Clarks Creek Experimental Riparian Buffers: Monitoring, Function, and Implications for Agriculture

Summary Riparian buffers are widely considered to be a good land stewardship practice because of their ability to reduce agriculture-related non-point pollution. The performance and effectiveness of buffers is highly variable and site specific. Studies indicate that buffers of 15-30 meters (50-100 feet) provide adequate protection to aquatic resources under most circumstances, but disproportionately wider buffers are needed to obtain greater function [1][2]. However, data on riparian buffer function and design is 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. More importantly, there is little post-implementation information regarding their function with respect to reducing non-point pollutants coming from agricultural activities.

Clarks Creek is a salmon bearing tributary of the Puyallup River in Western Washington and has recently been selected by the Puyallup River Watershed Council and Pierce County Water Programs as a high priority area for improving water quality. Some of the key problems identified include stream bank erosion, fecal coliform, sediment and nutrient loading, invasive species, illegal dumping, and native forest clearing associated with development. Land use along Clarks Creek watershed is currently 4.7% agriculture, 43.7 % low density residential, 1.2% moderate density residential, and 49.1 % public parks and facilities and open space. Beginning in April of 2006 a series of experimental riparian buffers were established along the creek on Washington State University property adjacent to its research farm consisting of 3 treatments: mixed buffer of grass filter plus hybrid poplar, grass filter plus red alder, and grass alone. Each buffer treatment was replicated twice. Nitrate nitrogen and phosphate concentration in shallow ground water and soil solution were monitored in each plot beginning December 2006 and continued until December 2008. This study tracks the nitrate-nitrogen and soluble phosphate 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.

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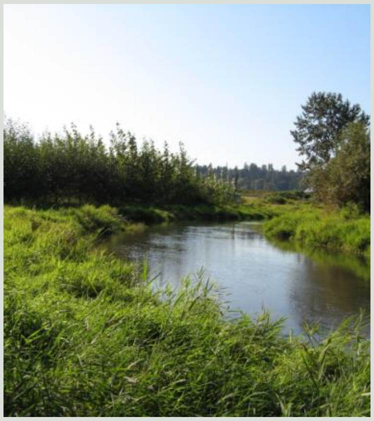
Objectives/Performance Targets Our overall goal is to identify what constitutes a functional riparian buffer that protects and restores water quality and improves salmon habitat on agricultural land in western Washington. While our research setting is agricultural, the principles learned about buffer function, design, establishment, and maintenance may also be applicable to suburban and urban areas of the state.

Specific objectives include: 1) determine effective buffer width for our site and nutrient loading conditions, 2) determine the effect of species composition on buffer function, 3) develop and disseminate science-based buffer recommendations and decision-making tools to farmers, farm agencies, regulators and policy makers dealing with farmland along lowland watercourses in western Washington.



Project description Experimental buffers on Clarks Creek were established in 2006 with funding from a Washington Department of Ecology Section 319 DIF grant. In March 2006, the experimental buffer site was cleared of debris and weeds. The following month buffer plots consisting of 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. Each tree plot measured 100 ft along the bank contour by 50ft width. An additional 25 feet of perennial rye grass was planted upslope of the tree plots. Two additional 100 by 75ft plots were planted in perennial rye grass (Fig.1). Throughout the first summer, and in subsequent years, the tree plots were kept free of weed competition by a combination of mowing and herbicide application. The grass plots were periodically mowed. Both grass clippings and leaf litter were left on the plots. Sprinkler irrigation was applied in the summer months as needed to mitigate water stress during tree establishment. A 4 ft high wire fence was installed along the creek to protect the trees from beaver damage.

In September 2006, 48 shallow groundwater wells (piezometers) were installed in the six plots; each plot with two transects with 4 piezometers. An initial groundwater sampling with nitrate nitrogen and phosphate analysis was conducted in December 2006.

In January 2007, 96 soil solution samplers (suction lysimeters) 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 water and sediment 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. Both piezometers and suction lysimeters were sampled thereafter on March 4, May 8, June 18 and Nov. 7, 2007. Sampling and analysis was continued under a phase II Section 319 DIF grant on Dec.18, 2007, and on March 4, May 7, June 3 and Dec.1, 2008. On each sampling date in 2008 we also measured dissolved oxygen in groundwater at each piezometer. After three growing seasons poplar tree heights range from 13 to 29 ft, and alder tree heights range from 4.5 to 25 ft.

