Nonpoint Source Abatement Costs in the Kentucky River Watershed

Zheng Liu, Jack Schieffer, Wuyang Hu, and Angelos Pagoulatos
Agricultural Economics, University of Kentucky

Corresponding Author:
Jack Schieffer
jack.schieffer@uky.edu

May 2, 2011

Selected Paper prepared for presentation at the Agricultural & Applied Economics Association's 2011 AAEA & NAREA Joint Annual Meeting, Pittsburgh, Pennsylvania, July 24-26, 2011.

Abstract

A growing share of water pollution in the U.S. can be attributed to nonpoint sources (USEPA 2002). Some of this trend can be attributed to declining point source (PS) emissions as a result of regulation under the Clean Water Act (CWA). However, fertilizer-intensive practices used to improve agricultural productivity over recent decades have also increased nitrate loads and resulted in water quality impairments.

Nonpoint source (NPS) pollution from agricultural practices is generally exempt from federal regulation. However, some voluntary programs allow point sources subject to the CWA's effluent limitations to meet their standards by purchasing offset credits reflecting reductions in NPS discharges to the same waters (USEPA 2004). Such water quality trading (WQT) programs have been implemented in a number of states to reduce pollution abatement costs (Breetz et al 2004). In this setting, NPS supply pollution abatement when they implement best management practices (BMP) that reduce nutrient loads, and the cost of BMPs form a supply curve for credits. WQT programs are supported by the EPA as an important means for efficiently pursuing water quality goals (USEPA 2003a).

Among the BMPs available for water quality management, riparian buffer strips have proven effective in mitigating the movement of nutrients and other pollutants into surface waters (Qiu et al 2006). Estimates of riparian buffer costs would be valuable for developing policy related to WQT and other conservation programs. This paper estimates the annual costs of buffer strips in six counties in the Lower Kentucky River Basin, as part of a project evaluating the feasibility of WQT programs in that area.

1 Introduction

In this paper, we develop estimates of the costs to implement riparian buffer strips on agricultural land within the Kentucky River watershed. Riparian buffers are one method that agricultural producers could use to reduce nutrient loadings, primarily nitrogen and phosphorus, that impair surface water quality in that watershed. If producers are rewarded for emission-reducing practices with offset credits that can be sold in a water quality trading (WQT) program, then the costs of implementing buffer strips imply a supply curve for those offset credits.

WQT is promoted as a policy mechanism for achieving water pollution management goals at lower costs than those associated with technical standards or other forms of command-and-control regulation. Like other tradable permit systems, WQT exploits the cost heterogeneity among different pollution sources in order to pursue cost-effective abatement.

Point sources (PS) of water pollution—including municipal wastewater treatment plants, industrial facilities, and others—are regulated under the Clean Water Act (CWA) and would represent the primary demand for permits in a WQT system. Point sources that have lower marginal abatement costs could also be net suppliers of permits to higher-cost facilities. However, a system that encompasses only PS-PS trading will likely be unable to generate substantial improvements from current water quality levels and would forego potential cost savings from incorporating other sources of water pollution.

Bingham et al. (2000) argue that PS-only reductions offer a severely limited potential for better water quality, even in the unlikely event that PS emissions are reduced to zero. Instead, nonpoint sources (NPS) of pollution, such as agricultural producers and runoff from urban areas, offer the greatest scope for improved quality. The U.S. Environmental Protection Agency (2002, 2009) shows that agricultural NPS pollution has become the primary cause of impairment in rivers and streams.

The success of tradable permits program for air pollution—including the sulfur dioxide emissions program and the leaded gasoline phase-out in the U.S., and the European Union's carbon market—has generated support for translating this policy instrument to pollution in other media, notably water.

In contrast to air pollution, which is often modeled as uniformly mixing, water pollution exhibits a great deal of spatial heterogeneity in the marginal damages caused by a particular source to a particular victim or location. Tradable permit systems for non-uniformly mixed pollutants often call for restrictions designed to avoid increased degradation at any given site (i.e., "hot spots"). One such restriction might involve trading ratios (e.g., Hung and Shaw, 2005), in which a polluter must buy more than one unit of credits in order to increase his own emissions by one unit. Alternatively, the program may restrict trades to parties that are in close geographic proximity, so that expected marginal effects of their emissions are similar. Both of these methods potentially forego some cost-reducing trades in order to maintain local non-degradation standards.

A key factor in the demand for offset credits is the level of regulation on point sources. A point source's emissions level depends largely on its installed treatment equipment, which is a durable investment. If point sources can comply with emission limits using current capital equipment, their marginal abatements costs will be relatively low and thus they may have little demand for offset credits. However, reducing emissions to comply with tightening regulatory standards may require new or upgraded treatment equipment, a large expense that would make offset credits a more attractive option. One likely source for such tightening of regulation is the development of total maximum daily loads (TMDLs) for impaired waterways. For waterways that currently do not achieve targeted water quality levels, the development of TMDLs may lead regulators to reduce the emission levels from those currently allowed to point sources.

