LITERATURE REVIEW ON BUFFER POLLUTANT REMOVAL

March 29, 2010
Dan Yu

INTRODUCTION:

A riparian buffer (also known as riparian vegetative filter strips, or buffer strips) is an area of vegetated land surrounding a waterbody, potentially capable of filtering non-point source pollution in runoff from adjacent lands. Main pollutants studied include sediment, nitrogen, phosphorus, bacteria, and pesticides. Although the literature suggests a general consensus about a riparian buffer's ability to filter pollutants, efficiencies of removal have varied greatly for certain pollutants. Therefore, it is important to review current literature in order to determine the reasons for such a large range of removal rates.

This review was carried out with emphasis on the quantitative results of pollutant reduction as well as the methods of experimentation used to test riparian buffer efficiencies. Depending on the pollutant in question, resulting data fluctuates from study to study, and is discussed further on; however, in terms of the latter, the majority of studies examined used plot or soil boxes under monitored amounts of runoff and applied pollutants. While this method provides insightful data on a riparian buffer's filtration capability, only a few papers were found regarding the resulting effects on water quality of the waterbody that the riparian buffer is protecting. This is especially important in lakes and ponds where renewal of water is relatively low. The studies that observed the effect of riparian buffers on a watershed scale focused mainly on nitrogen and phosphorus levels due to agricultural practices. Watershed level pollutant removal studies are examined separately in order to compare and contrast their methodology for further research projects. They are discussed after analysis of pollutant removal in plot and field test.

POLLUTANT RETENTION BY RIPARIAN BUFFERS:

Riparian buffers may remove pollutant from runoff through a variety of processes, mainly deposition, infiltration, dilution, sorption, uptake by vegetation, and microbial activity (Dosskey 2001; Krutz et al. 2005). Factors that affect these filtration methods are mainly due to physical characteristics of the riparian buffer, including buffer width, slope, soil type, and type of vegetation (Abu-Zreig 2001). Other factors that may affect pollutant removal include the type of runoff flow, as well as the total surface area of land draining to the riparian buffer (Hickey and Doran 2004). Factors that allow for a longer residence time of runoff within the buffer (i.e. larger buffer width, sheet flow of runoff, lower slope) lead to higher removal of pollutants since the processes of filtration have more time to occur.

Sediment

Sediment retention by riparian buffers has been well documented in almost all studies found. Efficiencies have been shown to generally vary from 40% to 100% (Dosskey 2001). A large factor that greatly affects retention of sediment in buffers has to do with properties of the sediment itself. Sediment trapping is highly a function of particle size and mass. Larger, coarser, heavier sediments, such as sand, are more easily collected in a riparian buffer than finer particles such as clay (Hickey and Doran 2004). A flume study demonstrates this, as stiffgrass vegetative barriers removed 90% of sand-sized sediment, while removing only 20% of silt and clay-sized sediment (Dosskey 2001). The width of the buffer is significant only for the first few meters of the buffer, as riparian buffers 9.1m in width have been shown to reach 68% to 99% of sediment retention (Abu-Zreig 2001). Sediment retention can be increased by placing a grass barrier in series with the riparian buffer. A plot study with simulated rainfall done by Blanco-Canquil et al. (2006) demonstrated that a 0.7m grass barrier used in conjunction with an 8m riparian buffer led to a decrease in sediment runoff by 99% for both interrill and concentrated flow.

Buffer strips have been shown to be a sediment sink (Hickey and Doran 2004). Therefore, the long term fate of the sediment trapped by the riparian buffer should be examined. Remobilization of sediment may be a concern as well as sediment accumulation that would disrupt sheet flow (Dosskey 2001). Regular maintenance by sediment removal from the buffer may help alleviate the situation, but longer term data is needed.

Nitrogen

Data on nitrogen retention by riparian buffers have yielded varying results. Results accumulated by Dosskey (2001) demonstrate this variety. When comparing runoff from different plots, some with a vegetative buffer and others without, nitrogen reduction percentages (by mass) ranged between -140% to 30%. The percent reduction rate in concentration of total nitrogen ranged from 3% to 26%.

