Use of a Lidar Based Model for Remote Sensing of Ephemeral Wetlands in Anoka County, Minnesota USA

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Abstract

Lidar is a tool that can be used to define gradients that are not visible on aerial photos and are more accurate then topologic maps. Although still not widely available, Lidar is an excellent tool to aid in remote sensing of natural resources. A Lidar based model was used here to determine the potential locations of forested (wooded) ephemeral wetlands within two regional parks in Anoka County, Minnesota USA. Ephemeral wetlands are typically small isolated depressions within woodlands. Often they are overlooked as wetlands because they do not contain water for much of the year. However, ephemeral wetlands are critically important habitat for frogs and salamanders and are regulated by the Minnesota Wetland Conservation Act.

Introduction

Relatively small but yet important wetlands known as ephemeral basins are found in various locations within the United States (US). In the US, these types of wetlands may be called playas (southwestern states or Vernal Pools, California). By whatever name they are called, these wetland types are neither well understood nor identified across the landscape. Isolated wetlands like ephemeral basins are typically small shallow, seasonally inundated and lack predatory fish (Colburn, 2004; Brown and Jung, 2005). These basin characteristics influence distributions of organisms (Russell and Guynn, 2002; Comer, Goodin, Tomaino, Hammerson, Kittel, Menard, Nordman, Pyne, Reid, and Sneddon, 2005; Mitchell, Paton, and Raithel, 2008) in providing critical habitat for hydro-period sensitive plants and animals (Snodgrass, Komoroski, and Burger, 2000; Tiner, 2003) and carrying out a variety of other ecosystem functions including groundwater recharge and nutrient cycling. The US Fish and Wildlife Service (USFWS) states freshwater forested wetlands are the most endangered wetland type in the country (USFWS, 2002) and these ecosystems have continued to decline (Dahl, 2000). Most ephemeral basins in Minnesota are currently not federally regulated by the US Army Corps of Engineers (USACE) under the Clean Water Act Section 404 since they are isolated basins and do not have a significant nexus to a navigable water. Thus, isolated wetland regulation is delegated to each state. In Minnesota, rules governing wetland regulation are derived from the Minnesota Wetland Conservation Act (Minnesota Administrative Rules Chapter 8420, Wetland Conservation) encompasses regulatory protection for ephemeral

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wetlands. However these isolated basins are often difficult to identify and map due to their small size, shallowness, and occurrence under forest canopy (Burne and Lathrop, 2008; Pitt, Baldwin, Lipscomb, Brown, Hawley, Allard-Keese, and Leonard, 2011).

A number of remote sensing approaches have been applied to the detection of isolated wetlands and the success of remote detection varies due to local geomorphic conditions, availability of high-resolution, large extent, remotely sensed data, detection algorithms, and confounding environmental factors such as a dense forest canopy (Burne, 2001; Calhoun, Walls, Stockwell, and McCollough, 2003; Colburn, 2004; Lathrop, Montesano, Tesauro, and Zarate, 2005).

Historical and Current Methods for Detecting Wetlands

In 1979 the USFWS formalized the National Wetlands Inventory (NWI) completing fine scale (1:24,000) maps that currently encompass more than 90% of the conterminous United States (Wilen and Bates, 1995; Tiner, 2009). These maps were constructed using manual delineation off high-to-mid-level aerial photography (1:130,000-1:80,000) and satellite images followed by limited site visits. Variation in topography, canopy cover, passive sensors, and seasonality contribute to highly variable results for air photography interpretation of forested landscapes (Turner, Cohen, Kennedy, Fassnacht, and Briggs, 1999). NWI focuses on features >0.40 ha although it may be accurate to 0.04 ha under optimal conditions (Dahl and Bergeson, 2009). However, the results vary greatly and the inventory missed >50% of small isolated wetlands in at least two states (Snyder, Julian, Young, and King, 2005; Baldwin and deMaynadier, 2009). To improve detecting smaller isolated wetlands the use of low-level, high-water, leaf off, CIR imagery to photo interpret inundation has been used (Calhoun *et al*., 2003; Burne and Lathrop, 2008; Carpenter, Stone, and Griffin, 2011). This method works well but is time intensive and has the same problems exhibited by all passive sensors (impenetrable tree shadow and/or canopy cover). Recently active sensor technologies (which produce energy) such as Light Detection and Ranging (LiDAR) have been have been used for mapping forested landscapes due to its ability to pass through openings in the canopy cover and detect the underlying surface of the earth. Active sensors provide a distinct improvement of resolution of conifer–dominated forests over tradition photogrammetry methods (Reutebuch, McGaughey, Andersen, and Carson, 2003). A number of studies have demonstrated the promise of LiDAR for wetland detection (Hogg and Holland, 2008; Julian, Young, Jones, Snyder, and Wright, 2009; Lang and McCarty, 2009; Maxa and Bolstad, 2009), only a few have specifically used the technology for predicting small isolated wetlands in forested landscapes. Low relief forested landscapes such as those found in the Anoka Sand Plain may be an ideal study system to test LiDAR derived models for detecting small isolated wetlands. Soil saturation mapping, a common approach, has relied upon multiple surface-water indices (Hjerdt, McDonnell, Seibert, and Rodhe, 2004; Summerell, Dowling, Wild, and Beale, 2004) e.g. the topographic wetness index (TWI) (Beven and Kirkby, 1979) assume topography alone is an adequate proxy