2 Methods

2.1 Study Area

The Kentucky River Basin covers 4.5 million acres out of the 26 million acres in the state (Table 1). Of the 46 Kentucky counties within the watershed, we selected six—Fayette, Franklin, Grant, Jessamine, Madison, and Woodford—to form an initial study area. These counties were selected on the basis of two criteria. First, we identified areas in which agricultural nonpoint-source pollution is a substantial problem, so that NPS participation in the trading program is desirable. Second, we identified the areas deemed most likely to face tighter regulation in the foreseeable future, which would drive point sources to seek offset credits.

The feasibility of a tradable permit system for water pollution that includes offset credits for NPS emission reductions depends on both supply and demand factors. First, there must be sufficient nonpoint sources that can potentially reduce emissions and thereby generate the offsets. Second, there must be a need to reduce the emissions from current levels, so that point sources will potentially demand offsets credits as a lower-cost method to meet these abatement needs.

In the lower basin of the watershed, agricultural land—including row crops, pasture, and hay—comprises approximately 50% of the land area, compared with only 27% in the watershed as a whole (Table 1). Therefore, we focus our analysis on the lower basin to ensure sufficient potential for supplying offset activity, such as riparian buffers.

	State of Kentucky		Kentucky River		Lower Basin	
	Area (Acres)	% Total	Area (Acres)	% Total	Area (Acres)	% Total
Total Land Area	26,019,597	100%	4,457,425	100%	2,074,169	100%
Agricultural Land	8,510,312	33%	1,188,434	27%	1,030,673	50%
– Pasture/Hay	5,669,444	22%	1,126,847	25%	974,198	47%
– Crops	2,840,868	11%	61,587	1%	56,475	3%
Total Riparian			900,790	100%	435,290	100%
Agricultural Land			212,102	24%	160,280	37%
– Pasture/Hay			202,970	23%	152,993	35%
– Crops			9,132	1%	7,287	2%

Table 1 – Land Use in the Kentucky River Watershed

The selected counties exhibit significant water quality impairment (see Table 2 and Figure 1), especially with regard to nutrient-related impairments that can be mitigated by agricultural best management practices (BMPs) such as riparian buffers (KDOW, 2008) the majority of nutrient-impaired streams miles within the Lower Basin, and no such stream miles are found within the remainder of the Kentucky River watershed. In addition, total maximum daily loads (TMDLs) have been approved or are currently under development for the majority of nutrient-impaired streams and rivers in these counties (see Table 2 and Figure 2), again constituting the majority of such TMDLs within the entire watershed.

County	Stream Miles	Impaired	Nutrient-Impaired	Nutrient TMDLs
Fayette	549.4	53.5	50.6	45.0
Franklin	523.6	53.7	12.2	12.2
Grant	562.4	35.1	12.6	12.6
Jessamine	342.9	96.75	34.1	34.1
Madison	1054.9	72.15	13.3	6.5
Woodford	358.1	38	38.0	17.9
6-County Total	3391.3	349.2	160.8	128.3
Lower Basin	15691.7	1238.1	216.3	151.2
Entire Watershed	16070.8	1238.1	216.3	151.2

Table 2 – Impaired Waters and TMDLs (Stream Miles)

