Report for 2003CA40B: Evaluating the effectiveness of vegetated buffers to remove nutrients, pathogens, and sediment transported in runoff from grazed, irrigated pastures

- Dissertations:
    - Publications from 2003 Project Year Bedard-Haughn, A. 2004. Using 15N to quantify the effectiveness of vegetative buffers for sequestering N. Ph.D. Dissertation, Soil Science Graduate Group, University of California, Davis, CA 95616.
- Other Publications:
    - Publications from 2002 Project Year Bedard-Haughn, A., K.W. Tate, C. van Kessel. 2004. Using 15N to Quantify Vegetative Buffer Effectiveness for Sequestering N in Runoff. J. Environmental Quality. In Press. Publications from 2003 Project Year Bedard-Haughn, A., K.W. Tate, C. van Kessel. Quantifying the Impact of Regular Cutting on Vegetative Buffer Efficacy for 15N Sequestration. J. Environmental Quality. In Review. Bedard-Haughn, A., K.W. Tate, C. van Kessel. Impact of Buffer Management on 15N Attenuation from Surface and Subsurface water. J. Environmental Quality. In Review.

INTRODUCTION: Provide a brief overall introduction to your annual report.

Irrigated pastures are an essential source of low cost, green forage for livestock during summer months when the surrounding rangelands are dry and dormant. California's irrigated pastures are found throughout the Central Valley and Sierra Nevada's, within watersheds providing much of California's surface drinking water supplies. Significant amounts of surface water runoff can be generated from these pastures during irrigation, potentially transporting pathogens, nutrients, and sediment to nearby waterbodies. Our preliminary work indicates that nitrate, phosphorus, fecal coliforms, *E. coli*, *Cryptosporidium parvum* and sediment are transported from these pastures.

Vegetative buffers are often proposed to attenuate pollutants in runoff from grazed pastures. There is general evidence that buffers ranging anywhere from 3 to 200 m wide can protect aquatic resources from adjacent agricultural land use. Buffer recommendations are typically one-size-fits-all, and do not account for pasture characteristics or pollutant loading rates. A more applicable approach would be to base buffer size and management recommendations upon an understanding of the relationships between pollutant load in the pasture, buffer trapping efficiency, and buffer capacity over time for the suite of pollutants common to pastures (N, P, pathogens, and sediment). An understanding of the processes determining buffer efficiency and capacity will lead to more informed buffer establishment and management.

RESEARCH PROGRAM: Build your project information. The process for submitting each research project consists of the following progressive steps:

1.0. Research Problem

We examined the potential for vegetative buffers positioned at the bottom of flood irrigated, foothill pastures to attenuate nutrients, fecal borne bacteria, dissolve organic carbon and suspended solids contained pasture runoff during irrigation – runoff events.

2.0. Project Objectives

A. Quantify the effectiveness of buffers to attenuate N (NO_3, NH_4, total N), phosphorus (PO_4, total P), a common fecal borne indicator bacteria in livestock (*E. coli*), dissolved organic carbon, and suspended solids in surface water runoff from grazed, flood-irrigated pastures.

B. Employ the N isotope method to quantify N partitioning within pasture, buffer, and runoff.

C. Employ the N isotope method to determine whether buffer capacity for N decreases over time as buffer vegetation matures and species composition changes in the absence of grazing.

D. Extend the results of this research to the livestock industry, UCCE livestock and natural resource advisors, natural resources agency staff and water resource regulators.

3.0. Methodology

Research to achieve Objective A and B were conducted on existing research facilities at the University of California Sierra Foothill Research and Extension Center (SFREC) near Browns Valley in Yuba County. We developed a replicated infrastructure of 9 adjacent flood-irrigated plots allowing for the immediate implementation of this project in 2001. Buffer treatments (see below) were established on these plots in May 2000 and have been maintained continuously since that time. Research to achieve Objective C was conducted on plots established during this grant.

