Modeling Riparian Zones Utilizing DEMS and Flood Height Data

Sinan A. Abood, Ann L. Maclean, and Lacey A. Mason

Abstract

Riparian ecotones are unique, diverse networks of vegetation and soils in close proximity to streams, rivers, and lakes. Previous approaches to riparian boundary delineation utilized fixed width buffers, but using a fixed width riparian buffer only takes the watercourse into consideration; it does not consider the surrounding landscape. By hydrologically defining a riparian ecotone to occur at the 50-year flood height and incorporating digital elevation data, the spatial modeling capabilities of ArcMap® GIS are utilized to map riparian zones accurately. This approach better characterizes the watercourse and its associated floodplain. Riparian zones delineated using 10 versus 30 meter DEMs and stream course information from the National Hydrography Dataset differ significantly. Within our study areas, 30 meter DEMs are not adequate to map elevation changes for accurate riparian area delineation. The result is a robust GIS based model in an ArcMap® Toolbox format to delineate a variable-width riparian boundary.

Introduction

Riparian ecotones are unique, diverse networks of vegetation and soils in close proximity to streams, rivers, and lakes. For this study, a riparian ecotone is defined as "…a three-dimensional space of interaction that includes terrestrial and aquatic ecosystems that extend down into the groundwater, up above the canopy, outward across the floodplain, up the near-slopes that drain to the water, laterally into the terrestrial ecosystem, and along the water course at a variable width." (Verry *et al.*, 2004). The ecotone is linked to the watercourse network through flooding and intercepting upland runoff (Mitsch and Gosselink, 2000). It is important to note that riparian ecotones are typically defined by local conditions, but respond to climatic and geological processes on continental scales through interconnecting watersheds. Hence, any riparian zone delineation model must be scale independent. It is also important to note that vegetation communities along stream banks often delineate riparian boundaries (Naiman and McClain, 2005).

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Previous approaches to riparian area delineation, commonly found in Best Management Practices guidelines, have utilized fixed width buffers, but this methodology has proven to be inadequate. Palik *et al.* (2000) determined that fixed-width buffers do not emulate natural riparian corridors since they have no functional relationship to the naturally varying watercourse. Suggested buffer width guidelines from the Minnesota Forest Resources Council were evaluated by Skally and Sagor (2001) in a single-case pilot study. Their report described the difficulty in using the guidelines of fixed-width buffers because many watercourse variables, such as site condition and water body type, need to be incorporated into the delineation process. Their research also concluded that the riparian ecotone boundary was on average 2.5 times farther from the stream than that mapped by a fixed width buffer.

Developing an all-encompassing definition for riparian ecotones, because of their high variability, is challenging. However, there are two factors that all riparian ecotones are dependent on: the watercourse and its associated floodplain. Using a fixed width riparian buffer only takes the watercourse into consideration and ignores the critical surrounding geomorphology and associated vegetation.

Research by Ilhardt *et al.* (2000) determined the 50-year floodplain was the optimal hydrologic descriptor of a riparian ecotone along a moving watercourse. This flood recurrence interval was selected because the 50-year flood elevation, in most cases, intersects the first terrace or other upward sloping surface and supports the same microclimate and geomorphology as the stream channel. The 50-year flood plain also coincides with measurements that quantify a valley to its stream using two measurements: the entrenchment ratio (valley width at the first terrace or up slope to the stream width at full bank), and the belt width ratio visible on aerial photos or maps (Ilhardt *et al.*, 2000).

Upper Midwest lakes are not as impacted by floodwaters compared to moving watercourses, but typically have a defined high water mark. This presents an issue of how to define a riparian ecotone boundary around standing, open water bodies. Within 30 meters of lakes, forest cover contributed 60 to 80 percent of its influencing habitat function, such as shade, woody debris recruitment, bank stability and litter fall as noted by Ilhardt *et al.* (2000), and this width is utilized around all open water bodies in our research. This study develops a GIS model to map riparian zones adequately and efficiently along moving watercourses by hydrologically defining a riparian ecotone to occur at the 50-year flood height and incorporating digital elevation data.

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Methods

Data Inputs and Study Areas

The model utilizes ArcGIS® Desktop 10 produced by Esri, Inc. (Esri, 1999-2010) for all data manipulation, management, and spatial analyses. Inputs into the model are setup as a file geodatabase (FGDB). The riparian zone delineation model uses the coding language Python 2.6 and is based on a procedure originally discussed by Aunan *et al.* (2005). The model, which continues the work by Mason (2007), creates riparian ecotone boundaries based on stream and lake locations, digital elevation data and the 50-year flood height variable associated with each stream segment order. Specific data inputs and their sources are listed in Table 1 and discussed below.

The National Hydrography Dataset (NHD) is a feature-based dataset organized into ArcMap® FGDBs. The data provides continuous, national coverage of stream reaches and water drainage systems and is overseen by the United States Geological Survey (USGS). The NHD is comprised of water-related entities such as natural river courses lakes, ditches, industrial discharges, drinking water supplies, etc.

TABLE 1. INITIAL DATA INPUTS AND SOURCES FOR THE RIPARIAN BUFFER DELINEATION MODEL

Input data	Source
Streams	USGS National Hydrography Dataset (NHD) *http://nhd.usgs.gov/* Michigan Center for Geographic information *http://www.michigan.gov/cgi* Minnesota DNR Data Deli *http://deli.dnr.state.mn.us/*
Lakes	Michigan Center for Geographic information *http://www.michigan.gov/cgi* Minnesota DNR Data Deli *http://deli.dnr.state.mn.us/*
10 m Digital Elevation Model	GIS Data Depot *http://data.geocomm.com/*
30 m Digital Elevation Model	USGS, The National Map *http://nationalmap.gov/*

Each entity has an assigned address that establishes its location and connections to other entities in the drainage network (USGS, 2010). Currently, there is nationwide coverage at 1:100 000 with larger scale coverage being developed at 1:24 000 and 1:12 000. For this study, 1:24 000 data is used to maintain a consistent scale for the stream data while assessing the impact of different spatial resolutions for the digital elevation model (DEM). Data gaps are filled with information from state supported GIS systems. Both Michigan and Minnesota maintain hydrography data at a scale of 1:24 000.

USGS DEMs are raster formatted elevation information sampled at regularly spaced ground locations. DEMs with spatial resolutions of 10 and 30 meters are utilized. The 10 meter DEM data are downloaded in a 7.5′ quadrangle format with a Universal Transverse Mercator (UTM) projected coordinate system from the GIS Data Depot (GeoCommunity, 2010) and mosaicked to create a continuous coverage. The 30-meter DEMs, are downloaded from The National Map Seamless Server as 1 arc-second data and reprojected to the UTM coordinate system (USGS Geography, 2010).

