PRECISION DESIGN OF VEGETATIVE BUFFERS

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ABSTRACT

Precision agriculture techniques can be applied at field margins to improve performance of water quality protection practices. Effectiveness of vegetative buffers, conventionally designed to have uniform width along field margins, is limited by spatially non-uniform runoff from fields. Effectiveness can be improved by placing relatively wider buffer at locations where loads are greater. A GIS tool, AgBufferBuilder, was developed that accounts for non-uniform flow and produces more-effective, variable-width, designs. The design model was developed by simulation modeling using the Vegetative Filter Strip Modeling System (VFSMOD-W) to produce relationships between pollutant trapping efficiency and buffer area ratio. To apply them, one relationship is selected that best describes a given field situation based on slope, soil texture, field cover management, and pollutant type. That equation is used to determine the buffer area ratio that would produce a desired level of trapping efficiency and it would be applied to the contributing area to each segment of field margin. The equation also can be used in reverse to estimate the performance of existing or hypothetical buffers. The design model was, then, adapted for use in a GIS. The GIS tool employs an aerial photo to define the field margin and a DEM grid to segment the field margin and determine contributing areas and slopes to each one. The photo is used again to map the resulting buffer design on the ground. Results using the GIS tool on case study fields suggest that pollutant trapping performance per unit area of buffer can be increased substantially over conventional designs by using a precision variable-width approach.

Keywords: Precision agriculture, GIS, Filter strip, Nonpoint pollution, Runoff, Terrain analysis, Water quality

INTRODUCTION

Vegetative buffers such as filter strips and riparian 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). That method utilizes precise mapping of runoff flow paths from fields and it was recently 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 GIS tool, called AgBufferBuilder, was used in this study 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 AgBufferBuilder program can be downloaded from the website http://www2.ca.uky.edu/BufferBuilder/ along with a user's guide, documentation, practice data sets, and other supporting materials. The program is used with ArcGIS v.10.0 and v.10.1 (ESRI, Redlands, CA). In this study, it 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 selected and designed and assessed in this way, and the results compared.

The core design model was developed by simulation modeling using the Vegetative Filter Strip Modeling System (VFSMOD v.1.04; Muñoz-Carpena and Parsons, 2000, 2005) to produce relationships between pollutant trapping efficiency and buffer area ratio. To apply them, one relationship is selected that best describes a given field situation based on slope, soil texture, field cover management, and pollutant type. That equation is used to determine the buffer area ratio that would produce a desired level of trapping efficiency and it would be applied to the contributing area to each segment of field margin. The equation also can be used in reverse to estimate the performance of existing or hypothetical buffers. The design model was, then, adapted and programmed (in Python and ModelBuilder) for use in the GIS.

The key feature of AgBufferBuilder 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://nationalmap.gov/ and were resampled to a 5 m grid.

RESULTS

An example of an AgBufferBuilder-designed vegetative buffer is shown in figure 1 (in red). The sinuous elevation 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 estimated to provide a constant 72% sediment trapping efficiency along the entire field margin.

An example of an assessment using AgBufferBuilder 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 (and contours) indicates that most runoff would leave the field. It was drawn to have the same total area (4.0 ha) as the AgBufferBuilder-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.

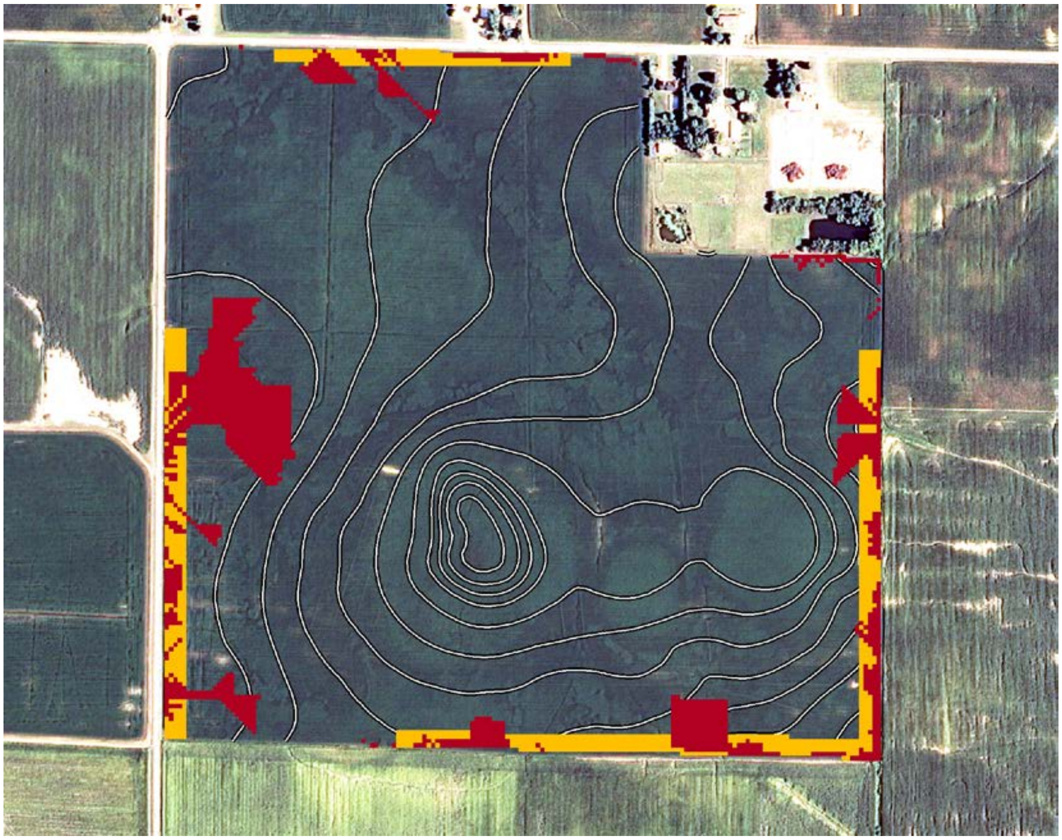

Figure 1. An aerial photo of a 59.3 ha field in Madison Co., IL showing 1-m contours and a constant-width (20-25 m) buffer (in yellow) having the same total area as the AgBufferBuilder design (in red). The sediment trapping efficiency of the constant-width configuration on a whole-field basis was estimated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

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 AgBufferBuilder was estimated to perform 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.

DISCUSSION

Results from this study are consistent with an earlier study in Nebraska (Dosskey et al., 2002) 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. Although the field scenarios in table 1 were not intended to be statistically representative of the Midwestern U.S., the results of this sample point toward better performance by variable-size buffers, often by very large margins.

Table 1. A comparison of whole-field sediment trapping efficiency of AgBufferBuilder-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 (%) AgBufferBuilder design	Sediment Trapping Efficiency (%) 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

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. 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 AgBufferBuilder-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 AgBufferBuilder-designed buffers, but that approach would add substantially to the total cost of the buffer. Both effectiveness and cost-effectiveness of buffers could be substantially enhanced simply by configuring the buffer area to match detailed spatial patterns of field runoff.

The AgBufferBuilder program offers planners a method for precision design of vegetative buffers of overland runoff from agricultural fields, but its results should be used cautiously. At this time, the validity of the AgBufferBuilder program is based mainly on the validity of VFSMOD-W from which the core design model was developed. Performance of the GIS adaptation of that model, AgBufferBuilder, requires further testing under a variety of different site conditions and comparison to field measurement.

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 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 using 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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