GA-0044 2009

Kallestad, Jeff C.

Monitoring Riparian buffer functions to reduce non-point pallution -- final project report for C0700115 & C0800235

FINAL PROJECT REPORT

FOR

C0700115 & C0800235

Monitoring Riparian Buffer Functions to Reduce Non-Point Pollution

Recipient: *Jon D. Johnson*

Report author:
Jeff C. Kallestad

Project #C0700115 (Phase 1: Installation of instrumentation and monitoring)

Total cost of Project:	$71,857
Grant or loan amount:	$50,000
Project Start Date:	July 1, 2006
End Date:	December 31, 2007

Project #C0800235 (Phase 2: Buffer maintenance and monitoring)

Total Cost of Project:	$47,032
Grant or Loan Amount:	$30,430
Project Start Date:	November 1, 2007
End Date:	August 31, 2009

John D. Stark (signature) &/or ______________ 9-11-09

(AUTHORIZED SIGNATORY) DATE (PROJECT MANAGER) DATE

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Overview

Riparian buffers are widely considered to be a good land stewardship practice because of their ability to reduce agriculture-related non-point pollution. Buffers have been shown to reduce sediment transport, improve the quality of surface and ground water by removing excess nutrients, moderate temperature of adjacent water bodies, provide an intercept zone to prevent pesticide drift and soil nutrient amendments from directly entering surface water, and provide habitat for terrestrial and aquatic organisms. However, data on riparian buffer function and design are limited for low gradient streams, rivers and associated floodplains, and is non-existent for low gradient areas in western Washington watersheds where agriculture takes place. Because of the immediacy of action required by the Endangered Species Act in listing many of the water bodies adjacent to lowland agriculture, regulatory agencies are considering the use of upland riparian data to guide rule-making decisions for downstream agricultural riparian areas. While these guidelines are based on "best available science" and sound ecological principles from studies spanning multiple decades, standardized buffer recommendations are necessarily generalized and conservative in providing protections for most cases. The implementation of wide buffers, appropriate for steep forested areas, to all lowland fish bearing streams and ditches could challenge the economic viability of many western Washington farms by eliminating thousands of acres of productive land. This study seeks to reexamine recommended buffer widths for lowland agricultural areas situated on western Washington floodplains and to determine if a narrower minimum width might adequately improve water quality while serving the interests of both agriculture and conservation.

Beginning in April of 2006, a series of 75 foot wide by 100 foot long forested riparian buffer plots were established along Clarks Creek, a 303(d)-listed salmon-bearing tributary of the Puyallup River in Pierce County, at the Washington State University research farm. The buffers consisted of 3 vegetation treatments: a mixed buffer of grass filter strip plus hybrid poplar trees, a mixed buffer of grass filter strip plus red alder trees, and a grass filter strip alone. Each buffer treatment was replicated twice. Nitrate nitrogen and ortho-phosphate concentration in shallow groundwater and soil solution were measured at set sampling positions across two transects in each plot on a quarterly basis beginning December 2006 and continued until December 2008. This study tracks the nutrient load reductions in the various buffer treatments during early stages of tree development, and examines the role of tree inputs in the processes of denitrification and nutrient immobilization. While the apparent benefits to water quality measured in nutrient reduction efficiency were not statistically higher in the forested buffers relative to grass buffers during their first years of establishment, the carbon inputs and tree respiration in the forested plots contributed to a low soil oxygen environment favorable to denitrification. Soil porosity and depth to groundwater were the most important site variables affecting buffer efficiency and tree performance. After three growing seasons a distance-dependant effective buffer width can not yet be determined, but as the trees age, deeper and more extensive root exploration should improve nutrient extraction and assimilation.

The use of fast growing trees native to riparian areas of western Washington, such as red alder and black cottonwood, in forested buffers can accelerate site occupation and stream bank stabilization and more rapidly promote the development of a functional buffer. Once established, management options include thinning to creating suitable planting sites for shade-tolerant native conifers and/or sustainable harvesting of the trees for supplemental farm income.

Objectives and Performance Targets

1) Establish and maintain buffers, and conduct routine sampling of groundwater from piezometers and soil porewater using suction lysimeters located in each buffer plot.

2) Determine an effective buffer width for our site and nutrient loading conditions. By sampling at set distances along transects across the buffers, we can infer the distance-dependant width of buffer needed to reduce groundwater nutrient loads below maximum allowable levels and/or attain maximum buffer efficiency. In addition, surface water flow collectors placed in each buffer type will allow us to quantify the effectiveness of the grass filter strip in capturing overland water and sediment flow by comparing the upslope collections with downslope collections, which can then be related to slope and rainfall intensity.

3) Determine the effect of species composition on buffer function. By utilizing replicated plots with 3 vegetation species treatments we can compare nutrient reduction efficiencies resulting from species effects. By incorporating red alder in the design, we hope to investigate whether nitrogen-fixing microbial root symbionts associated with alder contribute additional nitrate to the groundwater.

4) Develop and disseminate science-based buffer recommendations and decision-making tools to farmers, farm agencies, regulators and policy makers dealing with farmland along watercourses in western Washington. By locating these buffer plots along Clarks Creek at WSU-Puyallup we will be able to use the site for demonstration purposes, providing for outreach programs to farmers and other interested groups, as well as conduct long-term monitoring.

Project description

Study Site:

The riparian buffer study site is located in Pierce County Washington along the left bank of Clarks Creek, a 303(d)-listed salmon-bearing tributary of the Puyallup River. The site is on Washington State University Research and Extension Center property, 2 miles west of the city of Puyallup. Clark's Creek is within the Puyallup-White River watershed (WRIA 10) and lower Puyallup River sub-watershed (HUC # 17100140599), in Township 20N, Range 04E, Section 19. Geographic coordinates of the experimental site are Lat. 47° 11' 42.96"N, Long 122° 19' 48.42" W (Figure 1).

The study site is situated on a floodplain-terrace landform in recent alluvium parent material. The soil is well drained, classified as Puyallup fine sandy loam (coarse-loamy over sandy, mixed, mesic Vitrandic Haploxeroll). The experimental plots are on a north-facing, gently sloping bank ranging from 6.1 to 12.6% grade. During the winter months the soil adjacent to the creek is occasionally saturated and the study site is occasionally subjected to partial flooding, with creek levels rising 3-4 ft and extending 1/3 upslope into some experimental plots.

Adjacent agricultural land upslope from the experimental plots, also owned by Washington State University, is dedicated to agricultural research and has received various fertility management regimes in recent decades including chicken manure, biosolids, organic compost, and conventional inorganic fertilizer. Previous land use included dairy and poultry farming operations, which have contributed to high levels of residual phosphate in the soil. Recent soil tests in these adjacent plots indicate phosphorous levels ranging from 201-609 mg/kg in 2007 and 188-268 mg/kg in 2008. Plant-available nitrogen was applied in these fields at rates averaging 40 lbs/ac in 2007, and 36 lbs/ac in 2008.

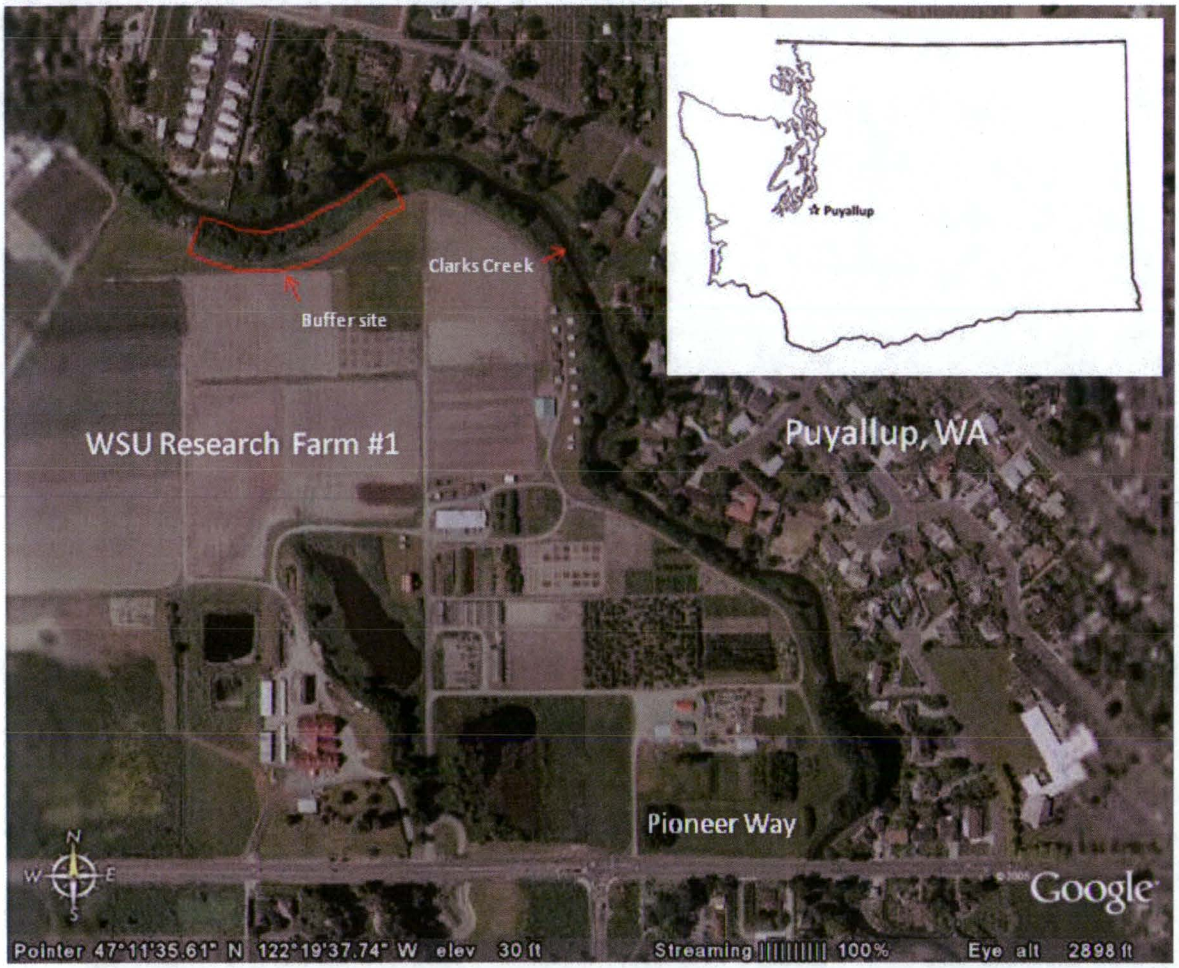

Figure 1, Satellite photo of the study site before buffer establishment.

Experimental plots

In April 2006 the study site was cleared of all vegetation. Six 50 x 100 ft buffer plots were planted with 3 species treatments. Hybrid poplar and red alder trees were planted in separate plots in 7 x 7 ft offset spacing along rows that follow the contour of the stream bank, 8 rows per plot, 14-15 trees per row, and grass plots were seeded with perennial rye. Each plot was replicated twice (Figure 2). In addition, a perennial ryegrass filter was planted in a 25 ft strip upslope of each buffer plot, making each treed plot a mixed buffer system 75 ft x 100 ft, with the grass strip functioning as a sediment capture zone. Since establishment, all plots have been maintained with mowing, herbicide applications to reduce weed competition, replanting dead and or small trees, and providing irrigation throughout the summer months.

In September 2006, 48 piezometers were installed in the six plots, each plot with two upslope to downslope transects with 4 piezometers. Along each transect piezometers were positioned from the upper edge of the buffer-grass filter interface (0 ft.), and at 10, 25, and 50 ft downslope. The piezometers at 50 ft position are in line with the furthest downslope row of trees and within 10 ft of the edge of Clarks Creek during low flow periods. Piezometers at the 0 ft position are in line with the furthest upslope row of trees.

In January 2007, 96 soil solution samplers were installed at the site, with two co-located at each piezometer at 12" and 18" depth. Forty-eight soil tensiometers were also installed, co-located at each piezometer of the upstream transect in each plot, and at the same depths as the soil solution samplers. Six overland flow collectors were installed, 2 per plot in the downstream block, one at the upslope edge of the buffer plot and the other at the downslope edge (Figure 2).