Flood height data is downloaded in a tabular format from the USGS Real-Time Water data site (USGS, 2007). The USGS Real-Time water data collection system is composed of monitoring sites that record data at 15 to 60 minute intervals. The information is either stored onsite or transmitted to a USGS office in one to four hour increments. The data is transmitted using satellite, telephone or radio, and is available for viewing within minutes of arrival. During critical events, recording and transmission times are more frequent.

The study sites (Figure 1) are comprised of multiple watersheds in three locations: northeast Minnesota, the central Upper Peninsula (UP) of Michigan and the northeastern Lower Peninsula (LP) of Michigan. These locations were selected based on 10-meter DEM data availability and provide a representative sample of the complex and diverse landforms found in the area.

The northeastern Minnesota study sites consist of two landforms, border lakes and Lake Superior highlands. Both have numerous lakes. The border lakes are composed of

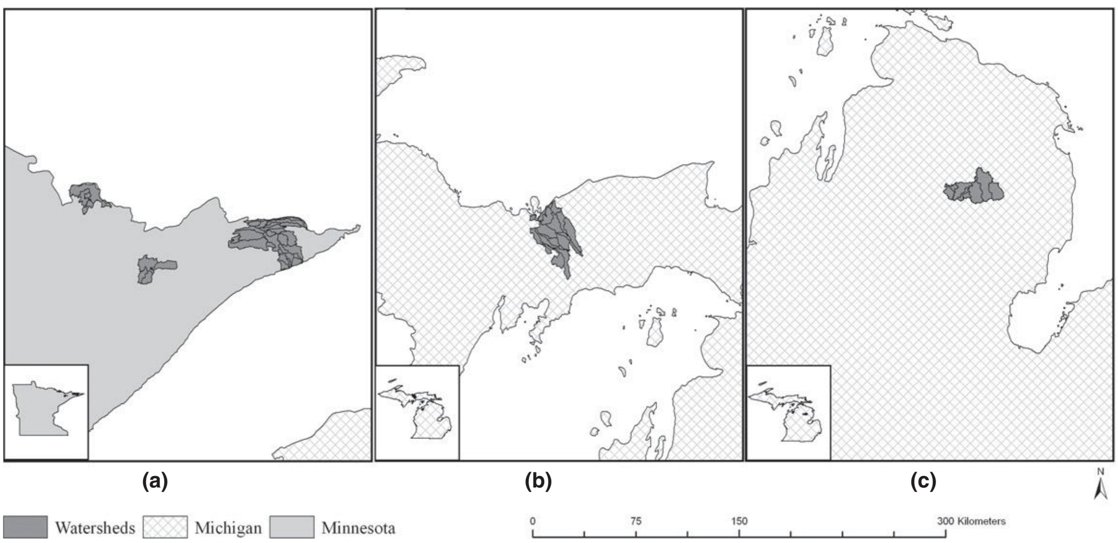

Figure 1. (a) Northeastern Minnesota study areas made up of three noncontiguous groups of five, four, and 26 adjacent watersheds, (b) Michigan's Upper Peninsula study area composed of 21 adjacent watersheds, and (c) Michigan's Lower Peninsula study area composed of nine adjacent watersheds.

scoured bedrock uplands or shallow soils on bedrock interspersed with outwash plains. Ground moraine and end moraine of the Superior Lobe label this area part of the Lake Superior Highlands. A clay lake plain forms a broad band along the Lake Superior shoreline, that is flat to rolling, with steep, narrow ravines creating numerous short, 15 to 25 km, streams (Albert, 1995).

The Michigan UP study site is also made up of two major landforms, Grand Marais sandy end moraine and outwash and Seney sand lake plain, both of lacustrine origin. The Grand Marais landform is composed of sandy ridges of end moraine. The moraine contains droughty sand dunes and beach ridge deposits, as well as poorly and very poorly drained glacial lacustrine deposits (Albert, 1995). The Seney sand lake plain contains broad, poorly drained embayments with beach ridges and swales, sand spits, transverse sand dunes and sand bars. Along the northern margins of the embayments deltaic deposits occur where glacial streams carried massive amounts of sand into shallow waters (Albert, 1995).

The Michigan LP study site is located on a high plateau. This landform is mostly outwash plain with large sandy ground and end moraines, plus ice-contact ridges. The site covers two subsections including Cadillac (sandy end-moraine) towards the southwest and Grayling (ice-contact topography) to the northeast (Albert, 1995).

Hydrologic Estimations

Before running the model, a determination of an appropriate 50-year flood height is necessary and is a vital input into the model. To estimate flood heights, data from ten Minnesota and eight Michigan sites which occurred within or near each of the study areas was obtained from the USGS Real-Time Water Data website (USGS, 2007). The data included the annual average stream flow rate and periodic measurements of flow rate, velocity and width.

The annual average flow rate measurements are organized by year and sorted from fastest to slowest for each stream gauge location. After sorting, the annual flow rate measurements are ordinally ranked, so the fastest flow rate receives a value of 1. To calculate the recurrence interval, the rank number is divided by the number of measurements. The flow rate is plotted against the logarithmic recurrence interval to develop a flood occurrence regression (Bedient and Huber, 2002). An individual site regression is shown in Figure 2a. The cross-sectional area (flow rate divided by velocity) is plotted against flow rate measurements (Figure 2b). Figure 2c shows the regression of width versus cross-sectional area. An R-squared value of 0.85 or higher is noted for all calculations. The width and cross-sectional area are determined from the previous regressions and the stream height calculated by dividing the cross-sectional area by the width (Mason, 2007).

Using the regression equations for each site, 1-year (to provide a baseline) and 50-year flood heights are determined. The flood height calculation results range between 0.3 and 1.75 meters for the study sites. To facilitate model development, a single average flood height of 1 meter is utilized in the model.

