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IDENTIFICATION OF CANDIDATE RIPARIAN BUFFER ZONES

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**ABSTRACT:** Best management practices such as riparian buffers, can significantly reduce the amount of agricultural nonpoint source (NPS) pollution. In an effort to reduce NPS pollution in Vermont, the Natural Resource Conservation Service (NRCS) established a program to provide financial incentives to farmers to develop riparian buffers adjacent to their agricultural fields. The NRCS approach involved identifying candidate agricultural fields by manually interpreting hardcopy aerial photographs. This approach, however, does not account for geophysical factors such as soil type, slope, land cover, and hydrology that also significantly and directly influence agricultural runoff. A method based on the Revised Universal Soil Loss Equation (RUSLE) that incorporates hydrologic flow modeling to identify and prioritize candidate agricultural fields for riparian buffer development has been developed and is presented here. Implementation of the RUSLE model within a GIS framework also provides a methodology that can be readily extrapolated to surrounding regions in a cost effective manner. The model proved to be effective in providing a rapid assessment of fields most likely to contribute NPS pollution to nearby aquatic ecosystems, but was limited in its ability to accurately model hydrologic flow patterns due to the coarse resolution of elevation data and over-simplification of the flow patterns by the flow modeling algorithm.

**KEY TERMS:** GIS, riparian, buffer, non-point source pollution, agriculture

INTRODUCTION

Nonpoint source (NPS) pollution from agriculture remains a persistent problem in the United States. The link between agriculture and NPS pollution has long been established (Braden and Uchtman, 1985). NPS pollutants from agriculture include pathogens, sediment, nutrients, pesticides, and salts (USEPA, 1996). NPS pollution in aquatic ecosystems can lead to closures of beaches, algal blooms, habitat destruction, fish kills, and reductions in biodiversity.

The Mad River, located in central Vermont, is one of the state's 117 impaired rivers listed by the EPA, due to its excessive pathogen levels (USEPA, 2001). Sampling of 37 sites during the summer of 2003 indicated that 17 sites violated state water quality standards for pathogens more than 50% of the time (Friends of the Mad River, 2003). Although pathogens are released into the Mad River from multiple sources, fecal contaminants in runoff from agricultural fields plays a major role. To enhance water quality in the Mad River watershed, the United States Department of Agriculture (USDA) Natural Resource Conservation Service (NRCS) embarked on a program to provide financial incentives to encourage the establishment of vegetative filter strips and riparian buffer zones (hereafter referred to collectively as riparian buffers) adjacent to agricultural fields. One of the challenges NRCS personnel faced was identifying those fields that were already protected by existing buffers and those fields that were candidates for the establishment of riparian buffers. To characterize riparian buffers adjacent to fields NRCS personnel manually delineated existing buffers along the main channel of the Mad River on black and white hardcopy aerial photographs. This information was then cross-referenced with Farm Service Agency (FSA) maps to determine ownership, and compiled in spreadsheet format for subsequent analysis.

There existed enormous potential to improve both the effectiveness and efficiency of NRCS efforts by designing a model to identify and rank candidate parcels for the establishment of riparian buffers within a Geographic Information System (GIS) using an existing NPS pollution model, such as the Revised Universal Soil Loss Equation (RUSLE). By employing a GIS-based method, the potential also existed to quantify upslope areas protected by existing riparian buffers through hydrologic flow modeling. The traditional method of identifying existing buffers follows the definition that a riparian buffer is vegetation that lies between a field and an adjacent stream. However, riparian buffers could be more accurately defined based on hydrologic flow. The objective of this study was to develop and test an integrated approach to rank agriculture fields based on their NPS pollution potential and determine which fields, or portions of fields, were protected by existing riparian buffers, thereby giving NRCS a more effective means to target specific fields for riparian buffer establishment.