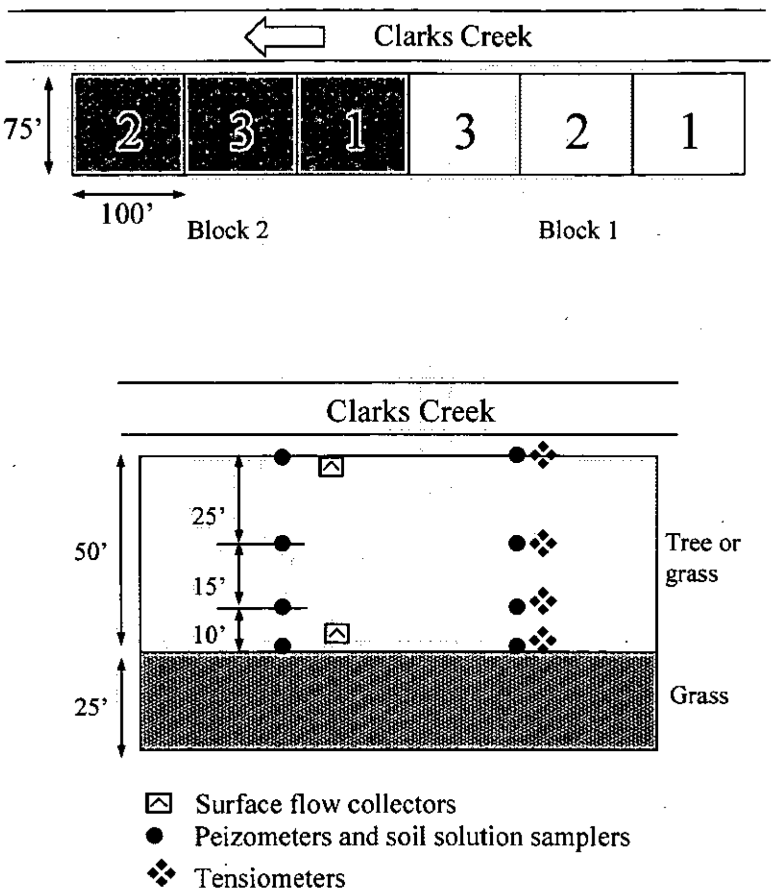

Figure 2, Schematic of all buffer plots along Clarks Creek shown in upper panel. Plots 1 = grass, 2 = hybrid poplar, 3 = red alder. Lower panel shows layout of instruments in a plot.

Analysis for nitrate and phosphate content in shallow groundwater and soil solution samples was performed at two laboratories using the same standardized EPA method 300.0. Samples collected from December 2006 to July 2007 (Phase 1, contract #C0700115) were analyzed at the Oregon State University Central Analytical Laboratory, and those collected from November 2007 to December 2008 (contract #C0800235) were analyzed at the University of Washington Analytical Laboratory, accredited by the Department of Ecology. Data collected for the parameters; nitrate, ortho-phosphate, and depth to static water sampled from the piezometers (Washington State Resource protection wells BBB151 to BBB198), and from suction lysimeters clustered near these wells, are available in the Ecology EIM database under study number C0800235. For an itemized sampling protocol see appendix 2.

Study period

Sampling of shallow groundwater from piezometers began December 14, 2006 in accordance with Washington Department of Ecology Section 319 DIF contract agreement # C0700115. Both piezometers and suction lysimeters were sampled thereafter on March 4, May 8, June 18 and Nov. 7, 2007. Sampling was continued at this site under contract agreement #C0800235 in 2008. Both piezometers and suction lysimeters were sampled on Dec.18, 2007, March 4, 2008, May 7, June 3 and Dec.1, 2008. In this report the term "study period" will refer to the combined contract sampling periods for which both groundwater and soil solution were sampled and tested, beginning March 4, 2007 and ending Dec 1, 2008.

Outcome

Buffer establishment and maintenance

Hybrid poplar (*Populus trichocarpa* x *P. deltoides,* family 15 clone 29) cuttings, and bare root seedlings of red alder (*Alnus rubra*, accession developed by Weyerhaeuser Corp.) planted in April of 2006 in the treed buffer plots were selected for their rapid growth characteristics and suitability to western Washington climate conditions. Trees failing to thrive or damaged by pests have been replaced each season. Plots have been treated with glyphosate herbicide before bud break each spring and have been mowed during the growing season to control weeds. The plots have been irrigated in the summer months to mitigate water stress. Site heterogeneity and soil conditions, along with the natural species adaptations to episodic root hypoxia and water stress, have contributed to the bulk of the heterogeneity in tree performance over 3 full growing seasons. As of December 2008, poplar tree heights ranged from 13-29 feet and alder tree heights ranged from 2.5 - 25 feet. This variability includes the heights of the replants, some of which lag by 2 years.

The net amount of nitrate and phosphate extracted from groundwater, assimilated into new tree growth, and returned in root turnover, root exudates, and leaf litter is difficult to quantify or account for in a mass balance endeavor. However, one measurable and highly correlated indicator of assimilation is above-ground productivity as measured by stem volume. As shown in Figure 3, large differences in tree performance exist between plots. The soil in block 2 plots contains more sand, which resulted in higher frequency of tree drought stress. Both poplar and alder in block 2 have lower row-averaged stem volumes than counterparts in block 1. Trees in the center portion of alder plot in block 2 have up to a 10-fold decrease in stem volume compared to alder in block 1. It is likely that trees in the furthest upslope rows of poplar block 2 and both plots of alder show reduced performance due to higher moisture stress and sun scald. Effects of frequent soil saturation are also evident in the different performance trends of each species at the furthest downslope rows. Average stem volume in both poplar plots and in alder block 1 decreased closer to the creek, where groundwater was shallower. This may indicate a species difference in tolerance to root hypoxia. However, a strong increase in performance is seen in both alder stands in the furthest downslope row where light competition is reduced.

The amount of nitrate nitrogen in shallow groundwater entering the buffer plots was heterogeneous and correlated to the proximity of the adjacent agricultural fields where plant-available nitrogen was applied at a rate of 40-60 lb/acre (Figure 4). Adjacent agricultural plots were 70 to 150 feet away from the buffer plots in block 1, but only 5 to 60 feet away from the plots in block 2. Generally, nitrate levels entering the buffer were relatively low in the upstream buffers and decreased over the measurement period whereas nitrate levels in the downstream plots closest to the agricultural field (grass plot 2 and alder plot 2) increased over the measurement period. Differences in site characteristics, tree performance, and the heterogeneous

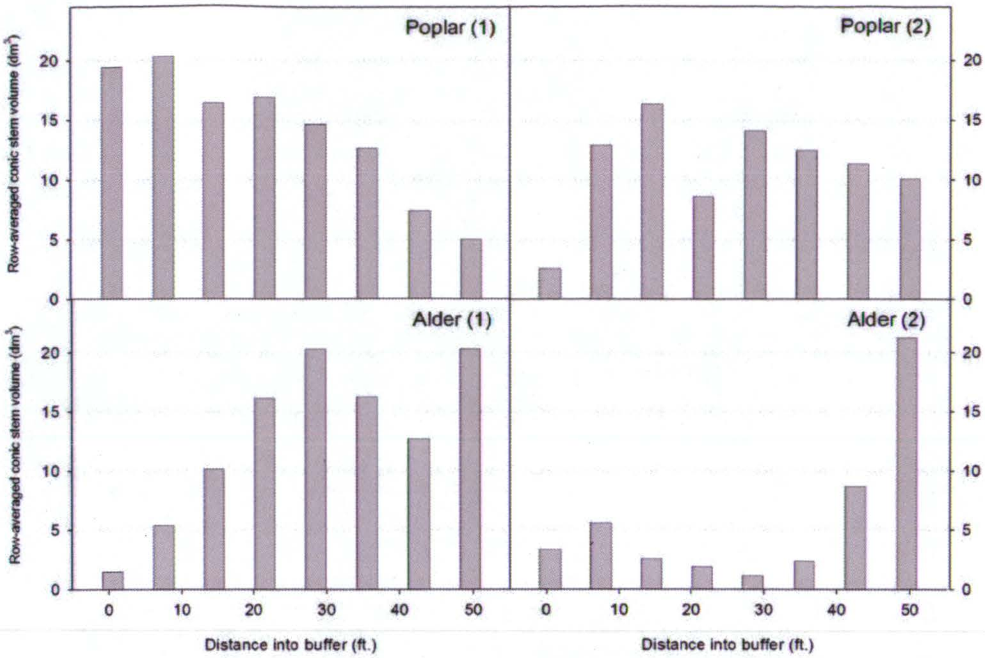

Figure 3. Row-averaged conic stem volume in treed buffer plots. Distance = 0 is the furthest upslope row.

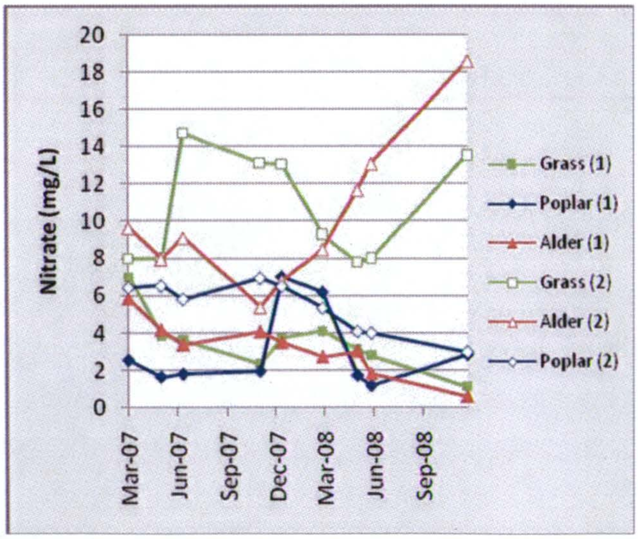

Figure 4. Groundwater nitrate influx at each buffer plot during the sampling period. Data points represent the average of both transects in each buffer plot at the furthest upslope positions.

nitrate inputs have important negative implications for the statistical inferences that can be made from this study.

To estimate the amount of nitrogen and carbon returned to the soil in leaf fall, shed leaves were collected in suspended litter bags at 6 locations per plot during the fall of 2007 and 2008 until the trees were defoliated. In 2007 leaf litter was subjected to carbon-nitrogen analysis to determine percent weight of each element. Carbon returned as litter increased 6 -10 fold, from 25-50 g/m^2 in 2007 to 150–290 g/m^2 2008 across all tree plots (Figure 5). Nitrogen inputs from litter increased 2 -10 fold, from 1-3 g/m^2 in 2007 to 3-12 g/m^2 in 2008. The variability in litter is directly tied to differences in tree performance in each plot. The averaged amount of carbon and nitrogen in alder leaf litter was 50.27% C and 2.78% N, and for poplar, 45.78% C and 1.87% N. It should be noted that after leaf fall the decomposed litter was observed to drift into piles along the beaver fence at the furthest downslope edge of the plots. This may have provided a source of soluble nutrients measured at the 50 ft lysimeters and groundwater wells that was not present at the 0 ft lysimeters and wells.

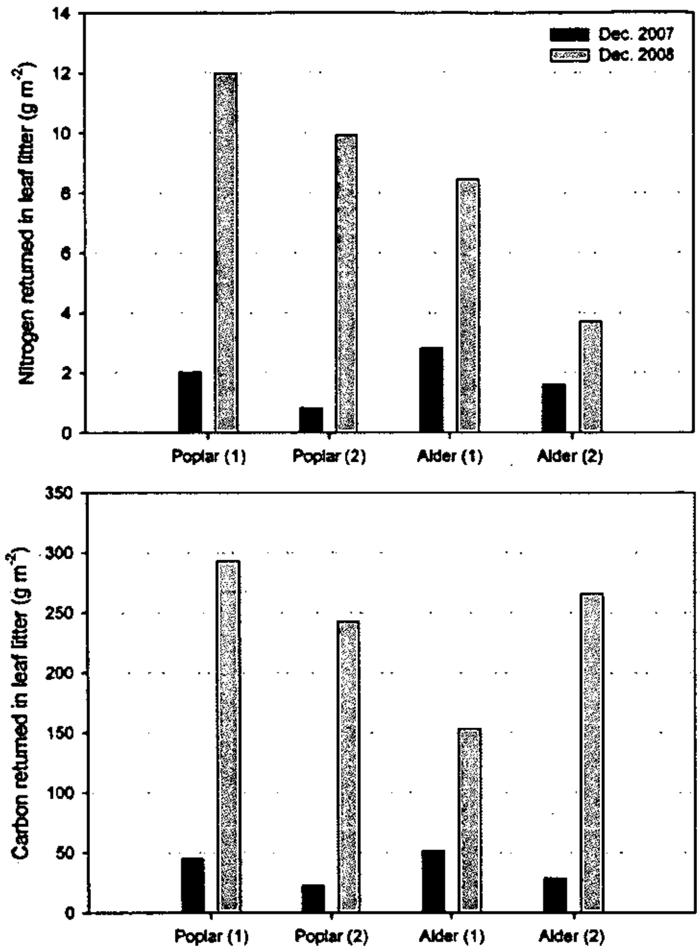

Figure 5. Estimated carbon and nitrogen returned to the soil in the form of leaf litter in 2007 and 2008.

Monitoring groundwater and soil solution for nitrate and ortho-phosphate

One of the objectives of the groundwater and soil solution measurements for nitrate nitrogen and ortho-phosphorous concentration was to determine the extent of attenuation of these potential pollutants as they moved through the buffer. Additionally, we wanted to estimate a minimum buffer width in these conditions that would reduce the concentration below the EPA MCL of 10 mg/L for nitrate, or below the concentrations found in the creek water. Since buffers of differing widths were not planted, an alternate approach was to determine if the extent of attenuation would converge on minimum value that could be associated with a particular downslope distance.

