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Identifying Riparian Zones Best Suited to Installation of Saturated Buffers: A Preliminary Multi-Watershed Assessment

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Disciplines
Natural Resources and Conservation | Natural Resources Management and Policy | Soil Science

Comments

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In the U.S. Midwest, agricultural nutrient losses that are carried by artificial subsurface (tile) drainage water have been associated with impacts on water quality

Abbreviations: ACPF, Agricultural Conservation Planning Framework; LiDAR, light detection and ranging; MLRA, Major Land Resource Area; RPAs, Riparian Assessment Polygons. M.D. Tomer, D.B. Jaynes, S.A. Porter, and D.E. James, USDA-ARS, National Laboratory for Agriculture and the Environment, Ames, IA; T.M. Isenhart, Department of Natural Resource Ecology and Management, Iowa State University, Ames, IA. *Corresponding author (mark.tomer@ars.usda.gov)

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(David et al., 2010; Raymond et al., 2012). A number of measures can be put in place to reduce nutrient losses from tile drainage, including cover crops (Kaspar et al., 2012), drainage water management (Adeuya et al., 2012), denitrifying bioreactors (Schipper et al., 2010), and nutrient removal wetlands (Tomer et al., 2013). Riparian buffers are also known to be capable of removing subsurface nutrients, particularly nitrate, but from groundwater that passes beneath riparian buffers rather than tile drainage (Mayer et al., 2007). Tile drainage water typically bypasses riparian zones via installed drainage pipes, preventing any interaction of drainage water with riparian soils or vegetation. A recent advance to overcome this bypass issue has been the saturated buffer (Jaynes and Isenhart, 2014). This riparian practice enables a subsurface discharge of drainage water along distribution pipes laid at shallow depth (0.3–0.6 m) and installed along the upper edge of a riparian zone. A water level control gate is installed to direct normal tile flows toward these subsurface discharge pipes. Larger flow rates that occur during times of increased precipitation can pass through the gate structure to ensure drainage rates from farmed fields are not impeded by the gate diversion. The saturated buffer practice has been evaluated in several settings, and removal rates may be (but are not always) equivalent to the proportion of tile drainage volume that is diverted to subsurface discharge (D.B. Jaynes, 2016, unpublished data).

The purpose of this chapter is to propose a mapping technique that identifies locations that are most appropriate for installation of saturated riparian buffers in Midwestern tile drained watersheds. Prediction of actual N removal rates from tile drainage water using this practice is difficult on a site by site basis, but we believe it possible to identify where high rates of N removal should most readily be achievable, and identify where this practice can be installed with minimal risks of unintended consequences. Saturated buffers are inexpensive to install compared to other types of practices that require more land area and/or significant construction costs (Jaynes and Isenhart, 2014); this is especially true where riparian buffers are already established. Therefore, even modest N removal rates (i.e., <30%) may achieve N removal at acceptable costs compared to other types of N-removal practices that require more land area. Where high rates of N removal can be achieved, the saturated buffer practice will be among the most preferred practice options on grounds of cost efficiency. However, more information is needed to identify the extent of sites that are suitable for saturated riparian buffer installations before the potential role of this practice in reducing watershed-scale nutrient loads can be fully elucidated.

**Context**

We are developing an approach that identifies riparian sites suited for saturated buffers for inclusion in the Agricultural Conservation Planning Framework (ACPF) toolbox for ArcGIS (ESRI, 2014), and to be consistent with the riparian assessment tools that are part of that toolbox (Tomer et al., 2015a, 2015b). The riparian assessment includes an approach to discretize all of a watershed’s riparian corridors into a series of 250- by 90-m polygons that are each evaluated and ranked in terms of upland runoff-contributing area and apparent width of shallow water table zones, as determined through analyses of high resolution (1- to 5-m grid) digital elevation models. The rankings convey the relative importance of opportunities at a riparian site to use buffer vegetation for slowing or filtering
surface runoff and for interacting with shallow groundwater, as compared to other riparian sites across that watershed. Once cross-classified according to these rankings, buffer designs are suggested that identify buffer widths and types of vegetation appropriate to riparian settings throughout the watershed. See Tomer et al. (2015a) for further details. The approach used to classify opportunities to install saturated buffers employs the same spatial discretization of the riparian corridor into Riparian Assessment Polygons (RAPs). However, our current intent, in the context of the ACPF toolbox, is to allow the saturated buffer siting tool to be run independent of (i.e., with or without) the riparian assessment.

