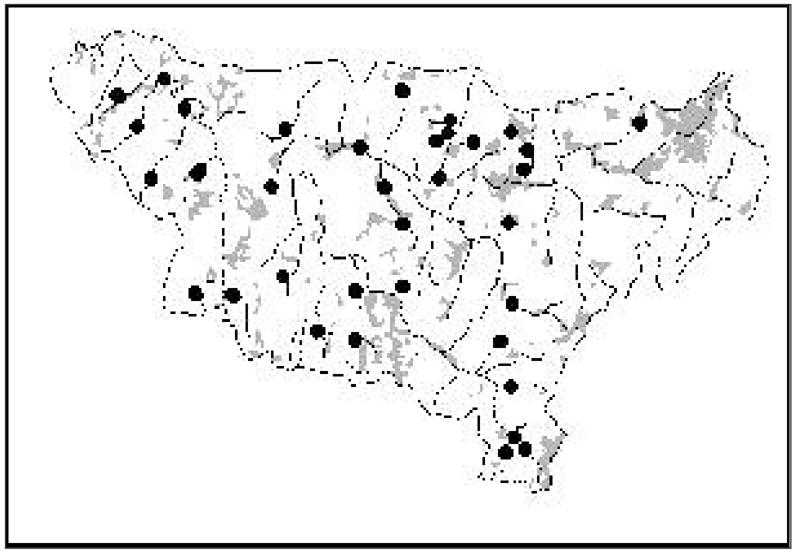


**Figure 3g. Pocomoke watershed in Wicomico and Somerset counties (21,830 ha, 30 sites)**

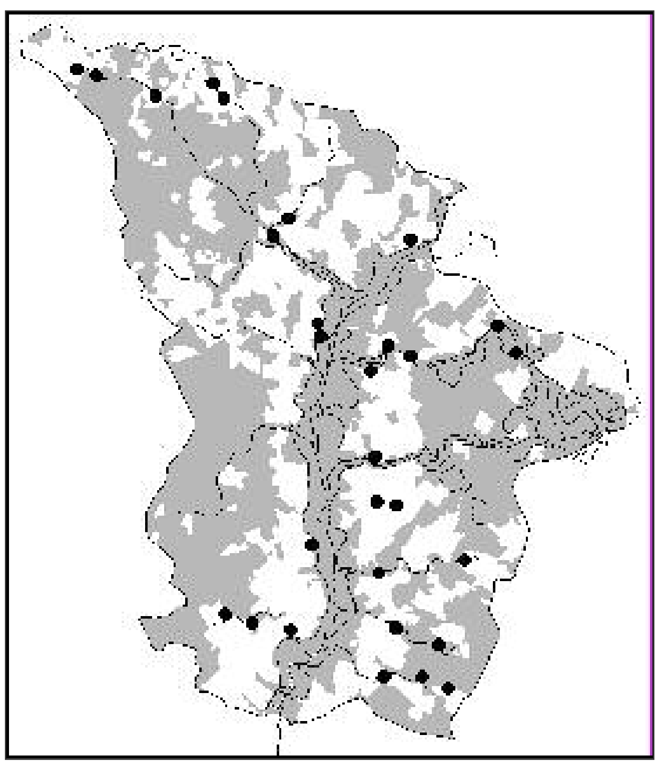
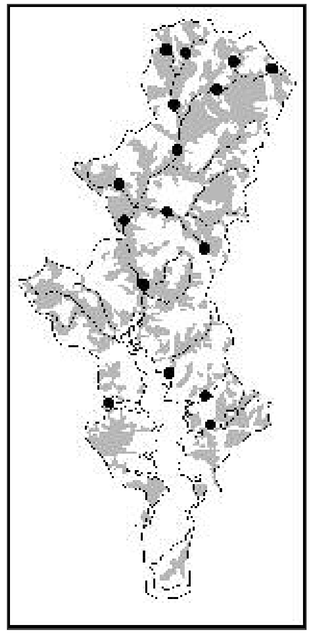


**Figure 3h. St. Mary's watershed in Calvert County (10,730 ha, 16 sites)**



**Site characterization**

Each survey site consisted of the stream, riparian zone and adjacent fields along both sides of a 30 to 90 meter stream reach. Field and map measurements fell into six key categories (Giles and Trani, 1999): location, topography, surface and groundwater hydrology, land use and stream channel morphology (Table 4). If a buffer was present, vegetation and width measurements were also taken.

Two scales of data were considered. Site characterization provided ground-truthed information about the local riparian landscape below the resolution of remotely sensed data. These data were obtained from on-site surveys. Because one of the directives of the University of Maryland Buffer Survey Project was to collect "easily obtainable data", fieldwork was restricted to a suite of structural landscape measurements that could be obtained in a single visit of less than one hour

(Appendices 1 and 2). Information at the site watershed scale provided insight about cumulative impacts and sources of agricultural NPS pollution. These data were developed from soil surveys, USGS topographic maps, and publicly available EPA, USGS and state GIS files (Appendix 3).

Land use provided information about the source of agricultural NPS pollutants to the adjacent stream (Basnyat et al., 1999; Richards et al., 1996). Because many decisions are made at the watershed scale using surface water quality as the regulatory criteria of interest, both adjacent land use at the site (crop, pasture, forest, other) and overall land use in the site's contributing watershed (percent forest, percent agriculture, percent crops, Confined Animal Feeding Operation area) were considered. Watershed land use distribution was obtained from Maryland Office of Planning GIS land use files. Land use at the site was recorded from visual observation as buffer presence and adjacent field use on either side of the stream.

Buffer characterization included buffer width, fragmentation (or bypass) and vegetation measures (USDA, 1999). The riparian buffer was defined as an area of land between a stream channel and an agricultural land use area. If the adjacent field was cropped up to the side of the stream, or was a pasture allowing full animal access to the stream, the buffer width was recorded as 0 feet. However, in two watersheds, several sites were characterized by row crop extending to the top incision of a broad channel with gently sloping sides thickly covered in vegetation. For these sites, the width of vegetation on each side of the channel was considered as an “in-channel” buffer. In the Piedmont watersheds, many sites were characterized by pasture with sufficient vegetation to restrict animal access to the stream to specific channelized routes. These sites were considered to have a buffer. The maximum width for a riparian buffer was defined as 305 meters (1000 feet) (personal communication, R. Tjaden). In all cases, buffer width was reported as the average width on one side of the stream. Even a wide, densely vegetated buffer can be rendered ineffective if the polluted water is able to bypass or short-circuit travel through this zone (Skaggs and Chescheir, 1999). Therefore, an attempt was made to ascertain the presence of drain tiles at the survey sites, but this proved unsuccessful. A subjective measure of gullying was estimated to provide a measure of buffer bypass at the site-specific scale. Measures of buffer fragment length (km along the stream) were taken from watershed aerial photos to provide a measure of buffer bypass at the stream reach scale. Buffer vegetation was described by tree type (predominance of hardwood or pines), Diameter at Breast Height (DBH) and Basal Area (square feet of trees in an area of observation).

Topography affects the transport of surface runoff, which carries sediment and particle-bound pollutants, such as phosphorus. Site topography was described by riparian buffer and adjacent field slope. These were taken as single measurements in the field. Watershed topography was characterized by a topographic index, calculated as maximum topographic relief divided by the area of the 16-digit hydrologic unit area within which the site was located. Watershed elevation data were obtained from GIS files.

Surface water hydrology affects the transport of pollutants to and by the stream. Watershed drainage density (area of land drained per length of stream) was given as a measure of hydraulic loading to the stream complex. Sinuosity (tortuosity) was calculated as the length of the longest continuous channel from the uppermost headwater to the bottom of the watershed, divided by the straight distance between these two points. Stream gradient and order were taken from USGS 7.5-minute topographic quadrangle maps. Stream velocity was reported as the average of three measurements of surface velocity.

Groundwater hydrology affects the transport and transformation of soluble pollutants, such as nitrogen. Control of agricultural nitrate pollution is primarily accomplished by plant use, denitrification, and dilution (Cirmo and McDonnell, 1997; Hill, 1996). Denitrification capacity is directly related to water table depth (Gold et al., 2000). Dilution is affected by infiltration capacity, which was characterized by hydraulic conductivity (K) and drainage class (good or poor). Hydraulic conductivity was reported as the median value of the range given in the soil survey. Depth to the layer of minimum hydraulic conductivity was reported to indicate any limiting layer for shallow groundwater movement. Hydraulic conductivity and depth to the layer of minimum hydraulic conductivity were reported as the median value of the range given in soil surveys.

Stream channel morphology has been shown to be affected by buffers (Schlosser and Karr, 1981). Channel size, width: depth ratio, and subjective measures of bank erosion were reported to provide indications of the erosive power of the stream. Channelization or straightening of the stream was evidence of deliberate channel disruption. All measures of stream channel morphology were determined by visual observation.

Tables 1 and 2 present the site descriptors and range of values obtained through the combination of fieldwork, map work and GIS work. Site survey measurements that were taken as multiple replicates (channel width and depth, bank angles, stream velocity, riparian buffer width) were reduced to average values. Therefore, these 34 parameters represented over 150 individual measurements characterizing 207 sites.

**Table 1. Descriptors used to characterize the agricultural riparian landscape in the 1998 University of Maryland Agricultural Riparian Buffer Survey.**

| Descriptor Category | Riparian Landscape Descriptor | Units | Range of Values |
|---|---|---|---|
| **Land Use** | Survey watershed % agriculture[2] | % | 38.2 - 76.1 |
| | Survey watershed % forest[2] | % | 26.1 – 45.0 |
| | Site contributing watershed % agriculture[2] | % | 36.9 – 100.0 |
| | Site contributing watershed % crops[2] | % | 26.3 – 100.0 |
| | Adjacent land use[1] | crop/past/forest/other | |
| **Buffer Char-acter-ization** | Buffer width[1] | m | 0 – 304.8 |
| | Length of buffer fragment[3] | km | 0.02 - 6.9 |
| | Forest buffer DBH[1] | cm | 3.8 - 84.3 |
| | Forest buffer basal area[1] | $m^2$ | 0 - 15.5 |
| | Shrub height[1] | m | 0.3 - 6.1 |
| **Topo-graphy** | Watershed topographic index [2] | $m/m^2$ | 0.9 - 30.1 |
| | Riparian buffer slope[1] | % | -2.5 - 62.3 |
| | Adjacent field slope[1] | % | 0 - 37.5 |
| | Ratio riparian buffer : adjacent field slope[1] | unitless | -0.11 - 35.2 |
| **Surface Hydrology** | Watershed drainage density[2] | $km^2/km$ | 1.02 - 1.25 |
| | Mainstem sinuosity[2] | km/km | 1. 1- 1.4 |
| | Stream gradient[1] | % | 0 – 4.0 |
| | Stream velocity[1] | m/sec | 0 – 1.0 |
| | Stream order [1,2] | unitless | 1 - 4 |

[1] from on-site field work [2] from GIS work [3] from soil survey

**Table 1.** **(continued) Descriptors used to characterize the agricultural riparian landscape in the 1998 University of Maryland Agricultural Riparian Buffer Survey.**

| Descriptor Category | Riparian Landscape Descriptor | Units | Range of Values |
|---|---|---|---|
| **Ground-water Hydrology[3]** | Riparian buffer avg. depth to water table | m | 0 - 10.7 |
| | Adjacent field avg. depth to water table | m | 0 - 10.7 |
| | Riparian buffer surface K * | cm/hour | 0.03 - 15.2 |
| | Adjacent field surface K * | cm/hour | 0.1 - 15.2 |
| | Riparian buffer minimum K * | cm/hour | 0.03 - 15.2 |
| | Adjacent field minimum K * | cm/hour | 0.05 - 15.2 |
| | Riparian buffer soil drainage class | variable/poor/ good/ excellent | |
| | Adjacent field soil drainage class | variable/poor/ good/ excellent | |
| | Riparian buffer depth of minimum K * | m | 0.03 - 15.5 |
| | Adjacent field depth of minimum K * | m | 1.7 - 15.1 |
| **Channel Morphology[1]** | Channel width | m | 0.4 - 21.6 |
| | Channel depth | m | 0.2 - 5.6 |
| | Channel cross-sectional area | $M^m$ | 0.1 – 50.5 |
| | Channel width : depth ratio | m/m | 0.27 – 30.0 |
| | Substrate | mud/sand/ gravel/ cobble | |
| | Channel shape | natural/ triangular | |
| | Channel straightened? | yes/no | |
| | Presence of berms | yes/no | |
| | Degree of gullying | low/moderate /severe | |
| | Average bank angle (degrees) | degrees | 5.7 – 90.0 |
| | Degree of bank erosion | low/moderate/ severe | |
| | Livestock access | yes/no | |

* K = hydraulic conductivity
[1] from on-site field work [2] from GIS work [3] from soil survey

**Table 2. Values of categorical descriptors used to characterize the agricultural riparian landscape in the 1998 University of Maryland Agricultural Riparian Buffer Survey.**

| | | | | | | |
|---|---|---|---|---|---|---|
| **Buffer Characterization** | **Buffer tree type** | **hardwood** 85.94 | **mix** 13.28 | **pine** 0.78 | | |
| **Groundwater Hydrology** | **Adjacent field soil drainage class** | **excellent** 11.06 | **good** 58.65 | **poor** 13.46 | **variable** 16.83 | |
| | **Riparian buffer soil drainage class** | **excellent** 5.77 | **good** 18.75 | **poor** 67.31 | **variable** 8.17 | |
| **Channel Morphology** | **Channel substrate** | **boulder** 2.5 | **cobble** 24 | **sand/ gravel** 32 | **sand** 13.5 | **mud** 28 |
| | **Channel shape** | **natural** 91.22 | **triangular** 8.78 | | | |
| | **Channel straightened** | **yes** 27.18 | **no** 72.86 | | | |
| | **Berms** | **yes** 10.73 | **no** 89.27 | | | |
| | **Gullying** | **high** 3.11 | **medium** 7.77 | **low** 54.92 | **none** 34.2 | |
| | **Bank erosion** | **high** 21.52 | **medium** 53.8 | **low** 22.15 | **none** 2.53 | |
| | **Livestock access** | **yes** 20.39 | **no** 79.61 | | | |

### Data analysis

The data were analyzed to provide univariate measures (mean, standard deviation, and coefficient of variation) and correlation measures to describe the state of Maryland's agricultural buffers and for use in further research. All analysis was performed using SAS software. Watersheds were of unequal sizes and did not have the same number of sites. Therefore the SAS Proc Mixed procedure (SAS/STAT User's Guide, 1988) was used to develop ANOVA to identify regional variation among quantitative descriptors.

## RESULTS AND DISCUSSION

Through a combination of fieldwork, map work and GIS work, over 150 individual measurements and values were obtained for each survey site. Many of these values were aggregated into average values, so that analysis was performed on a suite of approximately 30 descriptors (Tables 1 and 2). These data provided information about the state of agricultural riparian buffers in Maryland and their landscape settings, as well as relationships between buffer characteristics and physiographic and cultural settings.

Average statewide values and regional values were determined for all quantitative riparian landscape descriptors by means of ANOVA (Table 3). Because there were unequal numbers of sites among watersheds, a mixed model was used. All F-tests and t-tests performed on watershed and site values of landscape descriptors used $\alpha = 0.05$. All statewide average values are presented in Table 3, and regional values are presented if the F-test showed a significant difference between regions.

**Table 3. Statewide and regional values and standard deviations for riparian landscape descriptors in the 1998 University of Maryland Agricultural Riparian Buffer Survey.**

| Descriptor Category | Riparian Landscape Descriptor | State ** mean (SD) | Coastal Plain mean (SD) | Piedmont mean (SD) |
|---|---|---|---|---|
| **Land Use** | Survey watershed % agriculture | 55.8 (14.0) | | |
| | Survey watershed % forest | 32.2 (15.9) | 54.9 (7.3) | 23.3 (5.4) |
| | Adjacent land use % crop | 44.2 (21.2) | | |
| | Adjacent land use % pasture | 29.4 (23.2) | | |
| | Adjacent land use % forest | 15.3 (10.6) | | |
| | Adjacent land use % other | 11.1 (7.4) | | |
| **Buffer Width** | Total buffer width (m) | 48.8 (61.6) | | |
| | Zoned buffer width (m) | 57.3 (64.0) | | |
| | Forested buffer width (m) | 58.2 (61.9) | | |
| | Grass buffer width (m) | 25.9 (42.7) | 13.4 | 36.0 |
| **Buffer Condition** | Length buffer fragment (m) | 856 (710) | 1263 (274) | 469(269) |
| | Forest buffer DBH | 36 (11) | | |
| | Forest buffer basal area | 5.1 (2.4) | 6.5 (0.4) | 3.8 (0.4) |
| **Topo-graphy** | Watershed topographic index | 12.1 (9.7) | 3.9 (3.9) | 19.6 (3.0) |
| | Riparian buffer slope | 8.7 (9.3) | 6.5 (1.3) | 10.0 (1.3) |
| | Adjacent field slope | 5.3 (4.3) | | |
| **Surface Hydrology** | Watershed drainage density | 1.1 (0.3) | | |
| | Mainstem sinuosity | 1.2 (0.1) | | |
| | Stream gradient (%) | 1.1 (0.9) | | |
| | Stream velocity (mps) | 0.3 (0.2) | 0.2 (0.1) | 0.3 (0.1) |
| | Stream order | 1.8 (0.9) | 1.6 (0.1) | 2.0 (1.0) |

**Table 3. (continued) Statewide and regional values and standard errors for riparian landscape descriptors in the 1998 University of Maryland Agricultural Riparian Buffer Survey.**

| | | | | |
|---|---|---|---|---|
| **Groundwater Hydrology** | Riparian water table depth (m) | 1.1 (1.3) | | |
| | Field water table depth (m) | 3.2 (1.6) | | |
| | Riparian surface K (cm/hr) * | 4.1 (1.3) | | |
| | Field surface K (cm/hr) * | 4.1 (1.3) | | |
| | Riparian minimum K (cm/hr) * | 3.1 (2.8) | 1.5 (0.5) | 4.3 (0.5) |
| | Field minimum K (cm/hr) * | 4.1 (7.6) | | |
| | Riparian minimum K depth (m) * | 7.8 (3.2) | 8.8 (0.3) | 7.56 (0.3) |
| | Field minimum K depth (m) * | 6.1 (3.2) | 7.2 (0.7) | 4.6 (0.6) |
| **Channel Morphology** | Channel width: depth ratio | 4.9 (6.0) | | |
| | Average bank angle | 46.4 (14.7) | | |

* K = hydraulic conductivity
** Where there was no significant difference in regional values, only the statewide average value is given.

**Maryland's agricultural riparian buffers: distribution by type**

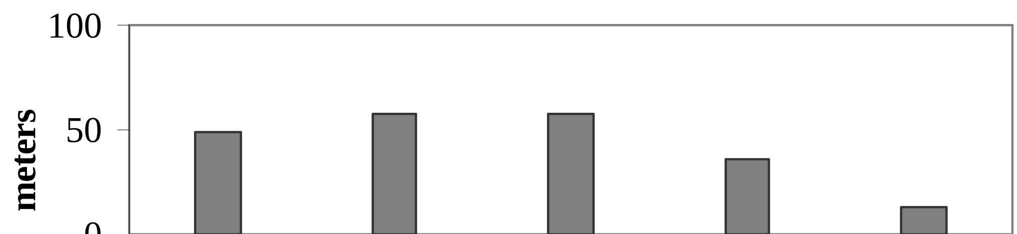
Riparian buffers were found to be composed of trees, shrubs, grass, and in-channel vegetation. Although shrub buffers were distinguished from forest buffers by visual inspection, shrub buffers had an average height of 1.9 meters. Therefore, although the differentiation between shrub and forest buffers was subjective, it was clear. In-channel vegetation was considered part of the buffer if there was very little off-channel buffer and the bank vegetation was a large proportion of the land between the field and the stream. This could be a considerable width in sites on the lower Eastern Shore with wide channels and gently sloping banks (average width of in-channel vegetation was 2.1 m, with a maximum value of 8.8 m). Therefore four types of buffers were recognized: forested, "zoned" (forest and grass, as described in Lowrance et al., 1997), grass, and "other" (any other combination of trees, grass, shrubs and in-channel vegetation).

Almost all sites (93.2%) had some type of buffer. Forest buffers were the predominant type (52%) and zoned buffers were fairly rare (7%). Statewide, there were approximately three times as many forested buffers as grass buffers. The distribution of buffer type varied by physiographic region. Most Coastal Plain buffers were forested (50%) and most Piedmont buffers were grass (50 %). These results were in marked contrast to the popular belief that people on the Eastern Shore of Maryland are reticent to install forested buffers. Ninety-six percent of buffered sites were buffered on both sides of the stream. Unbuffered Piedmont sites were primarily associated with pastures allowing livestock access to the stream.

**Maryland's agricultural riparian buffers: width**

The average statewide buffer width (one side of the stream) over all buffer types was 48.8 meters and buffer widths ranged between 0.6 m and the defined maximum of 305 meters. An F-test performed on buffer width vs. physiographic region and shore demonstrated no significant difference in buffer width for overall buffer width, forested buffer width and zoned buffer width (Figure 5). This result was in contrast to the popular belief that buffers on the Eastern Shore are narrower than buffers elsewhere in the state. (Despite associated water quality problems, the Pocomoke watershed had the widest buffers on the Eastern Shore, and the largest amount of forested area of any sampled watershed.) Results of the F-test performed on buffer width vs. physiographic region and shore demonstrated that Piedmont grass buffers were significantly wider than Coastal Plain grass buffers (Coastal Plain: 13.4 ± 6.7 m, Piedmont: 36.0 ± 6.0 m).

**Figure 4. Average agricultural riparian buffer widths by type, as determined by the 1998 University of Maryland Agricultural Riparian Buffer Survey.**




| | all buffers | forest | zoned | grass - Pd | grass - CP |
|---|---|---|---|---|---|
| buffer width | 48.8 | 57.9 | 57.3 | 36 | 13.4 |

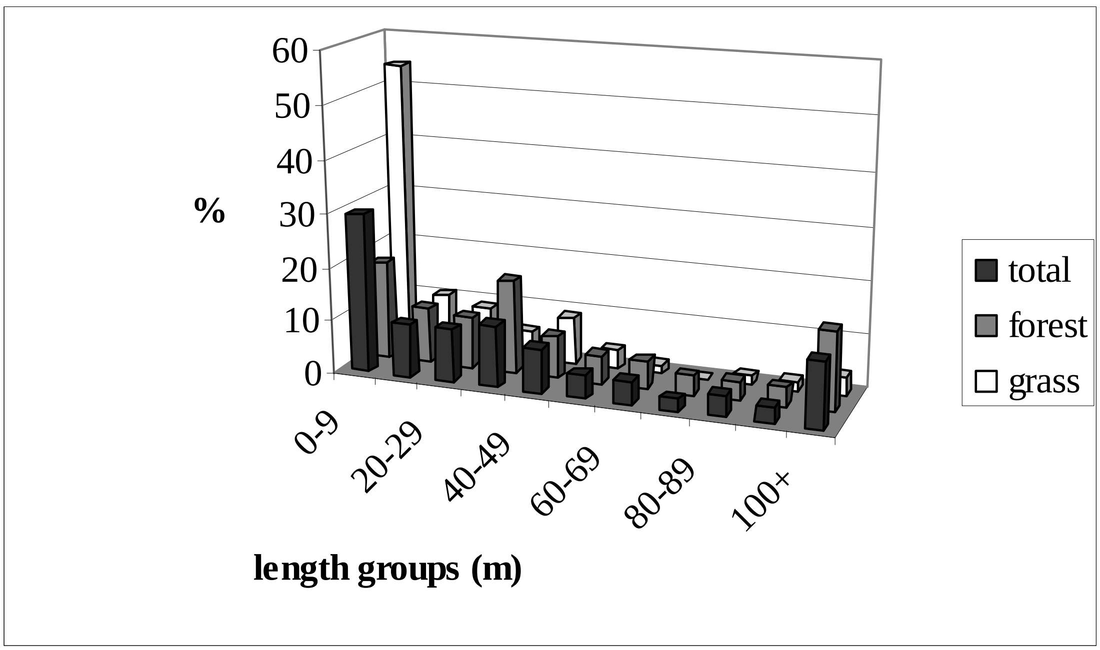
* Pd = Piedmont, CP = Coastal Plain

**Maryland's agricultural riparian buffers: distribution of buffer width classes**

A significant number of buffers surveyed were quite narrow, and this was especially true for grass buffers (Figure 5). Sixteen percent of all buffers and 38% of grass buffers had a total width (both sides of the stream) of less than 10 meters. Sixty-five percent of these buffers were in the Piedmont. This could be problematic for buffer surveys performed using remotely sensed data, which often have a resolution of 10 or 30 meters (Hewitt, 1990; Muller et al., 1993). At a satellite photo resolution of

10 meters, 28% of all buffers, 20% of Piedmont buffers and 38% of grass buffers would not be recognized. For RS data with a resolution of 30 meters, almost 50% of buffers would not be included. These results indicate that surveys done with RS data (Day et al., 1996) may drastically underestimate the number and extent of agricultural buffers in Maryland.

**Figure 5.** **Histogram of agricultural riparian buffer widths for forested, grass buffers and all buffer types combined, as determined by the 1998 University of Maryland Agricultural Riparian Buffer Survey.**




**Maryland's agricultural riparian buffers: fragmentation**

Riparian buffer fragmentation is a concern throughout the Chesapeake Bay watershed (Alliance for the Chesapeake Bay, 1998). The average buffer fragment length along the stream channel was 885 m. A t-test performed on buffer fragment length indicated that Coastal Plain Eastern Shore buffers were significantly longer than Central Maryland Piedmont

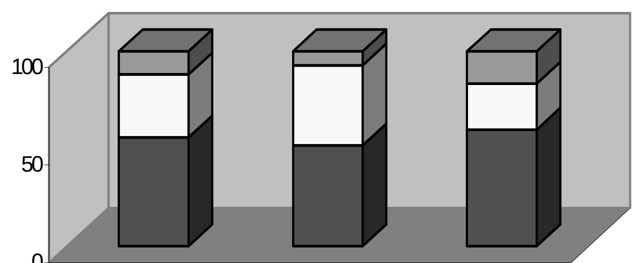
**Maryland's agricultural riparian buffers: vegetation**

The vegetative condition of forest buffers was quantified using DBH, basal area, and tree type. The statewide average DBH was 36 $\pm$ 15 cm. A t-test performed on DBH vs. physiographic region indicated no significant difference. However, a t-test performed on basal area vs. physiographic region showed the Coastal Plain buffers to have significantly larger basal area (Coastal Plain: 6.5 $\pm$ 0.4 $m^2$, Piedmont: 3.8 $\pm$ 0.4 $m^2$). Therefore, buffers were seen to have fairly small trees across the state, but buffers had higher biomass per area in the Coastal Plain. This may reflect native fertility or species differences. Both measures of forest vegetation showed low correlations with buffer width. Buffer tree types were distinguished as hardwood, pine, and mixed hardwood and pines, but no pine buffers were found. Hardwood buffers predominated in both the Piedmont and Coastal Plain (78% of Coastal Plain sites and 93% of Piedmont sites) but most mixed forests were found in the Coastal Plain. The Pocomoke watershed was the only representative of the lower Easter Shore, and had a distinctly different tree composition from all other sampled watersheds, with 73% of its forested buffers as mixed hardwood and pines. All other watersheds had less than 25% mixed forests.

**Agricultural riparian landscapes**

*Land use*. The sampling protocol deliberately selected watersheds with predominantly agricultural land use. The average extent of agricultural land use among sampled watersheds was 56% with average forest area of 32%, as determined from the Maryland Office of Planning land use/land cover GIS files (Figure 6). An F-test performed on percent agriculture of the survey watershed vs. physiographic region (n = 8) indicated that there was no regional difference in amount of agriculture for surveyed watersheds. Visual inspection of the land use maps suggested that most forested area in each watershed was associated with riparian areas. In heavily agricultural watersheds, such as the German Branch, riparian buffers constitute essentially all of the forested area. A t-test performed on the forested area vs. shore did not indicate a significant difference between forested area on the western and Eastern shores.

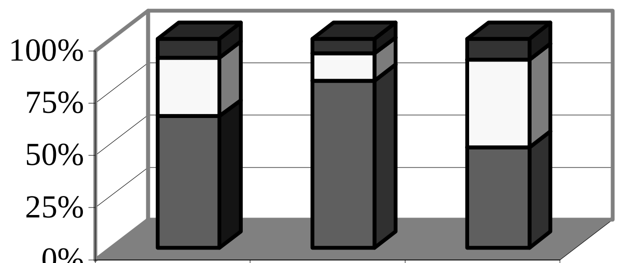
**Figure 6. Statewide and regional land use patterns for the 1998 University of Maryland Agricultural Riparian Buffer Survey watersheds.**




| | State | C.Pl. | Pd |
|---|---|---|---|
| other | 12.0 | 7.38 | 16.62 |
| % forest | 32.2 | 40.93 | 23.56 |
| % ag | 55.8 | 51.69 | 59.82 |

There were strong regional differences in the agricultural practices within Maryland (Figure 7). Although on a statewide basis there was more cropping (63% of sites) than pasture (28% of sites); most pasture sites were found in the Piedmont (79% of pasture sites). Whereas the Coastal Plain sites were primarily row crops (80% of sites), Piedmont watersheds had an almost equal split of crop and pasture land usage (48% crops: 42% pasture). Sixty-four percent of sites had the same type of land use on both sides of the stream.

**Figure 7.** **Agricultural land use patterns, as determined by the 1998 University of Maryland Agricultural Riparian Buffer Survey.**




| | state | CP | P |
|---|---|---|---|
| forest | 9 | 7 | 10 |
| pasture | 28 | 13 | 42 |
| crop | 63 | 80 | 48 |

*** P = Piedmont, CP = Coastal Plain**

*Topography.* Topographic differences between the Coastal Plain and Piedmont physiographic regions are well documented. However, at the watershed scale, only topographic index showed a significant regional difference in landscape relief (Coastal Plain = 3.9 $\pm$ 3.9 m/m$^2$x10$^6$, Piedmont = 19.6 $\pm$ 3.0 m/m$^2$x10$^6$). At the site scale, only buffer slope showed a significant difference between physiographic regions (Coastal Plain = 6.5, Piedmont = 10.0).

*Surface Hydrology.* At the watershed scale, no regional differences were seen. However, the topographic difference between the regions was reflected at the site scale by significant difference in average regional values for stream gradient (Coastal Plain = 0.91, Piedmont = 1.42) and velocity (Coastal Plain = 0.2, Piedmont = 0.3).

*Channel morphology*. The F-test (n = 8) indicated no significant difference between the sinuosity of the longest continuous stream channels in the two physiographic regions. However, at the site scale, 87% of sites with straightened streams were in the Coastal Plain. The apparent conflict of these results illustrates the effect of scale. Many larger agricultural streams on Maryland's Eastern Shore were straightened, or channelized, in the 1930's and 40's to improve drainage and reduce the threat of flooding. However, survey sample sites were primarily on low-order streams. Therefore, survey data reflect straightened low-order streams and constructed drainage ditches. Another indication of channel engineering was a triangular shape. Although triangular channels were rare (9% of all sites), they were concentrated in two watersheds (25% of German Branch sites and 13% of Monocacy sites). This result suggests that straightened stream reaches are concentrated in local areas of both physiographic regions.

*Groundwater hydrology*. No F-tests on measures of groundwater hydrology in the field adjacent to the riparian buffer showed a significant difference between regions. However, F-test on riparian buffer water table vs. physiographic region did not show a significant difference and a t-test indicated that average riparian buffer water table was significantly higher than average field water table. The average water table within the buffer (1.1 m) was at the lower limit of the rooting depth for trees, and lower than the rooting depth for grass. These results suggest that the primary mechanism of reduction of groundwater pollution in these agricultural buffers may not be plant uptake. The average depth to the riparian water table in the Pocomoke watershed (10 cm) was higher than all other watersheds (32 cm to 4 m). An F-test indicated that buffer K was significantly higher in the Coastal Plain than in the Piedmont. This suggests that one may expect Coastal Plain buffers to infiltrate a greater volume of water and infiltrate more rapidly, reducing surface runoff to a greater extent. The F-test on depth of minimum K for buffers did not show a regional difference.

Buffer soil drainage was poor for 67% of sites, which was consistent with riparian wetland hydrology. Field soil drainage was essentially the opposite, with 69% of sites in the good/excellent categories. These results are consistent with the agricultural engineering history of this land to improve drainage in order to increase production. Poor productivity in riparian areas due to poor drainage is one historical reason buffers have been allowed to grow in an agricultural region.

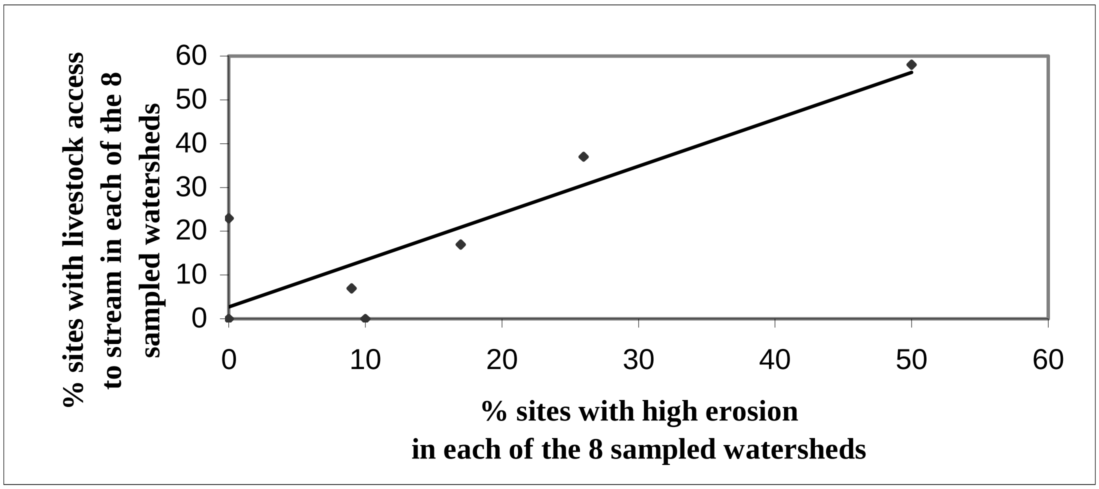
**Comments on the correlation matrix**

Correlations were analyzed for the full data set and for each physiographic region separately (Appendix 4). Many measures showed different correlation values for the two physiographic regions, but plots of the data showed that these values were misleading due to extreme scatter in the data. The strongest correlation value was that of the relationship between buffer width and length of buffer fragment ($R = 0.23$), but this was almost entirely due to Coastal Plain sites ($R = 0.47$). Overall correlations for buffer width and topographic measures were weak (all $R < 0.23$) but the Piedmont showed a fairly strong relationship between buffer width and field slope ($R = 0.40$). There was no strong correlation between buffer width and stream order (the strongest value was R = 0.31 for forested buffers in the Piedmont). Relationships between buffer width and measures of groundwater hydrology were also fairly weak. The strongest relationship was between width of Piedmont forested buffers and the depth of the least hydraulically conductive soil in the riparian buffer (R = 0.31). Correlation coefficients between buffer width and measures of buffer vegetation ($R_{basal\ area}$ = -0.02, $R_{DBH}$ = 0.005) indicated that they were not associated. These indicators of buffer condition were only weakly correlated with all other buffer and landscape measures (all $R < 0.23$). The lack of strong correlations indicates that landscape measures are fairly independent at the site-level riparian landscape scale. These results indicated that although strong correlations may be seen at larger scales, such as basin and physiographic region, these small landscapes are highly variable.

**Buffer impact on streambank erosion**

A strong correlation (R = 0.90) was seen between livestock access to the stream and channel bank erosion (Figure 8). Almost all unbuffered sites were pasture sites where animals were allowed direct access to the stream and showed high streambank erosion. Areas with dense cropping that had buffers showed low streambank erosion. Statewide, 20% of the sampled sites allowed livestock access to the stream. Ninety-five percent of these sites were in the Piedmont. Statewide, 90% of the sites with high channel bank erosion were in the Piedmont. Only 5% of sites with high erosion were in the Coastal Plain, even though there was heavy cropping (80% of Coastal Plain sites). These data indicate that current cropping best management practices (BMPs) are effectively minimizing streambank erosion but that current pasturing practices are not.

**Figure 8.** **Percent of sites with livestock access to the stream vs. percent of sites with high erosion, as determined by the 1998 University of Maryland Agricultural Riparian Buffer Survey.**




## SUMMARY

Most sampled sites had some sort of riparian buffer and most buffers were forested. There were very few zoned buffers in Maryland, and most grass buffers were in the Piedmont physiographic region. Buffer width was widely variable. The correlation between buffer width and buffer fragment length was quite low, which suggested that buffer width may be a function of the individual property owner. The statewide average buffer width for all buffer types was approximately 49 meters. A t-test performed on buffer width vs. type indicated that forested buffers were significantly wider than grass buffers. A t-test performed on buffer width vs. shore indicated that buffers were as wide on the Eastern Shore as the western shore. A t-test performed on buffer fragment length vs. shore indicated that the Eastern Shore had longer buffer fragments along the stream.

These results present the first comprehensive structural characterization of Maryland's Coastal Plain and Piedmont agricultural riparian buffers and their landscapes. There are two major strengths of these results. Ground-truthed information is provided at the site-specific scale. The site-specific scale of these field-truthed data revealed that a significant portion of buffers were less than 10 meters wide, especially in the Piedmont. With an overall statewide average buffer width of approximately 49 meters, almost 50% of buffers may not be detected by RS data with a resolution of 30 meters. It can be reasonably concluded that surveys using remotely sensed data have significantly underestimated the degree of buffering in Maryland. This also has implications for the accuracy of modeling studies of buffer impact on nutrient mitigation to agricultural streams, such as Richards et al., (1996), Tufford et al., (1998), and Basnyat et al., (1999), in which buffer impact on instream nitrate was modeled using a GIS approach based on remotely-sensed data of buffer extent. In addition to accurate representation of the site-specific buffer landscape, this research has presented information at the 16-digit watershed scale in order to discuss these buffers in the context of a larger landscape. Weaknesses of the data include the subjective nature of some of the qualitative variables (level of erosion, degree of buffer gullying). In addition, although characterization of buffer bypass is critical for watershed-level analysis of buffer function, the only measure successfully obtained was a measure of buffer fragmentation (length of buffer fragment).

These results also provide objective information for further analysis of buffer implementation patterns among different farming cultures. The belief has long been held that Maryland's Eastern Shore has few forested buffers and a significant percentage of unbuffered sites. These results refute this belief, in that the number and width of forested buffers on the Eastern Shore were not significantly different from buffers elsewhere in the state.

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# CHAPTER 3 –

# CLASSIFICATION OF AGRICULTURAL RIPARIAN ZONE LANDSCAPES IN THE COASTAL PLAIN AND PIEDMONT PHYSIOGRAPHIC REGIONS OF MARYLAND

## ABSTRACT

The purpose of this study is to present a riparian classification system for the agricultural riparian landscapes of the Coastal Plain and Piedmont physiographic regions of Maryland. These landscapes form a continuum from the typical Coastal Plain setting on the Eastern Shore, characterized by a high water table, flat land, row crops, and a channelized stream, to the typical Piedmont setting in central Maryland, characterized by a deeper water table, rolling land, pasture, and a natural stream. In 1998, the University of Maryland, Maryland Cooperative Extension, and the Forestry Division of Maryland's Department of Natural Resources conducted a fieldwork-based survey of agricultural riparian buffers in Maryland's Chesapeake Bay watershed. Characterization of the riparian landscape was performed at 207 agricultural sites in eight agricultural watersheds in the Coastal Plain and Piedmont physiographic regions of Maryland. Categorization of riparian landscapes was performed using the CLUSTER procedure (average linkage method) in SAS, partitioning the riparian landscapes into six groups. Most sites were classified in a group with "average"

values of all landscape descriptors. Other groups described sites that had at least one extreme landscape parameter. These results present the first comprehensive structural characterization of Atlantic seaboard agricultural riparian buffers and their landscapes, and provide a method for quickly ascertaining a subset of sites for targeted analysis. While these are empirical results specific to Maryland, the general findings and approach are of use to other locations throughout the United States where the establishment of forest buffers is considered as a water quality improvement measure.

## INTRODUCTION

### Background

Riparian buffers have received much attention for their role in stream ecosystem function (Vannote et al., 1980) and for their capacity to mitigate non-point-source (NPS) pollution (Lowrance et al., 1984, 1997; Correll, 1996; Barling and Moore, 1994). Streamside forests are complex ecosystems that help provide optimum food and habitat for stream communities. They can be effective in removing excess nutrients and sediment from surface runoff and shallow groundwater and shading streams to optimize light and temperature conditions for aquatic plants and animals. Streamside forests also ameliorate the effects of some pesticides and directly provide dissolved and particulate organic food needed to maintain high biological productivity and diversity in the adjoining stream. In October 1996, the Executive Council of the Chesapeake Bay Program established a goal of restoring riparian forest buffers on

2010 miles of streams in the Chesapeake Bay watershed by 2010 (Chesapeake Bay Program, 1996). This action exemplified the widespread acceptance of riparian buffers as an important tool for the reduction of non-point-source pollution.

Because physical variation in riparian areas may aid or prevent the interception and transformation of pollutants (Hill, 1996; Weller et al., 1998), understanding the underlying natural variation in riparian buffer landscapes can augment interpretation of the impact of land use patterns on aquatic conditions. Without a comprehensive description of site geology, vegetation, hydrology, and soils, research findings are hard to generalize or extrapolate to other sites (Correll, 2000). Management would often like to be able to readily examine riparian characteristics using Geographic Information Systems (GIS), land-use and soil maps in order to determine what riparian management alternatives might contribute to decreasing nonpoint source pollution impacts on surface waters (Delong and Brusven, 1991). However, a system for conducting these comparisons in a logical manner has yet to be developed. As the plenary speaker for the American Water Resources Association International Conference on Riparian Ecology and Management in Multi-Use Watersheds, held in Portland, Oregon, in August 2000, Dr. David Correll of the Smithsonian Environmental Research Center stated that "one of the most urgent needs in riparian research is to develop and utilize an adequate system of classification for riparian buffers" (Correll, 2000).

Most riparian classification systems have focused on a few selected attributes of riparian areas, such as hydric soil or hydrophilic plant associations (Dick-Peddie and Hubbard, 1977, cited in Szaro and Patton, 1986; Brown et al., 1979, cited in Hauer and Smith, 1998; Norton et al., 1980, 1981; Batchelor, 1982; Winward, 1984; Youngblood et al., 1985a, 1985b, cited in Kovalchik and Chitwood, 1990; Curry and Slater, 1986; Szaro and Patton, 1986; Kovalchik, 1987, cited in Kovalchik and Chitwood, 1990; Baker, 1989, cited in Imhof et al., 1996; Padgett et al., 1989, cited in Kovalchik and Chitwood, 1990; Kovalchik and Chitwood, 1990; Durkin et al., 1996; Girard et al., 1997; Alpert and Kagan, 1998; Lyon and Sagers, 1998; Arbuckle et al., 1999). Many of these riparian classification systems were developed for management agencies such as United States Department of Agriculture Forest Service, US Department of Wildlife, US Bureau of Land Management, and the National Forest System. Therefore, many of these systems were developed for specific settings in the western United States (Colorado, Idaho, Kansas, Montana, Nevada, New Mexico, Oregon, Utah and Wyoming). Although these perspectives adequately characterized the terrestrial riparian plant communities, they provided little understanding of the wide array of ecological processes associated with the land-water interface (Gregory et al., 1991).

Few studies have expanded the focus of the classification system to include the landscape setting. Kovalchik and Chitwood (1990) added geomorphology to a floristic classification system they developed in 1987. Their work was conducted in the western United States, and sites were assigned to groups using geomorphic features (location in the watershed, gradient, elevation, fluvial surface, and soil type). Whereas this was a landscape study, it was conducted at a large scale, and the settings are specific to the western United States. Delong and Brusven (1991) developed a classification system to identify areas at risk for erosion. Six riparian zone characteristics (including vegetation type and height) were assigned discrete categorical values. Therefore, this study was conducted without quantification of any landscape characteristics.

Quinn et al. (2000) developed a third classification system including the landscape setting. This landscape classification system was developed for large-scale riparian settings in New Zealand. The aim of this study was to evaluate the potential for classification of stream riparian zones by accounting for the differences in function of riparian areas in different parts of the catchment. Twenty-nine sites covering a range of stream and riparian characteristics were grouped into broad classes that reflected similarities in morphology, riparian functions, human uses, and likely riparian management options. A subjective knowledge-based approach was used rather than a statistical clustering method, due to the wide variety of attributes that were included and the small number of sites. Although this classification system focused on the riparian landscape rather than the vegetation, it was conducted at a much broader scale and did not focus on agricultural sites.

**Purpose**

The purpose of this paper is to present a riparian classification system for the agricultural riparian landscapes found in the Coastal Plain and Piedmont physiographic regions of Maryland. In addition to focusing on agricultural systems, these landscapes are distinctively different from the landscapes in which all other riparian buffer classification systems have been developed. Maryland's agricultural riparian landscapes form a continuum from the typical Coastal Plain agricultural setting on the Eastern Shore, characterized by a high water table, flat land, row crops, and a channelized stream, to the typical Piedmont agricultural setting in central Maryland, characterized by a deeper water table, rolling land, pasture, and a natural stream. This study investigated a method to discretize this continuum into objective, quantitative categories. This classification system is intended for use as a management tool for incentive programs funding the installation of agricultural buffers at sites that may be without any buffer, or have an inadequate buffer. Therefore, the focus is the physical riparian landscape, not existing riparian vegetation. Additionally, this classification system is intended as a technique to reduce error when modeling buffer effectiveness, by identifying homogeneous sites. While the data used here are specific to Maryland, the general findings and approach are of use to other locations throughout the United States where the establishment of forest buffers is considered as a water quality improvement measure.

**Objectives**

1. To discretize the continuum of agricultural riparian landscapes of the Coastal Plain and Piedmont physiographic regions of Maryland's Chesapeake Bay watershed.
2. To develop a classification system for agricultural riparian buffer landscapes in the Coastal Plain and Piedmont regions of Maryland.

## METHODS

### Overall summary of methods

The agricultural riparian landscape was conceptualized as the stream channel, buffer, and adjacent agricultural field (Figure 9). The 1998 University of Maryland Agricultural Riparian Buffer Survey characterized 207 of these landscapes in eight primarily agricultural watersheds (>38% agriculture) of the Coastal Plain and Piedmont physiographic regions of Maryland (Figure 10). The SAS clustering procedure was then used with these data to create discrete categories of landscapes. (SAS is an integrated suite of software facilities for exploratory data modeling, statistical analysis and graphical display.)

**Figure 9. Schematic of the agricultural riparian landscape as defined for the 1998 University of Maryland Agricultural Riparian Buffer Survey.**

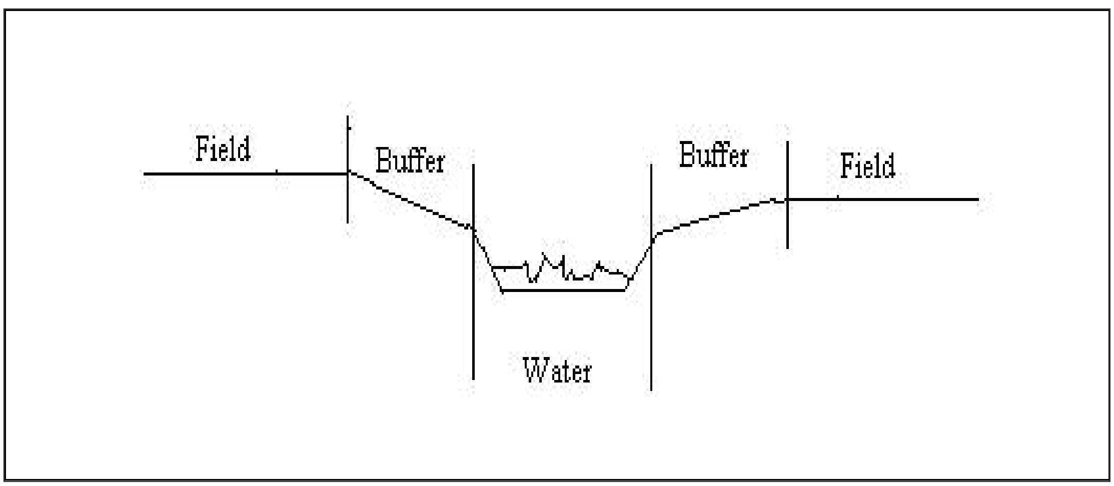
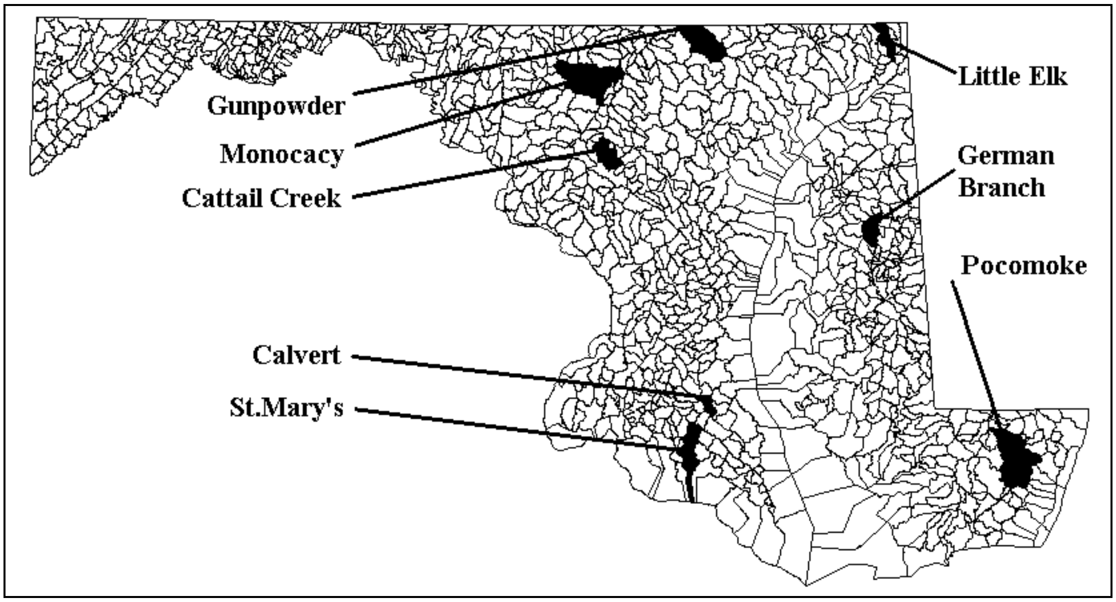


**Figure 10. Map of University of Maryland 1998 Agricultural Riparian Buffer Survey sample watershed locations superimposed over 16-digit Hydrologic Unit Code watersheds as defined by USGS.**




**Data development**

In 1998, the University of Maryland, the Maryland Agricultural Cooperative Extension Service, and the Forestry Division of Maryland's Department of Natural Resources conducted a fieldwork-based survey of agricultural riparian buffers in the Coastal Plain and Piedmont physiographic regions of Maryland's Chesapeake Bay watershed. (The Appalachian Plateau was not surveyed due to budget restraints.) Because agencies are typically restricted to "rapid assessment"-type surveys, this survey described these landscapes using "easily obtainable" data. Field surveys were designed to take less than one hour per site, and map and other landscape data were obtained from county soil surveys and publicly-available GIS files. Therefore, the methodology can be reproduced by state agencies. This survey provided the first extensive, ground-truthed data set describing a large set of agricultural riparian buffers, the surrounding land, and to a lesser extent, the land and streams within the buffers.

*Site characterization***.** Each survey site consisted of the stream, riparian zone and adjacent fields along both sides of a 30 to 90 meter stream reach. Field and map measurements fell into six key categories (Giles and Trani, 1999): location, topography, surface and groundwater hydrology, land use and stream channel morphology (Table 4). If a buffer was present, vegetation and width measurements were also taken. However, buffer data were not pertinent to this classification exercise because the riparian landscape was the focus of study, not the buffer within the landscape.

Two scales of data were considered. Site characterization provided ground-truthed information about the local riparian landscape below the resolution of remotely sensed data. These data were obtained from on-site surveys. Because one of the directives of the University of Maryland Buffer Survey Project was to collect "easily obtainable data", fieldwork was restricted to a suite of structural landscape measurements that could be obtained in a single visit of less than one hour (Appendices 1 and 2). Information at the site watershed scale provided insight about cumulative impacts and sources of agricultural NPS pollution. These data were developed from soil surveys, USGS topographic maps, and publicly available EPA, USGS and state GIS files (Appendix 3).

*Preparation of data for cluster analysis.* The original data set included 207 sites with three adjacent land use categories (crop, pasture and forest). Sites with adjacent forest or unknown land use were eliminated for this analysis. Because clustering programs will not consider sites with missing values, those sites were also eliminated, resulting in a final set of 96 sites. Site characterization included both quantitative and qualitative descriptors. Both quantitative and categorical landscape descriptors were used in the clustering procedure. A Shapiro-Wilks test for normality indicated that no quantitative landscape descriptors were normally distributed (all $Pr < W$ were less than 0.04). Therefore, in order to reduce the effect of skewness, quantitative descriptors were log-transformed prior to analysis. The clustering program uses only quantitative variables, so categorical variables were coded as "dummy" values of "0" or "1"; region (Coastal Plain, Piedmont), straightening of the stream channel (yes/no), adjacent field use (crop/pasture), soil drainage class (good/poor), channel shape (natural/triangular), presence of levees or berms (yes/no) and stream order ($1^{st}$ and $2^{nd}$, $3^{rd}$ and $4^{th}$ order). Mean values and standard deviations for site descriptors are given in Table 4.

**Cluster analysis and interpretation of results**

Categorization was performed using the CLUSTER procedure (average linkage method) in SAS. SAS code for cluster analysis is presented in Appendix 18. This is an aggregation method that hierarchically clusters the observations. Each observation begins in a cluster by itself. The two closest clusters are merged to form a new cluster that replaces the two old clusters. Merging of the two closest clusters is repeated until only one cluster is left. The standardization option was used, in order to give all variables equal weight, a common procedure in cluster analysis. Following the Cluster procedure, sites were partitioned into a specific number of groups. The ultimate grouping of sites was determined by repeated trials with 4 to 8 groups of sites and examination of the univariate statistics of the resultant groups.

**Table 4. Mean values and standard deviations for riparian landscape descriptors in the 1998 University of Maryland Agricultural Riparian Buffer Survey.**

| Landscape Descriptor | n | Mean | Std. Dev. |
|---|---|---|---|
| **Location** | | | |
| Physiographic region * | 207 | 0.55 | 0.50 |
| Distance downstream (km) | 206 | 3.25 | 4.86 |
| Site watershed area (ha) | 207 | 3.46 | 9.23 |
| **Land Use** | | | |
| Adjacent crop? * | 205 | 0.62 | 0.49 |
| Adjacent pasture? * | 207 | 0.36 | 0.48 |
| **Riparian Zone Characterization** | | | |
| Length buffer fragment (km) | 174 | 0.88 | 1.18 |
| **Topography** | | | |
| Field slope (%) | 196 | 4.78 | 5.40 |
| Riparian slope (%) | 193 | 8.17 | 9.65 |
| **Surface Hydrology** | | | |
| Stream order < 3? * | 207 | 0.79 | 0.41 |
| Stream gradient (%) | 207 | 1.12 | 0.86 |
| Channel straightened? * | 205 | 0.27 | 0.45 |
| **Groundwater Hydrology** | | | |
| Riparian soil drainage class* | 199 | 0.24 | 0.43 |
| Field soil drainage class* | 203 | 0.79 | 0.41 |
| Depth to riparian water table (m) | 207 | 1.2 | 2.6 |
| Depth to field water table (m) | 207 | 3.7 | 3.2 |
| Riparian surface K (cm/hr) | 207 | 3.8 | 2.8 |
| Field surface K (cm/hr) | 205 | 4.8 | 3.0 |
| Riparian minimum K (cm/hr) | 207 | 3.0 | 2.8 |
| Field minimum K (cm/hr) | 205 | 3.2 | 2.2 |
| Depth to riparian minimum K (m) | 201 | 8.1 | 3.0 |
| Depth to field minimum K (m) | 205 | 6.1 | 3.2 |

* coded descriptors have values of "0" or "1"

Physiographic region: Coastal Plain = 0, Piedmont = 1
Adjacent crop or pasture: no = 0, yes = 1
Stream order <3: yes = 0, no = 1
Channel straightened: no = 0, yes = 1
Riparian and field soil drainage class: poor = 0, good = 1

# RESULTS AND DISCUSSION

By repeatedly performing the SAS Proc Cluster procedure on the data using 4 to 8 final numbers of clusters indicated that for this group of sites, there were four optimal number of site clusters. Most sites were classified in a cluster with "average" values of all landscape descriptors, and other clusters contained small numbers of sites (Table 5). The landscape descriptors that differentiated the site clusters represented physiographic region, adjacent land use, surface hydrology and channel morphology (Table 6). Sites were differentiated from the "average-values" cluster by being described by at least one landscape parameter with an extreme value (Table 7). The four clusters were designated as follows:

1. "Average sites" - sites with any land use with low drainage density.
2. Coastal Plain crop sites on channelized high-order streams.
3. Coastal Plain or Piedmont crop sites on low-order streams with high drainage density catchments.
4. Piedmont pasture sites on 2nd-3rd-4$^{th}$ -order streams.

**Table 5.** **Number of sites per cluster resulting from the SAS Proc Cluster Procedure. Multiple procedures were performed to produce 4 – 8 clusters of sites, using the 1998 University of Maryland Agricultural Riparian Buffer Survey data.**

| **Number of Clusters** | $N_{Cluster\ 1}$ | $N_{Cluster\ 2}$ | $N_{Cluster\ 3}$ | $N_{Cluster\ 4}$ | $N_{Cluster\ 5}$ | $N_{Cluster\ 6}$ | $N_{Cluster\ 7}$ | $N_{Cluster\ 8}$ |
|---|---|---|---|---|---|---|---|---|
| **4** | 87 | 10 | 4 | 1 | | | | |
| **5** | 83 | 10 | 4 | 4 | 1 | | | |
| **6** | 83 | 9 | 4 | 4 | 1 | 1 | | |
| **7** | 80 | 9 | 4 | 4 | 3 | 1 | 1 | |
| **8** | 80 | 9 | 4 | 4 | 2 | 1 | 1 | 1 |

**Table 6.** **Riparian landscape descriptors that differentiated clusters of sites and corresponding descriptor categories, based on data from the 1998 University of Maryland Agricultural Riparian Buffer Survey.**

| **Descriptor Category** | **Descriptor** |
|---|---|
| Location | Region |
| Land Use | Adjacent land use |
| Surface Hydrology | Stream order |
| | Drainage density[1] |
| Channel Morphology | Straightened? |

[1] Drainage density was described by the product of site watershed area and distance downstream along the main channel of the stream.

**Table 7. Landscape descriptor qualities for clusters of sites produced by the Agricultural Riparian Classification System (ARCS), based on data from the 1998 University of Maryland Agricultural Riparian Buffer Survey.**

| Cluster | Number of sites | Straightened stream? | Drainage density [1] | Stream order | Region | Adjacent land use |
|---|---|---|---|---|---|---|
| **1** | 83 | mix | low | all | mix | all |
| **2** | 10 | yes | low | high | C. Plain | crop |
| **3** | 4 | no | high | low | mix | crop |
| **4** | 4 | no | low | high | Piedmont | pasture |

[1] Drainage density was described by the product of site watershed area and distance downstream along the main channel of the stream.

*An example of the Agricultural Riparian Classification System (ARCS).* An agricultural site in Montgomery County (Piedmont physiographic region) was classified with the ARCS as an example of the application of the system. A topographic map provided stream order. Fieldwork consisted of observation of the adjacent land use and whether the stream was channelized (straightened) or natural. This information was gathered by a drive-by observation. Because this was a Piedmont site with adjacent pasture on a natural (unchannelized) 3rd order stream, it was placed in ARCS category 4.

## CONCLUSIONS

This riparian classification system provides the first method for categorizing agricultural riparian landscapes of for the Coastal Plain and Piedmont physiographic regions of Maryland. The study was based on structural characteristics. Sites were characterized with easily obtainable information and represented a gradient of settings from cropland on channelized streams in the Coastal Plain to pastures on natural streams in the Piedmont. The results indicated that, for the Coastal Plain and Piedmont physiographic regions of Maryland, the continuum of agricultural riparian landscapes could be categorized into discrete groupings with recognizable characteristics.

Although there are distinct structural differences between representative landscapes of the Coastal Plain and Piedmont physiographic regions, at the riparian landscape scale, most sites in both regions demonstrated average structural characteristics. Other groups of sites deviated from this set of average values in some way. The elements associated with deviance from average values can be obtained from soil surveys, USGS topographic maps and minimal site work. Although minimal, fieldwork is necessary to perform the ARCS because Remote Sensing data do not currently provide the necessary resolution for this work. Data with finer resolution may be available from GIS data sets in the future.

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# CHAPTER 4 –

# AGRICULTURAL RIPARIAN BUFFER SURVEY – USE OF TWO DATA SETS: 1995-1997 MBSS AND 1998 UNIVERSITY OF MARYLAND BUFFER SURVEY

## ABSTRACT

The purpose of this paper is to present two field-based data sets that were used to characterize the distribution of riparian buffers in agricultural settings within the Coastal Plain and Piedmont physiographic regions of Maryland. The first data set is the University of Maryland Agricultural Riparian Buffer Survey, an extensive field-based survey conducted in the summer of 1998. This survey provided extensive, ground-truthed information about agricultural riparian buffers, the surrounding land, and to a lesser extent, the land and streams within the buffers, within the Coastal Plain and Piedmont physiographic regions of Maryland. The second data set is an altered version of the 1995-1997 Maryland Biological Stream Survey (MBSS), conducted by Maryland Department of Natural Resources. This annual survey is conducted to assess water quality, physical habitat, and biological conditions in first through third order, non-tidal streams. Although buffer characterization is not the primary purpose of the survey, MBSS data include limited site-specific, ground-truthed information on riparian buffers as well as land use information for catchments upstream of the

sampled sites. A subset of the MBSS data set was selected to represent agricultural sites in primarily agricultural watersheds of the Coastal Plain and Piedmont physiographic regions. The original University of Maryland Survey data were censored to reflect the same defined maximum buffer width used in the MBSS. Comparison of the two data sets indicated excellent agreement. Comparison of the censored data sets to the original UM Survey demonstrated the critical effect of defined maximum buffer width: a defined maximum buffer width of 50 meters yielded an average buffer width of approximately 30 meters, whereas original UM Survey with a defined maximum buffer width of 305 meters (1000 feet) yielded an average width of approximately 49 meters. Since average buffer width is a key value for management, this effect has important implications for policymakers. These two data sets provide extensive, ground-truthed, field-based information on riparian buffers in the state of Maryland.

## INTRODUCTION

### Background

In 1998, the University of Maryland, the Maryland Agricultural Cooperative Extension Service, and the Forestry Division of Maryland's Department of Natural Resources joined together to conduct a fieldwork-based survey of agricultural riparian buffers in Maryland's Chesapeake Bay watershed. This research provided the first extensive, ground-truthed attempt to describe a large set of agricultural riparian buffers, the surrounding land, and to a lesser extent, the land and streams within the buffers. The research has been summarized in Chapter 2. The only other data set that includes extensive, ground-truthed information on Maryland's riparian buffers is the Maryland Biological Stream Survey (MBSS). The Maryland Department of Natural Resources (DNR) conducts this annual survey to assess water quality, physical habitat, and biological conditions in first through third order, non-tidal streams. Although buffer characterization is not the primary purpose of the survey, MBSS data includes limited site-specific, ground-truthed information on riparian buffers as well as land use information for catchments upstream of the sampled sites.

**Purpose**

The purpose of this chapter is to compare and contrast these two field-based data sets in order to characterize the distribution of riparian buffers in agricultural settings within the Coastal Plain and Piedmont physiographic regions of Maryland. The MBSS data enabled an objective validation and critique of the results obtained in Chapter 2. One of the key findings of Chapter 2 was the inability of remotely sensed data to distinguish a large percentage of Maryland's agricultural buffers. Therefore, the development of data sets that accurately portray the width and distribution of Maryland's agricultural buffers is critical for the development of empirical models of buffer effectiveness.

**Objectives**

1. To develop a parsed data set from the MBSS 195-1997 data that will be representative of agricultural riparian landscapes in Maryland's Coastal Plain and Piedmont regions, and suitable for model development.

2. To evaluate the parsed MBSS data set and confirm that is as representative of agricultural riparian landscapes in Maryland's Coastal Plain and Piedmont physiographic regions as data from the 1998 University of Maryland Agricultural Riparian Buffer Survey.

## METHODS

### Overall summary of methods

Two ground-truthed databases were examined, compared and contrasted to characterize the extent and nature of agricultural riparian buffers in the Coastal Plain and Piedmont physiographic regions of Maryland. The first data set was the University of Maryland (UM) Agricultural Riparian Buffer Survey, an extensive field-based survey conducted in the summer of 1998. The second data set was the 1995-1997 MBSS, conducted by Maryland DNR. The data sets were examined and censored to create two new data sets with comparable characteristics. Univariate analysis on the data sets provided contrast and validation of their effectiveness to represent the Maryland's agricultural riparian landscapes.

### Description of the data sets

The 1995-1997 MBSS used a rapid bioassessment protocol to collect site-level data on the stream channel and adjacent land during the spring and early summer (Kazyak, 1997). Although buffer characterization was not the primary purpose of the survey, limited information was taken on the riparian zone (buffer width, vegetation type). Land use information for the site catchment was obtained from Geographic

Information System (GIS) data. About 300 sites (75 meter stream segments) were sampled each year during the three-year period 1995-97, producing a data set with over 900 sites intended to be representative of all basins in the state. An MBSS data collection site was represented by approximately 160 variables. Numerous location variables and time variables identified exactly where and when the samples were collected. Not only were the immediate sites described but some adjacent land use data were also recorded. Variables describing site landscapes are described briefly:

- Percent agriculture and rowcrops in catchment: Percent agricultural land use in the site catchment and % rowcrops in catchment were based on the 1996 Multi-Resolution Land Use Classification (MRLC) land cover data base for EPA Region III (MRLC, 1996a; MRLC, 1996b).
- Maximum depth: maximum depth within the 75-meter segment (cm).
- Area: the site catchment area, reported in acres.
- Stream order: represents the Strahler (1957) convention used for ranking stream reaches by order. Stream order determination was based on a stream reach file digitized from 1:250,000 scale topographic maps for the MBSS in 1987.
- Riparian width: the width of the vegetated riparian buffer was estimated (m), to a maximum of 50 m. If the buffer was greater than or equal to 50 m, a value of 50 was entered. This measure was the width of the riparian buffer on the side of the stream with the smallest buffer.

The 1998 University of Maryland Agricultural Riparian Survey characterized riparian landscapes in eight primarily agricultural watersheds of Maryland's Coastal Plain and Piedmont physiographic regions. Site survey measurements that were taken as multiple replicates (channel width and depth, bank angles, stream velocity, riparian buffer width) were reduced to average values. Therefore, these 34 parameters represented over 150 individual measurements characterizing 207 sites. Tables 8 and 9 present the site descriptors and range of values obtained through the combination of fieldwork, map work and GIS work.

**Table 8. Landscape descriptors used to characterize the agricultural riparian landscape in the 1998 University of Maryland Agricultural Riparian Buffer Survey.**

| Descriptor Category | Riparian Landscape Descriptor | Units | Range of Values |
|---|---|---|---|
| **Land Use** | Survey watershed % agriculture[2] | % | 38.2 - 76.1 |
| | Survey watershed % forest[2] | % | 26.1 – 45.0 |
| | Site contributing watershed % agriculture[2] | % | 36.9 – 100.0 |
| | Site contributing watershed % crops[2] | % | 26.3 – 100.0 |
| | Adjacent land use[1] | crop/pasture/ forest/other | |
| **Buffer Char-acter-ization** | Buffer width[1] | m | 0 – 304.8 |
| | Length of buffer fragment[3] | km | 0.02 - 6.9 |
| | Forest buffer DBH[1] | cm | 3.8 - 84.3 |
| | Forest buffer basal area[1] | $m^2$ | 0 - 15.5 |
| | Shrub height[1] | m | 0.3 - 6.1 |
| **Topo-graphy** | Watershed topographic index [2] | $m/m^2$ | 0.9 - 30.1 |
| | Riparian buffer slope[1] | % | -2.5 - 62.3 |
| | Adjacent field slope[1] | % | 0 - 37.5 |
| | Ratio riparian buffer:adjacent field slope[1] | unitless | -0.11 - 35.2 |
| **Surface Hydrology** | Watershed drainage density[2] | $km^2/km$ | 1.02 - 1.25 |
| | Mainstem sinuosity[2] | km/km | 1. 1- 1.4 |
| | Stream gradient[1] | **%** | 0 – 4.0 |
| | Stream velocity[1] | m/sec | 0 – 1.0 |
| | Stream order [1,2] | unitless | 1 - 4 |

[1] from on-site field work [2] from GIS work [3] from soil survey

**Table 8. (continued) Descriptors used to characterize the agricultural riparian landscape in the 1998 University of Maryland Agricultural Riparian Buffer Survey.**

| Descriptor Category | Riparian Landscape Descriptor | Units | Range of Values |
|---|---|---|---|
| **Ground-water Hydrology[3]** | Riparian buffer avg. depth to water table | m | 0 - 10.7 |
| | Adjacent field avg. depth to water table | m | 0 - 10.7 |
| | Riparian buffer surface K * | cm/hour | 0.03 - 15.2 |
| | Adjacent field surface K * | cm/hour | 0.1 - 15.2 |
| | Riparian buffer minimum K * | cm/hour | 0.03 - 15.2 |
| | Adjacent field minimum K * | cm/hour | 0.05 - 15.2 |
| | Riparian buffer soil drainage class | variable/poor/ good/ excellent | |
| | Adjacent field soil drainage class | variable/poor/ good/ excellent | |
| | Riparian buffer depth of minimum K * | m | 0.03 - 15.5 |
| | Adjacent field depth of minimum K * | m | 1.7 - 15.1 |
| **Channel Morphology[1]** | Channel width | m | 0.4 - 21.6 |
| | Channel depth | m | 0.2 - 5.6 |
| | Channel cross-sectional area | $m^2$ | 0.1 – 50.5 |
| | Channel width : depth ratio | m/m | 0.27 – 30.0 |
| | Substrate | mud/sand/ gravel/ cobble | |
| | Channel shape | natural/ triangular | |
| | Channel straightened? | yes/no | |
| | Presence of berms | yes/no | |
| | Degree of gullying | low/moderate/ severe | |
| | Average bank angle (degrees) | degrees | 5.7 – 90.0 |
| | Degree of bank erosion | low/moderate/ severe | |
| | Livestock access | yes/no | |

* K = hydraulic conductivity
[1] from on-site field work [2] from GIS work [3] from soil survey

**Table 9. Values of categorical descriptors used to characterize the agricultural riparian landscape in the 1998 University of Maryland Agricultural Riparian Buffer Survey.**

| | | | | | | |
|---|---|---|---|---|---|---|
| **Buffer Characterization** | **Buffer tree type** | **hardwood** 85.94 | **mix** 13.28 | **pine** 0.78 | | |
| **Groundwater Hydrology** | **Adjacent field soil drainage class** | **excellent** 11.06 | **good** 58.65 | **poor** 13.46 | **variable** 16.83 | |
| | **Riparian buffer soil drainage class** | **excellent** 5.77 | **good** 18.75 | **poor** 67.31 | **variable** 8.17 | |
| **Channel Morphology** | **Channel substrate** | **boulder** 2.5 | **cobble** 24 | **sand/ gravel** 32 | **sand** 13.5 | **mud** 28 |
| | **Channel shape** | **natural** 91.22 | **triangular** 8.78 | | | |
| | **Channel straightened** | **yes** 27.18 | **no** 72.86 | | | |
| | **Berms** | **yes** 10.73 | **no** 89.27 | | | |
| | **Gullying** | **high** 3.11 | **medium** 7.77 | **low** 54.92 | **none** 34.2 | |
| | **Bank erosion** | **high** 21.52 | **medium** 53.8 | **low** 22.15 | **none** 2.53 | |
| | **Livestock access** | **yes** 20.39 | **no** 79.61 | | | |

**Differences between the two databases**

Because the two databases were developed for different purposes, they contained different landscape information on two different populations of sites. The MBSS data included a far wider range of site types than the University of Maryland Buffer Survey. MBSS data included non-agricultural sites, watersheds that were not primarily agricultural, and physiographic regions other than the Coastal Plain and Piedmont. In addition, the two databases contained different site descriptors (land uses adjacent to the site, land uses in the site watershed, physiographic regions) and buffer descriptors. Buffer vegetation was described slightly differently in the two data sets. In the MBSS data, riparian buffer type was designated by one of the land use/land cover types used for adjacent land cover. Although there was one descriptor for "forest" buffer, there were multiple adjacent land use descriptors describing "grass" buffers (tall grass, old field, and lawn). In the UM Buffer Survey, buffer types were divided into forest, grass and "other". Although the width of buffer at a site was defined in both data sets as the average buffer width on one side of the stream, this value was derived slightly differently. The MBSS reported the width of the narrowest buffer on one side of the stream. The UM Buffer Survey reported the average of 6 readings, 3 on each side of the stream. Maximum buffer width was defined differently, as well. MBSS defined maximum buffer width as 50 m (Mercurio et al., 1999). The UM Buffer Survey defined maximum buffer width as 305 m.

