USING LIDAR DERIVED INFORMATION FOR PREDICTING BEAVER DAM SITE SELECTION AT MINGO NATIONAL WILDLIFE REFUGE

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The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

MASTER OF SCIENCE

Natural Resource Management

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ABSTRACT

Characterizing features that influence beaver (*Castor Canadensis*) to select a site to construct a dam may have important implications for managing damage to select stands of bottomland hardwood forest by beaver activity. This study was initiated to determine and develop a quick and simple approach for managers to determine areas of most concern. Advanced Light Detection and Ranging (LiDAR) was collected for the study area in November of 2009. The study utilized software that has been developed to extract topographic features from a Digital Elevation Model (DEM). The extracted data was used to identify landscape variables to try and specify presence, future presence, and suitability of an area to support dam sites. This study, however, found that the development and use of such advanced LiDAR and DEM creation was error prone, which resulted in errors in the metrics that were calculated relative to the DEM.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Beaver (*Castor canadensis*) populations have increased largely over the past 40 years in response to regulations on trapping. Increased populations of beaver have caused severe damage to valuable timberland through timber girdling and flooding of bottomland forests (Arner and Dubose 1980; Hill 1982; Bullock and Arner 1985; Bhat et al. 1993). A survey done by J.E. Miller (Bhat et al. 1993) estimated that beavers in southern forests cause an estimated $10 million loss annually. Many state and federal land managers are given the responsibility to manage stands of forest that are sometimes the only remaining track of forest in the area and possibly the only suitable or natural habitats due to increased habitat fragmentation from anthropogenic factors (agriculture, expansion, roads, ditches etc.)

Considerable progress toward understanding the ecology of beavers has been made; however, this subject is still being researched and developed to further understand preferences for habitat and geographic distribution at regional and site specific scales. Increasing our knowledge of beaver habitat selection and predicting their geographic distribution in Southeast Missouri using spatially explicit information and maps within a geographic Information System (GIS) is one step toward aiding in their conservation and management.

This study looks to use remote sensing techniques to potentially determine beaver dams that occur in an area that is managed for wildlife. The use of remote sensing techniques to find beaver dam affected areas can help alleviate the need for laborious ground surveys. This can save refuge land managers time and money while providing a quick and effective way to find dams and inundated timber stands.

The objectives of the study were to:

1. Determine if Light Detection and Ranging (LiDAR) measurements of stream and landscape geomorphology analyzed with current GIS analysis tools could be used to determine beaver impoundments.
2. Develop quick and effective ways to find dams holding water on forest stands.
3. Determine what type of habitat beavers are selecting for on Mingo NWR.

Remote sensing data can be obtained over large spatial scales and then be used to determine areas of suitable habitat for beaver dam construction. The quality of remotely sensed data collected has greatly advanced since it has become available. The many advancements especially LiDAR, has led to much more fine scale information depicting habitat structure and land topography. With the finer scale data collection it is thought that there would be a better representation of the true ground surface when analyzed with certain GIS tools (Lefsky 2002) resulting in better understanding of certain habitats. Managers at Mingo National Wildlife Refuge attained LiDAR data to better understand their water management and to help characterize habitat for various species. With nuisance beavers becoming more of a problem when managing water levels in the bottomland hardwood forests, there is a need for determining areas that are affected by beaver dams. Advanced LiDAR, along with GIS analysis tools and habitat suitability models, will be used in an attempt to determine areas of the most concern when trying to predict areas subject to beaver damming and inundation of trees.

LITERATURE REVIEW

History of Beavers

Preceding European colonization of North America, the beaver (*Castor canadensis)* population was estimated to be between 60-400 million (Seton 1929). Inhabiting nearly all available aquatic habitats, their geographic range was estimated at roughly 15 million km² (Jenkins and Busher 1979). In the early seventeenth century, beavers were intensely harvested for their pelts, which were used in the fur trade. In North America there were over 10,000 beavers harvested per year in Connecticut and Massachusetts between 1620 and 1630 (Moloney 1976). Approximately 80,000 per year were harvested in the years from 1630 to 1640 from the Hudson River to western New York (Hays 1871). As populations declined western expeditions went out solely in search for newfound trapping areas (Cline 1974). During the late nineteenth and early twentieth centuries, beavers were nearly extirpated (Jenkins and Busher 1979).

Although trapping and hunting may be the only direct impact on population declines, the loss of habitat since 1834 has had a large impact. Approximately 195,000 to 260,000 km² of wetlands in the United States have been drained and converted to dry lands (Shaw and Fredine1971).

Currently, with reintroductions, laws regulating trapping and the absence of predators, beavers are as before occupying many streams, lakes, and wetlands in North America and are becoming a concern for management (Larson and Gunson 1983). Current population estimations gauge the population between 6 and 12 million individuals. With their ability to influence the structure, function, and resources of ecosystems through dam building and foraging, they are defined as ecosystem

engineers in lotic and adjacent terrestrial habitats (Jones et al. 1994). Beaver activity leads to increased diversity in fishes, invertebrates, and plants in watersheds they occupy (McDowell and Naiman 1986; Snodgrass and Meffe 1998; Wright et al. 2003). Another consequence of beaver activity is damage of aesthetic and economic values by cutting specific species of trees (Beier and Barrett 1987), flooding timber, and damaging human constructs such as roads and bridges (Arner and Dubose 1980; Bullock and Arner 1985; Hill 1982; McKinstry and Anderson 1999). A survey of foresters reported that among all vertebrate animals, beavers have caused the most damage in the southern forests at an annual estimated loss of $10 million (J.E. Miller, unpublished manuscript, cited in Bhat 1993).

Ecology and Behavior

Beavers are social animals and very territorial. They live in colonies which typically consist of two parental adults, offspring born the year previous, and the young of the year (Wilson 1971). The average colony size observed and calculated by McTaggart and Nelson (2003) is 5.6 beavers. The size of the colony depends upon the carrying capacity, duration of establishment, and the success of the adults and offspring. The young are born in May-June with an average litter size of 3-4 kits per year. Young beaver typically leave the parental colony at the age of 2 years to start a colony of their own typically dispersing within a 16 km radius of their natal pond. If the dispersers fail to establish themselves, they may return to the parental colony (Wilson 1971; Hartman 1994). Density of colonies is largely dependent upon habitat quality. Beavers were released into a previously unoccupied area in the Netherlands, they

settled in good habitat and sequentially less suitable habitat, and then became floaters (Nolet and Rosell 1994). Beavers are known to occupy both lotic and lentic habitats.

Beavers are generalized herbivores. They consume the leaves, twigs, and bark of woody plants as well as aquatic and terrestrial herbaceous vegetation. Food preferences for the beaver in much of northern North America are in this order; *Populus tremuloides, Salix spp, Populus balsamifera, and Alnus spp* (Denney 1952). Foraging upon coniferous trees has been known to happen (Brenner 1962; Williams 1965). Winter forage is known to be *Cornus stolonifera*, *Fraxinus pennsylvanica*, and *Salix spp*. (Hammond 1943). Rhizomes and roots of aquatic vegetation is also an important source of food in the winter (Longley and Moyle 1963). Tree cutting occurs any time of the year (Jenkins 1979) but mostly in the late fall and early spring when green vegetation is limited.

Dams

Dam construction occurs in lotic environments. Dam size differs in correlation to topography and the availability of materials for construction (Curry-Lindahl 1967). Dams are rarely built in streams greater than 4th order (Strahler order system). Larger order streams pose problems during periods of high flow (Naiman et al. 1986).

Past studies considered the availability of food, with high regards to *Populus tremuloides*, to be an important determinant of habitat suitability for beavers. Barnes and Mallik (1997) found no evidence of beavers choosing dam sites based on the presence of food items. Beavers chose to construct dams at stream sections with high shoreline densities of woody vegetation with diameters 1.5 – 2.4 cm, 2.3 – 3.4 cm, and

3.5 – 4.4 cm (Howard and Larson 1985; Beire and Barrett 1987; McComb et al. 1990; Barnes and Mallik 1997).

In a northern boreal watershed, it was found that the most significant habitat determinant for location of a beaver dam was the upstream watershed area (Howard and Larson 1985; Barnes and Mallik 1997). In the upper coastal plains of South Carolina, beavers are more likely to impound streams in a watershed 1000 to 5000 ha, lower gradient streams 0 to 0.6% gradient, and in streams crossed by roads (Jakes et al. 2007). Using a graphical model, McComb et al. (1990) showed that stream gradient and stream cross-section could be used to identify dam sites in eastern Oregon. They stressed that this method may need to be tested for regional variations at other dam sites. In the upper coastal plain of South Carolina, beavers showed a preference for second order streams and also impounded substantial lengths of intermittent streams, effectively converting them to permanent streams (Snodgrass 1997). Johnston and Naiman (1990a) found that beavers preferred fourth order streams in the northern boreal forest landscape of Minnesota.

Structural components have also been closely linked to beaver dam selection sites. A survey conducted in 1995 by D'Eon et al. found that culvert blockage and road flooding were the two most frequent types of beaver damage reported. Damages occur when beavers plug culverts or construct dams that impound water against the road base. The inundation saturates the roadbed, causing settling and formation of potholes. This saturation of the roadbed, along with obvious inundation of the actual road and washing out of the roads, can cause serious damage. These issues present both economic and human safety concerns (Jensen et al. 2001). The probability of a culvert

being plugged is mainly influenced by the area of the inlet opening (m^2) (Jensen et al. 2001). At plugged sites, stream width was twice the width of the culvert inlet opening (mean ratio=2.0), whereas at non-plugged sites, culverts did not severely constrict the stream (mean ratio=1.3) (Jensen et al. 2001). In addition to culverts, bridges and larger box culverts influence dam site selection. A study done by Curtis and Jensen (2004) found that occupied beaver dams were within 200 m upstream or downstream of the road. Open areas had the strongest influence on whether beaver colonized a roadside area (Curtis and Jensen 2004). There have been authors that suggest extensive land clearing associated with highways, agriculture, and residential areas may be a major limiting factor on beaver habitat suitability (Rue 1964; Slough and Sadleir 1977; Munther 1981; Dieter and McCabe 1989). Suzuki and McComb 1998 found in Oregon that beaver occupancy was negatively associated with percent cover of woody vegetation. Stream gradient was also a factor in dam site selection. The study suggested that beaver occupy streams with gradients between zero and 3% (Smith 1950; Slough and Sadleir 1977; Beier and Barret 1987; Suzuki and McComb 1998). These areas are typical for having mud, silt, and soft clay that enables more efficient dam construction.

Studies have reported that stream width has an effect on dam site selection. Suzuki and McComb (1998) suggested that beaver preferred streams with shorter widths. This was found by Curtis and Jensen (2004) as well. The opposite was reported by Howard and Larson (1985) reporting that beaver preferred wider streams. It is reported that the sound of running water is a factor that triggers dam building activity by beavers (Novak 1987). Therefore, the flow of water is also needed in order for habitat to be suitable.

There are two types of beaver ponds: 1) Stream Channel ponds are long, narrow, typically less than 0.4 ha, and typically short lived, 2) Flood Plain ponds consist of larger impoundments, cover several hectares of land and remain for longer periods of time (Pullen 1971). In a study done by Johnston and Naiman (1990) over a 46 year period in Minnesota, pond sizes ranged from 1-45 ha, with 1-2 ha being the most frequent, while the size averaged 4.3 ha. Each colony averaged 2.2 ponds with a total average of 10 ha of pond area per colony. They also found that beaver selected for areas that created the largest ponds with the greatest potential for expansion first, and as more of these sites were occupied, new pond creation decreased and was limited to less desirable sites.

The period of which an area is inundated can have large effects on the flora and fauna. Often the ponds tend to contain living trees during the first three years, though this depends on the tree species inhabiting the area. As time progresses and inundation continues emergent vegetation becomes more abundant with standing dead trees being present from 4 to 10 years. In addition, water levels in the ponds tend to be greater than 0.3 m with 40-50% open water. Senescent ponds contain water only near the dam and emergent aquatic vegetation is very thick. They typically have a water depth of less than 0.3 m and few visible standing dead trees. Eventually, the beavers will abandon a pool or pond and a “beaver meadow” often is the result. The creation of these meadows is due to the dam trapping nutrient-rich sediment and by killing woody vegetation in the riparian zones, whether by inundation, girdling, or herbivory.

Although beavers are known largely for construction of dams and huts, they often burrow into banks of rivers and create dens (Frisch 1975; Danilov and Kan’shiev 1982).

Beavers excavate canals in order to float branches to safe feeding locations and caching food for winter (Richard 1983; Wilsson 1971). Canals are constructed in low gradient areas, generally 30-60 cm wide and 20-35 cm deep, and may stretch for several hundred meters (Stocker 1985).

Dam Impacts

Through their dam creation beavers create wetlands and open water habitat that provides valuable habitats for fish, invertebrates, amphibians, and waterfowl. Despite these positive effects, negative impacts are of concern for management. Often beaver populations can severely degrade riparian habitats and bottomland hardwoods to the detriment of other species. Beaver dam construction can cause flooding of roads, agricultural lands, and developed property. Dams can act as barriers for migrating fish if large enough and can damage spawning sites of certain species by reducing stream flow and causing excessive siltation of the spawning gravel (Knudsen 1962). Siltation and increased organic material effect invertebrate communities. Dams raise water levels. An increase in water levels about 40 cm result in deposition of sandy silt and reduce the total number of emerging insects, especially of obligate lotic species *Ephemeroptera*, *Plecoptera* and *Trichoptera*, with an increase of *Chironomidae* (Sprules 1941). Dams impact the structure of fish communities by changing water temperatures and changing lotic systems into lentic systems.

It is very common for culverts to be installed in small streams instead of building bridges. These culverts, if not closely monitored, become barriers when dammed by beavers. Beavers use the constriction of the stream at the upstream end of the culvert as a point to dam, increasing the water level upstream and blocking the culvert.

Light Detection and Ranging (LiDAR)

LiDAR is a technology that measures properties of scattered light to find the range (distance) or other information of a distant target (Lefsky et al. 2002). It uses laser pulses to determine distance to an object or surface. The distance is the measurement of time delay between transmission of a pulse and detection of the reflected signal. Data collected for this study are discrete-return, small footprint LiDAR (ground level laser beam diameter range of 0.2-1.0m). Discrete-return airborne LiDAR systems were developed over the last 22 years for mapping terrain (Wehr and Lohr 1999). Airborne laser scanning systems are conducted with four major hardware components: (1) a laser emitter-receiver scanning unit, (2) differential global positioning systems (GPS; aircraft), (3) a highly sensitive inertial measurement unit (IMU) attached to the scanning unit, and (4) a computer to control the system and store data from the first three components.

Terrain mapping scanners emit near-infrared laser pulses at 10,000-100,000/second (Reutebuch et al. 2005). The computer stores the position and altitude of the plane and records the time it takes for the pulse to complete the return distance from scanner to the object. Most systems can detect several reflections “returns” from a single pulse. Pulses can partially hit vegetation or other objects and continue to a lower object. Most flights for terrain mapping occur during leaf off to maximize the number of pulses that reach the ground. Large areas of terrain are surveyed by a series of swaths that overlap one another by 20% or more. A swath is the area of terrain under the aircraft being surveyed through lateral deflection of laser pulses and forward movement of the aircraft. The scanning pattern is established by an oscillating mirror or rotating

prism, which causes the pulses to sweep across the landscape in a consistent pattern. The data collected results in a three dimensional “point cloud” from vegetation/objects and terrain with millions of measurements per square kilometer.

LiDAR system developers quote errors of 10-15 cm vertical and 50-100 cm horizontal for terrain mapping products (Reutebuch 2005). With the advances in technology and LiDAR in the mainstream commercial terrain mapping sector, many vendors offer data processing software and a complete range of mapping services. Delivery of processed data can come in a vast array of formats including digital terrain models, contour maps, and extraction of infrastructure locations and characteristics.

The applications of LiDAR systems have been greatly developed over the years through the paralleled advances in global positioning systems as well as inertial navigation systems. Many such applications include flood plain inundation mapping (Overton 2005), as well as, bird and vegetation modeling (Bradbury et al. 2005). Most LiDAR data is delivered in the .las format and must be converted in order to analyze. The .las file formats are files that efficiently contain elevation data for every point detected by LiDAR sensors. Many types of classifications can exist for various features across different landscapes. See Table 1 for most common point cloud classifications.

Table 1: List of the possible classifications for various LiDAR returns.