for hydraulic gradients. TWI is less reliable in low relief areas for two primary reasons: 1) surface flow across subtle elevation changes is unpredictable (Schmidt and Persson, 2003), and 2) low relief groundwater gradients often differ significantly from surface slopes (Grabs, Seibert, Bishop, and Laudon, 2009). Conversely, surface shape can be used to characterize wetland landscapes (Lichvar, Finnegan, Newman, and Ochs, 2006; Maxa and Bolstad, 2009; Richardson, Mitchell, Branfireun, and Kolka, 2010). Comparable to a terrain shape index (TSI) (McNab, 1989), modeling surface shape is widely referenced as an elevation residual analysis (Wilson and Gallant, 2000). This index attempts to model local elevation changes highlighting curvature; thus we would predict that curvature would be an effective method of determining forested isolated wetlands in low-relief areas.
The goal of this study was to develop a simplified remote sensing method using LiDAR to aid in the detection of small isolated or ephemeral depression wetlands in forested areas.

Methods

Study Area

The study area incorporated two regional parks located in Anoka County Minnesota USA (Figure 1). The two regional parks included Bunker Hills and Rum River Central Regional Parks.

Regional parks were selected because of their relatively large size, diversity of landforms, limits on disturbance, and intact nature. These two regional parks are located in the west central portion of the county. Rum River Central Regional Park is located within the Cities of Ramsey and Oak Grove. Bunker Hills Regional Park is located within the Cities of Andover, Blaine, and Coon Rapids (Figure 2).

Figure 1. Location of Selected Regional Parks in the Twin Cities Metro Area.

Figure 2. Rum River Central and Bunker Lake Regional Parks.

Anoka County lies within the Anoka Sand Plain Subsection of the Minnesota Department of Natural Resources Ecological Classification System (Minnesota Department of Natural Resources, 2012). The major landform is a broad sandy lake plain which contains small dunes, kettle lakes, and tunnel valleys. The topography is level to gently rolling. The soils have developed mainly from the fine sands of the lake plain. Most of the soils in the Anoka Sand Plain are droughty and excessively drained. The western portion of the county receives approximately 27 inches of rainfall in an average year. Rapid infiltration occurs within the sandy soils. The water table is seasonally high during the spring but generally drops thereafter.

Analysis

The uses of lidar are still being developed. In fact to date, only 27 states currently have lidar datasets for their states and of these, only seven states have complete lidar datasets (Gesch, Oimoen, Greenlee, Nelson, Steuck, and Tyler, 2002). Part of the reason lidar datasets have not been widely developed is the high cost of collecting lidar, funding issues, and agency coordination. However, Minnesota is one of the seven states that have complete lidar datasets.

Although Minnesota has a complete lidar dataset, the use of lidar for remote sensing is still being developed. Many state and local government agencies are currently using lidar data for water quality analysis and protection (Minnesota Geospatial Information Office [MnGeo] For Minnesota Pollution Control Agency [MPCA] June, 2013).

A GIS model was developed as part of a United States Environmental Protection Agency (USEPA) Region 7 Wetland Development Grant to the Kansas Water Office. The model, known as The Topographic Wetland Identification Process (TWIP) (Houts, Neel, Norman, Baker, and Peterson [eds], 2013), provides a standard methodology for identifying existing wetland locations. The model was used here, and subsequently modified for analysis for the two regional parks in Anoka County.

Because traditional methods of identifying wetlands use aerial imagery to identify wetlands based on vegetation or standing water, they can vary greatly depending on recent rainfall, time of year, and the wetland type. The development of this model uses lidar to determine depressions and incorporates flow accumulation. The methods were created as an ArcGIS toolbox as a three step process. The first step incorporated the input of a lidar image of the watershed containing the two regional parks. The Coon Rapids and Rum River Watersheds encompassed the two regional parks. The areas of the lidar imagery containing the parklands were clipped from these watersheds. The tool's output was a polygon shapefile of the potential wetland areas (PWA's).

The second step involved input of the PWA polygon file and several other data layers including roads, water bodies, and channels. The tool added attributes to the PWA polygons to provide context. These attributes provide the reader with the knowledge of where a wetland may be located whether it is along a stream, lake, ditch, or in the open landscape. Between the two steps outlined above, potential wetland areas can be determined to a set size. A minimum wetland size of three square meters was used as most ephemeral wetlands are generally small and isolated.

The third step of the model used classified imagery to determine where potential wetlands might occur. Since several of the datasets used in this step have minimum standard wetland sizes greater then typically might occur for ephemeral basins this step was not used. Not using classified imagery would not affect the model for purposes of the study since this step was considered optional.