**Development of modified data sets**

Two new data sets (designated MBSS* and Survey*) were created by modifying the original data sets. The MBSS* data set was created by taking a subset of the original MBSS data to include only agricultural sites in primarily agricultural watersheds of the Coastal Plain and Piedmont physiographic regions. A "primarily agricultural watershed" was defined as one whose percent agriculture was greater than 35%, consistent with the minimum site percent agriculture found in the UM Buffer Survey. These restrictions reduced the MBSS data from 904 sites to 279 sites. Because censorship of the MBSS data removed sites, univariate values for the MBSS* data set were different from the original MBSS data set. The Survey* data set was created, not by removing any sites, but by re-defining maximum buffer width. All buffer widths between 50 meters and 305 meters in the Survey data set were defined as 50 meters. Therefore maximum buffer width was the only significant change between the UM Buffer Survey data set and the Survey* data set.

The data were analyzed to provide univariate measures (mean, standard deviation, and percents), distribution measures (statewide distribution of buffer types, regional distribution of buffer types, width histograms) and correlation (Appendices 6 and 7) for agricultural buffers in Maryland. Values from the two data sets were compared to determine if they represented the same population of sites. All data were analyzed using SAS software.

# RESULTS AND DISCUSSION

## Comparison of the modified databases

Comparison of the original and altered data sets is summarized in Table 10. Survey* and MBSS* data sets both represented approximately the same number of sites. Univariate analysis of several landscape descriptors indicated that the two databases represented the same population of sites. All sites were limited to the Coastal Plain and Piedmont physiographic regions of Maryland. Both data sets showed approximately 60% watershed agriculture. Both data sets showed approximately 17% grass buffers, and between 55 to 70% forest buffers. Average buffer width using the MBSS* and Survey* data sets was approximately 30 meters and were not statistically different at the 95% level of confidence. These results indicated that the two censored data sets portrayed the same population of sites.

**Table 10.** **Comparison of the original 1998 University of Maryland Agricultural Riparian Buffer Survey (Survey), 1995-1997 Maryland Biological Stream Survey (MBSS), modified Survey (Survey*), and modified MBSS (MBSS*) data sets.**

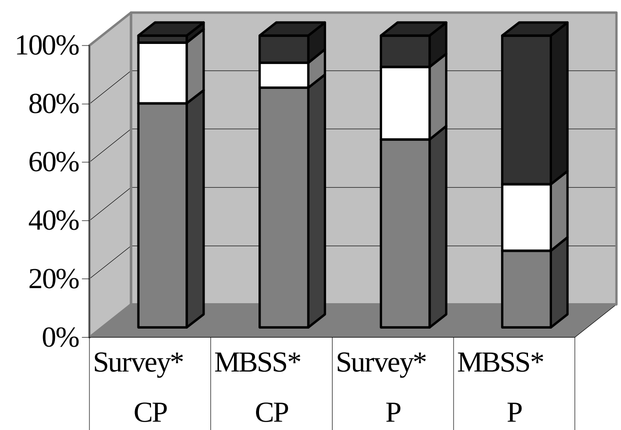
| | | Survey | MBSS | Survey* | MBSS* |
|---|---|---|---|---|---|
| **Number sites** | | 207 | 954 | 207 | 279 |
| **Number physiographic regions** | | 2 | 6 | 2 | 2 |
| **% forest buffers** | | 70.5 | 56.0 | 70.5 | 55.4 |
| **% grass buffers** | | 16.4 | 10.0 | 16.4 | 17.4 |
| **% unbuffered sites** | | 6 | | 6 | 24 |
| **Site % ag** | Mean | 56.0 | 44.2 | 56.0 | 64.7 |
| | SD | 14.0 | 26.52 | 14.0 | 14.0 |
| | Max | 100.0 | 96.8 | 100.0 | 96.8 |
| | Min | 38.2 | 0 | 38.2 | 37.3 |
| **Site % crops** | | | | 44.2 | 41.8 |
| **Site % pasture** | | | | 29.4 | 21.84 |
| **Buffer width (m)** | Mean | 48.8 | 24.2 | 24.9 | 31.1 |
| | SD | 57.7 | 20.4 | 18.3 | 20.2 |
| | Max | 304.8 | 45.7 | 45.7 | 45.7 |
| | Min | 0 | 0 | 0 | 0 |

**Distribution of buffer types**

Distribution of buffer type was depicted as the relative statewide number of sites with no buffer, forested buffer, or grass buffer. Both data sets showed the same relative distribution of forested to grass buffers in the Coastal Plain (Figure 11). The data sets differed in the amount of unbuffered agricultural sites. Survey* data showed 6% unbuffered sites, whereas MBSS* data showed approximately 24% unbuffered sites. Users may find that this is the primary difference in the two data sets.

Both data sets showed the same pattern for distribution of buffers across physiographic region (Figure 12), although the MBSS* data reflected a higher percentage of unbuffered sites in the Piedmont.  The Piedmont (P) had more unbuffered sites and grassed buffers than the Coastal Plain (CP).  The Coastal Plain had more forested buffers than grass buffers.   These results are in marked contrast to the belief that farmers on the Eastern Shore of Maryland (in the Coastal Plain) are less likely to install buffers at all, and forested buffers in particular.

**Figure 11. Distribution of agricultural riparian buffers by type and physiographic region, as determined by Survey* and MBSS* data.**




| | Survey* CP | MBSS* CP | Survey* P | MBSS* P |
|---|---|---|---|---|
| none | 2.33 | 9.3 | 10.75 | 50.9 |
| Grass | 20.93 | 8.6 | 24.73 | 22.7 |
| RFB | 76.74 | 82.1 | 64.52 | 26.4 |

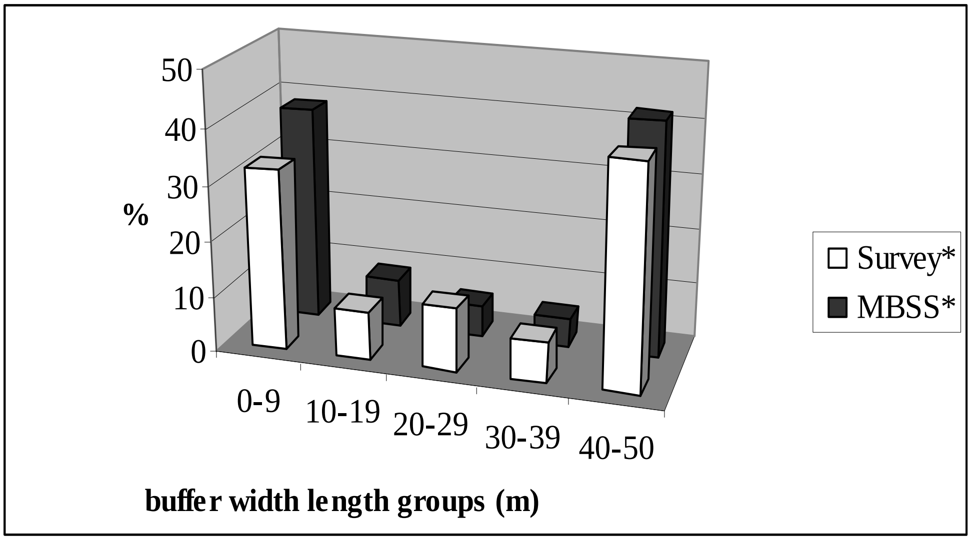
- Survey* and MBSS* data represent riparian agricultural sites in catchments with > 35% agriculture, in the Coastal Plain and Piedmont physiographic regions of Maryland.  (RFB = riparian forest buffer, CP = Coastal Plain, P = Piedmont).

**Buffer width**

Although the average buffer widths developed from Survey* and MBSS* data were not significantly different, average buffer width developed from the original UM Survey data was approximately 49 meters, and was significantly wider. This effect demonstrated the critical effect of maximum buffer width. The Survey data with defined maximum buffer width of 305 meters produced a greater average value than the Survey* data, which censored buffer widths to no wider than 46 meters. Since average buffer width is a key value for management, this effect has important implications for policymakers.

Buffer width histograms were constructed using MBSS* and Survey* data (Figure 12). Most sites fell into one of two width groups; the narrowest width group of buffers less than 10 meters (30 ft) wide and the widest width group of buffers greater than 40 meters (120 ft). Further resolution of buffer width is impossible within these categories. Therefore, a larger defined maximum buffer width, such as used in the UM Buffer Survey, would enable finer delineation of the distribution of buffer widths.

**Figure 12. Histogram of agricultural buffer width for all buffer types combined, based on Survey* and MBSS* data.**

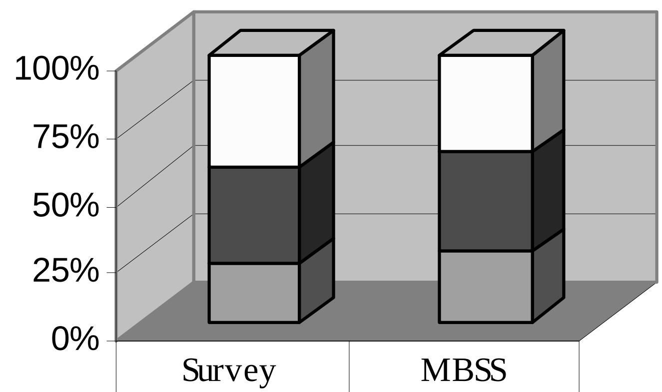



* Buffer widths greater than 50 meters have been censored to 50 meters.

**Usefulness of remotely sensed data**

The buffer width histograms for the MBSS* data verified the implications concerning the usefulness of RS data for buffer surveys determined from the 1998 University of Maryland Agricultural Riparian Buffer Survey. Most buffer surveys have been performed with remotely sensed (RS) data because of the exhaustive nature of the fieldwork. RS data are generally available in 10-meter and 30-meter resolution. Figure 13 illustrates the inaccuracy inherent in RS data used for this work. Both data sets indicated that approximately 30% of agricultural riparian buffers were less than 10 meters wide, and approximately 50% of buffers were less than 30 meters wide. Even considering the total width of buffer on both sides of a stream, surveys performed with RS data would drastically underestimate the number and amount of agricultural buffers in Maryland. This would be especially problematic in the Piedmont, where grass buffers were more prevalent, since remote sensing technologies currently have difficulty distinguishing grass from low-level crops or pasture.

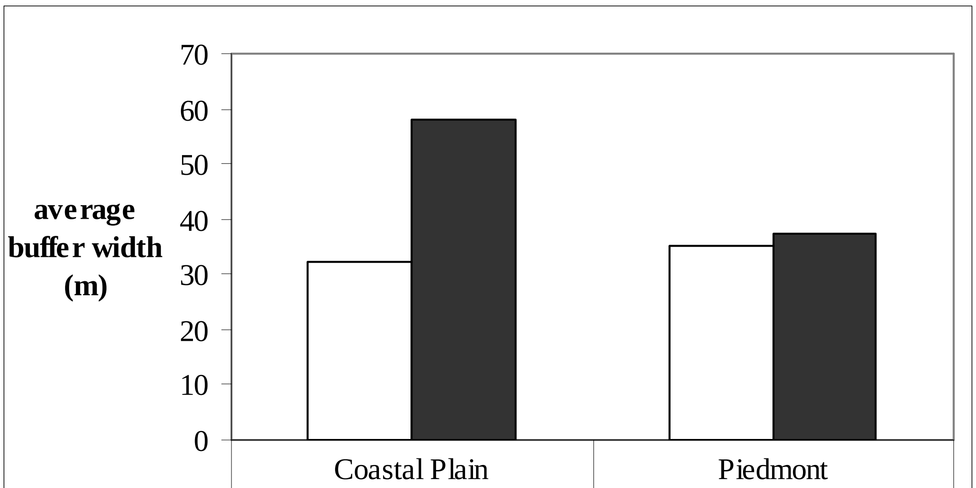
**Figure 13. Percent of agricultural riparian buffers in the Coastal Plain and Piedmont physiographic regions of Maryland that are narrower than the resolution of remotely sensed data, based on the 1998 University of Maryland Agricultural Riparian Buffer Survey.**




| | Survey | MBSS |
|---|---|---|
| what's seen | 54 | 50 |
| width <30m | 46 | 50 |
| width <10m | 29 | 36 |

Average buffer width over all buffer types was compared between the two physiographic regions (Figure 14). Analysis of the MBSS* data set indicated that Coastal Plain buffers were the same width as Piedmont buffers and the Survey* data indicated that Coastal Plain buffers were wider than Piedmont buffers. These results were not surprising, since the data indicated more forested buffers in the Coastal Plain and that forested buffers were wider than grass buffers. However, the result that Coastal Plain buffers were as wide or wider than Piedmont buffers was in direct contrast to the popular but anecdotal impressions that Eastern Shore (Coastal Plain) has narrow buffers.

**Figure 14. Average agricultural riparian buffer width in the Coastal Plain and Piedmont physiographic regions of Maryland, as determined by Survey* and MBSS* data.**




| | Coastal Plain | Piedmont |
|---|---|---|
| □ MBSS* | 32.3 | 35.4 |
| ■ Survey* | 57.9 | 37.5 |

## CONCLUSIONS

Both the UM Agricultural Buffer Survey and the MBSS provided extensive, ground-truthed, field-based information on riparian buffers in the state of Maryland. These two independent data sets, created for different purposes, were subset and censored to provide information about a common population of sites. The two modified data sets produced same or similar descriptions of the nature and extent of riparian buffers at agricultural sites in highly agricultural watersheds of Maryland's Coastal Plain and Piedmont physiographic regions.

Because of the similarity of results, these data sets are considered trustworthy for use in development of models of agricultural buffer effectiveness. The use of MBSS* data confirmed the accuracy of the following results reported in Chapter 2:

(1) Most agricultural sites had buffers.

(2) The Coastal Plain was dominated by forested buffers, whereas the Piedmont had a higher proportion of grass buffers,

(3) Forested buffers were wider than grass buffers,

(4) Average width of Coastal Plain buffers was the same or greater than Piedmont buffers,

(5) A significant portion of buffers were narrower than the current resolution of RS data, indicating that buffer surveys performed with RS data drastically underestimate the number and amount of agricultural buffers in Maryland.

MBSS* data differed from the UM Survey data in the estimate of the number of unbuffered agricultural sites. Further work is necessary to determine a more accurate estimate of the distribution of unbuffered sites in Maryland.

This use of two independent data sets also provided insight into interpretation of MBSS data. The use of a 150-foot defined maximum buffer width drastically censored interpretation of actual buffer width and caused a significant underestimation of average buffer width. Therefore, buffer width values reported from MBSS data (Boward et al., 1999; Roth et al., 1999) should be viewed with caution.

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# CHAPTER 5 –

# INITIAL MODELING TO INVESTIGATE THE EFFECTS OF AGRICULTURAL RIPARIAN BUFFERS TO MITIGATE NITRATE STREAM POLLUTION

## INTRODUCTION

This chapter presents the initial exploratory work to model the effect of agricultural riparian buffers on instream nitrate. The effect of buffers on instream nitrate was prompted by the regulatory interest in agriculture's contribution of nitrate to the Chesapeake Bay. These exploratory procedures were performed on the data developed by combining landscape data from the 1998 University of Maryland Buffer Survey and nitrate data provided by the Smithsonian Environmental Research Center. The work is presented in three parts:

I Examination of explanatory variables

II Modeling nitrate change along a reach

III Modeling nitrate - land use relationships

## I. EXAMINATION OF DESCRIPTOR VARIABLES

### METHODS

The UM Buffer Survey data included over 30 landscape descriptors that were candidates as explanatory variables for multiple linear regression models. Environmental descriptors are well known to cause collinearity problems in modeling, so work was performed to attempt to reduce the number of explanatory variables used by reducing the number of correlated variables. The SAS Proc Mixed procedure (SAS Institute Inc., 1988) was used to test the quantitative landscape descriptors for regional differences, using one average value per descriptor per watershed. The Fisher exact test was used to determine regional differences for qualitative landscape descriptors. Finally, the overall correlation matrix with all descriptors and all sites was developed and examined (Appendix 4).

### RESULTS AND DISCUSSION

*Proc mixed results.* The SAS Proc mixed regression procedure was used to test the hypothesis that Coastal Plain sites showed differences from Piedmont sites. These models demonstrated that some variables did show a statistically significant difference between physiological regions (Table 11). All log values were tested, but only log values that showed $Pr < 0.05$ are presented. Regional differences were seen for all categories of landscape descriptors except channel morphology. This exercise was done to reduce the number of explanatory variables used in multiple regression modeling. However, the use of the SAS R-square search procedure and collinearity diagnostics in the final modeling procedure eliminated the need to reduce initial variables.

*Fisher exact test results.* Regional differences were seen for all qualitative landscape descriptors except drain tiles and channel shape (Table 12). Closer examination of these data revealed that there were very few data for "presence of drain tiles", so this descriptor was eliminated in later modeling work.

**Table 11. Least squares means values (and standard deviations) for quantitative landscape descriptors based on mixed models analysis of the significant difference between Coastal Plain and Piedmont sites, based on data from the 1998 University of Maryland Agricultural Riparian Buffer Survey.**

| | All data | Coastal Plain | Piedmont | Pr>F |
|---|---|---|---|---|
| **Topography** | | | | |
| Riparian slope (%) | 8.17 (9.65) | 6.85 (1.13) | 9.18 (1.02) | 0.18 |
| LOG riparian slope | 0.79 (0.37) | 0.69 (0.05) | 0.88 (0.06) | 0.06 |
| Field slope (%) | 4.78 (5.40) | 2.82 (1.16) | 5.66 (1.15) | 0.13 |
| Riparian slope: Field slope | 2.66 (4.62) | 3.15 (0.80) | 2.79 (0.76) | 0.76 |
| Topographic index ($m/m^2$) | | 3.87 (3.94) | 19.56 (3.03) | **0.03** |
| LOG Topographic index | | .43 (.20) | 1.23 (.14) | **0.03** |
| **Surface Hydrology** | | | | |
| Drainage density ($km^2/km$) | | 1.22 (.09) | 1.12 (.08) | 0.44 |
| Site watershed area: stream distance ($km^2/km$) | 1.58 (1.99) | 1.94 (0.37) | 1.40 (0.36) | 0.35 |
| Stream gradient (%) | 1.11 (0.86) | 1.42 (0.22) | 0.91(0.22) | 0.15 |
| Velocity (m/sec) | 0.3 (0.2) | 0.2 (0.05) | 0.3 (0.05) | 0.78 |
| Tortuosity (km/km) | | 1.16 (.07) | 1.28 (.02) | 0.26 |
| Stream order | 1.83 (0.89) | 1.62 (0.11) | 1.99 (0.99) | **0.04** |
| LOG Stream order | 0.21 (0.20) | 0.16 (0.03) | 0.25 (0.03) | **0.03** |
| **Land Use** | | | | |
| % agriculture | 55.75 (7.16) | 39.54 (8.12) | 60.79 (6.09) | 0.10 |
| % forest | | 54.9 (7.3) | 23.3 (5.4) | **0.03** |
| %forest:%agriculture | | 1.9 (0.4) | 0.4 (0.3) | **0.04** |

**Table 11. (continued) Least squares means values (and standard deviations) for quantitative landscape descriptors based on mixed models analysis of the significant difference between Coastal Plain and Piedmont sites (1998 University of Maryland Agricultural Riparian Buffer Survey).**

| | All data | Coastal Plain | Piedmont | Pr>F |
|---|---|---|---|---|
| **Groundwater Hydrology** | | | | |
| Riparian water table (m) | 1.2 (2.6) | | | 0.16 |
| Field water table (m) | 3.7 (3.2) | | | 0.26 |
| Riparian K at surface (cm/hr) | 3.8 (2.8) | | | 0.06 |
| Log riparian K at surface | 0.36 (0.17) | 0.29 (0.03) | 0.42 (0.03) | **0.02** |
| Riparian minimum K (cm/hr) | 3.0 (2.8) | 1.6 (0.4) | 4.2 (0.4) | **0.01** |
| LOG riparian minimum K | 0.29 (0.20) | 0.18 (0.03) | 0.38 (0.03) | **0.002** |
| Field avg. K at surface (cm/hr) | 4.8 (4.8) | | | 0.28 |
| Field minimum K (cm/hr) | 3.2 (2.2) | | | 0.17 |
| LOG field minimum K (cm/hr) | 0.33 (0.14) | 0.29 (0.02) | 0.36 (0.02) | **0.03** |
| Depth of riparian minimum K (m) | 8.1 (3.0) | 8.8 (0.3) | 7.5 (0.3) | **0.02** |
| Depth of field minimum K (m) | 6.1 (3.2) | 7.2 (0.7) | 4.6 (0.7) | **0.03** |
| LOG depth of field minimum K (m) | 1.27 (0.22) | 1.35 (0.06) | 1.14 (0.06) | **0.04** |
| **Channel Morphology** | | | | |
| Channel width (m) | | | | |
| Channel depth (m) | 3.3 (2.3) | | | 1.00 |
| Channel cross-sectional area ($m^2$) | 6.1 (8.0) | | | 0.53 |
| Channel width:depth ratio | 5.8 (3.9) | | | 0.51 |
| Average bank angle | 45.2 (18.4) | | | 0.67 |
| **Buffers** | | | | |
| Total buffer width (m) | 65.5 | | | 0.85 |
| Log total buffer width | 1.77 | | | 0.03 |
| Average tree buffer width (m) | 55.8 | | | 0.85 |
| Log average tree width | 1.09 | | | 0.03 |
| Average grass buffer width (m) | 7.4 | | | 0.73 |
| Average shrub buffer width | 1.0 | | | 0.09 |
| Average in-channel buffer width (m) | 0.4 | | | 0.05 |
| Log average in-channel buffer width | -0.4 | | | 0.04 |
| DBH (cm) | 36.1 | | | 0.22 |
| Basal area ($m^2$) | 5.2 | | | 0.78 |
| Buffer width:slope | 1175 | | | 0.69 |
| Shrub height (m) | 1.9 | | | 0.99 |
| Average length of buffer fragments (m) | 885 (1183) | 901 (319) | 779 (328) | 0.80 |

**Table 12. Fisher exact probability indicating significant difference between Coastal Plain and Piedmont values for qualitative landscape descriptors, based on 1998 University of Maryland Agricultural Riparian Buffer Survey data.**

| **Groundwater Hydrology** | **Units** | **Fisher Exact Prob** |
|---|---|---|
| Riparian zone drainage class | variable/poor/good/excellent | 9.60E-07 |
| Drain tiles presence | yes/no | 0.0692 |
| Field drainage class | variable/poor/good/excellent | 9.10E-07 |
| **Land Use** | | |
| Adjacent field use | crop/pasture/forest | 4.70E-06 |
| **Channel Morphology** | | |
| Substrate | mud/sand/gravel/cobble | 7.83E-27 |
| Rosgen score | unitless | 3.30E-07 |
| Channel shape | natural/triangular | 0.8717 |
| Channelization | yes/no | 7.53E-14 |
| Streambank erosion | high/medium/low | 2.40E-05 |

*Correlation results*: The UM Buffer Survey provided at least one buffer/landscape description on 8 reaches of first through third order streams with upstream/downstream nitrate values from the SERC nitrate survey (Figures 15 and 16). There were 4 reaches in the German Branch watershed and 4 reaches in the Gunpowder watershed. These data provided a set of 35 sites with both riparian landscape and nitrate information, identified as the SERC* data set.

**Figure 15.** **Map of the 1998 University of Maryland Agricultural Riparian Buffer Survey's German Branch watershed (5,690 ha), with SERC nitrate sampling sites (n = 21), assigned average spring baseflow nitrate values, forest and CAFO areas.**

| • survey sites, grey = forested area, dark grey = CAFO area |
|---|

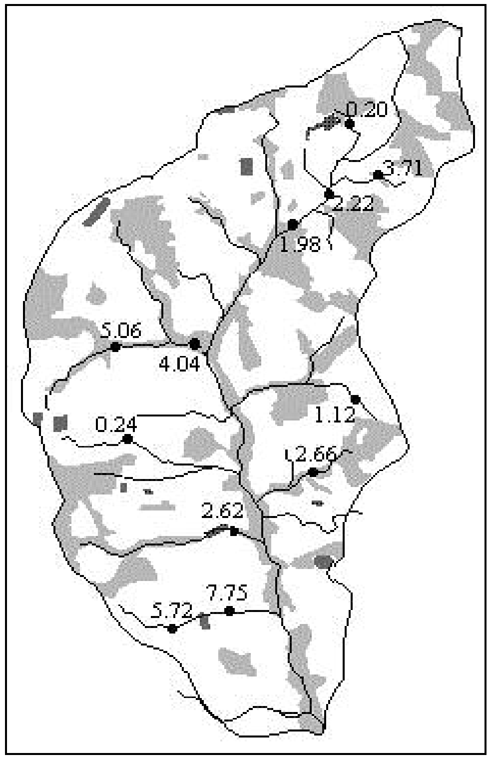
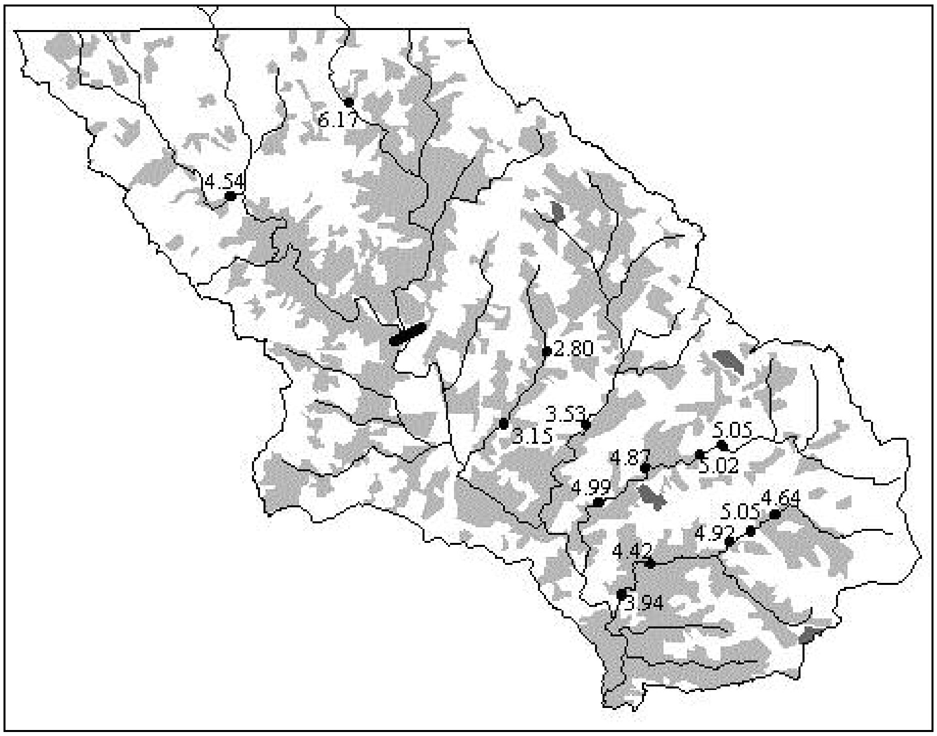


**Figure 16.** **Map of the 1998 University of Maryland Agricultural Riparian Buffer Survey's Gunpowder watershed (12,880 ha) with SERC nitrate sampling sites (n = 14), average spring baseflow nitrate values, forest and CAFO areas.**

• survey sites, grey = forested area, dark grey = CAFO area




A strong scale effect was discovered among the landscape descriptors. Intercorrelation values among landscape and land use descriptors that were developed at the watershed scale were often as high as 0.7-0.8. Absolute values for correlation coefficients of site-level scale descriptors vs. instream nitrate were all less than 0.35. Absolute values for correlation coefficients of watershed-scale descriptors vs. instream nitrate were all greater than or equal to 0.44 (Table 13). These high correlation values were not, in fact, due to a strong relationship between the landscape descriptors and instream nitrate, but were an artifice of censoring the data and causing repeated values for different sites. Therefore, in order to more accurately reflect physical relationships, all final models were limited to site catchment data.

**Table 13. Correlation coefficients for landscape descriptors vs. instream nitrate and scale of influence, based on SERC* data (35 sites from the 1998 University of Maryland agricultural Riparian Buffer Survey that were assigned nitrate values).**

| Landscape descriptor | R | scale |
|---|---|---|
| % agriculture in watershed | -0.46 | w |
| % forest:ag in watershed | 0.46 | w |
| Topographic index | 0.46 | w |
| Stream tortuosity | 0.45 | w |
| % forest in site catchment | 0.44 | w |
| Field water table | 0.34 | s |
| CAFO area in site catchment | 0.34 | s |
| Field slope | 0.31 | s |
| Basal area | -0.26 | s |
| Riparian K minimum depth | -0.26 | s |
| Riparian slope | 0.25 | s |
| Riparian K @ minimum depth | -0.24 | s |
| Forest buffer width | -0.24 | s |
| % ag in site catchment | 0.24 | s |
| Riparian K @ surface | -0.23 | s |
| Stream gradient | 0.18 | s |
| Grass buffer width | 0.18 | s |
| Buffer tree portion width | -0.18 | s |
| DBH | 0.17 | s |
| Riparian water table depth | 0.16 | s |
| % crops in site catchment | 0.15 | s |
| Buffer slope:field slope | -0.13 | s |
| Total buffer width | -.006 | s |

w = watershed scale: values calculated for survey watersheds
s = site scale: values calculated for site catchments or field site location

## II. MODELING NITRATE CHANGE ALONG A REACH

The 1998 University of Maryland Agricultural Buffer Survey was part of a larger study funded by the Fund for Rural America, under the United State Department of Agriculture. Because of the focus on reduction of agricultural contributions to nitrate in the Chesapeake Bay, one of the objectives of this project was to determine buffer impact on instream nitrate.

### METHODS

Multiple linear regression modeling was performed in SAS (SAS Institute Inc., 1988) using the R-square search method. Explanatory variables were the landscape and land use descriptors that had shown highest correlations from the Proc Mixed work. The criteria variable was the change along the reach in average spring baseflow nitrate concentration, expressed in ppm/km. These values were developed as the difference in average spring nitrate values for the upstream and downstream sites, divided by the distance between sites. Development of site nitrate values for the SERC* data set is presented in Appendix 5.

## RESULTS AND DISCUSSION

The overall average change of nitrate along a reach (from upstream to downstream) was an increase of 0.26 ppm/km. This was surprising, since the average buffer width was 67 m (193 ft) and no sites were completely without a buffer. This was primarily due to behavior in the German Branch watershed (Figure 17). Since three of the four German Branch reaches showed a nitrate gain, the overall nitrate change in German Branch was nitrate gain (Table 14). The land use was examined to explain this rather surprising result. Both watersheds were heavily agricultural areas, with an average of 62% agriculture and 57% crops in the site catchments. However, all German Branch sites had higher % agriculture and % crops than the Gunpowder sites, 3 sites had smaller buffers than those in the Gunpowder, and all German Branch sites had less % forest. Correlation values of broad land use terms were strong and reasonable; % agriculture was related to increase in nitrate (0.83) and % forest was related to reduction in nitrate (-0.83). However, correlation values of landscape descriptors suggested senseless relationships. Increasing buffer width was related to increase in nitrate (0.29) and increase in confined animal feeding operation (CAFO) area was positively related to reduction in nitrate (-0.13).

**Figure 17.** **Change in average spring baseflow nitrate concentration along a reach (ppm/km) vs. estimated average buffer width along the reach, for upstream-downstream sampled segments of the German Branch (n = 4) and Gunpowder (n = 4) watersheds, based on the 1998 University of Maryland Agricultural Riparian Buffer Survey.**

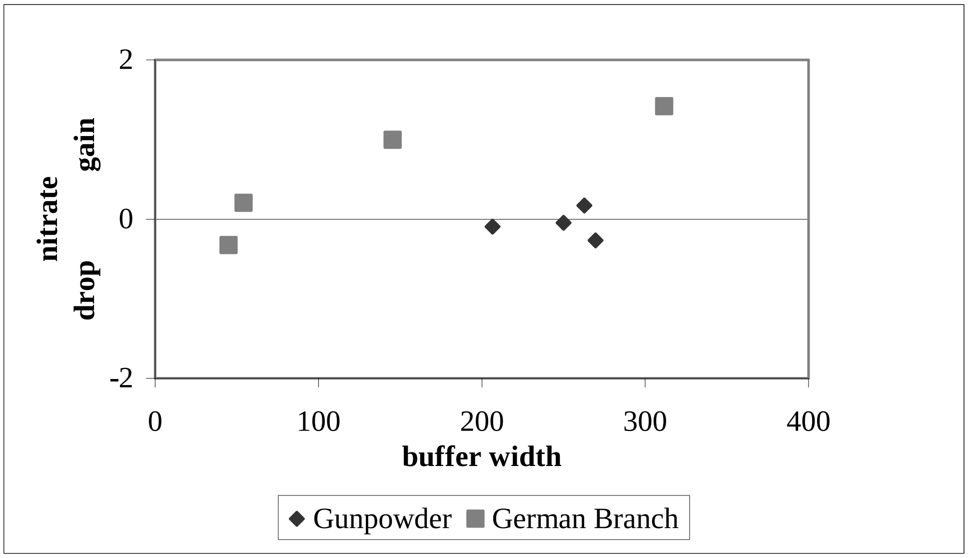



**Table 14.** **Average values of nitrate decrease along a reach, riparian and land use for sites in the contributing watershed, based on SERC* data.**

| DATA | ΔNO3 (ppm/km) | Ag % | Crop % | Pasture % | Forest % | CAFO (ha) | Buffer width (m) | Basal area ($m^2$) |
|---|---|---|---|---|---|---|---|---|
| all data | -0.26 | 62. | 57 | 5 | 38 | 4 | 67 | 4.2 |
| Gunpowder | 0.06 | 50 | 39 | 11 | 50 | 6.5 | 86 | 3.6 |
| German Branch | -0.57 | 74 | 74 | 0 | 26 | 1.5 | 48 | 4.8 |

The SAS R-square search produced the following model for change in nitrate as a function of the explanatory variables:

$$\Delta \text{NO3} = -1.71 + 0.02 \text{ (\% crop)} + 0.003 \text{ (buffer width, ft.)} \quad (5.1)$$

The model was significant (Pr > F = 0.005) and the adjusted $R^2$ was 0.84. No collinearity problems were evident and the residuals were normally distributed. However, this model contained an illogical sign indicating that wider buffers were related to nitrate gain along a reach. This result was concluded to be an artifice of the data. The relationship in the model reflected the individual sites in this very small data set, not larger trends. Whereas this study was investigating non-point-source (NPS) effects, these data suggested that point sources might be effectively overwhelming NPS effects in this small watershed (5,590 ha).

## III. MODELING NITRATE - LAND USE RELATIONSHIPS

### METHODS

This portion of the research investigated more closely the nitrate – land use relationships in the German Branch and Gunpowder watersheds. Spring baseflow nitrate values were considered in relation to site location, adjacent land use, watershed, and stream order. Visual examination of Figures 16 and 17 led to the suspicion that confined animal feeding operations (CAFO) might be acting as point sources and overwhelming NPS effects. To study this relationship further, CAFO factors were developed for the site catchments:

$$\text{CAFO area} = \text{CAFO area in site catchment (ha)} \qquad (5.2)$$

$$\text{CAFO factor} = \text{CAFO area / distance from site (ha/ km)} \qquad (5.3)$$

$$\text{CAFO factor}^2 = \text{CAFO area / distance from site}^2\ (\text{ha}^2/\text{km}^2) \qquad (5.4)$$

Correlation analysis was conducted and models were then developed in SAS (multiple linear regression) and S-PLUS (regression tree analysis). SAS and S-PLUS are both integrated suites of software facilities for exploratory data modeling, statistical analysis and graphical display. S-PLUS is an enhanced version of *S* distributed by Statistical Sciences, Inc., Seattle, Washington, that includes a regression tree function.

## RESULTS AND DISCUSSION

Whereas visual examination of the maps indicated "hot spots" near CAFOs, the correlation analysis verified this effect. German Branch, a Coastal Plain watershed, had fewer and smaller CAFOs than the Gunpowder watershed (Table 15). The correlation of CAFO area in the site catchment vs. nitrate was fairly strong for all sites (R = 0.34). The complete correlation matrix for the SERC* data set is presented in Appendix 6. However, when the correlation was conducted on the individual watersheds, German Branch showed a much stronger response (R = 0.51) than the Gunpowder (0.12).

**Table 15. Confined Animal Feeding Operation (CAFO) and instream baseflow nitrate information for German Branch and Gunpowder watersheds, based on SERC* data.**

| | # of CAFOs | CAFO area (ha) | Ave. $NO_3$ |
|---|---|---|---|
| German Branch | 3 | 3-6 | 0.58 |
| Gunpowder | 5 | 8-17 | 3.57 |

Linear regression modeling indicated that the primary controls on instream nitrate were agricultural land use. A two-term model used percent agriculture and CAFO area in the site catchment as the explanatory variables ($R^2$ = 0.17) (Table 16). Percent crops have been shown in past studies to be a strong influence on instream nitrate (Taraba et al., 1996) These data showed percent agriculture to be a stronger influence than percent crops. CAFO presence was found to be a profound influence.

Therefore the inclusion of CAFOs in the general agriculture designation may have caused percent agriculture to show a stronger control over nitrate than percent crops.

**Table 16. Linear regression model predicting instream nitrate at a site using SERC* data of the 1998 University of Maryland Agricultural Riparian Buffer Survey.**

| Variable | Parameter estimate |
|---|---|
| $b_0$ | 0.449 |
| $b_1$ (CAFO area) | 0.038 |
| $b_2$ (% agriculture in site catchment) | 0.215 |

## SUMMARY

This preliminary work provided guidance that was used in all subsequent modeling exercises. Models were successfully developed to predict nitrate at a site from onsite and catchment descriptor variables. Based on these results, land use was expected to be the strongest predictor of nitrate. Detailed site characteristics were not shown to be important predictors for instream nitrate. These models were developed from the 1998 University of Maryland Agricultural Riparian Buffer Survey data. Because there was no measurement of CAFO area in the MBSS, models developed from these data will be unable to capture CAFO effect.

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# CHAPTER 6 –

# MODELING THE EFFECTS OF AGRICULTURAL RIPARIAN BUFFERS TO MITIGATE NITRATE STREAM POLLUTION


## ABSTRACT

Whereas numerous studies have considered buffer effect on groundwater at the field scale, most decisions are made at the watershed scale, using surface water quality as the regulatory criteria of interest. The purpose of this study was to quantify the effect of agricultural riparian buffers on instream nitrate utilizing readily available data. Multiple linear regression models and regression tree models were developed to predict instream nitrate concentration from landscape characteristics at both the site and the site catchment scales. Two sets of models were developed. In the first modeling exercise, nitrate, landscape and buffer information were all obtained from the 1995-1997 Maryland Biological Stream Survey data set. In the second modeling exercise, nitrate data were provided by the Smithsonian Environmental Research Center in Edgewater, Maryland, and landscape and land use information were obtained from the 1999 University of Maryland Agricultural Buffer Survey. In both approaches, the original data were partitioned to develop a data set that represented

spring baseflow conditions at agricultural sites in heavily agricultural watersheds of the Coastal Plain and Piedmont physiographic regions.

It was demonstrated that catchment characteristics exert a much stronger influence on instream nitrate than riparian buffers. Extent of agricultural land use showed a strong relationship to instream nitrate (R = 0.55). Confined animal feeding operations (CAFOs) were also often associated with elevated instream nitrate levels, or “hot spots”. Multiple linear regression, regression tree models and ANOVA all indicated that agricultural land use, especially the presence of CAFOs, overshadowed any on-site buffer effects in control over instream nitrate at that site. These results were repeated for a subset of first-order stream sites. Although previous studies have reported significant reduction of nitrate in groundwater passing laterally to a stream, buffers have little effect on total instream nitrate adjacent to the site.

## INTRODUCTION

### Background

In 1983, concern about worsening water quality in the Chesapeake Bay led to the formation of the Chesapeake Bay Program (CBP), a multi-jurisdictional cooperative effort to restore the nation's largest estuary. The Chesapeake Executive Council set restoration of the Bay's "living resources" as a primary goal in 1987. To achieve that goal, it called for a number of actions to improve water quality, including a 40% reduction in the amount of nitrogen and phosphorus entering the Bay (Chesapeake Bay Program, 1996).

Efforts to implement these actions focused first on coastal tributaries of the Bay. By 1994, however, attention had expanded to the complete watershed, with the development of a set of goals and actions to increase the focus on riparian stewardship and to enhance efforts to conserve and restore riparian forest buffers (Alliance for the Chesapeake Bay, 1996). Forest buffers were singled out in part for their nutrient reduction capabilities, but also because they were reminiscent of the natural landscape in which the stream channel and stream ecosystems of the Bay watershed had evolved.

In October 1996, the Executive Council of the CBP established a goal of restoring riparian forest buffers on 2010 miles of streams in the Chesapeake Bay watershed by 2010. This action exemplified the widespread acceptance of riparian buffers as an important tool for the reduction of non-point-source pollution. In May of 2002, the CBP published nutrient reduction estimates for various management plans in the Chesapeake Bay watershed. One plan estimated reduction of 62 millions pounds of nitrogen per year through "maximum participation" in current voluntary pollution reduction programs (Alliance for the Chesapeake Bay, 2002). Projected implementation and effectiveness of agricultural riparian buffers was a major portion of this pollution reduction estimate.

There are now over 700 publications on the water quality functions of riparian buffers (Correll, 2000) and there is general agreement on the qualitative capacity of riparian buffers to mitigate non-point-source (NPS) pollution (Peterjohn and Correll, 1984; Lowrance et al., 1984, 1997; Barling and Moore, 1994; Correll, 1996; Hill, 1996). However, attempts to quantitatively relate riparian information, watershed information and water quality have met with mixed success and very few studies have been conducted at the watershed scale (Gregory et al., 1991; Whigham et al., 1988; Osborne and Wiley, 1988; Wissmar and Beschta, 1998; Tufford et al., 1998; Perry et al., 1999; Herlihy and Kaufman, 2000). These studies have not resulted in a tool that can enable policymakers to predict or quantify the water quality effect of a given riparian buffer scenario at the watershed level.

**Purpose**

Whereas numerous studies have considered buffer effect on groundwater at the field scale, most decisions are made at the watershed scale, using surface water quality as the regulatory criteria of interest. The purpose of this study was to quantify the effect of agricultural riparian buffers on instream nitrate concentration under spring baseflow conditions. Multiple linear regression models and non-parametric regression tree models were developed to predict instream nitrate based on riparian landscape and site catchment characteristics. The models were then examined to elucidate the nature and strength of buffer effect on instream nitrate. These results are of theoretical use to scientists investigating the functional role of buffers in water quality protection, as well as practical use to the agencies that administer the funds to establish riparian forest buffers in Maryland. While these are empirical results specific to Maryland, the general findings are of use to other locations throughout the United States where the establishment of forest buffers is considered a water quality management tool.

**Objectives**

1. To determine the relative importance of riparian buffer vs. catchment characteristics on instream nitrate.

2. To verify results through the use of two independent data sets and models developed from two different algorithms (multiple linear regression and regression tree analysis).

# METHODS

## Overall summary of methods

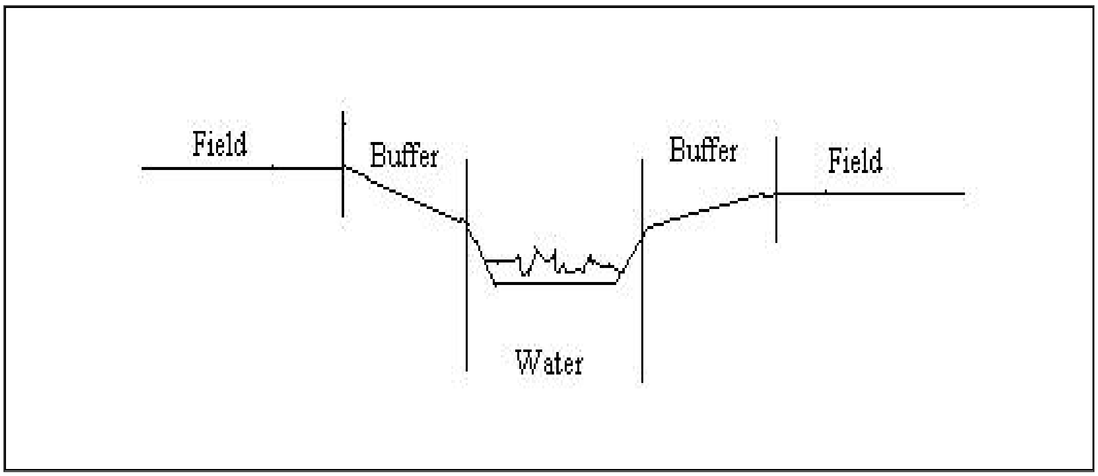
Empirical models were developed to predict instream nitrate concentration at a site from landscape characteristics at both watershed and riparian landscape scales. Instream nitrate concentration data were combined with easily obtainable watershed and site data to develop physio-chemical profiles of agricultural sites in the Coastal Plain and Piedmont physiographic regions of Maryland's Chesapeake Bay watershed. Both multiple linear regression and regression tree modeling were used to investigate the water quality impact of agricultural land use and riparian buffer management.

## Data development

Two modeling approaches were utilized, using different data sets to develop the models. For each approach, the original data were either modified or partitioned in order to describe a population of agricultural sites.

*Site characterization*. In both data sets, each survey site consisted of the stream, riparian zone and adjacent land along both sides of a 30 to 90 meter stream reach. Two scales of data were considered. Site characterization provided ground-truthed information about the local riparian landscape (Figure 18). These data were obtained from on-site surveys using a rapid assessment approach. Information at the site watershed scale provided insight about cumulative impacts and sources of NPS pollution. These data were developed from soil surveys, USGS topographic maps, and publicly available EPA, USGS and state GIS files (Appendix 3).

**Figure 18. Schematic of the agricultural riparian landscape as defined for the 1998 University of Maryland Agricultural Riparian Buffer Survey.**




***Data for the SERC* models.*** In the first modeling approach, two data sets were combined. Landscape and buffer information were obtained from the University of Maryland (UM) Agricultural Buffer Survey, a field survey of over 200 sites. Details of this research were presented in Chapter 2. The purpose of the survey was to characterize the nature and extent of riparian buffers in agricultural watersheds of Maryland's Coastal Plain and Piedmont physiographic regions. Site-level data were obtained by fieldwork performed in the summer of 1998. A suite of structural riparian buffer landscape measurements was taken to describe the agricultural riparian landscape for each site. Detailed procedures are presented in Appendices 1-2. Measurements fell into six key categories: land use, buffer characterization, topography, surface hydrology, groundwater hydrology, and stream channel morphology. Data for each site's catchment were derived from GIS work using land use/land cover files available from the Maryland Department of Planning Appendix 3). The explanatory variables from the SERC* data set that were used in developing models to explain instream nitrate are presented in Table 17.

The Smithsonian Environmental Research Center (SERC) in Edgewater, Maryland provided the nitrate data used in this modeling approach. In 1996, SERC conducted a sampling survey of nitrate in selected stream networks of Maryland's Chesapeake Bay watershed. Nitrate concentration was measured along the mainstem and at upstream-downstream locations on low-order feeder streams within these stream networks. Grab samples were taken approximately every six weeks to produce eight samples for each site.

**Table 17. Explanatory variables from the SERC* data set used to develop models predicting instream nitrate.**

| Descriptor Category | Riparian Landscape Descriptor | Units |
| --- | --- | --- |
| **Land Use** | Site contributing watershed % agriculture[2] | % |
| | Site contributing watershed % crops[2] | % |
| **Buffer Character-ization** | Buffer width[1] | m |
| | Length of buffer fragment[3] | km |
| | Forest buffer DBH[1] | cm |
| | Forest buffer basal area[1] | $m^2$ |
| **Surface Hydrology** | Stream gradient[1] | **%** |
| | Stream velocity[1] | m/sec |
| **Ground-water Hydrology[3]** | Riparian water table depth | m |
| | Field water table depth | m |
| | Riparian buffer surface K * | cm/hour |
| | Adjacent field surface K * | cm/hour |
| | Riparian buffer minimum K * | cm/hour |
| | Adjacent field minimum K * | cm/hour |
| | Riparian buffer depth of minimum K * | m |
| | Adjacent field depth of minimum K * | m |
| **Channel Morph-ology[1]** | Channel width | m |
| | Channel depth | m |
| | Channel cross-sectional area | $m^2$ |
| | Channel width : depth ratio | unitless |

* K = hydraulic conductivity
[1] from on-site field work  [2] from GIS work  [3] from soil survey

Two watersheds were common to both the UM Agricultural Buffer Survey and the SERC nitrate survey. Locations of the German Branch watershed (Eastern Shore, Coastal Plain physiographic region) and Gunpowder watershed (western shore, Piedmont physiographic region) are shown in Figure 19. Watersheds, forested area and site locations are presented in Figures 20 and 21 (not to scale; the Gunpowder watershed (128.8 ha) was roughly twice as large as the German Branch watershed (56.9 ha)).

**Figure 19. Map of 1998 University of Maryland Agricultural Riparian Buffer Survey watershed locations superimposed over 16-digit Hydrologic Unit Area (HUA) code watersheds as defined by USGS.**

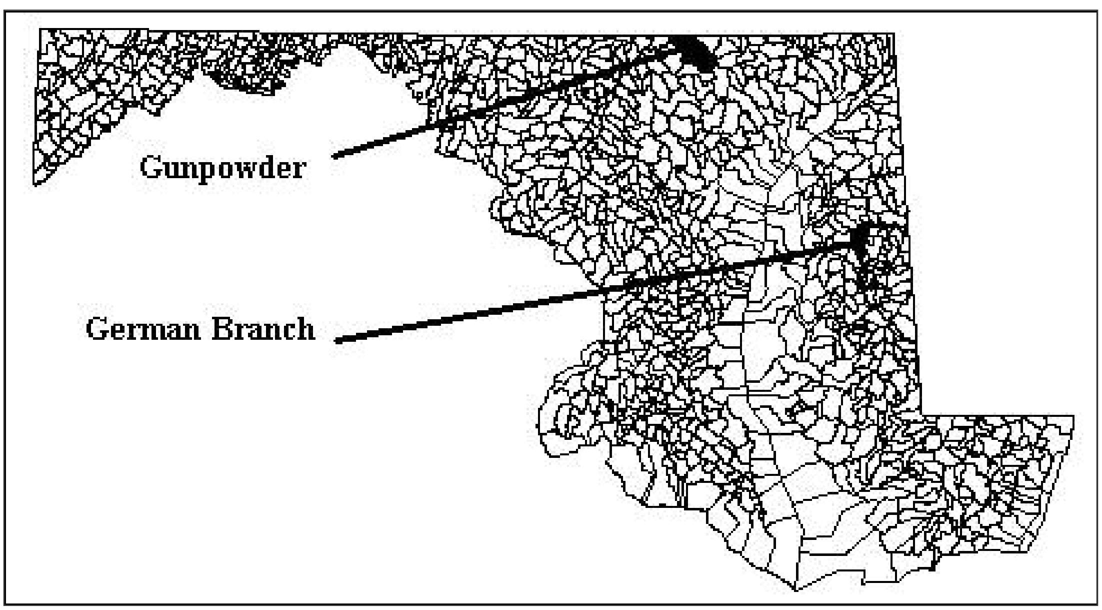


**Figure 20. Map of 1998 University of Maryland Agricultural Riparian Buffer Survey German Branch watershed (5,690 ha), with SERC nitrate sampling sites (n = 21), assigned average spring baseflow nitrate values, forest and CAFO areas.**

| • survey sites, grey = forested area, dark grey = CAFO area |
|---|

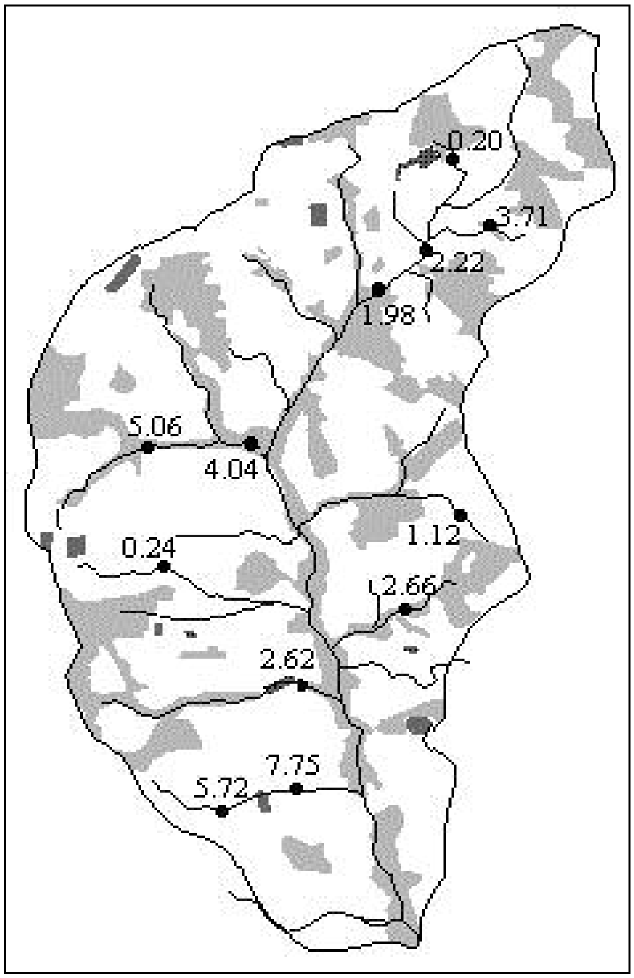
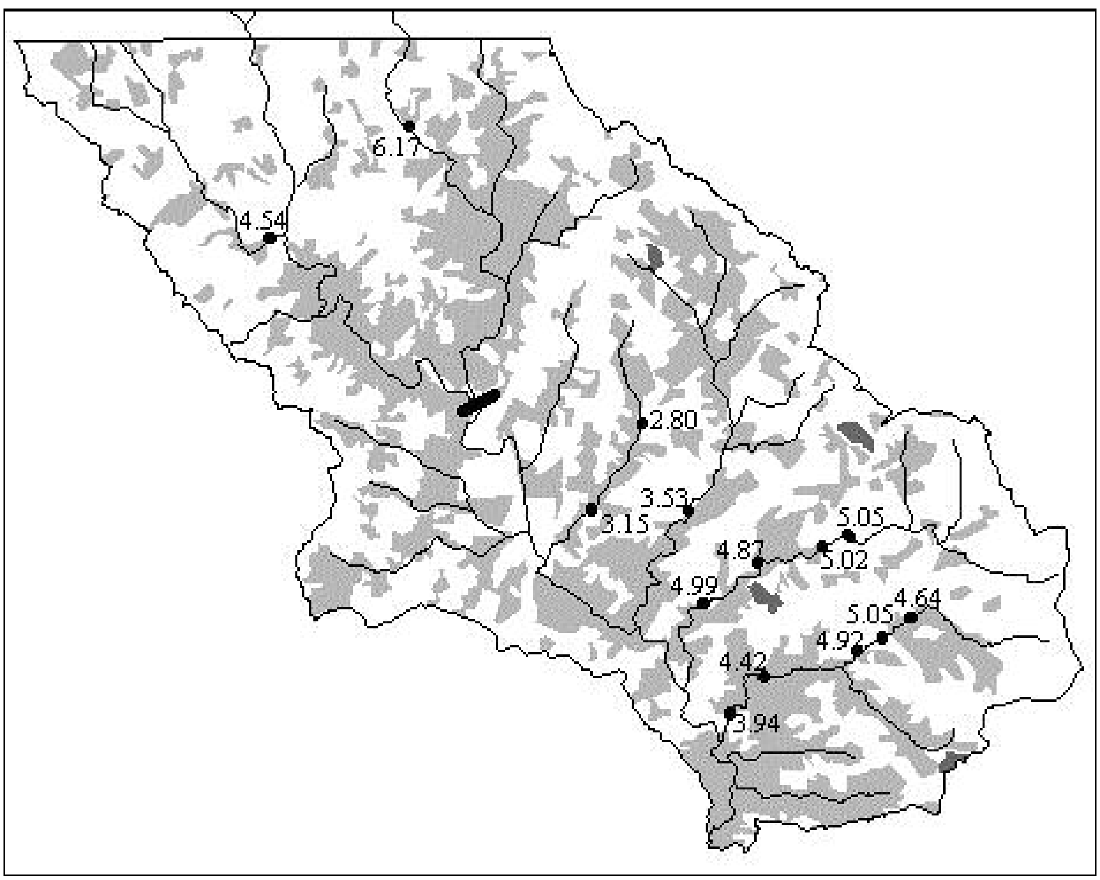


**Figure 21. Map of 1998 University of Maryland Agricultural Riparian Buffer Survey Gunpowder watershed (12,880 ha) with SERC nitrate sampling sites (n = 14), average spring baseflow nitrate values, forest and CAFO areas.**

• survey sites, grey = forested area, dark grey = CAFO area




Information from the UM Buffer Survey and SERC nitrate survey was used to develop physio-chemical characterization of 35 sites for use in modeling. This data set was designated "SERC*". SERC* data parameters and summary statistics are presented in Table 18, and the correlation matrix is presented in Appendix 6. All sites were on low-order streams, either within 20 meters of a SERC nitrate sampling site or between two SERC sampling sites. An average spring nitrate value was developed for each site. SERC sample values for March through May were averaged to develop an average spring value for each SERC sampling site. If a UM Buffer site was within 20 meters of a SERC sampling site, the SERC nitrate value was assigned to the UM site. If the UM Buffer site was between two SERC sampling sites, the nitrate values were assigned by linear interpolation. SERC site values provided the upper and lower values for interpolation, and the distance along the stream between the sites was the measure used for interpolation. Development of site nitrate values is presented in Appendix 5. Landscape information was obtained from UM Buffer Survey data. Because these models were to be compared with models derived from MBSS data, the maximum defined buffer width was reduced from the UM Buffer Survey value of 1000 feet to 50 meters, the maximum value used in the MBSS.

Visual examination of Figures 21 and 22 led to the suspicion that confined animal feeding operations (CAFO) might be acting as point sources and overwhelming NPS effects. To study this relationship further, CAFO factors were developed for the site catchments:

$$\text{CAFO area} = \text{CAFO area in site catchment (ha)} \quad (6.1)$$

$$\text{CAFO factor} = \text{CAFO area / distance from site (ha/ km)} \quad (6.2)$$

$$\text{CAFO factor}^2 = \text{CAFO area / distance from site}^2\ (\text{ha}^2/\text{km}^2) \quad (6.3)$$

**Table 18.** **Values for SERC* landscape descriptors: all sites, German Branch and Gunpowder watersheds.**

| | All sites (n = 35) | | German Branch (n = 21) | | German Branch (n = 14) | |
|---|---|---|---|---|---|---|
| **Variable** | **Mean** | **S.D.** | **Mean** | **S.D.** | **Mean** | **S.D.** |
| NO3 (ppm) | 3.38 | 2.03 | 2.63 | 2.25 | 4.50 | 0.88 |
| % agriculture | 66.42 | 17.30 | 70.62 | 19.29 | 60.12 | 11.78 |
| % crops | 63.46 | 18.81 | 70.15 | 19.74 | 53.42 | 12.05 |
| CAFO (ha) | 1.78 | 3.86 | 0.58 | 1.55 | 3.57 | 5.43 |
| CAFOfctr | 1.55 | 3.73 | 0.74 | 1.47 | 5.51 | 5.51 |
| CAFOfcsq | 1.21 | 4.55 | 0.51 | 1.28 | 7.04 | 7.04 |
| Forest buffer width (m) | 40.8 | 67.9 | 36.6 | 67.1 | 47.5 | 71.9 |
| Grass buffer width (m) | 0.7 | 1.8 | 0.7 | 1.9 | 0.4 | 1.6 |
| Total buffer width (m) | 57.9 | 71.6 | 53.6 | 71.3 | 64.3 | 74.4 |
| DBH (in) | 31.4 | 18.5 | 30.5 | 19.1 | 33.0 | 18.3 |
| Basal area ($m^2$) | 4.7 | 3.1 | 5.7 | 3.2 | 3.1 | 2.0 |
| Riparian slope (%) | 9.06 | 6.92 | 5.73 | 3.88 | 14.08 | 7.55 |
| Adjacent field slope (%) | 5.87 | 5.45 | 3.17 | 2.31 | 9.93 | 6.33 |
| Riparian slope:field slope | 2.23 | 1.71 | 2.33 | 1.78 | 2.09 | 1.64 |
| Stream gradient (%) | 0.88 | 0.45 | 0.81 | 0.42 | 0.99 | 0.48 |
| Stream order | 2.11 | 0.68 | 2.19 | 0.81 | 0.39 | 0.39 |
| Riparian water table depth(m) | 0.6 | 0.5 | 0.6 | 0.6 | 0.7 | 0.5 |
| Riparian surface K (cm/hr) | 4.3 | 2.0 | 4.8 | 2.5 | 3.3 | 0.00 |
| Riparian minimum K (cm/hr) | 4.1 | 2.3 | 4.6 | 2.8 | 0.00 | 0.00 |
| Riparian min. K depth(m) | 7.1 | 3.0 | 6.7 | 3.8 | 7.7 | 0.8 |
| Field water table depth (m) | 2.9 | 1.6 | 2.2 | 1.5 | 3.8 | 1.0 |
| Field surface K (cm/hr) | 3.3 | 0.2 | 3.2 | 0.2 | 3.3 | 0.1 |
| Field minimum K (cm/hr) | 3.0 | 0.7 | 2.8 | 0.9 | 3.3 | 0.1 |
| Field minimum K depth (m) | 3.6 | 1.8 | 3.2 | 2.1 | 0.15 | 0.15 |
| Channel width (m) | 4.6 | 2.7 | 5.2 | 2.4 | 3.6 | 2.9 |
| Channel depth (m) | 1.2 | 0.6 | 0.9 | 0.4 | 0.5 | 0.7 |
| Channel cross-section ($m^2$) | 57.45 | 69.25 | 53.19 | 42.08 | 64.32 | 0.76 |
| Channel width:depth | 5.01 | 4.08 | 6.24 | 4.15 | 2.50 | 2.50 |
| Bank angle (degrees) | 35.98 | 17.48 | 39.19 | 15.64 | 27.42 | 20.69 |

***Data for the MBSS models.*** In the second modeling exercise, instream nitrate concentrations, landscape and buffer information were obtained from the 1995-1997 Maryland Biological Stream Survey (MBSS) data set. The MBSS is an ongoing effort by the Monitoring and Non-Tidal Assessment Division of Maryland's Department of Natural Resources (DNR). The purpose of the MBSS is to assess water quality, physical habitat, and biological conditions in first through third order, non-tidal streams throughout the state of Maryland (Klauda et al., 1998). About 300 sites (75 meter stream segments) were sampled each year during the three-year period 1995-97. These data have been made available to the public through the Maryland DNR website.

MBSS data collection sites were described by approximately 160 variables. Although buffer characterization was not the primary purpose of the survey, limited information was taken on the riparian buffer at the site (presence, vegetation type and width). Site-level data (including instream nitrate) was obtained by field surveys performed during the spring and early summer. Land use information for the site watersheds was obtained by GIS work. The explanatory variables from the MBSS* data set that were used in developing models to explain instream nitrate are described briefly:

- ANC: Acid neutralizing capacity was given in micro-eq/L.
- Area: the site catchment area, reported in acres.
- Average thalweg depth: the deepest portion of the lateral transect of the stream, was measured in centimeters at the 0, 25, 50, and 75 meter

points of the sample segment. Average thalweg depth was the average of these measures (cm).

- Blackwater conditions: blackwater was coding indicating whether the site was located in a blackwater stream. A value of "1" indicated that the site was blackwater, a value of "0" indicated that it was not.
- Conductance: reported in micro-mho/cm.
- Embeddedness: embeddedness was a given as the percentage that gravel, cobble, and boulder particles were surrounded by sediment or flocculent material.
- Flow, or streamflow, was calculated from raw data collected at each stream segment and reported as cfs. At most sites, a standard transect method was employed. The field crew constructed a velocity/depth profile of the segment using a current meter to measure stream velocity and recording stream depth at 5 to 20 regular intervals across the stream. At each location along the transect, velocity was measured at a point 0.6 of the distance from the water surface to the bottom. Calculation of discharge from raw velocity, depth, and lateral location data followed standard procedures.
- Instream habitat and bank stability: Instream habitat structure and bank stability were assigned qualitatively, based on visual observations within the 75-m stream ample segment. Scores ranged from 0 to 20 in four categories from poor to optimal. Instream habitat was based on

the percentage of stable habitat. Bank stability was based on the percent of banks with erosional scars or erosion potential.

- Maximum depth: maximum depth within the 75-meter segment (cm).
- Percent land use: land use in the site catchment was based on the 1996 Multi-Resolution Land Use Classification (MRLC) land cover data base for EPA Region III (MRLC, 1996a; MRLC, 1996b). High intensity urban land use: a land use classification describing heavily built up urban centers with very little vegetation and high population densities.
- pH: given in standard pH units.
- Riparian width: the width of the vegetated riparian buffer was estimated (m), to a maximum of 50 m. If the buffer was greater than or equal to 50 m, a value of 50 was entered. This measure was the width of the riparian buffer on the side of the stream with the smallest buffer.
- $SO_4$: Sulfate, nitrate nitrogen, and dissolved organic carbon concentrations were given as mg/L.
- Stream order: represents the Strahler (1957) convention used for ranking stream reaches by order. Stream order determination was based on a stream reach file digitized from 1:250,000 scale topographic maps for the MBSS in 1987.
- Average velocity: thalweg velocity was measured with a flow meter at the deepest portion of the lateral transect at the 0, 25, 50, and 75 meter points of the sample segment and presented in meters per second.

- Water temperature: given in degrees C.
- Woody debris: the number of pieces of woody debris at each site was recorded.

The 1995-1997 MBSS data set contains 907 sites representing all physiographic regions and random land uses in Maryland. Sites with the following characteristics were partitioned from the original data set: agricultural land use, catchment percent agricultural greater than 35%, located in the Coastal Plain and Piedmont physiographic regions. The resultant reduced data set of 279 sites was designated "MBSS*". MBSS* stream and landscape descriptors and summary statistics for agricultural sites in the Coastal Plain and Piedmont physiographic regions of Maryland are presented in Table 19. The MBSS* correlation matrix is presented in Appendix 7.

**Table 19. Riparian landscape descriptors and summary values for MBSS* data.**

| Variable | **n** | **Mean** | **Std Dev** | **Min** | **Max** |
|---|---|---|---|---|---|
| NO3 (ppm) | 278 | 3.49 | 2.28 | 0.26 | 16.16 |
| Riparian width (m) | 279 | 34.6 | 21.28 | 0 | 50.00 |
| Water temperature ($^{o}$C) | 279 | 19.79 | 3.36 | 12.00 | 30.90 |
| % agriculture | 279 | 63.67 | 13.39 | 35.09 | 91.92 |
| % urban land use | 279 | 2.25 | 4.05 | 0 | 31.80 |
| % forest | 279 | 33.33 | 12.68 | 7.19 | 61.53 |
| Stream order | 279 | 1.94 | 0.80 | 1.00 | 3.00 |
| Dissolved oxygen (ppm) | 278 | 8.47 | 1.92 | 1.00 | 14.00 |
| pH | 279 | 7.09 | 0.48 | 5.27 | 8.82 |
| Conductance, field (μ-mho/cm) | 279 | 176.10 | 91.14 | 54.00 | 980.00 |
| Acid Neut. Capacity (μ-eq/L) | 278 | 435.30 | 285.54 | -26.90 | 1722.2 |
| SO4 (ppm) | 278 | 11.28 | 6.00 | 1.43 | 33.91 |
| Adjacent pasture presence (no = 0, yes = 1) | 279 | 0.14 | 0.35 | 0 | 1.00 |

**Table 19. (continued) Riparian landscape descriptors and summary values for MBSS* data.**

| Variable | n | Mean | Std Dev | Min | Max |
|---|---|---|---|---|---|
| Instream habitat | 279 | 12.86 | 4.06 | 1.00 | 19.00 |
| Epifaunal substrate | 279 | 11.33 | 4.64 | 1.00 | 19.00 |
| Velocity depth (cm) | 279 | 11.54 | 4.30 | 1.00 | 20.00 |
| Pool quality | 279 | 12.66 | 3.89 | 1.00 | 19.00 |
| Riffle quality | 279 | 11.97 | 4.88 | 0 | 20.00 |
| Channel alteration | 279 | 9.93 | 4.44 | 0 | 18.00 |
| Bank stability | 279 | 10.36 | 4.14 | 1.00 | 19.00 |
| Embeddedness | 279 | 55.32 | 32.26 | 0 | 100 |
| Channel flow ($m^3/s$) | 279 | 7.50 | 1.56 | 3.48 | 34.80 |
| Shading | 279 | 66.36 | 23.21 | 5.00 | 98.00 |
| Remoteness | 279 | 11.11 | 4.63 | 1.00 | 19.00 |
| Aesthetics | 279 | 14.15 | 3.44 | 1.00 | 19.00 |
| Woody debris | 279 | 3.73 | 3.78 | 0 | 21.00 |
| Number rootwads | 279 | 1.91 | 2.39 | 0 | 25.00 |
| Max. channel depth (cm) | 279 | 66.45 | 28.92 | 9.00 | 200.00 |
| Stream gradient (%) | 279 | 0.90 | 1.17 | 0 | 10.50 |
| Avg. stream width (m) | 279 | 5.68 | 4.04 | 0.05 | 23.03 |
| Avg. thalweg (m/s) | 279 | 10.05 | 5.18 | 0.60 | 25.66 |
| Avg. velocity (m/s) | 279 | 0.19 | 0.14 | 0 | 1.72 |
| Site catchment area (ha) | 279 | 3000 | 3816 | 31 | 29069 |
| % wetlands | 279 | 0.28 | 0.33 | 0 | 2.50 |
| % barren | 279 | 0.08 | 0.40 | 0 | 4.35 |
| % water | 279 | 0.32 | 0.48 | 0 | 4.64 |
| % high urban land use | 279 | 0.30 | 0.51 | 0 | 3.82 |
| % high urban land use | 279 | 1.94 | 3.63 | 0 | 27.98 |
| % pasture | 279 | 21.84 | 10.50 | 1.82 | 62.07 |
| % probable row crops | 279 | 29.86 | 10.42 | 3.51 | 85.47 |
| % row crops | 279 | 11.96 | 8.65 | 0.39 | 34.43 |
| % coniferous forest | 279 | 3.06 | 4.61 | 0 | 25.41 |
| % deciduous forest | 279 | 21.50 | 10.48 | 2.00 | 55.73 |
| % mixed forest | 256 | 3.71 | 2.74 | 0 | 12.29 |
| % emergent wetlands | 203 | 0.19 | 0.34 | 0 | 2.50 |
| % woody wetlands | 123 | 3.36 | 6.31 | 0 | 29.92 |
| Blackwater conditions (no = 0, yes = 1) | 50 | 0.04 | 0.19 | 0 | 1.00 |

*Comparison of the data sets.* The two data sets used for modeling (MBSS* and SERC*) were parsed from the original data sets in order to provide description of the same population of sites. Both the MBSS* and SERC* data sets represented agricultural sites in agricultural watersheds of the Coastal Plain and Piedmont regions of the Central and Eastern portions of the state. Average percent agriculture, average NO3, and average buffer width were not significantly different between the two data sets (t-test, $\alpha = 0.05$). Therefore, the two data sets were considered comparable. Table 20 provides a summary of the site characterization descriptors for the two data sets.