Class Code	Classification Type
0	Created, never classified
1	Unclassified
2	Ground
3	Low vegetation
4	Medium vegetation
5	High vegetation
6	Building
7	Low points (noise)
8	Model key
9	Water
17	Ground overlap
19	Ground overlap

Geographic Information Systems (GIS)

Geographic Information Systems allow users to visualize, question, analyze, and interpret data in various ways. This data can help to understand relationships, patterns, and trends. Since remote sensing has been available, it has been known as a technology with the capability of supporting the development of wildlife habitat maps over large spatial scales (McDermid 2005). The tools developed for remote sensing revolve around what type of information a resource manager needs to better manage important resources and habitats. Remote sensing techniques applied to habitat can reach a large range of spatial scales. There are predictive models using topographic features such as elevation, slope, aspect and ruggedness that predict muskoxen habitat in Northern Alaska (Danks and Klein 2002). There are many other projects that use LiDAR to assess habitats and biodiversity (Negendra 2001). Habitat suitability models have been developed for various species of wildlife.

ArcGIS (version 9.3 and 10) (ESRI, Redlands, California) provides tools that are designed to process and analyze various types of data, providing certain types of information and that are applicable to resource management. The following sections provide information of how these tools can help process data into applications important to resource managers.

Spatial Analyst

This toolbox provides tools to perform raster (cell based) analysis. The raster data set provides the most comprehensive modeling environment for spatial analysis compared to vector and Triangulated Irregular Network (TIN) data sets. This cell-based system divides the world into discrete uniform cells based on a grid structure. Every cell represents a certain portion of the earth, such as square meter. These cells are given values that correspond to the features and characteristics that are described or located within the cell. These values may represent elevations, soil type, or residential classification. The geographic location is not an attribute but is stored as structure which is also known as the location perspective. This allows for the data to be stored as continuous data, where each location has a quantity, magnitude, or intensity assigned and are relative to one another.

Hydrology Toolset

Many projects require an understanding of how water flows across the landscape and how changes in that area may affect flow. Modeling of this type derives models of where water came from and where it is going. The following tools are used to derive models that analyze hydrologic functions to model the movement of water across a

surface. A Digital Elevation Model (DEM) must be used as the input for these tools to extract hydrologic information.

Flow Direction

This process determines the direction of steepest descent from each cell (ESRI 2011). This is calculated as change in z-value / distance x 100. The designated D8 (8 flow directions) method for identifying flow direction was introduced by O'Callaghan and Mark (1984) and has been commonly used. It assigns a flow from each pixel to one of its eight nearest neighbors, either adjacent or diagonally, in the direction with the steepest downward slope.

Sinks

Sinks are topographic depressions contained in DEMs. They are defined as areas that lack an outlet. A sink cell or cells are those that cannot be assigned a value in a flow direction raster. This typically occurs when all surrounding cells are higher in elevation than the cell being processed or when two adjacent cells flow into each other, which creates a looping effect. This tool is designed to assign a value to that cell that is the sum of the possibly directions of flow. The filling of these sinks is needed to create an accurate raster representation of the flow direction and the flow accumulation by creating a smooth surface for water to flow across. It is thought that most sinks in elevation data are due to errors in the data. The errors occur due to sampling effects and the rounding of elevations to integer numbers. Sinks that are 10 meters or larger are often considered to not naturally occur except in glacial or karst areas (O'Callaghan and Mark 1984). More recently, with the advanced higher resolution and more accurate DEMs, it is expected that the finding of artificial depressions should reduce. It has been

found, however, that the high resolution DEMs have a very large number of sinks due to greater surface roughness and finer resolutions (MacMillan et al, 2003). It was also stated that as the cell size increases, the number of sinks in the dataset also often increases. In contrast to that, Zandbergen (2006) found that the number of sinks increases as cell resolution decreases. He explains that this operation can be explained by an inverse power relationship between the number of depressions and the cell size. It also appears that algorithms that rely on the identification of depressions are at their limit to process high resolution DEMs (Lindsay and Creed 2005).

Flow Accumulation

With the use of the flow direction data set a flow accumulation can be performed. Each cell is assigned a value equal to the number of cells that flow to it (O'Callaghan and Mark, 1984). Flow accumulation values of zero (no flow from surrounding cells) corresponds to ridges. Due to cells in a depressionless DEM having a path to the data set edge, patterns formed by highlighting cells with higher values than some threshold delineates a fully connected drainage network. When the threshold value is increased, the drainage network density decreases.

Snap Pour Point

The Snap Pour Point (Spatial Analyst) tool is implemented to ensure the selection of points of high accumulated flow when delineating drainage basins using the ArcGIS Watershed tool (ESRI 2011). Snap Pour Point tool will search within a specified snap distance for the cell of highest accumulated flow and move the pour point to that location. The output is an integer raster after the pour point locations have been snapped to locations of higher accumulated flow.

Stream Network

Delineation of stream networks can be done using a DEM and the output from the Flow Accumulation tool (Spatial Analyst tools). Applying a threshold value to the results of the Flow Accumulation and using the Con or Set Null tools, a stream network can be delineated. This can also be done using the raster calculator. Cells with more than the threshold value flowing into them are assigned a value of one, and all other cells are assigned NoData. The resulting output can be further analyzed using the Stream Order, Stream Link, and Stream to Feature tools for ordering (ranking) the streams, assigning unique IDs to stream links, or creating a feature dataset, respectively (Tarboton and Bras 1991). Setting a threshold value that represents permanent streams or the beginning of a stream channel is affected by not only the contributing area but also by climate, slope, and soil characteristics.

Stream to Feature

The Stream to Feature tool uses an algorithm designed for vectorization of stream networks or any other type of raster that represents a raster linear network that has a corresponding direction (Tarboton and Bras 1991). The tool uses a direction raster to aid in vectorizing intersecting and adjacent cells (ESRI 2011). This way it is possible for two adjacent linear features of the same value to be vectorized as two parallel lines. In contrast, the Raster to Polyline tool, is more aggressive and collapses these parallel lines together. The input features should be contiguous with the same value on a background of NoData. Stream to Feature should not be used on a raster in which there are few adjacent cells of the same value.

Watershed

Watersheds are the upslope area that contributes flow of water and sediment to a common outlet as concentrated drainage. It can consist of parts of larger watersheds and contain smaller sub-basins. Drainage divides are boundaries between watersheds. The pour point, or outlet, is the point on the surface at which water flows out of an area. It is the lowest point along the boundary of a watershed. Delineation of watersheds can be determined from a DEM by computing the flow direction and inputting into the Watershed tool. To determine the area of contribution, a direction of flow must first be created with the Flow Direction tool. Locations to determine catchment areas for must be provided. Source locations may be features. Flow accumulation thresholds may also be used. When the threshold is used to define a watershed, the pour points (created with Snap Pour Points tool) will be the junctions of a stream network derived from flow accumulation. Therefore, a flow accumulation raster and the minimum number of cells that constitute a stream (threshold value) must be specified. The output is then a raster of watersheds.

Surface Toolset

This toolset can be used to acquire information through production of new datasets that identify specific patterns in original datasets. Patterns produced are not readily apparent in the original surface, such as contours, angle of slope, aspect, hillshade, and viewshed.

Slope

The slope represents the rate of change in elevation for each DEM cell (ESRI 2011). The inputs for the function are the DEM and the z-factor. The z-factor adjusts the units

of measure for the z (elevation) units when they differ from the x,y (horizontal) units. When the x,y units and z units are the same unit of measure, the z-factor is 1. Apply a z-factor of 0.3048 when the x,y units are in meters and the z unit is measured in feet to convert the elevation from feet to meters. The Slope tool calculates the rate of change in value from each cell to its neighbors. It determines the maximum change in elevation of the distance between the cell and its eight neighbors identifying the steepest downhill descent from the cell. A plane is then constructed of the z-values of a 3 x 3 cell neighborhood around the center cell. This is calculated using the average maximum technique (Burrough et al. 1998). The direction the plane faces is the aspect for the cell. The lower the slope value the flatter the terrain; the higher the slope value the steeper the terrain. If a NoData z-value is present the z-value of the center cell will be assigned to the location. Three cells outside of the raster extent will contain NoData and will be assigned the center cell's z-value. This flattens the 3 x 3 plane fitted to the edge cells, which leads to a reduction in the slope. Slope can be calculated in two types of units, degrees or percent (percent rise).

Hillshade

The hillshade tool gathers the hypothetical illumination of the surface by illumination values for each cell in a raster. It does so by setting a position for a hypothetical light source and calculates the illumination values of each cell in relation to its neighboring cells. It greatly enhances the visualization of a surface for display or analysis. The default is output in shades of gray that correspond to the shadow and light with integers between zero and 255 which increases from black to white correspondingly. Cells in shadows of other cells are coded 0; all other cells are coded

with integers from 1 to 255. These values may be reclassified to produce a binary output raster if desirable. In order to calculate the shade values, the altitude and azimuth of the light source are needed. These values are processed along with calculations for slope and aspect to determine the final hillshade value for each cell within the output raster.

Forest Canopy

Varied remote sensing systems and techniques have been explored for forestry applications. Most optical sensors can only provide information on the horizontal distribution of vegetation in forests. LiDAR remote sensing is capable of providing both horizontal and vertical sampling, depending on the type of LiDAR and the systems used. The Canadian Forestry Service demonstrated the application of profiling LiDAR for the estimation of stand heights, crown cover density, and ground elevation below the forest canopy (Aldred and Bonner 1985). With the ability to accurately measure topography, it was realized that certain forest attributes could be quantified from forest canopy profiles derived from LiDAR data. Unambiguously, various forest attributes can be directly retrieved from LiDAR data, such as canopy height, sub-canopy topography, and vertical distributions of canopies. Models from LiDAR data can predict above ground biomass, basal area, mean stem diameter, vertical foliar profiles, and canopy volume, dependent on the type of LiDAR data collected (Means et al.1999; Lefsky et al. 1999; Dubayah and Drake 2000).

LiDAR point data typically comes in .las format. This must be loaded into the geodatabase using the .las to Multipoint geoprocessing tool (ESRI 2011). If the data has been processed into classifications, one can specify the proper class codes to filter the

multipoint feature class. If the data has not been processed this way, taking the first returns may be used. Determining canopy density proceeds by dividing the study area into equal-sized units through rasterization. In each cell, the aboveground returns are compared to the total number of returns. The first step is to implement the Point to Raster geoprocessing tool on the aboveground points with the COUNT option. The resulting data will contain NoData cells. These must be converted to zero so that later operations read a cell with no points as zero. This step involves using the IsNull geoprocessing tool followed by the Con geoprocessing tool. Both of the previous steps must be done with both the ground multipoints and the canopy multipoints. The ouputs from the previous step must be added together using the Plus geoprocessing tool. A floating raster must be produced using the Float geoprocessing tool with the output from the Plus geoprocessing tool. The resulting output can then be divided using the Divide geoprocessing tool to compare the floating point total count raster and the aboveground count raster. The ratio of the output data is from 0.0 to 1.0, this represents no canopy and very dense canopy, respectively. When determining the height of the canopy, subtraction of the bare earth surface (DEM) from the first return surface (DSM) must be done. The Minus geoprocessing tool will determine the difference between these two raster datasets. The resulting difference is the height of the canopy.

STUDY AREA

Investigation of relationships involving stream geomorphology, landscape geomorphology, man-made structures and beaver impoundments took place at Mingo National Wildlife Refuge (Mingo NWR). Mingo NWR is located in Wayne and Stoddard Counties (Figure 1) in the Bootheel region of southeast Missouri (GPS Coordinates: 36°58′5.5345″N 90°8′48.6600″W).

The refuge was established under the authority of the Migratory Bird Treaty Act in 1944 (USFWS 2007). Once part of 1,011,000 ha of bottomland hardwood forest, Mingo NWR is the largest remaining portion with 6070 ha of bottomland hardwood forest. The refuge is 8737 ha with 2023 ha of marsh and water, 526 ha of cropland and moist soil units, and 161 ha of grasslands (Figure 2). The refuge contains seven natural areas. These areas were established by the National Wilderness Preservation System, where legislation set aside certain federal lands as wilderness areas. The policy permits hiking, backpacking, fishing, wildlife observation, and environmental education and interpretation. It prohibits any motorized activities. The refuge also contains 99 archaeological sites.

Mingo NWR sits in the abandoned Mississippi river channel that flowed during the Quaternary Period (USFWS 2007). The channel is formed by Crowley's Ridge to the south and the Ozark highlands to the west. The channel sits in the Advance Lowlands. The channel was abandoned and aggradated with glacial outwash when the Mississippi River shifted east of Crowley's Ridge in the late Pleistocene (Fisk 1944). The channel

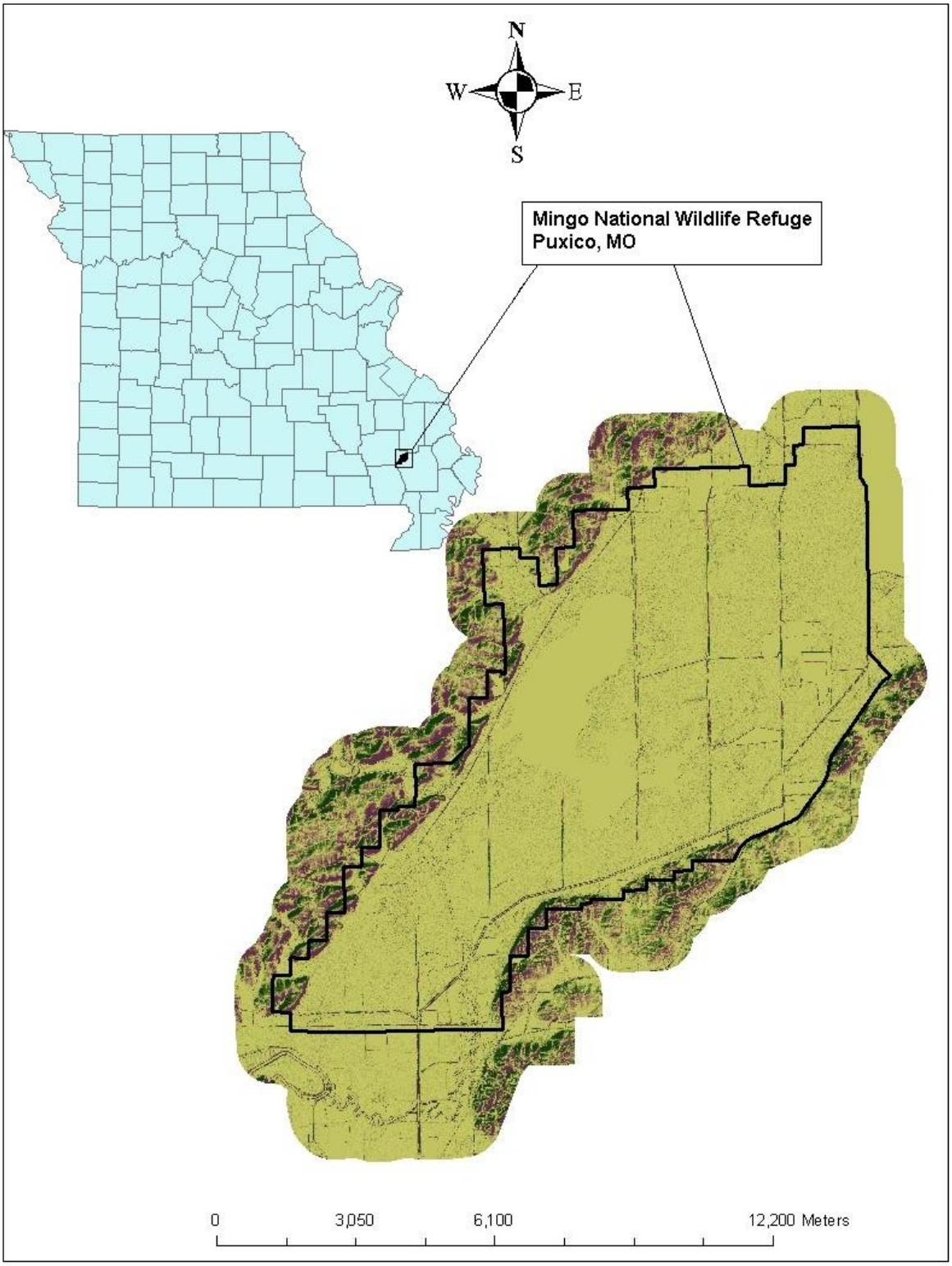

Figure 1: The location and hillshade map of Mingo NWR, MO.

