SPECIFIC CATCHMENT AREA AS A BASIS OF DESIGN FOR PRECISION RIPARIAN BUFFERS

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Abstract. One of the most important functions of a riparian buffer is to act as a filter strip that removes sediment, nutrients and pollutants from stormwater runoff. Therefore, as a water treatment process, it is only logical that hydraulic loading should be an important factor in the effectiveness of the process. Using terrain analysis techniques, the areas of greater surface runoff can be identified so that buffer widths can be increased to reduce the hydraulic loading. This analysis is best performed using a contour based terrain model. In a contour based terrain model, every segment of contour line has an associated upslope drainage area. This area divided by the length of the contour line is the specific catchment area. Although other factors such as slope, soil type and vegetative cover affect the rate of surface runoff, the catchment area is a major factor and one that can be easily and objectively determined. Because of its objectivity, it can be used as a design criterion for precisely delineating variable-width buffers that will be more effective than fixed-width buffers in improving the quality of stormwater runoff.

INTRODUCTION

The use of riparian buffers is considered to be an important strategy for the reduction of non-point source water pollution. Riparian buffers also provide other functions such as streambank stabilization and wildlife habitat (Wenger 1999). Georgia has adopted legislation requiring a minimum buffer width of 25 feet along streams. In cases where water quality is considered to be more critical, such as water supply reservoirs, the state requires that buffer widths be increased to as much as 150 feet. Also, many local governments have adopted ordinances requiring buffer widths greater than that mandated by state law. Since these ordinances are considered to be a taking of private property rights, considerable opposition has arisen from landowners. To defend such legislative action, it is important that buffer requirements be based on sound science rather than arbitrary decisions. Unfortunately, many researchers have found that fixed-width buffer designs are not highly efficient for removing pollutants from surface runoff. It can be shown that a high percentage of a fixed-width buffer area receives minimal surface runoff, whereas critical areas may be hydraulically overloaded and provide no appreciable reduction of pollutants (Dosskey et al 2002). To be effective, buffers should receive surface runoff in a dispersed, sheet-flow condition. Where canalized flow passes through a buffer, there is virtually no effectiveness for pollutant reduction. Fixed-width buffers are certainly better than no buffers and may be the only feasible method for prescribing riparian buffers that can be implemented by law. However, if optimal pollutant reduction is desired, the approach of designing variable-width precision riparian buffers should be seriously considered.

THE NEED FOR NON-POINT SOURCE POLLUTANT REDUCTION

In the last half of the 20th century, the U.S. made great strides in reducing the quantity of point source water pollution coming from industries and public sewer systems. To further improve water quality in streams and lakes, and to allow for future growth, the challenge is now to reduce non-point source pollution. An item of particular importance is phosphorus loading to lakes.

Lake Allatoona is an important example of the need to reduce phosphorus in non-point sources. The Georgia Environmental Protection Division (EPD) has estimated during the standards development process based on a wet year that the total annual phosphorus load to Lake Allatoona is 472,800 pounds per year. Of this amount, approximately 18,000 pounds, or 4%, comes from permitted wastewater discharges (MacGregor 2006). The current EPD policy is to deny requests for new wastewater discharges, except for minimal cold weather releases from reuse systems. Dawson County, which is a rapidly growing county in the Lake Allatoona watershed, was recently denied a permit request for a continuous discharge that would release less than 400 pounds per year of phosphorus.

Vegetative buffers that function well can be effective at removing phosphorus from surface runoff. The majority of studies conducted under a variety of vegetation types and buffer widths have reported phosphorus removal rates of 60% to 90% (Polyakov et al 2005).

Fixed-width Buffers

Fixed-width buffers are designed simply by specifying a fixed distance between the stream or water body and the boundary of the buffer. This approach is easily implemented since it requires minimal design effort. However, controversies can arise when trying to define what constitutes a stream. It is sometimes thought that larger streams should have wider buffers but, in actuality, the opposite is the case. Riparian buffers are more important along the smaller headwater streams which make up the majority of stream miles in any basin (Wenger 1999). Many of these streams are ephemeral in nature and may not be included in buffer ordinances. In fact, there is no clear demarcation between surface runoff and ephemeral streams. The use of specific catchment area can be shown to be more effective than stream definition for determining the optimum location of buffers.

Delineation of Precision Riparian Buffers

The effectiveness of buffers, also denoted as vegetative filter strips, for pollutant reduction depends on a number of factors. Some of these are: runoff contributing area, land use, slope, soil type, vegetation and climate. Many of these factors are difficult to quantify and may be subjective in nature. However, with accurate topographic data, the runoff contributing area can be accurately and objectively measured.

