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Modeling and classifying variable width riparian zones utilizing digital elevation models, flood height data, digital soil data and national wetlands inventory : a new approach for riparian zone delineation

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MODELING and CLASSIFYING VARIABLE WIDTH RIPARIAN ZONES UTILIZING DIGITAL ELEVATION MODELS, FLOOD HEIGHT DATA, DIGITAL SOIL DATA and NATIONAL WETLANDS INVENTORY: A NEW APPROACH FOR RIPARIAN ZONE DELINEATION

By

Sinan A. Abood

A DISSERTATION

Submitted in partial fulfillment of requirements for the degree of

DOCTOR OF PHILOSOPHY

(Environmental Engineering)

MICHIGAN TECHNOLOGICAL UNIVERSITY

2011

This dissertation, "Modeling and Classifying Variable Width Riparian Zones Utilizing Digital Elevation Models, Flood Height Data, Digital Soil Data, and National Wetlands Inventory: A New Approach for Riparian Zone Delineation," is hereby approved in partial fulfillment of the requirements for the degree of DOCTOR OF PHILOSOPHY IN ENVIRONMENTAL ENGINEERING

School of Forest Resources and Environmental Science

Signatures:

Dissertation Advisor: ___________________________________
Dr. Ann L. Maclean

Dean: ___________________________________
Dr. Margaret R. Gale

Date: ___________________________________

To My Father in heaven and my Mother and Sister in Iraq I dedicate this work to you. Thank you for your help, support, and sacrifices. I hope you are proud of me.

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PREFACE

This dissertation is based upon studies conducted between January 2008 and July 2011 at the School of Forest Resources and Environmental Science, Michigan Technological University, Houghton-Michigan, United States.

I would like to express my sincere gratitude to my supervisor Dr. Ann Maclean. Without her advice and unique support this dissertation would never had become a reality. Further I would like to thank my colleague, Lacey Mason, for her great co-operation and help.

Chapter 2 has been accepted with minor revisions for publication in *Photogrammetric Engineering and Remote Sensing.* Lacy Mason and I collected the data and I analyzed all of the data and developed the new code in the new model presented in this chapter.

ACKNOWLEDGMENTS

"The whole of science is nothing more than a refinement of everyday thinking" (Albert Einstein). This quote reflects exactly what my advisor Dr. Maclean and I did in order to reach our findings. I am and always will be grateful for Dr. Ann Maclean, whose knowledge, guidance, patience, and unlimited support made this research possible and successful.

Many thanks to Dr. Margaret Gale, Dean of the School of Forest Resources and Environmental Science, at Michigan Technological University, Houghton, Michigan for providing a wonderful research environment. Also, I would like to thank the Sustainable Features institute (SFI) at Michigan Technological University for providing access to their supercomputing cluster.

Thanks to my committee members for their help and guidance.

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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 critical geomorphology, associated vegetation and soil characteristics. Our approach offers advantages over other previously used methods by utilizing: the geospatial modeling capabilities of ArcMap GIS; a better sampling technique along the water course that can distinguish the 50-year flood plain, which is the optimal hydrologic descriptor of riparian ecotones; the Soil Survey Database (SSURGO) and National Wetland Inventory (NWI) databases to distinguish contiguous areas beyond the 50-year plain; and land use/cover characteristics associated with the delineated riparian zones. The model utilizes spatial data readily available from Federal and State agencies and geospatial clearinghouses. An accuracy assessment was performed to assess the impact of varying the 50-year flood height, changing the DEM spatial resolution (1, 3, 5 and 10m), and positional inaccuracies with the National Hydrography Dataset (NHD) streams layer on the boundary placement of the delineated variable width riparian ecotones area. The result of this study is a robust and automated GIS based model attached to ESRI ArcMap software to delineate and classify variable-width riparian ecotones.

CHAPTER 1

INTRODUCTION

Defining a Riparian Zone

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 management agencies, various scientific disciplines and/or functional perspective. Each definition provides criteria to define and delineate the boundary of a riparian area.

Riparian ecosystems are dynamic systems between aquatic and terrestrial ecosystems and represent the transitional zone between two adjacent ecosystems with well defined vegetation and soil characteristics (Mitsch and Gosselink, 1993). A spatial description is clearly illustrated in Figure 1.1 (Minshall *et al.*, 1989). 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 includes wetlands as defined by Cowardin *et al.* (1979) and adjacent lands that have a moderate or well balanced supply of moisture (Mitsch and Gosselink, 1993).

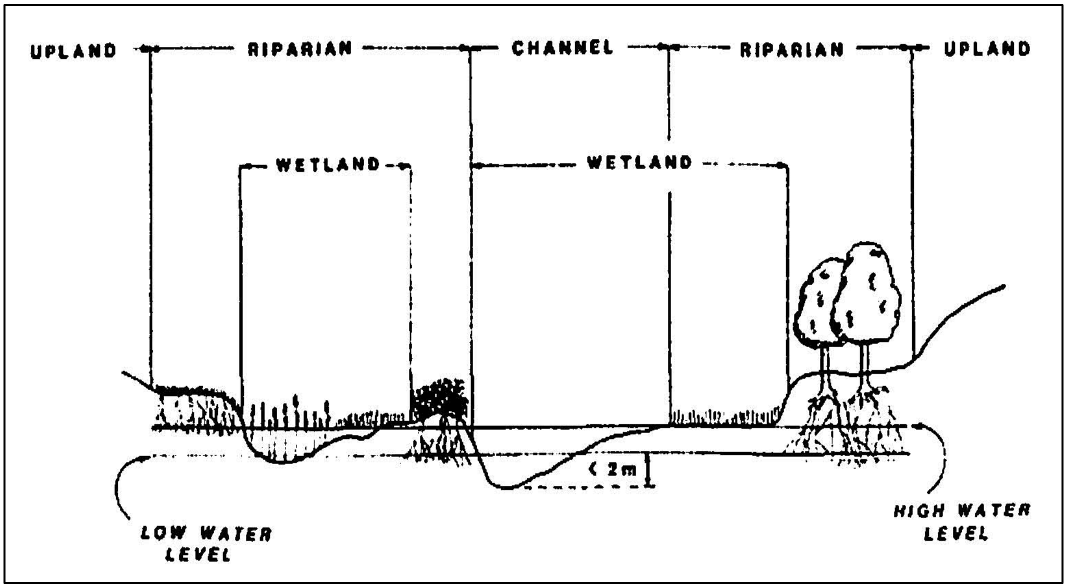

Figure 1.1 Riparian vs. wetland habitat from Minshall *et al.* (1989).

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

- Riparian ecosystems generally have a liner form as a 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.

Before an all encompassing riparian definition can be developed, more verification and illustration of ecosystem versus ecotone terminology is required (Verry *et al.*, 2004).

By definition an ecosystem is a "community of organisms together with their physical environment, viewed as a system of interacting and interdependent relationships and including such processes as the flow of energy through trophic levels and the cycling of chemical elements and compounds through living and nonliving components of the system" (Kleinedler *et. al.* (Eds.) 2005). The *America Heritage Science Dictionary* (2005) and Verry *et al*. (2004) interpret the previous definition as anything from a single cell organism to the vast universe. On the other hand, an ecotone is "A transitional zone between two ecological communities, as between a forest and grassland, or a river and its estuary. An ecotone has its own characteristics in addition to sharing certain characteristics of two communities" (*America Heritage Science Dictionary*, 2005). By this definition, a single ecotone consists of many ecosystems that interact together.

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). Using the term ecotone would minimize confusion between different scientific fields and management agencies, and eliminate the approach in delineating riparian ecotones as a fixed width buffer or by a single characteristic such as hydric soils or land cover (Verry *et al.*, 2004).

A riparian ecotone carries out many functions (physical, ecological and biological) and has many economic and social values. One of the main functions is trapping and removing phosphorus and nitrogen which are the main causes of lake and stream eutrophication (Wenger, 1999). Riparian ecotones are also responsible for woody debris contributions and its movement in channels as well as channel morphology. Riparian vegetation is an important source of particulate and dissolved organic matter for adjacent aquatic ecosystems and helps regulate the nutrient, pesticide, and sediment transport between agricultural lands and aquatic ecosystems (Naiman *et al.*, 1997). Riparian ecosystems (vegetated buffer zones) along shorelines and streams courses are one of the most effective approaches to reduce, trap and clean polluted runoff (Xiang *et al.*, 1993).

Previous approaches to riparian area delineation have utilized fixed width buffers, but this methodology has proven to be inadequate as this type of buffer only takes the watercourse into consideration and ignores the critical surrounding geomorphology and associated vegetation. 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 the suggested 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.

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).

Upper Midwest lakes in Michigan, Minnesota and Wisconsin 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 100 ft. of lakes, forest cover contributed 60-80% of its influencing habitat function such as shade, woody debris recruitment, bank stability and litter fall as noted by Ilhardt *et al.* (2000). For this study we are adopting this recommendation and placing a fixed width 100 ft buffer around all lakes since the research is focusing on the moving watercourse or stream.

Scope of the Research

This research further develops and refines the GIS model originally developed by Mason (2007) to map riparian zones along moving watercourses by hydrologically defining a riparian ecotone to occur at the 50-year flood height and incorporating digital elevation data. The model was originally developed with watersheds in Michigan and Minnesota. The research also evaluates the impact of additional inputs into the model, including hydric soils, wetlands as delineated by the National Wetlands Inventory (NWI) and digital elevation models (DEMs) of varying spatial resolution (1, 3, 5 and 10 m.).

The main objectives of this study are:

- Develop a second generation GIS model that is more robust and automated than the original model developed by Mason (2007) to map variable width riparian zones adequately and efficiently along moving watercourses by hydrologically defining a riparian ecotone to occur at the 50-year flood height utilizing varying spatial resolution DEMs.

- Incorporate National Wetlands Inventory (NWI) data and Soil Survey Data (SSURGO) digital soils data into the model and evaluate the outcome compared to only utilizing the 50-year flood height and 10 or 30m DEM data.

- Evaluate the National Hydrography Dataset (NHD) positional accuracy on the riparian boundary placement.

- Evaluate the outcome of varying DEM spatial resolutions on the riparian model delineation accuracy.

- Incorporate land use/cover information such as the National Land Cover Data (NLCD) and/or the National Agricultural Statistical Services (NASS) Crop Data Layer (CDL) to improve the utility of the delineated riparian buffers.

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CHAPTER 2

MODELING RIPARIAN ZONES UTILIZING DEMS AND FLOOD HEIGHT DATA VIA GIS

ABSTRACT[1]

Riparian ecotones are unique, diverse networks of vegetation and soils in close proximity to streams, rivers and lakes. These ecotones are linked to the watercourse network via flooding and intercepting upland runoff. Vegetation communities along stream banks often delineate riparian boundaries. Previous approaches to riparian boundary delineation utilized fixed width buffers, but this methodology proved to be inadequate as 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. Previous research determined the 50-year floodplain to be the optimal hydrologic descriptor of a riparian ecotone. 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 and efficiently. This approach offers advantages over other previously used methods by better characterizing the watercourse and its associated floodplain. Riparian zones delineated using 10 versus 30 meter DEMs and with stream course information from the National Hydrography Data differ significantly, and in many areas of the upper Midwest the coarser scale of 30m DEMs is not sufficient to adequately map elevation changes for accurate riparian area delineation. The result of this study is a robust GIS based model to delineate a variable-width riparian boundary.

KEY WORDS: riparian ecotones, fixed buffer, GIS, delineate, and variable-width riparian boundary

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[1] "The material contained in this chapter has been accepted for publication in the journal of *Photogrammetric Engineering and Remote Sensing"*

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 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 (Naiman and McClain, 2005).

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 at 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 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).

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 100 ft of lakes, forest cover contributed 60-80% 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 can serve as a riparian buffer.

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. The model is robust and can accommodate a variety of landscapes from flat to mountains terrain.

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 under WingIDE Professional version 3.2 and is based on a procedure 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 segments order. Specific data inputs and their sources are listed in Table 2.1 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. 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 was used where available. Data gaps were filled in with information from state supported GIS systems.

The USGS Digital Elevation Models (DEMs) are raster based elevation information sampled at regularly spaced ground locations and registered to the UTM (Universal Transverse Mercator) projected coordinate system. DEMs with spatial resolutions of 10 and 30m were utilized. The 10m DEM data, which has a per pixel area of 100 square meters (0.025 acres), were downloaded in a 7.5’ quadrangle format from the GIS Data Depot (GeoCommunity, 2007) and mosaiced to create a continuous coverage. The 30m DEMs, covering 900 square meters per pixel (0.22 acres), were downloaded from The National Map Seamless Server (USGS, 2010).

Table 2.1 Initial data inputs and download sources for the riparian delineation model from Mason, 2007).

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/
10m Digital Elevation Model	GIS Data Depot http://data.geocomm.com/
30m Digital Elevation Model	USGS, The National Map http://nationalmap.gov/

Flood height data was 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 15-60 minute intervals. The information is either stored onsite or transmitted to a USGS office in 1 to 4 hour increments. The data is transmitted via 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 2.1) are comprised of multiple watersheds in 3 locations: northeast Minnesota, the central Upper Peninsula (UP) of Michigan and the eastern Lower Peninsula (LP) of Michigan. These locations were selected based on 10m DEM data availability, and to 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 with numerous lakes. The border lakes are composed of 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 (10-15 miles), streams (Albert, 1995).

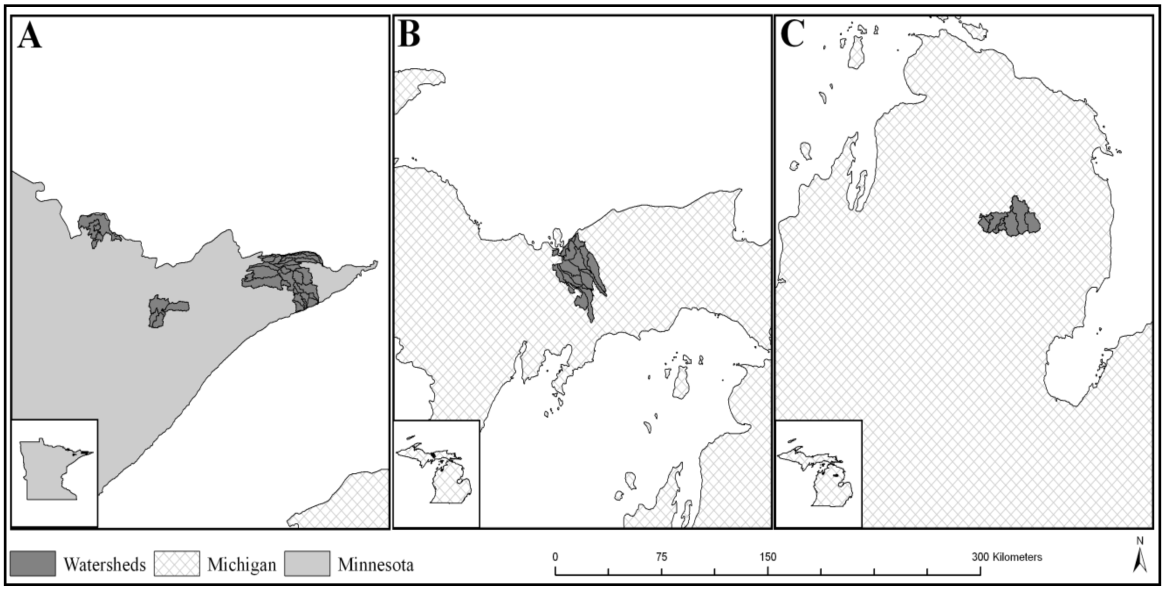


Figure 2.1 A: Northeastern Minnesota study areas. This area includes 3 noncontiguous areas with groups of 5, 4 and 26 adjacent watersheds. B: Upper Peninsula of Michigan study area. This area is composed of 21 adjacent watersheds. C: Lower Peninsula of Michigan study area. The area is composed of 9 watersheds (from Mason, 2007).

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 embayment 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 critical 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 channel width.

The annual average flow rate measurements were 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 that 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 2.2A. The cross-sectional area (flow rate divided by velocity) is plotted against flow rate measurements (Figure 2.2B).

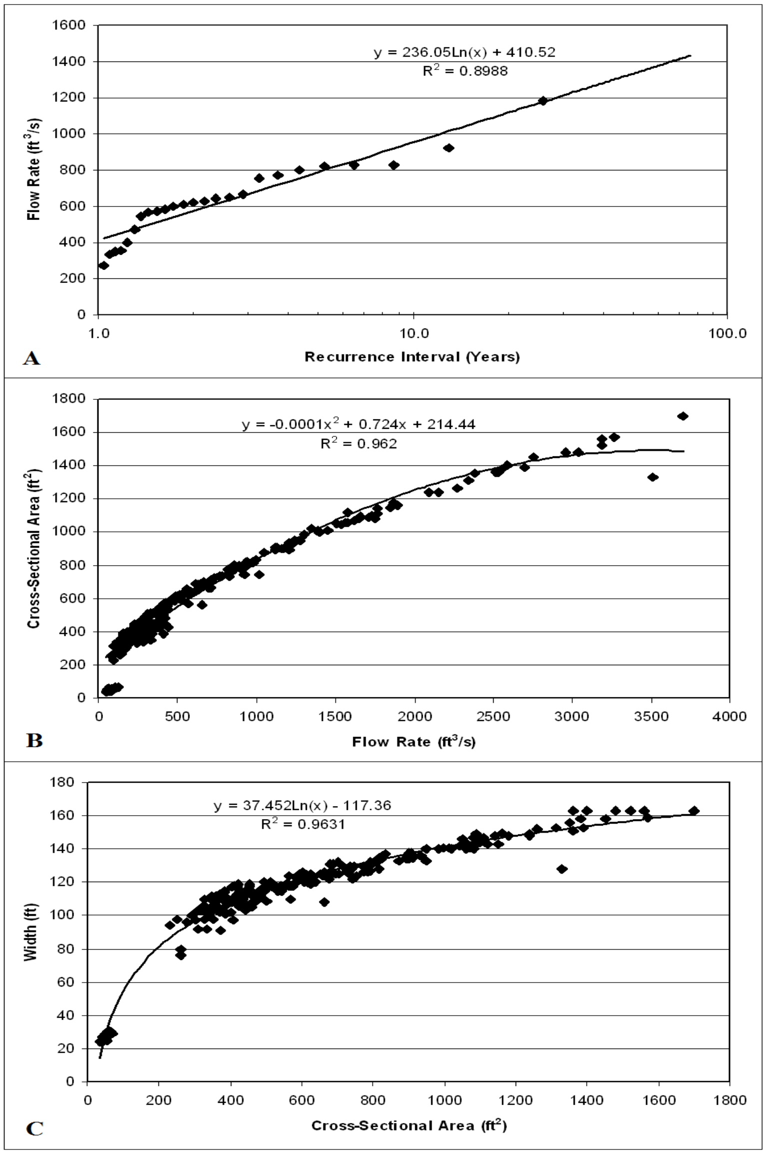


Figure 2.2 Regression graphs of the hydrologic estimators for determining an approximate flood height (from Mason, 2007).

Figure 2.2C shows the regression of the width versus the cross-sectional area. An R-squared value of 0.85 or higher was 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 were determined. The flood height calculation results ranged between 0.3 and 1.75 m for the data sites. To facilitate model development a single average flood height of 1 meter is utilized in the model.

MODEL DEVELOPMENT

The modeling language Python 2.6 was used to develop the Riparian Delineation model (Figure 2.3). 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 (Appendices A and B). The model interface has five required inputs and two optional inputs (Figure 2.4). 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 along streams; 4) determining the outside edge of the variable-width buffer; and 5) creating an easy to use riparian boundary polygon. This facilitates customization of the model.

Processing begins 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 were dissolved by reach code to remove extraneous nodes. Next, stream segments delineated within a lake or other open water bodies (Figure 2.5A) are erased, as mapping of a riparian zone along these segments would be erroneous (Figure 2.5B). Lastly, a 30.48m (100ft) 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 (Figure 2.6).

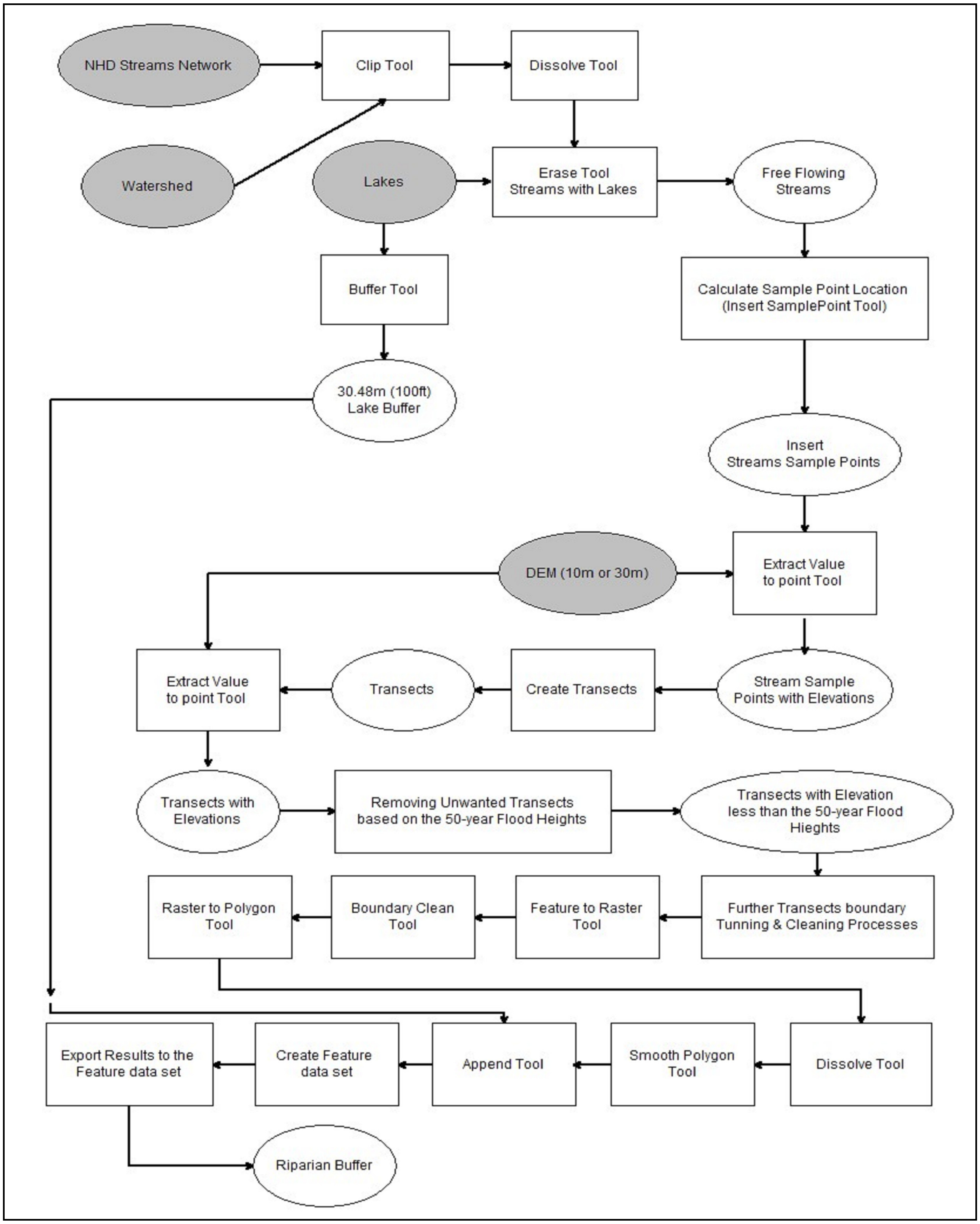
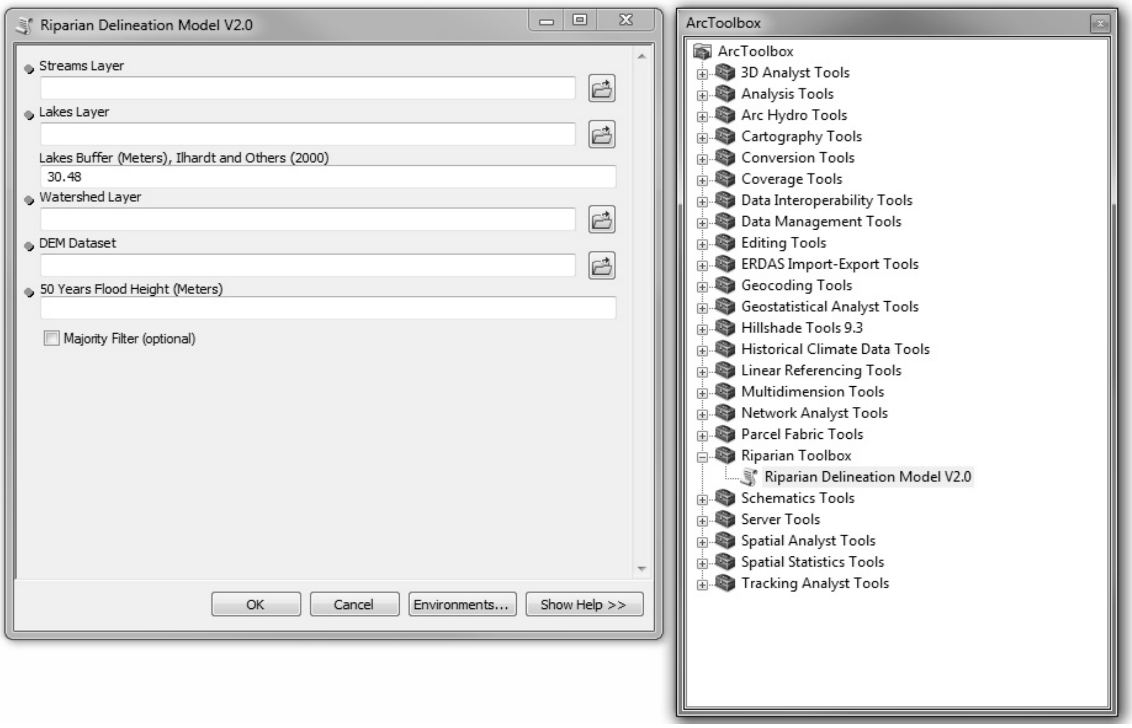


Figure 2.3 Flowchart of the riparian delineation model, version2.2.



Riparian Delineation Model V2.0

Streams Layer

Lakes Layer

Lakes Buffer (Meters), Ilhardt and Others (2000)
30.48

Watershed Layer

DEM Dataset

50 Years Flood Height (Meters)

☐ Majority Filter (optional)

Figure 2.4 Riparian Delineation Model V2.0 GIS toolbox and interface.

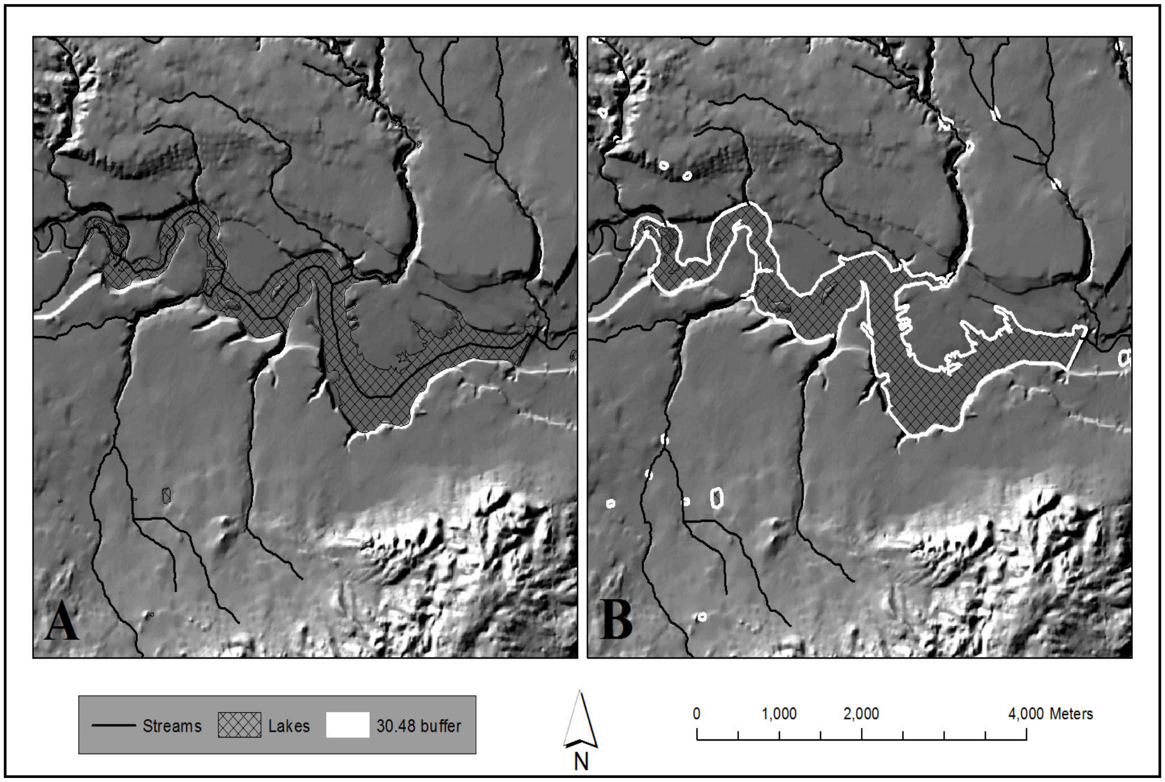


Figure 2.5 Example area showing the streams and lakes layer before (A) and after (B) the erase function.

After point placement and elevation extraction, transects are produced around each sample point (Figure 2.7) for 360°. 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 202.5m (664.2ft) was imposed for the 10m DEM and 607.5m (1992.6ft) for the 30m DEM around each sample point. This is to insure a high processing efficiency and to account for the variation in the landscape along stream network.

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 transects points elevation associated with each sample point along the stream and flags the edge of the riparian zone then deleting any other transects points after the edge point (Figure 2.8).