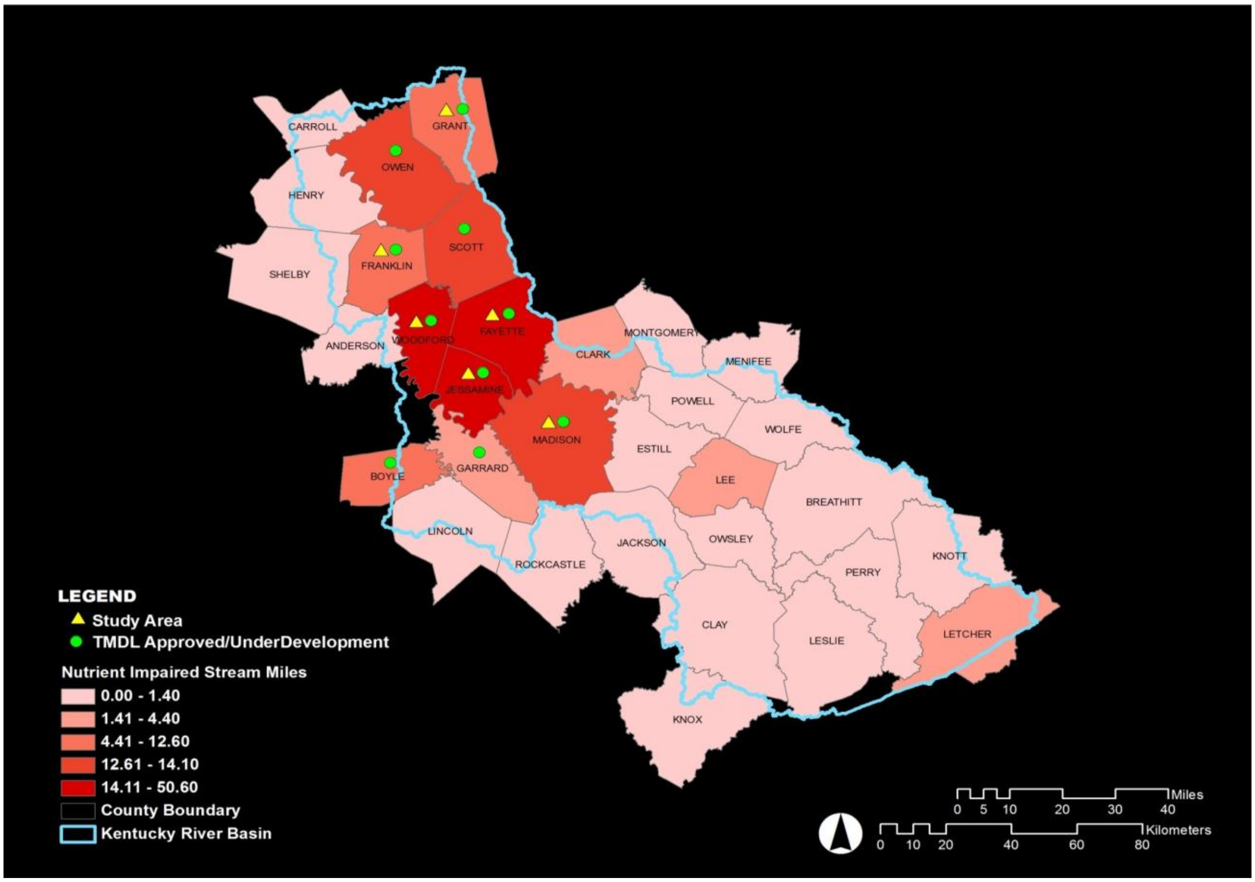

Figure 1 – Nutrient Impairments in the Lower Basin

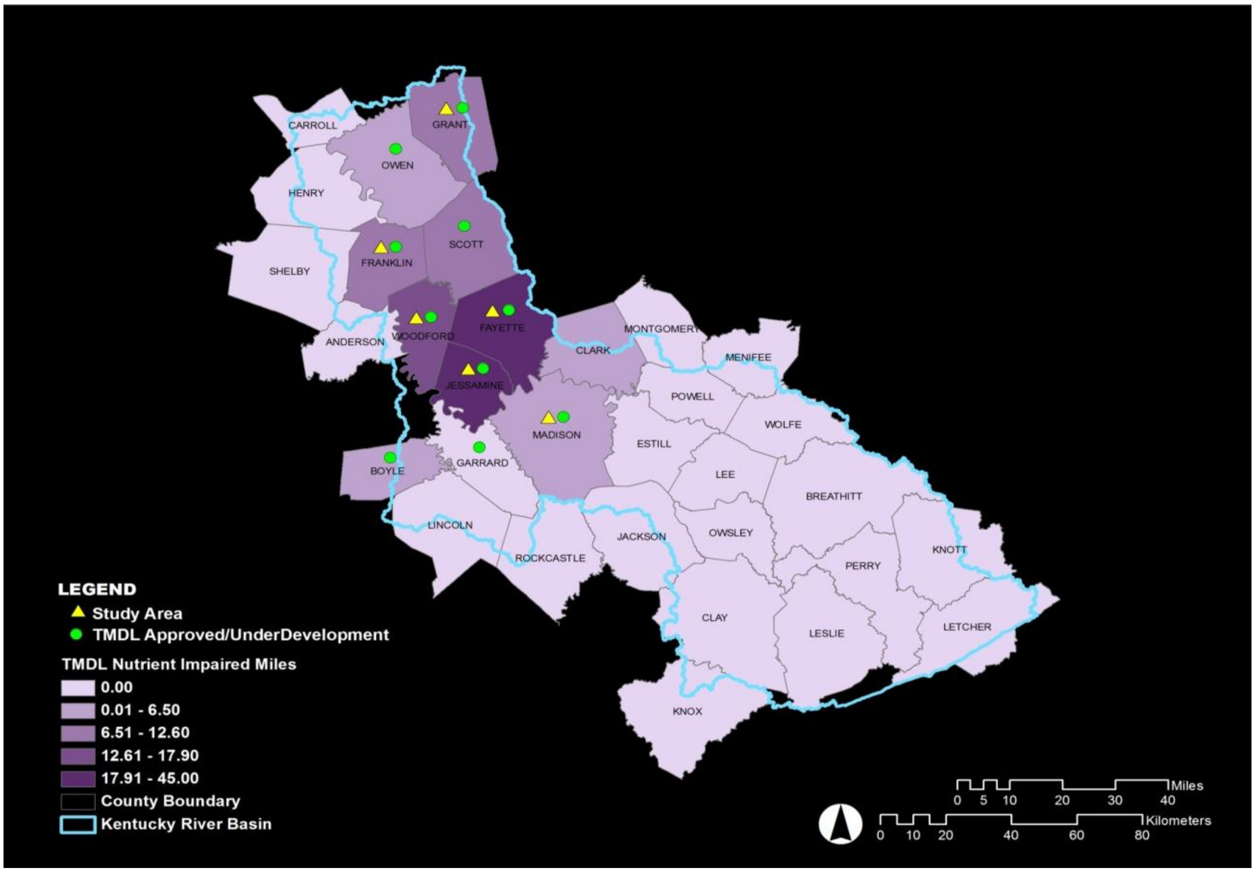

Figure 2 – Nutrient-Based TMDLs in the Lower Basin

Thus, the characteristics of the initial study area comprises six counties indicate favorable conditions, at least relative to the remainder of watershed, for a WQT program restricting nutrient loadings and featuring participation by agriculture via offset credits. In further research, we plan to extend the analysis to encompass all 46 counties in the watershed.

2.2 Cost Estimation

We estimate the costs to agricultural producers associated with installing riparian buffer strips in a zone measuring 200 feet on either side of waterways. Our methodology is adapted from Roberts et al (2009), with two procedures for estimating costs: one for agricultural land used in row crop production and another for land used as pasture or for hay production. Figure 3 illustrates the varying land uses within the potential riparian buffer area, as classified in the National Land Cover Database (USGS, 2001).