**Table 20. Comparison of key parameters of the SERC* and MBSS* data.**

| **Data set** | **MBSS*** | **SERC*** |
|---|---|---|
| **# Sites** | 279 | 35 |
| **Physiographic regions** | Coastal Plain, Piedmont | Coastal Plain, Piedmont |
| **State areas** | Eastern Shore, Central Md. | Eastern Shore, Central Md. |
| **Adjacent land use** | Forest, Crop, Pasture | Forest, Crop, Pasture |
| **Average % agriculture** | 63.7 | 66.4 |
| **Range % agriculture** | 35-92 | 37-100 |
| **Average $NO_3$ , ppm** | 3.5 | 3.4 |
| **Range $NO_3$** | 0.3-16.2 | 0.2-7.8 |
| **Average buffer width, m** | 34.6 | 30.2 |
| **Max buffer width, m** | 50.0 | 50.0 |

**Modeling**

Correlation analysis was conducted and models were then developed in SAS (multiple linear regression) and S-PLUS (regression tree analysis). SAS and S-PLUS are both integrated suites of software facilities for exploratory data modeling, statistical analysis and graphical display. S-PLUS is an enhanced version of *S* distributed by Statistical Sciences, Inc., Seattle, Washington, that includes a regression tree function.

All models were expected to take the general form that instream nitrate was a function of source terms (such as agricultural land use) and mitigation factors. Any buffer term in the models would be a quantification of buffer effectiveness. Validation of MBSS* models was conducted using a data set of 10 percent of sites withheld from the MBSS* data (n = 27p). The accuracy of these nitrate predictions was assessed using an $R^2$ value developed from the correlation of observed and predicted values. SERC* models were not validated because of the small number of sites (35 sites).

***Multiple linear regression models.*** Multiple linear regression models were constructed using landscape measures as explanatory variables to predict instream nitrate.

Therefore the model structure was

$$Y = B_0 + B_1X_1 + B_2X_2 + \dots B_nX_n + \text{error} \tag{6.4}$$

where

$Y$ = average spring nitrate concentration for a site,

$X_1 ... X_n$ = site descriptor measurements.

Linear regression modeling was performed with SAS software, using a Proc Reg $R^2$ search procedure (SAS, 1988). The $R^2$ search procedure in SAS is more comprehensive than traditional stepwise regression methods for multiple regression model development, because every possible combination of terms is analyzed. This procedure constructs multiple linear regression models from all combinations of explanatory variables. Search results are presented as a list of model terms and associated adjusted $R^2$ values. In order to compare the explanatory power of models with different numbers of terms, the adjusted $R^2$ statistic was used. This statistic is adjusted for the degrees of freedom of the sums of squares associated with $R^2$ and was calculated as

$$\text{Adj } R^2 = 1-[(SSE / (n-p))/ (CSS / (n-1))] = 1-[(n-1)/ (n-p)] (1- R^2). \qquad (6.5)$$

where

SSE = sum of squares of error,

n = sample size,

p = degrees of freedom,

CSS = corrected sum of squares,

$R^2$ = square of the correlation between response variable and predicted values.

[As a cautionary note, this procedure must be used with a data set without missing values to obtain consistent Adj-$R^2$ values.] Suggested model terms were then used in a standard regression procedure to determine parameter coefficients and significance.

***Regression tree models***. Like multiple linear regression models, regression trees explain variation of a single response variable by one or more explanatory variables. The tree is constructed by repeatedly splitting the data into two mutually exclusive groups, each of which is as homogeneous as possible. The objective is to partition the response into homogenous groups, but also to keep the tree reasonably small. Each group is characterized by the mean value of the response variable, group size, and the values of the explanatory variables that define it (De'ath and Fabricius, 2000). Regression trees do not have non-significant terms. However, the terms are arranged in descending order of explanatory power. Regression tree models cannot predict a continuous distribution of nitrate values (as do linear regression models), but group sites into "terminal nodes" with an average nitrate value for each group of sites. Therefore, regression tree models visually present the range of nitrate values found among the data, distributed among different conditions. For example, in Figure 28, average nitrate values ranged from 1.5 ppm nitrate at the group of sites with lowest percent agriculture in the site catchment to 5.90 at sites with highest percent agriculture. The efficacy of the overall model and its parts is described by Residual Mean Deviance (RMD), which is the sums of squares of the error corrected for the degrees of freedom. It should be noted that $R^2$ is a measure of explained variation and RMD is a measure of unexplained variation, and that although the range of $R^2$ is constrained to values between 0 and 1, RMD values can take values greater than 1. Because the model is in the form of a "decision tree", these models are more effective than multiple linear regression in elucidating threshold effects.

***Comparison of linear and regression tree models.*** The linear models and regression tree models developed from the two data sets were compared between and among one another. The primary explanatory variables identified by the models were compared, as well as their scales of effect. Diagnostics of several models indicated that, although the SAS R-square search provided a selection of linear models with 2 - 20 terms, no more than 5 terms were consistently significant ($\alpha$ of 0.05%) for models constructed from the MBSS* data, and no more than 3 terms were consistently significant for models constructed from the SERC* data. Therefore, the terms and explanatory power of the 3- or 5-term SAS multiple linear regression models were compared with the terms and explanatory power of 3- or 5-term regression tree models. Developing a common measure of accuracy enabled comparison of the relative accuracy of comparable linear and regression tree models. A coefficient of determination ($R^2$) was created for the regression tree models that could be compared to the $R^2$ of the linear regression models. $R^2$ for the pruned regression tree models was developed as follows:

$$R^2 = 1 - (\text{Residual SSE} / \text{Corrected Total SSE}) \qquad (6.6)$$

where

$$\text{Residual SSE} = \Sigma\,(NO3_i - NO3_{predicted})^2 = \Sigma\,(\text{deviance for terminal node})^2$$

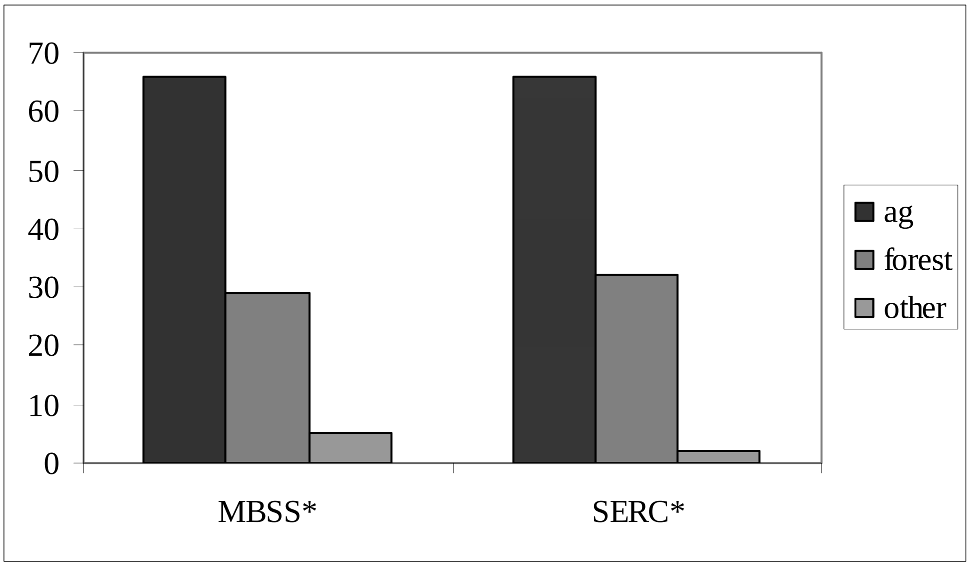
$$\text{Corrected Total SSE} = \Sigma\,(NO3_i - NO3_{mean})^2 .$$

## RESULTS AND DISCUSSION

### Graphical data exploration and correlation analysis

***Land use***. Land use distribution was compared for the two modeling data sets, as shown in Figure 22. The original 16 land use categories in the MBSS data set were collapsed to the 3 categories used in the SERC data set (agriculture, forest and other). The MBSS* and SERC* data sets were very similar in their depiction of land use distribution.

**Figure 22. Comparison of land use distribution for agricultural riparian landscapes in Maryland's Coastal Plain and Piedmont physiographic regions, as determined from MBSS* and SERC* data sets.**

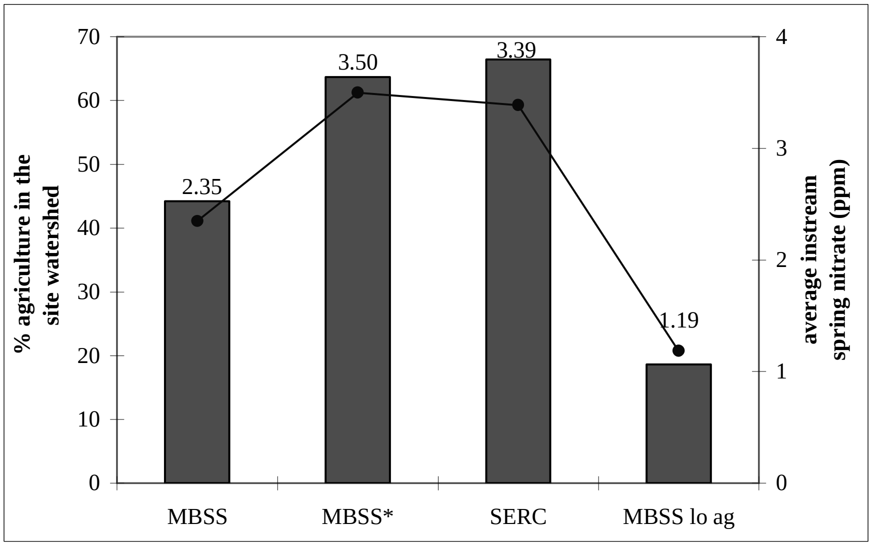



**The SERC* data set (n = 35) was constructed from landscape data from the 1998 University of Maryland Agricultural Riparian Buffer Survey and the 1996 SERC Agricultural Watersheds Stream Chemistry Survey. MBSS is the 1995-1997 Maryland Biological Stream Survey (MBSS*) data set. MBSS* is a subset of the MBSS data, representing riparian agricultural sites in catchments with > 35% agriculture, in the Coastal Plain and Piedmont physiographic regions of Maryland. MBSS lo ag is a subset of the 1995-1997 MBSS data representing riparian agricultural sites in catchments with < 35% agriculture, in the Coastal Plain and Piedmont regions of Maryland.**

***Nitrate***. The MBSS nitrate data were obtained during the spring and early summer, the same time frame used to develop the average spring nitrate values from the SERC data. ANOVA performed on the data sets indicated that the SERC* and MBSS* average nitrate values were not significantly different at the 95% level of confidence. Although both the SERC and MBSS data were derived from grab samples and did not capture the transient effect of rain events, both data sets captured the increased transport capacity of spring precipitation (Felton, 1996). Average site values using only spring values from the SERC data set were statistically higher than average annual site values (t-test, $\alpha = 0.05$). Detailed information on the development of nitrate values is given in Appendix 5. These spring baseflow values were not significantly different from the nitrate values derived from MBSS data collected in spring and early summer (t-test, $\alpha = 0.05$). Therefore, the nitrate values presented in this research can be considered representative of the upper range of baseflow conditions.

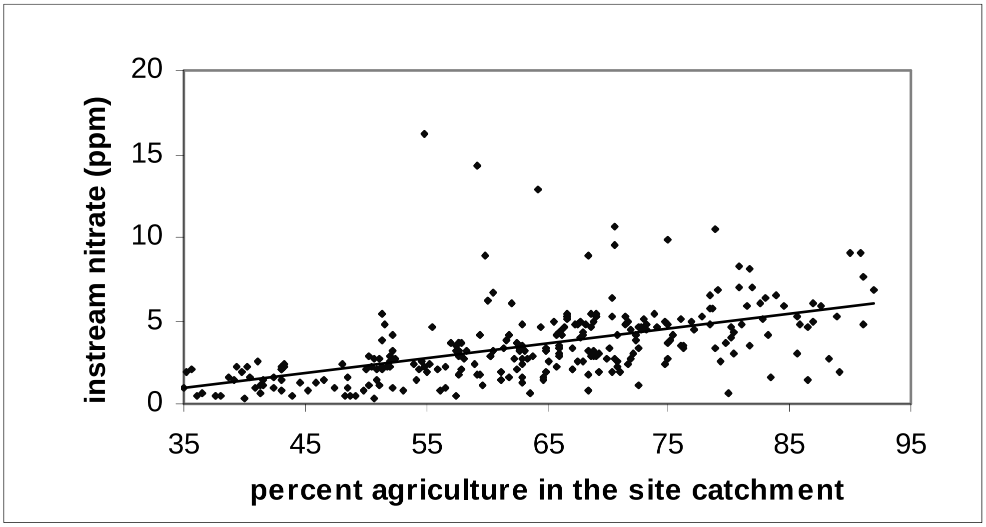
Average instream nitrate showed a strong relationship to percent agriculture in the site's catchment (Figures 23 and 24). These results were similar to Taraba et al. (1996). Four data sets were used to represent low, medium and high levels of agriculture: MBSS sites in watersheds with less than 35% agriculture in the Coastal Plain and Piedmont regions ("MBSS lo ag"), all MBSS sites in the Coastal Plain and Piedmont regions (MBSS), and the MBSS* and SERC* data sets. The average nitrate value of the MBSS* set with 65% agriculture (3.5 ppm) was significantly higher than the average nitrate value of the original MBSS data set with 43% agriculture (2.35 ppm). The correlation coefficient between instream nitrate and percent agriculture in the site's catchment for the data sets represented in Figure 24 was 0.995.

**Figure 23. Nitrate (points) vs. percent agriculture (bars) in the site catchment for four data sets with varying degrees of agriculture.**




The relationship between instream nitrate and agriculture was also investigated by developing correlations using all sites in the data sets. The correlation coefficients for percent agriculture vs. nitrate for the two SERC* watersheds were similar to each other (German Branch R = 0.43, n = 21; Gunpowder R = 0.55, n = 14). Figure 25 shows the relationship between instream nitrate and percent agriculture in the site catchment for the MBSS* data set. The correlation coefficient (R = 0.55, n = 279) was similar in strength to those seen in the SERC* data set. As a comparison, Taraba (1996) found that percent row crops explained 79% of variation in average instream nitrate concentration. However, this relationship was confined to karst watersheds with well and moderately drained soils, and used only 15 sites to develop the regression.

**Figure 24. Instream nitrate vs. percent agriculture in the site contributing watershed, based on MBSS* data.**




*** y = 0.0214x + 25.503, $R^2$ = 0.1759, n = 161**

Visual examination of the land use and nitrate values on the watershed maps indicated elevated instream nitrate levels, or "hot spots", near CAFOs. Eight of the thirty-five sites had a CAFO in their catchments. These were often associated with German Branch, the Coastal Plain watershed, had fewer and smaller CAFOs than the Gunpowder watershed (Table 21). Correlation analysis verified the "hot spot" effect. The correlation of CAFO area in the site catchment vs. nitrate was fairly strong for all sites (R = 0.34). When the correlation was conducted on the individual watersheds, the German Branch watershed showed a much stronger response (R = 0.51) than the Gunpowder watershed (0.12).

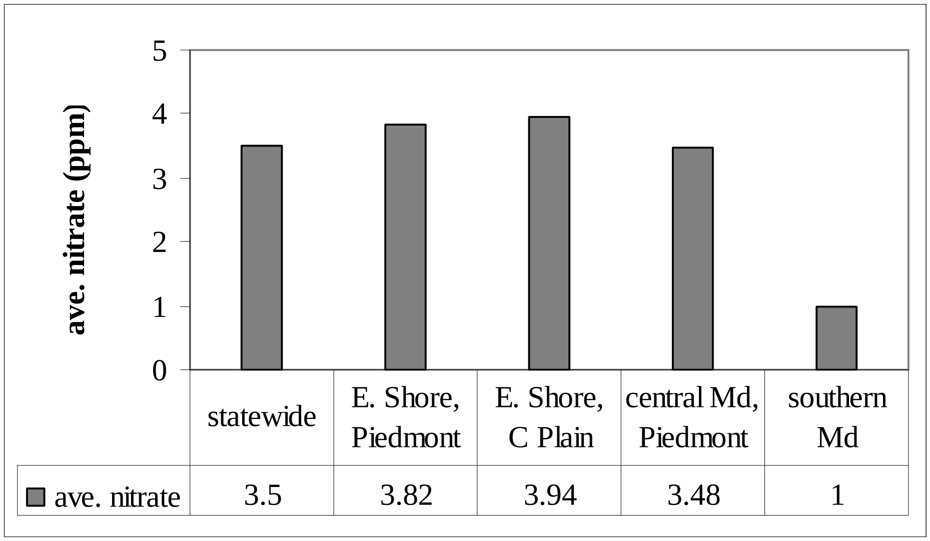
**Table 21. Confined Animal Feeding Operation (CAFO) and instream baseflow nitrate information for German Branch and Gunpowder watersheds, as determined from SERC* data.**

| | # of CAFOs | CAFO area (ha) | Ave. $NO_3$ (ppm) |
|---|---|---|---|
| **German Branch** | 3 | 3-6 | 0.58 |
| **Gunpowder** | 5 | 8-17 | 3.57 |

Although these data were insufficient to develop a strong analysis, this information does serve to illustrate the potential that point sources have to modify NPS contributions. Another potential point source for agricultural nitrate is the tile drain system common in Coastal Plain areas with high water tables. These under-field drainage systems collect drainage water that may be discharged directly to the stream, bypassing the riparian zone and modifying NPS values.

***Instream nitrate vs. location***. The data were partitioned by physiographic and geographic region to investigate instream nitrate as a function of location. Figure 25 presents the results of ANOVA. When sites were partitioned only by physiographic region, there was no significant difference in average instream nitrate values. Although the common belief may be otherwise, the Eastern Shore did not have significantly a higher instream nitrate than the overall statewide average value. However, when sites were partitioned by both physiographic and geographic regions, Southern Maryland (central Maryland geographic region, Coastal Plain physiographic region) had a significantly lower nitrate value than the other three areas using an F test ($\alpha = 0.05$).

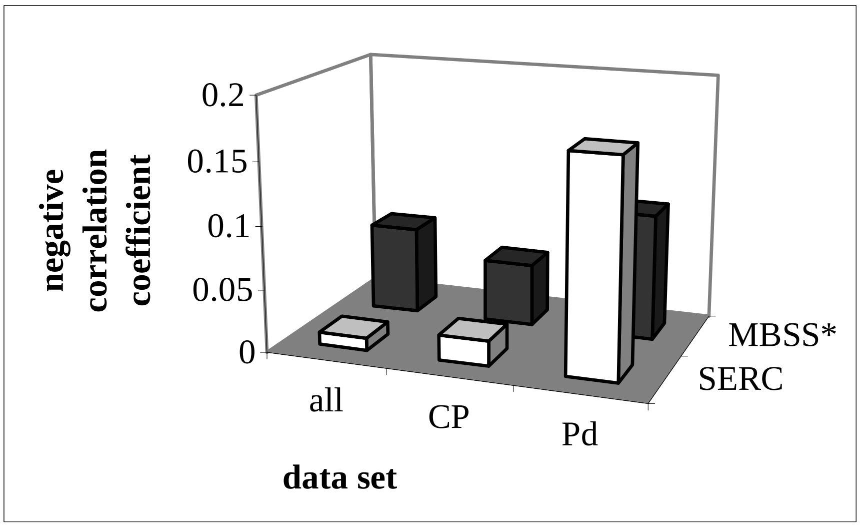
**Figure 25. Instream nitrate for five groups of sites, based on MBSS* data.**




***Instream nitrate vs. buffer presence.*** Only MBSS* data were used to investigate the relationship between instream nitrate and buffer presence, because there was only one SERC* site without a buffer. ANOVA indicated that buffer presence and type had no significant effect on instream nitrate at that site ($\alpha = 0.05$). Nor was there a significant difference when the data were partitioned by physiographic region ($\alpha = 0.05$). These results indicate that buffer presence has no effect on instream nitrate adjacent to that site.

***Instream nitrate vs. buffer characteristics.*** Correlation analyses were conducted between average instream nitrate and all available buffer measures in both data sets. For example, Figure 26 presents the correlation coefficients for buffer width vs. nitrate using all buffer types. The correlation values for the two overall data sets were comparable at -0.01 to -0.07. When the data were partitioned by physiographic region, both data sets showed a slightly stronger signal in the Piedmont. Not only buffer width, but also all buffer characteristics showed weak relationships to instream nitrate at the adjacent site (absolute value of all correlation coefficients less than 0.2). Correlation matrices for SERC* and MBSS* data are given in Appendices 6 and 7.

**Figure 26. Correlation between instream nitrate and buffer width, for all sites, Coastal Plain and Piedmont sites, from MBSS* and SERC* data.**




*** CP = Coastal Plain, Pd = Piedmont**

***Regional differences***. Univariate analysis was performed to investigate differences between physiographic regions. Table 22 presents a summary of statewide and regional statistics for the MBSS* data set. Although the difference in average nitrate values between Piedmont and Coastal Plain sites was not significantly different, variance of nitrate values was lower among Piedmont sites than Coastal Plain sites. This was true of SERC* data, as well. The Coastal Plain had a higher percentage of buffered sites than the Piedmont. Piedmont sites demonstrated a significant difference between nitrate and buffered and unbuffered sites, and showed stronger correlation strength between nitrate and width, % agriculture, and channelization than did Coastal Plain sites. These results suggested that models might show regional differences in the effect of buffers, or show greater accuracy if developed with regional data. Therefore, models were developed for both statewide and regional analysis.

**Table 22. Instream spring baseflow nitrate values and selected agricultural riparian landscape descriptors in the Coastal Plain and Piedmont physiographic regions of Maryland, based on MBSS* data.**

| | All sites | Coastal Plain | Piedmont |
|---|---|---|---|
| $NO_3$ avg. (mg/l) | 3.5 | 3.4 | 3.6 |
| NO3 Std. Dev. (mg/l) | 2.28 | 2.89 | 1.65 |
| $NO_3$ avg. buffered sites (mg/l) | 3.5 | 3.4 | 3.5 |
| $NO_3$ avg. unbuffered sites (mg/l) | 3.8 | 3.3 | 4.0 |
| Avg. buffer width (m) | 34.6 | 34.4 | 39.0 |
| % Buffered sites | 84 | 93 | 78 |
| R between %ag: %forest | 0.95 | 0.95 | 0.94 |
| R between width: NO3 | -0.07 | -0.05 | -0.10 |
| R between $NO_3$: channelization | 0.19 | 0.14 | 0.29 |
| R between %ag: NO3 | 0.52 | 0.48 | 0.68 |

**Modeling results**

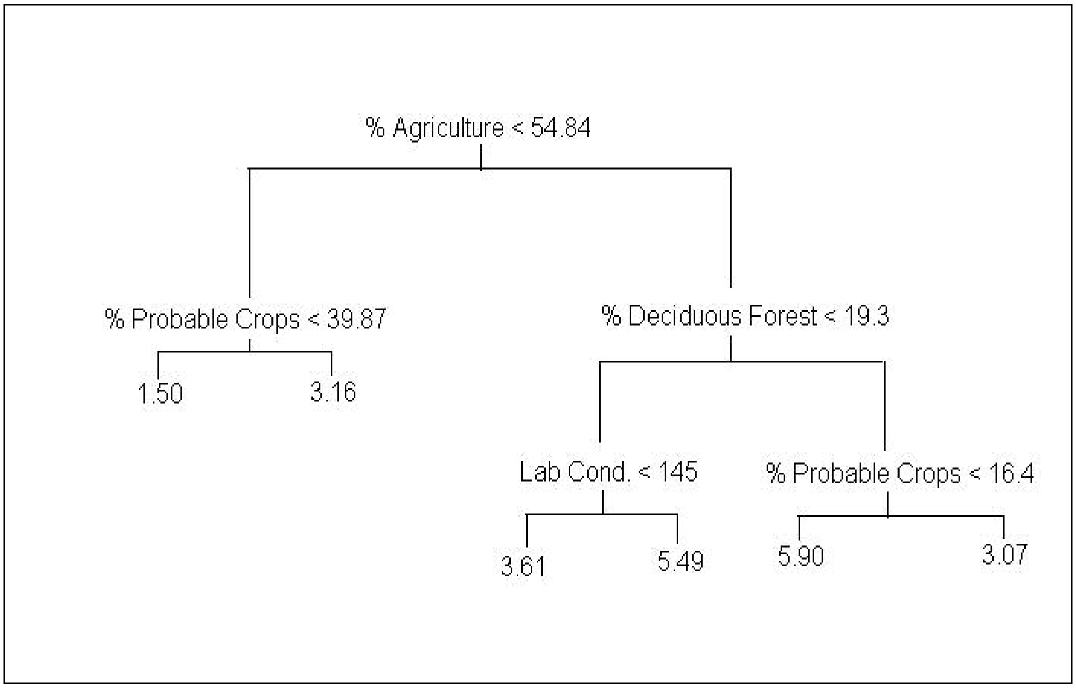
Although linear regression and regression trees use very different algorithms, this work showed strong agreement between the two model types. The difference in the models was not found in the informational content of the models, but rather in the structure of that information. Summary documents of linear regression and regression tree modeling are given in Appendices 8 - 11. Table 23 presents the terms and $R^2$ values for both multiple linear regression and regression tree models.

All models consistently designated agricultural land use in the site catchment as the dominant explanatory variables (Table 23). These results were consistent with past studies, in which agriculture (Allan et al., 1997), and percent crops in particular (Taraba et al., 1996), were shown to exert a strong influence on instream nitrate. The particular influence of percent crops was demonstrated in the MBSS* regression tree model, in which it enters the model twice as an explanatory variable (Figure 27).

**Table 23. Comparison of model terms and accuracy for regression tree and multiple linear regression (MLR) models predicting instream spring baseflow nitrate for agricultural riparian sites statewide, Coastal Plain (CP) and Piedmont (Pd) physiographic regions of Maryland, based on data from the SERC* and MBSS* data sets.**

| | | **Regression Tree** | **MLR** |
|---|---|---|---|
| **SERC* All n = 35** | **Model terms** | Channel width: depth < 3.7<br>CAFO area < 1.5 ha<br>% ag in site catchment < 71% | CAFO area<br>% crops in site catchment |
| | **$R^2$** | 0.52 | 0.17 |
| **SERC* CP n = 21** | **Model terms** | % ag in site catchment < 58%<br>stream order < 2.5 | |
| | **$R^2$** | 0.41 | |
| **SERC* Pd n = 14** | **Model terms** | % crop in site catchment < 51% | |
| | **$R^2$** | 0.52 | |
| **MBSS* All $n_{cal}$ = 254 $n_{val}$ = 25** | **Model terms** | % ag in site catchment < 55%<br>% crop in site catchment < 40%<br>% deciduous forest < 19%<br>conductance < 145<br>% crop in site catchment < 16% | % ag in site catchment<br>adjacent crop presence<br>geographic region<br>conductance<br>acid neutralizing capacity |
| | **$R^2$** | 0.48<br>(Validation $R^2$ = 0.58) | 0.41<br>(Validation $R^2$ = 0.55) |
| **MBSS* CP n = 124** | **Model terms** | % pasture < 20%<br>% deciduous forest < 20%<br>conductance < 224 | % forest<br>% pasture<br>embeddedness |
| | **$R^2$** | 0.51 | 0.65 |
| **MBSS* Pd n = 155** | **Model terms** | % ag in site catchment < 73%<br>% ag in site catchment < 57%<br>% crop in site catchment < 34 | |
| | **$R^2$** | 0.56 | |

**Figure 27. Regression tree model predicting instream nitrate (ppm) from MBSS* data (n = 249).**

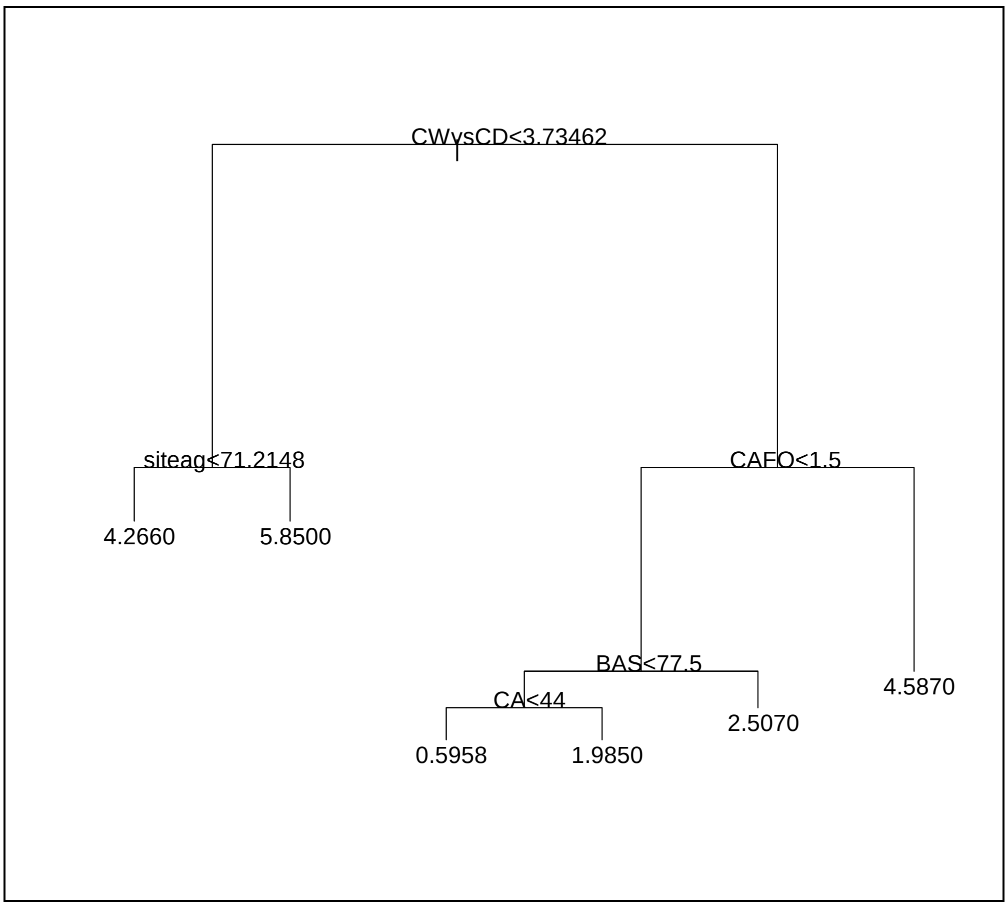



*** true values are to the left of the decision, values at the terminal nodes of the decision tree are average instream baseflow nitrate (ppm) for the sites in that grouping.**

This study was somewhat unique, because CAFO area in the site catchment was an explanatory variable in the SERC* data. Both the SERC* multiple linear regression and regression tree models identified CAFO area as the primary explanatory variable to predict instream nitrate, indicating the particular influence of this type of agriculture.

Models also showed physiographic region to have an influence. The SERC* regression tree model used the ratio of channel width:depth to perform the initial "split" of the data (Figure 28), but examination of the actual grouping of sites revealed that this created an almost perfect split by physiographic region. The MBSS* linear regression model designated physiographic region as the third explanatory variable. These results were consistent with preliminary results presented in Chapter 5, indicating that models developed from regional data may be more powerful.

**Figure 28. Regression tree model predicting instream nitrate (ppm) for all sites using SERC* data (n= 35).**




* **true values are to the left of the decision, values at the terminal nodes of the decision tree are average instream baseflow nitrate (ppm) for the sites in that grouping.**

Regression tree models developed to predict instream nitrate by physiographic region also consistently identified percent agriculture and percent crops in the site catchment as primary explanatory variables. The influence of CAFO area in the site catchment was again demonstrated by the SERC* Coastal Plain regression tree model. Although percent agriculture in the site catchment and stream order were the explanatory variables used, examination of the actual grouping of sites revealed that this created an almost perfect grouping of CAFO sites. This group had the highest average nitrate value of all groups (4.49 ppm vs. 1.0 and 2.25 ppm). There were no buffer terms in any regional models.

To investigate the effect of buffer location within the stream network, a multiple linear regression model was developed for first order sites using MBSS* data (n = 108). Model accuracy was approximately equal for the model using all sites (Adj-$R^2$ = 0.40 for 1$^{st}$-order sites and 0.42 for all sites), and the terms were essentially the same. There were no buffer terms in this model. These results were consistent with ANOVA, which showed that instream nitrate was not significantly lower at buffered first-order sites.

With the exception of the SERC* multiple regression model, the $R^2$ statistic for all models was fairly high (0.41 to 0.56), indicating that approximately half of the variation in nitrate data was explained by the "easily obtainable" site-level landscape data contained in these data sets. $R^2$ values for the MBSS* calibration models (n = 254) were remarkably similar (0.48 and 0.41), indicating that the regression tree and multiple linear regression algorithms were equally effective for these data. MBSS* model validation $R^2$ values were quite high and also remarkably similar (0.58 and 0.55), indicating that these models captured true signals in the data.

## CONCLUSIONS

There have been numerous studies published on the effects of land use and riparian buffers on water quality. This study is unique, both in the scale and nature of the data and the technical approach used. Most studies have focused on the effect of buffers on reduction of nitrate in groundwater. However, most management decisions are concerned with much larger and more complex systems. This study included agricultural riparian settings with crop and pasture land use, on $1^{st}$- through $4^{th}$-order streams, in both Coastal Plain and Piedmont physiographic regions, covering almost 2/3 of the state of Maryland. The environmental issue of interest was distribution of instream nitrate concentrations within a watershed.

Two data sets were used, both of which represented the same specific population of sites across a large geographic area. The SERC* data were unique because they contained detailed site landscape information and CAFO area in the site catchment. The MBSS* data were unique by containing general site landscape and land use information for over 250 sites. The SERC* and MBSS* data sets both confirmed the primary importance of agricultural land use to predict instream nitrate. The two data sets also provided different and unique insights into the behavior of the system. The SERC* data set provided information on the significance of CAFOs. CAFO presence was a primary explanatory variable for instream nitrate at a site as determined by both linear regression and regression tree algorithms. Thus CAFOs exerted an overwhelming influence on instream nitrate where present, acting essentially as point sources of nitrate to the stream. These results were supported by correlation analysis, in that the correlation coefficient between CAFO presence and instream nitrate was three times that of CAFO presence and percent of crops in the site catchment.

Whereas models developed from both data sets identified essentially the same explanatory variables, the SERC* model $R^2$ values were inconsistent (0.17 to 0.65). MBSS* models demonstrated relatively consistent $R^2$ values (0.41- 0.56), and the data set was large enough (n = 279 sites) to enable model validation. Although both data sets were essentially "snapshot" data, the selection of structural explanatory variables renders these models less sensitive to changes over time.

The technical approach to this study was not to find a single "best" model for the prediction of instream nitrate, but to develop multiple models and consider the pattern of primary explanatory descriptor variables and goodness-of-fit. All models demonstrated that land-based sources of nitrate exert a much stronger influence on instream nitrate than riparian buffers. All models indicated that, although buffers may be actively removing nitrate from groundwater at a site, buffer mitigating effects are overwhelmed by agricultural activity. These results are not surprising, in that instream nitrate at a site is an integration of upstream and lateral effects, and this study indicated that adjacent buffer effect was not strong enough to predominate over catchment-level effects.

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# CHAPTER 7 –

# USE OF MARYLAND BIOLOGICAL STREAM SURVEY DATA (1995-1997) TO DETERMINE EFFECT OF AGRICULTURAL RIPARIAN BUFFERS ON MEASURES OF BIOLOGICAL STREAM HEALTH

## ABSTRACT

The purpose of this study was to determine the ability of agricultural riparian buffers to mitigate the effects of agricultural pollution on measures of biological stream health, indicated by fish and benthic macroinvertebrate Index of Biotic Integrity (IBI) and Physical Habitat Index. The Maryland Biological Stream Survey (MBSS) 1995-1997 data set was partitioned to represent a population of agricultural sites in Maryland's Coastal Plain and Piedmont regions. ANOVA, multiple linear regression models and regression tree models were developed using riparian and site catchment landscape characteristics. Results indicated that fish, benthic macroinvertebrates, and instream habitat are controlled by environmental drivers at different scales, and that riparian buffers vary in their impact on different measures of biological stream health. Fish IBI at all sites, and benthic IBI and physical habitat index (PHI) in the Piedmont region were unaffected by buffer presence. Because FIBI was not directly affected by buffer presence, use of FIBI to measure success of buffer installation or restoration would give false results. Benthic IBI and PHI in the Coastal

Plain were affected by buffer presence, type and width and regression tree modeling was able to delineate a range of minimum effective buffer width between 22-38 meters. While these are empirical results specific to Maryland, the general findings are of use to other locations where the establishment of forest buffers is considered as an aquatic ecosystem restoration measure.

## INTRODUCTION

### Background

In 1983, concern about worsening water quality in the Chesapeake Bay led to the formation of the Chesapeake Bay Program (CBP), a multi-jurisdictional cooperative effort to restore the nation's largest estuary. The Chesapeake Executive Council set restoration of the Bay's "living resources" as a primary goal in 1987. To achieve that goal, it called for a number of actions to improve water quality, including a 40% reduction in the amount of nitrogen and phosphorus entering the Bay (Alliance for the Chesapeake Bay, 1996a). Efforts to implement these actions focused first on coastal tributaries of the Bay. By 1994, however, attention had expanded to the complete watershed, with the development of a set of goals and actions to increase the focus on riparian stewardship and to enhance efforts to conserve and restore riparian forest buffers (Alliance for the Chesapeake Bay, 1996b). Forest buffers were singled out in part for their nutrient reduction capabilities, but also because they were reminiscent of the natural landscape in which the stream channel and stream ecosystems of the Bay watershed had evolved.

In October 1996, the Executive Council of the CBP established a goal of restoring riparian forest buffers on 2010 miles of streams in the Chesapeake Bay watershed by 2010. This action exemplified the widespread acceptance of riparian buffers as an important tool for the reduction of non-point-source pollution. The Conservation Reserve Program (CRP) and its enhancement (the Conservation Reserve Enhancement Program CREP) are additional programmatic indications of the trust in agricultural buffers to mitigate pollution. There are now over 700 publications on the water quality functions of riparian buffers (Correll, 2000) and there is general scientific agreement on the qualitative capacity of riparian buffers to mitigate non-point-source (NPS) pollution (Lowrance et al., 1984, 1997; Correll, 1996; Barling and Moore, 1994). However, attempts to quantitatively relate riparian and watershed information with aquatic conditions have met with mixed success and very few studies have been conducted at the watershed scale. Herlihy and Kaufman (2000) conducted an empirical analysis of Pacific and East Coast North American Water Quality Assessment (NAWQA) data sets, looking at the effect of landscape and habitat variables on fish, macroinvertebrates and instream nitrate. Roth et al. (1998) used the Maryland Department of Natural Resources' (DNR) 1995-1997 Maryland Biological Stream Survey (MBSS) data to investigate the effects of stressors on stream health, but this study was much broader in scope, and did not focus on agricultural sites.

**Purpose**

State agencies justify programs, focus resources, allocate funds for projects, and control where money gets spent and work gets done. Decisions are usually made on a state wide or regional basis. State agencies seldom perform in-depth data collection studies to guide or support decisions, but rather, depend on readily available data. Two current regulatory questions concern the use of biocriteria in the development of TMDLs and the effectiveness of riparian buffers to mitigate NPS pollution. The purpose of this study was to determine the ability of agricultural riparian buffers to mitigate the effects of agricultural pollution on stream health, indicated by fish and benthic macroinvertebrate Indices of Biotic Integrity (IBI) and Physical Habitat Index (PHI). The results are of theoretical use to scientists investigating the functional role of buffers in aquatic ecosystem protection, as well as practical use to the agencies that develop Total Maximum Daily Loads (TMDL) and administer the money to establish riparian forest buffers in Maryland. While these are empirical results specific to Maryland, the general findings are of use to other locations throughout the United States where the establishment of forest buffers is considered as an aquatic ecosystem restoration measure.

**Objectives**

1. To determine the effectiveness of agricultural riparian buffers to mitigate the effects of agricultural pollution on measures of biological stream health.
2. To use the MBSS 1995-1997 database to represent a population of agricultural sites.

3. To provide scientific guidance for buffer management strategies for maximum ecosystem benefit.
4. To assess applicability of IBIs for local and regional decision-making.

## METHODS

The 1995-1997 MBSS data set was partitioned to create a data set representative of agricultural sites in heavily agricultural watersheds of Maryland's Coastal Plain and Piedmont physiographic regions (Barker, 2003). Statistical analysis techniques were then applied to the data to determine buffer effect on criteria of interest. Empirical models were developed to predict instream index values at a site from landscape characteristics at both watershed and riparian landscape scales. ANOVA, multiple linear regression and Classification and Regression Tree (CART) analysis were used to model the water quality impact of agricultural land use and riparian buffer management. The criterion variables were Fish IBI, Benthic IBI and PHI. Overall comparisons of model structure and terms enabled determination of buffer effect, controlling factors, and the scale of controlling factors.

### Description of MBSS database

All information was obtained from the 1995-1997 MBSS data set. The MBSS is an ongoing effort by the Monitoring and Non-Tidal Assessment Division of Maryland's Department of Natural Resources. The purpose of the MBSS is to assess water quality, physical habitat, and biological conditions in first through third order, non-tidal streams throughout the state of Maryland (Klauda et al., 1998). A rapid bioassessment protocol was followed (Kazyak, 1997) to collect site-level data on the stream channel and adjacent land during the spring and early summer. Although buffer characterization was not the primary purpose of the survey, limited information was taken on the riparian zone (buffer width, vegetation type). The MBSS recorded the width of buffer on the side of the stream with the smallest buffer, with a defined range of values from 0 to 50 meters and land use information for the site catchment was obtained from GIS land cover data sets (Mercurio et al., 1999). Several stream health indicators were developed and included in the MBSS data. This study used three indicators of biological stream health as criteria variables; fish and benthic macroinvertebrate Indices of Biotic Integrity and Physical Habitat Index (PHI). The fish IBI, benthic IBI and PHI were calibrated separately for low-gradient Coastal Plain streams and for higher gradient non-Coastal-Plain streams.

An MBSS data collection site was represented by approximately 160 variables. Numerous location variables and time variables identified exactly where and when the samples were collected. Not only were the immediate sites described but some adjacent land use data were also recorded. Those variables that were used in developing models in this paper are described briefly.

- ANC: Acid neutralizing capacity was given in μ-eq/L.
- Area: the site catchment area, reported in acres.
- Average thalweg depth: the deepest portion of the lateral transect of the stream, was measured in centimeters at the 0, 25, 50, and 75 meter points of the sample segment. Average thalweg depth was the average of these measures (cm).

- Blackwater conditions: blackwater was coding indicating whether the site was located in a blackwater stream. A value of "1" indicated that the site was blackwater, a value of "0" indicated that it was not.
- Conductance: reported in micro-mho/cm.
- Embeddedness: embeddedness was a given as the percentage that gravel, cobble, and boulder particles were surrounded by sediment or flocculent material.
- Flow, or streamflow, was calculated from raw data collected at each stream segment and reported as cfs. At most sites, a standard transect method was employed. The field crew constructed a velocity/depth profile of the segment using a current meter to measure stream velocity and recording stream depth at 5 to 20 regular intervals across the stream. At each location along the transect, velocity was measured at a point 0.6 of the distance from the water surface to the bottom. Calculation of discharge from raw velocity, depth, and lateral location data followed standard procedures.
- High intensity urban land use: a land use classification describing heavily built up urban centers with very little vegetation and high population densities.
- Instream habitat and bank stability: Instream habitat structure and bank stability were assigned qualitatively, based on visual observations within the 75-m stream ample segment. Scores ranged from 0 to 20 in four categories from poor to optimal. Instream habitat was based on

the percentage of stable habitat. Bank stability was based on the percent of banks with erosional scars or erosion potential.

- Maximum depth: maximum depth within the 75-meter segment (cm).
- Percent land use: Percent land use in the site catchment were based on the 1996 Multi-Resolution Land Use Classification (MRLC) land cover database for EPA Region III (MRLC, 1996a; MRLC, 1996b).
- pH: given in standard pH units.
- Riparian width: the width of the vegetated riparian buffer was estimated (m), to a maximum of 50 m. If the buffer was greater than or equal to 50 m, a value of 50 was entered. This measure was the width of the riparian buffer on the side of the stream with the smallest buffer.
- SO4: Sulfate, nitrate nitrogen, and dissolved organic carbon concentrations were given as mg/L.
- Stream order: represents the Strahler (1957) convention used for ranking stream reaches by order. Stream order determination was based on a stream reach file digitized from 1:250,000 scale topographic maps for the MBSS in 1987.
- Average velocity: thalweg velocity was measured with a flow meter at the deepest portion of the lateral transect at the 0, 25, 50, and 75 meter points of the sample segment and presented in meters per second.
- Water temperature: given in degrees C.
- Woody debris: the number of pieces of woody debris at each site was recorded.

**Database partitioning**

In order to focus on the effects of agricultural riparian buffers, a new data set was created by parsing and censoring the original MBSS data (Table 24). The MBSS sampled approximately 300 sites (75 meter stream segments) each year during the three-year period 1995-97, producing a data set with 907 sites representative of all basins in the state. For this study, only agricultural sites in primarily agricultural catchments of the Coastal Plain and Piedmont physiographic regions were considered. An agricultural site in a "primarily agricultural" catchment was defined as one whose adjacent land use was some form of agriculture and percent agriculture in that catchment exceeded 35 percent. Riparian buffer vegetation is described in the original MBSS data set using one "forest" buffer descriptor and multiple "grass" buffer descriptors (tall grass, old field, and lawn). These descriptors were collapsed to "forest", "grass" and "other". The resulting reduced data set was designated "MBSS*" to distinguish it from the original data set (Barker, 2003).

**Table 24. Comparison of the original 1995-1997 Maryland Biological Stream Survey data (MBSS) and modified 1995-1997 Maryland Biological Stream Survey data (MBSS*).**

| Variable | MBSS | MBSS* |
|---|---|---|
| Sites | 954 | 279 |
| No. physiographic regions | 6 | 2 |
| No. geographic regions | 3 | 2 |
| Site land use types | 16 | 5 |
| Minimum site %ag | 0 | 35 |
| Average site %ag | 44.2 | 63.7 |
| Average site area (ha) | 14,988 | 18,315 |
| % buffers | 66.6 | 84.2 |
| Average buffer width (m) | 24.2 | 34.6 |

Table 25 summarizes the population characteristics of the MBSS* data set, which represented sites in the Coastal Plain and Piedmont physiographic regions, in Eastern Shore and central geographic regions, with adjacent agricultural land use (crop, pasture, forest, orchard, grass), and with a minimum of 35% agriculture in the site catchment. These restrictions produced a data set of 279 sites representing a population of sites with more buffered sites and wider buffers than the statewide averages.

**Table 25. Criteria and explanatory variables and values for agricultural sites in Coastal Plain and Piedmont physiographic regions of Maryland, based on MBSS* data.**

| Variable | n | Mean | Std Dev | Min | Max |
|---|---|---|---|---|---|
| % barren | 279 | 0.08 | 0.40 | 0 | 4.35 |
| % water | 279 | 0.32 | 0.48 | 0 | 4.64 |
| % high urban land use | 279 | 0.30 | 0.51 | 0 | 3.82 |
| % high urban land use | 279 | 1.94 | 3.63 | 0 | 27.98 |
| % pasture | 279 | 21.84 | 10.50 | 1.82 | 62.07 |
| % probable row crops | 279 | 29.86 | 10.42 | 3.51 | 85.47 |
| % row crops | 279 | 11.96 | 8.65 | 0.39 | 34.43 |
| % coniferous forest | 279 | 3.06 | 4.61 | 0 | 25.41 |
| % deciduous forest | 279 | 21.50 | 10.48 | 2.00 | 55.73 |
| % mixed forest | 256 | 3.71 | 2.74 | 0 | 12.29 |
| % emergent wetlands | 203 | 0.19 | 0.34 | 0 | 2.50 |
| % woody wetlands | 123 | 3.36 | 6.31 | 0 | 29.92 |
| Blackwater conditions* | 50 | 0.04 | 0.19 | 0 | 1.00 |

* no = 0, yes = 1

**Table 25.** **(continued) Variables used in modeling and values for agricultural sites in highly agricultural the Coastal Plain and Piedmont physiographic regions of Maryland.**

| **Variable** | **n** | **Mean** | **Std Dev** | **Min** | **Max** |
|---|---|---|---|---|---|
| NO3 (ppm) | 278 | 3.49 | 2.28 | 0.26 | 16.16 |
| BIBI | 276 | 3.07 | 0.760.87 | 1.00 | 4.78 |
| FIBI | 260 | 3.71 | 0.76 | 1.00 | 5.00 |
| PHI | 279 | 60.05 | 28.21 | 1.27 | 98.47 |
| Riparian width (m) | 279 | 31.02 | 21.28 | 0 | 50.00 |
| Water temperature ($^{o}$C) | 279 | 19.79 | 3.36 | 12.00 | 30.90 |
| % agriculture | 279 | 63.67 | 13.39 | 35.09 | 91.92 |
| % urban land use | 279 | 2.25 | 4.05 | 0 | 31.80 |
| % forest | 279 | 33.33 | 12.68 | 7.19 | 61.53 |
| Stream order | 279 | 1.94 | 0.80 | 1.00 | 3.00 |
| Dissolved oxygen (ppm) | 278 | 8.47 | 1.92 | 1.00 | 14.00 |
| pH | 279 | 7.09 | 0.48 | 5.27 | 8.82 |
| Conductance, field (μ-mho/cm) | 279 | 176.10 | 91.14 | 54.00 | 980.00 |
| ANC (μ-eq/L) | 278 | 435.30 | 285.54 | -26.90 | 1722.2 |
| SO4 (ppm) | 278 | 11.28 | 6.00 | 1.43 | 33.91 |
| Adjacent pasture presence | 279 | 0.14 | 0.35 | 0 | 1.00 |
| Instream habitat | 279 | 12.86 | 4.06 | 1.00 | 19.00 |
| Epifaunal substrate | 279 | 11.33 | 4.64 | 1.00 | 19.00 |
| Velocity depth (cm) | 279 | 11.54 | 4.30 | 1.00 | 20.00 |
| Pool quality | 279 | 12.66 | 3.89 | 1.00 | 19.00 |
| Riffle quality | 279 | 11.97 | 4.88 | 0 | 20.00 |
| Channel alteration | 279 | 9.93 | 4.44 | 0 | 18.00 |
| Bank stability | 279 | 10.36 | 4.14 | 1.00 | 19.00 |
| Embeddedness | 279 | 55.32 | 32.26 | 0 | 100.00 |
| Channel flow ($m^3$/s) | 279 | 7.50 | 1.56 | 3.48 | 34.80 |
| Shading | 279 | 66.36 | 23.21 | 5.00 | 98.00 |
| Remoteness | 279 | 11.11 | 4.63 | 1.00 | 19.00 |
| Aesthetics | 279 | 14.15 | 3.44 | 1.00 | 19.00 |
| Woody debris | 279 | 3.73 | 3.78 | 0 | 21.00 |
| Number rootwads | 279 | 1.91 | 2.39 | 0 | 25.00 |
| Max. channel depth (cm) | 279 | 66.45 | 28.92 | 9.00 | 200.00 |
| Stream gradient (%) | 279 | 0.90 | 1.17 | 0 | 10.50 |
| Avg. stream width (m) | 279 | 5.68 | 4.04 | 0.05 | 23.03 |
| Avg. thalweg | 279 | 33.46 | 16.77 | 2.00 | 84.25 |
| Avg. velocity | 279 | 0.19 | 0.14 | 0 | 1.72 |
| Site catchment area (ha) | 279 | 3000 | 3816 | 31 | 29069 |
| % wetlands | 279 | 0.28 | 0.33 | 0 | 2.50 |

## Modeling

Both multiple linear regression and regression tree models were developed. Each modeling procedure provided different insights into the data. SAS multiple linear regression procedures provide extensive diagnostic information about the relative importance of explanatory variables in a model. Regression tree analysis allows the inclusion of quantitative and qualitative variables, and provides information about threshold effects. Three criteria were used to represent measures of biological stream health (fish IBI, benthic IBI and Physical Habitat Index). All models were expected to take the general form that the criterion variable was a function of source terms (such as agricultural land use) and mitigation factors. All MBSS land use descriptors are developed at the scale of the site catchment. Therefore, source terms included percent agriculture and crops in the site catchment. Examples of mitigation factors were percent forest and wetlands in the site catchment and buffer descriptors. These were limited to buffer width and type. Model verification was conducted by determining the accuracy of predictions for a set of 10 percent of sites withheld from the MBSS* data.

Values for fish IBI, benthic IBI and PHI were not assigned for every site. The number of sites with all criteria variable values assigned was only 36. Therefore, models were developed using individual data sets (n = 233, 247, 233).

The intent of this analysis was not to produce a single predictive model, but to elucidate patterns of buffer effect and the controlling factors and scales of effect for the criteria of interest. Therefore, ANOVA was also performed to determine effect of buffer presence and type. A significant effect was demonstrated by a difference at the 95% confidence level.

***Multiple linear regression models.*** Multiple linear regression models were constructed using landscape measures as explanatory variables. Therefore the multiple linear regression model structure was

$$Y = B_0 + B_1X_1 + B_2X_2 + \ldots B_nX_n + \text{error} \qquad (7.1)$$

where

Y = fish IBI, benthic IBI, or PHI,

$X_1 \ldots X_n$ = site descriptor measurements.

Modeling was performed with SAS software. The initial step was an R-square search performed within the PROC REG procedure (SAS, 1988). This procedure constructs multiple linear regression models from all combinations of explanatory variables. The R-square search procedure is more comprehensive than traditional stepwise regression methods for multiple regression model development, because every possible combination of terms is analyzed. Results are presented as a list of model terms and associated adjusted R-square values. This statistic is adjusted for the degrees of freedom of the sums of squares associated with $R^2$ and is calculated as

$$\text{Adj } R^2 = 1-[(SSE / (n-p))/ (CSS / (n-1))] = 1-[(n-1)/ (n-p)] (1- R^2). \qquad (7.2)$$

where

SSE = sum of squares of error,

n = sample size,

p = degrees of freedom,

CSS = corrected sum of squares,

$R^2$ = square of the correlation between response variable and predicted values.

This procedure must be used with a data set without missing values to obtain consistent Adj-$R^2$ values. Suggested model terms are then used in a standard regression procedure to determine parameter coefficients, significance and collinearity.

***Regression tree models***. Like multiple linear regression models, regression trees explain variation of a single response variable by one or more explanatory variables. The tree is constructed by repeatedly splitting the data into two mutually exclusive groups, each of which is as homogeneous as possible. The objective is to partition the response into homogenous groups, but also to keep the tree reasonably small. Each group is characterized by the mean value of the response variable, group size, and the values of the explanatory variables that define it (De'ath and Fabricius, 2000). Regression trees do not have non-significant terms. However, the terms are arranged in descending order of explanatory power. Because the model is in the form of a "decision tree", these models are more effective than multiple linear regression in elucidating threshold effects. Regression tree models cannot predict a continuous distribution of criteria variable values (as do linear regression models), but group sites into "terminal nodes" with an average value for the criteria variable. Therefore, regression tree models visually present the range of values for the criteria variable, distributed among different conditions. For example, in Figure 30, fish IBI values ranged from 2.56 in shallow streams with poor instream habitat to 4.05 in high-order, deeper streams with low urban land use. The efficacy of the overall model and its parts is described by Residual Mean Deviance (RMD), which is the sums of squares of the error corrected for the degrees of freedom. It should be noted that $R^2$ is a measure of explained variation and RMD is a measure of unexplained variation, and that although the range of $R^2$ is constrained to values between 0 and 1, RMD values can take values greater than 1.

***Comparison of linear and regression tree models.*** The linear models and regression tree models developed from the two data sets were compared between and among one another. The primary explanatory variables identified by the models were compared, as well as their scales of effect. Diagnostics of several models indicated that, although the SAS R-square search provided a selection of linear models with 2 - 20 terms, no more than 5 terms were consistently significant ($\alpha$ of 0.05%). Therefore, the terms and explanatory power of the 5-term SAS multiple linear regression models were compared with the terms and explanatory power of 5-term regression tree models. Developing a common measure of accuracy enabled comparison of the relative accuracy of comparable linear and regression tree models.
A coefficient of determination ($R^2$) was created for the regression tree models that could be compared to the $R^2$ of the linear regression models. $R^2$ for the pruned regression tree models was developed as follows:

$$R^2 = 1 - (\text{Residual SSE} / \text{Corrected Total SSE}) \qquad (7.3)$$

where

$$\text{Residual SSE} = \Sigma\,(NO_{3i} - NO_{3predicted})^2 = \Sigma\,(\text{deviance for terminal node})^2$$

$$\text{Corrected Total SSE} = \Sigma\,(NO_{3i} - NO_{3mean})^2.$$

# RESULTS AND DISCUSSION

## Buffer effect on fish IBI

Because fish IBI was stratified by physiographic region, modeling was performed on all sites, Coastal Plain and Piedmont sites. There was strong agreement among all models. Differences between the models were not found in the informational content of the models, but rather in the structure of that information. Summary documents of fish IBI linear regression and regression tree modeling are given in Appendices 12 - 13. Table 26 presents the terms and $R^2$ values for both multiple linear regression and regression tree models. All models identified measures of instream habitat and location in the stream network as dominant explanatory factors. ANOVA analysis demonstrated increase in fish IBI with stream order, as well. These results were consistent with past studies, in which stream order and instream habitat were highly correlated to fish IBI (Roth et al., 1998). No models included any buffer terms or any other land-based terms at the site-level scale. Because instream hydrology and geomorphology are reflective of factors at the fairly broad scale, all models indicated that the site watershed scale is the dominant scale of influence. There were no buffer terms in the models.

**Table 26. Comparison of model terms and accuracy for regression tree and multiple linear regression models predicting fish IBI for agricultural riparian sites in the Coastal Plain and Piedmont physiographic regions of Maryland, based on data from the MBSS* data set.**

| | | Regression Tree | MLR |
|---|---|---|---|
| **All sites**<br>n = 233 | Model terms | maximum depth < 38.5 cm<br>instream habitat < 13.5<br>acreage < 2235.5 ac<br>average thalweg < 37.5 cm<br>high urban land use < 1.8% | instream habitat<br>stream order<br>pH<br>conductance<br>"blackwater" conditions* |
| | $R^2$ | 0.51<br>(Validation $R^2$ = 0.26) | 0.46<br>(Validation $R^2$ = 0.32) |
| **Coastal Plain**<br>n = 116 | Model terms | maximum depth < 38.5 cm<br>instream habitat < 8.5<br>% pasture < 13.1%<br>acreage < 12467 ac<br>epifaunal substrate < 13.5 | |
| | $R^2$ | 0.74 | |
| **Piedmont**<br>n = 117 | Model terms | velocity depth < 10.5 cm<br>% row crops < 10.9%<br>ANC < 993<br>instream habitat < 14.5<br>maximum depth < 76.5 cm | |
| | $R^2$ | 0.53 | |

*** "**blackwater" refers to water with high tannin content, giving it a brown appearance.

Regression tree models developed to predict fish IBI were very similar. They identified measures of velocity, depth and structural variation within the channel as primary explanatory variables, and included a land use term. Models developed by physiographic region identified the same hydrologic and geomorphologic factors, but in different order. There were no buffer terms in any regional models. The $R^2$ value for the Coastal Plain model (0.74) showed stronger goodness-of-fit than the general model (0.51) and the Piedmont model (0.53).

Land use was different in all models. The regression model using all sites indicated percent high urban land use as a primary explanatory variable. This result was consistent with other published studies of the entire MBSS data set (Roth et al., 1998; Boward et al., 1999). However, they used linear regression to identify urban land use as the most influential land use on fish IBI, and this linear regression model using agricultural sites did not identify any type of land use an a primary explanatory factor. Regression tree models developed form data partitioned into physiographic regions identified agricultural land use as an important influence on fish IBI.

Instream habitat, which appeared in all models, is a complex explanatory variable, assigned based on subjective judgment of several instream characteristics. It was highly correlated several other explanatory variables in the models: velocity depth (R = 0.72), epifaunal substrate (R = 0.78), maximum depth (R = 0.41), and average thalweg (R = 0.40).

The $R^2$ statistic for all models was fairly high (0.46 to 0.74), indicating that approximately half of the variation in fish IBI was explained by the "easily obtainable" site-level landscape data contained in these data sets. $R^2$ values for the MBSS* calibration models (n = 233) were similar (0.51 and 0.46), indicating that the regression tree and multiple linear regression algorithms were equally effective for these data. The linear regression model had the lowest $R^2$ value (0.46). Whereas the regression tree models employed stable structural characteristics as explanatory variables, the linear regression models included pH and conductance as explanatory variables. The "snapshot" nature of these data may have added "noise" and reduced the explanatory power of the model. Validation $R^2$ values for the regression tree and linear regression models (using all sites) were low but reasonable (0.26 and 0.32), indicating that these models captured true signals in the data.

All models indicated strong watershed-level control on fish IBI, mediated through the hydrology and geomorphology of the stream. These results are consistent with fish biology, in that fish are highly dependent on instream features, and can swim away from a specific site (field scale). Overall analysis indicated that riparian buffers have no effect on fish IBI that could be captured by these data.

**Buffer effect on benthic IBI**

Because benthic IBI was stratified by physiographic region, modeling was performed on all sites, Coastal Plain and Piedmont sites. Models indicated that there are different scales of controlling influences on benthic IBI between regions. Summary documents of benthic IBI linear regression and regression tree modeling are given in Appendices 14 - 15. Table 27 presents the terms and $R^2$ values for both multiple linear regression and regression tree models.

**Table 27. Comparison of model terms and accuracy for regression tree and multiple linear regression models predicting benthic macroinvertebrate IBI for agricultural riparian sites in the Coastal Plain and Piedmont physiographic regions of Maryland, based on MBSS* data.**

| | | **Regression Tree** | **MLR** |
|---|---|---|---|
| **All sites**<br>n = 247 | Model terms | embeddedness < 85<br>woody debris < 0.5<br>riparian width < 37.5 m<br>SO4 < 10.25 mg/l<br>bank stability < 3.5 | embeddedness<br>woody debris<br>riparian width<br>SO4 mg/l<br>pH |
| | $R^2$ | 0.53<br>(Validation $R^2$ = 0.02) | 0.40<br>(Validation $R^2$ = 0.10) |
| **Coastal Plain**<br>n = 94 | Model terms | epifaunal substrate < 6.5<br>adjacent cover = crop, pasture<br>SO4 < 12.5 ppm<br>riparian width < 37.5 m<br>woody debris < 0.5 | |
| | $R^2$ | 0.53 | |
| **Piedmont**<br>n = 153 | Model terms | SO4 < 12.5 ppm<br>% crops < 52.2%<br>avg. velocity < 0.14 m/s<br>conductance < 268<br>adjacent cover = grass | |
| | $R^2$ | 0.64 | |

Both regression tree and linear models using all sites indicated that forest buffers were influential on benthic IBI (the regression tree model used riparian width and linear regression identified woody debris). ANOVA analysis demonstrated the influence of buffers, as well. Benthic IBI was higher at forested buffer sites (3.3) than other sites (2.8). These results were consistent with the studies of Roth et al. (1998), which were conducted on the entire MBSS data set. For Coastal Plain sites, explanatory variables reflected non-hydrologic instream conditions (epifaunal substrate, woody debris), adjacent landscape influence (crop and pasture presence, adjacent cover, riparian width), and chemistry (SO4). Thus conditions at the site were dominant for benthic IBI in the Coastal Plain. For Piedmont sites, explanatory variables reflected hydrologic instream conditions (average velocity), chemistry (SO4, conductance) and landscape influence (percent crops in the site catchment, adjacent cover). These explanatory variables indicated weak watershed-level control on benthic IBI in the Piedmont, mediated through the hydrology and chemistry of the stream.

The $R^2$ statistic for all models were very consistent (0.40 to 0.64), demonstrating that approximately half of the variation in benthic IBI was explained by the "easily obtainable" site-level landscape data contained in these data sets. $R^2$ values for the MBSS* calibration models (n = 247) were similar (0.53 and 0.40), indicating that the regression tree and multiple linear regression algorithms were equally effective for these data. Validation $R^2$ values for models using all sites were very low (0.02 and 0.10), further verifying that the factors influencing benthic IBI differ by physiographic region.

**Buffer effect on physical habitat index**

PHI is a mathematical function of six explanatory variables (Hall et al., 1999). Instream habitat, embeddedness, velocity/depth diversity, and aesthetic rating were used in both the Coastal Plain, and non-Coastal-Plain PHI. Pool quality and maximum depth were used in the Coastal Plain PHI. Riffle/run quality and number of rootwads were used in the non-Coastal-Plain PHI. Several of these variables used to develop the PHI were also used as explanatory variables in fish IBI and benthic IBI models. Due to collinearity effects, PHI models could not be developed using all possible explanatory variables. Therefore, PHI models were developed withholding the independent variables used to develop the PHI. Because PHI was stratified by physiographic region, modeling was performed on all sites, Coastal Plain and Piedmont sites.

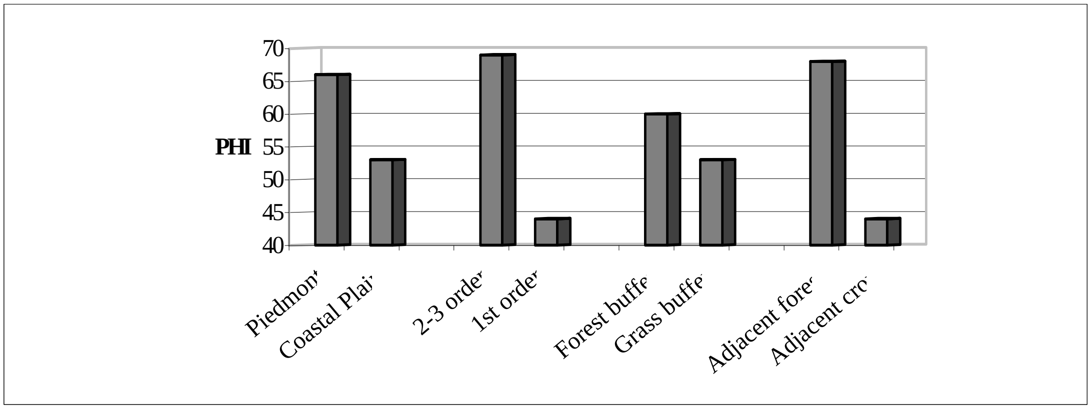
Because PHI was stratified by physiographic region, modeling was performed on all sites, Coastal Plain and Piedmont sites. Models indicated that there are different scales of controlling influences on PHI between regions. Summary documents of linear regression and regression tree modeling are given in Appendices 16 - 17. Table 28 presents the terms and $R^2$ values for both multiple linear regression and regression tree models.

**Table 28. Comparison of model terms and accuracy for regression tree and multiple linear regression models predicting PHI for agricultural riparian sites in Coastal Plain and Piedmont physiographic regions of Maryland, based on MBSS* data.**

| | | Regression Tree | MLR |
|---|---|---|---|
| **All sites**<br>n = 243 | Model terms | average thalweg < 25.6 cm<br>average velocity < 0.11 m/s<br>flow < 0.20 cfs<br>water temperature <21.65 °C<br>riparian width < 3.5 m | average thalweg<br>average velocity<br>acreage<br>% rowcrops in site catchment<br>riparian width |
| | $R^2$ | 0.57<br>(Validation $R^2$= 0.48) | 0.45<br>(Validation $R^2$= 0.52) |
| **Coastal Plain**<br>n = 122 | Model terms | avg. thalweg < 26.4 cm<br>stream gradient < 0.95<br>flow < 0.49<br>avg. velocity < 0.1<br>riparian width < 22.5 m | |
| | $R^2$ | 0.71 | |
| **Piedmont**<br>n = 153 | Model terms | stream width < 2.2 m<br>avg. thalweg < 10.9 cm<br>stream gradient < 0.22<br>avg. velocity < 0.13 m/s<br>avg. thalweg < 26.1 cm | |
| | $R^2$ | 0.51 | |

The regression tree and linear models for all sites selected almost identical explanatory variables, indicating hydrology and riparian width were dominant. Both models indicated that forest buffers were influential on PHI. ANOVA demonstrated the influence of buffers, as well (Figure 29). PHI was higher for sites with forested buffers (60) than for sites with grass buffers (53), and PHI was higher for sites with forest as the adjacent cover than sites with adjacent crops (68 vs. 44).

**Figure 29. ANOVA results for PHI versus physiographic region, stream order, adjacent buffer type, and adjacent agricultural land use (n = 243).**




Both Coastal Plain and Piedmont models used several hydrologic factors (average thalweg, average surface velocity, stream gradient, flow), emphasizing the dominant control of hydrology on PHI. There were no land use or chemistry variables in either model. The riparian buffer influence seen in both regression tree and linear regression models with all sites was limited to the Coastal Plain, and was the only difference between the regional models. Thus watershed-influenced hydrologic conditions are dominant in both regions, and riparian buffers are also important for PHI in the Coastal Plain.

The $R^2$ statistic for all models were very consistent (0.45 to 0.71), demonstrating that slightly more than half of the variation in PHI was explained by the "easily obtainable" site-level landscape data contained in these data sets. $R^2$ values for the MBSS* calibration models (n = 243) were similar (0.57 and 0.45), indicating that the regression tree and multiple linear regression algorithms were equally effective for these data. Validation $R^2$ values for models using all sites were reasonable (0.48 and 0.52), indicating that these models captured true signals in the data.

**Comparison of analysis techniques.**

There was overall excellent agreement among ANOVA, multiple linear regression and regression tree models. Both types of models showed the same overall patterns and scales of effect. ANOVA was able to show the effect of buffer presence and type, whereas multiple linear regression and regression tree models were able to show buffer width effect and indirect forest buffer effects (woody debris, bank stability). The combination of techniques worked in a synergistic manner to provide a good overall picture of buffer effect on the system.

