MODELING RIPARIAN ZONES UTILIZING DEMS, FLOOD HEIGHT DATA, DIGITAL SOIL DATA AND NATIONAL WETLAND INVENTORY VIA GIS

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ABSTRACT

Riparian zones are dynamic, transitional ecosystems between aquatic and terrestrial ecosystems with well defined vegetation and soil characteristics. Development of an all-encompassing definition for riparian ecotones, because of their high variability, is challenging. However, there are two primary factors that all riparian ecotones are dependent on: the watercourse and its associated floodplain. Previous approaches to riparian boundary delineation have utilized fixed width buffers, but this methodology has proven to be inadequate as it only takes the watercourse into consideration and ignores the critical surrounding geomorphology, associated vegetation and soil characteristics. This approach offers advantages over other previously used methods by utilizing a better sampling technique along the water course that can distinguish the 50-year flood edge associated with the floodplain and by utilizing the Digital Soil Data (DSD) and National Wetland Inventory (NWI) databases to distinguish riparian soils and vegetation characteristics associated and adjacent with riparian zones of the same floodplain. The result of this study is a GIS based model in a form of an ArcGIS tool box attached to ESRI ArcMap software to delineate a variable-width riparian boundary.

KEYWORDS: riparian zone, GIS spatial model, variable width buffer

INTRODUCTION

Riparius, the original Latin term for riparian means "of or belonging to the bank of a river" (Naiman et al., 1997). Across the fields of science and engineering, definitions for riparian areas range from simple to complex. Fischer et al. (2001) mentioned more than 35 terminologies for riparian areas and the vegetation adjacent to aquatic systems. Verry et al. (2004) summarized 100 years of definitions and concepts published in the literature. The definitions vary, depending on agencies, various disciplines or a functional perspective. Each definition has criteria to define and delineate the boundary of a riparian area.

Riparian ecosystems are dynamic ecosystems between aquatic and terrestrial ecosystems or a transitional zone between two adjacent ecosystems with well defined vegetation and soil characteristics (Mitsch & Gosselink, 1993). A spatial description is clearly illustrated in Minshall et al. (1989) and shown in Figure 1. A riparian zone is "Land inclusive of hydrophytes and/or with soil that is saturated by ground water for at least part of the growing season within the rooting depth of potential native vegetation". This definition combines the wetland definition developed by Cowadin et al., 1979 and the adjacent areas that have a moderate or well balanced supply of moisture (Mitsch & Gosselink, 1993).

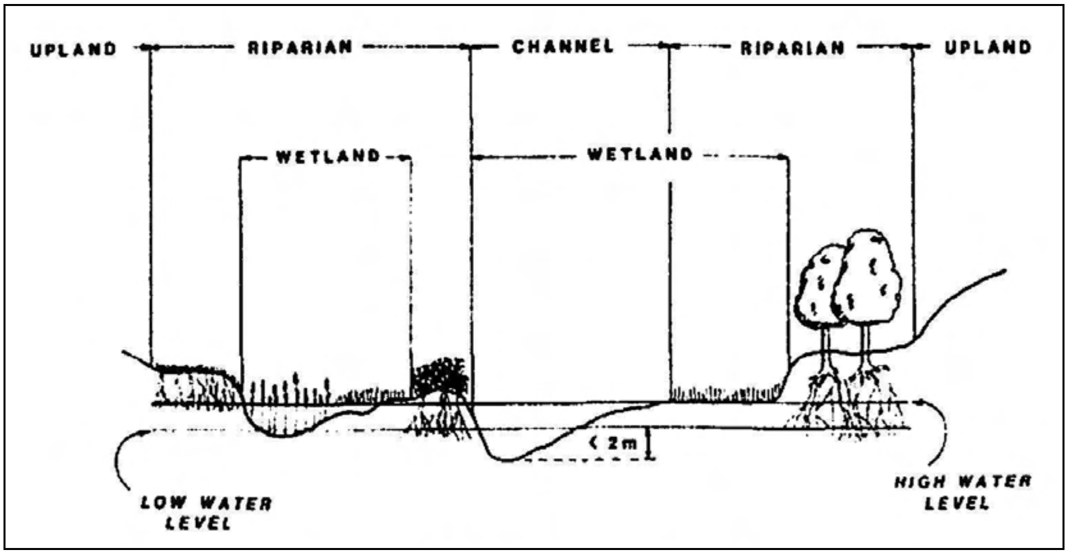

Figure 1.Riparian, wetland and upland habitat delineations (from Minshall *et al*., 1989).

In general riparian zones or ecosystems throughout the United States are found along streams, rivers, and lakes where energy and nutrients pass from and into terrestrial and aquatic ecosystems.