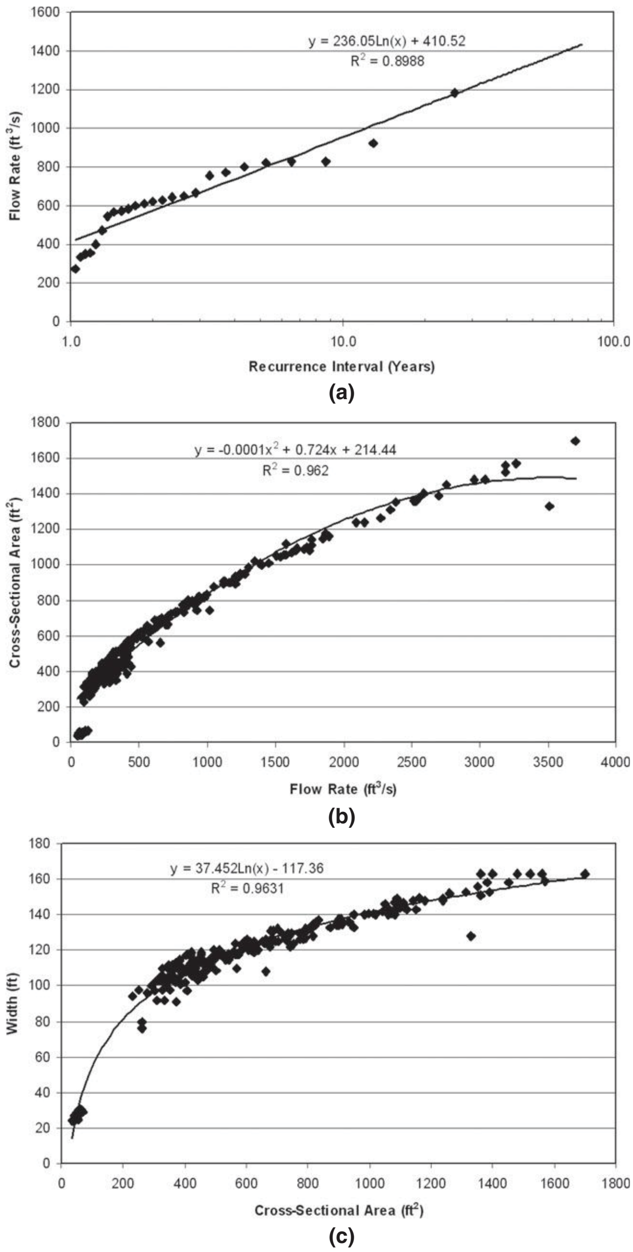

Figure 2. Regression graphs for the hydrologic estimators for determining the approximate 50-year flood height (from Mason, 2007): (a) Recurrence Interval (Years), (b) Flow Rate (ft^3/s), and (c) Cross-Sectional Area (ft^2).

Model Development

The modeling language Python 2.6 was used to develop the Riparian Buffer Delineation Model (RBDM) (Figure 3). Inputs must be in ArcMap® FGDB format and the user must have access to the spatial analyst extension. The riparian model is presented as an ArcMap® toolbox with the Python programming embedded within. The model interface has five required inputs and two optional inputs. The data processing is divided into the following components: (a) prepare input data and creating the lake buffers, (b) build sample points along streams, (c) build transects around sample points along streams, (d) determine the outside edge of the variable-width buffer, and (e) create an easy to use riparian boundary polygon.

Processing begins by editing the streams and lakes feature classes. Each stream length is typically made up of several stream segments designated with a reach code. To optimize transects building, the stream segments are dissolved by reach code to remove extraneous nodes. Next, stream segments within a lake or other open water bodies, which represent an artificial path to ensure the hydrographic network is complete (Figure 4a), are erased, as mapping of a riparian zone along these segments would be erroneous

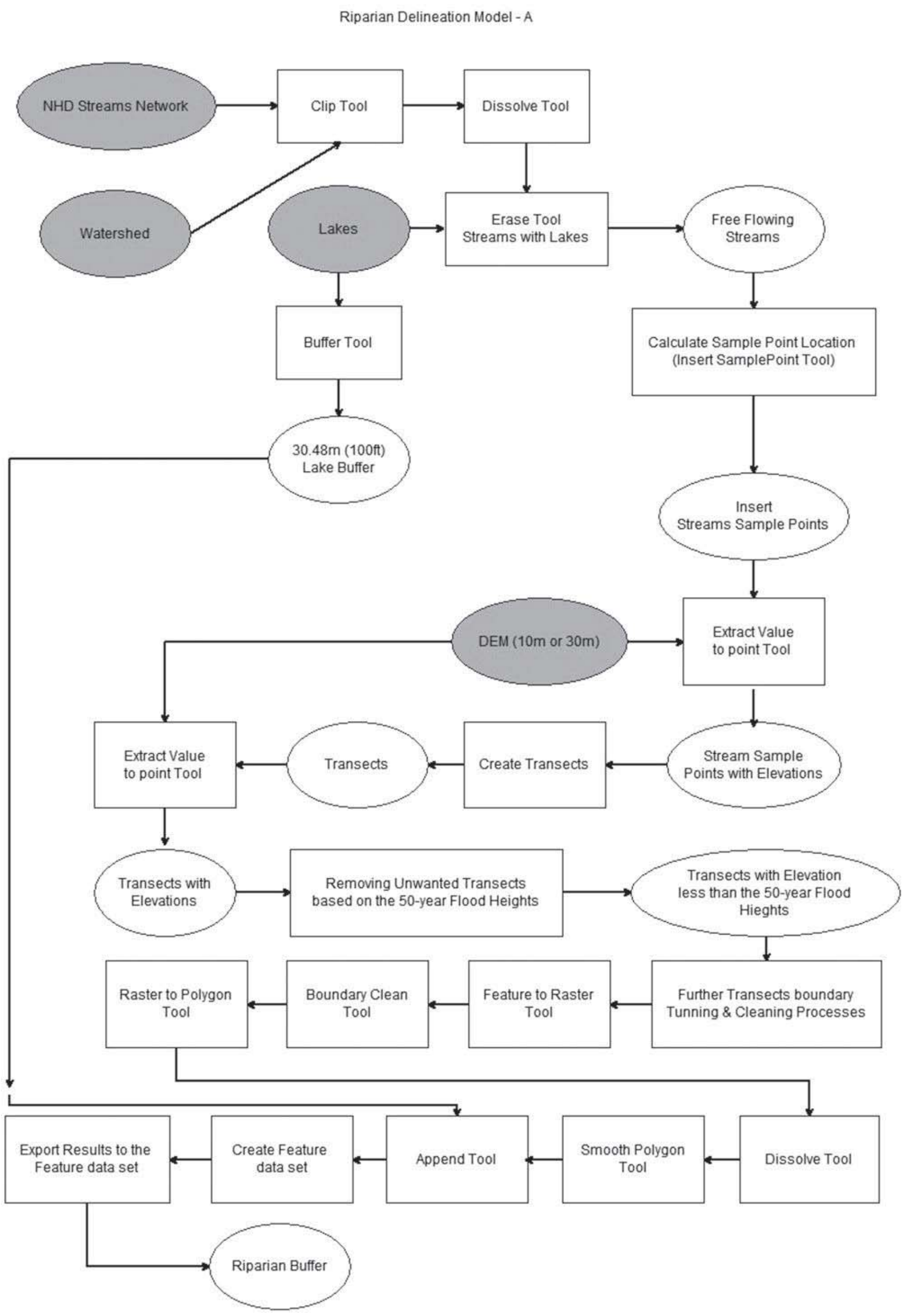

Figure 3. Flowchart for the Riparian Buffer Delineation Model.