Buffer-Area Ratio Method. Bren (2000) developed a method that consisted of dividing the length of a waterway into segments and designing buffers with a constant ratio of buffer area to runoff area that drains to it. Dosskey et al. (2002), using the Vegetative Filter Strip Model (VFSMOD) applied to four farms in Nebraska, showed a relationship between sediment trapping efficiency and the ratio of buffer area to runoff contributing area. The relationships are shown graphically in Figure 1.

Terrain Analysis Techniques. To better understand the mechanics of surface water flow, it is helpful to have some grounding in the science of terrain analysis. Terrain analysis uses the geometric properties of the surface landform to derive meaningful topographic attributes. The attribute of specific catchment area, A_s, is particularly useful for estimating the relative intensity of surface water flow during storm events. To visualize the flow patterns of stormwater, it is best to use a vector-based elevation data set (contour map). Flow paths are orthogonal to contour lines. Figure 2 shows an example contour map. This example map also shows the stream tube concept first proposed by Onstad and Brakensiek (1968). All segments of contour lines will have an associated upslope catchment area. Extending flow paths upslope from each end of the contour line segment until they meet or intersect a ridge line forms the stream tube. By definition, all surface flow that is generated by rainfall landing upon the stream tube area leaves the stream tube only through the downstream contour. No flow crosses the side boundaries of the stream tube.

Relationship between sediment trapping efficiency (i.e., percent of input load retained by the buffer) and buffer-area ratio developed using VFSMOD for conditions on four farms in southeastern Nebraska. Buffer-area ratio = (Buffer area / field runoff area). (Figure from Dosskey et al., 2002.)

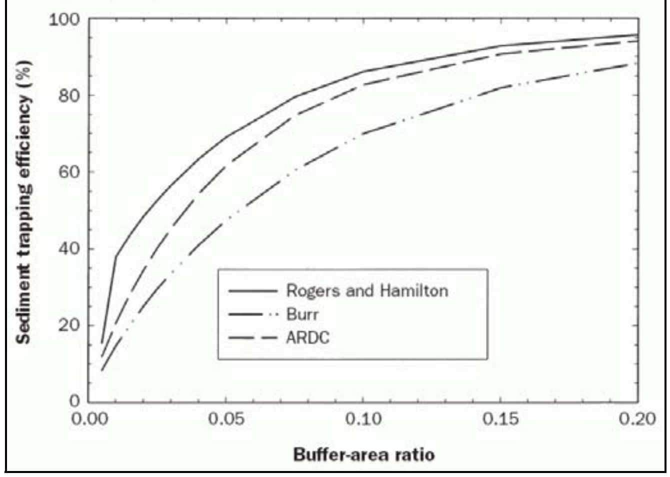

Figure 1

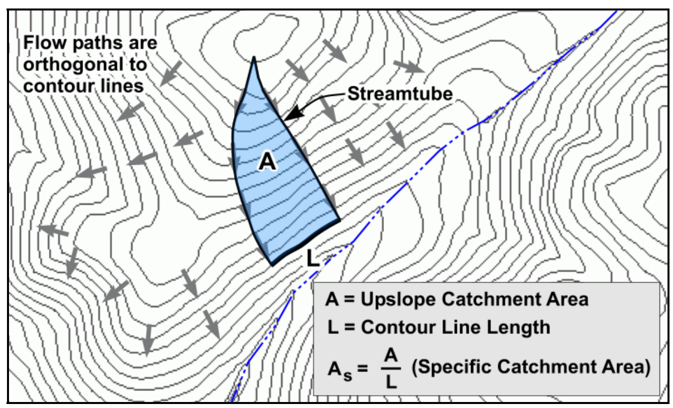

Figure 2

The specific catchment area (A_s) is defined as the stream tube area divided by the downstream contour length. The units are area divided by length, such as square feet per foot. The factor that most affects the value of A_s is the curvature of the upslope contour lines. Figure 3 shows an example of this. For convex contours, where the flow is diverging, A_s will be smaller. This is the case because as the area increases going downslope, the contour line length also increases. The opposite is true for concave contours, thus causing A_s to increase more rapidly going downslope. Higher values of A_s are therefore indicative of concentrated flow.