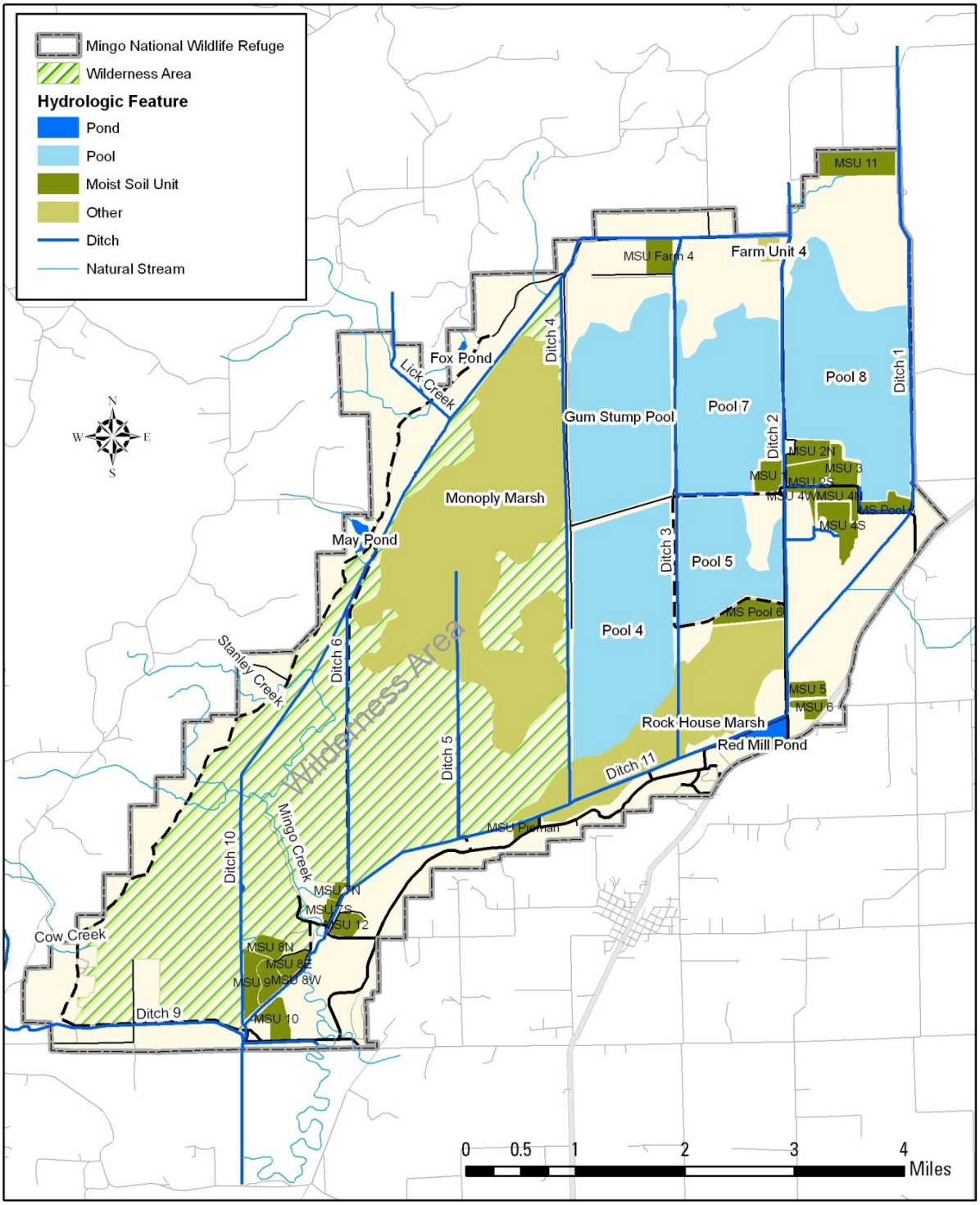

Figure 2: Map showing Mingo NWR, MO boundary and the land type areas within the refuge.

remains filled from surface runoff after the St. Francis River slowed drainage with the formation of a delta across the mouth of the old Mingo River.

The alluvium filled and poorly drained channel formed the Mingo Swamp (USFWS 2007). From the 1880's into the 1930's the region's hardwood forests were harvested for lumber and railroad ties. Drainage districts were financed through legislation. There were over twenty districts in Stoddard County in 1914. Mingo Drainage District north of Puxico, Missouri was included. This drainage district struggled immensely with overflow from the St. Francis River, and the soils proved less productive than other areas for farming as well as grazing. The Mingo Drainage District, like many others, struggled financially, and when land values plummeted during the Great Depression, the Mingo District defaulted on bond payments and went bankrupt. Unregulated land uses followed until the United States Fish & Wildlife Service (Service) acquired the property in 1945. By the time the Service acquired the land it had been deforested, drained with an extensive series of ditches, and grazed indiscriminately by livestock. Careful stewardship by the Service allowed the land to recover over time.

Climate

The climate of the Southeastern Lowlands is a humid continental type with long, hot summers and rather cool winters. The mean annual temperature is 15.0° C. The summer average daily temperature is 25.6° C, and the average daily maximum temperature is 32.2° C. The winter average temperature is 2.8° C, and the average daily minimum temperature is -2.2°C. The total annual precipitation is 121.9 cm. Half of the annual precipitation occurs between April and September. Thunderstorms occur on average about 55 days each year. The average annual snowfall is 27.9 cm. The

average relative humidity mid-day is about 55 percent. The humidity in the evenings is about 80 percent. The sun shines 75 percent of the time possible in summer and 50 percent in the winter. The wind on average is from the south with an average speed of 19.31 kilometers per hour. Severe storms and tornadoes also strike on occasion in short durations, and damage accrued is typically variable (USFWS 2007).

Soils

In the bottomlands of the refuge, the soils type is Waverley Silt Loam (Coarse-silty, mixed, active, acid, thermic Fluvaquentic Endoaquepts) with grayish brown silt loam surface layer and gray silt loam subsoil that is mottled throughout (USFWS 2007) These are poorly drained acidic soils formed under wet conditions and a high water table. The heavy waxy clays have low permeability and poor surface runoff that associates with the low bottomlands periodic seasonal inundation. Falaya Silt Loam (Coarse-silty, mixed, active, acid, thermic Aeric Fluvaquents) occupies Stanley Creek and Lick Creek and borders the upland channel of the Mingo Creek (USFWS 2007). Falaya soils have brown silt loam surface layers over grayish brown silt loam underlain at about 101.6 cm by silty clay loam. Organic soils occupy 323 and 364 ha in the Rockhouse and Monopoly marshes, respectively and consist of dark colored soils derived from organic matter. They were formed under wet marshy conditions in some of the lowest elevations.

The upland soils are of cherty soils of the steep slopes and stone outcropping along the west side of the Refuge are of the Doniphan series (Scrivner et al., 1966). Doniphan soils (Very-fine, mixed, semiactive, mesic Typic Paleudults) have light brown cherty silt loam surface layers and red clay subsoils. The ridge tops are narrow and

undulating and have about three feet of loess deposits forming Union silt loams. Union silt loams (Fine, mixed, active, mesic Oxyaquic Fragiudalfs) are moderately well-drained and have dark grayish brown silt loam surfaces horizons that are underlain by brown silty clay loam subsoils. Fragipan layers occur at depths of 6.096 or 9.144 cm. The moderate slopes of the uplands are deep, well drained soils. The soils are Loring (Fine-silty, mixed, active, thermic Oxyaquic Fragiudalfs) and Memphis (Fine-silty, mixed, active, thermic Typic Hapludalfs) Silt Loams and have brown silt loam surface layers and brown silt loam subsoils.

Geology/Topography

Mingo NWR lies in a basin formed in an ancient, abandoned channel of the Mississippi River. When the Mississippi River shifted east approximately 18,000 years ago, it abandoned its original channel and left behind a basin, now called Mingo Basin. The basin is bordered on the west by the Missouri Ozarks and on the east by a terrace called Crowley's Ridge, a prominent landform in the otherwise flat Mississippi floodplain. The St. Francis River flows from the Ozark Hills into the Advance Lowlands just south and west of the Refuge (USFWS 2007). When the Mississippi River shifted course, an alluvial fan built up where the St. Francis River entered the lowlands. The alluvial fan, which typically forms at the base of topographic features, acts as a natural levee, slowing drainage through the basin. Several small sand ridges interrupt the otherwise level basin area. The ridges, which vary in shape, may be ancient sand bars deposited by the Mississippi River or sand forced to the surface by earthquakes. The Refuge is in the New Madrid seismic zone, but most of the quakes that have occurred recently are

only detectable by sensitive instruments, and there have been no substantial impacts on the Refuge.

Hydrology

The refuge is located within the lower portion of the St. Francis River basin (USFWS 2007). It serves as a reservoir during periods of inundation. Water flows from all directions until runoff is complete and water levels stabilize. Water flow on the Refuge is very complex and depends upon water depths within each of the pools. Poor drainage of the basin is slowed by dikes, levees, and ditches across the Refuge. Water departs the Refuge and flows south to the St. Francis River via the Mingo drainage ditch. The St. Francis River flows 362 km from Iron County, MO to the Arkansas/Missouri border and another 333 km through Arkansas where it joins the Mississippi River.

Plant Communities

The following plant community list was compiled from the Comprehensive Conservation Plan for Mingo, Pilot Knob, and Ozark Cavefish National Wildlife Refuges, U.S. Fish and Wildlife Service (2007).

Wetlands

With the majority of the refuge subject to seasonal flooding the study site plant communities are mostly of wetland type. There are four community types on the Refuge based upon dominant species, elevation, and inundation.

a. Terrace Bottoms

Terrace bottoms are located at the base of larger slopes, flat bank, and watercourse margins. These well drained and rarely flooded transitional areas support a mixture of upland and flood plain woody species.

b. Oak Hardwood Bottoms

This community is the most extensive bottomland forest type on the refuge. These Pin Oak flats occupy shallowly inundated areas along the banks between drainage ditch levees and the low floodplains surrounding Rockhouse and Monopoly Marshes.

c. Mixed Soft-Hardwood Levees

The Mixed Soft-Hardwood community type is found along drainage ditch levees, stream margins, roadside embankments, and other watercourse boundaries.

d. Shallow Swamps

This community type is found in inundated areas such as Monopoly Marsh, Rockhouse Marsh, Mingo Creek, and Stanley Creek.

Upland Forests

This dominant Oak-hickory forest type is found on the cherty upland areas. Three community types are recognized.

a. Upland Old Fields

This community consists of scattered woodland clearings, abandoned fields or pastures, and ridge roadsides which are reverting to an oak-hickory forest.

b. Xeric Ridge Crests

This community is the driest and most exposed forest community that exists on ridge crests, bluff tops, and upper slopes on thin, excessively drained soils.

c. Mesic Slopes

This community supports the greatest species diversity due to the improved temperature-moisture conditions.

Adjacent Land use

Surrounding the refuge is a variety of land use types. To the northeast of the refuge sits the Missouri Department of Conservation Duck Creek management area, which has similar interests in managing resources as Mingo NWR. To the south of the refuge, the land use is primarily harvested row crop production, fallow fields, as well as pasture lands. To the northwest of the refuge is deciduous forest in the foothills of the Ozark Mountains.

Current Management

The management objectives for the refuge are to: 1) Provide breeding and migration habitat for migratory birds, 2) Provide habitat for resident wildlife, 3) Protect endangered and threatened species, 4) Provide for biodiversity, and 5) Provide public opportunities for outdoor recreation and environmental education (USFWS 2007). Being the largest tract of bottomland hardwoods left in the Bootheel of Missouri, conservation of the forest is of great interest by managers.

DATA AQCUISITION

The Missouri Department of Conservation, USFWS, and U.S. Geological Survey (USGS) required high-resolution digital elevation data be developed from an aerial LiDAR sensor to cover portions of Bollinger, Butler, Stoddard, and Wayne counties in Missouri to the quarter-quad tile resolution. The LiDAR elevation data for this project was collected with a Leica ALS-50II MPIA aerial LiDAR sensor system, developed by Leica Geosystems which is part of the Hexagon Group, Sweden. The project design called for acquisition of LiDAR data with flight lines aligned with the length of the project area (Figure 3). The nominal collection scenario called for the acquisition of 1 point per meter on the ground. The mapping took place in November of 2009. The refuge was in complete drawdown and the condition of the trees was leaf off to enhance to depiction of the ground and insure at least 1 point per meter for ground returns.

The project specified deliverables which were tested and met vertical and horizontal accuracy as stated in the National Digital Elevation Program (NDEP) guidelines for digital elevation for 2 foot contours (horizontal accuracy of 1.33 meters and vertical of 18.5 centimeters root mean square error (RMSE)). The Surdex Corporation processed the LiDAR data and produced a “bare earth” DEM model with vertical accuracy on flat, bare ground of 15 centimeters or better and 40 centimeters or better in vegetation or on hillsides (overall accuracy meeting NDEP guidelines of 18.5 centimeters RMSE). The mapping project was completed under a task order contract with the St. Louis District of the Army Corps of Engineers in the spring of 2009.

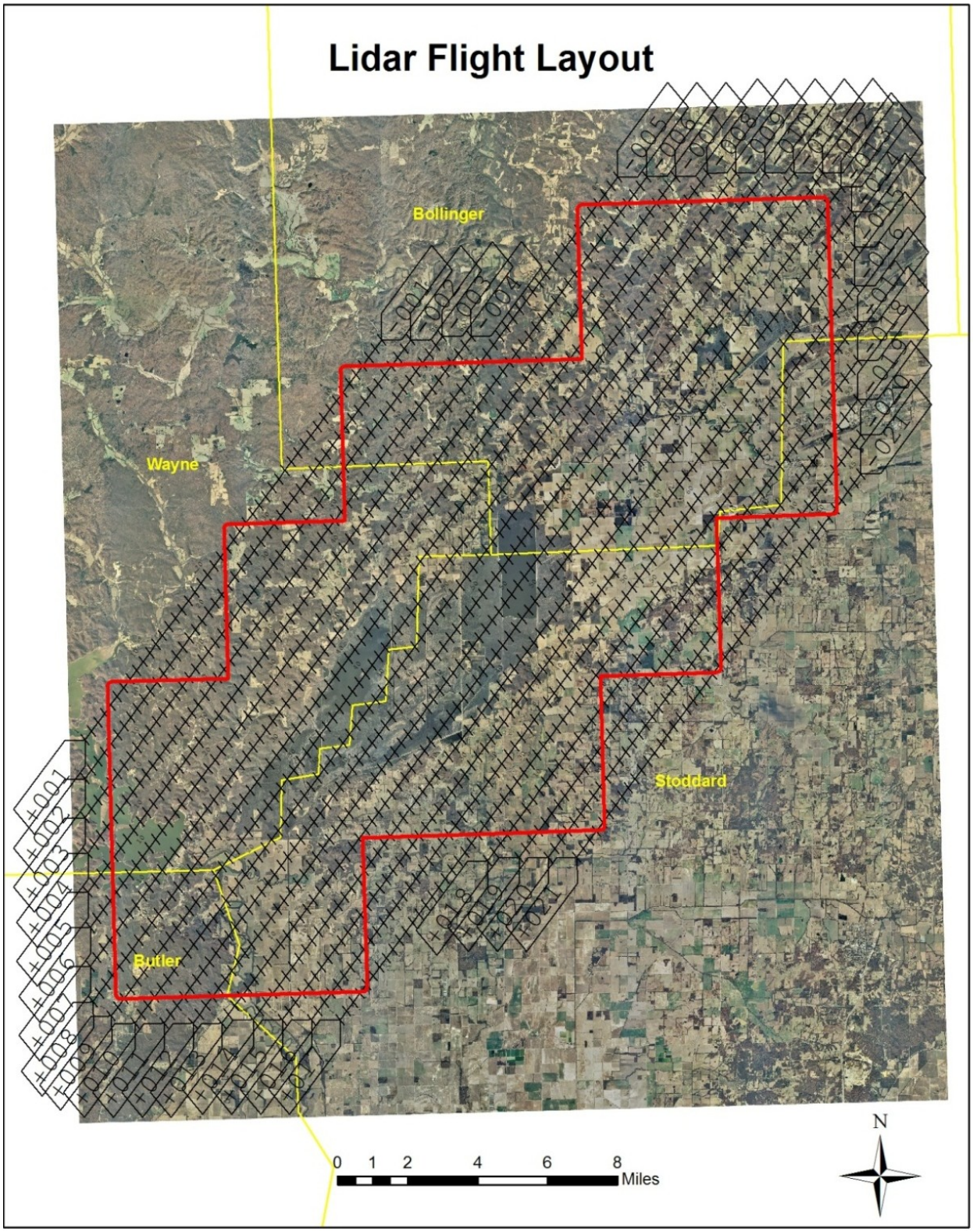

Figure 3: Mingo NWR, MO LiDAR flight paths. A series of 21 swaths were taken across the project area.

The field survey for LiDAR accuracy consisted of 110 check points distributed over the project area. These points consisted of various types of ground cover including asphalt, gravel, short grass, tall grass, and trees (Figure 4). The required LiDAR elevation data values were derived within the Global Mapper software from the bare earth .las files. For each control point location a LiDAR elevation value was derived and exported. These derived values were imported into Excel, and comparisons were performed to generate statistics by ground cover type and for the overall dataset.

