A Functional Approach to Riparian Area Delineation Using Geospatial Methods

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ABSTRACT

Riparian areas are diverse ecotones that provide numerous, valuable ecosystem functions. However, many riparian delineation methods use a fixed minimum width to create a riparian buffer or setback that may not adequately protect actual riparian function. A method for riparian area delineation across landscapes is presented that incorporates riparian function and moves beyond the fixed-width buffer approach. Using geospatial data and tools, riparian areas were delineated functionally for the Cuyahoga Valley National Park in northeastern Ohio and compared to fixed-width buffers in terms of extent and protection of riparian function. We suggest that functional riparian area delineation be incorporated into watershed management planning to improve protection and restoration of the valuable ecological functions provided by riparian areas across landscapes.

Keywords: riparian, delineation, GIS, watershed management

Riparian areas provide numerous and valuable ecosystem functions including regulating the flow of water, sediments, and nutrients across system boundaries; contributing organic matter to aquatic ecosystems; and increasing bank stability and reducing erosion, as well as providing unique habitat with high species diversity that can be used as potential dispersal corridors and refugia for wildlife species (Gregory et al. 1991). Over the past several decades, our understanding of the ecological services that riparian areas provide and their importance to overall watershed health has increased greatly (Costanza et al. 1997). As a result, there has been a surge in stream and riparian restoration projects, as well as increased emphasis on maintaining riparian buffers within our managed landscapes.

Many efforts to restore riparian areas or protect riparian functions have focused on local conditions without the consideration of larger landscapes, in part because the scale and scope of these activities across a landscape poses significant challenges to resource managers and policymakers. For example, many riparian restoration programs occur without a framework to prioritize restoration efforts often resulting in uncertainty associated with policy decisions, poor and random implementation, and questionable success in terms of restoring important ecosystem functions (Timm et al. 2004). One aspect that all these efforts have in common is that they lack an approach to delineate the functional extent of the riparian area. Historically, there have been a variety of methods used to delineate riparian areas, including those based on physical attributes, such as erosion (e.g., Trimble and Sartz 1957, Sparovek et al. 2002), streamside shading based on tree heights (Brown 1980), hydric soils (US Forest Service 1994), and hydrologic processes (Hupp and Osterkamp 1996). Others have proposed using biological attributes to delineate riparian areas including amphibian habitat use (Semlitsch and Bodie 2003, Perkins and Hunter 2006, Crawford and Semlitsch 2007), freshwater metazoan species (Ward et al. 1998), plant community vegetation patterns (Hagan et al. 2006, Yang 2007), the presence of wetland or wetland facultative species (Dall et al. 1998), and the minimum width to conserve maximum species richness (Spackman and Hughes 1995).

Despite these efforts, we often attempt to determine the "minimum width" of riparian areas and use this value to set aside riparian buffers. Riparian areas, however, are more than just floodplains or the near-stream environments. As a result, these unique ecotones often can not be encompassed using a common, simple fixed-width approach (e.g., a 50-ft buffer, 1-pixel buffers using LANDSAT imagery). Fixed-width ap-

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proaches may result in significant errors when determining riparian extent and characteristics (MacNally et al. 2008). Additionally, fixed-width buffers, including fixed-width buffers modified to incorporate adjacent slope (as many state riparian best management practices suggest), are not based on the functional relationships of riparian areas per se and may not reflect the actual extent of the riparian area on the ground. For example, areas that are clearly considered riparian, such as broad floodplains associated with the larger rivers, may extend beyond a fixed-width buffer. Alternatively, lands that are arguably nonriparian might be included in a fixed-width buffer, especially along first-order or headwater streams.

A Functional Geospatial Approach to Riparian Delineation

To properly manage, restore, and conserve riparian areas for their unique ecological functions, delineation methods need to incorporate a holistic view to be more accurate and representative of the complexity and functions provided by these ecotones (Swanson and Franklin 1992). Ilhardt et al. (2000) and Verry et al. (2004) suggested a hydrogeomorphic delineation model that uses stream valley geomorphology to predict flood-prone area and the likely extent of the riparian area surrounding a stream or river. This functional definition includes a variety of ecosystem functions, including those occurring in aquatic (e.g., channel), flood-prone (e.g., flood dispersal of sediment, plants, and animals), and upland zones (e.g., slumps, slides, subsurface water, and nutrient flow) that interact strongly with the surface water during base, bankfull, and flood flow conditions (Verry et al. 2004). This method is described by Verry et al. (2004) as a probabilistic approach rather than a fixed-width approach because areas delineated are those likely to be riparian, thus protecting the valuable functional ecosystem services riparian areas provide (Figure 1). The advantage of a functional delineation is that the approach is framed around delineating the extent of important ecological functions rather than a set width, which may or may not be ecologically based.

When developing landscape management plans, geospatial methods are ideal for landscape-scale analyses such as delineating riparian areas because of their connection to the terrestrial and aquatic ecosystems across watersheds (Bren 1995). Typical geospatial approaches to riparian delineation require accurate stream channel data around which buffers are created to determine riparian setbacks or riparian management zones. However, because of the dynamic constructive and destructive fluvial processes that structure riparian areas, stream channel data must be frequently updated and have high resolution to be considered accurate. Because the Verry et al. (2004) field method for functional riparian area delineation is based on stream valley geomorphology, rather than the typical fixed-width approach based on the stream channel, it is possible to use digital data sources to delineate relatively stable riparian areas remotely on a landscape scale. When planning riparian management across a large landscape, such remote delineation is efficient and ideal.