Percent retention of nitrogen compounds varies when the method of experimentation changes. Instead of comparing runoff between a vegetated and bare plot, many studies instead compare influent concentration of nitrogen entering a buffer strip to the concentration of nitrogen in effluent runoff. For example, a study done by Mankin et al. (2007) indicated a high level of nitrogen filtration. By setting up test sites in an already established grass-shrub riparian buffer (mean width of 9.7m), the group ran synthesized runoff through the buffer and then collected the filtered runoff. Results of the study indicated a decrease in total nitrogen by 92.1% (by mass) and 44.4% (by concentration), with the process of infiltration accounting for more than 90% of the total nitrogen reduction. They concluded that water quality improvements can be achieved with grass shrub riparian buffers as narrow as 8 m, as long as adequate infiltration is achieved.

Discrepancies in the amount of nitrogen reduction most likely stem from the properties of the buffer itself as well as processes that alter the chemical state of nitrogen. Main factors may include the rates of denitrification and nitrogen fixation in which nitrogen is exchanged with the atmosphere and surrounding environment (Hickey and Doran 2004). Nitrogen uptake by plants has also been cited as a source of nitrogen removal; however, recent studies have suggested that uptake by plants only accounts for approximately 5% per meter of buffer of total nitrogen reduction (Vidon et al. 2009).

Phosphorus

Filtration of phosphorus has been shown to be effective on a short term basis, though more information on the fate of phosphorus in the long run is required. Removal of phosphorus is carried out through sorption onto soil particles, by sedimentation, or through uptake by plants (Hickey and Doran 2004). However, unlike nitrogen, there are no mechanisms for phosphorus exchange between the buffer and atmosphere. This suggests that the buffer's ability to retain phosphorus is finite, and may eventually become ineffective. Mankin et al. (2007) found phosphorus levels in their plot study decreased 91.8% by mass when using a seven-year-old established grass-shrub buffer. Despite this, more studies need to be conducted on the long term ability of a riparian buffer to retain phosphorus.

Bacteria and Parasites

Retention of bacteria and parasites by riparian buffers has been shown to be quite effective in most plot studies. Plot studies by Entry et al. (2000) indicate removal of coliform from water occurs exclusively within soil and groundwater. After discharging a pulse of wastewater over the experimental plots, they found a 10% decrease of total and fecal coliform numbers in soil water and groundwater, but no appreciable decrease in surface runoff. The study also examined the effect of type of vegetation, but found that removal rates remained approximately the same when using either forested or grass buffers. Reductions in total coliform by 99% were reported by Sullivan et al. (2007) in a study of runoff from manure treated pasturelands using only natural rainfall events, regardless of buffer width. In contrast, the plot study by Nunez-Delgado et al. (2001) using simulated rainfall resulted in a minor decrease in coliform concentrations, with levels remaining high throughout the course of the experiment. This may indicate that coliform retention may significantly decrease during heavy rainfall events, as simulated by Nunez-Delgado et al. (2001).

Similarly, a study of E. coli retention in grassland buffers by Tate et al. (2006) found that a riparian buffer's ability to remove bacteria is highly dependent on rainfall intensity. Using natural rainfall events for the study, they found very high retention rates (94.8% to 99.9%) of E. coli within 0.1m downslope of the manure application area, irrespective of buffer width. However, it was concluded that such a high retention rate would not be sustained in cases of intensive rainfall events. Thus, high retention rates for bacteria can usually be achieved for light to moderate rainfall events.

Another pollutant of interest is *Cryptosporidium parvum,* which has been shown to be highly retained by vegetated buffers. Atwill et al. (2002) tested the removal efficiency of *Cryptosporidium parvum* in different soil types and buffer slopes during simulated rainfall events. Using plots with 85% vegetative cover, they found higher retention rates in soils with higher bulk densities (sand) than those with lower bulk densities (clay). It was also suggested that the effect of riparian buffer slope on *Cryptosporidium* retention is dependent on soil texture and bulk density. It was concluded that for 99.9% removal of *Cryptosporidium*, the buffer should be at least 3m wide with a slope of at least 20%, which can vary depending on soil type. Another publication by Tate et al. (2004) also confirmed the results of Atwill et al. (2002) in soil box experiments, testing the retention of *Cryptosporidium parvum* by grass vegetated buffers. *Cryptosporidium parvum* oocysts were placed one meter upslope from the bottom of the soil boxes and runoff was collected from a simulated two hour rainfall event. Results indicated a reduction in the range of 15% to 28% *Cryptosporidium parvum* flux through one meter of grass vegetated buffer. Both studies indicate that a reduction of riparian buffer slope leads to an increased reduction of parasite flux.