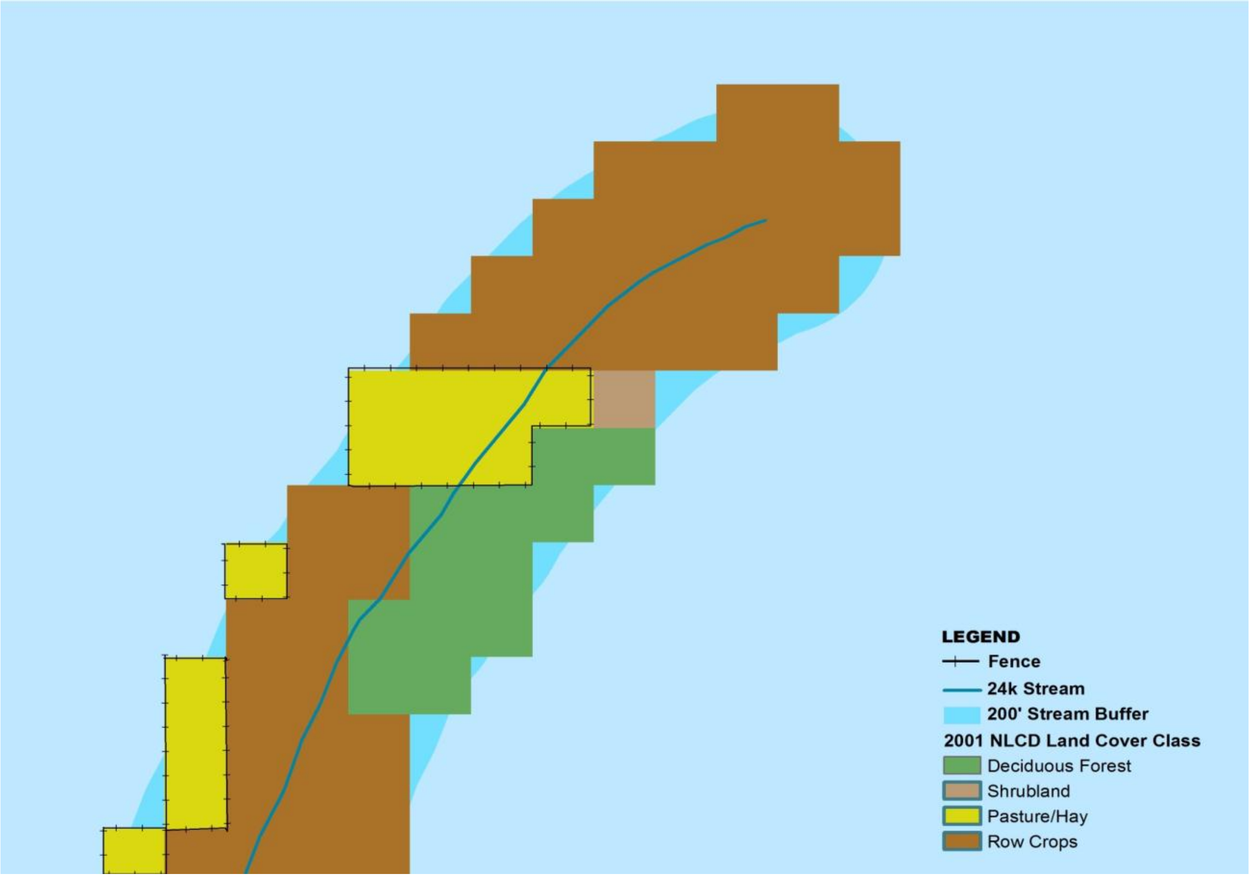

Figure 3 – Land Uses within a Potential Riparian Buffer Area

Waterways and their associated potential buffer areas were located with geographic information system software (ArcGIS) and the land uses within those areas were identified from the National Land Cover Database (NLCD). A 200-foot buffer strip throughout the entire Lower Basin would cover 435,290 acres, or 21% of all land in that basin (Table 1). Regarding the land uses within this potential buffer area, 160,280 acres (36.8%) is classified as agricultural use: 152,993 acres in pasture/hay and 7,287 acres in row crops. This agricultural land represents the potential supply of riparian buffers, and the economic feasibility of converting land to this use depends on the cost of such conversion to the landowners.