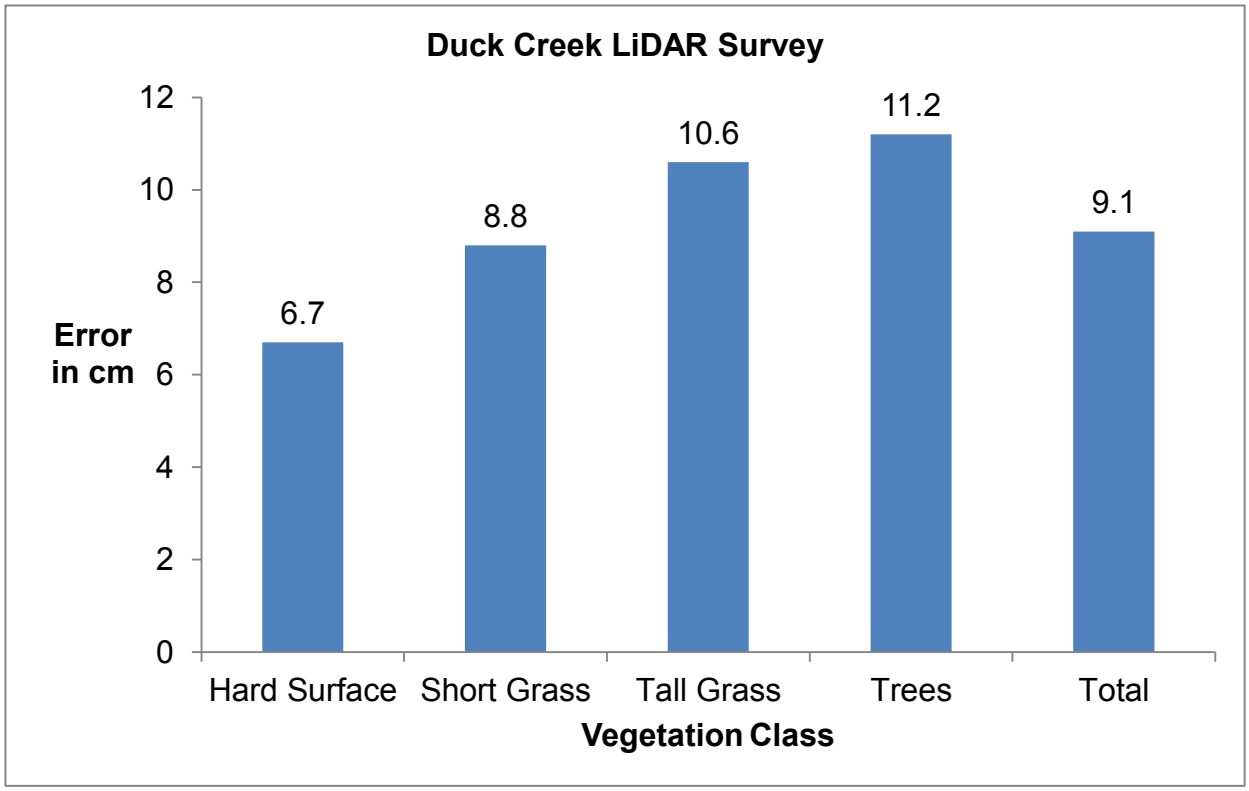

Figure 4: The Root Mean Square Error of bare earth elevation data collected by LiDAR under different types of features. (Obtained from the survey done by the Missouri Department of Conservation, Duck Creek Conservation Area to test the accuracy of the LiDAR data collected.)

The data was found to be within the project limits of 15 cm vertical RMSE for hard surfaces and 40 cm vertical RMSE in trees. Therefore, the Duck Creek elevation data

has been statistically validated to meet the project specifications, i.e. topographic feature points have an overall RMSE of 9.1 cm which is below the project limit of 18.5 cm.

Projection

A projection is a means of taking an image of the globe and rendering it on a 2 dimensional surface. Because of the change in shape of the image, distortion occurs. Different projections distort maps in different ways. The projection used for the analyses was Universal Transverse Mercator Zone 15 North with North American Datum of 1983 (NAD 83). The projection used for the vertical data was that of the North American Vertical Datum of 1988 (NAVD 88).

METHODS

Basemap and Data Preparation

Data acquired was analyzed solely with the use of ESRI's ArcGIS (version 9.3 and 10) (ESRI, Redlands, California) and tools provided in the software tool pack, 3-D Analyst, Spatial Analyst, and Geostatistical Analyst. All layers were clipped to the Mingo NWR boundary and included with a 150 meter buffer around the boundary. Layers used were created by Mingo NWR staff as well as created during this study.

Sink Methods

Utilizing the LiDAR values for bare earth, a 130 meter resolution DEM was created. This was accomplished by taking each LiDAR data tile within the Mingo NWR and converting them to multipoint datasets using ESRI's ArcGIS toolbox LAS to Multipoint tool. Each bare earth value tile was input with an average point spacing of 1.3 as determined by using the pointfile information tool. The only classified points processed for the DEM creation were bare earth as coded by the provider, 2, 17, and 19. The two classification codes 17 and 19 represent bare earth data points that overlap each other. This multipoint data was then generated into a raster DEM using the Point to Raster tool in ESRI's ArcGIS toolbox. In doing so, the output raster can be set to any cell size that is deemed necessary.

The minimum value of all the point values within the cell was to set the cell elevation value. The 130 m resolution or 1.69 ha area was determined by using the reference of Johnston and Naiman (1990), who found the majority of beaver pond sizes to range from 1-2 ha. Each of the raster tiles were then mosaicked together using the Mosaic to New Raster tool. The pixel type was set to match the 32 bit pixel depth of the

original data as well as the number of bands (1). The result was then a seamless raster of all the tiles. In order to clip the raster to just include the refuge and a 150 meter buffer around the refuge, the Extract by Mask tool was used. The flow direction was then determined with the use of the Flow Direction tool. The output of this was then input into the Sink tool. The output of the Sink tool was then overlaid with the known beaver dam locations to determine if it could predict beaver dams across the extent of Mingo NWR.

Habitat Suitability Methods

Digital Elevation Model (DEM)

A 3 meter DEM was used for the habitat suitability models. The DEM used was the one provided by the Surdex Corporation from the 2009 LiDAR data acquisition where all the sinks and other errors were removed. Removal of these sinks and errors ensure that there were limited errors in the data and allowed for a more accurate representation of flow directions and subsequent accumulated flow. The grid DEMs consist of a matrix data structure with each pixel containing topographic elevations stored in a matrix node. Grid DEMs are simple to use and have widespread application to the analysis of hydrologic problems (Moore et al. 1991). Tiles were added to ArcMap, and the tool Mosaic to Raster was used in order to stitch the many raster grid tiles together. This created a seamless DEM in order to correctly perform analyses across the landscape.

Stream Analyses

With the original DEM provided by the Surdex Corportaion as the input, the Flow Direction tool in the Spatial Analyst Tools was used. This output was then used as the input to the Flow Accumulation tool. In order to determine the flow length of the streams,

the output from the flow direction process was input into the Flow Length tool. The direction of measurement was set to upstream in order to measure the length of the streams upstream of the beaver dams.

Using the output from the Flow Accumulation tool, a threshold value was set using the raster calculator. All cells more than 150 cells flowing into them are assigned the value 1, and all other cells are assigned NoData. The stream network was then further analyzed using the Stream Order tool. The inputs were the stream network raster as well as the flow direction raster originally created. The resulting output was the Stream order. The stream network was also put into the Stream to Feature tool with the flow direction raster and the option to simplify checked. The output then had the capabilities of analyzing the length of each reach of the stream.

Watershed

Watershed delineation was attempted first by taking the known beaver dams locations and snapping pour points on the flow accumulation raster to the dam locations. The output of the Snap Pour Point tool was then an input for the Watershed tool along with the flow direction raster. The result is a watershed map layer depicting the watersheds for each beaver dam in order to analyze the size of the watersheds.

Structures

Culvert and Bridge locations were recorded along with the size of the culvert openings and the length of the culvert. This was done by surveying the roads over the entire refuge. This data was then input into ESRI's ArcGIS and a point file layer was created. For analysis of the distance a dam was created from a structure, the Create Near Table tool was used, and the inputs were the dams and the culverts and bridges.

Forest Canopy

The forest canopy density layer was created using the .las files. The .las files were converted for each tile to two different point files. The first point files used the ground points, input class codes as 2, 17, and 19, with the average point spacing of 1.3 m. The ground point's file has all the values set to a factor of 1. The aboveground point files were created using the LAS to Multipoint tool as well. The .las tiles were input into the LAS to Multipoint tool with no input class codes, since the canopy was not coded by the company. The average point spacing remained at 1.3 m. The input return values were set to only the first returns in order to get the very first returns that depict the canopy. The z factor was again set at a value of 1. Both the aboveground and the ground data sets were converted using the Point to Raster tool. The value field was ignored since the priority field was set to count in order to get the number of points per cell in the output. The cell sizes were set at 3. For the bareground tiles the minimum was set for the cell assignment type, and for the aboveground tiles, the maximum was set to give a value to each cell. Both sets of raster tiles were mosaicked together using the Mosaic to New Raster tool. The pixel types were set to a 32 bit pixel depth, and the number of bands was set to one to match the original data. The new rasters were then clipped using the extract by mask in order to get just Mingo NWR and the 150 meter buffer around the boundary. Each of the new rasters (aboveground and bareground) were input into the Is Null tool followed by the Con tool. The inputs for the Con tool were output from the Is Null tool with the input true raster or constant value set at zero, and the input false raster or constant value was the raster created by the Multipoint to Raster tool. The resulting two rasters (aboveground and bareground) were then combined using the Plus tool. In order to divide the rasters and get a depiction of the

canopy, one layer is needed to be in the float data type. The Float tool was used with the output from the Plus tool. The final step was then to divide the float layer from the original aboveground raster created. The result is then the canopy cover with a value ratio from 0.0 to 1.0 corresponding to no canopy and very dense canopy.

Ground Truthing Method

The ground truthing process occurred from June to July, 2011. Transects along the streams within the refuge were conducted. A complete inventory of all dams across Mingo NWR was done. The locations were recorded with a Garmin GPSMAP 60CSx Handheld GPS Navigator. All data points taken were within an accuracy of +/- 6.096 meters. Transects were done on foot or by kayak. Dams within the stream as well as on any tributary were included. Locations of culverts and bridges were done by vehicle and recorded with the same GPS device.

The ground truthing took place later into the summer due to very wet and flooding conditions. At the nearby Wappapello Lake in Stoddard County, MO (USACE) the water elevations set a new record at nearly a foot above the old record of 121.64 m above sea level set in April 1945. The area received 63.5 cm above average rainfall as well as record snowfalls in the northern part of the state. The water at Mingo NWR topped all of the manmade levees and flooded the entire refuge. The exact water levels recorded on the refuge was 104.68 m above mean sea level with the crest occurring on May 4th, 2011.

RESULTS AND DISCUSSION

Using Sinks to Predict Beaver Dams

Background and Rational

Beavers dam streams and channelized overland water flow to create ponding for various reasons (Richard 1983). These ponds can be important to management and can have positive and/or negative effects on resources and property. The ability to predict and map beaver ponds in forested landscapes would be useful to land owners and managers alike. These areas can be closely watched in order to keep high levels of water from inundating and killing valuable timber.

The basis of the idea to use sinks to determine beaver dam locations is that sinks in the landscape could potentially be utilized by beavers to create ponds. These natural pooling sites under the canopy should be considered areas where water is easily dammed to inundate the forest. When water levels rise or rain flows across the landscape and fills these pools the water eventually starts to flow out of them. Beavers then respond and dam this movement of water creating impounded areas.

The remote sensing product LiDAR was chosen to map the sinks based on its ability to collect fine detailed elevation data at a meter scale resolution over large spatial scales. Since the LiDAR utilized was flown during a period where there were no leaves on the trees and the refuge was in a complete drawdown period, a better depiction of the land surface was obtained. With less interference from foliage the laser beams had a better chance for reaching the ground surface resulting in more returning pulses that reached the bare ground. The higher bare ground returns produce a fine detailed depiction of the ground surface allowing sinks to be identifiable using GIS algorithms.

A limitation of most LiDAR data for sink identification is that, before delivery, the data is processed to create a depressionless DEM. A depressionless DEM has had all the sinks filled through a GIS process creating a DEM where all cells in the DEM have a flow direction. This was evidenced by the fact that when running the sink tool on the DEM from the LiDAR provider there were no sinks identified. It has always been thought that these sinks were errors in LiDAR data and other elevation data caused by sampling effects and the rounding of elevations to integer numbers (ArcGIS 10 Help). Rounding data points to the nearest integer creates variations in elevation between adjacent cells increasing the chance there was not another cell adjacent that has a lower elevation. To avoid using a depressionless DEM for beaver pond prediction will require that a new bare earth layer be developed from raw LiDAR data.

The creation of bare earth DEM from raw LiDAR for beaver pond prediction has been enhanced with the current advanced LiDAR capabilities. Advanced LiDAR have more returns that are detectable resulting in sub-meter vertical resolution. In the past, vertical resolutions were much greater than a meter. It was typical of past LiDAR data to have a large vertical RMSE with a few empirical studies suggesting accuracies of 26 cm to 153 cm RMSE for large scale mapping applications (Adams and Chandler 2002; Bowen and Waltermine 2002; Hodgson et al. 2003). These errors were dependent on the height and scale at which the LiDAR was collected. With such error levels sinks due to data, errors were more common in older LiDAR products. With the advancements in LiDAR now being able to detect multiple returns creating sub-meter vertical resolution, the likelihood that sinks were artifacts due to resolution issues and error would, in theory, be reduced. Therefore, it was theorized that the chance of detecting sinks that

are beaver ponds or naturally occurring sinks is much higher when using advanced LiDAR.

The LiDAR used in this analysis had a vertical resolution of or a RMSE of 9.1 cm and was anticipated to produce a bare earth DEM that is much less error prone and more capable of finding actual sinks and ponds. Given the flat, floodplain terrain of the refuge the more detailed data could help identify natural areas that are easily pooled due to shallow slopes and low elevations. Mingo NWR, having a unique geographic setting with its floodplain terrain, presented an opportunity to determine if natural sinks could be found using advanced LiDAR and GIS analysis tools.

Beaver Dam Prediction Process

The first step in the sink process required that a new bare earth DEM be created. The eight tiles of LiDAR data for the refuge were each converted to a multipoint feature class using ESRI's ArcGIS LAS to Multipoint tool. The point cloud classification codes selected were those that were coded for bare ground returns only. They consisted of class codes 2, 17, and 19; respectively bare ground, overlap ground, and overlap ground. In order to analyze the ground surface, the multipoint feature was then converted into the raster format, which creates a map with the cell sizes that are adjustable. This process utilized the ESRI ArcMap tool Multipoint to Raster using the minimum elevation process to determine the elevation of each raster cell. Each tile was then stitched together in order to create a seamless image for data processing.

The Sink tool was then utilized to determine areas within the study area that would classify as a sink. Sinks are cells whose flow direction cannot be assigned to one of the eight adjacent cells in a flow direction raster. A sink occurs when all neighboring cells

are higher than the processing cell or when two cells flow into each other, creating a two-cell loop.

Results and Discussion of the Prediction Process

After many trials to create a GIS layer to exclude very small sinks in the landscape and include larger sinks of areas that could potentially be areas suitable to beavers, a 130 meter cell size resolution was determined to be best fit for the DEM to produce naturally occurring sinks. The 130 m resolution or 1.69 ha area corresponds to 1-2 ha found for the majority of beaver pond sizes by Johnston and Naiman (1990). During this process, successively larger cell resolution sizes were used. As the cell resolution increased the number of sinks declined with an increase in the size. At the 130 meter cell size, the number of sinks identified were 31 (Table 2), and the size of these sinks was a better match to size of beaver ponds found during the ground truthing.

Table 2: The DEM resolution and resulting number of sinks and total number of sink cells as derived from the sink tool comparing one tile of data.

DEM Resolution (meters)	Sinks	Total number of sink cells
1	1256256	too large to create attribute table
3	83311	173246
6	20897	43172
30	664	1304
61	133	258
130	31	58
152	24	45
305	7	14
610	2	3

Mark (1984) stated that naturally occurring sinks with a cell size of 10 meters or larger are rare except in glacial or karst areas and can be considered errors. Mark also

states that as the cell size increases, the numbers of sinks in the dataset often increases. This analysis, in contrast, found that as the cell size increased the number of sinks in the data decreased (Figure 5).