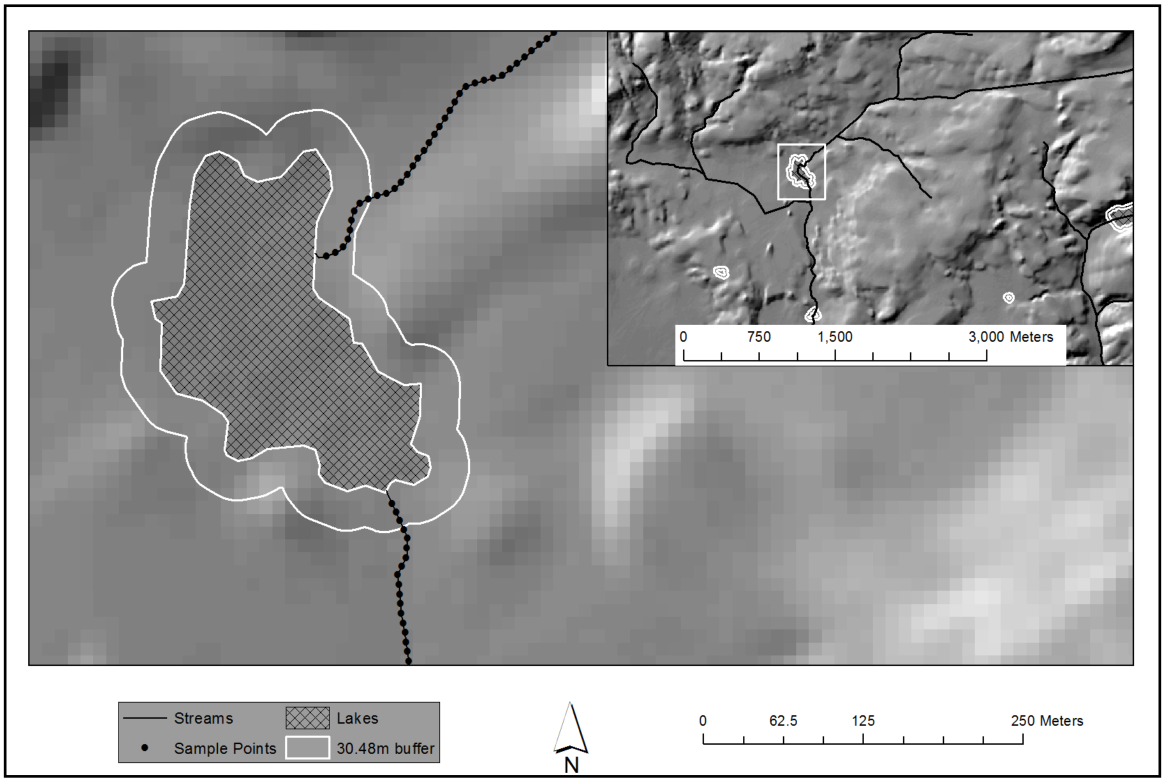


Figure 2.6 Example of sample points generated along streams.

The cleaned transects feature class is rasterized with a spatial resolution equal to the input DEM spatial resolution (Figure 2.9), 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 in the buffer after processing. Otherwise, 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 30.48m (100ft) 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 additional boundary smoothing to create one contiguous buffer around adjacent hydrologic features (Figure 2.10).

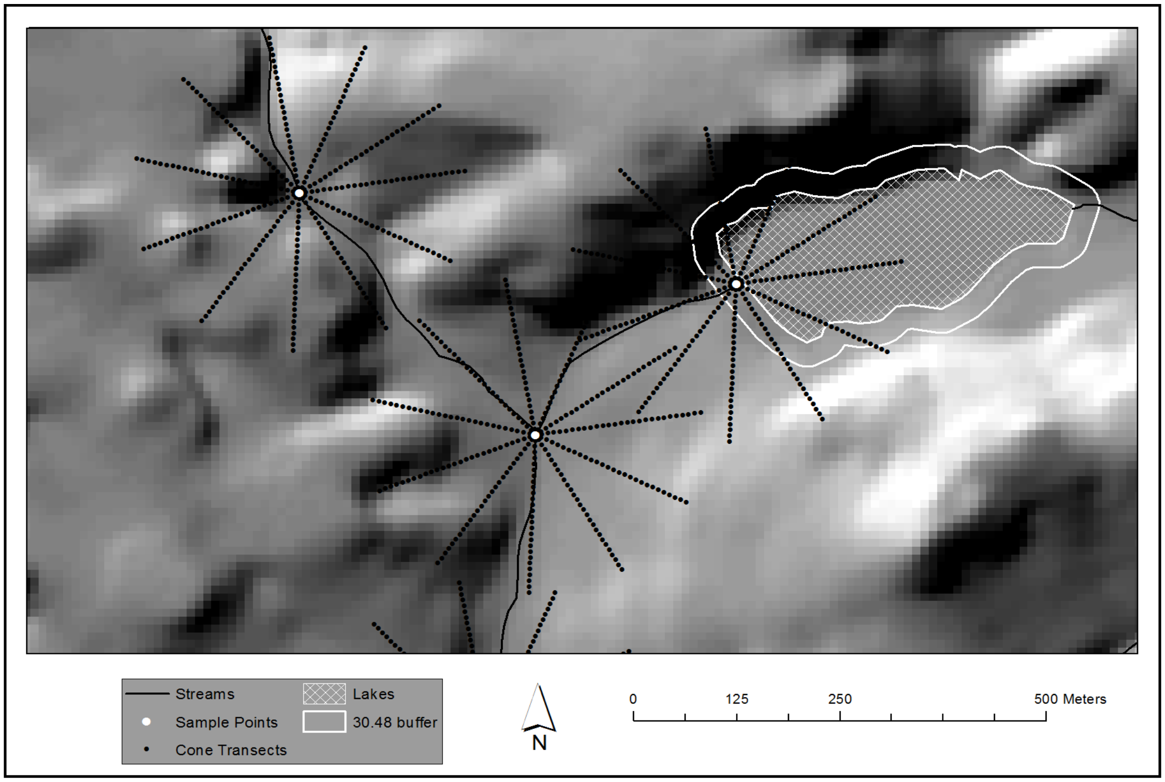


Figure 2.7 Transects points generated along sample points.

STATISTICAL ASSESSMENT

The impact of different spatial resolutions riparian buffers was evaluated using the approach developed by Mason (2007). Buffers are calculated using the 10m and 30m DEMs. The riparian zone area for each of the 3 study sites, excluding lake surface area, is calculated and placed in an attribute table. Additional fields in this 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 is a statistically significant difference between the riparian areas delineated with the 10 meter versus the 30 meter DEMs.

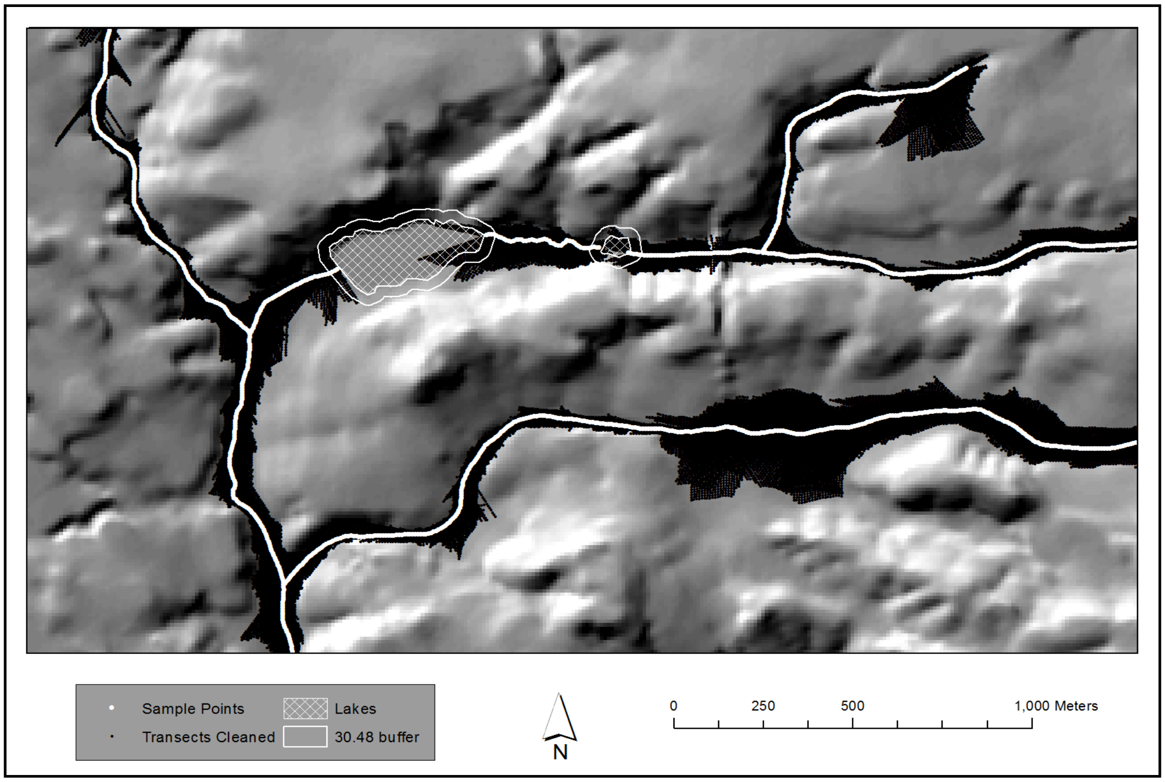


Figure 2.8 Transects points cleaned and smoothed.

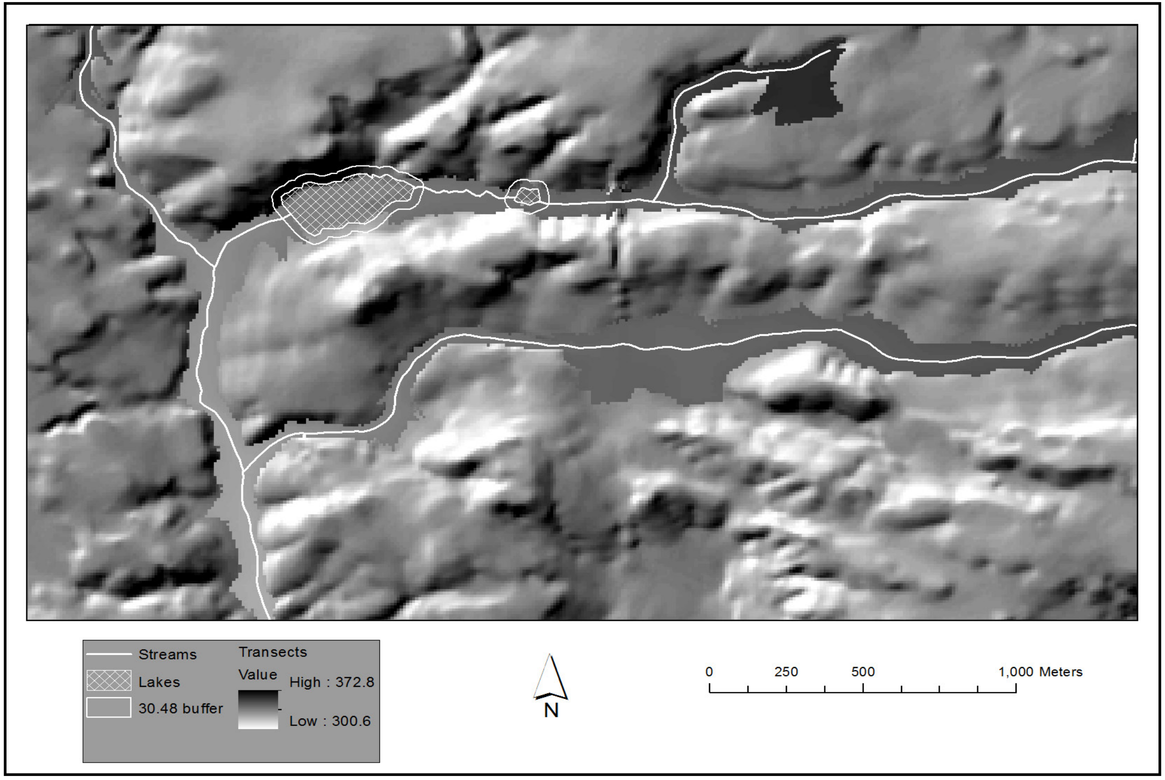


Figure 2.9 Rasterization of points within the riparian zone. The spatial resolution is equal to that of the DEM elevations used as input into the model.

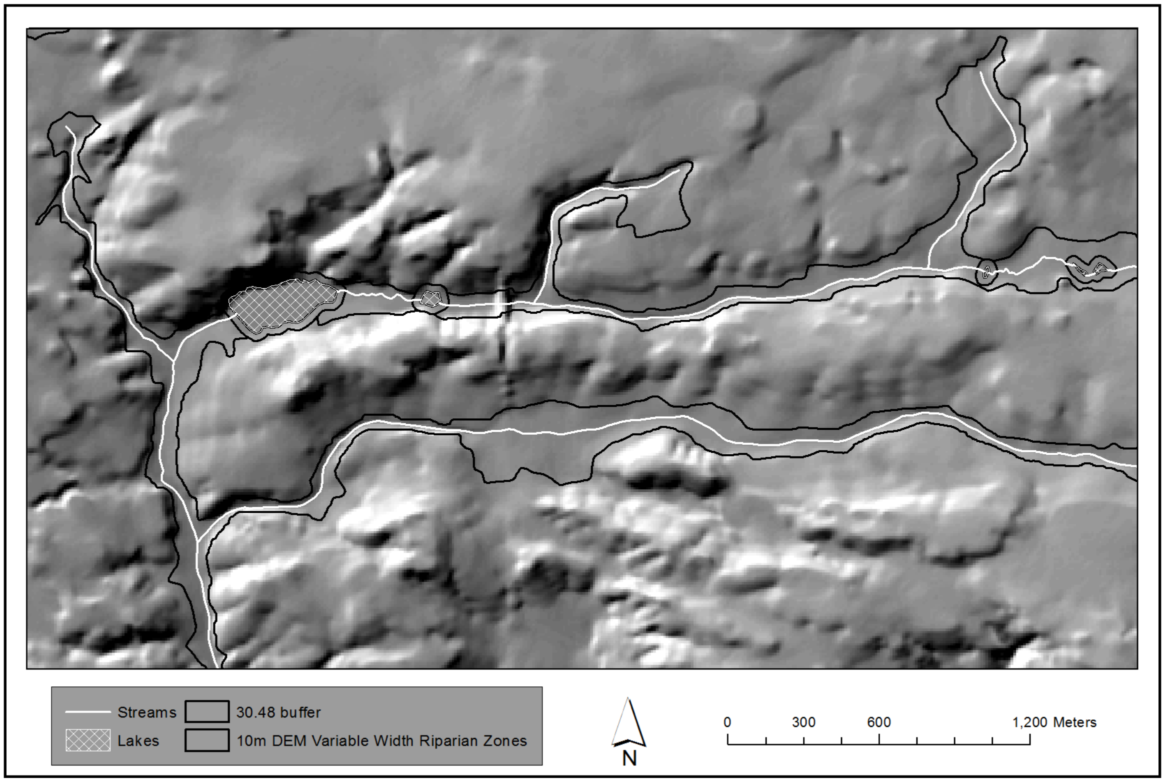


Figure 2.10 Example of final riparian buffer merged with 100ft lake buffer.

An analysis of variance is used to test whether riparian zone delineation method or landform had a statistically significant effect on estimated riparian area. Since the delineation is repeatedly applied to the same subject (i.e., same watershed), 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, or delineation method, 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. A block-treatment interaction occurs when the treatment effect on experimental units is not independent of the block effect. In other words, the treatment effect differs by block. 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 (delineation method) was applied more than once to the same experimental unit (watershed) (Mason, 2007).

Model estimation is performed in the R statistical environment (R Development Core Team, 2005). Fitting uses a linear mixed-effects function, which relies upon maximizing the restricted log-likelihood (Pinheiro and Bates 2000). This approach permit’s 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 m 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.

SENSITIVITY ANALYSIS

DEM pixel resolution (10m vs. 30m) and pixel type (floating point vs. integer) are important model parameters to identify the riparian edge. The first version of the Riparian Delineation Model adopted an integer pixel type DEM to decrease the intensive computational time (Mason, 2007). The current version is designed to use floating point pixel type DEM to preserve the continuity in the elevation data and decrease the error in delineation caused by rounding the DEM elevation values. Figure 2.11 shows the variation between the riparian zones boundary delineated utilizing float point DEM and Integer DEM with the same 50 year flood height. Table 2.2 shows the difference in riparian zones delineation area between the different DEM pixel types with the same model inputs. Table 2.2 also shows an area increase when using floating point DEM pixel type instead of integer DEM pixel type for both 10m and 30m pixel spatial resolution.

The 50 year flood height is another important model parameter. The hydrological estimation showed a range of flood height values from 0.3m to 1.75m across our study area (LP-Michigan, UP-Michigan and, Minnesota). The first version of the Riparian Delineation Model utilized an average 50 years flood height of 1.0m due to having an integer pixel type DEM as an input and to decrease the intensive computational time. In this study a comparison is made to test the second version of the Model sensitivity to different flood heights across the three study areas. Three values are used as the flood heights inputs for the model (0.3m, 1.0m and, 1.75m); the other model inputs are 10m and 30m floating point DEMs (Table 2.2).

RESULTS AND DISCUSSION

The variable-width riparian areas calculated from the 10 meter and 30 meter DEMs produce very different area totals and spatial extents. A representative sample is illustrated in Figure 2.12. For all of the watersheds in the 3 study areas, the riparian areas derived from the 30 meter DEM are larger than those calculated using the 10 meter data (Table 2.3). Based on a qualitative assessment of key locations in the 3 study areas, portions of the riparian buffers generated 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 9X larger than the 10 meter. However, what is more important is the fact that we have effectively shown the inadequacies of the 30 meter DEM to accurately map elevation changes in a landscape heavily impacted by glaciation

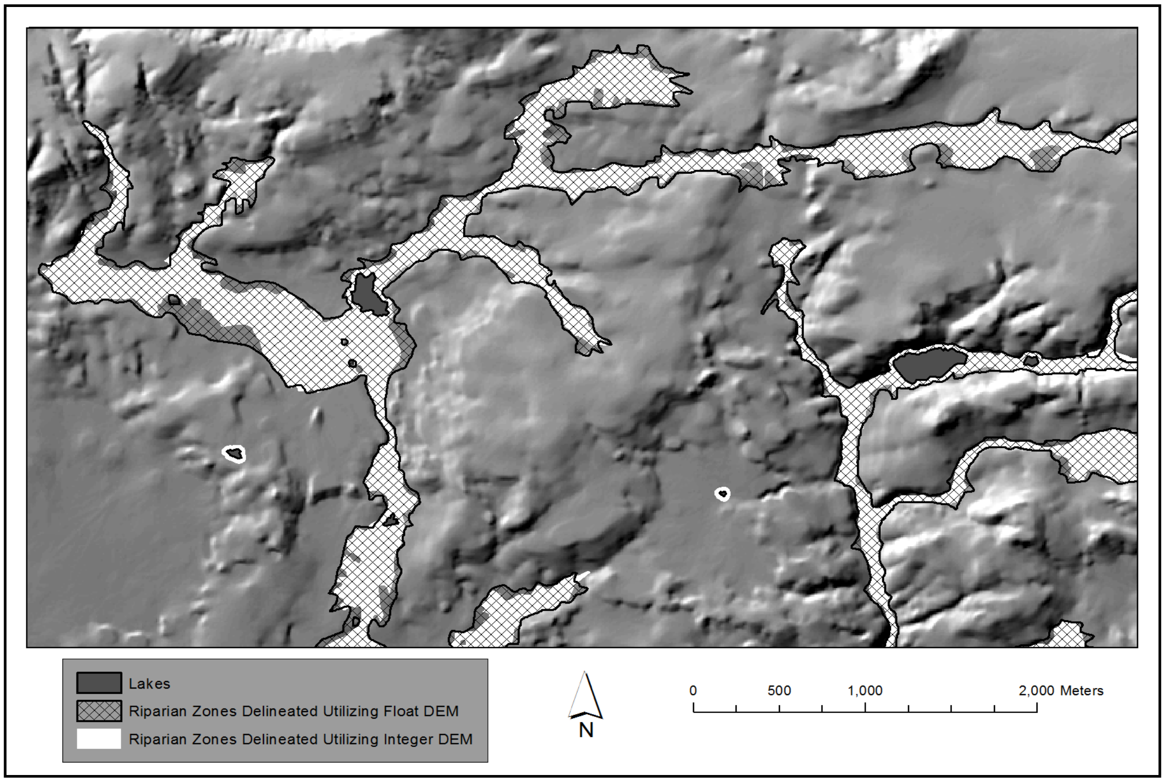


Figure 2.11 Sample of the comparison between riparian zones delineation utilizing the same 10m DEM resolution and different pixel type (float vs. integer).

which has resulted in significant elevation differences over short distances (in this study, less than 30 m). The statistical assessment confirms that the riparian areas produced from 10 meter and from 30 meter DEMs are significantly different ($p < 0.001$). A simple regression analysis for the riparian zones delineated using 10m and 30m DEM's and three flood height values (0.3, 1.0 and, 1.75m) with the 61 watersheds area shows that there is no linear correlation between the watersheds area and the delineated riparian zones ($p < 10^{-14}$) and the Riparian Delineation Model is independent of landform .

The study also supports the conclusions of Palik *et al.* (2004) that riparian areas determined via fixed width buffers do not accurately delineate riparian areas since they do not incorporate landscape features such as changes in elevation. The 30m and 60m fixed-width buffers delineated around the streams of the 3 study areas consistently underestimated the total riparian area, and also did an inadequate job of accurately delineating the spatial location of the 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 that area which highly influences the stream.

Table 2.2 50-year flood height sensitivity analysis

10m Floating Point DEM			
UP-Michigan			
50-yrs Flood Height	**0.3m**	**1.0m**	**1.75m**
Total Riparian Zone Area (Hectares)	12,077.79	15,847.95	17,873.54
% of Watershed Area	13.13	17.22	19.43
LP-Michigan			
Total Riparian Zone Area (Hectares)	4,242.88	6,802.85	8,450.56
% of Watershed Area	7.16	11.48	14.26
Minnesota			
Total Riparian Zone Area (Hectares)	39,043.56	42,553.13	45,052.09
% of Watershed Area	23.15	25.23	26.71
30m Floating Point DEM			
UP-Michigan			
50-yrs Flood Height	0.3m	1.0m	1.75m
Total Riparian Zone Area (Hectares)	19,097.91	2,994.66	35,312.57
% of Watershed Area	20.76	32.27	38.38
LP-Michigan			
Total Riparian Zone Area (Hectares)	6,166.4	10,833.73	14,297.9
% of Watershed Area	10.4	18.28	24.12
Minnesota			
Total Riparian Zone Area (Hectares)	41,188.34	46,107.41	50,414.22
% of Watershed Area	24.42	27.34	29.89

CONCLUSIONS

The task of delineating an accurate variable-width riparian zone utilizing 50-year flood heights and digital elevation data 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.

The second version of the Riparian Delineation Model successfully utilizes floating point 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 very sensitive to the flood height value. The area of riparian zones delineated increases with increasing the 50 year flood height.

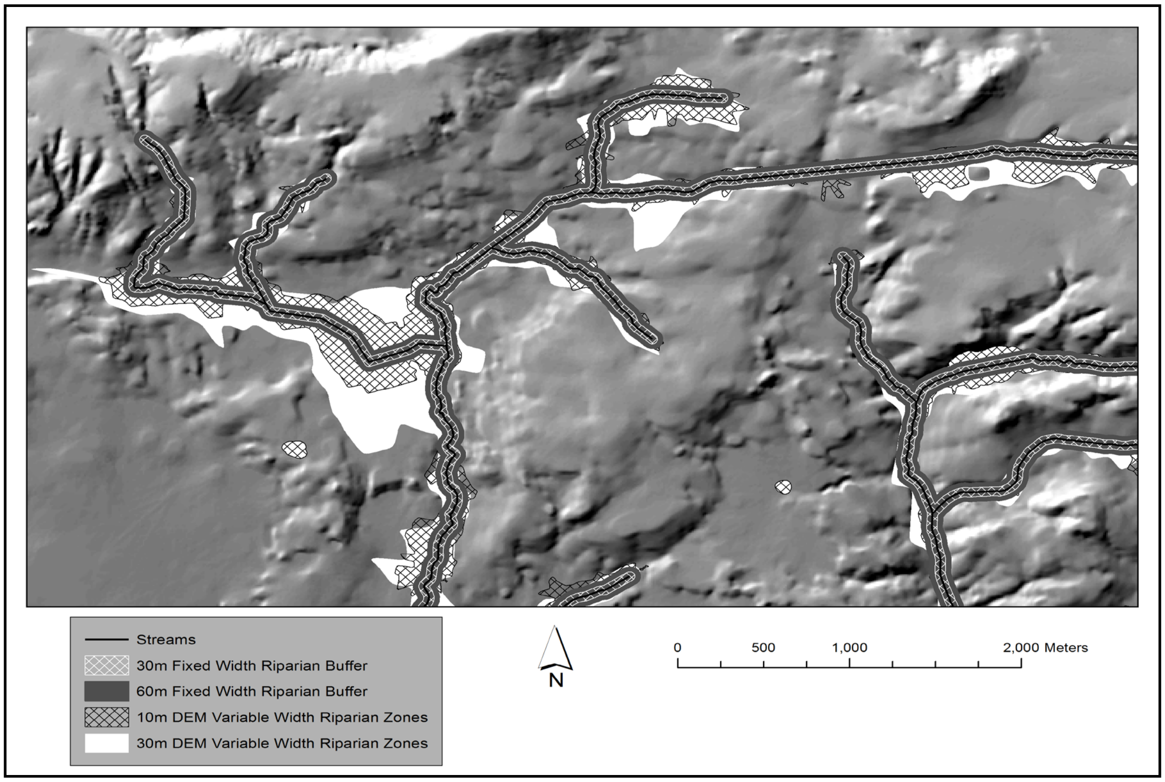


Figure 2.12 Enlarged view of a potion of the Lower Peninsula Michigan area, comparing the riparian-width model results from the 10m DEM resolution and 30m DEM resolution and the fixed-width buffer of 30m and 60m distance.

Analysis of three representative study sites in the Upper Midwest illustrates that a model can be designed to accurately and within a reasonable amount of computing time, 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.

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 by any GIS user. With the addition of higher resolution DEMs and additional hydrologic information, even more detailed delineations could be accomplished.

Table 2.3 Area summaries for the 3 study sites using the riparian delineation model

Integer DEM			
Study Site	**Minnesota**	**UP-Michigan**	**LP-Michigan**
Total Watershed Area (Hectares)	168641.54	92008.80	59273.96
Model Parameters	**10m DEM & 1.0m 50yrs Flood Height**		
Riparian Zone Area (Hectares)	40201.08	14033.61	6516.43
% of Watershed Area	23.84	15.25	10.99
Model Parameters	**30m DEM & 1.0m 50yrs Flood Height**		
Riparian Zone Area (Hectares)	44587.53	23244.61	8088.80
% of Watershed Area	26.44	25.26	13.65
Float DEM			
Model Parameters	**10m DEM & 1.0m 50yrs Flood Height**		
Riparian Zone Area (Hectares)	42553.13	15847.95	6802.85
% of Watershed Area	25.23	17.22	11.48
Model Parameters	**30m DEM & 1.0m 50yrs Flood Height**		
Riparian Zone Area (Hectares)	46107.41	29694.66	10833.73
% of Watershed Area	27.34	32.27	18.28
% Increase in Delineation Area			
Study Site	**Minnesota**	**UP-Michigan**	**LP-Michigan**
10m DEM Integer vs. Float	5.53	11.45	4.21
30m DEM Integer vs. Float	3.30	21.72	25.34

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CHAPTER 3

MODELING RIPARIAN ECOTONES VIA GIS UTILIZING GEOPHYSICAL AND VEGETATIVE INPUTS

ABSTRACT

Riparian ecotones are dynamic and transitional ecotones between aquatic and terrestrial ecosystems with well defined vegetation and soil characteristics. Development of an all-encompassing definition for riparian zones, because of their high variability, is challenging. However, there are two primary physical factors that all riparian ecotones are dependent on: the watercourse and its associated floodplain. Previous approaches to riparian boundary delineation have utilized only vegetation or fixed width buffers. The first approach ignores the flood plain boundary; while the second has proven to be inadequate as it only considers the watercourse and ignores the critical surrounding geomorphology, associated vegetation and soil characteristics. This approach offers advantages by utilizing a sampling technique along the water course delineates the 50-year flood plain boundary and incorporate the Soil Survey Geographic (SSURGO) Database along with National Wetland Inventory (NWI) maps. Inputting hydric soils and wetlands vegetation associated with and adjacent to the initially delineated riparian ecotones provides a more complete boundary determination. This approach also introduces a riparian zone classification system combining the National Land Cover Database (NLCD) and the Cropland Data Layer (CDL) to provide an understanding of riparian ecotones land use/cover and evaluate land use/cover change. The GIS spatial based model in an ArcGIS toolbox format delineates variable-width riparian ecotones utilizing geophysical and vegetative inputs.

KEY WORDS: riparian ecotones, GIS spatial model, variable width buffer, riparian land use/cover change

INTRODUCTION

Riparian ecotones are dynamic zones between aquatic and terrestrial ecosystems or a transitional zone between two adjacent ecosystems with well defined vegetation and soil characteristics (Mitsch and Gosselink, 1993). Based on work by Cowardin *et al.* (1979) and Mitsch and Gosselink (1993) we are defining a riparian zone or ecotone as "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" (Abood *et al.,* 2011). In general riparian ecotones throughout the United States are found along streams, rivers and lakes where energy and nutrients pass from and into terrestrial and aquatic ecosystems.

We used the term ecotone rather than ecosystem to minimize confusion across many disciplines and agencies, and to eliminate the approach in delineating riparian ecotones by a single characteristic such as hydric soils or vegetation (Verry *et al.,* 2004). The term ecotone is a biological term that represents the zone of interaction between an aquatic 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).