We follow two procedures to determine the cost of supplying riparian buffers, based on the two agricultural uses identified by the NLCD. For cropland, the cost of buffers includes the opportunity cost of forgone production, as well as the cost of establishing and maintaining the buffer strip vegetation. On pasture land, the cost of riparian buffers is estimated from average rental rates of the land and the cost of livestock exclusion (fencing), as well as establishment and maintenance expenses.

The major row crops grown in our study area are corn, soybeans, wheat, and burley tobacco (USDA, 2011). We index these crops by *i* for the variables shown in Table 3 below. The counties are indexed by *j* and the soil types (map units) identified in the Web Soil Survey are indexed by *k*.

Description	Variable	Data Source
Crop proportions	P_{ij}	National Agricultural Statistics Service
Cropland in buffer area	RC_j	National Land Cover Database
Soil type (map unit) size	A_{jk}	Web Soil Survey
Crop yield	Y_{ik}	Web Soil Survey
Crop-soil acreage	μ_{ijk}	(Calculated)
Crop returns to land	Φ_{ik}	University of Kentucky Cooperative Extension

Table 3 – Variables and Data Sources

Using the NLCD and ArcGIS, we identify the amount (in acres) of agricultural land dedicated to row crops within the potential buffer strip of each county (RC_j). Using data from the National Agricultural Statistical Survey (USDA, 2011), we determine the proportion of acreage in each county devoted to each of the four crop types (P_{ij}). Although the use of land for row crops can be identified within the potential buffer area, data about the individual crops grown in a specific location is not available in our data set. Thus, we assume that the P_{ij} proportions also apply to the subset of cropland within the potential buffer area of each county. Table 4 presents this data for the six-county study area.

	Corn		Soybean		Wheat		Tobacco	
County	Acres	%	Acres	%	Acres	%	Acres	%
Fayette	2000	26.0%	3300	43.0%	800	10.4%	1580	20.6%
Franklin	900	42.5%	600	28.3%	0	0.0%	620	29.2%
Grant	350	33.7%	0	0.0%	0	0.0%	690	66.3%
Jessamine	0	0.0%	0	0.0%	600	58.3%	430	41.7%
Madison	1200	60.3%	0	0.0%	0	0.0%	790	39.7%
Woodford	1300	31.3%	1600	38.5%	0	0.0%	1260	30.3%
Total	5750	31.9%	5500	30.5%	1400	7.8%	5370	29.8%

Table 4 – Crop Proportions for 2010

The Web Soil Survey data (USDA, 2009) maps the soil types (map units) within each county. Using ArcGIS, we identify the soil types within the potential buffer strip and their sizes (A_{jk}) in acres. The Web Soil Survey data indicates the estimated yield by soil type for each of the four major row crops (Y_{ik}). Soils types with zero yields for the major crops were excluded from our dataset. For example, crops would not grow well or at all on steeply sloped land, rock outcrops, water, or developed areas.

We assume that the row crops are produced on arable soil types within the buffer strip area. Thus, we calculate the number of acres of crop *i* cultivated on soil type *k* within the buffer strip area of county *j* (μ_{ijk}) as:

$$\mu_{ijk} = P_{ij} \times \frac{RC_j}{\sum_k A_{jk}} \times A_{jk}$$

Crop budgets developed by the University of Kentucky Cooperative Extension (2011a, 2010, 2009) were used to estimate the returns to land for each crop and yield level. We denote $\Phi_{ik} = \Phi_i(Y_{ik})$ as the per acre return for crop *i* cultivated on soil type *k*. Following Roberts et al (2009), we assume that returns are linearly related to crop yields, with a zero return assumed for an expected yield of zero. The return functions used in the analysis are:

$\Phi_{Corn} = 2.500Y_{ik}$

$\Phi_{Soybean} = 7.523Y_{ik}$

$\Phi_{Wheat} = 3.357Y_{ik}$

$\Phi_{Tobacco} = 0.181Y_{ik}$

No-till production is typical for Kentucky agriculture. The corn budget is based on no-till practices with a yield of 150 bu/acre and a price of $5.25/bu. The soybean budget is based on no-till practices with a yield of 44 bu/acre and a price of $12.50/bu. The wheat budget is based on no-till practices with a yield of 70 bu/acre and a price of $6.70/bu. The tobacco budget is based on a yield of 2200 lbs/acre and a price of $1.70/lb. The budgets all include some fixed costs (equipment, overhead, insurance) as well as variable costs, so that the return functions above represent returns to land, management, and risk.

