AN ABSTRACT OF THE THESIS OF

Daniel M. Evans for the degree of Master of Science in Forest Engineering presented on May 1, 2007.

Title: Dissolved Nitrogen in Surface Waters and Nitrogen Mineralization in Riparian Soils within a Multi-Land Use Basin

Abstract approved:

Stephen H. Schoenholtz

The growing population of Oregon's Willamette River Basin places an increasing demand on the basin's surface waters. Watershed-scale research addressing spatial trends of dissolved nitrogen (DN) and its relationship with landuse and soil N dynamics, such as N mineralization, is sparse in the Willamette Basin. I measured DN along 124 km of the Calapooia River, a tributary to the Willamette River, and in 44 non-nested sub-basins to the Calapooia River for three years. Relationships between land-use and DN concentrations were explored using correlation and regression analysis. Additionally, I measured net N mineralization at monthly intervals for one year in surface soils (0-15cm) of the riparian zone at 32 locations along the length of the Calapooia River.

Results show that there was consistently more DN in lower sub-basin surface waters dominated by poorly drained soils and agricultural production when compared to upper sub-basins that are dominated by well-drained soils and timber production. Nitrate-N was >10 mg L^{-1} for eight lower-basins and total N was >10 mg L^{-1} for nine lower basins during at least one sample period. Dissolved organic N (DON) represented a greater proportion of DN in the upper basin, but had lower concentrations relative to the

lower basin. Seasonal nitrate-N concentrations had strong positive correlations to the percent of a sub-basin that was managed for agriculture (%AG) in all seasons except summer, whereas seasonal DON concentrations had strong positive correlations to %AG in all seasons. This study indicated that DN concentrations and components varied widely among seasons and years relative to precipitation amount and timing, soil drainage, and land management. Efforts to reduce or regulate DN in the Calapooia Basin or similar basins in the Willamette Basin must address this large temporal variability and should include consideration of soil drainage because of its influence on hydrological connections between terrestrial and aquatic systems.

Net N mineralization in riparian soils had seasonal trends with relatively low mean net mineralization rates in the fall and winter and relatively high mean rates in the spring and summer when conditions for microbial activity and decomposition were enhanced. Annual net N mineralization was positively correlated with total N and labile N in surface soils and with basal area of hardwoods within the riparian zone. Annual net N mineralization per unit area was lower in riparian soils along the upper reaches of the basin compared to the lower reaches. This difference was primarily caused by higher amounts of coarse fragments in soils along the upper reaches. This demonstrates that there is an inherent likelihood of more N mineralization in riparian soils of the lower Calapooia Basin because of a lack of coarse fragments when compared to the upper basin. Net N mineralization per kg of soil-size fraction may be a more appropriate measure when exploring relationships with riparian conditions on watershed scales.

Dissolved Nitrogen in Surface Waters and Nitrogen Mineralization in Riparian Soils within a Multi-Land Use Basin

by
Daniel M. Evans

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Daniel M. Evans, Author

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CONTRIBUTION OF AUTHORS

Dr. Stephen H. Schoenholtz assisted with study design, data interpretation and writing of Chapters 2 and 3. Dr. Parker J. Wigington assisted with study design and data interpretation for Chapters 2 and 3. Dr. Stephen M. Griffith assisted with study design, data collection and lab analysis for Chapters 2 and 3. Dr. George Mueller-Warrant assisted with data collection for Chapter 2.

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Chapter 1: Introduction

1.1 Introduction

Surface water quality is a growing concern in Oregon's Willamette River Basin because 70% of Oregon's population lives within the Willamette Basin. This growing population puts pressure on surface waters to provide drinking water, recreation, transportation, sport fishing, aquatic habitat and irrigation for crops, as well as countless other market and non-market amenities. The Willamette River Basin is used for a diverse range of land uses such as timber production, urban and rural housing, wildlife reserves and agriculture. Since there is a predominance of agriculture and forestry in the Willamette Basin, which have the potential to increase nutrient levels in surface waters, nutrients and their relationship with land use are a high priority for protecting surface waters.

High levels of dissolved nitrogen (DN), particularly nitrate-N, are associated with multiple water-quality concerns. Excess levels of DN can trigger eutrophication of surface waters which can exacerbate effects of high water temperatures on oxygen levels, leading to hypoxic conditions and negative impacts on aquatic systems. A secondary concern is a life threatening condition in infants known as methogloblimenia or blue baby syndrome, which is caused by drinking water high in nitrate-N.

Land use and land cover (LULC) have been strongly linked to DN, particularly nitrate-N, export into aquatic systems (Jordan et al. 1997; Wernick 1998; Howarth et al.

2002; Donner et al. 2004; Pellerin et al. 2006) Specifically, strong relationships are often noted between the amount of agriculture in a basin and nitrate-N concentrations in streams (Johnson et al.1997; Howarth et al. 2002; Floyd 2005; Poor and McDonnell 2006; Pellerin et al. 2006), with higher concentrations of nitrate-N often observed in streams draining agriculturally dominated basins. However, few studies in western North America have addressed these relationships in multiple land-use settings such as the Willamette Basin. The Willamette Basin is distinct from more highly studied basins, such as the Chesapeake and Mississippi River Basins, because of the prevalence of well-sorted, poorly drained soils in the lower area of the basin and a generally mild climate with distinct wet and dry seasons.

An additional research gap exists relative to N dynamics in riparian soils. Research from eastern North America has demonstrated the importance of riparian buffers in agricultural and forested settings in removing DN from soil water before it reaches surface waters. However, there is mounting evidence that the winter rains of western Oregon and poorly drained soils in the lower, agriculturally dominated areas of the Willamette Basin frequently combine to shift hydrologic connections to overland flowpaths and deliver DN directly to surface waters (Wigington et al. 2003, 2005). Some emphasis has therefore shifted toward identifying environmental controls on N processes in this system and determining optimal management of riparian areas for nutrient retention.

The Calapooia River, with its headwaters in the western Cascade Mountains, is a tributary to the Willamette. The Calapooia Basin has a similar mix of land uses as the greater Willamette Basin, with forest management and agriculture as the predominant land uses. The Calapooia Basin provides a good opportunity to address DN in surface waters and N processing in soil systems across a multi-land use basin.

This study includes a synoptic sampling of DN in surface waters of the Calapooia River and 44 of its tributaries. Sampling was maintained for three complete water years to address seasonal and annual variation. These data were used to investigate both seasonal and spatial trends of DN in surface waters of the Calapooia Basin and to evaluate relationships between LULC and DN levels within independent sub-basins. The study also includes an evaluation of the potential of riparian soils to release or retain N along the length of the Calapooia River using *in situ* net N mineralization incubations. These incubations were performed for one year to produce annual estimates of net N mineralization and to test for relationships between net N mineralization and both site vegetation and soil characteristics.

1.2 Objectives, Related Research Questions, and Hypotheses

Objective 1: To observe temporal, spatial, and seasonal changes in DN concentrations throughout the Calapooia Basin over a three-year time period.

Related Research Questions: Are annual patterns of DN similar among the three years of study? Are DN concentrations consistently higher in the lower sub-basins? Are high DN concentrations consistently measured in any particular sub-basins or do the high DN levels shift among different sub-basins? Are there any instances of high DN concentrations in the upper sub-basins? Are the highest levels of DN consistently found in the winter?

Hypothesis 1: Dissolved nitrogen concentrations are higher in sub-basins and mainstem sample points in the lower areas of the Calapooia Basin when compared to the upper areas of the basin.

Objective 2: To test for relationships between LULC and DN concentrations throughout the Calapooia Basin for three years.

Related Research Question: Are there strong positive relationships between area of sub-basin in agriculture, area with poorly drained soils, or area with woody vegetation and DN levels?

Hypothesis 2: There is a strong positive correlation between the amount of area in a sub-basin managed for agriculture and DN concentrations.

Objective 3: To investigate the presence of temporal and spatial patterns of *in situ* soil net N mineralization across the existing range of vegetation/soil systems in riparian zones along the mainstem of the Calapooia River.

Related Research Questions: Do soils in the riparian zones along the mainstem of the Calapooia River have the potential to act as sources of DN? Are there seasonal or temporal patterns of net N mineralization? Is there a relationship between riparian vegetation and net N mineralization in riparian zones?

Hypothesis 3: Nitrogen mineralization is greater in riparian soils within the lower Calapooia Basin compared to upper areas.

Hypothesis 4: Nitrogen mineralization is positively correlated to total nitrogen and hardwood basal area and is negatively correlated to conifer basal area.

Chapter 2: Temporal and Spatial Trends of Dissolved Nitrogen within a Multi-Land Use Basin

2.0 Abstract

The growing population of Oregon's Willamette River Basin places an increasing demand on the basin's surface waters. Research on nutrients and their relationship with land use is a high priority for protecting the Willamette Basin's surface waters because of the predominance of agriculture and forestry within the basin. Watershed-scale research addressing spatial trends of dissolved nitrogen (DN) and its correlation with land-use is sparse in the Willamette Basin. Patterns of DN occurrence will likely be different than in the heavily studied basins of eastern of North America because of the dominance of poorly drained soils in the bottomlands of the basin and a distinct climatic regime. Dissolved N was measured along 124 km of the Calapooia River, a tributary to the Willamette River, and in 44 non-nested sub-basins to the Calapooia River for three years. Relationships between land-use and DN concentrations in the 44 sub-basins were explored using correlation and regression analysis.

Results show that there was consistently more DN in lower sub-basins dominated by poorly-drained soils and agricultural production when compared to upper sub-basins that are dominated by well-drained soils and timber production. Eight lower-basins had at least one sample period with nitrate-N >10 mg L^{-1}, with peak measures occurring during high-flow events, and nine lower basins had at least one sample period with total N >10 mg L^{-1}. The mainstem of the Calapooia River had lower concentrations of DN than surface waters of the sub-basins, often by an order of magnitude, showing a muting

of the high concentrations observed in individual sub-basins. Dissolved organic N represented a greater proportion of DN in the upper basin, but had lower concentrations relative to the lower basin. Seasonal nitrate-N concentrations had strong positive correlations to the percent of a sub-basin that was managed for agriculture (%AG) in all seasons except summer (Spearman's Rho= 0.77 to 0.91), whereas seasonal dissolved organic N concentrations had strong positive correlations to %AG in all seasons (Spearman's Rho= 0.78 to 0.90). Dissolved N concentrations also had strong positive correlations to the proportion of a sub-basin managed with soil conservation practices in grass seed agriculture, indicating that there may not be a benefit from soil conservation practices in terms of surface water DN concentrations. Results indicated that DN concentrations and forms vary widely among seasons and years and were related to precipitation and discharge amount and timing, soil drainage, and land management. Efforts to reduce or regulate DN in the Calapooia Basin or similar tributary basins in the Willamette Basin must address this large temporal and spatial variability of DN and should include consideration of relative contributions of DN from the multiple land-uses and land covers present.

2.1 Introduction

Surface water quality is a growing concern in Oregon's Willamette River Basin because 70% of Oregon's rapidly expanding population lives within this basin. This growing population puts increasing pressure on surface waters to provide drinking water, recreation, transportation, aquatic habitat, irrigation for crops, and countless other market and non-market amenities. The Willamette River Basin is used for a diverse range of land uses such as timber production, urban and rural housing, wildlife reserves, cattle and poultry operations, and field crop production. Seventy percent of the basin is managed as forest and 22% is managed for agriculture production. Grass seed is the primary agricultural crop, while wheat, hay, oats, clover, corn, alfalfa, and nut crops are also grown (Wentz et al. 1998). Research on nutrients and their relationship with land use is a high priority for protecting surface waters, because of the predominance of agriculture and forestry in the Willamette Basin, which have the potential to increase surface water nutrient levels.

Nitrogen is one of the most widely studied nutrients because it often limits productivity of terrestrial and aquatic ecosystems. This plant nutrient is frequently supplied via fertilizers in agricultural operations and intensive forestry operations. It is well-documented that an excess supply of N in soil systems related to fertilization or other management activities can lead to conditions favoring buildup and leaching of DN in agricultural and forestry operations (Gadgil and Gadgil 1978; Binkley et al. 1993; Dinnes et al. 2002; Warren 2002; Fox 2004; Nelson et al. 2006).

High concentrations of DN, particularly nitrate-N, are associated with multiple water-quality threats. Excess levels of DN can trigger eutrophication of surface waters which can exacerbate effects of high water temperatures on oxygen levels, leading to hypoxic conditions and negative impacts on aquatic systems. A secondary concern is a life threatening condition in infants known as methogloblimenia or blue baby syndrome, which is caused by drinking water high in nitrate-N.

Land use has been linked to DN export into aquatic systems (Jordan et al. 1997; Howarth et al. 2002; Wernick 1998; Donner et al. 2004; Pellerin et al. 2006). Strong positive relationships are often noted between the amount of agriculture in a basin and nitrate-N concentrations in that basin's streams (Johnson 1997; Howarth et al. 2002; Floyd 2005; Pellerin et al. 2006; Poor and McDonnell 2006). Few studies address these relationships in multiple land-use settings in western North America such as the Willamette Basin. The Willamette Basin is distinct from more highly studied basins, such as the Chesapeake and Mississippi River Basins, because of a distinct climate, low atmospheric deposition of N and the prevalence of well-sorted, poorly drained soils in the lower area of the basin. In contrast to eastern North American basins, there is mounting evidence that the winter rains of western Oregon and the poorly drained soils in the Willamette Basin combine to shift hydrologic flowpaths overland and deliver DN directly to surface waters, bypassing riparian buffer zones (Wigington et al. 2003, 2005).

This study was conducted in the Calapooia Basin within the greater Willamette Basin. The Calapooia Basin has a similar mix of land uses as the Willamette Basin and has been found to have high levels of DN (Bonn 1996; ODEQ 1996). Forest management and agriculture, particularly grass seed production, are the primary land uses, with rural residential and urban development as minor components. The National Water Quality Assessment Program reported that the Calapooia River had annual median nitrate-N concentrations that were higher than the national median average and the third highest nitrate-N and total-N concentrations of all tributaries to the Willamette River (Bonn 1996). The Oregon Department of Environmental Quality rated the Calapooia River's overall water quality as poor because of high levels of nitrate-N and ammonium-N (ODEQ 1996). However, extensive synoptic measurement of DN across the entire Calapooia Basin, or other tributaries to the Willamette River, had not been completed prior to this study. Multiple-year research addressing DN and its relationships with land use and local soil characteristics along the length of a tributary to the Willamette Basin is also lacking. This study includes a basin-wide synoptic sampling of DN in the Calapooia River and its tributaries that allows for analysis of spatial and temporal trends and for determination of areas that are contributing relatively high levels of DN to surface waters. Sampling was maintained for three water years (2004-2006) to address seasonal and annual variation of DN in surface waters of the Calapooia River Basin and to evaluate relationships between both land use and soils in 44 independent sub-basin's and DN concentrations. Additionally, analysis is provided addressing relationships between soil conservation techniques in grass seed agriculture and surface water DN for two water years (2005-2006).

2.2 Methods

2.2.1 Site Description: Calapooia Basin

The Calapooia River, spanning 124 km and draining 966 km^2, flows out of the western Cascade Mountains in the southern Willamette River Basin (Figure 2.2.1). Climate in the region is described as Mediterranean with dry, hot summers and cool, wet winters. Average yearly precipitation in the lower area (hereafter referred to as the Lower Zone) of the watershed is 914 mm and in the upper area (hereafter referred to as the Upper Zone) is 1524 mm with 80% occurring from October through March

(Woodword et al. 1998). Nitrogen deposition is low (1-3 kg N ha^{-1} yr^{-1}) due to the lack of large anthropogenic sources between the basin and the Pacific Ocean (http://nadp.sws.uiuc.edu/nadpdata/annualReq.asp?site=OR97).

The Lower Zone is generally flat with average slopes ranging from 0-5%, low perennial stream drainage densities, and mean river gradients of 0.11%, with sections of constrained and unconstrained, braided river channels. A diversion canal, Sodom Ditch, diverts up to 50% of the discharge in this zone, which is reconnected before the Calapooia's confluence with the Willamette River. Agriculture is the primary land use in the Lower Zone. Grass seed grown in concert with sheep grazing is the primary management regime with a few cattle and poultry operations, as well as minor production of wheat, oats, mint, hazelnuts, walnuts, sugar beets and various other horticultural/greenhouse crops. Rural residential housing and small towns are prevalent in the Lower Zone of the watershed. The two largest towns in the basin, Albany (pop. 42,000) and a portion of Lebanon (pop. 19,000) are in the Lower Zone. Poorly drained soils derived from the Missoula Floods that occurred approximately 12,000 to 15,000 years ago (Alt 2005) dominate the Lower Zone. These floods delivered well-sorted, fine sediment across the bottomlands of the Willamette Valley, covering the lower portion of the Calapooia Basin.

The Upper Zone of the Calapooia Basin is comprised of steep, well-defined hillslopes with a mean river gradient of 2.4% and a generally constrained river channel. The primary land use is timber production by private enterprises with short-rotation (~40-yr) Douglas-fir (*Pseudotsuga menziesii*) management using clearcutting as the primary silvicultural treatment. Fertilization of forest stands is common, though no fertilization is known to have occurred during my study period. The uppermost reaches of the basin are owned and managed by the U.S.D.A. Forest Service. This area is managed for multiple uses with recreation trails to Tidbits Mountain, remnant old-growth stands, small active surface mining claims, and long-rotation forest management. No permanent residences are located in this area. The geology in the upper section of the watershed is comprised of weathered volcanic rock, such as basalts, andesites and tuffs with well-drained rocky soils.

2.2.2 Field Methods

A basin-wide synoptic water-quality sampling regime designed by Floyd (2005) was conducted for three water years starting in October of 2003 and ending in September of 2006, including a total of 41 sample runs. Seventy five sampling sites were selected to cover the range of land uses in the Calapooia Basin (Figure 2.2.1) with 31 on the mainstem of the river, 44 on independent tributaries and two sites on the Sodom Ditch diversion canal. All sites were sampled between storms on a bi-weekly to monthly basis to measure seasonal baseflow conditions. Samples were collected in acid-washed, 250-ml plastic bottles within a 10-hr period to ensure similar flow conditions for each sample. During transport the samples were stored at 4°C. Ten percent of sample points were randomly double-sampled during each sample period to test field and lab methods for precision. Samples were collected using a weighted depth-integrated rope sampler or a grab sample technique. Streams that are >10 m in width had multiple samples taken across the channel that were then composited and subsampled in the field. Field blanks were used to test for background field and laboratory contamination.

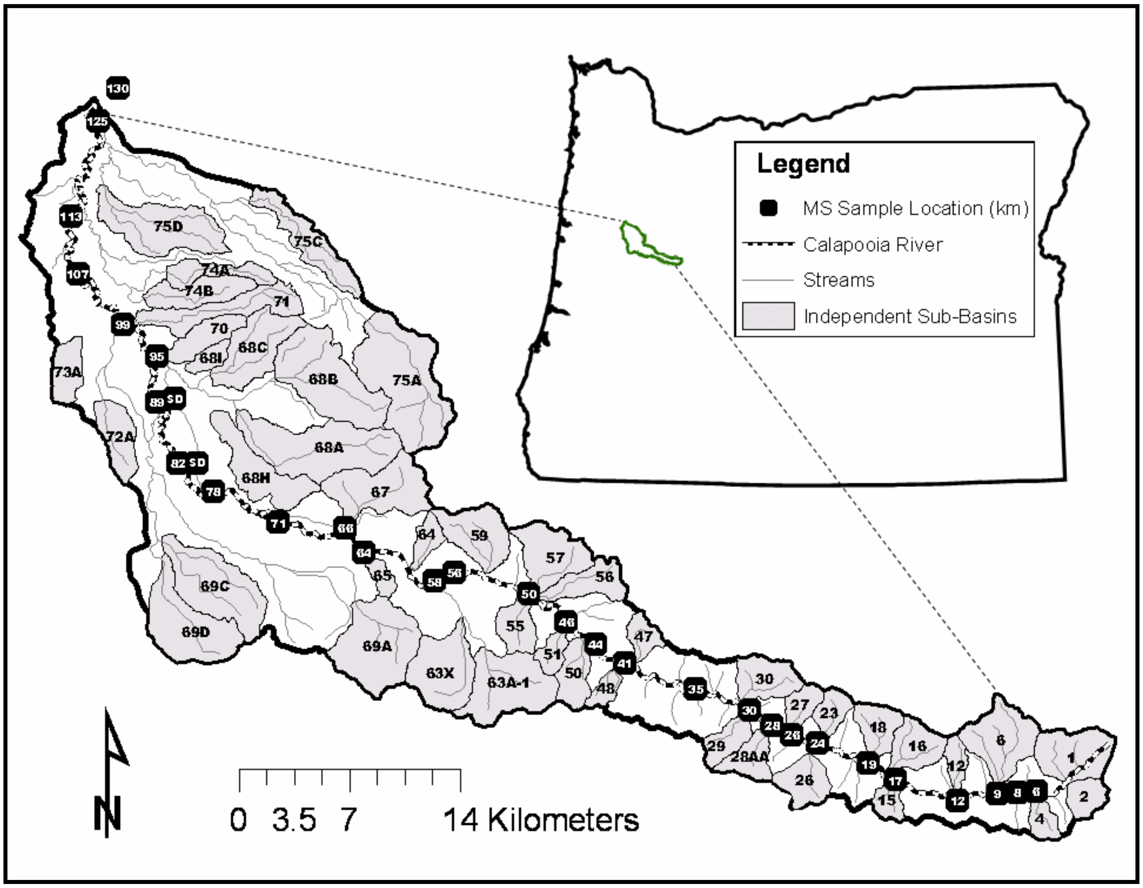

Figure 2.2.1 Location of the Calapooia River Basin in Oregon and synoptic sampling points on the mainstem (MS) of the Calapooia River and 44 sub-basins.

2.2.3 Laboratory Methods

Water samples were stored at 4°C if analyzed within 48 h of sampling or frozen at -20°C if analyzed after 48 h. Before analysis, samples were vacuum filtered using 0.45 μm filters. Total nitrogen (TN) was analyzed using a PC-Controlled Total Organic Carbon Analyzer using the catalytic thermal decomposition and chemi-luminescence method (Shimadzu Corp., Kyoto, Japan) with a minimum detection limit of 0.04 mg N

L^{-1}. Nitrate-N and ammonium-N were analyzed using a Lachat Quick Chem 4200 analyzer (Lachat Instruments, Loveland, Colorado). Minimum detection limits for the Lachat were 0.1 mg N L^{-1} from October 2003 through February 2004 and 0.04 mg N L^{-1} thereafter. Dissolved organic nitrogen (DON) was calculated by subtracting nitrate-N + ammonium-N from TN.

Values for LULC classifications were complied for each of the 44 independent sub-basins from multiple existing datasets. The percent of sub-basins in agriculture (%AG) was produced using 30-m Landsat imagery, last updated in 1999 and provided by the Pacific Northwest Ecosystem Research Consortium (source:http://oregonstate.edu/dept.pnw-ercl, delineations: Floyd, 2005). Percent area of sub-basin in agriculture includes all agriculture such as grass seed, row crops, orchards, nurseries, pasture, hay fields and Christmas tree farms. Percent of sub-basins with soils described as poorly drained (%PD) by the U.S.D.A. Natural Resources Conservation Service (NRCS) was produced using the STATSGO and SSURGO databases provided by the Pacific Northwest Ecosystem Research Consortium (delineations: Floyd, 2005). These data are derived from multiple county and regional soil surveys and were last updated in 1995. Soil hydrogroup D was chosen as the soil group comprising the %PD class in this study and is defined as having a high water table or shallow depth to impervious layers, fine texture and a high clay content. Percent of sub-basins with woody vegetation (%WV) was produced using 30-cm resolution ortho-rectified airphotos flown in the spring of 2000 by Linn County (delineations: Floyd, 2005). Woody vegetation delineations include everything from blackberry shrubs to old-growth forest.

Each of the 44 sub-basins was further delineated into the percent area in grass seed agriculture (%GRASS) which was sub-divided by soil conservation (%CGRASS) and traditional (%NCGRASS) grass seed production practices. These were generated from U.S.D.A. Common Land Unit GIS shapefiles that were ground truthed in the fall of the 2004-2005 and 2005-2006 water years. Additional ground truthing was conducted the following spring of each year to confirm fall grass species identification in young stands. Soil conservation practices are defined as established perennial grasses, annual ryegrass using full-straw-chop management or new grass seed stands using a no-till system. Traditional practices are defined as all other grass seed scenarios, including new grass seed stands that were conventionally tilled and planted, fallow ground after till-out or spray-out and annual ryegrass (source: www.fsa.usda.gov/Internet/FSA_File/cp_581.pdf., delineations: Mueller-Warrant).

2.2.4 Data Analysis

Preliminary analysis revealed strong relationships between %AG and %WV (R^2 = 0.95) and between %AG and %PD (R^2 =0.85) (Figure 2.2.2). I choose to limit correlation and regression analysis to DN vs. %AG because of the strength and linearity of these relationships between explanatory variables. It is important to note that within the Calapooia Basin, the flat, poorly drained soils have developed in the bottomlands, which is the area where agricultural operations are predominant. Therefore any results addressing relationships between %AG and DN may be influenced by relationships between %PD and DN and should not be considered causal without further study.

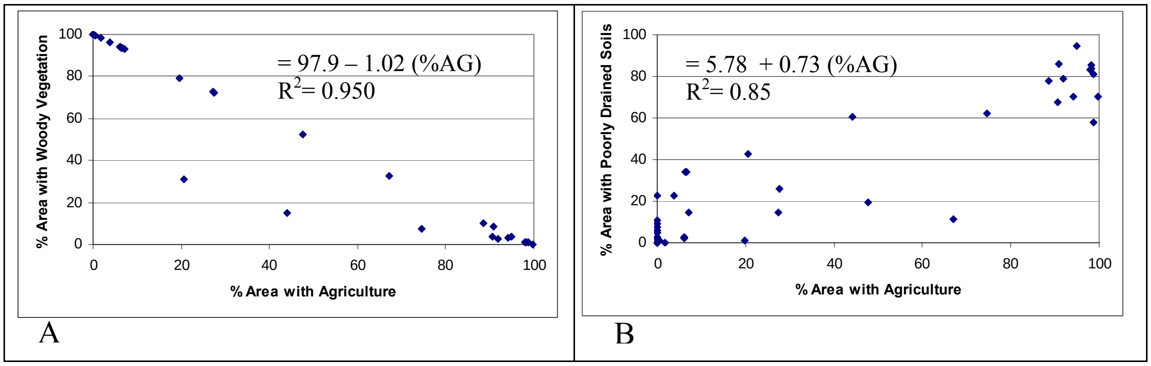

Figure 2.2.2. Percent area with agriculture versus (A) percent area with woody vegetation and (B) percent area with poorly drained soils in sub-basins within the Calapooia Basin, OR.