There are three properties mentioned by Mitsch & Gosselink (1993) to distinguish riparian ecosystems from the adjacent ecosystems:

- Riparian ecosystems generally have a linear form as consequence of their proximity to rivers and streams;
- Energy and material from the surrounding landscape pass through riparian ecosystems in much greater amounts than those of any other wetland ecosystem; and
- Riparian ecosystems are functionally connected to upstream and downstream ecosystems and are laterally connected to upslope (upland) and down slope (aquatic) ecosystems.

Using the term ecotone concept would minimize confusion across many fields and agencies and eliminate the approach in delineating riparian ecotones by a single characteristic such as hydric soils or land cover (Verry et al., 2004). The term ecotone is a biological term that represents the zone of interaction between a stream ecosystem and a terrestrial ecosystem which includes the geomorphology and functional parameters of a riparian ecotone, and it also suggests that a riparian boundary is not a fixed distance from the stream ecosystem bank but has a variable width (Ilhardt et al., 2000).

Previous approaches to riparian area delineation 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 designated 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 suggested by a specified 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.

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 via 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 via 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.

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 via 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).

This study further developed and refined the GIS riparian delineation model originally developed by Mason (2007) to map these areas adequately and efficiently along watercourses by hydrologically defining a riparian ecotone to occur at the 50-year flood height and incorporating digital elevation data. The updated model introduces the use of national wetland inventory data (NWI) and digital soil data to better delineate riparian zones by highlighting the adjacent wetlands and digital soil units in direct interaction with riparian zones and confirms that riparian zones are not confined to the floodplain definition, but extend to other surface waters like lakes and wetlands in order to encompass riparian zones functional, hydrological and ecological characteristics (Palik *at al*., 2004).

OBJECTIVES

- Build a second generation GIS-based model that delineates a variable-width riparian boundary utilizing 10m and 30m digital elevation model (DEMs) and the 50 years flood height data that is more robust and automated than the original model developed by Mason (2007).
- Evaluate the outcome of incorporating digital soils data and/or NWI data into the model for improved riparian zone delineation when compared to only utilizing digital elevation data and flood height data.
- Estimate the total area and spatial extent of riparian zones associated with updated riparian zones definition criteria (NWI and Digital Soil Data) in our study area.

METHODS

Study Area and Model Inputs

The study sites are comprised of multiple watersheds in 2 locations: the central Upper Peninsula (UP) of Michigan and the eastern Lower Peninsula (LP) of Michigan (Figure 2). These locations were selected based on 10m DEM data and digital soil data (spatial and tabular) availability, and to provide a representative sample of the complex and diverse landforms found in the region.

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 under WingIDE Professional version 3.2 produced by Archaeopteryx Software Inc. dba Wingware (1999-2010) and is based on a procedure originally discussed by Aunan et al., (2005).

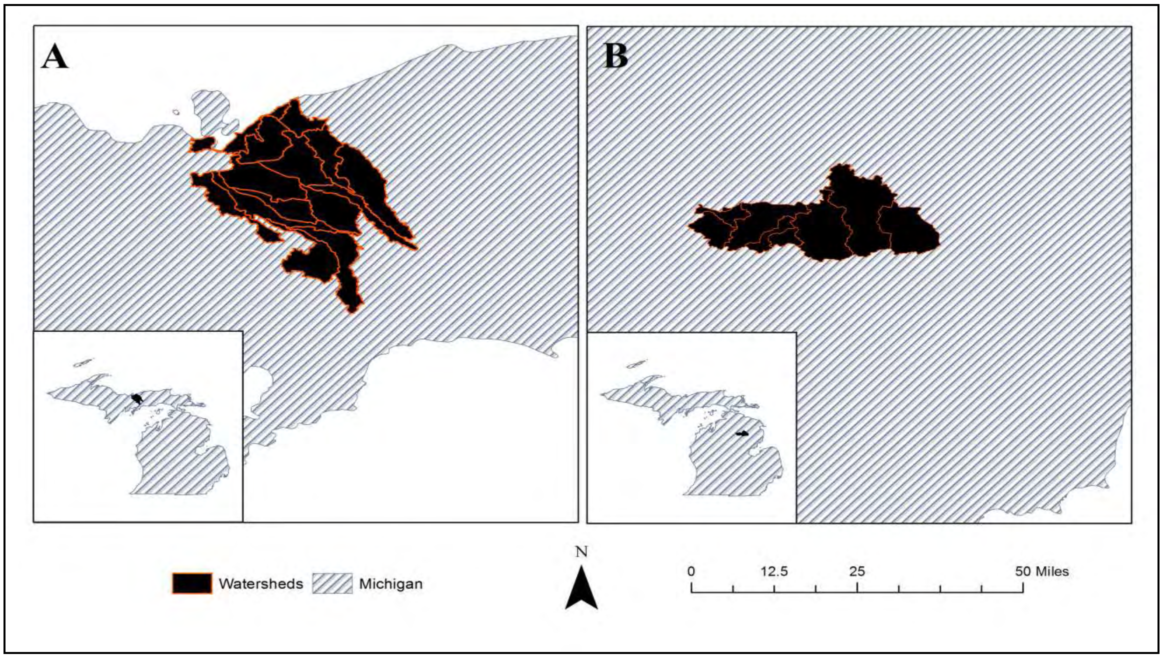

Figure 2. Study Area A) Upper Peninsula and B) Lower Peninsula of Michigan.