The return functions represent the opportunity cost associated with removing land from row crop production. In addition, establishment and maintenance expenses were estimated at $32.79 per acre, based on available literature (Bonham et al, 2006). This expense represents the annualization of establishment costs over an expected 10-year life of a buffer plus annual maintenance costs. For land currently used in row crop production, the sum of the opportunity and establishment/maintenance costs is the cost of supplying an acre of riparian buffer strip in exchange for offset credits.

Although a small amount of corn in Kentucky is harvested for silage (less than 6% of corn acres statewide), it is primarily used on-farm as feed. Our analysis treats all corn acreage as grown for grain; thus, the grain value serves as a proxy for the small proportion of corn grown for silage.

For land currently used as pasture, the cost of a riparian buffer comprises three elements: the cost of fencing to exclude livestock from the buffer area, the opportunity cost of foregoing the use of pasture, and the costs of establishing and maintaining the buffer vegetation.

All land designated as pasture/hay in the NLCD data was assumed to be used for grazing livestock, necessitating the use of fencing to exclude livestock from buffer strip areas. This assumption will lead to some overestimation of the costs for riparian buffers in this land category, since exclusion fencing would not be necessary for land used only for hay production. The cost of fencing was estimated at $366.67 per kilometer (USEPA, 2003b).

The amount of fencing required to protect a given buffer strip depends on the shapes and sizes of the pasture land parcels within the potential buffer area. We calculate the average amount of fencing per acre at the county level, by calculating the amount of fencing required to exclude all acres of pasture/hay land use within the potential buffer and dividing by the number of acres of pasture/hay land use in that county's buffer area.

Average rental rates by county for pasture and hay land were taken from a survey of county agents (University of Kentucky Cooperative extension, 2011b) to represent the opportunity cost component for pasture. In the study area, these rates are $35/acre for all six counties. As with crop land, annualized establishment and maintenance expenses for buffer vegetation were estimated at $32.79 per acre (Bonham et al, 2006). The costs of converting pasture into riparian buffers within the study area is summarized in Table 5.

County	Pasture (acres)	Fencing (km)	Exclusion	Rental	Establishment	Total
Fayette	16,745	1719.8	$37.65	$35.00	$32.79	$105.44
Franklin	8,403	1278.4	$55.77	$35.00	$32.79	$123.56
Grant	7,386	1219.1	$60.51	$35.00	$32.79	$128.30
Jessamine	6,503	879.8	$49.59	$35.00	$32.79	$117.38
Madison	21,795	3020.7	$50.81	$35.00	$32.79	$118.60
Woodford	9,239	1204.0	$47.77	$35.00	$32.79	$115.56

Table 5 – Riparian Buffer Costs on Pasture Land ($/acre)

3 Results and Discussion

Within the initial study area, if all agricultural land within 200 feet of streams were converted to riparian buffers, the total cost would be $9.4 million for 73,021 acres of buffer strips. For example, regulation mandating a 200-foot riparian buffer on all agricultural land would impose this cost on the agricultural landowners. Table 6 summarizes this cost for the study area.

County	Acres	Cost
Fayette	17,598.7	$2,108,740
Franklin	8,729.9	$1,176,801
Grant	7,485.6	$995,636
Jessamine	7,001.9	$948,276
Madison	22,666.2	$2,951,275
Woodford	9,539.6	$1,204,194
Total	73,021.7	$9,384,922

Table 6 – Costs for Implementing All Potential Riparian Buffers

However, there is substantial cost heterogeneity within the potential supply of riparian buffers. Figure 4 shows the supply curves for each of the six counties in the study area, including both crop and pasture lands. The total annualized costs of riparian buffers on cropland, including opportunity costs and establishment and maintenance costs, range from a minimum of $110.00/acre to a maximum of $621.04/acre. Similarly, the costs of riparian buffers on land currently used for pasture or hay range from $105.44/acre to $128.30/acre. This heterogeneity suggests that much of the potential reduction in agricultural nutrient loading could be obtained at relatively low cost. Such cost heterogeneity is a primary motivation for market-based policies, such as offset credits in a water quality trading system.

Figure 4 presents county-level supply curves for riparian buffers on agricultural land. In order to meet local non-degradation constraints, permit trading may be restricted to sources within close proximity to each other. In this analysis, we consider only within-county trades.