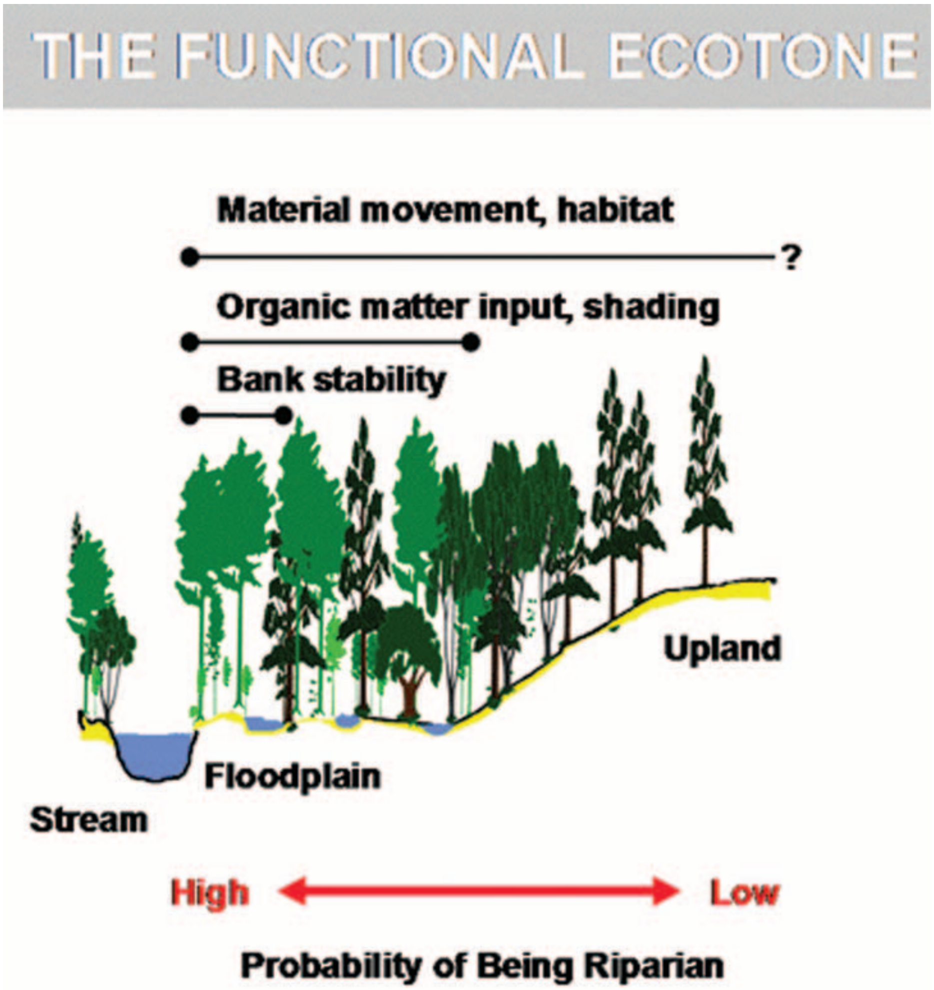

Figure 1. Graphical representation of the functional riparian ecotone following Ilhardt et al. (2000).

Implementing the Functional Approach in the Cuyahoga Valley National Park

The Cuyahoga Valley National Park (CVNP) in northeastern Ohio encompasses over 33,000 ac for conservation and recreation, including 22 mi of the Cuyahoga River and over 190 mi of ephemeral and perennial tributary streams. The CVNP was first designated a national recreation area in 1974 and became a national park in 2000. The location of the CVNP is between the two major Ohio metropolitan areas of Cleveland and Akron creates unique management implications because of the diverse urban–rural interface that characterizes the landscape, including balancing ecological conservation with recreation to serve the approximately 3 million annual visitors. Much of the development in the CVNP has occurred in the floodplain of the Cuyahoga River, including past and current agriculture, a municipality (Peninsula), and several high-impact recreational areas such as ski areas and golf courses. The large remainder of the CVNP is undeveloped land characterized by steep, forested ravine systems formed along the multiple tributaries to the Cuyahoga River. The forests are second growth (more than 70 years old) and are composed of mixed-mesophytic species (e.g., sugar maple, *Acer saccharum* Marsh.; American beech, *Fagus grandifolia* Ehrh.; northern red oak, *Quercus rubra* L.; shagbark hickory, *Carya ovata* [P. Mill] K. Koch; and yellow-poplar, *Liriodendron tulipifera* L.). With the large number of riparian areas associated with a variety of stream orders, all in various conditions, CVNP managers and ecologists desire to develop a comprehensive riparian management plan that moves beyond the fixed-width method to a functional riparian delineation approach.