The model utilizes inputs readily available from federal and state agencies to create riparian ecotone boundaries based on stream and lake locations, digital elevation data, the 50-year flood height variable associated with each stream segments order, adjacent wetlands utilizing the NWI, and digital soil spatial data to the variable width riparian zones. Specific data inputs and their sources are listed in Table 1 and discussed below.

Table 1. Riparian model data inputs and sources.

Input Data	Sources
Streams, Watersheds	USGS National Hydrography Dataset (NHD) http://nhd.usgs.gov/
Lakes	Michigan Center for Geographic information http://www.michigan.gov/cgi
National Wetland Inventory (NWI)	National Wetlands Inventory (NWI) http://www.fws.gov/wetlands/Data/DataDownload.html
Digital Soil Data	Natural Resources Conservation Service (NRCS) http://soildatamart.nrcs.usda.gov/
10m Digital Elevation Model	GIS Data Depot http://data.geocomm.com/

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. Mason (2007) used USGS gauge station flood heights data from 10 Minnesota and 8 Michigan sites. The flood height calculation results ranged between 0.3 and 1.75m. Three flood heights values used as a model inputs 0.3, 1.0, and 1.75m which represents the minimum, average and maximum flood heights across the study area.

Model Development

The modeling language Python 2.6 was used to develop the riparian delineation model. Inputs must be in ArcMap FGDB format and the user must have access to the spatial analyst extension. The riparian model is formatted as an ArcMap toolbox with the Python programming embedded within. The model interface has five required inputs and two optional inputs (Figure 3). The data processing is divided into the following components: 1) preparing input data and creating the lake buffers; 2) building sample points along streams; 3) building transects around sample points; 4) determining the outside edge of the variable-width buffer; 5) creating an easy to use riparian boundary polygon; 6) identifying adjacent wetlands and creating a continuous riparian boundary with them; and 7) utilizing adjacent digital soil data criteria and creating a continuous riparian boundary with adjacent digital soil data. Multiple components facilitate customization of the model.

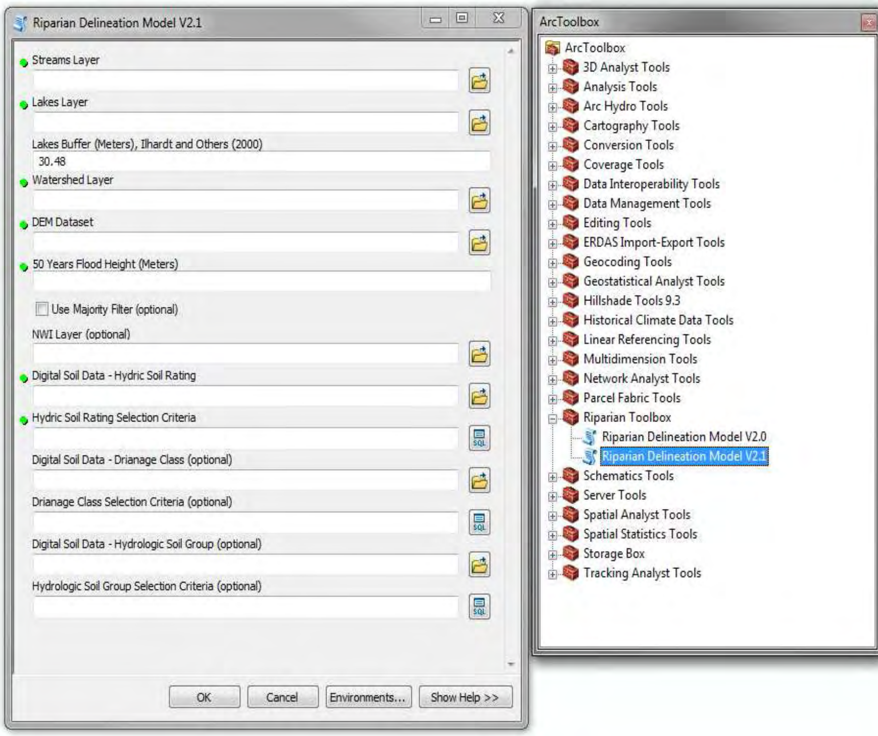

Figure 3. Riparian Delineation Model V2.1.