## CONCLUSIONS

The MBSS data were successfully partitioned to represent the population of sites. The data showed four scales of effect - instream, site-level, watershed, and regional. The analyses were able to provide answers to questions about buffer effect. The general agreement among ANOVA, multiple linear regression and regression tree analyses provided confidence that the answers are reflecting genuine behavior of the system. Forest buffers were seen to be important, although secondary controls for benthic IBI and PHI in the Coastal Plain. Because critical forested buffer widths of 22.5 and 37.5 meters were identified by these models, a grass buffer or forested buffer less than 10 meters can be reasonably assumed to be fairly ineffective for protection of stream health. These results are consistent with the general values reported for buffer width effectiveness in the review article on buffer size requirements by Castelle et al. (1994).

Hydrology and stream geomorphology were the controlling factors for fish IBI at all sites (and for BIBI and PHI in Piedmont systems). Insofar as buffers can mediate hydrologic effects on flow conditions in a stream, they may indirectly affect fish IBI. Because fish are not found in very small headwater streams, the installation of buffers in areas of strong hydrologic impact under storm conditions in larger 2nd order streams may have more effect on fish IBI, if that is the primary goal. Because FIBI was not directly affected by buffer presence, use of FIBI to measure success of buffer installation or restoration would give false results.

These results can provide significant guidance for agencies seeking to restore or plant buffers. Depending on the endpoint, placement and width of buffers can be an effective tool to mitigate the effects of agricultural non-point-source pollution on biological measures of stream health.

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# CHAPTER 8 –

# FINAL CONCLUSIONS

The purpose of the research was to quantify the effectiveness of agricultural riparian buffers in protecting stream health in Maryland's Coastal Plain and Piedmont physiographic regions. State and federal agencies charged with development and implementation of riparian buffer management cannot use highly complex, data-intensive models. This research used easily obtainable data to develop scientific guidance for buffer management strategies. Three data sets were used; the 1998 University of Maryland Agricultural Buffer Survey, the 1996 Smithsonian Environmental Research Center (SERC) Water Quality Survey and the 1995-1997 Maryland Biological Stream Survey. Collectively, these data represented baseflow water quality and landscape conditions in small agricultural watersheds characteristic of the Coastal Plain and Piedmont physiographic regions of Maryland.

The 1998 University of Maryland Agricultural Buffer Survey was conducted to develop a set of easily obtainable landscape characteristics describing the agricultural riparian landscape. Six key data categories were addressed: land use, buffer characterization, topography, surface and groundwater hydrology and stream channel morphology. All information was successfully obtained through a combination of rapid assessment fieldwork, map work, and publicly available Geographic Information System (GIS) files.

From these structural descriptors, a classification system of the riparian landscape was developed. This classification system provided the first method for understanding and categorizing the structure of the agricultural riparian landscapes of for the Coastal Plain and Piedmont physiographic regions of Maryland. Although there are distinct structural differences between the Coastal Plain and Piedmont physiographic regions, most riparian landscapes demonstrated similar structural characteristics. Results indicated that classification of a site can be accomplished with minimal site work (in most cases, a drive-by can provide the on-site information necessary), map work, and soil survey information. Therefore, if a research question focuses on one subset of sites, the classification system can provide assistance identifying sites.

Both the University of Maryland Agricultural Buffer Survey and the Maryland Biological Stream Survey (MBSS) data provided extensive, ground-truthed, field-based information. This research successfully parsed and censored these two independent data sets, created for different purposes, to provide information about a common population of sites. The two modified data sets were used to develop the first comprehensive structural characterization of riparian landscapes in agricultural catchments in Maryland's Coastal Plain and Piedmont physiographic regions. Most agricultural sites had buffers. The Coastal Plain was dominated by forested buffers, whereas the Piedmont had a significant portion of grass buffers. Because forested buffers were wider than grass buffers, the average width of Coastal Plain buffers was the same or greater than Piedmont buffers. Comparison of these data demonstrated the effect of censored data. For example, average buffer width was found to be strongly influenced by maximum defined buffer width. Therefore, use of censored data sets should be viewed with caution.

There are two major strengths of these results. Ground-truthed information was provided at the site-specific scale. Additionally, this research presented information at the 16-digit watershed scale in order to discuss these buffers in the context of a larger landscape. The site-specific scale of these field-truthed data revealed that a significant portion of buffers was less than 10 meters wide, especially in the Piedmont. With an overall statewide average buffer width of approximately 160 feet, almost 50% of buffers would not be detected by RS data with a resolution of 30 meters. It can be reasonably concluded that surveys depending solely on remotely sensed data have significantly underestimated the degree of buffering in Maryland.

Once the nature and distribution of Maryland's agricultural riparian landscapes were elucidated, modeling was used to investigate buffer effectiveness. The classification system was not used in final modeling work for two reasons. The SERC* data set was too small to be further subdivided by classification for nitrate modeling. Although the MBSS* data set was of adequate size, further field work and soil survey was needed to provide the on-site slopes and water table information necessary to use the classification system with the MBSS* data set. Neither data set was compatible with a paired watershed approach. Therefore, due to limitations in these easily obtainable data, all models predicted some measure of stream health at a site as a function of landscape characteristics.

Both multiple linear regression and regression tree modeling were used. SAS regression procedures provided diagnostic information about relative importance of the explanatory variables. Regression tree analysis allowed inclusion of quantitative and qualitative variables, and provided information about threshold effects. The general agreement among ANOVA, multiple linear regression and regression tree analysis provided confidence that the models accurately portrayed the system.

All models indicated that nitrate source terms overshadowed any on-site buffer effects. Although no direct buffer effect on instream nitrate was seen in this study, as buffers are installed or widened, land may be taken out of agricultural use, reducing nitrate input to the stream. Whereas this study focused on agricultural non-point-source (NPS) effects, confined animal feeding operations (CAFOs) and pastures were found to act as point sources, overwhelming and confounding NPS effects. Therefore, livestock best management practices (BMPs) are critical for the reduction of nitrate and sediment input to streams.

Forest buffers were not seen to be a controlling factor for fish IBI at a site, but hydrology and stream geomorphology were. Therefore, insofar as buffers can mediate hydrologic effects on flow conditions in a stream, they may indirectly affect fish IBI. Because fish are not found in very small headwater streams, the installation of buffers in areas of strong hydrologic impact under storm conditions in larger 2nd order streams may have more effect on fish IBI, if that is the primary goal. This research showed that use of this index to measure success of a buffer installation or restoration project had the potential to give false results.

Forest buffers were seen to be secondary controls for benthic IBI and PHI in the Coastal Plain. Regression tree modeling elucidated a minimum effective width between 22 – 38 meters. Because riparian forest buffers directly affected the habitat for benthic invertebrates, there is an indirect relationship between benthic IBI and PHI. Although these easily-obtainable data could not capture the strength of this indirect relationship, results indicate that installation of buffers could stabilize stream systems and affect the benthic communities.

A functional instream ecosystem may be critical for nitrate reduction as it moves from the headwaters to the Chesapeake Bay. Forested riparian buffers serve as a primary source of nutrients to low-order streams, fueling and mediating the energy base of instream ecosystems. Branches, roots and other tree parts that fall into the stream channel provide shelter for instream inhabitants, retain sediment, and contribute to the maintenance of habitat diversity through the development of riffles and pools. Streamside vegetation also contributes to channel stability and shape by holding bank sediment and reducing erosion during periods of high flow. Therefore, riparian zones may act more importantly as source zones to protect habitat and provide food for the instream community that process nitrate, than as buffers that mitigate the input of nitrate to the stream.

This research indicated that instream nitrate concentration, fish, benthic macroinvertebrates, and instream habitat were controlled by environmental drivers at different scales, and that riparian buffers varied in their importance. Because buffers act differently on these measures of biological stream health, clear definition of the criteria used to define buffer effectiveness is critical. There was no one recommended "minimum width" of buffer to protect stream health. Depending on the objective, however, buffers can be an effective tool to mitigate the effects of agricultural non-point-source pollution on biological measures of stream health.

Specific management suggestions from this research include:

- Installation of buffers at least 4 m wide on as many low-order stream miles as possible
- Caution against using instream nitrate or fish IBI to measure effectiveness of site level land use management strategies, such as buffer installation.
- Caution against using benthic IBI or PHI to measure effects of regional management strategies.

While this research provided empirical results specific to Maryland, the general findings are of use to other locations throughout the United States where the establishment of forest buffers is considered as an aquatic ecosystem restoration measure.

# CHAPTER 9 –

# FUTURE WORK

Attempts to model comprehensive buffer effects, such as change in nitrate along a reach were unsuccessful. Ground-truthed data were too limited to develop trustworthy models of integrative buffer effects. This research determined that resolution of remotely sensed data used in publicly available GIS files was insufficient to adequately characterize distribution and width of agricultural buffers. Should adequate, higher resolution data become available, the methods developed in this research might be used to model integrative buffer effects.

Although all models indicated that buffers were secondary or ineffective in controlling measures of stream health, there are clearly more complex relationships at work than could be captured by these easily obtainable data. Future research should focus on elucidating the nature and strength of the relationship between riparian forests and instream biological communities. A better understanding of this relationship may well provide the key for effective land use decisions to maximize the effectiveness of the instream biological processing of unavoidable nitrate inputs from the headwaters of the Chesapeake Bay.

The weakness of regression models developed in this research may also be due to missing key explanatory variables. These data did not contain some measures that would be expected to explain significant portions of the variation of buffer effectiveness. There were no measures of agricultural BMP implementation, such as tillage and nutrient management. There were no good measures of buffer bypass, such as fragmentation and agricultural drain tiles. This research used easily obtainable measures such as gradient, tortuosity, drainage density, water table depth, and drainage to indirectly describe the transport efficiency of the site catchment. A better description (index) of transport efficiency could provide a way to explain more of the variation in buffer effectiveness, especially for measures that are strongly influenced by hydrology, such as nitrate and fish IBI. Should better measures of these landscape and land use descriptors become available, the methods developed in this research could be used to create better models of buffer effect.

There were inherent limits to the usefulness of easily obtainable data as the criteria variables. Use of the indices developed by the MBSS as criteria variables injected variation into the modeling relationships, because they were themselves blended measures. If the species are partitioned into more specific sub-groupings, according to chemical or hydrological sensitivity, buffer effect on specific endpoints might be better elucidated. Use of instream nitrate as a criteria variable is also, in a sense, a blended measure. Stream water is a mix of surface runoff and groundwater of different ages that have arrived in the stream by various pathways. The mix of ages in streamwater may affect these relationships, for if the majority of the water in the stream is old, having traveled through deep pathways, there may be negligible riparian effects. Further work considering the age of the streamwater or the dominance of a particular flow path may provide better guidance for placement of buffers for maximum effectiveness.

This research focused on nitrate as the measure of stream chemistry, due to interest in reduction of agricultural nitrate to the Chesapeake Bay. However, phosphate has become a topic of regulatory concern, as well. These data sets contain information on phosphate and can be analyzed using the same techniques to provide information on the effectiveness of agricultural buffers to control instream phosphate.

This research focused on agricultural riparian buffers. Urban buffers are quickly becoming a topic critical interest in land use planning. The techniques developed here could be easily employed to investigate the effects of stormwater BMPs, zoning and land use management.

The data sets developed through this work can be further explored. Although the Survey* data were not particularly useful to model buffer effectiveness, they provide a unique and comprehensive description of Maryland's agricultural landscapes. These data have not been fully investigated to ascertain all that can be said about these landscapes. Similarly, the MBSS* data set provides a different, but unique and comprehensive description of Maryland's agricultural riparian landscapes. Neither of these data sets has not been fully investigated.

Finally, the data and results of this work can be integrated with the socioeconomic information developed from the University of Maryland project entitled "Environmental Benefits and Costs of a Voluntary Riparian Forest Buffer Program", funded by USDA's Fund for Rural America in 1998. The project had a number of research objectives, including environmental and sociological characterization of agricultural riparian settings in Maryland. From these data, future work can match the physiographic information about riparian buffer sites developed in this research with information about agronomic land use and socio-economic information about site owner. Results should provide proximate level and type of environmental benefits one might reasonably expect from a voluntary incentive-based program to establish riparian buffers in the Maryland portion of the Chesapeake Bay watershed.

# APPENDICES

## APPENDIX 1:

## UNIVERSITY OF MARYLAND AGRICULTURAL BUFFER SURVEY

## FIELD SHEET

***Riparian Buffer Project Field Data***

Site number:
Date:
Time:
Team type:
Team number:
Names:
Watershed:
Water station #:
Rain past 24 hours:

**Buffer**
Continuous length:
Site length:
Number of sides: 1 or 2
Type: T / T-G / G / S
Trees - H / HP / PH / P
Shrubs/u'growth ht.:
Grass - fallow / planted
N fixers? Y / N
Gullying - L / M / S
Berms? N / L / R / L&R

| **Transect** | **Buffer** | | | |
|---|---|---|---|---|
| | **width** | **slope** | **DBH** | **bas.area** |
| | **L R** | **L R** | **L R** | **L R** |
| **T1** | | | | |
| **T2** | | | | |
| **T3** | | | | |

Riparian Buffer Project Field Data

Stream

Channelization -Y/ N

Velocity: (depth):

Channel shape: TRI RECT ROUND

Substrate: MS / S / SG / SGC / G / C

Sketch / Comments

Adjacent Land (facing upstream)

Right side land use:

Field slope:

Apparent slope length:

Left side land use:

Field slope:

Apparent slope length:

Tiling? Y / N

| Stream | | | | |
|---|---|---|---|---|
| Top width | Incision to depth | RB Angle/ erosion | LB Angle/ erosion | Water depth |
| | | | | R P |
| | | | | R P |
| | | | | R P |

***Riparian Buffer Project Map Information***

Site number:

Nearest water station:

Team type:

Team number:

Names:

Watershed:

County:

Physiographic region:

Latitude:

Longitude:

Stream order:

Stream gradient (%):

Stream distance upstream of buffer (ft):

Stream drainage area (sq mi):

Upstream water station:

Downstream water station:

Distance between water stations (ft):

% of distance represented by buffer:

***Riparian Buffer Project Map Information***

Soil info

LB soil type(s):

LB Wtr Tbl (ft):

LB Drainage: Poor / Good / Well / Excessive

LB Surface "Permeability" (ft):

LB Min "Permeability" (ft):

depth range at min:

RB soil type(s):

RB Wtr Tbl (ft):

RB Drainage: Poor / Good / Well / Excessive

RB Surface "Permeability" (ft):

RB Min "Permeability" (ft):

depth range at min:

LF soil type(s):

LF Wtr Tbl (ft):

LF Drainage: Poor / Good / Well / Excessive

LF Surface "Permeability" (ft):

LF Min "Permeability" (ft):

depth range at min:

RF soil type(s):

RF Wtr Tbl (ft):

RF Drainage: Poor / Good / Well / Excessive

RF Surface "Permeability" (ft):

RF Min "Permeability" (ft):

depth range at min:

## APPENDIX 2:

## UNIVERSITY OF MARYLAND AGRICULTURAL BUFFER SURVEY

## GUIDE TO FIELD AND MAP MEASUREMENTS

The purpose for taking the following measurements is to quantify the characteristics of an agricultural riparian buffer zone.

**Field Sheet ID Info:**

| | |
|---|---|
| *Site number:* | in the order that you visit them |
| *Date:* | date measurements were taken |
| *Time:* | time of day (military time) |
| *Team Type:* | Linda or Jim |
| *Team Number:* | your team number |
| *Names:* | of team members |
| *Watershed:* | Watershed name (German Branch, Cattail Creek) |
| *Water station #:* | corresponding water quality data site for this buffer (Linda's team will fill this in.) |
| *Rain:* | approximate inches in the past 24 hours |

**Field Measurements:**

*Stream:*

- channelization
- velocity
- depth at velocity measurement
- channel shape
- channel bed substrate
- width
- incision to stream bed
- bank angles
- bank erosion
- water depth (in riffles and pools)

*Buffer:*

- continuous length of buffer
- site length
- number of sides
- type
- tree types
- height of undergrowth
- type of grass
- presence of nitrogen fixers
- gullying
- berms

width
slope
DBH (diameter of trees at breast height)
basal area

*Adjacent fields:*

land use
slope and slope length
presence of drain tiles

**Instruments and gear:**

*Measuring equipment:*

100-foot tape measure,
(stiff) 8-foot measuring tape,
basal area prism,
DBH (diameter at breast height) stick,
Abbey level,
fishing float attached to a 20-foot string,
fishing pole with weight
pencils, covered clipboard, lanyards,
map

*Personal equipment:*

rubber boots, extra socks
poison ivy block, soap-water-cloth, poison ivy gel, antibiotic salve
sunscreen, hat
tick spray
light colored pants and shirt
light-weight field jacket or long-sleeved shirt
rain gear and towel
lots of liquids
tissue and bag
cell phone, emergency telephone numbers
University ID, copy of project introductory letter
1st aid kit, small pocket knife

**Description of measurements:**

***Stream:***

***Stream overall measurements:***

**Channelization.** Channelization has occurred when the path of the stream has been straightened. Berms (levees, or mounds of dirt parallel to the stream) can be evidence of channelization. (Note: DO NOT use the angle formed by the berm as the slope angle.) *Record as: Yes / No*

**Velocity (depth).** The velocity of the stream can be measured by the use of a second hand watch and a device made of a bobber and twenty feet of line. By tossing the bobber upstream, the velocity can be calculated by timing how long the bobber takes to travel the distance of the line and dividing the length by the time. Record as units of x feet per y seconds, and calculate feet per second later. Try to measure in the center of the stream at a riffle, and take note of the depth of the water where velocity was measured. Record as: x feet per y seconds

**Channel shape**. The shape of the channel or stream between banks.
Record as: rectangular, round, or triangular

**Stream channel bed substrate**. Look in both riffles and pools.
Record as: M (mud/silt), S (sand), SG (sand/gravel), G (gravel - up to 1.5 inches diameter), C (cobbles - up to 4 inches in diameter), SGC.

**ROSGEN score.** *Only applicable to Linda's teams.*
This is a method of categorizing streams. A Rosgen score is a letter/number combination. The letter references the channel shape, sinuosity, incision and apparent instability (erosion of banks). The number references the substrate material. Agricultural streams OFTEN do not fit neatly into the Rosgen system, yet it is often used. Part of the work of this project is to consider the usefulness of the Rosgen system here in Maryland. Therefore, put the stream in the closest Rosgen category, even though it may not be a good fit.
*Channel form:*
For low gradient streams (<2%):
C = point bars present, entrenched, rectangular shape, low sinuosity, fairly stable.
F = no point bars, entrenched, rectangular shape, low sinuosity, unstable (erosion)

E = not very entrenched, triangular shape, highly sinuous, vegetated banks
For moderate gradient streams (2–4%)
B = moderately entrenched, triangular/round shape, stable banks, low sinuosity

***Stream transect measurements:***

**Top width.** The top width is the measured distance from one bank to the opposite bank. The stream bank is determined as the "slope break" between the buffer and the stream. Use a measuring tape or cast a weight across the stream to determine the distance and record its measurement in feet.
Record as: Top width is measured to the nearest half foot.

**Incision to depth**. The incision to depth is the distance from the bottom of the stream to the level of the banks. This measurement can be calculated by standing in the stream and marking the level at which the top width was taken and then measuring from this height to the bottom of the stream. Record as: Incision is measured to the nearest half foot.

**Bank angles and bank erosion.** The bank angles and the erosion are taken on each side. All measures are referenced to facing upstream. The angles can be either calculated by taking the rise and run of the banks to the nearest half foot or by approximation or by using a protractor. After obtaining the rise and run the bank angle can be calculated on a calculator as $\tan^{-1}$ of rise/run.
Record as: rise/run or as degrees.
The banks' erosion are ranked using the following categories; none, low (these will probably be vegetated), high (lots of slumped dirt), and moderate (in between "minimum" and "high"). Record as: N, L, M, H

**Water depth.** Average depth from the surface of the water to the bottom of the stream is taken in both a riffle area where the water is shallower and in a pool area where the water is still. These depths can be taken using a small measuring tape.
Record as: to the nearest inch.

***<u>Buffer</u>:***

***Buffer overall measurements:***

**Continuous length.** Determine how long the buffer appears to run – either from the aerial photo or from visual observation. Record as: feet

**Site length.** Measure the length of the site at which you take measurements by adding the distance between transects. Use the average value paced by two people.
Record as: feet

**Number of sides.** Note if the buffer is present on both sides of the stream or just one.
Record as: 1 or 2

**Type**. There are basically 4 types of buffers – trees, trees and grass, grass, and shrub/undergrowth. Record as: T, T-G, G, S

**Trees.** For forested buffers, record the type of trees.
Record as: H (hardwood), HP (hardwood and pine mix, predominantly hardwoods), PH (hardwood and pine mix, predominantly pine), P (pines).

**Grass**. For grass buffers, record whether the buffer is planted grass or wild.
Record as: fallow or planted

**Shrub buffers.** Record the height of the undergrowth. Record as: feet.
**Presence of nitrogen fixers.** Some plants, such as black locust trees, do not use nitrate from the soil water, but "fix" nitrogen from the air by means of symbiotic bacteria. <u>A large proportion</u> of these plants will affect the buffer's uptake of nitrate. A "yes" means there is a significant proportion of nitrogen fixers in the buffer.
Record as: Yes / No.

**Gullying.** Small gullies or side ditches will sometimes run through the buffer and act as an effective by-pass through the buffer. These gullies can be filled with water or dry and full of vegetation. Record as: Low, Moderate, Severe.

**Berms.** Berms or levees are sometimes found along the one or both banks of the stream, especially if there has been channelization. Record their presence as you face upstream. Record as: N (none), L (left), R (right), LR, left and right).

***Buffer transect measurements:***

**Buffer width.** Width of the buffer (between the stream and the adjacent farm field) is measured by pacing perpendicular to the stream. It is important to occasionally re-measure your average stride with the 100-foot tape or compare the team members' paced-off values to ensure accuracy. (If the stream is very sinuous, guess an average stream direction and measure perpendicularly to the average stream path.) The buffer width is measured for each individual type of buffer: - trees, grass, and shrubs. Combined these values give the total buffer width. The streamside end of the buffer is at the slope break between the stream bank and the buffer, and is the demarcation between buffer and stream bank. You need to pay attention here – sometimes the demarcation between buffer and bank is not obvious. The field-edge end of the buffer is at the edge of cultivation.
All measurements are referenced facing upstream.
If there is no buffer on one side, record "none". If there is a buffer but you do not have access to it, record "no access", estimate the appropriate measurements and note them in the transect comments section.
Record as: feet to the nearest ½ foot.

**Buffer slope.** Slope is measured with the abbey level. Align the level line in the sight with a point at the same height as the observer's eye. Move the level to center the bubble on the level line. The slope is read from the % scale. Take the average, representative value of buffer slope.
Record as: %.

**DBH.** The diameter of the dominant trees in the buffer is measured at breast height with the DBH stick. Note the values in the margin of the field sheet, and record the average. Record as: inches.

**Basal area**. Basal area is a measurement of square footage of trees in an area. Use a basal area prism to determine the square footage by holding the instrument at arm's length from the observer and at chest height. Pivot about a fixed point while looking though the prism and count the amount of trees that do not become "disconnected" through the prism. The number of trees is multiplied by ten to give the square footage.
Record as: square feet.

***Adjacent fields:***

***(All are overall measurements)***

**Adjacent land use.** Record the land use on each side of the buffer.
Record as: crop, pasture, livestock, houses, and forest. (Call us if you have anything else.)

**Slope and Slope length.** Use the same procedure used to determine the buffer slope.
Record as: %.
Also record the distance to any apparent slope change – either pace off the distance or visually estimate it. Record as: yards.

**Presence of drain tiles**. Tiling is a rerouting of water from the fields to the stream through the use underground pipes (tiles) under the root zone. This method of farming can sometimes be detected by looking for a small vent structure in the field - this tower allows a constant atmospheric pressure to be maintained in the system.
Record as: Yes / No.

**Map Measurements:**

General information:

- Site number
- Team Type
- Team Number
- Names
- Watershed
- County
- Physiographic region
- Latitude/Longitude or Maryland Grid XY coordinates
- Stream order
- Stream gradient
- Upstream distance
- Stream site drainage area

**The following measurements will be filled in by Linda's team:**

- Nearest water station
- Upstream water station
    - Downstream water station
    - Distance between water stations
    - % of distance represented by buffer

Soil information:

Left and Right buffer -

- soil type
- water table
- drainage
- surface hydraulic conductivity "permeability"
- minimum hydraulic conductivity "permeability"
- depth at minimum hydraulic conductivity

Left and Right adjacent field -

- soil type
- water table
- drainage
- surface hydraulic conductivity "permeability"
- minimum hydraulic conductivity "permeability"
- depth at minimum hydraulic conductivity

**Instruments and gear:**

County street map
topographic map
County soil map
aerial photos of watershed
ruler
pencil
thin string
grid chart

**Description of measurements:**

***General information:***

**Latitude.** The latitude is the vertical measure of a fixed position; this coordinate is expressed in degrees, minutes, and seconds
**Longitude.** Longitude is the horizontal measure of a fixed position.
OR
**Maryland grid: x coordinate.** The Maryland grid x coordinate is the vertical position as is latitude on a map, but this measurement is in feet. The division of this is an indicator every one hundred thousand feet.
**Maryland grid: y coordinate.** The Maryland grid y coordinate is the horizontal position.

**Stream order.** Stream order as determined by the Strahler system will be between 1 - 4.
A $1^{st}$ order stream has no tributaries.
Two $1^{st}$-order streams run together to make a $2^{nd}$-order stream.
A $2^{nd}$-order stream does not increase order if joined by a $1^{st}$-order stream.
Record as: 1,2,3,4.

**Stream gradient.** The stream gradient is a calculation of the slope of the stream. This gradient can be calculated by using a topographic map to determine the drop in elevation per length of stream for a length of stream around the buffer. The drop is then divided by the length to give the stream gradient. Record as: %.

**Upstream distance.** The total distance of stream that is traversed to get to the data sampling site can be calculated using a thin line and the map scale. Arrange the line on the map so that it traces the path of the stream from its source to the site of the buffer. Next take the length of measured line and place it so that the distance can be calculated using the legend on the map. Do not use the lengths of side tributaries above the buffer site, only the main path of the stream from the buffer back to the stream source. Record as: feet.

**Stream drainage area.** The stream drainage area is the approximate area of the surrounding lands that drain into the stream at the point of interest. This measurement is determined from the USGS topographic map of the watershed, and is calculated by using a ruler to measure the length and width of the land that drains into the stream at the buffer, then multiplying the two figures to give area. Record as: square miles.

***Soil information:*** *All values are recorded for left/right buffer and left/right field. All values and the soil survey map are located in the county soil survey book.*

**Soil type.** Soil type is determined from the soil survey map. After mapping the location of the field site, obtain the soil type code from the map. The name of the soil types are arranged alphabetically in the tables in the soil survey book.
Record as: name of soil type.

**Water table.** The depth to the water table is located in two possible places. There will either be a column for "depth to seasonally high water table" in the "engineering properties of the soils" table, or the information will be given in a description of the soil type. Record as: a range of feet.

**Drainage.** Drainage for the soil type is designated as poor, good, well or excessive. This information is located in two possible places, either as a designated column in the "engineering properties of the soils" table, or in the description of the soil type. You may have to interpret the language to designate the drainage as one of the categories. Record as: poor, good, well or excessive.

**Surface permeability.** This is actually a measure of hydraulic conductivity. The soil table will have a column to the right of the soil description titled "depth to surface". The top range will always be (0 – some value). Further to the right, there is a column titled "permeability". Take the value corresponding to this top depth range for surface permeability. Record as: a range of inches.

**Minimum permeability.** This is also a measure of hydraulic conductivity. In the column titled "permeability", there may be more than one range of permeabilities at different depths. Use the minimum value.
Record as: a range of inches.

**Depth at minimum.** This is the range in the column to the right of the soil description titled "depth to surface" that corresponds to the minimum value for permeability. Record as: a range of feet.

**Description of Survey variables**

| Name | Description | Units |
|---|---|---|
| **ACCESS** | Did livestock have access to the stream? | Y/N |
| **AREA** | Site watershed area | sq.mi. |
| **B** | Was there a buffer at all? | Y/N |
| **BAS1O** | Basal area: overall measurement for both stream sides: 1st | sq.ft. |
| **BAS2O** | Basal area: overall measurement for both stream sides: 2nd | sq.ft. |
| **BAS3O** | Basal area: overall measurement for both stream sides: 3rd | sq.ft. |
| **BAS1L** | Basal area: L stream side: 1st measuremt | sq.ft. |
| **BAS2L** | Basal area: L stream side: 2nd measuremt | sq.ft. |
| **BAS3L** | Basal area: L stream side: 3rd measuremt | sq.ft. |
| **BAS1R** | Basal area: R stream side: 1st measuremt | sq.ft. |
| **BAS2R** | Basal area: R stream side: 2nd measuremt | sq.ft. |
| **BAS3R** | Basal area: R stream side: 3rd measuremt | sq.ft. |
| **BDL** | Buffer soil type: L side | |
| **BDR** | Buffer soil type: R side | |
| **BDRL** | Buffer drainage class: L side | |
| **BDRR** | Buffer drainage class: R side | |
| **BERM** | Were there berms at the site? | |
| **BETW** | Distance between SERC sampling stations | ft |
| **BG1L** | Buffer grass width: L side: 1st measuremt | ft |
| **BG2L** | Buffer grass width: L side: 2nd measuremt | ft |
| **BG3L** | Buffer grass width: L side: 3rd measuremt | ft |
| **BG1R** | Buffer grass width: R side: 1st measuremt | ft |
| **BG2R** | Buffer grass width: R side: 2nd measuremt | ft |
| **BG3R** | Buffer grass width: R side: 3rd measuremt | ft |
| **BGRASS** | Buffer grass type | |

| Name | Description | Units |
|---|---|---|
| **BIN1L** | Buffer in-channel vegetation width: L side: 1st measuremt | ft |
| **BIN2L** | Buffer in-channel vegetation width: L side: 2nd measuremt | ft |
| **BIN3L** | Buffer in-channel vegetation width: L side: 3rd measuremt | ft |
| **BIN1R** | Buffer in-channel vegetation width: R side: 1st measuremt | ft |
| **BIN2R** | Buffer in-channel vegetation width: R side: 2nd measuremt | ft |
| **BIN3R** | Buffer in-channel vegetation width: R side: 3rd measuremt | ft |
| **BKMDLM** | Buffer minimum K depth: L side: min value of range | ft |
| **BKMDRM** | Buffer minimum K depth: R side: min value of range | ft |
| **BKMLM** | Buffer minimum K : L side: min value of range | in/hr |
| **BKMRM** | Buffer minimum K: R side: min value of range | in/hr |
| **BKSLM** | Buffer surface K : L side: min value of range | in/hr |
| **BKSRM** | Buffer surface K : R side: min value of range | in/hr |
| **BS1L** | Buffer slope: L side: 1st measuremt | % |
| **BS2L** | Buffer slope: L side: 2nd measuremt | % |
| **BS3L** | Buffer slope: L side: 3rd measuremt | % |
| **BS1R** | Buffer slope: R side: 1st measuremt | % |
| **BS2R** | Buffer slope: R side: 2nd measuremt | % |
| **BS3R** | Buffer slope: R side: 3rd measuremt | % |
| **BSH1L** | Buffer shrub width: L side: 1st measuremt | ft |
| **BSH2L** | Buffer shrub width: L side: 2nd measuremt | ft |
| **BSH3L** | Buffer shrub width: L side: 3rd measuremt | ft |
| **BSH1R** | Buffer shrub width: R side: 1st measuremt | ft |
| **BSH2R** | Buffer shrub width: R side: 2nd measuremt | ft |
| **BSH3R** | Buffer shrub width: R side: 3rd measuremt | ft |
| **BT1L** | Buffer tree width: L side: 1st measurement | ft |
| **BT2L** | Buffer tree width: L side: 2nd measurement | ft |
| **BT3L** | Buffer tree width: L side: 3rd measurement | ft |
| **BT1R** | Buffer tree width: R side: 1st measurement | ft |
| **BT2R** | Buffer tree width: R side: 2nd measurement | ft |
| **BT3R** | Buffer tree width: R side: 3rd measurement | ft |
| **BWLM** | Buffer water table: L side: minimum value of range | ft |
| **BWLX** | Buffer water table: L side: maximum value of range | ft |
| **BWRM** | Buffer water table: R side: minimum value of range | ft |
| **BWRX** | Buffer water table: R side: maximum value of range | ft |

| Name | Description | Units |
|---|---|---|
| **CA1L** | Channel bank angle: L side: 1st measurement | degrees |
| **CA2L** | Channel bank angle: L side: 2nd measurement | degrees |
| **CA3L** | Channel bank angle: L side: 3rd measurement | degrees |
| **CA1R** | Channel bank angle: R side: 1st measurement | degrees |
| **CA2R** | Channel bank angle: R side: 2nd measurement | degrees |
| **CA3R** | Channel bank angle: R side: 3rd measurement | degrees |
| **CD1** | Channel depth: 1st measurement | ft |
| **CD2** | Channel depth: 2nd measurement | ft |
| **CD3** | Channel depth: 3rd measurement | ft |
| **CE1L** | Channel bank erosion: L side: 1st measurement | |
| **CE3L** | Channel bank erosion: L side: 3rd measurement | |
| **CE1R** | Channel bank erosion: R side: 1st measurement | |
| **CE2R** | Channel bank erosion: R side: 2nd measurement | |
| **CE3R** | Channel bank erosion: R side: 3rd measurement | |
| **CHNZ** | Is the stream channelized? | Y/N |
| **CO** | County | |
| **CP1** | Pool depth: 1st measurement | in |
| **CP2** | Pool depth: 2nd measurement | in |
| **CP3** | Pool depth: 3rd measurement | in |
| **CR1** | Riffle depth: 1st measurement | in |
| **CR2** | Riffle depth: 2nd measurement | in |
| **CR3** | Riffle depth: 3rd measurement | in |
| **CW1** | Channel width: 1st measurement | ft |
| **CW2** | Channel width: 2nd measurement | ft |
| **CW3** | Channel width: 3rd measurement | ft |
| **DATE** | Date field work was conducted | in |
| **DBH1O** | Overall Diameter at Breast Height: both stream sides: 1st | in |
| **DBH2O** | Overall Diameter at Breast Height: both stream sides: 2nd | in |
| **DBH3O** | Overall Diameter at Breast Height: both stream sides: 3rd | in |
| **DBH1L** | Diameter at Breast Height: L side: 1st measurement | in |
| **DBH2L** | Diameter at Breast Height: L side: 2nd measurement | in |
| **DBH3L** | Diameter at Breast Height: L side: 3rd measurement | in |
| **DBH1R** | Diameter at Breast Height: R side: 1st measurement | in |
| **DBH2R** | Diameter at Breast Height: R side: 2nd measurement | in |
| **DBH3R** | Diameter at Breast Height: R side: 3rd measurement | in |

| Name | Description | Units |
|---|---|---|
| **DIST** | Distance from this site to the headwater | ft |
| **FDL** | Field soil class: L side | |
| **FDR** | Field soil class: R side | |
| **FDRL** | Field drainage class: L side | |
| **FDRR** | Field drainage class: R side | |
| **FKMDLM** | Field minimum K depth: L side: min value of range | in/hr |
| **FKMDLX** | Field minimum K depth: L side: max value of range | in/hr |
| **FKMDRM** | Field minimum K depth: R side: min value of range | in/hr |
| **FKMDRX** | Field minimum K depth: R side: max value of range | in/hr |
| **FKMLM** | Field minimum K : L side: min value of range | in/hr |
| **FKMLX** | Field minimum K : L side: max value of range | in/hr |
| **FKMRM** | Field minimum K : R side: min value of range | in/hr |
| **FKMRX** | Field minimum K : R side: max value of range | in/hr |
| **FKSLM** | Field surface K : L side: min value of range | in/hr |
| **FKSLX** | Field surface K : L side: max value of range | in/hr |
| **FKSRM** | Field surface K : R side: min value of range | in/hr |
| **FKSRX** | Field surface K : R side: max value of range | in/hr |
| **FSL** | Field slope: L side | % |
| **FSR** | Field slope: R side | % |
| **FSL** | Length of field or length used to calculate slope: L side | yds |
| **FSR** | Length of field or length used to calculate slope: R side | yds |
| **FUL** | Field use: L side | |
| **FUR** | Field use: R side | |
| **FWLM** | Field water table: L side: minimum value of range | ft |
| **FWLX** | Field water table: L side: maximum value of range | ft |
| **FWRM** | Field water table: R side: minimum value of range | ft |
| **FWRX** | Field water table: R side: maximum value of range | ft |
| **GRA** | Stream gradient | % |
| **GULLY** | What degree of gullying is there through th ebuffer? | |
| **INOUT** | Is the buffer in-channel or on the land? | |
| **LAT** | Latitude of site | |
| **LBUF** | Length of buffer fragment | ft |
| **LONG** | Longitude of site | |

| Name | Description | Units |
|---|---|---|
| **LSITE** | Length of the site | ft |
| **N/A** | Team member names that conducted the site visit. | |
| **NFIX** | Is the buffer vegetation predominated by N-fixers? | Y/N |
| **ORD** | Strahler stream order | |
| **RAIN** | Has it rained at this site in the past 24 hours? | Y/N |
| **REG** | Physiographic region | |
| **REP** | % of the distance between SERC sites that this site represents | |
| **ROS** | Rosgen classification of the stream | |
| **SHAPE** | Channel shape (rectangular, triangular, round) | |
| **SHRUBHT** | For shrub vegetation - height | ft |
| **SIDES** | How many sides of the stream have buffers? | |
| **SITENUM** | Site sampling number | |
| **STADN** | Number of downstream SERC sampling station | |
| **STAUP** | Number of upstream SERC station | |
| **SUB** | Stream substrate | |
| **SVEG** | Site vegetation | |
| **TEAMNO** | Team number | |
| **TEAMTYPE** | Linda or Jim's team | |
| **TIL** | Is there evidence of drain tiles? | |
| **TIME** | Starting time of site visit | |
| **TREE** | What is/are the dominant type of trees in the buffer? | |
| **VELD** | Depth of channel used to calculate velocity | in |
| **VELL** | Length used to calculate velocity | ft |
| **VELT** | Time used to calculate velocity | sec |
| **VELW** | Width of channel used to calculate velocity | ft |
| **WSHED** | Name of watershed | |
| **X** | X coordinate | |
| **Y** | Y coordinate | |

## APPENDIX 3:

## DEVELOPMENT OF GIS WATERSHED AND LANDSCAPE DESCRIPTORS

**Drainage density** **Scale:12-digit watershed**

| *wshed* | *sub-wshed* | *Total watershed area* ($m^2$) | *Total stream length* (m) | *Drainage density* ($m^2$/m) /1000 |
|---|---|---|---|---|
| **GB** | 556 | 56915564 | 54199.0 | 1.05 |
| **P** | 916 | 55902604 | 29142.0 | 1.92 |
| | 938 | 11244993 | 9077.0 | 1.24 |
| | 953 | 13424478 | 19926.0 | 0.67 |
| | 952 | 30835410 | 59029.0 | 0.52 |
| | 974 | 17950372 | 9864.0 | 1.82 |
| | 972 | 24469914 | 28261.0 | 0.87 |
| | 985 | 14281884 | 7205 | 1.98 |
| | 977 | 24166924 | 26414 | 0.91 |
| | 992 | 26041828 | 22539.0 | 1.16 |
| | | | | **1.2** |
| **StM** | 908 | 21876292 | 16751.00 | 1.31 |
| | 930 | 16815686 | 15335.0 | 1.10 |
| | 948 | 9576821 | 8471.0 | 1.13 |
| | 949 | 35845358 | 28750 | 1.25 |
| | | | | **1.19** |
| **Cal** | 835 | 15293606 | 31563 | 0.48 |
| **E** | 39 | 14324647 | 9576 | 1.50 |
| | 106 | 37354528 | 37096 | 1.01 |
| | | | | **1.25** |
| **G** | 65 | 20772786 | 17942 | 1.16 |
| | 66 | 27002656 | 23049 | 1.17 |
| | 127 | 64961724 | 60248 | 1.08 |
| | 150 | 16078304 | 17503 | 0.92 |
| | | **128815470** | | **1.08** |
| **M** | UL | 34566940 | 30147 | 1.15 |
| | U2L | 19687981 | 14282 | 1.38 |
| | U3L | 23428182 | 27606 | 0.85 |
| | UR | 29735160 | 22792 | 1.30 |
| | BL | 18982308 | 13815 | 1.37 |
| | B2L | 25133874 | 24352 | 1.03 |
| | B3L | 31699351 | 30550 | 1.04 |
| | B4L | 16752963 | 15900 | 1.05 |
| | BR | 15850822 | 14344 | 1.11 |
| | | | | **1.14** |
| **Cat** | 421 | 6125971 | 4827 | 1.27 |
| | 427 | 10679008 | 14544 | 0.73 |
| | 435 | 50582976 | 48408 | 1.04 |
| | | | | **1.02** |

| **Tortuosity** | | **Scale:12-digit watershed** | |
|---|---|---|---|
| ***sub-wshed*** | ***strm m* (m)** | ***wshed length* (m)** | ***tortuosity* (strm m/w** |
| 556 | 13892 | 12645 | **1.1** |
| 916 | 11938 | 12405 | 1.0 |
| 938 | 5001 | 4953 | 1.0 |
| 953 | 7514 | 5148 | 1.5 |
| 952 | 12663 | 9847 | 1.3 |
| 974 | 6832 | 5957 | 1.1 |
| 972 | 13056 | 9014 | 1.4 |
| 985 | 5473 | 5493 | 1.0 |
| 977 | 8035 | 6040 | 1.3 |
| 992 | 8315 | 5758 | 1.4 |
| | | | **1.2** |
| 908 | 6453 | 5575 | 1.2 |
| 930 | 6233 | 5431 | 1.1 |
| 948 | 2906 | 2816 | 1.0 |
| 949 | 4337 | 4295 | 1.0 |
| | | | **1.09** |
| 835 | 11714 | 8511 | **1.4** |
| 39 | 3968 | 3656 | 1.1 |
| 106 | 17201 | 12308 | 1.4 |
| | | | **1.24** |
| 65 | 9180 | 6111 | 1.5 |
| 66 | 12627 | 7552 | 1.7 |
| 127 | 16606 | 11189 | 1.5 |
| 150 | 4864 | 4709 | 1.0 |
| | | | **1.42** |
| UL | 13323 | 8077 | 1.6 |
| U2L | 5740 | 4636 | 1.2 |
| U3L | 8170 | 5709 | 1.4 |
| UR | 8155 | 7626 | 1.1 |
| BL | 8490 | 8710 | 1.0 |
| B2L | 10195 | 8633 | 1.2 |
| B3L | 13353 | 11586 | 1.2 |
| B4L | 7892 | 6245 | 1.3 |
| BR | 5768 | 4460 | 1.3 |
| | | | **1.3** |
| 421 | 4827 | 4400 | 1.1 |
| 427 | 4986 | 4550 | 1.1 |
| 435 | 13299 | 10331 | 1.3 |
| | | | **1.16** |

| Topographic Inde | Scale:12-digit watershed | | | | |
|---|---|---|---|---|---|
| *wshed* | *sub-wshed* | *max elev* | *min elev* | *delta* | *index* |
| **shed m)** | | **(m)** | **(m)** | | **(m/mˆ)E6** |
| **GB** | 556 | 61.6 | 12.3 | 49.3 | 0.87 |
| **P** | 916 | 86.3 | 12.3 | 74 | 1.32 |
| | 938 | 36.9 | 12.3 | 24.6 | 2.19 |
| | 953 | 36.9 | 12.3 | 24.6 | 1.83 |
| | 952 | 24.6 | 12.3 | 12.3 | 0.40 |
| | 974 | 36.9 | 12.3 | 24.6 | 1.37 |
| | 972 | 36.9 | 12.3 | 24.6 | 1.01 |
| | 985 | 36.9 | 12.3 | 24.6 | 1.72 |
| | 977 | 36.9 | 12.3 | 24.6 | 1.02 |
| | 992 | 36.9 | 12.3 | 24.6 | 0.94 |
| | | | | | **1.3** |
| **StM** | 908 | 160.2 | 36.9 | 123 | 5.64 |
| | 930 | 147.9 | 12.3 | 136 | 8.06 |
| | 948 | 123.2 | 12.3 | 111 | 11.58 |
| | 949 | 135.6 | 12.3 | 123 | 3.44 |
| | | | | | **7.18** |
| **Cal** | 835 | 147.9 | 12.3 | 136 | 8.87 |
| **E** | 39 | 456.1 | 234.2 | 222 | 15.49 |
| | 106 | 431.48 | 36.98 | 395 | 10.56 |
| | | | | | **13.03** |
| **G** | 65 | 899.9 | 468.5 | 431 | 20.77 |
| | 66 | 949.2 | 468.5 | 481 | 17.80 |
| | 127 | 813.6 | 295.9 | 518 | 7.97 |
| | 150 | 825.9 | 406.8 | 419 | 26.07 |
| | | | | | **18.15** |
| **M** | UL | 650.4 | 325 | 325 | 9.41 |
| | U2L | 690.1 | 404.7 | 285 | 14.50 |
| | U3L | 737.5 | 427.7 | 310 | 13.22 |
| | UR | 914.1 | 487.8 | 426 | 14.34 |
| | BL | 693.7 | 393.8 | 300 | 15.80 |
| | B2L | 773.2 | 307.1 | 466 | 18.54 |
| | B3L | 881.6 | 437.2 | 444 | 14.02 |
| | B4L | 849.1 | 451.6 | 398 | 23.73 |
| | BR | 885.2 | 404.7 | 481 | 30.31 |
| | | | | | **17.10** |
| **Cat** | 421 | 801.3 | 493.1 | 308 | 50.31 |
| | 427 | 813.6 | 480.8 | 333 | 31.16 |
| | 435 | 813.6 | 369.8 | 444 | 8.77 |
| | | | | | **30.08** |

**Land Use** **Scale:12-digit watershed**

| *wshed* | *sub-wshed* | *ag* (m²) | *% ag* | *forest* (m²) | *% forest* | **% Land Use Explained** |
|---|---|---|---|---|---|---|
| **GB** | 556 | 4.1E+07 | 72.88 | 14857613 | 26.1 | **99.0** |
| **P** | 916 | 2.3E+07 | 40.30 | 31112891 | 55.7 | |
| | 938 | 5419200 | 48.19 | 5624172 | 50.0 | |
| | 953 | 6435769 | 47.94 | 6693087 | 49.9 | |
| | 952 | 1E+07 | 32.90 | 20455166 | 66.3 | |
| | 974 | 1863530 | 10.38 | 16036882 | 89.3 | |
| | 972 | 7850681 | 32.08 | 16412816 | 67.1 | |
| | 985 | 7490371 | 52.45 | 6679140 | 46.8 | |
| | 977 | 8612412 | 35.64 | 14580260 | 60.3 | |
| | 992 | 1.2E+07 | 44.24 | 14160430 | 54.4 | |
| | | | **38.2** | | **60.0** | **98.2** |
| **StM** | 908 | 5469504 | 25.00 | 12566745 | 57.4 | |
| | 930 | 6733723 | 40.04 | 8583656 | 51.0 | |
| | 948 | 4574044 | 47.76 | 4545859 | 47.5 | |
| | 949 | 1.8E+07 | 51.58 | 14584291 | 40.7 | |
| | | | **41.10** | | **49.16** | **90.3** |
| **Cal** | 835 | 8339525 | 54.5 | 4357106 | 28.5 | **83.0** |
| **E** | 39 | 1E+07 | 72.08 | 1800763 | 12.6 | |
| | 106 | 1.4E+07 | 38.38 | 12603072 | 33.7 | |
| | | | **55.23** | | **23.16** | **78.4** |
| **G** | 65 | 8481172 | 40.83 | 9338777 | 45.0 | |
| | 66 | 1.7E+07 | 62.35 | 7589699 | 28.1 | |
| | 127 | 3.3E+07 | 50.78 | 27182097 | 41.8 | |
| | 150 | 4821351 | 29.99 | 6232361 | 38.8 | |
| | | | **45.98** | | **38.42** | **84.4** |
| **M** | UL | 3E+07 | 86.77 | 2871521 | 8.31 | |
| | U2L | 1.5E+07 | 77.01 | 2223716 | 11.29 | |
| | U3L | 2E+07 | 83.41 | 2678773 | 11.43 | |
| | UR | 1.5E+07 | 50.38 | 4872916 | 16.39 | |
| | BL | 1.6E+07 | 84.02 | 1998227 | 10.53 | |
| | B2L | 2.1E+07 | 85.30 | 2187812 | 8.70 | |
| | B3L | 2.3E+07 | 72.18 | 5764327 | 18.18 | |
| | B4L | 1.3E+07 | 77.50 | 1876505 | 11.20 | |
| | BR | 1.1E+07 | 68.15 | 2377833 | 15.00 | |
| | | | **76.08** | | **12.3** | **88.4** |
| **Cat** | 421 | 3633599 | 59.31 | 1278561 | 20.9 | |
| | 427 | 7524421 | 70.46 | 1594412 | 14.9 | |
| | 435 | 2.8E+07 | 56.22 | 12728429 | 25.2 | |
| | | | **62.00** | | **20.32** | **82.3** |

## APPENDIX 4:

## UNIVERSITY OF MARYLAND AGRICULTURAL BUFFER SURVEY

## CORRELATION MATRIX FOR BUFFER SURVEY DATA

**(See Appendix 2 for description of parameters)**

| | LBUF | ORD | Log ORD | GRA | VEL | CWavg | CDavg | CXSavg |
|---|---|---|---|---|---|---|---|---|
| **LBUF** | 1.00 | 0.24 | 0.24 | -0.16 | 0.03 | 0.13 | 0.22 | 0.22 |
| **ORD** | 0.24 | 1.00 | 0.98 | -0.33 | 0.46 | 0.37 | 0.34 | 0.42 |
| **logORD** | 0.24 | 0.98 | 1.00 | -0.36 | 0.42 | 0.32 | 0.31 | 0.36 |
| **GRA** | -0.16 | -0.33 | -0.36 | 1.00 | -0.12 | -0.07 | -0.19 | -0.11 |
| **VEL** | 0.03 | 0.46 | 0.42 | -0.12 | 1.00 | 0.27 | 0.38 | 0.35 |
| **CWavg** | 0.13 | 0.37 | 0.32 | -0.07 | 0.27 | 1.00 | 0.39 | 0.83 |
| **CDavg** | 0.22 | 0.34 | 0.31 | -0.19 | 0.38 | 0.39 | 1.00 | 0.72 |
| **CXSavg** | 0.22 | 0.42 | 0.36 | -0.11 | 0.35 | 0.83 | 0.72 | 1.00 |

| | logCXS | CW vsCD | CA avg | Log CA | BS avg | FSavg | BSvs FS | BTavg |
|---|---|---|---|---|---|---|---|---|
| **LBUF** | 0.22 | 0.02 | 0.18 | 0.17 | -0.07 | -0.03 | -0.03 | 0.47 |
| **ORD** | 0.38 | 0.04 | 0.18 | 0.18 | -0.04 | 0.10 | 0.00 | 0.09 |
| **logORD** | 0.34 | 0.01 | 0.18 | 0.19 | -0.03 | 0.09 | 0.01 | 0.11 |
| **GRA** | -0.22 | 0.05 | -0.17 | -0.24 | 0.06 | 0.11 | 0.02 | -0.08 |
| **VEL** | 0.40 | 0.00 | 0.24 | 0.21 | 0.01 | 0.15 | -0.05 | 0.07 |
| **CWavg** | 0.81 | 0.56 | 0.10 | 0.07 | -0.11 | -0.02 | -0.09 | -0.02 |
| **CDavg** | 0.67 | -0.28 | 0.22 | 0.18 | -0.07 | 0.18 | -0.13 | 0.16 |
| **CXSavg** | 0.76 | 0.16 | 0.11 | 0.10 | -0.10 | 0.15 | -0.13 | 0.06 |
| **logCXSav** | 1.00 | 0.20 | 0.19 | 0.17 | -0.06 | -0.02 | -0.07 | 0.07 |
| **CWvsCD** | 0.20 | 1.00 | -0.18 | -0.26 | -0.08 | -0.11 | 0.00 | -0.08 |
| **CAavg** | 0.19 | -0.18 | 1.00 | 0.95 | -0.13 | -0.04 | -0.15 | 0.15 |
| **logCA** | 0.17 | -0.26 | 0.95 | 1.00 | -0.08 | -0.04 | -0.11 | 0.13 |
| **BSavg** | -0.06 | -0.08 | -0.13 | -0.08 | 1.00 | 0.36 | 0.56 | -0.04 |
| **FSavg** | -0.02 | -0.11 | -0.04 | -0.04 | 0.36 | 1.00 | -0.21 | 0.23 |
| **BSvsFS** | -0.07 | 0.00 | -0.15 | -0.11 | 0.56 | -0.21 | 1.00 | -0.13 |
| **BTavg** | 0.07 | -0.08 | 0.15 | 0.13 | -0.04 | 0.23 | -0.13 | 1.00 |

| | BTvar | DBH | BAS | BGav | SHRht | BSH | BIN | BTOT |
|---|---|---|---|---|---|---|---|---|
| **BTvar** | 1.00 | -0.01 | 0.00 | -0.04 | -0.05 | 0.10 | -0.06 | 0.98 |
| **DBHavg** | -0.01 | 1.00 | 0.19 | -0.04 | -0.11 | -0.18 | -0.05 | 0.00 |
| **BASavg** | 0.00 | 0.19 | 1.00 | 0.06 | -0.30 | 0.03 | -0.04 | -0.02 |
| **BGav** | -0.04 | -0.04 | 0.06 | 1.00 | -0.04 | -0.05 | -0.03 | 0.07 |
| **SHRht** | -0.05 | -0.11 | -0.30 | -0.04 | 1.00 | 0.00 | -0.05 | -0.03 |
| **BSHav** | 0.10 | -0.18 | 0.03 | -0.05 | 0.00 | 1.00 | -0.06 | 0.09 |
| **BINav** | -0.06 | -0.05 | -0.04 | -0.03 | -0.05 | -0.06 | 1.00 | -0.07 |
| **BTOT** | 0.98 | 0.00 | -0.02 | 0.07 | -0.03 | 0.09 | -0.07 | 1.00 |

| | Tree | G | SH | IN | BW | FW | BKS | Log BKS1 |
|---|---|---|---|---|---|---|---|---|
| **TTOT** | 1.00 | -0.23 | -0.05 | -0.29 | -0.25 | -0.31 | -0.05 | 0.01 |
| **GTOT** | -0.23 | 1.00 | -0.03 | -0.07 | 0.05 | 0.00 | -0.03 | 0.09 |
| **SHTOT** | -0.05 | -0.03 | 1.00 | -0.03 | -0.04 | -0.07 | 0.08 | 0.20 |
| **INTOT** | -0.29 | -0.07 | -0.03 | 1.00 | 0.32 | 0.24 | -0.11 | -0.13 |
| **BWav** | -0.25 | 0.05 | -0.04 | 0.32 | 1.00 | 0.57 | -0.13 | -0.13 |
| **FWav** | -0.31 | 0.00 | -0.07 | 0.24 | 0.57 | 1.00 | -0.10 | -0.26 |
| **BKSav** | -0.05 | -0.03 | 0.08 | -0.11 | -0.13 | -0.10 | 1.00 | 0.34 |
| **logBKS1** | 0.01 | 0.09 | 0.20 | -0.13 | -0.13 | -0.26 | 0.34 | 1.00 |

| | FKS | BKM | logBKM1 | FKM | BKMD | FKMD | Log FKDM |
|---|---|---|---|---|---|---|---|
| **FKS** | 1.00 | 0.01 | -0.26 | 0.78 | 0.49 | 0.06 | -0.50 |
| **BKMav** | 0.01 | 1.00 | 0.23 | 0.06 | -0.33 | -0.02 | 0.12 |
| **logBKM** | -0.26 | 0.23 | 1.00 | -0.15 | -0.51 | 0.01 | 0.30 |
| **FKM** | 0.78 | 0.06 | -0.15 | 1.00 | 0.48 | -0.10 | -0.45 |
| **BKMD** | 0.49 | -0.33 | -0.51 | 0.48 | 1.00 | -0.05 | -0.68 |

# APPENDIX 5:

## SERC* NITRATE DATA DEVELOPMENT

| station | March 1-4 | April 5-7 | May 3-6 | mean/stn | std/stn |
|---|---|---|---|---|---|
| **German Branch** | | | | | |
| **Mainstem stations** | | | | | |
| 325 | 3.90 | 4.56 | 3.95 | **4.13** | **0.37** |
| 322 | 3.80 | 3.06 | 3.54 | **3.47** | **0.38** |
| 327 | 4.16 | 3.59 | 3.76 | **3.84** | **0.29** |
| 310 | 4.38 | 3.82 | 4.38 | **4.19** | **0.32** |
| **Upper watershed** | | | | | |
| 332 | 2.18 | 1.73 | 2.04 | **1.98** | **0.23** |
| 312 | 0.10 | 0.34 | 0.16 | **0.20** | **0.13** |
| 311 | 4.25 | 3.46 | 3.41 | **3.71** | **0.47** |
| 306 | 2.45 | 1.91 | 2.31 | **2.22** | **0.28** |
| 313 | 5.34 | 4.77 | 5.21 | **5.11** | **0.30** |
| 326 | 7.67 | 6.93 | 7.25 | **7.28** | **0.37** |
| 314 | 4.78 | 4.91 | 5.49 | **5.06** | **0.38** |
| 328 | 4.12 | 3.74 | 4.25 | **4.04** | **0.26** |
| **Lower watershed** | | | | | |
| 323 | 2.34 | 1.32 | 1.38 | **1.68** | **0.57** |
| 321 | 1.34 | 1.95 | 0.06 | **1.12** | **0.96** |
| 320 | 3.43 | 2.45 | 2.10 | **2.66** | **0.69** |
| 319 | 0.21 | 0.76 | 0.01 | **0.33** | **0.39** |
| 317 | 0.82 | 0.61 | 0.51 | **0.65** | **0.16** |
| 331 | 2.93 | 3.20 | 3.72 | **3.28** | **0.40** |
| 318 | 7.95 | 6.48 | 2.74 | **5.72** | **2.68** |
| 330 | 8.98 | 8.82 | 8.84 | **8.88** | **0.08** |

| station | March 1-4 | April 5-7 | May 3-6 | mean/stn | std/stn |
|---|---|---|---|---|---|
| **Gunpowder** | | | | | |
| 411 | 4.05 | 3.19 | 3.34 | **3.53** | **0.46** |
| 412 | 0.82 | 0.67 | 0.74 | **0.74** | **0.08** |
| 413 | 4.60 | 3.52 | 3.70 | **3.94** | **0.58** |
| 414 | 5.63 | 4.38 | 4.75 | **4.92** | **0.64** |
| 415 | 5.09 | 4.15 | 4.48 | **4.58** | **0.48** |
| 416 | 5.60 | 4.67 | 4.78 | **5.02** | **0.51** |
| 417 | 3.95 | 3.05 | 3.11 | **3.37** | **0.50** |
| 418 | 4.22 | 3.21 | 3.18 | **3.53** | **0.59** |
| 419 | 3.91 | 3.35 | 3.44 | **3.56** | **0.30** |
| 420 | 3.50 | 2.76 | 2.84 | **3.03** | **0.41** |
| 421 | 3.16 | 2.59 | 2.64 | **2.80** | **0.31** |
| 422 | 3.00 | 3.47 | 3.64 | **3.37** | **0.34** |
| 423 | 3.95 | 2.04 | 2.22 | **2.74** | **1.05** |
| 424 | 3.12 | 2.11 | 2.15 | **2.46** | **0.57** |
| 425 | 4.77 | 4.09 | 4.36 | **4.40** | **0.34** |
| 426 | 4.14 | 3.33 | 3.31 | **3.59** | **0.47** |
| 427 | 2.98 | 2.14 | 2.23 | **2.45** | **0.46** |
| 428 | 6.70 | 5.95 | 5.87 | **6.17** | **0.46** |
| 429 | 8.05 | 7.46 | 7.54 | **7.68** | **0.32** |
| 430 | 4.79 | 4.50 | 4.32 | **4.54** | **0.24** |
| 431 | 8.74 | 7.95 | 8.08 | **8.26** | **0.42** |

## APPENDIX 6:

## SERC* DATA CORRELATION MATRIX

**(See Appendix 2 for description of parameters)**

| | NO3 | pctAG | pctFOR | forag | siteag | sitecrop | CAFO |
|---|---|---|---|---|---|---|---|
| **NO3** | 1.00 | -0.46 | 0.44 | 0.46 | 0.24 | 0.15 | 0.34 |
| **siteag** | 0.24 | 0.29 | -0.31 | -0.29 | 1.00 | 0.97 | -0.22 |
| **sitecrop** | 0.15 | 0.42 | -0.43 | -0.40 | 0.97 | 1.00 | -0.28 |
| **CAFO** | 0.34 | -0.38 | 0.40 | 0.37 | -0.22 | -0.28 | 1.00 |
| **CAFOfctr** | 0.19 | -0.26 | 0.29 | 0.26 | -0.17 | -0.23 | 0.73 |
| **CAFOfcsq** | 0.12 | -0.19 | 0.20 | 0.19 | -0.21 | -0.26 | 0.69 |
| **ZONED** | 0.13 | -0.13 | 0.14 | 0.13 | -0.28 | -0.32 | 0.49 |
| **RFB** | -0.24 | -0.05 | 0.06 | 0.04 | -0.32 | -0.28 | 0.08 |
| **Gbuf** | 0.18 | 0.07 | -0.06 | -0.07 | 0.40 | 0.37 | 0.00 |
| **BTOT** | -0.01 | -0.05 | 0.06 | 0.04 | -0.30 | -0.28 | 0.38 |
| **BT** | -0.18 | -0.12 | 0.13 | 0.11 | -0.43 | -0.41 | 0.33 |

| | CAFOfctr | CAFOfcsq | ZONED | RFB | Gbuf | BTOT |
|---|---|---|---|---|---|---|
| **NO3** | 0.19 | 0.12 | 0.13 | -0.24 | 0.18 | -0.01 |
| **siteag** | -0.17 | -0.21 | -0.28 | -0.32 | 0.40 | -0.30 |
| **sitecrop** | -0.23 | -0.26 | -0.32 | -0.28 | 0.37 | -0.28 |
| **CAFO** | 0.73 | 0.69 | 0.49 | 0.08 | 0.00 | 0.38 |
| **CAFOfctr** | 1.00 | 0.96 | 0.75 | -0.07 | 0.02 | 0.29 |
| **CAFOfcsq** | 0.96 | 1.00 | 0.79 | -0.08 | -0.04 | 0.29 |
| **ZONED** | 0.75 | 0.79 | 1.00 | -0.21 | -0.12 | 0.22 |
| **RFB** | -0.07 | -0.08 | -0.21 | 1.00 | -0.21 | 0.80 |
| **Gbuf** | 0.02 | -0.04 | -0.12 | -0.21 | 1.00 | 0.02 |
| **BTOT** | 0.29 | 0.29 | 0.22 | 0.80 | 0.02 | 1.00 |
| **BT** | 0.28 | 0.29 | 0.18 | 0.92 | -0.24 | 0.89 |

| | BT | BG | BSH | BIN | DBH | BAS | shrubHt |
|---|---|---|---|---|---|---|---|
| **NO3** | -0.18 | 0.03 | -0.22 | 0.13 | -0.17 | -0.26 | 0.01 |
| **siteag** | -0.43 | -0.05 | -0.08 | 0.00 | -0.36 | -0.16 | -0.24 |
| **sitecrop** | -0.41 | -0.06 | -0.03 | -0.06 | -0.30 | -0.09 | -0.28 |
| **CAFO** | 0.33 | -0.09 | -0.11 | -0.08 | 0.07 | -0.17 | 0.32 |
| **CAFOfctr** | 0.28 | 0.03 | -0.05 | 0.08 | -0.06 | -0.04 | 0.21 |
| **CAFOfcsq** | 0.29 | 0.01 | -0.04 | -0.02 | -0.04 | 0.01 | 0.16 |
| **ZONED** | 0.18 | 0.56 | -0.08 | -0.06 | 0.06 | 0.10 | 0.11 |
| **RFB** | 0.92 | -0.25 | -0.11 | -0.10 | 0.13 | 0.23 | 0.09 |
| **Gbuf** | -0.24 | 0.07 | -0.08 | 0.53 | -0.59 | -0.54 | -0.19 |
| **BTOT** | 0.89 | 0.03 | -0.16 | -0.12 | 0.00 | 0.13 | 0.10 |
| **BT** | 1.00 | -0.12 | -0.14 | -0.12 | 0.14 | 0.25 | 0.15 |

| | topo | RZSlope | Fslope | Bwidslo | BSvsFS | tortuous |
|---|---|---|---|---|---|---|
| **NO3** | 0.45 | 0.25 | 0.31 | 0.04 | -0.15 | -0.36 |
| **siteag** | -0.17 | 0.00 | -0.23 | 0.44 | -0.21 | -0.16 |
| **sitecrop** | -0.28 | -0.08 | -0.34 | 0.44 | -0.19 | -0.13 |
| **CAFO** | 0.21 | 0.20 | 0.56 | 0.08 | -0.13 | -0.05 |
| **CAFOfctr** | 0.13 | 0.15 | 0.51 | 0.01 | -0.13 | 0.03 |
| **CAFOfcsq** | 0.10 | 0.03 | 0.45 | 0.01 | -0.10 | 0.04 |
| **ZONED** | 0.05 | -0.01 | 0.45 | -0.08 | 0.08 | -0.06 |
| **RFB** | 0.03 | 0.21 | 0.23 | -0.17 | 0.44 | 0.40 |
| **Gbuf** | -0.10 | 0.02 | -0.10 | 0.63 | -0.18 | -0.11 |
| **BTOT** | 0.00 | 0.12 | 0.40 | 0.07 | 0.40 | 0.33 |
| **BT** | 0.07 | 0.21 | 0.43 | -0.19 | 0.44 | 0.38 |

| | ORDER | RZwtr | RZKsurf | RZKmin | RZKminD |
|---|---|---|---|---|---|
| **NO3** | -0.06 | 0.16 | -0.16 | -0.27 | 0.07 |
| **siteag** | 0.09 | 0.07 | -0.07 | -0.11 | -0.07 |
| **sitecrop** | 0.13 | 0.05 | 0.00 | -0.04 | -0.07 |
| **CAFO** | -0.03 | 0.29 | -0.08 | -0.06 | 0.06 |
| **CAFOfctr** | 0.06 | 0.14 | -0.12 | -0.04 | 0.10 |
| **CAFOfcsq** | 0.05 | 0.03 | -0.11 | -0.05 | 0.11 |
| **ZONED** | -0.08 | -0.07 | 0.11 | 0.02 | -0.03 |
| **RFB** | -0.30 | 0.12 | -0.14 | 0.00 | -0.39 |
| **Gbuf** | -0.18 | 0.20 | 0.02 | 0.05 | 0.20 |
| **BTOT** | -0.40 | 0.27 | -0.12 | -0.01 | -0.43 |
| **BT** | -0.31 | 0.10 | -0.11 | -0.01 | -0.38 |

| | Fkmin | FKminD | CW | CD | CXS |
|---|---|---|---|---|---|
| **NO3** | 0.07 | 0.23 | -0.01 | -0.16 | 0.12 |
| **siteag** | -0.10 | 0.12 | -0.01 | -0.13 | -0.06 |
| **sitecrop** | -0.14 | 0.13 | -0.04 | -0.11 | -0.10 |
| **CAFO** | 0.15 | 0.01 | 0.15 | 0.21 | 0.27 |
| **CAFOfctr** | 0.18 | 0.01 | -0.01 | 0.12 | 0.16 |
| **CAFOfcsq** | 0.15 | 0.01 | 0.01 | 0.06 | 0.16 |
| **ZONED** | 0.08 | -0.13 | -0.08 | 0.21 | 0.01 |
| **RFB** | -0.17 | -0.39 | -0.10 | 0.47 | -0.25 |
| **Gbuf** | -0.12 | 0.23 | -0.13 | -0.16 | -0.04 |
| **BTOT** | -0.06 | -0.44 | -0.06 | 0.50 | -0.18 |
| **BT** | -0.12 | -0.41 | -0.12 | 0.51 | -0.22 |

| | CWvsCD | CA | Fwtr | Fksurf | gradient |
|---|---|---|---|---|---|
| **NO3** | -0.04 | 0.07 | -0.06 | -0.06 | 0.19 |
| **siteag** | -0.10 | 0.08 | -0.13 | -0.17 | -0.16 |
| **sitecrop** | -0.05 | 0.05 | -0.17 | -0.19 | -0.20 |
| **CAFO** | 0.23 | 0.18 | 0.09 | 0.02 | 0.31 |
| **CAFOfctr** | 0.04 | 0.29 | 0.15 | -0.03 | 0.35 |
| **CAFOfcsq** | -0.01 | 0.29 | 0.12 | -0.07 | 0.37 |
| **ZONED** | 0.09 | 0.09 | 0.14 | 0.14 | 0.38 |
| **RFB** | 0.55 | -0.45 | 0.54 | 0.49 | 0.22 |
| **Gbuf** | -0.14 | 0.07 | -0.14 | -0.22 | 0.05 |
| **BTOT** | 0.53 | -0.40 | 0.56 | 0.47 | 0.38 |
| **BT** | 0.55 | -0.37 | 0.57 | 0.50 | 0.38 |

| | NO3 | pctAG | pctFOR | forag | siteag |
|---|---|---|---|---|---|
| **BG** | 0.03 | 0.11 | -0.09 | -0.10 | -0.05 |
| **BSH** | -0.22 | 0.19 | -0.19 | -0.19 | -0.08 |
| **BIN** | 0.13 | -0.21 | 0.22 | 0.20 | 0.00 |
| **DBH** | -0.17 | -0.02 | 0.05 | 0.01 | -0.36 |
| **BAS** | -0.26 | 0.44 | -0.42 | -0.44 | -0.16 |
| **shrubHt** | 0.01 | -0.24 | 0.27 | 0.24 | -0.24 |
| **topo** | 0.45 | -0.85 | 0.76 | 0.81 | -0.17 |
| **RZSlope** | 0.25 | -0.58 | 0.58 | 0.57 | 0.00 |
| **Fslope** | 0.31 | -0.57 | 0.59 | 0.55 | -0.23 |
| **Bwidslo** | 0.04 | 0.29 | -0.28 | -0.28 | 0.44 |
| **BSvsFS** | -0.15 | -0.09 | 0.09 | 0.08 | -0.21 |
| **tortuous** | -0.36 | 0.11 | -0.11 | -0.11 | -0.16 |
| **gradient** | 0.19 | -0.27 | 0.24 | 0.24 | -0.16 |
| **ORDER** | -0.06 | 0.16 | -0.15 | -0.14 | 0.09 |
| **RZwtr** | 0.16 | -0.07 | 0.08 | 0.07 | 0.07 |

| | sitecrop | CAFO |
|---|---|---|
| **BG** | -0.06 | -0.09 |
| **BSH** | -0.03 | -0.11 |
| **BIN** | -0.06 | -0.08 |
| **DBH** | -0.30 | 0.07 |
| **BAS** | -0.09 | -0.17 |
| **shrubHt** | -0.28 | 0.32 |
| **topo** | -0.28 | 0.21 |
| **RZSlope** | -0.08 | 0.20 |
| **Fslope** | -0.34 | 0.56 |
| **Bwidslo** | 0.44 | 0.08 |
| **BSvsFS** | -0.19 | -0.13 |
| **tortuous** | -0.13 | -0.05 |
| **gradient** | -0.20 | 0.31 |
| **ORDER** | 0.13 | -0.03 |
| **RZwtr** | 0.05 | 0.29 |