Using the Geographic Information System to Functionally Delineate Riparian Areas in the CVNP

Using the functional approach of Ilhardt et al. (2000) and Verry et al. (2004), we used geospatial methods to functionally delineate riparian areas within the CVNP (Figure 2). To aid in the digital delineation of riparian areas, we used several digital data sources available from national sources, county engineers, and the CVNP itself (Table 1). All geographic information system (GIS) analyses were conducted with ArcGIS 9.1 software, ESRI (Redlands, CA). Using a 1-mi buffer around the CVNP boundary, we included riparian areas of small headwater streams that originate just outside the park boundary as well those inside the park. For ease of digital delineation, we divided the area into 27 subwatersheds each flowing into the Cuyahoga River. Because the functional riparian area delineation approach is based on stream valley geomorphology and not the digital representation of streams, riparian areas could be delineated with topographic data only. However, for ease and improved accuracy, several additional files, such as aerial photos and local roads, were consulted to help delineate riparian areas where natural stream valley topography appeared altered (e.g., road culverts and bridge areas). Addition-

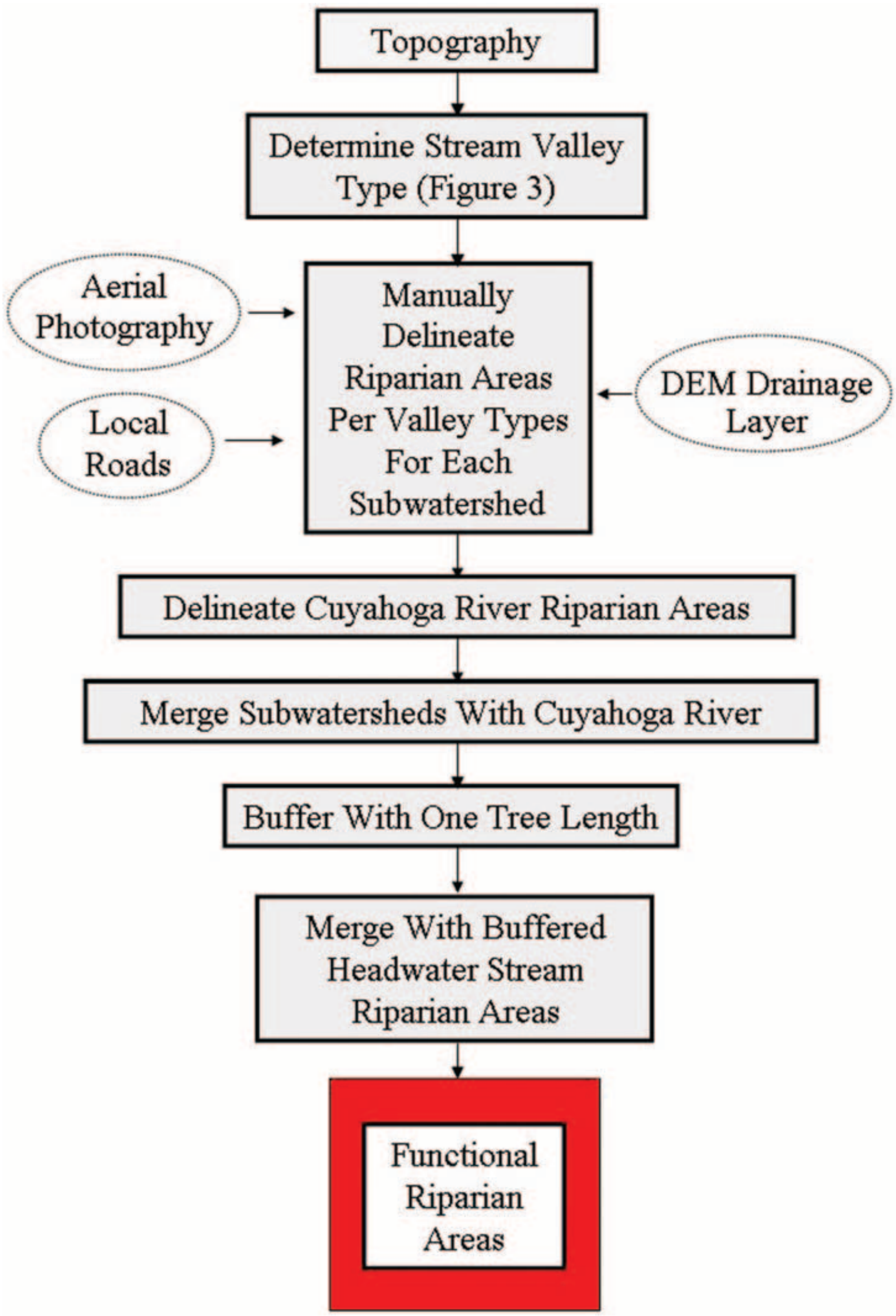

Figure 2. Flow chart of methodology used to delineate the functional riparian areas of the CVNP.

Table 1. Digital data used in the delineation of riparian areas of the CVNP.

Data	Source	Scale
Topography	United States Geological Survey	1:24,000
National park boundary	Cuyahoga Valley National Park	1:24,000
Aerial photography	Ohio: Summit and Cuyahoga County Engineers	1-m Resolution
DEM	United States Geological Survey	30-m Resolution
Roads	United States Geological Survey	1:24,000
Hydrography	United States Geological Survey	1:24,000

ally, we generated a drainage layer from a digital elevation model (DEM; 98.4-ft or 30-m resolution) using the hydrologic analysis tools in ArcGIS Spatial Analyst (ESRI). Following the Ohio Environmental Protection Agency's 20-mi^2 definition for headwater stream drainage area (Ohio Environmental Protection Agency 2002), we created a streamflow network layer using 100 cells of our DEM to define flow accumulation using the hydrologic analysis tools within ArcGIS. In conjunction with our knowledge of the area and conversations with CVNP natural resource managers, we determined 100 cells to best approximate the headwater streams on our landscape. Once generated, this drainage layer was used for reference on natural drainage flow patterns in addition to the topographic data when delineating riparian areas, particularly in headwater reaches where topographic relief became minimal.