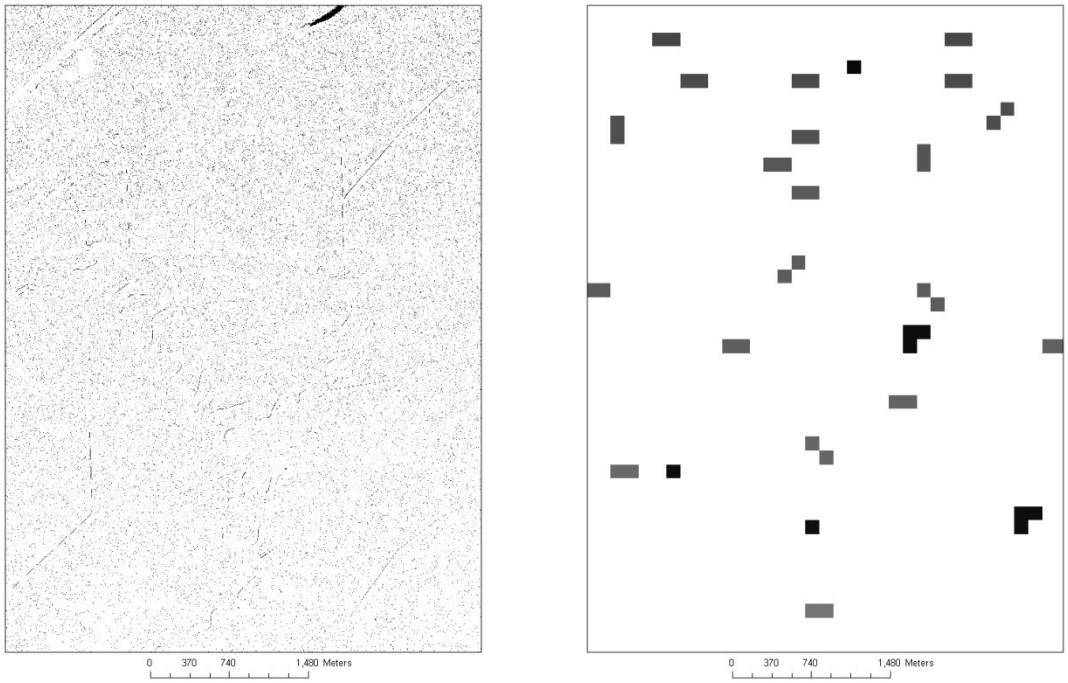

Figure 5: Sink layers derived from the 1 meter cell sized DEM (A) compared to that of the sinks derived from the130 cell resolution DEM (B) for a portion of Mingo National Wildlife Refuge, Missouri.

The developments in data acquisition as well as processing techniques seem to have resulted in the opposite effects as stated by Mark (1984). The fine-scale resolution DEMs are much more accurate and depict in finer detail the topographical features, which then resulted in a large number of sinks for the finer scale resolutions compared to the coarser resolution DEMs. Zandbergen (2006) also found that the number of sinks appeared to decrease with increasing cell size and many of the small and shallow depressions, which are most likely artificial, disappeared with increasing cell size, even though a number of single-pixel sinks persist.

The ability to determine if a sink is an artifact of the data or is real is needed. At this time, there is no technique or process that can determine whether a sink is an artifact or real without requiring intensive field verification. This emphasizes the need to use high resolution DEMs to characterize depressional storage, especially in areas of moderate to low slopes (Zandbergen 2006).

An analysis of the sinks produced for various DEM resolutions was done for comparison on one tile of LiDAR data (3709063se) (Table 2). Comparison to Zandbergen's (2006) findings finds that the patterns are similar despite the fact that he used the Planchon and Darboux (2001) algorithm, and this study used the Jenson and Domingue (1988) algorithm. Zandbergen's findings are congruent with this study, finding that the number of grid cells for a given area decreases by a power of 2 with increasing cell size. For every ten-fold increase in cell size, the number of cells required to represent the exact same area is reduced 100-fold, which is represented by a power factor of 2. In comparison he found the relationship between number of depressions and DEM cell resolution with $y=476146x^{-1.5098}$ with an $R^2 = 0.999$. Compared to this data (Figure 6) $y=912508x^{-2.083}$ with an R value of 0.998. The relationships are similar with this data having a steeper slope accounted for by the greater change in number of sinks as the cell size increases.

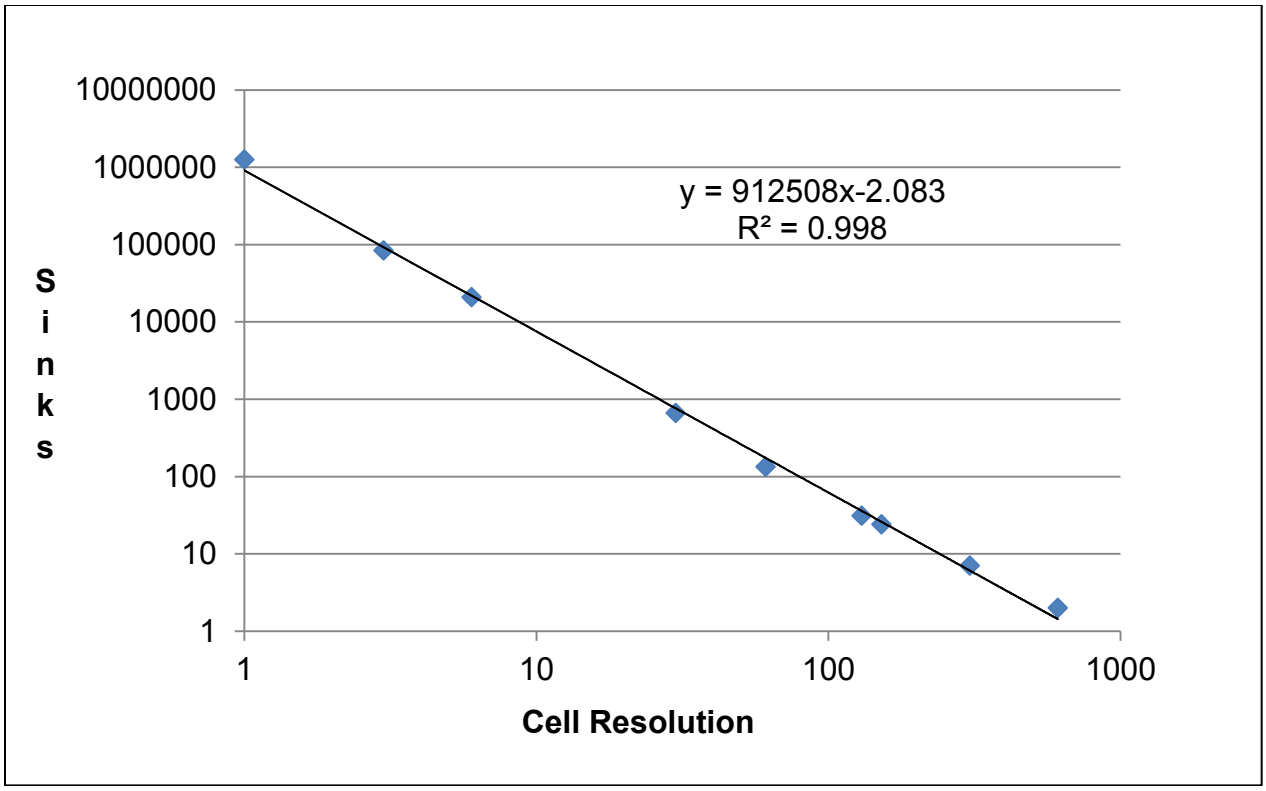

Figure 6: Relationship between number of sinks and DEM cell resolution for one LiDAR data tile on the Mingo National Wildlife Refuge, MO. Both x and y axes are in a logarithmic scale.

One of the possible explanations that there is a decreasing number of sinks for the increasing cell size could be related to the provider delivered classification of ground values which included various other features of the landscape. Examining the slope map derived from the ground classified elevations, there are meter sized spots where slopes quickly change (Figure 7). These changes in slopes are due to the bases and the buttress of trees being classified as ground. With the bases and buttresses being classified as ground, there is fine scale variability in the elevations which then results in the slope map showing many small (meter sized) humps with steep slopes (Figure 7 and Figure 8).

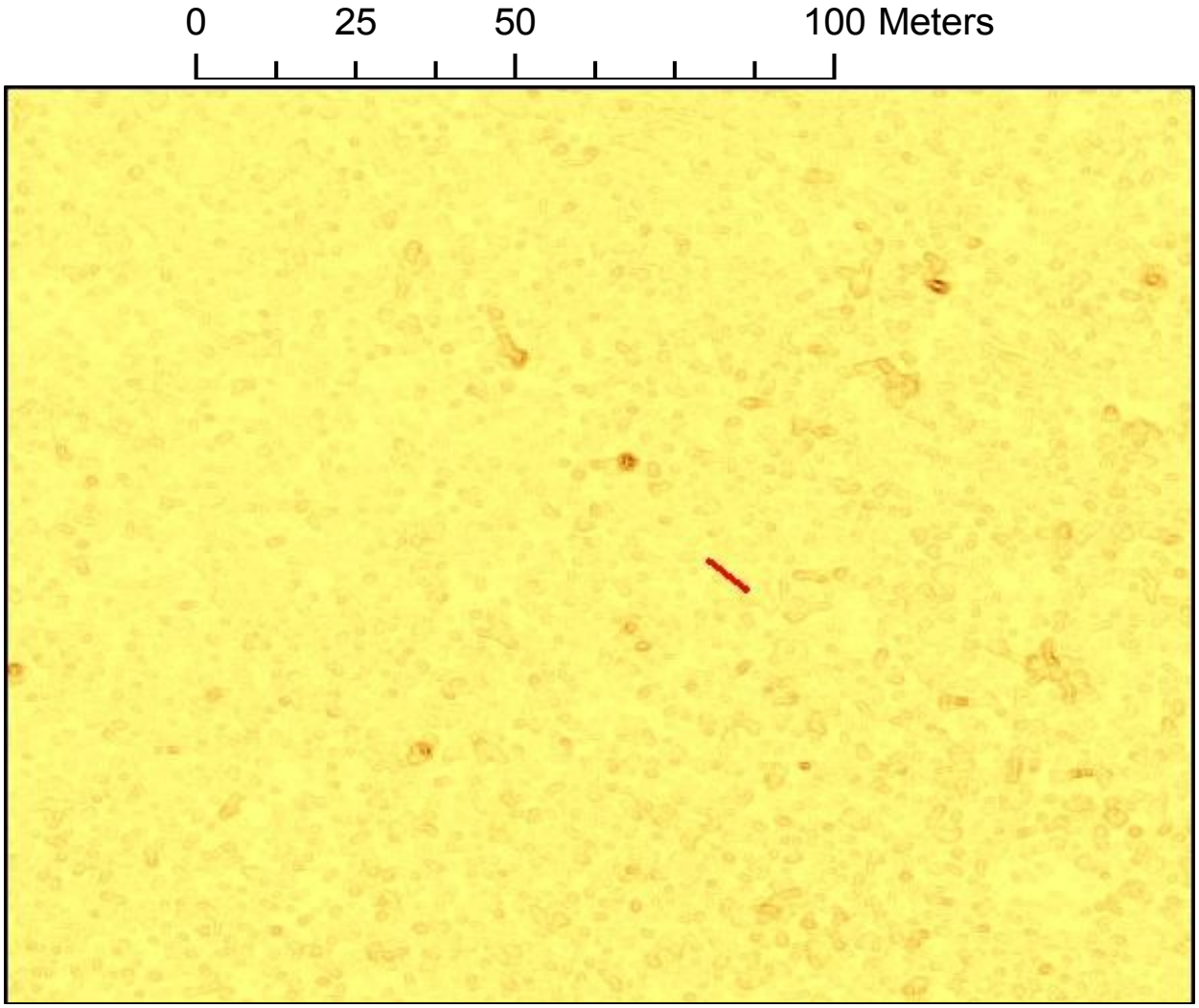

Figure 7: Slopes from the 1 m resolution DEM derived from LiDAR for one tile in the Mingo National Wildlife Refuge, MO. The many small circles represent the bases and buttress of trees across the landscape. The red line is the transect in which a profile was taken to visualize the change in elevations across the land surface (see Figure 8).

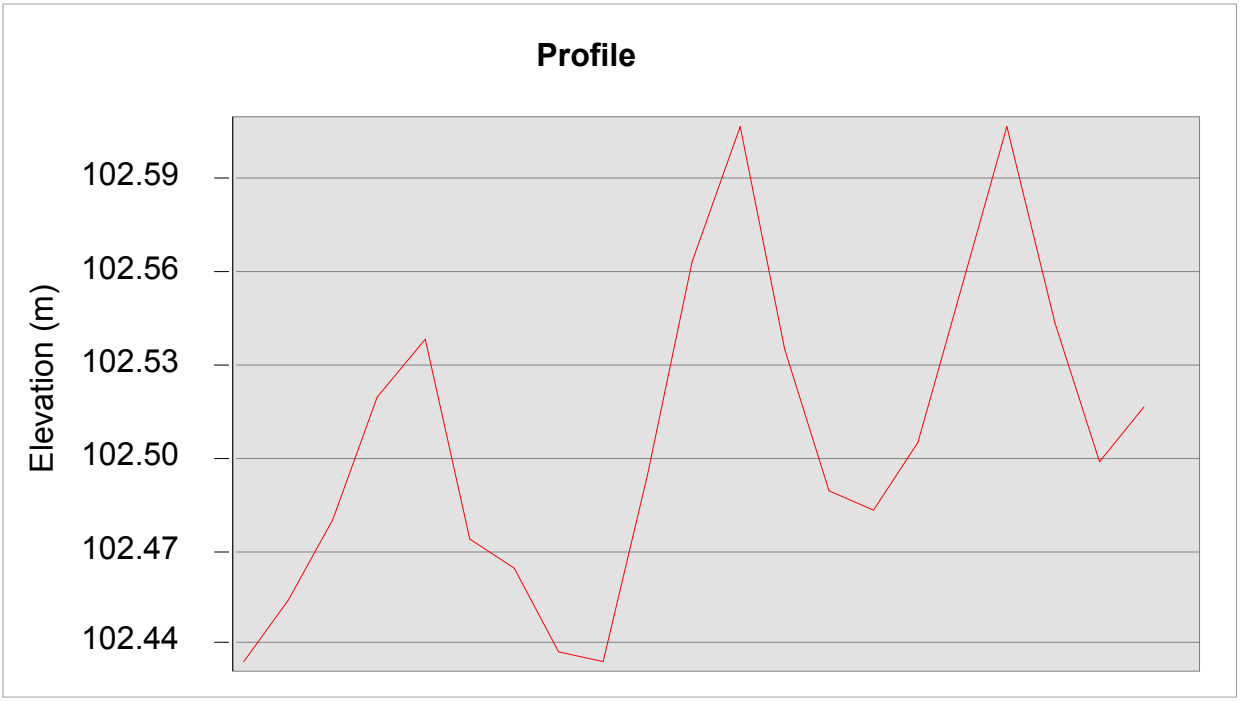

Figure 8: Profile of the change of elevation, in meters above sea level, of the length of the red line depicted in Figure 7.

Using the smaller cell option when developing a sink layer means that cells are similar in size as the humps with one too many cells in the spaces between the humps (bases and buttress of trees). This then results in cells in between the trees having cells adjacent to them at a higher elevation. Therefore, the cells between the trees can be surrounded by higher elevation cells (bases and buttresses) resulting in these cells being identified as a sink. With this kind of fine scale artifact in the data, it was no wonder the sink operation found a large number of sinks for the fine resolution DEM.

Successively increasing the cell size or resolution resulted in averaging out the fine scale variation. This averaging occurs because in increasing the cell size, the lowest cell elevation (minimum option) from all the ground points within the cell was chosen to represent the elevation for that cell. As the cell size got larger more points were used to choose from to represent the cell elevation, effectively smoothing out the fine scale variability from the higher points like the tree bases and buttresses. The larger

cell size used in the sink operation would now be free of the fine scale artifacts, yet leaving the ability of the advanced LiDAR to find the lowest ground elevation in the cell due to the smaller resolution and lower error found in the raw LiDAR data.

The ground classification system used by the provider was not able to filter out the fine scale variability due to reflections off hard objects like tree bases and buttresses close to ground. The fine scale variability can also be due to dense vegetation close to the ground. In the study area, much of the understory vegetation is thin with an open aspect under the canopy, so in this case, the understory vegetation had only a small effect on the ground classification. There is need to develop a tool that can determine what the true bare ground looks like in order to determine actual sinks when using fine resolution cell sizes.

The influence of fine scale errors and objects has been studied by Evans and Hudak (2007), and they promote the multiscale curvature classification (MCC) algorithm when classifying points within the point cloud. This method maximizes the number of classified ground returns, making it an attractive algorithm for many applications. They point out the potential commission errors vary from low amplitude errors representing understory vegetation to entire non-ground objects that models fail to identify. Some level of surface modulation is to be expected in forested areas due to low understory vegetation, logs, stumps, and other ground debris. Evans and Hudak (2007) also state that increasing the cell size to identify the minimum ground height that effectively smoothes the data at the coarser resolutions. The MCC method with the high LiDAR sampling frequency produces a contiguous grid of ground estimates that is consistently derived across the landscape, which is convenient for some applications but decouples

the highly variable nonground samples that are of primary interest for many other applications. Using the MCC algorithm could potentially enhance the ability to map the true bare earth and would be a viable alternative in this case and should be considered by others if the averaging out of the fine scale variation is needed to identify lowest elevation areas and the flow of water through the landscape.

