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CONCENTRATED RUNOFF FLOW: IMPLICATIONS FOR BUFFER DESIGN AND WATER QUALITY BENEFITS

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ABSTRACT

Non-uniform or concentrated flow of surface runoff from agricultural fields can reduce the pollutant trapping effectiveness of buffer strips having constant width along a riparian zone or field margin. Effectiveness and cost-effectiveness might be improved by reconfiguring the buffer to be larger where more runoff flows and smaller where runoff is less. A GIS tool has been developed that accounts for non-uniform patterns of runoff flow which can be used for assessing performance of buffers and for designing them. This tool was used to assess the effect of non-uniform runoff on sediment trapping efficiency of constant-width buffer designs and to compare performance of constant-width and variable-size configurations.

The tool is an ArcGIS extension based on the design model of Dosskey *et al.* (2011). It employs a digital elevation model (DEM) to divide the riparian area or field margin into many segments, determine contributing area and slope to each one and, then, design for a buffer area ratio that provides a specified level of trapping efficiency. The assessment procedure employs these same algorithms, but in a different order; first, determining the existing buffer area ratio and, then, calculating it's trapping efficiency.

Results using this tool on a sample of fields in the Midwestern U.S. suggest that variable-size designs can be more than twice as effective per unit buffer area as conventional constant-width designs. Producing cost-effective designs and accurate performance assessments of buffers requires accounting for detailed spatial patterns of runoff flow from agricultural fields.

Keywords: design, GIS, nonpoint pollution, precision conservation, riparian, terrain analysis

INTRODUCTION

Vegetative buffers reduce the load of sediment, nutrients, and other pollutants in runoff from fields to waterways. Typically, they are designed to have a constant width along an entire field margin. Several methods have been developed for determining an appropriate width for a buffer where runoff is uniformly distributed along the field margin (e.g., Dillaha and Hayes 1991; Suwandono *et al.* 1999; NRCS 2007; Dosskey *et al.* 2008).

In many situations, however, runoff is not uniformly distributed and moves as concentrated flow across only portions of a field margin (Dillaha *et al.* 1986, 1989; Dosskey *et al.* 2002; Pankau *et* *al.* 2012). One study of farms in eastern Nebraska estimated sediment trapping efficiency under observed non-uniform runoff flow to be less than half of what would be expected if runoff flow was uniform (Dosskey *et al.* 2002). Trapping efficiency was reduced by elevated loads to segments receiving concentrated flows. Other segments of buffer received little or no runoff and contributed little to reducing sediment from these farms. Runoff could be spread more evenly by grading the field or constructing spreaders, but these actions would add substantial cost. A more cost-effective design would simply vary the width of filter strip according to the amount of runoff received; larger where runoff is greater and smaller where runoff is less (Dosskey *et al.* 2005).

A design method was developed recently for sizing buffers that can account for non-uniform overland runoff (Dosskey *et al.* 2011). This method, however, is time-consuming to apply manually because it requires precise mapping of runoff flow paths from fields. To make it easier to use, the design method was automated by adapting it to terrain analysis in a GIS. Its utility was further enhanced by modifying these procedures to enable estimation of performance of existing and hypothetical buffers. The automated tool, called *BufferBuilder*, was used to (1) assess the impact of concentrated or non-uniform flow on sediment trapping by constant-width buffers, and (2) determine if performance can be improved by reconfiguring buffer area to match non-uniform patterns of runoff flow.

MATERIALS AND METHODS

The *BufferBuilder* program, an extension of ArcGIS v.10.0 and v.10.1 (ESRI, Redlands, CA, USA), was used to design variable-size buffers having a specified sediment trapping efficiency and to assess the corresponding trapping efficiency of constant-width buffers having identical total area. Several sample farm fields across the Midwestern U.S. were designed and assessed in this way, and the results compared.

The key feature of *BufferBuilder v.1.0* is that it sizes buffer in segments along a field margin in proportion to the size of field area that drains to each segment, i.e., buffer area ratio. This approach can account for varying sizes and irregular shapes of contributing areas that produce non-uniform runoff. The appropriate buffer area ratio is determined by additional information on slope, soil texture, tillage conditions, and the level of trapping efficiency that is desired for a design storm of 61 mm in 1 hr (Dosskey et al. 2011). In the GIS, a digital elevation model (DEM) is used to divide the field margin into segments, determine contributing area and slope to each segment, and to provide a grid structure for calculating and mapping buffer area for many segments around a field margin.