Studies of *Giarda* have been done to a lesser degree. Winkworth et al. (2008) tracked levels of *Giardia* as simulated runoff traversed through a vegetative buffer and through bare soil. When comparing the results from the two different plots, it was found that levels of *Giardia* decreased by 26% in the vegetative buffer plot. More studies on retention of *Giardia* by riparian buffers will help validate these results.

Pesticides and Herbicides

Herbicide retention varies depending on the properties of the chemical. Based on a review by Krutz et al. (2005), herbicides that are transported with finer sediments through sorption may not be as well filtered out as those that are transported with coarser particles. Increases in buffer width increase the retention of moderately sorbed herbicides. Cases of doubling or tripling a buffer width increased herbicide retention by at least 38% (Krutz et al. 2005). Leaching of herbicides from the riparian buffer to the groundwater has also been reported and may be a cause of concern.

A study of pesticide removal by Syversen and Haarstad (2005) compared retention rates of the root zone of a vegetated buffer versus soil with low biological activity. The results indicate that pesticide retention was approximately 60% for most pesticides tested, for both vegetated and soil columns, implying a riparian buffer would have no effect on pesticide retention. Furthermore, the study also found higher retention in soils with lower microbial activity. Pesticide retention decreased when higher concentrations of pesticides were used.

EFFECTIVENESS OF RIPARIAN BUFFERS ON A WATERSHED SCALE:

Although a majority of studies have focused solely on riparian buffer pollutant removal in plot and field studies, much less information is available on the effects of riparian buffers at a watershed scale.

Meals and Hopkins (2002) provide data on phosphorus reductions in Lake Champlain in Vermont due to the effects of riparian restoration. The study was conducted using a paired watershed design, in which one watershed remains the control of the experiment, while the other receives the treatment to be tested. The watersheds examined were similar in land properties and land use, with the control watershed accounting for annual variations in climate or hydrologic inputs. During a calibration period, water quality data from both watersheds were collected but no treatment was put into practice. The post-treatment period compared the effectiveness of the riparian buffer treatment to data collected during the calibration period. This study used two treatment watersheds in order to gauge different levels of riparian restoration. Precipitation was monitored continuously by gages in each watershed. Streamflow was continuously monitored using a bubbler-type flow meter. Water samples were collected in refrigerated automatic samplers and composited into a weekly sample. The samples were collected weekly, handled and transported following U.S. EPA procedure methods. Phosphorus was analyzed using U.S. EPA method 365.1, with a detection limit of 0.003 mg/L (Meals and Hopkins 2002).

Based on two years of data following riparian buffer restoration, total phosphorus concentrations in the two watersheds decreased by approximately 20%. A decrease of 20% to 50% in mean total phosphorus load was also observed, with a larger reduction occurring in the watershed that received more extensive restoration treatments. The study also found phosphorus reductions decreased during periods of high runoff.

Data collected during the study also included measurements of total Kjeldahl nitrogen (TKN), total suspended solids (TSS), indicator bacteria, and macroinvertebrate and fish communities, but they are not present in the paper since the focus of the report concerns eutrophication of Lake Champlain in regards to phosphorus. Measurements of these parameters, as well as longer term data past two years will increase the argument for riparian buffer pollutant removal.

A study conducted by Casteel et al. (2005) examined the bacterial removal effect of riparian buffers on the water quality of Lake Merced, located in California. Stormwater that would have naturally flowed directly into the lake was intentionally diverted through a natural riparian buffer area, with an average width of 46 m, and then travel into the lake. The authors compared concentrations of bacterial contaminants of water samples collected from: the lake during the dry season (May to September), the lake during the wet season (with no diversion of stormwater), the stormwater, the lake after stormwater diversion, and the stormwater after diversion.