Slope can have an effect on DEM accuracy, but the nature of how slope influences LiDAR vertical error accuracy remains random and unpredictable (Tinkham et al. 2012). There is no predictive relationship to tell if a pulse will travel parallel or perpendicular to a slope. In this case with the slopes relatively shallow 0-10%, there is minimal variability in vertical accuracy which is more likely to occur at slopes that exceed 30°. In areas of steep slopes, the increased planimetric error causes increased DEM error. This is more likely to be a problem in areas of high topographic relief commonly found in the western United States and mountainous areas and therefore not a concern in this study.

Results from the 130 meter cell size sink operation found the sinks consisted of at least 130 square meters. The sink operation found throughout the landscape of Mingo NWR, including the floodplains and uplands to the west, a total of 83 sinks consisting of various sizes and magnitudes. Examining the sink layer and the dam locations found that the sinks and dams occurred in the same location only 7 times out of the 75 dams that were present on the refuge (Table 3).

Table 3: Frequency of beaver dams within different distance classes to the nearest sink and their percentage of all dams.

Distance to Sink (m)	Frequency of Dams	Proportion
0	7	0.093
0.01-16	4	0.053
16-150	9	0.12
150-300	17	0.227
300-450	14	0.187
450-600	6	0.08
600-750	5	0.067
750-900	7	0.093
>900	6	0.08
Total	75	1.00

When dams were included that were within 16 m of a sink, the 16 m accounting for the error of the handheld GPS under dense canopy of the summer months and the actual size of dams, 14.7% of total dams were located with sinks. There was an overestimation of 72 sinks where dams were not present as well as an underestimation of 64 dam locations where no sinks were detected (Table 4 and Figure 9).

Table 4: Number of sinks and dams that were found to co-occur and the number of sinks that did not occur with dams (errors of commission) and number of dams that did not occur with sinks (errors of omission).

Dams	Sinks	Sinks with Dams	Sinks with no dam	Dams with no sinks
75	83	11	72	64

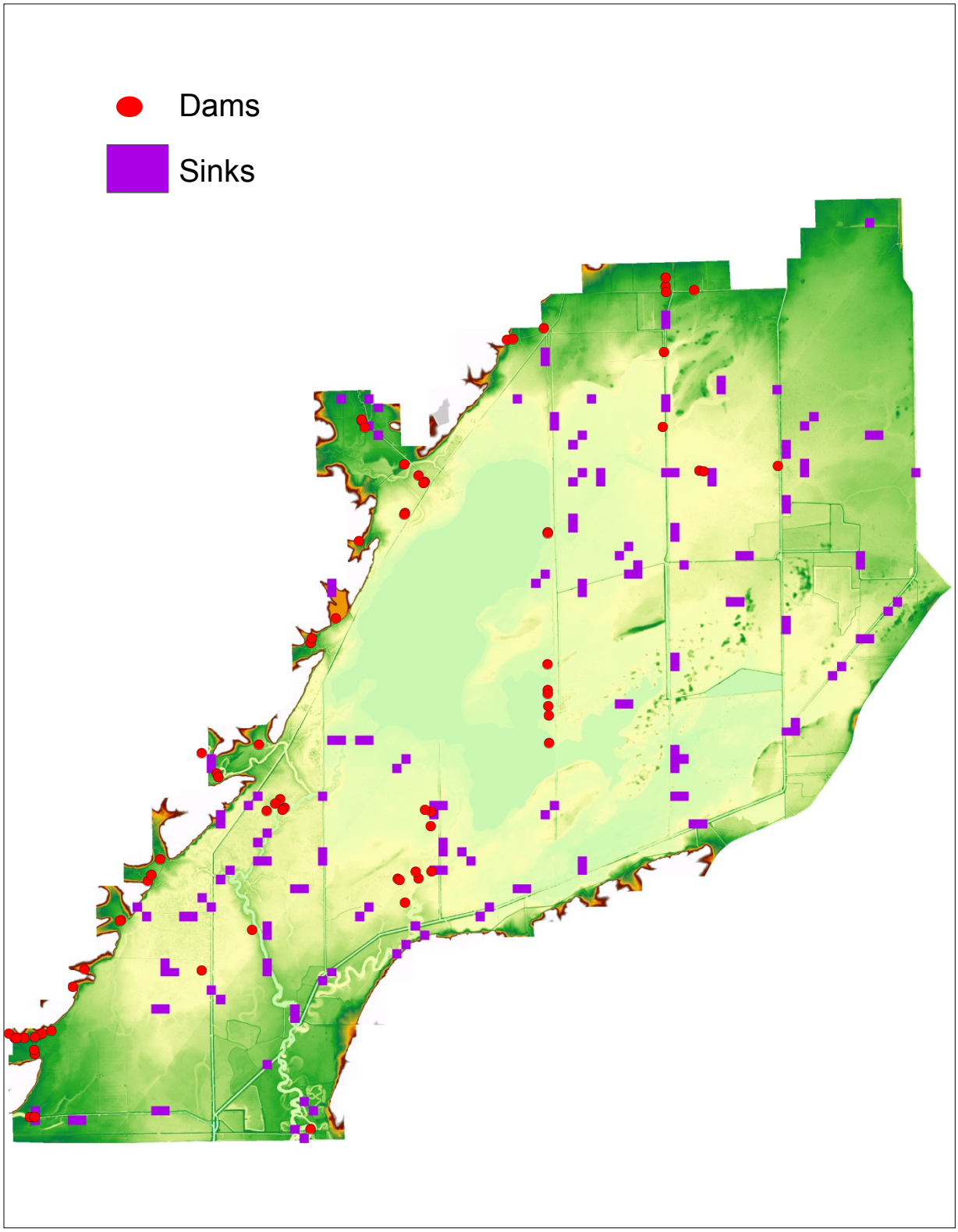

Figure 9: Map showing the locations of both the sinks (purple shapes) at the 130 m cell size and beaver dams (red dots) across Mingo National Wildlife Refuge, MO.

When the sink operation was performed at the 61 meter DEM resolution across the entire refuge, 485 sinks were determined, and the sinks that accounted for dams were not any different from the 130 m resolution data while hundreds more sinks were found that had no dams associated with them. Therefore, reducing the resolution to 61 m did not increase predictability but increased the overestimation rate and resulted in poor prediction compared to the 130 m resolution dataset.

Zandbergen (2006) states as the cell size increased, many of the small artificial depressions disappeared because they were smaller than the new cell size. This study found the same pattern,as the cell size increases the small depressions disappear. Although Zandbergen strongly suggests the characterization of sinks becomes much less meaningful at cell sizes larger than 61 meters, in this study, there was a need to match cell size to the size of a sink that would support a beaver pond. The larger cell size matched where dams would flood a large flat area to provide beavers with the habitat needed. Zandbergens's study was accomplished using the Planchon and Darboux (2001) algorithm used for large datasets with a high complexity. This algorithm along with methods suggested by Wang and Liu (2006) are expected to perform well with the large dataset sizes of LiDAR where depression filling is needed. These algorithms and methods have not been implemented in ArcGIS and associated hydrological software and were not used in this study. If further analysis was considered, use of these algorithms and methods may be beneficial to the detection and determination of beaver dams.

The results of the analysis using advanced LiDAR found low predictability with high rates of errors, both omission and commission. The high number of LiDAR sinks

from the analysis that were errors of commission and then conversely the high number of errors of omission of the LiDAR analysis would indicate that using LiDAR sink analysis with advanced LiDAR was not a useful prediction tool for beaver dams. Part of the reason for this might be the terrain in the study area. The floodplain has very poorly defined flow features across the flat landscape making it difficult to determine exactly where ponding may occur. It may remain difficult to determine an ideal resolution for analyses of various types including beaver impoundments. The fine resolution created too many small ponds, but this same fine resolution is what is needed for detecting a better detailed canopy.

Both the sink process and beaver dam locations are spatially sparse. Because of this sinks and dams can be considered completely independent with low probability of co-occurrence. With low probability of co-occurrence, there is no need for a correction like the Kappa coefficient to be used for this analysis.

There was no ground truthing to determine if sinks from the 130 m cell size or the 61 m cell size were actual sinks or artifacts. It is suggested that a ground truthing would allow for a better determination of how accurate the sink process was at identifying actual sinks. Refining the sink process using the ground data could increase the predictability of the sink process to detect beaver dams.

There was a potential mismatch between timing of when the LiDAR was flown and when the ground truthing for beaver dams occurred. The LiDAR was flown in 2009 and the ground truthing was performed in 2011. Normally, beaver dams are long-lived features on the landscape but with the occurrence of an epic flood event in 2011 prior to the beaver dam survey, there is the possibility that the flood removed or obscured dams

making the survey not an accurate reflection of the 2009 imagery. That said, most of the dams were found in the survey tended to be in places where refuge staff have recently recorded problems from beaver dams. In addition, there was potential for some new dams as well because of the flooding driving beavers into new habitats and the alteration of the drainage system due to the high level of flooding. This movement of beavers out into new habitats could also be due to the effects of trapping in the years preceding the survey.

Given that the beaver dam survey was of current dams, there is high likelihood there is suitable habitat like existing sinks that were not occupied due to the flooding and the trapping by the refuge that reduced populations and activity in prime beaver habitat. Therefore, the sinks with no dams could potentially be areas where dams have or could exist, but currently were not occupied.

Beavers are very adaptable in their choice of habitat. If preferred habitat is unavailable (i.e., occupied or flooded) they are likely to actively change habitats to suite. If there is flowing water, they are able to create ponds and wetlands; therefore raising the water table. The rising water table coupled with varying water levels can mean that there are endless possibilities as to where beavers may dam water moving across the landscape. In some areas very small dams (<25.4 cm) are sufficient in damming substantial amounts of water and inundating areas of trees.

It was initially thought that with the advanced LiDAR available providing the fine detail of the ground surface, there was a possibility to actually map the beaver dam feature itself. With the dam shape detailed from the LiDAR, the sink process should then detect the sink in front of the dam. For a small number of cases in this study, this

procedure may be responsible for some of the co-occurrence of dams and sinks, but the small number occurrences point to this method not being viable. Reason for the method not being viable are related to:

1. The high number of small sinks found at the finer cell size will obscure any real chance for a true sink associated with a beaver dam to be recognized.
2. When the data was processed to the larger cell size to remove the sinks associated with the tree bases and buttresses, it removed the data needed to detect dams since the dams are a few meters in width.
3. Open water was classified as no data since LiDAR used in this study had pulses absorbed or deflected by the water, so no returns were gathered and thus no elevation was reported for those areas. These no data points generated cells of no data when using the smaller cell sizes, and at the larger cell sizes the lowest bare ground elevation within the cell was used for the elevation of the cell. Allowing the water areas to have no data or the elevation of adjacent ground surface without water results in these areas appearing as flat but not as sinks. Having elevation data of the ground surface below water would have resulted in better sink detection. Using bathymetric LiDAR (Wang and Philpot 2006) that detects the ground surface below shallow water would lead to better sink detection in those areas where there was water coverage.

There are tools to detect ponds that have water present in them under the canopy of the forest. Lang and McCarty (2009) found that enhanced Lee filtering was found to increase the ability of LiDAR intensity data to distinguish between areas with and without inundation, which would greatly increase the ability to detect ponding and

wetlands under the canopy if water were present. In this case, many of the areas, when the LiDAR was flown, were not holding water. Having more recent flights when water is being pooled could definitely enhance the detection of dams inundating the forest. It would be more costly to fly LiDAR more frequently, but if the cost of the loss timber outweighs flight costs, it may be an option to better manage beaver dams.

Tools and technology will forever be changing. With finer and higher quality LiDAR data collection comes the necessity to update or create new tools to better understand the data that is collected. Finding beaver pond locations has proven to be difficult even with the advanced LiDAR data and implementing the tools that are available. There is room for improvement, which could be seen with the buttress of trees being classified as ground. Tools to filter this type of data can enhance the true topography and better understand areas where water may pool. There seems to be a faster development of data collection than there is tool development. It may be deemed difficult or impossible to improve tools to the point where we can extract certain features and understand all that is going on, especially in areas with as little relief as Mingo NWR. Other areas similar in relief would expect to have the same difficulty. In areas with more relief, one would expect these methods would be better at determining actual sinks, and the methods be less prone to the errors that occurred in this case.

Overall, despite the development of advanced LiDAR and depression removal techniques/ algorithms, it seems that there are limitations to the technologies used when processing high resolution DEMs to predict beaver impoundments. For the purpose of finding sinks and predicting beaver dams with this technology, there needs to be further development of tools and research to improve the predicative abilities. As

filters are developed to make use of the fine scale elevation data smoothing out the errors and artifacts to produce a more useable depiction of the land surface, there should be a better understanding and analysis of the land surface. In the end, it may be that at the fine scale, no land surface is truly flat. Instead of reducing this inherent variability this variability can be incorporated into a more complex process, reflecting the true nature of the land surface.

Beaver Dam Detection Using No Data Cells

An alternative way to predict beaver dams and ponds would utilize LiDAR's ability to detect water. It was postulated that during the 2009 LiDAR flight, only beaver ponds within the canopy would have water, so areas detected as water could be used to predict beaver ponds. A 3 m cell resolution DEM was created that reflect only those cells that had no data which are interpreted as water. The LiDAR used is absorbed by water or reflected sideways resulting in no LiDAR returns for those locations leaving those locations as having no data.

The result from the no data analysis found that there were a large number of no data or cells with water within the forest canopy (Figure 10). Large, open areas that were covered with water and known as not being beaver dams were well depicted. These large areas have previously been ignored in the prior analyses using sinks to identify beaver dams since it was determined that none of the sites were in timber areas nor greatly influenced by beaver dams at that time.

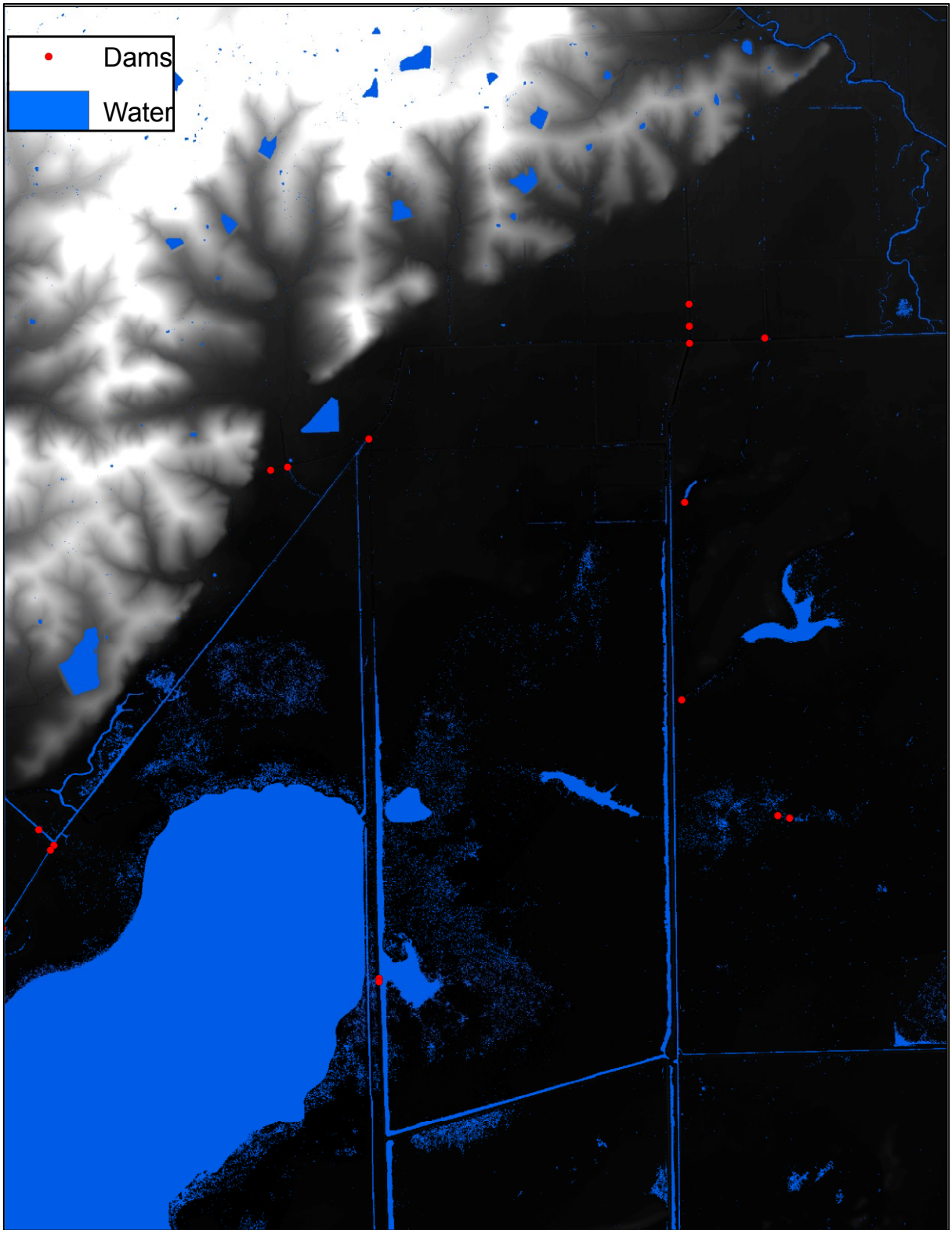

Figure 10: Image of no data LiDAR classified returns (water) in blue at a 3 meter resolution cell overlaid with the locations of the beaver dams.