There are three properties mentioned by Mitsch and Gosselink (1993) to distinguish riparian ecotones from adjacent areas:

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

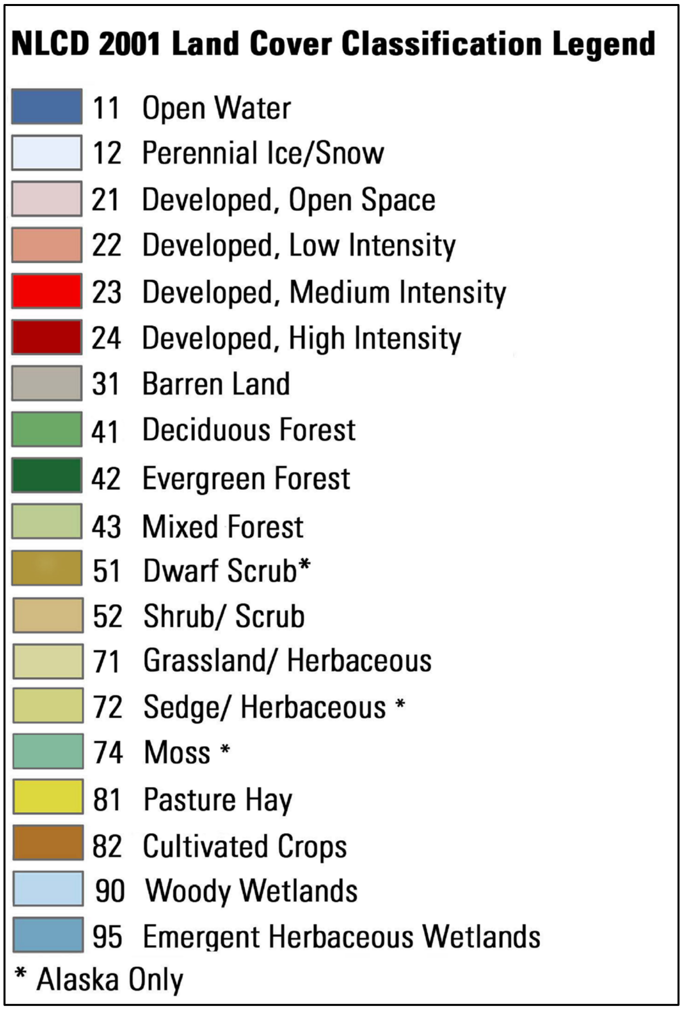
This study expands the functionality of the GIS riparian zone delineation model originally developed by Mason (2007) and refined by Abood *et al.* (2011) (Appendices A and B) to map these areas adequately and efficiently by hydrologically defining a riparian ecotone to occur at the 50-year flood height and incorporating digital elevation data. The expanded model discussed here, National Wetland Inventory data (NWI) and the Soil Survey Geographic (SSURGO) Database overseen by the Natural Resources Conservation Service (NRCS) to improve the delineation of riparian ecotones. The approach is based on recommendations by Palik *et al*. (2004) since riparian ecotones may not be confined only to the floodplain these zones can also extend to other surface waters such as contiguous lakes and wetlands in order to more fully encompass the riparian ecotones functional, hydrological and ecological characteristics.

Including NWI information, which contains vegetation attributes, raises the question of the utility of land use/cover data for delineating riparian boundaries. Not all riparian areas meet the criteria to be defined as a wetland. Hence the NWI cannot provide complete coverage of land use/cover data for mapped riparian areas. Two possible sources of vegetation information which do provide synoptic coverage of the United States are the National Land Cover Database (NLCD) and the Cropland Data Layer (CDL).

The NLCD is overseen by the Multi-Resolution Land Characteristics Consortium (MRLC). The MRLC is a partnership between the U.S. Geological Survey (USGS), the National Oceanic and Atmospheric Administration (NOAA), the U.S. Environmental Protection Agency (EPA), the U.S. Department of Agriculture (USDA), the Natural Resources Conservation Service (NRCS), the U.S. Forest Service (USFS), the National Park Service (NPS), the U.S. Fish and Wildlife Service (USFWS), the Bureau of Land Management (BLM), the National Aeronautics and Space Administration (NASA), and the Office of Surface Mining (OSM). The NLCD database was developed to achieve two main goals. First provide a multi-source and multi-layer continuous land use/cover database for the conterminous United States, Alaska, Hawaii and Puerto Rico. Second maintain a general data framework for land use/cover classification and standardize the classification so it can be simply and quickly updated and transferable for users across different scientific and commercial fields (Homer *et al.*, 2004).

Previously, the NLCD consisted of three major data releases based on a 10-year cycle. These include a circa 1992 conterminous U.S. land use/cover dataset with one thematic layer (NLCD, 1992), a circa 2001 50-state/Puerto Rico updated United States land use/cover database (NLCD, 2001) with three layers including thematic land cover, percent imperviousness, and percent tree canopy, and a 1992/2001 Land Cover Change Retrofit Product. With these national data layers, there is often a 5-year time lag between the image capture date and product release. In some areas, the land use/cover can undergo significant change during production time, resulting in products that may be perpetually out of date. To address these issues, the circa 2006 NLCD land cover product (NLCD, 2006) was conceived to meet user community needs for more frequent land cover monitoring (moving to a 5-year cycle), and reduce the production time between image capture and product release. The 2006 NLCD is designed to provide the user both updated land use/cover data, and additional information that can be used to identify the pattern, nature, and magnitude of changes occurring between 2001 and 2006 for the conterminous United States at a medium spatial resolution (30m) (MRLC, 2006).

The NLCD utilizes Landsat-5 Thematic Mapper (TM) and Landsat-7 Enhanced Thematic Mapper (ETM+) satellite imagery to map the land use/cover combined with multi-source ancillary data including 30m digital elevation models (DEMs) and derived slope, aspect and slope position index. The NLCD is composed of 16 land use/cover classes (Figure 3.1). The average accuracy assessment is 83.9% (Homer *et al.*, 2004 and 2007).



NLCD 2001 Land Cover Classification Legend

11	Open Water
12	Perennial Ice/Snow
21	Developed, Open Space
22	Developed, Low Intensity
23	Developed, Medium Intensity
24	Developed, High Intensity
31	Barren Land
41	Deciduous Forest
42	Evergreen Forest
43	Mixed Forest
51	Dwarf Scrub*
52	Shrub/ Scrub
71	Grassland/ Herbaceous
72	Sedge/ Herbaceous *
74	Moss *
81	Pasture Hay
82	Cultivated Crops
90	Woody Wetlands
95	Emergent Herbaceous Wetlands

* Alaska Only

Figure 3.1 NLCD 2001 land use/cover classes (MRLC, 2006)

The Cropland Data Layer (CDL) is developed and released by the National Agricultural Statistics Service (NASS). The main objective is to develop a continuous land cover classification with an emphasis on crops types, their distribution, and detailed geospatial locations. Preliminary research into using remotely sensed data to develop a cropland data layer (CDL) started in the 1970s (Johnson *et al.*, 2010), and began in earnest in 1997.

The CDL 2010 primary sources of satellite imagery are the Resourcesat-1 Advanced Wide Field Sensor (AWIFS) with a spatial resolution of 56m and Landsat-5 with a spatial resolution of 30m (NASS, 2010). The cropland data layer utilizes the USGS 30m National Elevation Dataset (NED), forest canopy data, imperviousness and the NLCD as ancillary data in the classification procedure (Johnson *et al.*, 2010). A maximum classification accuracy of 90% can be achieved in intensive agricultural areas like the US Corn Belt" and the Mississippi River Delta for closed canopy crops like corn, soybeans, wheat, rice and cotton. Accuracies of 80% can be achieved with less widely planted crops such as potatoes, sunflowers, canola and barley. The overall classification accuracy for crop lands is 78%. Overall accuracy of non-agricultural classes is equal to that of the NLCD 2001 (Johnson *et al.*, 2010). The CDL 2010 uses the same NLCD 2001 classification scheme, except for the agriculture classes (81 and 82) which are detailed to specific crops such as corn, wheat, barley, rice, and other commodities (Table 3.1) (NASS, 2010).

Table 3.1 Agricultural land use classes for Michigan from the CDL 2010 (NASS, 2010).

Class Name	Attribute Code	Class Name	Attribute Code
Corn	1	Sod/Grass Seed	59
Sorghum	4	Switch grass	60
Soybeans	5	Fallow/Idle Cropland	61
Sunflower	6	Cherries	66
Sweet Corn	12	Peaches	67
Pop. or Orn. Corn	13	Apples	68
Barley	21	Grapes	69
Spring Wheat	23	Christmas Trees	70
Winter Wheat	24	Triticale	205
Rye	27	Carrots	206
Oats	28	Asparagus	207
Millet	29	Cantaloupes	209
Speltz	30	Prunes	210
Canola	31	Broccoli	214
Flaxseed	32	Peppers	216
Alfalfa	36	Plums	220
Other Hay	37	Strawberries	221
Camelina	38	Squash	222
Sugarbeets	41	Apricots	223
Dry Beans	42	Pumpkins	229
Potatoes	43	Blueberries	242
Watermelons	48	Cabbage	243
Onions	49	Celery	245
Peas	53	Radishes	246
Tomatoes	54	Turnips	247
Herbs	57	Cranberries	250
Clover/Wildflowers	58		

In this research, a case study was performed to introduce a new classification scheme showing the land use/cover distribution within the mapped riparian ecotones in Lower Michigan. Change detection analysis was done between 2001 and 2010 to asses land use/cover practices within the mapped riparian ecotones. This case study illustrates the applied side of the second version riparian delineation model in delineating, classifying, and land use/cover assessment within mapped riparian ecotones.

OBJECTIVES

The objectives for this study include:

- Evaluate the outcome of incorporating NWI data and/or digital soils data (SSURGO) into the model for improved riparian zone delineation when compared to only utilizing digital elevation data and flood height data as developed by Mason (2007) and Abood *et al*. (2011);
- Increase the utility of the delineated riparian ecotones by utilizing the NLCD 2001 and 2006 and the CDL 2010 in the model; and
- Perform a case study for within the mapped riparian ecotones between 2001 and 2010.

METHODS

Study Area and Model Inputs

The study sites consist of multiple watersheds in two locations: the central Upper Peninsula (UP) of Michigan and the eastern Lower Peninsula (LP) of Michigan (Figure 3.2). These locations were selected based on the availability of 10m DEM data and SSURGO digital soil data (spatial and tabular). The sites provide a representative sample of the complex and diverse landforms found in the Upper Midwest region (Mason, 2007).

The riparian ecotone boundary delineation model utilizes ArcGIS Desktop 10 produced by ESRI, Inc. (ESRI, 1999-2010) for all data input, management and spatial analyses. The model uses the coding language Python 2.6 under WingIDE Professional version 3.2 ERDAS Imagine is used to for the change detection analysis (ERDAS, 2010) .

Data inputs are readily available from federal and state agencies to create variable width riparian ecotone boundaries based on stream and lake locations. These include DEMs, the 50-year flood height variable associated with each stream segment's order, NWI maps, SSURGO soils data, NLCD 2001 and 2006 and CDL 2010 land use/cover information. Specific data inputs and their sources are listed in Table 3.2.

Before running the model, a determination of an appropriate 50-year flood height is required and is a vital input into the model. Mason (2007) used USGS gauge station flood heights from eight Michigan sites for the two study areas. The flood height calculation results ranged between 0.3 and 1.75m. Three flood heights values are used as inputs (0.3, 1.0, and 1.75m which represent the minimum, average and maximum flood heights respectively) to test the sensitivity of the model to varying flood height inputs.

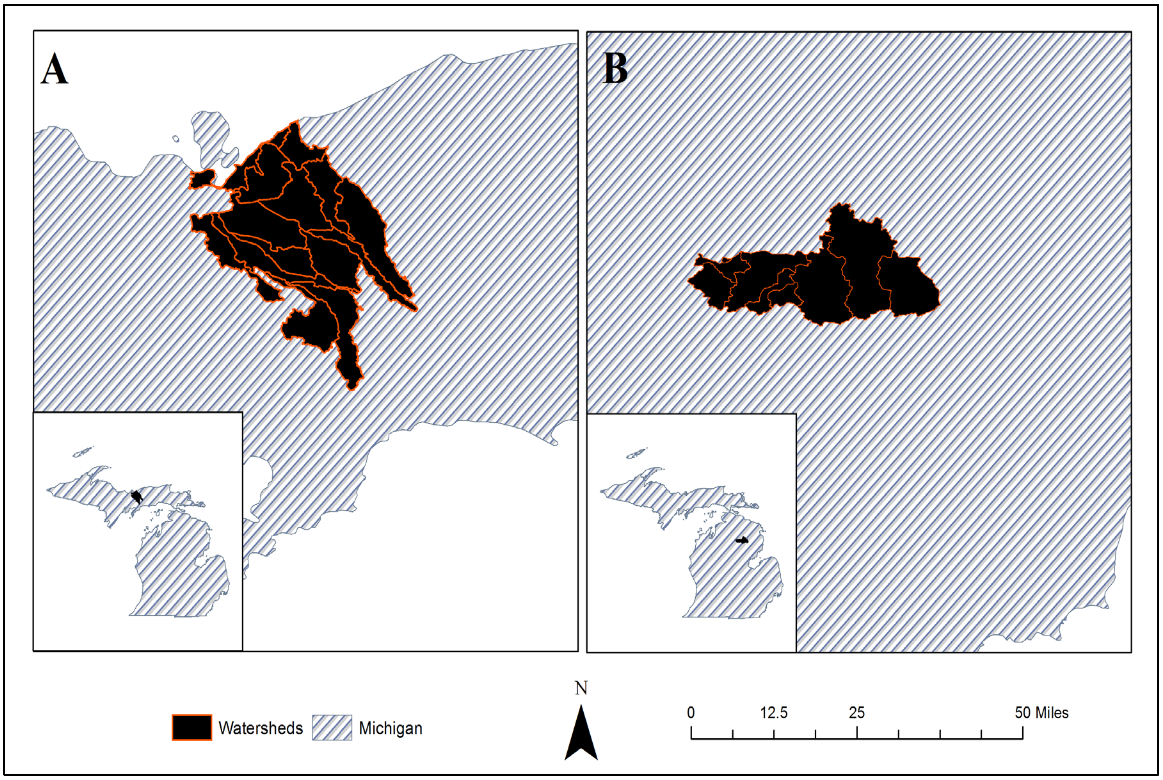


Figure 3.2 Riparian ecotone study areas: A) Upper Peninsula and B) Lower Peninsula of Michigan (from Mason, 2007).

Table 3.2 Riparian model data inputs and sources. Streams, watershed, lakes and the DEM are required inputs.

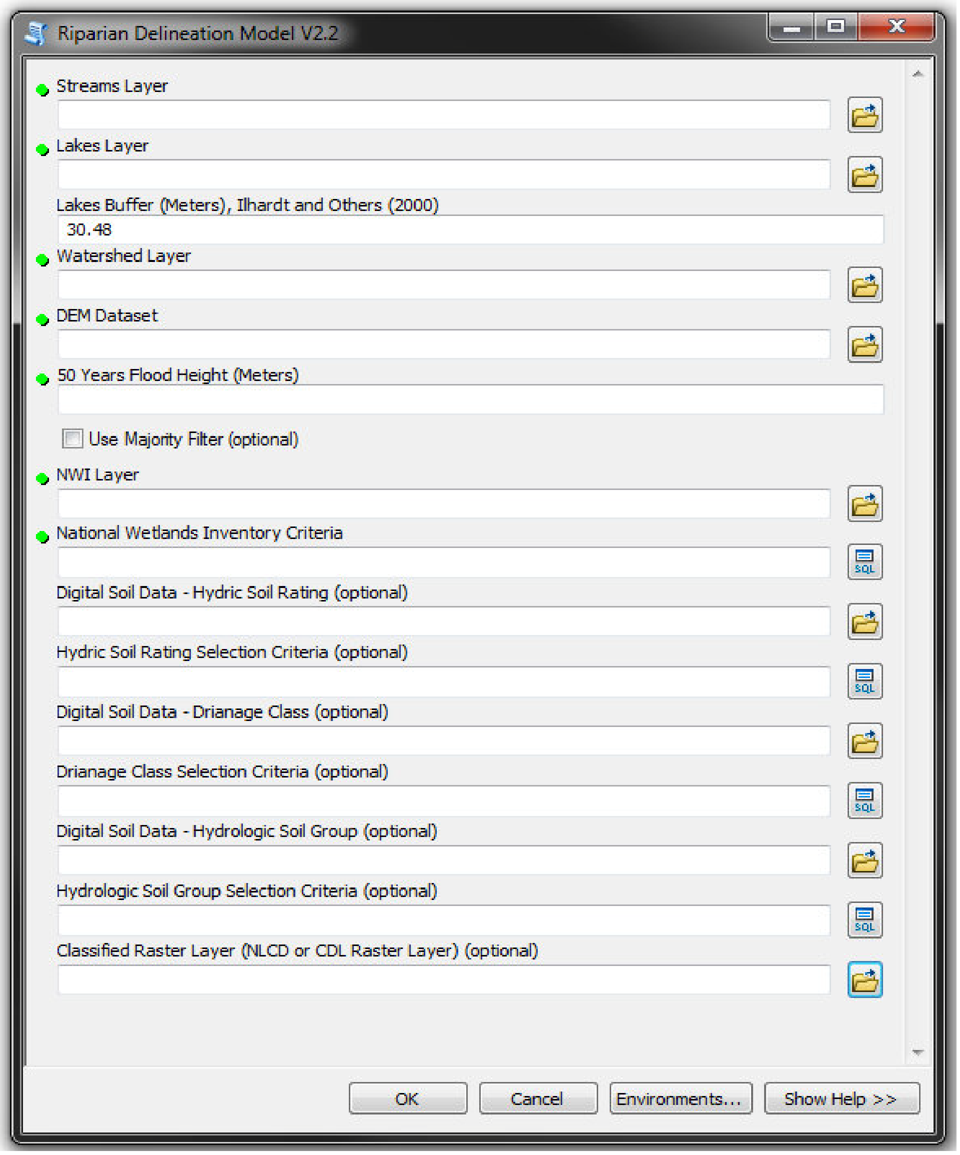
Input Data	Sources
Streams, Watersheds	USGS National Hydrography Dataset (NHD) http://nhd.usgs.gov/
Lakes	Michigan Center for Geographic information http://www.michigan.gov/cgi
National Wetland Inventory	National Wetlands Inventory (NWI) http://www.fws.gov/wetlands/Data/DataDownload.html
Digital Soil Data	Natural Resources Conservation Service (NRCS) http://soildatamart.nrcs.usda.gov/
10m Digital Elevation Model	GIS Data Depot http://data.geocomm.com/
National Land Cover Database	www.mrlc.gov
Cropland Data Layer	http://www.nass.usda.gov/research/Cropland/SARS1a.htm

All inputs must be in ArcMap File Geodatabase (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 seven required inputs and nine optional inputs (Figure 3.3) and Appendix B. The data processing is divided into the following components:

- Prepare input data and create the lake buffers;
- Calculate sample point’s locations along streams;

- Build transects around sample points;
- Determine the outside edge of the variable-width buffer;
- Create an easy to use riparian boundary polygon;
- Identify adjacent wetlands and create a continuous riparian boundary area;
- Utilize digital soil data criteria and create an expanded continuous riparian area;
- Incorporate NLCD and/or CDL data for the mapped riparian ecotone.

Multiple components facilitate easy customization of the model for various applications by a variety of users.



Lakes Buffer (Meters), Ilhardt and Others (2000)
30.48

Figure 3.3 Riparian Delineation Model V2.2.

Data processing starts 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 transect 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 by the NHD to ensure hydrologic connectivity are erased, as mapping of a riparian zone along these segments would be erroneous. Lastly, a 30.5m (100 ft) buffer is computed around all lakes and other open water bodies based on the recommendations of Ilhardt *et al.* (2000).

The x, y coordinates for the starting point of each transect are mapped along the watercourse (Figure 3.4). Input parameters include the DEM's spatial resolution and a pixel ratio, expressed as a percentage of pixel size which is embedded in the script. 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 DEMs accuracy standard (USGS, 1997). Point spacing along the stream segment is calculated using Euclidean distance from one point to the next. 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 3.4) for 360°. 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 transect's points feature class, a maximum transect length of 202.5m (664.2 ft) was imposed for the 10m DEM and 607.5m (1992.6 ft) for the 30m DEM around each sample point. These lengths were determined from initial runs of the model with the Michigan data and may need to be changed depending on the landform.

Based on elevation change, the model determines if the transect's points are part of the riparian buffer. If the elevation change is greater than 1m (the average calculated 50-year flood height for the study areas) between the sample point and the transect point, the point is considered outside the riparian buffer. Duplicate points (same x, y coordinate) along the edge of the riparian zone are deleted to reduce processing time. The model reads the elevations associated with each sample point along each transect, flags the edge of the riparian zone and deletes any other transect points beyond the edge point (Figure 3.5).

The cleaned transect's points feature class is rasterized to a spatial resolution equal to the input DEM and the resulting raster is smoothed to remove ragged edges. 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 delineated riparian ecotones are converted to vector polygons. At this point the ecotone area consists of the stream riparian zone (polygon) merged with the NHD lakes and their associated 30.48m (100 ft) buffers. The newly generated riparian zone is typically composed of many irregularly shaped, adjacent polygons, and the model continues processing to remove area overlaps inside the riparian boundary and an additional boundary smoothing to create one continuous zone around adjacent hydrologic features (Figure 3.6).

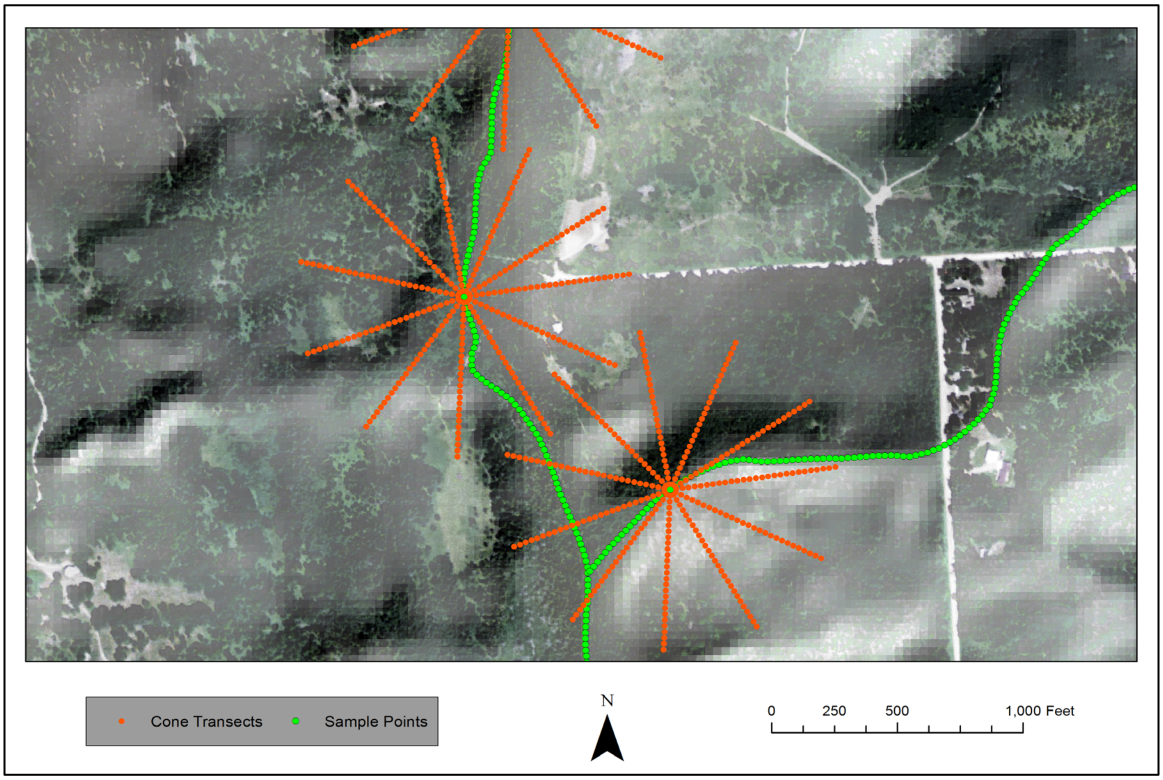


Figure 3.4 Example of cone transects constructed around selected sample points (from Abood *et al*., 2011). The actual sampling is denser.

The next step incorporates the NWI wetlands contiguous or adjacent to the calculated riparian buffer to expand the riparian ecotone beyond the 50-year flood height. It is important to note that the NWI polygon must share a common boundary to be included in the riparian ecotone (Figure 3.7).

Based on recommendations by Verry *et al.* (2004) and Palik *et al.* (2004), assessment of the change in the placement of the riparian ectone boundary by incorporating digital soils data information is warranted. The Digital Soil Viewer (Soil Survey Staff, 2008) is used to generate three feature classes. Three major characteristics (flood plain, wetlands, and frequently flooded areas) are used and are found in the Hydric Soils, Hydrologic Soil Group, and Drainage Class attribute tables (Table 3.3).

The SSURGO data consists of two parts- spatial and tabular data. The Digital Soil Viewer links the tabular attribute information to the map units (soil polygons) and generates a spatial layer with a specific attribute which is formatted to a feature class.

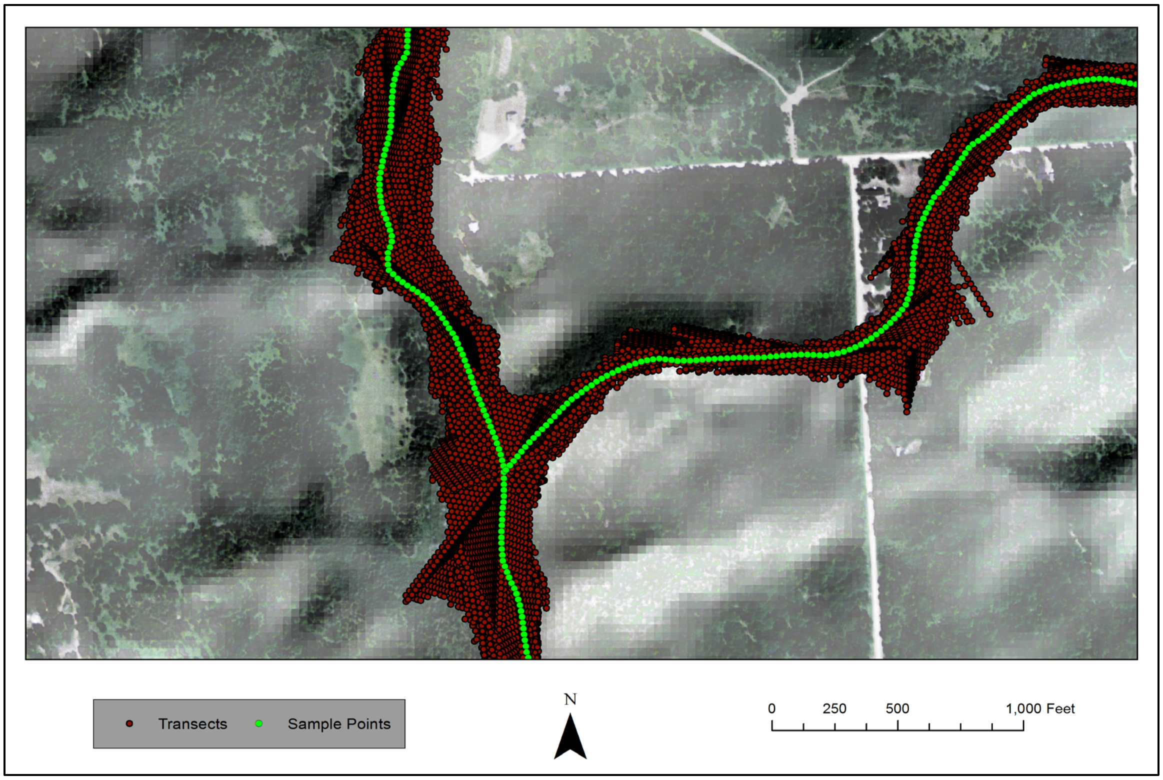


Figure 3.5 Example of transect points delineating riparian ecotone boundaries (from Abood *et al*., 2011).

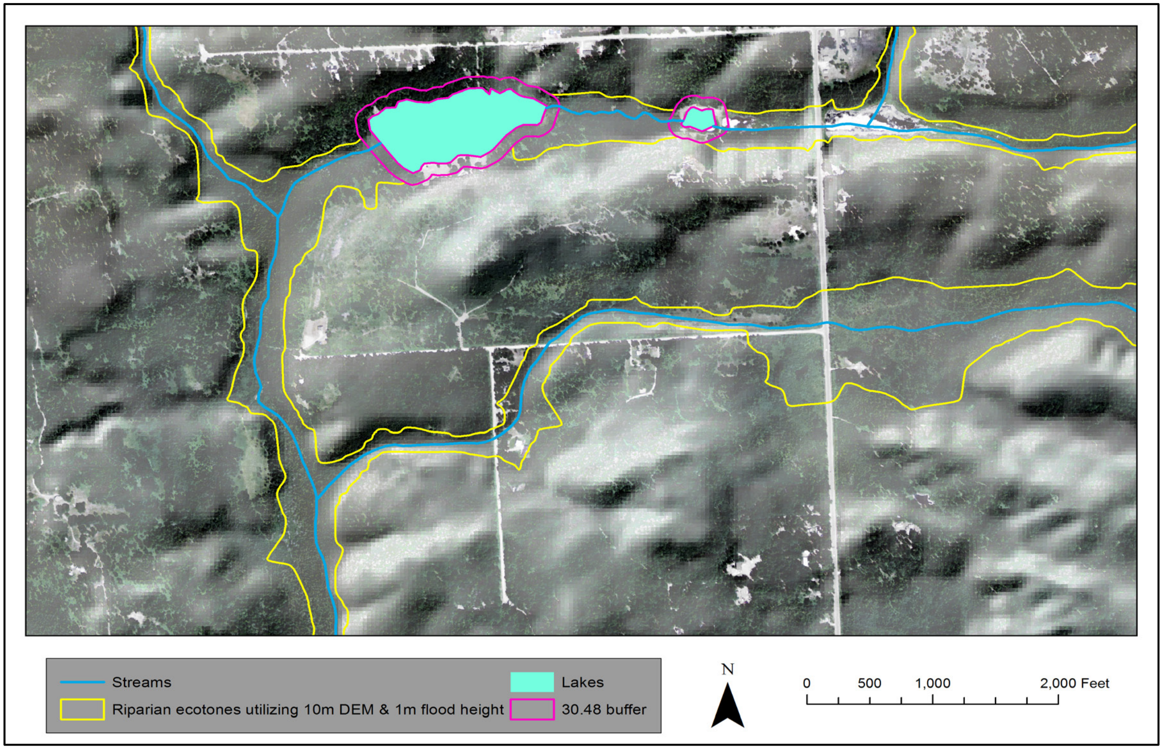


Figure 3.6 Final riparian ecotone boundary utilizing 10m DEM and 1.0m flood height from the study area in the Lower Peninsula of Michigan (from Abood *et al.,* 2011).

The resulting three feature classes are combined into one polygon feature class via an intersection function. The model then selects the polygons contiguous to the riparian buffer and appends them to expand the areal coverage of the riparian buffer zone (Figure 3.8).