All samples of water were grab samples, with stormwater samples collected during storm events, and lake samples being collected within 24 hours of discharge to the riparian buffer. Lake samples were taken at the shoreline, and at locations 40 m to 80 m offshore. The results from all three were complied into an average value for contaminant levels of the lake. Samples were taken to a laboratory and analyzed within six hours of collection. For analysis, the samples were serially diluted in sterile buffered water, and were then mixed with Colisure media (E. coli and total coliforms detection) or Enterolert media (enterococci detection). The mixtures were incubated for one to two days and most probably numbers (MPN) of bacteria were determined by visual inspection. The results of the study are reported as log(MPN)/100 mL.

Results of the study are favorably indicative that riparian buffers can reduce bacterial contaminants before reaching a waterbody. Lake levels of E. coli, total coliforms, and enterococci were approximately 99% to 99.9% lower than levels found in stormwater. However, results of this study also suggest that riparian buffers may not be as effective during large rainfall events with higher inputs of stormwater. Data from heavy rainfall events may be skewed from stormwater inputs entering the lake from uncontrollable sources that were not diverted to the riparian buffer.

Although promising, the findings of the study can be slightly unrealistic when applying riparian buffer to shoreline restoration projects. Removal rates found in the experiment used a riparian region approximately 50m in width, which is relatively large in comparison to other studies on riparian buffer. Also, longer term results would also be necessary, as the experiment of diverting the stormwater was only carried out for a year. In low water renewal systems such as lakes, it is important to observe the longer term effects that may occur with time.

In comparison, a watershed based study done by Sutton et al. (2009) found no significant changes in nutrient concentrations when comparing water quality before and after riparian buffer installations throughout the Choptank River Watershed of the Chesapeake Bay. Water quality data from a previous study done in 1986 provided a basis for comparison. Sutton et al. (2009) conducted the same study, sampling the same locations in the period of 2003 to 2006. Sampling was conducted during baseflow conditions (at three days without rain), with all sampling sites located at road crossings. Water was collected from the middle of the stream by lowering a sampling bucket into the water from a bridge or culvert. Analysis occurred within 12 hours of collecting the sample, in the same laboratory as the previous study, following QA/AC procedures.

Increase in riparian buffer coverage was recorded from marked aerial photographs. It was noted that although riparian buffer streamside cover increased from 33% in the 1990's to 44% in 2005, nitrogen and phosphorus concentrations have not changed over the 20 year period. The authors conclude that multiple reasons may have played a role in the results, such as riparian buffer coverage not being extensive enough or increase in agricultural nutrient inputs. Another factor that may play a role is that the riparian buffers were not well established at the time of the study. Since riparian buffer implementation occurred as late as 2006, more time may be needed before significant quantitative results become apparent.

Rather than focusing on surface waters, Yamada et al. (2007) studied the effect of a riparian buffer on levels of groundwater nitrate. The study examined groundwater nitrate levels adjacent to a stream in a deep loess region of western Iowa before and after installation of a riparian buffer. A buffer was on the west bank of the stream and planted as a 183 m long three part riparian buffer: a 15m strip of trees adjacent to the stream edge; a 5m strip of alfalfa and brome grass; and finally a 5m strip of switch grass. There was no riparian buffer installation on the east bank in order to provide reference conditions.

Measurements were carried out using multiple piezometer nests placed throughout the stream bank based on transect position and proximity to the stream. This was done to determine the individual effects of each riparian buffer layer on groundwater nitrate levels. Levels of head were made weekly using an electric sensor. The piezometers were sampled monthly and analyzed by an auto-analyzer technique that provides the total levels of nitrate-nitrogen (NO_3-N) plus nitrite-nitrogen (NO_2-N) without quantitative results for each. Data collection began in 1997, while the riparian buffer installation occurred in 2000 to 2001.