Seasonal mean DN concentrations in the Calapooia River and the 44 sub-basins were examined for spatial and temporal trends. Seasons were defined as three-month periods beginning with the start of the water year on October 1st. Relationships between three DN components (nitrate-N, ammonium-N or DON) versus %AG were explored. Spearman's Rho was used to describe the correlations between each component of DN and %AG. Spearman's Rho is a non-parametric measure of correlation based on a ranking of the response variable. It was chosen for this analysis because it gives less influence to outliers and does not require a linear relationship between variables to produce accurate estimates of correlation.

Simple linear regression (SLR) was used to produce models of the relationships between %AG and DN among the 44 sub-basins. For this analysis I assumed that the sub-basins are independent of each other. Log transformation of response variables (i.e., DN) was used to improve model fits for %AG versus nitrate-N and DON. However, no transformation satisfactorily corrected non-normality and uneven spread of residuals in the relationship between %AG and ammonium-N. Therefore, regression analysis for the 44 sub-basins is presented for nitrate-N and DON only.

Additional regression analysis within the sub-basins containing %AG ≥ 10% was conducted to determine if a relationship existed between %AG and DN. For this analysis I used seasonal means of DN as the response variable to reduce temporal correlation. In order to perform SLR I assumed that the sub-basins containing %AG ≥ 10% are independent of each other. Log transformation of the response variable was required to meet the assumptions of SLR when addressing the relationship between %AG and nitrate-N. Multiple transformations did not correct for uneven spread of residuals and non-normality when addressing ammonium-N and DON. Therefore SLR on these sub-basins was only conducted for nitrate-N.

An exploratory analysis is included addressing relationships between soil-conservation grass seed production and traditional grass seed production versus DN concentrations within the sub-set of sub-basins that had some degree of grass seed production for the 2004-2005 and 2005-2006 water years. For this analysis I used Spearman's Rho values to provide a non-parametric quantification of these relationships.

2.3 Results

2.3.1 Dissolved Nitrogen in Sub-Basins of the Calapooia River

Strong temporal and spatial trends are evident in the DN data collected from 44 sub-basins in the Calapooia Basin (Figure 2.3.1.1). During the fall and winter in the sub-basins of the Lower Zone mean seasonal TN concentrations exceeded 10 mg L^{-1} in nine sub-basins and peaked above 14 mg L^{-1} in the fall of the 2005-2006 water year. The maximum observed TN concentration of 43.0 mg L^{-1} occurred at sub-basin 72A in the spring of the 2004-2005 water year. In the forested sub-basins of the Upper Zone, TN was frequently at or near the detection limit of 0.04 mg L^{-1}.

Ammonium-N rarely exceeded detection limits in the sub-basins above 68B and 68C and was a small component of TN at all sub-basins during all seasons and years, except for sub-basins 74A and 72A (Figure 2.3.1.1). These two sub-basins had high concentrations of ammonium-N which represented high proportions of TN in the 2004-2005 water year.

Nitrate-N concentrations increased notably below sub-basin 64 (Figure 2.3.1.1). Above this sub-basin, nitrate-N concentrations were consistently <0.5 mg L^{-1} with most measurements $\leq$detection limits. In locations below sub-basin 64 nitrate-N concentrations were greater, with some mean seasonal concentrations exceeding 10 mg L^{-1} and maximum measured concentration of 19.70 mg L^{-1} at sub-basin 72A in the fall of the 2004-2005 water year. Many of the lower sub-basins consistently had nitrate-N concentrations >10 mg L^{-1}, particularly in the fall and winter months. Many lower sub-basins had no flow during the driest of summer months.

Concentrations of DON in the sub-basins did not have a clear seasonal trend (Figure 2.3.1.1). However, there was a spatial pattern. Concentrations of DON above sub-basin 64 were low with values rarely exceeding 0.20 mg L^{-1}. Below sub-basin 64 DON concentrations were higher with mean seasonal values often exceeding 1.0 mg L^{-1} in all seasons and years.

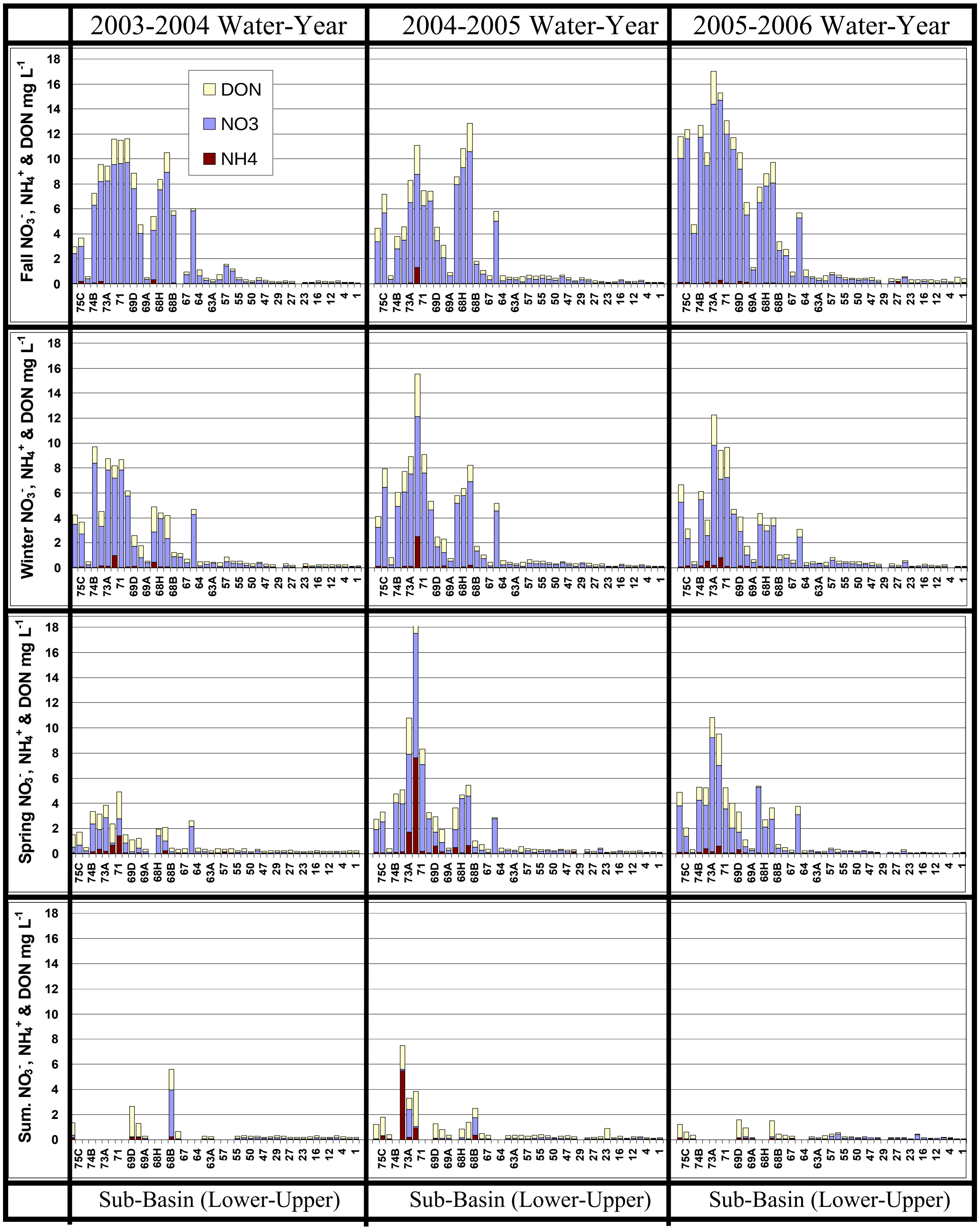

Figure 2.3.1.1. Total DN, DON, ammonium-N and nitrate-N concentrations averaged per season for three water years in 44 sub-basins of the Calapooia River, Oregon. Each bar represents an independent sub-basin graphed in order from the bottom of the watershed on the left side of each graph. Total DN is represented by the total height of each bar. Detection limit set at 0.04 mg L^{-1} for TN, DON, ammonium-N and nitrate-N.

Ratios of DIN:DON varied across the sub-basins (Figure 2.3.1.2), with higher DIN:DON ratios occurring in the lower sub-basins than in the upper sub-basins in the fall, winter and spring. This indicates that DIN dominates in the lower sub-basins and DON provides a relatively larger contribution of DN in the upper sub-basins.

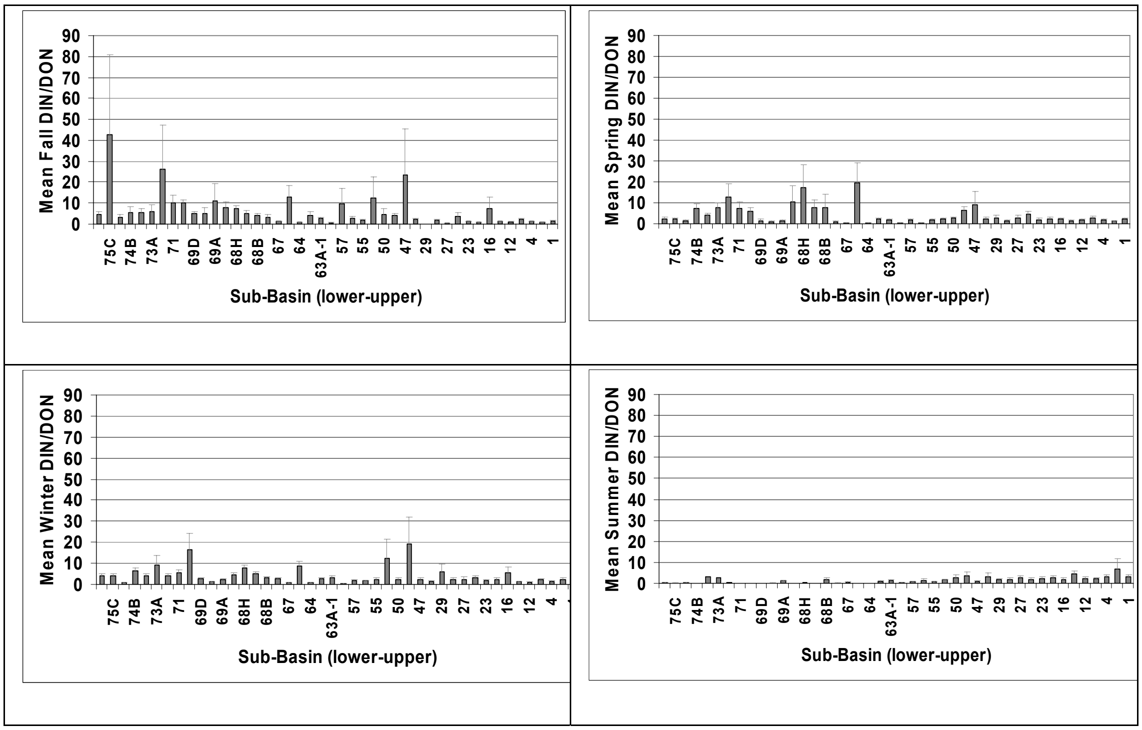

Figure 2.3.1.2. Mean seasonal DIN:DON ratios for 44 sub-basins in the Calapooia Basin of Oregon. Error bars represent standard error of the seasonal mean.

2.3.2 Dissolved Nitrogen in the Mainstem of the Calapooia River

Strong temporal and longitudinal trends were also evident for DN concentrations in the mainstem of the Calapooia River (Figure 2.3.2). Concentrations of TN were consistently an order of magnitude lower than in the sub-basins that discharge to the mainstem of the river. Concentrations of TN were lower (often by an order of magnitude) in the upper reaches of the mainstem of the Calapooia River when compared to the lower reaches. Peak TN values occurred below river km 89 with mean seasonal concentrations between 0.5 and 4.0 mg L^{-1} in the fall and winter. Maximum individual measurements of 8.64 mg L^{-1} at river km 89 in the fall of the 2005-2006 water year and 11.58 mg L^{-1} at river km 24 in the summer of the 2005-2006 water year were observed. A maximum seasonal TN concentration of 0.58 mg L^{-1} was observed in Sodom Ditch, which was consistently lower than the adjacent mainstem of the Calapooia River.

Nitrate-N comprised the largest component of TN, particularly in the lower sections of the river (Figure 2.3.2). Nitrate-N concentrations were consistently higher in the lower sections of the river for all seasons and all years with peak values occurring in the fall and winter. The highest measured concentration for nitrate-N in the mainstem of the river was 7.67 mg L^{-1} in the fall of the 2005-2006 water year at river km 125. Nitrate-N concentrations increased substantially between river km 82 and 89 in all seasons and years.

Ammonium-N rarely exceeded detection limits above river km 89 in any season or year and was generally a small portion of TN at sample locations in the lower reaches of the river (Figure 2.3.2). Concentrations of DON were also generally low compared to nitrate-N, with higher DON concentrations in the lower reaches of the river and higher DON concentrations in the fall and winter periods compared to spring and summer (Figure 2.3.2). One exception to this pattern was in the summer of 2006 when one sample period showed a notable spike of DON of 11.54 mg L^{-1} at river km 24, with dilution of this concentration evidenced at downstream sample points. Dissolved organic N contributed a greater portion of TN in the upper reaches of the river, where TN values were lower.

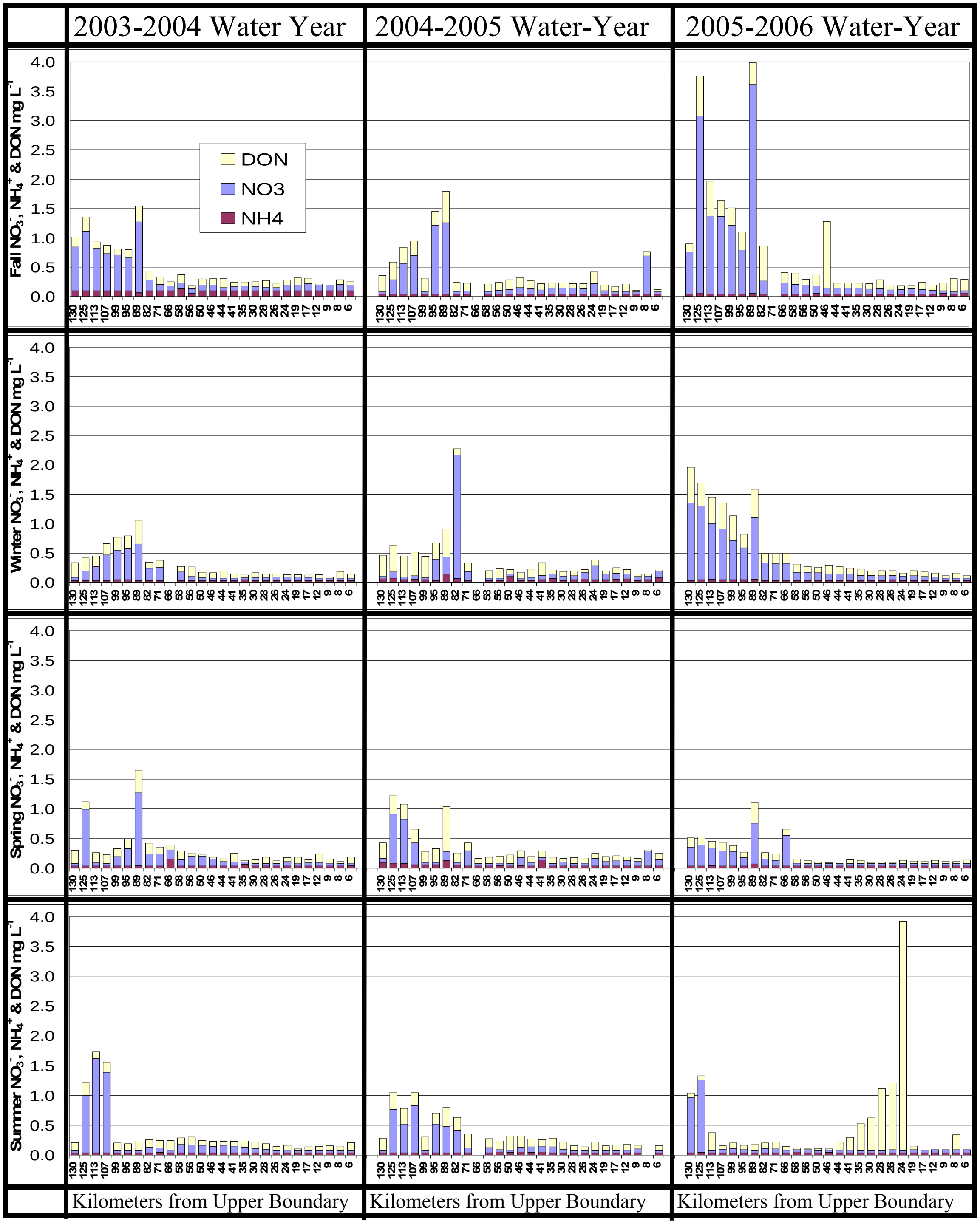

Figure 2.3.2 Total N, DON, ammonium-N and nitrate-N concentrations averaged per season for three water years in the mainstem of the Calapooia River, Oregon. Each bar represents a location along the mainstem of the river graphed in order from the bottom of the watershed on the left side of each graph. Total DN is represented by the total height of each bar

2.3.3 Relationship between %AG and Nitrate-N

In fall, winter, and spring in all three water years nitrate-N in the sub-basins increased as %AG increased (Figure 2.3.3). Spearman's Rho values were all >0.77 for these seasons and were consistent across these three seasons with maximum between-year shifts of 0.05 for the spring relationships. Sub-basins with <15% of their area in agriculture tended to have nitrate-N levels at or just above detection limits. The relationship between %AG and nitrate-N was less clear and consistent in the summer, with two positive Rho values and one negative for the three water years. The summer relationships between %AG and nitrate-N also had distinct outliers, often in basins with intermediate levels of %AG.

2.3.4 Relationships between %AG and DON

Dissolved organic N increased as %AG increased in all seasons and water years (Figure 2.4.4). Spearman's' Rho values were >0.78 and were consistent for each season across the three water years. Dissolved organic N concentrations in the sub-basins with <15% agriculture were consistently above detection limits, but were often an order of magnitude lower than basins with high %AG. There were strong outliers in some of the sub-basins with high %AG.

2.3.5 Relationship between %AG and Ammonium-N

Ammonium-N increased as %AG increased in all seasons and all years (Figure 2.3.5). However, these relationships were not as consistent as the relationships of nitrate-N and DON with %AG. The Spearman's Rho values were variable in each season among the three water years' with shifts up to 0.24 in the fall and summer seasons. There are also strong outliers, particularly in sub-basins that are dominated by agriculture (Figure 2.3.5).

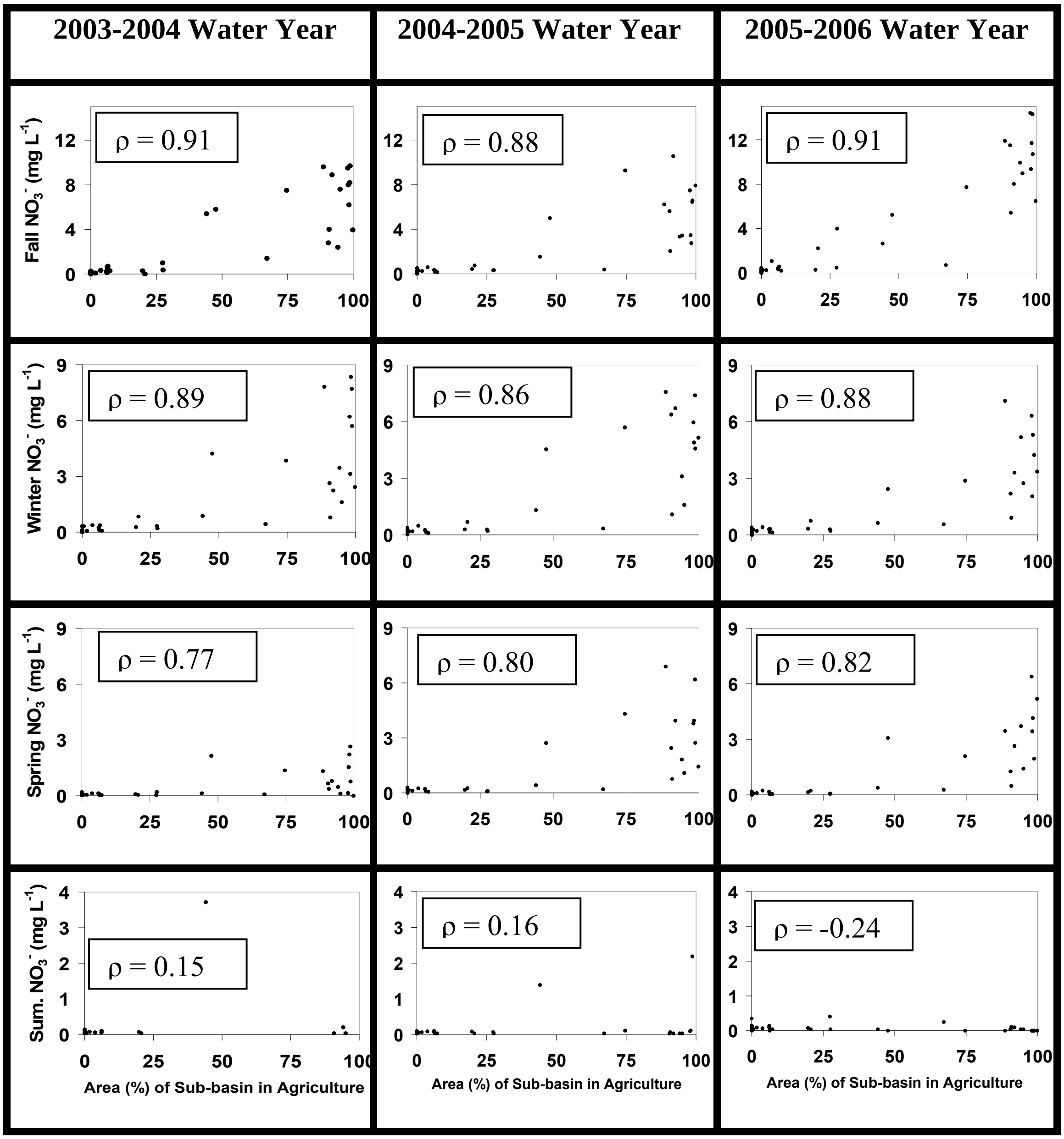

Figure 2.3.3. Plot of percent area of sub-basin in agriculture versus mean seasonal nitrate-N concentrations of surface water draining sub-basins for three water years including Spearman's Rho (ρ) for the Calapooia River Basin, Oregon. Note that the y-axis scale for nitrate-N changes among seasons.