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## Revised Universal Soil Loss Equation

Many NPS pollutants are associated with sediment erosion and sediment transport (Nelson et al., 1976; USEPA, 1993). As such, soil loss is often considered a surrogate for NPS pollution. Presently, NRCS staff use the Revised Universal Soil Loss Equation (RUSLE) to predict soil erosion and help plan BMPs for agricultural fields. RUSLE (Renard et al., 1997; Renard et al., 1991) predicts average annual soil loss per unit area ( $A$ ) (typically in tons/acre/year) as a function of rainfall-runoff erosivity ( $R$ ), soil erodibility ( $K$ ), topography ( $LS$ ), land use/land cover ( $C$ ), and conservation practices ( $P$ ):

$$A = R \times K \times LS \times C \times P$$

Most of the same factors that are taken into account by RUSLE are also important for the transport of pathogens and other NPS pollutants (Sutton, 1976; Thurston-Enriquez, 2003). Although soil erosion modeling will not predict the loading of individual pollutants, it can provide an indication of NPS pollution potential, and more importantly, identify areas that warrant the implementation of riparian buffer zones.

Because its components are available as either direct products of, or derivatives of commonly available georeferenced data sets, well-established methods for incorporating RUSLE into a GIS framework have been developed (Pelletier, 1985; Hession and Shanholtz, 1988; Mellerowicz et al., 1994; Millward and Mersey, 1999; Bartsch et al., 2002).

## METHODS

## Study Area

The study area encompassed a 5 km by 20 km portion of the Mad River watershed representing a patchwork of agricultural and forest lands. Most agricultural land is located in the valleys near the Mad River and its tributaries between 130 m and 400 m in elevation. The agricultural land is primarily used to grow corn and hay or to provide pasture for cattle.

## Model Overview

Our integrated approach was implemented in two steps: (1) NPS pollution potential was calculated on a per field basis using the RUSLE, and (2) hydrologic flow modeling was employed to identify those agricultural fields, or portions of fields, protected by existing riparian buffers (Figure 1). All data management and analyses were performed with ArcINFO (ESRI, 2000).

## Calculating Nonpoint Source Pollution Potential

Data inputs for the RUSLE were acquired directly or derived from federal and state GIS archives or commercial imagery. Data layers were converted to raster format as needed with a 4m grid cell spacing equal to that of the IKONOS satellite imagery from which the land use/land cover data layer was derived.

Rainfall-runoff erosivity ( $R$ ) was determined based on the NRCS Electronic Field Office Technical Guide (USDA/NRCS, 2003). Due to the limited areal extent and topographic range of the study area, a fixed value of 95 was assigned to the  $R$  factor. Soils data were obtained from the National Soil Survey Geographic (SSURGO) database. Values of  $K$  for the uppermost soil layer were linked with corresponding soil polygons which were then converted to raster format.  $K$ -values for fields in this study ranged from 0.15 to 0.49.

Point elevation data, compiled by the Vermont Mapping Program (VT Department of Taxes) in support of the State's 1:5000 orthophotography program, were interpolated using the IDW algorithm (ArcInfo TOPOGRID) to create a 4 m raster digital elevation model (DEM) consistent with the IKONOS satellite imagery (Hutchinson, 1988; Hutchinson, 1989). Within a 100m buffer of the Mad River, there was an average of 5.7 points per 25m x 25m cell based on a combination of mass points (60 m spacing) and break points. To ensure that flow adhered to existing stream channels, a hydrologically-correct DEM was generated using stream burning and sink filling operations (Saunders, 2000). The topographic factor ( $LS$ ) was then computed based on the DEM using an iterative slope length process developed by Hickey (2000). Average  $LS$ -values for the fields in this study ranged from 0.62 to 5.67.

A land use/land cover (LULC) data layer for the study area was generated by applying object-oriented image classification techniques (*eCognition*, Definiens AG, Germany) to two mosaicked 4 m spatial resolution, multispectral IKONOS images (Space Imaging LLC, Thornton, CO). Land use/land cover-management values ( $C$ ) were then assigned each LULC class according to the NRCS Electronic Field Office Technical Guide (USDA, 2003) and the data converted to raster format. Two crop cover types dominated the study area, hay/pasture and corn. Average values for  $C$  of 0.14 and 0.30 were assigned each cover type respectively. Farm data detailing conservation practices ( $P$ ) were not available for our study area. The parameter  $P$  was therefore assigned a constant value of 1.