3.1. Objective A and B

During the summers of 2000 and 2001 we established 9 adjacent plots within an existing flood-irrigated pasture. A completely random study design was employed to allocate 3 buffer treatments in 3 replicates to 9 plots. Buffer treatments consists of a 3:1 pasture to buffer area ratio, a 6:1 pasture to buffer area ratio, and a no buffer control. Each plot has a 240 m^2 (5 m wide by 48 m long) pasture area. The 3:1 pasture to buffer area treatment has a buffer area of 80 m^2, and the 6:1 pasture to buffer area treatment has a buffer area of 40 m^2. Buffer length for the 3:1 and 6:1 buffer treatment is 16 and 8 m, respectfully. Plots were set out perpendicular to the slope and thus irrigation flow. Irrigation water is applied to each plot via adjustable flow rate irrigation pipe. Plots are irrigated for 4 hours every 11 days from April 15 to October 15. No irrigation occurs during the November to March wet season. Irrigation application amount was calibrated to ~ 6.0 and 4.0 L sec^{-1} per plot for 4 hours, in 2002 and 2003, respectively. These rates represent typical application rates for the region. Earthen berms separate adjacent plots to prevent water crossing from one plot to another. PVC collection troughs installed across the bottom of each plot collect all surface water runoff from each plot, allowing for the measurement of surface water runoff and collection of water samples for analysis.

Grazing on pasture areas was by mature beef cattle. Buffer areas and the collection troughs of all plots are fenced to exclude cattle. During 2002 cattle grazing was uniform across all 9 plots, with a grazing event occurring every 30 days, or approximately 1-2 days before every other irrigation event of the season. During 2003 cattle grazing was managed to establish a rest from grazing (days) treatment across the 9 plots such that over 8 trials each plot had at 2, 15, and 30 days rest from grazing prior to irrigation with a minimum of 2 replicates of rest treatment per plot. Each rest duration by buffer treatment combination was present in each trial.

3.1.1. 2003 Trials for Objective A

Eight study trials were conducted in 2003. Trials occurred bimonthly starting June 1. Cumulative cattle fecal load (kg/ha) was quantified in each plot's pasture area the day prior to each study trial via the comparative fecal load method. Buffers were excluded from grazing, fertilization, and all other forms of management. For each plot, surface water runoff (L/s) was measured via stop-watch and graduated cylinder, and water samples were collected at 1 (leading edge of runoff), 15, 30, 60, 90, and 120 minutes following commencement of runoff from each plot during each trial. Plot runoff water samples were analyzed for suspended solids (organic and inorganic), turbidity, pH, electrical conductivity, NO_3, NH_4, total N, PO_4, total P, dissolved organic carbon (DOC), and *E. coli* concentration. Analysis for *E. coli* was conducted within 24 hours of collection at the SFREC laboratory using the standard direct membrane filtration method. The remaining analyses were conducted at UCD following standard methods. Flux (load) of each pollutant per irrigation event was calculated as sum of the mean concentration by flow for each sample period. Linear mixed effects analysis was employed to evaluate buffer treatment effects and effect of rest from grazing and cumulative cattle fecal load on pollutant concentration and flux.

3.1.2. 2002 Use of ^{15}N for Objective B

In June 2002, ^{15}N-labeled KNO_3 was applied at a rate of 5 kg N ha^{-1} and 99.7 atom%^{15}N. The ^{15}N was applied across all 9 plots along the entire width of the experiment. The area to be labeled was 0.5 m wide and located 1 m above the buffer strips. Surface runoff water samples were collected during 12 irrigation trials (11 day schedule) starting 1 day after ^{15}N application. Samples were collected at 1, 15, 30, 60, 90, and 120 minutes following runoff commencement and analyzed for ^{15}N content. Soil water samples within pasture and buffers will be collected after each irrigation event and analyzed for ^{15}N content. Representative plant samples from the pasture and the buffer strips were collected at Days 1, 12, 31, 65, and 86 following application of the tracer and analyzed for ^{15}N content. ^{15}N isotope analyses were performed on all three N pools: NO_3^-, NH_4^+, and total N. To determine how far the ^{15}N-fertilizer moved into the buffer strip, plants were sampled along a down slope transect with a sample spacing of 1 to 2 m and analyzed for ^{15}N isotopic composition. Total aboveground biomass of the vegetation will be determined. Buffers were excluded from grazing, fertilization, and all other forms of management. Linear mixed effects analysis was employed to evaluate buffer treatment effect and effect of time after application and distance down slope from application on ^{15}N concentration and flux.