It was determined that there were too many water cells identified within the tree canopy for this method to be usable to predict beaver dams. An overlay of the beaver dams on the map with just water cells found few cells with water associated with most of the dams, while there was a large number of water cells scattered over the refuge not associated with dams. It was thought that during the 2009 LiDAR collection much of the refuge was dry. Given that there were many points classified as no data or water, either there was more surface water present to absorb or reflect the LiDAR signal, or there were errors due to sensor problems or classification problems. The classification of no data by the provider could be influenced by their filters and thresholds used when processing the original signals. Because the provider uses proprietary processes in producing the different return classifications, it is unknown the effect these might have on the classification of no data. Therefore, the use of the no data/water classification is problematic for use as a predictor of ponds within the canopy. Using the methodology of Lang and McCarty (2009) would be a better choice to find surface water within the canopy which uses intensity values from the LiDAR rather than the classified returns.

Habitat Suitability

Slope

Beavers tend to prefer to dam small, low gradient streams and channelized overland flow with unconfined valleys (Pollock and Werner 2003). Pollock and Pess (1998) found that out of 341 beaver ponds in Washington, 91% were in slopes less than 4% and had unconfined valleys. Beavers built dams on 82% of all low slope (1-3%) streams, 73% of reaches with 4-6% slopes, and 61% of reaches with 7-9% slopes. The use of streams with a slope greater than 9% dropped dramatically, and in streams with

slopes greater than 15%, only 1 dam was found (Retzer et al, 1956). Steep topography prevents the establishment of a food transportation system. Suzuki and McComb (1998) investigated 170 dams in Oregon and found that more than 90% occurred on slopes of less than 6%. Across the refuge there is a wide range of slopes and many channelized overland flows with unconfined stream channels. Beaver dams were present in areas of very shallow slopes 0-5% (Figure 11) with all of the dams in areas with 0-1% slopes just outside of the channels of streams. No dams occupied sites of greater than 5% slopes. These findings are very consistent to those studies cited above. All of the areas with shallow slopes happen to be in areas associated with the floodplain. Slopes ranging from 0-5% accounted for 71% of the refuge, leaving a very small portion of the refuge with slopes greater than 5% which are not suitable habitat for beaver dam selection (Table 5).

Table 5: Slope classifications and the respective area, in hectares, of Mingo National Wildlife Refuge, MO.

Percent Slope	Total Hectares	Proportion
0-5	10611.70	0.711
5-10	1436.84	0.096
10-15	1015.16	0.067
15-20	694.84	0.046
>20	1230.63	0.082

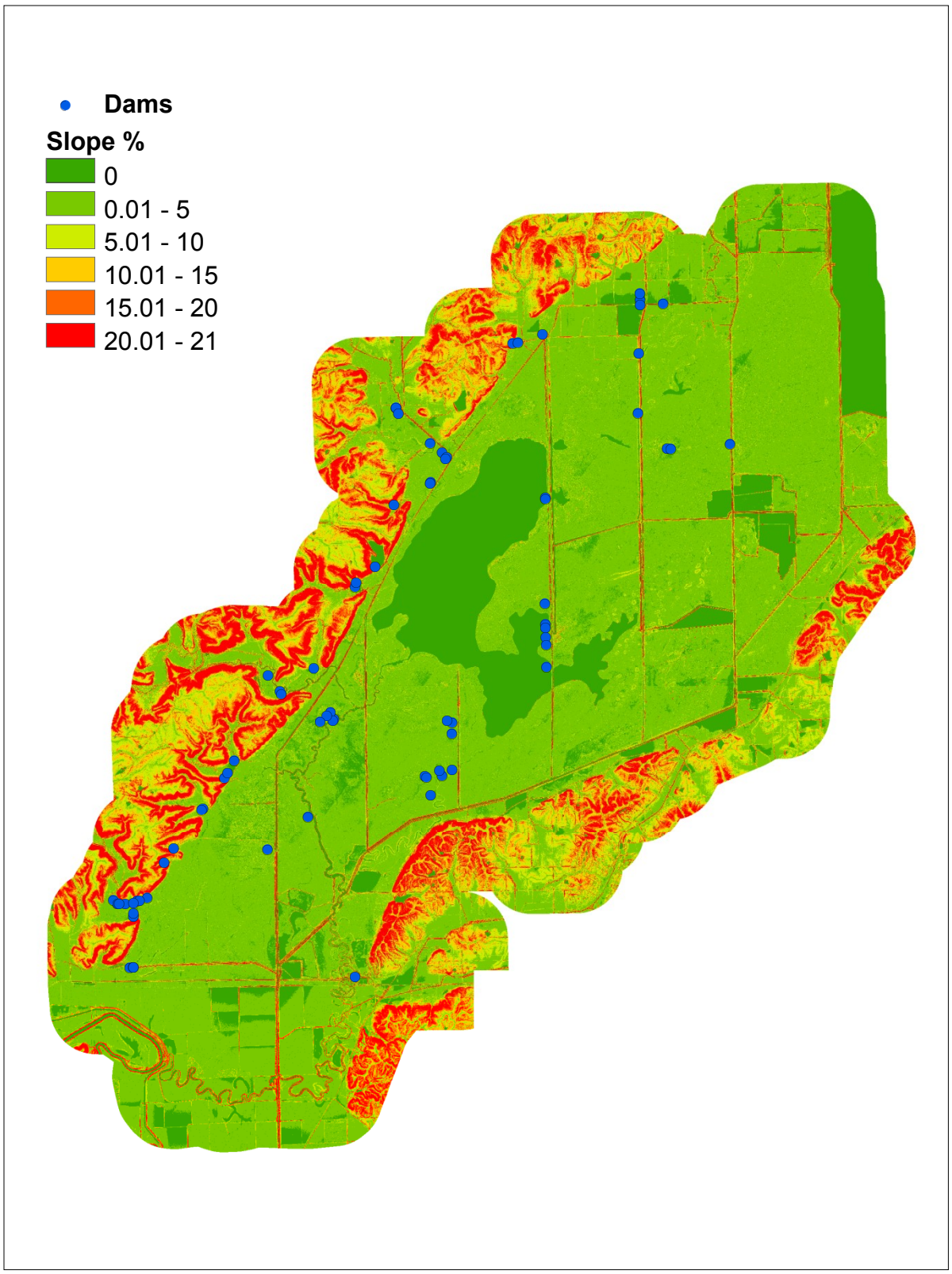

Figure 11: Map depicting the slopes (in percent) across Mingo NWR, MO overlaid with the location of beaver dams.

Stream Variables

Stream length and stream order were calculated from the stream network created for the refuge using the hydrology tool package. Stream length with dams present ranged from 23.7 to 14,436 m upstream of the dam site, with an average stream length of 3,168.8 m. Out of the measurements upstream of the dam sites, 54 of the streams were greater than 1,000 m leaving 21 with stream lengths less than 1,000 m. The majority of the streams with dams present were less than 4500 m of stream length with most dams occurring on streams 0 to 1500 meters in length (Table 6).

Table 6: Frequency of beaver dams for different stream lengths broken into categories determined by the standard deviation of all dammed streams divided by two for the Mingo NWR, MO.

Stream Length (m)	Dam Frequency	Percentage
0-1500	25	33.33%
1500-3000	21	28.00%
3000-4500	13	17.33%
4500-6000	5	6.67%
6000-7500	3	4.00%
7500-9000	0	0.00%
9000-10500	5	6.67%
10500-12000	2	2.67%
12000-13500	0	0.00%
13500-15000	1	1.33%
Total	75	100.00%

Stream Order

Stream orders were assigned to results of the stream network using the ArcGIS 10 GeoAnalysisStreamOrderStrahler method in the stream order tool pak. The stream orders ranged from an order of one to eleven with number of reaches decreasing as order increases (Table 7).

Table 7: Number of stream reaches for each stream order found through the stream network process for Mingo NWR, MO.

Stream Order	Count
1	43783453
2	8213230
3	3673818
4	1836737
5	920085
6	487032
7	218617
8	132718
9	68254
10	25847
11	8818

The high number of orders and the high order level are due to the fine detail resulting from the stream network process. The stream network process detailed all channels possible with most from fourth order and below being ephemeral and intermediate streams. The largest channel that leaves the refuge is classified as an eleventh order. This classification differs from the Strahler ordering system (Strahler 1957) used for perennial streams due to the inclusion of small overland flow channels. The eleventh order stream is classified as a true fifth order stream when only using perennial streams in the Strahler method (Conservation Commission of Missouri 2012). Despite ditches not being natural drainage ways they were included in the stream order

classification as well since they are a part of the habitat. Beavers did use these small overland flow channels to dam the flow of water (Figure 12). Beaver dams were present on streams with orders ranging one to ten. The most frequently dammed stream order was seven.

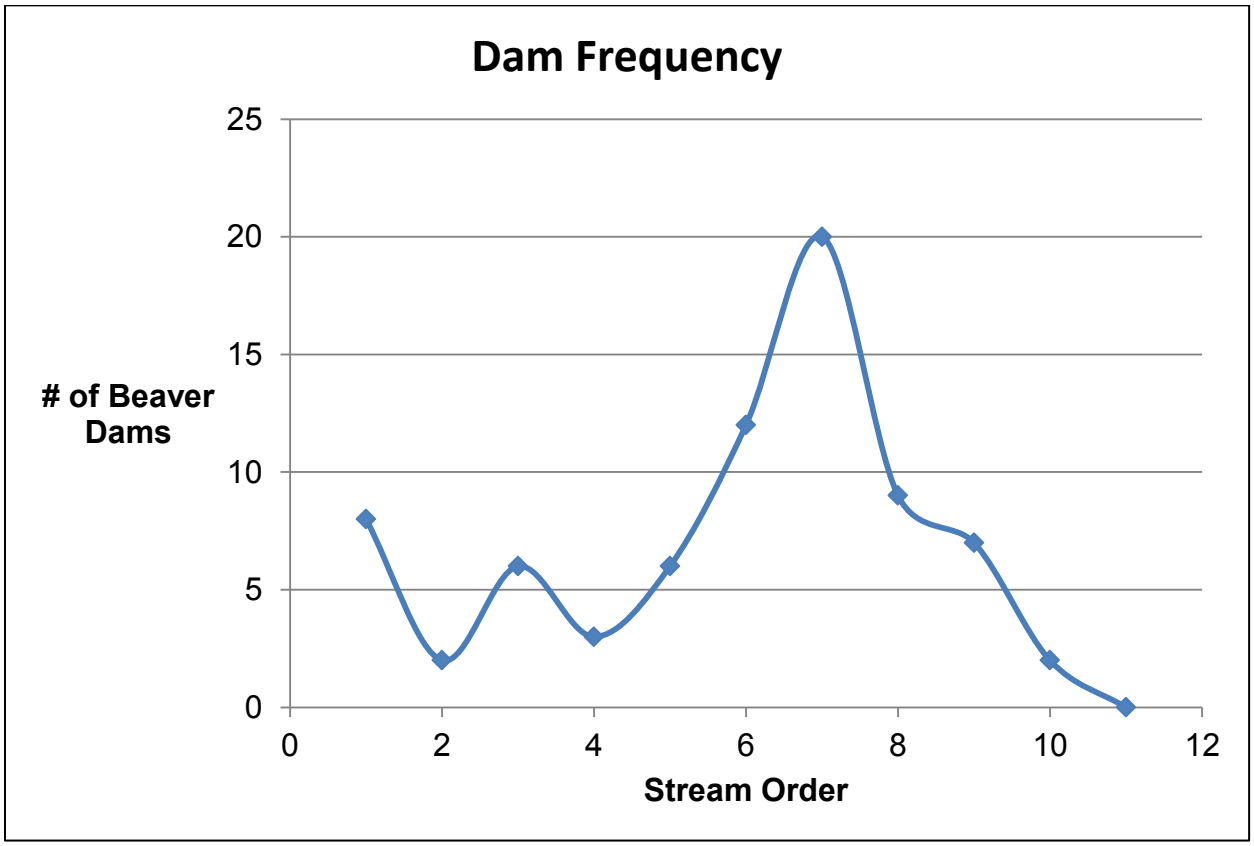

Figure 12: Frequency of dams located on the different stream orders from the stream network classification of Mingo NWR, MO.

Naiman et al (1986) stated that dams are rarely built in streams greater than Strahler fourth order streams. In the upper coastal plain of South Carolina, beavers showed a preference for second order streams and impounded substantial lengths of intermittent streams (Snodgrass 1997). In Minnesota, it was found that beavers preferred fourth order streams in the northern boreal forest (Johnston and Naiman 1990a). In comparison, the stream order used for this study was much more fine in detail, where the classified stream order of seven would be comparative to a second

order stream in the perennial stream Strahler classification system (Strahler 1957). Therefore, a stream order of two would account for 20 of the dams on the refuge with none of the dams occurring at more than a fifth order stream. This is more comparable to what Suzuki and McComb (1998) found in Central Oregon, where density was highest in first order and second order streams and decreases in third order streams and greater.

Problems occurred when trying to determine the stream networks of the refuge. The tools used were found to have troubles with areas of very little slope. The majority of the refuge is 0-3% slope. It was also found, while processing large amounts of data, the infinity flow accumulation was unable to provide any flow models (use of tiff files). It might also be that the infinity flow direction was more easily caught in a looping effect in flat areas. The D-8 flow model performed sufficiently except in areas of 0% slopes because of the looping effect.

Determination of stream classifications were based off of the Strahler stream order technique (Strahler 1957), but varied due to the much finer scale waterways in which were included in the classification. The smaller waterways were included in the stream network by determining a criteria of searching for cells that have a flow of 150 cells or greater into them. There is also a very intricate ditch system to control water levels throughout the refuge that was included in the classification. This is not typically done, but since these ditches act as natural waterways and can have perennial flows with the potential to be dammed, they were included in the analysis.

Streams in floodplains and areas of low elevation changes with lots of ground water are hard to determine. Since much of the refuge is in an abandoned stream

channel, there are areas of sandbars as well as clay type soils. Water can freely flow through the sand, and when they encounter soils acting as an aquiclude, they breach to the surface creating a stream. What could normally be classified as an ephemeral stream could potentially be considered a perennial stream or a stream of higher order in this regard. Stream length can also incur problems developing from the same explanations. Therefore, first order streams in this case may have sufficient flow to support beaver dam ponding.

Culverts and Bridges

Culverts and bridges in relation to beaver dams have been analyzed in previous studies in New York. The method used by Curtis and Jensen (2004) searched for dams that were 200 meters or less from a road crossing to include in their analysis. In order to compare results of culvert and bridge influence, the same distance was analyzed in this study.