Processing starts by editing the streams and lakes feature classes for input. 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 delineated within a lake or other open water bodies are erased, as mapping of a riparian zone along these segments would be erroneous. Lastly, a 30.5 m (100 ft) 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. Input parameters include the DEM's spatial resolution and a pixel ratio, expressed as a percentage of pixel size. The distance between sample points is set to a distance of 75% of the pixel's spatial resolution along each stream segment. This is done to minimize the influence of the DEM's spatial resolution on the distribution of the sample points along the stream course, but not assume a horizontal accuracy better than the DEM's 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 the elevation for each sample point from the DEM and writes the value to the sample point attribute table.

After point placement and elevation extraction, transects are produced around each sample point (Figure 4) for 360^{o}. This ensures a realistic mapping of the riparian area as all variations in elevation and changes in stream course direction are captured. To optimize processing time and to reduce the size of the generated transects points feature class, a maximum transect length of 202.5 m (664.2 ft) was imposed for the 10m DEM and 607.5 m (1992.6 ft.) for the 30m DEM around each sample point.

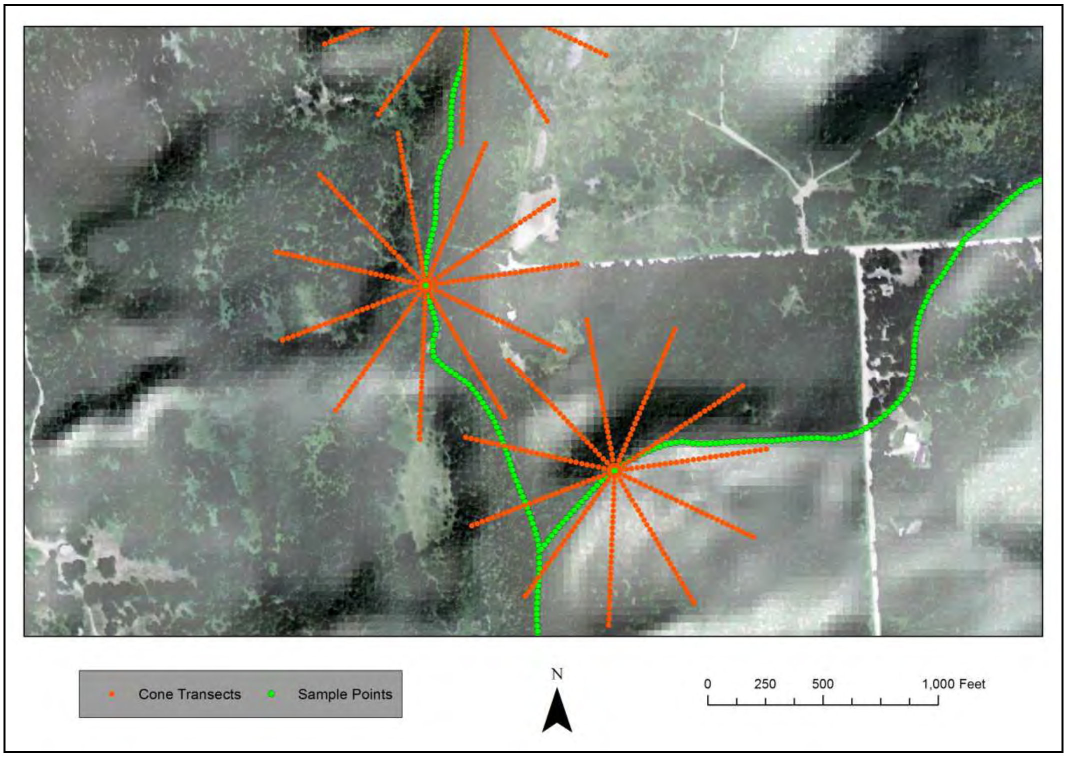

Figure 4. Cone transects constructed around selected sample points.

Based on elevation change, the model determines if the transect points are part of the riparian buffer. If the elevation change is greater than 1 meter (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. The next step removes duplicate points along the edge of the riparian zone to reduce processing time. The model reads the transect points elevations associated with each sample point and flags the edge of the riparian zone and deletes any other transect points beyond the edge point (Figure 5).

The cleaned transects points feature class is rasterized with a spatial resolution equal to the input DEM and the resulting 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 in the buffer after processing. Otherwise, if the buffer is only one pixel wide, these individual pixels are not prioritized and are 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 30.48 m (100 ft) lake buffer. The newly generated buffer is typically composed of many irregularly shaped, adjacent polygons at this point. As a final step, the model performs additional processing to remove area overlaps inside the riparian boundary and an additional boundary smoothing to create one contiguous buffer around adjacent hydrologic features (Figure 6).