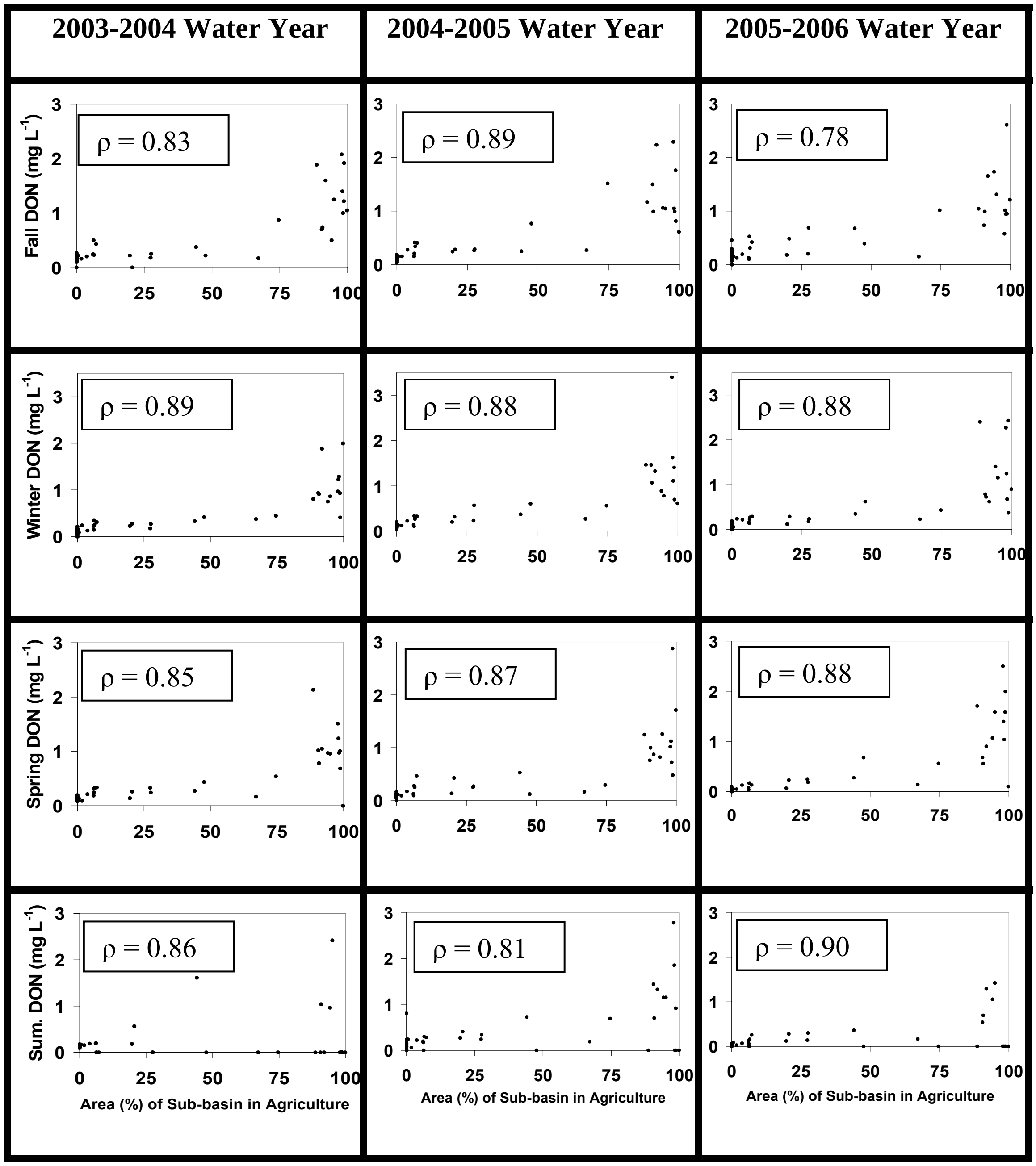

Figure 2.3.4. Percent area of sub-basin in agriculture versus mean seasonal DON concentrations of surface water draining sub-basins for three water years including Spearman's Rho (ρ) for the Calapooia River Basin, Oregon

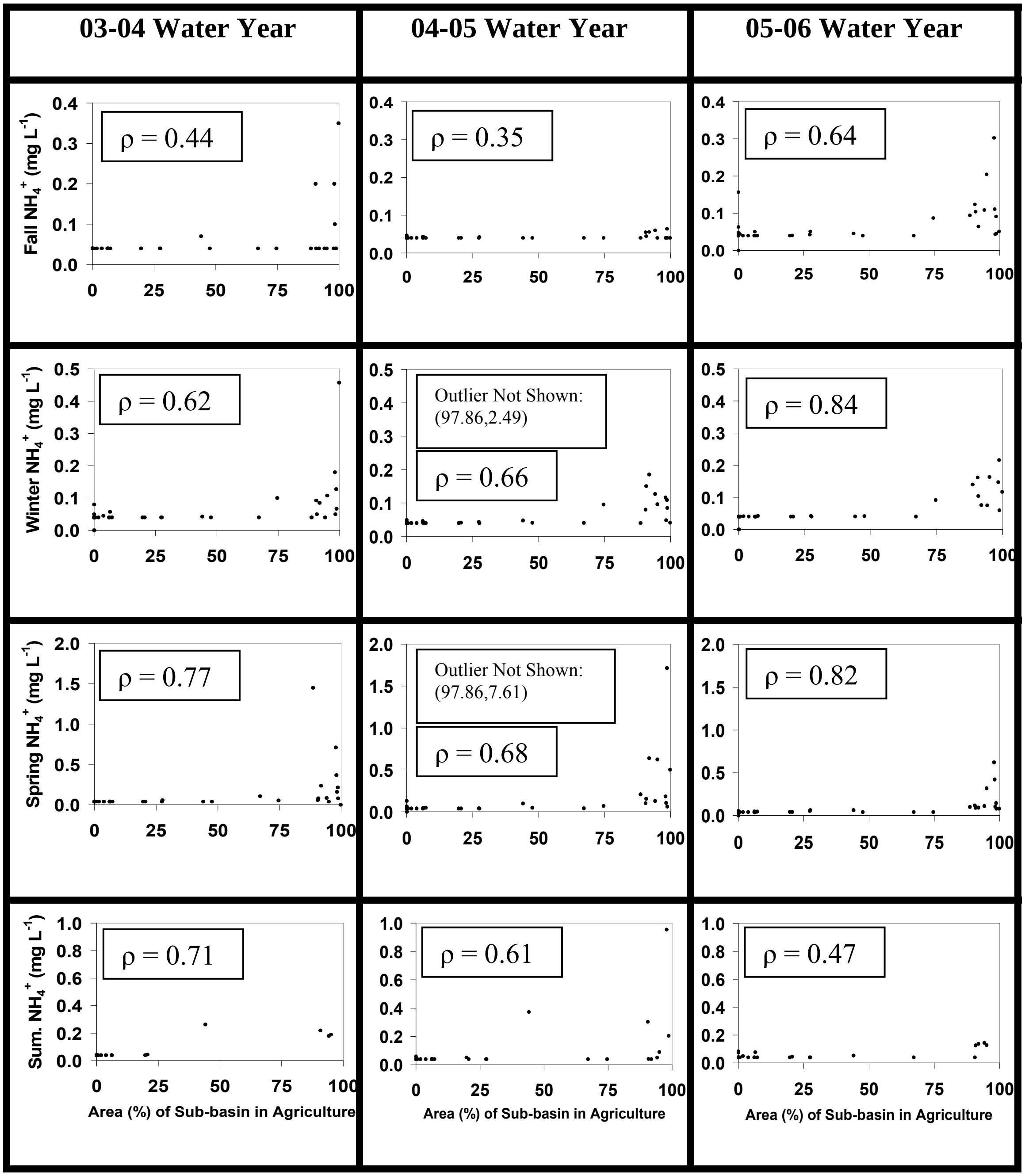

Figure 2.3.5. Plot of percent area of sub-basin in agriculture versus mean seasonal ammonium-N concentrations of surface water draining sub-basins for three water years including Spearman's Rho (ρ) for the Calapooia River Basin, Oregon. Note that the y-axis scale for ammonium-N changes among seasons.

2.3.6 Regression Models in Forty Four Non-Nested Sub-Basins

Simple linear regression model equations describing the relationships between 1) %AG and DON and 2) %AG and nitrate-N in 44 sub-basins, across the range of land uses in the Calapooia Basin, were consistent with the Spearman's Rho values provided above (Figures 2.3.3 - 2.3.5). All of the models had high (≥ 0.81) R^2 values and similar parameter values, indicating increasing nitrate-N and DON values with increasing %AG, across seasons except for the summer nitrate-N relationships with %AG (Table 2.3.6). This relationship was not significant at an alpha level of 0.05 (p-value 0.09). All other relationships were significant at the 0.05 alpha level.

Table 2.3.6. Summary of Simple Linear Regression Analysis describing relationships between %AG with Nitrate-N and DON in surface water draining sub-basins within the Calapooia River Basin

Model	N^1	R^2	B_0	B_0 95% CI	B_1	B_1 95% CI	p-value
Log Fall NO_3^- = %AG	44	0.83	-1.96	-2.28, -1.64	0.042	0.036, .0480	<0.0001
Log Winter NO_3^- = % AG	44	0.82	-2.17	-2.48, -1.87	0.039	0.033, 0.044	<0.0001
Log Spring NO_3^- = % AG	44	0.83	-2.67	-2.95, -2.40	0.038	0.032, 0.043	<0.0001
Log Summer NO_3^- = %AG	38	0.08	-2.61	-2.97, -2.26	0.006	-0.001, 0.014	0.0929
Log Fall DON= %AG	44	0.86	-1.78	-1.92, -1.64	0.021	0.018, 0.023	<0.0001
Log Winter DON = % AG	44	0.84	-2.09	-2.26, -1.92	0.023	0.020, 0.026	<0.0001
Log Spring DON = % AG	44	0.87	-2.27	-2.43, -2.11	0.025	0.022, 0.022	<0.0001
Log Summer DON = %AG	38	0.81	-2.17	-2.37, -1.97	0.026	0.021, 0.030	<0.0001

1N: number of sub-basins

2.3.7 Regression Models in Agriculture-Dominated Sub-Basins

Analyses of regression models for the sub-set was limited to evaluating relationships between %AG and nitrate-N, because of the challenges with meeting the assumptions of SLR when addressing a sub-set of sub-basins with ≥10% agricultural land-use. Equation coefficients and R^2 values for these relationships were similar for fall, winter and spring (Table 2.3.7). Each of these models was significant at an alpha level of 0.05, except for the summer values. They indicate that there are strong positive relationships between % AG and nitrate-N within the 19 sub-basins that are dominated by agriculture as was also observed when models were based on all 44 sub-basins (Table 2.3.6).

Table 2.3.7. Summary of Simple Linear Regression Analysis describing relationships between percent of sub-basin in agriculture with Nitrate-N in surface water draining sub-basins with ≥10% agriculture land use in the Calapooia Basin, Oregon

Model	[1]N	R^2	B_0	B_0 95% CI	B_1	B_1 95% CI	p-value
Log Fall NO_3^- = %AG	19	0.81	-0.36	-0.85, 0.13	0.025	0.019, 0.031	<0.0001
Log Winter NO_3^- = % AG	19	0.70	-1.32	-2.10, -0.55	0.030	0.020, 0.040	<0.0001
Log Spring NO_3^- = % AG	19	0.71	-2.20	-3.06, -1.34	0.033	0.023, 0.044	<0.0001
Log Summer NO_3^- = %AG	13	0.01	-2.42	-4.52, -0.30	0.004	-0.023, 0.030	0.7434

[1]N: number of sub-basins.

2.3.8 Relationships between Soil Conservation Practices and DN

Relationships between %GRASS, %CGRASS, and %NCGRASS versus mean seasonal nitrate-N and DON in surface waters draining the sub-basins were all positive except summer nitrate-N, as indicated by Spearman’s Rho values (Table 2.3.8). Spearman’s Rho values were generally consistent across %CGRASS and %NCGRASS (Table 2.3.8). Traditional grass-seed agriculture did not have stronger relationships with nitrate-N and DON than conservation-grass agriculture. In fact, nine of the possible 16 comparisons between %CGRASS and %NCGRASS versus nitrate-N and DON had higher Spearman’s Rho values for the %CGRASS (Table 2.3.8).

Table 2.3.8. Spearman's Rho values (ρ) for relationships between proportion of sub-basin in grass-seed production, subset of grass-seed production using soil-conservation practices, and subset of grass-seed production using traditional, non-conservation practices versus mean seasonal Nitrate-N and DON concentrations in surface water draining sub-basins (2004-05 and 2005-06 water years) in the Calapooia River Basin, Oregon.

Season, Water Year & DN Component (sample size)	% Grass AG 04-05	% Grass AG 05-06	% Conservation Grass 04-05	% Conservation Grass 05-06	% Non-Conservation Grass 04-05	% Non-Conservation Grass 05--6
	(ρ)					
Fall 2004 NO_3^- (19)	0.61		0.60		0.57	
Winter 2005 NO_3^- (19)	0.70		0.73		0.48	
Spring 2005 NO_3^- (19)	0.73		0.77		0.39	
Summer 2005 NO_3^- (13)	0.29		0.49		-0.37	
Fall 2005 NO_3^- (19)		0.75		0.62		0.72
Winter 2006 NO_3^- (19)		0.78		0.60		0.69
Spring 2006 NO_3^- (19)		0.82		052		0.74
Summer 2006 NO_3^- (9)		0.10		0.41		-0.19
Fall 2004 DON (19)	0.60		0.57		0.54	
Winter 2005 DON (19)	0.73		0.67		0.61	
Spring 2005 DON (19)	0.71		0.74		0.49	
Summer 2005 DON (13)	0.80		0.63		0.79	
Fall 2005 DON (19)		0.64		0.53		0.67
Winter 2006 DON (19)		0.70		0.48		0.80
Spring 2006 DON (19)		0.60		0.61		0.52
Summer 2006 DON (19)		0.98		0.93		0.77

2.3.9 Precipitation and Stream Discharge

Figure 2.3.9.1 shows the measured precipitation at the nearest reliable precipitation station in Cascadia OR, within the Santiam River Basin adjacent to the Calapooia River Basin. The yearly mean precipitation, based on 30-years of record, for this site is 1641 mm. The 2003-2004 water year was near average with 1629 mm of precipitation. The 2004-2005 water year was drier, with 348 mm less precipitation than the 30-year mean and presence of a few substantial spring storms. The 2005-2006 water-year was 292 mm wetter than the 30-year mean with a series of strong late fall storms and an average spring.

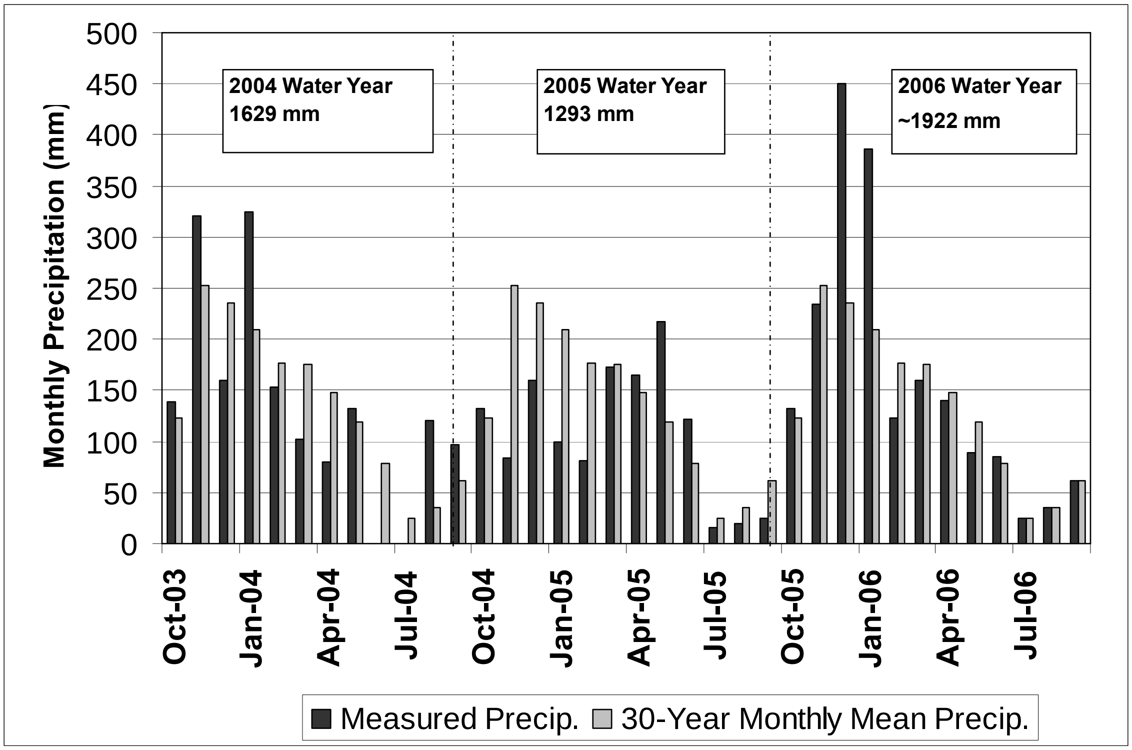

Figure 2.3.9.1. Measured monthly precipitation at Cascadia, OR for study period with 30-year mean precipitation included for reference. (June, July and August of 2006 estimated from 30-year mean due to missing data).

Figure 2.3.9.2 shows daily discharge at Wiley Creek which is adjacent to the upper Calapooia Basin. Precipitation patterns for the study period are seen in the response of the hydrograph at Wiley Creek, with lower discharges in the fall and winter of the 2004-2005 water year when precipitation was relatively low and the highest discharge during the fall and early winter of the 2005-2006 water year when precipitation was relatively high (Figure 2.3.9.1).

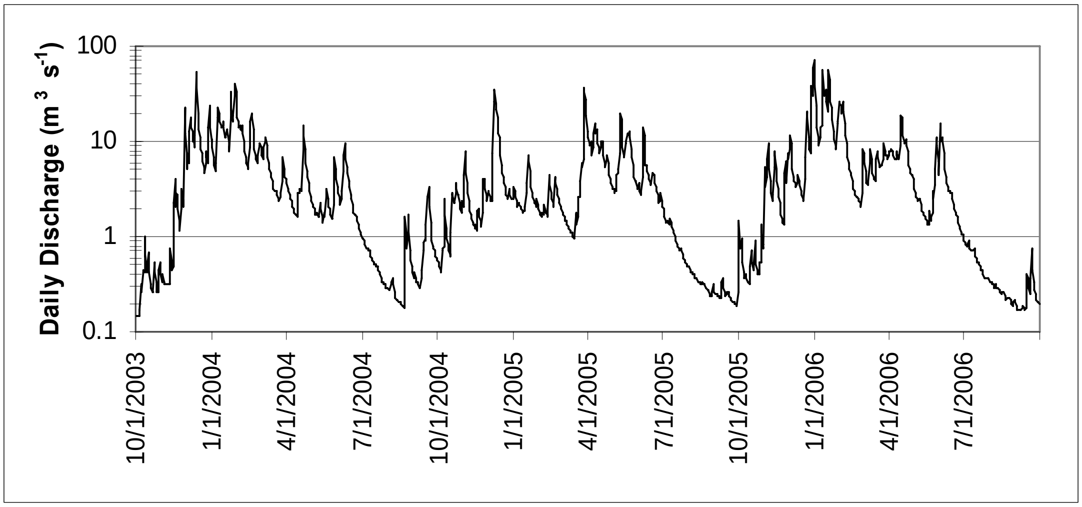

Figure 2.3.9.2. Daily discharge of Wiley Creek during study period.

2.4 Discussion

2.4.1 Spatial Trends of DN

The clear spatial trends showing higher DN concentrations in the lower sub-basins of the Calapooia River Basin, which are dominated by agriculture, are consistent with similar studies addressing land use and DN (Omernik 1976; Brett 2005; Pellerin 2006; Johnson 1997; Poor and McDonnell 2006). The low concentrations of DN in the upper sub-basins are also consistent with the DN discharge values that Vanderbilt et al. (2003) found in the forested H.J. Andrews research forest adjacent to the Calapooia Basin. One explanation for these low DN values in the upper Calapooia sub-basins is that the soils in this system tend to be N-deficient. This leads to efficient uptake of available N in these forested systems with minimal leaching of N (Fredriksen 1972; Henderson et al. 1979; Vanderbilt et al. 2003).

Although occurring at lower concentrations, the spatial trends of DN in the mainstem of the Calapooia River are similar to those observed in the sub-basins. These lower concentrations of DN may be caused by a dilution effect of the water with low DN from the upper area of the Calapooia Basin mixing with the waters from the lower sub-basins which have higher concentrations of DN.

There is some evidence that Sodom Ditch, a diversion canal along the mainstem of the lower Calapooia River may be playing a role in N dynamics in the lower reaches of the system. The reach between river km 82 and 89 was often a transition point for increased DN in multiple seasons (Figure 2.3.2). These sample points were below the diversion of flow into Sodom Ditch. There was often a drop in Calapooia River DN concentrations as the Sodom Ditch water was reconnected with the mainstem of the river just before river km 95. Sodom Ditch water was sampled at each of the 41 sample runs and produced a maximum TN value of 0.58 mg L^{-1}, which was often lower than the parallel Calapooia River. These results were unexpected. Reduced flow and velocity of the mainstem of the Calapooia River parallel to the Sodom Ditch should provide for reduction in DN due to processing by microbes and uptake by aquatic plants. Possible explanations for increased DN concentrations in the mainstem of the Calapooia River, after diversion to the Sodom Ditch, include interaction of Calapooia River flood waters with local septic systems or confined cattle or poultry operations. Additional work needs to be done to identify the source of these DN spikes at river km 82 and 89 to determine if it has come from upriver or from the localized area.

2.4.2 Seasonal Trends in DN

Seasonal trends in DN for the Calapooia Basin are evident. Dissolved N concentrations are highest in the wet fall and winter months, with the lowest concentrations in the drier summer months. For the three water years of this study, DN levels increased as precipitation began in the fall following Oregon's summer drought season (2.3.1 and 2.3.2). Examination of Figure 2.3.1 and 2.3.2 demonstrates that the seasonal DN concentrations track the precipitation pattern in figures 2.3.9.1 with higher concentrations during periods of higher precipitation. In particular, the highest DN concentrations occurred during the fall of the 2003-2004 water year, spring of the 2004-2005 water year, and fall of the 2005-2006 water year, which were all periods of above-average precipitation. Discharge at the adjacent Wiley Creek gauge (2.3.9.2) can be used to describe this pattern further. Analysis of the hydrograph against the DN concentrations in the Calapooia sub-basins shows that as discharge increases, DN concentrations increase regardless of season. This positive correlation between flow and DN has been found in the Appalachian Mountains (Buffman et al. 2001) and in the Adirondack Mountains (McHale et al. 2000). This relationship may occur because of increased hydrological connection between the sources of DN in terrestrial systems and the aquatic system during high precipitation and flow events (Hewlett and Hibbert 1967; Dunne and Black 1970). The compounded effect of increased DN concentrations at periods of high discharge indicates that yields of N from the Calapooia River into the Willamette River are greatest during the wet fall through spring months (Wigington, 2005).

The relatively low amount of nitrate-N in the summer months can be explained by considering the source of flow in the summer. As precipitation strongly reduces in the summer, the Calapooia River and lower tributaries may become a gaining system, deriving their base flow from the Willamette Aquifer under the Willamette Silt layer (Woodward et al.1998). This base-flow water has likely had less interaction with anthropogenic sources of N and likely has lower levels of nitrate-N. Dissolved organic N concentrations do not decrease as sharply as nitrate-N in the summer months, which is consistent with the work of Willett et al. (2004) in Wales and Arheimer et al. (1995) in Sweden and Finland. This may be due to increased biological activity in the summer months leading to increased in-stream processing of particulate organic N (Arheimer et al. 1995). Low-flow conditions also allow for lesser amounts of DON to produce higher concentrations.

2.4.3 Dissolved Organic Nitrogen and DIN:DON Trends

The relatively high proportion of DN made up by DON in the upper Calapooia Basin is supported by research in the adjacent H.J. Andrews Research Forest. In a long-term study Vanderbilt et al. (2003) found that DON was the predominant form of N that was exported in six small sub-basins. They found that discharge was a positive predictor of DON in all of their study sub-basins. Discharge was a positive predictor of nitrate-N for only one of six of their study watersheds. In a meta-analysis involving 348 watersheds across North America, Pellerin et al. (2006) found similar results showing that DON accounted for half of the DN in forested watersheds and in 100 streams in South America Perakis and Hedin (2002) found DON to be the primary form of N export in unpolluted forests. In a study of forested catchments in Europe, 80% of N export was in the form of organic N. The primary hypothesis explaining the dominance of DON export in forested watersheds focuses on soil and stream processes favoring more rapid removal and transformation of DIN than DON (Vanderbilt et al. 2003).

In the Calapooia sub-basins I found lower DN concentrations and higher DIN:DON ratios in the Upper Zone compared to the Lower Zone, often by an order of magnitude. Therefore, the relative yield of N as DON from the upper sub-basins is quite small when compared to the yield of N as DON from lower sub-basins. Although DON concentrations increased in sub-basins in the Lower Zone of the Calapooia Basin, the proportion of DN that was made up of DON decreased. The remainder of DN was comprised primarily of an increased proportion of nitrate-N in the lower sub-basins. This pattern was also reported by Pellerin et al. (2006). The increased levels of DN and DON are generally thought to come from increased N loading in agriculture and urban dominated sub-basins (Johnson 1997; Pellerin et al. 2006) and from changes in hydrologic function that deliver DN to aquatic systems (Brett and Hartley 2005; Poor and McDonnell 2006).

2.4.4 Relationship between Proportion of Land-Use in Agriculture and DN

The strong positive correlations between %AG and DN concentrations in Calapooia River sub-basins for fall, winter and spring confirms expectations and is similar to results found across North America (Pionke et al. 1996; Johnson 1997; Jordon et al. 1997; Pionke et al. 1999; Brett and Hartley 2005; Pellerin et al. 2006; Poor and McDonnell 2006). Volumes of research have been conducted addressing the causes of increased nutrient flux out of agricultural systems, with tillage, artificial drainage, and fertilization as the most cited causes. Tillage increases the amount of N mineralization that occurs at a given site due to the general increase of microbial activity after tillage and the associated oxidation of soil organic matter (Randall et al. 1997; Dinnes et al. 2001; Nelson et al. 2006). The timing, type and amount of fertilization with N-containing compounds are relevant because of the possibility of N in these compounds being delivered to surface water and shallow ground water. Loss of N can occur when N-sinks such as vegetation and microbial uptake and denitrification are inadequate to utilize or transform additional N (Griffith et al. 1997a; Griffith et al. 1997b; Dinnes et al. 2001). Installation of tile drains generally lowers the water table, which increases the oxygen content of soils and enhances conditions for nitrifying bacteria and accelerates delivery of DN to receiving waters (Warren 2002).

Hornneck and Hart (1988) noted that areas of the Willamette Valley of western Oregon that are primarily used for grass seed production are often fertilized at rates up to 30% more than local extension service recommendations. Other researchers have stressed the importance of timing of tillage and fertilization. Spring applications have been recommended in preference to fall applications because of the Willamette Valley's late fall and winter rains and subsequent likelihood to leach nitrate-N to groundwater and surface water in excess of system needs (Nelson et al 2006). Griffith et al. (1997a) recommended balancing N application with the needs of the growing crops based on indices such as growing degree days. Nelson et al. (2006) stressed the importance of balancing applications of fertilizer to background levels of N in soils caused by natural changes in N mineralization from climatic and soil conditions. They argued that less fertilizer may be necessary for crop growth if conditions have allowed for robust background N mineralization. Following these recommendations would leave less DN available for leaching to surface- and ground-waters. In a study conducted in the poorly drained soils of the Lower Zone of the Calapooia Basin, Wigington et al. (2003) supported these conclusions and stated that appropriate rates and timing of fertilizer may be more effective at reducing leaching of nitrate-N from grass seed fields than establishing and retaining grassed riparian management zones.

The positive correlations between %AG and DN are surprisingly consistent among the three water years across all seasons except for summer. This lack of correlation in the summer months is likely caused by the low concentrations of nitrate-N found in all sub-basins in the summer months, which may be related to the source of flow shifting to a domination of groundwater (Woodward 1998, Wigington 2005).

The positive correlations for DON with %AG are strong in all seasons and years, without exception. Dissolved organic N concentrations do not decrease as sharply as nitrate-N in the summer. This pattern is difficult to explain with my data but may occur because of higher levels of biological activity in the summer months that add to the sources of DON (Arheimer et al. 1995). The relationship between proportion of sub-basins in agriculture with ammonium-N is less consistent. This may simply be due to ammonium-N concentrations being generally low and often inconsistent from year to year.