We begin with two disclaimers. First, locations of tile drainage outfalls and expected flow rates are not readily available for most watersheds. A full application of this tool toward saturated buffer installations requires local knowledge, which we did not access in the watersheds used for demonstration in this chapter. Runoff flow paths that can be identified through the ACPF toolbox (or other terrain analyses programs) will often provide a good indicator of where tile outfalls can be found. However, major outfalls may carry greater flows than this practice can readily accommodate. Initial field trials of this practice have focused on field-scale drainage systems less than 160 acres in size (D.B. Jaynes, 2016, unpublished data). Second, the reader is advised that the saturated buffer tool described here is in draft form, and subject to revision on inclusion in the ACPF toolbox (Porter et al., 2015).

The saturated buffer siting tool, as conceived and demonstrated herein, should highlight riparian soils and slope conditions that are most conducive to installation and successful performance of this practice, provided field-scale drainage systems discharge in those same vicinities. Detailed knowledge of the local drainage system will be necessary for saturated buffer installation. One critical limitation to the design and performance of this system is to ensure sediment does not accumulate and clog the distribution pipes. Surface intakes, if part of the contributing drainage system, pose a risk for reducing subsurface discharge. Outletting the distribution pipes to the stream should reduce this risk, and should be included in saturated buffers receiving drainage from surface intakes. Note this means the system will have more than one discharge outlet, which will make performance monitoring more difficult.

**Approach and Methods**

**Criteria for site selection**

Our approach comprises criteria intended to identify suitable soil conditions, presence of shallow groundwater, and appropriate slope conditions. These criteria are tested using soils data extracted from the g5SURGO (soil survey) (Natural Resources Conservation Service, 2014) database, and high-resolution topographic data (see Tomer et al., 2015a, 2015b) obtained through Light Detection and Ranging (LiDAR) surveys.

Suitable soil conditions are associated with a sufficient residence time and a source of organic carbon at depth in the soil to encourage nitrate removal through denitrification. A sufficient residence time should occur where soils are fine textured, such that water will take at least several hours to drain away and that the water table will become mounded around (or just below) the distribution pipes. An environment conducive to denitrification will encourage nitrate
concentrations to be halved every 6 to 12 h of residence time (Moorman et al., 2015); during which lateral flows through the soil (rather than vertical flows to depths where soil organic matter decreases) should dominate. Coarse-textured, sandy soils may not provide the desired flow rate (not rapid) and direction (lateral), especially where coarse-textured soils are found at depth. We set a criterion to only include soils that have < 50% sand at 0.75- to 1.2-m depth, as an average calculated by weighting textural data by horizon thickness. The second soil criterion ensures the presence of organic carbon to enable denitrification to occur at depth in the soil. The criterion we chose was > 1% soil organic matter (SOM) at the 0.75-to 1.2-m depth interval. Note that while high SOM contents are common in Midwestern riparian subsoils, deep sandy soils are also found in riparian areas where glacial outwash deposits are present.

The final soils criterion was set to ensure the presence of a shallow water table within the riparian zone, to identify and prioritize sites where lateral water flows that encourage denitrification should occur. Soil survey information includes seasonal (April–June) water table depth information to support land use suitability interpretations. Soils exhibiting a seasonal water table within 1.0 m of the surface were considered suitable. While sites with shallower (i.e., < 0.5 m) water table depths may exhibit the greatest denitrification rates because greater (e.g., > 4%) SOM concentrations occur in the upper profile of many riparian soils, there is also a risk of seepage flows and rainfall-runoff erosion where the saturated buffer practice brings the water table to, or very near, the surface. This consideration led us to choose an intermediate (< 1.0 m) seasonal water table depth criteria. Riparian assessment polygons were considered to have soils suitable for the saturated buffer practice where soil map units meeting these three conditions (SOM and sand contents at 0.75–1.2 m, and shallow seasonal water table) occupied at least a 20-m width along the 250-m long RAP.