(Figure 4b). Lastly, a 30.5-meter (100 feet) buffer is computed around all lakes and other open water bodies based on the recommendations of Ilhardt *et al.* (2000).

The second model component calculates the x, y coordinates for the starting point of each transect, which provide direction for the change in elevation to be calculated. Input parameters include the DEM spatial resolution and a pixel ratio, expressed as a percentage of pixel size. The distance between sample points along the stream course and along each transect is set to a distance of 75 percent of the pixel's spatial resolution along each stream segment. This is done to minimize the influence of the DEM spatial resolution on the distribution of the sample points along the stream course, but not assume a horizontal accuracy better than the DEM accuracy standard (USGS, 1997). Point spacing is calculated using Euclidean distance from one point to the next along the stream segment. The stream segments are treated as continuous features to avoid sampling gaps and maintain a constant spacing distance. Upon completion of the stream sample point calculations, the program retrieves

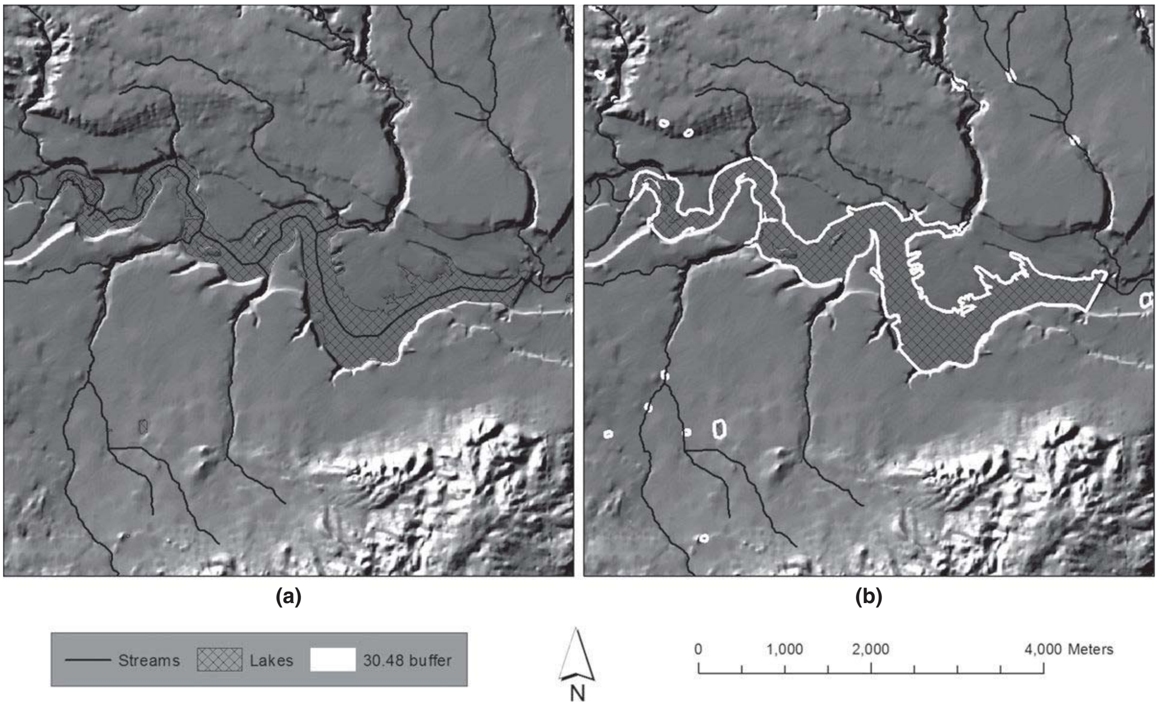

Figure 4. Example of streams and lakes layer (a) before, and (b) after the erase function.

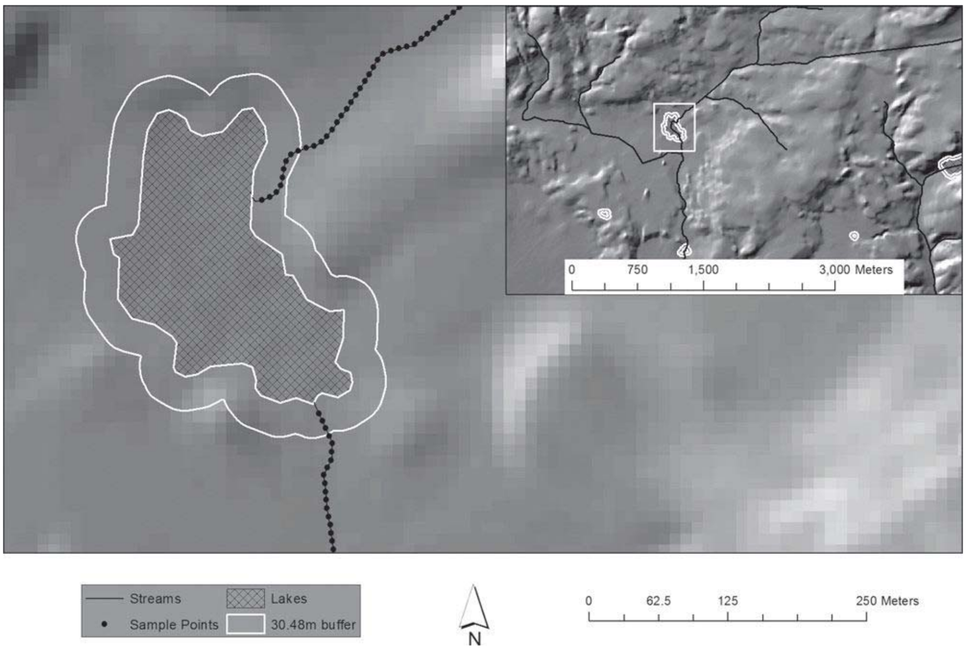

Figure 5. Illustration of sample points distribution along streams.

the elevation for each sample point from the DEM and writes the value to the sample point attribute table (Figure 5).