2.4.5 Soil Conservation Practices and DN

During two water years within the sub-basins dominated by agriculture, soil conservation practices in grass seed agriculture did not demonstrate benefits for lowering DN in the Calapooia Basin. Soil conservation grass seed practices had similar positive relationships with nitrate-N and DON as traditional grass seed agriculture. This result is reasonable when consideration is given to the methods involved in soil conservation practices such as no-till and perennial grass crops. These systems rely on inputs of N in the form of fertilizer which have the capability to leach to aquatic systems (Hornneck and Hart 1988; Dinnes et al. 2001; Fox 2004). Soil conservation practices do not necessarily follow nutrient management suggestions for poorly drained Willamette River Basin soils such as avoiding fall fertilization or fertilizing according to the needs of the crops by accounting for growing degree days or background N mineralization. These cropping systems may have other benefits such as soil retention and development of organic matter, but they appear to be prone to delivering DN at similar or higher rates than conventional grass-seed systems used in the Calapooia River Basin. In a study in poorly drained soils under row-crops, Udawatta et al. (2006) found similar results showing high N losses from rowcrop systems managed using no-till techniques due to precipitation patterns and fertilization practices. Additionally, other factors may confound soil-conservation systems relationship with DN, such as the presence of livestock or poultry operations in particular sub-basins.

2.5 Conclusions

This research shows distinct spatial and temporal trends in DN in 44 sub-basins within the Calapooia River Basin and along the mainstem of the river. Dissolved N concentrations were highest in the seasons with above-average precipitation and in lower sub-basins dominated by poorly drained soils and agriculture. Concentrations of nitrate-N were higher than the EPA standard for drinking water in many lower sub-basins and some sub-basins had seasonal DN concentrations that were markedly higher than assumed background levels. Dissolved N concentrations were lower in the mainstem of the river than in individual sub-basins in the Lower Zone because of dilution of the lower sub-basin water by the upper sub-basin water. I expect that comparable DN patterns exist in similar basins in the Willamette River Basin that are dominated by grass seed agriculture on poorly drained soils and by forests on well drained soils in the higher-elevation areas of watersheds.

As hypothesized, strong and consistent positive associations were evident between the amount of agriculture in a sub-basin and the concentrations of DN components. Care should be taken to avoid drawing cause-and-effect conclusions from these spatial trends. Agriculture in the Calapooia Basin dominates the Lower Zone soils that tend to be poorly drained. These soils may enhance the tendency to deliver DN to aquatic systems due to stream channel expansion and overland flow. Additionally, N uptake by diverse plant communities is often removed in agricultural systems. The lack of uptake by plants in sub-basins dominated by agriculture on poorly drained soils, particularly in spring months when plants would normally begin N uptake in these systems, is likely to play a role in overall N cycling dynamics.

There does not appear to be a benefit in terms of DN in aquatic systems from soil conservation practices in the lower Calapooia Basin. Further study should be focused on plot-scale studies in the agriculture-dominated sub-basins to determine the extent that suggested nutrient management strategies, such as spring fertilization or fertilization based on background N mineralization, can shift DN dynamics and export. Additionally, attention should be given to the effects of in-stream processing on DN components as they move through aquatic systems. It is likely that nutrient spiraling within the system is a relevant factor determining what DN components are in the system at any point in time or space. At this time it is uncertain how much of the DON in the upper areas of the basin is being utilized in the aquatic system or converted to DIN and transported downstream.

This research highlighted the need for watershed-scale studies that address DN across multiple land-uses. Reducing DN in any system through changes in management or regulation requires an understanding of the range of DN concentrations that occur along the system and identification of scenarios that result in high DN concentrations. My study indicated that DN concentrations and components can vary widely among seasons and water years because of natural factors that are beyond the control of land managers. Efforts to reduce or regulate DN must address this large temporal variability. Additionally, maintenance of low DN concentrations in forested upper-basin systems must be maintained to dilute the higher DN concentrations in lower agricultural and urban systems

Chapter 3: Nitrogen Mineralization in Riparian Soils within a Multi-Landuse Basin

3.0 Abstract

Nitrogen (N) dynamics, such as N mineralization, in terrestrial systems are important to aquatic systems because excess N can leach to groundwater and surface waters. Nitrogen mineralization has been extensively studied in agricultural fields, forested settings, and riparian management areas (RMAs) adjacent to managed forests and agricultural systems. However, N dynamics are often addressed within one land-use type and are rarely studied on watershed scales. I measured net N mineralization at monthly intervals for one year at 32 riparian sites over the 124 km length of the Calapooia River in western Oregon. The Calapooia River Basin has a mix of land-uses with agriculture dominating the lowlands and timber production dominating the uplands. Net N mineralization had seasonal trends with relatively low mean net mineralization rates in the fall and winter (29.8 and 30.1 kg N ha^{-1} yr^{-1}, respectively) and relatively high mean rates in the spring and summer (122.1 and 99.7 kg N ha^{-1} yr^{-1}, respectively) when conditions for microbial activity and decomposition were likely enhanced. Recommendations for N fertilization based on background N mineralization levels are supported by evidence of a spring flush of N mineralization. Annual net N mineralization per kg of soil did not demonstrate distinct spatial patterns within riparian soils along the length of the river. Annual net N mineralization was positively correlated with total nitrogen ($r = 0.49$; p-value=0.009), and labile nitrogen ($r = 0.43$; p-value=0.024) in surface (0-15 cm) soils and with basal area of hardwoods within the riparian zones

($r=0.41$; p-value=0.034). Annual net N mineralization per ha was lower in riparian soils along the upper reaches of the basin compared to the lower reaches. This difference was primarily caused by higher amounts of coarse fragments in soils along the upper reaches, effectively diluting the potential amount of biologically available N in these areas. This demonstrates that there was more N mineralization in the lower Calapooia Basin soils when compared to the upper basin because of a lack of coarse fragments in the lower basin rather than different rates of mineralized N within the soil sized fraction. Net N mineralization per kg of soil-size fraction may be a more appropriate measure when exploring relationships with riparian conditions on watershed scales.

3.1 Introduction

Surface water quality is a growing concern in Oregon's Willamette River Basin because 70% of Oregon's population lives within this basin. This growing population puts increasing pressure on surface waters to provide drinking water, recreation, transportation, aquatic habitat and irrigation for crops as well as countless other market and non-market amenities. The Willamette River Basin provides a diverse range of land uses such as timber production, urban and rural housing, wildlife reserves, livestock operations and cropland agriculture. Research on nutrients and their relationship with land use is a high priority for protecting its surface waters, because of the predominance of agriculture and forestry in the Willamette Basin, which have the potential to increase surface water nutrient levels.

Nitrogen is one of the most widely studied nutrients because it often limits terrestrial and aquatic ecosystem productivity. This vital plant nutrient is frequently supplied as fertilizer in agricultural operations and intensive forestry operations. An excess supply of N in terrestrial systems and misapplication or poor timing of N fertilizer can lead to conditions favoring leaching of dissolved nitrogen (DN) (Binkley et al. 1999; Dinnes et al. 2001; Brady and Weil 2002; Fox 2004). Excess levels of DN, particularly nitrate-N, are associated with multiple water-quality concerns. The foremost of which is caused by DN which can contribute to the eutrophication of surface waters.

Research from eastern North America has demonstrated the importance of riparian buffers in agricultural and forested settings in removing DN from soil water before it reaches surface waters. Hill (1996) summarized the results of 15 riparian buffer tests in eastern North America and abroad. He noted that most of these studies reported that riparian buffers are effective at removing nitrate-N from soil water in agricultural settings. Similar work in western North America and, in particular, the Willamette River Basin soils is limited. Results from two studies in the Calapooia River Basin, a tributary to the Willamette River, indicate that riparian buffers may not enhance N retention. There is mounting evidence that the winter rains of western Oregon and poorly drained soils in the lower, agriculturally dominated section of the Willamette River Basin are combining to shift hydrologic flowpaths overland and deliver DN directly to surface waters (Wigington et al. 2003, 2005). Some emphasis has therefore shifted toward determining optimal management of riparian areas for nutrient retention in the Willamette River Basin.

There is considerable research addressing N cycling in agricultural and forested environments. Much of this research has focused on measuring human-induced changes in N cycling processes such as N mineralization. Nitrogen mineralization is known to increase due to increases in microbial-available N and increased soil aeration, as well as shifts of soil moisture, temperature and pH toward optimal microbial growth ranges (Brady and Weil 2002; Sylvia et al. 2005). Harvesting of timber has been found to increase N mineralization (Gadgil and Gadgil 1978; Vitousek and Matson 1985; Kimmins 1997). Application of herbicides in a forested setting can also increase soil temperatures, which can increase N mineralization rates (Gurlevik et al. 2004; Reynolds et al. 2000). Tillage in an agricultural setting increases N mineralization because of the general increase of microbial activity after tillage and the associated oxidation of soil organic matter (Randall et al. 1997; Dinnes et al. 2001; Nelson et al. 2006). Installation of tile drains lowers the water table which increases the oxygen content of soils. This process enhances conditions for nitrifying bacteria (Warren 2002).

Environmental controls on N processing in riparian systems have also been extensively addressed in the literature. The results of these studies are highly variable and tend to be related to particular ecosystems. In a multiple-continent review of riparian buffer-effectiveness studies, Hill (1996) concluded that hydrological structures of streamside environments provide the physical template that controls N processes. Groffman et al. (1996) reported that groundwater levels and soil organic matter were the best predictors of net N mineralization at four northeastern U.S. wetland sites. In upland ecosystems of humid tropical regions, disturbance, plant composition and soil type were found to be controlling factors of nitrification and denitrification (Robertson 1989). In a topo-sequence study in a savanna ecosystem, Bechtold and Naiman (2003) found that N mineralization related strongly to soil particle size and that N mineralization was greatest in fine-textured soils with high levels of total N.

There is also high variability in results of studies addressing landscape patterns of N processing in relation to vegetation in riparian zones. In a study across a range of riparian ecosystems in Europe, Hefting et al. (2005) found that plant production, N uptake and N retention were higher in forested buffer sites compared to herbaceous buffer sites. They also found that decaying leaf litter had an effect on N-retention during the winter months. Bischoff et al. (2001) reported that in forested wetlands the supply of N from mineralization was less than uptake and in an upland forest the supply of N from mineralization was greater than uptake, indicating a potential N source in the forested uplands and a sink in the wetlands. In an extensive review of research addressing buffer function, Osborne and Kovacic (1993) found that forested buffers reduced nitrate-N concentrations more than grass buffers. A landscape-level analysis relying on a literature review for data in North Carolina showed that many sites were at a balance point between acting as a source or sink of N (Garten and Ashwood 2003). These authors surmised that small changes in these systems could make large differences in terms of the source or sink potential of any site and that the timing of inputs and outputs on the landscape are a critical determinate of potential excess N.

At present the relative role and temporal and spatial variance of nutrient-cycling processes within commonly occurring riparian systems along the length of multiple-landuse basins are not well documented. An exploratory study has shown that a hardwood-dominated riparian area on the mainstem of the Calapooia River had higher seasonal N mineralization than a grassed riparian area on a tributary to the Calapooia River (Griffith, unpublished data). Research has also shown that DN concentrations in surface waters of the Calapooia Basin are highest in late fall through early spring, at a time when most vegetation is not active and many microbes are less active because of lower temperatures (Floyd 2005; Evans companion manuscript, Chapter 2). In riparian zones of the Willamette River Basin it is unclear how N processes change across the landscape and how N processes relate to site characteristics such as soil organic matter, nitrogen content or soil texture. It is also uncertain if these systems are acting as seasonal sinks for DN through plant uptake, microbial immobilization and denitrification or as seasonal sources of DN through N mineralization in excess of system retention.

I evaluated the seasonal fluxes and annual accumulation of soil N mineralization in riparian soils along the length of the mainstem of the Calapooia River by measuring *in situ* soil net N mineralization using monthly incubations at 32 sites for one year. I explored spatial and temporal patterns in N mineralization and related annual accumulation of mineralized N to soil and vegetation characteristics of the local riparian zone.

3.2 Methods

3.2.1 Site Description

The Calapooia River Basin is contained within the southern portion of the Willamette River Basin in western Oregon. The Calapooia River spans 124 km and drains 966 km^2. The lowest elevation in the watershed is 54 m at the confluence with the Willamette River in Albany and the highest elevation is 1,571 m at the headwaters on Tidbits Mountain in the western Cascade Mountains. The climate is Mediterranean with dry, hot summers and cool, wet winters. Average yearly precipitation is 914 mm in the lower area of the watershed and 1524 mm in the upper area with 80% falling from October through March (Woodword 1998). Atmospheric N deposition is low with an estimated range of 1-3 kg ha^{-1} yr^{-1} (http://nadp.sws.uiuc.edu/nadpdata/annualReq.asp?site=OR97).

The lower area of the basin is flat with average slopes ranging from 0-5%, low drainage densities and average river gradients of 0.11% with sections of constrained and unconstrained braided river channels. Grass seed grown in concert with sheep grazing is the primary management regime with minor production of wheat, oats, mint, hazelnuts, walnuts, sugar beets and various other horticultural and greenhouse crops. Rural residential housing and small towns are prevalent in the lower area of the basin including the two largest towns in the watershed, Albany (pop. 42,000) and a portion of Lebanon (pop. 19,000). The lower area of the basin is dominated by poorly drained soils, referred to as the Willamette Silt layer, derived from the Missoula Floods. Approximately 10,000 years ago these glacial lake floods delivered deep layers of well-sorted, fine-grained sediment across the bottomlands of the Willamette Valley, covering the lower portion of the Calapooia Basin. Soils in the lower area are dominated by xeric and mesic mollisols and alfisols. Two soil complexes dominate: 1) Dayton-Amity-Concord and 2) Woodburn-Aloha-Willamette (USDA NRCS 1987). Riparian management areas along the mainstem of the Calapooia River in the lower area of the basin range from first- and second-growth hardwood forest to blackberry thickets and managed grass buffers.

The upper area of the Calapooia Basin is comprised of steep, well-defined hillslopes with an average river gradient of 2.4% and a generally constrained river channel. The primary land use is private timber production using short rotation (~40-yr) Douglas-fir (*Pseudotsuga menziesii*) management with clearcuts as the primary harvest treatment. Fertilization of forest stands is common, though no fertilization is known to have occurred during my study period. The uppermost reaches of the basin are owned and managed by the USDA Forest Service. This area is managed for multiple uses with recreation trails to Tidbits Mountain, remnant mixed old-growth stands, active surface mining claims and long-rotation forest management. No permanent residences are located in this area. The geology in the upper section of the watershed is comprised of weathered volcanic rock, such as basalts, andesites and tuffs. The soils of the upper zone are well-drained and are dominated by udic, mesic and cryic soils in the entisol order with components of cobble and rock. Kinney, Keel and Hummington are the primary soil series (USDA NRCS 1987). Riparian management areas on the mainstem of the upper Calapooia River are dominated by mixed age classes of hardwood and coniferous tree species with isolated pockets of nitrogen-fixing red alder (*Anus rubra*).

3.2.2 Field Methods

The role of riparian soils and plant communities along the mainstem of the Calapooia River in relation to *in situ* net N mineralization was analyzed and compared across the gradient of existing riparian conditions at 32 sites throughout the basin

(Figure 3.2.1). These sites were located among a mix of ownerships, management regimes, and soil types. A random-number generator was used to fix plot locations to a point once legal and physical access to a particular length of the river was acquired. Plots were located five m perpendicular from the 'bank full' line of the river, with bank full defined as the point closest to the river with established vegetation. If this sample point occurred in an agricultural field it was moved toward the river until it was in the riparian zone.

Since most N mineralization occurs in surface mineral soils (Powers 1980; Hope & Li 1997) I measured net fluxes of inorganic-N at a depth of 0-15 cm in the surface mineral soil at approximately monthly intervals (20-35 days) for one year using the buried-bag method (Eno 1960). This method includes initial measurements of inorganic-N in combination with *in situ* incubations that are performed in buried plastic bags. Each month, two adjacent soil cores were taken with an impact corer at each sample site along the river. The soil cores were 15 cm deep and 5 cm across giving a core volume of 294.5 cm^3. Samples excluded the non-decomposed organic debris on the soil surface. This organic layer was removed before coring for the soil samples.

After coring the two adjacent samples, one sample was taken to the laboratory for processing and analysis, while the other sample was placed into a 3.78 L sealable polyethylene storage bag with an approximate wall thickness of 1mm. The core was then wrapped and sealed in the storage bag. This sample was buried for incubation using the original orientation in the hole from which it was sampled. Any removed organic material was then placed back on the top of the sealed soil core bag. Ten percent of the plots were randomly double-sampled each month to provide an estimate of precision.

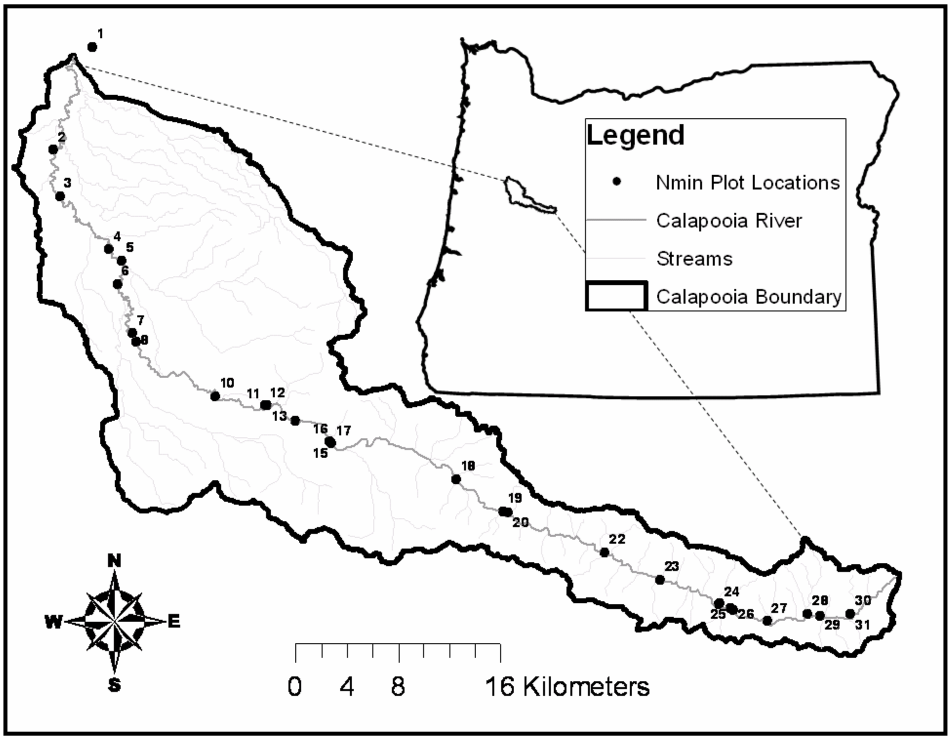

Figure 3.2.1. Nitrogen mineralization study plot locations along the riparian zone of the Calapooia River, Oregon.

A split-sleeve soil core sampler was used to collect intact soil cores for incubation. This approach was used in order to avoid errors in estimation of soil N mineralization caused by degradation of soil structure and homogenization of soil cores before incubation (Eno 1960; Vitousek & Matson 1985). This method reduces the changes in soil properties that homogenizing and disturbing the soil core can create and allows for a more accurate estimation of *in situ* conditions (Virzo de Santo 1982; Matson & Boone 1984; Nadelhoffer 1985; Raison 1987)

3.2.3 Laboratory Methods

Initial and incubated soil cores were passed through a 2 mm sieve to remove coarse fragments and to homogenize samples before laboratory determination of inorganic N. Coarse fragments were oven dried at 105 ˚C and weighed to determine relative fractions of coarse fragment and soil-size particles for each sample. A 2 *M* potassium chloride (KCl) extraction of inorganic-N was performed on 5 g of the field-wet soil sample. Moisture correction measures were performed on a sub-sample of the field-wet sieved soil. Routine use of blank KCl vials were processed and analyzed to measure background laboratory nitrate-N and ammonium-N levels. These background levels were subtracted from the estimates of nitrate-N and ammonium-N in the samples. All processing and KCl extraction were completed within five days of the cores being removed from the field. Soils were stored at 4°C when not being processed.

The KCl extractions were analyzed for nitrate-N and ammonium-N on a Lachet Quick Chem 4200 analyzer (Lachet Instruments, Loveland, Colorado) with a detection limit of 0.04 mg L^{-1}. Routine use of spikes, duplicates and check standards was used to ensure precision of measurements. Net N mineralization was estimated by subtracting the initial values of nitrate-N and ammonium-N from final incubated values.

Estimates of annual accumulated net N mineralization per kg of soil and per ha were calculated by adding the 12 monthly incubations together after weighting for the number of days of each incubation. In the case of missing incubations, I allowed one missing incubation value at any site to be interpolated from the two incubation values before and after the missing value. If more than one incubation failed at a site, annual accumulation values were not calculated for the site. This required the removal of five sites, resulting in 27 sites for annual analysis.

Seasonal net N mineralization values were calculated by averaging the three monthly incubations (weighted for incubation length) in each season. I used the beginning of the water year, October 1st, as the start of the fall season with three-month seasons continuing thereafter (i.e., October-December=Fall, January-March=Winter, April-June=Spring, July-September=Summer).

Soil characterization was performed once at each sample site during the spring of 2006. Samples of the forest floor were collected from three plots measuring 0.25 x 0.25 m square (0.0625 m^2) at a distance of one m from the central sample point. These samples were dried at 65˚C for three days and weighed. Bulk density volumetric cores were collected at 0-15 cm within each of the three plots at each sample site. These cores were dried at 105°C and weighed and then sieved to 2mm and weighed again to provide estimates of total- and soil-fraction bulk density. Bulk density at sites with coarse fragments too large to fit in the soil cores were estimated using the sand cone technique (Dane and Topp 2002). Additionally, ten 15 cm deep cores (punch tubes) were taken of surface mineral soil at each site and composited. These samples were air dried and sieved to 2mm for chemical characterization.

Labile C and N in the mineral soil were extracted using K_2SO_4 and analyzed with a Shimadzu TOC-Vcsh analyzer (Shimadzu Scientific Instruments, Columbia, Maryland). Sub-samples were digested using pressure and microwave-assisted nitric acid (HNO_3) digestion. These digests were analyzed on a Perkin Elmer ICP-OES Optima 4300 (Perkin Elmer Life and Analytical Sciences Inc., Waltham, Massachusetts) for Ca, Mg, Mn, K, Fe, Cu and P. I measured pH using a 2:1 distilled water:air-dried soil ratio with a Hanna HI98129 pH meter (Caprock Developments Inc., Morris Plains, Ney Jersey) with reported accuracy of ± 0.05. Particle-size analysis was performed using the pipet method (add citation). Additionally, sub-samples were ground and passed through a 0.85 mm sieve (20 mesh) and were analyzed for total nitrogen (TN) and total carbon (TC) on a LECO CNS 2000 analyzer (LECO Corporation, St. Joseph, Michigan) with a reported precision of 3%.

Vegetation characteristics of each sample site were measured during the summer of 2006. These measurements included basal area and composition of overstory trees using variable-radius plots. Sapling counts (2.54-7.62 cm at breast height), woody shrub stem count, and understory vegetation cover were measured in 3.14 m^2 circular plots. Ocular methods were used to estimate vegetation cover with categorical breakdown of fern, grass, herbaceous vegetation and Himalayan blackberry (*Rubus discolor*) within the 3.14 m^2 plots.

We analyzed annual accumulation of mineralized N per kg soil and per ha to explore temporal and spatial trends along the length of the Calapooia River. Two-sample t-tests were used to test for differences in mean annual net N mineralization per ha and mean annual net N mineralization per kg soil for sample sites located within the Willamette Silt layer (plots 1-14) and for sites up-river from the Willamette Silt layer (plots 15-33). Before implementing the two-sample t-test, checks were made to determine that the two groups had equal variances to ensure validity of the t-test. An alpha level of 0.05 was used for significance tests. Mean seasonal N mineralization was analyzed for annual and spatial trends along the length of the river. Relationships between annual N mineralization per kg soil and soil/vegetation characteristics at each of the sites were explored using Pearson's correlation coefficients and corresponding p-values.

3.3 Results

3.3.1 Seasonal Nitrogen Mineralization

Mean seasonal *in situ* net N mineralization in riparian soils along the length of the Calapooia River ranged from -166.3 to 973.6 kg N ha^{-1} yr^{-1}. There were clear seasonal trends in net N mineralization along the length of the river (Figure 3.3.1). In all seasons net N mineralization was generally higher in the soils along the lower reaches of the river relative to locations along the upper reaches. The most rapid mean net N mineralization occurred in the spring and summer months (122.1 and 99.7 kg N ha^{-1} yr^{-1}, respectively) and the lowest mean net N mineralization was in the fall and winter months (29.8 and 30.1 kg N ha^{-1} yr^{-1}, respectively). Many sites had negative values of net N mineralization, indicating that net immobilization had occurred during that season. Eight sites had net N immobilization in the fall, 10 in the winter, two in the spring, and four in the summer. Seasonal immobilization of N occurred sporadically across the entire length of the Calapooia River. However, there were a few sites (# 26, 30 & 31) in the upper basin that immobilized N across multiple seasons (Figure 3.3.1).