| | CAFOfctr | CAFOfcsq | ZONED | RFB | Gbuf |
|---|---|---|---|---|---|
| **BG** | 0.03 | 0.01 | 0.56 | -0.25 | 0.07 |
| **BSH** | -0.05 | -0.04 | -0.08 | -0.11 | -0.08 |
| **BIN** | 0.08 | -0.02 | -0.06 | -0.10 | 0.53 |
| **DBH** | -0.06 | -0.04 | 0.06 | 0.13 | -0.59 |
| **BAS** | -0.04 | 0.01 | 0.10 | 0.23 | -0.54 |
| **shrubHt** | 0.21 | 0.16 | 0.11 | 0.09 | -0.19 |
| **topo** | 0.13 | 0.10 | 0.05 | 0.03 | -0.10 |
| **RZSlope** | 0.15 | 0.03 | -0.01 | 0.21 | 0.02 |

| | BTOT |
|---|---|
| **BG** | 0.03 |
| **BSH** | -0.16 |
| **BIN** | -0.12 |
| **DBH** | 0.00 |
| **BAS** | 0.13 |
| **shrubHt** | 0.10 |
| **topo** | 0.00 |
| **RZSlope** | 0.12 |

| | CAFOfctr | CAFOfcsq | ZONED | RFB | Gbuf | BTOT |
|---|---|---|---|---|---|---|
| **Fslope** | 0.51 | 0.45 | 0.45 | 0.23 | -0.10 | 0.40 |
| **Bwidslo** | 0.01 | 0.01 | -0.08 | -0.17 | 0.63 | 0.07 |
| **BSvsFS** | -0.13 | -0.10 | 0.08 | 0.44 | -0.18 | 0.40 |
| **tortuous** | 0.03 | 0.04 | -0.06 | 0.40 | -0.11 | 0.33 |
| **gradient** | 0.35 | 0.37 | 0.38 | 0.22 | 0.05 | 0.38 |
| **ORDER** | 0.06 | 0.05 | -0.08 | -0.30 | -0.18 | -0.40 |
| **RZwtr** | 0.14 | 0.03 | -0.07 | 0.12 | 0.20 | 0.27 |

| | BT | BG | BSH | BIN | DBH | BAS | shrubHt |
|---|---|---|---|---|---|---|---|
| **BG** | -0.12 | 1.00 | -0.10 | 0.04 | -0.03 | 0.07 | -0.09 |
| **BSH** | -0.14 | -0.10 | 1.00 | -0.04 | -0.19 | -0.13 | 0.57 |
| **BIN** | -0.12 | 0.04 | -0.04 | 1.00 | -0.30 | -0.27 | -0.10 |
| **DBH** | 0.14 | -0.03 | -0.19 | -0.30 | 1.00 | 0.43 | -0.01 |
| **BAS** | 0.25 | 0.07 | -0.13 | -0.27 | 0.43 | 1.00 | -0.03 |
| **shrubHt** | 0.15 | -0.09 | 0.57 | -0.10 | -0.01 | -0.03 | 1.00 |
| **topo** | 0.07 | -0.13 | -0.17 | 0.12 | -0.10 | -0.44 | 0.10 |
| **RZSlope** | 0.21 | -0.03 | -0.19 | 0.45 | -0.09 | -0.14 | 0.16 |
| **Fslope** | 0.43 | 0.03 | -0.20 | 0.04 | 0.16 | -0.05 | 0.22 |
| **Bwidslo** | -0.19 | -0.01 | -0.07 | -0.07 | -0.38 | -0.28 | -0.14 |
| **BSvsFS** | 0.44 | 0.18 | -0.15 | -0.07 | 0.30 | 0.22 | 0.05 |
| **tortuous** | 0.38 | -0.05 | 0.34 | -0.02 | -0.11 | -0.11 | 0.12 |
| **gradient** | 0.38 | 0.12 | -0.13 | -0.16 | -0.11 | -0.25 | 0.24 |
| **ORDER** | -0.31 | -0.23 | 0.13 | 0.07 | 0.13 | 0.20 | 0.03 |
| **RZwtr** | 0.10 | -0.07 | -0.23 | -0.05 | 0.16 | -0.14 | -0.15 |

| | topo | RZSlope | Fslope | Bwidslo | BSvsFS | tortuous | gradient |
|---|---|---|---|---|---|---|---|
| **BG** | -0.13 | -0.03 | 0.03 | -0.01 | 0.18 | -0.05 | 0.12 |
| **BSH** | -0.17 | -0.19 | -0.20 | -0.07 | -0.15 | 0.34 | -0.13 |
| **BIN** | 0.12 | 0.45 | 0.04 | -0.07 | -0.07 | -0.02 | -0.16 |
| **DBH** | -0.10 | -0.09 | 0.16 | -0.38 | 0.30 | -0.11 | -0.11 |
| **BAS** | -0.44 | -0.14 | -0.05 | -0.28 | 0.22 | -0.11 | -0.25 |
| **shrubHt** | 0.10 | 0.16 | 0.22 | -0.14 | 0.05 | 0.12 | 0.24 |
| **topo** | 1.00 | 0.49 | 0.40 | -0.27 | 0.07 | -0.08 | 0.31 |
| **RZSlope** | 0.49 | 1.00 | 0.54 | -0.26 | 0.03 | 0.06 | 0.09 |
| **Fslope** | 0.40 | 0.54 | 1.00 | -0.15 | 0.32 | -0.23 | 0.39 |
| **Bwidslo** | -0.27 | -0.26 | -0.15 | 1.00 | -0.23 | -0.17 | -0.03 |
| **BSvsFS** | 0.07 | 0.03 | 0.32 | -0.23 | 1.00 | -0.06 | 0.31 |
| **tortuous** | -0.08 | 0.06 | -0.23 | -0.17 | -0.06 | 1.00 | 0.09 |
| **gradient** | 0.31 | 0.09 | 0.39 | -0.03 | 0.31 | 0.09 | 1.00 |
| **ORDER** | -0.16 | -0.09 | -0.27 | 0.02 | -0.46 | -0.30 | -0.55 |
| **RZwtr** | 0.02 | -0.01 | 0.15 | 0.16 | 0.02 | 0.02 | 0.00 |

| | ORDER | RZwtr | RZKsurf | RZKmin | RZKminD | Fwtr | Fksurf |
|---|---|---|---|---|---|---|---|
| **BG** | -0.23 | -0.07 | 0.15 | 0.14 | -0.15 | 0.19 | 0.27 |
| **BSH** | 0.13 | -0.23 | -0.12 | -0.10 | -0.21 | -0.10 | -0.16 |
| **BIN** | 0.07 | -0.05 | -0.08 | -0.06 | 0.15 | 0.01 | -0.11 |
| **DBH** | 0.13 | 0.16 | 0.41 | 0.22 | -0.12 | 0.16 | 0.24 |
| **BAS** | 0.20 | -0.14 | 0.17 | 0.31 | -0.19 | 0.16 | 0.19 |
| **shrubHt** | 0.03 | -0.15 | -0.09 | -0.12 | -0.23 | 0.15 | 0.23 |
| **topo** | -0.16 | 0.02 | -0.20 | -0.24 | -0.01 | 0.22 | 0.19 |
| **RZSlope** | -0.09 | -0.01 | -0.21 | -0.16 | -0.25 | 0.36 | 0.36 |

| | ORDER | RZwtr | RZKsurf | RZKmin | RZKminD | Fwtr | Fksurf |
|---|---|---|---|---|---|---|---|
| **Fslope** | -0.27 | 0.15 | 0.12 | -0.14 | -0.23 | 0.30 | 0.46 |
| **Bwidslo** | 0.02 | 0.16 | 0.06 | 0.13 | 0.09 | -0.30 | -0.26 |
| **BSvsFS** | -0.46 | 0.02 | 0.32 | 0.08 | -0.56 | 0.55 | 0.77 |
| **tortuous** | -0.30 | 0.02 | -0.38 | -0.10 | -0.32 | 0.38 | 0.09 |
| **gradient** | -0.55 | 0.00 | -0.03 | -0.21 | -0.13 | 0.36 | 0.48 |
| **ORDER** | 1.00 | -0.04 | -0.02 | 0.13 | 0.29 | -0.50 | -0.59 |
| **RZwtr** | -0.04 | 1.00 | 0.13 | 0.18 | -0.17 | 0.18 | 0.05 |

| | Fkmin | FKminD | CW | CD | CXS | CWvsCD | CA |
|---|---|---|---|---|---|---|---|
| **BG** | -0.04 | -0.22 | -0.14 | 0.38 | -0.17 | 0.22 | -0.19 |
| **BSH** | 0.07 | -0.14 | -0.03 | -0.10 | -0.01 | -0.09 | 0.10 |
| **BIN** | 0.14 | 0.05 | -0.28 | -0.03 | -0.11 | -0.08 | 0.15 |
| **DBH** | 0.19 | -0.22 | 0.12 | 0.25 | 0.12 | 0.18 | -0.04 |
| **BAS** | 0.05 | -0.30 | 0.17 | 0.17 | 0.03 | 0.15 | 0.03 |
| **shrubHt** | 0.09 | -0.25 | 0.02 | 0.18 | -0.04 | 0.13 | 0.06 |
| **topo** | 0.15 | 0.03 | -0.21 | -0.01 | -0.16 | 0.05 | -0.19 |
| **RZSlope** | 0.14 | -0.22 | -0.39 | 0.37 | -0.36 | 0.44 | -0.19 |
| **Fslope** | 0.05 | -0.23 | -0.11 | 0.38 | -0.08 | 0.50 | -0.16 |
| **Bwidslo** | 0.01 | 0.12 | 0.28 | -0.22 | 0.13 | -0.10 | 0.10 |
| **BSvsFS** | -0.18 | -0.52 | -0.30 | 0.53 | -0.45 | 0.44 | -0.63 |
| **tortuous** | -0.08 | -0.30 | -0.29 | 0.26 | -0.27 | 0.07 | -0.34 |
| **gradient** | -0.47 | -0.08 | -0.13 | 0.27 | -0.32 | 0.27 | -0.45 |
| **ORDER** | 0.55 | 0.18 | 0.22 | -0.48 | 0.27 | -0.33 | 0.76 |
| **RZwtr** | 0.13 | -0.06 | -0.08 | 0.09 | -0.02 | 0.03 | -0.12 |

| | NO3 | pctAG | pctFOR | forag | siteag | sitecrop | CAFO |
|---|---|---|---|---|---|---|---|
| **RZKsurf** | -0.16 | 0.24 | -0.23 | -0.23 | -0.07 | 0.00 | -0.08 |
| **RZKmin** | -0.27 | 0.27 | -0.27 | -0.26 | -0.11 | -0.04 | -0.06 |
| **RZKminD** | 0.07 | -0.03 | 0.05 | 0.06 | -0.07 | -0.07 | 0.06 |
| **Fwtr** | -0.06 | -0.23 | 0.22 | 0.20 | -0.13 | -0.17 | 0.09 |
| **Fksurf** | -0.06 | -0.24 | 0.24 | 0.22 | -0.17 | -0.19 | 0.02 |
| **Fkmin** | 0.07 | -0.22 | 0.23 | 0.23 | -0.10 | -0.14 | 0.15 |
| **FKminD** | 0.23 | -0.05 | 0.06 | 0.08 | 0.12 | 0.13 | 0.01 |
| **CW** | -0.01 | 0.27 | -0.27 | -0.29 | -0.01 | -0.04 | 0.15 |
| **CD** | -0.16 | -0.10 | 0.12 | 0.10 | -0.13 | -0.11 | 0.21 |
| **CXS** | 0.12 | 0.07 | -0.04 | -0.06 | -0.06 | -0.10 | 0.27 |
| **CWvsCD** | -0.04 | -0.14 | 0.16 | 0.14 | -0.10 | -0.05 | 0.23 |
| **CA** | 0.07 | 0.08 | -0.04 | -0.06 | 0.08 | 0.05 | 0.18 |

**APPENDIX 7:**

**MBSS* DATA CORRELATION MATRIX**

**Description of MBSS* variables**

| MBSS Variable Name | Description |
|---|---|
| NO3_LAB | NO3 |
| FIBI_98 | FIBI |
| BIBI_98 | BIBI |
| PHI | PHI |
| REGION_E | Geographic region |
| PHYS_CP | Physiographic region |
| ORDER_1 | Is the stream 1st order? |
| TEMP_FLD | Water temperature |
| DO_FLD | Dissolved oxygen |
| PH_FLD | Water pH (field and lab) |
| COND_FLD | Water conductivity (field and lab) |
| PH_LAB | Water pH (field and lab) |
| COND_LAB | Water conductivity (field and lab) |
| ANC_LAB | Water ANC |
| SO4_LAB | Water SO4 |
| DOC_LAB | Water DOC |
| ACID_NO | Presence of acid source |
| PASTURE | Presence of adjacent pasture |
| CHANNEL | Channeliztion? |
| INSTRHAB | Instream habitat score |
| EPI_SUB | Epifaunal substrate score |
| POOLQUAL | Pool quality score |
| RIFFQUAL | Riffle quality score |
| CHAN_ALT | Channel alteration score |
| BANKSTAB | Bank stability score |
| EMBEDDED | Embeddedness score |
| SHADING | Shading score |
| REMOTE | Remoteness score |
| AESTHET | Aesthetics score |
| WOOD_DEB | Woody debris score |
| NUMROOT | Number of rootwads |
| RIP_WID | Riparian buffer width |

| MBSS Variable Name | Description |
| --- | --- |
| FOR_BUFF | Presence of forest buffer |
| ADJ_CROP | Presence of adjacent crop |
| AGRI | Percent agriculture in site catchment |
| PASTUR | Percent pasture in site catchment |
| ROWCROP | Percent rowcrops in site catchment |
| PROBCROP | Percent probable crops in site catchment |
| cropmix | sum of probcrop & rowcrop |
| URBAN | Percent urban land use in site catchment |
| HIGHURB | Percent high urban land use in site catchment |
| LOWURB | Percent low urban land use in site catchment |
| FOREST | Percent forest in site catchment |
| CONIFER | Percent coniferous forest in site catchment |
| DECIDFOR | Percent deciduous forest in site catchment |
| MIXEDFOR | Percent mixed forest in site catchment |
| WETLANDS | Percent wetlands in site catchment |
| EMERGWET | Percent emergent wetlands in site catchment |
| WOODYWET | Percent woody wetlands in site catchment |
| BARREN | Percent barren land in site catchment |
| WATER | Percent water in site catchment |
| COALMINE | Percent coal mines in site catchment |
| MAXDEPTH | Channel maximum depth |
| VEL_DPTH | Velocity depth |
| ST_GRAD | Stream gradient |
| AVGWID | Channel average width |
| AVGTHAL | Average thalweg velocity |
| AVG_VEL | Average water velocity |
| CH_FLOW | Channel flow |
| ACREAGE | Site catchment acreage |
| TRANS | Percent transitional land use in site catchment |
| PROBCROP | % probable crops in site catchment |
| ROWCROP | % rowcrops in site catchment |
| cropmix | sum of probcrop & rowcrop |
| BKTRFLAG | Presence of brook trout |
| BLACKWAT | Presence of blackwater conditions |

**Correlation Matrix**

| | NO3_LAB | FIBI_98 | BIBI_98 | PHI | RIP_WIDm |
|---|---|---|---|---|---|
| **NO3_LAB** | 1.00 | 0.13 | 0.02 | 0.13 | -0.10 |
| **FIBI_98** | 0.13 | 1.00 | 0.12 | 0.47 | 0.00 |
| **BIBI_98** | 0.02 | 0.12 | 1.00 | 0.23 | 0.35 |
| **PHI** | 0.13 | 0.47 | 0.23 | 1.00 | 0.18 |
| **RIP_WIDm** | -0.10 | 0.00 | 0.35 | 0.18 | 1.00 |
| **TEMP_FLD** | -0.22 | 0.08 | 0.05 | -0.28 | 0.17 |
| **AGRI** | 0.54 | 0.19 | 0.04 | 0.21 | -0.14 |
| **URBAN** | -0.25 | -0.02 | 0.05 | -0.23 | 0.15 |
| **FOREST** | -0.39 | -0.19 | -0.09 | -0.05 | 0.02 |

| | TEMP_FLD | AGRI | URBAN | FOREST |
|---|---|---|---|---|
| **NO3_LAB** | -0.22 | 0.54 | -0.25 | -0.39 |
| **FIBI_98** | 0.08 | 0.19 | -0.02 | -0.19 |
| **BIBI_98** | 0.05 | 0.04 | 0.05 | -0.09 |
| **PHI** | -0.28 | 0.21 | -0.23 | -0.05 |
| **RIP_WIDm** | 0.17 | -0.14 | 0.15 | 0.02 |
| **TEMP_FLD** | 1.00 | -0.37 | 0.67 | -0.15 |
| **AGRI** | -0.37 | 1.00 | -0.48 | -0.71 |
| **URBAN** | 0.67 | -0.48 | 1.00 | -0.28 |
| **FOREST** | -0.15 | -0.71 | -0.28 | 1.00 |

| | ORDER | DO_FLD | PH_FLD | COND_FLD | PH_ LAB |
|---|---|---|---|---|---|
| **NO3_LAB** | -0.20 | 0.22 | -0.18 | 0.18 | -0.19 |
| **FIBI_98** | 0.08 | 0.05 | 0.11 | 0.00 | 0.00 |
| **BIBI_98** | 0.18 | 0.09 | 0.18 | -0.17 | 0.14 |
| **PHI** | -0.17 | 0.40 | 0.01 | 0.03 | -0.24 |
| **RIP_WIDm** | 0.21 | -0.13 | 0.15 | -0.06 | 0.12 |
| **TEMP_FLD** | 0.74 | -0.55 | 0.41 | -0.20 | 0.69 |
| **AGRI** | -0.38 | 0.39 | -0.16 | 0.04 | -0.37 |
| **URBAN** | 0.87 | -0.34 | 0.47 | -0.15 | 0.86 |
| **FOREST** | -0.31 | -0.13 | -0.20 | 0.08 | -0.31 |
| **ORDER** | 1.00 | -0.36 | 0.40 | -0.23 | 0.95 |
| **DO_FLD** | -0.36 | 1.00 | 0.06 | -0.03 | -0.35 |
| **PH_FLD** | 0.40 | 0.06 | 1.00 | -0.08 | 0.32 |
| **COND_FLD** | -0.23 | -0.03 | -0.08 | 1.00 | -0.23 |
| **PH_LAB** | 0.95 | -0.35 | 0.32 | -0.23 | 1.00 |
| **COND_LAB** | -0.30 | 0.23 | 0.01 | 0.49 | -0.29 |
| **ANC_LAB** | -0.11 | 0.05 | 0.30 | 0.27 | -0.11 |
| **SO4_LAB** | 0.93 | -0.37 | 0.25 | -0.20 | 0.98 |
| **DOC_LAB** | 0.09 | -0.53 | -0.32 | 0.07 | 0.08 |

| | COND_LAB | ANC_LAB | SO4_LAB | DOC_LAB |
|---|---|---|---|---|
| **NO3_LAB** | 0.26 | -0.14 | -0.20 | -0.20 |
| **FIBI_98** | -0.18 | -0.11 | -0.04 | -0.20 |
| **BIBI_98** | -0.19 | 0.01 | 0.10 | -0.26 |
| **PHI** | 0.09 | 0.06 | -0.26 | -0.32 |
| **RIP_WIDm** | -0.11 | -0.02 | 0.12 | 0.00 |
| **TEMP_FLD** | -0.29 | -0.06 | 0.67 | 0.26 |
| **AGRI** | 0.19 | 0.01 | -0.39 | -0.42 |
| **URBAN** | -0.09 | 0.00 | 0.83 | 0.03 |
| **FOREST** | -0.12 | 0.00 | -0.27 | 0.42 |
| **ORDER** | -0.30 | -0.11 | 0.93 | 0.09 |
| **DO_FLD** | 0.23 | 0.05 | -0.37 | -0.53 |
| **PH_FLD** | 0.01 | 0.30 | 0.25 | -0.32 |
| **COND_FLD** | 0.49 | 0.27 | -0.20 | 0.07 |
| **PH_LAB** | -0.29 | -0.11 | 0.98 | 0.08 |
| **COND_LAB** | 1.00 | 0.54 | -0.28 | -0.22 |
| **ANC_LAB** | 0.54 | 1.00 | -0.12 | -0.21 |
| **SO4_LAB** | -0.28 | -0.12 | 1.00 | 0.13 |
| **DOC_LAB** | -0.22 | -0.21 | 0.13 | 1.00 |

| | PASTURE | INSTR HAB | EPI_ SUB | VEL_ DPTH | POOL QUAL |
|---|---|---|---|---|---|
| **NO3_LAB** | -0.14 | 0.26 | 0.15 | 0.10 | 0.08 |
| **FIBI_98** | -0.03 | 0.41 | 0.35 | 0.44 | 0.42 |
| **BIBI_98** | 0.06 | 0.19 | 0.37 | 0.24 | 0.20 |
| **PHI** | -0.18 | 0.83 | 0.62 | 0.77 | 0.72 |
| **RIP_WID** | -0.23 | 0.07 | 0.18 | 0.16 | 0.22 |
| **TEMP_FLD** | 0.36 | -0.38 | -0.08 | -0.10 | -0.02 |
| **AGRI** | -0.16 | 0.33 | 0.19 | 0.21 | 0.13 |
| **URBAN** | 0.46 | -0.37 | 0.06 | 0.03 | 0.08 |
| **FOREST** | -0.21 | -0.06 | -0.26 | -0.25 | -0.21 |
| **ORDER** | 0.57 | -0.32 | 0.16 | 0.10 | 0.10 |
| **DO_FLD** | -0.20 | 0.49 | 0.36 | 0.46 | 0.22 |
| **PH_FLD** | 0.05 | -0.07 | 0.19 | 0.22 | 0.17 |
| **COND_FLD** | -0.16 | 0.05 | -0.14 | -0.04 | 0.06 |
| **PH_LAB** | 0.68 | -0.37 | 0.10 | 0.02 | -0.02 |
| **COND_LAB** | -0.21 | 0.18 | -0.05 | 0.07 | 0.13 |
| **ANC_LAB** | -0.08 | 0.06 | -0.09 | 0.09 | 0.14 |
| **SO4_LAB** | 0.70 | -0.38 | 0.05 | -0.01 | -0.05 |
| **DOC_LAB** | 0.05 | -0.35 | -0.38 | -0.45 | -0.31 |
| **PASTURE** | 1.00 | -0.25 | 0.00 | -0.03 | -0.14 |
| **INSTRHAB** | -0.25 | 1.00 | 0.67 | 0.64 | 0.60 |
| **EPI_SUB** | 0.00 | 0.67 | 1.00 | 0.64 | 0.51 |
| **VEL_DPTH** | -0.03 | 0.64 | 0.64 | 1.00 | 0.72 |
| **POOL QUAL** | -0.14 | 0.60 | 0.51 | 0.72 | 1.00 |
| **RIFF QUAL** | 0.03 | 0.55 | 0.69 | 0.70 | 0.38 |
| **CHAN _ALT** | -0.02 | 0.46 | 0.55 | 0.48 | 0.41 |
| **BANKSTAB** | -0.07 | 0.25 | 0.18 | 0.13 | 0.08 |
| **EMBEDDED** | -0.07 | -0.41 | -0.70 | -0.58 | -0.35 |

| | RIFFQUAL | CHAN_ALT | BANKSTAB | EMBEDDED |
|---|---|---|---|---|
| **NO3_LAB** | 0.08 | 0.20 | 0.19 | -0.11 |
| **FIBI_98** | 0.33 | 0.19 | 0.12 | -0.26 |
| **BIBI_98** | 0.30 | 0.25 | -0.04 | -0.41 |
| **PHI** | 0.60 | 0.41 | 0.16 | -0.47 |
| **RIP_WIDm** | 0.13 | 0.07 | -0.06 | -0.13 |
| **TEMP_FLD** | -0.05 | -0.17 | -0.02 | 0.03 |
| **AGRI** | 0.11 | 0.25 | 0.02 | -0.21 |
| **URBAN** | 0.06 | 0.03 | -0.03 | -0.13 |
| **FOREST** | -0.17 | -0.29 | 0.01 | 0.34 |
| **ORDER** | 0.14 | 0.02 | 0.02 | -0.20 |
| **DO_FLD** | 0.39 | 0.28 | 0.08 | -0.34 |
| **PH_FLD** | 0.24 | 0.09 | -0.14 | -0.29 |
| **COND_FLD** | -0.10 | -0.11 | -0.02 | 0.18 |
| **PH_LAB** | 0.07 | -0.03 | -0.02 | -0.19 |
| **COND_LAB** | -0.01 | 0.07 | -0.13 | 0.04 |
| **ANC_LAB** | -0.03 | 0.00 | -0.23 | -0.02 |
| **SO4_LAB** | 0.03 | -0.04 | -0.01 | -0.13 |
| **DOC_LAB** | -0.33 | -0.41 | 0.08 | 0.56 |
| **PASTURE** | 0.03 | -0.02 | -0.07 | -0.07 |
| **INSTRHAB** | 0.55 | 0.46 | 0.25 | -0.41 |
| **EPI_SUB** | 0.69 | 0.55 | 0.18 | -0.70 |
| **VEL_DPTH** | 0.70 | 0.48 | 0.13 | -0.58 |
| **POOLQUAL** | 0.38 | 0.41 | 0.08 | -0.35 |
| **RIFFQUAL** | 1.00 | 0.38 | 0.17 | -0.58 |
| **CHAN_ALT** | 0.38 | 1.00 | 0.34 | -0.51 |
| **BANKSTAB** | 0.17 | 0.34 | 1.00 | 0.01 |
| **EMBEDDED** | -0.58 | -0.51 | 0.01 | 1.00 |

| | FLOW | SHADE | REMOTE | AESTHET | WOOD_ DEB |
|---|---|---|---|---|---|
| **NO3_LAB** | 0.22 | -0.11 | -0.12 | 0.06 | -0.06 |
| **FIBI_98** | 0.10 | -0.20 | 0.03 | 0.12 | 0.07 |
| **BIBI_98** | 0.10 | 0.17 | 0.20 | 0.27 | 0.19 |
| **PHI** | 0.29 | -0.06 | -0.06 | 0.33 | 0.03 |
| **RIP_WIDm** | -0.11 | 0.26 | 0.32 | 0.29 | 0.25 |
| **TEMP_FLD** | -0.22 | -0.03 | 0.50 | -0.09 | 0.29 |
| **AGRI** | 0.27 | -0.04 | -0.29 | 0.06 | -0.21 |
| **URBAN** | -0.18 | 0.12 | 0.63 | -0.09 | 0.29 |
| **FOREST** | -0.16 | -0.06 | -0.20 | -0.01 | -0.02 |
| **ORDER** | -0.15 | 0.01 | 0.66 | 0.00 | 0.31 |
| **DO_FLD** | 0.21 | -0.07 | -0.24 | 0.09 | -0.29 |
| **PH_FLD** | -0.19 | 0.17 | 0.33 | 0.11 | 0.03 |
| **COND_FLD** | 0.04 | 0.01 | -0.20 | -0.12 | -0.09 |
| **PH_LAB** | -0.16 | 0.05 | 0.70 | 0.01 | 0.28 |
| **COND_LAB** | 0.09 | 0.09 | -0.24 | -0.14 | -0.15 |
| **ANC_LAB** | -0.07 | 0.13 | -0.07 | -0.03 | -0.08 |
| **SO4_LAB** | -0.16 | 0.03 | 0.64 | -0.02 | 0.28 |
| **DOC_LAB** | -0.12 | -0.13 | 0.01 | -0.21 | 0.12 |
| **PASTURE** | 0.00 | -0.11 | 0.39 | 0.00 | 0.07 |
| **INSTRHAB** | 0.30 | -0.08 | -0.17 | 0.24 | -0.04 |
| **EPI_SUB** | 0.16 | 0.07 | 0.15 | 0.23 | -0.01 |
| **VEL_DPTH** | 0.25 | -0.05 | 0.11 | 0.23 | -0.02 |
| **POOLQUAL** | 0.25 | -0.01 | 0.09 | 0.18 | 0.11 |
| **RIFFQUAL** | 0.21 | -0.02 | 0.13 | 0.24 | -0.08 |
| **CHAN_ALT** | 0.35 | 0.06 | 0.01 | 0.15 | -0.02 |
| **BANKSTAB** | 0.05 | -0.20 | -0.01 | 0.09 | -0.01 |
| **EMBEDDED** | -0.06 | -0.11 | -0.17 | -0.23 | 0.03 |
| **CH_FLOW** | 1.00 | -0.10 | -0.11 | -0.03 | -0.01 |
| **SHADING** | -0.10 | 1.00 | 0.27 | 0.10 | -0.16 |
| **REMOTE** | -0.11 | 0.27 | 1.00 | 0.32 | 0.09 |
| **AESTHET** | -0.03 | 0.10 | 0.32 | 1.00 | -0.17 |
| **WOOD_DEB** | -0.01 | -0.16 | 0.09 | -0.17 | 1.00 |
| **NUMROOT** | 0.07 | 0.11 | 0.07 | -0.03 | 0.42 |
| **MAXDEPTH** | 0.25 | 0.25 | 0.07 | 0.27 | -0.35 |
| **ST_GRAD** | -0.02 | -0.43 | -0.02 | -0.20 | 0.64 |
| **AVGWID** | 0.06 | 0.02 | 0.01 | -0.01 | -0.11 |

| | NUMROOT | MAXDEPTH | ST_GRAD | AVGWID |
|---|---|---|---|---|
| **NO3_LAB** | -0.09 | 0.04 | -0.06 | -0.05 |
| **FIBI_98** | 0.07 | 0.17 | 0.18 | 0.10 |
| **BIBI_98** | 0.18 | 0.02 | 0.12 | 0.03 |
| **PHI** | 0.23 | 0.45 | 0.08 | 0.12 |
| **RIP_WIDm** | 0.22 | 0.13 | 0.04 | 0.18 |
| **TEMP_FLD** | 0.17 | -0.17 | 0.23 | 0.23 |
| **AGRI** | -0.14 | 0.10 | -0.09 | -0.11 |
| **URBAN** | 0.24 | -0.16 | 0.23 | 0.25 |
| **FOREST** | -0.05 | 0.02 | -0.09 | -0.10 |
| **ORDER** | 0.25 | -0.15 | 0.27 | 0.36 |
| **DO_FLD** | -0.18 | 0.14 | -0.07 | -0.01 |
| **PH_FLD** | 0.04 | 0.01 | 0.09 | 0.25 |
| **COND_FLD** | -0.07 | 0.12 | -0.15 | -0.06 |
| **PH_LAB** | 0.23 | -0.21 | 0.26 | 0.19 |
| **COND_LAB** | -0.10 | 0.10 | -0.16 | -0.04 |
| **ANC_LAB** | 0.01 | 0.10 | -0.10 | 0.01 |
| **SO4_LAB** | 0.25 | -0.22 | 0.22 | 0.24 |
| **DOC_LAB** | 0.02 | -0.15 | 0.00 | -0.01 |
| **PASTURE** | 0.11 | -0.15 | 0.09 | 0.00 |
| **INSTRHAB** | 0.07 | 0.33 | 0.01 | 0.06 |
| **EPI_SUB** | 0.09 | 0.19 | 0.11 | 0.20 |
| **VEL_DPTH** | 0.16 | 0.40 | 0.11 | 0.28 |
| **POOLQUAL** | 0.24 | 0.53 | 0.13 | 0.28 |
| **RIFFQUAL** | 0.03 | 0.21 | 0.07 | 0.22 |
| **CHAN_ALT** | 0.11 | 0.10 | 0.06 | 0.23 |
| **BANKSTAB** | -0.02 | -0.03 | -0.01 | 0.19 |
| **EMBEDDED** | -0.06 | -0.05 | -0.18 | -0.11 |
| **CH_FLOW** | 0.07 | 0.25 | -0.02 | 0.06 |
| **SHADING** | 0.11 | 0.25 | -0.43 | 0.02 |
| **REMOTE** | 0.07 | 0.07 | -0.02 | 0.01 |
| **AESTHET** | -0.03 | 0.27 | -0.20 | -0.01 |
| **WOOD_DEB** | 0.42 | -0.35 | 0.64 | -0.11 |
| **NUMROOT** | 1.00 | 0.01 | 0.22 | 0.15 |
| **MAXDEPTH** | 0.01 | 1.00 | -0.54 | 0.31 |
| **ST_GRAD** | 0.22 | -0.54 | 1.00 | -0.25 |
| **AVGWID** | 0.15 | 0.31 | -0.25 | 1.00 |

| | THAL | VEL | FLOW | ACREAGE | WETLANDS |
|---|---|---|---|---|---|
| **NO3_LAB** | 0.02 | -0.05 | 0.01 | 0.01 | -0.04 |
| **FIBI_98** | 0.15 | 0.17 | 0.19 | 0.16 | 0.13 |
| **BIBI_98** | -0.07 | 0.10 | -0.02 | 0.05 | 0.08 |
| **PHI** | 0.42 | 0.06 | 0.27 | 0.17 | 0.05 |
| **RIP_WIDm** | 0.10 | 0.03 | 0.07 | 0.16 | 0.02 |
| **TEMP_FLD** | -0.11 | 0.33 | -0.02 | 0.05 | 0.31 |
| **AGRI** | 0.04 | -0.12 | 0.03 | -0.09 | -0.12 |
| **URBAN** | -0.08 | 0.31 | 0.11 | -0.08 | 0.29 |
| **FOREST** | 0.03 | -0.12 | -0.12 | 0.15 | -0.10 |
| **ORDER** | -0.06 | 0.36 | 0.17 | 0.04 | 0.35 |
| **DO_FLD** | 0.12 | -0.09 | 0.18 | -0.05 | -0.07 |
| **PH_FLD** | 0.00 | 0.14 | 0.19 | -0.04 | 0.12 |
| **COND_FLD** | 0.13 | -0.16 | 0.00 | 0.01 | -0.15 |
| **PH_LAB** | -0.16 | 0.34 | 0.05 | -0.09 | 0.34 |
| **COND_LAB** | 0.14 | -0.19 | 0.10 | -0.02 | -0.17 |
| **ANC_LAB** | 0.12 | -0.12 | 0.05 | -0.05 | -0.12 |
| **SO4_LAB** | -0.17 | 0.30 | 0.06 | -0.08 | 0.30 |
| **DOC_LAB** | -0.04 | 0.04 | -0.14 | 0.20 | 0.03 |
| **PASTURE** | -0.13 | 0.12 | -0.02 | -0.12 | 0.14 |
| **INSTRHAB** | 0.32 | -0.01 | 0.21 | 0.12 | -0.01 |
| **EPI_SUB** | 0.15 | 0.11 | 0.28 | 0.08 | 0.11 |
| **VEL_DPTH** | 0.39 | 0.11 | 0.45 | 0.13 | 0.09 |
| **POOLQUAL** | 0.51 | 0.13 | 0.32 | 0.19 | 0.08 |
| **RIFFQUAL** | 0.18 | 0.07 | 0.31 | 0.21 | 0.12 |
| **CHAN_ALT** | 0.14 | 0.03 | 0.28 | 0.06 | -0.02 |
| **BANKSTAB** | 0.06 | 0.04 | 0.14 | 0.13 | 0.07 |
| **EMBEDDED** | 0.04 | -0.15 | -0.19 | 0.09 | -0.16 |
| **CH_FLOW** | 0.34 | -0.02 | 0.20 | 0.23 | -0.02 |
| **SHADING** | 0.02 | -0.44 | -0.08 | -0.10 | -0.38 |
| **REMOTE** | 0.10 | 0.06 | 0.03 | 0.07 | 0.12 |
| **AESTHET** | 0.18 | -0.16 | 0.03 | 0.10 | -0.07 |
| **WOOD_DEB** | -0.26 | 0.65 | -0.17 | -0.17 | 0.55 |
| **NUMROOT** | -0.01 | 0.21 | 0.02 | -0.08 | 0.14 |
| **MAXDEPTH** | 0.82 | -0.53 | 0.33 | 0.45 | -0.43 |
| **ST_GRAD** | -0.43 | 0.95 | -0.19 | -0.23 | 0.77 |
| **AVGWID** | 0.42 | -0.21 | 0.69 | 0.51 | -0.20 |
| **AVGTHAL** | 1.00 | -0.41 | 0.52 | 0.60 | -0.32 |

| | BARREN | WATER | HIGHURB | LOWURB |
|---|---|---|---|---|
| **NO3_LAB** | -0.09 | -0.08 | -0.16 | -0.15 |
| **FIBI_98** | -0.07 | 0.02 | -0.12 | -0.10 |
| **BIBI_98** | 0.06 | 0.02 | -0.16 | -0.15 |
| **PHI** | -0.12 | 0.08 | -0.01 | 0.04 |
| **RIP_WIDm** | 0.14 | 0.02 | -0.02 | -0.03 |
| **TEMP_FLD** | 0.35 | 0.09 | -0.01 | -0.05 |
| **AGRI** | -0.18 | 0.07 | -0.28 | -0.26 |
| **URBAN** | 0.39 | -0.02 | 0.30 | 0.36 |
| **FOREST** | -0.15 | -0.10 | 0.09 | 0.03 |
| **ORDER** | 0.48 | -0.01 | -0.03 | -0.04 |
| **DO_FLD** | -0.16 | -0.03 | -0.13 | 0.02 |
| **PH_FLD** | 0.26 | 0.07 | 0.01 | 0.13 |
| **COND_FLD** | -0.11 | 0.00 | 0.15 | 0.18 |
| **PH_LAB** | 0.36 | -0.02 | -0.04 | -0.05 |
| **COND_LAB** | -0.14 | 0.02 | 0.34 | 0.47 |
| **ANC_LAB** | -0.06 | 0.12 | 0.14 | 0.29 |
| **SO4_LAB** | 0.43 | -0.04 | -0.02 | -0.04 |
| **DOC_LAB** | 0.02 | -0.11 | 0.05 | -0.13 |
| **PASTURE** | 0.11 | 0.02 | -0.06 | -0.06 |
| **INSTRHAB** | -0.17 | 0.06 | -0.06 | -0.01 |
| **EPI_SUB** | 0.07 | 0.03 | -0.12 | -0.11 |
| **VEL_DPTH** | 0.05 | 0.13 | -0.06 | 0.02 |
| **POOLQUAL** | 0.07 | 0.11 | 0.06 | 0.14 |
| **RIFFQUAL** | 0.04 | 0.08 | -0.12 | -0.05 |
| **CHAN_ALT** | 0.09 | -0.01 | -0.01 | 0.06 |
| **BANKSTAB** | 0.11 | -0.09 | -0.08 | -0.12 |
| **EMBEDDED** | -0.07 | -0.06 | 0.15 | 0.09 |
| **CH_FLOW** | -0.17 | 0.13 | 0.04 | 0.06 |
| **SHADING** | 0.07 | 0.12 | 0.05 | 0.17 |
| **REMOTE** | -0.03 | 0.01 | -0.06 | -0.03 |
| **AESTHET** | -0.13 | 0.09 | -0.16 | -0.09 |
| **WOOD_DEB** | 0.13 | -0.06 | 0.13 | -0.02 |
| **NUMROOT** | 0.29 | -0.01 | 0.13 | 0.10 |
| **MAXDEPTH** | -0.10 | 0.20 | 0.04 | 0.18 |
| **ST_GRAD** | -0.02 | -0.16 | 0.02 | -0.14 |
| **AVGWID** | 0.74 | 0.03 | 0.04 | 0.08 |
| **AVGTHAL** | -0.10 | 0.18 | 0.13 | 0.21 |

| | PASTUR | PROBCROP | ROWCROP | crop | CONIFER |
|---|---|---|---|---|---|
| **NO3_LAB** | 0.40 | 0.22 | 0.02 | 0.21 | -0.10 |
| **FIBI_98** | 0.10 | -0.01 | 0.14 | 0.02 | 0.06 |
| **BIBI_98** | 0.07 | -0.18 | 0.16 | -0.05 | 0.03 |
| **PHI** | 0.10 | -0.10 | 0.15 | 0.03 | -0.04 |
| **RIP_WIDm** | -0.04 | -0.08 | -0.03 | -0.10 | 0.07 |
| **TEMP_FLD** | -0.26 | -0.01 | 0.06 | -0.19 | 0.26 |
| **AGRI** | 0.52 | 0.36 | 0.26 | 0.49 | -0.19 |
| **URBAN** | -0.26 | -0.15 | 0.13 | -0.20 | 0.23 |
| **FOREST** | -0.35 | -0.27 | -0.39 | -0.37 | 0.03 |
| **ORDER** | -0.22 | -0.09 | 0.14 | -0.19 | 0.26 |
| **DO_FLD** | 0.25 | -0.07 | 0.18 | 0.14 | -0.17 |
| **PH_FLD** | -0.04 | -0.24 | 0.22 | -0.02 | 0.00 |
| **COND_FLD** | 0.08 | 0.06 | -0.15 | 0.07 | -0.13 |
| **PH_LAB** | -0.19 | -0.08 | 0.13 | -0.19 | 0.25 |
| **COND_LAB** | 0.18 | -0.01 | -0.02 | 0.13 | -0.21 |
| **ANC_LAB** | 0.12 | -0.20 | 0.05 | 0.00 | -0.19 |
| **SO4_LAB** | -0.20 | -0.07 | 0.09 | -0.21 | 0.23 |
| **DOC_LAB** | -0.24 | 0.15 | -0.38 | -0.25 | 0.23 |
| **PASTURE** | -0.11 | 0.06 | 0.06 | -0.04 | 0.08 |
| **INSTRHAB** | 0.18 | -0.06 | 0.14 | 0.08 | -0.07 |
| **EPI_SUB** | 0.11 | -0.14 | 0.28 | 0.09 | 0.02 |
| **VEL_DPTH** | 0.09 | -0.09 | 0.25 | 0.09 | -0.04 |
| **POOLQUAL** | 0.04 | -0.09 | 0.21 | 0.04 | -0.01 |
| **RIFFQUAL** | 0.06 | -0.12 | 0.21 | 0.06 | -0.01 |

| | DECIDFOR | MIXEDFOR | EMERGWET | WOODYWET |
|---|---|---|---|---|
| **NO3_LAB** | -0.32 | -0.20 | -0.12 | -0.06 |
| **FIBI_98** | -0.18 | 0.02 | 0.02 | -0.02 |
| **BIBI_98** | 0.06 | 0.06 | 0.08 | -0.17 |
| **PHI** | 0.06 | -0.11 | -0.08 | -0.17 |
| **RIP_WIDm** | 0.02 | 0.10 | 0.11 | 0.01 |
| **TEMP_FLD** | -0.17 | 0.22 | 0.39 | 0.16 |
| **AGRI** | -0.41 | -0.38 | -0.19 | -0.30 |
| **URBAN** | -0.06 | 0.25 | 0.37 | -0.13 |
| **FOREST** | 0.50 | 0.21 | -0.11 | 0.42 |
| **ORDER** | -0.12 | 0.24 | 0.48 | -0.04 |
| **DO_FLD** | 0.19 | -0.20 | -0.19 | -0.42 |
| **PH_FLD** | 0.22 | 0.01 | 0.11 | -0.27 |
| **COND_FLD** | 0.01 | -0.11 | -0.17 | 0.11 |
| **PH_LAB** | -0.12 | 0.26 | 0.39 | -0.08 |
| **COND_LAB** | 0.07 | -0.20 | -0.21 | -0.20 |
| **ANC_LAB** | 0.27 | -0.14 | -0.15 | -0.21 |
| **SO4_LAB** | -0.11 | 0.24 | 0.46 | -0.05 |
| **DOC_LAB** | -0.22 | 0.20 | 0.11 | 0.60 |
| **PASTURE** | -0.06 | 0.09 | 0.15 | -0.07 |
| **INSTRHAB** | 0.05 | -0.16 | -0.15 | -0.21 |
| **EPI_SUB** | 0.02 | -0.05 | 0.04 | -0.30 |
| **VEL_DPTH** | 0.08 | -0.11 | 0.04 | -0.35 |
| **POOLQUAL** | 0.03 | -0.08 | 0.06 | -0.24 |
| **RIFFQUAL** | 0.05 | -0.07 | 0.00 | -0.19 |

| | AVGTHAL | AVG_VEL | FLOW | ACREAGE | WET LANDS |
|---|---|---|---|---|---|
| **AVG_VEL** | -0.41 | 1.00 | -0.16 | -0.22 | 0.86 |
| **FLOW** | 0.52 | -0.16 | 1.00 | 0.53 | -0.15 |
| **ACREAGE** | 0.60 | -0.22 | 0.53 | 1.00 | -0.18 |
| **WETLANDS** | -0.32 | 0.86 | -0.15 | -0.18 | 1.00 |
| **BARREN** | -0.10 | 0.03 | 0.28 | -0.04 | -0.02 |
| **WATER** | 0.18 | -0.14 | 0.11 | 0.00 | -0.11 |
| **HIGHURB** | 0.13 | -0.02 | 0.10 | 0.07 | -0.03 |
| **LOWURB** | 0.21 | -0.14 | 0.13 | 0.03 | -0.12 |

| | BARREN | WATER | HIGHURB | LOWURB |
|---|---|---|---|---|
| **AVG_VEL** | 0.03 | -0.14 | -0.02 | -0.14 |
| **FLOW** | 0.28 | 0.11 | 0.10 | 0.13 |
| **ACREAGE** | -0.04 | 0.00 | 0.07 | 0.03 |
| **WETLANDS** | -0.02 | -0.11 | -0.03 | -0.12 |
| **BARREN** | 1.00 | -0.02 | -0.04 | -0.03 |
| **WATER** | -0.02 | 1.00 | -0.03 | 0.01 |
| **HIGHURB** | -0.04 | -0.03 | 1.00 | 0.76 |
| **LOWURB** | -0.03 | 0.01 | 0.76 | 1.00 |

| | PASTUR | PROBCROP | ROWCROP | crop | CONIFER |
|---|---|---|---|---|---|
| **CHAN_ALT** | 0.09 | -0.07 | 0.26 | 0.14 | -0.02 |
| **BANKSTAB** | 0.03 | 0.10 | -0.08 | -0.01 | 0.06 |
| **EMBEDDED** | -0.11 | 0.24 | -0.40 | -0.09 | 0.01 |
| **CH_FLOW** | 0.04 | 0.16 | 0.09 | 0.16 | -0.02 |
| **SHADING** | 0.26 | -0.07 | -0.11 | 0.25 | -0.41 |
| **REMOTE** | 0.04 | 0.05 | -0.09 | 0.01 | -0.04 |
| **AESTHET** | 0.20 | 0.03 | -0.11 | 0.25 | -0.29 |
| **WOOD_DEB** | -0.43 | -0.21 | 0.34 | -0.55 | 0.65 |
| **NUMROOT** | -0.16 | -0.15 | 0.12 | -0.24 | 0.23 |
| **MAXDEPTH** | 0.30 | 0.14 | -0.25 | 0.47 | -0.58 |
| **ST_GRAD** | -0.50 | -0.23 | 0.52 | -0.59 | 0.85 |
| **AVGWID** | 0.06 | -0.03 | -0.13 | 0.14 | -0.23 |
| **AVGTHAL** | 0.22 | 0.18 | -0.29 | 0.37 | -0.46 |
| **AVG_VEL** | -0.50 | -0.22 | 0.55 | -0.60 | 0.84 |
| **FLOW** | 0.11 | 0.00 | -0.05 | 0.16 | -0.21 |
| **ACREAGE** | 0.04 | 0.20 | -0.32 | 0.14 | -0.19 |
| **WETLANDS** | -0.41 | -0.19 | 0.45 | -0.49 | 0.69 |
| **BARREN** | -0.10 | -0.16 | 0.06 | -0.04 | 0.02 |
| **WATER** | 0.09 | 0.00 | 0.04 | 0.19 | -0.18 |
| **HIGHURB** | -0.23 | 0.02 | -0.15 | -0.12 | 0.03 |
| **LOWURB** | -0.12 | -0.13 | -0.06 | 0.00 | -0.16 |
| **PASTUR** | 1.00 | -0.05 | -0.28 | 0.27 | -0.59 |
| **PROBCROP** | -0.05 | 1.00 | -0.40 | 0.59 | -0.20 |
| **ROWCROP** | -0.28 | -0.40 | 1.00 | -0.16 | 0.46 |
| **crop** | 0.27 | 0.59 | -0.16 | 1.00 | -0.66 |
| **CONIFER** | -0.59 | -0.20 | 0.46 | -0.66 | 1.00 |
| **DECIDFOR** | 0.07 | -0.37 | -0.18 | 0.05 | -0.53 |
| **MIXEDFOR** | -0.56 | -0.28 | 0.24 | -0.66 | 0.84 |
| **EMERGWET** | -0.36 | -0.27 | 0.37 | -0.39 | 0.48 |
| **WOODYWET** | -0.09 | 0.27 | -0.53 | 0.00 | -0.13 |

| | DECIDFOR | MIXEDFOR | EMERGWET | WOODYWET |
|---|---|---|---|---|
| **CHAN_ALT** | 0.02 | -0.08 | 0.07 | -0.35 |
| **BANKSTAB** | -0.10 | -0.04 | 0.09 | 0.14 |
| **EMBEDDED** | -0.07 | 0.01 | -0.07 | 0.44 |
| **CH_FLOW** | -0.14 | -0.13 | -0.12 | -0.07 |
| **SHADING** | 0.34 | -0.34 | -0.15 | -0.18 |
| **REMOTE** | 0.01 | 0.01 | -0.09 | 0.03 |
| **AESTHET** | 0.18 | -0.26 | -0.30 | 0.01 |
| **WOOD_DEB** | -0.35 | 0.61 | 0.46 | -0.05 |
| **NUMROOT** | -0.09 | 0.16 | 0.37 | -0.04 |
| **MAXDEPTH** | 0.30 | -0.54 | -0.37 | 0.10 |
| **ST_GRAD** | -0.46 | 0.79 | 0.45 | -0.22 |
| **AVGWID** | 0.19 | -0.26 | 0.44 | 0.09 |
| **AVGTHAL** | 0.19 | -0.43 | -0.30 | 0.18 |
| **AVG_VEL** | -0.45 | 0.71 | 0.46 | -0.20 |
| **FLOW** | 0.15 | -0.24 | 0.11 | -0.06 |
| **ACREAGE** | -0.02 | -0.18 | -0.12 | 0.42 |
| **WETLANDS** | -0.38 | 0.57 | 0.32 | -0.16 |
| **BARREN** | 0.11 | -0.03 | 0.76 | -0.02 |
| **WATER** | 0.09 | -0.18 | -0.11 | -0.10 |
| **HIGHURB** | -0.03 | 0.12 | -0.01 | -0.02 |
| **LOWURB** | 0.17 | -0.08 | -0.11 | -0.13 |
| **PASTUR** | 0.07 | -0.56 | -0.36 | -0.09 |
| **PROBCROP** | -0.37 | -0.28 | -0.27 | 0.27 |
| **ROWCROP** | -0.18 | 0.24 | 0.37 | -0.53 |
| **crop** | 0.05 | -0.66 | -0.39 | 0.00 |
| **CONIFER** | -0.53 | 0.84 | 0.48 | -0.13 |
| **DECIDFOR** | 1.00 | -0.40 | -0.18 | -0.15 |
| **MIXEDFOR** | -0.40 | 1.00 | 0.37 | -0.06 |
| **EMERGWET** | -0.18 | 0.37 | 1.00 | -0.10 |
| **WOODYWET** | -0.15 | -0.06 | -0.10 | 1.00 |

| | COALMINE | TRANS | BKTRFLAG | BLACKWAT |
|---|---|---|---|---|
| NO3_LAB | 0.02 | 0.21 | 0.05 | -0.07 |
| FIBI_98 | 0.13 | -0.10 | 0.07 | -0.14 |
| BIBI_98 | 0.03 | -0.12 | 0.08 | -0.08 |
| PHI | 0.13 | -0.13 | 0.00 | -0.17 |
| RIP_WIDm | -0.03 | 0.11 | 0.08 | 0.00 |
| TEMP_FLD | 0.12 | 0.08 | 0.06 | 0.01 |
| AGRI | -0.06 | -0.10 | 0.00 | -0.16 |
| URBAN | 0.03 | 0.07 | -0.01 | -0.05 |
| FOREST | 0.03 | 0.03 | 0.01 | 0.22 |
| ORDER | 0.11 | 0.07 | 0.01 | -0.03 |
| DO_FLD | -0.02 | -0.19 | -0.04 | -0.19 |
| PH_FLD | -0.06 | 0.01 | 0.01 | -0.20 |
| COND_FLD | -0.04 | 0.23 | 0.01 | 0.01 |
| PH_LAB | 0.11 | 0.06 | -0.01 | -0.04 |
| COND_LAB | -0.07 | 0.08 | -0.01 | -0.15 |
| ANC_LAB | -0.06 | -0.04 | -0.01 | -0.21 |
| SO4_LAB | 0.13 | 0.07 | -0.01 | -0.02 |
| DOC_LAB | 0.09 | 0.13 | -0.01 | 0.40 |
| PASTURE | 0.08 | -0.01 | -0.01 | -0.07 |
| INSTRHAB | 0.08 | -0.16 | -0.03 | -0.11 |
| EPI_SUB | -0.01 | -0.14 | -0.01 | -0.13 |
| VEL_DPTH | 0.07 | -0.12 | -0.03 | -0.23 |
| POOLQUAL | 0.04 | -0.03 | -0.05 | -0.18 |
| RIFFQUAL | 0.02 | -0.12 | 0.04 | -0.13 |
| CHAN_ALT | -0.06 | -0.15 | -0.05 | -0.12 |
| BANKSTAB | 0.08 | -0.04 | 0.06 | 0.15 |
| EMBEDDED | -0.06 | 0.10 | -0.01 | 0.27 |
| CH_FLOW | 0.01 | -0.08 | -0.05 | -0.01 |
| SHADING | -0.33 | 0.04 | 0.01 | 0.00 |
| REMOTE | -0.11 | 0.05 | 0.05 | -0.01 |
| AESTHET | -0.09 | -0.01 | 0.08 | -0.05 |
| WOOD_DEB | 0.46 | 0.04 | 0.03 | -0.03 |
| NUMROOT | 0.17 | -0.04 | -0.02 | -0.02 |
| MAXDEPTH | -0.35 | -0.03 | -0.01 | -0.07 |
| ST_GRAD | 0.58 | 0.00 | -0.03 | -0.05 |
| AVGWID | -0.16603 | -0.02964 | -0.00376 | -0.02541 |

| | COALMINE | TRANS | BKTRFLAG | BLACKWAT |
|---|---|---|---|---|
| **AVGTHAL** | -0.28 | -0.04 | -0.01 | -0.05 |
| **AVG_VEL** | 0.67 | 0.01 | -0.03 | -0.04 |
| **FLOW** | -0.11 | -0.06 | -0.03 | -0.07 |
| **ACREAGE** | -0.14 | -0.02 | 0.09 | 0.12 |
| **WETLANDS** | 0.67 | 0.01 | -0.02 | -0.03 |
| **BARREN** | -0.01 | 0.00 | -0.01 | -0.01 |
| **WATER** | -0.10 | 0.04 | 0.01 | -0.06 |
| **LOWURB** | -0.09 | 0.00 | 0.01 | -0.07 |
| **PASTUR** | -0.34 | -0.04 | 0.02 | -0.13 |
| **PROBCROP** | -0.17 | 0.03 | 0.05 | 0.10 |
| **ROWCROP** | 0.39 | -0.08 | -0.06 | -0.16 |
| **CONIFER** | 0.53 | 0.04 | -0.04 | 0.17 |
| **DECIDFOR** | -0.29 | -0.06 | -0.03 | -0.14 |
| **MIXEDFOR** | 0.37 | 0.06 | -0.03 | 0.08 |
| **EMERGWET** | 0.34 | 0.00 | -0.02 | 0.03 |
| **WOODYWET** | -0.14 | 0.05 | 0.10 | 0.24 |
| **COALMINE** | 1.00 | -0.03 | -0.02 | -0.04 |
| **TRANS** | -0.03 | 1.00 | 0.02 | 0.10 |
| **BKTRFLAG** | -0.02 | 0.02 | 1.00 | -0.02 |
| **BLACKWAT** | -0.04 | 0.10 | -0.02 | 1.00 |

# APPENDIX 8:

# SERC* NO3 SAS MODELING

## Model Parameter Search

**SAS language**

```
DATA one ;
INFILE 'C:\Documents and Settings\lbarker\Desktop\apr5cafofctr.dat' ;
INPUT Sitenum$ NO3 pctAG pctFOR forag siteag sitecrop
CAFO CAFOfctr CAFOfcsq ZONED RFB test Gbuf BTOT
BT
BG BSH BIN DBH BAS shrubHt topo RZSlope Fslope
Bwidslo BSvsFS tortuous gradient test ORDER RZwtr RZKsurf
RZKmin RZKminD Fwtr Fksurf test Fkmin FKminD CW
CD
CXS CWvsCD CA ;
proc print; proc corr ;
proc reg ;
model NO3 = siteag sitecrop CAFO CAFOfctr CAFOfcsq ZONED
RFB Gbuf BTOT BT BG BSH DBH BAS shrubHt
RZSlope Fslope Bwidslo BSvsFS gradient ORDER RZwtr RZKsurf
RZKmin RZKminD Fwtr Fksurf Fkmin FKminD CW CD
CXS CWvsCD CA / selection=rsquare adjrsq best=3;
run; quit;
```

**Results**

R-Square Selection Method

| Number in Model | $R^2$ | Adjusted R-Square | Variables in Model |
|---|---|---|---|
| 1 | 0.1125 | 0.0856 | CAFO |
| 1 | 0.0982 | 0.0708 | Fslope |
| 1 | 0.0707 | 0.0425 | RZKmin |
| 2 | 0.2179 | 0.1690 | BT Fslope |
| 2 | 0.2141 | 0.1650 | siteag CAFO |
| 2 | 0.2032 | 0.1534 | CAFO BT |
| 3 | 0.3210 | 0.2553 | BTOT BT Fslope |
| 3 | 0.2915 | 0.2229 | BT Fslope RZKsurf |
| 3 | 0.2844 | 0.2152 | siteag Fslope FKminD |
| 4 | 0.3938 | 0.3130 | BTOT BT Fslope FKminD |
| 4 | 0.3850 | 0.3030 | BTOT BT Fslope RZKsurf |
| 4 | 0.3709 | 0.2870 | BTOT BT RZSlope FKminD |

## Model Calibration

### SAS language

```
*Using the parameters: siteag CAFO;
model NO3 = siteag CAFO / collinoint tol  VIF R influence ;
output out=resNO3  residual = NO3res;
proc univariate normal plot;
var NO3res  ;
run;      quit;
```

### Results

Analysis of Variance

| **Source** | **DF** | **Sum of Squares** | **Mean Square** | **F Value** | **Pr > F** |
|---|---|---|---|---|---|
| Model | 2 | 30.20774 | 15.10387 | 4.36 | **0.0212** |
| Error | **32** | **110.85382** | 3.46418 | | |
| Corrected Total | 34 | 141.06155 | | | |

| | | | |
|---|---|---|---|
| Root MSE | 1.86123 | R-Square | 0.2141 |
| Dependent Mean | 3.38686 | Adj R-Sq | **0.1650** |
| Coeff Var | 54.95453 | | |

**Parameter Estimates**

| Variable | DF | Parameter Estimate | Standard Error | t Value | Pr > \|t\| | Tolerance | Variance Inflation |
|---|---|---|---|---|---|---|---|
| Intercept | 1 | 0.44894 | 1.33552 | 0.34 | 0.7389 | . | 0 |
| siteag | 1 | 0.03848 | 0.01892 | 2.03 | 0.0503 | 0.95172 | 1.05073 |
| CAFO | 1 | 0.21487 | 0.08476 | 2.54 | 0.0163 | 0.95172 | 1.05073 |

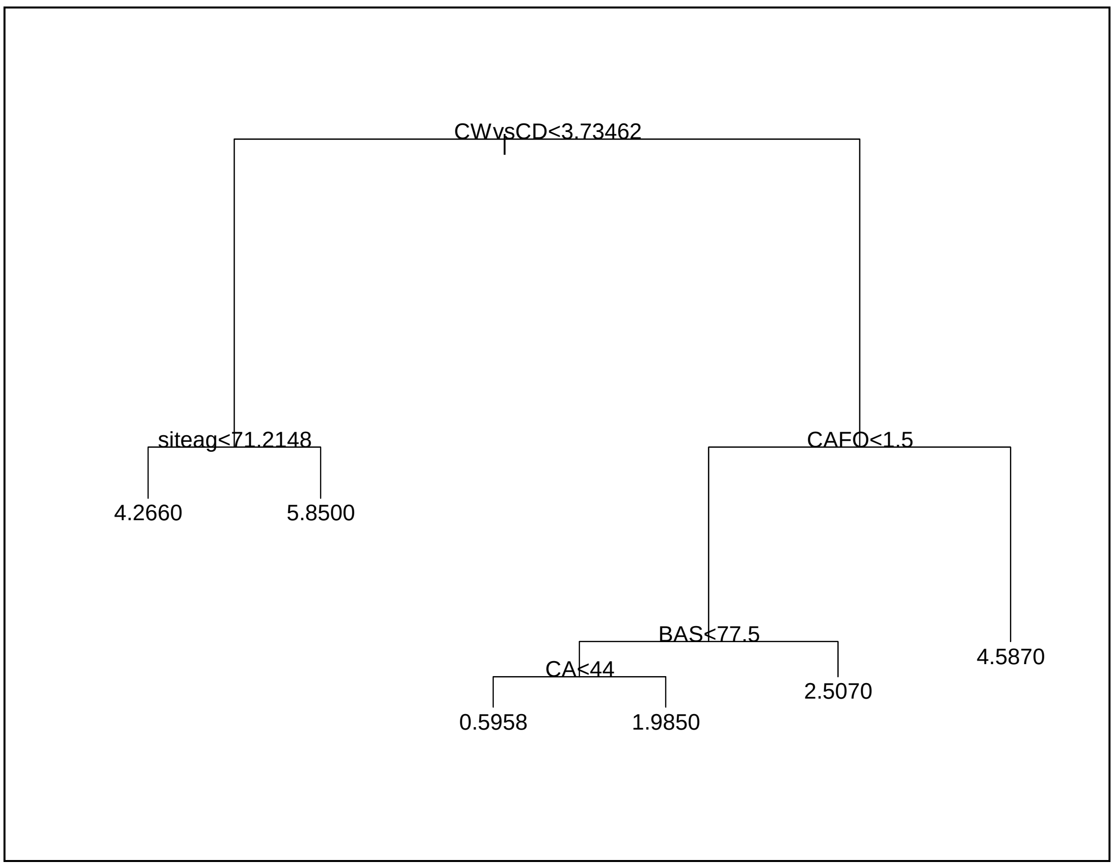
Collinearity Diagnostics (intercept adjusted)

| Number | Eigenvalue | Condition Index | --Proportion of Variation- siteag | CAFO |
|---|---|---|---|---|
| 1 | 1.21974 | 1.00000 | 0.39013 | 0.39013 |
| 2 | 0.78026 | 1.25030 | 0.60987 | 0.60987 |

## APPENDIX 9:

## SERC* NO3 S-PLUS MODELING

### Regression tree model with all parameters – all sites



**Regression Tree with all Parameters**

**tree(formula** = NO3 ~ siteag + sitecrop + CAFO + CAFOfctr + CAFOfcsq + ZONED + RFB + Gbuf + BTOT + BT + BG + BSH + BIN + DBH + BAS + shrubHt + topo + RZSlope + Fslope + Bwidslo + BSvsFS + tortuous + gradient + ORDER + RZwtr + RZKsurf + RZKmin + RZKminD + Fwtr + Fksurf + Fkmin + FKminD + CW + CD + CXS + CWvsCD + CA, data = Apr5.CAFOfctr, na.action = na.exclude, mincut = 5, minsize = 10, mindev = 0.01)

Variables actually used in tree construction: "CWvsCD""siteag""CAFO""BAS""CA"
Number of terminal nodes: **6**
Residual mean deviance: **1.491 = 43.23 / 29**

| **node), split,** | **n,** | **deviance,** | **yval** | *** denotes terminal node** |
|---|---|---|---|---|
| 1) root | 35 | 141.100 | 3.3870 | |
| 4) siteag<71.2148 | 9 | 5.246 | 4.2660 * | |
| 5) siteag>71.2148 | 5 | 3.508 | 5.8500 * | |
| 3) CWvsCD>3.73462 | 21 | 75.590 | 2.4230 | |
| 12) BAS<77.5 | 10 | 9.636 | 1.2900 | |
| 24)CA<44 | 5 | 3.014 | 0.5958 * | |
| 25) CA>44 | 5 | 1.796 | 1.9850 * | |
| 13) BAS>77.5 | 6 | 9.782 | 2.5070 * | |

**Total deviance for 2-term model is sum of RMD for all terminal nodes**
**RMD for 5-term model = total deviance/ (total n - number of terminal nodes)**

| | | | |
|---|---|---|---|
| 2) CWvsCD<3.73462 | 14 | 16.820 | 4.8320 |
| 6) CAFO<1.5 | 16 | 24.970 | 1.7470 |
| 7) CAFO>1.5 | 5 | 19.880 | 4.5870 * |
| **total deviance =** | | **61.67** | |
| **total n =** | | **35** | |
| **number of terminal nodes =** | | **3** | |
| RMD = | | 1.93 | |

## Development of equivalent $R^2$ for regression tree model

| Phys | NO3 | delta | square |
|---|---|---|---|
| CP | 5.72 | 3.08 | 9.50 |
| CP | 1.12 | -1.52 | 2.32 |
| CP | 2.15 | -0.49 | 0.24 |
| CP | 0.24 | -2.40 | 5.78 |
| CP | 2.22 | -0.42 | 0.17 |
| CP | 0.20 | -2.44 | 5.96 |
| CP | 7.28 | 4.64 | 21.57 |
| CP | 1.98 | -0.66 | 0.43 |
| CP | 1.55 | -1.09 | 1.19 |
| CP | 3.71 | 1.07 | 1.14 |
| CP | 3.28 | 0.64 | 0.41 |
| CP | 1.68 | -0.96 | 0.92 |
| CP | 5.06 | 2.42 | 5.84 |
| CP | 4.04 | 1.40 | 1.95 |
| CP | 2.62 | -0.02 | 0.00 |
| CP | 0.65 | -1.99 | 3.97 |
| CP | 1.14 | -1.50 | 2.24 |
| CP | 2.66 | 0.02 | 0.00 |
| CP | 0.20 | -2.44 | 5.96 |
| CP | 7.75 | 5.11 | 26.09 |
| CP | 0.20 | -2.44 | 5.96 |
| P | 6.17 | 1.67 | 2.78 |
| P | 2.80 | -1.71 | 2.92 |
| P | 4.92 | 0.41 | 0.17 |
| P | 3.94 | -0.56 | 0.32 |
| P | 4.87 | 0.36 | 0.13 |
| P | 4.64 | 0.13 | 0.02 |
| P | 5.05 | 0.55 | 0.30 |
| P | 5.02 | 0.51 | 0.26 |
| P | 4.54 | 0.03 | 0.00 |
| P | 5.05 | 0.54 | 0.29 |
| P | 3.53 | -0.97 | 0.95 |
| P | 3.15 | -1.36 | 1.84 |
| P | 4.99 | 0.49 | 0.24 |
| P | 4.42 | -0.08 | 0.01 |

| mean | |
|---|---|
| **CP** | 2.64 |
| **P** | 4.51 |
| **ALL** | 3.39 |

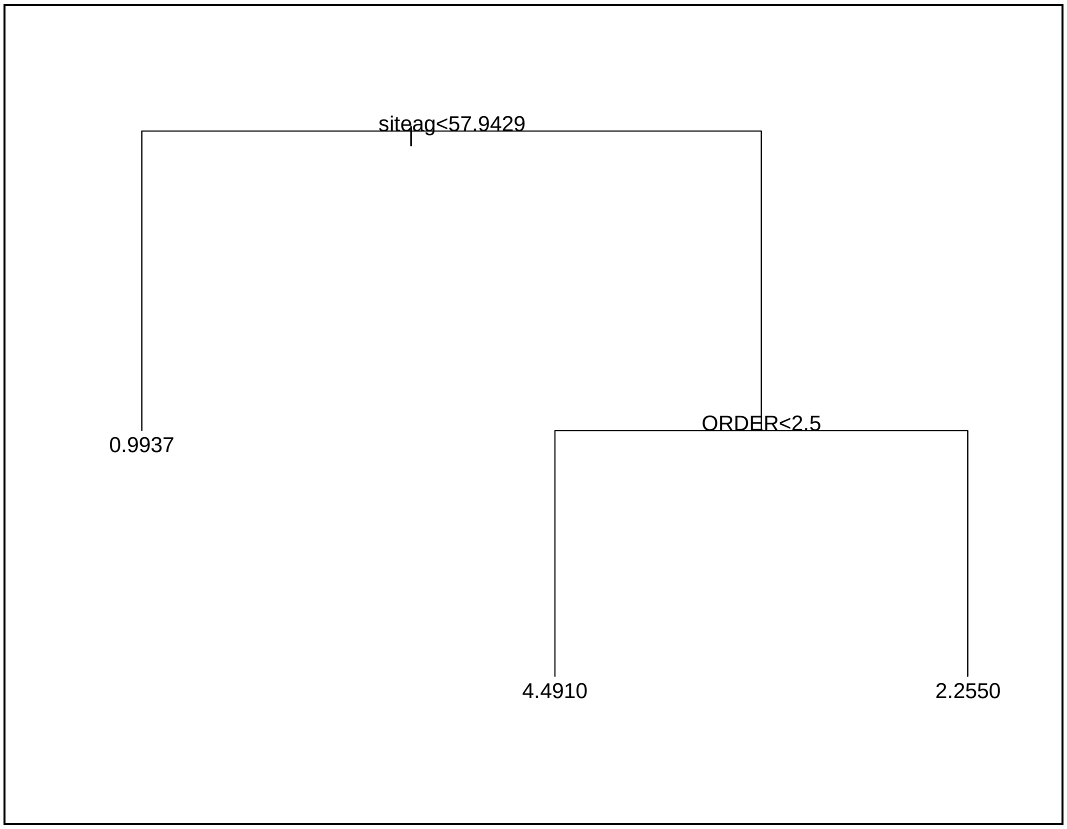
| corrected total SS | |
|---|---|
| 101.65 | **CP** |
| 10.22 | **Pd** |
| 111.88 | **ALL** |

| Resid SS | deviance |
|---|---|
| **CP** | 4.13 |
| | 46.86 |
| | 9.18 |
| | |
| | **60.17** |
| **Pd** | 2.88 |
| | 2.07 |
| | |
| | **4.95** |
| **ALL** | 5.25 |
| | 3.51 |
| | 24.97 |
| | 19.88 |
| | |
| | **53.61** |

| Res/Cor SS | |
|---|---|
| **CP** | 0.59 |
| **Pd** | 0.48 |
| **ALL** | 0.48 |