Based on non-parametric statistical methods, nitrogen concentrations in shallow groundwater showed a decrease after the buffer installation. Significant change began in 2003, approximately three years after implementation of the buffer. The authors interpreted these significant reductions after 2003 to substantial growth and establishment of the buffer. Measurements of dissolved oxygen were also taken. Levels of dissolved oxygen were not shown to decrease, which may indicate that plant uptake was responsible for most nitrogen removal rather than denitrification, contrary to the suggestions of Vidon et al. (2009). Groundwater levels of nitrate and dissolved oxygen did not show a significant change under the non-buffered bank of the stream. Although not providing data on water quality of the stream itself, the study gives valuable insight on nitrogen pollutant removal by a riparian buffer on a field based study.

Some studies take into account other best management practices (BMPs) that are implemented in addition to riparian buffers. For example, a study done by Line (2002) examined the effect of conservation practices on surface water in the Long Creek watershed of North Carolina. The 8,190ha watershed was sampled from 1993 to 2001 and focused on the effects on water quality due mainly to agricultural and dairy practices. Use of land surveys conducted in 1988 and 1998 were used in order to observe changes in land use for a large part of the study period. During the time between the surveys, there was a 60% decrease in cropland, with more than 200% increases in land being used for housing development. In addition, a large number of BMPs were implemented, mostly during 1989 to 1994. Of these BMPs, approximately 2.1km of shoreline buffer was installed in the watershed.

Sampling began in April 1993. Grab samples were taken at five sites weekly, biweekly, or monthly. Sampling frequency increased during the crop planting season between December through May. Additional funding during the last three years of the study allowed for bi-weekly sampling during June through November. The grab samples were analyzed within six hours of collection for the following parameters: nitrite (NO_2) and nitrate (NO_3), TKN, total phosphorus (TP), and TSS concentrations. Methods for analysis were: 353.1, 351.2, and 365.4 from USEPA (Line 2002) for NO_2+NO_3, TKN, and TP and 2540D from APHA (Line 2002) for TSS. Samples were also analyzed for fecal coliforms and fecal streptococci using methods 9222D and 9230C, respectively, from APHA (Line 2002). To confirm the quality and representativeness of the samples, duplicate, split, blank, and spiked samples were also analyzed. Three rain gauges located near the middle of the watershed were used to monitor rainfall amounts during the period of the study. Daily mean discharge rate was measured at the furthest site downstream and maintained by the U.S. Geological Survey.

The results indicated a 70% reduction in median total phosphorus concentrations. There was little to no reduction in nitrogen levels. Fecal coliform and streptococci levels significantly declined during the last four years of monitoring; however, this decrease was attributed to the implementation of waste management practices and exclusion fencing on dairy operations during the course of the study.

The study conducted by Line (2002) demonstrates the total effect of all BMPs implemented on water quality rather than just one method. In regards to pollutant removal by riparian buffers, the study does show reductions of certain pollutants (namely, phosphorus and bacteria) that have been generally been shown to be removed in riparian buffer plot studies. However, since the magnitude of the number of BMPs implemented is much larger than the total riparian buffers installed, a cautionary conclusion can be that riparian buffers played some role. In addition, samples were collected only after and during the majority of BMP installations. Greater reductions may have been seen if water quality data were collected before the implementation of any of the BMPs.

McKergow et al. (2003) present a before and after study of the effects on water quality due to a riparian buffer installation. The study was located in a 6 km^2 agricultural catchment area draining from four farms in Western Australia. After water quality monitoring for six years, 1.7km of the stream reach was fenced, planted, and periodically managed. Water quality data were then collected for the next four years for observations on the effects of installation.

Data were collected downstream at the end of the fenced riparian area and included measurements of flow, nutrient concentration, and sediment concentrations. Rainfall measurements were collected via a tipping bucket rain gauge, as well as a manual rain gauge. Flow measurements began in 1991 and were conducted via a sharp-crested v-notch weir. At first, water levels were recorded by a capacitance probe and logger (1991-1997) but later was measured by a pressure transducer and stored on a data logger every 15 minutes (May 1997 to September 2000). Nutrient and sediment measurements were carried out through manual grab samples, rising stage samples (via an air displacement sampler), and automatic samplers. Sampling intervals varied from 45 minutes (during storm events) to 4 weeks. Calculations of sediment and nutrient loads were estimated using interpolation and regression methods.