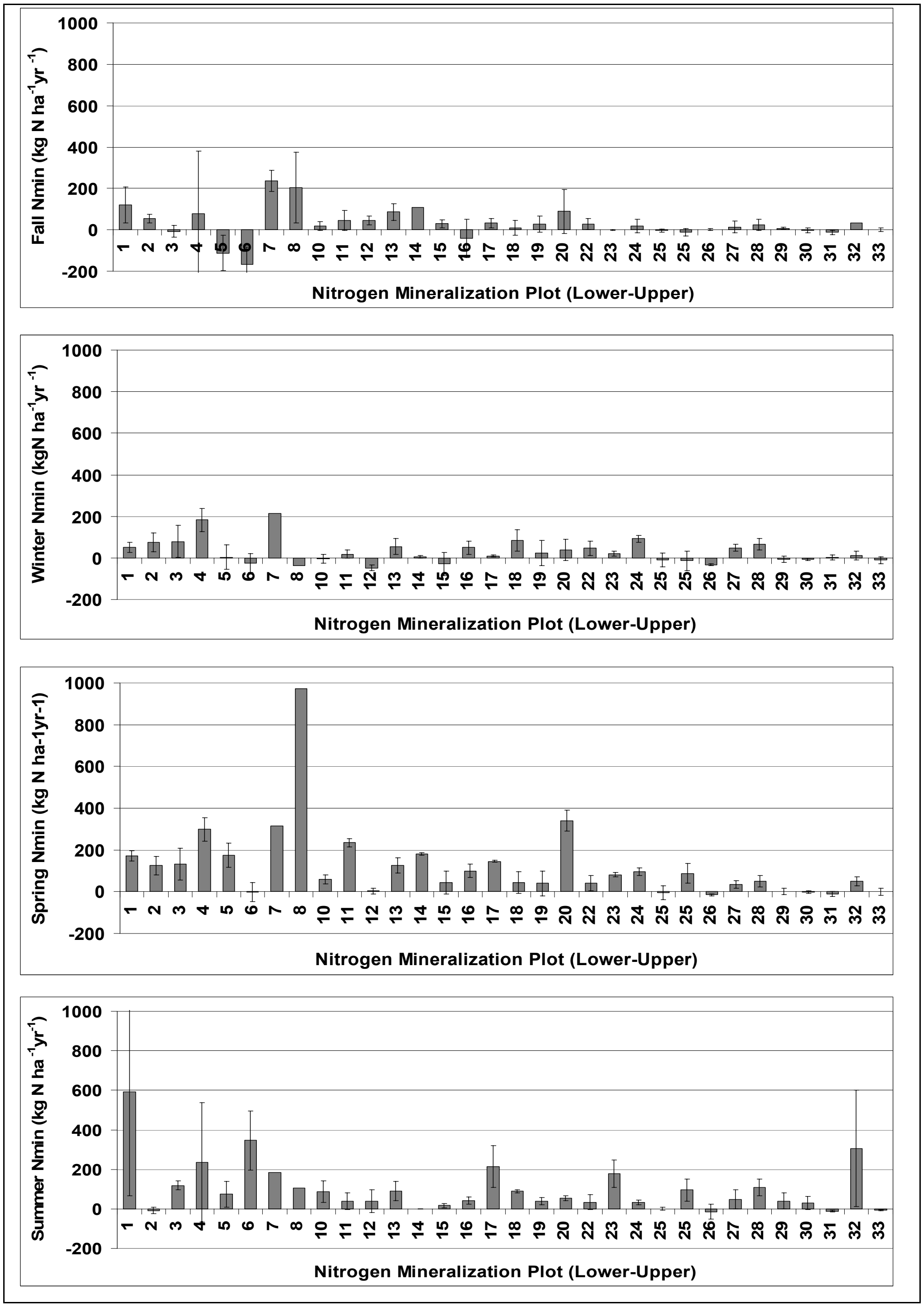

Figure 3.3.1. Mean seasonal net nitrogen mineralization (Nmin) in riparian soils along the length of the Calapooia River, Oregon. Seasonal means are an average of three incubations weighted for incubation length. Each bar represents a location along the mainstem of the river graphed in order from the bottom of the watershed on the left side of each graph. Lack of an error bar indicates that only one incubation was successful for that site and season.

3.3.2 Annual Nitrogen Mineralization

Annual net N mineralization ranged from -16.2 to 207.1 mg N kg soil^{-1} yr^{-1}, with a mean value across the length of the Calapooia River of 64.4 mg N kg soil^{-1} yr^{-1}(Figure 3.3.2). Annual net N mineralization had no clear spatial trends. Four sites (# 25, 26, 31 & 33) in the upper section of the basin had an annual net immobilization of N. However, there were also sites in the upper and middle areas of the basin with annual net N mineralization that was greater than the average for the basin, with three upper sites (# 23, 24 & 28) in the upper quartile of values at 150-200 mg N kg soil^{-1} yr^{-1}. The mean net N mineralization for plots in the Willamette Silt layer was 66.5 mg N kg soil^{-1} yr^{-1}, whereas it was 63.4 mg N kg soil^{-1} yr^{-1} in plots up-river from the Willamette Silt layer. This difference of 2.1 mg N kg soil^{-1} yr^{-1} is not statistically significant (p-value=0.9087).

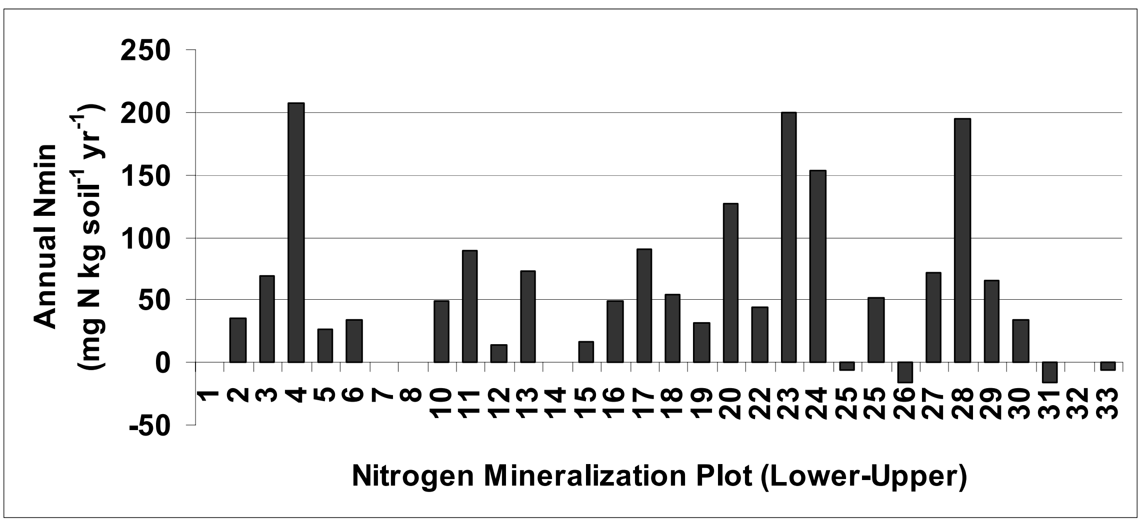

Figure 3.3.2. Annual net nitrogen mineralization per kg of soil (Nmin) in riparian soils along the length of the Calapooia River. Annual values computed from accumulation of nitrogen over 12 monthly incubations. Values <0 represent annual net nitrogen immobilization. Each bar represents a location along the mainstem of the river graphed in order from the bottom of the watershed on the left side of the graph. Missing values indicate multiple failed incubations.

3.3.3 Selected Characteristics of Riparian Zones

Concentration of total N in the surface (0-15cm) mineral soils varied across the riparian areas along the Calapooia River, with generally higher concentrations of total N at the upper reaches of the river (Figure 3.3.3.1). Labile N (K_2SO_4 - hydrolysable) in the surface mineral soils also varied across the riparian areas along the Calapooia River, with higher concentrations of labile N at the upper reaches of the river (Figure 3.3.3.2). Hardwood basal area varied across the riparian areas along the Calapooia River with a marginal trend of more hardwood basal area at sites along the lower reaches (Figure 3.3.3.3). There were strong trends of total- and soil-fraction bulk density across the riparian zones along the Calapooia River with higher bulk densities along the lower reaches and lower bulk densities along the upper reaches (3.3.3.4).

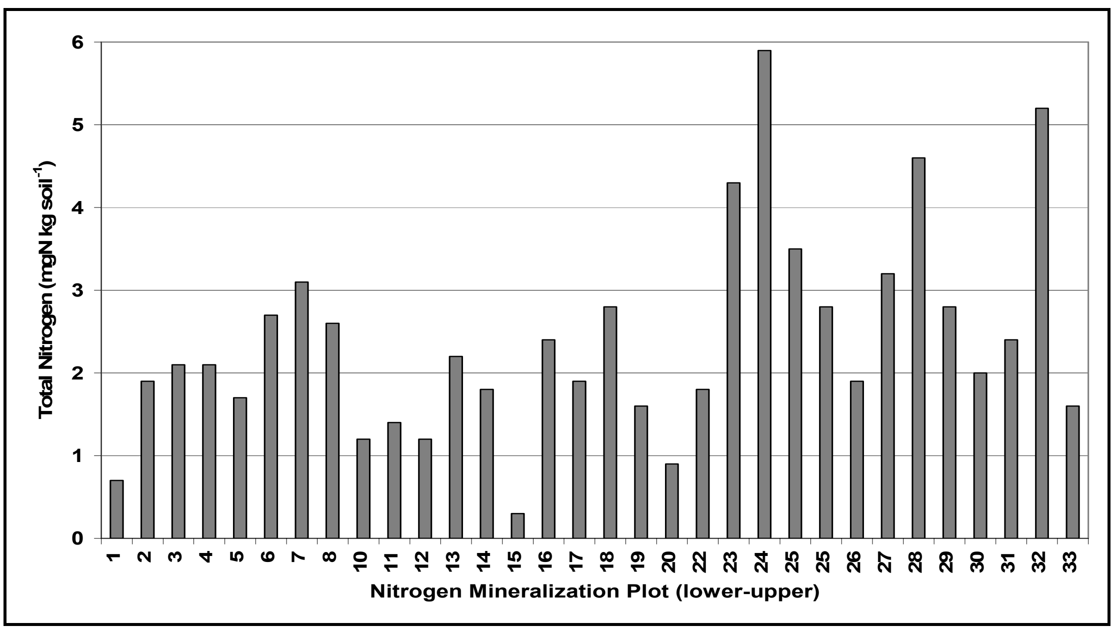

Figure 3.3.3.1. Concentration of total nitrogen in surface (0-15cm) mineral soils collected at nitrogen mineralization plots in riparian zones of the Calapooia River, Oregon.

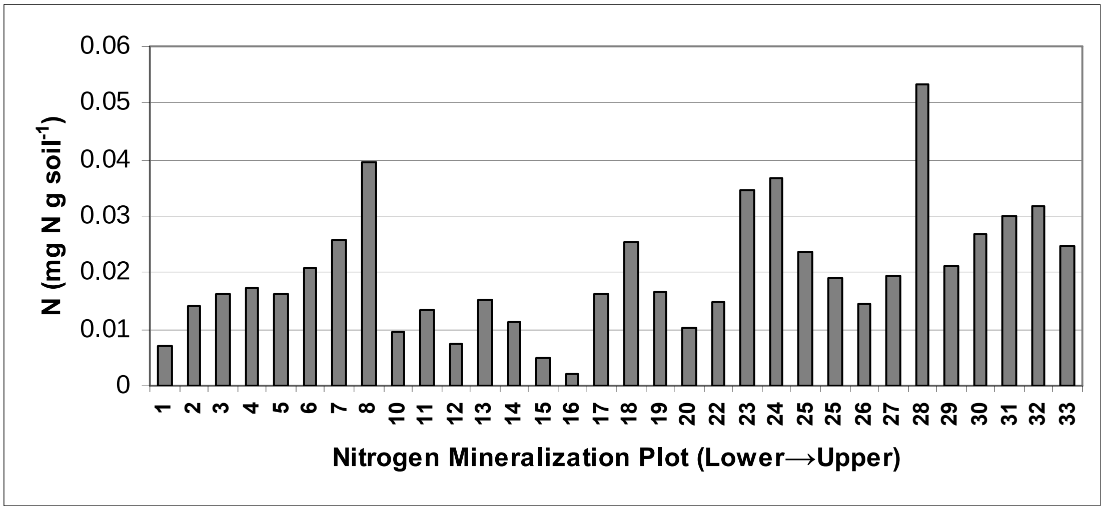

Figure 3.3.3.2. Concentration of labile nitrogen (K_2SO_4 hydrolysable nitrogen) in surface (0-15cm) mineral soils collected at nitrogen mineralization plots in riparian zones of the Calapooia River, Oregon. Each bar represents a location along the mainstem of the river graphed in order from the bottom of the watershed on the left side of the graph.

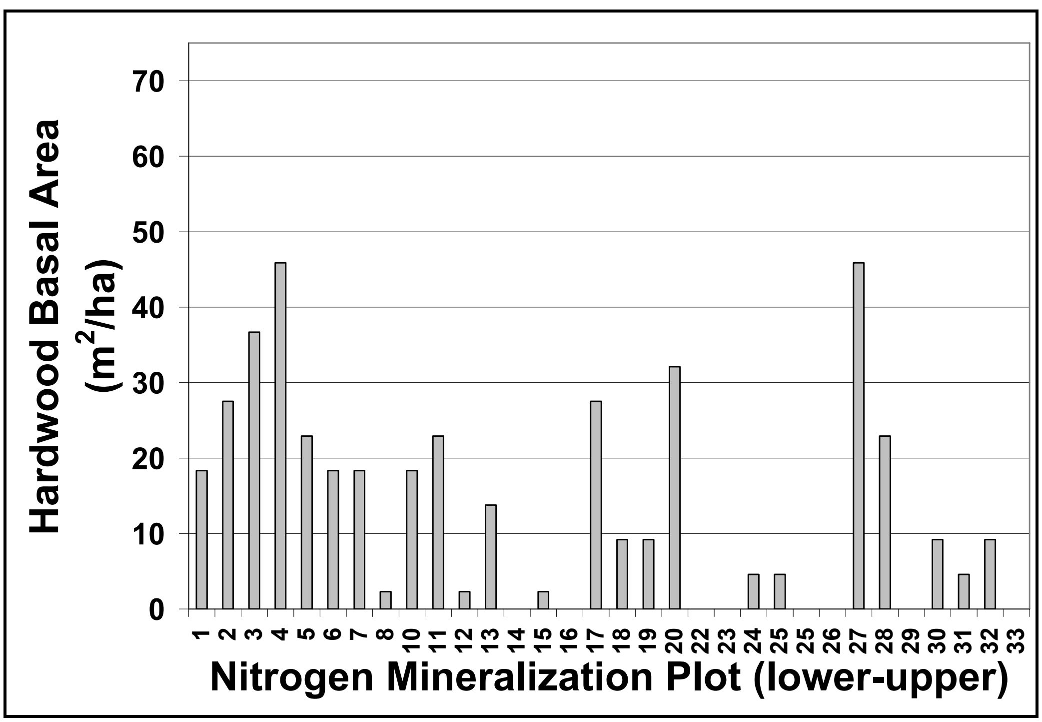

Figure 3.3.3.3. Hardwood basal area at nitrogen mineralization plots in riparian zones along the Calapooia River, Oregon. Each bar represents a location along the mainstem of the river graphed in order from the bottom of the watershed on the left side of the graph.

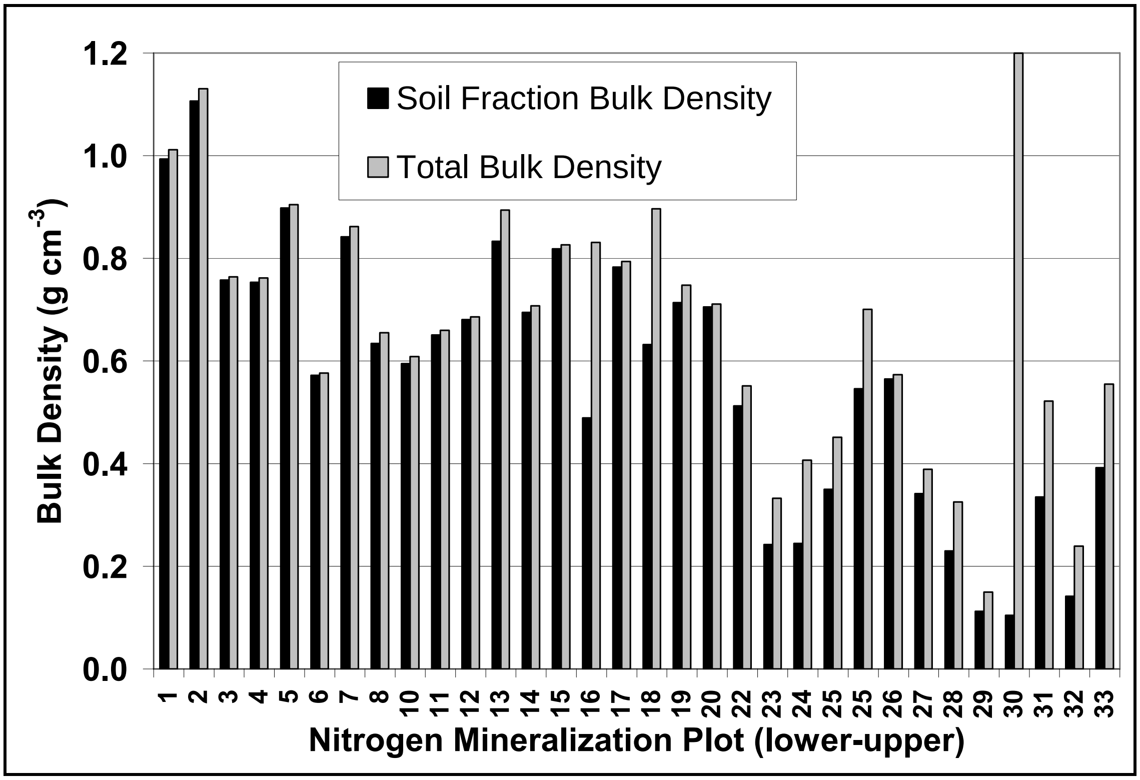

Figure 3.3.3.4 Total- and soil-fraction bulk density in surface (0-15cm) mineral soils across riparian zones along the Calapooia River, Oregon. Each bar represents a location along the mainstem of the river graphed in order from the bottom of the watershed on the left side of the graph. Difference between bars for each plot is coarse-fragment portion of total bulk density.

3.3.4 Relationships between Nitrogen Mineralization and Selected Characteristics of Riparian Zones

Annual net N mineralization per kg of soil was significantly and positively correlated with TN, labile N, and hardwood basal area (p-values; 0.009, 0.024, and 0.034, respectively (Table 3.3.4 and Figures 3.3.4.1, 3.3.4.2 & 3.3.4.3)). These significant correlations indicate that as the amount of TN, labile N and hardwood basal area increased, N mineralization rate also increased. Analyses of scatterplots suggest the presence of generally linear relationships (Figures 3.3.4.1, 3.3.4.2 & 3.3.4.3). Soil phosphorus and total C had significant positive correlations with annual net N mineralization per kg of soil at an alpha of 0.10 (p-values=0.057 and 0.069 respectively) (Table 3.3.4). Conifer basal area did not have a significant correlation with net N mineralization per kg of soil (p-value=0.58).

Table 3.3.4. Pearson correlation coefficients for relationships between nitrogen mineralization per kg of soil and soil/site characteristics in riparian areas along the Calapooia River, Oregon.

Parameter[1]	**Pearson r**	**p-value**	**N**[2]
TN (g kg-1)	0.491	0.009	27
Labile N (mg kg soil^{-1})	0.434	0.024	27
Hardwood (m^2 ha^{-1})	0.410	0.034	27
P (ug g soil^{-1})	0.370	0.057	27
TC (g kg^{-1})	0.356	0.069	27
Sapling Count	-0.320	0.111	26
Mn (ug g soil^{-1})	0.292	0.139	27
% Clay	-0.290	0.142	27
Grass (% cover)	0.261	0.189	27
Total Bulk Density (g cm^{-3})	-0.256	0.198	27
Ca (ug g soil^{-1})	0.249	0.211	27
Woody Stem Count	-0.241	0.226	27
Tree Total (m^2 ha^{-1})	0.216	0.279	27
Forest Floor (g m^{-2})	0.179	0.371	27
Fe (ug g soil^{-1})	-0.174	0.386	27
Total Understory (% cover)	0.163	0.417	27
Soil Bulk Density (g cm^{-3})	-0.150	0.455	27
Cu (ug g soil^{-1})	0.145	0.469	27
Labile C (g C kg-1)	0.139	0.489	27
Forb (% cover)	-0.135	0.501	27
Fern (% cover)	-0.135	0.501	27
K (ug K g soil-1)	-0.131	0.514	27
% Sand	0.131	0.516	27
C:N	-0.111	0.580	27
Conifer (m^2 ha$^{-1)}$	-0.111	0.582	27
Himalayan Blackberry (% cover)	-0.091	0.652	27
Mg (ug Mg g soil^{-1})	0.073	0.716	27
pH	-0.004	0.983	27
% Silt	-0.001	0.996	27

[1]TN:total nitrogen; TC: total carbon.
[2]N=number of samples (sites).

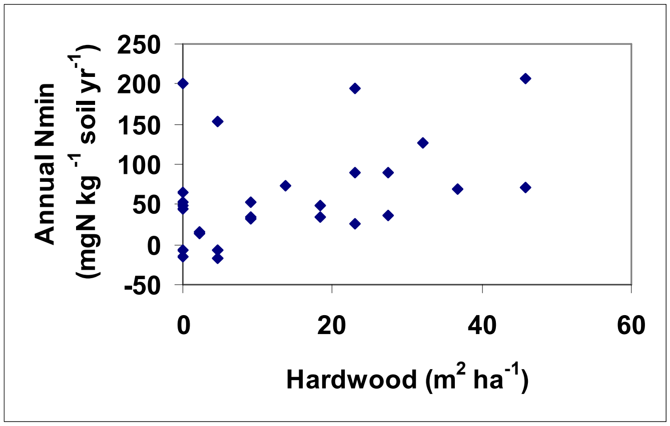

Figure 3.3.4.1. Scatterplot of hardwood basal area versus annual net nitrogen mineralization per kg of soil (Nmin) in 27 riparian areas along the Calapooia River, Oregon.

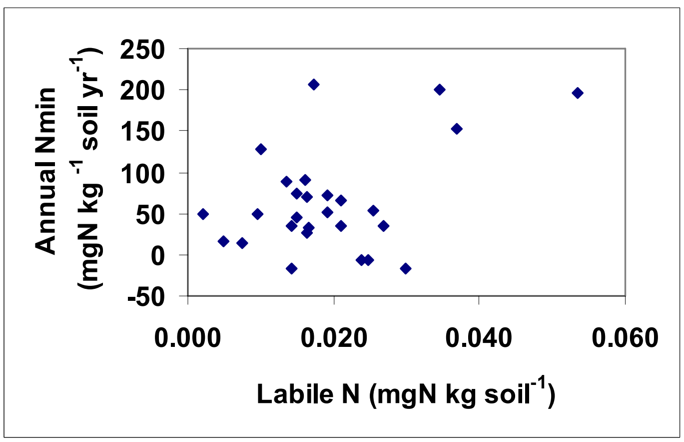

Figure 3.3.4.2. Scatterplot of labile N versus annual net N mineralization per kg of soil (Nmin) in 27 riparian areas along the Calapooia River, Oregon.

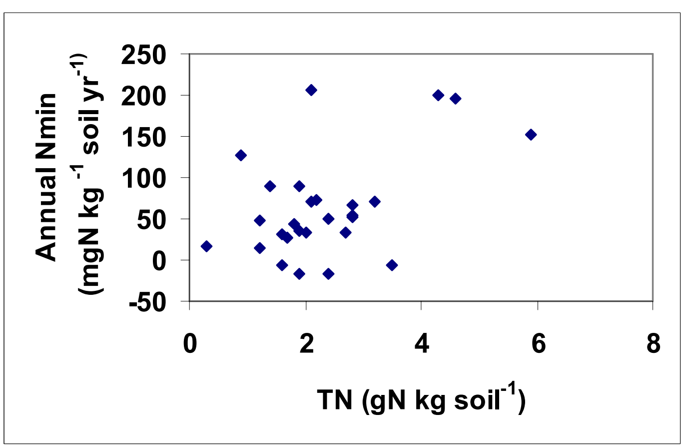

Figure 3.3.4.3. Scatterplot of Total nitrogen (TN) versus annual net N mineralization per kg of soil (Nmin) in 27 riparian areas along the Calapooia River, Oregon.

3.3.5 Annual Net Nitrogen Mineralization per Hectare

Annual net N mineralization per ha ranged from -13.5 to 234.0 kg N ha^{-1} yr^{-1} with a mean for all sites of 50.1 kg N ha^{-1} yr^{-1} (Figure 3.3.5). There was a spatial trend in annual net N mineralization per ha across the basin. The highest values were in riparian zones along the lower and middle reaches of the basin, whereas lower values were observed in plots located along the upper reaches. Four sites (# 25, 26, 31 & 33) in the upper basin had net immobilization of N per ha. Mean annual net N mineralization per ha for plots in the Willamette Silt layer was 74.8 kg N ha^{-1} yr^{-1}, whereas it was 37.7 kg N ha^{-1} yr^{-1} in plots located along reaches upstream from the Willamette Silt layer. This difference of 37.1 kg N ha^{-1} yr^{-1} was not statistically significant (p-value=0.0789).

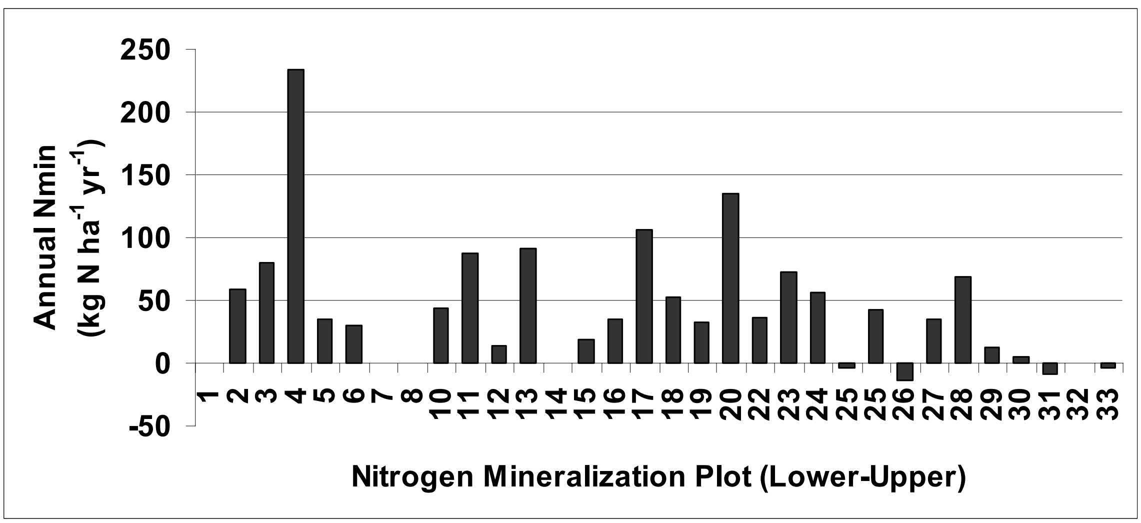

Figure 3.3.5. Annual net nitrogen accumulation per hectare (Nmin) in riparian soils along the length of the Calapooia River, Oregon. Annual values computed from accumulation of nitrogen over 12 incubations. Each bar represents a location along the mainstem of the river graphed in order from the bottom of the watershed on the left side of the graph. Values <0 represent annual net N immobilization. Missing values indicate multiple failed incubations.