Seasonally, the highest levels of nitrate in shallow groundwater were observed in the period from November 2007 to early May 2008 in the alder and poplar plots in block 1 and the alder plot in block 2 (Figure 6). This co-occurred with tree dormancy and the season with the highest rainfall. Fall and winter precipitation in 2007 was greater than in 2008 (Figure 7), which may explain the lower nitrate levels leaching into groundwater in the winter of 2008. Lower nitrate levels occurred in groundwater during the summer months when evapotranspiration is greatest. We observed lower nitrate levels in the 0 ft piezometers than at the 10 and 25 ft distance in the tree plots, suggesting that additional nitrates are being introduced by the trees, either from returned leaf litter, root turnover, or from symbiotic root-associated microbes. Levels in the grass plots were observed to stay true to an upslope to downslope gradient, and changed little seasonally. Rarely were nitrate concentration means significantly different by the effects of species or distance into the buffer, and these occurred during the summer months in 2008 (Tables 1, 2 appendix 1).

Levels of nitrate in the soil solution were 10 fold higher in some tree plots than in grass plots (Figure 8), suggesting that trees are likely introducing nitrates into the buffer soil system, which could potentially leach into groundwater during the periods of high precipitation. Seasonally, the nitrate levels in the tree plots are highest in the summer and fall months, May to November 2007 and June 2008, co-occurring with periods of highest evapotranspiration (Figure 7). One explanation for this trend is that the observed increases are due to a concentrating effect from the extraction of soil moisture by trees. The increase in nitrates in the soil may also be facilitated by greater soil microbial activity, new root growth with accompanying exudates, and root turnover, all associated with seasonal increases in soil temperature. Opposite of nitrates sampled from groundwater, nitrate levels in the soil solution decrease in the fall and winter months either from leaching, root dormancy, or reduced soil temperatures leading to reduced microbial activity, or some combination of all of these.

It was not feasible to directly evaluate the relationship between nitrate in soil solution and soil moisture content since the AMI tensiometer valve-stoppers increasingly malfunctioned during the study period and the matric potential data became unreliable. In May 2008 we acquired a new tension-measuring device and new stoppers were installed. Since we did not have a complete soil water potential data set spanning the whole study period or even 1 year, a regression analysis of soil solution nitrate as a function of soil moisture was not possible.

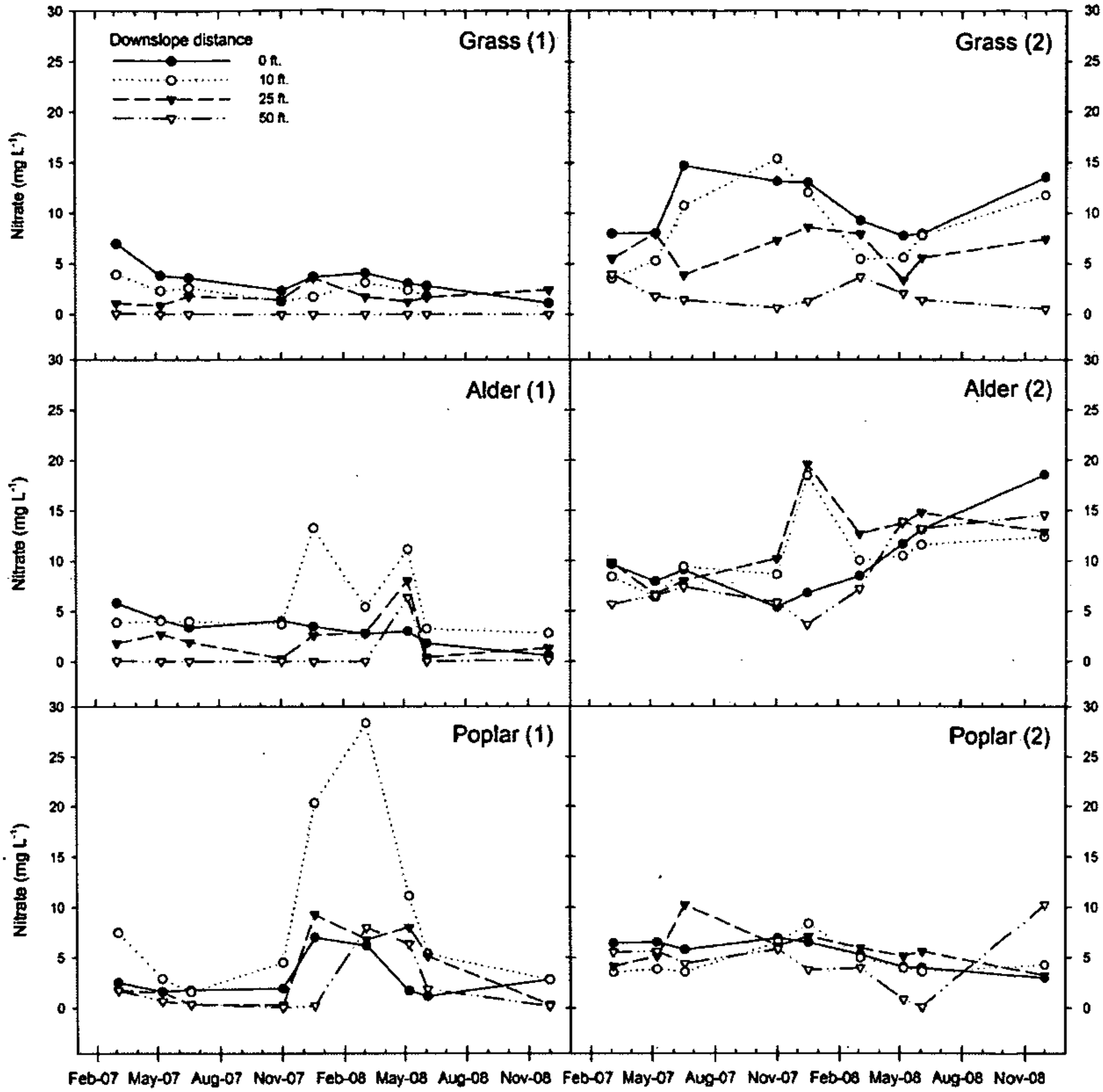

Figure 6. Time-series graphs of nitrate nitrogen concentration in shallow groundwater sampled from piezometers. Each point is the average of both transects at a downslope position

The levels of nitrate in soil solution did not appear to consistently follow a distance-dependant trend along the plot transects (Figure 8). Given the low slope angle of the creek bank and the well-drained nature of the soil, we expect that nitrate concentration in the shallow soil solution to be heterogeneous and influenced more by adjacent individual tree performance and less by the sequential extraction of nitrate by a group of trees along a lateral transport vector, especially in the upslope half of the buffer plots where the soil is frequently unsaturated. In the downslope portion of the buffer plots where soils are frequently saturated we would expect more horizontal component to solute transport, and therefore more sequential extraction. In contrast, we expect solutes in groundwater to move more by lateral transport and be influenced by sources outside the buffer system (influenced by mixing), as well as by solutes transported vertically that originate from buffer vegetation.

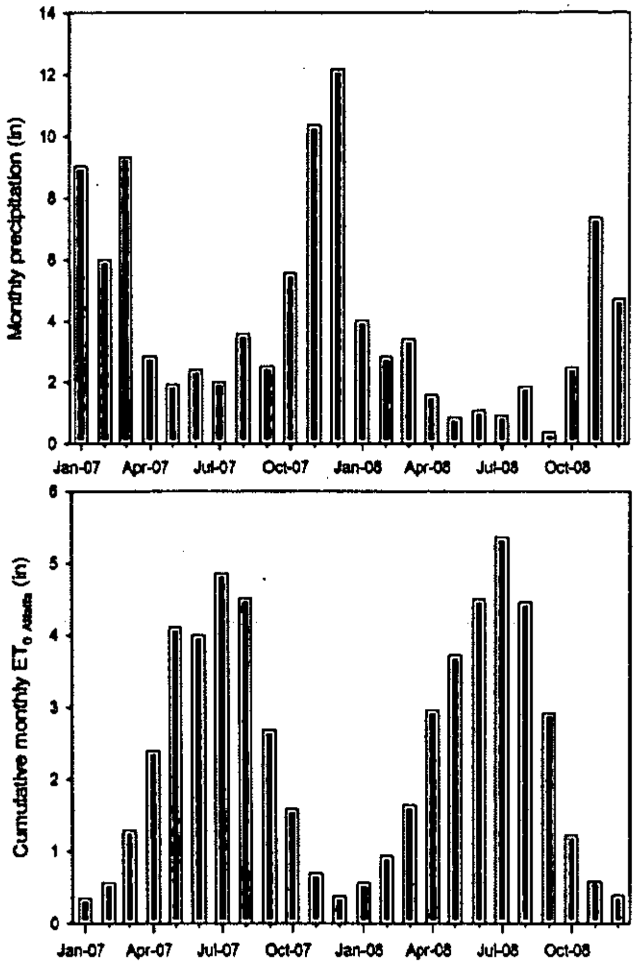

Figure 7. Graphs of cumulative monthly precipitation (upper) and potential evapotranspiration (lower) during the study period.

One of the concerns that we addressed by including alder as a buffer treatment was whether *Frankia*, a nitrogen fixing actinomycete and root symbiont of red alder, would increase the abundance of nitrate in the soil and thereby reduce the nitrate load reduction effectiveness of the buffer . Looking at this problem from the whole plot level over time we see mixed results. First, there are also no clear trends of increasing nitrate in the soil solution over time in the alder plots relative to poplar plots shown in Figure 8. Also, the concentration of groundwater nitrate under alder plot 1 (Figure 6), where the trees were performing well and the effect of adjacent agricultural fields is relatively small, has not increased over time. There was an interesting pulse of nitrates in the May 2008 sampling that did not occur in the May 2007 sampling, which may be correlated to a temporary pulse in the volume of groundwater as was indicated by a temporary decrease in depth to groundwater (data not shown). However, nitrate levels in June and December 2008 dropped below what they were the previous year, suggesting an overall downward trend. The observed increasing trend in alder plot 2 may be confounded by increasing nitrate influx from the near by agricultural field (Figure 4), which is also evident in the increasing trends in the adjacent grass 2 plot. Given the relatively poor tree performance of the alder 2 plot it is not likely that the observed trend is due to *Frankia* inputs.

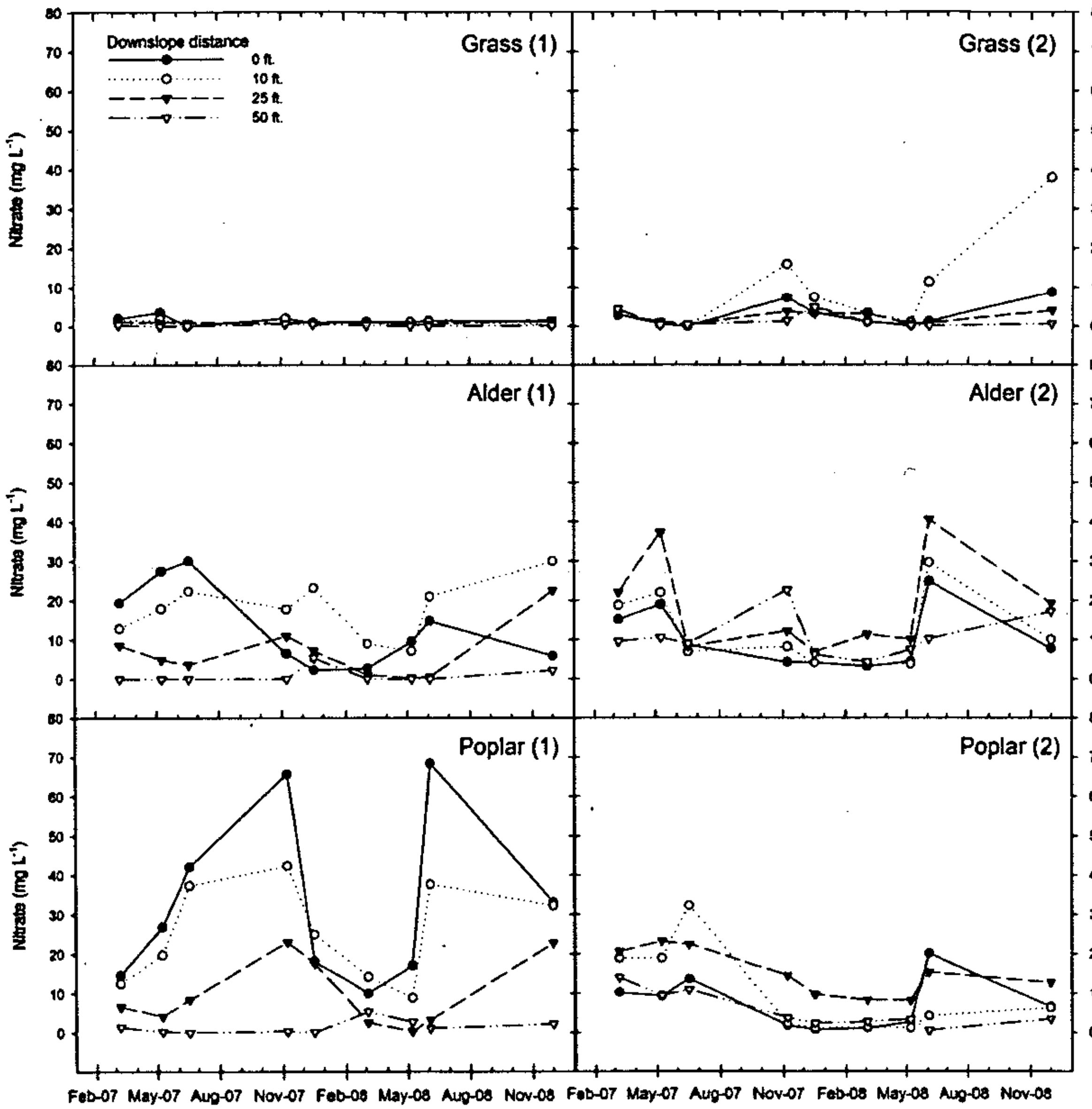

Figure 8. Time series graphs of nitrate nitrogen concentration sampled from the soil solution through suction lysimeters. Each point is the average of concentrations sampled from 18 inches and 24 inches depth at each downslope position for both transects.