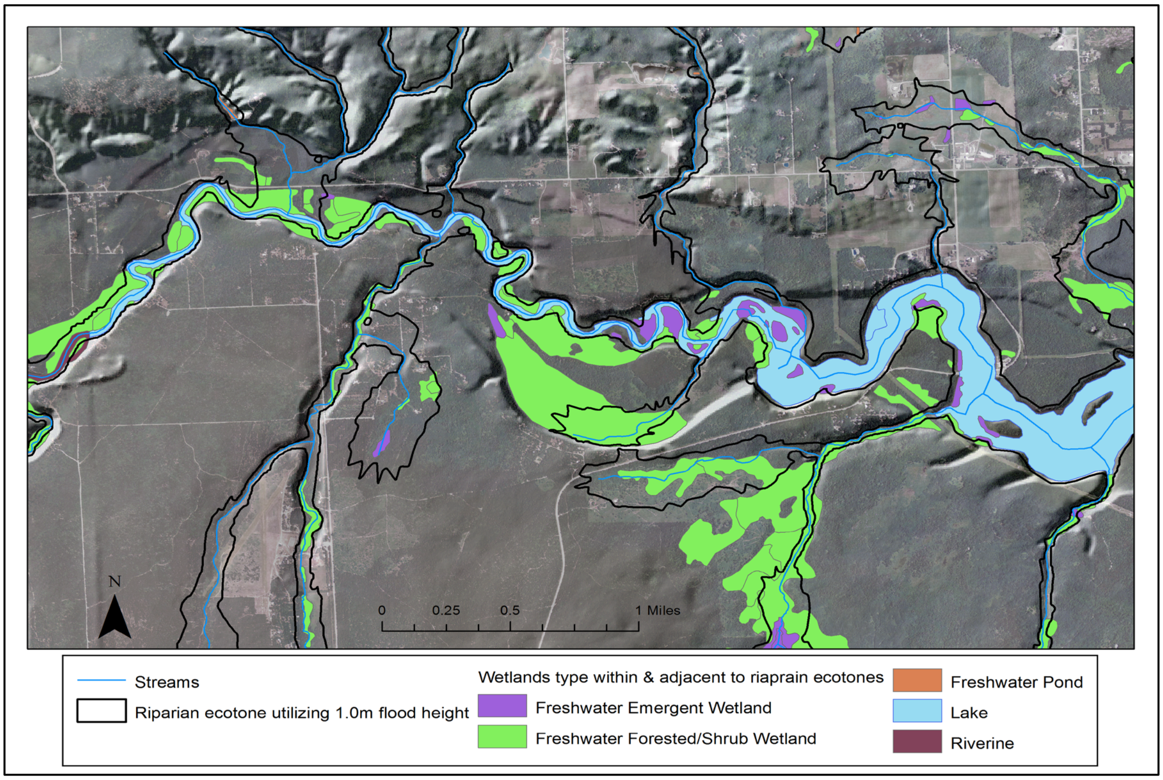


Figure 3.7 An example of riparian ecotone boundaries including the adjacent NWI wetlands for a portion of the study area in the Lower Peninsula of Michigan.

The last step in the model incorporates the NLCD and/or the CDL raster layers. Figure 3.9 illustrates the data processing flow to produce the detailed riparian ecotones feature class. The expanded riparian ecotone boundary is used to extract the land use/cover from the NLCD and/or the CDL and produce a classified land use/cover within the riparian ecotone boundary (Figure 3.10).

To assess changes in land use/cover patterns with the riparian ecotones the model utilized the NLCD 2001 and 2006, and the CDL 2007, 2008, 2009 and 2010 layers as inputs to the land use/cover classification step of the model. This provides a time series of six classified variable width riparian ecotones for 2001, 2006, 2007, 2008, 2009 and 2010. The riparian ecotones using the CDL as a classified raster layer have detailed agricultural commodities classes such as corn, rice and barley (Figure 3.10) however, for the change detection analysis, all the agricultural commodities are summed in one class cultivated crops (82 as classified by the NLCD) and alfalfa and other hay were merged to Pasture/Hay (81 as classified by the NLCD) in order to have the same classification scheme for riparian ecotones between 2001and 2010. A change detection matrix was built using data from 2001 and 2010 to evaluate land use/cover changes during the decade. The matrix shows “what changed to what” (Jensen, 2005). The analysis is done using a pixel by pixel comparison utilizing the Matrix function in ERDAS IMAGINE 2011 (ERDAS, 2011).

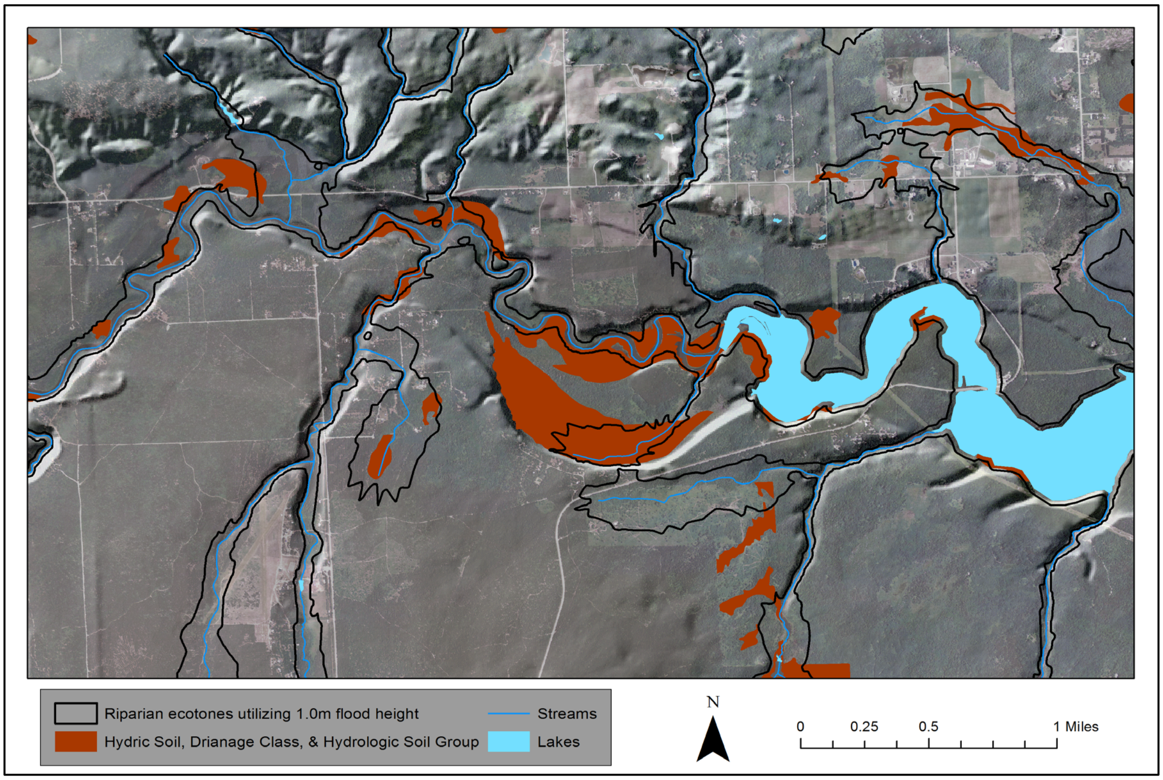


Figure 3.8 Example of riparian ecotone boundaries incorporating contiguous Hydric Soils, Drainage Class and/or Hydrologic Soil Group polygons from the SSURGO data set from a portion the study area in the Lower Peninsula of Michigan.

RESULTS AND DISCUSSION

An example of a delineated riparian ecotone utilizing 1.0m flood height with adjacent wetlands is shown in Figure 2.7. Utilizing the NWI mapped wetlands with the riparian zone calculated from the DEM and the 50-year flood height provides a comprehensive mapping of the riparian area. This spatial adjacency verifies that riparian ecotones are not limited to just stream and river floodplains but includes areas associated with other types of surface water such as lakes and wetlands. This is due in part to the extensive glaciation which took place in the Upper Midwest.

Studies conducted by the Environmental Protection Agency (EPA) have shown that a majority of wetlands adjacent to streams and lakes drain into these water bodies and have a direct impact on water quality. Water quality, specifically nutrients, impacts the health and diversity of these surface waters. Chronic nutrient over enrichment of a water body can lead to the following consequences: low dissolved oxygen, fish kills, algal blooms, overabundance of macrophytes, likely increased sediment accumulation rates, and species shifts of both flora and fauna. Excessive nutrients can also result in potential human health risks and threaten public water supplies drawn from lakes and reservoirs (EPA, 2000). Hence the inclusion of contiguous wetlands in the riparian ecotone is justified.

Table 3.3 Digital soil data criteria and definitions for including an area into the riparian zone based on recommendations by Verry *et al.* (2004) and Palik *et al.* (2004).

Soil Attribute	Definition
Hydric Rating by Map Unit	"All Hydric" Hydric soils are defined by the National Technical Committee for Hydric Soils (NTCHS) as soils that formed under conditions of saturation, flooding, or ponding long enough during the growing season to develop anaerobic conditions in the upper part (Federal Register, 1994),
Drainage Class	"Poorly Drained (P)" Soils may have a saturated zone, a layer of low haydraulic conductivity, or seepage. Depth to water table is less than 1 foot.
	"Very Poorly Drained (VP)" Soils are wet to the surface most of the time. Depth to wate table is less than 1 foot, or is ponded.
	"Somewhat Poorly Drained (SP)" Soils commonly have a layer with low hydraulic conductivity, wet state high in profile. Depth to water table is 1 to 3 ft.
Hydrologic Soil Group	"Group C" Soils having a slow infiltration rate when thoroughly wet. Soils having a layer that impedes the downward movement of water or soils of moderately fine texture or fine texture. These soils have a slow rate of water transmission
	"Group D" Soils having a very slow infiltration rate (high runoff potential) when thoroughly wet. These consist chiefly of clays that have a high shrink-swell potential, soils that have a high water table, soils that have a clay pan or clay layer at or near the surface, and soils that are shallow over nearly impervious material. These soils have a very slow rate of water transmission.
	"A/D", "B/D", and "C/D" Drained/undrained hydrology class of soils that can be drained and are classified

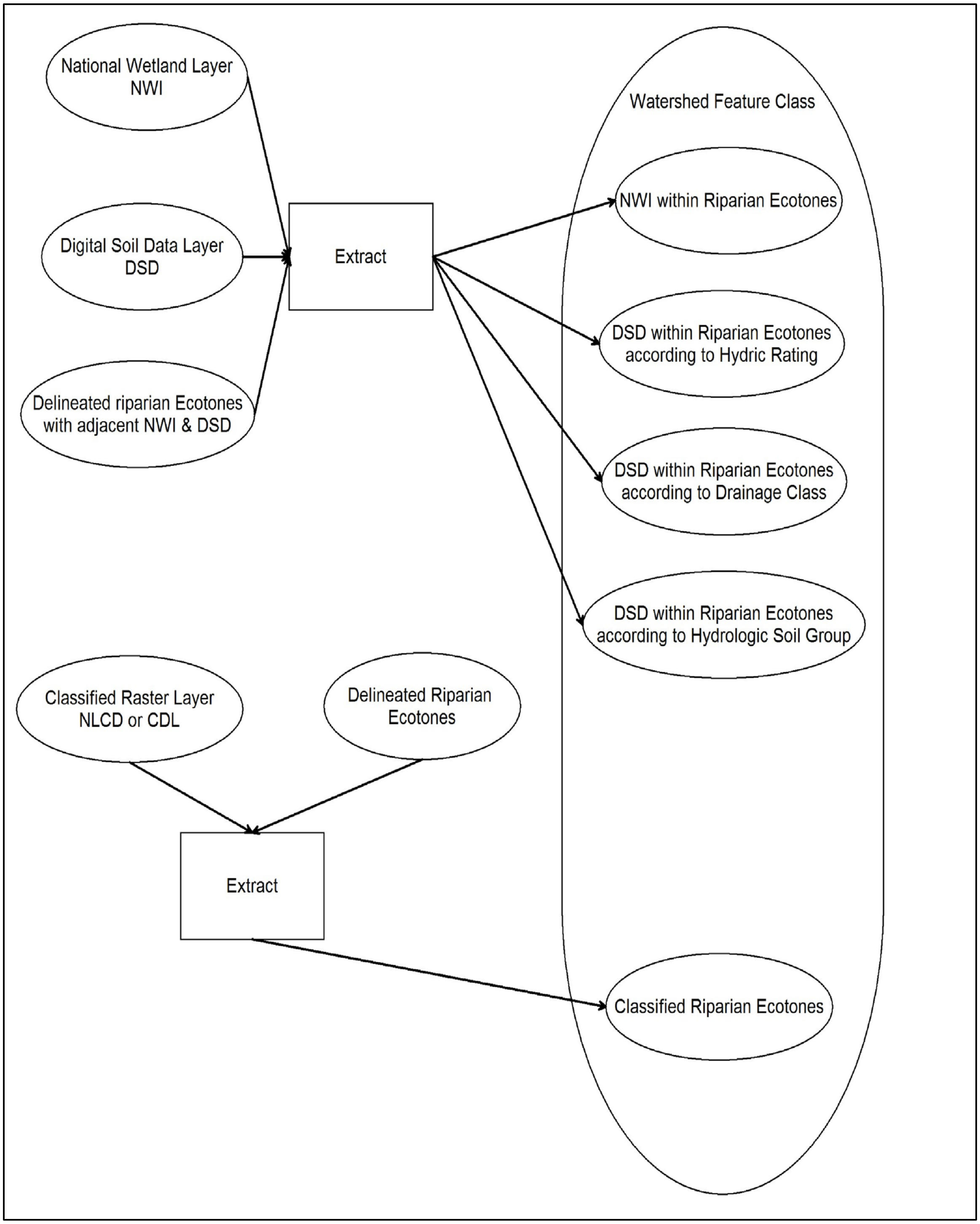


Figure 3.9 Flowchart for expanding the riparian ecotone boundaries by incorporating appropriate soils information from the SSURGO digital soils data and land use/cover information from the NLCD and/or the CDL.

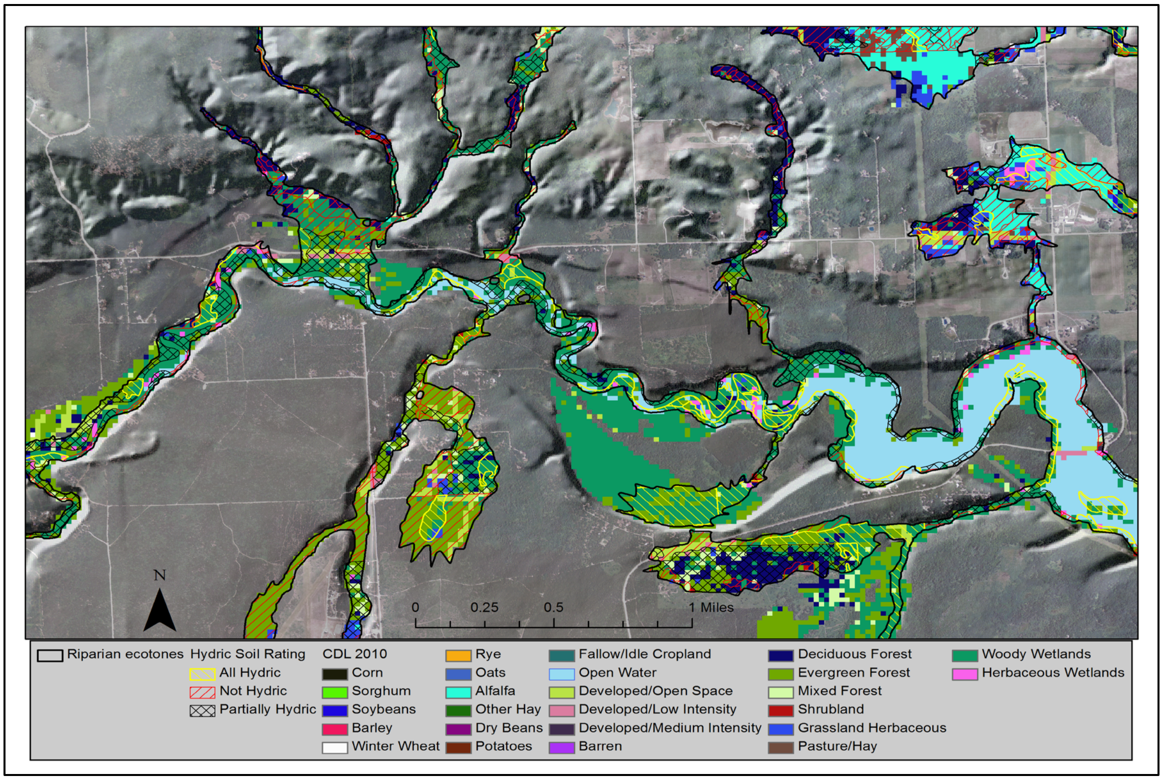


Figure 3.10 Example of expanded variable width riparian ecotone boundaries incorporating land use/cover information with specific agriculture crops from the CDL 2010 from the study area in the Lower Peninsula of Michigan.

The change in the riparian ecotone boundary location by incorporating digital soils information (Figure 3.8) is not so clear cut and is difficult to validate as soil maps are created from point samples taken in the field. This information is translated into soil mapping units by soil scientists drawing polygons on aerial imagery. Studies have shown 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. If the soils polygons are to be used to expand the riparian ecotone, field validation of these areas is warranted. Our recommendation is to use the soils data to confirm that the NWI polygons are inclusive of hydric soils.

Figure 3.11 illustrates a representative variable width riparian ecotone utilizing 10m DEM and the minimum, average, and maximum flood heights. The variable width riparian areas calculated produce different area totals and spatial extents. The results in Table 3.4 show an increase in the riparian zones delineation and riparian ecotones delineation with NWI and/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 in flood heights and can affect the accuracy of the boundary delineation.

Riparian ecotones for the study area in the Lower Peninsula including land use/cover information were generated utilizing the delineated variable width riparian ecotones with NLCD 2001, NLCD 2006 and CDL 2010 providing the land use/cover information. A change detection analysis was performed and the results are presented in Figure 3.12. All common NLCD and CDL classes are used in the change detection calculation. As noted in the methodology, the detailed crop classes from the CDL were merged to cultivated crops (NLCD class 81) and pasture/hay (NLCD class 82). Figure 3.13 illustrates the land cover classification within the delineated variable width riparian ecotones. A decrease in woody wetlands, open water, and emergent herbaceous wetlands classes was observed between 2001and 2010 compared to an increase in evergreen and deciduous forests, and grassland herbaceous classes within the same period of time.

More detailed information regarding cultivated crops with the riparian zones obtained by using the CDL. Figure 3.13 shows the increased in cultivated crops class observed in Figure 3.12. Alfalfa increased dramatically (86%) between 2007 and 2010, while other crop acreages stayed the same.

Table 3.4 Impact of variable flood height on the riparian ecotone area.

Lower Michigan Study Area			
	Flood Height (m)		
	0.3	**1.0**	**1.75**
Riparian ecotones Area (Hectare)	4,030.1	6,575.3	8,197.6
% Watersheds Area	6.9	11.2	14.0
Riparian ecotones + NWI Area (Hectare)	7,202	9,262.1	10,662
% Watersheds Area	12.3	15.8	18.2
Riparian ecotones + SSURGO Area (Hectare)	6,992.7	9,111	10,535.8
% Watersheds Area	11.9	15.6	18.0
Riparian ecotones + NWI + SSURGO Area (Hectare)	8,916.8	10,771.7	12,056.7
% Watershed Area	15.2	18.4	20.6
Upper Michigan Study Area			
	Flood Height (m)		
	0.3	**1.0**	**1.75**
Riparian ecotones Area (Hectare)	11,109	15,038.4	16,772
% Watersheds Area	12.2	16.5	18.4
Riparian ecotones + NWI Area (Hectare)	42,715.7	44,241	45,238
% Watersheds Area	47.0	48.6	49.7
Riparian ecotones + SSURGO Area (Hectare)	16,992.5	20,526.5	22,140
% Watersheds Area	18.7	26.7	24.3
Riparian ecotones + NWI + SSURGO Area (Hectare)	42,928.8	44,373.3	45,347.5
% Watershed Area	47.2	48.8	50

Post classification comparison was performed between two dates 2001 and 2010 (Jensen, 2005). The classified riparian ecotones layer generated from NLCD 2001 is the “From” and the classified riparian ecotones layer generated from CDL 2010 is the “To”. The result of the change analysis is the change matrix (Table 3.5). The change matrix has 14 classes. The matrix diagonal axis represents the unchanged acreages for all 14 classes from 2001 to 2010. The first column represents the change in acreages from different land cover/use classes to cultivated crops class. Similarly all the acreages from different land cover classes from 2001 that changed to woody wetlands class is illustrated in column 10. In column 9 a 1784 acres of cultivated crops class changed to pasture/hay class from 2001-2010 more over 290 acres grassland changed to pasture/hay over the same period of time.

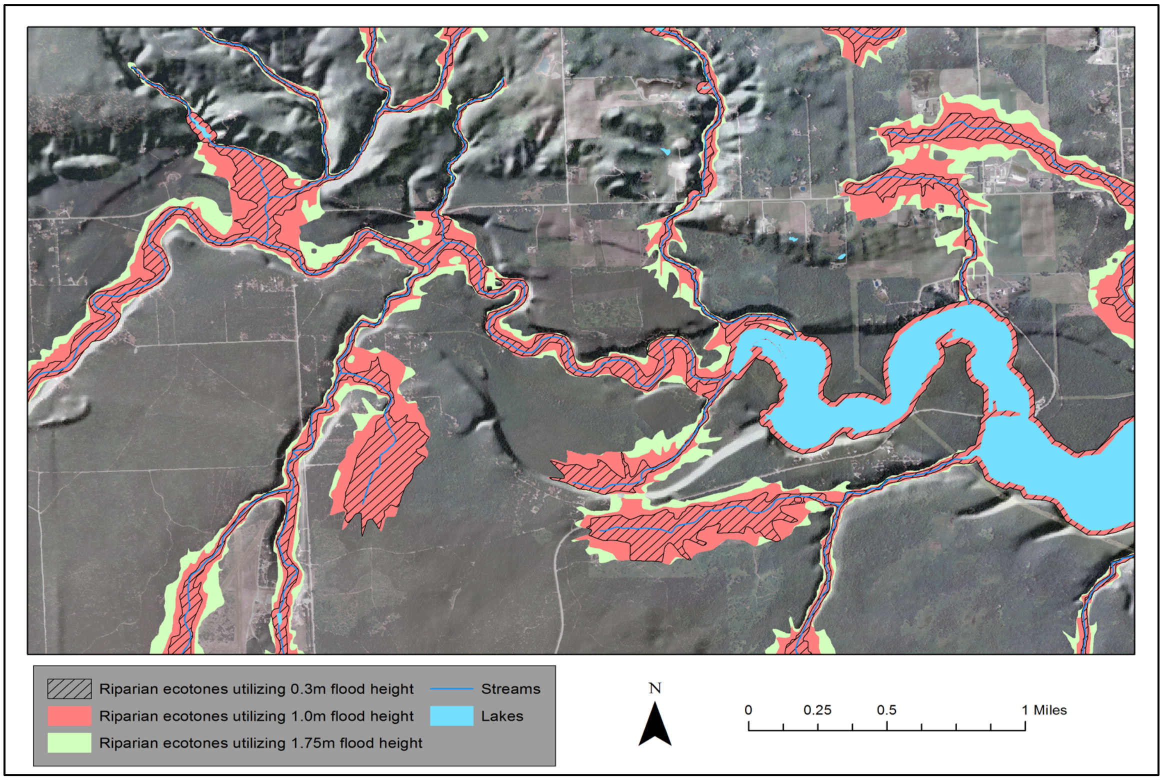


Figure 3.11 Example of riparian ecotones delineated utilizing minimum, average, and maximum flood heights from the USGS stream gauge data from the study area in the Lower Peninsula of Michigan.

CONCLUSIONS

This study offers a comprehensive approach to riparian ecotone boundary delineation. Using the 50-year flood height data along with 10m DEMs allows accurate mapping of the riparian boundary based on geophysical variables. These data sets are widely available allowing the model to be employed across the United States and elsewhere. The model is written so the user can vary the flood height value and assess its impact on boundary location. Analysis of two representative study sites in Michigan illustrate that the model was designed to accurately and robustly delineate riparian areas. This approach offers advantages over other previously used methods of riparian zone mapping by better characterizing the watercourse. The current version of the riparian ecotone delineation model successfully utilizes floating point 10m DEMs to increases the accuracy of delineation within a reasonable processing time.

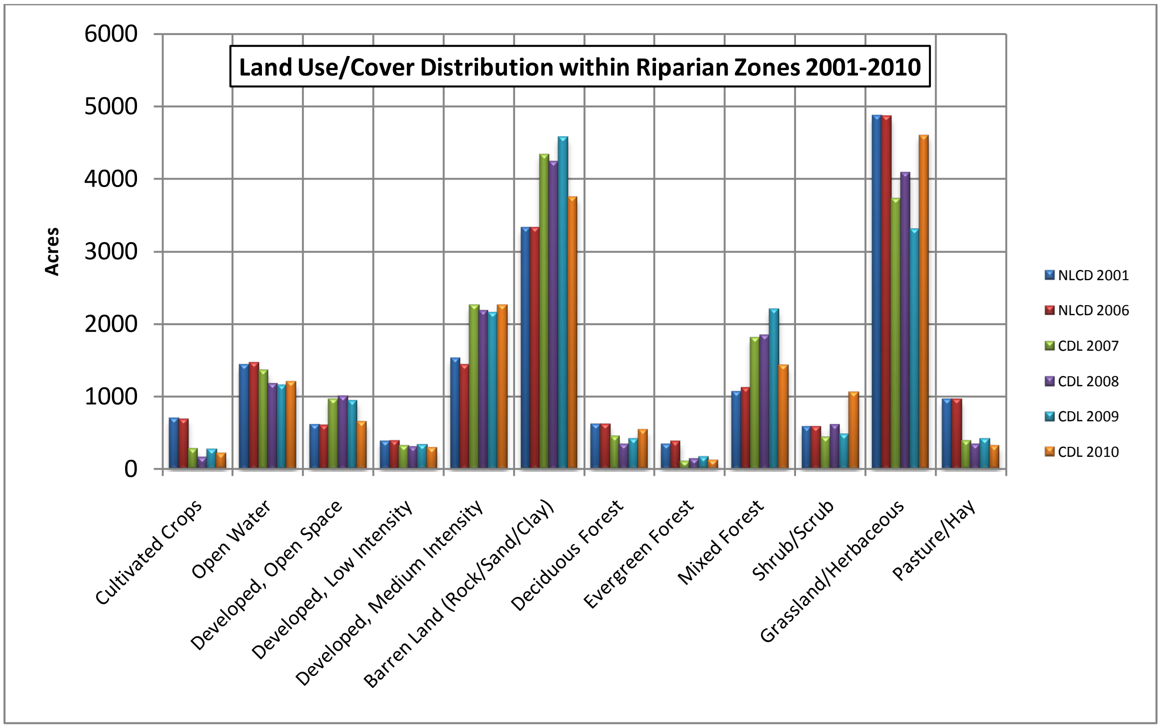


Figure 3.12 Land use/cover based on the NLCD classes found within the mapped riparian ecotones between 2001 and 2010 for the study area in the Lower Peninsula of Michigan.

Incorporation of digital soils and NWI data can relocate the riparian boundary as needed to include areas which are contiguous and should be incorporated in the riparian ecotone for varying ecological and resource management considerations. Inclusion of either variable is optional in the model. This allows the user to assess the variation in boundary location and evaluate "what if" scenarios. It also expands the model to include information beyond the geophysical characteristics of the landscape.

Utilizing land use/cover information permits assessment of land practices within the riparian ecotone. This can help decision makers monitor ecotones within a riparian setting over time, show land cover distribution and change, and guide conservation efforts for various uses. The classification system employed for this study is a hybrid classification scheme achieved by merging detailed crop classes from the CDL with the NLCD. Once again, nationally available data is being used and provides data constancy, flexibility and known classification accuracies.

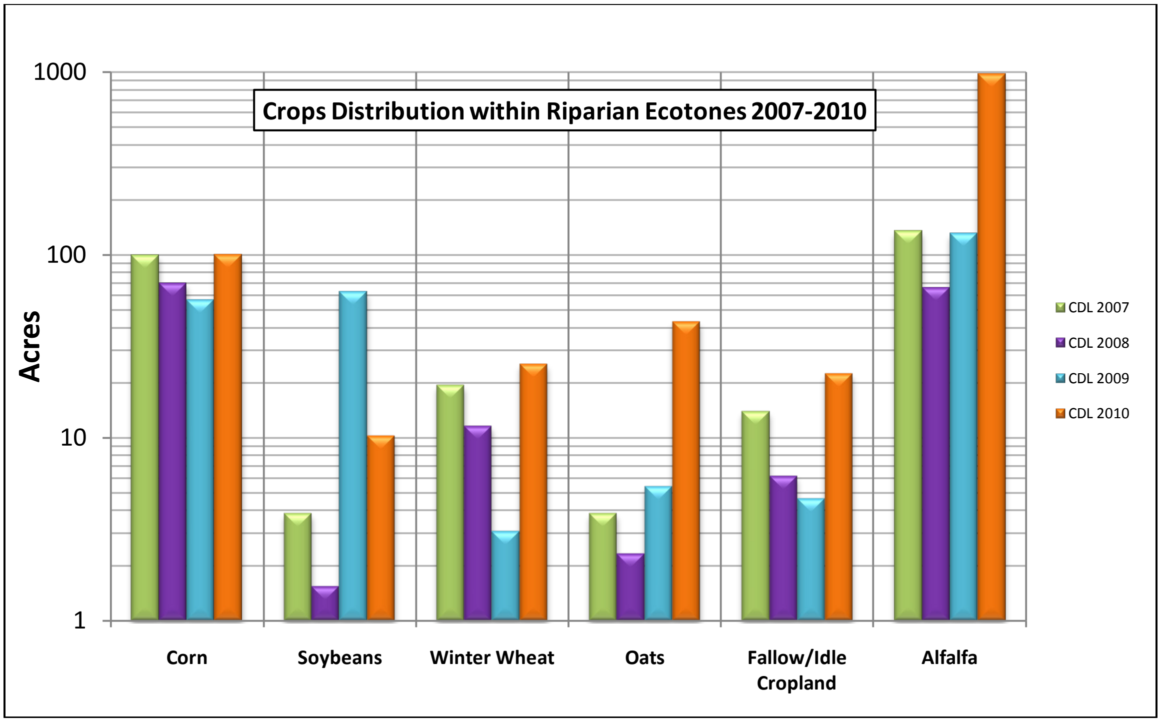


Figure 3.13 Crop distribution based on the CDL classes found within the mapped riparian ecotones between 2007 and 2010 for the study area in the Lower Peninsula of Michigan.