3.4 Discussion

3.4.1 Seasonal Nitrogen Mineralization

Seasonal changes in mean N mineralization observed in riparian zones across the length of the Calapooia River agreed with well-supported theories of soil microbial activity (Brady and Weil 2002; Sylvia et al. 2005). It is likely that cooler temperatures in the fall and winter months suppressed microbial activity, which resulted in lower N mineralization in these seasons. With the onset of warmer temperatures in the spring, microbial activity is likely to have increased thereby promoting observed increases in N mineralization. Moisture conditions and oxygen levels are also likely to play a role in the seasonal changes in N mineralization I observed in riparian areas (Groffman 1996). Spring and summer moisture conditions in riparian zones of the Calapooia River may be more optimal to microbial activity than in fall and winter due to unsaturated conditions and corresponding higher oxygen levels. Increased retention of N in the cooler seasons was also found by Hefting (2005). The increase in net immobilization in the winter months may be due to lower mineralization rates with continued demand for nitrate-N and ammonium-N by microbes that require N to breakdown carbon compounds. It is unlikely that denitrification played a significant role in cases where I observed net immobilization because the buried-bag method excluded rainfall and occurrence of saturation from the incubating soil cores. The seasonal fluxes in N mineralization support the hypothesis that the riparian areas along the Calapooia River may be both net sources and sinks of N during different seasons. During warm seasons, N mineralization in riparian soils may be high, resulting in net sources of N. Whereas in the cooler fall and winter months, N mineralization may be low, resulting in potential net sinks of N. Additions of surface litter in hardwood riparian areas is also seasonal and may shift the soils from sinks to sources of N as the hardwood litter decomposes. This agrees with the work of Garten and Ashwood (2003) who emphasized the importance of timing of N inputs and outputs for systems to function as a seasonal source or sink of N.

The seasonal values of N mineralization in riparian soils also align well with research in the Calapooia Basin indicating that DN in surface waters of the basin are highest during the onset of Oregon's winter rains and during high precipitation periods in spring (Floyd 2005; Evans: companion manuscript Chapter 2). Late fall and winter rains have been observed to hydrologically connect overland runoff to surface waters and deliver excess DN (Wigington 2003, 2005), which was mineralized throughout a sub-basin during the dry season. The spring flush of N mineralization could also be delivered to surface waters by strong spring storms, if these storms occurred before the onset of vegetation uptake.

3.4.2 Annual Nitrogen Mineralization Relationship to Site Characteristics

The lack of distinct patterns in annual N mineralization in riparian soils along the length of the Calapooia River was not as hypothesized. Nitrogen mineralization in the soil fraction should be driven by environmental conditions and soil attributes that have been consistently found to increase N mineralization, such as temperature, moisture and litter quality (Van Cleeve 1993; Stump & Binkley 1993; Groffman 1996; Scott and

Binkley 1997). These variables tend to vary across the basin and form gradients of change from riparian zones in the lower area of the basin to those in the upper. I expected to see patterns in N mineralization across the basin that tracked changes in environmental conditions. One possible explanation is that the five missing sites have skewed the annual results, because four of these sites occurred in the lower basin. It is also possible that the gradient covered in my sampling design does not cover enough range to demonstrate region-wide patterns.

Site characteristics that had the highest correlations with N mineralization were TN, labile N and hardwood basal area. The relationships between TN, labile N and N mineralization are easily explained. Labile N and TN are highly correlated to each other (Pearson = 0.78). As the total amount of N in the soil fraction increases, one would expect the amount of labile N to increase. As TN and labile N increase, there is more N in the system for microbes to mineralize and hence there is a greater potential for higher N mineralization. Interestingly, concentrations of TN and labile N tended to be higher at the upper sites compared to the lower sites (Figure 3.3.4.1 & 3.3.4.2). This is likely related to presence of more surface litter and greater amounts of organic material in soils of the upper area of the basin.

The third site factor that had a significant positive correlation with N mineralization was hardwood basal area. This correlation is supported by a body of research addressing litter quality and N mineralization. Research has identified the amount of lignin or the lignin:N ratio as a primary controller of N mineralization across various climates and forest ecosystems, with less N mineralization occurring as the amount of lignin or lignin:N ratios increase (Fogel and Cromack 1977; Melillo et al.

1982; Van Cleeve 1993; Stump & Binkley 1993; Scott and Binkley 1997). Hardwood litter has less lignin than conifer litter and is therefore of a higher quality for microbial decay. The hardwood trees on my sites may contribute litter of a higher quality, which is more easily decomposed and allows for higher N mineralization on an annual or seasonal basis. Hardwood species composition tends to vary across the Calapooia Basin, but hardwood basal area has only a marginal trend across the riparian zones (Figure 3.3.3.3). This lack of distinct spatial pattern in hardwood basal area coincides with the lack of spatial pattern in N mineralization.

Conifer basal area did not have a significant relationship with N mineralization as hypothesized. This may be due to the distinct spatial pattern of conifer basal area showing more conifers in the upper area of the basin and a lack of distinct spatial pattern of net N mineralization per kg of soil.

3.4.3 Annual N mineralization per Hectare

There are clear spatial trends in N mineralization per ha in the riparian soils along the length of the Calapooia River. The highest N mineralization per ha was found along the lower and middle reaches, with lower N mineralization per ha observed along the upper reaches of the river. This trend is highly dependent on the use of soil-fraction bulk density to scale N mineralization per kg of soil to N mineralization per ha. This removes the non-soil-sized coarse-fragment materials from the calculation. Coarse–fragment content, and hence differences between total bulk density and soil-fraction bulk density, vary systematically across the measured riparian soils. Moving up the basin, the amount of coarse fragments increases steadily (Figure 3.3.4.4), with a few sites in the upper basin dominated by cobbles and rock. In the upper basin, where total- and soil-fraction bulk density were quite different, N mineralization per ha was lowered substantially when correction for coarse fragments was utilized. This creates spatial trends in N mineralization, indicating more N mineralization in riparian soils at lower reaches of the river compared to upper reaches, which are directly related to changes in soil-fraction bulk density.

The role of soil bulk density has important implications for watershed-scale research addressing N processes. Many studies of N mineralization scale their data to N mineralization per ha. If this is done without regard for changes in coarse fragment amounts in different locations, erroneous relationships will be found for variables that tend to co-vary with coarse fragments. Nitrogen mineralization per ha is clearly a better descriptor of the significant N mineralization on an ecosystem or watershed scale at each of the plots. For example, in my study, the upper sites have relatively high fractions of rock and cobble, which effectively dilutes the amount of biologically available N on a per-ha basis, even in the presence of high N mineralization rates per kg of soil-size fraction. However, N mineralization on a mg kg^{-1} basis is a better variable to use when exploring relationships with site characteristics because it is not confounded by effects of bulk density across the landscape. If N mineralization per ha is used for correlation or regression analysis in a watershed-scale study, care must be taken to consider the influence that soil-fraction bulk density has on N mineralization estimates across a landscape.

3.5 Conclusions

Nitrogen mineralization in surface soils of riparian zones along the Calapooia River had clear seasonal trends that are likely related to changes in soil temperature and moisture. If similar seasonal trends in N mineralization also occur in terrestrial systems outside of riparian zones across the basin, then seasonal DN trends in surface waters of the Calapooia Basin can be explained, to some extent, by seasonal N mineralization patterns across the basin. Additionally, nutrient application recommendations based on measurement of background N mineralization levels (Nelson et al 2006) are supported by the patterns that I encountered. For example, fertilization with N containing compounds during the spring flush of background N mineralization that I measured may overwhelm ecosystem uptake capacity and lead to leaching of N during heavy spring precipitation events.

Annual net N mineralization per kg of soil did not have detectable spatial patterns along the length of the Calapooia River's riparian zone, but was correlated with surface-soil TN, labile N, and hardwood basal area within the riparian zone. In contrast, when soil-fraction bulk density was taken into account, annual net N mineralization per ha did have spatial patterns within the Calapooia Basin. These patterns of N mineralization demonstrated the importance of coarse fragments in the soil in reducing estimates of the potentially available N in the riparian zone in the upper basin and indicate that there is more overall N mineralization in the lower Calapooia Basin soils due a lack of coarse fragments when compared to the upper basin.

Although N mineralization per kg of soil proved to be a better dependent variable for exploring relationships between site variables and N mineralization because it removes the confounding effect of coarse fragments, any future work on basin-wide scales, should consider the role of coarse fragments in modifying relationships between soil N mineralization and other site factors controlling N mineralization. Additional work at the watershed scale should focus on measuring full N budgets in riparian zones to provide more information about how N is cycling within and moving through these interfaces between the terrestrial and aquatic systems.

Chapter 4: Conclusions and Recommendations

Dissolved N in surface waters of the Calapooia River Basin are inherently linked to physical attributes of terrestrial systems and how they are managed. I found evidence that the amount of N mineralization per kg of soil in riparian systems had strong positive relationships with the total amount of soil N, labile soil N, and the basal area of hardwood trees in the riparian zone. These relationships are well-documented in the literature and are easily explained. As more N is present in a soil system, there is more available to be mineralized. Also, as there is more high-quality leaf litter from hardwood trees, there is a greater likelihood of rapid decomposition of the litter and subsequent excess soil N to be mineralized. Higher N mineralization rates in areas with these attributes provide greater potential for N to be leached or drained out of the terrestrial system to the aquatic system.

The amount of non-soil-sized material is clearly a controlling factor determining my estimates of N mineralization per ha. In the upper Calapooia River Basin the high rock percentages strongly reduce estimates of N mineralization on a per-ha basis when compared with soils in the lower basin that have fewer coarse fragments. Nitrogen mineralization per ha is a good estimate of the amount of biologically available N within an ecosystem for uptake or loss. Hence, the relative lack of coarse fragments in the lower basin results in a higher total N per ha in those systems and therefore a greater amount of N to be mineralized and used by plants and microbes or lost to aquatic systems. If these results are extrapolated outside of the riparian zones, there are implications for the patterns of DN that I observed in surface waters of the Calapooia

Basin. The higher levels of DN in the lower areas of the basin may be influenced by N mineralization occurring in excess of demand in areas with relatively high amounts of soil per ha. In riparian zones of the upper reaches of the Calapooia Basin, there are greater amounts of coarse fragments that reduce the total amount of N mineralized on a per ha basis across the landscape. This relatively high rock content results in less total N in the soil system and therefore may lead to more efficient use of the limited N that is present under these conditions. Therefore, the positive relationships between DN and agriculture observed in this study are likely exacerbated by the lack of coarse fragments and also by the poorly drained soils in the lower basins.

Implications for management can also by drawn from a synthesis of the surface water DN and riparian zone N mineralization findings. The lower sub-basins with poorly drained soils and low amounts of coarse fragments have the highest DN concentrations. Management of these systems should include consideration for the nature of the soils. Relatively large pools of TN and labile N in riparian soils of the lower basin will have relatively high potential to produce flushes of N mineralization under optimal environmental conditions (e.g., warm, moist soils). When these conditions are present, the value of carefully following nutrient management recommendations is important because of the potential for adding N to a system with high levels of background N.

Results of this study suggest that future research should focus on process-based investigations which further explore N dynamics in terrestrial systems of the Willamette Basin to determine the specific impact of various nutrient management strategies on N retention and losses under year-round soil- and weather conditions. This will provide information which will help land managers and regulatory agencies determine appropriate levels of allowable DN in Willamette Basin surface waters and potential benefits of improved nutrient management methods. Research is also needed to address in-stream processing of DN, particularly over multiple years with varying climate. The role of in-stream processing is poorly understood in these systems and may play a crucial role in determining where, when, and which DN components are in surface waters.

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Appendices

Appendix A1. Independent sub-basins land-use (portion of area)

Sub-Basin	Woody Vegetation (2000 30cm ortho photos)	Agriculture (1999 30m Landsat imagery)	Poorly Drained Soils (STATSGO & SSURSGO)	2004-2005 Conservation	2005-2006 Conservation	2004-2005 Non-Conservation	2005-2006 Non-Conservation
1	1.00	0.00	0.00				
2	1.00	0.00	0.00				
4	1.00	0.00	0.05				
6	1.00	0.00	0.03				
12	1.00	0.00	0.11				
15	1.00	0.00	0.06				
16	1.00	0.00	0.03				
18	1.00	0.00	0.00				
23	1.00	0.00	0.00				
26	1.00	0.00	0.05				
27	1.00	0.00	0.00				
28AA	1.00	0.00	0.02				
29	1.00	0.00	0.07				
30	1.00	0.00	0.09				
47	1.00	0.00	0.23				
48	1.00	0.00	0.00				
50	0.98	0.02	0.00				
51	0.94	0.06	0.02				
55	0.79	0.20	0.01				
56	0.73	0.27	0.14				
57	0.33	0.67	0.11				
59	0.93	0.07	0.15				
63A-1	1.00	0.01	0.01				
63X	0.94	0.06	0.03				
64	0.94	0.06	0.34	0.05		0.00	0.05
65	0.52	0.48	0.19	0.09	0.24	0.30	0.17
67	0.94	0.06	0.34				
68A		0.21	0.43	0.06	0.08	0.08	0.07
68B	0.15	0.44	0.61	0.16	0.20	0.14	0.10
68C	0.03	0.92	0.79	0.31	0.47	0.52	0.37
68H	0.08	0.75	0.62	0.29	0.38	0.33	0.26
68I	0.00	1.00	0.70	0.45	0.40	0.44	0.55
69A	0.96	0.04	0.23		0.01	0.00	0.01
69C	0.09	0.91	0.86	0.27	0.45	0.50	0.33
69D	0.04	0.95	0.94	0.30	0.43	0.51	0.42
70	0.01	0.99	0.81	0.38	0.59	0.53	0.34
71	0.10	0.89	0.78	0.43	0.52	0.37	0.30
72A	0.01	0.98	0.83	0.48	0.39	0.42	0.51
73A	0.01	0.99	0.58	0.66	0.39	0.26	0.54
74A	0.01	0.98	0.85	0.45	0.55	0.45	0.35
74B	0.01	0.98	0.84	0.54	0.62	0.40	0.31
75A	0.72	0.28	0.26	0.01	0.06	0.02	0.02
75C	0.04	0.91	0.67	0.15	0.29	0.59	0.47
75D	0.03	0.94	0.70	0.29	0.33	0.51	0.46

Appendix A2. Independent sub-basins sample point location

Site ID	Stream Name	Easting UTM 10 NAD 83	Northing	Elevation (m)	Basin Location	Basin Area (square km)
1		551196	4898655	745.4	Upper	13.38
2		551211	4898619	754.3	Upper	4.94
4	United States Creek	549324	4898127	662.9	Upper	3.93
6	North Fork Calapooia River	546801	4898071	547.1	Upper	15.38
12	King Creek	544149	4897623	537.5	Upper	3.73
15		540390	4898817	425.5	Upper	3.46
16	Potts Creek	539890	4899098	424.3	Upper	8.61
18	Hands Creek	538838	4899927	409.6	Upper	7.19
23	Washout Creek	535528	4901193	360.1	Upper	5.00
26	McKinley Creek	535029	4900592	0.0	Upper	7.86
27		533871	4901659	364.0	Upper	4.64
28AA		532405	4902143	284.0	Upper	6.48
29	Blue Creek	531190	4903258	283.5	Upper	5.71
30	Biggs Creek	530949	4903369	277.5	Upper	9.38
47	Cedar Creek	523714	4906074	280.1	Upper	4.32
48		522836	4905990	234.4	Upper	3.12
50	Pugh Creek	520318	4907974	177.5	Middle	7.52
51	Sawyer Creek	519594	4908805	172.4	Middle	3.97
55		517410	4910371	167.6	Middle	6.89
56		517532	4910492	164.3	Middle	8.49
57		517528	4910521	191.9	Middle	13.42
59	Johnson Creek	514440	4911990	151.3	Middle	12.38
64		509557	4912314	140.5	Middle	5.26
65		506757	4913232	117.2	Middle	3.06
67	Warren Creek	505465	4914821	118.1	Middle	18.34
70		493697	4925680	74.1	Lower	7.69
71		492278	4927892	58.8	Lower	14.03
63A-1	Brush Creek	514378	4907279	179.7	Middle	19.51
63X	West Brush Creek	512946	4909153	154.7	Middle	16.69
68A	Cochrane Creek	498617	4922399	79.2	Middle	28.47
68B	Butte Creek	501018	4924338	82.6	Middle	26.67
68C	Plainview Creek	497007	4924515	75.3	Lower	15.67
68H		496970	4921970	84.2	Lower	15.44
68I		495375	4924946	75.8	Lower	3.39
69A	Courtney Creek	506169	4910188	129.4	Middle	23.63
69C	Spoon Creek	493910	4914000	84.7	Lower	22.59
69D	Spoon Creek	493917	4912869	100.8	Lower	27.89
72A		490197	4922957	74.9	Lower	9.79
73A		488900	4926966	70.8	Lower	7.89
74A	Lake Creek	494193	4931139	69.8	Lower	7.25
74B	Lake Creek	492755	4929373	66.9	Lower	9.99
75A	Oak Creek	506920	4927969	83.8	Middle	32.22
75C	Little Oak Creek	499448	4935564	83.3	Lower	16.99
75D		490239	4936564	66.0	Lower	21.02

Appendix A3. Fall Calapooia River sub-basin dissolved nitrogen means

Site ID	Fall 2003 TN (mg L^{-1})	Fall 2003 NH4-N (mg L^{-1})	Fall 2003 NO3-N (mg L^{-1})	Fall 2003 DON (mg L^{-1})	Fall 2004 TN (mg L^{-1})	Fall 2004 NH4-N (mg L^{-1})	Fall 2004 NO3-N (mg L^{-1})	Fall 2004 DON (mg L^{-1})	Fall 2005 TN (mg L^{-1})	Fall 2005 NH4-N (mg L^{-1})	Fall 2005 NO3-N (mg L^{-1})	Fall 2005 DON (mg L^{-1})
1	0.10	0.04	0.04	0.10	0.12	0.04	0.04	0.04	0.40	0.06	0.04	0.30
2	0.13	0.04	0.04	0.13	0.11	0.04	0.04	0.04	0.54	0.04	0.04	0.46
4	0.13	0.04	0.04	0.13	0.14	0.04	0.04	0.06	0.15	0.04	0.04	0.07
6	0.24	0.04	0.09	0.17	0.30	0.04	0.18	0.09	0.37	0.04	0.14	0.19
12	0.16	0.04	0.04	0.16	0.22	0.04	0.06	0.12	0.24	0.04	0.06	0.15
15	0.22	0.04	0.06	0.19	0.20	0.04	0.08	0.08	0.33	0.04	0.06	0.23
16	0.24	0.04	0.09	0.17	0.35	0.05	0.21	0.10	0.32	0.04	0.15	0.14
18	0.13	0.04	0.04	0.13	0.16	0.04	0.04	0.08	0.34	0.04	0.04	0.26
23	0.12	0.04	0.04	0.12	0.13	0.04	0.04	0.05	0.34	0.04	0.04	0.26
26					0.21	0.04	0.07	0.10	0.60	0.04	0.44	0.12
27	0.19	0.04	0.04	0.19	0.25	0.04	0.04	0.17	0.30	0.16	0.06	0.15
28AA	0.24	0.04	0.09	0.18	0.37	0.04	0.22	0.11	0.40	0.04	0.18	0.19
29	0.15	0.04	0.04	0.15	0.49	0.04	0.29	0.16				
30	0.19	0.04	0.04	0.19	0.26	0.04	0.12	0.10	0.29	0.04	0.12	0.14
47	0.29	0.04	0.13	0.19	0.51	0.04	0.28	0.19	0.50	0.05	0.23	0.22
48	0.50	0.04	0.26	0.26	0.68	0.04	0.52	0.12	0.45	0.04	0.31	0.10
50	0.23	0.04	0.09	0.16	0.45	0.04	0.26	0.15	0.41	0.04	0.25	0.13
51	0.34	0.04	0.13	0.24	0.60	0.04	0.35	0.21	0.47	0.04	0.32	0.10
55	0.49	0.04	0.29	0.22	0.71	0.04	0.43	0.24	0.50	0.04	0.28	0.18
56	1.18	0.04	1.00	0.18	0.62	0.04	0.32	0.26	0.72	0.04	0.47	0.20
57	1.57	0.04	1.40	0.17	0.70	0.04	0.39	0.27	0.90	0.04	0.70	0.15
59	0.73	0.04	0.30	0.43	0.59	0.04	0.14	0.41	0.66	0.04	0.20	0.42
63A-1	0.32	0.04	0.13	0.22	0.49	0.04	0.29	0.16	0.45	0.04	0.25	0.15
63X	0.47	0.04	0.26	0.24	0.54	0.04	0.35	0.15	0.59	0.04	0.42	0.13
64	1.10	0.04	0.60	0.50	0.65	0.04	0.20	0.41	1.10	0.05	0.53	0.53
65	6.02	0.04	5.80	0.22	5.81	0.04	5.00	0.77	5.67	0.04	5.24	0.39
67	0.93	0.04	0.70	0.23	0.66	0.04	0.27	0.34	0.93	0.04	0.58	0.31
68A					1.07	0.04	0.75	0.28	2.74	0.04	2.22	0.48
68B	5.85	0.07	5.40	0.38	1.46	0.04	1.54	0.25	3.37	0.05	2.64	0.68
68C	10.50	0.04	8.90	1.60	12.84	0.06	10.55	2.24	9.74	0.06	8.02	1.65
68H	8.37	0.04	7.50	0.87	10.83	0.04	9.27	1.52	8.83	0.09	7.73	1.02
68I	5.38	0.35	3.95	1.05	8.57	0.04	7.92	0.61	7.74	0.05	6.48	1.21
69A	0.50	0.04	0.33	0.20	0.92	0.04	0.60	0.28	1.31	0.04	1.08	0.19
69C	4.74	0.04	4.00	0.74	3.08	0.04	2.04	0.99	6.52	0.10	5.43	0.99
69D	8.85	0.04	7.60	1.25	4.52	0.04	3.43	1.05	10.49	0.20	8.98	1.31
70	11.62	0.04	9.70	1.92	7.43	0.04	6.58	0.81	11.70	0.05	10.70	0.95
71	11.49	0.04	9.60	1.89	7.44	0.04	6.23	1.17	13.04	0.09	11.90	1.04
72A	11.58	0.04	9.50	2.08	11.08	1.30	7.49	2.29	15.28	0.30	14.40	0.58
73A	9.42	0.04	8.20	1.22	8.28	0.06	6.45	1.76	17.00	0.09	14.30	2.61
74A	9.54	0.20	8.00	1.40	4.55	0.04	3.46	1.05	10.49	0.11	9.36	1.01
74B	7.26	0.10	6.20	1.00	3.79	0.04	2.76	0.99	12.69	0.04	11.70	0.95
75A	0.56	0.04	0.37	0.25	0.66	0.04	0.33	0.29	4.73	0.05	3.99	0.69
75C	3.66	0.20	2.80	0.70	7.17	0.06	5.62	1.50	12.36	0.12	11.50	0.73
75D	2.95	0.04	2.40	0.50	4.45	0.06	3.33	1.06	11.78	0.11	9.94	1.73