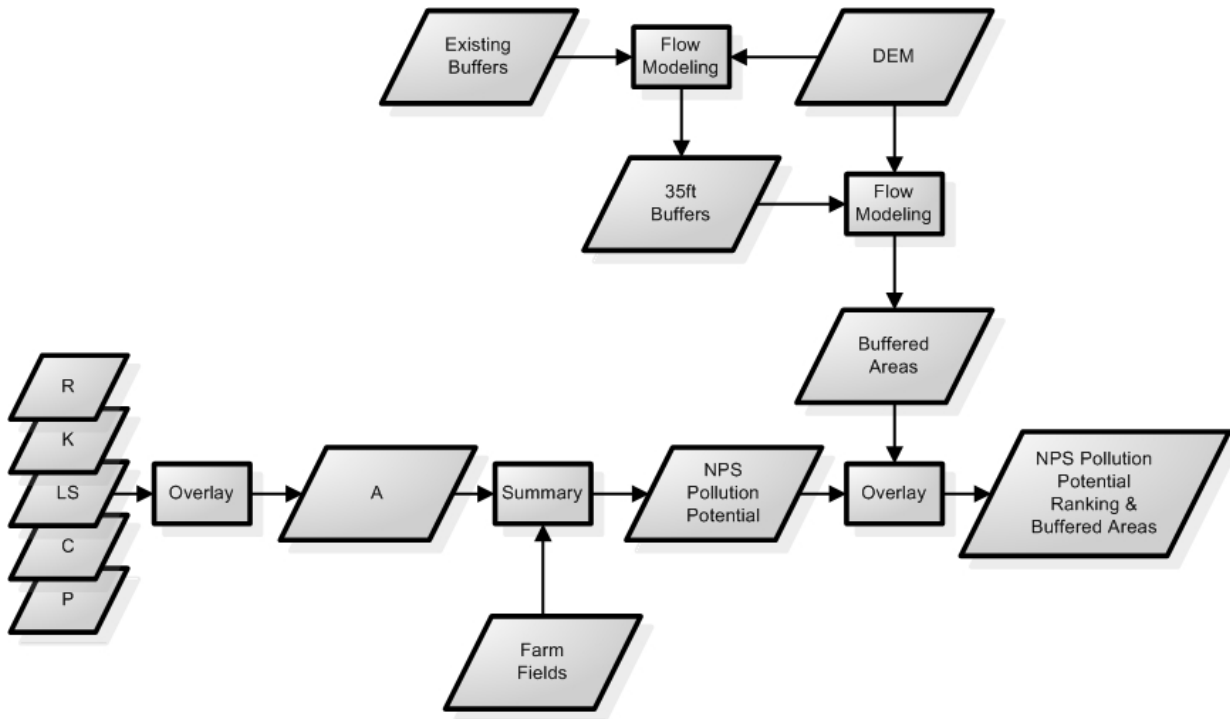


Figure 1: Model process. The RUSLE factors are used to provide a relative NPS pollution potential ranking for each agricultural field, while hydrologic flow modeling is used to map areas protected by existing riparian buffers.

The RUSLE was computed from the respective data layers using map algebra. The output was comprised of a new raster layer in which each grid cell located within an agricultural field (based on the LULC data layer) was assigned the computed average annual soil loss (A) value. The A values were then averaged on a per field basis using USDA Common Land Unit (CLU) field boundaries (n = 41 fields) and grouped into three equal interval classes (low, medium, high) indicating relative nonpoint source pollution potential.