While soils criteria were selected to prioritize soil conditions suitable for nitrate removal, topographic criteria were selected to minimize the risk of unintended consequences from saturated buffer installation. First, we sought to eliminate areas with steep banks, where raising the water table could increase the risk of bank sloughing. Provisionally, a 10-m minimum width of land area within a RAP having a surface elevation within 1.5 m of the channel (Tomer et al., 2015a) was selected for this criterion. The width of this “low-lying” land area along the channel was determined using tools in the ACPF riparian assessment (Porter et al., 2015; Tomer et al., 2015a). Field reviews of several watersheds have led us to believe this criterion will successfully avoid steep banks. The NRCS standard for the saturated buffer (Natural Resources Conservation Service, 2016) specifies a maximum bank height of 2.4 m.

The third and final criterion is intended to avoid areas with a flat riparian zone, where crops planted just above the riparian buffer could be inundated by buffer saturation. However, in addition, sloping riparian terrain may not be suited to optimal performance of the saturated buffer practice because of increased flow rates including preferential flows that can carry water rapidly downslope; return flows (Kirkby, 1988) could lead to runoff and erosion across a steep riparian zone with a mounded water table, and could be a problem in some settings. Noting that wider riparian buffers may be necessary to adequately filter runoff where slopes are > 10% (Liu et al., 2008), we selected a slope range of 2 to 8% as being in the range that would avoid risks of saturated buffers being either too flat or too steep. Those RAPs where 2 to 8% slopes occupy at least 35% of the RAP area were
deemed suitable for saturated buffers for the purpose of this study. Our intent with the final development of this tool for the ACPF toolbox is to provide user options under most if not all criteria; that is, the minimum SOM at depth could be selected at 0.5%, enabling flexibility for Midwest areas where greater SOM concentrations are seldom found deep in the profile, considering that roots of buffer vegetation may provide a reasonable carbon source to facilitate denitrification (Dosskey et al., 2010). Allowing the user to select the fraction of the RAP that must have 2 to 8% slopes to meet the slope criterion is another option being considered.

A key point is that our intent is not to dictate where saturated buffers should or should not be placed, but simply to identify locations where the practice should perform well in terms of nitrate removal efficiency, and to help avoid areas where some risk of unintended consequences is apparent. As we learn more about saturated buffers and how well they perform in different settings, the prudence of each of these criteria will become clearer.

Description of test watersheds
We applied this demonstration analysis to three headwater watersheds in Iowa and Illinois (Fig. 1). Bear Creek in north central Iowa has been the subject of several studies on riparian buffers (Schultz et al., 2004), and comprises hummocky terrain or recent glacial origin (Wisconsinan age; 12,000–14,000 yr ago) that is drained through a valley carved by glacial meltwater. Lime Creek, located in northern Illinois, was identified as watershed 6 in an initial assessment of the ACPF riparian assessment tools (Tomer et al., 2015a), and was described in some

![Fig. 1. Map showing locations of three test watersheds and the Major Land Resources Areas (MLRA) in which they are found. See http://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/?cid=ncrs142p2_053624 for further details on MLRAs.](image-url)
detail by Tomer et al. (2015b, 2013). This watershed is bounded to the north by a terminal moraine from a Wisconsinan age glacial advance and its southern half is dominated by a glacial-lacustrine plain. Bear and Lime Creek watersheds are of similar age in terms of glacial origin, but are contrasted in terms of type and extent of fluvial deposits. Mud Creek and Prairie Creek are found on a landscape that originated as Illinoian till, which has been more dissected by stream development given the older age (approx. 500,000 yr).

Digital elevation models for these three watersheds were derived from LiDAR survey data at 1- to 3-m grids, and preprocessed to eliminate false impoundments such as at bridges and culverts (discussed by Tomer et al., 2013) using a ‘cutter’ tool that is available in the ACPF toolbox (Porter et al., 2015). Following flow routing analysis that maps upslope contributing areas and channelized flows across the watersheds, the extents of perennial streams were identified using hillshade images of topographic data and aerial photographs. The perennial stream network and adjoining riparian lands were then discretized using 250- by 180-m RAPs as described by Tomer et al. (2015a). This method uses the ‘strip-map index’ feature of ArcGIS (Ver. 10.3; ESRI, 2014) to create the series of polygons; the stream polyline is then used to split each RAP enabling results to be tabulated separately for each side of the stream. Data that were used to evaluate soils criteria (SOM, texture, seasonal water table) were extracted from the gSSURGO database (Natural Resources Conservation Service, 2014); data used to evaluate topographic criteria (i.e., area of 2–8% slopes, and minimum 10-m width of area within 1.5 m of channel for bank height interpretation) were obtained from terrain analysis tools that calculate slope and flow accumulation rasters as described by ESRI, (2014) and Porter et al. (2015).