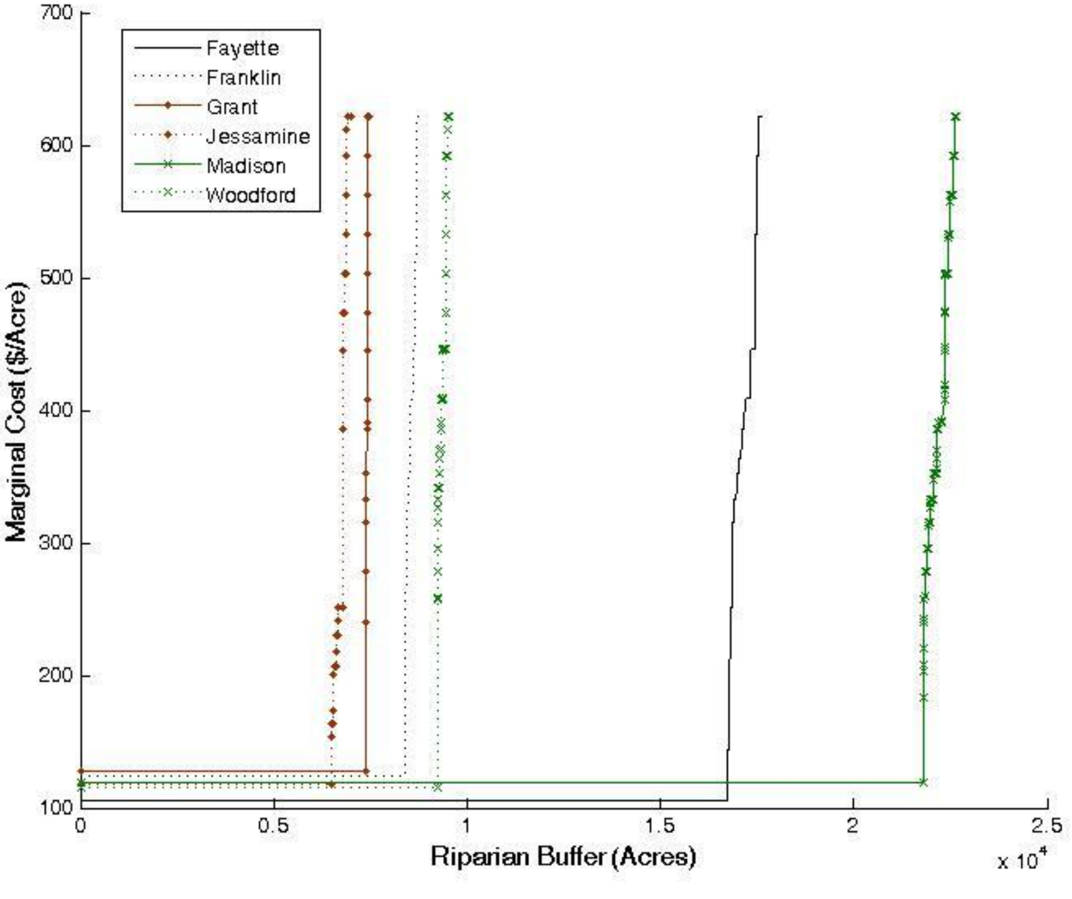

Figure 4 – Supply Curves for Riparian Buffers

The inclusion of agriculture in a WQT system by means of offset credits would allow the program to exploit cost heterogeneity in pursuit of lower abatement costs. Relative to regulation such as mandated buffer strips, such a program also shifts the impact of those abatement costs from landowners to the point sources who buy the offset credits. In fact, landowners would enjoy a net producer surplus because some of the landowners would be able to supply credits for a cost less than the prevailing market price for credits.

Pasture dominates the agricultural land in the initial study area, accounting for the vast majority (95.5%) of potential riparian buffer area (Table 1), as well as possessing a lower opportunity cost than almost all cropland. Pasture accounts for the relatively flat portions of the supply curves in Figure 4. Cropland is represented by the more steeply sloped portions of the supply curves. Since cropland accounts for a only a small share of the potential supply and has a higher cost, most riparian buffers provided by agricultural producers for offset credits will likely displace pasture. This raises two important points about this analysis.

First, the current analysis treats pasture as homogeneous within each county. Incorporating spatial heterogeneity in the opportunity cost of pasture would improve the estimation results. Given that pasture is the likely source of foreseeable buffer supply, more effort toward improving the analysis of that supply component is warranted.

Second, the opportunity cost piece of the estimation is very sensitive to agricultural prices, especially for cropland. The crop budgets from which the return functions are calculated are based on recent prices, and the prices for grains have been at high levels relative to historical trends. Significant changes in corn, soybean, or wheat prices could affect the cropland components of the supply curves substantially.

4. Conclusion

This paper has developed estimates for the costs of implementing riparian buffer strips on agricultural land in the Kentucky River watershed. Policy-makers have shown interest in the feasibility of a water quality trading system to alleviate nitrogen and phosphorus loading. Agricultural nonpoint sources are often touted for their potential to reduce abatement costs in such a trading system, and offset credits are often proposed as a mechanism for incorporating these parties into the trading system.

These estimates of riparian buffer costs will inform policy-making in this area. Combined with information on the abatement costs of point sources and the levels of abatement required to meet water quality targets, this analysis investigates the feasibility of water quality trading to reach policy objectives.