3.2. Objective C

To determine whether buffer N capacity decreases with increasing maturity of vegetation, a second set of non-grazed, non-fertilized buffer plots were established in the first year of this project (2002). This set contained 10 adjacent plots with the 1:3 buffer treatment (80 m^2, and 16 m buffer length). Among these 10 plots, 5 were allowed to develop to full maturity and 5 will be cut monthly from June through October to allow for maximum vegetation regrowth. In the second year, ^{15}N will be applied as a tracer to all ten plots, using the methodology outlined above, to determine whether new growth increases the demand for N, thus improving the efficacy of the buffers to trap N in runoff. Soil, soil water, plant materials, and surface runoff were collected as described above and tested for ^{15}N.

4.0. Principle Findings and Significance

4.1. Objective A

Buffers were relatively inefficient at attenuating pollutants under the irrigation application rate and resulting runoff conditions examined in this experiment. Neither buffer treatment resulted in a significant change (increase or decrease) in total flux of *E. coli*, total suspended solids (organic or inorganic), turbidity, total N, nitrate, or total P. This can likely be accounted for by the fact that there was no significant reduction in runoff volume (flux) due to either buffer. Thus, the primary mechanism for buffer efficacy, infiltration, was not sufficient to attenuate these pollutants. The hydrologic transport capacity was too great, and the residency time too short, in the buffer to allow for effective attenuation. There were apparent decreases in total N, nitrate and total P within the buffers indicating some attenuation of these pollutants within buffers and agreeing with results reported for Objective B. However, there were apparent increases in TSS, VTSS, and turbidity, while there were significant increases in DOC ($p=0.048$) at the 3:1 pasture to buffer area treatment. The buffer areas were serving as sources for particulate and dissolved organic matter. Discharge volume (m^3/ha) was positively related to all pollutants, illustrating the dominating influence of hydrologic transport capacity in this system. Duration of rest from grazing (2, 15, and 30 days) prior to irrigation event was significantly related to both the concentration and flux of all pollutants examined. Reduction in pollutant fluxes ranged from 10 to 40% for irrigations events occurring 30 days post grazing compared to irrigation occurring 2 days post grazing.

4.2. Objective B

Regardless of the form of runoff N (NO_3^-, NH_4^+, or DON), more ^{15}N was lost from the non-buffered treatments than from the buffered treatments. The majority of the N attenuation was by vegetative uptake. Over the course of the study, the 8 m buffer decreased NO_3^--^{15}N load by 28% and the 16 m buffer decreased load by 42%. For NH_4^+-^{15}N, the decrease was 34% and 48%, and for DON-^{15}N, the decrease was 21% and 9%. Although the buffers were effective overall, the majority of the buffer impact occurred in the first four weeks after ^{15}N application, with the buffered plots attenuating nearly twice as much ^{15}N as the non-buffered plots. For the remainder of the study, buffer effect was not as marked; there was a steady release of ^{15}N, particularly NO_3^--^{15} and DON-^{15}N, from the buffers into the runoff. This suggests that for buffers to be sustainable for N sequestration there is a need to manage buffer vegetation to maximize N demand and retention.