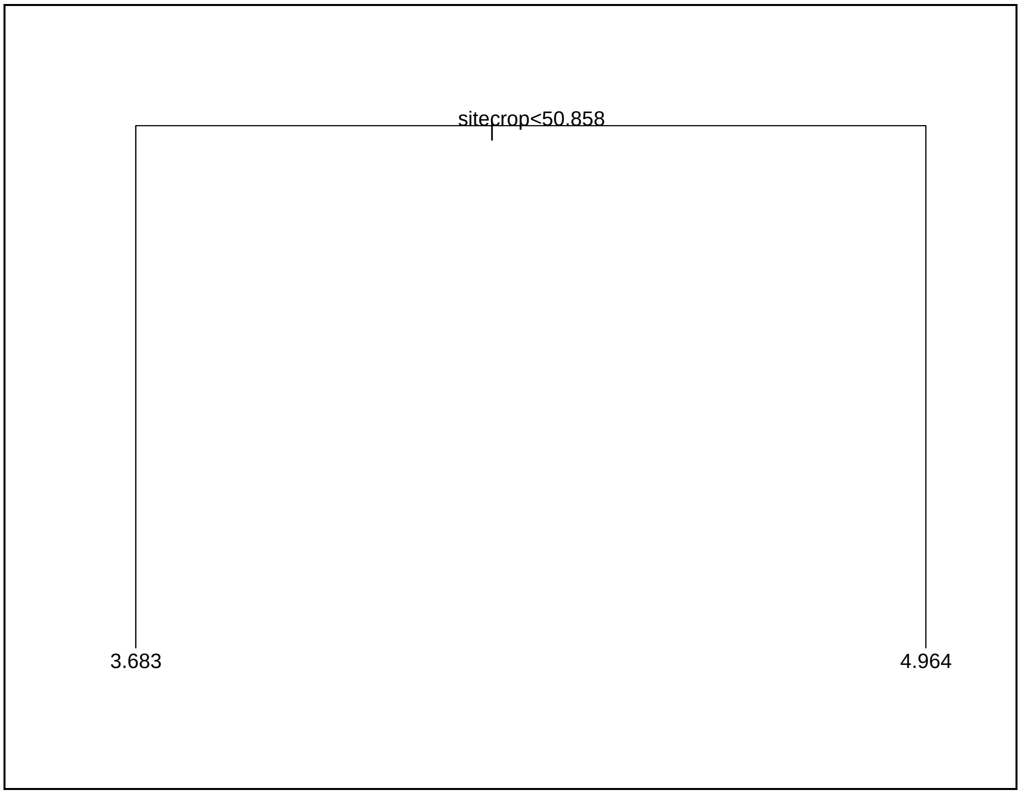
| $R^2$ | |
|---|---|
| **CP** | **0.41** |
| **Pd** | **0.52** |
| **ALL** | **0.52** |

**SERC* NO3 S-PLUS Modeling**
**Coastal Plain = German Branch**




```
Regression tree:
tree(formula = NO3 ~ siteag + sitecrop + CAFO + CAFOfctr + CAFOfcsq +
       ZONED + RFB + Gbuf + BTOT + BT + BG + BSH + BIN + DBH + BAS +
       shrubHt + topo + RZSlope + Fslope + Bwidslo + BSvsFS + tortuous +
       gradient + ORDER + RZwtr + RZKsurf + RZKmin + RZKminD + Fwtr +
       Fksurf + Fkmin + FKminD + CW + CD + CXS + CWvsCD + CA, data =
       SERC.CP, na.action = na.exclude, mincut = 5, minsize = 10,
       mindev = 0.01)
Variables actually used in tree construction:
[1] "siteag" "ORDER"
Number of terminal nodes:  3
Residual mean deviance:  3.346 = 60.22 / 18
Distribution of residuals:
     Min.  1st Qu.   Median     Mean  3rd Qu.     Max.
 -4.25400 -0.78220 -0.03148  0.00000  1.02700  3.25700
node), split,             n,     deviance,     yval
      * denotes terminal node
1) root                   21     101.700       2.6400
  2) siteag<57.9429       6      4.193         0.9937 *
  3) siteag>57.9429       15     74.700        3.2980
    6) ORDER<2.5          7      46.860        4.4910 *
    7) ORDER>2.5          8      9.177         2.2550 *
```

**SERC* NO3 S-PLUS Modeling**
**Piedmont= Gunpowder**




```
Regression tree:
tree(formula = NO3 ~ siteag + sitecrop + CAFO + CAFOfctr + CAFOfcsq +
       ZONED + RFB + Gbuf + BTOT + BT + BG + BSH + BIN + DBH + BAS +
       shrubHt + topo + RZSlope + Fslope + Bwidslo + BSvsFS + tortuous +
       gradient + ORDER + RZwtr + RZKsurf + RZKmin + RZKminD + Fwtr +
       Fksurf + Fkmin + FKminD + CW + CD + CXS + CWvsCD + CA, data =
       SERC.P, na.action = na.exclude, mincut = 5, minsize = 10,
       mindev = 0.01)
Variables actually used in tree construction:
[1] "sitecrop"
Number of terminal nodes:  2
Residual mean deviance:  0.4126 = 4.951 / 12
Distribution of residuals:
     Min.  1st Qu.   Median     Mean  3rd Qu.     Max.
 -0.88680 -0.40190 -0.07044  0.00000  0.08862  1.31100
node), split,             n,     deviance,     yval
      * denotes terminal node

1)     root                 14     10.220        4.507
  2)   sitecrop<50.858      5      2.877         3.683 *
  3)   sitecrop>50.858      9      2.074         4.964 *
```

## APPENDIX 10:

## MBSS* NO3 SAS MODELING

### Model Search

**SAS language**

```
DATA    one  ;
INFILE  'd:\f nitrate paper\app\sascaldata.dat'          ;
INPUT NO3     RIP_WIDm     TEMP_FLD     For_Buff     CROP     Reg_East
AGRI         PHYS_CP     URBAN     FOREST     ORDER_1     DO_FLD
PH_FLD     COND_FLD     PH_LAB     COND_LAB     ANC_LAB     SO4_LAB
DOC_LAB     ACID_no        PASTURE     INSTRHAB     EPI_SUB
VEL_DPTH     POOLQUAL     RIFFQUAL     CHAN_ALT   BANKSTAB
EMBEDDED     CH_FLOW     SHADING     REMOTE     AESTHET
WOOD_DEB       NUMROOT     MAXDEPTH     ST_GRAD     AVGWID
AVGTHAL   AVG_VEL     FLOW     ACREAGE   WETLANDS     BARREN
WATER     HIGHURB     LOWURB     PASTUR     PROBCROP     ROWCROP
cropmix     CONIFER     DECIDFOR     MIXEDFOR   EMERGWET
WOODYWET    COALMINE     TRANS     BKTRFLAG     BLACKWAT   ;
*proc print;    * proc corr  ;
proc reg  ;
*model NO3 =   RIP_WIDm     TEMP_FLD     For_Buff     CROP     Reg_East
AGRI   PHYS_CP     URBAN     FOREST     ORDER_1     DO_FLD     PH_FLD
COND_FLD   PH_LAB     COND_LAB     ANC_LAB     SO4_LAB     DOC_LAB
ACID_no     PASTURE     INSTRHAB     EPI_SUB     VEL_DPTH
POOLQUAL     RIFFQUAL     CHAN_ALT     BANKSTAB     EMBEDDED
CH_FLOW     SHADING     REMOTE     AESTHET     WOOD_DEB
NUMROOT     MAXDEPTH     ST_GRAD     AVGWID     AVGTHAL
AVG_VEL     FLOW     ACREAGE     WETLANDS     BARREN     WATER
HIGHURB     LOWURB     PASTUR     PROBCROP     ROWCROP     cropmix
CONIFER     DECIDFOR     MIXEDFOR   EMERGWET     WOODYWET
COALMINE     TRANS     BKTRFLAG     BLACKWAT       / selection=rsquare
adjrsq best=3;
```

**Results**

R-Square Selection Method

| Number in Model | $R^2$ | Adjusted R-Square | Variables in Model |
|---|---|---|---|
| 1 | 0.2444 | 0.2413 | AGRI |
| 1 | 0.1956 | 0.1924 | FOREST |
| 1 | 0.1250 | 0.1215 | DECIDFOR |
| 2 | 0.2984 | 0.2927 | Reg_East AGRI |
| 2 | 0.2895 | 0.2837 | AGRI BARREN |
| 2 | 0.2817 | 0.2758 | AGRI BANKSTAB |
| 3 | 0.3618 | 0.3540 | AGRI COND_LAB ANC_LAB |
| 3 | 0.3361 | 0.3279 | Reg_East AGRI COND_LAB |
| 3 | 0.3327 | 0.3245 | Reg_East AGRI BARREN |
| 4 | 0.4044 | 0.3946 | Reg_East AGRI COND_LAB ANC_LAB |
| 4 | 0.3945 | 0.3845 | AGRI COND_LAB ANC_LAB BANKSTAB |
| 4 | 0.3852 | 0.3751 | AGRI COND_LAB ANC_LAB BARREN |
| 5 | 0.4213 | 0.4094 | Reg_East AGRI COND_LAB ANC_LAB BARREN |
| 5 | 0.4181 | 0.4061 | Reg_East AGRI COND_LAB ANC_LAB BANKSTAB |
| 5 | 0.4174 | 0.4054 | CROP Reg_East AGRI COND_LAB ANC_LAB |

## Model Calibration

**SAS language**

* Using the variables CROP Reg_East AGRI COND_LAB ANC_LAB **;**
model **NO3 = CROP Reg_East AGRI COND_LAB ANC_LAB** / collinoint tol VIF R influence ;
output out=resNO3 residual = NO3res;
proc univariate normal plot;
var NO3res ;
run; quit;

**Results**

| Analysis of Variance | | Sum of | Mean | | |
|---|---|---|---|---|---|
| Source | DF | Squares | Square | F Value | Pr > F |
| Model | 5 | 543.27044 | 108.65409 | 34.82 | <.0001 |
| Error | **243** | **758.31690** | 3.12065 | | |
| Corrected Total | 248 | 1301.58734 | | | |

| | | | |
|---|---|---|---|
| Root MSE | 1.76653 | R-Square | 0.4174 |
| Dependent Mean | 3.48863 | **Adj R-Sq** | **0.4054** |
| Coeff Var | 50.63686 | | |

**Parameter Estimates**

| Variable | DF | Parameter Estimate | Standard Error | t Value | Pr > \|t\| | Tolerance |
|---|---|---|---|---|---|---|
| Intercept | 1 | -2.79256 | 0.59976 | -4.66 | <.0001 | . |
| CROP | 1 | 0.67960 | 0.29186 | 2.33 | 0.0207 | 0.97686 |
| Reg_East | 1 | 0.89173 | 0.22946 | 3.89 | 0.0001 | 0.95248 |
| AGRI | 1 | 0.07470 | 0.00818 | 9.13 | <.0001 | 0.95556 |
| COND_LAB | 1 | 0.01257 | 0.00211 | 5.96 | <.0001 | 0.71594 |
| ANC_LAB | 1 | -0.00258 | 0.000494 | -5.21 | <.0001 | 0.72175 |

**Model Validation**

**SAS Language**

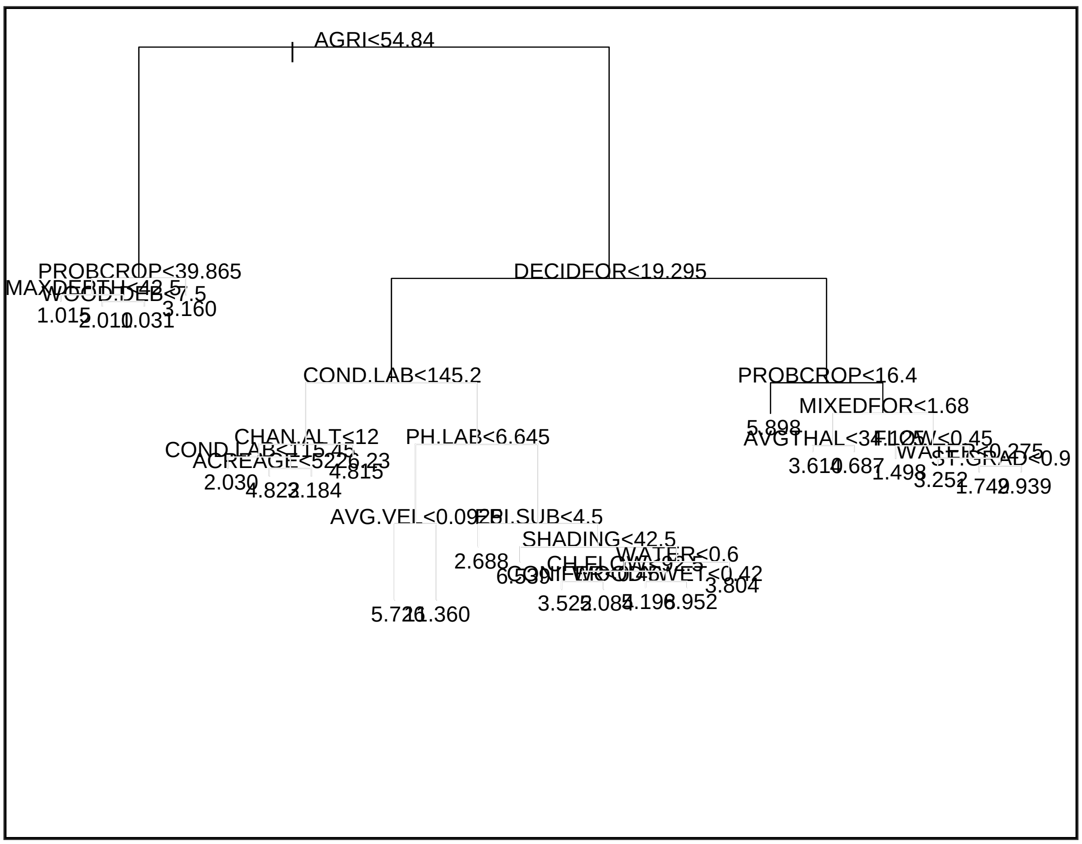
```
DATA   one  ;
INFILE  'd:\f nitrate paper\app\sasvaldata.dat'  ;
INPUT NO3     RIP_WIDm     TEMP_FLD     For_Buff     CROP     Reg_East
AGRI   PHYS_CP     URBAN     FOREST     ORDER_1     DO_FLD     PH_FLD
COND_FLD     PH_LAB     COND_LAB     ANC_LAB     SO4_LAB
DOC_LAB     ACID_no   PASTURE     INSTRHAB     EPI_SUB     VEL_DPTH
POOLQUAL     RIFFQUAL     CHAN_ALT  BANKSTAB     EMBEDDED
CH_FLOW     SHADING     REMOTE     AESTHET     WOOD_DEB
NUMROOT     MAXDEPTH     ST_GRAD     AVGWID     AVGTHAL
AVG_VEL     FLOW     ACREAGE     WETLANDS     BARREN     WATER
HIGHURB     LOWURB     PASTUR     PROBCROP     ROWCROP     cropmix
CONIFER     DECIDFOR     MIXEDFOR   EMERGWET     WOODYWET
COALMINE     TRANS     BKTRFLAG     BLACKWAT   ;
NO3pred = -2.79 + 0.68*CROP + 0.89*Reg_East +0.075*AGRI
+0.013*COND_LAB -0.002*ANC_LAB;
res = NO3 - NO3pred ;  proc print;    Proc corr;  run; quit;
```

**Results: Correlation of NO3 and NO3pred** 0.74371 **so $R^2$ = 0.553**

# APPENDIX 11:

## MBSS* NO3 S-PLUS MODELING

### Regression Tree with all Parameters



**Tree Model with all Parameters**

tree(formula = NO3.LAB ~ RIP.WIDm + TEMP.FLD + BUFF.TYP + ADJ.COVR + REGION + AGRI + PHYCPIO + URBAN + FOREST + ORDER + DO.FLD + PH.FLD + COND.FLD + PH.LAB + COND.LAB + ANC.LAB + SO4.LAB + DOC.LAB + ACIDSRC + PASTURE + INSTRHAB + EPI.SUB + VEL.DPTH + POOLQUAL + RIFFQUAL + CHAN.ALT + BANKSTAB + EMBEDDED + CH.FLOW + SHADING + REMOTE + AESTHET + WOOD.DEB + NUMROOT + MAXDEPTH + ST.GRAD + AVGWID + AVGTHAL + AVG.VEL + FLOW + ACREAGE + WETLANDS + BARREN + WATER + HIGHURB + LOWURB + PASTUR + PROBCROP + ROWCROP + crop + CONIFER + DECIDFOR + MIXEDFOR + EMERGWET + WOODYWET + COALMINE + TRANS + BKTRFLAG + BLACKWAT, data = Dec13.MBSS.NO3.model.data, na.action = na.exclude, mincut = 5, minsize = 10, mindev = 0.01)

**Variables actually used in tree construction**: "AGRI" "PROBCROP" "MAXDEPTH" "WOOD.DEB" "DECIDFOR" "COND.LAB"] "CHAN.ALT" "ACREAGE" "PH.LAB" "AVG.VEL" "EPI.SUB" "SHADING" ] "ADJ.COVR" "RIP.WIDm" "SO4.LAB" "REMOTE" "MIXEDFOR" "AVGTHAL" "FLOW" "WATER" "ST.GRAD"

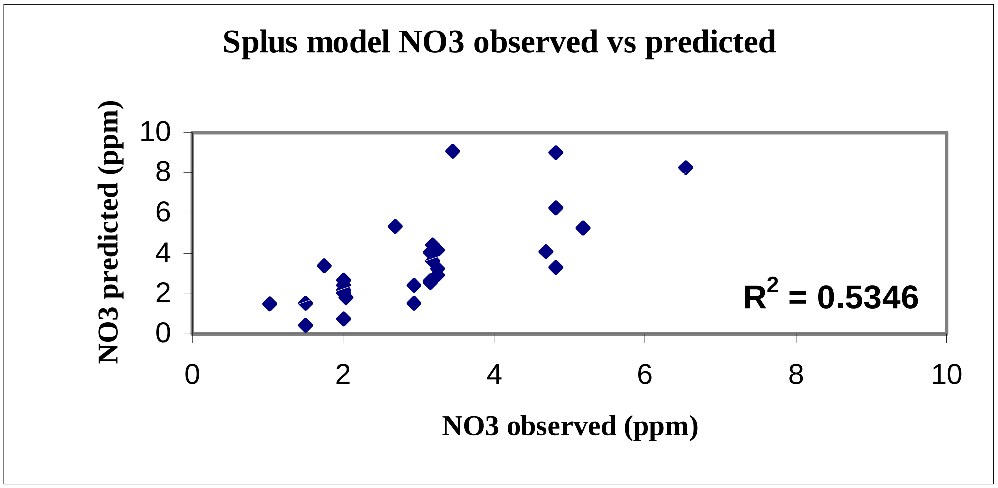
Number of terminal nodes: 25
Residual mean deviance: 1.478 = 331.1 / 224

**node), split, n, deviance, yval** *** denotes terminal node**

```
 1) root 249 1290.000  3.500
   2) AGRI<54.84 64   64.270  1.689
     4) PROBCROP<39.865 56   30.730  1.479
       8) MAXDEPTH<42.5 22    5.701  1.015 *
       9) MAXDEPTH>42.5 34   17.220  1.779
        18) WOOD.DEB<7.5 26    7.902  2.010 *
        19) WOOD.DEB>7.5 8    3.458  1.031 *
     5) PROBCROP>39.865 8   13.750  3.160 *
   3) AGRI>54.84 185  943.200  4.126
     6) DECIDFOR<19.295 99  573.800  4.898
      12) COND.LAB<145.2 31   58.140  3.608
        24) CHAN.ALT<12 23   34.180  3.189
          48) COND.LAB<115.45 7    4.870  2.030 *
          49) COND.LAB>115.45 16   15.800  3.696
            98) ACREAGE<5226.23 5    2.531  4.822 *
            99) ACREAGE>5226.23 11    4.040  3.184 *
        25) CHAN.ALT>12 8    8.262  4.815 *
      13) COND.LAB>145.2 68  440.500  5.486
        26) PH.LAB<6.645 12  199.900  8.072
          52) AVG.VEL<0.0925 7   77.790  5.726 *
```

```
     53) AVG.VEL>0.0925 5   29.630 11.360 *
   27) PH.LAB>6.645 56  143.300  4.932
     54) EPI.SUB<4.5 5    5.915  2.688 *
     55) EPI.SUB>4.5 51  109.700  5.152
      110) SHADING<42.5 8   10.420  6.539 *
      111) SHADING>42.5 43   81.040  4.894
        222) ADJ.COVR:LN,PA 13   14.100  4.045
          444) COND.LAB<184.3 5    2.691  4.990 *
          445) COND.LAB>184.3 8    4.148  3.454 *
        223) ADJ.COVR:CP,FR,OF,SL 30   53.480  5.263
          446) RIP.WIDm<45 10   19.430  6.176
            892) SO4.LAB<10.975 5    7.263  7.156 *
            893) SO4.LAB>10.975 5    2.561  5.196 *
          447) RIP.WIDm>45 20   21.540  4.806
            894) REMOTE<14 5    6.846  3.694 *
            895) REMOTE>14 15    6.448  5.177 *
7) DECIDFOR>19.295 86  242.500  3.237
 14) PROBCROP<16.4 5   89.380  5.898 *
 15) PROBCROP>16.4 81  115.500  3.073
   30) MIXEDFOR<1.68 24   18.330  4.148
     60) AVGTHAL<34.125 12    8.852  3.610 *
     61) AVGTHAL>34.125 12    2.523  4.687 *
   31) MIXEDFOR>1.68 57   57.750  2.620
     62) FLOW<0.45 10    5.052  1.498 *
     63) FLOW>0.45 47   37.430  2.859
      126) WATER<0.275 26   12.270  3.252 *
      127) WATER>0.275 21   16.160  2.372
        254) ST.GRAD<0.9 10    2.598  1.749 *
        255) ST.GRAD>0.9 11    6.141  2.939 *
```

**Model Validation**




| NO3 obs | pred | NO3 obs | pred |
|---|---|---|---|
| 0.43 | 1.498 | 3.23 | 3.25231 |
| 0.76 | 2.00962 | 3.3 | 4.815 |
| 1.48 | 1.03125 | 3.39 | 1.749 |
| 1.52 | 2.93909 | 3.64 | 3.18364 |
| 1.54 | 1.498 | 4.05 | 3.16 |
| 1.82 | 2.03 | 4.11 | 4.68667 |
| 2.03 | 2.00962 | 4.17 | 3.25231 |
| 2.16 | 2.00962 | 4.4 | 3.18364 |
| 2.41 | 2.00962 | 5.28 | 5.17667 |
| 2.42 | 2.93909 | 5.35 | 2.688 |
| 2.56 | 3.16 | 6.25 | 4.815 |
| 2.65 | 3.16 | 8.27 | 6.53875 |
| 2.66 | 2.00962 | 9.01 | 4.815 |
| 2.91 | 3.25231 | 9.07 | 3.45375 |

**Development of equivalent $R^2$ for regression tree model**

| PHYCPIO | NO3 | delta | square |
|---|---|---|---|
| CP | 0.52 | -2.87 | 8.23 |
| CP | 1.12 | -2.27 | 5.15 |
| CP | 1.92 | -1.47 | 2.16 |
| CP | 1.94 | -1.45 | 2.10 |
| CP | 2.56 | -0.83 | 0.69 |
| CP | 2.86 | -0.53 | 0.28 |
| CP | 4.53 | 1.14 | 1.30 |
| CP | 4.82 | 1.43 | 2.05 |
| CP | 9.59 | 6.20 | 38.46 |
| CP | 3.18 | -0.21 | 0.04 |
| CP | 4.73 | 1.34 | 1.80 |
| CP | 5.21 | 1.82 | 3.32 |
| CP | 12.92 | 9.53 | 90.85 |
| CP | 1.63 | -1.76 | 3.09 |
| CP | 1.88 | -1.51 | 2.28 |
| CP | 4.57 | 1.18 | 1.40 |
| CP | 0.26 | -3.13 | 9.79 |
| CP | 0.54 | -2.85 | 8.12 |
| CP | 0.79 | -2.60 | 6.75 |
| CP | 2.23 | -1.16 | 1.34 |
| CP | 3.62 | 0.23 | 0.05 |
| CP | 6.67 | 3.28 | 10.77 |
| CP | 1.38 | -2.01 | 4.03 |
| CP | 1.98 | -1.41 | 1.98 |
| CP | 3.53 | 0.14 | 0.02 |
| CP | 4.05 | 0.66 | 0.44 |
| CP | 4.06 | 0.67 | 0.45 |
| CP | 4.52 | 1.13 | 1.28 |
| CP | 5.29 | 1.90 | 3.61 |
| CP | 0.79 | -2.60 | 6.75 |
| CP | 5.96 | 2.57 | 6.61 |
| CP | 0.43 | -2.96 | 8.75 |
| CP | 2.1 | -1.29 | 1.66 |
| CP | 3.65 | 0.26 | 0.07 |
| CP | 0.88 | -2.51 | 6.29 |
| CP | 1.02 | -2.37 | 5.61 |
| CP | 1.65 | -1.74 | 3.02 |
| CP | 2.9 | -0.49 | 0.24 |
| CP | 6.1 | 2.71 | 7.35 |
| CP | 3.62 | 0.23 | 0.05 |
| CP | 1.63 | -1.76 | 3.09 |

| mean | |
|---|---|
| **CP** | 3.39 |
| **P** | 3.59 |
| **ALL** | 3.50 |
| **SD** | |
| **CP** | 2.89 |
| **P** | 1.65 |
| **corrected total SS** | |
| **CP** | 1018.62 |
| **Pd** | 418.90 |
| **ALL** | 1437.51 |
| **Resid SS** | |
| **CP** | **deviance** |
| | 102.8 |
| | 9.1 |
| | 271.1 |
| | 116.6 |
| | **499.6** |
| **Pd** | **deviance** |
| | 10.67 |
| | 65.22 |
| | 54.2 |
| | 52.24 |
| | **182.33** |
| **ALL** | **deviance** |
| | 30.73 |
| | 13.75 |
| | 58.14 |
| | 440.5 |
| | 89.38 |
| | 115.5 |
| | **748** |
| **Res/Cor SS** | |
| **CP** | 0.49 |
| **Pd** | 0.44 |
| **ALL** | 0.52 |
| **$R^2$** | |
| **CP** | 0.51 |
| **Pd** | 0.56 |
| **ALL** | 0.48 |

| | | | |
|---|---|---|---|
| CP | 4.7 | 1.31 | 1.72 |
| CP | 8.9 | 5.51 | 30.37 |
| CP | 10.44 | 7.05 | 49.72 |
| CP | 0.39 | -3.00 | 8.99 |
| CP | 5.41 | 2.02 | 4.09 |
| CP | 0.98 | -2.41 | 5.80 |
| CP | 1.44 | -1.95 | 3.80 |
| CP | 2.55 | -0.84 | 0.70 |
| CP | 3.39 | 0.00 | 0.00 |
| CP | 3.72 | 0.33 | 0.11 |
| CP | 1.41 | -1.98 | 3.92 |
| CP | 2.77 | -0.62 | 0.38 |
| CP | 4.29 | 0.90 | 0.81 |
| CP | 14.26 | 10.87 | 118.19 |
| CP | 7.64 | 4.25 | 18.07 |
| CP | 1.46 | -1.93 | 3.72 |
| CP | 1.82 | -1.57 | 2.46 |
| CP | 6.27 | 2.88 | 8.30 |
| CP | 0.52 | -2.87 | 8.23 |
| CP | 1.54 | -1.85 | 3.42 |
| CP | 2.47 | -0.92 | 0.84 |
| CP | 2.85 | -0.54 | 0.29 |
| CP | 0.42 | -2.97 | 8.81 |
| CP | 0.44 | -2.95 | 8.69 |
| CP | 0.46 | -2.93 | 8.58 |
| CP | 0.49 | -2.90 | 8.40 |
| CP | 0.61 | -2.78 | 7.72 |
| CP | 0.67 | -2.72 | 7.39 |
| CP | 0.69 | -2.70 | 7.28 |
| CP | 0.71 | -2.68 | 7.18 |
| CP | 0.76 | -2.63 | 6.91 |
| CP | 0.76 | -2.63 | 6.91 |
| CP | 0.83 | -2.56 | 6.55 |
| CP | 0.93 | -2.46 | 6.05 |
| CP | 0.98 | -2.41 | 5.80 |
| CP | 1.11 | -2.28 | 5.19 |
| CP | 1.12 | -2.27 | 5.15 |
| CP | 1.12 | -2.27 | 5.15 |
| CP | 1.16 | -2.23 | 4.97 |
| CP | 1.24 | -2.15 | 4.62 |
| CP | 1.38 | -2.01 | 4.03 |
| CP | 1.48 | -1.91 | 3.64 |
| CP | 1.55 | -1.84 | 3.38 |
| CP | 2.01 | -1.38 | 1.90 |

| | | | |
|---|---|---|---|
| CP | 2.05 | -1.34 | 1.79 |
| CP | 2.09 | -1.30 | 1.69 |
| CP | 2.09 | -1.30 | 1.69 |
| CP | 2.22 | -1.17 | 1.37 |
| CP | 2.25 | -1.14 | 1.30 |
| CP | 2.28 | -1.11 | 1.23 |
| CP | 2.34 | -1.05 | 1.10 |
| CP | 2.58 | -0.81 | 0.65 |
| CP | 2.65 | -0.74 | 0.55 |
| CP | 2.67 | -0.72 | 0.52 |
| CP | 2.79 | -0.60 | 0.36 |
| CP | 2.81 | -0.58 | 0.33 |
| CP | 2.87 | -0.52 | 0.27 |
| CP | 2.88 | -0.51 | 0.26 |
| CP | 2.92 | -0.47 | 0.22 |
| CP | 3.2 | -0.19 | 0.04 |
| CP | 3.25 | -0.14 | 0.02 |
| CP | 3.64 | 0.25 | 0.06 |
| CP | 3.76 | 0.37 | 0.14 |
| CP | 3.77 | 0.38 | 0.15 |
| CP | 4.4 | 1.01 | 1.02 |
| CP | 4.59 | 1.20 | 1.44 |
| CP | 4.64 | 1.25 | 1.57 |
| CP | 4.96 | 1.57 | 2.47 |
| CP | 5.12 | 1.73 | 3.00 |
| CP | 5.17 | 1.78 | 3.17 |
| CP | 5.2 | 1.81 | 3.28 |
| CP | 5.24 | 1.85 | 3.43 |
| CP | 5.26 | 1.87 | 3.50 |
| CP | 5.28 | 1.89 | 3.58 |
| CP | 5.35 | 1.96 | 3.85 |
| CP | 5.45 | 2.06 | 4.25 |
| CP | 5.45 | 2.06 | 4.25 |
| CP | 6.25 | 2.86 | 8.19 |
| CP | 8.82 | 5.43 | 29.50 |
| CP | 9.88 | 6.49 | 42.14 |
| CP | 10.71 | 7.32 | 53.60 |
| CP | 16.16 | 12.77 | 163.11 |
| P | 0.5 | -3.09 | 9.53 |
| P | 0.89 | -2.70 | 7.27 |
| P | 1.07 | -2.52 | 6.33 |
| P | 1.35 | -2.24 | 5.00 |
| P | 1.74 | -1.85 | 3.41 |
| P | 2.16 | -1.43 | 2.04 |

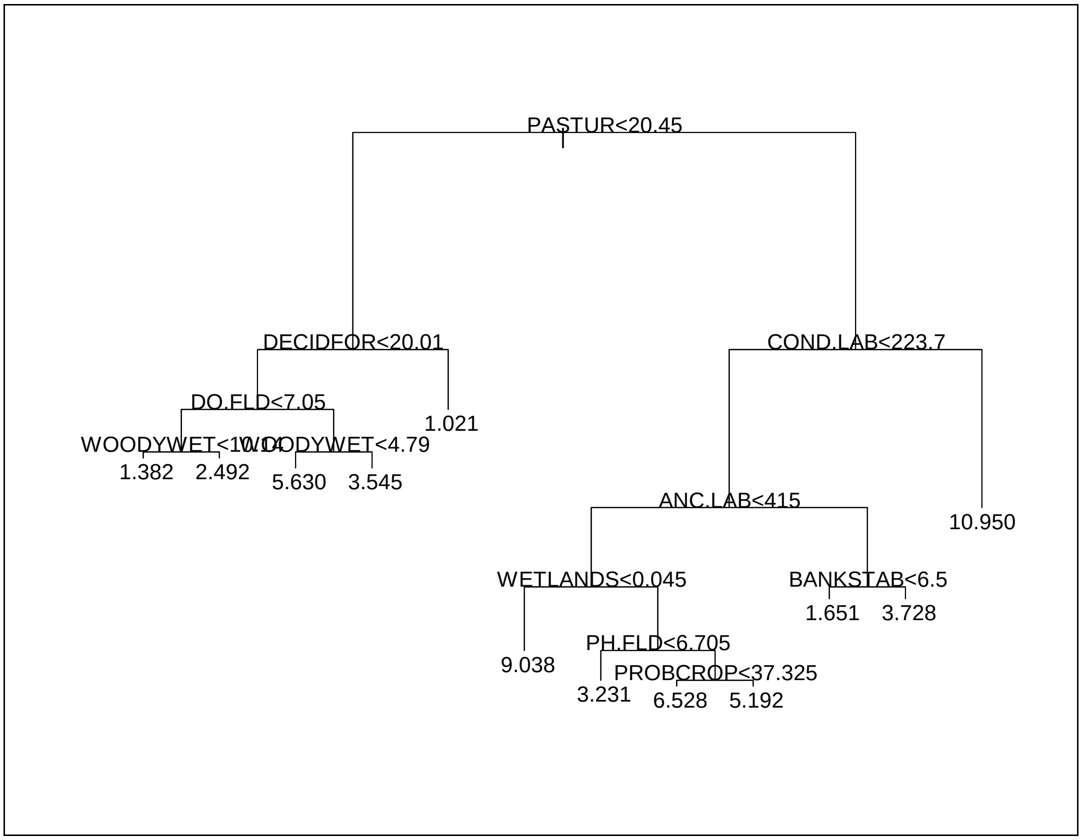
| | | | |
|---|---|---|---|
| P | 2.28 | -1.31 | 1.71 |
| P | 2.28 | -1.31 | 1.71 |
| P | 2.3 | -1.29 | 1.66 |
| P | 2.58 | -1.01 | 1.01 |
| P | 3.08 | -0.51 | 0.26 |
| P | 3.4 | -0.19 | 0.03 |
| P | 3.47 | -0.12 | 0.01 |
| P | 3.47 | -0.12 | 0.01 |
| P | 3.53 | -0.06 | 0.00 |
| P | 3.82 | 0.23 | 0.05 |
| P | 3.9 | 0.31 | 0.10 |
| P | 4.05 | 0.46 | 0.21 |
| P | 4.06 | 0.47 | 0.22 |
| P | 4.09 | 0.50 | 0.25 |
| P | 4.11 | 0.52 | 0.27 |
| P | 4.15 | 0.56 | 0.32 |
| P | 4.47 | 0.88 | 0.78 |
| P | 4.61 | 1.02 | 1.05 |
| P | 4.71 | 1.12 | 1.26 |
| P | 4.77 | 1.18 | 1.40 |
| P | 5.26 | 1.67 | 2.80 |
| P | 5.44 | 1.85 | 3.43 |
| P | 5.74 | 2.15 | 4.64 |
| P | 5.83 | 2.24 | 5.03 |
| P | 6.06 | 2.47 | 6.12 |
| P | 6.5 | 2.91 | 8.49 |
| P | 6.81 | 3.22 | 10.39 |
| P | 6.94 | 3.35 | 11.24 |
| P | 9.01 | 5.42 | 29.41 |
| P | 2.04 | -1.55 | 2.39 |
| P | 5.06 | 1.47 | 2.17 |
| P | 1.84 | -1.75 | 3.05 |
| P | 1.58 | -2.01 | 4.03 |
| P | 1.93 | -1.66 | 2.74 |
| P | 3.39 | -0.20 | 0.04 |
| P | 3.73 | 0.14 | 0.02 |
| P | 4.88 | 1.29 | 1.67 |
| P | 1.23 | -2.36 | 5.55 |
| P | 3.07 | -0.52 | 0.27 |
| P | 3.25 | -0.34 | 0.11 |
| P | 4.26 | 0.67 | 0.45 |
| P | 5.88 | 2.29 | 5.26 |
| P | 3.26 | -0.33 | 0.11 |
| P | 3.49 | -0.10 | 0.01 |

| | | | |
|---|---|---|---|
| P | 2.03 | -1.56 | 2.42 |
| P | 5.89 | 2.30 | 5.31 |
| P | 2.41 | -1.18 | 1.38 |
| P | 2.44 | -1.15 | 1.31 |
| P | 4.82 | 1.23 | 1.52 |
| P | 4.84 | 1.25 | 1.57 |
| P | 4.49 | 0.90 | 0.82 |
| P | 3.38 | -0.21 | 0.04 |
| P | 4.03 | 0.44 | 0.20 |
| P | 2.42 | -1.17 | 1.36 |
| P | 3.53 | -0.06 | 0.00 |
| P | 3.01 | -0.58 | 0.33 |
| P | 3.17 | -0.42 | 0.17 |
| P | 4.77 | 1.18 | 1.40 |
| P | 2.34 | -1.25 | 1.55 |
| P | 5.25 | 1.66 | 2.77 |
| P | 2.18 | -1.41 | 1.98 |
| P | 4.74 | 1.15 | 1.33 |
| P | 5.74 | 2.15 | 4.64 |
| P | 2.21 | -1.38 | 1.90 |
| P | 2.32 | -1.27 | 1.60 |
| P | 8.14 | 4.55 | 20.73 |
| P | 9.07 | 5.48 | 30.07 |
| P | 2.62 | -0.97 | 0.93 |
| P | 3.26 | -0.33 | 0.11 |
| P | 4.85 | 1.26 | 1.60 |
| P | 0.76 | -2.83 | 7.99 |
| P | 0.91 | -2.68 | 7.16 |
| P | 1.31 | -2.28 | 5.18 |
| P | 1.42 | -2.17 | 4.69 |
| P | 1.49 | -2.10 | 4.40 |
| P | 1.52 | -2.07 | 4.27 |
| P | 1.53 | -2.06 | 4.23 |
| P | 1.77 | -1.82 | 3.30 |
| P | 1.77 | -1.82 | 3.30 |
| P | 1.83 | -1.76 | 3.09 |
| P | 1.85 | -1.74 | 3.02 |
| P | 1.91 | -1.68 | 2.81 |
| P | 1.99 | -1.60 | 2.55 |
| P | 2.03 | -1.56 | 2.42 |
| P | 2.05 | -1.54 | 2.36 |
| P | 2.06 | -1.53 | 2.33 |
| P | 2.09 | -1.50 | 2.24 |
| P | 2.11 | -1.48 | 2.18 |

| | | | |
|---|---|---|---|
| P | 2.13 | -1.46 | 2.12 |
| P | 2.16 | -1.43 | 2.04 |
| P | 2.17 | -1.42 | 2.01 |
| P | 2.42 | -1.17 | 1.36 |
| P | 2.43 | -1.16 | 1.34 |
| P | 2.5 | -1.09 | 1.18 |
| P | 2.55 | -1.04 | 1.07 |
| P | 2.6 | -0.99 | 0.97 |
| P | 2.64 | -0.95 | 0.90 |
| P | 2.66 | -0.93 | 0.86 |
| P | 2.69 | -0.90 | 0.80 |
| P | 2.71 | -0.88 | 0.77 |
| P | 2.71 | -0.88 | 0.77 |
| P | 2.72 | -0.87 | 0.75 |
| P | 2.76 | -0.83 | 0.68 |
| P | 2.77 | -0.82 | 0.67 |
| P | 2.77 | -0.82 | 0.67 |
| P | 2.82 | -0.77 | 0.59 |
| P | 2.88 | -0.71 | 0.50 |
| P | 2.91 | -0.68 | 0.46 |
| P | 2.96 | -0.63 | 0.39 |
| P | 3.07 | -0.52 | 0.27 |
| P | 3.12 | -0.47 | 0.22 |
| P | 3.14 | -0.45 | 0.20 |
| P | 3.15 | -0.44 | 0.19 |
| P | 3.22 | -0.37 | 0.13 |
| P | 3.23 | -0.36 | 0.13 |
| P | 3.25 | -0.34 | 0.11 |
| P | 3.29 | -0.30 | 0.09 |
| P | 3.3 | -0.29 | 0.08 |
| P | 3.31 | -0.28 | 0.08 |
| P | 3.41 | -0.18 | 0.03 |
| P | 3.61 | 0.02 | 0.00 |
| P | 3.69 | 0.10 | 0.01 |
| P | 3.86 | 0.27 | 0.07 |
| P | 4.1 | 0.51 | 0.26 |
| P | 4.16 | 0.57 | 0.33 |
| P | 4.17 | 0.58 | 0.34 |
| P | 4.19 | 0.60 | 0.36 |
| P | 4.34 | 0.75 | 0.57 |
| P | 4.38 | 0.79 | 0.63 |
| P | 4.44 | 0.85 | 0.73 |
| P | 4.58 | 0.99 | 0.99 |
| P | 4.59 | 1.00 | 1.01 |

| | | | |
|---|---|---|---|
| P | 4.62 | 1.03 | 1.07 |
| P | 4.67 | 1.08 | 1.17 |
| P | 4.7 | 1.11 | 1.24 |
| P | 4.76 | 1.17 | 1.38 |
| P | 4.81 | 1.22 | 1.50 |
| P | 4.91 | 1.32 | 1.75 |
| P | 4.91 | 1.32 | 1.75 |
| P | 4.95 | 1.36 | 1.86 |
| P | 4.95 | 1.36 | 1.86 |
| P | 5.07 | 1.48 | 2.20 |
| P | 5.11 | 1.52 | 2.32 |
| P | 5.27 | 1.68 | 2.83 |
| P | 6.4 | 2.81 | 7.91 |
| P | 6.58 | 2.99 | 8.96 |
| P | 6.78 | 3.19 | 10.20 |
| P | 6.95 | 3.36 | 11.31 |
| P | 8.27 | 4.68 | 21.93 |

**MBSS* NO3 S-PLUS Modeling**
**Coastal Plain Data**




% pasture < 20.45

Deciduous forest < 20.01 Cond lab < 223.7

ANC lan < 415

Wetlands < 0.045 bank stability < 6.5

**Regression tree:**

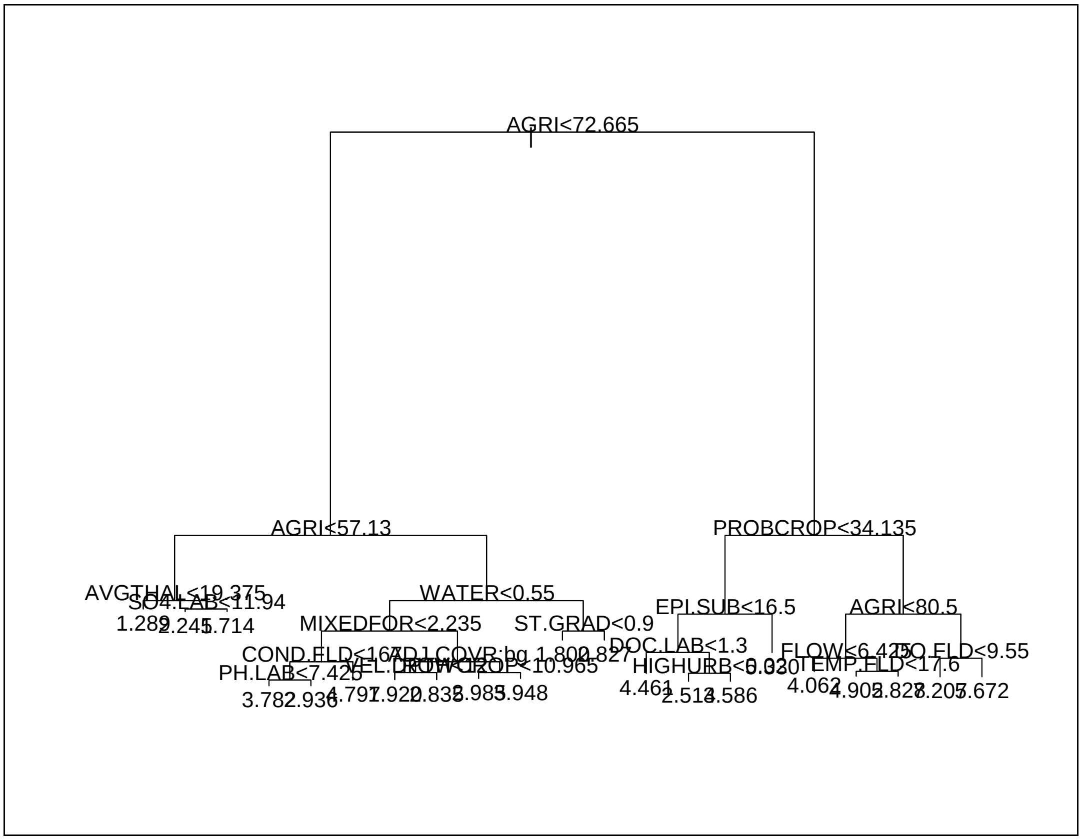
```
tree(formula = NO3.LAB ~ RIP.WIDm + TEMP.FLD + RIP.WID + BUFF.TYP +
      ADJ.COVR + REGION + AGRI + PHYCPIO + URBAN + FOREST + ORDER +
      DO.FLD + PH.FLD + COND.FLD + PH.LAB + COND.LAB + ANC.LAB +
      SO4.LAB + DOC.LAB + ACIDSRC + PASTURE + INSTRHAB + EPI.SUB +
      VEL.DPTH + POOLQUAL + RIFFQUAL + CHAN.ALT + BANKSTAB + EMBEDDED +
      CH.FLOW + SHADING + REMOTE + AESTHET + WOOD.DEB + NUMROOT +
      MAXDEPTH + ST.GRAD + AVGWID + AVGTHAL + AVG.VEL + FLOW +
      ACREAGE + WETLANDS + BARREN + WATER + HIGHURB + LOWURB + PASTUR +
      PROBCROP + ROWCROP + crop + CONIFER + DECIDFOR + MIXEDFOR +
      EMERGWET + WOODYWET + COALMINE + TRANS + BKTRFLAG + BLACKWAT,
      data = NO3.MBSS.CP, na.action = na.exclude, mincut = 5, minsize
       = 10, mindev = 0.01)
```

**Variables actually used in tree construction:**

```
 [1] "PASTUR"   "DECIDFOR" "DO.FLD"   "WOODYWET" "COND.LAB" "ANC.LAB"
 [7] "WETLANDS" "PH.FLD"   "PROBCROP" "BANKSTAB"
Number of terminal nodes:  12
Residual mean deviance:  1.829 = 201.2 / 110
Distribution of residuals:
      Min.   1st Qu.    Median      Mean   3rd Qu.      Max.
 -8.368000 -0.468800  0.003655  0.000000  0.375200  5.212000
```

```
node), split,                     n,     deviance,     yval
      * denotes terminal node

  1) root                         122    1010.0000     3.413
    2) PASTUR<20.45               73     182.2000      2.230
      4) DECIDFOR<20.01           44     102.8000      3.027
        8) DO.FLD<7.05 23   19.5100  2.010
          16) WOODYWET<10.14 10    2.7150  1.382 *
          17) WOODYWET>10.14 13    9.8290  2.492 *
        9) DO.FLD>7.05 21   33.4000  4.140
          18) WOODYWET<4.79 6    6.7170  5.630 *
          19) WOODYWET>4.79 15    8.0480  3.545 *
      5) DECIDFOR>20.01           29     9.1020        1.021 *
    3) PASTUR>20.45               49     573.2000      5.176
      6) COND.LAB<223.7           44     271.1000      4.520
       12) ANC.LAB<415            30     157.2000      5.512
         24) WETLANDS<0.045       5      25.7400       9.038 *
         25) WETLANDS>0.045       25     56.8600       4.807
           50) PH.FLD<6.705 9    6.6820  3.231 *
           51) PH.FLD>6.705 16   15.2600  5.693
            102) PROBCROP<37.325 6    7.7620  6.528 *
            103) PROBCROP>37.325 10    0.8058  5.192 *
       13) ANC.LAB>415            14     21.0600       2.393
         26) BANKSTAB<6.5         9      4.1370        1.651 *
         27) BANKSTAB>6.5         5      3.0550        3.728 *
      7) COND.LAB>223.7 5  116.6000 10.950 *
```

## MBSS* NO3 S-PLUS Modeling
## Piedmont Data




agri < 72.665

agri < 57.13 probable crops < 34.135

epifaunal substrate < 16.5 agriculture < 80.5

```
Regression tree:
tree(formula = NO3.LAB ~ RIP.WIDm + TEMP.FLD + RIP.WID + BUFF.TYP +
       ADJ.COVR + REGION + AGRI + URBAN + FOREST + ORDER + DO.FLD +
       PH.FLD + COND.FLD + PH.LAB + COND.LAB + ANC.LAB + SO4.LAB +
       DOC.LAB + ACIDSRC + PASTURE + INSTRHAB + EPI.SUB + VEL.DPTH +
       POOLQUAL + RIFFQUAL + CHAN.ALT + BANKSTAB + EMBEDDED + CH.FLOW +
       SHADING + REMOTE + AESTHET + WOOD.DEB + NUMROOT + MAXDEPTH +
       ST.GRAD + AVGWID + AVGTHAL + AVG.VEL + FLOW + ACREAGE +
       WETLANDS + BARREN + WATER + HIGHURB + LOWURB + PASTUR +
       PROBCROP + ROWCROP + crop + CONIFER + DECIDFOR + MIXEDFOR +
       EMERGWET + WOODYWET + COALMINE + TRANS + BKTRFLAG + BLACKWAT,
       data = NO3.MBSS.P, na.action = na.exclude, mincut = 5, minsize
        = 10, mindev = 0.01)
Variables actually used in tree construction:
 [1] "AGRI"     "AVGTHAL"  "SO4.LAB"  "WATER"    "MIXEDFOR" "COND.FLD"
```

```
 [7] "PH.LAB"   "ADJ.COVR" "VEL.DPTH" "ROWCROP"  "ST.GRAD"  "PROBCROP"
[13] "EPI.SUB"  "DOC.LAB"  "HIGHURB"  "FLOW"     "TEMP.FLD" "DO.FLD"
Number of terminal nodes:  21
Residual mean deviance:  0.4683 = 62.75 / 134
Distribution of residuals:
    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
 -1.3910 -0.3455  0.0240  0.0000  0.3035  3.7400
node), split,                     n,     deviance,    yval
      * denotes terminal node

 1) root                          155    418.9000     3.587
   2) AGRI<72.665                 96     104.1000     2.755
     4) AGRI<57.13                28     10.6700      1.911
       8) AVGTHAL<19.375 7   2.7650 1.289 *
       9) AVGTHAL>19.375 21   4.2880 2.119
        18) SO4.LAB<11.94 16   2.0240 2.245 *
        19) SO4.LAB>11.94 5   1.1900 1.714 *
     5) AGRI>57.13                68     65.2200      3.103
      10) WATER<0.55 53  41.0600 3.336
        20) MIXEDFOR<2.235 23  12.9500 3.907
          40) COND.FLD<167 16   4.3270 3.518
            80) PH.LAB<7.425 11   1.6540 3.782 *
            81) PH.LAB>7.425 5   0.2141 2.936 *
          41) COND.FLD>167 7   0.6523 4.797 *
        21) MIXEDFOR>2.235 30  14.8500 2.898
          42) ADJ.COVR:FR,TG 19   5.0180 2.594
            84) VEL.DPTH<12 5   0.9716 1.920 *
            85) VEL.DPTH>12 14   0.9624 2.835 *
          43) ADJ.COVR:CP,LN,OF,PA 11   5.0510 3.423
            86) ROWCROP<10.965 6   1.2190 2.985 *
            87) ROWCROP>10.965 5   1.3030 3.948 *
      11) WATER>0.55 15  11.1100 2.279
        22) ST.GRAD<0.9 8   0.7266 1.800 *
        23) ST.GRAD>0.9 7   6.4460 2.827 *
   3) AGRI>72.665                 59     140.5000     4.940
     6) PROBCROP<34.135 30  54.2000 4.193
      12) EPI.SUB<16.5 21  19.1000 3.706
        24) DOC.LAB<1.3 9   3.7630 4.461 *
        25) DOC.LAB>1.3 12   6.3550 3.139
          50) HIGHURB<0.02 5   2.3270 2.514 *
          51) HIGHURB>0.02 7   0.6774 3.586 *
      13) EPI.SUB>16.5            9      18.4800      5.330 *
     7) PROBCROP>34.135 29  52.2400 5.712
      14) AGRI<80.5               15     12.3500      4.931
        28) FLOW<6.425 5   0.9739 4.062 *
        29) FLOW>6.425 10   5.7130 5.365
          58) TEMP.FLD<17.6 5   0.6591 4.902 *
          59) TEMP.FLD>17.6       5      2.9100       5.828 *
      15) AGRI>80.5               14     20.9200      6.549
        30) DO.FLD<9.55 8   9.0900 7.207 *
        31) DO.FLD>9.55 6   3.7410 5.672 *
```

# APPENDIX 12:

# FISH IBI SAS MODELING

## Model Parameter Search

**SAS language**

```
DATA    one  ;
INFILE  'D:\g MBSS paper\SAS\SAS split data\FIBIcaldata.dat'        ;
INPUT      FIBI        RIP_WIDm      TEMP_FLD      BUFF_FOR     CROP
REGION_E PHYS_CP         ACID_NO      AGRI      URBAN FOREST      ORDER
DO_FLD       PH_FLD        COND_FLD      PH_LAB      COND_LAB
ANC_LAB      SO4_LAB      DOC_LAB    PASTURE       INSTRHAB    EPI_SUB
         VEL_DPTH POOLQUAL      RIFFQUAL    CHAN_ALT       BANKSTAB
EMBEDDED CH_FLOW      SHADING      REMOTE   AESTHET      WOOD_DEB
NUMROOT      MAXDEPTH   ST_GRAD      AVGWID      AVGTHALAVG_VEL
FLOW  ACREAGE      WETLANDS      BARREN      WATER      HIGHURB
         LOWURB      PASTUR        PROBCROP     ROWCROP      cropmix
         CONIFER      DECIDFOR      MIXEDFOR EMERGWET     WOODYWET
COALMINE    TRANS      BKTRFLAG      BLACKWAT;
proc print;    * proc corr  ;
*proc reg  ;
*model BIBI =   RIP_WIDm      TEMP_FLD      For_Buff      CROP      Reg_East
AGRI      PHYS_CP      URBAN      FOREST      ORDER_1      DO_FLD
PH_FLD      COND_FLD      PH_LAB      COND_LAB      ANC_LAB      SO4_LAB
DOC_LAB      ACID_no PASTURE      INSTRHAB      EPI_SUB      VEL_DPTH
POOLQUAL      RIFFQUAL      CHAN_ALT      BANKSTAB      EMBEDDED
CH_FLOW      SHADING      REMOTE      AESTHET      WOOD_DEB
NUMROOT      MAXDEPTH      ST_GRAD      AVGWID      AVGTHAL
AVG_VEL      FLOW      ACREAGE      WETLANDS      BARREN      WATER
HIGHURB      LOWURB      PASTUR      PROBCROP      ROWCROP      cropmix
CONIFER      DECIDFOR      MIXEDFOR   EMERGWET      WOODYWET
COALMINE      TRANS      BKTRFLAG / selection=rsquare adjrsq best=3;
run;      quit;
```

**Results**

**Dependent Variable: FIBI**
**R-Square Selection Method**

| Number in Model | R-Square | Adjusted R-Square | Variables in Model |
|---|---|---|---|
| 1 | 0.2420 | 0.2387 | INSTRHAB |
| 1 | 0.1791 | 0.1755 | BUFF_FOR |
| 1 | 0.1769 | 0.1733 | SO4_LAB |
| 2 | 0.3365 | 0.3308 | BUFF_FOR INSTRHAB |
| 2 | 0.3246 | 0.3188 | PH_LAB INSTRHAB |
| 2 | 0.3197 | 0.3138 | SO4_LAB INSTRHAB |
| 3 | 0.4008 | 0.3930 | ORDER PH_LAB INSTRHAB |
| 3 | 0.3771 | 0.3689 | TEMP_FLD BUFF_FOR INSTRHAB |
| 3 | 0.3754 | 0.3672 | ORDER PH_LAB VEL_DPTH |
| 4 | 0.4369 | 0.4270 | ORDER PH_LAB COND_LAB INSTRHAB |
| 4 | 0.4225 | 0.4124 | ORDER PH_LAB INSTRHAB TRANS |
| 4 | 0.4213 | 0.4112 | ORDER PH_LAB INSTRHAB REMOTE |
| 5 | 0.4685 | 0.4567 | ORDER PH_LAB COND_LAB INSTRHAB BLACKWAT |
| 5 | 0.4615 | 0.4497 | ACID_NO ORDER PH_LAB COND_LAB INSTRHAB |
| 5 | 0.4557 | 0.4437 | RIP_WIDm ORDER PH_LAB COND_LAB INSTRHAB |

## Model Calibration

**SAS language**

```
* Using the model variables  ORDER     PH_LAB     COND_LAB      INSTRHAB
          BLACKWAT     ;
*model FIBI = ORDER PH_LAB COND_LAB INSTRHAB BLACKWAT
          / collinoint tol  VIF R influence ;
*output out=resFIBI  residual = FIBIres;
*proc univariate normal plot;
*var FIBIres  ;
```

**Results**

**Dependent Variable: FIBI**
**Analysis of Variance**

| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Model | 5 | 72.77296 | 14.55459 | 40.01 | **<.0001** |
| Error | 227 | 82.57319 | 0.36376 | | |
| Corrected Total | 232 | 155.34615 | | | |

| | | | |
|---|---|---|---|
| Root MSE | 0.60312 | R-Square | 0.4685 |
| Dependent Mean | 3.69103 | **Adj R-Sq** | **0.4567** |
| Coeff Var | 16.34026 | | |

**Parameter Estimates**

| Variable | DF | Parameter Estimate | Standard Error | t Value | Pr > \|t\| | Tolerance | Variance Inflation |
|---|---|---|---|---|---|---|---|
| Intercept | 1 | 3.29201 | 0.17654 | 18.65 | <.0001 | . | 0 |
| ORDER | 1 | 0.31572 | 0.05269 | 5.99 | <.0001 | 0.06860 | 4.57734 |
| PH_LAB | 1 | -0.08316 | 0.01092 | -7.62 | <.0001 | 0.06566 | 5.22911 |
| COND_LAB | 1 | -0.00284 | 0.000630 | -4.50 | <.0001 | 0.91897 | .08818 |
| INSTRHAB | 1 | 0.06751 | 0.01041 | 6.49 | <.0001 | 0.85680 | 1.16714 |
| BLACKWAT | 1 | -0.67212 | 0.18308 | -3.67 | 0.0003 | 0.95352 | .04875 |

**Variable: FIBIres (Residual)**

| | | | |
|---|---|---|---|
| N | 233 | Sum Weights | 233 |
| Mean | 0 | Sum Observations | 0 |
| Std Deviation | 0.59658941 | Variance | 0.35591893 |
| Skewness | -0.1911917 | Kurtosis | -0.2596319 |
| Uncorrected SS | 82.5731915 | Corrected SS | 82.5731915 |
| Coeff Variation | . | Std Error Mean | 0.03908387 |

Tests for Normality

| Test | --Statistic--- | | -----p Value------ | |
|---|---|---|---|---|
| Shapiro-Wilk | W | 0.992425 | Pr < W | 0.2766 |

## Model Validation

### SAS language

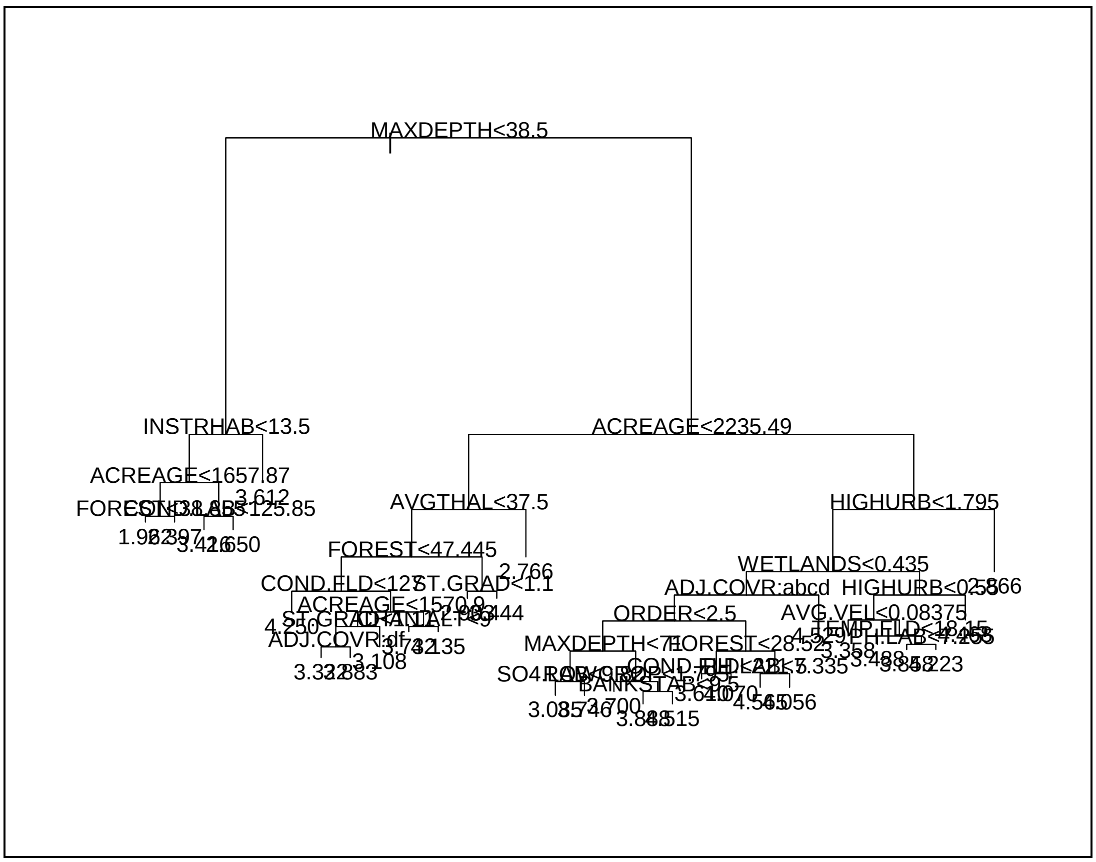
```
DATA    one  ;
INFILE  'D:\g MBSS paper\SAS\SAS split data\FIBIvaldata.dat'        ;
INPUT NO3     RIP_WIDm     TEMP_FLD     For_Buff     CROP     Reg_East
AGRI  PHYS_CP     URBAN     FOREST     ORDER_1     DO_FLD     PH_FLD
COND_FLD     PH_LAB     COND_LAB     ANC_LAB     SO4_LAB
DOC_LAB     ACID_no     PASTURE     INSTRHAB     EPI_SUB     VEL_DPTH
POOLQUAL     RIFFQUAL     CHAN_ALT   BANKSTAB     EMBEDDED
CH_FLOW     SHADING     REMOTE     AESTHET     WOOD_DEB
NUMROOT     MAXDEPTH     ST_GRAD     AVGWID     AVGTHAL
AVG_VEL     FLOW     ACREAGE     WETLANDS     BARREN     WATER
HIGHURB     LOWURB     PASTUR     PROBCROP     ROWCROP     cropmix
CONIFER     DECIDFOR     MIXEDFOR   EMERGWET     WOODYWET
COALMINE     TRANS     BKTRFLAG     BLACKWAT   ;

FIBIpred = 3.29 +.316*ORDER - .0832*PH_LAB -.0028*COND_LAB +
.0675*INSTRHAB - .6721*BLACKWAT ;
res = FIBI - FIBIpred ;  proc print;     Proc corr;  run; quit;
```

**Results:** Correlation Coefficient  for FIBI  vs FIBIpred = 0.56446 s**o $R^2$ = 0.32**

# APPENDIX 13:

# FISH IBI S-PLUS MODELING

## Regression Tree with all Parameters – all sites



**Tree Model with all Parameters**

tree(formula = FIBI.98 ~ RIP.WIDm + TEMP.FLD + BUFF.TYP + ADJ.COVR + REGION +AGRI + PHYCPIO + URBAN + FOREST + ORDER + DO.FLD + PH.FLD + COND.FLD + PH.LAB + COND.LAB + ANC.LAB + SO4.LAB + DOC.LAB +
ACIDSRC + PASTURE + INSTRHAB + EPI.SUB + VEL.DPTH + POOLQUAL + RIFFQUAL + CHAN.ALT + BANKSTAB + EMBEDDED + CH.FLOW + SHADING +
REMOTE + AESTHET + WOOD.DEB + NUMROOT + MAXDEPTH + ST.GRAD + AVGWID +AVGTHAL + AVG.VEL + FLOW + ACREAGE + WETLANDS + BARREN + WATER +HIGHURB + LOWURB + PASTUR + PROBCROP + ROWCROP + crop + CONIFER +DECIDFOR + MIXEDFOR + EMERGWET + WOODYWET + COALMINE + TRANS + BKTRFLAG + BLACKWAT,
data = FIBI.cal.data, na.action = na.exclude, mincut = 5, minsize = 10, mindev = 0.01)

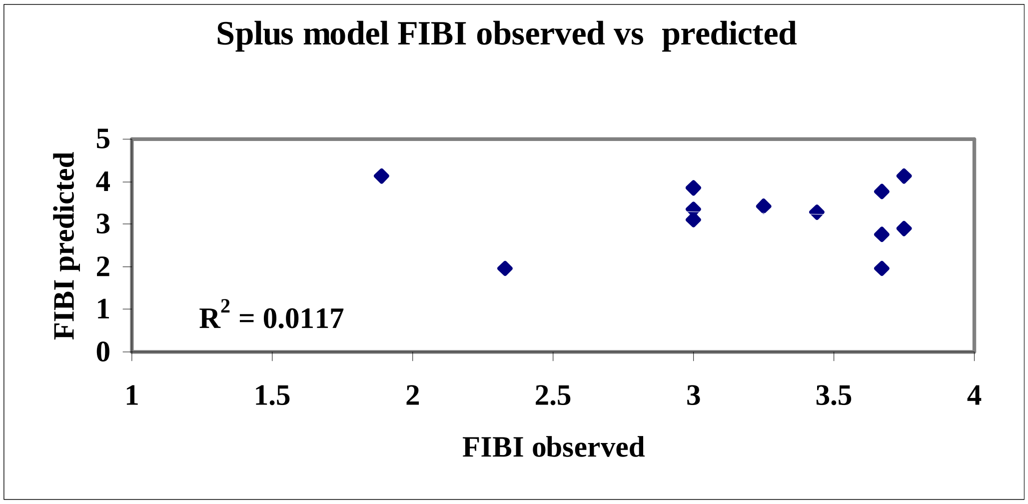
Variables actually used in tree construction: "MAXDEPTH" "INSTRHAB" "ACREAGE" "FOREST" "COND.LAB" "AVGTHAL" "COND.FLD" "ST.GRAD" "ADJ.COVR" "CHAN.ALT" "HIGHURB" "WETLANDS" "ORDER" "SO4.LAB" "ROWCROP" "BANKSTAB" "PH.LAB" "AVG.VEL" "TEMP.FLD"
Number of terminal nodes: 30
Residual mean deviance: 0.1284 = 26.06 / 203

**node), split, n, deviance, yval** * denotes terminal node

```
 1) root 233 128.5000 3.719
   2) MAXDEPTH<38.5 31  14.8300 2.767
     4) INSTRHAB<13.5 25   9.3160 2.564
       8) ACREAGE<1657.87 15   1.3980 2.252
        16) FOREST<38.855 5   0.4263 1.962 *
        17) FOREST>38.855 10   0.3408 2.397 *
       9) ACREAGE>1657.87 10   4.2580 3.033
        18) COND.LAB<125.85 5   1.4660 3.416 *
        19) COND.LAB>125.85 5   1.3250 2.650 *
     5) INSTRHAB>13.5 6   0.2041 3.612 *
   3) MAXDEPTH>38.5 202  81.2600 3.865
     6) ACREAGE<2235.49 68  26.1500 3.582
      12) AVGTHAL<37.5 61  20.3600 3.675
        24) FOREST<47.445 50  13.4400 3.791
          48) COND.FLD<127 9   2.1190 4.250 *
          49) COND.FLD>127 41   9.0060 3.690
            98) ACREAGE<1570.9 27   6.1180 3.549
             196) ST.GRAD<1.11 19   2.5080 3.735
               392) ADJ.COVR:OF,PA 5   0.2491 3.322 *
               393) ADJ.COVR:CP,FR,LN 14   1.1000 3.883 *
             197) ST.GRAD>1.11 8   1.3910 3.108 *
```

```
        99) ACREAGE>1570.9 14   1.3160 3.962
          198) CHAN.ALT<9 6   0.4345 3.732 *
          199) CHAN.ALT>9 8   0.3240 4.135 *
      25) FOREST>47.445 11   3.2060 3.149
        50) ST.GRAD<1.1 6   1.9120 2.903 *
        51) ST.GRAD>1.1 5   0.4973 3.444 *
     13) AVGTHAL>37.5 7   0.5954 2.766 *
   7) ACREAGE>2235.49 134  46.8900 4.008
     14) HIGHURB<1.795 129  37.4900 4.053
       28) WETLANDS<0.435 88  25.2800 4.149
         56) ADJ.COVR:CP,FR,LN,OF 72  21.4100 4.064
          112) ORDER<2.5 33  10.7900 3.831
            224) MAXDEPTH<71 14   3.7540 3.463
              448) SO4.LAB<9.82 6   0.8976 3.085 *
              449) SO4.LAB>9.82 8   1.3570 3.746 *
            225) MAXDEPTH>71 19   3.7320 4.103
              450) ROWCROP<1.795 5   0.3000 3.700 *
              451) ROWCROP>1.795 14   2.3320 4.246
                902) BANKSTAB<9.5 6   0.3759 3.888 *
                903) BANKSTAB>9.5 8   0.6098 4.515 *
          113) ORDER>2.5 39   7.3110 4.262
            226) FOREST<28.52 11   1.4520 3.861
              452) COND.FLD<221.5 5   0.2986 3.610 *
              453) COND.FLD>221.5 6   0.5766 4.070 *
            227) FOREST>28.52 28   3.3960 4.419
              454) PH.LAB<7.335 20   1.1600 4.565 *
              455) PH.LAB>7.335 8   0.7602 4.056 *
         57) ADJ.COVR:PA,TG 16   1.0430 4.529 *
       29) WETLANDS>0.435 41   9.6370 3.846
         58) HIGHURB<0.55 35   6.4790 3.739
          116) AVG.VEL<0.08375 9   1.2960 3.358 *
          117) AVG.VEL>0.08375 26   3.4210 3.871
            234) TEMP.FLD<18.15 5   0.5387 3.488 *
            235) TEMP.FLD>18.15 21   1.9740 3.962
              470) PH.LAB<7.255 15   0.8318 3.858 *
              471) PH.LAB>7.255 6   0.5699 4.223 *
         59) HIGHURB>0.55 6   0.4351 4.468 *
     15) HIGHURB>1.795 5   2.6250 2.866 *
```

## Model Validation




| FIBI_98 | Pred | FIBI_98 | Pred |
|---|---|---|---|
| 1.89 | 4.13 | 3.89 | 4.08 |
| 2.33 | 1.96 | 3.89 | 4.13 |
| 3 | 3.86 | 4 | 3.60 |
| 3 | 3.36 | 4 | 4.62 |
| 3 | 3.11 | 4.11 | 3.53 |
| 3 | 3.86 | 4.11 | 4.16 |
| 3.25 | 3.42 | 4.25 | 3.36 |
| 3.44 | 3.28 | 4.25 | 4.62 |
| 3.67 | 2.77 | 4.33 | 4.62 |
| 3.67 | 3.77 | 4.75 | 4.62 |
| 3.67 | 1.96 | 4.75 | 4.62 |
| 3.75 | 4.13 | 4.78 | 4.72 |
| 3.75 | 2.90 | 4.78 | 4.16 |