Following the on-the-ground riparian area delineation guidelines of Verry et al. (2004) (Figure 3), we used digital topography to determine the stream valley type associated with the various streams and river segments. Using the topographic data layer (10-ft contours), we determined the location of fluvial landforms, specifically floodplains and terraces, as well as stream valley walls. Based on our field reconnaissance and knowledge of the area, we determined for this landscape that tight, successive contour lines adjacent to a stream indicated stream valley wall slopes greater than 5%, whereas floodplain and terrace landforms were identified by widely spaced contour lines between the stream valley wall slopes. These distinct relief patterns (Figure 4) characterized our landscape and allowed for a simple, relatively fast on-screen manual delineation of riparian areas. Similar topographic relief patterns can be adapted to other landscapes for simple delineation, or if needed, measurement of landform widths could be incorporated based on field knowledge. When only valley walls and a narrow channel were present, riparian areas in the CVNP were delineated at the top of the valley wall (type I valley, Figure 3; e.g., Figure 4). However, when widely spaced contour lines were present between valley walls, thereby indicating floodplain and terrace landforms, the riparian area was delineated at the base of the valley wall (type II valley, Figure 3; e.g., Figure 4).

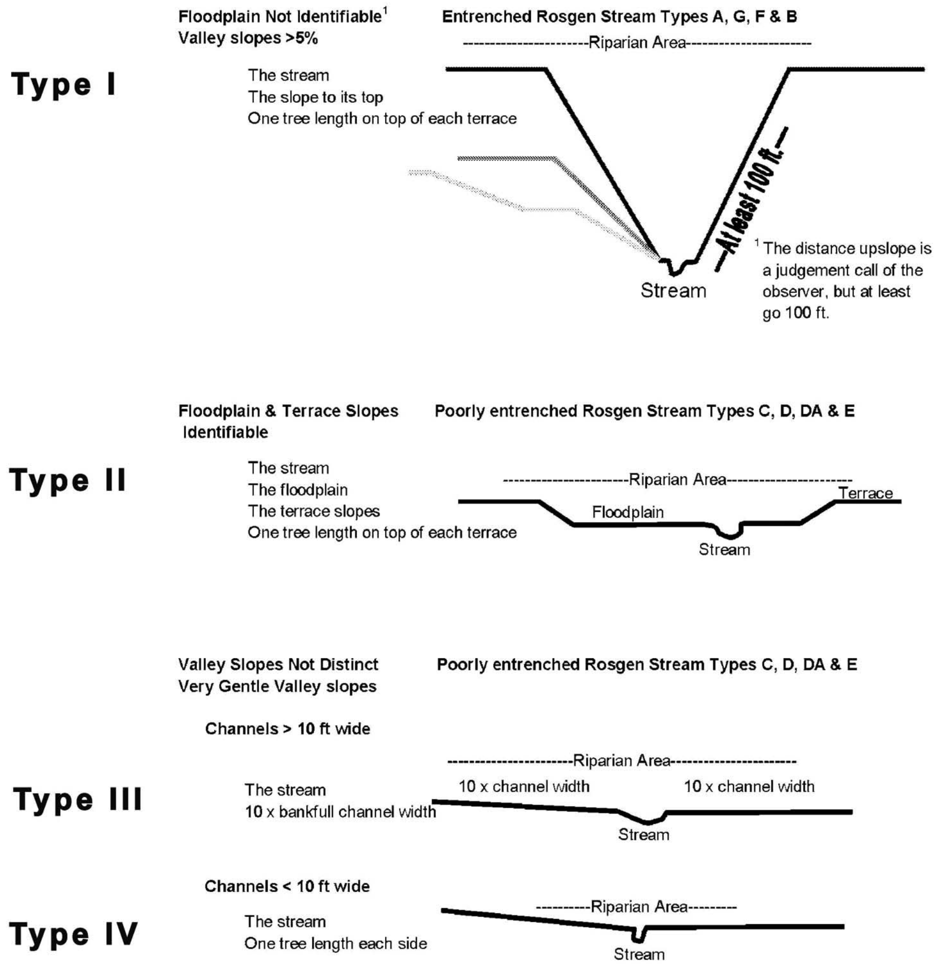

Figure 3. The four stream valley types (from Verry et al. 2004) used in the functional delineation of riparian areas.