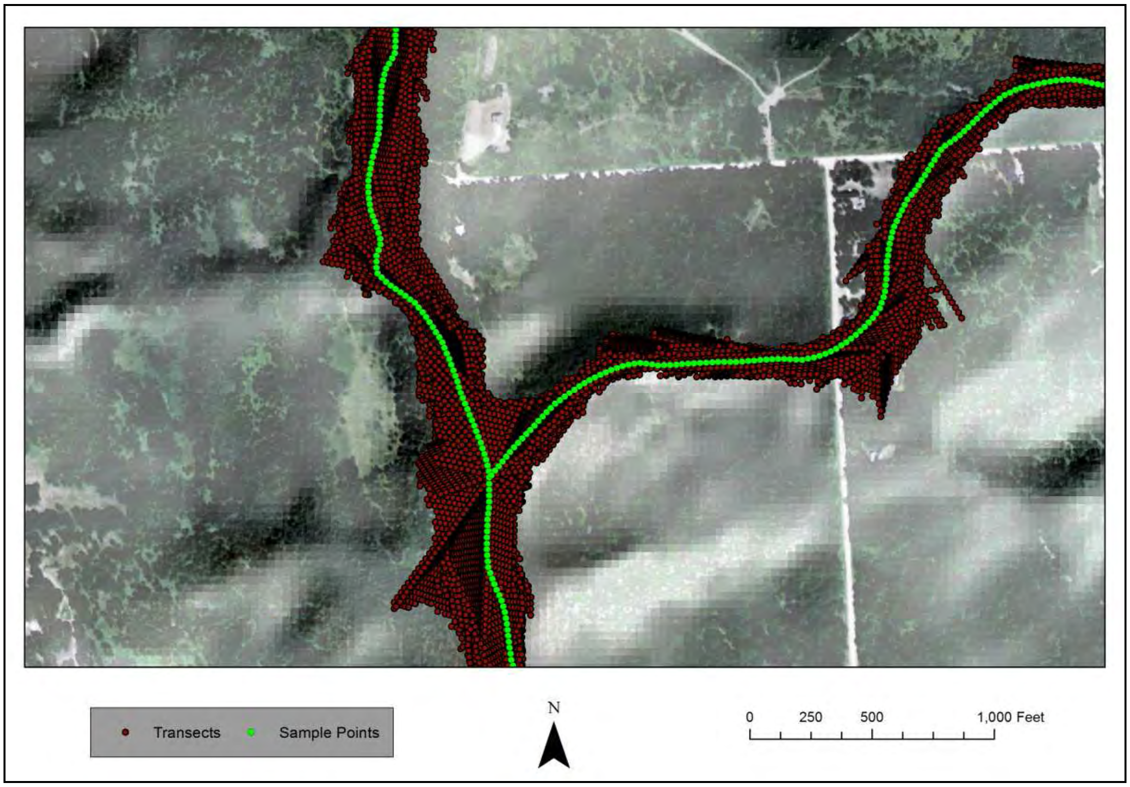

Figure 5. Transects points delineating riparian zone boundaries.