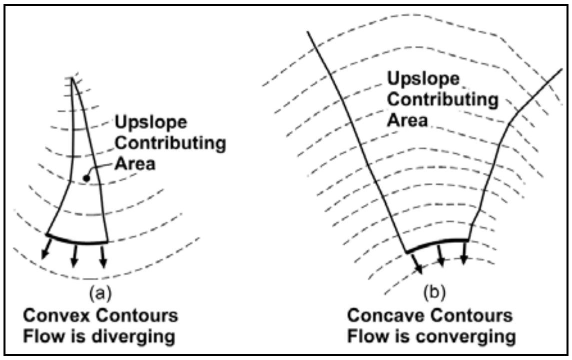

Figure 3

Precision Buffer Design Example

To illustrate the process for designing precision riparian buffers using terrain analysis, the following example is presented. Figure 4 shows an example watershed of approximately 56 acres. The stream is drawn on the contour map of the watershed and divided into segments of 100 feet. In Figure 5, for each stream segment, the associated stream tube is drawn with lines orthogonal to the contour lines. Note that both sides of the stream segment have an associated stream tube. The stream tube area is measured and the value of the area is divided by the stream segment length. This gives the specific catchment area for the stream segment in square feet per foot. These values are shown on Figure 5.

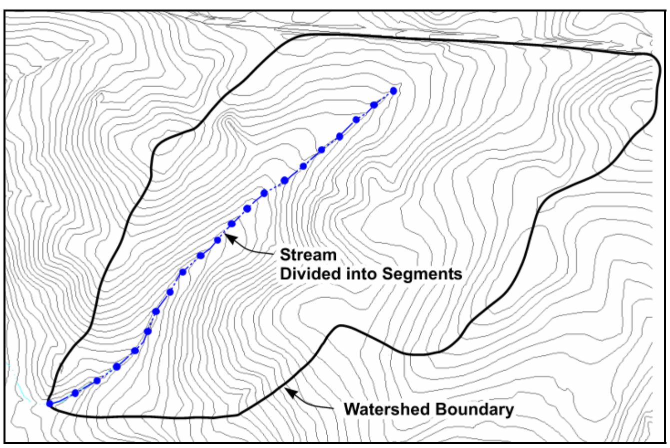

Figure 4

The values of A_s for this stream range from 77 to 5680. Where stream tube areas exceed a certain threshold value, they should be treated as a sub-watershed and analyzed separately with their own associated stream. The stream tube associated with the A_s value of 5680 has an area of 568,000 square feet or 13 acres. Ten acres may be a reasonable threshold value to use for identifying a sub-watershed.

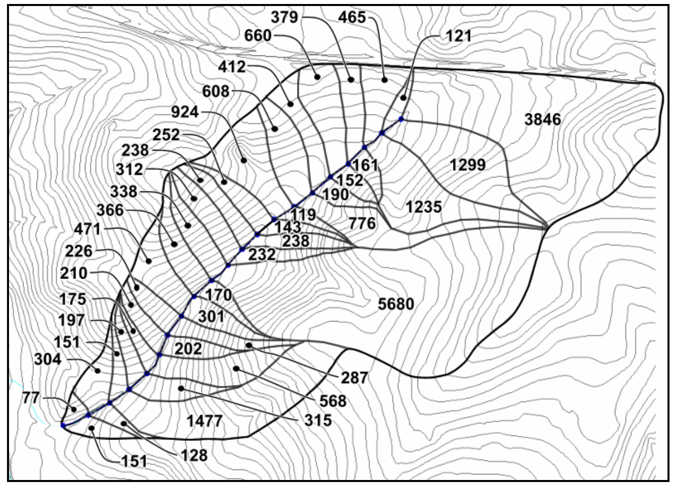

Figure 5

The end of the stream presents a special case. This would be the headwaters stream tube, which theoretically drains down to a point and would have an infinite value for A_s. In order to show a similar value for this segment, it can be assumed that an arc with a length similar to the stream segment lengths can be drawn around the endpoint of the stream. Buffers for the headwaters stream tube would still be designed using the buffer-area method. To optimize the placement of buffers within this stream tube, it could be divided further with radial stream path lines drawn out from the end of the stream.