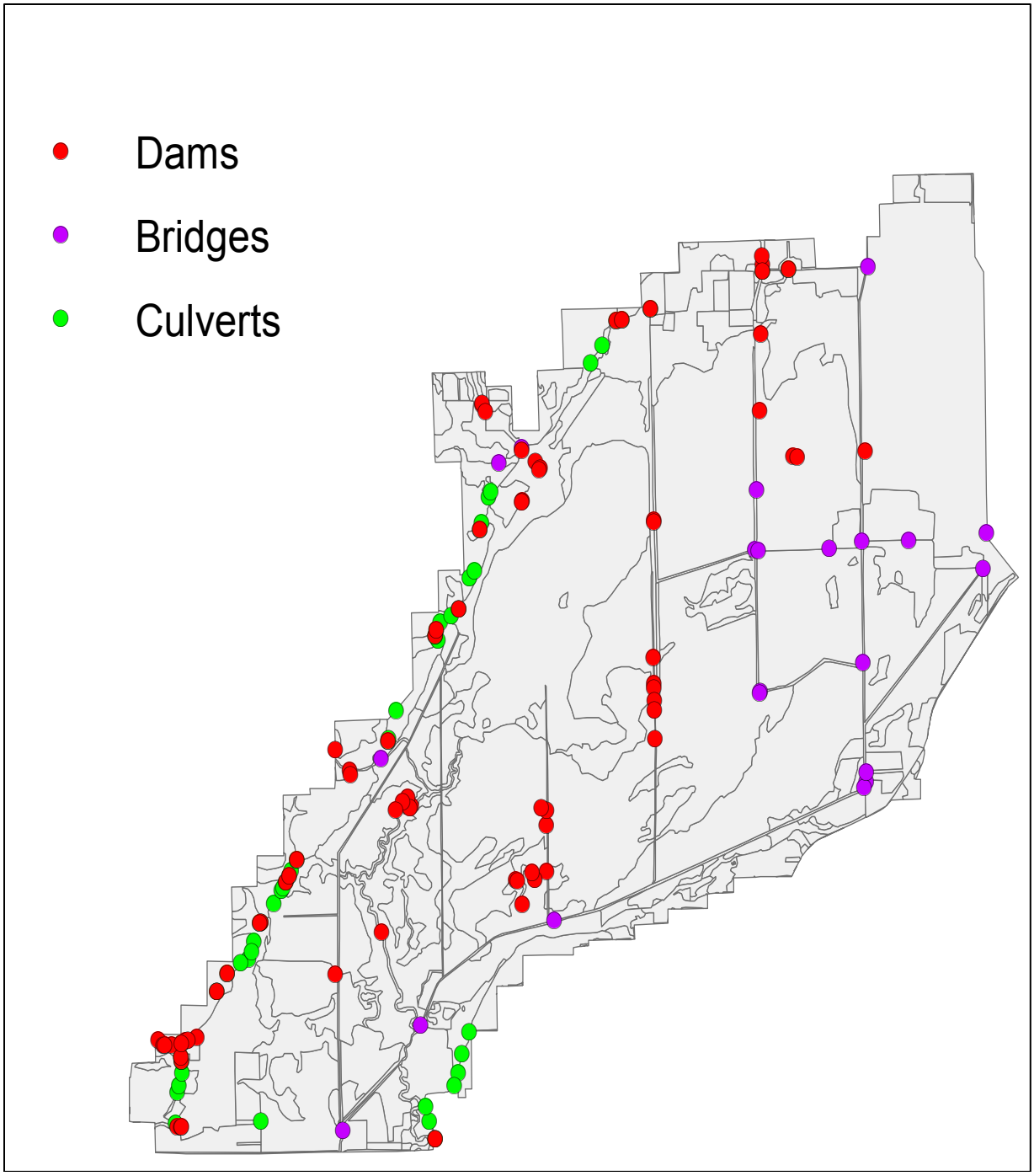

Figure 13: Map depicting the locations of dams, bridges, and culverts within the boundary of Mingo NWR, MO.

At Mingo NWR, there are a total of 54 culverts that range in size from 0.61 x 9.75 m to 1.22 x 2.44 x 9.75 m. Of the total culverts located within the refuge, 23 contained dams. The size of the culvert did not seem to be selected for or against in regards to

being dammed. The culverts that were dammed tended to be in areas where the slopes were relatively shallow and that have the stream lengths similar to the prior analysis of stream length above dams. The numbers of dams found within 200 m of road crossings were 30 of 75 dams when combining the 0-200 m distances from both bridges and culverts (Table 8 and 9). The most frequent dam distance from bridges was 600-1000 m, whereas the 0-200 m distance from culverts accounted for 29 of 75 dams. The high frequency of dams associated with culverts is most likely due to the ability of beavers to plug culverts due to a pinching of the stream channel. Bridges do not tend to constrain the channel as culverts do.

Table 8: Frequency of dams at each of categorized distances between dams and bridges along with the proportion of the total dams that each category represents.

Distance From Bridge (meters)	Dam Frequency	Proportion
0-200	1	0.01
200-600	7	0.09
600-1000	19	0.25
1000-1400	5	0.07
1400-1800	15	0.2
1800-2200	6	0.08
2200-2600	7	0.09
2600-3000	14	0.19
>3000	1	0.01

Table 9: Frequency of dams at each of the categorized distances between dams and culverts along with the proportion of the total dams that each category represents.

Culvert Distance (meters)	Dam Frequency	Proportion
0	22	0.30
0.1-200	7	0.10
200-600	8	0.11
600-1000	13	0.16
1000-1400	4	0.05
1400-1800	1	0.02
1800-2200	6	0.08
2200-2600	10	0.14
>2600	3	0.04

These findings were similar to Curtis and Jensen (2004) that found occupied beaver dams were within 200 meters upstream or downstream of the road. The majority of the dams did occur within the 200 meter buffer but did not account for all dams on the refuge. All of the culverts that had suitable slopes, canopy, stream order, and stream length were dammed. The limiting factor in which Curtis and Jensen (2004) found was open areas along the roadside which had the strongest influence. The Mingo NWR analysis of the canopy vegetation cover proved to be dense where culverts were present so there would be no limiting factor due to lack of trees or openness.

The constriction of the streams by the culverts may contribute to the culverts being easily dammed. It is also thought that since beavers damming behavior is triggered by the sound of running water that culverts enhance this sound (Barnes and Mallik 1997). Other studies have found that the larger the culvert the less likely the beavers are to plug it. Although this analysis found no significant correlation ($p>0.05$, $r = -0.15$) (Table 10), it may be that smaller culverts are more easily plugged. Therefore, in

management perspective, it may be beneficial to have larger culverts that are not as easily plugged and may also have the possibility of easier de-plugging with larger machinery. Larger culverts may have more flow as well, which could be harder to lodge debris and plug.

Table 10: Categorized size of culvert inlets and the number of dams found in each category.

Culvert Inlet Size (meters)	Dams Present
0.31	1
0.46	0
0.61	4
0.91	3
1.22	12
1.52	2
1.22 x 2.44	0
2.13	0

Jensen et al, (2001) stated that the culvert inlet opening is the most important determinant of whether a culvert will be dammed by beavers. This analysis also found that large culverts and bridges were not plugged, possibly being that they are less likely to impact the flow of water and do not constrict the stream. Smaller culverts were more likely plugged. Small culverts often constrict streams, which increases stream velocity and generates sound that beavers may respond to (Novak 1987). Larger culverts maintain the natural stream width, so stream velocity is not changed. The type of culvert did not seem to make a difference with both the box and the pipe culverts being dammed (Table 11).

Table 11: Categorized type of water structures and the number of them found plugged or non-plugged.

Structure	Plugged	non-plugged
Box Culvert	5	4
Bridge	0	23
Pipe	18	27

Observations on what might be the controlling factor on whether beavers plugged the culverts or not appeared to be the slope on the upstream side of the culvert. If the slope was so great or an area was unlikely to support a pool of water, the culvert was never dammed. The velocity of water was probably too great to dam, and if it were to be dammed, it would not result in a pond that could be habitable for the beavers.

Forest Canopy

An adequate source of food must be present for the establishment of a beaver colony (Slough and Sadleir 1977). Most of the trees utilized by beaver in Massachusetts were within 30 m of the water's edge (Jenkins 1980). In another study, Bradt (1938) reported foraging distances of up to 200m from the water's edge. Biomass of the vegetation is likely not to limit the suitability of an area to support beaver activity (Boyce 1981). It may have an impact during the winter when food is cached for winter diets. The trees and shrubs closest to the pond or stream edge are generally utilized first (Brenner 1962; Rue 1964).

The density of the canopy is medium to high for the vast majority of the refuge (Figure 14) with most all the refuge having some sort of vegetation cover except those areas covered by surface water.

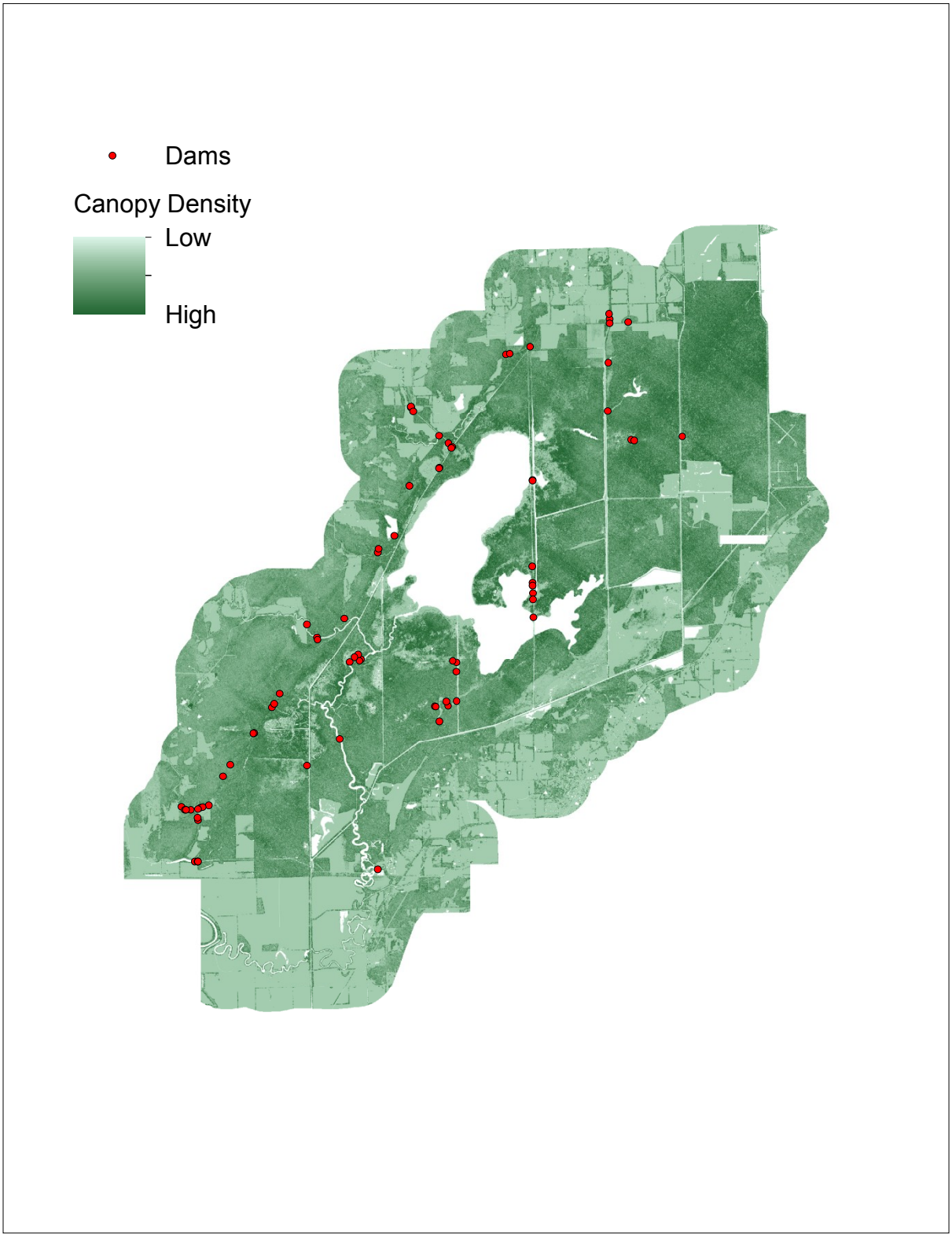

Figure 14: Image of the canopy density and the beaver dam locations of Mingo NWR, MO. Areas of dark green represent dense canopy. Lighter areas depict little canopy and white depicts water with no above ground vegetation.

All beaver dams are within 15 m of dense canopy and follows what was found in the previously mentioned studies for acceptable habitat for beavers. Based on the canopy imagery, there is sufficient vegetation for beavers to feed and to use for dam building. Canopy is not always positively associated with beaver. Suzuki and McComb (1998) found in Oregon that beaver occupancy was negatively associated with percent cover of woody vegetation, and Barnes and Mallik (1997) found no evidence of beavers choosing dam sites based on the presence of food items in a northern boreal watershed.

The habitat of Mingo NWR for beavers appears to provide sufficient vegetation, along with slopes and water channels, so the possibilities of where beavers could truly dam water are endless. Beaver occupancy within the refuge is probably only limited by water levels and the density of the beaver population that occurs within the boundary of Mingo NWR.

CONCLUSION

The models used for prediction of beaver dams in this study performed poorly. Poor performance of this prediction process is can be attributed to many factors. At the time of the study, beaver numbers were low. The previous year, the refuge contracted trappers to bring down the population of nuisance beavers. Population control, paired with the large flooding that occurred in the spring of 2011, possibly resulted in low populations in the area. When areas where beavers inhabit are flooded, they are pushed out of suitable habitat to other areas. These floods were powerful enough to blow out dams that had been in place before the flood as well. Although the ground truthing of dams was very rigorous and all dams present on the refuge were surveyed, many dams were likely blown out and floated away and not included in the survey. The low population numbers coupled with the catastrophic flood have implications on how much of the available habitat was occupied by beavers on the refuge. With low occupancy predicting beaver dams would be limited and an overestimation of probable dam sites likely.

The promise of advanced LiDAR increasing the ability to detect surface features that can be used to predict beaver dams was not realized. Determining what is the true ground surface was complicated by small sinks, fallen timber, last return errors, and the bases and buttresses of the many trees. There is a need to find a way to filter these complicating factors out so ground surface that contains features like true sinks and the beaver dams themselves are readily discernible.

In conclusion, much of Mingo NWR is suitable habitat for beavers, with the most suitable being perennial streams to the less sought after ephemeral and overland

channelized flows. All of the streams and ditches fall within stream orders that beavers are known to inhabit and have stream lengths and shallow areas easily inundated with minimal efforts. Much of the refuge is vegetated with few areas void of trees, shrubs, and plants, utilized by beavers for forage and dam construction materials. The lower elevation floodplain landscape provides seemly shallow slopes, allowing easy manipulation of water flows as well as navigation via water when at full water capacity. As water fluctuation and manipulation occurs, especially during flood up, parts of the refuge less suitable for beavers become more attractive. Culverts and inlet/outlet openings create areas where flows are constricted and easily impeded. Overall, it is very hard to determine exact locations of where beavers will blockade flows on Mingo NWR. We do know that beavers will utilize habitat available to them, and Mingo NWR has plenty of suitable areas for their utilization.

The application and tools to process LiDAR data is growing in the terms of land management. However, there is need to develop them accordingly to fit certain needs. They are important and useful tools to understand and calculate aspects regarding habitats for various wildlife. It must also be kept in mind that there will always be some restrictions in the data collected and the tools used to process the data. In future applications, different tools and programs designed in regards to beaver dam site locations are needed. With the easily accessible toolsets available it is difficult to imagine creating a very precise application to finding dams in this type of area, especially when we truly do not know how beavers select for specific sites and not others.

MANAGEMENT IMPLICATIONS

The determination of exact beaver dam site selection using very fine scale DEMs is impractical in the floodplain landscape of Mingo NWR. I would expect similar results in comparable landscapes. Taking into consideration the habitat suitability models used to assess Mingo NWR, much of the refuge has suitable slopes, vegetation, and depending on the time of the year, water to support beaver activity. Special attention to water control structures is obligatory. These seemed to be the areas of most activity. With Mingo having the largest remaining tract of bottomland hardwoods left today, management and concerns of this resource is a large focus. Therefore, the management of beavers is most valid with their abilities to affect large stands of trees directly through girdling or indirectly through inundation.

The large area and number of trees at Mingo NWR rules out the practice of using fencing around individual trees or areas of trees to keep beavers out. It would be costly and time consuming and would inhibit other wildlife movements throughout the refuge. The best piece of advice for the management of beaver on Mingo NWR would be to have data on the number of beaver colonies and managing the populations and focusing on areas that seem most problematic, culverts.

Population management is number one priority. If populations are in check, activity will likely take place in the most suitable areas, which in this case would be perennial streams. There is no guarantee that the beavers will not affect other areas, we truly do not know or understand how they choose sites and we may never fully understand their behavior. It seems that the ability of beavers to create dams on Mingo

NWR is dependent upon the water levels, since the majority of the refuge is suitable habitat.

Refuge staff may find the need to determine better or different ways to keep beavers from damming culverts, since these areas were dammed most consistently. There are many structures out there that block beavers from damming culverts or certain areas. One very well-known device is the Beaver Deceiver (Lisle 1999), available through Beaver Deceivers International. Some of the system modifications is reducing the noise of running water and by reducing the slope of the culvert or by physically fencing around the culverts keeping beavers at a distance so they cannot determine where the point of outflow is. This keeps their activities to areas that they cannot impede the flow of water or damming the inlet of the culvert. The receiver fence serves to exclude the beaver from the outlet of the pond. In many situations all that might be required would be a receiver fence to exclude the beavers from a culvert opening. Where a receiver fence must be smaller than desired because of site characteristics, then a pipe that extends upstream from the receiver fence may be installed with the end of the pipe protected by a round fence.

The overall management of beaver populations will require much more understanding of site specific behaviors. Management will have to balance the fine line of desired population levels while not exceeding tolerance levels, which will be difficult. With continuous data and understanding, wildlife managers will be better able to make decisions necessary to implement responsive and successful management practices. Inventorying and taking spatial reference of all dams found over many years would be a great idea and provide a lot of data for analysis. Accompanying this extensive data set

with the LiDAR data, the possibility of a better suited model may come to be created as well as a better understanding of sites being selected for. Implementation and development of beaver exclusions should also be considered until a practice that works is determined.

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