After point placement and elevation extraction, transects are produced around each sample point (Figure 6) for 360°. Initially each transect was calculated to be 3,000 meters to ensure complete mapping of the riparian area so all variations in elevation and changes in stream course direction are captured. However, this proved to be computationally intensive. To optimize processing time and to reduce the size of the generated transects points feature class, the distance to map the 50-year flood height change in elevation was determined by noting the actual maximum distance where the required elevation change took place during preliminary testing of the model.

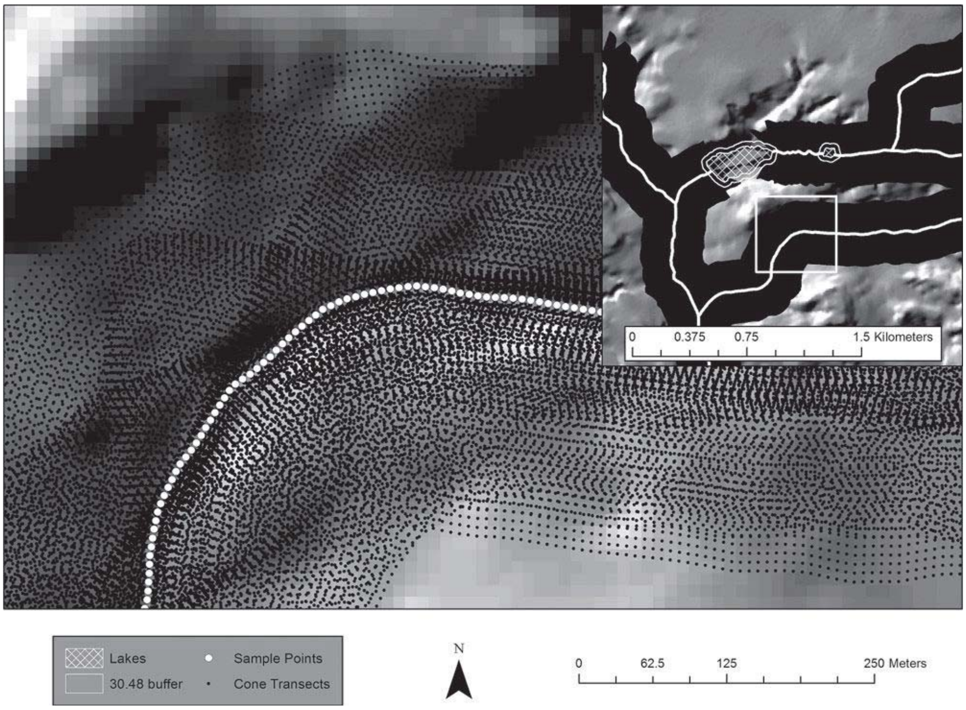

Figure 6. Transects points generated along sample points. The enlarged view shows the overlap and density of the sample points along transects.

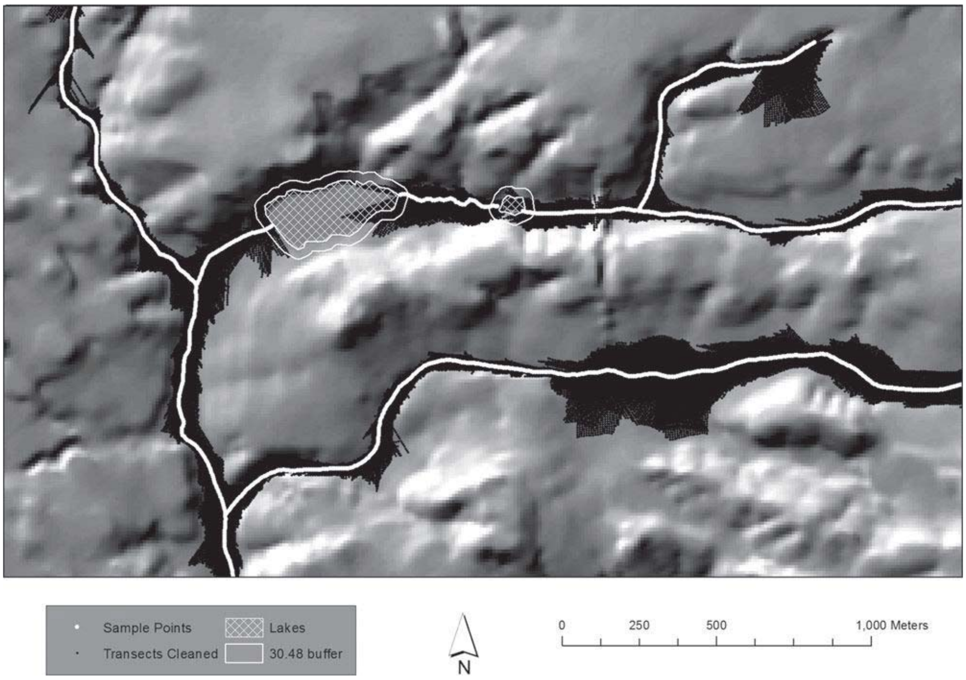

Figure 7. Transects points cleaned and smoothed.

For the study areas in Minnesota and Michigan, a maximum transect length of 202.5 meters was imposed for the 10-meter DEM and 607.5 meters for the 30-meter DEM around each sample point. This improved the processing efficiency and yet accounted for the variation in the landscape along stream networks. The model allows the user to customize the maximum length of the transects as the maximum required length will vary with different landscapes.

Based on elevation change, the model determines if the transect points are part of the riparian buffer. If the elevation change is greater than the average calculated 50-year flood height between the sample point and the transect point, the point is considered outside the riparian zone and is deleted.