For this study, digital aerial orthophotos of the fields were obtained from the USDA-NRCS Geospatial Data Gateway website (http://datagateway.nrcs.usda.gov). Digital elevation models having approximately 10-m grid spacing were obtained from the USGS National Elevation Database website at http://seamless.usgs.gov/ and were resampled to a 5 m grid.

RESULTS

An example of a *BufferBuilder*-designed buffer is shown in figure 1 (in red). The sinuous contours suggest that runoff does not distribute uniformly to the field margin around this field. Consequently, the designed filter strip has a highly variable configuration. Despite the variable configuration, this design is expected to provide a constant 72% sediment trapping efficiency along the entire field margin.

Figure 1. Aerial photo of a 59.3 ha field in Madison Co., IL showing 1-m contours and a constant-width (20-25 m) buffer (in yellow) having the same total area as the *BufferBuilder* design (in red). The sediment trapping efficiency of the constant-width configuration on a whole-field basis was estimated to be 35% while that of the *BufferBuilder* design was estimated to be 72%.

An example of an assessment using *BufferBuilder* is also shown in figure 1. In this scenario, a 20-25 m-wide buffer was drawn along the margin (in yellow) where the design procedure indicates that most runoff would leave the field. It was drawn to have the same total area (4.0 ha) as the *BufferBuilder*-designed buffer. This constant-width buffer was estimated to have 35% sediment trapping efficiency or about 35% of the sediment delivered to the field margin from this field would be trapped by this buffer.

Several additional fields were analyzed using both the design and the assessment procedures in the same manner as the example in figure 1. In every scenario the design produced by *BufferBuilder* performed better than the constant-width configuration having the same total area (table 1). On average the variable-size configuration would trap 67% of the sediment in field runoff compared to only 30% by the constant-width configuration.

Table 1. Comparison of whole-field average sediment trapping efficiency of *BufferBuilder*-designed and constant-width buffers having equivalent total area for selected fields in the Midwestern U.S.

Field Location	**Field area (ha)**	**Buffer area (ha)**	**Sediment Trapping Efficiency (%)**	
			***BufferBuilder* design**	**Constant-width design**
Madison Co., IL	59.3	4.0	72	35
Shelby Co., KY	25.1	3.4	67	40
Cedar Co., IA	14.9	0.9	69	62
Clinton Co., MO	30.1	0.8	66	24
Clinton Co., MO	4.0	0.1	64	16
Dekalb Co. MO	15.2	0.8	64	33
		Average	67	30

DISCUSSION

Results from this study are consistent with an earlier study in Nebraska which estimated that observed patterns of non-uniform runoff limited the sediment trapping efficiency to less than half of what would be expected if runoff was distributed uniformly through the existing buffers (Dosskey et al. 2002). Although the field scenarios in table 1 were not intended to be statistically representative of the Midwestern U.S., the results of this sample invariably point toward better performance by variable-size buffers, often by very large margins.

Since installation costs and program incentives (e.g. USDA Conservation Reserve Enhancement Program) for buffers are proportional to the total area of the buffer installation, these results translate directly into greater water quality improvement per dollar spent for *BufferBuilder*-designed variable-size buffers than for constant-width configurations. Alternatively, additional structural practices could be installed that distribute runoff uniformly through the constant-width filter strips and bring the trapping efficiency up to the level determined for *BufferBuilder*-designed buffers, but that approach would add substantially to the total cost of the buffer. Both effectiveness and cost-effectiveness of buffers could be enhanced simply by configuring the buffer area to match detailed spatial patterns of field runoff.

The results of this study suggest that producing cost-effective designs and accurate performance assessments of buffers requires accounting for detailed spatial patterns of runoff flow from agricultural fields. Failure to do so could result in substantial underperformance of buffer installations and overestimation of water quality benefits.

CONCLUSIONS

Pollutant trapping effectiveness of constant-width buffers can be greatly limited by concentrated or non-uniform runoff flow. Better designs would match size of buffer to the runoff load along riparian zones and field margins. The design model of Dosskey et al. (2011), which can account for non-uniform runoff, was programmed into a GIS tool for designing and assessing performance of water quality buffers. Variable-size designs developed for sample fields with this tool were estimated to trap substantially greater amounts of sediments than constant-width configurations having the same total area. This result translates directly into greater cost-effectiveness of variable-size designs compared to constant-width configurations where runoff is non-uniform. Producing cost-effective designs and accurate performance assessments of buffers requires accounting for detailed spatial patterns of runoff flow from agricultural fields.

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