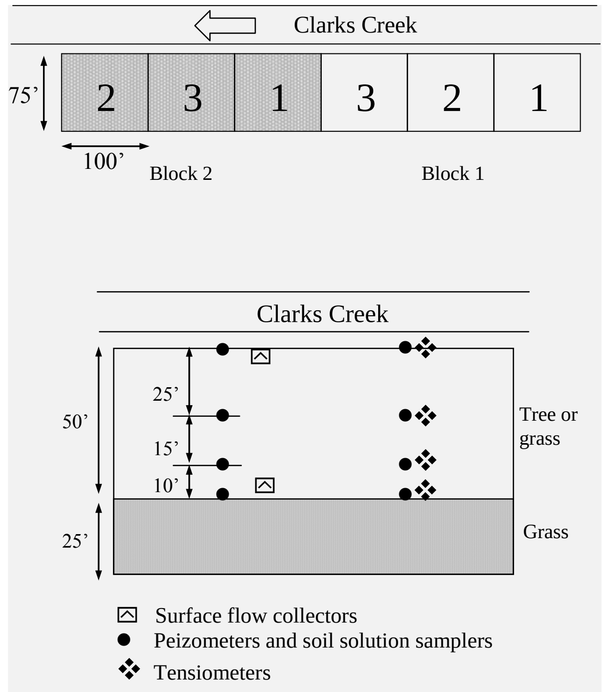


Figure 1 Schematic of all buffer plots along Clarks Creek shown in upper panel. Plots 1 = grass, 2 = hybrid poplar, 3 = red alder. Lower panel shows layout of instruments in a plot.

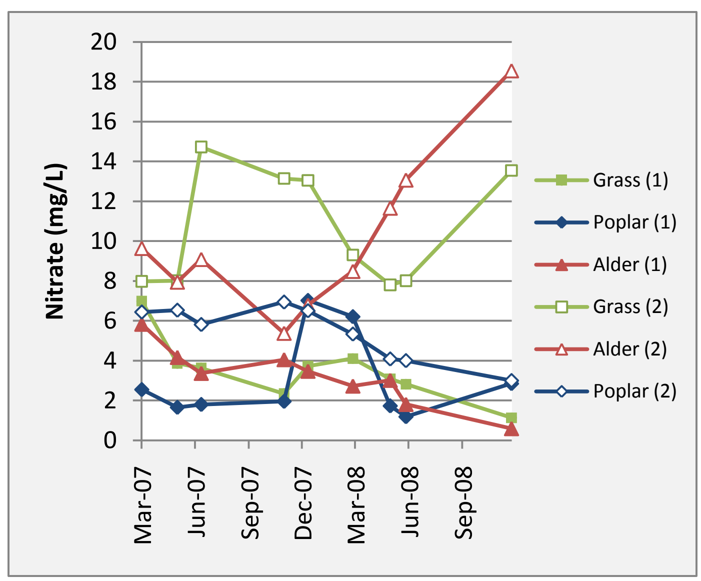


Figure 2 Groundwater nitrate nitrogen influx at each buffer plot during the sampling period. Data points represent the average of both transects per buffer plot at the furthest upslope position.

Outcome Environmental inputs and tree performance both contributed to groundwater nutrient reduction levels in the early years of tree establishment. Alder and poplar trees in the downstream buffers (block 2) experienced some reduced growth due to high soil permeability and more frequent water stress during the dry summer months while upstream tree plots thrived in organic rich soil and shallower depth to groundwater. Groundwater nitrate influx increased in 2008 in the Grass (2) and Alder (2) plots, which were adjacent an agricultural field receiving plant-available nitrogen applied at a rate of 40-60 lb/acre (Fig.2). Generally, nitrate levels entering the buffer were relatively low in the upstream buffers and decreased over the measurement period. Buffer plots in block 1 and the downstream poplar buffer were more distant from agricultural fields. Seasonally, depth to groundwater at the top of the buffers ranged from 4.3 to 7.8ft.and at the bottom ranged from 0.25 to 2.5 ft.