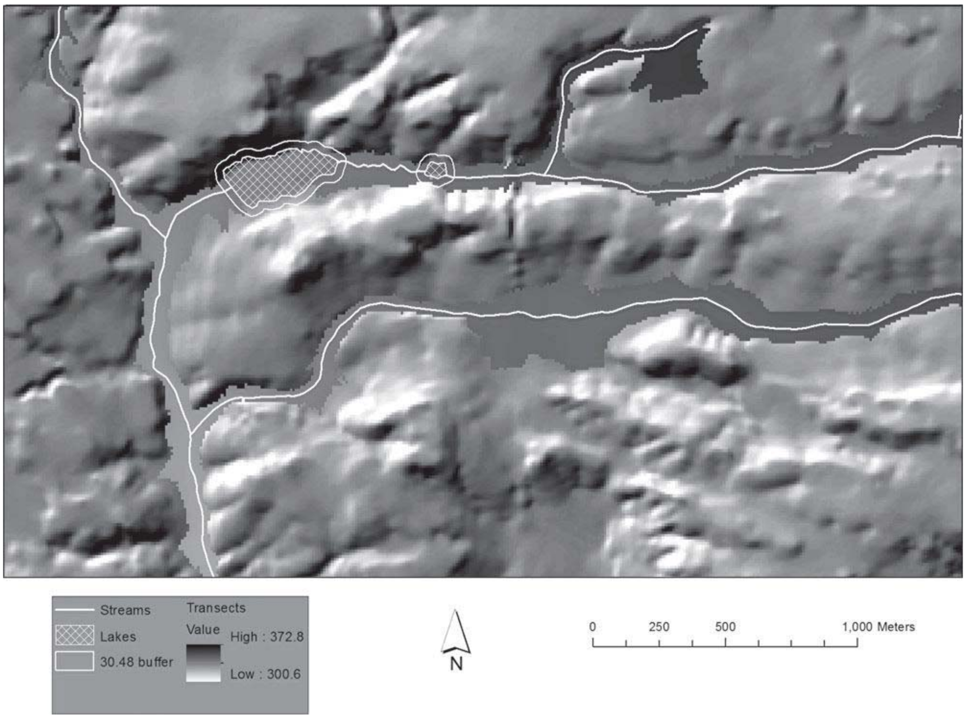

Figure 8. Rasterization of points within the riparian zone.

The next step removes duplicate points along the edge of the riparian zone to reduce processing time. Duplicate points occur if the transects overlap due to the curvilinear shape of the steam course. The model reads the transect points elevation associated with each sample point along the stream and flags the edge of the riparian zone. Transect points after the edge point are then deleted (Figure 7).

The cleaned transects feature class is rasterized with a spatial resolution equal to that of the input DEM (Figure 8), and the raster is smoothed to remove ragged edges between riparian zones. The one-way sort option which controls the direction of the smoothing process is selected to enable the sample points on the stream segment to remain part of the buffer after processing. If the buffer is only one pixel wide, these individual pixels are not prioritized and would be removed in a two- way sort (Esri, 1999-2010). Once the boundary edges are smoothed, the riparian zones are converted to a vector polygon. The final riparian buffer consists of the stream riparian zone (polygon) merged with the 30.5 meter lake buffer, and is composed of many irregularly shaped, adjacent polygons. As a final step, the model performs additional processing to remove area overlaps inside the riparian boundary and boundary smoothing to create one contiguous buffer around adjacent hydrologic features (Figure 9).

Statistical Assessment

The DEM is a required input, and it is important to understand how its characteristics (integer versus floating point format and the spatial resolution) influence model output. The first version of the RBDM used integer DEMs to decrease processing time (Mason, 2007). The current version is programmed to be more computationally efficient and developed to use floating point DEMs to preserve the continuity in the elevation data and decrease error introduced by the rounded integer elevation values.

The impact of both of these variables of is evaluated using the approach developed by Mason (2007). Details are presented here as the approach is complex. Using 10- and 30-meter DEMs in integer and floating point formats, riparian areas are calculated for each of the study sites, excluding lake surface area and placed in an attribute table. Additional required fields in the attribute table include a unique ID for each watershed and the DEM spatial resolution. This information is input into the program R for Statistical Computing (R Core Development Core Team, 2005) and analyzed to ascertain if there are statistically significant differences between the riparian areas for integer versus floating point DEMs and between different DEM spatial resolutions (10- and 30-meters).

An analysis of variance tests whether the DEMs format, its spatial resolution, and the landform as described for each study site by Albert (1995) have a statistically significant effect on the calculated riparian area. Since the delineation is repeatedly applied to the same subject (individual watersheds), the appropriate analytical approach is to analyze the results as a repeated measures design (Kutner *et al.*, 2005). The corresponding linear, mixed-effects model includes several components. The riparian area is the response; the treatment effect (DEM format and spatial resolution) is a change in the response variable due to the application of a treatment. The landform is the block effect that describes the change in the response variable due to membership in an experimental unit (watershed) in a given block (landform). The landform is not a treatment in this study because it is not assigned randomly to an experimental unit (watershed). A block- treatment interaction occurs when the treatment effect on experimental units is not independent of the block effect. In other words, landform cannot be explained by the DEM. The subject effect (watershed) is treated as random. The subject effect, essentially a block effect, is the change in the response variable due to the fact that the treatment was applied more than once to the same experimental unit.

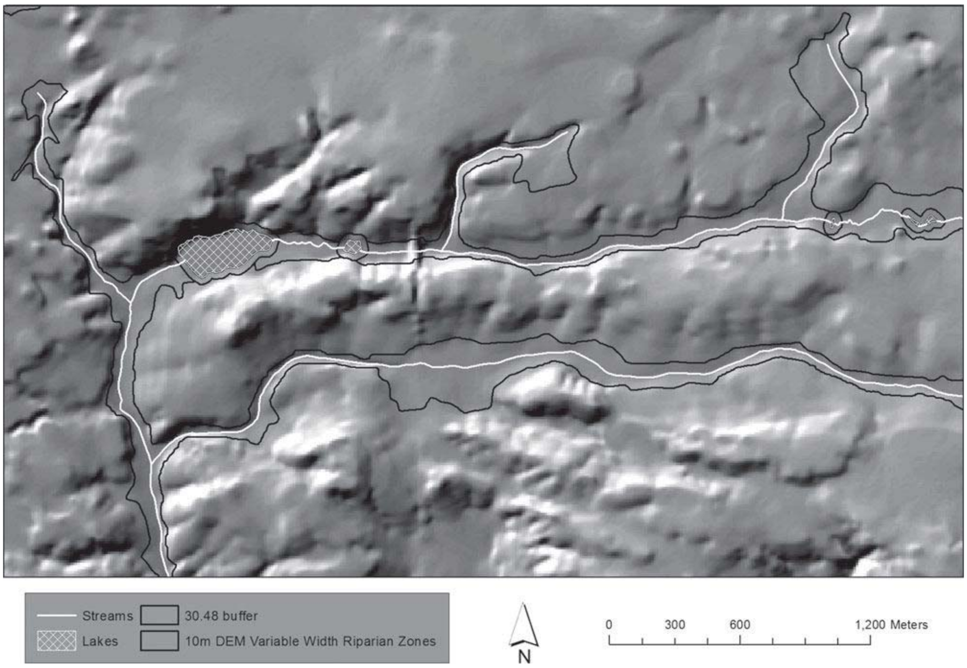

Figure 9. Final riparian buffer merged with 30.5-meter lake buffer.