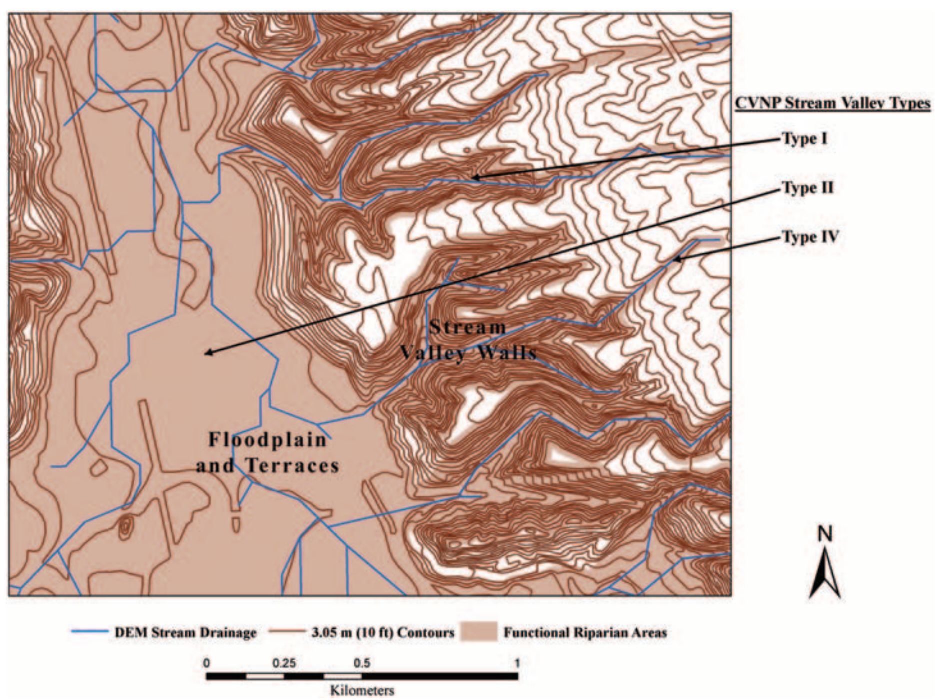

Figure 4. A screenshot of the CVNP riparian areas highlighting the topography of the three stream valley types found in the park and their functionally delineated riparian areas.

Using this approach, riparian areas were manually delineated following the topography in a continuous manner across stream valleys in each of the watershed basins at a 1:5,000 scale wherever the drainage layer indicated streams should be present on the landscape. When fluvial geomorphology changed between stream types (e.g., type I to type II), the riparian area delineation changed by manually delineating from the base of a stream valley wall in a type I valley and then ascended a valley wall ridge to the top of a valley wall for a type II valley. In instances where topography indicated stream valley walls but the drainage layer did not show a stream, these valleys were assumed to be associated with ephemeral streams and were included in the delineation. In headwater areas where topography became more gently sloping or nearly level and stream valley walls were no longer evident from the topographic layer (e.g., type IV stream valley, Figure 3; e.g., Figure 4), the delineated riparian area only included the stream channel based on the method as described by Verry et al. (2004). To include these riparian areas, we manually digitized a new stream layer on the screen in ArcGIS that followed topography from the edge of the stream valley walls, apparent from the tight topographic contours, to where the drainage layer ended. After each watershed basin had been completed, the Cuyahoga River riparian areas were delineated following the base of the valley walls (type II stream, Figure 3).

Once the riparian areas of each basin and the Cuyahoga River had been delineated, all delineated riparian areas were merged into a single GIS layer. Following Verry et al. (2004), a one-tree-length wide buffer was then added, which our previous research in mature, second-growth riparian forests of the CVNP suggests an average canopy tree height of 60 ft (Holmes 2008). Because the width of this one-tree-length buffer is based on the average height of mature individuals within the riparian area, it is adaptable to specific landscapes and would increase the total area of the functional riparian area if the mature riparian trees in this landscape were taller. A similar one-tree-width buffer was added to the new stream layer that was digitized for headwater areas. Finally, we merged the buffered stream layer to the buffered delineated riparian areas, creating the final functional riparian areas of the CVNP (Figure 5).