While poplar trees performed poorly relative to alder in frequently saturated hypoxic soil near the creek (Fig 3), the comparative species effects on nitrate extraction from shallow groundwater was not consistent or significant over the sampling period (Fig 4). Groundwater nitrate levels within the tree plots peaked in the fall and winter months of 2007-2008 when trees were dormant and rainfall was highest. In contrast, nitrate-nitrogen measured in the soil solution was found to be highest during the late spring and summer months when evapotranspiration was highest, likely a concentrating effect from the depletion of soil moisture by the trees, as well as declining seasonal hydraulic flux and reduced leaching. In many cases we observed higher groundwater nitrate levels in the tree plots at the 10 and 25 foot downslope distance position than at the top of the buffer. Some of this can be attributed to site heterogeneity, but also to tree inputs from root turnover and leaf litter decomposition (Fig 4).

Carbon inputs originating from trees play an important role in the processes of denitrification and nitrogen immobilization in saturated soil of forested riparian buffers. Facultative anaerobic soil microbes that utilize nitrate instead of oxygen for cellular respiration require carbon derived from decomposing root and leaf tissue, humic substances, and simple sugars found in root exudates. To determine the extent of hypoxic or anaerobic soil conditions in the buffer that would favor denitrification, we measured dissolved oxygen in the groundwater sampled in piezometers within a few days of the nitrate sampling dates

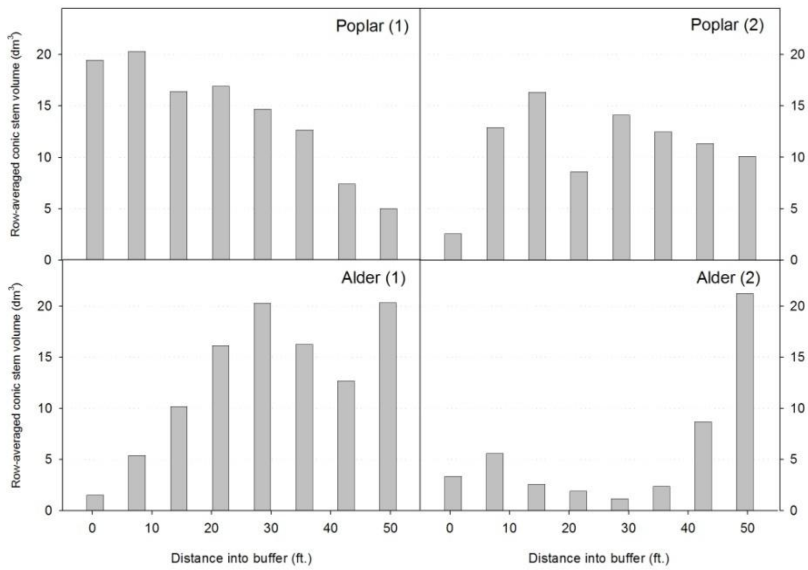


Figure 3 Tree performance after 3 growing seasons, expressed as row-averaged conic stem volume as a function of downslope distance into the buffer.