Table 3.5 Change detection matrix.

Unchanged	**To Image CDL 2010**														
	Acres	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
From Image NLCD 2001	**1**	1708	14	95	107	6	6	92	693	1784	181	72	166	78	34
	2	3	3975	14	15	0	6	6	12	1	587	357	13	263	33
	3	54	62	1043	280	9	0	39	116	30	245	36	119	604	70
	4	66	27	191	492	28	7	9	26	10	112	36	25	184	13
	5	0	0	7	19	7	0	0	1	0	9	0	0	5	0
	6	2	1	0	0	0	0	0	2	2	0	3	0	0	0
	7	26	10	12	4	0	0	68	132	20	79	69	57	36	29
	8	678	85	222	151	4	10	443	2234	290	504	761	308	327	91
	9	110	1	7	8	1	1	8	24	191	7	1	12	1	2
	10	60	1539	207	125	2	4	187	234	39	11067	1541	800	3090	536
	11	19	303	11	12	0	5	33	47	12	324	508	15	92	11
	12	131	90	192	78	0	2	246	533	54	2537	371	3660	767	725
	13	52	382	468	268	5	4	219	348	23	4591	449	400	7897	581
	14	13	29	53	27	1	0	66	105	8	724	66	335	483	304

1	Cultivated Crops	8	Grassland
2	Open Water	9	Pasture\Hay
3	Developed Open Space	10	Woody Wetlands
4	Developed Low Intensity	11	Herbaceous Wetlands
5	Developed Medium Intensity	12	Deciduous Forest
6	Barren	13	Evergreen Forest
7	Shrub land	14	Mixed forest

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CHAPTER 4

DEM SPATIAL RESOLUTION and NATIONAL HYDROGRAPHY DATASET POSITIONAL INACCURACIES IMPACT ON RIPARIAN ECOTONES DELINEATION

ABSTRACT

Riparian ecotones are complex, dynamic and diverse zones along aquatic ecosystems. The location of riparian ecotones between upland and aquatic systems is becoming increasingly important for watershed management and serving as ecological reserves and biological corridors. Delineating riparian areas is a challenge for resource managers and decision makers due to variation in the definition of a riparian area. There as widely varying interpretations across Federal and State agencies and between academic disciplines. We are defining a riparian area as an area 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 for this study. Previous approaches to riparian area delineation have utilized fixed width buffers, but this methodology has proven to be inadequate. We have developed, verified and documented a riparian delineation model which utilizes the 50 year flood height and digital elevation data with optional inputs of digital soils data, wetlands maps and land use/cover information. Digital Elevation Models with coarser spatial resolutions and positional inaccuracies of the National Hydrography Dataset streams have a negative impact on the riparian boundary delineation. It is critical that inputs into the model be evaluated for correctness.

KEY WORDS: riparian areas, biological corridor, riparian delineation model, and digital elevation model

INTRODUCTION

How is a riparian area defined? Federal agencies define riparian areas differently according to the specific agency's management objectives. The Environmental Protection Agency (EPA) defines riparian areas as vegetated ecosystems with a distinctive high water table presence (US EPA, 1993). The Bureau of Land Management (BLM) defines riparian areas as a type of wetland along streams adjacent to uplands (USDI BLM, 1993). Academic researchers define riparian areas according to specific criteria directly related to their scientific discipline. Definitions depend on various factors such as vegetation type, soil characteristics, and proximity to surface and ground waters (Ilhardt *et al.,* 2000 and Verry *et al.,* 2004). Brosofske *et al*. (1996) define riparian areas according to aquatic plant presence and soil characteristics, such as hydric soils, and Gregory *et al.* (1991) define them according to high soil water content when compared to adjacent uplands.

In order to assist in delineating riparian areas, an overall unified definition should be adopted in order to develop a GIS based model for delineating riparian areas accurately and have the output be available for a broad range of applications. Ilhardt *et al*. (2000) developed a functional definition adopted by Aunan *et al*. (2005) when they proposed the idea of a GIS based model to delineate riparian zones. This definition recognizes riparian areas as a corridor between aquatic and terrestrial ecosystems, and that they are a function of a variable width floodplain defined by the 50-year flood height plain as the hydrologic descriptor.

Mason (2007) used digital elevation models (DEMs) and stream gauge data to develop a new hydrological estimation method to estimate the 50-year flood height utilizing USGS gauge station water data, and developed the first generation GIS based Riparian Zone Delineation Model. She illustrated the inaccuracy of the fixed width buffer approach in characterizing riparian ecotones for two study sites in Michigan and three sites in Minnesota. These sites encompassed a variety of glacial landforms to insure the model's success was not dependent on the landscape.

Abood *et al*. (2011a) improved the Riparian Zone Delineation Model by incorporating a new sampling technique to increase variable width boundary accuracy and streamlined the program for shorter computation times. This version optionally incorporated National Wetland Inventory (NWI) maps and SSURRGO (Soil Survey Geographic Database) soils data to capture riparian areas beyond the geophysical floodplain (Abood *et al*., 2011b). Additional functionality was also added to include land use\cover classification data such as the National Land Cover Database (NLCD) and the Cropland Data Layer (CDL).

This study presents an accuracy analysis for the updated model. All of the model inputs have defined spatial and attribute inaccuracies associated with them and thus introduce boundary delineation errors. These errors are evaluated as part of this analysis. The impact of the DEM spatial resolution is considered first; followed by an evaluation of the impact of positional inaccuracies in the National Hydrography Dataset (NHD) streams layer.

OBJECTIVES

The objectives of this research include:

- Expand the Riparian Delineation Model developed by Abood (2011b) to utilize a LIDAR generated DEM with 1m spatial resolution to delineate variable width riparian ecotones;
- Evaluate the model output for mountainous terrain for an area in Latah County, Idaho where the LIDAR data was collected;
- Evaluate the impact of DEM spatial resolution for mapping variable width riparian areas by utilizing 3, 5 and 10m DEMs, and compare the results to the delineated riparian ecotones utilizing the 1m spatial resolution DEM as a baseline; and
- Evaluate the impact of NHD streams positional inaccuracies on delineating variable width riparian boundaries utilizing 1, 3m, 5 and 10m DEMs with the calculated average 50-year flood height;

METHODS

Study Area

The study site (Figure 4.1) is comprised of nine watersheds with an area of 32315.5 hectares (80788.7 acres) in Latah County, Idaho. The area is a high elevation, complex terrain that reaches a maximum elevation of 1519 meters (4983 ft) at Moscow Mountain. Land cover is mostly mixed conifer forest with a diverse species composition including Ponderosa Pine (*Pinus ponderosa*) and Douglas Fir (*Pseudotsuga menziesii*). Land ownership is divided between private timber companies and public ownership (Falkowski, 2009). This location was selected based on the availability of LIDAR derived 1m DEM data and digital soils data (spatial and tabular) to evaluate the model's performance utilizing a high resolution DEM in rugged terrain as opposed to the moderately changing elevation landscapes previously evaluated in Michigan and Minnesota utilizing 10 and 30m DEMs.

Model Inputs and Processing

The second generation Riparian Zone Delineation Model (Appendix A) developed by Abood *et al*. (2011b) is utilized to delineate variable width riparian areas in the study area. The model is attached as a toolbox to ArcGIS 10 and uses Python 2.6 as a scripting language (Appendix A). The model has six required and eight optional inputs. The required inputs are the NHD streams, lakes and watershed boundaries, a DEM (1m, 3m, 5m, and 10m

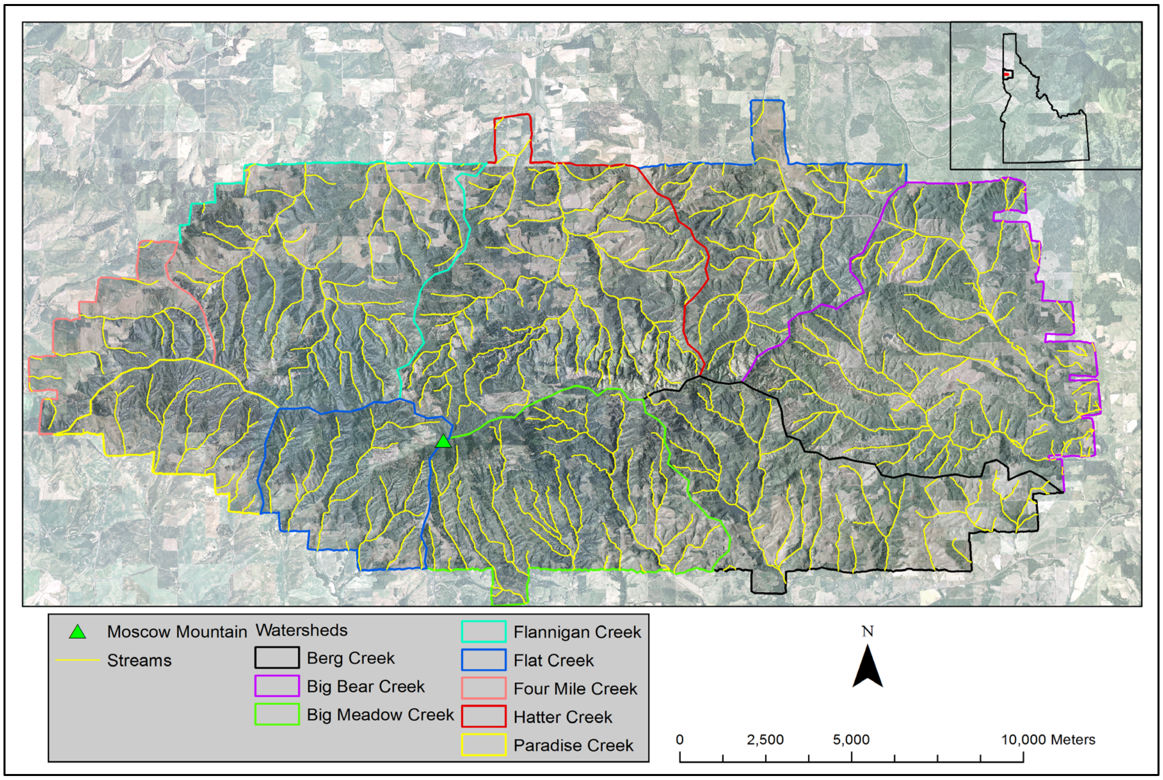

Figure 4.1 Study area made up of nine watersheds located in central Latah County, Idaho.

spatial resolutions are available), the average 50-year flood height (minimum, average and maximum are calculated), the NWI data, and the digital soils data. The model processing is divided into the following:

- Calculate 50-year flood height
- Prepare streams network layer and lakes layer inputs for processing;
- Create sample points along streams;
- Generate transects around each sample point;
- Delineate the variable width riparian boundary; and
- Incorporate adjacent NWI wetlands and digital soils data (SSURGO) and delineate an extended riparian boundary.

Model inputs are listed in Table 4.1. The model uses public domain data provided by Federal and State agencies and commercial clearinghouses (Abood *et al.*, 2011a). Details on the data inputs can be found in Chapter 3 of this document.

The 1m spatial resolution DEM is provided by Falkowski *et al.* (2009). Due to problems with running the Multiscale Curvature (MCC) algorithm developed by Evans *et al.* (2007) to generate 3 and 5m DEMs from the original raw LIDAR data, the 1m DEM is re-sampled to 3m and 5m pixels using bilinear interpolation to determine elevation values according to a weighted distance average of the four nearest cardinal direction pixels to maintain the continuous data format (ESRI, 2010). The model is run with each of the four

(1, 3, 5 and 10m) spatial resolutions to assess the impact of changing the DEMs level of detail in the riparian boundary delineation and its accuracy.

Table 4.1 Riparian zone delineation model data inputs and sources.

Input Data	Sources
Streams, Lakes, Watersheds	USGS National Hydrography Dataset (NHD) http://nhd.usgs.gov/
National Wetland Inventory (NWI)	National Wetlands Inventory (NWI) http://www.fws.gov/wetlands/Data/DataDownload.html
Digital Soil Data (SSURGO)	Natural Resources Conservation Service (NRCS) http://soildatamart.nrcs.usda.gov/
1m digital Elevation Model	Falkowski *et al.* (2009)
10m Digital Elevation Model	Geospatial Data Gateway http://datagateway.nrcs.usda.gov/

The hydrologic estimation for the minimum, average and maximum 50-year flood heights is calculated according to the procedure developed by Mason (2007). Table 4.2 lists the available USGS gauge stations used. The heights range between 0.28 and 1.93m with the average 50-year flood height equal to 0.9m.

Table 4.2 50-year flood height calculations for the available USGS gauge stations.

Gauge Station ID	Gauge Station Locations	Calculated 50-year Flood Height, m
USGS 13345000	Palouse River NR Potlatch, Idaho	0.97
USGS 13346800	Paradise CR at University of Idaho at Moscow, Idaho	0.28
USGS 13342450	Lapwai CR NR Lapwai, Idaho	0.48
USGS 12414900	St. Maries River NR Santa, Idaho	0.92
USGS 13340600	Clearwater River NR Canyon Ranger Station, Idaho	1.93

The 50-year flood height is a critical parameter in the model. Abood *et al.* (2011a) noted the model's sensitivity to changes in the 50-year flood height value by comparing the results from inputting the minimum, average and maximum flood height values. There is an increase in the riparian zone area as the flood height value increases.

The updated model utilizes NWI and SSURGO information to identify contiguous (adjacent) wetlands and soil polygons in order to capture riparian areas beyond the floodplain as recommended by Palik *et al.* (2004). The criteria to select contiguous wetlands and digital soil data along delineated variable width riparian ecotones are provided by Palik *et al.* (2004) and Verry *et al.* (2004) and are listed in Table 4.3.

Table 4.3 National Wetlands Inventory (NWI) and Soil Survey Geographic Database (SSURGO) soils data attributes to expand the riparian area boundary based on contiguity.

Input Data Layer	Attribute
National Wetlands Inventory	Palustrine, Lacustrine, and Riverine
Digital Soil Data Layer – Hydric	All Hydric
Digital Soil Data Layer – Drainage Class	Poorly Drained (P), Very Poorly Drained (VP), or Somewhat Poorly Drained (SP)
Digital Soil Data Layer – Hydrologic Soil Group	Groups C, D, A/D, B/D, or C/D

The NHD streams layer is a required input. In 2007 USGS completed the compilation of this high resolution (1:24000) data set which represents surface water across the conterminous United States (USGS, 2011). Important attributes utilized in the model are Reach Code, FCode and Stream Level (order). The impact of the NHD streams layer on the riparian ecotones delineation accuracy is, at a minimum, the inherited positional accuracy of the NHD streams layer. According to USGS standards for 1:24000 data, a feature should be within 12m (40 ft) of its true geospatial position (USGS, 2011). Figure 4.2 shows examples of positional inaccuracies of two streams within the study area. The streams fail to capture the real stream path at the bottom of the valley terrain. Instead the NHD streams are delineated as running on the side of the hill. Distances between the NHD streams and true watercourse locations were measured in ArcMap and ranged between 10 and 30m. These positional inaccuracies are present throughout the entire study area.

In order to estimate the impact of NHD positional inaccuracy on the riparian boundary delineation the streams network for the study area is calculated using ArcGIS10 Hydrology Toolbox (ESRI, 2010). The newly generated streams layer has greater detail than the NHD data and includes a large number of intermittent streams. To eliminate these steams, manual editing is performed to match the ArcMap delineated stream reaches with the corresponding NHD streams. This is done to maintain the same level of detail between the two stream feature classes. Figure 3.4 shows the ArcGIS streams compared to the NHD streams before and after editing. The ArcGIS delineated streams layer is utilized in the model to delineate riparian boundaries and compare the results with the riparian boundaries delineated with the NHD streams layer and its positional inaccuracies.

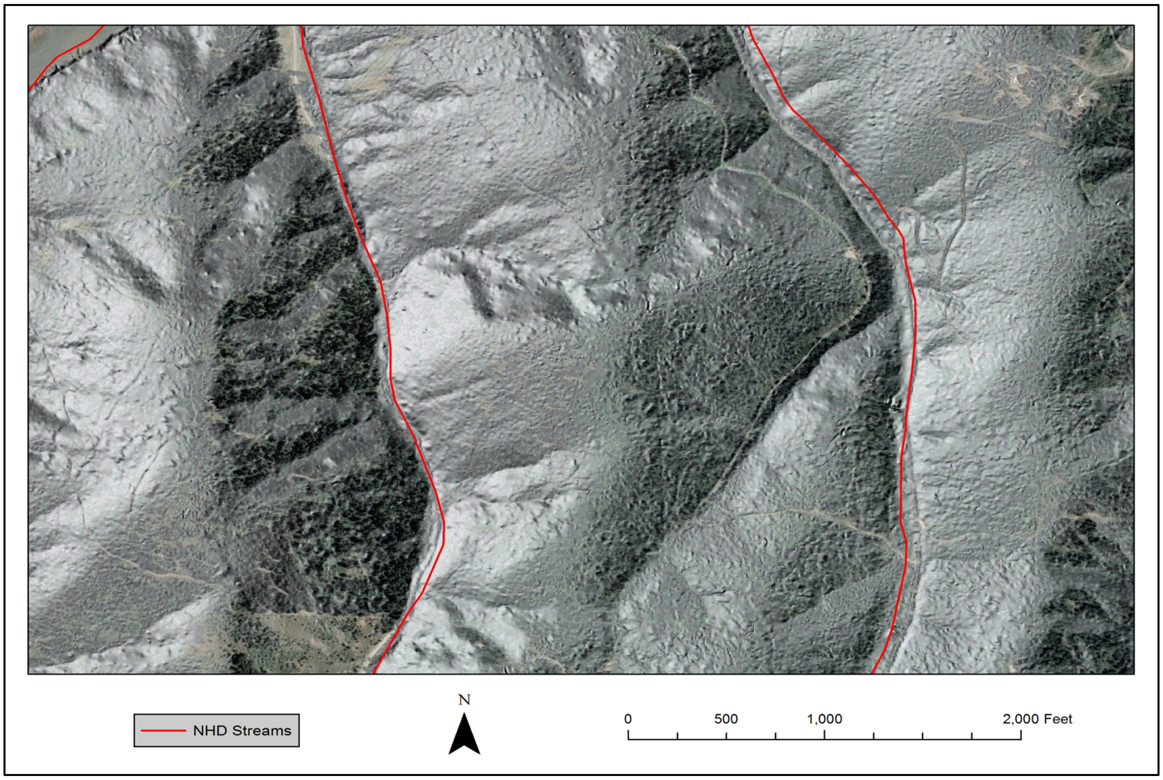

Figure 4.2 Apparent NHD streams positional inaccuracies. Note the streams are flowing along the side of the hill, not in the bottom of the valley.

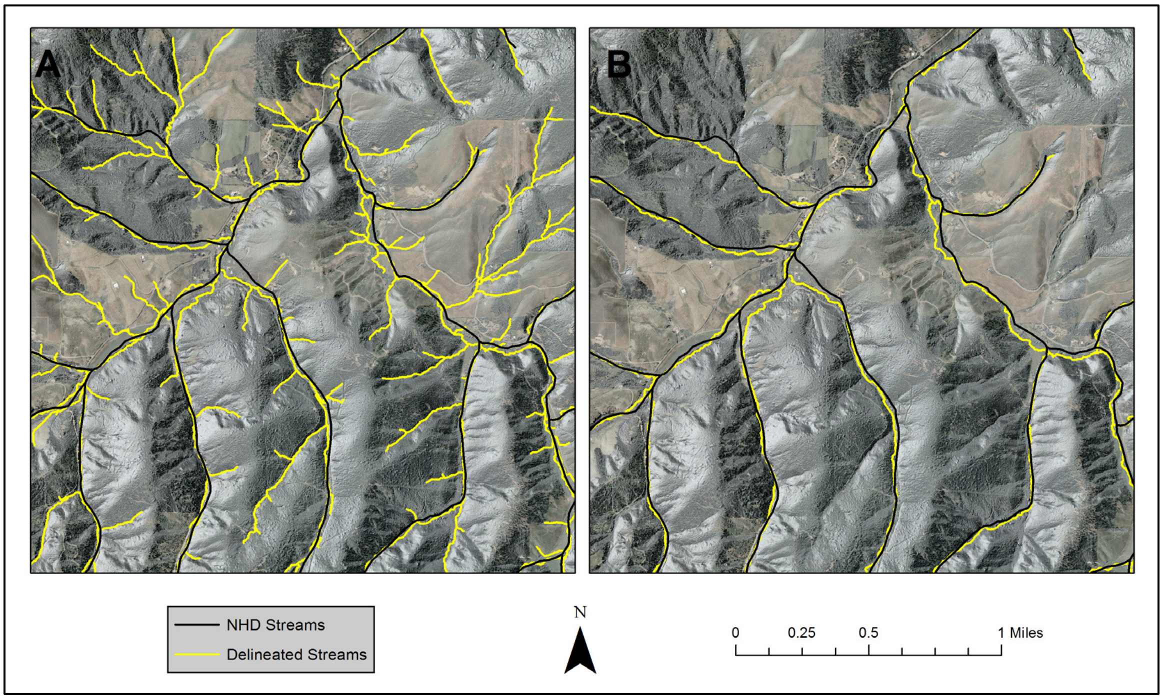

Figure 4.3 ArcMap Hydrology Toolset calculated streams: A) original stream network and B) stream network after manual editing.

RESULTS AND DISCUSSION

Previous work with the riparian model was completed in the Upper Midwest in areas with gradually changing elevation. This study confirms that the model performs well in rugged terrain as well. Using the LIDAR derived 1m DEM, the calculated 50-year flood height of 0.9m, NHD streams and incorporating NWI and SSURGO data, riparian boundaries were delineated for the entire study area (nine watersheds). Table 4 lists the riparian areas for each watershed. No area change is observed between the basic riparian areas and those with the NWI wetlands incorporated as no wetlands were mapped in this mountainous area. However, this does not mean there are no wetlands in the study area, as there are hydric soils present beyond the immediate streambed as shown in Figure 4.4. Additional riparian area contributed by the SSURGO data is minimal as there are few hydric and partially hydric soils in the study area and represent a very low percentage of the soil map units (2.0 and 2.4% respectively).

Table 4.4 Mapped riparian areas utilizing a calculated average 0.9m 50-year flood height and 1m LIDAR derived DEM.

Watershed No.	**Basic Riparian Area (Hectares)**	**Riparian + NWI Area (Hectares)**	**Riparian + SSURGO Area (Hectares)**
1	279.5	279.5	433.9
2	485.6	485.6	687.7
3	254.4	254.4	254.4
4	353.6	353.6	353.6
5	265.8	265.8	265.8
6	144.5	144.5	144.5
7	79.6	79.6	79.6
8	503.3	503.3	503.3
9	104.4	104.4	104.4

Changes in riparian area due to changing the spatial resolution of the DEM (1, 3, 5, and 10m) and using the average 50-year flood height are summarized in Figure 5. In general an increase in area is observed as the spatial resolution becomes smaller. This difference is observed clearly between areas generated from the 1m DEM versus the 10m in all watersheds except watersheds 6 and 9. As expected, the 3, 5 and 10m DEMs would include more riparian areas due to a coarser resolution of 9x, 25x and 100x respectively compared to the 1m DEM. This decrease in spatial resolution directly impacts the model sampling technique by sampling a greater distance along the transect and by increasing the distance between each transect's origin along the stream course.

However, this observation does not hold true in watersheds 6 and 9. The NHD streams positional inaccuracy impacts the position of the riparian boundaries position which leads

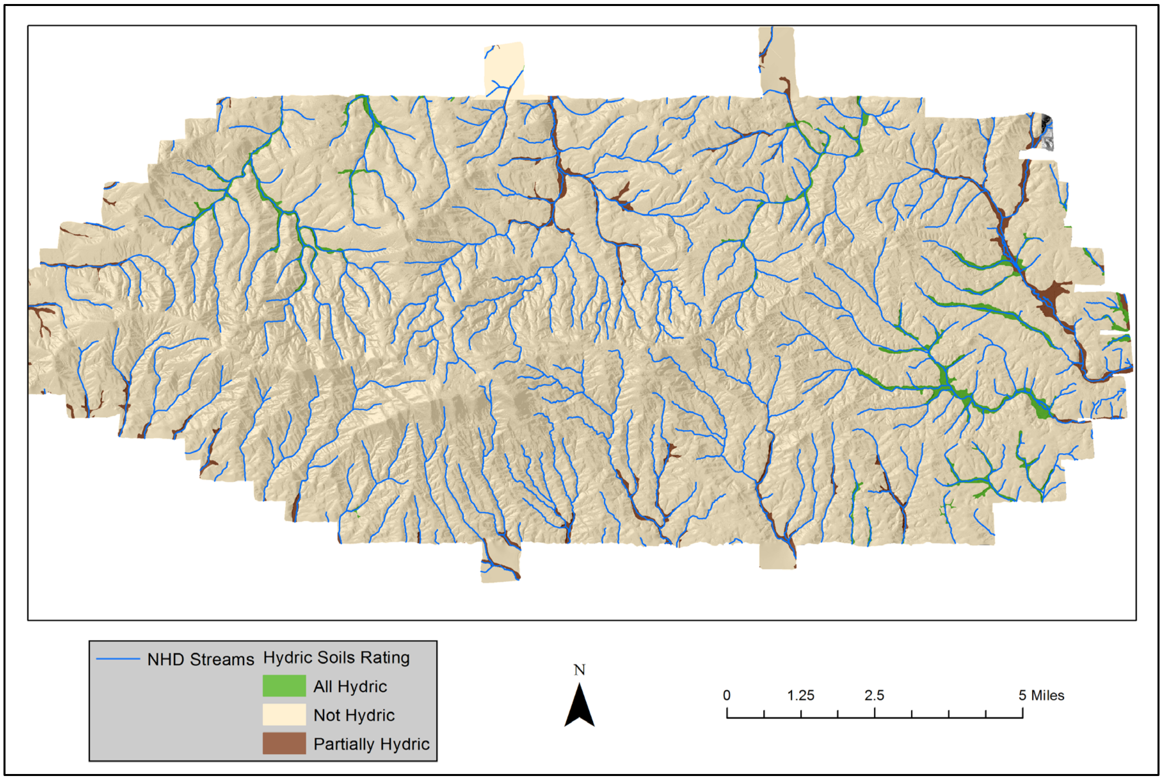

Figure 4.4 Hydric soils distribution in the study area.

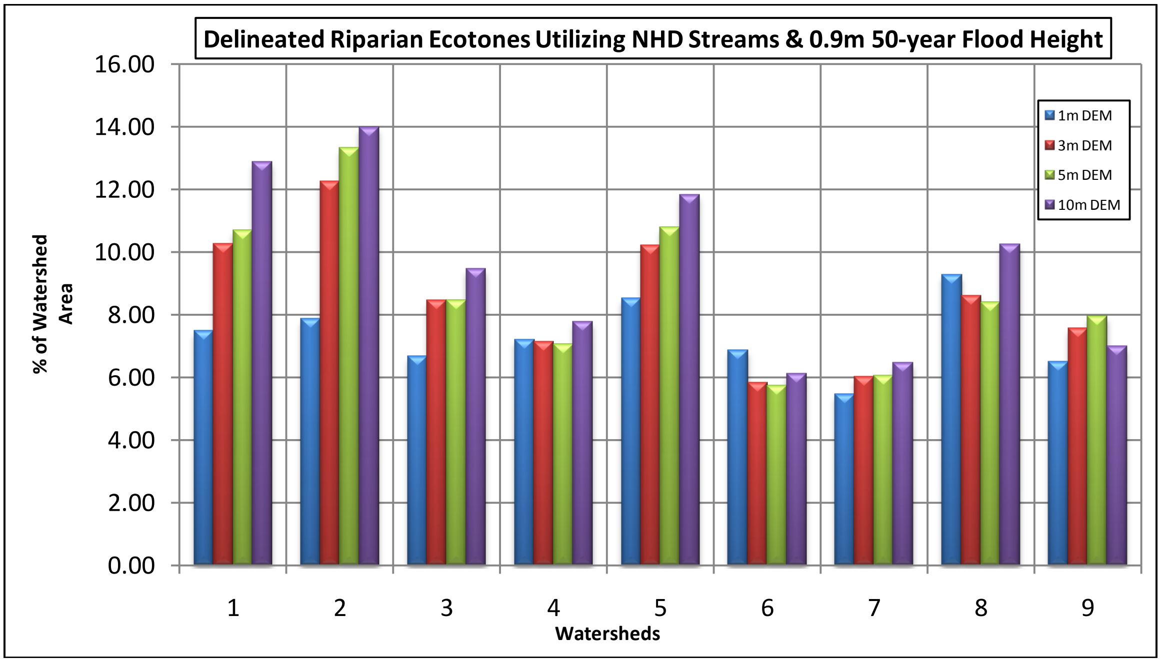

Figure 4.5 Delineated riparian ecotones area utilizing different DEM pixel resolutions.

to a decrease in riparian area for the 3, 5 and 10m DEMs compared to riparian areas mapped with the 1m DEM in watershed 6 and an increase in riparian area with the 3 and 5m DEMs compared to the area utilizing 1 and 10m DEMs in watershed 9 (Figure 4.6).