4.3. Objective C

Although maximum plant ^{15}N uptake and sequestration occurred within the zone of ^{15}N application, over-cutting of the pasture vegetation led to belowground N losses. Some of this ^{15}N was subsequently immobilized within the microbial biomass further down slope, but was still a potential source for leaching or runoff N losses. In the buffers, the cutting effect was not significant in the first few weeks following ^{15}N application, but over the irrigation season, cut buffers sequestered 2.3 times the ^{15}N of uncut buffers corresponding to an increase in above-ground biomass following cutting. Cutting and removing vegetation allowed the standing biomass to take advantage of soil ^{15}N as it was released by microbial mineralization. In contrast, the uncut buffers showed very little change in ^{15}N sequestration or biomass, suggesting senescence and a corresponding decrease in N demand. The doubling of ^{15}N sequestration in the cut buffers confirms that regular cutting and harvest of buffer vegetation increases N demand and uptake and thus, vegetative buffer effectiveness.

The greatest effect of cutting on runoff ^{15}N concentration occurred in the NO_3^- and total dissolved N pools: the uncut buffers had higher ^{15}N concentrations than the cut buffers. This same trend could be observed throughout the duration of the experiment in the NH_4^+ and DON pools. Soil solution ^{15}N concentrations in the A horizon were also significantly higher in the uncut buffer than in the cut buffer; however there was no corresponding significant difference in 0-15 cm soil atom % ^{15}N excess. Overall, cutting significantly improved ^{15}N attenuation from both surface and subsurface water. However, the effect was temporally related, and only became significant 21-42 d after ^{15}N application. The dominant influence on runoff water quality from irrigated pasture remains irrigation rate: reducing the rate by 75% relative to the typical rate resulted in a 50% decrease in total runoff losses and a 7-fold decrease in ^{15}N concentration.

4.4. Overall Significance

These results clearly illustrate that under typical high rates of irrigation application and resulting runoff it is unreasonable to expect significant attenuation of pollutants in runoff by non-grazed vegetative buffers installed at the base of flood irrigated foothill pastures. The hydrologic transport capacity and flushing ability of these high runoff rates reduce infiltration and residence time of pasture water entering the buffer and serve to mobilize and transport pollutants contained within the buffer. These results clearly illustrate that improvement of runoff from these pastures can be achieved primarily through integration of improved irrigation efficiency to reduce runoff and grazing management designed to off-set the grazing events from irrigation events, with the secondary implementation of managed (cut or moderately grazed) buffers once runoff rates delivered to the buffer are in balance with the buffer's infiltration capacity. Regular removal of vegetation in buffers is critical to maintain the buffer vegetation's nutrient uptake capacity and to reduce the build up of organic matter which can serve as a source for VTSS and DOC. Our future work in this system will examine the efficiency of buffers under irrigation application timing and rate determined by plant water demand and soil infiltration capacity in conjunction with multiple grazing management scenarios.

INFORMATION TRANSFER PROGRAM: Provide a brief description of information transfer activities supported with section 104 and required matching funds during the reporting period.

This study has played a major role in the University of California's *Rangeland Watershed Program's* (RWP) extension activities over the past several years. Since 1997 the *Ranch Water Quality Planning Short Course* conducted by the RWP has helped more than 400 ranchers voluntarily complete water quality plans covering more than 1 million acres of private ranches. The results of this research have been integrated into the numerous extension activities we conduct as part of the RWP including the ranch water quality short course. UC SFREC, the project site, has a mandate for extension education and information transfer of all research knowledge generated on the facility. We have been active in conducting field tours at the project site and have participated in the SFREC annual field day which is attended by ~150 individuals each year. In addition, the project site will be the site of a 2 day workshop on vegetative buffers to be held in Fall 2004 for agriculturalists from Chile. Finally, the results of this project have been reported nationally via presentations at professional meetings and conferences.

Extension presentations, field tours, professional presentations include:

2003 and 2004. SFREC Annual Field Day – site was a stop on the annual field tour and presentations were made to the group by project leaders and graduate students.

2003. CA Society for Range Management field tour at SFREC - site was a stop on the field tour and presentations were made to the group by project leaders and graduate students.

2003. Results were reported to CA State Water Resources Control Board – Surface Water Ambient Monitoring Program Continuing Conference.

2003. USDA NRCS Continuing Education Field Day - site was a stop on the field tour and presentations were made to the group by project leaders and graduate students.