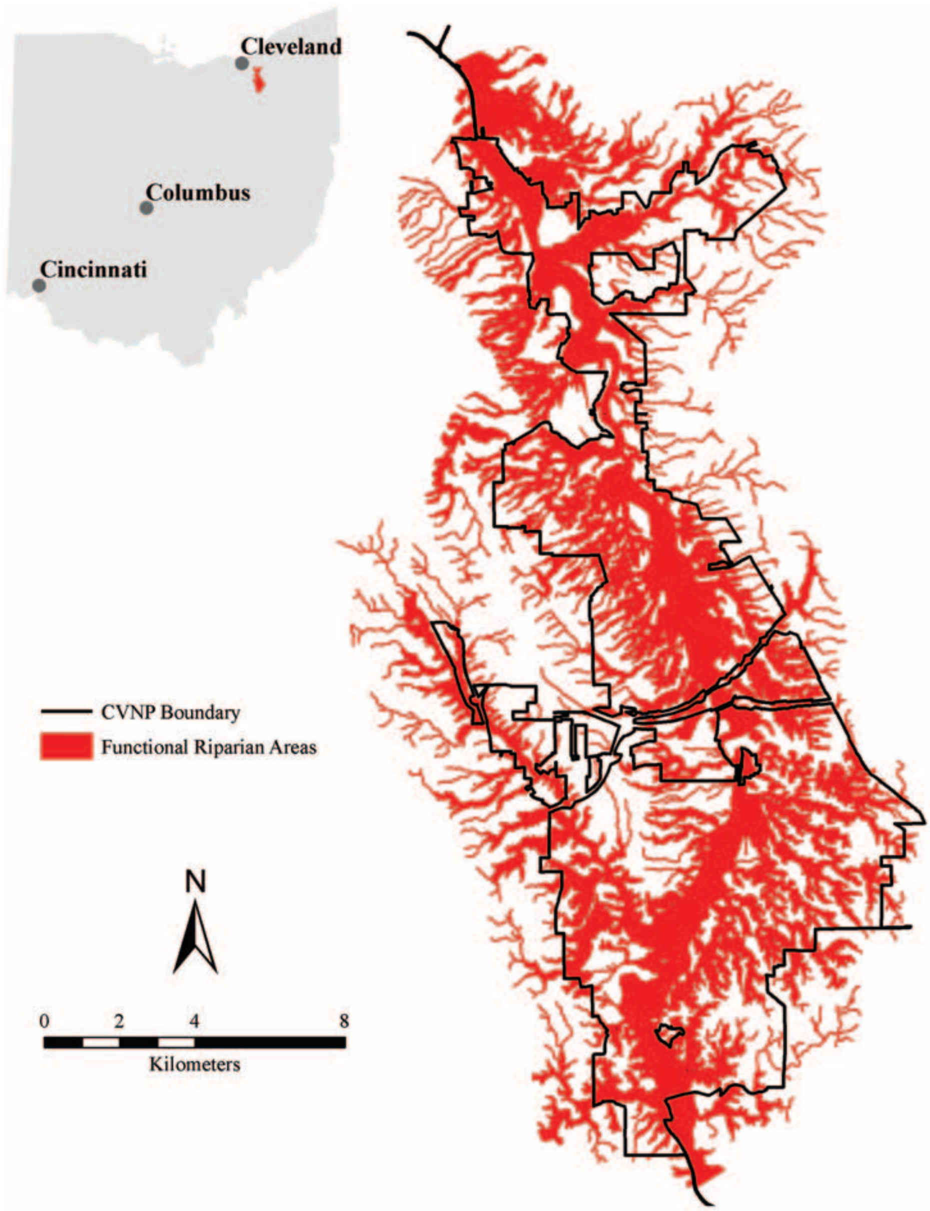

Figure 5. The functionally delineated riparian areas of the CVNP, Ohio.

Functional Riparian Areas versus Fixed-Width Buffers in the CVNP

The functionally delineated riparian areas of the CVNP encompass 18,052 ac or 53% of the total land area within the park boundary. In contrast, the more traditional fixed-width buffer approach to riparian delineation encompasses significantly less area of the park (Figure 6). As a result, a fixed-width buffer of 300 ft most closely delineates a similar amount of area with 16,573 ac or 49% of the CVNP delineated as riparian. However, the fixed-width buffer of 300 ft has significant spatial differentiations from the functional riparian areas with nearly 40% of the digital pixels in spatial disagreement (Table 2). Commonly used fixed-width buffer sizes (e.g., 50, 75, and 120 ft) are significantly narrower and may fail to protect many riparian functions that the functional ecotone delineation protects. For example, areas along the broad Cuyahoga River floodplain are significantly underdelineated in terms of function with the 300-ft buffer compared with the functional delineation (Figure 7). Conversely, fixed-width buffers may overdelineate land as riparian in headwaters when compared with the functional riparian delineation approach in these areas (Figure 7). Fixed-width buffers often do not protect ephemeral streams be-

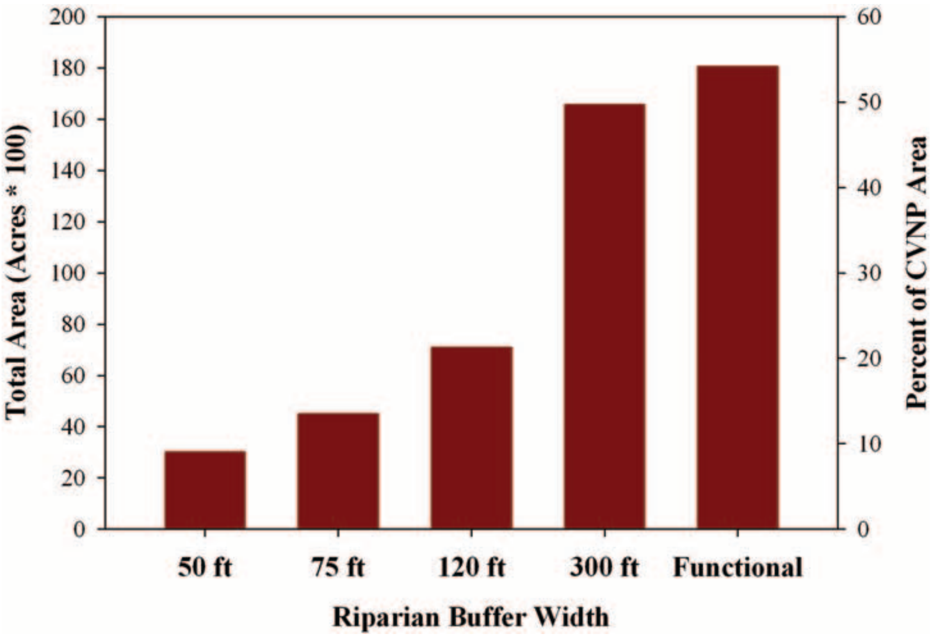

Figure 6. A comparison of riparian delineation methods by area delineated and the percent of the CVNP land considered riparian: fixed-width buffers versus the functional delineation.

Table 2. Percent spatial agreement and disagreement of digital pixels between fixed-width buffers and functionally delineated riparian areas.