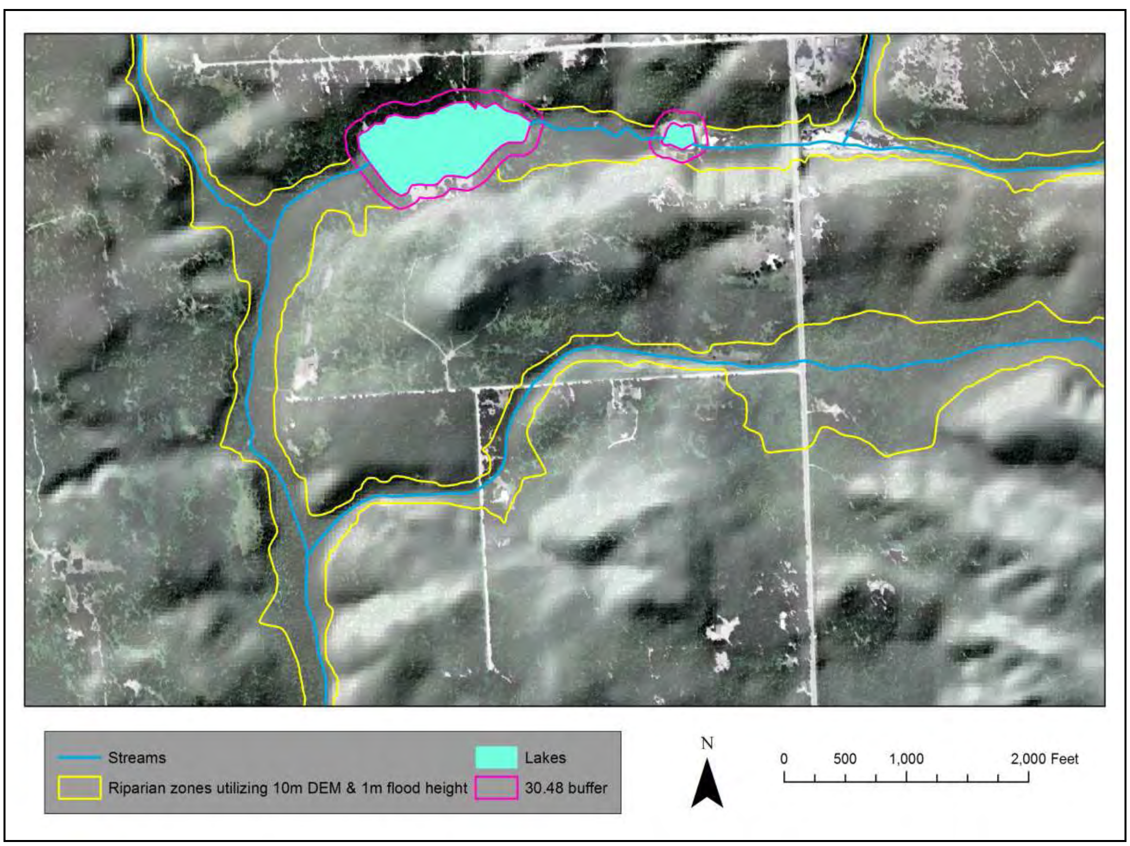

Figure 6. Final riparian zone utilizing 10 m DEM and 1.0 m flood height.

The model has the capability to incorporate NWI wetlands adjacent to the riparian buffer to expand the riparian zone beyond the 50 flood height and produce a more ecologically encompassing riparian zone (Figure 7).

The Digital Soil Viewer (SSURGO Data Packaging and Use, 2007) is used to generate three feature classes. These are selected according to soil criteria and include Hydric Soils, Hydrologic Soil Group, and Drainage Class. The criteria were chosen based on recommendations by Verry *et al.* (2004) and Palik *et al.* (2004). The information from these is combined in one polygon feature class. The model then selects the soil polygons adjacent to the riparian buffer. The last step merges the adjacent soil polygons to the riparian buffer to create the final variable width riparian zone.

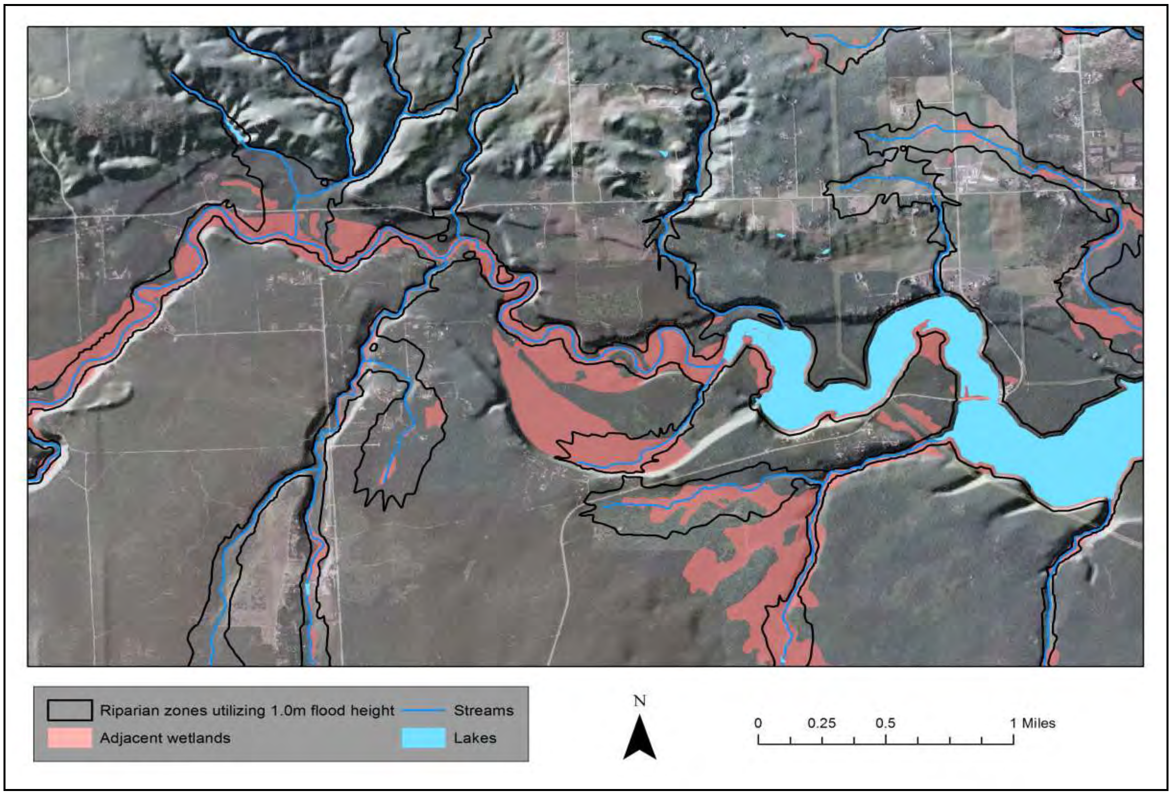

Figure 7. Riparian zones delineated with adjacent wetlands.