Phosphate levels in groundwater exhibited an inconsistency in the decreasing upslope to downslope gradient that was observed for nitrates. As shown in Figure 9, concentrations in the 25 and 50 ft piezometers were occasionally observed to be much higher than concentrations in the upslope piezometers, particularly in the May and June 2007 in both grass plots and in the alder plot in block 1. The initial high levels could be a lagging effect from soil disturbances during site preparations. An alternate hypothesis is that phosphates associated with sediments are routinely deposited on the buffer during creek flooding events, which have on several occasions extended up to the 25 ft piezometers in the plots of block 1 and in the grass plot of block 2. Lesser increases were seen in the spring of 2008 in all plots. The small phosphate increases below all plots in May and June 2008, but more so in the block 2 plots may be due to lateral transport of solute from the adjacent agricultural field and correlates to the curious increase in groundwater volume during that period, or it may relate to winter leaching that lags in its appearance in groundwater because of its interaction with soil particles. Generally, groundwater phosphate concentrations in 2008 were at or near the analytically detectable limit.

In the soil solution there are large differences in phosphate levels between blocks (Figure 10). Generally levels in block 2 are 3 to 5 fold higher than in block 1. Given the poor tree performance in block 2, one explanation for these differences may be close proximity of the adjacent agricultural field receiving fertilizer. However, because of high residual phosphate from previous land use, recent applications of soil fertility amendments have not contained phosphate. An alternative hypothesis is that the gradients result from residual phosphate from fertilizer applied in years before the buffer was established. In this case, levels would be expected to be higher away from the creek bank. Soil disturbances associated with the buffer site preparation would have redistributed some of this residual. Farm operations in the adjacent field have also deposited soil with higher residual phosphate when tractors traveling over the grass filter strip inevitably drop soil attached to implements during turning maneuvers. The plots in block1 would not be affected by these farming operations.

Generally, levels of phosphate in soil solution increased in the wet months from November 2007 through May 2008 and decreased in June 2007 and June 2008, when soil moisture is lower and tree growth is greatest (Figure 10). With exception to the grass and alder plots in block 2, where the concentration at the 10 ft position was greater than the 0 ft position, levels decreased with increasing distance downslope, with concentrations at the 50 ft position near the lower limits of detection. In most plots, especially at the upslope lysimeters, there appears to be an increase in influx concentration over the study period. However this trend does not appear in water sampled from the 50 ft lysimeters, or in the poplar plot in block 1. Since this increasing trend also appears in the grass plots, tree inputs are likely not a factor.

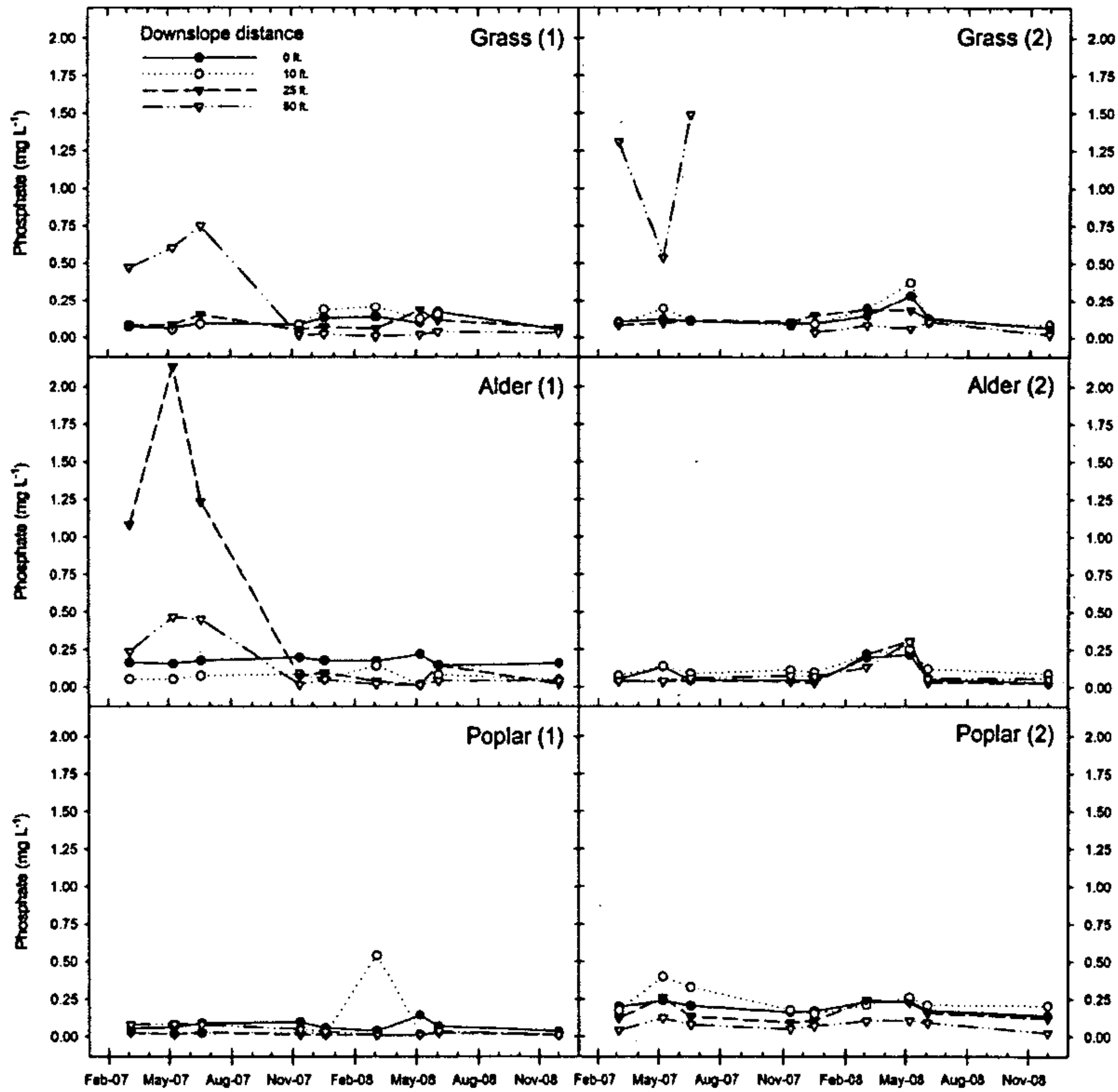

Figure 9. Time series graphs of ortho-phosphate concentration in shallow groundwater sampled from piezometers. Each point is the average of both transects at a downslope position

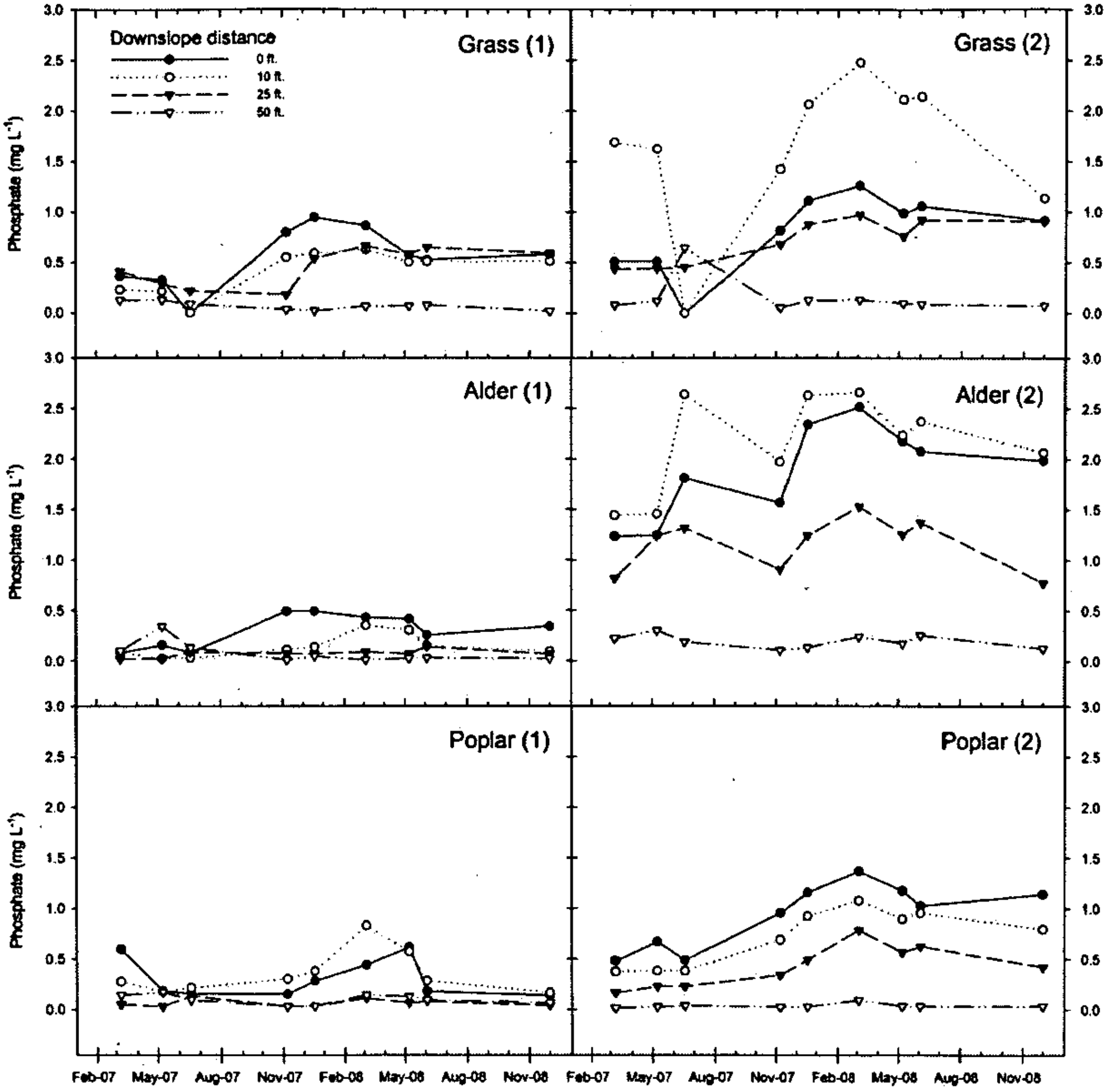

Figure 10. Time series graphs of phosphate concentration sampled from the soil solution through suction lysimeters. Each point is the average of concentrations sampled from 18 inches and 24 inches depth at each downslope position for both transects.

Monitoring dissolved oxygen in shallow groundwater

Carbon and nitrogen inputs originating from trees likely play an important role for certain soil microbes in saturated soils in carrying out the processes of denitrification. To determine the extent of hypoxic or anaerobic soil in the buffer area, we measured dissolved oxygen of the groundwater in piezometers as an indicator of favorable conditions for denitrification. As shown in Figure 11, grass plots had higher levels of dissolved oxygen, as well as steeper gradients as a function of downslope distance into the buffer compared to tree plots.