**Results and Discussion**

Three test watersheds showed a range of riparian conditions meeting the above-described provisional criteria to identify potential sites for saturated buffer installations (Table 1). In general, however, soil survey information suggests suitable soil conditions are common, and may be nearly ubiquitous in some watersheds. Many Midwest watersheds exhibit riparian soil conditions with SOM > 1% to depth, fine subsoil textures, and seasonal water table depths within 1.0 m of the surface. In Bear and Lime Creeks, of these three soils criteria, riparian soils failed to meet the SOM criteria ( > 1% SOM at 0.75–1.2 m) most frequently, but 79 to 84% of the RAPs still passed this criteria. Coarse-textured outwash materials have been identified in the lower part of Bear Creek watershed and were found to reduce buffer performance for nitrate removal by Simpkins et al. (2002). However, these coarse textures occur below fine sediments that have accumulated during and since the Holocene, and/or are not extensive enough to be identified as separate map units in the gSSURGO database. This emphasizes the need for on-site investigation to confirm soil conditions are suitable when designing and installing saturated buffers. In general, soil survey information indicates most riparian soils in these watersheds are conducive to conditions that would be sought for saturated buffer installations that should achieve substantial reductions in tile-drainage nitrate loads (Fig. 2, top row).

Topographic criteria may be more important than soil criteria because they are aimed at preventing unintended consequences that could lead to stream bank
failure or crop inundation. Damage of either type can increase economic costs associated with this practice beyond those anticipated during design, which could lead to this practice becoming unpopular among landowners. Results for these three watersheds indeed suggest that topographic criteria may limit the extent of suitable saturated buffer sites more frequently than do soil criteria, at least in areas of the Midwest dominated by finer-textured glacial deposits. In all three watersheds, the number of RAPs meeting any individual criterion was least for one of the two topographic criteria, compared to the number of RAPs meeting any of the soils criteria (Table 1, Fig. 2).

In Bear Creek watershed, soils with low SOM at depth in the upper part of the watershed, and steep slopes near the stream in the middle lengths of the watershed (see Fig. 3, top) were the two most common apparent limitations on the potential extent of saturated

### Table 1. Summary of results indicating extent of conditions that are favorable for riparian buffer installations in three test watersheds.

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Bear Creek</th>
<th>Lime Creek</th>
<th>Mud Creek and Prairie Creek</th>
</tr>
</thead>
<tbody>
<tr>
<td>Watershed area, ha</td>
<td>7489</td>
<td>6965</td>
<td>6720</td>
</tr>
<tr>
<td>Total stream length, km</td>
<td>50.1</td>
<td>51.4</td>
<td>52.3</td>
</tr>
<tr>
<td>Stream length captured by RAPσ†, km</td>
<td>44.6</td>
<td>49.8</td>
<td>46.7</td>
</tr>
<tr>
<td>Stream bank length captured by RAPσ†, km; equal to twice stream length</td>
<td>89.2</td>
<td>99.7</td>
<td>93.4</td>
</tr>
<tr>
<td>Number of RAPσ†</td>
<td>274</td>
<td>350</td>
<td>298</td>
</tr>
<tr>
<td>Number of RAPσ† meeting soils criterion</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soil texture ( &lt; 50% sand at 0.75–1.2 m depth)</td>
<td>266</td>
<td>350</td>
<td>298</td>
</tr>
<tr>
<td>SOMσ‡ ( &gt; 1% at 0.75–1.2 m depth)</td>
<td>217</td>
<td>296</td>
<td>297</td>
</tr>
<tr>
<td>Seasonal water table &lt; 1.0 m</td>
<td>268</td>
<td>337</td>
<td>297</td>
</tr>
<tr>
<td>Number of RAPσ† meeting topographic criteria</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bank height ( &gt; 10 m width is &lt; 1.5 m above channel)</td>
<td>268</td>
<td>194</td>
<td>221</td>
</tr>
<tr>
<td>Slope ( &gt; 35% of RAPσ† is 2–8% slopes)</td>
<td>213</td>
<td>211</td>
<td>209</td>
</tr>
<tr>
<td>Number of RAPσ† meeting all five criteria</td>
<td>164</td>
<td>103</td>
<td>162</td>
</tr>
<tr>
<td>Stream bank length meeting all five criteria, km</td>
<td>54.7 (61%)</td>
<td>30.6 (31%)</td>
<td>52.3 (56%)</td>
</tr>
</tbody>
</table>