Fitting uses a linear mixed-effects function, which relies upon maximizing the restricted log- likelihood (Pinheiro and Bates, 2000). This approach permits straightforward accounting for lack of balance in the data because the number of watersheds in each landform, or block, is not the same (Kutner *et al.*, 2005). Normality was assessed using normal probability plots and assumptions of within-subject variance homogeneity and additively is examined using scatter plots.

Continuous fixed-width buffers of 30- and 60-meters were generated to compare to the variable width buffers calculated by the model. These widths were chosen based on the recommendations by Palik *et al.* (2004) and permit a direct comparison to their findings.

The 50-year flood height is another important model parameter. The hydrological estimation has a range of flood height values from 0.3 to 1.75 meters for the study areas. The first version of the model utilized only the average 50-year flood height (1 meter) to decrease the intensive computational time. A comparison is made to evaluate the model's sensitivity to different flood heights. Three values (minimum, average, and maximum) are used as the flood height inputs (0.3 m, 1.0 m, and, 1.75 m respectively). The analysis was completed using 10-and 30-meter floating point DEMs.

Results and Discussion

Figure 10 illustrates a typical example of the variation between the riparian zones boundary delineated utilizing integer versus float point DEMs with the same 50-year flood height. The floating point DEMs consistently map a greater riparian buffer area than the integer DEMs and occurs with both the 10- and 30-meters DEMs (Table 2). The boundaries of the riparian zones output by the model are compared to boundaries digitized manually by an expert aerial photo interpreter and considered to be "truth". Overlaying the boundaries produced from the floating point 10-meter DEM and the average 50-year flood height showed a coincident boundary ($\pm$ 5 meters) of 90 percent compared to an agreement of 81 percent for the output from the integer 10-meter DEM. The floating point DEM represents elevations with greater detail and less abrupt changes in elevation than the integer DEM. The model takes advantage of this characteristic by delineating the boundaries more accurately. The rounding error inherent in the integer DEMs represents a loss of elevation detail, and elevation differences between adjacent pixels are greater and reach the 50-year flood height value quicker along the transect.

The variable-width riparian areas calculated from the 10- and 30-meter floating point DEMs produce different area totals and spatial extents (Table 2). For all of the watersheds in the study areas, the riparian areas derived from the 30-meter DEMs are greater than those calculated using the 10-meter data. A representative sample of the variation in spatial extent is illustrated in Figure 11. As noted previously, overlaying the boundaries produced from the floating point 10 m DEM shows a coincident boundary ($\pm$ 5 meter) of 90 percent. Overlaying the boundaries produced form the floating point 30-meter DEM has a coincident boundary agreement of 51 percent. Almost half of the riparian boundaries delineated with the 30-meter DEM are located beyond the boundary of the actual riparian area. This result was anticipated given that the spatial resolution of the 30-meter DEM is nine times larger than the 10-meter and shows the inadequacies of the 30-meter DEM to accurately map elevation changes in a landscape heavily impacted by glaciation which has caused significant elevation differences over short distances (in this study $<$30 meters). The statistical assessment confirms that the riparian areas produced from 10- and 30-meter DEMs are significantly different ($p < 0.001$) and the riparian delineation model is independent of landform ($p < 10^{-14}$). This is highlighted by the study area in Michigan's UP. The area within the Grand Marais sandy end moraine has elevation changes occurring over very short distances within the 50-year flood plain and the floating point DEMs capture this as shown at the bottom of Table 2.

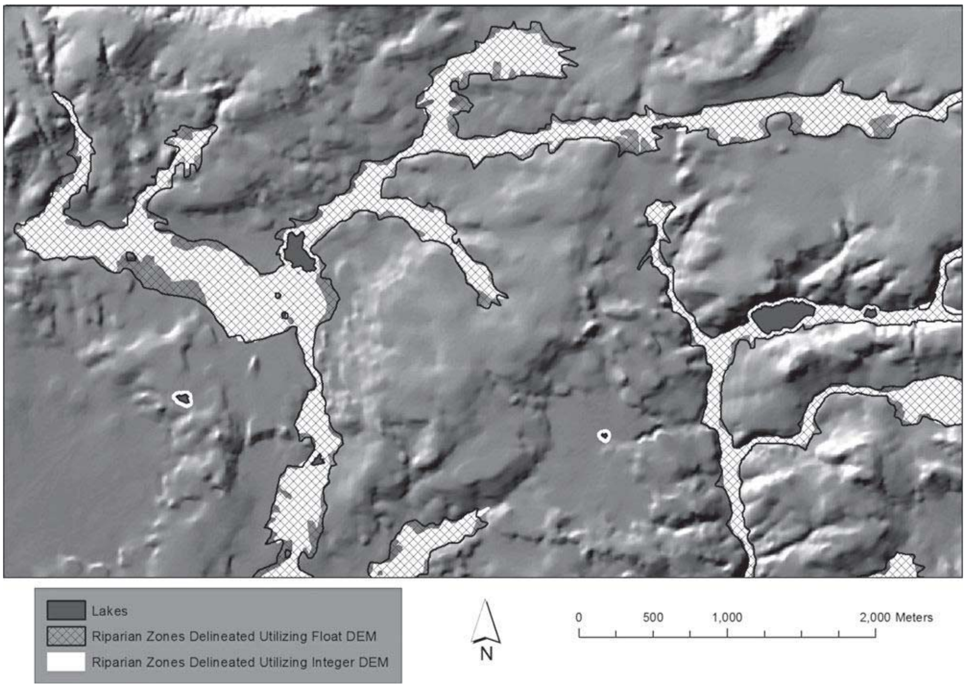

Figure 10. Comparison between riparian zones delineation utilizing the 10-meter DEM and two format types (floating versus integer).