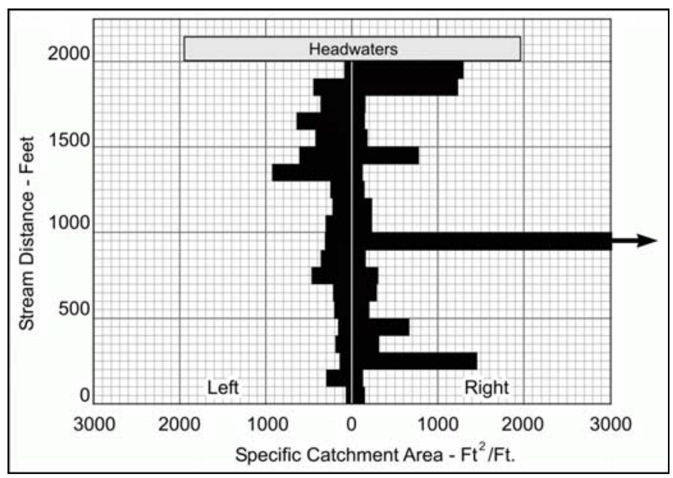

Figure 6

Figure 6 shows a graph of the specific catchment area along the stream. With a few exceptions, the larger values occur more often in the upper segments of the stream. This graph also places the headwaters catchment area into perspective. Protection of the headwaters area is known to be of critical importance and is difficult to accomplish using fixed-width stream buffers.

Figure 7 shows a fixed-width buffer applied to the watershed stream. A 50 foot buffer having a total width of 100 feet is shown. Figure 8 shows a precision buffer designed with a buffer-area ratio of 0.1. The buffer-area ratio will be equal to the portion of the watershed area that is dedicated to riparian buffers. It could therefore be said that 10% of this watershed is set aside for greenspace and that the greenspace has been delineated to produce maximum water quality benefits. This technique would be useful for optimum design of conservation developments.

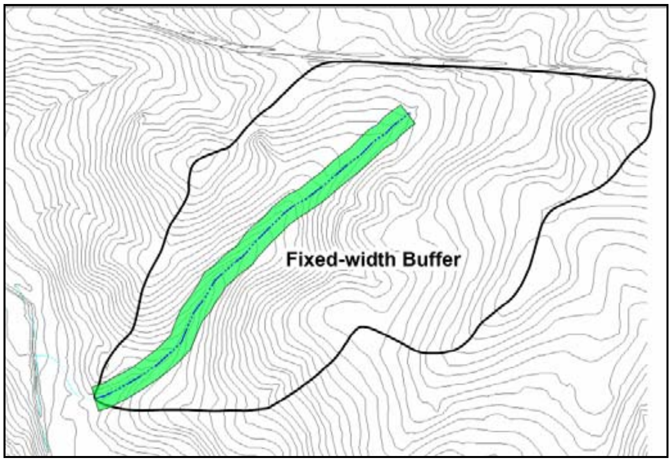

Figure 7

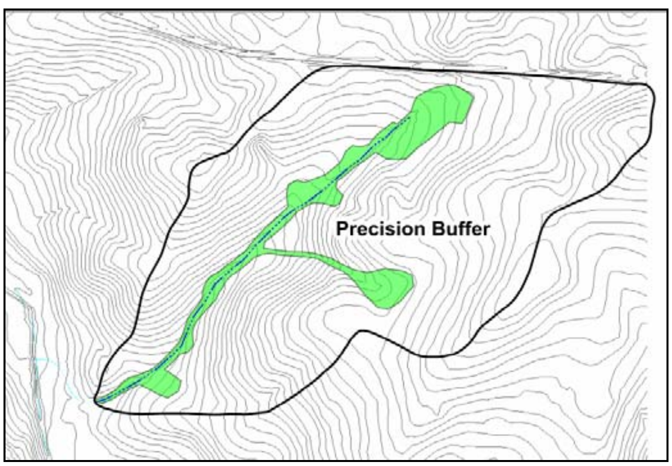

Figure 8

It should be noted that a specified minimum amount of stream buffer should always be required for streambank stabilization. In stream segments with low specific catchment areas, the buffer width should not be less than an established minimum distance.

FEASIBILITY OF IMPLEMENTATION

Precision riparian buffers will require much more effort to design than fixed-width buffers. It will be necessary to have an accurate topographic map, preferably with a contour interval of not more than two feet. Five foot contour intervals could be acceptable, but would significantly reduce the precision of the design. Computer tools could be developed that would facilitate the design process. However, it is doubtful that it could be completely automated. With proper training, any engineer, surveyor or landscape architect should be capable of performing the design. The major advantage of this approach is its objectivity. Two designers, working independently with the same topographic map, should arrive at essentially the same results.

Laying out the buffers on the ground will also require much more effort. GPS technologies with the ability to use real world or state plane coordinates during the layout process will be helpful.

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