### Hydrologic Flow Modeling

Hydrologic flow modeling was used to identify both those riparian buffers that met NRCS’s required buffer width (35 ft) and those agricultural areas that were already protected by existing buffers. All natural vegetation, wetlands and ponds were considered to be buffers since they have the ability to collect overland flow. On this basis, an *existing riparian buffers* layer was generated from the LULC data layer by extracting all grid cells classified as forest, shrub, wetland, and pond.

An overland *flow direction* data layer was generated from the hydrologically-correct DEM data using the D8 algorithm (Jenson and Domingue, 1988). Downstream flow length was then computed from these data for all *existing riparian buffer* cells to represent the effective overland flow length of the existing buffers. Those grid cells whose flow length value was equal to or greater than the NRCS specified minimum buffer width of 35 ft were then selected to form a new *35 ft buffers* data layer. Next, the contributing region for each cell meeting the NRCS minimum buffer width requirement was determined to yield an *existing buffered areas* data layer.

### Candidate Riparian Buffer Error Assessment

Existing buffered areas predicted by our model were compared to actual buffered areas obtained from field surveys to assess the accuracy of the hydrologic flow modeling. Each of the 41 fields for which the NPS potential was computed was visited to interpret actual hydrologic flow patterns and record what portions of each field was protected by existing riparian buffers. The relative errors in the model estimates were computed on a per field basis and grouped into error classes based on the magnitude and sign of the error: ± 5%, 6% - 25%, 26% - 50%, and 51% - 75%.

RESULTS AND DISCUSSION

Model Output

Implementation of the RUSLE in a GIS framework was straightforward, demonstrating the effectiveness of this approach to rank agricultural fields by their NPS pollution potential. The value of integrating a hydrologic flow model in this context to quantify the proportion of agricultural fields draining into existing riparian buffers was also demonstrated (Figure 2). For the 41 fields bordering the Mad River, 90% of the buffer area estimates predicted by the model were within 25% of actual field measurements. Model error for more than half of these fields (22 of 41) was  $\leq 5\%$ . Predicted estimates from only four fields differed from actual by more than 25%. Sources of error in the predicted estimates were in part attributed to classification error in the LULC data layer, but more often were due to limitations in the hydrological flow model.

Overall, the integrated modeling and GIS approach demonstrated that the risk of NPS pollution from agricultural fields to the nearby Mad River was high. The results indicated that the majority of the fields bordering the river were not protected by existing buffers meeting NRCS guidelines and thus were candidates for establishing vegetative buffers. Of the fields bordering the Mad River, the RUSLE model alone predicted that two had a high, 17 a medium, and 22 a low NPS pollution potential. However, less than half of the area represented by these fields was protected by existing buffers meeting NRCS requirements as estimated by the hydrologic flow model. More specifically, 65%, 49%, and 50% of the area of those fields having a high, medium, or low NPS pollution potential respectively, was not protected by existing buffers. Even assuming that only 75% of the areal extent of each field need be protected, it was found that neither of the fields assigned a high NPS pollution potential and only 30% of those assigned a medium or low potential met this criterion. Additionally, 23% of agricultural lands within the study area not directly bordering the Mad River were identified as potential nonpoint sources warranting buffer establishment. Most of these lands were located either near the Mad River or adjacent to lower order streams that drained into it. Of these, 9%, 14%, and 39% respectively of the area of those fields assigned a high, medium, or low NPS pollution potential were not protected by existing riparian buffers.