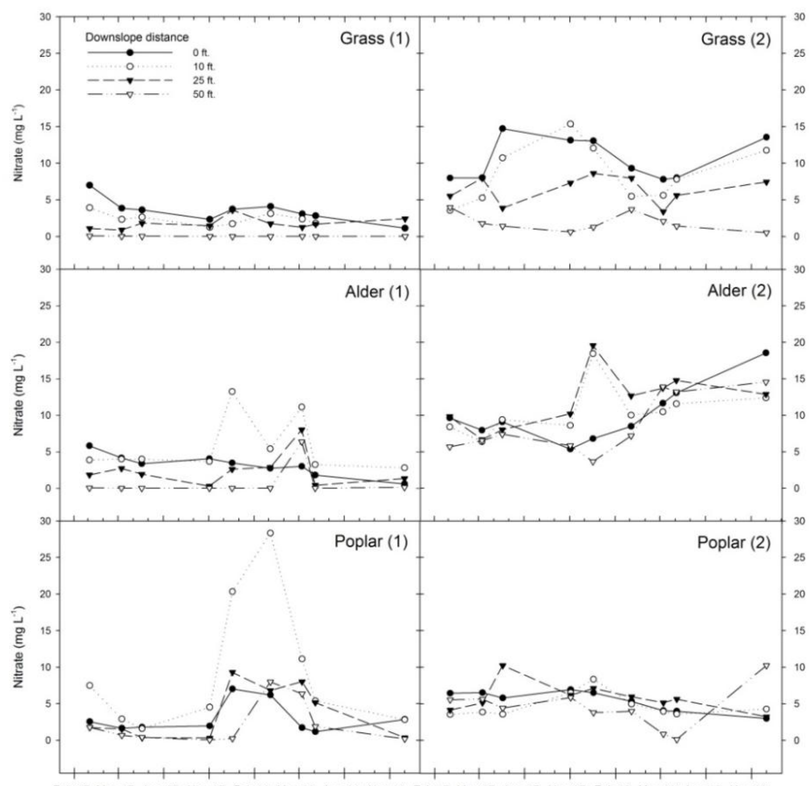


Figure 4 Time series plots of nitrate nitrogen concentration in shallow groundwater sampled from piezometers. Each point represents the buffer plot mean at each downslope position.

beginning in March 2008 (Fig. 5). Generally, grass plots had higher levels of dissolved oxygen at the 25 and 50 foot positions compared to the tree plots. Lower dissolved oxygen in the tree plots likely result from a combination of tree root respiration, greater carbon inputs from trees relative to grass, and the effect of shading on soil temperature. The lowest levels of dissolved oxygen occur in the summer months when the soil temperatures are higher, tree root and soil microbial metabolism is increased, and warmer groundwater will physically hold less dissolved oxygen.

Measured groundwater phosphate ranged from 0.01-2.25 mg L^{-1} over the sampling period. Computed phosphate reduction efficiency (not shown) was complicated by values being close to the lower limits of quantitation, except for initial high values that were possibly related to soil disturbance during the buffer site preparations.

Groundwater nitrate removal efficiency was computed as the percent difference between the extreme upslope and downslope concentrations averaged over both transects per plot. Efficiency was highly variable across plots and years, and did not correlate with species (Fig. 6). In 2007 upslope tree roots most likely did not have access to groundwater, and therefore high buffer efficiency is due primarily to extraction and assimilation by downslope trees as well as the processes of denitrification and nitrogen immobilization. Generally, trees in block 2 planted in sandier soils had poor growth performance which resulted in low buffer efficiency. For the poplars in block 2, the efficiency increase in June 2008 was transitory. Negative efficiency values have been noted by others to be associated with the early phases of buffer establishment where tree inputs increase soil fertility that can leach into groundwater.

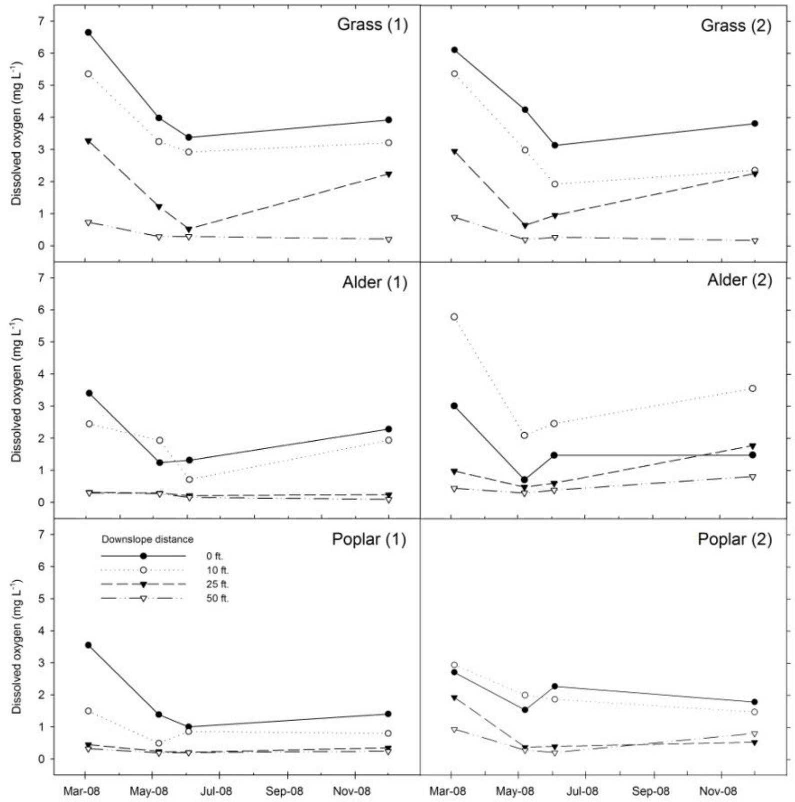


Figure 5 Plot-averaged dissolved oxygen in shallow groundwater measured in piezometers in 2008.