RESULTS AND DISCUSSION

Figure 7 illustrates a representative sample of a delineated riparian zone utilizing 1.0 m flood height with adjacent wetlands. Utilizing the NWI mapped wetlands with the riparian zone calculated from the DEM and the 50 year flood height provides a more complete mapping of the riparian area. This spatial adjacency verifies that riparian zones are not limited to streams and rivers floodplains but includes lands associated with other kinds of surface water in this case lakes and wetlands.

The additional information provided by incorporating digital soils information is not so clear cut and it more difficult to verify. Soil maps are created from point samples taken in the field. This information is then translated into soil mapping units by soil scientists drawing polygons on aerial imagery. Studies have show there is wide variation in the accuracy of the soil mapping unit boundaries (Drohan et al., 2003) and care must be taken when incorporating these boundaries into the riparian zone. Our recommendation is to use the soils data to confirm that the NWI polygons are inclusive of hydric soils. Figure 8 is a representative sample for the delineated riparian zones utilizing 1.0 meters flood height with adjacent digital soil data polygons.

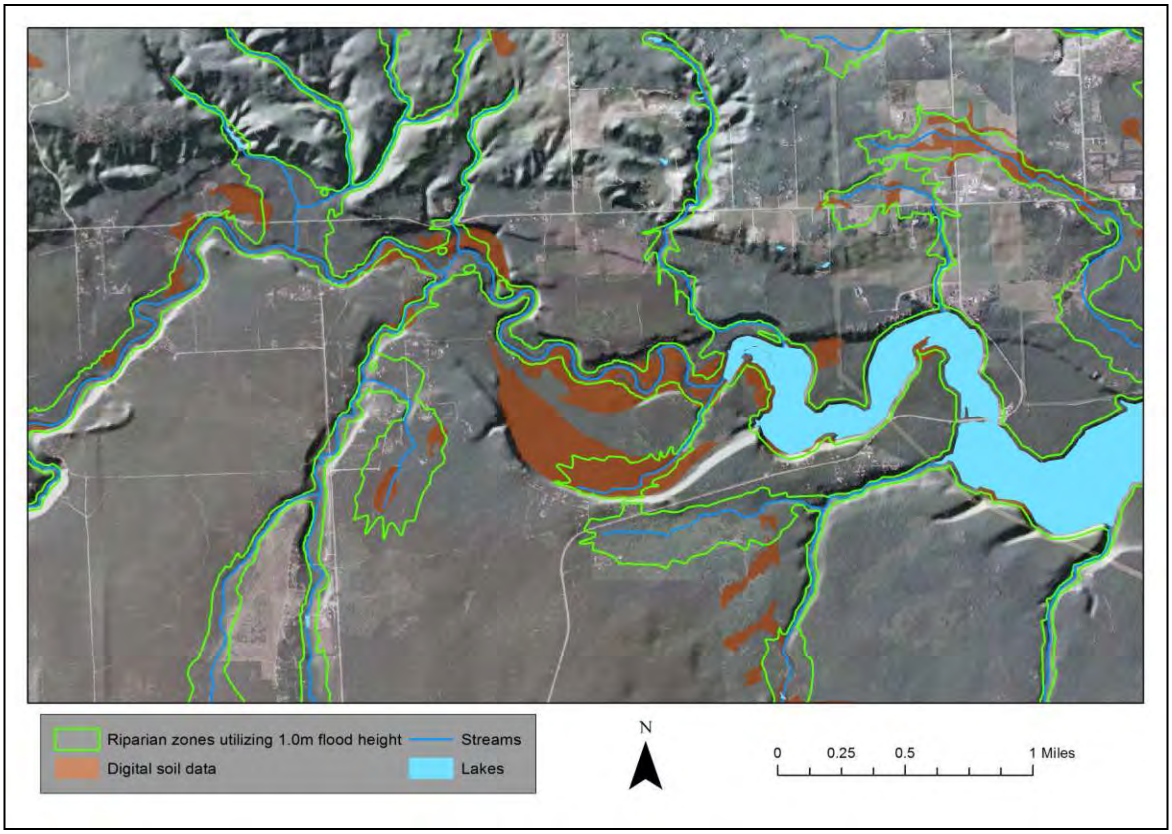

Figure 8. Riparian zones delineated with adjacent digital soil units.