**Development of equivalent $R^2$ for regression tree model**

| REGION | FIBI_98 | delta | square |
|---|---|---|---|
| CP | 1.75 | -1.94 | 3.78 |
| CP | 2 | -1.69 | 2.87 |
| CP | 2 | -1.69 | 2.87 |
| CP | 2.25 | -1.44 | 2.08 |
| CP | 2.25 | -1.44 | 2.08 |
| CP | 2.25 | -1.44 | 2.08 |
| CP | 2.25 | -1.44 | 2.08 |
| CP | 2.5 | -1.19 | 1.43 |
| CP | 2.5 | -1.19 | 1.43 |
| CP | 2.5 | -1.19 | 1.43 |
| CP | 2.5 | -1.19 | 1.43 |
| CP | 2.5 | -1.19 | 1.43 |
| CP | 2.5 | -1.19 | 1.43 |
| CP | 2.75 | -0.94 | 0.89 |
| CP | 2.75 | -0.94 | 0.89 |
| CP | 2.75 | -0.94 | 0.89 |
| CP | 2.75 | -0.94 | 0.89 |
| CP | 2.75 | -0.94 | 0.89 |
| CP | 3 | -0.69 | 0.48 |
| CP | 3 | -0.69 | 0.48 |
| CP | 3 | -0.69 | 0.48 |
| CP | 3 | -0.69 | 0.48 |
| CP | 3 | -0.69 | 0.48 |
| CP | 3 | -0.69 | 0.48 |
| CP | 3 | -0.69 | 0.48 |
| CP | 3 | -0.69 | 0.48 |
| CP | 3 | -0.69 | 0.48 |
| CP | 3 | -0.69 | 0.48 |
| CP | 3 | -0.69 | 0.48 |
| CP | 3.25 | -0.44 | 0.20 |

| corrected total SS | |
|---|---|
| **CP** | 67.01 |
| **Pd** | 75.65 |
| **ALL** | 142.66 |

| Resid SS | |
|---|---|
| | **deviance** |
| **CP** | 4.54 |
| | 0.17 |
| | 12.34 |
| | 0.61 |
| | **17.66** |
| **Pd** | 0.27 |
| | 8.67 |
| | 0.52 |
| | 11.1 |
| | 13.1 |
| | 1.89 |
| | **35.55** |
| **ALL** | 9.3 |
| | 0.2 |
| | 20.3 |
| | 0.59 |
| | 37.4 |
| | 2.62 |
| | **70.41** |

| | | | |
|---|---|---|---|
| CP | 3.25 | -0.44 | 0.20 |
| CP | 3.25 | -0.44 | 0.20 |
| CP | 3.25 | -0.44 | 0.20 |
| CP | 3.25 | -0.44 | 0.20 |
| CP | 3.25 | -0.44 | 0.20 |
| CP | 3.25 | -0.44 | 0.20 |
| CP | 3.25 | -0.44 | 0.20 |
| CP | 3.25 | -0.44 | 0.20 |
| CP | 3.5 | -0.19 | 0.04 |
| CP | 3.5 | -0.19 | 0.04 |
| CP | 3.5 | -0.19 | 0.04 |
| CP | 3.5 | -0.19 | 0.04 |
| CP | 3.5 | -0.19 | 0.04 |
| CP | 3.5 | -0.19 | 0.04 |
| CP | 3.5 | -0.19 | 0.04 |
| CP | 3.67 | -0.02 | 0.00 |
| CP | 3.75 | 0.06 | 0.00 |
| CP | 3.75 | 0.06 | 0.00 |
| CP | 3.75 | 0.06 | 0.00 |
| CP | 3.75 | 0.06 | 0.00 |
| CP | 3.75 | 0.06 | 0.00 |
| CP | 3.75 | 0.06 | 0.00 |
| CP | 3.75 | 0.06 | 0.00 |
| CP | 3.75 | 0.06 | 0.00 |
| CP | 3.75 | 0.06 | 0.00 |
| CP | 3.75 | 0.06 | 0.00 |
| CP | 3.75 | 0.06 | 0.00 |
| CP | 3.75 | 0.06 | 0.00 |
| CP | 3.75 | 0.06 | 0.00 |
| CP | 3.75 | 0.06 | 0.00 |
| CP | 3.75 | 0.06 | 0.00 |
| CP | 3.75 | 0.06 | 0.00 |
| CP | 3.75 | 0.06 | 0.00 |
| CP | 3.75 | 0.06 | 0.00 |
| CP | 3.75 | 0.06 | 0.00 |
| CP | 3.89 | 0.20 | 0.04 |

| **Res/Cor SS** | |
|---|---|
| **CP** | 0.26 |
| **Pd** | 0.47 |
| **ALL** | 0.49 |

| **$R^2$** | |
|---|---|
| **CP** | 0.74 |
| **Pd** | 0.53 |
| **ALL** | 0.51 |

| | | | |
|---|---|---|---|
| CP | 4 | 0.31 | 0.09 |
| CP | 4 | 0.31 | 0.09 |
| CP | 4 | 0.31 | 0.09 |
| CP | 4 | 0.31 | 0.09 |
| CP | 4 | 0.31 | 0.09 |
| CP | 4 | 0.31 | 0.09 |
| CP | 4 | 0.31 | 0.09 |
| CP | 4 | 0.31 | 0.09 |
| CP | 4 | 0.31 | 0.09 |
| CP | 4 | 0.31 | 0.09 |
| CP | 4 | 0.31 | 0.09 |
| CP | 4 | 0.31 | 0.09 |
| CP | 4 | 0.31 | 0.09 |
| CP | 4 | 0.31 | 0.09 |
| CP | 4.11 | 0.42 | 0.17 |
| CP | 4.25 | 0.56 | 0.31 |
| CP | 4.25 | 0.56 | 0.31 |
| CP | 4.25 | 0.56 | 0.31 |
| CP | 4.25 | 0.56 | 0.31 |
| CP | 4.25 | 0.56 | 0.31 |
| CP | 4.25 | 0.56 | 0.31 |
| CP | 4.25 | 0.56 | 0.31 |
| CP | 4.25 | 0.56 | 0.31 |
| CP | 4.5 | 0.81 | 0.65 |
| CP | 4.5 | 0.81 | 0.65 |
| CP | 4.5 | 0.81 | 0.65 |
| CP | 4.5 | 0.81 | 0.65 |
| CP | 4.5 | 0.81 | 0.65 |
| CP | 4.5 | 0.81 | 0.65 |
| CP | 4.5 | 0.81 | 0.65 |
| CP | 4.5 | 0.81 | 0.65 |
| CP | 4.5 | 0.81 | 0.65 |
| CP | 4.5 | 0.81 | 0.65 |
| CP | 4.5 | 0.81 | 0.65 |
| CP | 4.5 | 0.81 | 0.65 |
| CP | 4.56 | 0.87 | 0.75 |
| CP | 4.75 | 1.06 | 1.12 |

| | | | |
|---|---|---|---|
| CP | 4.75 | 1.06 | 1.12 |
| CP | 4.75 | 1.06 | 1.12 |
| CP | 4.75 | 1.06 | 1.12 |
| CP | 4.75 | 1.06 | 1.12 |
| CP | 4.75 | 1.06 | 1.12 |
| CP | 4.75 | 1.06 | 1.12 |
| CP | 4.75 | 1.06 | 1.12 |
| CP | 4.75 | 1.06 | 1.12 |
| CP | 4.75 | 1.06 | 1.12 |
| CP | 4.75 | 1.06 | 1.12 |
| CP | 4.75 | 1.06 | 1.12 |
| CP | 4.75 | 1.06 | 1.12 |
| CP | 5 | 1.31 | 1.71 |
| P | 1.67 | -2.08 | 4.32 |
| P | 1.89 | -1.86 | 3.45 |
| P | 1.89 | -1.86 | 3.45 |
| P | 1.89 | -1.86 | 3.45 |
| P | 2.11 | -1.64 | 2.68 |
| P | 2.11 | -1.64 | 2.68 |
| P | 2.11 | -1.64 | 2.68 |
| P | 2.33 | -1.42 | 2.01 |
| P | 2.33 | -1.42 | 2.01 |
| P | 2.33 | -1.42 | 2.01 |
| P | 2.56 | -1.19 | 1.41 |
| P | 2.56 | -1.19 | 1.41 |
| P | 2.56 | -1.19 | 1.41 |
| P | 2.78 | -0.97 | 0.94 |
| P | 2.78 | -0.97 | 0.94 |
| P | 2.78 | -0.97 | 0.94 |
| P | 2.78 | -0.97 | 0.94 |
| P | 3 | -0.75 | 0.56 |
| P | 3 | -0.75 | 0.56 |
| P | 3 | -0.75 | 0.56 |
| P | 3 | -0.75 | 0.56 |
| P | 3 | -0.75 | 0.56 |
| P | 3 | -0.75 | 0.56 |
| P | 3 | -0.75 | 0.56 |

| | | | |
|---|---|---|---|
| P | 3 | -0.75 | 0.56 |
| P | 3 | -0.75 | 0.56 |
| P | 3 | -0.75 | 0.56 |
| P | 3 | -0.75 | 0.56 |
| P | 3.22 | -0.53 | 0.28 |
| P | 3.22 | -0.53 | 0.28 |
| P | 3.22 | -0.53 | 0.28 |
| P | 3.22 | -0.53 | 0.28 |
| P | 3.22 | -0.53 | 0.28 |
| P | 3.22 | -0.53 | 0.28 |
| P | 3.22 | -0.53 | 0.28 |
| P | 3.22 | -0.53 | 0.28 |
| P | 3.22 | -0.53 | 0.28 |
| P | 3.44 | -0.31 | 0.10 |
| P | 3.44 | -0.31 | 0.10 |
| P | 3.44 | -0.31 | 0.10 |
| P | 3.44 | -0.31 | 0.10 |
| P | 3.44 | -0.31 | 0.10 |
| P | 3.44 | -0.31 | 0.10 |
| P | 3.44 | -0.31 | 0.10 |
| P | 3.44 | -0.31 | 0.10 |
| P | 3.44 | -0.31 | 0.10 |
| P | 3.67 | -0.08 | 0.01 |
| P | 3.67 | -0.08 | 0.01 |
| P | 3.67 | -0.08 | 0.01 |
| P | 3.67 | -0.08 | 0.01 |
| P | 3.67 | -0.08 | 0.01 |
| P | 3.67 | -0.08 | 0.01 |
| P | 3.67 | -0.08 | 0.01 |
| P | 3.67 | -0.08 | 0.01 |
| P | 3.67 | -0.08 | 0.01 |
| P | 3.67 | -0.08 | 0.01 |
| P | 3.67 | -0.08 | 0.01 |
| P | 3.67 | -0.08 | 0.01 |
| P | 3.67 | -0.08 | 0.01 |
| P | 3.67 | -0.08 | 0.01 |
| P | 3.67 | -0.08 | 0.01 |

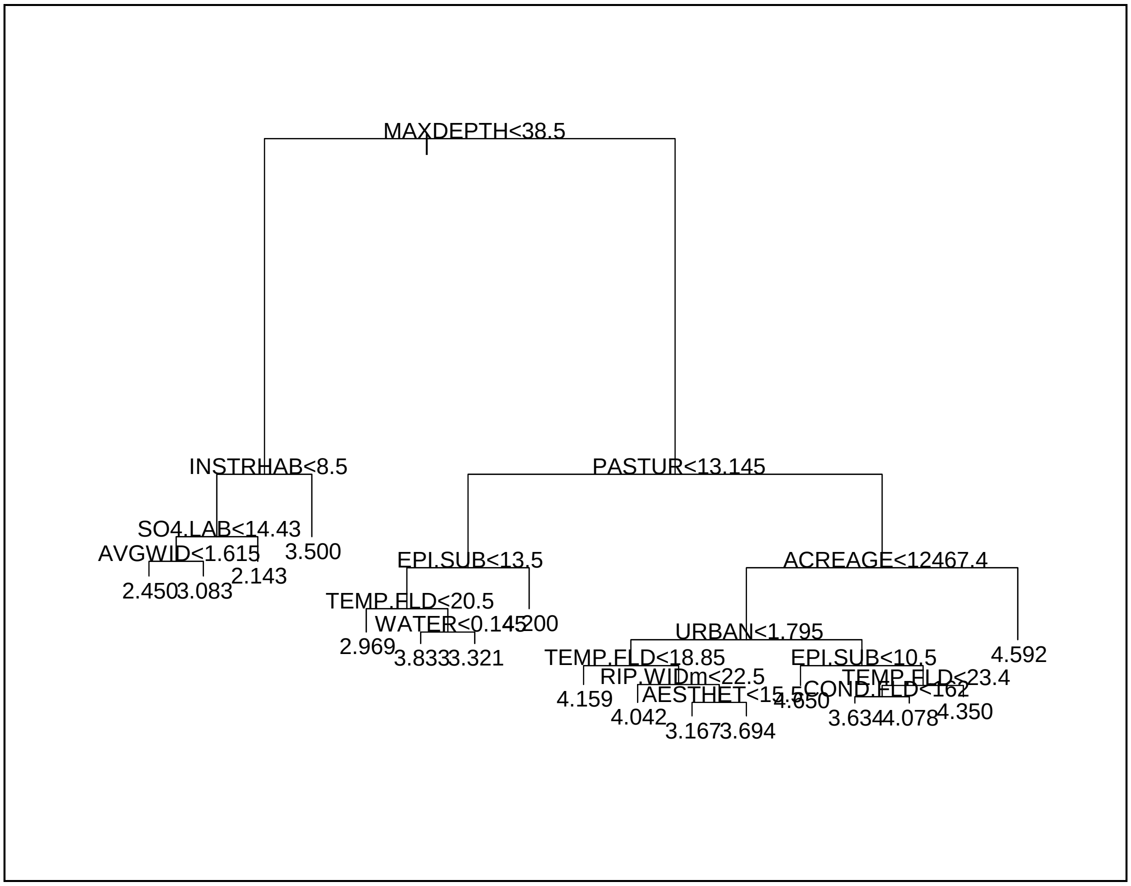
| | | | |
|---|---|---|---|
| P | 3.67 | -0.08 | 0.01 |
| P | 3.89 | 0.14 | 0.02 |
| P | 3.89 | 0.14 | 0.02 |
| P | 3.89 | 0.14 | 0.02 |
| P | 3.89 | 0.14 | 0.02 |
| P | 3.89 | 0.14 | 0.02 |
| P | 3.89 | 0.14 | 0.02 |
| P | 3.89 | 0.14 | 0.02 |
| P | 3.89 | 0.14 | 0.02 |
| P | 3.89 | 0.14 | 0.02 |
| P | 3.89 | 0.14 | 0.02 |
| P | 3.89 | 0.14 | 0.02 |
| P | 3.89 | 0.14 | 0.02 |
| P | 3.89 | 0.14 | 0.02 |
| P | 3.89 | 0.14 | 0.02 |
| P | 3.89 | 0.14 | 0.02 |
| P | 3.89 | 0.14 | 0.02 |
| P | 3.89 | 0.14 | 0.02 |
| P | 3.89 | 0.14 | 0.02 |
| P | 3.89 | 0.14 | 0.02 |
| P | 3.89 | 0.14 | 0.02 |
| P | 3.89 | 0.14 | 0.02 |
| P | 3.89 | 0.14 | 0.02 |
| P | 3.89 | 0.14 | 0.02 |
| P | 4.11 | 0.36 | 0.13 |
| P | 4.11 | 0.36 | 0.13 |
| P | 4.11 | 0.36 | 0.13 |
| P | 4.11 | 0.36 | 0.13 |
| P | 4.11 | 0.36 | 0.13 |
| P | 4.11 | 0.36 | 0.13 |
| P | 4.11 | 0.36 | 0.13 |
| P | 4.11 | 0.36 | 0.13 |
| P | 4.11 | 0.36 | 0.13 |
| P | 4.11 | 0.36 | 0.13 |
| P | 4.11 | 0.36 | 0.13 |
| P | 4.11 | 0.36 | 0.13 |
| P | 4.11 | 0.36 | 0.13 |

| | | | |
|---|---|---|---|
| P | 4.11 | 0.36 | 0.13 |
| P | 4.33 | 0.58 | 0.34 |
| P | 4.33 | 0.58 | 0.34 |
| P | 4.33 | 0.58 | 0.34 |
| P | 4.33 | 0.58 | 0.34 |
| P | 4.33 | 0.58 | 0.34 |
| P | 4.33 | 0.58 | 0.34 |
| P | 4.33 | 0.58 | 0.34 |
| P | 4.33 | 0.58 | 0.34 |
| P | 4.33 | 0.58 | 0.34 |
| P | 4.33 | 0.58 | 0.34 |
| P | 4.33 | 0.58 | 0.34 |
| P | 4.33 | 0.58 | 0.34 |
| P | 4.33 | 0.58 | 0.34 |
| P | 4.33 | 0.58 | 0.34 |
| P | 4.33 | 0.58 | 0.34 |
| P | 4.33 | 0.58 | 0.34 |
| P | 4.33 | 0.58 | 0.34 |
| P | 4.33 | 0.58 | 0.34 |
| P | 4.33 | 0.58 | 0.34 |
| P | 4.33 | 0.58 | 0.34 |
| P | 4.56 | 0.81 | 0.66 |
| P | 4.56 | 0.81 | 0.66 |
| P | 4.56 | 0.81 | 0.66 |
| P | 4.56 | 0.81 | 0.66 |
| P | 4.56 | 0.81 | 0.66 |
| P | 4.56 | 0.81 | 0.66 |
| P | 4.56 | 0.81 | 0.66 |
| P | 4.56 | 0.81 | 0.66 |
| P | 4.56 | 0.81 | 0.66 |
| P | 4.56 | 0.81 | 0.66 |
| P | 4.56 | 0.81 | 0.66 |
| P | 4.56 | 0.81 | 0.66 |
| P | 4.56 | 0.81 | 0.66 |
| P | 4.78 | 1.03 | 1.06 |
| P | 4.78 | 1.03 | 1.06 |
| P | 4.78 | 1.03 | 1.06 |

| | | | |
|---|---|---|---|
| P | 4.78 | 1.03 | 1.06 |
| P | 4.78 | 1.03 | 1.06 |
| P | 4.78 | 1.03 | 1.06 |
| P | 4.78 | 1.03 | 1.06 |
| P | 4.78 | 1.03 | 1.06 |
| P | 5 | 1.25 | 1.57 |
| P | 5 | 1.25 | 1.57 |

| **mean** | |
|---|---|
| **CP** | 3.69 |
| **P** | 3.75 |
| **ALL** | 3.72 |

**FIBI Regression Tree Model**
**Coastal Plain Data**




Max depth < 38.5
Instream habitat < 8.5 % pasture < 13.145
Epifaunal substrate < 13.5 acreage < 12467.4

**Regression tree:**

```
tree(formula = FIBI.98 ~ RIP.WIDm + TEMP.FLD + BUFF.TYP + ADJ.COVR +
      REGION + AGRI + URBAN + FOREST + ORDER + DO.FLD + PH.FLD +
      COND.FLD + PH.LAB + COND.LAB + ANC.LAB + SO4.LAB + DOC.LAB +
      ACIDSRC + PASTURE + INSTRHAB + EPI.SUB + VEL.DPTH + POOLQUAL +
      RIFFQUAL + CHAN.ALT + BANKSTAB + EMBEDDED + CH.FLOW + SHADING +
      REMOTE + AESTHET + WOOD.DEB + NUMROOT + MAXDEPTH + ST.GRAD +
      AVGWID + AVGTHAL + AVG.VEL + FLOW + ACREAGE + WETLANDS + BARREN +
      WATER + HIGHURB + LOWURB + PASTUR + PROBCROP + ROWCROP + crop +
      CONIFER + DECIDFOR + MIXEDFOR + EMERGWET + WOODYWET + COALMINE +
      TRANS + BKTRFLAG + BLACKWAT, data = FIBI.CP, na.action =
      na.exclude, mincut = 5, minsize = 10, mindev = 0.01)
```

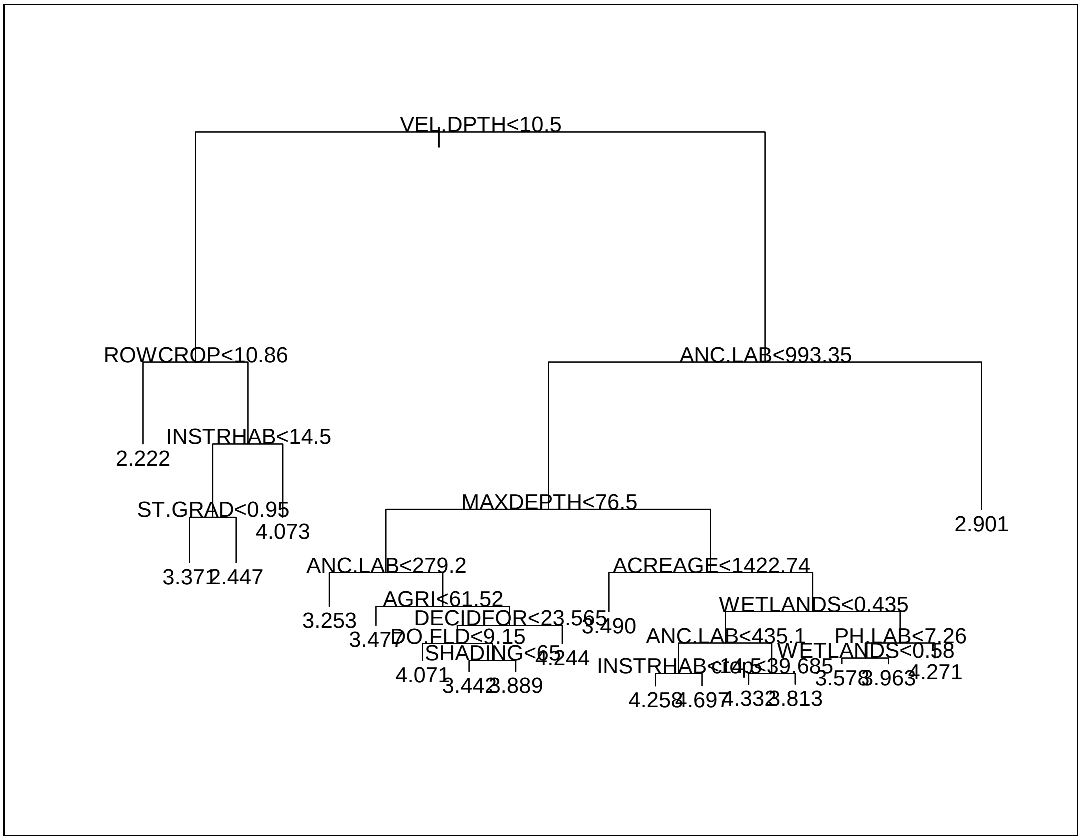
**Variables actually used in tree construction:**

```
 [1] "MAXDEPTH" "INSTRHAB" "SO4.LAB"  "AVGWID"   "PASTUR"   "EPI.SUB"
 [7] "TEMP.FLD" "WATER"    "ACREAGE"  "URBAN"    "RIP.WIDm" "AESTHET"
[13] "COND.FLD"

Number of terminal nodes:  17
Residual mean deviance:  0.08351 = 8.268 / 99
Distribution of residuals:
     Min.  1st Qu.   Median     Mean  3rd Qu.     Max.
 -0.63400 -0.17200 -0.01588  0.00000  0.15820  0.78130
```

**node), split, n, deviance, yval**

```
      * denotes terminal node

  1) root 116 67.0100 3.694
    2) MAXDEPTH<38.5             25     9.1600       2.810
      4) INSTRHAB<8.5            18     4.1560       2.542
        8) SO4.LAB<14.43 11  1.9770 2.795
         16) AVGWID<1.615 5  0.0500 2.450 *
         17) AVGWID>1.615 6  0.8333 3.083 *
        9) SO4.LAB>14.43 7  0.3571 2.143 *
      5) INSTRHAB>8.5            7      0.3750       3.500 *
    3) MAXDEPTH>38.5             91     32.9600      3.937
      6) PASTUR<13.145           26     7.7500       3.500
       12) EPI.SUB<13.5          21     4.5420       3.333
         24) TEMP.FLD<20.5 8  0.9297 2.969 *
         25) TEMP.FLD>20.5 13  1.8940 3.558
           50) WATER<0.145 6  0.3333 3.833 *
           51) WATER>0.145 7  0.7143 3.321 *
       13) EPI.SUB>13.5          5      0.1750       4.200 *
      7) PASTUR>13.145           65     18.2700      4.111
       14) ACREAGE<12467.4       48     12.3400      3.941
         28) URBAN<1.795 28  6.1790 3.772
           56) TEMP.FLD<18.85 7  0.8361 4.159 *
           57) TEMP.FLD>18.85 21  3.9460 3.643
            114) RIP.WIDm<22.5 6  0.8021 4.042 *
            115) RIP.WIDm>22.5 15  1.8080 3.483
              230) AESTHET<15.5 6  0.2083 3.167 *
              231) AESTHET>15.5 9  0.5972 3.694 *
         29) URBAN>1.795 20  4.2370 4.178
           58) EPI.SUB<10.5 5  0.0750 4.650 *
           59) EPI.SUB>10.5 15  2.6770 4.021
            118) TEMP.FLD<23.4 10  1.2890 3.856
              236) COND.FLD<162 5  0.5641 3.634 *
              237) COND.FLD>162 5  0.2317 4.078 *
            119) TEMP.FLD>23.4 5  0.5750 4.350 *
       15) ACREAGE>12467.4       17     0.6104       4.592 *
```

**FIBI Regression Tree Model**
**Piedmont Data**




```
            Vel depth < 10.5
Row crop < 10.86                        ANC lab < 993.35
     Instream habitat < 14.5            Max depth < 76.5
```

```
Regression tree:
tree(formula = FIBI.98 ~ RIP.WIDm + TEMP.FLD + BUFF.TYP + ADJ.COVR +
      REGION + AGRI + URBAN + FOREST + ORDER + DO.FLD + PH.FLD +
      COND.FLD + PH.LAB + COND.LAB + ANC.LAB + SO4.LAB + DOC.LAB +
      ACIDSRC + PASTURE + INSTRHAB + EPI.SUB + VEL.DPTH + POOLQUAL +
      RIFFQUAL + CHAN.ALT + BANKSTAB + EMBEDDED + CH.FLOW + SHADING +
      REMOTE + AESTHET + WOOD.DEB + NUMROOT + MAXDEPTH + ST.GRAD +
      AVGWID + AVGTHAL + AVG.VEL + FLOW + ACREAGE + WETLANDS + BARREN +
      WATER + HIGHURB + LOWURB + PASTUR + PROBCROP + ROWCROP + crop +
      CONIFER + DECIDFOR + MIXEDFOR + EMERGWET + WOODYWET + COALMINE +
      TRANS + BKTRFLAG + BLACKWAT, data = FIBI.P, na.action =
      na.exclude, mincut = 5, minsize = 10, mindev = 0.01)
Variables actually used in tree construction:
 [1] "VEL.DPTH" "ROWCROP"  "INSTRHAB" "ST.GRAD"  "ANC.LAB"  "MAXDEPTH"
 [7] "AGRI"     "DECIDFOR" "DO.FLD"   "SHADING"  "ACREAGE"  "WETLANDS"
[13] "crop"     "PH.LAB"
Number of terminal nodes:  19
Residual mean deviance:  0.1305 = 16.05 / 123
Distribution of residuals:
     Min.  1st Qu.   Median     Mean  3rd Qu.     Max.
 -0.81110 -0.18090  0.03909  0.00000  0.22140  1.22300
node), split,             n,     deviance,    yval
      * denotes terminal node

  1) root 142 75.6500 3.748
    2) VEL.DPTH<10.5       27     19.9000      3.066
      4) ROWCROP<10.86     6      0.2729       2.222 *
      5) ROWCROP>10.86     21     14.1200      3.308
       10) INSTRHAB<14.5   15     8.6730       3.001
         20) ST.GRAD<0.95 9  2.6550 3.371 *
         21) ST.GRAD>0.95 6  2.9420 2.447 *
       11) INSTRHAB>14.5 6  0.5243 4.073 *
    3) VEL.DPTH>10.5       115    40.2500      3.908
      6) ANC.LAB<993.35    106    28.4500      3.994
       12) MAXDEPTH<76.5   50     11.1000      3.782
         24) ANC.LAB<279.2 7  1.1230 3.253 *
         25) ANC.LAB>279.2 43  7.6980 3.868
           50) AGRI<61.52 7  1.0340 3.477 *
           51) AGRI>61.52 36  5.3880 3.944
            102) DECIDFOR<23.565 26  3.6250 3.828
              204) DO.FLD<9.15 11  0.6697 4.071 *
              205) DO.FLD>9.15 15  1.8340 3.651
                410) SHADING<65 8  0.4973 3.442 *
                411) SHADING>65 7  0.5941 3.889 *
            103) DECIDFOR>23.565 10  0.5158 4.244 *
       13) MAXDEPTH>76.5 56 13.1000 4.183
         26) ACREAGE<1422.74 5  0.5378 3.490 *
         27) ACREAGE>1422.74 51  9.9200 4.251
           54) WETLANDS<0.435 33  5.4180 4.401
            108) ANC.LAB<435.1 22  1.9740 4.577
              216) INSTRHAB<14.5 6  0.6557 4.258 *
              217) INSTRHAB>14.5 16  0.4791 4.697 *
            109) ANC.LAB>435.1 11  1.3980 4.049
              218) crop<39.685 5  0.1013 4.332 *
              219) crop>39.685 6  0.5633 3.813 *
           55) WETLANDS>0.435 18  2.3970 3.976
            110) PH.LAB<7.26 11  0.8278 3.788
              220) WETLANDS<0.58 5  0.2615 3.578 *
              221) WETLANDS>0.58 6  0.1613 3.963 *
            111) PH.LAB>7.26 7  0.5703 4.271 *
      7) ANC.LAB>993.35 9  1.8920 2.901 *
```

# APPENDIX 14:

# BENTHIC IBI SAS MODELING

## Model Parameter Search

### SAS language

```
DATA    one  ;
INFILE  'D:\g MBSS paper\SAS\SAS split data\BIBIcaldata.dat'        ;
INPUT BIBI              RIP_WIDm      TEMP_FLD      BUFFER      F0R_BUF
CROP      REG_EAST   PHYS_CP      ACID_no      AGRI      URBAN      FOREST
ORDER      DO_FLD      PH_FLD       COND_FLD      PH_LAB      COND_LAB
ANC_LAB      SO4_LAB   DOC_LAB   PASTURE      INSTRHAB      EPI_SUB
VEL_DPTH      POOLQUAL      RIFFQUAL      CHAN_ALT      BANKSTAB
EMBEDDED      CH_FLOW      SHADING      REMOTE      AESTHET
WOOD_DEB      NUMROOT
MAXDEPTH      ST_GRAD      AVGWID      AVGTHAL      AVG_VEL      FLOW
ACREAGE      WETLANDS      BARREN      WATER      HIGHURB      LOWURB
PASTUR      PROBCROP        ROWCROP      cropmix      CONIFER
DECIDFOR      MIXEDFOR      EMERGWET      WOODYWET      COALMINE
TRANS      BKTRFLAG      BLACKWAT   ;
*proc print;    * proc corr  ;
proc reg  ;
*model BIBI =   RIP_WIDm      TEMP_FLD      For_Buff      CROP      Reg_East
AGRI        PHYS_CP      URBAN      FOREST      ORDER_1      DO_FLD
PH_FLD      COND_FLD          PH_LAB      COND_LAB      ANC_LAB
SO4_LAB      DOC_LAB      ACID_no      PASTURE      INSTRHAB      EPI_SUB
VEL_DPTH      POOLQUAL      RIFFQUAL      CHAN_ALT      BANKSTAB
EMBEDDED      CH_FLOW      SHADING      REMOTE      AESTHET
WOOD_DEB  NUMROOT      MAXDEPTH      ST_GRAD      AVGWID
AVGTHAL   AVG_VEL      FLOW      ACREAGE      WETLANDS      BARREN
WATER      HIGHURB      LOWURB      PASTUR      PROBCROP   ROWCROP
cropmix      CONIFER      DECIDFOR      MIXEDFOR   EMERGWET
WOODYWET      COALMINE      TRANS      BKTRFLAG      BLACKWAT          /
selection=rsquare adjrsq best=3;
run;       quit;
```

**Results**

**R-Square Selection Method**

| Number in Model | $R^2$ | Adjusted R-Square | Variables in Model |
|---|---|---|---|
| 1 | 0.1440 | 0.1405 | RIP_WIDm |
| 1 | 0.1371 | 0.1336 | INSTRHAB |
| 1 | 0.1311 | 0.1275 | SO4_LAB |
| 2 | 0.2583 | 0.2522 | SO4_LAB EMBEDDED |
| 2 | 0.2488 | 0.2426 | BUFFER EMBEDDED |
| 2 | 0.2408 | 0.2345 | RIP_WIDm SO4_LAB |
| 3 | 0.3433 | 0.3352 | RIP_WIDm BUFFER EMBEDDED |
| 3 | 0.3426 | 0.3345 | RIP_WIDm SO4_LAB EMBEDDED |
| 3 | 0.3270 | 0.3187 | BUFFER F0R_BUF EMBEDDED |
| 4 | 0.3865 | 0.3764 | RIP_WIDm PH_LAB SO4_LAB EMBEDDED |
| 4 | 0.3701 | 0.3597 | RIP_WIDm BUFFER URBAN EMBEDDED |
| 4 | 0.3693 | 0.3589 | RIP_WIDm ORDER SO4_LAB EMBEDDED |
| 5 | 0.4120 | 0.3998 | RIP_WIDm PH_LAB SO4_LAB EMBEDDED WOOD_DEB |
| 5 | 0.3996 | 0.3871 | RIP_WIDm BUFFER URBAN EMBEDDED WOOD_DEB |
| 5 | 0.3991 | 0.3866 | RIP_WIDm PH_LAB SO4_LAB EMBEDDED NUMROOT |

## Model Calibration

**SAS language**

```
*Using the model variables RIP_WIDm  PH_LAB    SO4_LAB       EMBEDDED
          WOOD_DEB  ;
model BIBI = RIP_WIDm PH_LAB SO4_LAB EMBEDDED WOOD_DEB
          / collinoint tol  VIF R influence ;
output out=resBIBI  residual = BIBIres;
proc univariate normal plot;
var BIBIres  ;
```

**Results**

**Dependent Variable: BIBI**
**Analysis of Variance**

| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Model | 5 | 87.41057 | 17.48211 | 33.77 | <.0001 |
| Error | **241** | **124.74992** | 0.51763 | | |
| Corrected Total | 246 | 212.16049 | | | |

| | | | |
|---|---|---|---|
| Root MSE | 0.71947 | R-Square | 0.4120 |
| Dependent Mean | 3.02745 | **Adj R-Sq** | **0.3998** |
| Coeff Var | 23.76483 | | |

**Parameter Estimates**

| Variable | DF | Parameter Estimate | Standard Error | t Value | Pr > \|t\| | Tolerance |
|---|---|---|---|---|---|---|
| Intercept | 1 | 3.08441 | 0.12524 | 24.63 | <.0001 | . |
| RIP_WIDm | 1 | 0.01139 | 0.00223 | 5.10 | <.0001 | 0.92659 |
| PH_LAB | 1 | 0.03017 | 0.00641 | 4.71 | <.0001 | 0.08485 |
| SO4_LAB | 1 | -0.02156 | 0.00322 | -6.71 | <.0001 | 0.08385 |
| EMBEDDED | 1 | -0.00879 | 0.00144 | -6.11 | <.0001 | 0.94668 |
| WOOD_DEB | 1 | 0.03095 | 0.00958 | 3.23 | 0.0014 | 0.90725 |

**Variable: BIBIres (Residual)**

| | | | |
|---|---|---|---|
| N | 247 | Sum Weights | 247 |
| Mean | 0 | Sum Observations | 0 |
| Std Deviation | 0.71211902 | Variance | 0.5071135 |
| Skewness | -0.4123476 | Kurtosis | -0.0985222 |
| Uncorrected SS | 124.74992 | Corrected SS | 124.74992 |
| Coeff Variation | . | Std Error Mean | 0.04531105 |

Tests for Normality

| Test | --Statistic--- | | -----p Value------ | |
|---|---|---|---|---|
| Shapiro-Wilk | W | 0.985269 | Pr < W | 0.0119 |

## Model Validation

**SAS language**

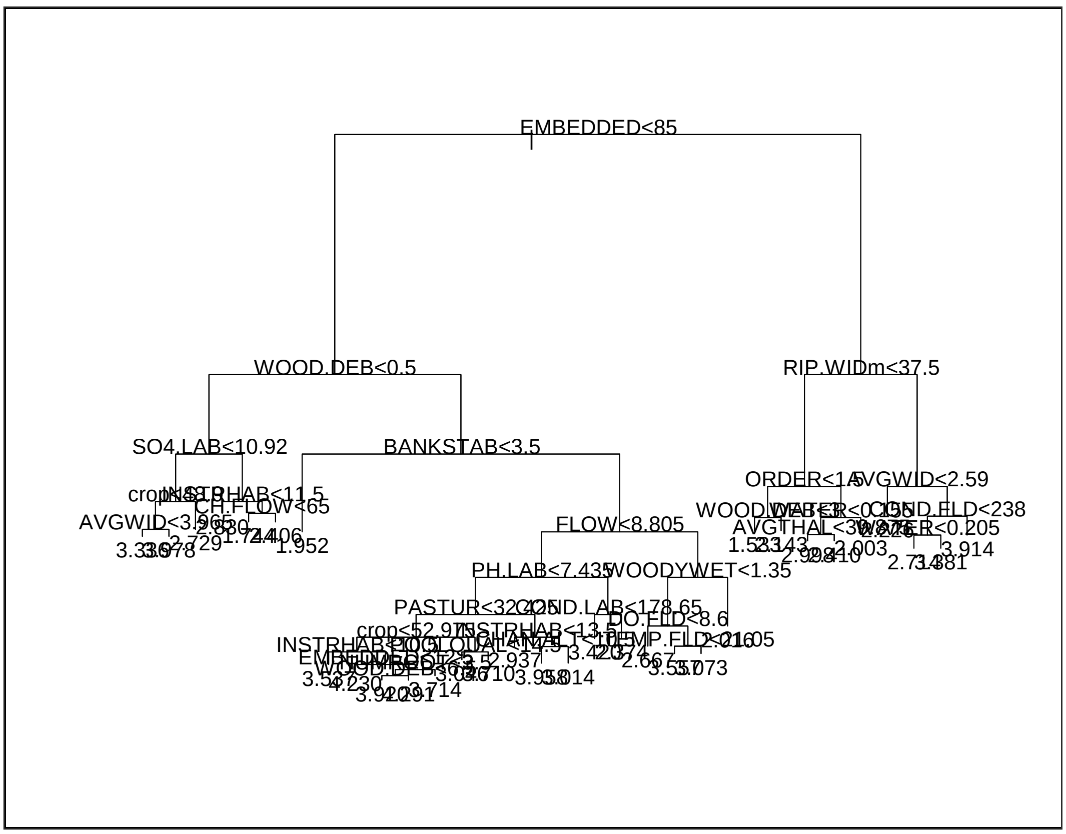
```
DATA    one  ;
INFILE  'D:\g MBSS paper\SAS\SAS split data\BIBIvaldata.dat'         ;
INPUT BIBI     RIP_WIDm     TEMP_FLD     For_Buff     CROP     Reg_East
AGRI        PHYS_CP     URBAN     FOREST     ORDER_1     DO_FLD
PH_FLD     COND_FLD     PH_LAB     COND_LAB     ANC_LAB     SO4_LAB
DOC_LAB     ACID_no     PASTURE     INSTRHAB     EPI_SUB     VEL_DPTH
POOLQUAL     RIFFQUAL     CHAN_ALT     BANKSTAB     EMBEDDED
CH_FLOW     SHADING     REMOTE     AESTHET     WOOD_DEB
NUMROOT     MAXDEPTH     ST_GRAD     AVGWID     AVGTHAL
AVG_VEL     FLOW     ACREAGE     WETLANDS     BARREN     WATER
HIGHURB     LOWURB     PASTUR     PROBCROP     ROWCROP     cropmix
CONIFER     DECIDFOR     MIXEDFOR   EMERGWET     WOODYWET
COALMINE     TRANS     BKTRFLAG     BLACKWAT   ;
BIBIpred = 3.084 + 0.0114*RIP_WIDm + 0.0302*PH_LAB - .022*SO4_LAB -
.0088*EMBEDDED +.0309*WOOD_DEB ;
res = BIBI - BIBIpred ;  proc print;     Proc corr;  run; quit;
```

**Results: Correlation Coefficients for** BIBI vs BIBIpred = 0.312 so $\mathbf{R^2 = 0.097}$

**APPENDIX 15:**

**BENTHIC IBI S-PLUS MODELING**

## Regression tree with all parameters



**Regression Tree Model with all Parameters**

tree(formula = BIBI.98 ~ RIP.WIDm + TEMP.FLD + BUFF.TYP + ADJ.COVR + REGION + AGRI + PHYCPIO + URBAN + FOREST + ORDER + DO.FLD + PH.FLD + COND.FLD + PH.LAB + COND.LAB + ANC.LAB + SO4.LAB + DOC.LAB + ACIDSRC + PASTURE + INSTRHAB + EPI.SUB + VEL.DPTH + POOLQUAL + RIFFQUAL + CHAN.ALT + BANKSTAB + EMBEDDED + CH.FLOW + SHADING + REMOTE + AESTHET + WOOD.DEB + NUMROOT + MAXDEPTH + ST.GRAD + AVGWID + AVGTHAL + AVG.VEL + FLOW + ACREAGE + WETLANDS + BARREN + WATER + HIGHURB + LOWURB + PASTUR + PROBCROP + ROWCROP + crop + CONIFER + DECIDFOR + MIXEDFOR + EMERGWET + WOODYWET + COALMINE + TRANS + BKTRFLAG + BLACKWAT,
data = BIBI.cal.data, na.action = na.exclude, mincut = 5, minsize = 10, mindev = 0.01)

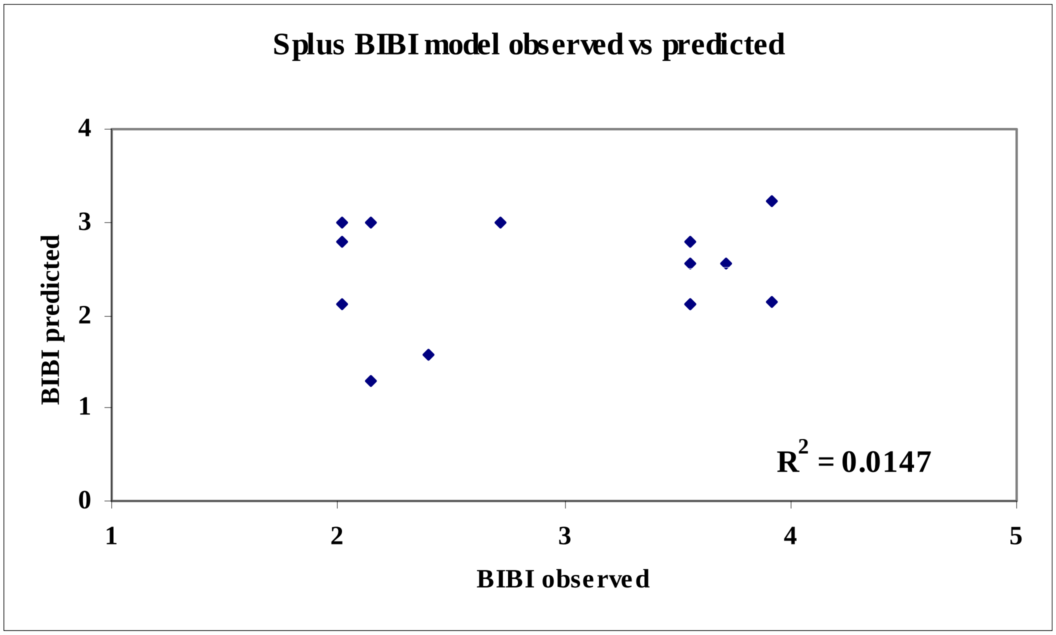
Variables actually used in tree construction: "EMBEDDED" "WOOD.DEB" "SO4.LAB" "crop" "AVGWID" "INSTRHAB" "CH.FLOW" "BANKSTAB" "FLOW" "PH.LAB" "PASTUR" "NUMROOT" "POOLQUAL" "CHAN.ALT" "COND.LAB" "WOODYWET" "DO.FLD" "TEMP.FLD" "RIP.WIDm" "ORDER" "WATER" "AVGTHAL" "COND.FLD"
Number of terminal nodes: 32
Residual mean deviance: 0.1751 = 37.64 / 215

**node), split, n, deviance, yval      * denotes terminal node**

```
  1) root 247 187.5000 3.076
    2) EMBEDDED<85 179 102.9000 3.309
      4) WOOD.DEB<0.5 36  21.6300 2.801
        8) SO4.LAB<10.92 19   8.4090 3.217
         16) crop<48.9 10   2.2880 3.657
           32) AVGWID<3.965 5   0.4997 3.336 *
           33) AVGWID>3.965 5   0.7579 3.978 *
         17) crop>48.9 9   2.0400 2.729 *
        9) SO4.LAB>10.92 17   6.2460 2.336
         18) INSTRHAB<11.5 5   1.8890 2.830 *
         19) INSTRHAB>11.5 12   2.6270 2.130
           38) CH.FLOW<65 5   0.7507 1.744 *
           39) CH.FLOW>65 7   0.5994 2.406 *
      5) WOOD.DEB>0.5 143  69.6400 3.436
       10) BANKSTAB<3.5 5   2.4230 1.952 *
       11) BANKSTAB>3.5 138  55.8000 3.490
         22) FLOW<8.805 101  34.4800 3.624
           44) PH.LAB<7.435 87  22.0900 3.716
             88) PASTUR<32.425 70  13.7800 3.813
              176) crop<52.975 60   9.0160 3.885
                352) INSTRHAB<10.5 12   1.6930 3.537 *
```

```
        353) INSTRHAB>10.5 48   5.5010 3.972
          706) EMBEDDED<12.5 9   1.0340 4.230 *
          707) EMBEDDED>12.5 39   3.7310 3.913
           1414) NUMROOT<3.5 25   2.3260 4.024
             2828) WOOD.DEB<6.5 18   1.1840 3.920 *
             2829) WOOD.DEB>6.5 7   0.4471 4.291 *
           1415) NUMROOT>3.5 14   0.5443 3.714 *
       177) crop>52.975 10   2.5620 3.378
        354) POOLQUAL<14.5 5   1.2170 3.046 *
        355) POOLQUAL>14.5 5   0.2430 3.710 *
      89) PASTUR>32.425 17   4.9890 3.320
       178) INSTRHAB<13.5 6   0.6057 2.937 *
       179) INSTRHAB>13.5 11   3.0200 3.529
        358) CHAN.ALT<10.5 6   0.2633 3.958 *
        359) CHAN.ALT>10.5 5   0.3251 3.014 *
    45) PH.LAB>7.435 14   6.9770 3.046
      90) COND.LAB<178.65 9   2.1090 3.420 *
      91) COND.LAB>178.65 5   1.3510 2.374 *
  23) FLOW>8.805 37  14.6000 3.126
    46) WOODYWET<1.35 32   7.2250 3.299
      92) DO.FLD<8.6 6   1.4500 2.667 *
      93) DO.FLD>8.6 26   2.8210 3.445
       186) TEMP.FLD<21.05 20   1.2920 3.557 *
       187) TEMP.FLD>21.05 6   0.4517 3.073 *
    47) WOODYWET>1.35 5   0.2603 2.016 *
3) EMBEDDED>85 68  49.4700 2.463
 6) RIP.WIDm<37.5 41  16.8500 2.065
  12) ORDER<1.5 22   5.6150 1.755
   24) WOOD.DEB<3 14   1.7680 1.533 *
   25) WOOD.DEB>3 8   1.9550 2.143 *
  13) ORDER>1.5 19   6.6650 2.424
   26) WATER<0.155 11   2.5940 2.731
     52) AVGTHAL<39.875 6   0.9919 2.998 *
     53) AVGTHAL>39.875 5   0.6578 2.410 *
   27) WATER>0.155 8   1.6140 2.003 *
 7) RIP.WIDm>37.5 27  16.2300 3.068
  14) AVGWID<2.59 5   1.2710 2.226 *
  15) AVGWID>2.59 22  10.6100 3.260
   30) COND.FLD<238 17   7.6100 3.067
     60) WATER<0.205 8   4.0780 2.714 *
     61) WATER>0.205 9   1.6450 3.381 *
   31) COND.FLD>238 5   0.2263 3.914 *
```

## Model Validation




| Pred | Obs | Pred | Obs |
|---|---|---|---|
| 2.1425 | 1.29 | 2.405714 | 3.29 |
| 2.405714 | 1.57 | 3.536667 | 3.44 |
| 3.5565 | 2.11 | 3.5565 | 3.44 |
| 2.016 | 2.11 | 2.728889 | 3.44 |
| 3.5565 | 2.11 | 3.914 | 3.57 |
| 3.92 | 2.14 | 4.23 | 3.67 |
| 3.714286 | 2.56 | 3.92 | 3.67 |
| 3.5565 | 2.56 | 1.952 | 3.89 |
| 2.016 | 2.78 | 2.374 | 4.11 |
| 3.5565 | 2.78 | 2.71375 | 4.14 |
| 2.1425 | 3 | 3.5565 | 4.33 |
| 2.016 | 3 | 2.226 | 4.43 |
| 2.71375 | 3 | 3.92 | 4.56 |
| 3.92 | 3.22 | | |

**Development of equivalent $R^2$ for regression tree model**

| REGION | BIBI | delta | square | corrected total SS | |
|---|---|---|---|---|---|
| CP | 1 | -1.83 | 3.36 | 115.08 | **CP** |
| CP | 1 | -1.83 | 3.36 | 78.93 | **Pd** |
| CP | 1.29 | -1.54 | 2.38 | 194.01 | **ALL** |
| CP | 1.29 | -1.54 | 2.38 | | |
| CP | 1.29 | -1.54 | 2.38 | **Resid SS** | |
| CP | 1.29 | -1.54 | 2.38 | | **deviance** |
| CP | 1.29 | -1.54 | 2.38 | **CP** | 6.67 |
| CP | 1.29 | -1.54 | 2.38 | | 0.72 |
| CP | 1.29 | -1.54 | 2.38 | | 3.75 |
| CP | 1.29 | -1.54 | 2.38 | | 5.69 |
| CP | 1.57 | -1.26 | 1.59 | | |
| CP | 1.57 | -1.26 | 1.59 | | 6.62 |
| CP | 1.57 | -1.26 | 1.59 | | 30.73 |
| CP | 1.57 | -1.26 | 1.59 | | **54.18** |
| CP | 1.57 | -1.26 | 1.59 | **Pd** | 25.75 |
| CP | 1.57 | -1.26 | 1.59 | | 0.59 |
| CP | 1.57 | -1.26 | 1.59 | | 3.54 |
| CP | 1.57 | -1.26 | 1.59 | | 9.76 |
| CP | 1.86 | -0.97 | 0.95 | | **39.64** |
| CP | 1.86 | -0.97 | 0.95 | **ALL** | 8.24 |
| CP | 1.86 | -0.97 | 0.95 | | 6.24 |
| CP | 1.86 | -0.97 | 0.95 | | 2.4 |
| CP | 1.86 | -0.97 | 0.95 | | 55.8 |
| CP | 1.86 | -0.97 | 0.95 | | 16.85 |
| CP | 1.86 | -0.97 | 0.95 | | 16.23 |
| CP | 1.86 | -0.97 | 0.95 | | **105.76** |
| CP | 1.86 | -0.97 | 0.95 | | |
| CP | 1.86 | -0.97 | 0.95 | **Res/Cor SS** | |
| CP | 1.86 | -0.97 | 0.95 | **CP** | 0.47 |
| CP | 1.86 | -0.97 | 0.95 | **Pd** | 0.50 |
| CP | 1.86 | -0.97 | 0.95 | **ALL** | 0.55 |
| CP | 1.86 | -0.97 | 0.95 | | |

| | | | |
|---|---|---|---|
| CP | 1.86 | -0.97 | 0.95 |
| CP | 1.86 | -0.97 | 0.95 |
| CP | 2.14 | -0.69 | 0.48 |
| CP | 2.14 | -0.69 | 0.48 |
| CP | 2.14 | -0.69 | 0.48 |
| CP | 2.14 | -0.69 | 0.48 |
| CP | 2.14 | -0.69 | 0.48 |
| CP | 2.14 | -0.69 | 0.48 |
| CP | 2.14 | -0.69 | 0.48 |
| CP | 2.14 | -0.69 | 0.48 |
| CP | 2.14 | -0.69 | 0.48 |
| CP | 2.43 | -0.40 | 0.16 |
| CP | 2.43 | -0.40 | 0.16 |
| CP | 2.43 | -0.40 | 0.16 |
| CP | 2.43 | -0.40 | 0.16 |
| CP | 2.43 | -0.40 | 0.16 |
| CP | 2.43 | -0.40 | 0.16 |
| CP | 2.71 | -0.12 | 0.02 |
| CP | 2.71 | -0.12 | 0.02 |
| CP | 2.71 | -0.12 | 0.02 |
| CP | 2.71 | -0.12 | 0.02 |
| CP | 2.71 | -0.12 | 0.02 |
| CP | 2.71 | -0.12 | 0.02 |
| CP | 2.71 | -0.12 | 0.02 |
| CP | 2.71 | -0.12 | 0.02 |
| CP | 2.71 | -0.12 | 0.02 |
| CP | 2.71 | -0.12 | 0.02 |
| CP | 3 | 0.17 | 0.03 |
| CP | 3 | 0.17 | 0.03 |
| CP | 3 | 0.17 | 0.03 |
| CP | 3 | 0.17 | 0.03 |
| CP | 3 | 0.17 | 0.03 |
| CP | 3 | 0.17 | 0.03 |
| CP | 3 | 0.17 | 0.03 |
| CP | 3 | 0.17 | 0.03 |
| CP | 3 | 0.17 | 0.03 |
| CP | 3 | 0.17 | 0.03 |

| **$R^2$** | |
|---|---|
| **CP** | **0.53** |
| **Pd** | **0.50** |
| **ALL** | **0.45** |

| | | | |
|---|---|---|---|
| CP | 3 | 0.17 | 0.03 |
| CP | 3 | 0.17 | 0.03 |
| CP | 3 | 0.17 | 0.03 |
| CP | 3.29 | 0.46 | 0.21 |
| CP | 3.29 | 0.46 | 0.21 |
| CP | 3.29 | 0.46 | 0.21 |
| CP | 3.29 | 0.46 | 0.21 |
| CP | 3.29 | 0.46 | 0.21 |
| CP | 3.57 | 0.74 | 0.54 |
| CP | 3.57 | 0.74 | 0.54 |
| CP | 3.57 | 0.74 | 0.54 |
| CP | 3.57 | 0.74 | 0.54 |
| CP | 3.57 | 0.74 | 0.54 |
| CP | 3.57 | 0.74 | 0.54 |
| CP | 3.57 | 0.74 | 0.54 |
| CP | 3.57 | 0.74 | 0.54 |
| CP | 3.57 | 0.74 | 0.54 |
| CP | 3.57 | 0.74 | 0.54 |
| CP | 3.57 | 0.74 | 0.54 |
| CP | 3.57 | 0.74 | 0.54 |
| CP | 3.57 | 0.74 | 0.54 |
| CP | 3.57 | 0.74 | 0.54 |
| CP | 3.86 | 1.03 | 1.06 |
| CP | 3.86 | 1.03 | 1.06 |
| CP | 3.86 | 1.03 | 1.06 |
| CP | 3.86 | 1.03 | 1.06 |
| CP | 3.86 | 1.03 | 1.06 |
| CP | 3.86 | 1.03 | 1.06 |
| CP | 3.86 | 1.03 | 1.06 |
| CP | 3.86 | 1.03 | 1.06 |
| CP | 3.86 | 1.03 | 1.06 |
| CP | 3.86 | 1.03 | 1.06 |
| CP | 3.86 | 1.03 | 1.06 |
| CP | 3.86 | 1.03 | 1.06 |
| CP | 3.86 | 1.03 | 1.06 |
| CP | 3.86 | 1.03 | 1.06 |
| CP | 3.86 | 1.03 | 1.06 |

| | | | |
|---|---|---|---|
| CP | 3.86 | 1.03 | 1.06 |
| CP | 4.14 | 1.31 | 1.71 |
| CP | 4.14 | 1.31 | 1.71 |
| CP | 4.14 | 1.31 | 1.71 |
| CP | 4.14 | 1.31 | 1.71 |
| CP | 4.14 | 1.31 | 1.71 |
| CP | 4.14 | 1.31 | 1.71 |
| CP | 4.14 | 1.31 | 1.71 |
| CP | 4.14 | 1.31 | 1.71 |
| CP | 4.14 | 1.31 | 1.71 |
| CP | 4.43 | 1.60 | 2.55 |
| CP | 4.43 | 1.60 | 2.55 |
| CP | 4.43 | 1.60 | 2.55 |
| CP | 4.71 | 1.88 | 3.52 |
| CP | 4.71 | 1.88 | 3.52 |
| P | 1 | -2.28 | 5.18 |
| P | 1.44 | -1.84 | 3.37 |
| P | 1.67 | -1.61 | 2.58 |
| P | 1.67 | -1.61 | 2.58 |
| P | 1.67 | -1.61 | 2.58 |
| P | 1.67 | -1.61 | 2.58 |
| P | 1.89 | -1.39 | 1.92 |
| P | 1.89 | -1.39 | 1.92 |
| P | 1.89 | -1.39 | 1.92 |
| P | 2.11 | -1.17 | 1.36 |
| P | 2.11 | -1.17 | 1.36 |
| P | 2.11 | -1.17 | 1.36 |
| P | 2.11 | -1.17 | 1.36 |
| P | 2.11 | -1.17 | 1.36 |
| P | 2.33 | -0.95 | 0.89 |
| P | 2.33 | -0.95 | 0.89 |
| P | 2.33 | -0.95 | 0.89 |
| P | 2.33 | -0.95 | 0.89 |
| P | 2.33 | -0.95 | 0.89 |
| P | 2.33 | -0.95 | 0.89 |
| P | 2.56 | -0.72 | 0.51 |
| P | 2.56 | -0.72 | 0.51 |

| | | | |
|---|---|---|---|
| P | 2.56 | -0.72 | 0.51 |
| P | 2.56 | -0.72 | 0.51 |
| P | 2.56 | -0.72 | 0.51 |
| P | 2.56 | -0.72 | 0.51 |
| P | 2.56 | -0.72 | 0.51 |
| P | 2.56 | -0.72 | 0.51 |
| P | 2.56 | -0.72 | 0.51 |
| P | 2.56 | -0.72 | 0.51 |
| P | 2.56 | -0.72 | 0.51 |
| P | 2.56 | -0.72 | 0.51 |
| P | 2.56 | -0.72 | 0.51 |
| P | 2.78 | -0.50 | 0.25 |
| P | 2.78 | -0.50 | 0.25 |
| P | 2.78 | -0.50 | 0.25 |
| P | 2.78 | -0.50 | 0.25 |
| P | 2.78 | -0.50 | 0.25 |
| P | 2.78 | -0.50 | 0.25 |
| P | 2.78 | -0.50 | 0.25 |
| P | 3 | -0.28 | 0.08 |
| P | 3 | -0.28 | 0.08 |
| P | 3 | -0.28 | 0.08 |
| P | 3 | -0.28 | 0.08 |
| P | 3 | -0.28 | 0.08 |
| P | 3 | -0.28 | 0.08 |
| P | 3 | -0.28 | 0.08 |
| P | 3 | -0.28 | 0.08 |
| P | 3 | -0.28 | 0.08 |
| P | 3 | -0.28 | 0.08 |
| P | 3 | -0.28 | 0.08 |
| P | 3 | -0.28 | 0.08 |
| P | 3 | -0.28 | 0.08 |
| P | 3 | -0.28 | 0.08 |
| P | 3 | -0.28 | 0.08 |
| P | 3 | -0.28 | 0.08 |
| P | 3.22 | -0.06 | 0.00 |
| P | 3.22 | -0.06 | 0.00 |
| P | 3.22 | -0.06 | 0.00 |

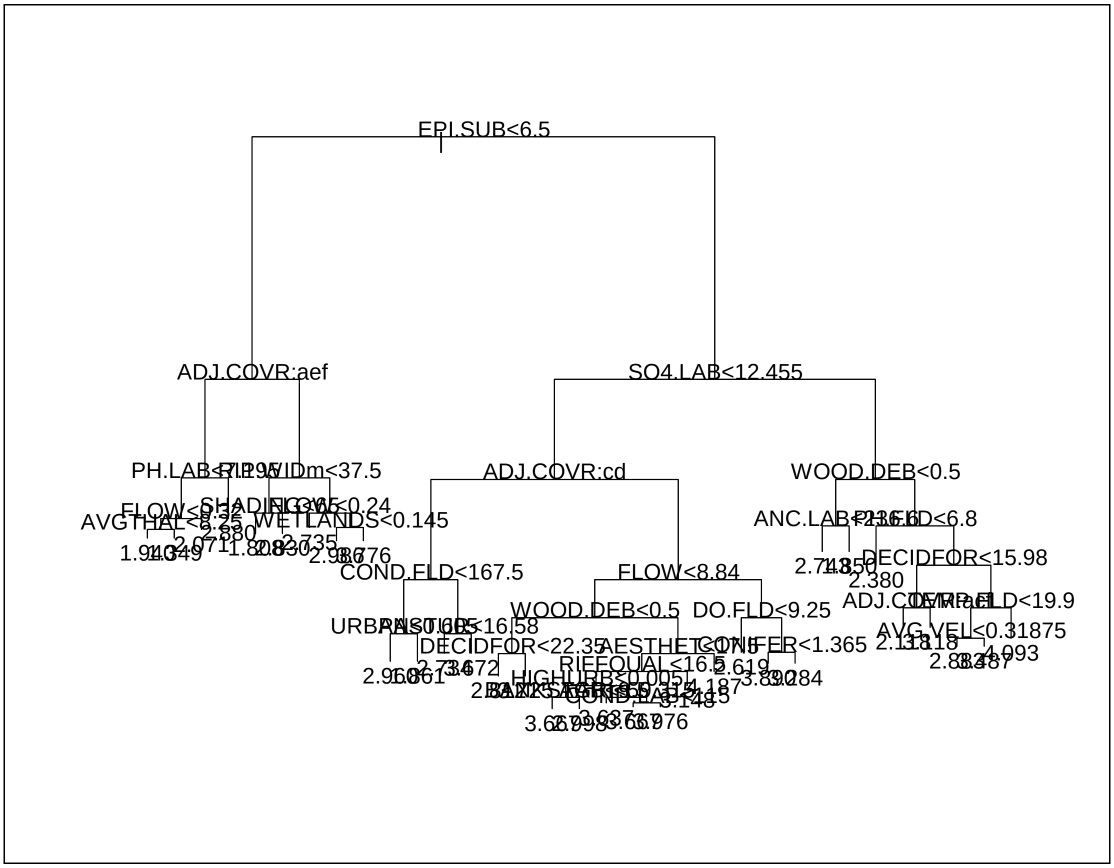
| | | | |
|---|---|---|---|
| P | 3.22 | -0.06 | 0.00 |
| P | 3.22 | -0.06 | 0.00 |
| P | 3.22 | -0.06 | 0.00 |
| P | 3.22 | -0.06 | 0.00 |
| P | 3.22 | -0.06 | 0.00 |
| P | 3.22 | -0.06 | 0.00 |
| P | 3.22 | -0.06 | 0.00 |
| P | 3.22 | -0.06 | 0.00 |
| P | 3.22 | -0.06 | 0.00 |
| P | 3.22 | -0.06 | 0.00 |
| P | 3.22 | -0.06 | 0.00 |
| P | 3.22 | -0.06 | 0.00 |
| P | 3.44 | 0.16 | 0.03 |
| P | 3.44 | 0.16 | 0.03 |
| P | 3.44 | 0.16 | 0.03 |
| P | 3.44 | 0.16 | 0.03 |
| P | 3.44 | 0.16 | 0.03 |
| P | 3.44 | 0.16 | 0.03 |
| P | 3.44 | 0.16 | 0.03 |
| P | 3.44 | 0.16 | 0.03 |
| P | 3.44 | 0.16 | 0.03 |
| P | 3.44 | 0.16 | 0.03 |
| P | 3.44 | 0.16 | 0.03 |
| P | 3.44 | 0.16 | 0.03 |
| P | 3.44 | 0.16 | 0.03 |
| P | 3.44 | 0.16 | 0.03 |
| P | 3.44 | 0.16 | 0.03 |
| P | 3.44 | 0.16 | 0.03 |
| P | 3.44 | 0.16 | 0.03 |
| P | 3.44 | 0.16 | 0.03 |
| P | 3.44 | 0.16 | 0.03 |
| P | 3.44 | 0.16 | 0.03 |
| P | 3.44 | 0.16 | 0.03 |
| P | 3.44 | 0.16 | 0.03 |
| P | 3.67 | 0.39 | 0.16 |
| P | 3.67 | 0.39 | 0.16 |

| | | | |
|---|---|---|---|
| P | 3.67 | 0.39 | 0.16 |
| P | 3.67 | 0.39 | 0.16 |
| P | 3.67 | 0.39 | 0.16 |
| P | 3.67 | 0.39 | 0.16 |
| P | 3.67 | 0.39 | 0.16 |
| P | 3.67 | 0.39 | 0.16 |
| P | 3.67 | 0.39 | 0.16 |
| P | 3.67 | 0.39 | 0.16 |
| P | 3.67 | 0.39 | 0.16 |
| P | 3.67 | 0.39 | 0.16 |
| P | 3.67 | 0.39 | 0.16 |
| P | 3.67 | 0.39 | 0.16 |
| P | 3.67 | 0.39 | 0.16 |
| P | 3.67 | 0.39 | 0.16 |
| P | 3.89 | 0.61 | 0.38 |
| P | 3.89 | 0.61 | 0.38 |
| P | 3.89 | 0.61 | 0.38 |
| P | 3.89 | 0.61 | 0.38 |
| P | 3.89 | 0.61 | 0.38 |
| P | 3.89 | 0.61 | 0.38 |
| P | 3.89 | 0.61 | 0.38 |
| P | 3.89 | 0.61 | 0.38 |
| P | 3.89 | 0.61 | 0.38 |
| P | 3.89 | 0.61 | 0.38 |
| P | 3.89 | 0.61 | 0.38 |
| P | 3.89 | 0.61 | 0.38 |
| P | 3.89 | 0.61 | 0.38 |
| P | 3.89 | 0.61 | 0.38 |
| P | 3.89 | 0.61 | 0.38 |
| P | 3.89 | 0.61 | 0.38 |
| P | 3.89 | 0.61 | 0.38 |
| P | 3.89 | 0.61 | 0.38 |
| P | 3.89 | 0.61 | 0.38 |
| P | 3.89 | 0.61 | 0.38 |
| P | 3.89 | 0.61 | 0.38 |
| P | 3.89 | 0.61 | 0.38 |
| P | 3.89 | 0.61 | 0.38 |

| | | | |
|---|---|---|---|
| P | 4.11 | 0.83 | 0.70 |
| P | 4.11 | 0.83 | 0.70 |
| P | 4.11 | 0.83 | 0.70 |
| P | 4.11 | 0.83 | 0.70 |
| P | 4.11 | 0.83 | 0.70 |
| P | 4.11 | 0.83 | 0.70 |
| P | 4.11 | 0.83 | 0.70 |
| P | 4.11 | 0.83 | 0.70 |
| P | 4.11 | 0.83 | 0.70 |
| P | 4.33 | 1.05 | 1.11 |
| P | 4.33 | 1.05 | 1.11 |
| P | 4.33 | 1.05 | 1.11 |
| P | 4.33 | 1.05 | 1.11 |
| P | 4.33 | 1.05 | 1.11 |
| P | 4.33 | 1.05 | 1.11 |
| P | 4.33 | 1.05 | 1.11 |
| P | 4.33 | 1.05 | 1.11 |
| P | 4.56 | 1.28 | 1.65 |
| P | 4.56 | 1.28 | 1.65 |
| P | 4.78 | 1.50 | 2.26 |

| **mean** | |
|---|---|
| **CP** | 2.83 |
| **P** | 3.28 |
| **ALL** | 3.08 |

**Regression Tree Model of BIBI**
**For Coastal Plain Data**




Epifaunal substrate < 6.5
Adjacent cover :aef SO4 lab < 12.455
PH lab Rip width < 37.5 adjacent cover:cd
woody debris < 0.5

**Regression tree:**

```
tree(formula = BIBI.98 ~ RIP.WIDm + TEMP.FLD + BUFF.TYP + ADJ.COVR +
       REGION + AGRI + URBAN + FOREST + ORDER + DO.FLD + PH.FLD +
       COND.FLD + PH.LAB + COND.LAB + ANC.LAB + SO4.LAB + DOC.LAB +
       ACIDSRC + PASTURE + INSTRHAB + EPI.SUB + VEL.DPTH + POOLQUAL +
       RIFFQUAL + CHAN.ALT + BANKSTAB + EMBEDDED + CH.FLOW + SHADING +
       REMOTE + AESTHET + WOOD.DEB + NUMROOT + MAXDEPTH + ST.GRAD +
       AVGWID + AVGTHAL + AVG.VEL + FLOW + ACREAGE + WETLANDS + BARREN +
       WATER + HIGHURB + LOWURB + PASTUR + PROBCROP + ROWCROP + crop +
       CONIFER + DECIDFOR + MIXEDFOR + EMERGWET + WOODYWET + COALMINE +
       TRANS + BKTRFLAG + BLACKWAT, data = BIBI.CP, na.action =
       na.exclude, mincut = 5, minsize = 10, mindev = 0.01)
```