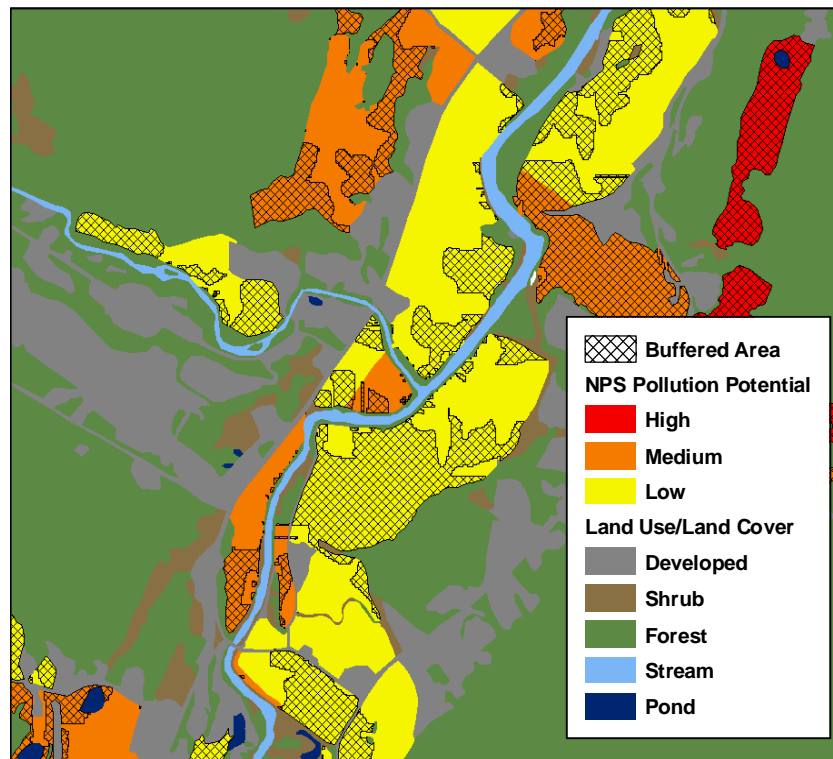


Figure 2: Model output showing the relative NPS pollution potential ranking of agricultural fields along with the portions of those fields protected by existing buffers.

## Model Limitations

Although the potential of an integrated GIS-based modeling approach was demonstrated, limitations of the hydrologic flow model undoubtedly compromised efforts to quantify those areas protected by existing riparian buffers. This limitation was driven by both data and model uncertainties and constraints. For example, the spatial and vertical resolution of the digital elevation data and imagery used in the analyses, precluded identification and modeling of smaller, low relief drainages (e.g. drainage ditches) that may negate the effectiveness of riparian buffers. Similarly, the D8 algorithm allows overland flow only to go to one of eight neighboring cells. A more realistic flow model would account for more dispersed flow in the agricultural fields along the Mad River Valley's floor due to the gentle slope of the terrain.

A limited sensitivity analysis on selected RUSLE factors indicated that *K* and *C* have greater influence over NPS pollution potential estimates than *LS*, suggesting that efforts to ensure the accuracy of soil and LULC classifications may prove beneficial. Fortunately, detailed sensitivity and uncertainty analyses have documented the limitations of the RUSLE (Hession et al., 1996; Renard and Ferreira, 1993; Risse et al., 1993; Gertner et al., 2002; Wischmeier, 1976). One key limitation is that in areas represented by large tracts of continuous agricultural fields, the model can be somewhat misleading because it does not account for erosion from upslope fields being deposited on downslope fields. This was not a significant issue in this study because of the heterogeneous and heavily forested landscape, but in areas where it may occur, a cost distance function should be considered to give less weight to the potential contribution of fields as their distance from a stream increases.

## CONCLUSIONS

Implementation of the RUSLE model within a GIS framework provides an effective means for ranking agricultural fields based on their NPS pollution potential. While this approach is useful for identifying fields that may be sources of high amounts of NPS pollutants, its integration with a hydrologic flow model is crucial for determining what fields, or portions of fields, are protected by existing riparian buffers. Because this approach relies on readily-available and GIS-ready data, it can be extrapolated to relatively large areas in a cost efficient manner, thus providing a robust method for rapidly prioritizing agricultural fields in need of riparian buffer establishment and thus aid management of resources to most effectively reduce NPS pollution. While this integrated approach proved to be effective in assessing fields most likely to contribute NPS pollution to nearby aquatic ecosystems, it was limited in its ability to accurately model the surface hydrology. Future efforts should explore the potentials of improved elevation data and overland flow modeling algorithms.

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