2003. Bedard-Haughn, A., Tate, K.W., and van Kessel, C. Attenuation of nitrate-^{15}N by vegetated buffers in an irrigated pasture system. American Geophysical Union Fall Meeting, San Francisco, CA. Oral presentation

2003. Bedard-Haughn, A., Tate, K.W., and van Kessel, C. Vegetative buffer efficiency in an irrigated pasture system. Canadian Society of Soil Science Annual Meeting, Montréal, QC. Oral presentation.
Awarded: C.F. Bentley Student Presentation Award for Excellence in Oral Presentations (1st place)

2004. Bedard-Haughn, A., Tate, K.W., and van Kessel, C. Increasing the demand: The impact of regular cutting on vegetative buffer ^{15}N uptake. Soil Science Society of America and Canadian Society of Soil Science Joint Annual Meeting, Seattle, WA. Oral presentation.

2004. Tate, K.W., Bedard-Haughn, A., and van Kessel, C. Sink or source? Managing vegetative buffers to minimize N in runoff. Soil Science Society of America and Canadian Society of Soil Science Joint Annual Meeting, Seattle, WA. Oral presentation.
2004. Bedard-Haughn, A., Tate, K.W., and van Kessel, C. Using ^{15}N to quantify vegetative buffer efficiency for sequestering N in runoff. Ecological Society of America Annual Meeting, Portland, OR. Oral presentation.
2004. Bedard-Haughn, A., Tate, K.W., and van Kessel, C. Using ^{15}N to quantify vegetative buffer efficiency in an irrigated pasture system. Riparian Ecosystems and Buffers: Multi-scale Structure, Function, and Management. American Water Resource Association, Summer Specialty Conference, Olympic Valley, CA. Oral presentation.

STUDENT SUPPORT: A summary of the number of students supported resulting from work supported by your project funding and by supplemental grants during the reporting period.

Please fill in the table below where applicable.

	Total Project Funding		Supplemental Awards	Total
	Federal Funding	State Funding		
Undergrad.	5,364.51			5,364.51
Masters				
PhD.	1,956.73			1,956.73
Post-Doc.				
Total	7,321.24			7,321.24

NOTABLE ACHIEVEMENTS AND AWARDS: Provide a brief description of any especially notable achievements and awards resulting from work supported by your project funding and by supplemental grants during the reporting period.

Tate, K.W., E.R. Atwill, C. van Kessel, J. Six, R.A. Dahlgren. 2004-2008. Implementation of Vegetative Buffer, Irrigation, and Grazing Best Management Practices to Reduce Pathogens, Organic Carbon, and Colloids in Runoff from Rangelands and Irrigated Pastures. CALFED Proposition 50 Drinking Water Quality Program. $886,133.
Jastro-Shields Graduate Research Scholarship, University of California, Davis. 2003 ($1,600), 2002 ($2,200).
UC Davis Dissertation Year Fellowship, University of California, Davis (2003-2004)
C.F. Bentley Student Presentation Award for Excellence in Oral Presentations (1st place), Canadian Society of Soil Science Annual Meeting (2003)

Publications from 2002 Project Year

Bedard-Haughn, A., K.W. Tate, C. van Kessel. 2004. Using ^{15}N to Quantify Vegetative Buffer Effectiveness for Sequestering N in Runoff. J. Environmental Quality. In Press.

Publications from 2003 Project Year

Bedard-Haughn, A. 2004. Using ^{15}N to quantify the effectiveness of vegetative buffers for sequestering N. Ph.D. Dissertation, Soil Science Graduate Group, University of California, Davis, CA 95616.
Bedard-Haughn, A., K.W. Tate, C. van Kessel. Quantifying the Impact of Regular Cutting on Vegetative Buffer Efficacy for ^{15}N Sequestration. J. Environmental Quality. In Review.
Bedard-Haughn, A., K.W. Tate, C. van Kessel. Impact of Buffer Management on ^{15}N Attenuation from Surface and Subsurface water. J. Environmental Quality. In Review.