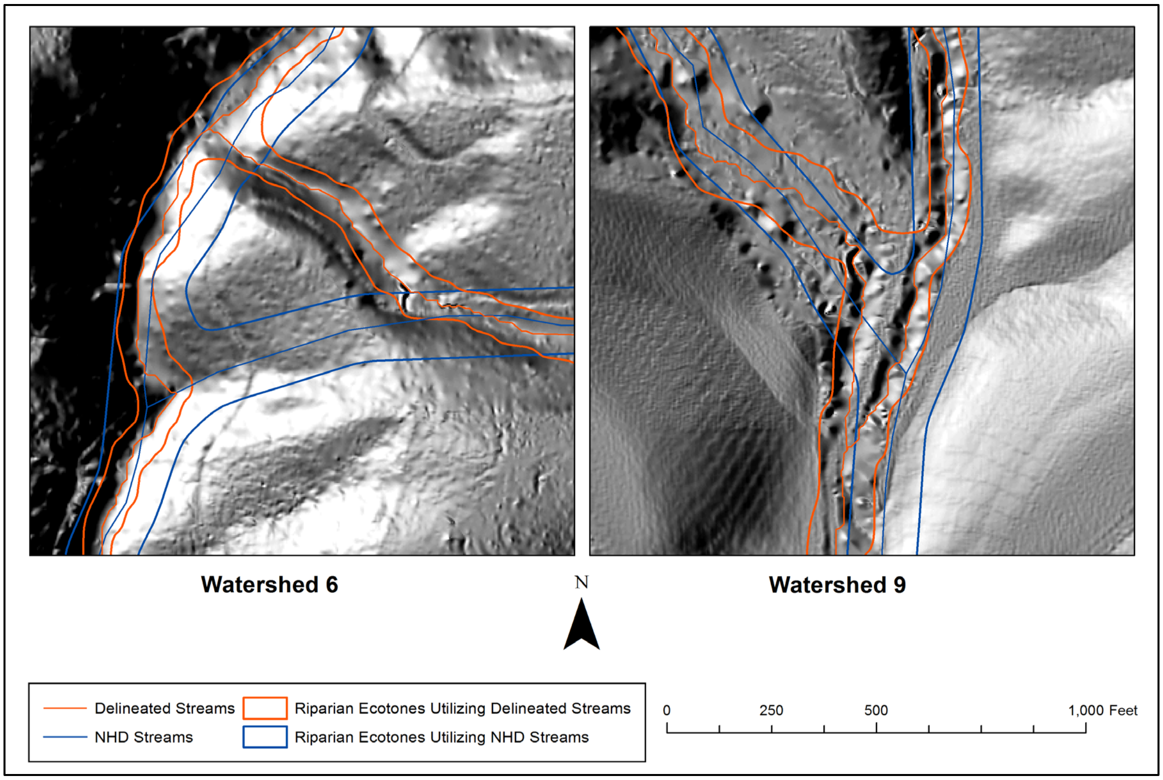

Figure 4.6 Positional accuracy impact in watershed 6 and 9.

The mapped riparian zones for the entire study area are added together for each spatial resolution DEM to determine the percent of the total watershed area (Table 4.5). An increase in riparian area is observed with a decrease in DEM resolution. Linear regression analysis is applied to the results in Table 4.5 to ascertain the relationship between percent mapped area versus DEM spatial resolution. Figure 4.7 shows a linear relationship exists between the total delineated riparian area and DEM spatial resolution. This relationship with a R^2 equal to 88% show there will be an increase riparian ecotone area with a decrease in DEM spatial resolution. Analysis of variance (ANOVA) is performed on the linear regression results to investigate if the change in area is significantly different. The calculated P-value of 0.0617 indicates that this is true. It is recognized that a sample size of just 9 watersheds is very small and further analysis is required to explain this linear relationship. Utilizing a 10m spatial resolution DEM in the riparian ecotone delineation process can increase riparian ecotone area by up to 10.5% compared to a 1m DEM utilizing the same average 50m-year flood height.

However, the results do indicate that consideration should be given to the spatial resolution of the DEM input into the model depending on how the mapped areas will be used in resource management decisions. The more accurate the boundary placement needs to be, the finer the spatial resolution of the DEM such as mapping endangered species habitat. However, if a more "generalized" boundary will suffice, and then a 10m DEM may be adequate.

Table 4.5 Total delineated riparian ecotones area utilizing the average 50-year flood height and different DEM pixel resolutions.

	1m DEM	**3m DEM**	**5m DEM**	**10m DEM**
Overall riparian ecotones, Acres	6,176.75	7,328.13	7,549.99	8,366.84
% of watershed area	7.65	9.07	9.35	10.36

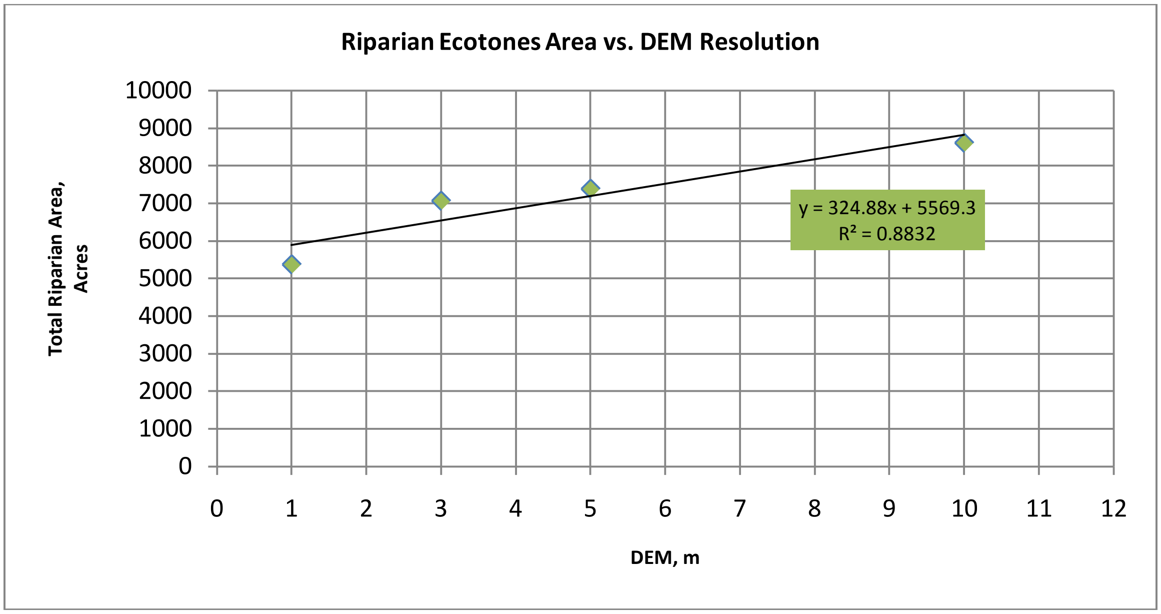

Figure 4.7 Riparian area vs. DEM spatial resolution utilizing the average 50-year flood height and the NHD stream network.

The model utilizes NHD streams as the streams network input to the model. The NHD streams layer has a positional accuracy of 40 ft (USGS, 2011). However, this does not hold true for all areas. There are positional inaccuracies which have an adverse impact on the placement of the riparian zone boundary. To evaluate the impact on the riparian ecotones delineation, areas are delineated utilizing the average 50-year flood height and the 1m DEM but with different stream inputs. First, the NHD streams are used; followed by the ArcMap Hydrology Toolset delineated streams for each watershed. Figure 8 shows a general increase in riparian area delineation with the NHD stream network.

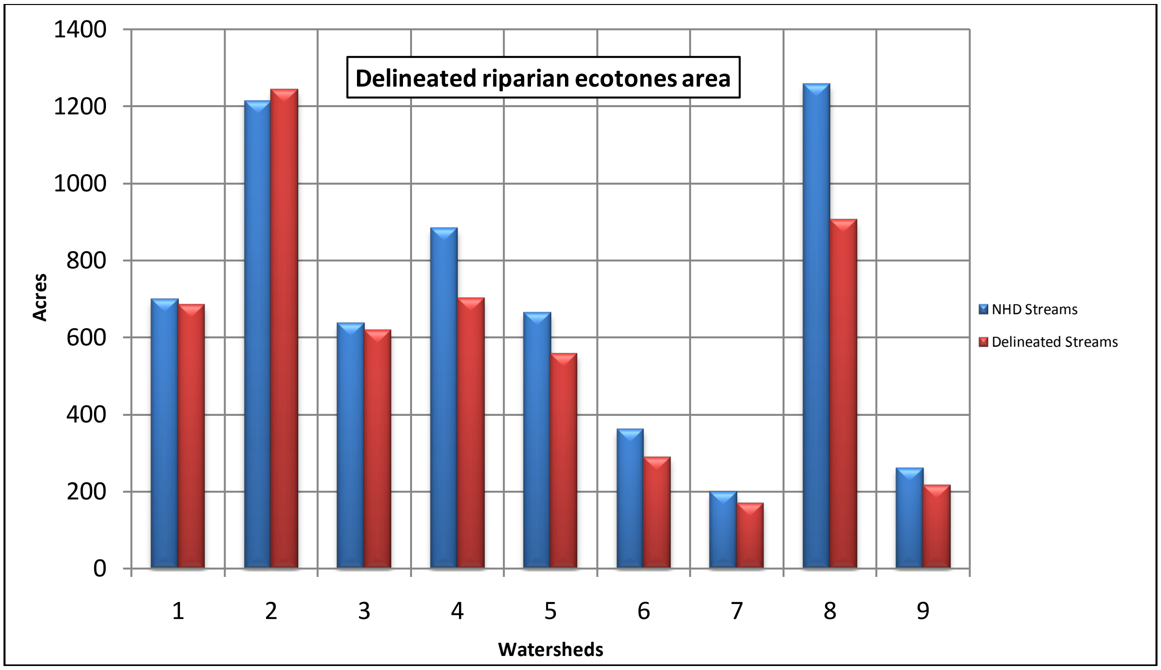

Figure 4.8 Delineated riparian ecotones utilizing 1m DEM pixel resolution and NHD streams vs. delineated streams.

This larger mapped area when compared to that mapped with the ArcMap streams can be explained by two facts. First the positional inaccuracies already noted mean a wider range of elevations is included along the streamcourse. This reduces the impact the 50-year flood height has in the model, as more averaging takes place. Secondly the NHD streams were not delineated using a 1m DEM. Hence the stream course is not as detailed or as accurate, and once again a wider range of elevations is being input into the model leading to what is a probable over estimation of the riparian area.

It is also important to better understand the how the stream course and the spatial resolution of the DEM interact with each other. Therefore, the next step is estimating the riparian ecotones area utilizing the average 50-year flood height, the 1, 3, 5 and 10m DEMs and the ArcMap delineated streams, and then comparing these results to the previously delineated riparian ecotones area utilizing the average 50 year flood height, 1, 3, 5 and 10m DEMs and the NHD streams data. Figure 4.9 and Table 4.6 illustrate an overall comparison in mapped riparian area. Inputting the NHD streams tends to overestimate riparian ecotone areas due to the positional inaccuracies. This error is clearly visible in Figure 4.10. The shifting in stream position reaches up to 75 meter (246 ft) in some locations and affects the final riparian boundary position and area.

Figure 4.10 also presents a second of the NHD positional inaccuracies. A pipe shape riparian boundary along the NHD streams is calculated compared to the more accurate riparian boundary utilizing the ArcMap delineated streams. This pipe shape is due to the NHD streams positional inaccuracy not reflecting the natural meandering nature of free flowing streams and rivers (Rosgen, 1996). Because the streams are “wandering” on the sides of hills and in some locations even crossing over hills instead of being confined to the valley bottoms, the variance in the stream course elevations is large enough to encompass the 50-year flood height and essentially create a fixed width buffer around the stream course.

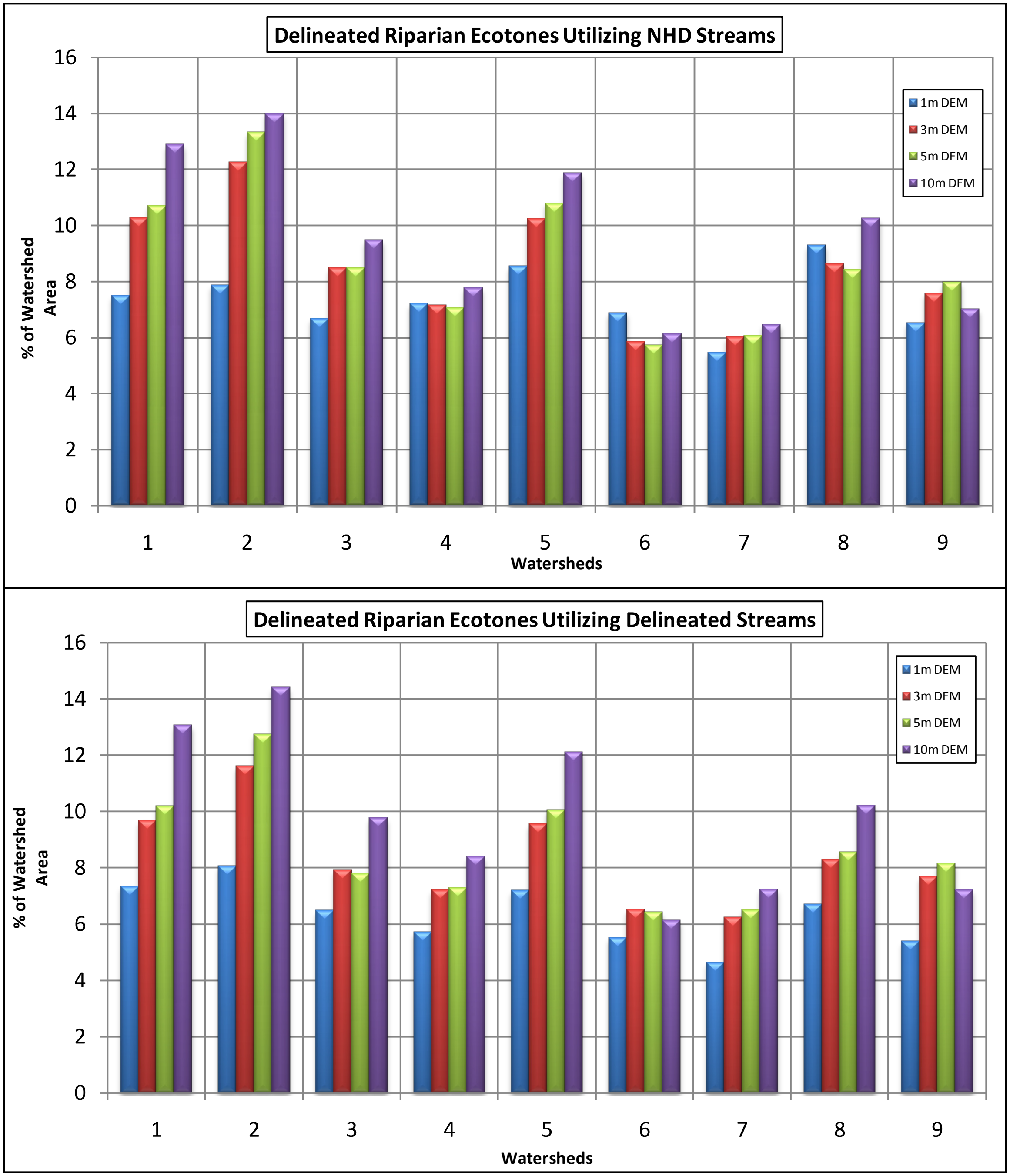

Figure 4.9 Delineated riparian ecotones area utilizing different streams layers for all nine watersheds.

Table 4.6 Detailed results of riparian ecotones utilizing NHD streams and delineated streams per watershed per DEM spatial resolution.

	1m DEM	**3m DEM**	**5m DEM**	**10m DEM**
Watershed No.	**Riparian Ecotones as % of Watershed**	**Riparian Ecotones as % of Watershed**	**Riparian Ecotones as % of Watershed**	**Riparian Ecotones as % of Watershed**
NHD				
1	7.48	10.27	10.70	12.89
2	7.87	12.26	13.33	13.99
3	6.67	8.47	8.48	9.48
4	7.20	7.15	7.06	7.78
5	8.54	10.23	10.79	11.85
6	6.88	5.84	5.73	6.12
7	5.47	6.02	6.06	6.46
8	9.29	8.62	8.42	10.25
9	6.52	7.58	7.96	7.01
Delineated Streams				
1	7.33	9.67	10.19	13.06
2	8.06	11.61	12.75	14.40
3	6.47	7.92	7.81	9.77
4	5.71	7.21	7.28	8.39
5	7.18	9.55	10.06	12.11
6	5.50	6.51	6.41	6.12
7	4.64	6.23	6.50	7.23
8	6.69	8.30	8.55	10.21
9	5.39	7.68	8.15	7.21

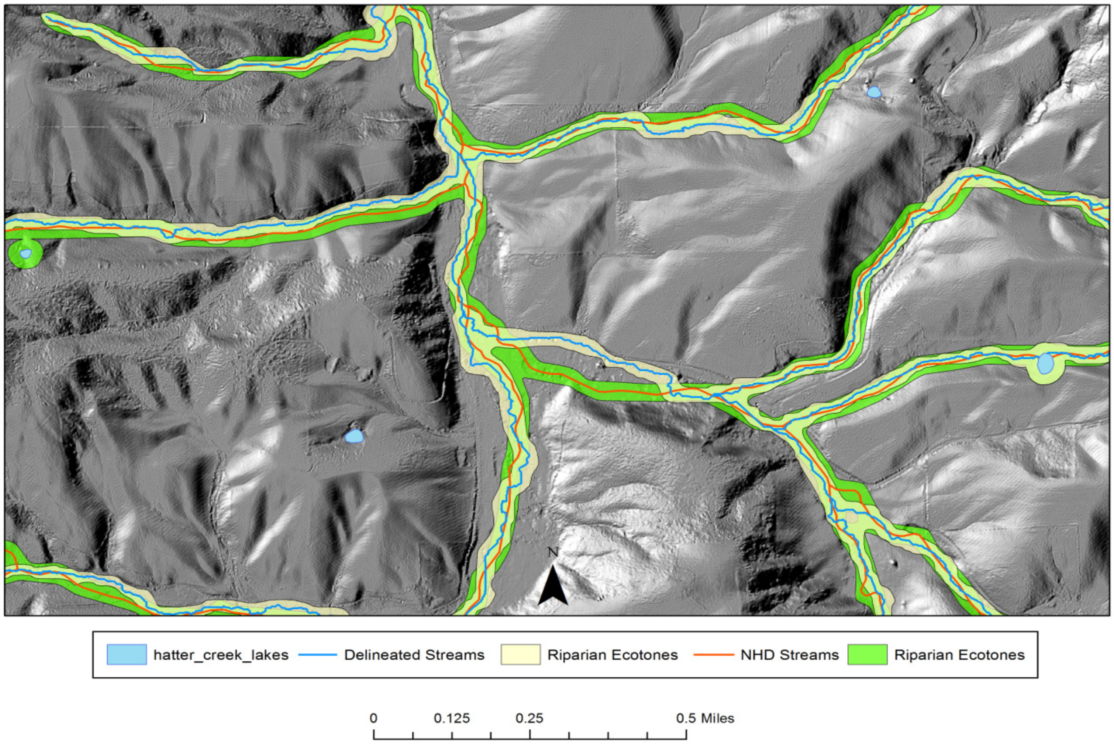

Figure 4.10 Difference between delineated riparian ecotones utilizing NHD streams vs. ArcMap delineated streams and the average 50-year flood height.

CONCLUSIONS

The Riparian Zone Delineation Model delineated riparian ecotones successfully in Latah County, Idaho utilizing the average 50-year flood height and varying fine scale DEMs. Incorporating a LIDAR derived high resolution DEM into the model is computationally intensive. The model utilizes several inputs from different sources such as an estimated 50-year flood height, DEM, NHD streams layer, National Wetlands Inventory (NWI) layer, and Digital Soil Data (DSD) layer. Each of these inputs introduces an inherited error to the riparian zone mapping process.

This study offers an accuracy assessment for the impact of DEM spatial resolution and NHD streams layer positional accuracy on the riparian ecotones area and boundary position. The decrease in DEM spatial resolution increases the riparian ecotone area. This increase can reach up to10.5% of the delineated riparian ecotones area if a 10m DEM is utilized to delineate riparian areas compared to a 1m DEM.

Regression and analysis of variance were performed on the total riparian ecotones area of the nine watersheds for each DEM spatial resolution. A linear relationship is observed between the increase in riparian ecotones area and the decrease in DEM spatial resolution. This linear trend is significant but due to a low number of samples further investigation will be performed to explain this linear trend.

The NHD reported a 40 ft positional accuracy for its high resolution NHD streams layer (USGS 2011). The 1m DEM spatial resolution was used to delineate more accurate streams layer to delineate riparian ecotones and evaluate the impact of positional accuracy on the final generated riparian area and boundary position. An overestimation in riparian area delineation is observed due to the positional inaccuracy. A pipe like shape of riparian ecotones was present due to the straight line shape streams found in the NHD streams layer which was opposite to the meandering nature of a flow flowing stream. Shift in all and parts of riparian ecotone boundaries is clearly present in Figure 8 due to the positional accuracy. This shift reached up to a distance up to 247 ft in the study area.

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CONCLUSIONS

Chapter 2 explains the development of the second version of the riparian delineation model (Appendices A and B) which introduces a new sampling technique that improves the mapping process of variable width riparian ecotones. This version of the riparian delineation model is successful in mapping the riparian ecotone edge utilizing the average 50 year flood height and digital elevation model (DEM). The second version also offers the advantage of utilizing floating digital elevation model (DEM) to increase the model sensitivity in mapping the edge of riparian ecotone utilizing the 50 year flood height.

In chapter 3, the discussion focuses on the additional inputs incorporated into the riparian delineation model by utilizing the National Wetlands Inventory (NWI) data and digital soils data (SURRGO). This approach considers that adjacent wetlands and riparian soils can extend outside of the floodplain boundary and need to be included in the mapped area. Incorporating land use/cover data in the model introduces a hybrid classification scheme by merging the National Land Cover Data (NLCD) and the Crop Data Layer (CDL) to produce a classified riparian ecotones class with additional attribute information to assist resource managers and decision makers in monitoring land practices within the riparian ecotone.

The riparian delineation model has a variety of inputs and variables that can affect the mapping process accuracy, the riparian ecotone boundary location and total area. Chapter 4 evaluates two important variables that impact the final delineated riparian ecotone layer: DEM spatial accuracy and NHD streams positional accuracy. The task of incorporating a high spatial resolution DEM in the model was successful. An assessment of NHD streams positional in accuracies illustrates the impact of inherited error in the NHD streams layer on the final delineated riparian ecotone boundary.

The updated riparian delineation model introduces a new delineation approach. This approach recognizes the dynamic and transitional nature of riparian ecotones by accounting for hydrologic, geomorphic, and vegetation data as inputs in the mapping process of riparian zones or ecotones boundary. Furthermore this approach permits the use of a hybrid land use/cover classification system within the mapped riparian boundary to help decision makers in their monitoring and conservation efforts within riparian ecotones.