	Functional riparian area	
Fixed-width buffer (ft)	Agreement (%)	Disagreement (%)
50	91.9	8.1
300	60.8	39.2

cause they are usually not part of the stream layer used in traditional fixed-width riparian delineation methods. The functional delineation approach we use here allows for delineation and protection of riparian areas along ephemeral streams. Additionally, using the functional riparian area delineation approach, riparian functions that vary based on stream valley type, corresponding volume, and positioning in the watershed, upstream versus downstream, may be more likely protected. One width for a fixed-width buffer should not be used throughout a landscape and must be changed to a smaller width in headwater reaches leaving hard boundaries between the two widths. A functional delineation always has transitions between stream valley types.

Another possible advantage of a functional approach is the focus on stream valleys rather than stream channels, in part because fixed-width buffers rely on accurate stream data and any errors within the stream network data will generate inaccurate buffer delineations. In our case, the DEM-generated stream network layer includes several areas along the Cuyahoga River where the data do not follow the stream valley topography. As a result, the fixed-width buffers in these areas are inaccurate, whereas the functionally delineated riparian areas follow the stream valley topography (Figure 7). Aerial photos verified the true location of the stream and its valley and the functional riparian areas were delineated according to these locations instead of the false stream network data layer.

Implications for Management

Incorporating ecological concepts such as riparian function into riparian delineation is an approach that poses new challenges for application and management (Table 3). Because of their simplicity, ease to set aside, and regulate, fixed-width buffers have been used frequently in past land management. However, because a fixed-width buffer may not adequately protect ecological function they are often modified to attempt to incorporate additional features such as wetlands, hydric soils, and steep slopes (Shepard et al. 2004). In the case of the CVNP, they have been using an approach to delineating riparian buffers that adjusts width based on stream order, slope, and the presence of wetlands or impervious surfaces (CVNP 2002). Although these modifications create more ecological, site-specific fixed-width buffers for field delineation, they are cumbersome and poor for remote sensing and landscape planning. For land managers wishing to conduct landscape-scale analyses, a functional riparian delineation can be done geospatially with the methods presented here as well as in the field with the methods developed by Verry et al. (2004). Additionally, because they are focused on more stable components of the landscape (e.g., stream valley), geospatial functional delineations do not require accurate stream channel locations such as fixed-width buffers, providing a useful tool for riparian delineation in disturbed landscapes or those with migrating channels.

A functional delineation requires significantly more ecological knowledge of the site or landscape to determine ecological functions and their relationships with the stream and its geomorphic valley. As a result, implementing a functional delineation may be more likely on public and large, private industrial lands because of the availability of trained land-management staff (Phillips et al. 2000). However a functional delineation may be possible for small, private landowners who seek technical assistance through their local and state conservation offices. Although a functional delineation may be more costly and time-consuming than a fixed-width buffer because of the required ecological knowledge and land manager assistance, the final delineation will more likely protect riparian function without under- or overprotecting land (Phillips et al. 2000).

Depending on the topography of the landscape, the functional delineation may encompass a large amount of land area in comparison with a fixed-width buffer. However, we want to emphasize that the functional delineation approach described here does not necessarily delineate large exclusionary management zones. Instead, our approach uses concepts of functional ecology to determine the likely extent of the functional riparian areas. Land managers must define the most important functions for the site or landscape and determine the extent of activity allowed based on the distance from the stream that will protect specific riparian functions (Palik et al. 2000). For example, in a landscape managed for conservation all of the riparian area may be excluded from management activities. For another landscape managed for other uses (e.g., timber