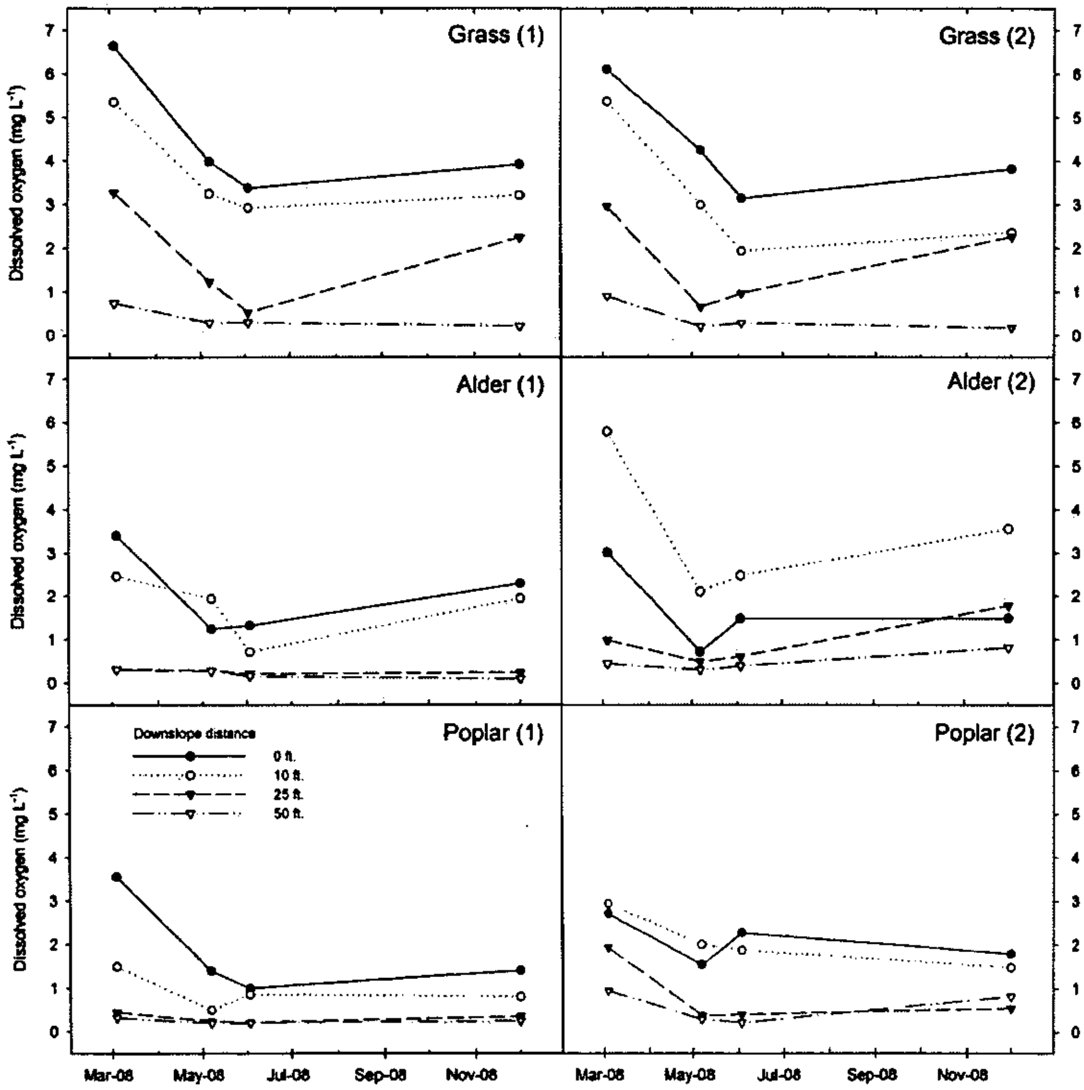

Figure 11. Time series graphs of dissolved oxygen content in shallow groundwater sampled from piezometers. Each point is the average of both transects at a downslope position

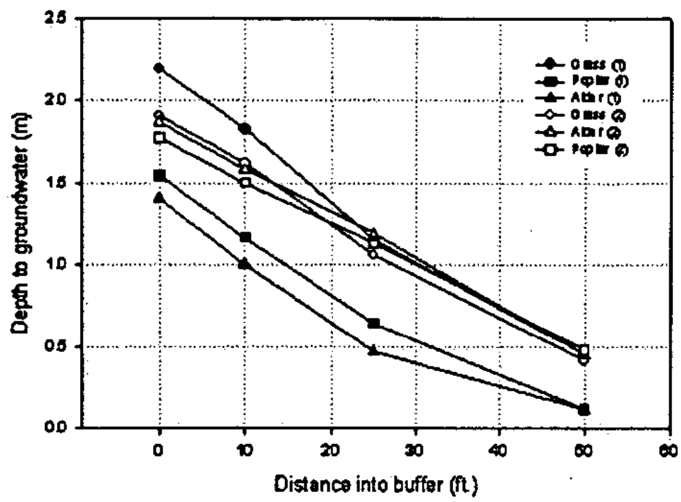

Figure 12. Depth to static groundwater as a function of distance into the buffer for each plot. Depths were sampled March 2008.

Lower dissolved oxygen in the tree plots likely results from a combination of effects: gas phase oxygen in soil pores diminished by tree root respiration, which is proportional to belowground biomass; and greater carbon inputs from trees, relative to grass, supply nutrients to soil microbes for aerobic and anaerobic metabolism. The lowest levels of dissolved oxygen occur in the summer months when the soil temperatures are higher, tree root respiration is higher, microbial metabolism is increased, and warmer groundwater physically holds less dissolved oxygen.

Another factor contributing to reduced levels of dissolved oxygen in groundwater is related to site topography. The poplar and alder plots in block 1 have the lowest elevation with respect to groundwater, and therefore experience longer periods of soil saturation than the higher elevation plots in block2, which contain more porous soil (Figure 12). This was evident in the very low levels of dissolved oxygen in the wells at 25 and 50 ft into the buffer in the alder and poplar plots of block 1 (Figure 11). Elevated oxygen levels at the 10 ft piezometers in the alder plot in block 2 may have resulted from local soil stratification effects.

Monitoring surface runoff and overland sediment flow

Vegetation in riparian buffers is important not only for nutrient uptake, but also in providing impedance to overland surface water flow or runoff. We monitored 6 surface flow collectors for water volume and captured sediment when rainfall events exceeded 0.5 inches (Table 1, also see Appendix 2 for sampling procedure). The collection apparatus (Figure 13), modified from a published design by Sheridan et al., (1996, Applied Engineering in Agriculture 12(2):183-188), is comprised of a series of two 12 inch wide by 12 inch long galvanized sheet metal pans linked by a 1 inch wide metal tube. One inch wide collection tubes divert water and sediment from a portion of the downslope edges of the two pans into collection bottles buried below the soil surface. Volumes collected from the upslope bottle represent 1/12th of the flow, and volume for the downslope bottle represent 1/144th of the total influx. A notched metal riffle strip was riveted just behind the leading edge of both pans to aid in preventing large debris from entering the pans, as well provide more even water flow distribution across the pan. Pans were covered with a sheet metal lid to prevent rainfall from directly entering the collection system.

The soil at this site was well drained and the upslope collectors in all plots receive overland flow (if any) over the grass 'filter strip'. Downslope collectors in the tree plots could potentially receive more sediment because these plots have been treated with herbicide and have less soil vegetation to impede flow. Also, in the wet winter months when trees are defoliated there is little effect of the trees on either interception or reducing the energy of raindrop impacts and therefore sediment transport in rain splash could be expected.

Three of the six recorded volumes were collected from the lower collection bottle (144 x volume multiplier) while the upper collection bottle was dry, suggesting that rain splash may have entered the back of the downslope collection pan (Table 1). Leaf litter can also contribute to directing rainfall into the collection pan that might otherwise fall outside of it. This was more likely in the downslope tree plot collectors where leaf litter tended to collect along the fence. The lack of consistency between amounts collected in all the upslope collection bottles, which all receive surface flow over grass, only highlights the difficulty we had in keeping the apparatus level, which were continually being disturbed by moles (*Scapanus townsendii*) burrowing under them. Erroneous collections were also likely attributed to the collection pan covering being too small or set back too far, allowing rainfall or rain splash to directly enter the collection system. Most of the solid material recovered from the collection bottles consisted of carcasses of coleopterans, arachnids, gastropods, and annelids or soil particles brought in by these soil-dwelling fauna. This "fall-trap" problem was later corrected by placing a coarse mesh fabric across the entrance of the collection bottle. These data are therefore considered unreliable indicators of surface flow in the buffer. While some sediment movement may have occurred within the treed plots by overland flow, greater amounts were more likely transported during creek flooding events.

Figure 13. Overland surface water and sediment collection apparatus.

Table 1. Water and sediment collected from 6 overland surface flow collectors after 6 rain events with accumulations greater than 0.5 inches.

			Collection date											
			12/04/07		1/11/2008		2/12/2008		3/17/2008		11/5/2008		11/13/2008	
			Rainfall accumulation (inches)											
			3.36		1.5		0.98		0.98		2.07		5.24	
Plot	Collector location	Volume Multiplier	Vol (ml)	Sed (g)	Vol (ml)	Sed (g)	Vol (ml)	Sed (g)	Vol (ml)	Sed (g)	Vol (ml)	Sed (g)	Vol (ml)	Sed (g)
Poplar (2)	Upslope	12x	<1	nc	0	0	0	0	0	0	0	0	0	0
		144x	<1	nc	0	0	22	<0.01	0	0	0	0	0	0
Poplar (2)	Downslope	12x	Sub	nc	0	0	0	0	0	0	0	0	0	0
		144x	Sub	nc	1.2	0.018	0	0	0	0	0.2	0	0	0
Alder (2)	Upslope	12x	<2	nc	0	0	0	0	0	0	0	0	0	0
		144x	<2	nc	0	0	0	0	0	0	0	0	0	0
Alder (2)	Downslope	12x	Sub	nc	0	0	0	0	0	0	0	0	7.55	<0.01
		144x	Sub	nc	0	0	0	0	0	0	0	0	0	0
Grass (2)	Upslope	12x	<2	nc	2.4	<0.01	0	0	0	0	0	0	2.7	<0.01
		144x	<1	nc	0	0	0	0	0	0	0	0	0	0
Grass (2)	Downslope	12x	Sub	nc	0	0	0	0	0	0	0	0	0	0
		144x	Sub	nc	3.8	<0.01	0	0	0	0	0.7	0	0	0

Vol = collected water volume
Sed = collected sediment
nc = data not collected
Sub = collector was submerged during flooding event

Monitoring Clarks Creek

As a benchmark for levels of nitrate and ortho-phosphate in groundwater we measured these in surface water samples taken from Clarks Creek at each sampling date in the study period (Figure 14). Nitrate levels were fairly constant throughout the study period, increasing steadily from 2.36 mg/L in March 2007 to 2.94 mg/L in March 2008, followed by a decline in May 2008 to 2.56 mg/L and a drop to 2.45 mg/L at the final sampling date in December 2008. Levels of phosphate were low, bordering on the lower limits of analytical detection, which is reported as 0.01 mg/L or 0.03 mg/L depending on the sample dilution factor and the reporting laboratory.

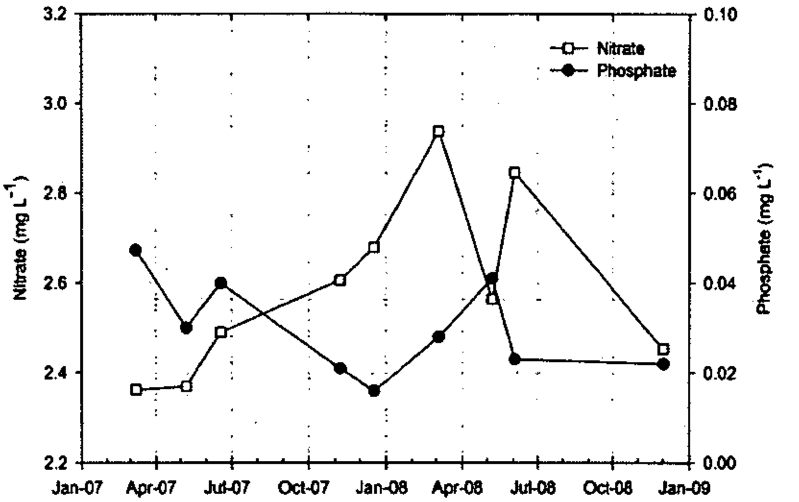

Figure 14. Nitrate-nitrogen and ortho-phosphate in Clarks Creek surface water

Nitrate levels in Clark's Creek were frequently, but not always higher than groundwater sampled from piezometers next to the creek. This finding suggests that a down-gradient exchange of solutes between creek water and the soil solution surrounding the piezometers at 50 ft was not greater than the rate of nitrate reduction or assimilation by vegetation in these soils. This observation further supports the hypothesis that nitrate levels in hyporheic zone next to the creek are reduced by the process of denitrification and not by dilution effects from the creek. Higher levels of nitrate in the creek-side piezometers in the alder and poplar plots in block 2 could result from their being at a higher elevation (above the hyporheic zone) and in sandier soil, which would facilitate greater nitrate mobility, and would allow more oxygen diffusion into the soil and thereby inhibit denitrification. Phosphate levels in creek water were similar or the same as levels in groundwater sampled from piezometers or suction lysimeters next to the creek (Figures 9, 10).

Evaluation

Measured buffer efficiency

A common holistic approach to evaluating a buffer system's capacity to reduce nutrient load, is to calculate the total change in groundwater nitrate concentration over the full transect divided by the influx concentration to obtain relative buffer efficiency. In our study, we computed efficiency as a function of vegetation treatment. As shown in Figure 15 the grass plots had consistent high efficiencies in both wet and dry seasons compared to the tree plots. Plausible explanations for low efficiencies in the alder and poplar plots in block 2 are poor tree performance, and reduced denitrification processes (and greater nitrate mobility) as a result of greater soil permeability and aerobic conditions. The reduced efficiencies in all the treed plots can also result from localized increases in soil fertility due to root turn over, root and litter decomposition, and root exudates.