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Appendix A
Python Code for the Second Generation Riparian Zone Delineation Model

```
################################################################################
# Program: RP_V2.2-riparian.py
# Purpose: deleniatin variable width reparian zones
#
# Inputs: streams, lakes, 10m DEM_float point, NWI
# Outputs: Variable Width Riparian Zone
#        1- Riparian Zones
#        2- Riparian Zones + NWI
# Author: Sinan Abood, Michigan technological University
#        saabood@mtu.edu
# Date:   06/14/2011
################################################################################


########################
# Declerations       #
########################
import arcpy, sys, traceback
import math, os, string, time
from arcpy import env
from arcpy import sys
from arcpy import os
from arcpy.sa import *

# check out the ArcGIS spatial Analyst extension
arcpy.CheckOutExtension("Spatial")
#try:
   #if arcpy.CheckExtension("Spatial") == "Available":
      #arcpy.CheckOutExtension("Spatial")
   #else:
      ## Raise a custom exception
      ##
      #raise LicenseError

#except LicenseError:
   #print "Spatial Analyst license is unavailable"
   #print "Please, Check the Spatial Analyst extention before running the Model"
#except:
   #print arcpy.GetMessages(2)
#finally:
   ## Check in the Spatial Analyst extension
```

```
    ##
    #arcpy.CheckInExtension("Spatial")



################################################################################
##
# Functionns
# delfile, AddprintMessage, insertsamplepoint, cartesianDist, Azimuth
################################################################################
##
def delfile(delfile):
    outtempstream = outpath + "\\" + delfile
    if arcpy.Exists(outtempstream):
        arcpy.RefreshCatalog(outtempstream)
        arcpy.AddMessage("Deleting file " + delfile + "......\n")
        print "Deleting file = " + delfile
        arcpy.Delete_management(outtempstream)

##############################################
# subroutine to insert sample points   ##
# into output.                         ##
##############################################
def insertsamplepoint(xi,yi,azimuthi,orderi,slopei,streamnumi,streampnti):
    pnti.X = xi
    pnti.Y = yi
    feati.azimuth = float(azimuthi)
    feati.StreamLeve = orderi
    feati.slope = slopei
    feati.Shape = pnti
    feati.streamnum = streamnumi
    feati.streampnt = streampnti
    curi.insertRow(feati)
##############################################
# subroutine to generate error msgs    ##
##############################################
def AddPrintMessage(msg, severity):
    print msg
    if severity == 0: arcpy.AddMessage(msg)
    elif severity == 1: arcpy.AddWarning(msg)
    elif severity == 2: arcpy.AddError(msg)
##############################################
# subroutine to calculate distance     ##
# between 2 points                     ##
##############################################
def CartesianDist(x1,y1,x2,y2):
```

```
    cdist = math.sqrt((x2 - x1)**2 + (y2 - y1)**2)
    return cdist
##########################################
# subroutine to calculate azimuth       ##
# between 2 points                      ##
##########################################
def Azimuth(x1,y1,x2,y2):
    if ((x1 == x2) and (y1 < y2)):
        Azimuth = 0
    elif ((x1 == x2) and (y1 > y2)):
        Azimuth = 180
    elif ((y1 == y2) and (x1 < x2)):
        Azimuth = 90
    elif ((y1 == y2) and (x1 > x2)):
        Azimuth = 270
    elif ((x1 < x2) and (y1 < y2)):
        Azimuth = 180 * ((math.atan(math.fabs(x1 - x2) / math.fabs(y1 - y2))) / 3.14159)
    elif ((x1 < x2) and (y1 > y2)):
        Azimuth = 180 * ((math.atan(math.fabs(y1 - y2) / math.fabs(x1 - x2))) / 3.14159) +
90
    elif ((x1 > x2) and (y1 > y2)):
        Azimuth = 180 * ((math.atan(math.fabs(x1 - x2) / math.fabs(y1 - y2))) / 3.14159) +
180
    elif ((x1 > x2) and (y1 < y2)):
        Azimuth = 180 * ((math.atan(math.fabs(y1 - y2) / math.fabs(x1 - x2))) / 3.14159) +
270
    return Azimuth


#########################################################################
#####
# this will create transects points 360 degree around each
# stream sample points
#########################################################################
#####
def
getconetransectpoints(xi,yi,slopei,streamlevi,orderi,pointi,streamnumi,streampnti,trandist
i,tranpointdist):
    if (slopei == 0):
        slopei = .000000000001
    extrapnts = 11
    i = 0
    while (i < extrapnts):
        i = i + 1
        totdisti = 0
        pointi = 0
```

```
        p1angle = (360/extrapnts) * i
        while (totdisti <= trandisti):
            totdisti = totdisti + tranpointdist
            newx = xi + (totdisti * math.cos(p1angle))
            newy = yi + (totdisti * math.sin(p1angle))
            pnti.X = newx
            pnti.Y = newy
            feati.ORDER_ = orderi
            feati.STREAMNUM = streamnumi
            feati.SLOPE = slopei
            feati.streamx = xi
            feati.streamy = yi
            feati.stream_ele = streamlevi
            feati.Shape = pnti
            feati.transect_n = i    #trani              #transect number (i+1)
            pointi = pointi + 1
            feati.point_num = pointi
            #feati.transect_l = 3                    #which side of stream - somewhat arbitrary in this case
            curi.insertRow(feati)

try:
    arcpy.AddMessage("Riparian Model Script Starts...")
    arcpy.AddMessage("Creating streambuffer ...\n")
    arcpy.OverwriteOutput = 1
    starttime = time.clock()
    streamlayer  = str(sys.argv[1])
    streamQ = str(sys.argv[2])
    lakeslayer = str(sys.argv[3])
    buffervalue = float(sys.argv[4])
    watershed = str(sys.argv[5])
    indem = str(sys.argv[6])
    floodheight = float(sys.argv[7])
    majfilter = bool(sys.argv[8])
    #inNWI = str(sys.argv[8])
    #wetlands = str(sys.argv[9])
    #inHydricClass = str(sys.argv[10])
    #hydricclass = str(sys.argv[11])
    #inDrianageClass = str(sys.argv[12])
    #drianageclass = str(sys.argv[13])
    #inHydrologicSoil = str(sys.argv[14])
    #hydrologicsoil = str(sys.argv[15])
    dem = indem
    spatialxy = arcpy.GetRasterProperties_management( dem, "CELLSIZEX")
    pixelsize = float(str(spatialxy))
    template = streamlayer
```

```
streams_wsh = "streams_wsh"
streams_selected = "streams_selected"
lakes_wsh = "lakes_wsh"
lakebuffer = "lakebuffer"

desc_st = arcpy.Describe
fullpath = desc_st(streamlayer).CatalogPath
outpath = (os.path.split(fullpath)[0])
env.workspace = outpath
arcpy.AddMessage("Outpath =" + outpath)
#========================================
# Scaning and Cleaning the geodatabase
#========================================
arcpy.AddMessage("Scanning and Cleaning the geodatabase...\n")
delfile("lakebuffer")
delfile("streams_wsh")
delfile("streams_selected")
delfile("lakes_wsh")
delfile("streamsnol")
delfile("sample_points")
delfile("tempstream")
delfile("temp_points_elev")
delfile("sample_points_elev")
delfile("transects")
delfile("transects_elev")
delfile("transects_cleaned")
delfile("pointraster")
delfile("riparian")
delfile("riparian_poly")
delfile("riparian_dissolve")
delfile("riparian_single")
delfile("riparian_V1_10m")
delfile("riparian_lpr")
delfile("rasterpoint")
delfile("raster_int")
delfile("rasterpointclean")
delfile("riparian_smooth")
delfile("riparian_clean")
delfile("lakebuffer_adjacent")
delfile("lakebuffer_lyr")
delfile("lprNWI")
delfile("lprNWI_dissolve")
delfile("lprNWI_multi")
delfile("lprNWI_adjacent")
delfile("riparian_nwi")
delfile("dsd_adjacent")
```

```
   delfile("dsd_dissolve")
   delfile("dsd_drianage_Criteria")
   delfile("dsd_Hydric_Criteria")
   delfile("dsd_hydrologic_Criteria")
   delfile("dsd_intersect")
   delfile("dsd_multi")
   delfile("dsd_multi_lyr")
   delfile("riparian_dsd")
   delfile("rpz_dsd")

   #=================================
   fclist = streamlayer
   outSR = arcpy.CreateSpatialReference_management("", streamlayer, "", "", "", fclist,
100)
   ##############################################################
   #  Clipping lakes to the selected watershed
   #  Create a 100' (30.48 m) buffer around the lakes.
   #  the buffer distance can be a /////variable/////
   ##############################################################
   arcpy.Clip_analysis(lakeslayer, watershed, lakes_wsh)
   arcpy.AddMessage("Creating lake buffer......\n")
   arcpy.Buffer_analysis(lakes_wsh,"lakebuffer",buffervalue)
   #############################################################
   # Clipping streams with the selected watershed
   # Selecting Streams according to FCode
   ############################################################
   arcpy.Clip_analysis(streamlayer, watershed, streams_wsh)
   arcpy.Select_analysis(streams_wsh, streams_selected, streamQ)


   ##############################################################
   #  Create a feature class containing the stream data without the portion
   #  of the stream running through the lakes.
   ##############################################################
   arcpy.AddMessage("Dissolving Streams......\n")
   arcpy.Dissolve_management(streams_selected,"tempstream","StreamLeve")
#REACHCODE
   arcpy.AddMessage("Creating stream layer without lakes......\n")
   arcpy.Erase_analysis("tempstream",lakeslayer,"streamsnol")


###########################################################################
######################
   # script (samplepoints starts)

###########################################################################
```

```
#####################
    arcpy.AddMessage("Creating samplepoints along streams network... \n")
    ############################################
    # Constants and housekeeping
    ############################################
    infc_samplepoint = "streamsnol"   #str(sys.argv[1])
    #pixelsize = long(10)    #long(sys.argv[3])
    pixelratio = float(0.75)     #float(sys.argv[4])                    # constant that
determines distance between sample points
    sample_points = "sample_points"
    sample_points_elev = "sample_points_elev"       #sys.argv[4]
    pointdist = pixelratio * pixelsize
    template_samplepoint = infc_samplepoint
    ############################################
    #Get Inputs (feature class and feature id)
    ############################################
    outlayer_samplepoint = outpath + "\\" + sample_points
    ########################################
    #  Create output sample point set   ####
    ########################################
    fclist_samplepoint = infc_samplepoint
    arcpy.AddMessage("infc_samplepoint = " + infc_samplepoint + "\n")
    outSR_samplepoint = arcpy.CreateSpatialReference_management("",
infc_samplepoint, "", "", "", fclist_samplepoint, 100)
    arcpy.CreateFeatureclass_management(outpath, sample_points,"POINT",
template_samplepoint,"DISABLED","DISABLED",outSR_samplepoint)
    arcpy.AddField_management(sample_points, "azimuth", "FLOAT")
    arcpy.AddField_management(sample_points, "slope", "FLOAT")
    arcpy.AddField_management(sample_points, "streamnum", "LONG")
    arcpy.AddField_management(sample_points, "streampnt", "LONG")
    arcpy.AddMessage("Created Output Layer:" + sample_points + "\n")
    ######################################################
    # Generate sample points by following stream segments
    ######################################################
    desc_samplepoint = arcpy.Describe(infc_samplepoint)
    rows = arcpy.SearchCursor(infc_samplepoint)
    row = rows.next()
    rowcount = 0
    curi = arcpy.InsertCursor(outlayer_samplepoint)
    pnti = arcpy.CreateObject("point")
    feati = curi.newRow()
    streamnum = 0              #stream segment number for correcting elevations
    while row:
        streampnt = 0          #sample point num on stream segment
        streamnum = streamnum + 1
        #get the geometry of the feature in question.
```

```
        feature = row.getValue(desc_samplepoint.ShapeFieldName)
        #if the feature class is of type polyline
        if desc_samplepoint.ShapeType.lower() == "polyline":
            rowcount = rowcount + 1
            partcount = feature.partCount
            neworder = row.getValue("StreamLeve")  #save for output to sample points
            arcpy.AddMessage("Processing Next stream segement:" + str(rowcount) + "\n")
            partnumber = 0
            #cycle through the parts
            while partnumber < partcount:
                part = feature.getPart(partnumber)
                pnt = part.next()
                pointnumber = 0
                #cycle through the points in each part
                leftdist = 0            #leftdist is distance left over between line segments
                while pnt:
                    lastx = pnt.X
                    lasty = pnt.Y
                    #Get the next point in the part
                    pnt = part.next()
                    if pnt:
                        dist = CartesianDist(lastx, lasty, pnt.X, pnt.Y)
                        azim = Azimuth(lastx, lasty, pnt.X, pnt.Y)
                        ###################################################
                        ##  Calculate the sample point locations #######
                        ###################################################
                        totdist = dist     # total length of segment
                        numsamppoints = 1      #number of sample points on line segment
                        newpointratio = ((pointdist*numsamppoints)-leftdist)/totdist
            #pointdist is a constant based on pixel size
                        while (newpointratio <= 1):
                            #we have enough distance to get a point in
                            newx = ((pnt.X - lastx)* newpointratio) + lastx
                            newy = ((pnt.Y - lasty)* newpointratio) + lasty
                            run = pnt.X - lastx
                            if run == 0:
                                run = .000000000000000000001
                            slope = (pnt.Y - lasty)/run
                            streampnt = streampnt + 1

insertsamplepoint(newx,newy,azim,neworder,slope,streamnum,streampnt)
                            numsamppoints = numsamppoints + 1
                            newpointratio = ((pointdist*numsamppoints)-leftdist)/totdist
            #pointdist is a constant based on pixel size
                        leftdist = totdist - ((numsamppoints-1)*pointdist) + leftdist  #use on next
line segment
```

```
                pointnumber += 1
            #end of while pnt
            partnumber = partnumber + 1
        else:
            arcpy.AddMessage("Input file must be of type polyline.\n")

        row = rows.next()
        if streampnt == 0:          #stream segment was too short to get a point in
            streamnum = streamnum - 1

    AddPrintMessage("\n", 0)
    arcpy.AddMessage("Creating samplepoints completed...\n")

    #####################################################
    #  End of Sample point generation section      #####
    #####################################################

#########################################################################
#############################

    #####################################################
    #  Now get the elevation of the sample points ######
    #####################################################
    arcpy.AddMessage("Getting elevation of sample points....\n")
    ExtractValuesToPoints(sample_points, dem, sample_points_elev, "NONE",
"VALUE_ONLY")
    #####################################################
    # Now correct elevations of sample points that do ##
    # not consistently rise or fall when going down   ##
    # the stream.                                     ##
    #####################################################

#########################################################################
###
    # cleaning the sample_points_elev from "RASTERVALU" = -9999
#########################################################################
###
    arcpy.AddMessage("Cleaning elevations with RASTERVALU = -9999...\n")
    rows = arcpy.UpdateCursor(sample_points_elev,"", "", "RASTERVALU", "")
    row = rows.next()
    while row:
        thiselev = row.getValue("RASTERVALU")
        if thiselev == -9999:
            rows.deleteRow(row)
        row = rows.next()
```

```
    del row
    del rows
    #del feature
    arcpy.AddMessage("Getting samplepoints elevations completed...")

#############################################################################
#################################

    arcpy.AddMessage("Generating transects starts...\n")
    arcpy.CheckOutExtension("Spatial")
    ###############################################
    # Constants - get this values from input or determine for final program
    ###############################################
    infc = sample_points_elev            #input sample_points_elev
    #pixelsize = long(10)              #long(sys.argv[2])
    pixelratio = float(0.75)              #float(sys.argv[3])           # constant that determines
distance between sample points
    numpixels = long(50)              #long(sys.argv[4])           #number of pixels to go out
on transect
    startpoint = long(1)              #long(sys.argv[5])
    endpoint = long(9999999)           #(sys.argv[6])
    transects_elev = "transects_elev"          #str(sys.argv[3])          #output transects
"transects_elevnew"
    transects = "transects"
    transects_cleaned = "transects_cleaned"

    ###########################################
    #  Cleanup old output files        ####
    ###########################################
    template = infc
    outlayer = outpath + "\\" + transects
    ###########################################
    #  Create output transect set   ####
    ###########################################
    desc_transects = arcpy.Describe(infc)
    fclist = infc
    arcpy.AddMessage("infc=" + infc + "\n")
    outSR = arcpy.CreateSpatialReference_management("", infc, "", "", "", fclist, 100)
    arcpy.CreateFeatureclass_management(outpath,
transects,"POINT","","DISABLED","DISABLED",outSR)
    arcpy.AddField_management(transects, "ORDER_", "FLOAT")
    arcpy.AddField_management(transects, "streamx", "DOUBLE")         #x coordinate of
stream
    arcpy.AddField_management(transects, "streamy", "DOUBLE")         #y coordinate of
stream
```

```
    arcpy.AddField_management(transects, "SLOPE", "FLOAT")             #carry through
for short transects
    arcpy.AddField_management(transects, "streamnum", "LONG")            #for use later
on
    arcpy.AddField_management(transects, "transect_n", "LONG")              #identifies
transect
    arcpy.AddField_management(transects, "point_num", "LONG")              #identifies
which point in transect
    #arcpy.AddField_management(transects, "transect_l", "LONG", 6)            #identifies
which side of stream
    arcpy.AddField_management(transects, "stream_ele", "FLOAT")
    arcpy.AddMessage("Created Output Layer:" + transects + "\n")
    #########################################################
    # Generate transects for desired sample points
    #########################################################
    query = "OBJECTID BETWEEN 1 AND 999999999"
    arcpy.AddMessage("Generating transects, please be patient.............\n")
    transectnum = 0              #this field will track the transect number later used in
determining buffer
    rows = arcpy.SearchCursor(infc,query)
    pnti = arcpy.CreateObject("point")
    curi = arcpy.InsertCursor(outlayer)
    feati = curi.newRow()
    row = rows.next()
    while row:
        #get the geometry of the feature in question.
        feature = row.getValue(desc_transects.ShapeFieldName)
        if desc_transects.ShapeType.lower() == "point":
            pnt = feature.getPart(1)
            neworder = row.getValue("StreamLeve")   #save for output to sample points
            newstreamnum = row.getValue("STREAMNUM")    #save for output to sample
points
            newstreampnt = row.getValue("STREAMPNT")     #which point on the stream
segment
            newstream_elev = row.getValue("RASTERVALU")
            new_slope = row.getValue("SLOPE")   #slope of line passing through stream
            trandist = numpixels * pixelsize             #length of transect(length of the total
transects vector)
            tranpointdist = pixelratio * pixelsize     #distance between points on transect
            point_num = 0                        #which point on the transect

getconetransectpoints(pnt.X,pnt.Y,new_slope,newstream_elev,neworder,point_num,news
treamnum,newstreampnt,trandist,tranpointdist)   #create transect point
            #end of while
        else:
            arcpy.AddMessage("Input file must be of type point.\n")
```

```
        row = rows.next()
    AddPrintMessage("\n", 0)
    del row
    del rows
    del curi
    del pnti
    del feati
    ####################################################
    #  End of transects generation section      #####
    ####################################################
    arcpy.AddMessage("Generating transects points completed.\n")
    arcpy.AddMessage("Getting elevation for transects points.\n")
    ExtractValuesToPoints(transects, dem, transects_elev, "NONE", "VALUE_ONLY")
    #query_0 = "RASTERVALU - STREAM_ELE = 0 OR RASTERVALU - STREAM_ELE = 1"
    #arcpy.AddMessage("Separating transects points with elevation diffrence = or less than 1m.\n")
    arcpy.Select_analysis(transects_elev, transects_cleaned)
    arcpy.AddMessage("Transects phase completed.\n")

###################################################################################
    # First Cleaning phase
###################################################################################

    arcpy.AddMessage("First step cleaning...\n")
    cur = arcpy.UpdateCursor(transects_cleaned)
    row = cur.next()
    i = 1
    flag = 000
    while row:
        pointnum = row.getValue("POINT_NUM")
        streamele = row.getValue("STREAM_ELE")
        rastervalu = row.getValue("RASTERVALU")
        if pointnum == 1:
            flag = 000
        if pointnum == i:
            if (rastervalu - streamele > floodheight) or (rastervalu - streamele <= -floodheight) or flag == 111:
                cur.deleteRow(row)
                flag = 111
            else:
                flag = 000
        i = i + 1
        if i == 28:
```

```
            i = 1
            flag = 000
        row = cur.next()

###########################################################
    # Second Cleaning Phase
###########################################################
    arcpy.AddMessage("Second Step cleaning...\n")
    cur = arcpy.UpdateCursor(transects_cleaned)
    row = cur.next()
    i = 1
    flag = 000
    while row:
        pointnum = row.getValue("POINT_NUM")
        streamele = row.getValue("STREAM_ELE")
        rastervalu = row.getValue("RASTERVALU")
        if pointnum == 1:
            flag = 000
        if (rastervalu - streamele == floodheight) or (rastervalu - streamele == - floodheight)
or flag == 111:
            cur.deleteRow(row)
            flag = 111
        else:
            flag = 000

        row = cur.next()

###############################################
        # last step
###############################################

    #temp1 = "rasterpoint"
    rasterpoint = "rasterpoint"
    #temp2 = "raster_int"
    #temp3 = "lakebuffer"
    lakebuffer = "lakebuffer"
    #temp33 = "rasterclean"
    #temp4 = "riparian_smooth"
    riparian_poly = "riparian_poly"
    riparian_smooth = "riparian_smooth"
    riparian = "riparian"
    riparian_dissolve = "riparian_dissolve"
    riparian_single = "riparian_single"
    riparian_clean = "riparian_clean"
    riparian_V1_10m = "riparian_V1_10m"
    feature_dataset_fds = watershed + "_fds"
```

```
    rpz = watershed + "_riparian"
    watershed_fds = watershed + "_watershed"
    streams_fds = watershed + "_streams"
    lakes_fds = watershed + "_lakes"
    nwi_fds = watershed + "_riparian_nwi"
    dsd_fds = watershed + "_riparian_dsd"
    riparian_single_lyr = "riparian_single_lyr"
    streams_wsh_lyr = "streams_wsh_lyr"
    streams_selected_lyr = "streams_selected_lyr"
    lakebuffer_lyr = "lakebuffer_lyr"
    lakebuffer_adjacent = "lakebuffer_adjacent"

    arcpy.AddMessage("Wraping up Step......\n")
    # Creating raster from the point feature transects
    arcpy.PointToRaster_conversion(transects_cleaned, "RASTERVALU", rasterpoint,
"MOST_FREQUENT", "NONE", "10")
    # convert float point raster to integer
    raster_int = Int(rasterpoint)
    raster_int.save()
    # cleaning the raster boundary
    rasterclean = BoundaryClean(raster_int, "NO_SORT","ONE_WAY")   #"NO_SORT",
"TWO_WAY")   #raster_int
    # use Majority filter for more boundary smoothing (optional)
    if majfilter == True:
        outmajfilter = MajorityFilter(rasterclean, "FOUR", "MAJORITY")
        inputraster = outmajfilter
    else:
        inputraster = rasterclean
    # Creating polygon from raster
    arcpy.RasterToPolygon_conversion(inputraster, riparian_poly, "SIMPLIFY",
"VALUE")
    # Dissolving all polygons
    arcpy.Dissolve_management(riparian_poly, riparian_dissolve)
    # Multi to single part
    arcpy.MultipartToSinglepart_management(riparian_dissolve, riparian_single)
    arcpy.DeleteField_management(riparian_single, "ORIG_FID")
    # Removing irregular shapes from the riparian layer
    # Convert to feature layer
    arcpy.MakeFeatureLayer_management(riparian_single, riparian_single_lyr)
    #arcpy.MakeFeatureLayer_management(streams_wsh, streams_wsh_lyr)
    arcpy.MakeFeatureLayer_management(streams_selected, streams_selected_lyr)
    # Select the riparian zones from irregular shapes
    arcpy.SelectLayerByLocation_management(riparian_single_lyr, "INTERSECT",
streams_selected_lyr, "", "NEW_SELECTION")
    # Select the clean riparian zone
    arcpy.Select_analysis(riparian_single_lyr, riparian_clean)
```

```
    # Smoothing polygons
    arcpy.SmoothPolygon_cartography(riparian_clean, riparian_smooth, "PAEK", "30")
    # Removing un adjacent lakes to riparian zones
    # Adding lake buffer to the riparian zones
    arcpy.MakeFeatureLayer_management(lakebuffer, lakebuffer_lyr)
    arcpy.SelectLayerByLocation_management(lakebuffer_lyr, "INTERSECT",
riparian_single_lyr, "", "NEW_SELECTION")
    arcpy.Select_analysis(lakebuffer_lyr, lakebuffer_adjacent)

    desc = arcpy.Describe(lakebuffer_adjacent)
    arcpy.DeleteField_management(lakebuffer_adjacent, "AREA; PERIMETER;
LAKES_; LAKES_ID;LKSRGO2_AR; LKSRGO2_PE; LAKE_OPE_; LAKE_OPE_I;
WB_TYPE; DEPTH_DESC; HAB_CLASS; WB_DESC; LAKE_SOURC; NWI_CODE;
ALT_NAME; SL_CLASS; Shape_Leng; Acreage; BUFF_DIST; LAKE_TYPE; NAME;
UNIQUE_ID; LAKE_NAME; COUNTY; NOTE24; NEW_KEY; HECTARES;
ACRES_GIS; FMU; Shape_Le_1; Shape_Le_2; Acres; ComID; FDate; Resolution;
GNIS_ID; GNIS_Name; AreaSqKm; Elevation; ReachCode; FType; FCode")
    appendlist = lakebuffer_adjacent
    arcpy.AddMessage("Adding adjacent lakebuffer to final buffer.\n")
    arcpy.Append_management(appendlist,riparian_smooth,"TEST")
    arcpy.Dissolve_management(riparian_smooth, riparian)


    # NWI part
    #----------------------------

    # NWi model variables
    #lprNWI = "lprNWI"
    #lprNWI_dissolve = "lprNWI_dissolve"
    #lprNWI_multi = "lprNWI_multi"
    #lprNWI_multi_lyr = "lprNWI_multi_lyr"
    #lprNWI_adjacent = "lprNWI_adjacent"
    #riparian_lpr = "riparian_lpr"
    #riparian_nwi = "riparian_nwi"

    #arcpy.AddMessage("NWI Module Started.....")
    #arcpy.AddMessage("   ")
    ## Selecting Palustrine, Lacustrine and Riverine wetlands
    #arcpy.Select_analysis(inNWI, lprNWI, wetlands)
    ## Deissolving all wetlands polygons
    #arcpy.Dissolve_management(lprNWI, lprNWI_dissolve)
    ## Converting multi part wetlands polygons to single part
    #arcpy.MultipartToSinglepart_management(lprNWI_dissolve, lprNWI_multi)
    ## Creating feature layer
    #arcpy.MakeFeatureLayer_management(lprNWI_dissolve, lprNWI_multi_lyr)
    ## Highlighting adjacent wetlands
```

```
   #arcpy.SelectLayerByLocation_management(lprNWI_multi_lyr, "INTERSECT",
riparian, "", "NEW_SELECTION")
   #arcpy.Select_analysis(lprNWI_multi_lyr,lprNWI_adjacent, "")
   ## Merging riaprain zones with selected nwi criteria
   #arcpy.Merge_management([riparian, lprNWI_adjacent], riparian_lpr, "")
   ## Dissolving all in one Layer
   #arcpy.Dissolve_management(riparian_lpr, riparian_nwi)
   #arcpy.AddMessage("Riparian buffer with NWI layer is generated.\n")

   ## Digital Soil Data part
   ##-----------------------------

   ## DSD model parameters
   #dsd_Hydric_Criteria = "dsd_Hydric_Criteria"
   #dsd_drianage_Criteria = "dsd_drianage_Criteria"
   #dsd_hydrologic_Criteria = "dsd_hydrologic_Criteria"
   #dsd_intersect = "dsd_intersect"
   #dsd_dissolve = "dsd_dissolve"
   #dsd_multi = "dsd_multi"
   #dsd_multi_lyr = "dsd_multi_lyr"
   #dsd_adjacent = "dsd_adjacent"
   #riparian_dsd = "riparian_dsd"
   #rpz_dsd = "rpz_dsd"


   #arcpy.AddMessage("DSD Module Started.....")
   #arcpy.AddMessage("   ")
   ## Selecting All Soil Criteria
   #arcpy.Select_analysis(inHydricClass, dsd_Hydric_Criteria, hydricclass)
   #arcpy.Select_analysis(inDrianageClass, dsd_drianage_Criteria, drianageclass)
   #arcpy.Select_analysis(inHydrologicSoil, dsd_hydrologic_Criteria, hydrologicsoil)
   ## Intersecting All Soil Criteria
   #infeatures = ["dsd_Hydric_Criteria", "dsd_drianage_Criteria",
"dsd_hydrologic_Criteria"]
   #arcpy.Intersect_analysis(infeatures, dsd_intersect, "", "", "")
   ## Dissolving All Soil Criteria Polygons
   #arcpy.Dissolve_management(dsd_intersect, dsd_dissolve)
   ## Converting multi part to single part
   #arcpy.MultipartToSinglepart_management(dsd_dissolve, dsd_multi)
   ## Creating feature layer
   #arcpy.MakeFeatureLayer_management(dsd_multi, dsd_multi_lyr)
   ## Highlighting adjacent Soil Polygon
   #arcpy.SelectLayerByLocation_management(dsd_multi_lyr, "INTERSECT", riparian,
"", "NEW_SELECTION")
   #arcpy.Select_analysis(dsd_multi_lyr,dsd_adjacent, "")
   ## Merging riaprain zones with lpr
```

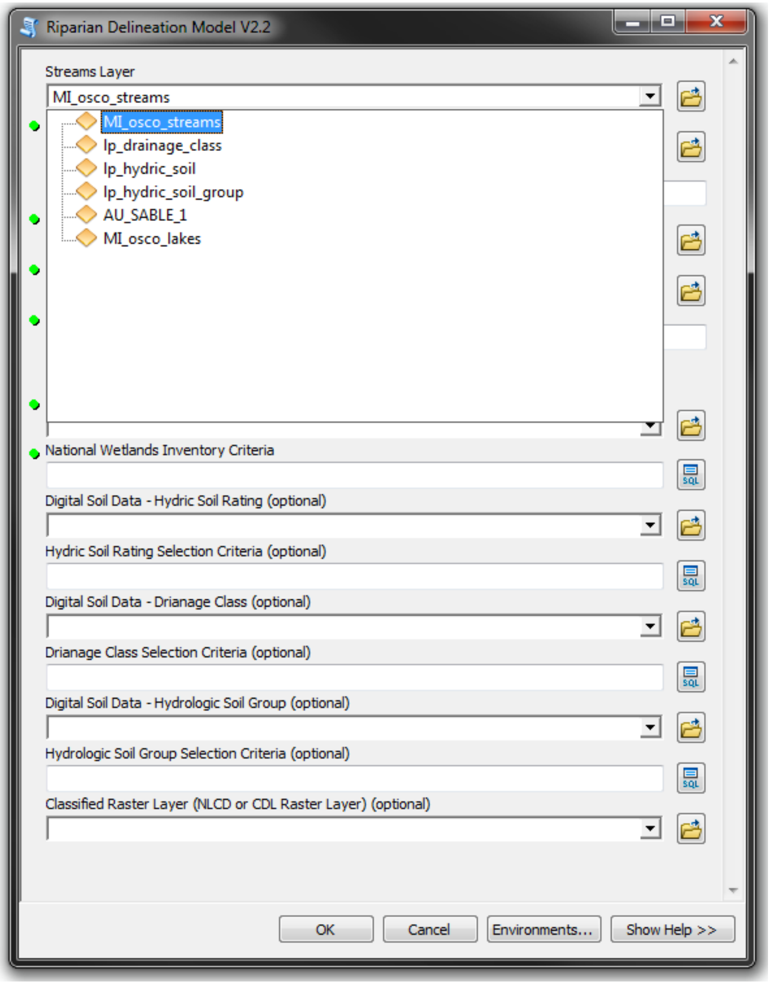
```
    #arcpy.Merge_management([riparian, dsd_adjacent], riparian_dsd, "")
    ## Dissolving all in one Layer
    #arcpy.Dissolve_management(riparian_dsd, rpz_dsd)
    #arcpy.AddMessage("Riparian buffer with DSD layer is generated.\n")

    # Creating feature dataset and exporting the result layers into it
    # Check if the feature dataset already exists
    if arcpy.Exists(feature_dataset_fds):
        arcpy.AddMessage(feature_dataset_fds + "...feature dataset already exists")
        arcpy.AddMessage("     ")
        # scanning and cleaning the feature dataset
        if arcpy.Exists(outpath + "\\" + feature_dataset_fds + "\\" + rpz):
            arcpy.Delete_management(outpath + "\\" + feature_dataset_fds + "\\" + rpz)
            arcpy.AddMessage(rpz + "...feature class deleted...\n")
            arcpy.AddMessage("     ")
        if arcpy.Exists(outpath + "\\" + feature_dataset_fds + "\\" + watershed_fds):
            arcpy.AddMessage(watershed_fds + "...feature class already exists...\n")
            arcpy.AddMessage("     ")
        if arcpy.Exists(outpath + "\\" + feature_dataset_fds + "\\" + streams_fds):
            arcpy.AddMessage(streams_fds + "...feature class already exists...\n")
            arcpy.AddMessage("     ")
        if arcpy.Exists(outpath + "\\" + feature_dataset_fds + "\\" + lakes_fds):
            arcpy.AddMessage(lakes_fds + "...feature class already exists...\n")
            arcpy.AddMessage("     ")
        if arcpy.Exists(outpath + "\\" + feature_dataset_fds + "\\" + nwi_fds):
            arcpy.AddMessage(nwi_fds + "...feature class already exists...\n")
            arcpy.AddMessage("     ")
        if arcpy.Exists(outpath + "\\" + feature_dataset_fds + "\\" + dsd_fds):
            arcpy.AddMessage(dsd_fds + "...feature class already exists...\n")
            arcpy.AddMessage("     ")
    else:
        sr = arcpy.CreateSpatialReference_management("#", template, "", "", "", "", "0")
        arcpy.CreateFeatureDataset_management(outpath, feature_dataset_fds, sr)
        arcpy.AddMessage(feature_dataset_fds + "...had been created...\n")
        arcpy.AddMessage("     ")

    # Exporting featureclasses inside featuredataset for each watershed
    if not arcpy.Exists(outpath + "\\" + feature_dataset_fds + "\\" + rpz):
        arcpy.FeatureClassToFeatureClass_conversion(riparian, feature_dataset_fds, rpz)
        arcpy.AddMessage("New riparian layer exported inside " + feature_dataset_fds)
        arcpy.AddMessage("     ")

    if not arcpy.Exists(outpath + "\\" + feature_dataset_fds + "\\" + watershed_fds):
        arcpy.FeatureClassToFeatureClass_conversion(watershed, feature_dataset_fds,
watershed_fds)
        arcpy.AddMessage("watershed layer exported inside " + feature_dataset_fds)
```

```
        arcpy.AddMessage("     ")

    if not arcpy.Exists(outpath + "\\" + feature_dataset_fds + "\\" + streams_fds):
        arcpy.FeatureClassToFeatureClass_conversion(streams_wsh, feature_dataset_fds,
streams_fds)
        arcpy.AddMessage("streams layer exported inside " + feature_dataset_fds)
        arcpy.AddMessage("     ")

    if not arcpy.Exists(outpath + "\\" + feature_dataset_fds + "\\" + streams_fds):
        arcpy.FeatureClassToFeatureClass_conversion(streams_selected,
feature_dataset_fds, streams_fds)
        arcpy.AddMessage("selected streams layer exported inside " + feature_dataset_fds)
        arcpy.AddMessage("     ")

    if not arcpy.Exists(outpath + "\\" + feature_dataset_fds + "\\" + lakes_fds):
        arcpy.FeatureClassToFeatureClass_conversion(lakes_wsh, feature_dataset_fds,
lakes_fds)
        arcpy.AddMessage("lakes layer exported inside " + feature_dataset_fds)
        arcpy.AddMessage("     ")

    if not arcpy.Exists(outpath + "\\" + feature_dataset_fds + "\\" + nwi_fds):
        arcpy.FeatureClassToFeatureClass_conversion(riparian_lpr, feature_dataset_fds,
nwi_fds)
        arcpy.AddMessage("riparian + nwi layer exported inside " + feature_dataset_fds)
        arcpy.AddMessage("     ")

    if not arcpy.Exists(outpath + "\\" + feature_dataset_fds + "\\" + dsd_fds):
        arcpy.FeatureClassToFeatureClass_conversion(rpz_dsd, feature_dataset_fds,
dsd_fds)
        arcpy.AddMessage("riparian + dsd layer exported inside " + feature_dataset_fds)
        arcpy.AddMessage("     ")


    # Deleting unwanted files
    arcpy.AddMessage("Deleting intermediate layers...\n")
    delfile("lakebuffer")
    delfile("streams_wsh")
    delfile("lakes_wsh")
    delfile("streamsnol")
    delfile("sample_points")
    delfile("tempstream")
    delfile("temp_points_elev")
    delfile("sample_points_elev")
    delfile("transects")
    delfile("transects_elev")
    delfile("transects_cleaned")
```

```
    delfile("pointraster")
    #delfile("riparian")
    delfile("riparian_poly")
    delfile("riparian_dissolve")
    delfile("riparian_single")
    delfile("riparian_V1_10m")
    delfile("riparian_lpr")
    delfile("rasterpoint")
    delfile("raster_int")
    delfile("rasterpointclean")
    delfile("riparian_smooth")
    delfile("riparian_clean")
    delfile("lprNWI")
    delfile("lprNWI_dissolve")
    delfile("lprNWI_multi")
    delfile("lprNWI_adjacent")
    #delfile("riparian_nwi")
    delfile("dsd_adjacent")
    delfile("dsd_dissolve")
    delfile("dsd_drianage_Criteria")
    delfile("dsd_Hydric_Criteria")
    delfile("dsd_hydrologic_Criteria")
    delfile("dsd_intersect")
    delfile("dsd_multi")
    delfile("dsd_multi_lyr")
    #delfile("riparian_dsd")
    delfile("rpz_dsd")
    delfile("lakebuffer_adjacent")
    delfile("lakebuffer_lyr")


    stoptime = time.clock()
    elaptime = stoptime - starttime
    print "Process time =" + str(round(elaptime))

except:
    tb = sys.exc_info()[2]
    tbinfo = traceback.format_tb(tb)[0]
    pymsg = "PYTHON ERRORS:\nTraceback Info:\n" + tbinfo + "\nError Info:\n    " + \
          str(sys.exc_type)+ ": " + str(sys.exc_value) + "\n"
    AddPrintMessage(pymsg, 2)

    msgs = "arcpy ERRORS:\n" + arcpy.GetMessages(2) + "\n"
    AddPrintMessage(msgs, 2)
```

Appendix B
Riparian Delineation Model Interface.