Overall, McKergow et al. (2003) found suspended solid concentrations to decrease by an order of magnitude following the riparian buffer installation, thus decreasing sediment export. This dramatic decrease was attributed to a reduction in bank erosion and increased channel stability due to the installation. Reduction in the total phosphorus concentration was limited; however, a change in the dominant form of phosphorus was observed. Prior to riparian management, approximately half of the phosphorus transport occurred by attachment to sediments. After implementation, concentrations of median filterable reactive phosphorus increased by 60%. The authors cite the low ability of the study area's soil for phosphorus sorption as a probable cause of low removal rates. Removal of nitrogen was also unclear as water quality data demonstrated decreased concentrations during times of high flow, but little change in the event mean concentration.

Uncertainty in the results of McKergow et al. (2003) are attributed to changes in land use over the ten year study, the addition of automated sampling after 1997, and the replacement of the weir in 1996. The authors still justify the results, believing these factors would only cause minor discrepancies. One factor that was acknowledged but may not have been accounted for was the sampling of only one site. Although the study provides insightful data of water quality before and after a riparian buffer installation, more sampling sites, especially upstream of the riparian buffer may have provided data on whether other factors such as changes in land use played a role in improving water quality. Measurements upstream of the riparian buffer could have changed the results of the study, or solidify them further. There is also uncertainty as to the extent of pollutant removal by the riparian buffer, as installation of the riparian area lead to livestock exclusion from the stream, which may have had a much larger impact of improvement of water quality.

CONCLUSIONS:

Although quantitative results for pollutant removal rates vary, it is apparent that riparian buffers have the ability to improve water quality. While removal of sediment and bacteria from runoff is highly agreed upon, removal of nutrients such as nitrogen and phosphorus have varied from study to study. Generally, controlled plot studies have proven to be more successful at pollutant removal than watershed scale studies. At a watershed scale, existing research is not extensive enough, and therefore it is imperative that further research be done that examines the effectiveness of a buffer installation to protect water quality. Many studies on riparian buffer installations or shoreline restoration projects focus on habitat and wildlife restoration rather than water quality. Even though restoration of a waterbody's habitat and wildlife may be indicative of water quality, quantitative data on the subject would be more credible. The few case studies of riparian buffer pollutant removal at a watershed provide useful insight and a strong foundation on the subject matter, but longer term data is needed. Remobilization of pollutants from riparian buffers, as found in plot studies, may have a large impact when considered at a watershed scale. This is of especial interest in systems of lakes and ponds, where water renewal is much lower than that of streams and rivers. Research should continue on riparian buffer pollutant removal at a watershed scale for a long-term basis.

REFERENCES:

1. Abu-Zreig, M. (2001). Factors affecting sediment trapping in vegetated filter strips: simulation study using VFSMOD. *Hydrological Processes, 15,* 1477-488.
2. Atwill, E. R., Hou, L., Karle, B. M., Harter, T., Tate, K.W., & Dahlgren R. A. (2002). Transport of Cryptosporidium parvum Oocysts through Vegetated Buffer Strips and Estimated Filtration Efficiency. *Applied and Environmental Microbiology, 68,* 5517-5527.
3. Blanco-Canqui, H., Gantzer, C. J., & Anderson S. H. (2006). Performance of Grass Barriers and Filter Strips under Interrill and Concentrated Flow. *Journal of Environmental Quality, 35,* 1969-1974.
4. Casteel, M. J., Bartow, G., Taylor, S. R., & Sweetland P. (2005, August). *Removal of bacterial indicators of fecal contamination in urban stormwater using a natural riparian buffer.* Presented at 10th International Conference on Urban Drainage, Copenhagen/Denmark
5. Dosskey, M. G. (2001). Toward Quantifying Water Pollution Abatement in Response to Installing Buffers on Crop Land. *Environmental Management, 28,* 577-598.
6. Entry, J. A., Hubbard, R. K., Thies, J. E., & Fuhrmann, J. J. (2000). The Influence of Vegetation in Riparian Filterstrips on Coliform Bacteria: I. Movement and Survival in Water. *Journal of Environmental Quality, 29*, 1206-1214.
7. Hickey, M. B. C., & Doran, B. (2004). A Review of the Efficiency of Buffer Strips for the Maintenance and Enhancement of Riparian Ecosystems. *Water Quality Resource Journal Canada, 39,* 311-317.
8. Krutz, L. J., Senseman, S. A., Zablotowicz, R. M., & Matocha, M. A. (2005). Reducing herbicide runoff from agricultural fields with vegetative filter stripes: a review. *Weed Science, 53,* 353-367.
9. Line, D. E. (2002). Changes in Land Use/Management and Water Quality in the Long Creek Watershed. *Journal of the American Water Resources Association, 38,* 1691-1701.
10. Mankin, K. R., Ngandu, D. M., Barden, C. J., Hutchinson, S. L., & Geyer, W. A. (2007). Grass-Shrub Riparian Buffer Removal of Sediment, Phosphorus, and Nitrogen from Simulated Runoff. *Journal of the American Water Resources Association, 43,* 1108-1116.
11. McKergow, L. A., Weaver, D. M., Prosser, I. P., Grayson, R. B., & Reed, A. E.G. (2003). Before and after riparian management: sediment and nutrient exports from a small agricultural catchment, Western Australia. *Journal of Hydrology, 270,* 253-272.