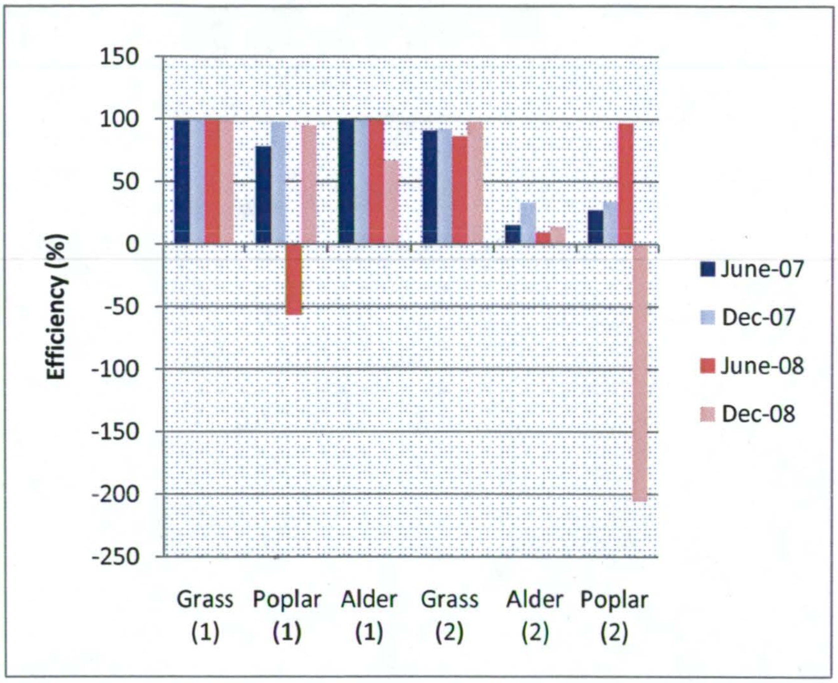

Figure 15. Buffer efficiency in reducing nitrate from shallow groundwater in the months of June and December.

By comparing efficiency values in treed plots obtained in June, when the trees are in full leaf and most actively assimilating nutrients, with those in December, when trees are dormant, one might assume that any change in efficiency would indicate a partitioning of the microbial effects of denitrification and immobilization from those related to plant assimilation. In fact there were no consistent trends (Figure 15). These data indicate that the controlling factors for buffer efficiency in the treed plots at this point in their development are localized, spatially heterogeneous, and not seasonal, even though the relative abundance of nutrients in both groundwater and soil solution follow seasonal trends. Grass plots, being more uniform in distribution, might be expected to have more spatially and seasonally consistent efficiency trends.

An alternative, hypothesis for what appears to be nutrient load attenuation by vegetation treatments, is that the gradient of solutes (nitrate and soluble phosphate) in the shallow groundwater may have resulted from historical application of soil nutrient amendments, which become diluted by mixing with deeper upwelling groundwater as it moves laterally toward the creek. This hypothesis was not tested. A hydrologic characterization of this particular reach of

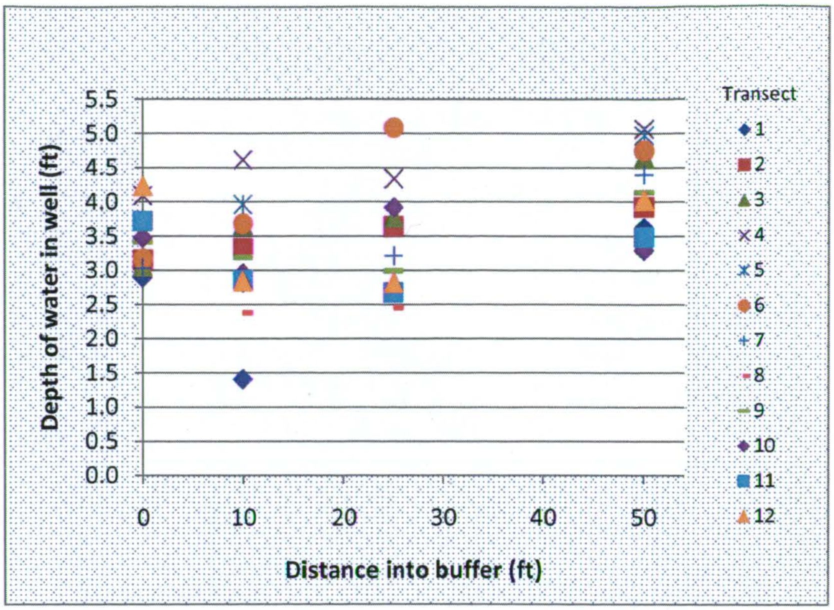

Figure 16. Depth of well penetration into shallow groundwater in March 2008.

Clarks Creek was not available, and we made no attempt to characterize the vertical profile of solute concentration in the groundwater or determine hydrologic flux. The range of penetration into groundwater from which we sampled was a fairly consistent 2.5 to 4.5 ft for all 48 piezometers (Figure 16). It is a reasonable expectation that if dilution was the main effect then nitrate concentration would be inversely proportional to distance from the nitrate application source and the buffer plots more proximal to the agricultural field would have less opportunity for dilution. These expectations are met when comparing the reduced efficiencies in the grass and alder plots in block 2 (Figure 15) with the higher nitrate influx levels in these plots shown in figure 4. However, while the overall efficiencies may suggest dilution as a plausible mechanism, an examination of the reduction efficiencies within transect segments of each plot suggest otherwise, and support the hypothesis that the processes of assimilation, immobilization, and denitrification, along with localized increases in soil fertility in the treed plots may play key roles in the overall measured efficiency.

Distance-dependant nutrient attenuation

One method to pinpoint an effective buffer width for nutrient load reduction within fixed width buffer plots is to determine a distance within the buffer at which the nitrate concentration asymptotically approaches its minimum value. Since the 4 piezometers were not uniformly distributed in transects, and there were only 3 segments per transect to compute reduction, this analysis would not be productive (see General Comments below). However, we did compare the nitrate reduction efficiencies for the upslope 25 ft versus the downslope 25 ft in each buffer plot in winter and summer, As shown in Figure 17, downslope segments in every treatment had consistently higher (and positive) efficiencies than the upslope segment. The seasonal trends within a segment were not consistent through the sampling period. These results suggest that nitrate reduction by plant assimilation is minimal in the upslope half of the buffer where plant roots do not have access to the capillary fringe of groundwater. Negative efficiencies are likely due to increases in soil fertility by trees. The inconsistent efficiency by season suggests that, in the context of site heterogeneity, denitrification may potentially be more important than assimilation. At this point in tree development a distance-dependant effective buffer width can not be determined, but as the trees age, deeper and more extensive root exploration should improve nutrient extraction and assimilation.

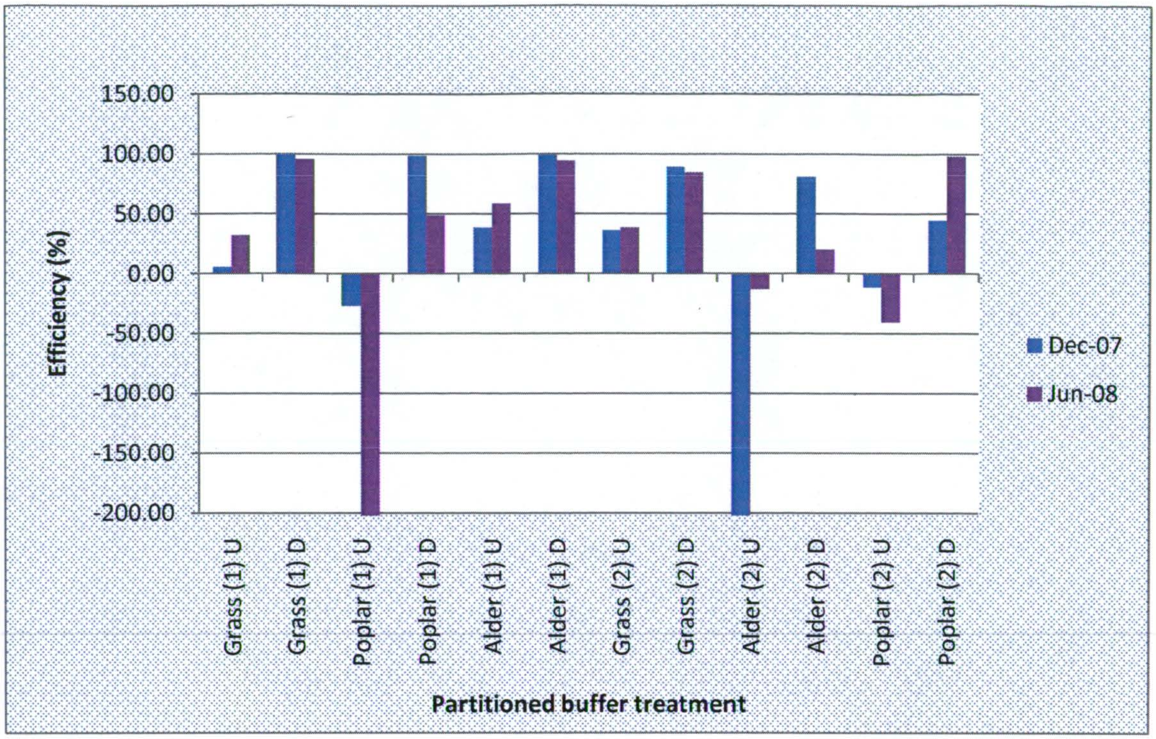

Figure 17. Groundwater nitrate reduction efficiency over the upslope 25ft (U) compared with the downslope 25ft (D) of buffer plots in winter 2007 and summer 2008. Bars represent plot means.

Significance of the outcome

There are three important considerations that have bearing on the inferences one can take from these nitrate and phosphate concentration data: a) the trees were at an immature stage of development with only limited root-exploration of the buffer soil, especially during the 2007growing season. For this reason, only 2008 measurements underwent statistical analysis. Treatment effects were not expected to play a large role even for the data collected in 2008; however, these data do provide an important baseline for future comparisons. b) The experimental site is heterogeneous to the point that the large difference between blocks (in terms of soil characteristics, tree performance, site elevation, and edge effects) stripped away some of the statistical power that would have been gained from having replicated plots under more uniform conditions, or with more replications. c) The natural (residual) levels of nitrate and phosphate in the soil from previous vegetation located on the site, and applied fertilizer in fields adjacent to some of the buffer plots were spatially heterogeneous and confounded attempts at determining a consistent distance-dependant attenuation relationship.

For the most of the sampling period soluble ortho-phosphate levels in shallow groundwater were at or near the analytical minimum detectable limit. Replicate blind tests for the same sample occasionally exceeded the 20% allowable measurement error defined in our QAPP. These discrepancies likely arise from samples with off-scale nitrate concentration but low phosphate requiring dilution before analysis. Since both analyte concentrations were determined from the diluted sample, an added potential dilution error for phosphate needs to be accounted for. This was not clearly defined in the QAPP. Ultimately, the overall meaning of the data did not change, just the assignation of statistical significance for these low concentration values.

Attempts at deriving a consistent groundwater nutrient load reduction regression as a function of buffer width and vegetation treatment were thwarted because there were no consistent significant differences in concentration between sampling points within a transect (Table 1, Appendix 1) or between species treatments (Table 2, Appendix 1) at this point in tree development. The most consistently significant effects were block differences. Significant distance effects that do appear in one season are frequently not significant in a subsequent season.

Surprisingly, the distance-dependant reduction of nitrate and phosphate in soil solution was more consistently significant throughout the 2008 sampling period (Table 3, Appendix 1), although differences for phosphate are more consistently significant than for nitrate. As shown in Figure 10, the seasonal trend for phosphate levels in soil solution increase slightly in the wet winter months, but throughout the sampling period the upslope-downslope gradient is fairly well preserved. One explanation is that this is a preexisting gradient resulting from the historical application of chicken manure, which probably diminished closer to the creek. Mechanistically, it seems improbable that a distance-dependant nutrient gradient in soil solution could develop via sequential extraction by vegetation, especially with low angled stream banks. Alternatively, nutrient immobilization by soil microbes is a possible mechanism for the horizontal attenuation along a downslope gradient of increasing soil moisture and potentially higher levels of soil carbon.

To further evaluate the importance of soil effects versus tree effects on nitrate and phosphate levels in groundwater and soil solution we employed Pearson correlation analysis to determine if continuous variables such as depth to groundwater, dissolved oxygen in groundwater, and the performance of trees (conic stem volume) surrounding each lysimeter, might be more significantly correlated than distance (Tables 4 and 5, Appendix 1). Generally, depth to groundwater, and dissolved oxygen are auto-correlated variables, but there are subtle differences that may provide some interpretive value. For example, depth to groundwater may account for differences in topology between plots better than the fixed effect of distance, and dissolved oxygen may account for differences in soil carbon and soil saturation. Both would be highly auto-correlated with the extent of soil moisture saturation. The tree performance (conic stem volume) variable would have negative coefficients if nitrates were extracted by the trees, but positive coefficients if nitrates were added by the trees.

The continuous variables most highly correlated and significant with soil solution nitrate were depth to groundwater and dissolved oxygen for all plots in block 1 in the dry months of May and June 2008, more so than in block 2 (Table 4, Appendix 1). There were, as expected, large differences between blocks. In the cooler wetter months of March and December when the trees are dormant, the soil is frequently saturated, and the general abundance of soil solution nitrate is lower in all plots, there are no significant correlations. Tree performance as indicated by stem volume was not significantly correlated in either block for winter or summer months. These findings are consistent with the hypothesis that low soil moisture concentrates nitrate levels in soil solution. For groundwater nitrate, continuous variables for soil water which had high correlation coefficients did not follow a seasonal trend nor were they consistently high for any buffer treatment.