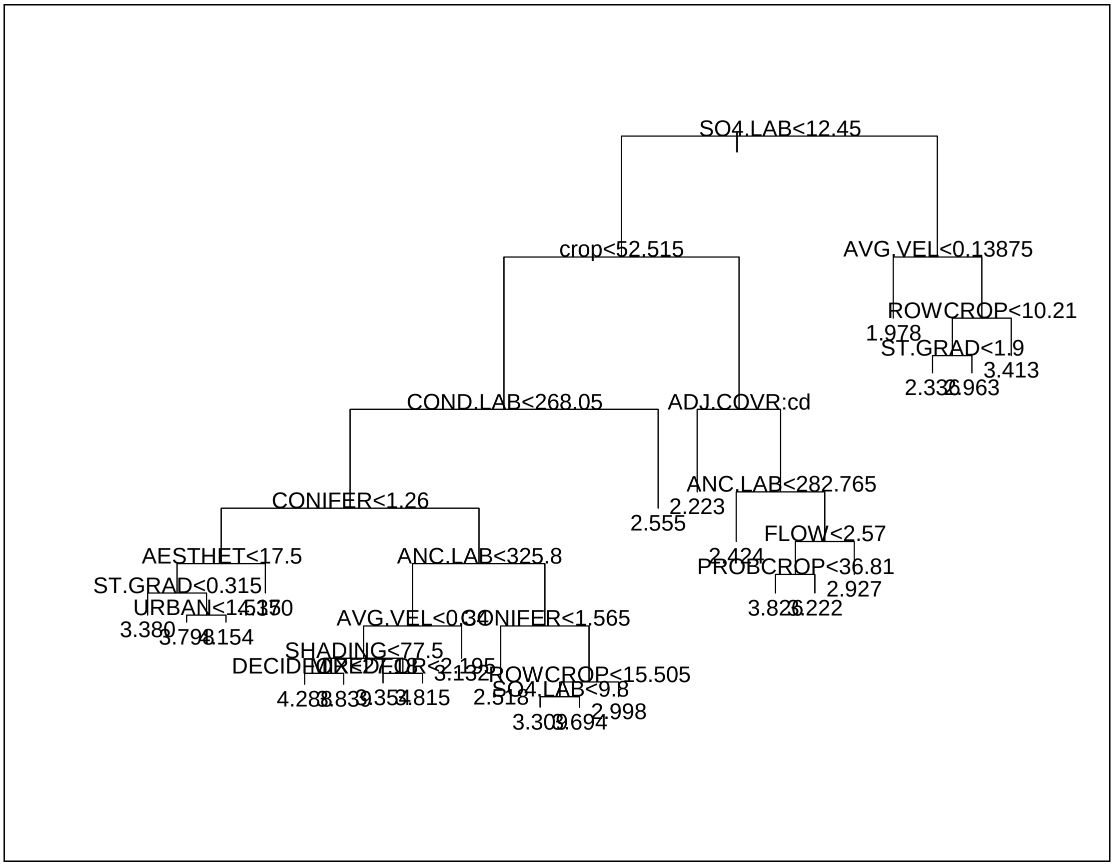
**Variables actually used in tree construction:**

```
 [1] "EPI.SUB"  "ADJ.COVR" "PH.LAB"   "FLOW"     "AVGTHAL"  "RIP.WIDm"
 [7] "SHADING"  "WETLANDS" "SO4.LAB"  "COND.FLD" "URBAN"    "PASTUR"
[13] "WOOD.DEB" "DECIDFOR" "AESTHET"  "RIFFQUAL" "HIGHURB"  "BANKSTAB"
[19] "AGRI"     "COND.LAB" "DO.FLD"   "CONIFER"  "ANC.LAB"  "PH.FLD"
[25] "TEMP.FLD" "AVG.VEL"
Number of terminal nodes:  33
Residual mean deviance:  0.163 = 39.27 / 241
Distribution of residuals:
      Min.    1st Qu.     Median       Mean    3rd Qu.      Max.
 -0.940000 -0.227100 -0.000556  0.000000  0.222900  1.480000
```

```
node), split,                        n,            deviance,     yval
      * denotes terminal node
   1) root 274 207.30000 3.080
     2) EPI.SUB<6.5                  58            41.14000      2.402
       4) ADJ.COVR:CP,OR,PA          29            13.03000      1.914
         8) PH.LAB<7.195             24            6.67300       1.713
           16) FLOW<0.32 16   2.90200 1.534
             32) AVGTHAL<8.25 5   1.35400 1.940 *
             33) AVGTHAL>8.25 11   0.34690 1.349 *
           17) FLOW>0.32 8   2.23100 2.071 *
         9) PH.LAB>7.195             5             0.72420       2.880 *
       5) ADJ.COVR:FR,LN,OF,SL       29            14.32000      2.889
        10) RIP.WIDm<37.5            11            3.75800       2.365
          20) SHADING<65 5   0.07148 1.808 *
          21) SHADING>65 6   0.83820 2.830 *
        11) RIP.WIDm>37.5            18      5.69700 3.209
          22) FLOW<0.24 6   1.24600 2.735 *
          23) FLOW>0.24 12   2.42500 3.447
            46) WETLANDS<0.145 5   0.32510 2.986 *
            47) WETLANDS>0.145 7   0.28100 3.776 *
     3) EPI.SUB>6.5                  216           132.30000     3.262
       6) SO4.LAB<12.455             157           74.47000      3.418
        12) ADJ.COVR:LN,OF           27            17.33000      2.763
          24) COND.FLD<167.5 14   5.30800 2.254
            48) URBAN<0.605 5   0.97360 2.960 *
            49) URBAN>0.605 9   0.45290 1.861 *
          25) COND.FLD>167.5 13   4.47200 3.312
            50) PASTUR<16.58 5   0.33710 2.734 *
            51) PASTUR>16.58 8   1.42500 3.672 *
        13) ADJ.COVR:CP,FR,PA,SL,TG 130            43.16000      3.554
          26) FLOW<8.84 100  27.24000 3.665
            52) WOOD.DEB<0.5 16   5.40000 3.154
             104) DECIDFOR<22.35 10   1.69200 2.812 *
             105) DECIDFOR>22.35 6   0.58150 3.725 *
            53) WOOD.DEB>0.5 84  16.87000 3.762
             106) AESTHET<17.5 72  13.24000 3.692
               212) RIFFQUAL<16.5 66   9.86900 3.741
```

```
                424) HIGHURB<0.005 17   3.65500 3.470
                  848) BANKSTAB<9.5 12   1.38600 3.667 *
                  849) BANKSTAB>9.5 5   0.69090 2.998 *
                425) HIGHURB>0.005 49   4.52900 3.835
                  850) AGRI<59.315 14   1.21600 3.637 *
                  851) AGRI>59.315 35   2.54300 3.915
                   1702) COND.LAB<115 7   0.20250 3.667 *
                   1703) COND.LAB>115 28   1.80500 3.976 *
              213) RIFFQUAL>16.5 6   1.43400 3.148 *
            107) AESTHET>17.5 12   1.11800 4.187 *
         27) FLOW>8.84 30  10.56000 3.184
           54) DO.FLD<9.25 10   2.02600 2.619 *
           55) DO.FLD>9.25 20   3.75400 3.466
            110) CONIFER<1.365 6   0.69980 3.890 *
            111) CONIFER>1.365 14   1.51300 3.284 *
      7) SO4.LAB>12.455          59            43.86000      2.848
       14) WOOD.DEB<0.5          18            6.62300       2.346
         28) ANC.LAB<236.6 10   1.70900 2.743 *
         29) ANC.LAB>236.6 8   1.37000 1.850 *

15) WOOD.DEB>0.5          41            30.73000     3.068
         30) PH.FLD<6.8 9   4.90200 2.380 *
         31) PH.FLD>6.8 32  20.37000 3.261
           62) DECIDFOR<15.98 11   5.40600 2.664
            124) ADJ.COVR:CP,LN,PA 5   1.35600 2.118 *
            125) ADJ.COVR:FR,OF 6   1.32000 3.118 *
           63) DECIDFOR>15.98 21   8.97600 3.574
            126) TEMP.FLD<19.9 12   3.57300 3.185
              252) AVG.VEL<0.31875 6   1.89900 2.883 *
              253) AVG.VEL>0.31875 6   0.58190 3.487 *
            127) TEMP.FLD>19.9 9   1.16000 4.093 *
```

**Regression Tree Model of BIBI**
**For Coastal Plain Data**




SO4 lab

Crop < 52.515 avg vel < 0.13875

Cond lab < 268.05 adj cover:

**Regression tree:**

```
tree(formula = BIBI.98 ~ RIP.WIDm + TEMP.FLD + BUFF.TYP + ADJ.COVR +
       REGION + AGRI + URBAN + FOREST + ORDER + DO.FLD + PH.FLD +
       COND.FLD + PH.LAB + COND.LAB + ANC.LAB + SO4.LAB + DOC.LAB +
       ACIDSRC + PASTURE + INSTRHAB + EPI.SUB + VEL.DPTH + POOLQUAL +
       RIFFQUAL + CHAN.ALT + BANKSTAB + EMBEDDED + CH.FLOW + SHADING +
       REMOTE + AESTHET + WOOD.DEB + NUMROOT + MAXDEPTH + ST.GRAD +
       AVGWID + AVGTHAL + AVG.VEL + FLOW + ACREAGE + WETLANDS + BARREN +
       WATER + HIGHURB + LOWURB + PASTUR + PROBCROP + ROWCROP + crop +
       CONIFER + DECIDFOR + MIXEDFOR + EMERGWET + WOODYWET + COALMINE +
       TRANS + BKTRFLAG + BLACKWAT, data = BIBI.P, na.action =
       na.exclude, mincut = 5, minsize = 10, mindev = 0.01)
```

**Variables actually used in tree construction:**

```
 [1] "SO4.LAB"  "crop"     "COND.LAB" "CONIFER"  "AESTHET"  "ST.GRAD"
 [7] "URBAN"    "ANC.LAB"  "AVG.VEL"  "SHADING"  "DECIDFOR" "MIXEDFOR"
[13] "ROWCROP"  "ADJ.COVR" "FLOW"     "PROBCROP"

Number of terminal nodes:  23
Residual mean deviance:  0.1311 = 17.04 / 130
Distribution of residuals:
    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
 -0.9780 -0.1883  0.0420  0.0000  0.2220  1.2170
```

```
node), split,                         n,            deviance,           yval
      * denotes terminal node
  1) root 153 78.9300 3.276
    2) SO4.LAB<12.45                  130           60.3600             3.369
      4) crop<52.515                  95            32.4800             3.533
        8) COND.LAB<268.05            89            25.7500             3.599
         16) CONIFER<1.26 30  4.8290 3.874
           32) AESTHET<17.5 24  2.5470 3.750
             64) ST.GRAD<0.315 7  0.3710 3.380 *
             65) ST.GRAD>0.315 17  0.8200 3.903
              130) URBAN<1.515 12  0.2380 3.798 *
              131) URBAN>1.515 5  0.1355 4.154 *
           33) AESTHET>17.5 6  0.4394 4.370 *
         17) CONIFER>1.26 59 17.4900 3.458
           34) ANC.LAB<325.8 30  5.8750 3.710
             68) AVG.VEL<0.34 25  3.6160 3.826
              136) SHADING<77.5 14  1.4610 3.999
                272) DECIDFOR<27.18 5  0.1409 4.288 *
                273) DECIDFOR>27.18 9  0.6719 3.839 *
              137) SHADING>77.5 11  1.2000 3.605
                274) MIXEDFOR<2.195 5  0.2579 3.354 *
                275) MIXEDFOR>2.195 6  0.3624 3.815 *
             69) AVG.VEL>0.34 5  0.2517 3.132 *
           35) ANC.LAB>325.8 29  7.7400 3.198
             70) CONIFER<1.565 6  1.2260 2.518 *
             71) CONIFER>1.565 23  3.0190 3.375
              142) ROWCROP<15.505 18  1.4190 3.480
                284) SO4.LAB<9.8 10  0.4137 3.309 *
                285) SO4.LAB>9.8 8  0.3478 3.694 *
              143) ROWCROP>15.505 5  0.6909 2.998 *
        9) COND.LAB>268.05            6             0.5986              2.555 *
      5) crop>52.515                  35            18.4200             2.924
       10) ADJ.COVR:LN,OF             8             3.5470              2.223 *
       11) ADJ.COVR:CP,FR,PA,TG       27            9.7630              3.132
         22) ANC.LAB<282.765 5  1.3380 2.424 *
         23) ANC.LAB>282.765 22  5.3480 3.293
           46) FLOW<2.57 13  2.4300 3.547
```

```
          92) PROBCROP<36.81 7  0.2704 3.826 *
          93) PROBCROP>36.81 6  0.9813 3.222 *
        47) FLOW>2.57 9  0.8712 2.927 *
3) SO4.LAB>12.45             23             11.0700              2.750
  6) AVG.VEL<0.13875         5              1.6380               1.978 *
  7) AVG.VEL>0.13875         18             5.6310               2.964
   14) ROWCROP<10.21 11  1.9010 2.678
     28) ST.GRAD<1.9 5  0.4005 2.336 *
     29) ST.GRAD>1.9 6  0.4275 2.963 *
   15) ROWCROP>10.21 7  1.4210 3.413 *
```

**APPENDIX 16:**

**PHI SAS MODELING**

**Model Parameter Search**

**SAS language**

```
DATA    one  ;
INFILE  'D:\g MBSS paper\SAS\SAS split data\PHIcaldata.dat'        ;
INPUT PHI     RIP_WIDm     TEMP_FLD     BUFF_FOR     CROP     REGION_E
PHYS_CP    ACID_NO     AGRI     URBAN     FOREST     ORDER     DO_FLD
PH_FLD     COND_FLD     PH_LAB     COND_LAB     ANC_LAB     SO4_LAB
DOC_LAB  PASTURE     ST_GRAD     AVGWID     AVGTHAL     AVG_VEL
FLOW     ACREAGE     WETLANDS     BARREN     WATER      HIGHURB
LOWURB     PASTUR     PROBCROP     ROWCROP      cropmix     CONIFER
DECIDFOR     MIXEDFOR     EMERGWET     WOODYWET    COALMINE
TRANS     BKTRFLAG       BLACKWAT   ;
*proc print;    * proc corr  ;
proc reg  ;
*model PHI =    RIP_WIDm     TEMP_FLD     BUFF_FOR     CROP
REGION_E     PHYS_CP    ACID_NO     AGRI     URBAN     FOREST
ORDER     DO_FLD     PH_FLD     COND_FLD     PH_LAB     COND_LAB
ANC_LAB     SO4_LAB     DOC_LAB  PASTURE     ST_GRAD
AVGWID     AVGTHAL     AVG_VEL     FLOW     ACREAGE     WETLANDS
BARREN     WATER    HIGHURB     LOWURB     PASTUR     PROBCROP
ROWCROP       cropmix     CONIFER    DECIDFOR     MIXEDFOR
EMERGWET     WOODYWET    COALMINE     TRANS     BKTRFLAG
BLACKWAT      / selection=rsquare adjrsq best=3;
run;      quit;
```

**Results**

**R-Square Selection Method**

| Number in Model | $R^2$ | Adjusted R-Square | Variables in Model |
|---|---|---|---|
| 1 | 0.2568 | 0.2537 | AVGTHAL |
| 1 | 0.1618 | 0.1584 | AVG_VEL |
| 1 | 0.1442 | 0.1407 | ORDER |
| 2 | 0.3843 | 0.3792 | AVGTHAL AVG_VEL |
| 2 | 0.3427 | 0.3372 | DO_FLD AVGTHAL |
| 2 | 0.3387 | 0.3332 | DOC_LAB AVGTHAL |
| 3 | 0.4183 | 0.4110 | RIP_WIDm AVGTHAL AVG_VEL |
| 3 | 0.4158 | 0.4085 | DOC_LAB AVGTHAL AVG_VEL |
| 3 | 0.4096 | 0.4022 | BUFF_FOR AVGTHAL AVG_VEL |
| 4 | 0.4458 | 0.4365 | RIP_WIDm DOC_LAB AVGTHAL AVG_VEL |
| 4 | 0.4447 | 0.4353 | RIP_WIDm DO_FLD AVGTHAL AVG_VEL |
| 4 | 0.4431 | 0.4337 | RIP_WIDm AVGTHAL AVG_VEL ACREAGE |
| 5 | 0.4635 | 0.4522 | RIP_WIDm AVGTHAL AVG_VEL ACREAGE ROWCROP |
| 5 | 0.4634 | 0.4521 | RIP_WIDm DO_FLD AVGTHAL AVG_VEL FLOW |
| 5 | 0.4626 | 0.4513 | RIP_WIDm DOC_LAB AVGTHAL AVG_VEL FLOW |

## Model Calibration

**SAS language**

```
* Using the model variables   RIP_WIDm    AVGTHAL     AVG_VEL   ACREAGE
        ROWCROP
model PHI = RIP_WIDm AVGTHAL AVG_VEL ACREAGE ROWCROP
         / collinoint tol  VIF R influence ;
output out=resPHBI  residual = PHIres;
proc univariate normal plot;
var PHIres  ;
```

**Results**

**Dependent Variable: PHI**
**Analysis of Variance**

| Source | DF | Sum of Squares | Mean | | |
|---|---|---|---|---|---|
| Model | 5 | 90102 | 18020 | 40.95 | <.0001 |
| **Error** | **237** | **104281** | 440.00401 | | |
| Corrected Total | 242 | 194382 | | | |

| | | | |
|---|---|---|---|
| Root MSE | 20.97627 | R-Square | 0.4635 |
| Dependent Mean | 59.53605 | **Adj R-Sq** | **0.4522** |
| Coeff Var | 35.23289 | | |

**Parameter Estimates**

| Variable | DF | Parameter Estimate | Standard Error | t Value | Pr > \|t\| | Tolerance |
|---|---|---|---|---|---|---|
| Intercept | 1 | 4.25150 | 4.28229 | 0.99 | 0.3218 | . |
| RIP_WIDm | 1 | 0.27104 | 0.06452 | 4.20 | <.0001 | 0.95939 |
| AVGTHAL | 1 | 0.95185 | 0.09817 | 9.70 | <.0001 | 0.67232 |
| AVG_VEL | 1 | 74.59470 | 9.65187 | 7.73 | <.0001 | 0.98151 |
| ACREAGE | 1 | -0.000636 | 0.000173 | -3.67 | 0.0003 | 0.65173 |
| ROWCROP | 1 | 0.38342 | 0.12763 | 3.00 | 0.0029 | 0.97658 |

**Variable: PHIres (Residual)**

| | | | |
|---|---|---|---|
| N | 243 | Sum Weights | 243 |
| Mean | 0 | Sum Observations | 0 |
| Std Deviation | 20.7584446 | Variance | 430.913023 |
| Skewness | -0.3351753 | Kurtosis | 0.2586999 |
| Uncorrected SS | 104280.952 | Corrected SS | 104280.952 |
| Coeff Variation | . | Std Error Mean | 1.33165484 |

**Tests for Normality**

| Test | --Statistic--- | | -----p Value------ | |
|---|---|---|---|---|
| Shapiro-Wilk | W | 0.984446 | Pr < W | 0.0093 |

## Model Validation

**SAS language**

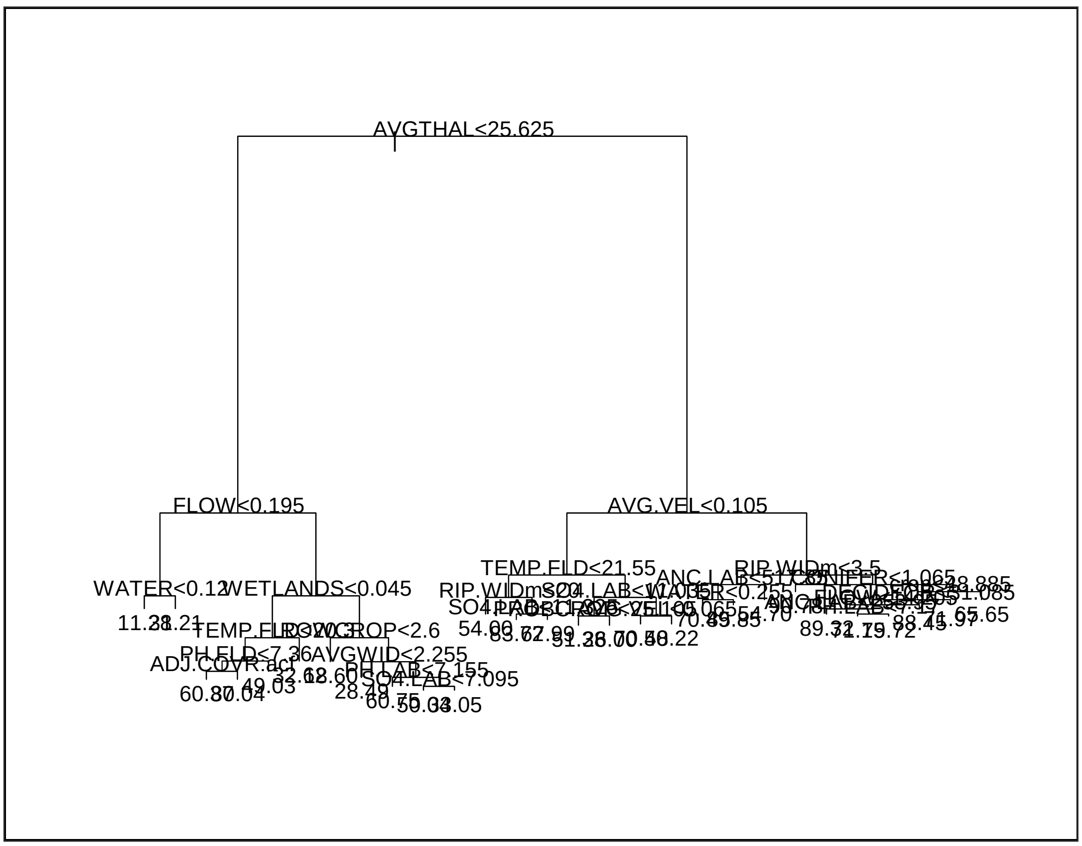
```
DATA    one  ;
INFILE  'D:\g MBSS paper\SAS\SAS split data\PHIvaldata.dat'        ;
INPUT PHI     RIP_WIDm     TEMP_FLD     BUFF_FOR     CROP     REGION_E
PHYS_CP    ACID_NO     AGRI     URBAN     FOREST     ORDER     DO_FLD
PH_FLD     COND_FLD      PH_LAB     COND_LAB     ANC_LAB
SO4_LAB     DOC_LAB    PASTURE    ST_GRAD     AVGWID     AVGTHAL
AVG_VEL     FLOW     ACREAGE     WETLANDS     BARREN     WATER
HIGHURB     LOWURB     PASTUR     PROBCROP     ROWCROP   cropmix
CONIFER
DECIDFOR     MIXEDFOR     EMERGWET     WOODYWET     COALMINE
TRANS     BKTRFLAG       BLACKWAT   ;
PHIpred = 4.251 + 0.271*RIP_WIDm + .952*AVGTHAL +74.595*AVG_VEL -
.00063*ACREAGE +.383*ROWCROP;
res = PHI - PHIpred ;  proc print;     Proc corr;  run; quit;
```

**Results:** Correlation Coefficient for PHI  vs  PHIpred = 0.722 so  **$R^2$ = .52**

## APPENDIX 17:

## PHI S-PLUS MODELING

### Regression tree with all parameters



**Regression Tree Model with all Parameters**

tree(formula = PHI ~ RIP.WIDm + TEMP.FLD + BUFF.TYP + ADJ.COVR + REGION + AGRI + PHYCPIO + URBAN + FOREST + ORDER + DO.FLD + PH.FLD + COND.FLD + PH.LAB + COND.LAB + ANC.LAB + SO4.LAB + DOC.LAB + ACIDSRC + PASTURE + ST.GRAD + AVGWID + AVGTHAL + AVG.VEL + FLOW + ACREAGE + WETLANDS + BARREN + WATER + HIGHURB + LOWURB + PASTUR + PROBCROP + ROWCROP + crop + CONIFER + DECIDFOR + MIXEDFOR + EMERGWET + WOODYWET + COALMINE + TRANS + BKTRFLAG + BLACKWAT,
data = PHI.cal.data, na.action = na.exclude, mincut = 5, minsize = 10,mindev = 0.01)

Variables actually used in tree construction: "AVGTHAL" "FLOW" "WATER" "WETLANDS" "TEMP.FLD" "PH.FLD" "ADJ.COVR" "ROWCROP" "AVGWID" "PH.LAB" "SO4.LAB" "AVG.VEL" "RIP.WIDm" "PROBCROP" "ANC.LAB" "CONIFER" "crop" "DECIDFOR"

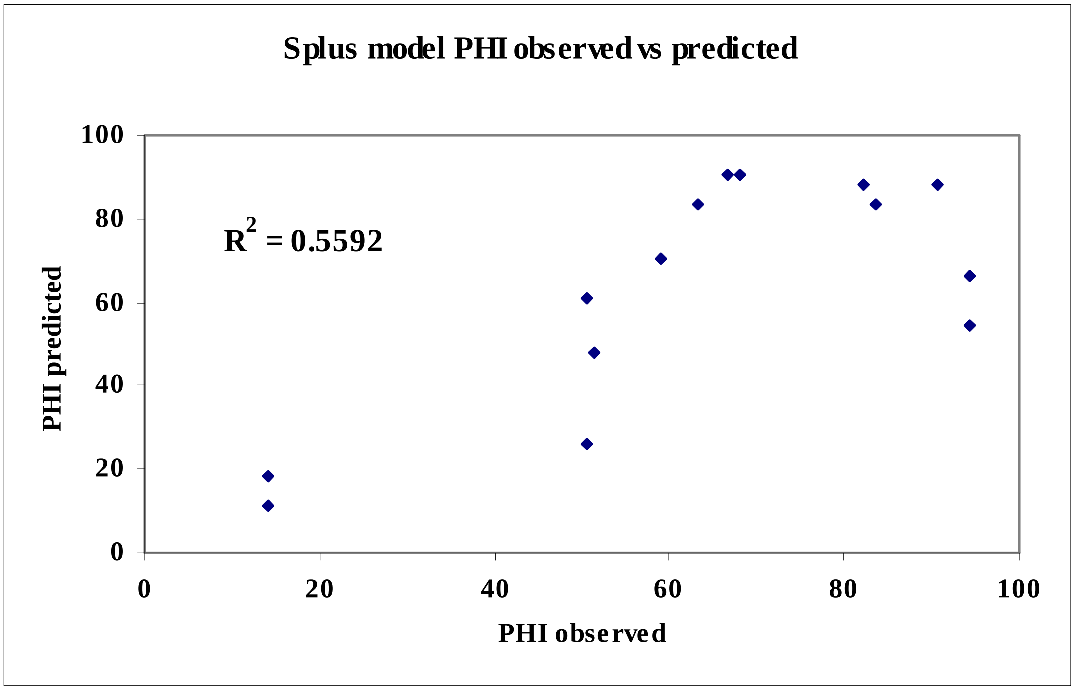
Number of terminal nodes: 28
Residual mean deviance: 184.3 = 39620 / 215

**node), split, n, deviance, yval      * denotes terminal node**

```
 1) root 243 194400.0 59.54
   2) AVGTHAL<25.625 92  62680.0 37.51
     4) FLOW<0.195 28   8439.0 17.69
       8) WATER<0.12 19   1812.0 11.28 *
       9) WATER>0.12 9   4201.0 31.21 *
     5) FLOW>0.195 64  38420.0 46.19
      10) WETLANDS<0.045 26  12860.0 59.66
        20) TEMP.FLD<20.3 21   5292.0 66.10
          40) PH.FLD<7.36 16   2921.0 71.43
            80) ADJ.COVR:CP,LN,PA 7    887.5 60.37 *
            81) ADJ.COVR:FR,OF 9    511.2 80.04 *
          41) PH.FLD>7.36 5    459.1 49.03 *
        21) TEMP.FLD>20.3 5   3040.0 32.62 *
      11) WETLANDS>0.045 38  17610.0 36.96
        22) ROWCROP<2.6 10   1122.0 18.60 *
        23) ROWCROP>2.6 28  11910.0 43.52
          46) AVGWID<2.255 9   1525.0 28.49 *
          47) AVGWID>2.255 19   7388.0 50.64
            94) PH.LAB<7.155 9   2547.0 60.75 *
            95) PH.LAB>7.155 10   3093.0 41.54
             190) SO4.LAB<7.095 5   2144.0 50.04 *
             191) SO4.LAB>7.095 5    226.7 33.05 *
   3) AVGTHAL>25.625 151  59900.0 72.95
```

```
6) AVG.VEL<0.105 50  27040.0 60.34
 12) TEMP.FLD<21.55 26   8911.0 69.20
   24) RIP.WIDm<20 9   3551.0 54.00 *
   25) RIP.WIDm>20 17   2181.0 77.24
     50) SO4.LAB<11.325 10    733.8 83.72 *
     51) SO4.LAB>11.325 7    427.1 67.99 *
 13) TEMP.FLD>21.55 24  13890.0 50.75
   26) SO4.LAB<11.035 11   5624.0 37.54
     52) PROBCROP<25.105 5    964.8 51.38 *
     53) PROBCROP>25.105 6   2903.0 26.00 *
   27) SO4.LAB>11.035 13   4717.0 61.93
     54) AVG.VEL<0.065 8    964.6 70.50 *
     55) AVG.VEL>0.065 5   2224.0 48.22 *
7) AVG.VEL>0.105 101  20960.0 79.20
 14) RIP.WIDm<3.5 24   7685.0 71.65
   28) ANC.LAB<517.85 17   3301.0 78.62
     56) WATER<0.255 8   1890.0 70.49 *
     57) WATER>0.255 9    412.2 85.85 *
   29) ANC.LAB>517.85 7   1549.0 54.70 *
 15) RIP.WIDm>3.5 77  11480.0 81.55
   30) CONIFER<1.065 13    288.1 90.78 *
   31) CONIFER>1.065 64   9863.0 79.68
     62) crop<48.885 57   7764.0 81.40
      124) DECIDFOR<31.085 48   4536.0 83.17
        248) FLOW<14.205 30   3200.0 79.99
          496) ANC.LAB<253.95 8    238.1 89.32 *
          497) ANC.LAB>253.95 22   2014.0 76.60
            994) PH.LAB<7.17 8    970.4 71.15 *
            995) PH.LAB>7.17 14    670.3 79.72 *
        249) FLOW>14.205 18    530.9 88.45 *
      125) DECIDFOR>31.085 9   2276.0 71.97 *
     63) crop>48.885 7    553.8 65.65 *
```

**Model Validation**




| Obs | Pred | Obs | Pred |
|---|---|---|---|
| 14.06 | 11.28 | 83.36 | 71.97 |
| 50.47 | 60.75 | 79.33 | 83.72 |
| 83.73 | 83.72 | 57.46 | 85.85 |
| 66.59 | 90.78 | 81.18 | 67.99 |
| 50.47 | 26.00 | 49.92 | 89.32 |
| 14.06 | 18.60 | 84.47 | 85.85 |
| 90.61 | 88.45 | 89.89 | 65.65 |
| 94.26 | 54.70 | 95.75 | 89.32 |
| 67.95 | 90.78 | 93.21 | 90.78 |
| 94.26 | 66.12 | 73.95 | 90.78 |
| 59.18 | 70.49 | 98.47 | 83.72 |
| 51.29 | 48.22 | 42.23 | 88.45 |
| 63.33 | 83.72 | 8.62 | 11.28 |
| 82.19 | 88.45 | 55.45 | 49.03 |

**Development of equivalent $R^2$ for regression tree model**

| REGION | PHI | delta | square |
|---|---|---|---|
| CP | 2.3 | -51.15 | 2616.47 |
| CP | 50.47 | -2.98 | 8.89 |
| CP | 33.24 | -20.21 | 408.50 |
| CP | 14.06 | -39.39 | 1551.68 |
| CP | 89.62 | 36.17 | 1308.17 |
| CP | 94.81 | 41.36 | 1710.53 |
| CP | 2.76 | -50.69 | 2569.62 |
| CP | 66.12 | 12.67 | 160.49 |
| CP | 6.89 | -46.56 | 2167.96 |
| CP | 15.73 | -37.72 | 1422.90 |
| CP | 9.72 | -43.73 | 1912.43 |
| CP | 23.66 | -29.79 | 887.53 |
| CP | 64.37 | 10.92 | 119.22 |
| CP | 61.55 | 8.10 | 65.59 |
| CP | 50.47 | -2.98 | 8.89 |
| CP | 10.83 | -42.62 | 1816.58 |
| CP | 40.66 | -12.79 | 163.62 |
| CP | 81.68 | 28.23 | 796.85 |
| CP | 78.15 | 24.70 | 610.02 |
| CP | 58.64 | 5.19 | 26.92 |
| CP | 3.31 | -50.14 | 2514.16 |
| CP | 76.02 | 22.57 | 509.34 |
| CP | 57.57 | 4.12 | 16.96 |
| CP | 43.89 | -9.56 | 91.42 |
| CP | 7.48 | -45.97 | 2113.37 |
| CP | 63.87 | 10.42 | 108.55 |
| CP | 53.22 | -0.23 | 0.05 |
| CP | 11.49 | -41.96 | 1760.76 |
| CP | 15.16 | -38.29 | 1466.23 |
| CP | 26.13 | -27.32 | 746.46 |
| CP | 81.52 | 28.07 | 787.85 |
| CP | 41.73 | -11.72 | 137.39 |
| CP | 34.47 | -18.98 | 360.29 |

| corrected total SS | |
|---|---|
| 107843.12 | **CP** |
| 99529.10 | **Pd** |
| 207372.22 | **ALL** |

| Resid SS | deviance |
|---|---|
| **CP** | 3491 |
| | 5936 |
| | 4493 |
| | 4721 |
| | 7278 |
| | 5775 |
| | **31694** |
| **Pd** | 75.8 |
| | 818 |
| | 5225 |
| | 4908 |
| | 15980 |
| | 22010 |
| | **49017** |
| **ALL** | 8439 |
| | 38420 |
| | 8911 |
| | 13890 |
| | 7685 |
| | 11480 |
| | **88825** |

| Res/Cor SS | |
|---|---|
| **CP** | 0.29 |
| **Pd** | 0.49 |
| **ALL** | 0.43 |

| | | | | | |
|---|---|---|---|---|---|
| CP | 66.37 | 12.92 | 166.89 | **$R^2$** | |
| CP | 83.73 | 30.28 | 916.79 | **CP** | 0.71 |
| CP | 50.47 | -2.98 | 8.89 | **Pd** | 0.51 |
| CP | 66.86 | 13.41 | 179.79 | **ALL** | 0.57 |
| CP | 56.49 | 3.04 | 9.23 | | |
| CP | 41.73 | -11.72 | 137.39 | | |
| CP | 12.06 | -41.39 | 1713.25 | | |
| CP | 14.06 | -39.39 | 1551.68 | | |
| CP | 6.15 | -47.30 | 2237.42 | | |
| CP | 69.02 | 15.57 | 242.38 | | |
| CP | 2.73 | -50.72 | 2572.66 | | |
| CP | 5.9 | -47.55 | 2261.14 | | |
| CP | 88.33 | 34.88 | 1216.52 | | |
| CP | 64.12 | 10.67 | 113.82 | | |
| CP | 78.34 | 24.89 | 619.44 | | |
| CP | 25.71 | -27.74 | 769.58 | | |
| CP | 55.13 | 1.68 | 2.82 | | |
| CP | 77.59 | 24.14 | 582.67 | | |
| CP | 90.32 | 36.87 | 1359.29 | | |
| CP | 93.48 | 40.03 | 1602.29 | | |
| CP | 68.78 | 15.33 | 234.97 | | |
| CP | 67.1 | 13.65 | 186.28 | | |
| CP | 16.94 | -36.51 | 1333.08 | | |
| CP | 87.63 | 34.18 | 1168.18 | | |
| CP | 59.18 | 5.73 | 32.82 | | |
| CP | 59.44 | 5.99 | 35.86 | | |
| CP | 51.29 | -2.16 | 4.67 | | |
| CP | 59.44 | 5.99 | 35.86 | | |
| CP | 19.91 | -33.54 | 1125.03 | | |
| CP | 76.02 | 22.57 | 509.34 | | |
| CP | 87.98 | 34.53 | 1192.22 | | |
| CP | 32.27 | -21.18 | 448.65 | | |
| CP | 56.49 | 3.04 | 9.23 | | |
| CP | 83.12 | 29.67 | 880.23 | | |
| CP | 95.33 | 41.88 | 1753.82 | | |
| CP | 70.64 | 17.19 | 295.45 | | |
| CP | 38.81 | -14.64 | 214.37 | | |

| | | | |
|---|---|---|---|
| CP | 28.99 | -24.46 | 598.36 |
| CP | 95.42 | 41.97 | 1761.36 |
| CP | 90.61 | 37.16 | 1380.76 |
| CP | 8.79 | -44.66 | 1994.64 |
| CP | 25.92 | -27.53 | 757.98 |
| CP | 94.18 | 40.73 | 1658.82 |
| CP | 90.61 | 37.16 | 1380.76 |
| CP | 81.18 | 27.73 | 768.88 |
| CP | 91.59 | 38.14 | 1454.55 |
| CP | 88.21 | 34.76 | 1208.16 |
| CP | 90.42 | 36.97 | 1366.68 |
| CP | 16.63 | -36.82 | 1355.82 |
| CP | 49.92 | -3.53 | 12.47 |
| CP | 34.72 | -18.73 | 350.87 |
| CP | 46.89 | -6.56 | 43.05 |
| CP | 95.75 | 42.30 | 1789.17 |
| CP | 41.46 | -11.99 | 143.79 |
| CP | 21.92 | -31.53 | 994.23 |
| CP | 87.02 | 33.57 | 1126.85 |
| CP | 84.18 | 30.73 | 944.25 |
| CP | 47.71 | -5.74 | 32.96 |
| CP | 64.88 | 11.43 | 130.61 |
| CP | 70.64 | 17.19 | 295.45 |
| CP | 1.27 | -52.18 | 2722.90 |
| CP | 10.62 | -42.83 | 1834.53 |
| CP | 86.64 | 33.19 | 1101.48 |
| CP | 44.16 | -9.29 | 86.33 |
| CP | 97.85 | 44.40 | 1971.24 |
| CP | 31.07 | -22.38 | 500.93 |
| CP | 63.1 | 9.65 | 93.10 |
| CP | 53.76 | 0.31 | 0.10 |
| CP | 93.21 | 39.76 | 1580.75 |
| CP | 25.5 | -27.95 | 781.28 |
| CP | 73.95 | 20.50 | 420.19 |
| CP | 14.33 | -39.12 | 1530.48 |
| CP | 93.48 | 40.03 | 1602.29 |
| CP | 94 | 40.55 | 1644.19 |

| | | | |
|---|---|---|---|
| CP | 15.3 | -38.15 | 1455.53 |
| CP | 33.97 | -19.48 | 379.52 |
| CP | 98.47 | 45.02 | 2026.67 |
| CP | 69.25 | 15.80 | 249.60 |
| CP | 10.73 | -42.72 | 1825.12 |
| CP | 66.61 | 13.16 | 173.15 |
| CP | 82.65 | 29.20 | 852.56 |
| CP | 89.42 | 35.97 | 1293.74 |
| CP | 64.63 | 11.18 | 124.96 |
| CP | 76.22 | 22.77 | 518.41 |
| CP | 24.47 | -28.98 | 839.92 |
| CP | 87.75 | 34.30 | 1176.39 |
| CP | 49.64 | -3.81 | 14.53 |
| CP | 44.7 | -8.75 | 76.59 |
| CP | 26.13 | -27.32 | 746.46 |
| P | 2.29 | -63.13 | 3985.33 |
| P | 73.05 | 7.63 | 58.22 |
| P | 71.82 | 6.40 | 40.97 |
| P | 36.37 | -29.05 | 843.87 |
| P | 75.4 | 9.98 | 99.61 |
| P | 47.29 | -18.13 | 328.68 |
| P | 40.74 | -24.68 | 609.08 |
| P | 52.4 | -13.02 | 169.51 |
| P | 60.44 | -4.98 | 24.80 |
| P | 34.04 | -31.38 | 984.67 |
| P | 66.59 | 1.17 | 1.37 |
| P | 94.26 | 28.84 | 831.78 |
| P | 11.57 | -53.85 | 2899.77 |
| P | 40.24 | -25.18 | 634.01 |
| P | 5.25 | -60.17 | 3620.37 |
| P | 35.9 | -29.52 | 871.40 |
| P | 76.52 | 11.10 | 123.22 |
| P | 80.32 | 14.90 | 222.03 |
| P | 96.68 | 31.26 | 977.22 |
| P | 87.65 | 22.23 | 494.20 |
| P | 58.46 | -6.96 | 48.43 |
| P | 90.25 | 24.83 | 616.55 |

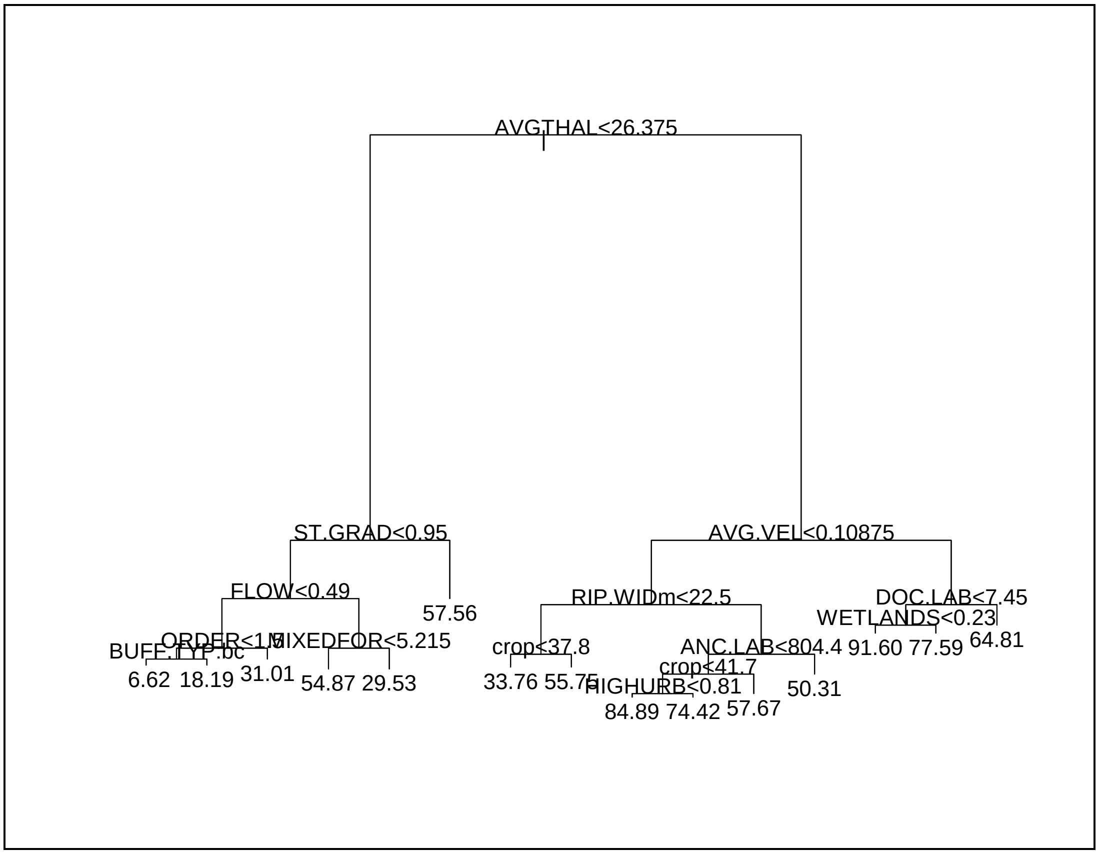
| | | | |
|---|---|---|---|
| P | 93.54 | 28.12 | 790.76 |
| P | 90.61 | 25.19 | 634.56 |
| P | 47.8 | -17.62 | 310.45 |
| P | 44.74 | -20.68 | 427.64 |
| P | 62.38 | -3.04 | 9.24 |
| P | 68.39 | 2.97 | 8.82 |
| P | 71.41 | 5.99 | 35.89 |
| P | 93.05 | 27.63 | 763.45 |
| P | 94.26 | 28.84 | 831.78 |
| P | 89.7 | 24.28 | 589.54 |
| P | 60.54 | -4.88 | 23.81 |
| P | 5.25 | -60.17 | 3620.37 |
| P | 87.65 | 22.23 | 494.20 |
| P | 67.05 | 1.63 | 2.66 |
| P | 66.14 | 0.72 | 0.52 |
| P | 20.13 | -45.29 | 2051.14 |
| P | 46.27 | -19.15 | 366.70 |
| P | 83.64 | 18.22 | 331.99 |
| P | 67.95 | 2.53 | 6.40 |
| P | 83.07 | 17.65 | 311.54 |
| P | 94.26 | 28.84 | 831.78 |
| P | 28.34 | -37.08 | 1374.89 |
| P | 87.2 | 21.78 | 474.39 |
| P | 91.76 | 26.34 | 693.82 |
| P | 80.32 | 14.90 | 222.03 |
| P | 68.83 | 3.41 | 11.63 |
| P | 91.12 | 25.70 | 660.52 |
| P | 88.3 | 22.88 | 523.52 |
| P | 19.48 | -45.94 | 2110.44 |
| P | 63.33 | -2.09 | 4.37 |
| P | 74.63 | 9.21 | 84.83 |
| P | 18.84 | -46.58 | 2169.65 |
| P | 51.38 | -14.04 | 197.11 |
| P | 77.25 | 11.83 | 139.96 |
| P | 57.96 | -7.46 | 55.64 |
| P | 74.24 | 8.82 | 77.80 |
| P | 93.54 | 28.12 | 790.76 |

| | | | |
|---|---|---|---|
| P | 51.38 | -14.04 | 197.11 |
| P | 79.33 | 13.91 | 193.50 |
| P | 82.19 | 16.77 | 281.25 |
| P | 87.42 | 22.00 | 484.02 |
| P | 94.15 | 28.73 | 825.44 |
| P | 5.78 | -59.64 | 3556.87 |
| P | 84.73 | 19.31 | 372.90 |
| P | 71.82 | 6.40 | 40.97 |
| P | 86.97 | 21.55 | 464.42 |
| P | 70.56 | 5.14 | 26.42 |
| P | 81.28 | 15.86 | 251.56 |
| P | 58.46 | -6.96 | 48.43 |
| P | 67.95 | 2.53 | 6.40 |
| P | 83.36 | 17.94 | 321.86 |
| P | 76.15 | 10.73 | 115.14 |
| P | 80.32 | 14.90 | 222.03 |
| P | 83.92 | 18.50 | 342.27 |
| P | 60.44 | -4.98 | 24.80 |
| P | 24.37 | -41.05 | 1685.06 |
| P | 79.33 | 13.91 | 193.50 |
| P | 84.47 | 19.05 | 362.92 |
| P | 89.12 | 23.70 | 561.71 |
| P | 57.46 | -7.96 | 63.35 |
| P | 93.44 | 28.02 | 785.15 |
| P | 68.83 | 3.41 | 11.63 |
| P | 72.64 | 7.22 | 52.14 |
| P | 25.91 | -39.51 | 1561.00 |
| P | 87.87 | 22.45 | 504.03 |
| P | 84.2 | 18.78 | 352.71 |
| P | 22.89 | -42.53 | 1808.76 |
| P | 37.81 | -27.61 | 762.28 |
| P | 77.25 | 11.83 | 139.96 |
| P | 43.73 | -21.69 | 470.43 |
| P | 48.92 | -16.50 | 272.23 |
| P | 92.21 | 26.79 | 717.73 |
| P | 92.78 | 27.36 | 748.60 |
| P | 74.63 | 9.21 | 84.83 |

| | | | |
|---|---|---|---|
| P | 92.21 | 26.79 | 717.73 |
| P | 52.81 | -12.61 | 159.00 |
| P | 30.9 | -34.52 | 1191.59 |
| P | 96.19 | 30.77 | 946.82 |
| P | 84.47 | 19.05 | 362.92 |
| P | 86.97 | 21.55 | 464.42 |
| P | 84.47 | 19.05 | 362.92 |
| P | 89.89 | 24.47 | 598.81 |
| P | 7.99 | -57.43 | 3298.15 |
| P | 78.31 | 12.89 | 166.17 |
| P | 77.61 | 12.19 | 148.61 |
| P | 86.5 | 21.08 | 444.39 |
| P | 76.89 | 11.47 | 131.57 |
| P | 84.73 | 19.31 | 372.90 |
| P | 88.92 | 23.50 | 552.27 |
| P | 37.81 | -27.61 | 762.28 |
| P | 70.56 | 5.14 | 26.42 |
| P | 77.61 | 12.19 | 148.61 |
| P | 67.95 | 2.53 | 6.40 |
| P | 89.51 | 24.09 | 580.35 |
| P | 50.87 | -14.55 | 211.69 |
| P | 48.31 | -17.11 | 292.73 |
| P | 22.89 | -42.53 | 1808.76 |
| P | 67.5 | 2.08 | 4.33 |
| P | 51.38 | -14.04 | 197.11 |
| P | 89.12 | 23.70 | 561.71 |
| P | 85.51 | 20.09 | 403.63 |
| P | 12 | -53.42 | 2853.64 |
| P | 16.47 | -48.95 | 2396.05 |
| P | 39.75 | -25.67 | 658.92 |
| P | 90.43 | 25.01 | 625.53 |
| P | 80.64 | 15.22 | 231.66 |
| P | 86.26 | 20.84 | 434.33 |
| P | 39.26 | -26.16 | 684.32 |
| P | 70.56 | 5.14 | 26.42 |
| P | 43.23 | -22.19 | 492.37 |
| P | 79 | 13.58 | 184.43 |

| | | | |
|---|---|---|---|
| P | 68.39 | 2.97 | 8.82 |
| P | 71.41 | 5.99 | 35.89 |
| P | 93.44 | 28.02 | 785.15 |
| P | 86.01 | 20.59 | 423.97 |
| P | 27.11 | -38.31 | 1467.62 |
| P | 86.5 | 21.08 | 444.39 |
| P | 92.47 | 27.05 | 731.73 |
| P | 76.15 | 10.73 | 115.14 |
| P | 57.46 | -7.96 | 63.35 |
| P | 5.15 | -60.27 | 3632.41 |
| P | 84.73 | 19.31 | 372.90 |
| P | 67.5 | 2.08 | 4.33 |
| P | 82.19 | 16.77 | 281.25 |
| P | 83.64 | 18.22 | 331.99 |
| P | 85.61 | 20.19 | 407.66 |
| P | 13.36 | -52.06 | 2710.19 |
| P | 50.35 | -15.07 | 227.09 |
| P | 91.12 | 25.70 | 660.52 |
| P | 69.7 | 4.28 | 18.32 |
| P | 42.23 | -23.19 | 537.75 |
| P | 8.62 | -56.80 | 3226.18 |
| P | 55.45 | -9.97 | 99.39 |
| **mean** | | | |
| **CP** | 53.45 | | |
| **P** | 65.42 | | |
| **ALL** | 60.15 | | |

**PHI Regression Tree Model**
**Coastal Plain Data**




Avg Thalweg < 26.375

Stream gradient < 0.95 Avg Velocity < 0.1085

Flow < 0.49 rip width < 22.5 DOC < 7.45

**Regression tree:**

```
tree(formula = PHI ~ RIP.WIDm + TEMP.FLD + BUFF.TYP + ADJ.COVR + REGION +
       AGRI + URBAN + FOREST + ORDER + DO.FLD + PH.FLD + COND.FLD +
       PH.LAB + COND.LAB + ANC.LAB + SO4.LAB + DOC.LAB + ACIDSRC +
       PASTURE + ST.GRAD + AVGWID + AVGTHAL + AVG.VEL + FLOW + ACREAGE +
       WETLANDS + BARREN + WATER + HIGHURB + LOWURB + PASTUR +
       PROBCROP + ROWCROP + crop + CONIFER + DECIDFOR + MIXEDFOR +
       EMERGWET + WOODYWET + COALMINE + TRANS + BKTRFLAG + BLACKWAT,
       data = PHI.CP, na.action = na.exclude, mincut = 5, minsize = 10,
       mindev = 0.01)
```

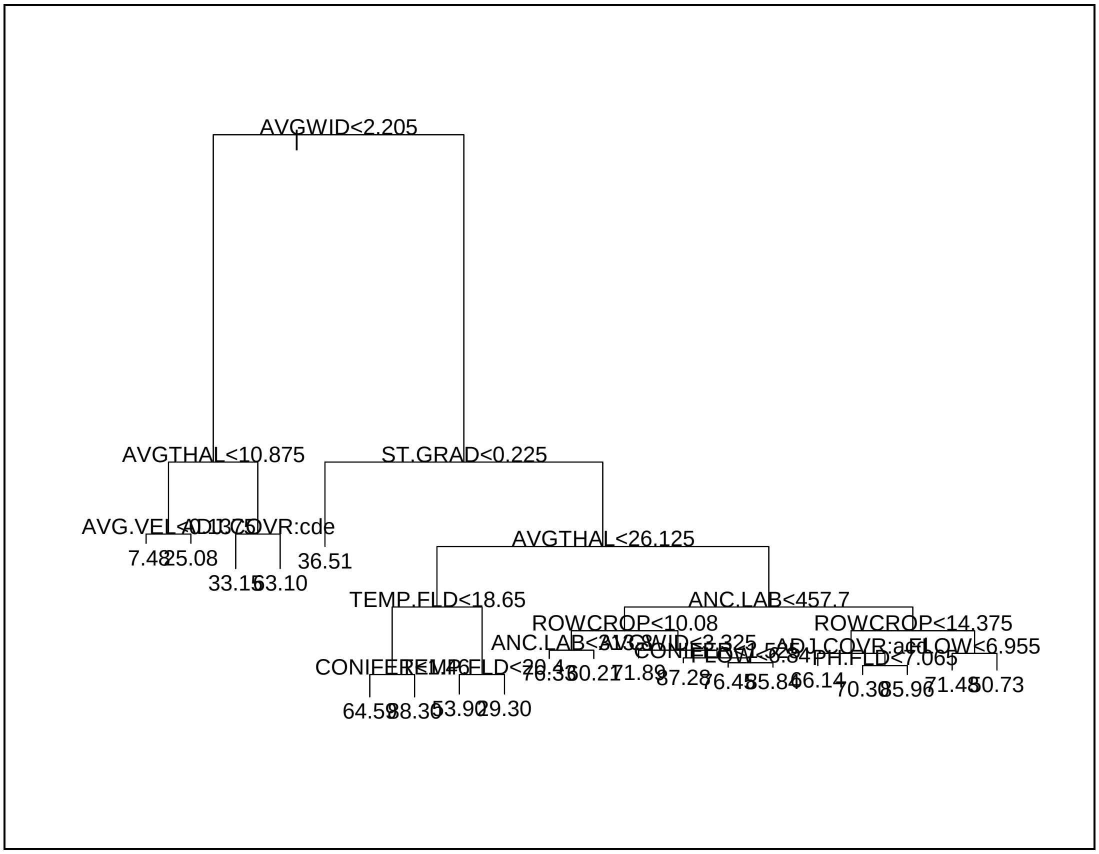
**Variables actually used in tree construction:**

```
 [1] "AVGTHAL"  "ST.GRAD"  "FLOW"     "ORDER"    "BUFF.TYP" "MIXEDFOR"
 [7] "AVG.VEL"  "RIP.WIDm" "crop"     "ANC.LAB"  "HIGHURB"  "DOC.LAB"
[13] "WETLANDS"
Number of terminal nodes:  15
Residual mean deviance:  158 = 16910 / 107
Distribution of residuals:
    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
 -50.670  -5.638   0.111   0.000   7.305  36.590
```

**node), split, n, deviance, yval**

```
      * denotes terminal node

  1) root                  122    107800.0     53.45
    2) AVGTHAL<26.375      52     27020.0      30.15
      4) ST.GRAD<0.95      44     15420.0      25.17
        8) FLOW<0.49       28     3491.0       16.35
         16) ORDER<1.5 23   1680.0 13.16
           32) BUFF.TYP:G,none 10    208.1  6.62 *
           33) BUFF.TYP:FR 13    715.9 18.19 *
         17) ORDER>1.5 5    501.3 31.01 *
        9) FLOW>0.49 16   5936.0 40.62
         18) MIXEDFOR<5.215 7    525.7 54.87 *
         19) MIXEDFOR>5.215 9   2883.0 29.53 *
      5) ST.GRAD>0.95      8      4493.0       57.56 *
    3) AVGTHAL>26.375      70     31630.0      70.76
      6) AVG.VEL<0.10875   40     18020.0      61.59
       12) RIP.WIDm<22.5   13     4721.0       43.91
         24) crop<37.8 7   1453.0 33.76 *
         25) crop>37.8 6   1706.0 55.75 *
       13) RIP.WIDm>22.5   27     7278.0       70.11
         26) ANC.LAB<804.4 22   4447.0 74.61
           52) crop<41.7 16   1365.0 80.96
            104) HIGHURB<0.81 10    719.5 84.89 *
            105) HIGHURB>0.81 6    234.7 74.42 *
           53) crop>41.7 6    714.7 57.67 *
         27) ANC.LAB>804.4 5    424.4 50.31 *
      7) AVG.VEL>0.10875   30     5775.0       82.98
       14) DOC.LAB<7.45    24     1917.0       87.52
         28) WETLANDS<0.23 17    378.5 91.60 *
         29) WETLANDS>0.23 7    565.1 77.59 *
       15) DOC.LAB>7.45    6      1384.0       64.81 *
```

**PHI Regression Tree Model**
**Piedmont Data**




Buffer width < 2.205
Avg thalweg < 10.85 stream gradient < 0.225
Avg velocity < avg thalweg < 26.125

```
Regression tree:
tree(formula = PHI ~ RIP.WIDm + TEMP.FLD + BUFF.TYP + ADJ.COVR + REGION +
       AGRI + URBAN + FOREST + ORDER + DO.FLD + PH.FLD + COND.FLD +
       PH.LAB + COND.LAB + ANC.LAB + SO4.LAB + DOC.LAB + ACIDSRC +
       PASTURE + ST.GRAD + AVGWID + AVGTHAL + AVG.VEL + FLOW + ACREAGE +
       WETLANDS + BARREN + WATER + HIGHURB + LOWURB + PASTUR +
       PROBCROP + ROWCROP + crop + CONIFER + DECIDFOR + MIXEDFOR +
       EMERGWET + WOODYWET + COALMINE + TRANS + BKTRFLAG + BLACKWAT,
       data = PHI.P, na.action = na.exclude, mincut = 5, minsize = 10,
       mindev = 0.01)
Variables actually used in tree construction:
 [1] "AVGWID"   "AVGTHAL"  "AVG.VEL"  "ADJ.COVR" "ST.GRAD"  "TEMP.FLD"
 [7] "CONIFER"  "ANC.LAB"  "ROWCROP"  "FLOW"     "PH.FLD"
Number of terminal nodes:  20
Residual mean deviance:  179 = 24160 / 135
Distribution of residuals:
     Min.  1st Qu.   Median     Mean  3rd Qu.     Max.
 -31.2600  -6.6340  -0.3113   0.0000   7.5440  53.2000

node), split,             n,     deviance,    yval
      * denotes terminal node

  1) root                 155    99530.0      65.42
    2) AVGWID<2.205        25     13530.0      33.76
      4) AVGTHAL<10.875    11     1739.0       15.48
        8) AVG.VEL<0.1375  6      75.8         7.48 *
        9) AVG.VEL>0.1375  5      818.4        25.08 *
      5) AVGTHAL>10.875    14     5225.0       48.13
       10) ADJ.COVR:LN,OF,PA 7  1460.0 33.15 *
       11) ADJ.COVR:CP,FR,TG 7   624.1 63.10 *
    3) AVGWID>2.205        130    56130.0      71.51
      6) ST.GRAD<0.225     6      4908.0       36.51 *
      7) ST.GRAD>0.225     124    43510.0      73.20
       14) AVGTHAL<26.125  27     15980.0      60.55
         28) TEMP.FLD<18.65 15  4756.0 74.08
           56) CONIFER<1.46 9  2580.0 64.59 *
           57) CONIFER>1.46 6   152.6 88.30 *
         29) TEMP.FLD>18.65 12  5057.0 43.65
           58) TEMP.FLD<20.4 7  2632.0 53.90 *
           59) TEMP.FLD>20.4 5   660.2 29.30 *
       15) AVGTHAL>26.125  97     22010.0      76.72
         30) ANC.LAB<457.7 60  8880.0 80.44
           60) ROWCROP<10.08 12  2653.0 69.61
            120) ANC.LAB<313.8 7   965.9 76.33 *
            121) ANC.LAB>313.8 5   928.9 60.21 *
           61) ROWCROP>10.08 48  4468.0 83.15
            122) AVGWID<3.325 5   950.2 71.89 *
            123) AVGWID>3.325 43  2811.0 84.46
              246) CONIFER<1.525 24   565.1 87.28 *
              247) CONIFER>1.525 19  1813.0 80.89
                494) FLOW<6.84 10   843.5 76.45 *
                495) FLOW>6.84 9   551.6 85.84 *
         31) ANC.LAB>457.7 37 10950.0 70.69
           62) ROWCROP<14.375 23  5228.0 76.52
            124) ADJ.COVR:CP,LN,OF 7  1256.0 66.14 *
            125) ADJ.COVR:FR,PA,TG 16  2886.0 81.06
              250) PH.FLD<7.065 5  1420.0 70.30 *
              251) PH.FLD>7.065 11   623.5 85.96 *
           63) ROWCROP>14.375 14  3655.0 61.10
            126) FLOW<6.955 7   657.3 71.48 *
            127) FLOW>6.955 7  1490.0 50.73 *
```

## APPENDIX 18:

## SAS PROGRAMS

***Program to look at qualitative variables Is there a difference between regions? ;**

```
DATA    one    ;
INFILE  'd:/ProcFreq/shape.dat' ;
INPUT   sitenum$  wshed$  reg$  shape$  ;
PROC freq  ;   TABLES shape  reg *shape ;
RUN ;   QUIT    ;
```

***Proc mixed for GIS variables;**

```
DATA    GIS ;         INFILE  'd:/ProcMixed/mar19gis.dat'  ;
INPUT   wshed$  reg$  shore$  DrDens  sinuous  topo  ag  forest  ; PROC print ;
PROC    mixed ;          CLASS   reg wshed  ;   MODEL  DrDens = reg  ;  RANDOM
wshed(reg)   / CL;   LSMEANS reg   ; RUN ;
PROC    mixed ;          CLASS   shore wshed  ; MODEL   forest = shore  ;  RANDOM
wshed(shore)   / CL;   LSMEANS shore   ; RUN ;   QUIT  ;
```

**SAS Code for Proc Cluster Analysis**

```
DATA    one             ;
INFILE  'd:/f Classification/Nov25SAS.dat'         ;
INPUT   SITENUM$     RZSlostd     FSloSTD     BSFSstd     RZwtrSTD
LBufSTD
 CXSstd     pctAGstd     ShapeSTD     ChanSTD     FieldSTD     RZdraSTD
OrderSTD  ;
proc cluster data=one  method=average std outtree=outtree2 pseudo ccc simple;
var  RZSlostd     FSloSTD     BSFSstd     RZwtrSTD     LBufSTD
 CXSstd     pctAGstd     ShapeSTD     ChanSTD     FieldSTD     RZdraSTD
OrderSTD ;
run;
goptions reset=all;         goptions ;
  /* vertical axis */
axis1 value=(font=swiss color=blue height=.2) label=(height=.2   color=green);
 /* horizontal axis */
axis2 value=(font=swiss color=red  height=.2) label=(height=.2   color=black);
title h=.5 'proc tree for average method - with standardized data';
data outtree2;        set outtree2;
if _name_ ne 'CL1' and _parent_ eq '' then delete;      run;
proc tree data=outtree2 horizontal vpages=3 hpages=3 vaxis=axis1  haxis=axis2;  run;
```

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Zinecker E. 2001. Poster at the Chesapeake Bay Watershed Restoration: Riparian and Wetland Stewardship Conference. Baltimore, Maryland. September 24-26, 2002

# CURRICULUM VITAE

**Linda S. Barker**
**barkerlinda@yahoo.com**

## RESEARCH INTERESTS

Stock assessment studies of finfish and other aquatic species of the Chesapeake Bay and its tributaties.

Quantification of the impact of riparian buffers on channel morphology, streamflow patterns, water-quality and instream benthic communities of low-order non-tidal streams.

Data mining and statistical analysis of existing environmental databases to determine environmental patterns and answer questions beyond the scope of the original design of the data.

Development of biological engineering and environmental education techniques and curricula.

## FORMAL EDUCATION

**1998-2003. University of Maryland, College Park, MD**
Ph.D. in Biological Resources Engineering – Water Resources Specialty. GPA 4.0
**1997-1998. University of Maryland at Baltimore County, Baltimore, MD**
One year of graduate classes in the Department of Biological Sciences. GPA 4.0
**1988-1991. McNeese State University, Lake Charles, LA**
M.S., Environmental Science. GPA 4.0
**1974-1978. Tulane University, New Orleans, LA**
B.S., Chemical Engineering and Pre-Med Studies. GPA 3.0

## PROFESSIONAL EXPERIENCE - Technical

**Research Statistician VI**
Maryland Department of Natural Resources, Fisheries Program. November 2003 –
Conduct statistical analyses and modeling, design sampling plans, review reports and proposals to support management of Chesapeake Bay resident and migratory species.

**Research Statistician VI**
Maryland Department of Natural Resources, Fisheries Service, Striped Bass Stock Assessment. January – October 2003.
Conduct statistical analyses, design sampling plans, and prepare reports and presentations to support management of the Chesapeake Bay and coastal migratory stock of Striped Bass (*Morone saxatilis*).

**Independent Research**
In association with the Biology Department, U.N.A.H., Tegucigalpa, Honduras. 2002.
Bio-hydrology and aquatic invertebrate studies of tropical low-order streams in the Rio Platano Biosphere Reserve of Honduras.

**Research Assistant and Doctoral Candidate**
University of Maryland, Department of Biological Resources Engineering.
Designed and coordinated the first large-scale, ground-truthed agricultural riparian buffer survey in Maryland. Designed fieldwork protocols and training materials, conducted fieldwork, trained and coordinated oversight of 8 other field teams, and helped to network with the appropriate agricultural agencies in the targeted agricultural watersheds. Managed data QA/QC & conducted statistical analysis using SAS & Splus. Used this database and the Md DNR MBSS database to interpret land use patterns, physical and biological systems, and hydrology in agricultural watersheds. Developed environmental models for the prediction of instream nitrate, biological and physical stream health parameters. Developed and presented technical and scientific papers at national conferences and for state agencies and committees.

**Expert Witness**
Eggleston and Wolf, Baltimore, Maryland. 1997.
Provided information that led to the out-of-court settlement of a drycleaner case.

**Director – Small Business Assistance Program.**
Maryland Department of the Environment. 1993-1997.
Integrated air- with water- and waste- compliance requirements at both the state and federal levels with pollution prevention opportunities. Created outreach programs for small businesses affected by environmental regulations. Initiated and coordinated cooperative partnerships with affected industries, conducted outreach and training for industry and state personnel. Handbooks were used as blueprints for similar programs in other states. Two awards of appreciation from local business organizations.

**Environmental Specialist**
Louisiana Dept. of Environmental Quality, Lake Charles, LA. 1991
Supervised ambient air quality monitoring for LA's southwest district. Provided technical training for air quality compliance personnel.

**Technical Specialist**
Dearborn Chemical Division, Houston District. 1990.
Provided technical support for water-quality and industrial equipment. Developed and conducted training for engineers, operators and maintenance personnel.

**Environmental Project Engineer**
W.R. Grace Chemical Plant, Lake Charles, LA. 1989.
As part of a cooperative program with McNeese State University. Analyzed industrial processes & made recommendations for minimization of wastewater discharge and effluent toxicity. Designed, constructed and operated an on-site industrial wastewater treatment pilot plant & designed a whole-plant WWT facility.

**Family leave-of-absence. 1980-1988.**
Provided care for my two young sons, one of whom is severely handicapped.

**Chemical Engineer**
PPG Industrial Chemical Plant, Lake Charles, LA. 1979-1980.
Performed industrial process and wastewater discharge analysis projects.

## PROFESSIONAL EXPERIENCE - Teaching

**Departmental Instructor**
University of Maryland, Dept. of Biological Resources Engineering. 2000 - 2001.
Taught ENBE 100 "Introduction to Biological Resources Engineering", a multi-disciplinary introduction to engineering principles core course for non-engineers.

**Teaching Assistant**
University of Maryland at Baltimore County. Fall 1998.
Oversight for 5 "Discussion Sections" (100 students) of Biology 101, the introductory Biology course for Biology majors. This course is taught under a NSF grant to explore "active learning" and interactive teaching.

**Departmental Instructor**
Essex Community College. 1994-1997.
Designed and taught the introductory Biology lecture and lab courses for students in the Med- Vet- Tech program and Introduction to Biology for non-science majors.

**Departmental Instructor**
Loyola College of Baltimore, Biology Department. 1993-1994.
Taught 4 sections (100 students) per semester of Biology lab for Biology majors.

**Teaching Assistant and Lab Coordinator.**
McNeese State University, Biology Department. 1988-1991.
Taught 4 sections (100 students) per semester of the Zoology lab course (Bio 102L).

## PROFESSIONAL PUBLICATIONS


**Barker, L.S. and H. Speir. 2003**. Effects of size limit increases on the harvest of striped bass in the Chesapeake Bay. Fisheries Technical Report No. 43. Maryland Dept. of Natural Resources, Annapolis. Md.

**Barker L.S. and G.K. Felton** 2002. Modeling the effects of agricultural riparian buffers to mitigate nitrate stream pollution. ASAE Paper 02-2044. ASAE Annual International Meeting, Chicago, Ill. July 28-31.

**Barker, L.S., G.K. Felton, and E. Russek-Cohen. 2001**. Use of a classification system to evaluate the impact of agricultural riparian buffers on instream nitrate concentrations. Presented at the annual conference of the American Water Resources Association. Albuquerque, New Mexico. November 12-15. p. 27.

**Montas, H.H., L.B. Moran and G.K. Felton. 2000**. Water-quality impact of agricultural riparian buffers in a small Maryland watershed. Presented at the annual conference of ASAE. Chicago, Illinois. July 2000.

**Moran, L.B. 1997**. Guide to Compliance and P2 for Small Maryland Printers. MDE. Baltimore, Md.

**Moran, L.B. 1996**. Guide to Compliance and P2 for Chrome Platers in Maryland. MDE. Baltimore, Md.

**Taddeo, L. and L.B. Moran. 1995**. Guide to Compliance and P2 for Autobody Shops in Maryland. MDE. Baltimore, Md.

**Moran, L.B. 1994**. Guide to Compliance and P2 for Maryland Drycleaners. MDE. Baltimore, Md.

## PROFESSIONAL PRESENTATIONS

**Barker, L.S. 2003.** Statistical analysis in stock assessment of Chesapeake Bay striped bass management. Presented as an ENBE departmental seminar. College Park, Md. April 2, 2003.
**Barker, L.S. 2003.** Use of the Maryland Biological Stream Survey (1995-1997) data to quantify the effectiveness of agricultural riparian buffers. Presented at the Mid-Atlantic Water Pollution Biology Workshop. Cacapon, West Virginia.
**Barker, L.S. 2002**. The effectiveness of agricultural riparian buffers to mitigate nitrate stream pollution. Presented at the Chesapeake Bay Watershed Conference. Baltimore, Maryland. September 24-26, 2002.
**Barker, L.S. 2002.** Agricultural buffers in Maryland and their effect on chemical, biological and physical measures of stream health. Presented by invitation to members of the Maryland CREP Advisory Panel. Annapolis, Maryland. August 29, 2002.
**Barker, L.S. and G.K. Felton. 2002**. Modeling the effects of agricultural riparian buffers to mitigate nitrate stream pollution. Presented at the annual conference of the American Society of Agricultural Engineers. Chicago, Ill. July 26-31, 2002.
**Barker, L.S. 2002**. Agricultural buffers in Maryland. Presented by invitation to the Maryland State Soil Conservation Committee. Annapolis, Maryland. June 20, 2002.
**Barker, L.S. 2002**. Agricultural buffers in Maryland and their effect on in-stream nitrate levels. Presented by invitation to the Maryland ReLeaf Committee. Annapolis, Maryland. February 7, 2002.

**1994-1996.** Over 50 presentations for Maryland's small business professional organizations - environmental regulatory compliance and pollution prevention opportunities.

**1995-1997.** Yearly presentations representing MDE at National Small Business Assistance conferences.

## HONORS AND AWARDS

- Distinguished Teaching Assistant. Dept. of Biol. Resources Engineering. 2002.
- Ilene Nagel Travel Grant for research in Honduras. U. Md. Graduate School. 2001.
- J.K. Goldhaber Travel Grant for research in Honduras. U. Md. Grad. School. 2002.
- Invited Reviewer. American Women in Science. 2001.
- Olive Lynn Salembier Re-entry Scholarship. Society of Women Engineers. 2000.
- S. Bufton Memorial Education Scholarship. Amer. Business Women’s Assn. 2000.
- Ruth Satter Fellowship. American Women in Science Educational Fdn. 2000.
- Elected to Sigma Xi (international scientific research honor society). 2000.
- Richard A Herbert Graduate Scholarship. American Water Resources Assn. 1999.
- Elected to Alpha Epsilon (ASAE honor society). 1999.
- Award of Appreciation. Korean Drycleaners Association of Maryland. 1996.