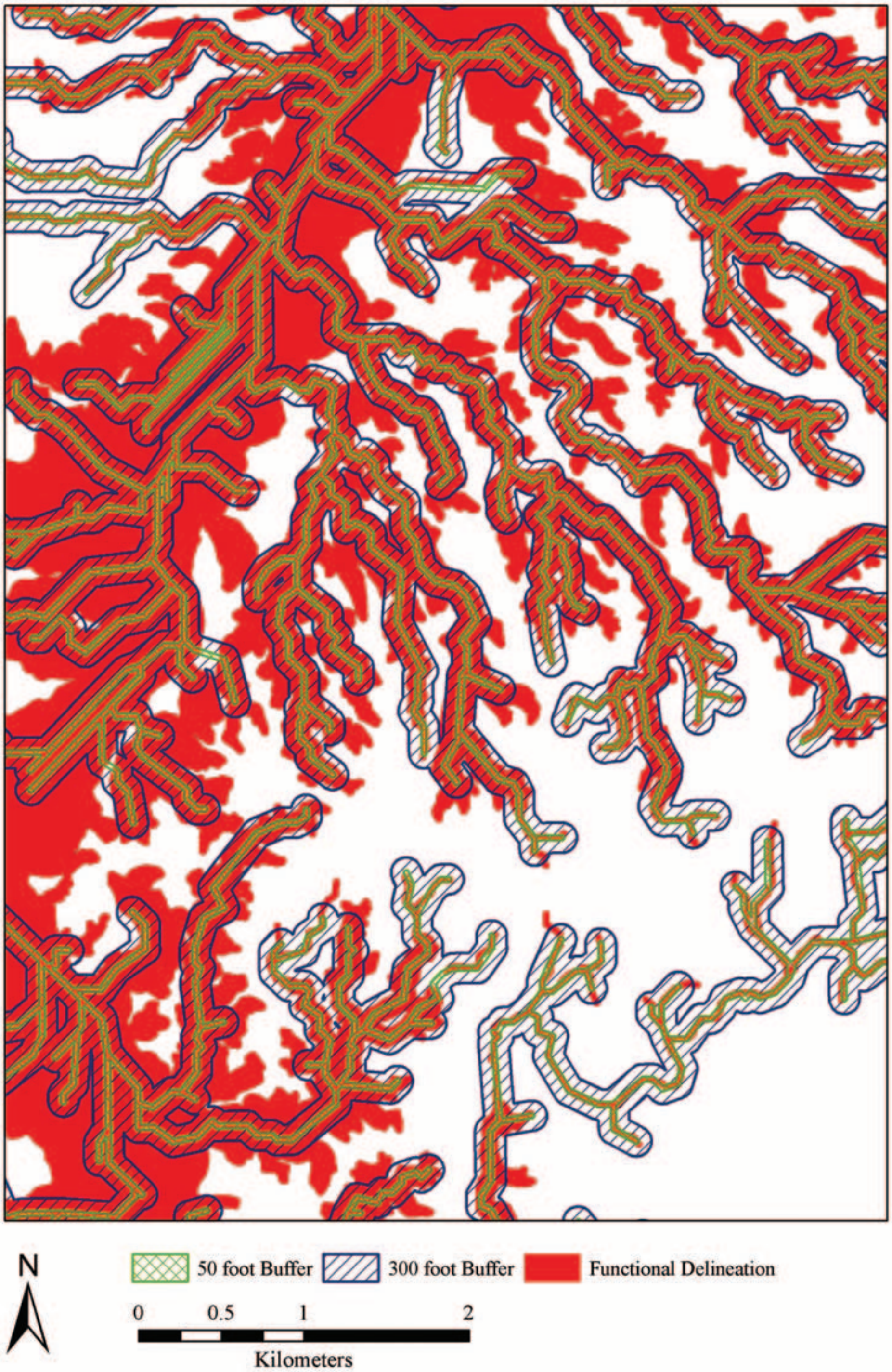

Figure 7. GIS comparison of 50- and 300-ft fixed-width buffers and the functionally delineated riparian areas along streams of the CVNP and the Cuyahoga River.

resources), certain riparian functions may need to be protected (e.g., sediment loading, shading, and temperature regulation for aquatic species) and harvest techniques within the riparian area should be designed to protect those ecological functions. Ultimately, the land manager decides how to best manage activity within a functionally delineated riparian area according to the ecological functions that require protection on their landscape.

Because the functional delineation is a probabilistic approach (Verry et al. 2004), areas closer to the stream have highest riparian function whereas areas farther from the stream are less likely to be within the functional riparian area. For this reason, management activities should reflect this gradient with less activity closest to the stream and increased activity farther away to protect riparian function (Palik et al. 2000). Selective logging techniques in riparian areas have been shown to have minimal effect on sediment loading (Kreutzweiser and Capell 2001, Rashin et al. 2006), amphibian populations (Fredericksen and Fredericksen 2004), macroinvertebrate and fish communities (Kreutzweiser et al. 2005, Chizinski et al. 2010), and stream water temperature (Kreutzweiser et al. 2009). Riparian function can also be maintained in areas with active management as a varying distance from the stream for leaf litter inputs (Muto et al. 2009), nutrient loading (Knoepp and Clinton 2009), large wood inputs (Meleason et al. 2003), microclimate (Rykken et al. 2007), vegetative structure (Clinton et al. 2010), and avian communities (Pearson and Manuwal 2001). However, because riparian areas are dynamic ecosystems, any management activity within these areas should be considered within the context of how it will impact aquatic ecosystems and focus on emulating natural variability and disturbance patterns to promote ecological function (Palik et al. 2000, Reeves et al. 2006, Holmes et al. 2010).

Because this approach requires that land managers define their management objectives and select the most important riparian functions to protect when determining usage of a functional riparian area, we suggest that the functional approach outlined here allows for high flexibility and portability throughout a landscape. As management objectives change, usage can also vary within the riparian areas. In contrast, a fixed-width approach is also quite portable with its relative ease of implementation; however, in our analyses using the CVNP as a model landscape, fixed-width buffers often underprotect riparian function along the Cuyahoga River or overprotect in the headwaters by including nonriparian areas, as expressed by ecological function.

Conclusions

As we work to incorporate ecological concepts into management, the functionally delineated riparian area approach may lead to improved protection and restoration of riparian function across landscapes. When planning riparian management across a large scale, geospatial methods can be used to functionally delineate riparian areas. This approach can be used and adapted as necessary to any location where geospatial data

Table 3. Comparison between the application and management of fixed-width buffers and functional delineations.

	Fixed-width	Functional
Application		
Planning management and restoration	Site specific	Landscape, site specific
Delineation methodology	Field	Geospatial, field
Focus of delineation	Centered on stream channel (dynamic)	Centered on stream valley (stable)
Relative effort	Less	More
Management		
Training required	Less	More
Riparian functions protected	Possibly	Likely
Portability	Good, but may limit functional protection	Good

exist, particularly topographical data. However, it should be emphasized that this method is not a substitute for on-the-ground delineation. Rather, it is a tool that uses remotely sensed data with a given level of accuracy that should be used for planning only. Actual on-the-ground delineation (Verry et al. 2004) should always be used for accurate measurement, such as that required for restoration. With education and implementation of the functional approach, management could improve protection of the unique and valuable ecological functions provided by riparian areas.

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