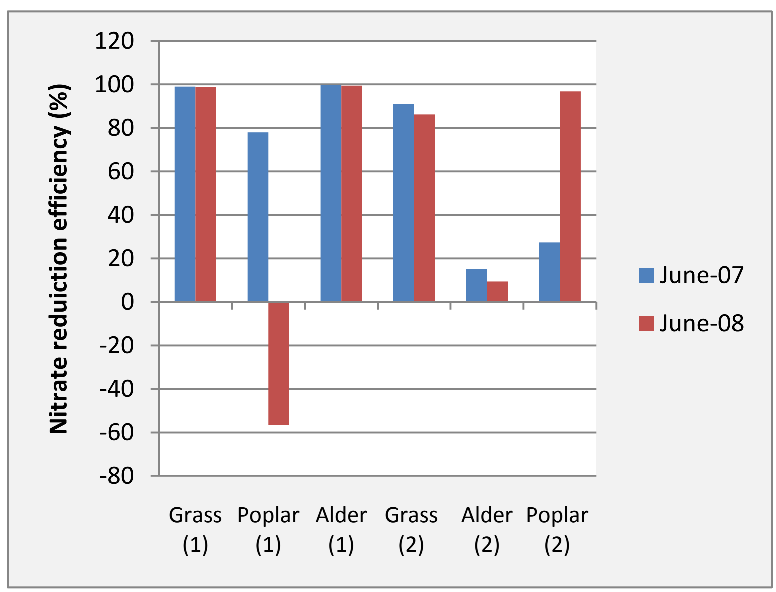


Figure 6 Buffer efficiency in removing nitrates from shallow groundwater during peak growing season in 2007 and 2008

For many of the sampling dates, groundwater nitrate nitrogen levels measured next to the creek were below the levels found in the creek, which ranged from 2.4 to 2.6 mg L^{-1} (Fig. 4).

Evaluation 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 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. In addition to extraction and assimilation of groundwater nutrients, 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.

Soil porosity and depth to groundwater were the most important site variables affecting buffer efficiency and tree performance. 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.

The effect of nitrogen fixation by red alder root symbionts on groundwater nitrate levels was confounded by increasing nitrate influx into the downstream alder plot (block 2). Nitrate measured in groundwater or soil solution was not significantly higher in the alder compared to poplar in block 1.

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.

Implications for agriculture Poplar and alder are among the fastest growing temperate region trees and as such they provide agricultural landowners in the Pacific Northwest a means to naturally and rapidly stabilize stream and drainage banks, reduce nutrient and sediments moving off-field, reduce stream temperature, and provide habitats for aquatic and terrestrial organisms. Both tree species are naturally adapted to riparian habitats and can withstand periodic flooding events. Mixed buffers with an upslope grass filter strip provides a runoff sediment capture zone and supply an easily manageable border between field crops and the forested riparian buffer. Mixed forested buffers also provide an intercept zone to prevent pesticide drift and soil nutrient amendments from directly entering surface water.

During the first years of tree establishment forested buffers will likely require water inputs during the dry summer months, especially in upslope well-drained highly porous soil where the groundwater is several feet deep. Weed management is also crucial to successful establishment. Our study indicates that even in the first years of tree development when groundwater nutrient assimilation has not progressed far, soil carbon inputs from root turn-over and leaf litter supply favorable conditions for denitrification even when the trees are dormant.


Mixed grass filter /forested riparian buffer USDA ARS image

Required buffer widths and recommended vegetation vary by site characteristics, land use, and water body attributes according to county and municipal ordinances. The width of buffers along salmon bearing streams should be based on its ability to provide habitat-based biological and physical requirements for spawning, incubation, rearing, feeding, sheltering, and migration.

References: [1] Meyer, P.M., S.K. Reynolds, and T.J. Canfield. 2005. Riparian buffer width, vegetative cover and nitrogen removal effectiveness: a review of current science and regulations. EPA/600/R-05/118. [2] Castelle, A.J., A.W. Johnson, and C. Conolly. 1994. Wetland and stream buffer size requirements-a review. J. Environ. Quality 23:878-882