The continuous variable most significantly (positively) correlated with phosphate in soil solution was depth to groundwater in both blocks, all seasons, and primarily in treed plots (Table 5, Appendix 1). This finding is the same as for the mean separation analysis of soil solution phosphate as a function of distance (Table 3, Appendix 1). However, alder tree performance in block 2 was also frequently (negatively) correlated. This suggests that the greater the aboveground biomass in alder trees, a proxy variable for belowground biomass, the greater the reduction in phosphate from the soil solution. However, since alder performance in block 2 was poor, especially in the middle of the plot, the effect of tree performance is amplified. The implication might just as well be that this correlation would be less significant in a more uniform stand of alders, as is the case for alder trees in block 1.

For groundwater phosphate there were no consistently significant correlations with soil moisture related continuous variables. This finding is consistent with the mean separation analysis found in Table 1 and 2, Appendix 1.

Overall conclusions

- At this early stage in buffer vegetation development, the relative abundance of nitrate in groundwater moving through the buffer system was affected most by nutrient influx levels and by seasonal environmental fluxes in the form of precipitation and evapotranspiration.
- Trees are contributing to soil fertility, which at this early stage in buffer establishment, have a negative impact on measurements of nitrate reduction efficiency relative to grass. But, tree contributions to soil carbon are likely having a positive impact to the soil microbial community that are actively fixing or denitrifying soluble nitrate.
- The effects of site (soil texture) heterogeneity, natural nutrient gradients and gradients resulting from historic applications if soil nutrient amendments, differing nitrate and phosphate influx levels, mixed tree performance, and relatively little root exploration of the buffer soil have confounded our efforts to determine a significant distance-dependant relationship with nutrient load attenuation, or a buffer species effect. However, these data will provide a valuable baseline for comparison in future monitoring efforts.

Water quality benefits

While the apparent benefits to water quality measured in nutrient load reduction efficiency were not significantly higher in the forested buffers relative to grass buffers during the first years of establishment, the carbon inputs and tree respiration in the forested plots contributed to a low soil oxygen environment favorable to denitrification. In addition, the rapid growth of poplar and alder trees provided stream bank stabilization, some shading of the creek, and supplied carbon energy in the form of leaf litter to the aquatic invertebrate habitats that support local and migrating fish.

Follow-up

To further our understanding of the effects of tree development and tree species on width-dependant effectiveness, groundwater nutrient monitoring will be continued at a future date as funding becomes available. Another project of interest that can be investigated at this site is to measure the effects of forest thinning followed by under-planting with native species on buffer effectiveness. In this case monitoring for groundwater and soil nutrient levels would be done in the year before and several years after thinning.

A major methodological issue in the testing of the efficacy of the experimental buffers' ability to attenuate nitrates is that they may not have been subjected to sufficiently high inputs to truly test the system. A possibility for future research is to till the adjacent ground upslope of the 25 ft grass filter strip and deliberately apply known amounts of nitrogen-containing fertilizers. This will help overcome high spatial variability in naturally-occurring or pre-existing soil nitrogen levels. Another possible activity is to assess the potential to generate commercial secondary products such as Christmas trees, horticultural products, or edible berries in the buffers following a thinning operation to enhance understory light availability.

General Comments

Since the outcome of the data collection and evaluation of this project occurred after Dr. Jon Johnson's fatal illness and passing, and because the intentions and expectations that informed his experimental design were not fully communicated with the author of this report in the few months we worked together, there are numerous questions about the experiment that remain unanswered. The project objectives stated at the beginning of this report were drafted by Dr. Johnson. The issues that result from the way the experimental design was set up are:

a) While using a uniform planting of a single species in an agroforestry buffer treatment is a desirable approach for controlling variables for research purposes, as practical demonstration model for a buffer application this approach has serious shortcomings.
   i. The premise that limited harvesting of a rapidly growing tree species along a buffer can provide supplemental farm income is, in many cases, not an allowable practice. State and county jurisdictions that define critical areas and set policy for buffer installation and management often prohibit harvest and require mixed native vegetation.
   ii. While a uniform planting of rapidly growing hybrid poplar may provide information about species effects on nutrient attenuation, there are justified concerns that the use of non-sterile hybrids could act a source of "genetic pollution" to local populations of native Black Cottonwood.
   iii. One of the premises of this project was to build and demonstrate how a managed forest buffer can produce a variety of forest products for supplemental farm income. However, a specific plan for tree thinning, under-planting, and harvest was not developed as part of a long term plan before the experiment started.

b) The buffer plots were not challenged uniformly. Because the plots were located at varying distances from the agricultural fields that received different rates of plant-available nitrogen, the experimental plots did not receive the same inputs, which undermined the power of a replicated trial. Had a 20 to 30 foot wide strip upslope of all the grass filter strips been disked and cultivated to simulate an agricultural field, and a high concentration nitrate fertilizer been evenly applied at a common application rate, then all the plots would have been challenged approximately the same.

c) The spacing of the piezometers along transects were apparently set with a bias to an expected rate of attenuation. The rationale is unclear. A more objective approach would have been even spacing, say 5 piezometers per transect spaced at 12.5 foot intervals, which may have improved the analysis of attenuation based on distance and produced a result better equipped to answer the question regarding minimum buffer width.

d) Buffer plots were not planted at varying widths. A greater number of replicates with varying widths would have addressed the buffer width question more directly.

e) Aside from the fact that the overland runoff and sediment flow collectors need to be redesigned to minimize soil disturbance during installation and from soil-dwelling fauna, no collectors were placed upslope of the grass filter strip at the edge of the cultivated fields to evaluate grass filter-strip effectiveness.

Education and Outreach

Formal presentation of the research site and findings occurred on two occasions; 1) On June 16, 2009, five classes of Puyallup High School students visited the buffer site for an educational field trip. We provided instruction on the functions of a buffer in an agricultural setting, and conducted hands-on demonstrations of how to take water samples from groundwater, the soil solution through suction lysimeters, and take clean samples from surface water. The students also learned about how tensiometers work, and did field testing for nitrate nitrogen in the samples they collected using the LaMotte test kit. 2) On August 3, 2009, we provided instruction to participants of the Tilth Producers Farm Walk Series held at WSU Puyallup Research and Extension Center. Participants rotated through four education stations, one of which was the buffer site. Jeff Kallestad presented a brief description of the research plots and outcomes to date, and a primer on basic buffer functions. Dr. Mark Swanson, Associate Professor of silviculture at WSU presented information on establishing and managing a forested riparian buffer. Carol Sikorski, Farmbudsman for Pierce County, and Diane Dieby, Biologist with the Pierce County Planning Department, presented information and literature about rules and regulations for buffers adjacent to critical shoreline areas. Printed material about the NRCS CREP program, and WSU extension publications on taking care of streams in Western Washington was also made available to participants. Approximately 80-100 people attended the farm walk, comprised of farmers, interested public, and representatives of various state and local agencies. The event was advertized on the Tilth Producers website, and a second advertizment was circulated by the WSU Western Washington Extension director to area-wide Extension offices.

A five page summary of the Clarks Creek buffer project including a project description, measurement outcomes, evaluation, follow-up, and implications for agriculture has been posted on the WSU Ag-buffer website (http://www.puyallup.wsu.edu/agbuffers/).

Networking: On April 15, 2009 , in a program sponsored by Puget Sound Partnership, environmental education providers interested in creating a county-wide network to exchange information, skills, and program partnership (an ECONet) met at the WSU Puyallup Research and Extension Center. Information about the riparian buffer research project along Clarks Creek was presented as an ongoing demonstration project that would be available for education purposes. This project will be an important part of WSU-Puyallup Research and Extension Center's expanding role in addressing issues related to the impacts of urban development on the environment.

Figure 18. A gathering of one of four groups to hear a field presentation about our research findings and information on buffer establishment and management at the 2009 Farm Walk held at WSU-Puyallup.

Figure 19. Puyallup High School students learn about groundwater sampling and test for nitrate levels in samples they collected from the buffer plots.

Acknowledgments

With gratitude we acknowledge the US Environmental Protection Agency, through the Washington State Department of Ecology, for providing the funding to install and maintain the buffer plots, and purchase the requisite instrumentation and analytical services. The original recipient of this grant award, Dr. Jon Johnson, was a seasoned researcher in intensive forestry and plant stress physiology. Jon tragically died due to illness before the completion of this project. It was his deep concern for protecting environmental quality of the Puget Sound that led him to find applications of intensive forestry in the installation of riparian buffers on agricultural lands. His concern and vision will continue with this project. With appreciation we also acknowledge the efforts of the technical support personnel that worked on this project, including: Joe Hudack, Chad Carter, William Simon, Coila Craig, and John Rockey. Thanks also to Dr. Mark Swanson for editorial support and insights.

Appendices

Appendix 1. Statistical results

Table 1. Result of mean separation analysis grouped by treatment (species) for the dependent variables of nitrate and phosphate concentration in groundwater as a function of downslope distance into the buffer, block, and distance by block interactions using SAS GLM procedure. Values indicate probability Pr >F at alpha =0.05, ns = not significant

Sample date	Species	Analyte	Distance	Block	Dist*Blk
Dec-07	Alder	N	0.0009	0.0015	0.0399
		P	ns	ns	ns
	Grass	N	0.0370	0.0033	ns
		P	ns	ns	ns
	Poplar	N	ns	ns	ns
		P	ns	ns	ns
Mar-08	Alder	N	ns	0.0006	ns
		P	ns	0.002	ns
	Grass	N	0.0336	0.0088	ns
		P	0.0303	0.019	ns
	Poplar	N	ns	0.0298	ns
		P	ns	0.0146	ns
May-08	Alder	N	ns	0.0006	ns
		P	ns	0.002	ns
	Grass	N	0.0336	0.0088	ns
		P	0.03	0.019	ns
	Poplar	N	ns	0.0298	ns
		P	ns	0.0146	ns
Jun-08	Alder	N	ns	0.0069	ns
		P	ns	ns	ns
	Grass	N	ns	0.0155	ns
		P	ns	ns	ns
	Poplar	N	0.0117	ns	ns
		P	ns	0.0384	ns
Dec-08	Alder	N	ns	0.0005	ns
		P	ns	ns	ns
	Grass	N	ns	ns	ns
		P	ns	ns	ns
	Poplar	N	ns	ns	ns
		P	ns	ns	ns

Table 2. Result of mean separation analysis for the dependant variables of nitrate and phosphate concentration in groundwater as a function of buffer species, downslope distance into the buffer, and block using SAS GLM procedure. Values indicate probability Pr >F at alpha =0.05, ns = not significant.

Sample date	Analyte	Species	Distance	Spp*Dist	Block	Spp*Blk	Dist*Blk	Spp*Dist*Blk
Dec-07	N	ns	0.0003	ns	0.0199	0.0172	ns	ns
	P	ns	ns	ns	ns	ns	ns	ns
Mar-08	N	ns	ns	ns	ns	0.0095	ns	ns
	P	ns	ns	ns	ns	ns	ns	ns
May-08	N	0.0031	ns	ns	0.0003	<0.0001	ns	ns
	P	ns	0.0249	ns	<0.0001	ns	ns	ns
Jun-08	N	0.0243	ns	ns	0.0002	0.0018	ns	ns
	P	ns	ns	ns	ns	0.032	ns	ns
Dec-08	N	ns	ns	ns	<0.0001	0.0564	ns	ns
	P	ns	ns	ns	ns	ns	ns	ns

Table 3. Result of mean separation analysis for the dependant variables of nitrate (N) or phosphate (P) concentration in soil solution as a function of downslope distance into the buffer, lysimeter depth, and block, grouped by treatment species using the SAS GLM procedure. Values indicate probability Pr >F, at alpha=0.05, ns = not significant at p>0.05.