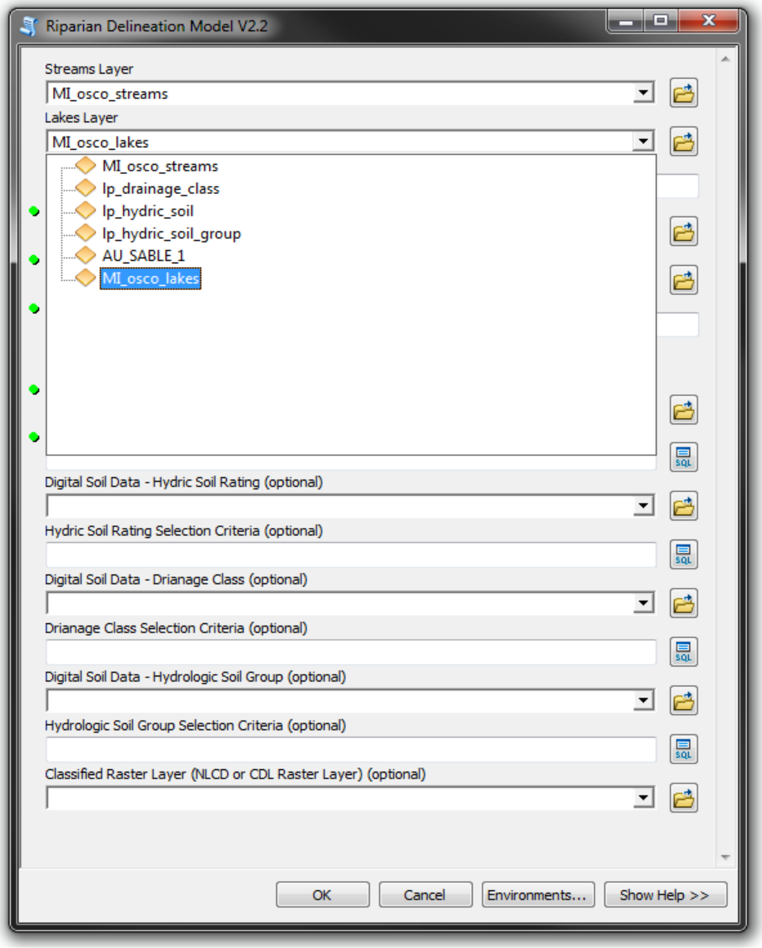
The second generation Riparian Delineation model (version 2.2) is compiled as an ArcToolbox attached to ArcGIS 10 software. The model interface consists of several required and optional inputs. The first input is the streams layer. The streams layer input represents the surface water streams network produced by the National Hydrography Dataset (NHD). The NHD streams layer can be downloaded at the National Map NHD viewer http://viewer.nationalmap.gov/viewer/nhd.html?p=nhd. The downloaded data is in a Geodatabase (GDBF) format. The Geodatabase contains spatial layers such as streams, lakes, ponds, and watersheds boundaries and many attributes tables such as flow lines. The green dot to the left of the streams layer filed indicates that this input layer is required to run the model (Figure B.1).



Streams Layer: MI_osco_streams

Figure B.1. Inputting streams layer into the model.

The second input is the lakes layer. The lakes layer is found within the downloaded NHD goedatabase (Figure B.2).



Streams Layer
MI_osco_streams
Lakes Layer
MI_osco_lakes

- MI_osco_streams
- lp_drainage_class
- lp_hydric_soil
- lp_hydric_soil_group
- AU_SABLE_1
- MI_osco_lakes

Digital Soil Data - Hydric Soil Rating (optional)
Hydric Soil Rating Selection Criteria (optional)
Digital Soil Data - Drianage Class (optional)
Drianage Class Selection Criteria (optional)
Digital Soil Data - Hydrologic Soil Group (optional)
Hydrologic Soil Group Selection Criteria (optional)
Classified Raster Layer (NLCD or CDL Raster Layer) (optional)

Figure B.2. Inputting lakes layer into the model.

The third required input is the buffer value around each lake. This value is predefined and equals 30.48 m as recommended Ilhardt *et al.* (2000). The buffer value can be modified according to user preference (Figure B.3).

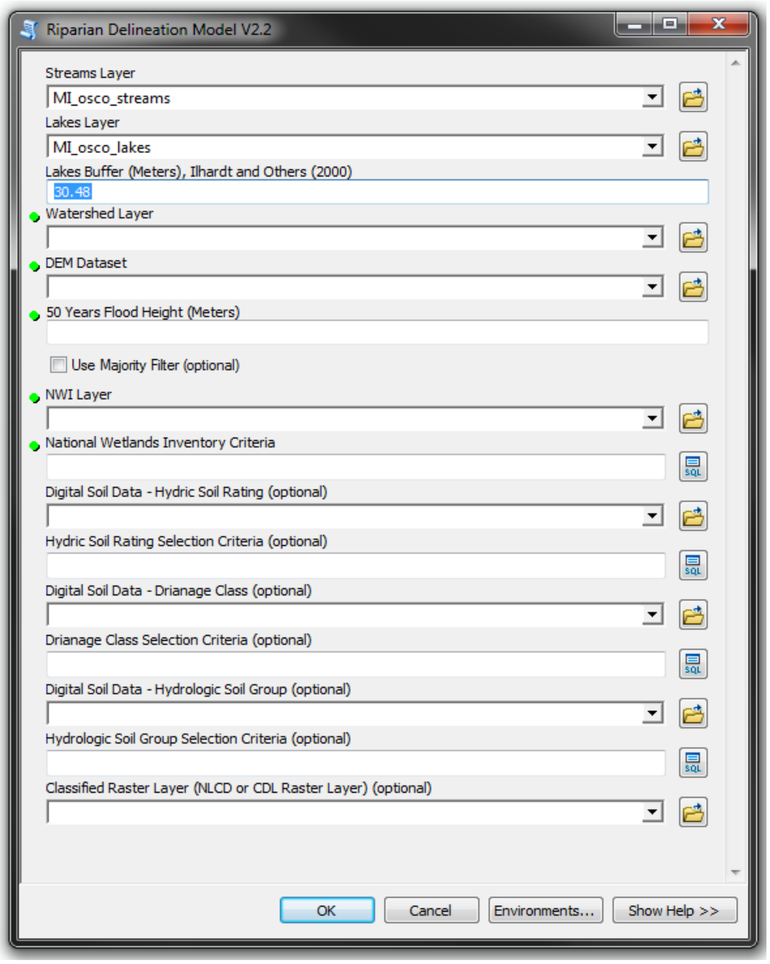
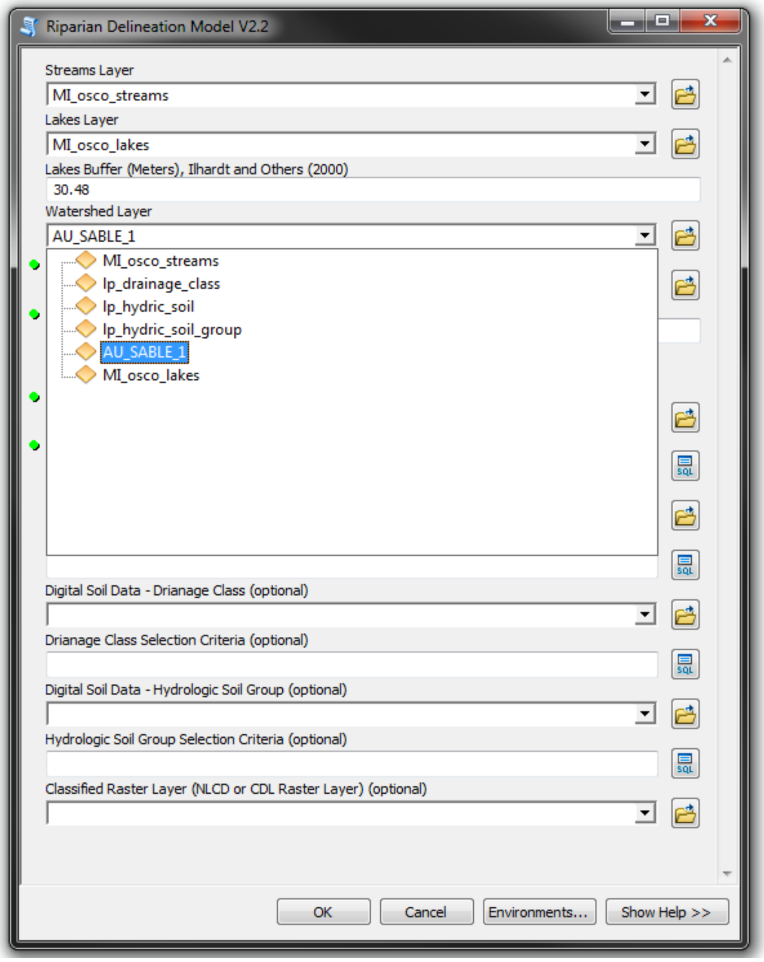

Streams Layer: MI_osco_streams
Lakes Layer: MI_osco_lakes
Lakes Buffer (Meters), Ilhardt and Others (2000): 30.48

Figure B.3. The lakes buffer value.

The watershed layer is an important input to the model. This layer guides the delineation process to be implemented within the specified watershed boundary. The watershed layer is part of the NHD Geodatabase (Figure B.4).



Streams Layer: MI_osco_streams

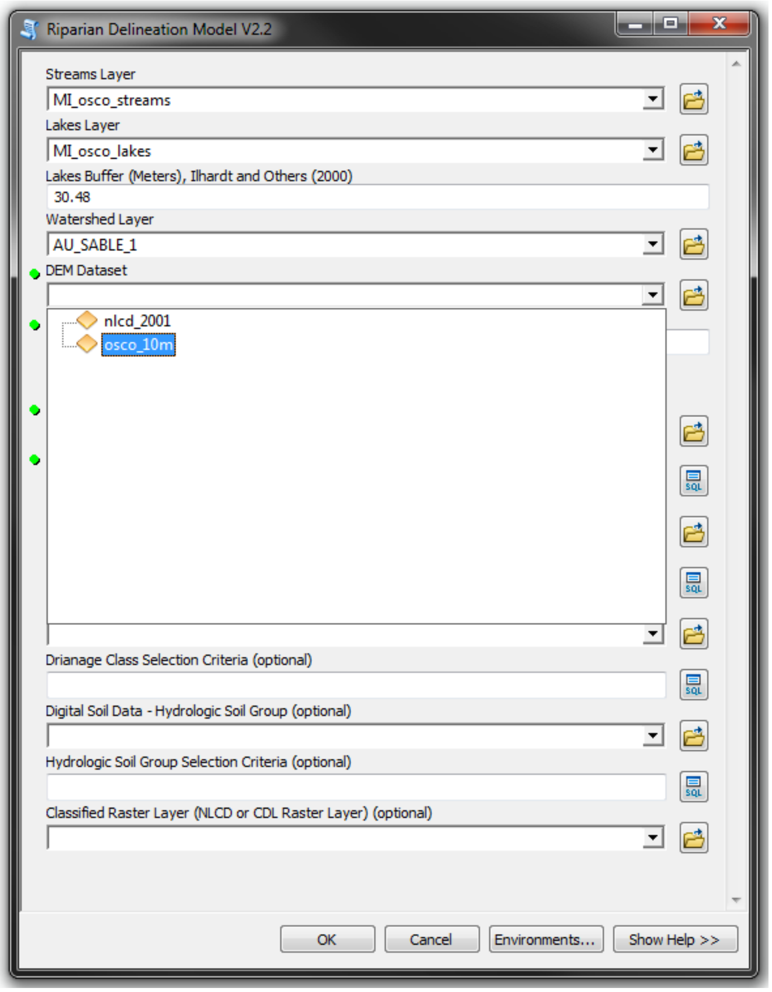
Lakes Layer: MI_osco_lakes

Lakes Buffer (Meters), Ilhardt and Others (2000): 30.48

Watershed Layer: AU_SABLE_1

Figure B.4. Watershed layer.

The next step is inputting the Digital Elevation Model (DEM) layer into the model. The DEM is a raster format layer with a specified spatial resolution. USGS DEMs can be downloaded at the Geospatial Data Gateway: http://datagateway.nrcs.usda.gov/ (Figure B.5).



Riparian Delineation Model V2.2

Streams Layer: MI_osco_streams

Lakes Layer: MI_osco_lakes

Lakes Buffer (Meters), Ilhardt and Others (2000): 30.48

Watershed Layer: AU_SABLE_1

DEM Dataset:

nlcd_2001

osco_10m

Drianage Class Selection Criteria (optional)

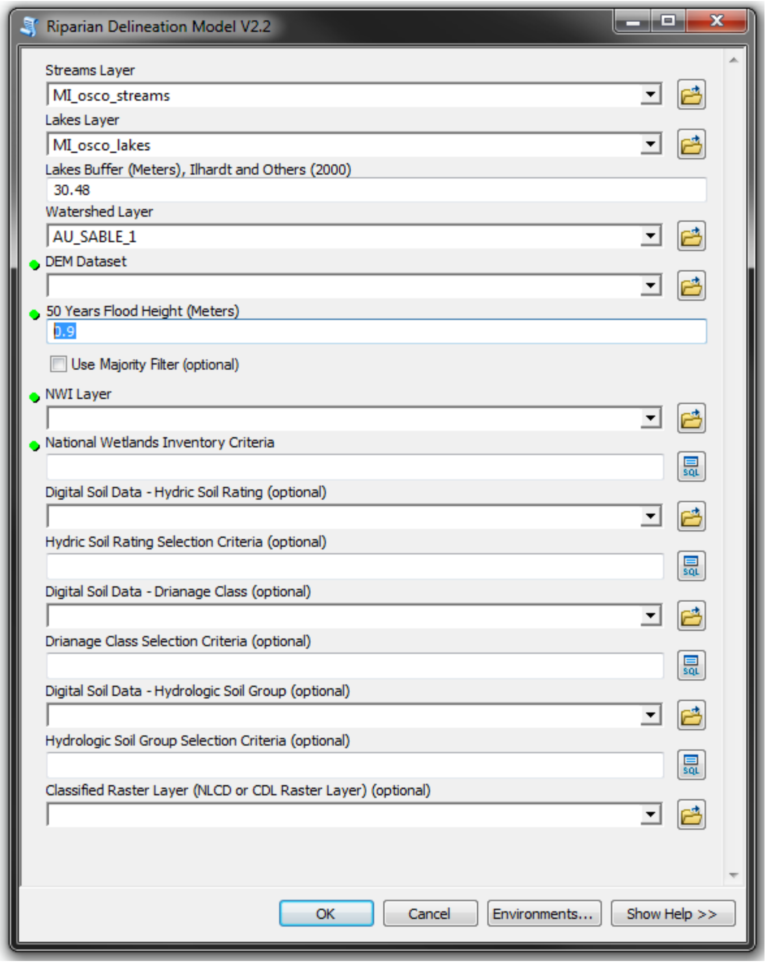
Digital Soil Data - Hydrologic Soil Group (optional)

Hydrologic Soil Group Selection Criteria (optional)

Classified Raster Layer (NLCD or CDL Raster Layer) (optional)

Figure B.5. DEM layer

Specifying the 50-year flood height is an important step in the model delineation process. This value can be estimated according to procedures developed by Mason (2007) (Figure B.6).

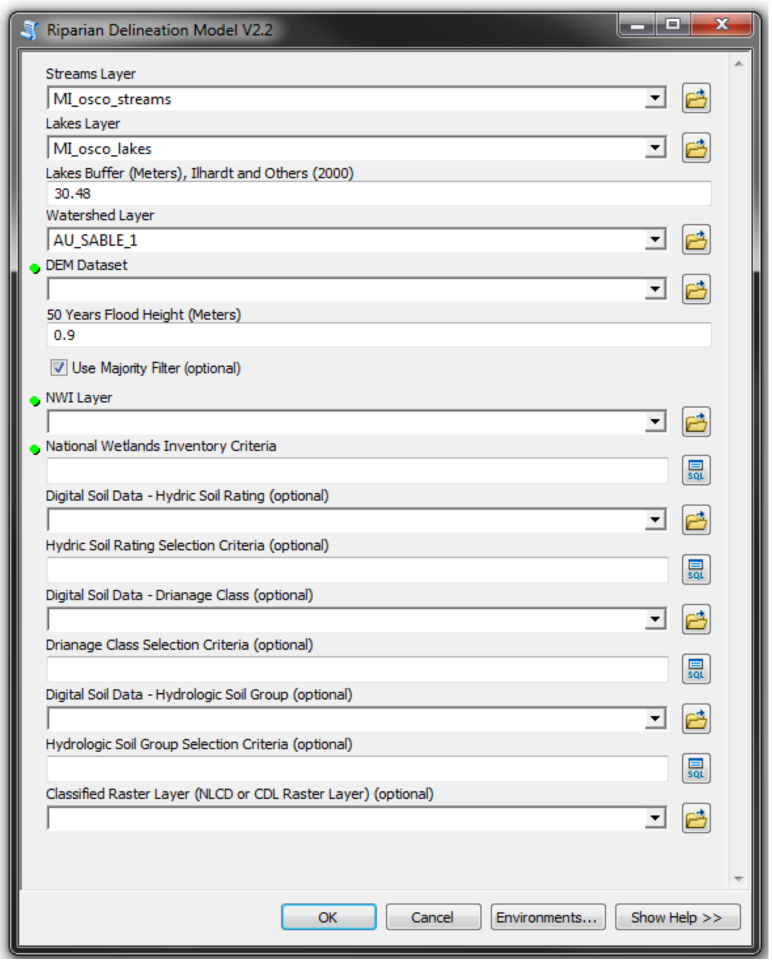


Riparian Delineation Model V2.2

Streams Layer: MI_osco_streams
Lakes Layer: MI_osco_lakes
Lakes Buffer (Meters), Ilhardt and Others (2000): 30.48
Watershed Layer: AU_SABLE_1
DEM Dataset
50 Years Flood Height (Meters): 0.9
☐ Use Majority Filter (optional)
NWI Layer
National Wetlands Inventory Criteria
Digital Soil Data - Hydric Soil Rating (optional)
Hydric Soil Rating Selection Criteria (optional)
Digital Soil Data - Drianage Class (optional)
Drianage Class Selection Criteria (optional)
Digital Soil Data - Hydrologic Soil Group (optional)
Hydrologic Soil Group Selection Criteria (optional)
Classified Raster Layer (NLCD or CDL Raster Layer) (optional)

Figure B.6. 50-year flood height.

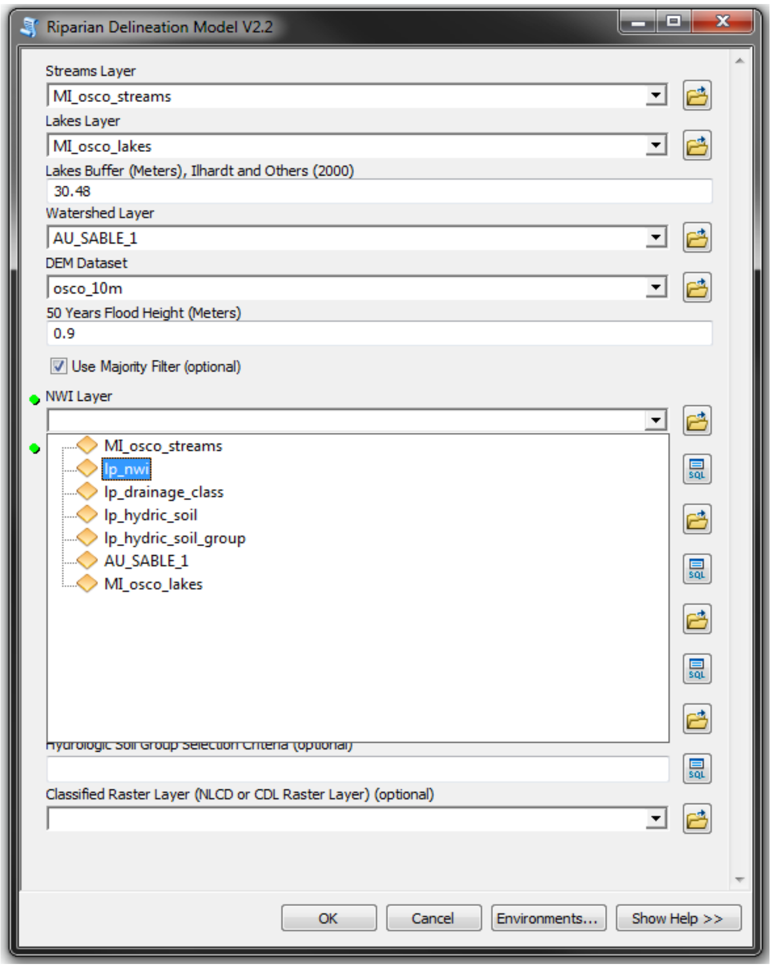
The majority filter box is an optional input to the model. If checked the riparian delineation model will perform extra smoothing on the final riparian ecotones layer (Figure B.7).



Streams Layer
MI_osco_streams
Lakes Layer
MI_osco_lakes
Lakes Buffer (Meters), Ilhardt and Others (2000)
30.48
Watershed Layer
AU_SABLE_1
DEM Dataset
50 Years Flood Height (Meters)
0.9
☑ Use Majority Filter (optional)
NWI Layer
National Wetlands Inventory Criteria
Digital Soil Data - Hydric Soil Rating (optional)
Hydric Soil Rating Selection Criteria (optional)
Digital Soil Data - Drianage Class (optional)
Drianage Class Selection Criteria (optional)
Digital Soil Data - Hydrologic Soil Group (optional)
Hydrologic Soil Group Selection Criteria (optional)
Classified Raster Layer (NLCD or CDL Raster Layer) (optional)

Figure B.7. Majority filter box.

An optional input to the model is the National Wetlands Inventory (NWI) layer. The NWI layer can be downloaded via the wetlands mapper tool http://www.fws.gov/wetlands/Data/Mapper.html (Figure B.8).



Riparian Delineation Model V2.2

Streams Layer
MI_osco_streams

Lakes Layer
MI_osco_lakes

Lakes Buffer (Meters), Ilhardt and Others (2000)
30.48

Watershed Layer
AU_SABLE_1

DEM Dataset
osco_10m

50 Years Flood Height (Meters)
0.9

☑ Use Majority Filter (optional)

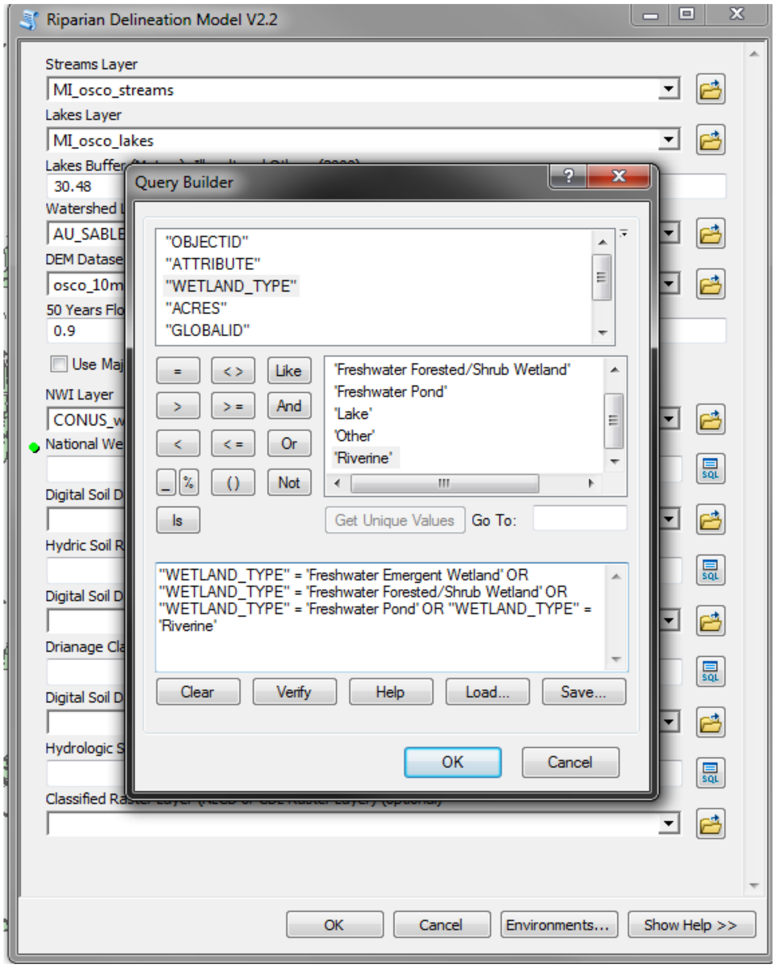
NWI Layer

Hydrologic Soil Group Selection Criteria (optional)

Classified Raster Layer (NLCD or CDL Raster Layer) (optional)

Figure B.8. NWI layer.

The next step after inputting the NWI layer is specifying the NWI query. Click on the SQL to open up the query window and specify the NWI layer according to Pilak *et al.* (2004) or according the user preference (Figure B.9).


Riparian Delineation Model V2.2

Streams Layer: MI_osco_streams

Lakes Layer: MI_osco_lakes

Lakes Buffer: 30.48

Watershed: AU_SABLE

DEM Datase: osco_10m

50 Years Flo: 0.9

☐ Use Maj

NWI Layer: CONUS_w

National We

Digital Soil D

Hydric Soil R

Digital Soil D

Drianage Cla

Digital Soil D

Hydrologic S

Classified Ra

Query Builder

"OBJECTID"
"ATTRIBUTE"
"WETLAND_TYPE"
"ACRES"
"GLOBALID"

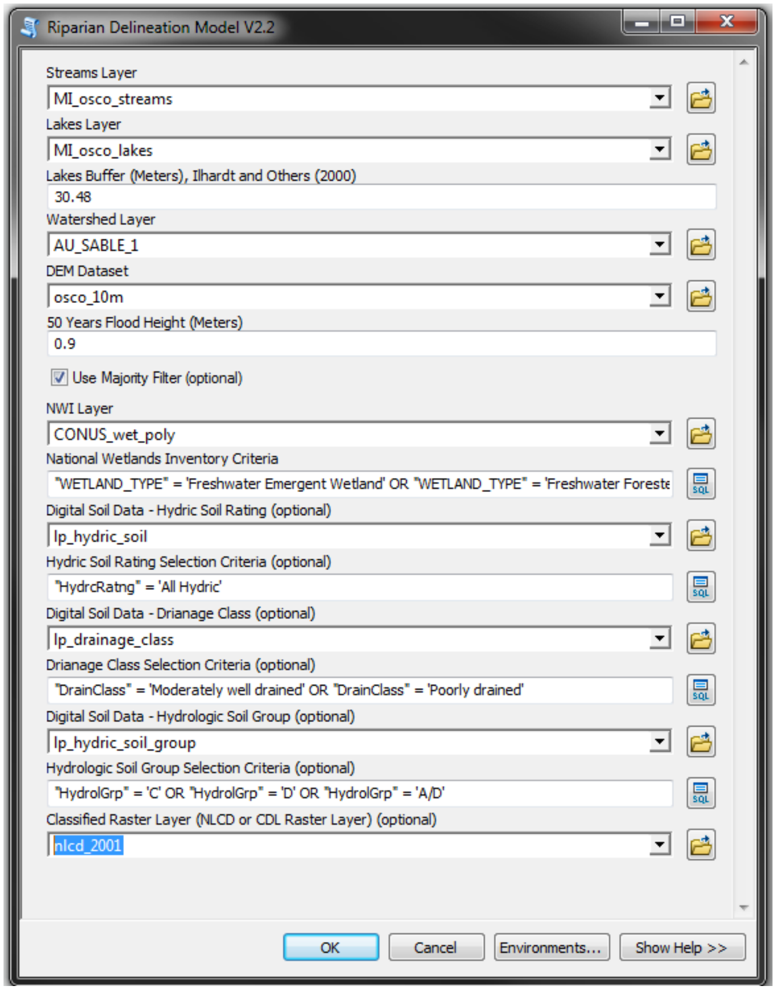
'Freshwater Forested/Shrub Wetland'
'Freshwater Pond'
'Lake'
'Other'
'Riverine'

```
"WETLAND_TYPE" = 'Freshwater Emergent Wetland' OR
"WETLAND_TYPE" = 'Freshwater Forested/Shrub Wetland' OR
"WETLAND_TYPE" = 'Freshwater Pond' OR "WETLAND_TYPE" =
'Riverine'
```

Figure B.9. NWI query builder.

The same steps are followed to input the Hydric Soils, Drainage Class, and Hydrologic Soil Group query for each of the Hydric Soils, Drainage Class, and Hydrologic Soil Group layers.

The last optional input is the land user/cover classified raster layer. In general, the model is designed to incorporate classified raster layers from two sources to generate riparian ecotones with two classification schemes. The first classification scheme is adopted from the National Land Cover Database (NLCD) and can be downloaded at http://www.mrlc.gov/ and the second classification scheme is adapted from the National Agricultural Statistics Services (NASS) Crop Data Layer (CDL) (Figure B.10).



Streams Layer
MI_osco_streams

Lakes Layer
MI_osco_lakes

Lakes Buffer (Meters), Ilhardt and Others (2000)
30.48

Watershed Layer
AU_SABLE_1

DEM Dataset
osco_10m

50 Years Flood Height (Meters)
0.9

☑ Use Majority Filter (optional)

NWI Layer
CONUS_wet_poly

National Wetlands Inventory Criteria
"WETLAND_TYPE" = 'Freshwater Emergent Wetland' OR "WETLAND_TYPE" = 'Freshwater Foreste

Digital Soil Data - Hydric Soil Rating (optional)
lp_hydric_soil

Hydric Soil Rating Selection Criteria (optional)
"HydrcRatng" = 'All Hydric'

Digital Soil Data - Drianage Class (optional)
lp_drainage_class

Drianage Class Selection Criteria (optional)
"DrainClass" = 'Moderately well drained' OR "DrainClass" = 'Poorly drained'

Digital Soil Data - Hydrologic Soil Group (optional)
lp_hydric_soil_group

Hydrologic Soil Group Selection Criteria (optional)
"HydrolGrp" = 'C' OR "HydrolGrp" = 'D' OR "HydrolGrp" = 'A/D'

Classified Raster Layer (NLCD or CDL Raster Layer) (optional)
nlcd_2001

Figure B.10. Inputting classified land use/cover raster layer.