TABLE 2. AREA SUMMARIES COMPARING INTEGER AND FLOATING POINT DEMS; THE AVERAGE 50-YEAR FLOOD HEIGHT (1 M) IS HELD CONSTANT

Study Site	Minnesota	Michigan-UP	Michigan-LP
Total Watershed Area (Hectares)	168,641.5	92,008.8	59,273.9
	Integer DEMs		
Model Parameters		**10 m DEM**	
Riparian Zone Area (Hectares)	40,201.1	14,033.6	6,516.4
% of Watershed Area	23.8	15.2	11.0
Model Parameters		**30 m DEM**	
Riparian Zone Area (Hectares)	44,587.5	23,244.6	8,088.8
% of Watershed Area	26.4	25.3	13.6
	Floating Point DEMs		
Model Parameters		**10 m DEM**	
Riparian Zone Area (Hectares)	42,553.1	15,847.9	6,802.8
% of Watershed Area	25.2	17.2	11.4
Model Parameters		**30 m DEM**	
Riparian Zone Area (Hectares)	46,107.4	29,694.7	10,833.7
% of Watershed Area	27.3	32.27	18.3
% Increase in Delineation Area			
10 m DEM Integer to Float. Point	5.5	11.4	4.2
30 m DEM Integer to Float. Point	3.3	21.7	25.3

The results in Table 3 show the model is sensitive to changes in the input flood height. As the flood height increases so does the area included in the riparian buffer, and the areas mapped are significantly different ($p < 0.05$) from each other. The value of this comparison lies in the application of the buffer. The model allows resource managers to evaluate the impact of utilizing of the minimum, average or maximum flood heights and apply the most appropriate flood height.

The study also supports the conclusions of Palik *et al.* (2004) that riparian areas determined using fixed width buffers do not accurately delineate riparian areas since they do not incorporate landscape features such as changes in elevation. The 30- and 60-meter fixed-width buffers delineated around the streams consistently underestimated the total riparian area, and do not accurately delineate the spatial location of the "true" boundary. Buffers generated in this manner do not protect enough of the riparian ecotone to maintain natural corridors. The variable-width buffer characterizes the stream better by considering the landform change around the stream and protecting the area which highly influences the stream (Figure 11).

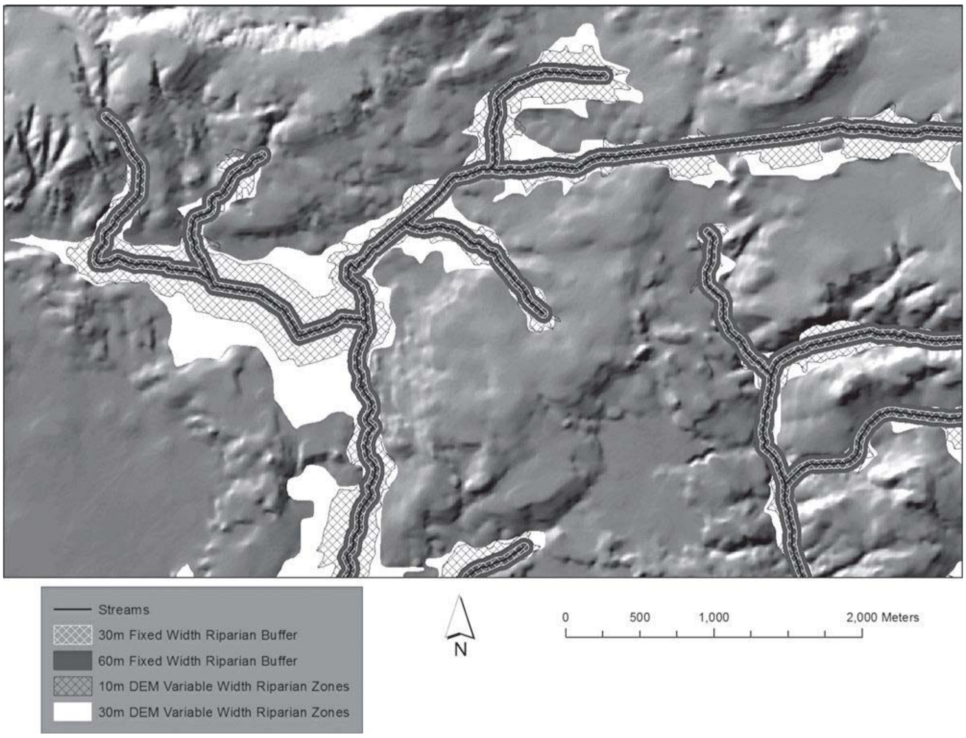

Figure 11. Example area comparing the riparian variable-width model results from the 10 m and 30 m floating point DEM with fixed-width buffers of 30 and 60 m.

Table 3. Sensitivity Analysis using Minimum, Average, and Maximum 50-year Flood Heights with Floating Point DEMs

	10 m Floating Point DEM			30 m Floating Point DEM		
50 yr Flood Ht. (min, avg., max)	0.3 m	1.0 m	1.75 m	0.3 m	1.0 m	1.75 m
		UP-Michigan			**UP-Michigan**	
Total Riparian Zones Area (Ha)	12,078.0	15,848.0	17,873.5	19,097.9	29,694.6	35,312.7
% of Watershed Area	13.3	17.2	19.4	20.7	32.2	38.3
		LP-Michigan			**LP-Michigan**	
Total Riparian Zones Area (Ha)	4,242.8	6,802.8	8,450.5	6,166.0	10,833.7	14,297.9
% of Watershed Area	7.1	11.4	14.2	10.4	18.2	24.1
		Minnesota			**Minnesota**	
Total Riparian Zones Area (Ha)	39,043.5	42,553.1	45,052.0	41,188.3	46,107.4	50,414.2
% of Watershed Area	23.1	25.2	26.7	24.4	27.3	29.8

Conclusions

The RBDM accurately maps riparian zones utilizing digital elevation data and hydrologic data that are widely available. The model takes advantage of the spatial analysis capabilities of ArcMap® and can be easily added as a Toolkit. The model is computational intensive, but executes within a reasonable amount of time per watershed. It is important to remember that the quality and accuracy of the output is dependent on the quality of the inputs. Factors to consider include age and quality of stream digitization, scale of the vector based stream data, and DEM spatial resolution and format.

Fixed-width riparian area delineation approaches did not adequately map the actual riparian areas in any of the study sites. Our research supports previous work which noted that fixed width delineation does not begin to characterize the water course and its surrounding riparian area. In all cases, this approach consistently underestimates the riparian area. Therefore, it is recommended that resource management agencies review their BMPs and consider revising their guidelines.

As land development continues and water resources become scarcer, it is important these areas are protected and maintained for future generations. This method of delineating riparian areas is easily implemented within ArcMap®. With the addition of higher spatial resolution DEMs, such as those derived from lidar, and additional hydrologic information, even more detailed delineations could be accomplished.

A copy of the Riparian Buffer Delineation Model is available for downloading free of charge by contacting Ann Maclean at *amaclean@mtu.edu*.

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