Appendix A4. Winter Calapooia River sub-basin dissolved nitrogen means

Site ID	Winter 04 TN (mg L^{-1})	Winter 04 NH4-N (mg L^{-1})	Winter 04 NO3-N (mg L^{-1})	Winter 04 DON (mg L^{-1})	Winter 05 TN (mg L^{-1})	Winter 05 NH4-N (mg L^{-1})	Winter 05 NO3-N (mg L^{-1})	Winter 05 DON (mg L^{-1})	Winter 06 TN (mg L^{-1})	Winter 06 NH4-N (mg L^{-1})	Winter 06 NO3-N (mg L^{-1})	Winter 06 DON (mg L^{-1})
1	0.08	0.04	0.04	0.08	0.13	0.05	0.04	0.04	0.11	0.04	0.04	0.04
2	0.07	0.04	0.04	0.05	0.13	0.04	0.04	0.05	0.10	0.04	0.04	0.04
4	0.16	0.04	0.04	0.16	0.15	0.04	0.04	0.06				
6	0.22	0.04	0.09	0.13	0.23	0.04	0.12	0.07	0.24	0.04	0.10	0.10
12	0.16	0.04	0.04	0.16	0.18	0.04	0.05	0.09	0.16	0.04	0.04	0.08
15	0.20	0.04	0.06	0.16	0.21	0.04	0.06	0.11	0.20	0.04	0.06	0.10
16	0.22	0.04	0.10	0.12	0.28	0.04	0.16	0.07	0.27	0.04	0.13	0.10
18	0.10	0.04	0.04	0.10	0.14	0.04	0.04	0.06	0.15	0.04	0.04	0.07
23	0.27	0.08	0.04	0.22	0.14	0.04	0.04	0.06	0.13	0.04	0.04	0.05
26					0.32	0.04	0.14	0.14	0.58	0.04	0.40	0.15
27	0.14	0.05	0.04	0.12	0.27	0.04	0.04	0.18	0.19	0.04	0.04	0.11
28AA	0.28	0.04	0.12	0.17	0.38	0.04	0.14	0.20	0.31	0.04	0.14	0.13
29					0.40	0.04	0.29	0.08				
30	0.17	0.04	0.05	0.16	0.33	0.04	0.10	0.19	0.27	0.04	0.11	0.12
47	0.25	0.04	0.10	0.16	0.36	0.04	0.19	0.13	0.41	0.04	0.18	0.19
48	0.43	0.04	0.32	0.11	0.47	0.04	0.37	0.07	0.35	0.04	0.24	0.08
50	0.28	0.04	0.07	0.24	0.35	0.04	0.19	0.12	0.49	0.04	0.21	0.24
51	0.32	0.04	0.17	0.15	0.40	0.04	0.25	0.11	0.49	0.04	0.31	0.14
55	0.49	0.04	0.27	0.23	0.53	0.04	0.29	0.20	0.49	0.04	0.33	0.12
56	0.51	0.04	0.34	0.18	0.55	0.04	0.28	0.23	0.52	0.04	0.30	0.18
57	0.80	0.04	0.44	0.38	0.65	0.04	0.34	0.27	0.83	0.04	0.56	0.23
59	0.37	0.04	0.08	0.31	0.47	0.04	0.10	0.33	0.46	0.04	0.13	0.29
63A-1	0.28	0.04	0.32	0.09	0.35	0.04	0.18	0.13	0.37	0.04	0.27	0.06
63X	0.47	0.04	0.24	0.23	0.44	0.05	0.25	0.14	0.48	0.04	0.29	0.15
64	0.44	0.04	0.11	0.34	0.56	0.04	0.19	0.33	0.42	0.04	0.15	0.23
65	4.64	0.04	4.23	0.42	5.18	0.04	4.53	0.61	3.09	0.04	2.43	0.62
67	0.66	0.06	0.37	0.26	0.44	0.04	0.13	0.27	0.62	0.04	0.31	0.27
68A	1.12	0.04	0.84	0.28	1.04	0.04	0.69	0.32	1.08	0.04	0.75	0.29
68B	1.22	0.04	0.88	0.33	1.73	0.05	1.31	0.37	1.02	0.04	0.63	0.35
68C	4.19	0.09	2.24	1.88	8.23	0.19	6.72	1.33	4.00	0.08	3.30	0.62
68H	4.37	0.10	3.85	0.45	6.35	0.10	5.69	0.56	3.40	0.09	2.88	0.43
68I	4.87	0.46	2.43	2.00	5.81	0.04	5.15	0.62	4.37	0.12	3.35	0.90
69A	0.52	0.05	0.38	0.13	0.75	0.04	0.49	0.23	0.67	0.04	0.41	0.22
69C	1.72	0.05	0.79	0.91	2.31	0.15	1.09	1.07	1.73	0.10	0.90	0.72
69D	2.56	0.11	1.62	0.86	2.40	0.10	1.59	0.78	4.06	0.16	2.74	1.15
70	6.17	0.07	5.71	0.41	5.36	0.09	4.58	0.70	4.67	0.06	4.24	0.37
71	8.63	0.04	7.82	0.81	9.09	0.04	7.58	1.47	9.65	0.14	7.11	2.40
72A	8.17	1.00	6.21	0.97	15.54	2.49	9.64	3.40	9.40	0.81	6.32	2.27
73A	8.76	0.13	7.71	0.93	8.91	0.11	7.39	1.41	12.25	0.22	9.60	2.43
74A	4.53	0.18	3.13	1.23	7.71	0.12	5.96	1.63	3.83	0.54	2.04	1.25
74B	9.66	0.05	8.35	1.29	6.05	0.05	4.89	1.11	6.13	0.15	5.31	0.68
75A	0.47	0.04	0.20	0.27	0.82	0.04	0.22	0.57	0.49	0.04	0.22	0.23
75C	3.65	0.09	2.64	0.94	7.92	0.08	6.38	1.46	3.14	0.16	2.19	0.79
75D	4.21	0.04	3.46	0.75	4.12	0.13	3.10	0.89	6.65	0.07	5.18	1.40

Appendix A5. Spring Calapooia River sub-basin dissolved nitrogen means

Site ID	Spring 04 TN (mg L^{-1})	Spring 04 NH4-N (mg L^{-1})	Spring 04 NO3-N (mg L^{-1})	Spring 04 DON (mg L^{-1})	Spring 05 TN (mg L^{-1})	Spring 05 NH4-N (mg L^{-1})	Spring 05 NO3-N (mg L^{-1})	Spring 05 DON (mg L^{-1})	Spring 06 TN (mg L^{-1})	Spring 06 NH4-N (mg L^{-1})	Spring 06 NO3-N (mg L^{-1})	Spring 06 DON (mg L^{-1})
1	0.15	0.04	0.04	0.15	0.12	0.04	0.04	0.04	0.05	0.05	0.04	0.01
2	0.18	0.04	0.04	0.18	0.15	0.04	0.04	0.07	0.05	0.04	0.04	0.02
4	0.13	0.04	0.04	0.13	0.12	0.04	0.04	0.04				
6	0.17	0.04	0.07	0.10	0.26	0.04	0.09	0.13	0.05	0.04	0.05	0.01
12	0.12	0.04	0.04	0.12	0.18	0.04	0.04	0.10	0.06	0.04	0.04	0.02
15	0.13	0.04	0.04	0.13	0.21	0.04	0.04	0.13	0.05	0.04	0.04	0.02
16	0.22	0.04	0.08	0.14	0.26	0.04	0.11	0.11	0.07	0.04	0.06	0.03
18	0.11	0.04	0.04	0.11	0.18	0.04	0.04	0.10	0.05	0.04	0.04	0.01
23	0.08	0.04	0.04	0.08	0.14	0.04	0.04	0.06	0.04	0.04	0.04	0.00
26	0.15	0.04	0.04	0.15	0.45	0.06	0.29	0.10	0.17	0.04	0.18	0.10
27	0.20	0.04	0.04	0.20	0.19	0.04	0.04	0.11	0.05	0.04	0.04	0.01
28AA	0.22	0.04	0.07	0.15	0.32	0.06	0.09	0.16	0.07	0.04	0.06	0.02
29	0.18	0.04	0.10	0.09								
30	0.16	0.04	0.04	0.16	0.32	0.13	0.07	0.12	0.08	0.04	0.05	0.05
47	0.14	0.04	0.06	0.09	0.27	0.05	0.13	0.10	0.09	0.04	0.09	0.03
48	0.33	0.04	0.20	0.13	0.35	0.04	0.24	0.07	0.14	0.04	0.16	0.05
50	0.14	0.04	0.05	0.09	0.25	0.04	0.12	0.09	0.10	0.04	0.10	0.05
51	0.36	0.04	0.12	0.25	0.32	0.04	0.19	0.09	0.13	0.05	0.14	0.04
55	0.22	0.04	0.08	0.14	0.34	0.04	0.17	0.13	0.14	0.04	0.14	0.07
56	0.33	0.04	0.04	0.33	0.37	0.04	0.08	0.25	0.22	0.05	0.06	0.24
57	0.31	0.11	0.08	0.17	0.40	0.04	0.20	0.16	0.27	0.04	0.28	0.14
59	0.34	0.04	0.04	0.34	0.57	0.05	0.06	0.46	0.13	0.04	0.04	0.13
63A-1	0.17	0.04	0.05	0.14	0.30	0.04	0.15	0.11	0.10	0.04	0.08	0.05
63X	0.32	0.04	0.13	0.19	0.38	0.04	0.22	0.12	0.16	0.04	0.17	0.08
64	0.42	0.04	0.11	0.32	0.43	0.05	0.11	0.28	0.16	0.04	0.04	0.17
65	2.58	0.04	2.15	0.44	2.89	0.05	2.72	0.12	2.11	0.04	3.07	0.68
67	0.33	0.04	0.04	0.33	0.38	0.05	0.08	0.25	0.17	0.04	0.07	0.17
68A	0.30	0.04	0.05	0.26	0.72	0.04	0.26	0.42	0.31	0.04	0.22	0.23
68B	0.41	0.04	0.13	0.27	1.04	0.10	0.41	0.52	0.44	0.06	0.38	0.28
68C	2.08	0.24	0.79	1.05	5.45	0.64	3.94	0.87	2.20	0.09	2.64	0.90
68H	1.93	0.05	1.36	0.54	4.67	0.07	4.31	0.29	1.59	0.04	2.09	0.56
68I					3.65	0.50	1.44	1.71	2.69	0.08	5.19	0.10
69A	0.35	0.04	0.13	0.21	0.46	0.04	0.25	0.17	0.23	0.04	0.23	0.13
69C	1.22	0.08	0.37	0.78	1.91	0.16	0.76	1.00	0.72	0.09	0.48	0.56
69D	1.06	0.04	0.12	0.96	2.97	0.62	1.09	1.26	2.15	0.32	1.41	1.58
70	1.51	0.08	0.77	0.69	3.27	0.06	2.73	0.48	2.60	0.08	1.95	2.00
71	4.89	1.45	1.32	2.14	8.34	0.21	6.89	1.25	3.30	0.10	3.45	1.71
72A	2.36	0.71	0.14	1.51	18.51	7.61	9.88	1.02	5.95	0.62	6.39	2.50
73A	3.85	0.22	2.65	1.01	10.78	1.71	6.19	2.88	6.18	0.14	9.08	1.59
74A	3.13	0.37	1.54	1.24	5.09	0.18	3.79	1.12	3.30	0.42	3.43	1.40
74B	3.36	0.16	2.22	0.98	4.77	0.11	3.94	0.72	3.30	0.10	4.15	1.04
75A	0.45	0.06	0.20	0.24	0.41	0.04	0.10	0.27	0.19	0.06	0.06	0.19
75C	1.70	0.06	0.66	1.02	3.31	0.10	2.45	0.76	1.32	0.12	1.27	0.68
75D	1.50	0.08	0.47	0.97	2.76	0.13	1.82	0.82	2.71	0.11	3.71	1.07

Appendix A6. Summer Calapooia River sub-basin dissolved nitrogen means

Site ID	Summer 04 TN (mg L^{-1})	Summer 04 NH4-N (mg L^{-1})	Summer 04 NO3-N (mg L^{-1})	Summer 04 DON (mg L^{-1})	Summer 05 TN (mg L^{-1})	Summer 05 NH4-N (mg L^{-1})	Summer 05 NO3-N (mg L^{-1})	Summer 05 DON (mg L^{-1})	Summer 06 TN (mg L^{-1})	Summer 06 NH4-N (mg L^{-1})	Summer 06 NO3-N (mg L^{-1})	Summer 06 DON (mg L^{-1})
1	0.14	0.04	0.04	0.14	0.15	0.04	0.04	0.07	0.10	0.04	0.04	0.02
2	0.12	0.04	0.04	0.11	0.09	0.04	0.04	0.03	0.09	0.04	0.04	0.01
4	0.18	0.04	0.04	0.16	0.18	0.04	0.05	0.09	0.16	0.08	0.06	0.02
6	0.29	0.04	0.14	0.15	0.25	0.04	0.11	0.11	0.18	0.04	0.14	0.02
12	0.17	0.04	0.07	0.11	0.24	0.04	0.07	0.14	0.12	0.04	0.09	0.01
15	0.12	0.04	0.04	0.12	0.11	0.04	0.04	0.03	0.11	0.04	0.05	0.03
16	0.30	0.04	0.13	0.18	0.26	0.06	0.06	0.14	0.14	0.04	0.12	0.01
18	0.15	0.04	0.04	0.15	0.16	0.04	0.04	0.08	0.45	0.04	0.35	0.06
23	0.13	0.04	0.04	0.13	0.89	0.04	0.04	0.81	0.09	0.04	0.04	0.01
26	0.12	0.04	0.04	0.12	0.23	0.04	0.06	0.13	0.14	0.04	0.09	0.02
27	0.15	0.04	0.05	0.11	0.18	0.04	0.04	0.11	0.14	0.04	0.09	0.02
28AA	0.24	0.04	0.10	0.13	0.18	0.04	0.06	0.08	0.15	0.04	0.09	0.03
29	0.27	0.04	0.14	0.14								
30	0.19	0.04	0.06	0.12	0.25	0.04	0.06	0.15	0.17	0.04	0.08	0.04
47	0.17	0.04	0.09	0.09	0.34	0.04	0.07	0.24	0.16	0.04	0.11	0.02
48	0.26	0.04	0.12	0.14	0.28	0.04	0.07	0.17	0.24	0.08	0.14	0.02
50	0.24	0.04	0.08	0.16	0.17	0.04	0.07	0.06	0.16	0.05	0.09	0.03
51	0.31	0.04	0.11	0.20	0.32	0.04	0.11	0.17	0.24	0.04	0.14	0.06
55	0.26	0.04	0.08	0.18	0.41	0.05	0.09	0.27	0.24	0.04	0.08	0.12
56					0.36	0.04	0.08	0.24	0.59	0.04	0.41	0.14
57					0.27	0.04	0.04	0.19	0.45	0.04	0.25	0.17
59					0.36	0.04	0.04	0.28	0.33	0.04	0.04	0.25
63A-1	0.21	0.04	0.05	0.17	0.35	0.04	0.07	0.24	0.17	0.04	0.05	0.08
63X	0.26	0.04	0.06	0.20	0.32	0.04	0.08	0.20	0.26	0.04	0.10	0.12
64												
65												
67					0.38	0.04	0.04	0.30	0.28	0.08	0.04	0.16
68A	0.59	0.05	0.04	0.57	0.49	0.04	0.04	0.41	0.36	0.04	0.04	0.28
68B	5.58	0.26	3.72	1.61	2.49	0.37	1.39	0.73	0.45	0.05	0.04	0.36
68C					1.41	0.04	0.04	1.33	1.52	0.14	0.10	1.29
68H					0.85	0.04	0.12	0.69				
68I												
69A	0.25	0.04	0.06	0.19	0.36	0.04	0.10	0.22	0.18	0.04	0.07	0.07
69C	1.27	0.22	0.04	1.04	0.82	0.04	0.08	0.70	0.93	0.13	0.11	0.70
69D	2.65	0.19	0.04	2.42	1.28	0.09	0.04	1.15	1.59	0.13	0.04	1.42
70												
71												
72A					3.84	0.95	0.10	2.78				
73A					3.31	0.20	2.19	0.92				
74A					7.48	5.50	0.12	1.86				
74B												
75A					0.42	0.04	0.04	0.34	0.38	0.04	0.04	0.30
75C					1.79	0.30	0.04	1.44	0.62	0.04	0.04	0.54
75D	1.34	0.18	0.21	0.97	1.24	0.05	0.04	1.15	1.24	0.14	0.04	1.06

Appendix B1. Calapooia River mainstem sample point information

Site ID	Easting (m)	Northing (m) UTM 10, NAD 83	Elevation (m)	Site Location	Kilometers from Upper Boundary
MS2	549324	4898127	662.9	Upper	6
MS3	548165	4898021	570.2	Upper	8
MS4	546883	4897982	547.1	Upper	9
MS5	544357	4897538	537.5	Upper	12
MS6	540413	4898802	425.5	Upper	17
MS8	538716	4899866	409.6	Upper	19
MS9	535498	4901140	360.1	Upper	24
MS10	533871	4901659	364	Upper	26
MS11	532616	4902291	284	Upper	28
MS12	531190	4903258	283.5	Upper	30
MS13	527781	4904577	260.2	Upper	35
MS14	523277	4906241	234.4	Upper	41
MS15	521398	4907411	177.5	Upper	44
MS16	519594	4908805	172.4	Middle	46
MS17	517205	4910615	178	Middle	50
MS19	512455	4911972	137.8	Middle	56
MS20	511205	4911414	144.3	Middle	58
MS23	505571	4914791	118.1	Middle	66
MS24	501332	4915114	109.7	Middle	71
MS26	494977	4918915	85.4	Lower	82
MS27	493633	4922746	83	Lower	89
MS28	493651	4925680	74.1	Lower	95
MS29	491470	4927686	0	Lower	99
MS30	488653	4930867	54.4	Lower	107
MS31	488235	4934509	61.4	Lower	113
MS32	489897	4940540	54.9	Lower	125
MS33	491192	4942643	64.5	Lower	130

Appendix B2. Fall Calapooia River mean dissolved nitrogen concentrations

Site ID	Fall 2003 Total Nitrogen (mg L^{-1})	Fall 2003 NH4-N (mg L^{-1})	Fall 2003 NO3-N (mg L^{-1})	Fall 2003 Dissolved Organic Nitrogen (mg L^{-1})	Fall 2004 Total Nitrogen (mg L^{-1})	Fall 2004 NH4-N (mg L^{-1})	Fall 2004 NO3-N (mg L^{-1})	Fall 2004 Dissolved Organic Nitrogen (mg L^{-1})	Fall 2005 Total Nitrogen (mg L^{-1})	Fall 2005 NO3-N (mg L^{-1})	Fall 2005 NH4-N (mg L^{-1})	Fall 2005 Dissolved Organic Nitrogen (mg L^{-1})
MS2	0.11	0.10	0.10	0.05	0.13	0.04	0.04	0.04	0.29	0.04	0.06	0.20
MS3	0.16	0.10	0.11	0.08	0.15	0.04	0.65	0.07	0.31	0.04	0.04	0.23
MS4	0.08	0.10	0.10	0.00	0.10	0.04	0.04	0.02	0.23	0.05	0.05	0.13
MS5	0.09	0.10	0.10	0.01	0.25	0.04	0.04	0.13	0.20	0.07	0.04	0.09
MS6	0.18	0.10	0.12	0.10	0.22	0.04	0.04	0.09	0.24	0.08	0.04	0.11
MS8	0.21	0.10	0.10	0.12	0.25	0.04	0.06	0.10	0.19	0.09	0.04	0.06
MS9	0.17	0.10	0.10	0.08	0.34	0.04	0.18	0.20	0.19	0.08	0.04	0.07
MS10	0.16	0.10	0.05	0.07	0.22	0.04	0.09	0.09	0.20	0.08	0.04	0.09
MS11	0.21	0.10	0.06	0.12	0.21	0.04	0.10	0.08	0.29	0.09	0.04	0.15
MS12	0.17	0.10	0.08	0.08	0.22	0.04	0.11	0.08	0.22	0.09	0.04	0.09
MS13	0.17	0.10	0.08	0.07	0.23	0.04	0.10	0.10	0.23	0.10	0.04	0.09
MS14	0.17	0.10	0.07	0.07	0.25	0.04	0.07	0.11	0.23	0.11	0.04	0.08
MS15	0.25	0.10	0.06	0.15	0.29	0.04	0.10	0.14	0.22	0.11	0.04	0.08
MS16	0.22	0.10	0.10	0.11	0.33	0.04	0.11	0.17	1.28	0.11	0.04	1.13
MS17	0.25	0.10	0.10	0.10	0.34	0.04	0.08	0.17	0.37	0.13	0.05	0.19
MS19	0.15	0.05	0.08	0.05	0.29	0.04	0.07	0.13	0.29	0.16	0.04	0.09
MS20	0.32	0.13	0.10	0.14	0.29	0.04	0.04	0.13	0.29	0.17	0.04	0.20
MS23	0.15	0.10	0.08	0.07					0.41	0.19	0.04	0.17
MS24	0.35	0.10	0.11	0.13	0.35	0.04	0.05	0.13				
MS26	0.39	0.10	0.18	0.15	0.38	0.04	0.04	0.16	0.86	0.22	0.04	0.59
MS27	2.65	0.06	1.21	0.27	1.61	0.04	1.22	0.53	3.99	3.56	0.05	0.38
MS28	1.40	0.10	0.56	0.14	0.74	0.04	1.17	0.24	1.09	0.76	0.04	0.30
MS29	1.09	0.10	0.61	0.10	0.75	0.04	0.04	0.24	1.51	1.17	0.04	0.30
MS30	1.04	0.10	0.63	0.14	0.79	0.04	0.66	0.24	1.64	1.31	0.05	0.28
MS31	1.22	0.10	0.72	0.11	0.80	0.04	0.52	0.28	1.96	1.32	0.05	0.59
MS32	1.24	0.10	1.01	0.24	0.88	0.04	0.25	0.30	3.75	3.02	0.06	0.67
MS33	1.16	0.10	0.75	0.16	0.86	0.04	0.04	0.28	0.90	0.72	0.04	0.14

Appendix B3. Winter Calapooia River mean dissolved nitrogen concentrations

Site ID	Winter 2003 Total Nitrogen (mg L^{-1})	Winter 2003 NH4-N (mg L^{-1})	Winter 2003 NO3-N (mg L^{-1})	Winter 2003 Dissolved Organic Nitrogen (mg L^{-1})	Winter 2004 Total Nitrogen (mg L^{-1})	Winter 2004 NH4-N (mg L^{-1})	Winter 2004 NO3-N (mg L^{-1})	Winter 2004 Dissolved Organic Nitrogen (mg L^{-1})	Winter 2005 Total Nitrogen (mg L^{-1})	Winter 2005 NH4-N (mg L^{-1})	Winter 2005 NO3-N (mg L^{-1})	Winter 2005 Dissolved Organic Nitrogen (mg L^{-1})
MS2	0.15	0.04	0.04	0.07	0.13	0.09	0.11	0.02	0.12	0.04	0.04	0.04
MS3	0.19	0.04	0.04	0.11	0.13	0.05	0.06	0.04	0.16	0.04	0.04	0.08
MS4	0.10	0.04	0.04	0.02	0.14	0.04	0.06	0.04	0.12	0.04	0.04	0.04
MS5	0.14	0.04	0.04	0.05	0.22	0.07	0.08	0.07	0.16	0.04	0.06	0.06
MS6	0.13	0.04	0.05	0.04	0.25	0.05	0.10	0.10	0.19	0.04	0.07	0.08
MS8	0.14	0.04	0.06	0.04	0.20	0.05	0.09	0.05	0.20	0.04	0.08	0.09
MS9	0.17	0.04	0.06	0.04	0.24	0.04	0.24	0.10	0.16	0.04	0.07	0.05
MS10	0.15	0.04	0.06	0.05	0.22	0.06	0.12	0.05	0.20	0.05	0.08	0.08
MS11	0.16	0.04	0.05	0.06	0.21	0.04	0.08	0.08	0.20	0.04	0.08	0.09
MS12	0.19	0.04	0.05	0.09	0.21	0.04	0.07	0.08	0.20	0.04	0.08	0.07
MS13	0.16	0.04	0.04	0.05	0.25	0.07	0.07	0.07	0.23	0.04	0.09	0.10
MS14	0.18	0.04	0.04	0.07	0.37	0.05	0.08	0.22	0.24	0.04	0.11	0.10
MS15	0.23	0.04	0.04	0.12	0.28	0.04	0.05	0.14	0.28	0.04	0.11	0.12
MS16	0.21	0.04	0.04	0.09	0.24	0.04	0.04	0.09	0.29	0.04	0.11	0.14
MS17	0.23	0.04	0.05	0.09	0.32	0.11	0.04	0.08	0.26	0.04	0.13	0.10
MS19	0.24	0.04	0.07	0.16	0.34	0.04	0.04	0.16	0.27	0.04	0.14	0.10
MS20	0.24	0.04	0.15	0.09	0.32	0.04	0.04	0.12	0.12	0.04	0.13	0.14
MS23									0.50	0.04	0.29	0.17
MS24	0.35	0.04	0.22	0.12	0.40	0.04	0.15	0.15	0.49	0.04	0.28	0.16
MS26	0.40	0.04	0.20	0.10	0.40	0.07	2.10	0.11	0.50	0.04	0.29	0.16
MS27	1.36	0.04	0.62	0.41	1.67	0.15	0.28	0.48	1.58	0.05	1.05	0.48
MS28	0.75	0.05	0.53	0.22	0.87	0.04	0.36	0.28	0.82	0.04	0.55	0.23
MS29	0.84	0.05	0.50	0.22	0.97	0.05	0.04	0.36	1.14	0.04	0.68	0.42
MS30	0.94	0.04	0.43	0.20	1.21	0.05	0.06	0.40	1.36	0.05	0.87	0.44
MS31	0.93	0.04	0.24	0.18	1.14	0.05	0.05	0.35	1.45	0.05	0.95	0.45
MS32	1.12	0.04	0.16	0.22	1.36	0.08	0.11	0.45	1.69	0.05	1.26	0.39
MS33	1.15	0.04	0.06	0.25	1.27	0.07	0.04	0.36	1.96	0.04	1.31	0.61

Appendix B4. Spring Calapooia River mean dissolved nitrogen concentrations

Site ID	Spring 2003 Total Nitrogen (mg L^{-1})	Spring 2003 NH4-N (mg L^{-1})	Spring 2003 NO3-N (mg L^{-1})	Spring 2003 Dissolved Organic Nitrogen (mg L^{-1})	Spring 2004 Total Nitrogen (mg L^{-1})	Spring 2004 NH4-N (mg L^{-1})	Spring 2004 NO3-N (mg L^{-1})	Spring 2004 Dissolved Organic Nitrogen (mg L^{-1})	Spting 2005 Total Nitrogen (mg L^{-1})	Spring 2005 NO3-N (mg L^{-1})	Spring 2005 NH4-N (mg L^{-1})	Spring 2005 Dissolved Organic Nitrogen (mg L^{-1})
MS2	0.19	0.04	0.04	0.10	0.18	0.04	0.11	0.10	0.14	0.04	0.04	0.06
MS3	0.11	0.04	0.04	0.03	0.10	0.04	0.25	0.02	0.11	0.04	0.04	0.03
MS4	0.15	0.04	0.04	0.07	0.12	0.04	0.08	0.04	0.11	0.04	0.04	0.03
MS5	0.23	0.04	0.06	0.15	0.14	0.04	0.09	0.06	0.13	0.04	0.04	0.05
MS6	0.13	0.04	0.05	0.05	0.17	0.04	0.09	0.08	0.12	0.04	0.04	0.04
MS8	0.17	0.04	0.05	0.09	0.18	0.04	0.07	0.09	0.12	0.04	0.04	0.04
MS9	0.14	0.04	0.07	0.06	0.17	0.04	0.13	0.08	0.13	0.04	0.04	0.05
MS10	0.12	0.04	0.04	0.04	0.17	0.04	0.05	0.08	0.10	0.04	0.04	0.02
MS11	0.18	0.04	0.04	0.10	0.19	0.04	0.04	0.10	0.10	0.04	0.04	0.02
MS12	0.14	0.04	0.04	0.06	0.18	0.04	0.06	0.06	0.10	0.04	0.04	0.02
MS13	0.13	0.06	0.04	0.03	0.19	0.04	0.04	0.10	0.13	0.04	0.04	0.05
MS14	0.23	0.04	0.06	0.15	0.30	0.14	0.04	0.11	0.15	0.04	0.04	0.07
MS15	0.14	0.04	0.07	0.06	0.19	0.04	0.06	0.10	0.08	0.04	0.04	0.00
MS16	0.11	0.04	0.12	0.03	0.22	0.05	0.13	0.12	0.09	0.04	0.04	0.01
MS17	0.10	0.04	0.16	0.02	0.24	0.04	0.04	0.14	0.10	0.04	0.04	0.02
MS19	0.13	0.04	0.17	0.05	0.22	0.05	0.04	0.12	0.13	0.04	0.04	0.05
MS20	0.22	0.04	0.11	0.14	0.21	0.04	0.04	0.10	0.14	0.04	0.04	0.07
MS23	0.16	0.16	0.16	0.08	0.19	0.04	0.04	0.08	0.20	0.51	0.04	0.10
MS24	0.21	0.04	0.20	0.11	0.28	0.04	0.26	0.13	0.24	0.09	0.04	0.11
MS26	0.30	0.04	0.20	0.19	0.34	0.05	0.05	0.16	0.26	0.12	0.04	0.11
MS27	0.48	0.05	1.22	0.38	1.23	0.13	0.16	0.76	1.11	0.68	0.07	0.35
MS28	0.29	0.04	0.29	0.17	0.64	0.06	0.04	0.23	0.27	0.13	0.04	0.09
MS29	0.25	0.04	0.16	0.13	0.61	0.06	0.04	0.18	0.38	0.24	0.04	0.10
MS30	0.27	0.04	0.04	0.15	0.72	0.06	0.37	0.23	0.43	0.25	0.04	0.15
MS31	0.30	0.04	0.05	0.17	0.76	0.08	0.75	0.25	0.46	0.29	0.04	0.12
MS32	0.25	0.04	0.95	0.13	0.98	0.08	0.82	0.33	0.52	0.35	0.04	0.13
MS33	0.34	0.04	0.04	0.22	0.95	0.10	0.07	0.26	0.52	0.31	0.04	0.16