Date	Species	Analyte	Distance	Depth	Dist*Dep	Block	Dist*Blk	Dep*Blk	Dist*Dep*Blk
Dec-07	Alder	N	ns	ns	ns	ns	ns	ns	ns
		P	<0.0001	ns	ns	<0.0001	0.0005	ns	ns
	Grass	N	ns	ns	ns	0.0256	ns	ns	ns
		P	0.0049	ns	ns	0.0267	ns	ns	ns
	Poplar	N	0.0022	ns	ns	<0.0001	0.0023	ns	ns
		P	0.0065	ns	ns	0.0031	ns	ns	ns
Mar-08	Alder	N	ns	ns	ns	ns	0.0184	ns	ns
		P	<0.0001	ns	ns	<0.0001	<0.0001	ns	ns
	Grass	N	ns	ns	ns	0.037	ns	ns	ns
		P	0.0279	ns	ns	0.0471	ns	ns	ns
	Poplar	N	ns	ns	ns	0.0054	0.002	ns	ns
		P	0.0093	ns	ns	0.0182	ns	ns	ns
May-08	Alder	N	ns	ns	ns	ns	ns	ns	ns
		P	<0.0001	0.0371	ns	<0.0001	0.0007	ns	ns
	Grass	N	0.0078	0.0081	0.0411	ns	ns	ns	ns
		P	0.0329	ns	ns	0.0495	ns	ns	ns
	Poplar	N	0.0085	ns	ns	0.0169	<0.0001	ns	ns
		P	0.0067	ns	ns	0.0528	ns	ns	ns
Jun-08	Alder	N	ns	ns	ns	0.0055	ns	ns	ns
		P	<.0001	0.0223	ns	<.0001	<.0001	0.037	ns
	Grass	N	ns	ns	ns	ns	ns	ns	ns
		P	0.0226	ns	ns	0.0262	ns	ns	ns
	Poplar	N	ns	ns	ns	ns	ns	ns	ns
		P	0.028	ns	ns	0.0015	ns	ns	ns
Dec-08	Alder	N	0.0052	ns	ns	ns	0.0048	ns	ns
		P	<.0001	ns	ns	<0.0001	<0.0001	ns	ns
	Grass	N	ns	ns	ns	ns	ns	ns	ns
		P	0.0075	ns	ns	0.0475	ns	ns	ns
	Poplar	N	0.0015	ns	ns	<.0001	0.0077	ns	ns
		P	0.0193	ns	ns	0.0011	ns	ns	ns

Table 4. Pearson product-moment correlation coefficients for the covariance of nitrate in soil solution or groundwater with the continuous independent variables of depth to groundwater (GW), dissolved oxygen, conic stem volume measured from of trees surrounding each lysimeter group. Soil solution nitrate values were averaged from both lysimeter depths and both transects per plot at each downslope distance position. Groundwater nitrate levels were averaged from both transects per plot at each downslope position. * Significant at $p<0.1$, ** significant at $p<0.05$.

			Soil solution nitrate			Groundwater nitrate	
Date	Block	Plot species	Depth to GW	Dissolved Oxygen	Stem Volume	Depth to GW	Dissolved Oxygen
Mar-08	1	Alder	0.492	0.369	-0.139	0.411	0.249
		Grass	0.400	0.597	-	0.843**	0.960**
		Poplar	0.474	0.113	0.630	0.357	0.075
	2	Alder	-0.094	-0.259	-0.142	0.219	-0.015
		Grass	0.320	0.104	-	0.524	0.226
		Poplar	-0.288	-0.110	0.467	0.155	0.269
May-08	1	Alder	0.785**	0.599	-0.425	0.876**	0.613
		Grass	0.815**	0.813**	-	0.852**	0.873**
		Poplar	0.887**	0.931**	0.407	-0.071	-0.456
	2	Alder	-0.388	-0.297	0.154	-0.394	-0.392
		Grass	0.404	0.195	-	0.812**	0.728**
		Poplar	-0.220	-0.391	0.431	0.543	0.375
Jun-08	1	Alder	0.817**	0.812**	-0.412	0.747**	0.661*
		Grass	0.855**	0.835**	-	0.715**	0.615
		Poplar	0.783**	0.921**	0.198	0.000	-0.080
	2	Alder	0.367	0.231	-0.585	-0.173	-0.004
		Grass	0.460	0.175	-	0.851**	0.551
		Poplar	0.598	0.382	-0.399	0.571	0.217
Dec-08	1	Alder	0.138	-0.160	0.432	0.240	0.318
		Grass	0.158	0.354	-	0.487	0.631
		Poplar	0.833**	0.628*	0.562	0.787**	0.819**
	2	Alder	-0.575	-0.120	0.320	0.191	-0.207
		Grass	0.476	0.087	-	0.721*	0.540
		Poplar	0.184	-0.255	0.346	-0.470	-0.157

Table 5. Pearson product-moment correlation coefficients for the covariance of phosphate in soil solution or groundwater with the continuous independent variables of depth to groundwater (GW), dissolved oxygen, conic stem volume measured from trees surrounding each pair of lysimeters. Soil solution phosphate values were averaged from both lysimeters depths at each downslope position. ND = no data collected, * significant at p<0.1, ** significant at p<0.05.

			PO_4 in Soil solution			PO_4 in Groundwater	
Date	Block	Species	Depth to GW	Dissolved Oxygen	Stem Volume	Depth to GW	Dissolved Oxygen
Mar-08	1	Alder	0.918**	0.878**	-0.452	0.665*	0.444
		Grass	0.564	0.768*	-	0.615	0.840*
		Poplar	0.673*	0.458	0.698*	0.418	0.128
	2	Alder	0.930**	0.761**	-0.842**	0.350	0.164
		Grass	0.693*	0.528	-	0.337	0.343
		Poplar	0.871**	0.497	-0.366	0.268	0.572
May-08	1	Alder	0.870**	0.547	-0.455	0.527	0.039
		Grass	0.401	0.371	-	0.263	0.180
		Poplar	0.839*	0.722*	0.588	0.686*	0.854**
	2	Alder	0.939**	0.636*	-0.838**	-0.556	-0.326
		Grass	0.682*	0.517	-	0.880**	0.753**
		Poplar	0.873**	0.404	-0.439	0.317	0.665*
Jun-08	1	Alder	0.867**	0.775**	-0.190	0.223	-0.107
		Grass	0.285	0.149	-	0.474	0.352
		Poplar	0.687*	0.738**	0.627	0.407	0.523
	2	Alder	0.916**	0.634*	-0.846**	0.181	0.664*
		Grass	0.701*	0.390	-	-0.050	0.156
		Poplar	0.821*	0.666*	-0.365	0.257	0.401
Dec-08	1	Alder	0.714**	0.462	-0.367	0.400	0.457
		Grass	0.345	0.562	-	0.203	0.479
		Poplar	0.726**	0.773**	0.559	0.404	0.554
	2	Alder	0.901**	0.657*	-0.724**	-0.002	0.590
		Grass	0.834**	0.530	-	0.650*	0.458
		Poplar	0.853**	0.741**	-0.411	0.279	-0.156

Appendix 2. Sample collection protocol

I. Piezometer sampling

1. Ensure all sampling equipment has been acid washed (1N HCL), triple rinsed in d-H_2O and dry.
2. Label collection bottles 1 – 49.
3. Measure water table depth to nearest cm with Solinst model 39931 water depth meter
4. Pump out piezometers to remove stagnant water.
   a. Pump until piezometer is dry or until 5 gallons have been pumped out.
5. Starting with piezometer #1 follow the process below – move sequentially through the transects.
   a. Drop weighted tube to bottom (fig. 3).
   b. Insert labeled collection bottle onto stopper (Fig. 2).
   c. Turn 3-way valve to by-pass collection bottle (Fig. 2).
   d. Pump until water moves into to the overflow carboy
   e. After 15 seconds, turn 3-way valve to fill collection bottle and fill to top.
   f. Once full, turn 3-way valve to seal vacuum in carboy, remove collection bottle and cap.
   g. Place the "wash" collection bottle on stopper, remove weighted tube from piezometer, place into 1N HCl reservoir and turn the 3-way valve to restore vacuum to tube. Take several 'sips' of HCl into tube followed by several sips of d-H_2O.
   h. Using the squeeze bottle, rinse outside of collection tube with HCl followed by d-H_2O.
   i. Remove the collection bottle and rinse stopper with d-H_2O.
   j. Move to next piezometer and repeat process.
   k. After collecting samples from one plot, place samples into cooler.
6. For sample 49, taken from Clarks Creek, take the clean collection bottle, attach to telescoping pole and extend bottle into the middle of the stream allowing the bottle to fill with water. Retrieve and decant sample into the labeled collection bottle. Place in cooler.
7. Transport samples in the cooler to the lab and place in lab refrigerator – check temperature (4C). Allow samples to sit overnight. The next morning, decant samples with sediment into clean, labeled bottles.
8. Samples are loaded into a cooler, blue ice added to the top and the list of samples place on top. Seal cooler with strapping tape.
9. Mail to OSU Central Analytical Lab by FEDEX overnight delivery or hand deliver to the University of Washington Analytical lab
10. Wash all sampling equipment with acid (1N HCL), triple rinsed in d-H_2O and then air dry in wash room.
11. Annually in the summer, brush, pump out and rinse each piezometer with d-H_2O.

Figure 1. Vacuum pump connected to carboy.

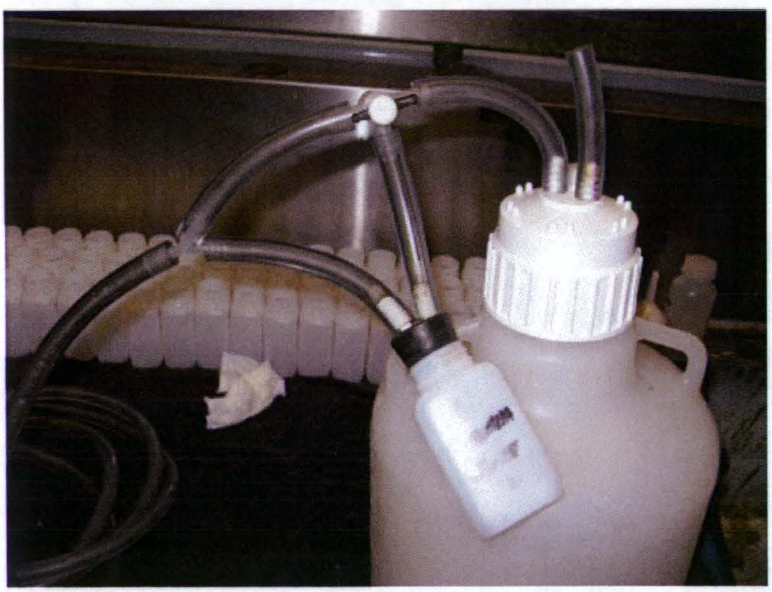

Figure 2. Collection bottle attached to stopper. The 3-way valve is used to direct sample stream first into carboy to rinse tubing, then turned to direct sample stream into the collection bottle.

Figure 3. Collection tube with weighted Teflon tip is dropped into piezometer. Collection bottle and 3-way valve are described in Fig. 2.

II. Soil Solution sampling

1. Day before sampling, pull vacuum on all soil water samplers using a 50 mL syringe provided.
   a. Connect syringe to 3-way valve, open valve to syringe and pull plunger (Fig.4).
   b. Close 3-way valve to keep vacuum in soil water sampler, depress plunger.
   c. Repeat steps a. and b. until the plunger is difficult to pull indicating the presence of a vacuum in the sampler.
2. Ensure all sampling equipment has been acid washed (1N HCL), triple rinsed in d-H_2O and dry.
3. Label collection bottles 1 – 48 and either 18 or 24 for sampler depth.
   a. Put each plot's bottles (16) into plastic ice bag and label.
4. To sample, detach 3-way valve on sampler tubing and insert a clean one attached to the syringe (Fig.4). Open valve to syringe and pull plunger. Water will be pulled into the syringe. Turn the 3-way valve to dispense sample into collection bottle. Repeat process until no more water is pulled from soil water sampler.
5. Replace "field' valve on tubing.
6. Wash syringe by pulling 1N HCl into syringe, dispense back into acid bottle. Rinse with d-H_2O. Move to next sampler and repeat process.
7. After collecting samples from one plot, place samples into cooler.
8. Transport samples in the cooler to the lab and place in lab refrigerator – check temperature (4C). Allow samples to sit overnight. The next morning, decant samples with sediment into clean, labeled bottles.
9. Samples are loaded into a cooler, as described above.
10. Wash all sampling equipment with acid (1N HCL), triple rinsed in d-H_2O and then air dry in wash room

Figure 4. Soil solution sampler showing sampler, tubing, 3-way valve and syringe.

III. Surface Flow and Sediment collection

Overland flow and sediments carried in this flow will be collected by Low Impact Flow Event (LIFE) samplers (Sheridan et al. 1996) to collect both 1/12 and 1/144 flow samples. A pair of collectors, one each at the upslope and down slope edge of the 50 foot buffer, was installed in all three plots of block 2 (downstream block, Fig. 1). After rain events of greater than 0.5 inches in 24 hours, the collectors will be sampled as follows:

1. Remove the 1L collection bottle of the 1/12 collector. If it is not full, then measure volume using an appropriate sized graduated cylinder; record to nearest milliliter. Swirl bottle to suspend sediments before pouring. If the bottle is full, then remove the bottle of the 1/144 collector and measure volume. In any case, rinse both bottles, shake dry and re-install.
2. Transfer liquid from graduated cylinder into a clean, acid-washed bottle appropriately labeled bottles making sure to transfer all sediments. Note if the sample came from the 1/12 or 1/144 bottle.
3. Take samples to laboratory.
4. Using pre-weighed, labeled Whatman #1 filter paper, filter the contents of each bottle under vacuum, making sure all sediments are washed out of the bottle into the filter.
5. Once all of the water has been filtered, remove filter with forceps and transfer to drying oven and dry for 24 hours at 60C.
6. Re-weigh filters, recording the weight. The difference in weight is the amount of sediments trapped in the collectors.
7. Calculate volume and sediment of surface flow by multiplying by 12 or 144, depending on bottle measured.
8. Using the width of collectors, expand volume and sediment loads to the 100' plot and record.