12. Meals, D.W., & Hopkins R.B. (2002). Phosphorus reductions following riparian restoration in two agricultural watersheds in Vermont, USA. *Water Science and Technology, 45*, 51-60.
13. Nunez-Delgado, A., Lopez-Periago, E., & Diaz-Fierros Viqueira, F. (2002). Chloride, sodium, potassium and faecal bacteria levels in surface runoff and subsurface percolates from grassland plots amended with cattle slurry. *Bioresource Technology, 82,* 261-271.
14. Stout, W. L., Pachepsky, Y. A., Shelton, D. R., Sadeghi, A. M., Saporito, L. S., & Sharpley, A. N. (2005). Runoff transport of faecal coliforms and phosphorus released from manure in grass buffer conditions. *Letters in Applied Microbiology, 41,* 230-234.
15. Sullivan, T. J., Moore, J. A., Thomas, D. R., Mallery, E., Snyder, K. U., Wustenberg, M., Wustenberg, J., Mackey, S. D., & Moore, D. L. (2007). Efficacy of Vegetated Buffers in Preventing Transport of Fecal Coliform Bacteria from Pasturelands. *Environmental Management, 40,* 958-965.
16. Sutton, A. J., Fisher, T. R., & Gustafson, A. B. (2009). Effects of Restored Stream Buffers on Water Quality in Non-tidal Streams in the Choptank River Basin. *Water Air Soil Pollution, DOI 10.1007/s11270-009-0152-3.*
17. Syversen, N., & Haarstad, K. (2005). Retention of pesticides and nutrients in a vegetated buffer root zone compared to soil with low biological activity. *International Journal of Environmental Analytical Chemistry, 85,* 1175-1187.
18. Tate, K. W., Atwill, E. R., Bartolome, J. W., & Nader, G. (2006). Significant *Escherichia coli* Attenuation by Vegetative Buffers on Annual Grasslands. *Journal of Environmental Quality, 35,* 795-805.
19. Tate, K. W., Pereira, M. D. G. C., & Atwill, E. R., (2004). Efficacy of Vegetated Buffer Strips for Retaining *Cryptosporidium parvum. Journal of Environmental Quality, 33,* 2243-2251.
20. Vidon, P., Tedesco, L., & Jacinthe, P. (2009). Effectiveness of Riparian Zones in Contaminant Mitigation. Aquisafe 1 D 3.2.1. Berlin. Kompetenzzentrum Wasser Berlin gGmbH.
21. Winkworth, C. L., Matthaei, C. D., & Townsend, C. R., (2008). Recently Planted Vegetation Strips Reduced *Giardia* Runoff Reaching Waterways. *Journal of Environmental Quality, 37,* 2256-2263.
22. Yamada, T., Logsdon, S. D., Tomer, M. D., & Burkart, M. R. (2007). Groundwater nitrate following installation of a vegetated riparian buffer. *Science of the Total Environment, 385,* 297-309.