Figure 9 illustrates a representative variable width riparian zone utilizing 10 meters DEM and the minimum, average, and maximum flood heights. The variable width riparian areas calculated produce different area totals and spatial extent. The results in Table 2 show an increase in the riparian zones delineation and riparian zones delineation with NWI or digital soil data area as the 50 year flood height increases. These results verify that the 50 year flood height is an important model parameter and that the model is sensitive to changes flood heights and it can affect the riparian zones delineation accuracy

CONCLUSIONS

The task of delineating an accurate variable-width riparian zone utilizing 50-year flood heights and 10 meter DEMS was successful. The modeling is computational intensive, but can be accomplished 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 DEM pixel type. The ease of using the NHD as it is in geodatabase format cannot be discounted, and the quality of the data is consistent over large geographic areas.

Table 2. Impact of variable flood height on the riparian zones area.

Lower Michigan			
Flood Height (m)	**0.3**	**1.0**	**1.75**
RPZ Area (Acres)	10075.246	16438.274	20494.025
% Watersheds Area	6.9	11.2	14.0
RPZ + NWI Area (Acres)	18004.884	23155.186	26654.625
% Watersheds Area	12.3	15.8	18.2
RPZ + DSD Area (Acres)	17481.648	22777.6	26339.5
% Watersheds Area	11.9	15.6	18.0
Upper Michigan			
Flood Height (m)	**0.3**	**1.0**	**1.75**
RPZ Area (Acres)	27772.154	37596.09	41929.894
% Watersheds Area	12.2	16.5	18.4
RPZ + NWI Area (Acres)	106834.37	110602.62	113096.47
% Watersheds Area	47.0	48.6	49.7
RPZ + DSD Area (Acres)	103576.62	112551.74	116662.29
% Watersheds Area	45.6	49.5	51.3

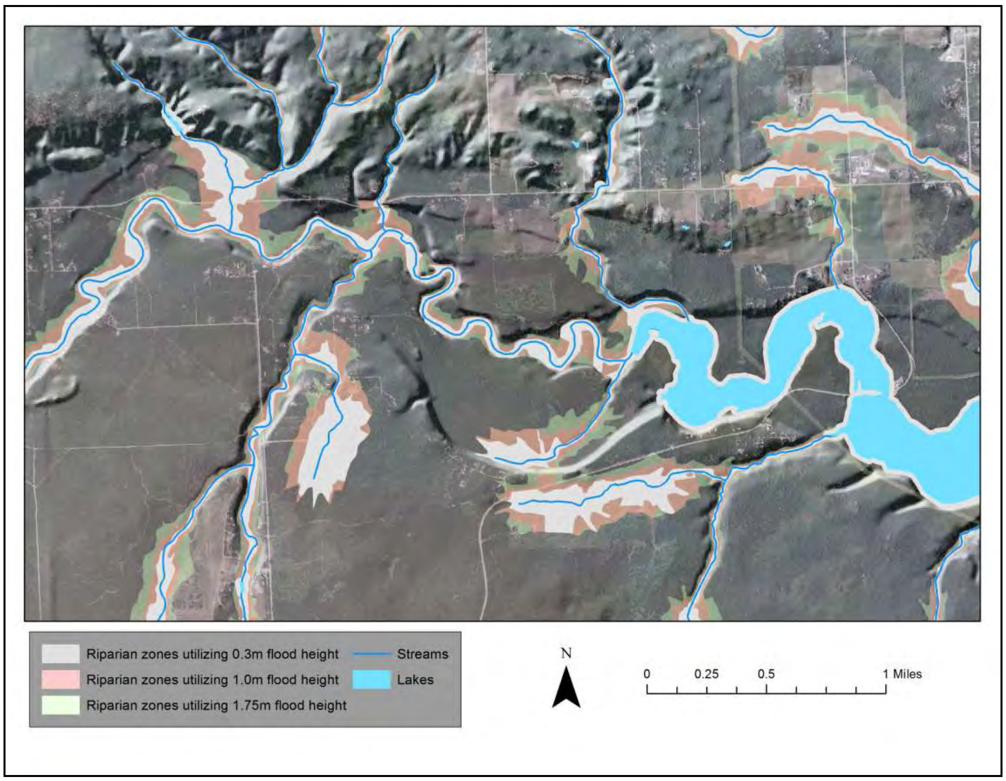

Figure 9. Riparian zones delineated utilizing different flood heights.

Analysis of two representative study sites in Michigan illustrates that a model can be designed to accurately and robustly can delineates riparian areas based on elevation and hydrographic and geomorphic data. This approach offers advantages over other previously used methods of riparian zone mapping by better characterizing the watercourse. The current version of the riparian zone delineation model successfully utilizes floating point 10 DEMs to increases the accuracy of delineation within a reasonable processing time which is a big advantage over the first version. The second version is sensitive to the flood height value change. The area of riparian zones delineated increases with increasing the 50 year flood height. The model utilizes the national wetland inventory data (NWI) and digital soil data. This new approach explains the variation in riparian zones extent associated with different surface water types through new riparian zones definitions that characterize water course, hydrologic, and functional approaches.

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