Appendix B5. Summer Calapooia River mean dissolved nitrogen concentrations

Site ID	Summer 2003 Total Nitrogen (mg L^{-1})	Summer 2003 NH4-N (mg L^{-1})	Summer 2003 NO3-N (mg L^{-1})	Summer 2003 Dissolved Organic Nitrogen (mg L^{-1})	Summer 2004 Total Nitrogen (mg L^{-1})	Summer 2004 NH4-N (mg L^{-1})	Summer 2004 NO3-N (mg L^{-1})	Summer 2004 Dissolved Organic Nitrogen (mg L^{-1})	Summer 2005 Total Nitrogen (mg L^{-1})	Summer 2005 NO3-N (mg L^{-1})	Summer 2005 NH4-N (mg L^{-1})	Summer 2005 Dissolved Organic Nitrogen (mg L^{-1})
MS2	0.16	0.04	0.04	0.13	0.16	0.04	0.04	0.08	0.09	0.05	0.04	0.00
MS3	0.15	0.04	0.04	0.07					0.34	0.05	0.04	0.25
MS4	0.16	0.04	0.04	0.08	0.14	0.04	0.07	0.06	0.08	0.05	0.04	0.00
MS5	0.14	0.04	0.04	0.06	0.17	0.04	0.05	0.09	0.09	0.05	0.04	0.00
MS6	0.14	0.04	0.04	0.06	0.18	0.04	0.04	0.09	0.09	0.05	0.04	0.00
MS8	0.11	0.04	0.04	0.03	0.17	0.04	0.04	0.08	0.15	0.05	0.04	0.06
MS9	0.16	0.04	0.04	0.08	0.22	0.04	0.04	0.14	3.92	0.04	0.04	3.84
MS10	0.15	0.04	0.04	0.07	0.14	0.04	0.04	0.06	1.21	0.05	0.04	1.12
MS11	0.17	0.04	0.06	0.09	0.17	0.04	0.04	0.08	1.11	0.04	0.04	1.03
MS12	0.18	0.04	0.07	0.10	0.21	0.04	0.06	0.13	0.62	0.04	0.04	0.54
MS13	0.19	0.04	0.09	0.11	0.22	0.04	0.10	0.14	0.53	0.04	0.04	0.45
MS14	0.16	0.04	0.11	0.08	0.20	0.05	0.10	0.11	0.30	0.04	0.04	0.21
MS15	0.15	0.04	0.12	0.07	0.22	0.05	0.09	0.13	0.22	0.04	0.04	0.14
MS16	0.17	0.04	0.10	0.09	0.28	0.05	0.08	0.18	0.11	0.04	0.04	0.02
MS17	0.16	0.04	0.12	0.08	0.37	0.05	0.04	0.23	0.11	0.04	0.04	0.03
MS19	0.21	0.04	0.13	0.13	0.24	0.05	0.04	0.15	0.11	0.05	0.04	0.01
MS20	0.19	0.04	0.14	0.11	0.23	0.04	0.08	0.15	0.12	0.04	0.05	0.02
MS23	0.24	0.04	0.04	0.16					0.15	0.04	0.04	0.06
MS24	0.21	0.04	0.07	0.13	0.34	0.04	0.08	0.24	0.22	0.07	0.04	0.11
MS26	0.21	0.04	0.09	0.12	0.33	0.04	0.37	0.22	0.20	0.07	0.04	0.09
MS27	0.24	0.04	0.04	0.16	0.38	0.04	0.44	0.33	0.18	0.04	0.04	0.10
MS28	0.20	0.04	0.04	0.11	0.27	0.04	0.48	0.19	0.17	0.05	0.04	0.07
MS29	0.22	0.04	0.04	0.12	0.31	0.04	0.04	0.22	0.20	0.07	0.04	0.09
MS30	0.25	0.04	1.35	0.17	0.31	0.04	0.79	0.22	0.15	0.06	0.04	0.05
MS31	0.20	0.04	1.58	0.12	0.35	0.04	0.48	0.26	0.38	0.04	0.04	0.30
MS32	0.31	0.04	0.96	0.23	0.37	0.04	0.73	0.29	1.33	1.22	0.04	0.07
MS33	0.21	0.04	0.04	0.13	0.28	0.04	0.04	0.20	1.04	0.92	0.04	0.08

Appendix C1. Nitrogen Mineralization Site Locations, Particle Size Analysis, Total and Labile[1] Nitrogen and Carbon

Site ID	Easting (UTM 10, NAD 83)	Northing	Approx River km	Willamette Silt Zone	%Sand	%Silt	%Clay	Total C ($g\ kg^{-1}$)	Total N ($g\ kg^{-1}$)	Labile N ($g\ kg^{-1}$)	Labile C ($g\ kg^{-1}$)
1	491087	4942562	129.6	Yes	66.5	21.3	12.1	11.5	0.7	0.007	0.068
2	488125	4934639	112.5	Yes	50.7	31.5	17.8	26.5	1.9	0.014	0.154
3	488643	4931016	106.5	Yes	24.6	53.6	21.8	29.5	2.1	0.016	0.128
4	492511	4926855	96.7	Yes	18.9	63.9	17.2	35.1	2.1	0.017	0.152
5	493484	4925944	95.03	Yes	32.8	51.2	16.0	25.4	1.7	0.016	0.070
6	493153	4924170	86.49	Yes	6.4	62.7	30.9	34.0	2.7	0.021	0.135
7	494325	4920303	84.59	Yes	18.5	59.4	22.1	35.7	3.1	0.026	0.157
8	494617	4919609	83.4	Yes	20.7	64.3	14.9	37.7	2.6	0.039	0.136
10	500733	4915412	71.95	Yes	60.5	29.8	9.7	27.0	1.2	0.010	0.112
11	504694	4914609	66.74	Yes	56.2	30.3	13.5	28.3	1.4	0.013	0.133
12	504685	4914624	66.71	Yes	19.5	53.2	27.3	17.3	1.2	0.008	0.094
13	504836	4914635	66.65	Yes	28.8	47.3	23.9	31.2	2.2	0.015	0.152
14	507081	4913418	66.7	No	40.9	45.9	13.2	39.1	1.8	0.011	0.112
15	509660	4911877	59.7	No	8.3	84.8	6.9	7.5	0.3	0.005	0.048
16	509811	4911811	59.49	No	34.9	42.1	23.0	45.5	2.4	0.002	0.112
17	509877	4911664	59.34	No	40.7	38.4	20.9	33.9	1.9	0.016	0.143
18	519571	4908925	46.1	No	28.4	41.9	29.7	44.9	2.8	0.025	0.214
19	523288	4906363	40.79	No	36.4	43.5	20.1	31.8	1.6	0.017	0.240
20	523705	4906283	40.33	No	60.0	32.9	7.1	23.0	0.9	0.010	0.111
22	531241	4903212	29.99	No	45.4	42.9	11.7	43.2	1.8	0.015	0.308
23	535542	4901053	24	No	54.4	38.4	7.3	101.0	4.3	0.034	0.350
24	540232	4899129	17.1	No	40.2	49.5	10.2	167.9	5.9	0.037	0.348
25	541100	4898806	16.2	No	64.4	28.4	7.2	91.9	3.5	0.024	0.236
25.5	540171	4899120	17.05	No	55.5	35.1	9.4	50.4	2.8	0.019	0.157
26	541342	4898638	15.8	No	35.2	46.8	18.0	35.4	1.9	0.014	0.304
27	543969	4897832	13	No	47.7	43.7	8.6	77.5	3.2	0.019	0.162
28	547146	4898339	9.14	No	55.4	35.0	9.6	106.0	4.6	0.053	0.503
29	548103	4898226	8	No	55.5	27.9	16.6	88.1	2.8	0.021	0.465
30	550521	4898335	5	No	54.5	31.0	14.6	66.6	2.0	0.027	0.263
31	550521	4898335	4.79	No	49.8	36.1	14.1	90.5	2.4	0.030	0.596
32	550521	4898335	4.8	No	69.4	21.9	8.7	135.7	5.2	0.032	0.262
33	550521	4898335	4.81	No	37.1	39.7	23.1	57.5	1.6	0.025	0.224

Appendix C2. Soil Characterization

Site ID	K (ug g^{-1})	P (ug g^{-1})	Mg (ug g^{-1})	Mn (ug g^{-1})	Fe (ug g^{-1})	Ca ((ug g^{-1})	Cu (ug g^{-1})	pH	Total Bulk Density (g (cm^3)$^{-1}$)	Soil Fraction Bulk Density (g (cm^3)$^{-1}$)	Forest Floor (g (0.25m^2)$^{-1}$)
1	674	617	4114	596	24100	4381	19.4	6.27	1.01	0.99	102.59
2	1318	966	5794	823	34220	5665	29.1	5.7	1.13	1.11	348.65
3	1427	840	7247	1023	40950	7432	50.7	5.96	0.76	0.76	69.69
4	902	989	8238	1120	42430	9189	46.8	6.38	0.76	0.75	306.01
5	953	838	7530	939	39320	7731	50.2	6.06	0.90	0.90	83.12
6	1052	1260	6984	1280	42630	6906	47.5	5.77	0.58	0.57	27.04
7	1118	1163	7591	1043	41370	7311	48.3	5.2	0.86	0.84	355.48
8	1117	1023	7799	1079	42460	8207	52.3	5.63	0.66	0.63	47.37
10	1126	802	8739	876	40310	9101	42.0	6.59	0.61	0.59	138.21
11	855	844	8262	914	39650	8320	42.1	6.23	0.66	0.65	119.28
12	864	894	9106	1204	47060	7787	49.5	6.56	0.69	0.68	55.65
13	1015	990	7878	1031	41060	7339	46.7	5.98	0.89	0.83	7.38
14	1035	855	9037	1029	42560	8983	50.1	6.06	0.71	0.69	51.44
15	961	844	9289	798	40160	8994	38.0	6.53	0.83	0.82	25.06
16	1189	1209	4633	769	28720	4105	37.4	6.13	0.83	0.49	253.36
17	994	773	5129	821	28190	4815	39.5	6.06	0.79	0.78	334.79
18	976	1153	3463	727	43860	3461	35.3	5.74	0.90	0.63	104.65
19	750	497	8096	1098	44520	4346	41.3	5.66	0.75	0.71	235.89
20	1146	809	10840	1049	43660	9306	63.8	5.84	0.71	0.71	108.62
22	653	554	9413	915	44950	1905	45.2	5.2	0.55	0.51	122.93
23	542	1540	5664	1227	35220	3157	41.0	5.11	0.33	0.24	218.35
24	684	1077	5667	751	33480	4988	36.3	4.68	0.41	0.24	171.22
25	647	1280	4232	578	34550	1875	31.3	5.16	0.45	0.35	259.71
25.5	1020	1232	8141	989	38870	4987	35.7	5.58	0.70	0.55	185.70
26	1106	963	8733	1091	42420	2279	35.9	5.11	0.57	0.56	74.24
27	870	871	8289	901	29970	5785	31.4	5.38	0.39	0.34	765.92
28	932	1484	6284	1186	29030	3413	26.4	4.64	0.33	0.23	623.48
29	1541	535	4045	438	25690	1252	23.0	4.47	0.15	0.11	615.72
30	1173	939	5108	1123	31300	3101	17.4	5.39	1.20	0.10	375.93
31	531	736	2743	764	26370	1794	22.5	4.23	0.52	0.33	414.85
32	1329	857	7956	1094	31910	4440	25.5	4.56	0.24	0.14	356.41
33	1101	991	6674	891	48800	682	46.4	4.69	0.55	0.39	431.83

Appendix C3. Vegetation Characterization

Site ID	Hardwood Basal Area (m^2 ha^{-1})	Conifer Basal Area (m^2 ha^{-1})	Total Basal Area (m^2 ha^{-1})	Woody Shrub Stem Count (stems/0.25m^2)	Sapling Count (stems/0.25m^2)	Grass (%cover)	Fern (%cover)	Forb (%cover)	*Rubus discolor* (%cover)	Total Understory Cover (%cover)
1	18.3	0.0	18.3	0	0	5	0	1	100	106
2	27.5	0.0	27.5	0	3	5	5	5	50	65
3	36.7	0.0	36.7	2	0	10	0	20	1	31
4	45.9	0.0	45.9	3	0	100	0	60	0	160
5	22.9	0.0	22.9	0	2	1	0	10	20	31
6	18.3	0.0	18.3	3	0	20	0	1	5	26
7	18.3	0.0	18.3	0	0	0	0	1	5	6
8	2.3	0.0	2.3	0	0	85	0	10	0	95
10	18.3	0.0	18.3	60	0	5	0	0	10	15
11	22.9	0.0	22.9	0	0	0	0	1	100	101
12	2.3	0.0	2.3	10	0	30	0	1	0	31
13	13.8	0.0	13.8	0	0	100	0	0	0	100
14	0.0	0.0	0.0	0	0	100	0	1	20	121
15	2.3	9.2	11.5	0	5	1	0	1	50	52
16	0.0	36.7	36.7	30	0	5	5	5	100	115
17	27.5	18.4	45.9	0	0	0	0	0	1	1
18	9.2	0.0	9.2	10		0	0	100	0	100
19	9.2	32.1	41.3	32	0	1	1	10	10	22
20	32.1	4.6	36.7	17	0	0	1	20	0	21
22	0.0	27.5	27.5	14	0	0	45	10	0	55
23	0.0	36.7	36.7	9	0	0	10	1	0	11
24	4.6	0.0	4.6	0	0	95	1	1	0	97
25	4.6	13.8	18.4	60	0	0	20	1	0	21
25.5	0.0	4.6	4.6	0	1	30	70	15	0	115
26	0.0	13.8	13.8	12	1	80	0	10	0	90
27	45.9	18.4	64.2	15	1	0	15	50	0	65
28	22.9	18.4	41.3	5	3	0	1	1	0	2
29	0.0	36.7	36.7	14	6	0	1	1	0	2
30	9.2	64.3	73.4	2	7	0	25	1	0	26
31	4.6	13.8	18.4	2	7	0	10	1	0	11
32	9.2	45.9	55.1	0	7	0	50	10	0	60
33	0.0	55.1	55.1	17	5	0	5	30	0	35

Appendix C4. N Mineralization per Kg of Soil per Incubation with Annual Estimate

Site ID	Inc. 1 (kg N kg soil^{-1} d^{-1}) (29 days)	Inc. 2 (kg N kg soil^{-1} d^{-1}) (28 days)	Inc. 3 (kg N kg soil^{-1} d^{-1}) (21 days)	Inc. 4 (kg N kg soil^{-1} d^{-1}) (20 days)	Inc. 5 (kg N kg soil^{-1} d^{-1}) (29 days)	Inc. 6 (kg N kg soil^{-1} d^{-1}) (35 days)	Inc. 7 (kg N kg soil^{-1} d^{-1}) (28 days)	Inc. 8 (kg N kg soil^{-1} d^{-1}) (34 days)	Inc. 9 (kg N kg soil^{-1} d^{-1}) (28 days)	Inc. 10 (kg N kg soil^{-1} d^{-1}) (35 days)	Inc. 11(kg N kg soil^{-1} d^{-1}) (35 days)	Inc. 12 (kg N kg soil^{-1} d^{-1}) (35 days)	Annual N Mineralization (kg N kg soil^{-1} yr^{-1})
1			0.05	0.14		0.49	0.10		1.86	-0.07	0.06	0.38	
2	0.03	-0.01	0.23	0.20	0.32	0.30	-0.02	-0.04	-0.01	0.01	0.15	0.09	35.75
3	-0.05	-0.14	0.45	0.38	0.44	0.26	0.26	0.19	0.27	0.39	0.11	-0.11	69.83
4	-0.02	0.25	0.72	0.43	0.14	1.19	0.74	-0.09	1.37	1.45	1.53	-0.97	207.06
5	0.12	-0.10	-0.09	0.26	0.31	0.61	0.09	0.19	0.38	-0.07	-0.29	-0.46	26.11
6	-0.21	-0.32	-0.01	0.19	-1.49	-0.14	1.69	0.68	1.63	0.67	-0.28	-1.05	34.31
7			0.46		0.65	0.87	0.49	0.74	-0.11	0.47	0.62	0.41	
8				-0.11	2.98		2.63	0.19	0.68	0.10	0.10	1.08	
10	0.19	-0.10	-0.02	0.12	0.13	0.47	-0.15	0.09	0.63	0.15	-0.03	0.05	48.62
11	-0.01	0.03	-0.03	0.16	0.67	0.98	0.25	0.21	-0.15	0.21	0.39	-0.03	89.05
12	0.22	-0.07	-0.19	-0.15	-0.11	0.12	-0.01	0.36	-0.17	0.07	0.02	0.14	14.02
13	0.04	-0.02	0.24	0.19	0.30	0.39	0.12	0.04	0.13	0.40	0.35	0.15	73.29
14	0.28		0.03	0.00	0.11	0.94	0.26						
15	-0.01	-0.25	-0.04	0.18	-0.02	0.20	0.09	0.00	0.08	0.03	0.05	0.17	15.97
16	-0.83	0.09	0.08	0.44	0.34	0.46	0.30	0.06	0.30	0.13	0.36	-0.06	49.54
17	0.12	0.04	0.02	0.01	0.38	0.30	0.34	0.18	0.30	0.97	0.14	-0.05	90.02
18	-0.19	0.00	0.32	0.51	0.02	0.18	0.16	0.20	0.24	0.28	0.07	0.13	53.65
19	-0.04	0.06	-0.20	0.34	0.06	0.19	0.03	0.14	0.00	0.14	-0.02	0.30	32.11
20	-0.13	-0.01	0.12	0.25	0.36	0.35	2.08	0.14	0.08	0.19	0.76	0.00	127.33
22	-0.07	0.01	0.13	0.43	0.02	0.19	0.22	-0.11	0.11	0.35	0.08	0.19	44.65
23	0.02	0.25	0.18	-0.04	-0.25	0.15	2.09	1.75	2.05	0.38	-0.04	0.00	200.19
24	-0.38	0.60	0.54	0.97	0.56	1.11	0.35	0.26	0.43	0.09	0.48	0.22	153.12
25	0.00	-0.16	0.31	-0.26	-0.20	0.11	0.00	-0.05	-0.03	0.07	-0.10	0.07	-5.97
25.5	0.06	-0.32	0.23	0.05	0.20	0.20	0.50	0.63	-0.01	0.29	-0.14	-0.01	52.25
26	0.02	-0.08	-0.11	-0.14	-0.19	0.10	-0.08	-0.28	0.05	0.10	-0.03	0.03	-15.92
27	0.34	0.10	0.39	0.36	0.56	0.01	0.02	-0.14	0.75	0.26	0.08	-0.10	71.35
28	0.57	0.89	0.17	0.40	0.22	0.54	1.03	1.53	0.56	0.46	-0.16	0.17	195.25
29	0.12	-0.12	0.33	-0.54	-0.28	0.05	0.23	0.62	1.99	-0.37	0.00	0.12	66.00
30	-0.10	0.02	-0.32	-0.08	-0.06	-0.02	-0.04	0.00	1.73	0.04	0.31	-0.37	34.15
31	-0.18	-0.09	0.05	0.13	-0.33	0.16	-0.07	-0.03	-0.06	-0.09	-0.05	0.05	-16.22
32	0.42	-0.13	0.74	-0.01	0.28	0.66	1.01	1.51	11.98	-0.10			
33	0.06	-0.18	0.05	0.04	-0.01	0.07	-0.06	-0.01	-0.06	-0.04	-0.08	0.04	-6.05

Appendix C5. N Mineralization per Hectare per Incubation with Annual Estimate

Site ID	Inc. 1 (kg N ha^{-1} d^{-1}) (29 days)	Inc. 2 (kg N ha^{-1} d^{-1}) (28 days)	Inc. 3 (kg N ha^{-1} d^{-1}) (21 days)	Inc. 4 (kg N ha^{-1} d^{-1}) (20 days)	Inc. 5 (kg N ha^{-1} d^{-1}) (29 days)	Inc. 6 (kg N ha^{-1} d^{-1}) (35 days)	Inc. 7 (kg N ha^{-1} d^{-1}) (28 days)	Inc. 8 (kg N ha^{-1} d^{-1}) (34 days)	Inc. 9 (kg N ha^{-1} d^{-1}) (28 days)	Inc. 10 (kg N ha^{-1} d^{-1}) (35 days)	Inc. 11(kg N ha^{-1} d^{-1}) (35 days)	Inc. 12 (kg N ha^{-1} d^{-1}) (35 days)	Annual N Mineralization (kg N ha^{-1} yr^{-1})
1			0.08	0.21		0.72	0.15		2.77	-0.10	0.09	0.56	
2	0.04	-0.01	0.38	0.33	0.52	0.49	-0.04	-0.07	-0.02	0.02	0.24	0.14	59.3
3	-0.06	-0.16	0.51	0.43	0.50	0.30	0.30	0.22	0.31	0.44	0.12	-0.13	79.4
4	-0.02	0.28	0.81	0.49	0.16	1.35	0.83	-0.11	1.55	1.64	1.73	-1.10	234.0
5	0.16	-0.13	-0.13	0.35	0.42	0.82	0.13	0.26	0.52	-0.10	-0.39	-0.62	35.2
6	-0.18	-0.27	-0.01	0.16	-1.28	-0.12	1.45	0.58	1.40	0.58	-0.24	-0.90	29.4
7			0.59		0.83	1.10	0.62	0.93	-0.13	0.59	0.79	0.51	
8				-0.10	2.83		2.50	0.18	0.65	0.09	0.09	1.02	
10	0.17	-0.09	-0.02	0.11	0.12	0.42	-0.13	0.08	0.56	0.13	-0.03	0.04	43.4
11	-0.01	0.03	-0.03	0.16	0.66	0.96	0.24	0.20	-0.15	0.20	0.38	-0.03	86.9
12	0.22	-0.07	-0.20	-0.15	-0.11	0.12	-0.01	0.37	-0.17	0.07	0.02	0.14	14.3
13	0.05	-0.03	0.30	0.24	0.37	0.48	0.15	0.06	0.16	0.50	0.44	0.19	91.6
14	0.29		0.03	0.00	0.12	0.98	0.27						
15	-0.01	-0.31	-0.05	0.22	-0.02	0.24	0.11	0.01	0.10	0.04	0.06	0.18	18.5
16	-0.61	0.07	0.06	0.32	0.25	0.34	0.22	0.05	0.22	0.09	0.27	-0.08	35.2
17	0.14	0.04	0.02	0.01	0.45	0.36	0.39	0.21	0.36	1.14	0.17	-0.04	106.5
18	-0.18	0.00	0.30	0.48	0.02	0.17	0.15	0.19	0.22	0.26	0.06	0.15	51.9
19	-0.05	0.06	-0.21	0.36	0.06	0.21	0.03	0.15	0.00	0.15	-0.03	0.28	33.1
20	-0.14	-0.01	0.13	0.27	0.38	0.37	2.20	0.14	0.09	0.20	0.80	0.00	134.7
22	-0.06	0.00	0.10	0.33	0.02	0.15	0.17	-0.08	0.08	0.27	0.06	0.20	36.3
23	0.01	0.09	0.07	-0.01	-0.09	0.05	0.76	0.64	0.74	0.14	-0.02	0.00	72.9
24	-0.14	0.22	0.20	0.35	0.20	0.41	0.13	0.09	0.16	0.03	0.17	0.08	56.1
25	0.00	-0.09	0.16	-0.14	-0.11	0.06	0.00	-0.02	-0.01	0.04	-0.05	0.03	-3.5
25.5	0.05	-0.26	0.18	0.04	0.16	0.16	0.41	0.52	-0.01	0.23	-0.12	-0.01	42.9
26	0.02	-0.07	-0.09	-0.11	-0.16	0.08	-0.07	-0.24	0.04	0.09	-0.02	0.02	-13.5
27	0.18	0.05	0.20	0.18	0.28	0.01	0.01	-0.07	0.38	0.13	0.04	-0.09	35.3
28	0.20	0.31	0.06	0.14	0.07	0.19	0.36	0.53	0.19	0.16	-0.06	0.09	68.4
29	0.02	-0.02	0.06	-0.09	-0.05	0.01	0.04	0.10	0.33	-0.06	0.00	0.04	11.9
30	-0.02	0.00	-0.05	-0.01	-0.01	0.00	-0.01	0.00	0.27	0.01	0.05	-0.06	5.2
31	-0.09	-0.05	0.03	0.07	-0.17	0.08	-0.03	-0.01	-0.03	-0.05	-0.02	0.01	-8.8
32	0.09	-0.03	0.16	0.00	0.06	0.14	0.21	0.32	2.54	-0.02			
33	0.04	-0.11	0.03	0.03	-0.01	0.04	-0.04	0.00	-0.03	-0.03	-0.05	0.02	-3.7