†RAP, Riparian Assessment Polygon.
‡SOM, Soil Organic Matter.

![Fig. 2. Map matrix illustrating the extent of Riparian Assessment Polygons that met soil and topographic conditions in three test watersheds.](image-url)
Fig. 3. Maps of three test watersheds illustrating the spatial distribution of riparian soil and topographic conditions meeting provisional criteria for siting saturated buffers. Zoomed in maps show areas where RAPs (Riparian Assessment Polygons) were excluded due to being too steep (> 8%) along Bear Creek (top), too flat (< 2% slopes) along Lime Creek (middle), and where bank heights may be too great along Mud Creek and Prairie Creek (lower).
buffer installations. Nevertheless, 61% of the RAPs in this watershed met all five provisional criteria for saturated buffer installation. One of the research sites being used to monitor and evaluate this practice is in Bear Creek (Jaynes and Isenhart, 2014), and this site met all five criteria (not shown).

Lime Creek watershed had the least extent of RAPs indicated as suitable for saturated buffer placements. Low SOM contents at depth occurred along some upper stream lengths, while deeply dug ditches and flat landscapes in the lower parts of the watershed led to topographic criteria being failed in lower parts of the watershed. Areas that were too flat to meet the slope criteria for Lime Creek watershed are shown in Fig. 3 (center panel). There were 31% of the RAPs in Lime Creek that met all five criteria, however, most of these were found along headwater reaches in the northwest part of the watershed. The upper (most northern) reaches of Lime Creek watershed drain farmlands dominated by a terminal moraine, which are sloping and may not have extensive tile drainage. Again, on-site investigation would be required to ascertain this.

The Mud Creek and Prairie Creek watershed has the most favorable soil conditions for saturated buffer sites, compared to Bear and Lime Creek watersheds (Table 1). Topographic criteria essentially provide the only limitations to siting saturated buffers along Mud Creek and Prairie Creek, with flat slopes and/or incised banks providing the main limitations along the lower main channel, and steep slopes and or incised streambank conditions occurring along upper reaches. Upper reaches with incised conditions are depicted in Fig. 3 (lower panel). More than half the RAPs (56%) nevertheless met all five criteria for potential saturated buffers.

Conclusions

This study has illustrated a draft tool for identifying potential sites for installation of saturated buffers (Jaynes and Isenhart, 2014), which on being finalized will be added to the ACPF toolbox (Porter et al., 2015; Tomer et al., 2015a, 2015b). Results from three watersheds located in separate landscape regions (MLRAs) suggest that suitable sites should be relatively common in many Midwest watersheds with tile-drained croplands. Topographic criteria should be regarded as more important than soil criteria to minimize the risk of unintended consequences from the saturated buffer practice. Ongoing research should help clarify soils criteria that will achieve optimal N removal in saturated buffers. Results from this study suggest that topographic conditions will most commonly limit site suitability in most Midwestern watersheds, but also suggest 30 to 60% of riparian zones may be suited to installation. Limitations we found were consistent with expectations based on distributions of slopes and incised channels that are common in these watersheds. Per the advice in the NRCS standard for this practice (Natural Resources Conservation Service, 2016), on-site soil investigations should be undertaken to confirm site and soil suitability as an early step in the saturated buffer design and installation process.
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design-types with application to assess and map stream corridors. J. Environ. Qual. 44:768–779. doi:10.2134/jeq2014.09.0387