There are several avenues for improving this analysis. The authors plan to extend the current methods to include all 46 counties in the Kentucky River watershed. Although the six counties in the initial study area likely represent the best opportunities for using agricultural offset credits to reduce nutrient loadings, a comprehensive view of the entire watershed is worthwhile.

The analytical methods could also be extended to provide more accurate and robust estimates of the costs of riparian buffers. Incorporating spatial heterogeneity in the opportunity cost of pasture would be a valuable step, because that land use accounts for the lion’s share of potential buffer supply in the watershed. Additionally, the researchers will identify the specific soil types associated with cropland in the potential buffer areas, rather than relying on weighted averages.

Finally, the current analysis treats acres of riparian buffers as the unit of interest. A measure of nutrient reduction would be a more appropriate criterion for the benefits establishing buffers on agricultural land. Reductions in nutrient loadings depend not only on the size of the buffer area, but also on factors such as its geophysical characteristics, the properties of the associated streams, and the nature of adjacent land uses. Although the issue is complex, some attempt to map the implementation of a riparian buffer to the resulting nutrient loadings is necessary for designing an appropriate trading system.

References

Bingham, Tayler H., Timothy R. Bondelid, Brooks M. Depro, Ruth C. Figueroa, A. Brett Huber, Suzanne J. Unger, and George L. Van Houtven, 2000. *A Benefits Assessment of Water Pollution Control Programs Since 1972: Part 1, The Benefits of Point Source Controls for Conventional Pollutants in Rivers and Streams*. Research Triangle Institute for the U.S. Environmental Protection Agency, Office of Water, Research Triangle Park, NC.

Bonham, J.G., D.J. Bosch, and J.W. Pease, 2006. “Cost-Effectiveness of Nutrient-Management and Buffers: Comparisons of Two Spatial Scenarios.” *Journal of Agricultural and Applied Economics* 38(1): 17-32.

Breetz, H.L., K. Fisher-Vanden, L. Garzon, H. Jacobs, K. Kroetz, and R. Terry. 2004. “Water Quality Trading and Offset Initiatives in the U.S.: A Comprehensive Survey.” Report prepared for U.S. Environmental Protection Agency. Hanover, NH: Dartmouth College Rockefeller Center.

Hung, Ming-Feng and Daigee Shaw, 2005. “A Trading-Ratio System for Trading Water Pollution Discharge Permits,” *Journal of Environmental Economics and Management* 49: 83-102.

KDOW, 2008. *Final 2008 Integrated Report to Congress on the Condition of Water Resources in Kentucky. Volume II. 303(d) List of Surface Waters*. Frankfort, KY: Kentucky Environmental and Public Protection Cabinet, Division of Water.

Qiu, Z., T. Prato, and G. Boehm. 2006. “Economic Valuation of Riparian Buffer and Open Space in a Suburban Watershed.” *J. Amer. Water Resources Assoc.* 42: 1583-1596.

Roberts, David C., Christopher D. Clark, Burton C. English, William M. Park, and Roland K. Roberts. 2009. “Estimating Annualized Riparian Buffer Costs for the Harpeth River Watershed.” *Review of Agricultural Economics*, 31(4): 894-913.

University of Kentucky Cooperative Extension, 2011a. *Corn and Soybean Budgets 2011*. Department of Agricultural Economics, University of Kentucky.

University of Kentucky Cooperative Extension, 2011b. *Kentucky ANR Agent Land Value and Cash Rent Survey*. AEC 2011-01. Department of Agricultural Economics, University of Kentucky.

University of Kentucky Cooperative Extension, 2010. *Wheat and Wheat Double-Crop Soybean Budgets 2010-2011*. Department of Agricultural Economics, University of Kentucky.

University of Kentucky Cooperative Extension, 2009. *2009 Burley Production Budget*. Department of Agricultural Economics, University of Kentucky.

USDA, 2011. *Quick Stats*. Washington, DC: National Agricultural Statistics Service, U.S. Department of Agriculture.

USDA, 2009. *Web Soil Survey*. Washington, DC: Natural Resource Conservation Service, U.S. Department of Agriculture.

USEPA, 2009. *National Water Quality Inventory: Report to Congress, 2004 Reporting Cycle*. Washington, DC: U.S. Environmental Protection Agency.

USEPA, 2004. *Water Quality Trading Assessment Handbook*. EPA 841-B-04-001. Washington, DC: U.S. Environmental Protection Agency.

USEPA, 2003a. *Water Quality Trading Policy*. Washington, DC: Office of Water, U.S. Environmental Protection Agency.

USEPA, 2003b. *National Management Measures for the Control of Nonpoint Pollution from Agriculture*. Washington, DC: Office of Water, U.S. Environmental Protection Agency.

USEPA, 2002. *National Water Quality Inventory: 2000 Report*. EPA-841-R-02-001. Washington, DC: Office of Water, U.S. Environmental Protection Agency.

USGS, 2001. *National Land Cover Database 2001*. Washington, DC: U.S. Geological Survey.