Two additional data layers were added that were not previously incorporated into the model. Soils were added to provide context where confining layers might occur. The confining layers are important since well drained soils would not support ephemeral basins. The soils considered had a defined Bt layer which is particularly important since many of the soils in Anoka County are sandy and well drained. A Bt layer in soils indicates an accumulation of silicate clay that either has formed within a horizon and subsequently has been translocated within the horizon or has been moved into the horizon by illuviation, or both. Additionally, the forested areas of the two county Regional Parks were extracted from the land use layer as ephemeral wetlands in Eastern Minnesota are generally found in forested areas.

These layers (soils and forested) were then integrated with each other using the intersect tool (Figures 5, 6, 12, and 13). Since ephemeral wetlands are typically small, a minimum size equal to or less than 1000 square meters was used to define wetlands that could potentially be ephemeral.

Statistical Analysis

Basic statistical analysis was conducted on the two parks. The statistics were run for the Potential Wetland Areas (PWA's), Forested Areas, and final analysis. The statistics included count, and sum.

Results

Spatial Analysis

The spatial analysis for this study incorporated two regional parks as these areas are less likely to have man-induced impacts. The Topographic Wetland Identifcation Process model was run for each park. Step 1 was run to determine the PWA's within each park and develop PWA layer.

Rum River Central

The PWA indicted significant potential wetland areas within the park (Figures 3 and 4).

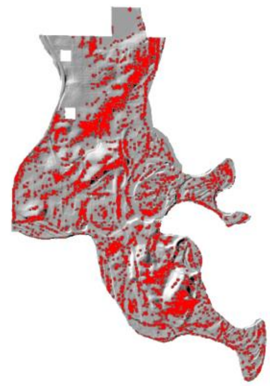

Figure 3. Step 1 model analysis - Potential Wetland Areas within the Rum River Central Park - lidar base map.

Figure 4. Step 1 model analysis - Potential Wetland Areas within the Rum River Central Park - aerial photo base map.

The sum of the potential wetland areas within the park was approximately 504,295 square meters of the parks

1,756,336 square meters (29%). There were 645 PWA indentified in Step 1 of the model run. The Step 2 analysis further refined the areas of potential wetland by incorporating land use (forested areas) into the analysis (Figures 5 and 6). There were 679 forested wetlands identified during this process.

Figure 5. Step 2 Model Analysis - Potential Wetland Areas in forested areas within the Rum River Central Park - lidar base map.

Figure 6. Step 2 Model Analysis - Potential Wetland Areas in forested within the Rum River Central Park - aerial photo base map.

The analysis was further refined by reducing the size of the wetlands since ephemeral basins are typical less than 2023 square meters. For this study, wetlands up to 1000 square meters were selected since the forested wetlands are assumed even smaller (Figures 7 and 8).

These maps indicate where there is a high potential for ephemeral wetlands to occur. Once the forested wetland identified in Step 2 were reduced to those areas that were less than 1000 square meters approximately 505 wetlands were found. The total area was 158716 square meters, 9 % of the total park.

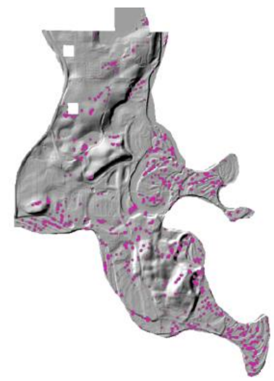

Figure 7. Reduction of Potential Wetland Areas on lidar basemap within the Rum River Central Park.

Figure 8. Reduction of Potential Wetland Areas on aerial basemap within the Rum River Central Park.

To further validate the model of where potential ephemeral wetlands might occur, a field check was conducted on a selected area of the Rum River Central Park where access was readily available. Two of the sites examined did in fact show observed ephemeral wetlands within woodlands (Figure 9).

Bunker Lake Park showed similar Potential Wetland Areas developed from Step 1 of the model (Figures 10 and 11). The sum of the potential wetland areas within the park was approximately 2,351,764 square meters.

Figure 9. Photos of observations of two wetland locations identified from the model in Rum River Central Park.

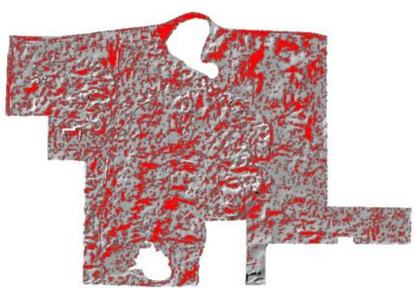

Figure 10. Step 1 model analysis -Potential Wetland Areas within Bunker Hills Park - lidar base map.

This is 36% of the park's area (6,474,970 square meters). There were 2,761 PWA's indentified in Step 1 of the model. The Step 2 analysis further refined areas of potential wetland by incorporating land use (forested areas) into the analysis (Figures 12 and 13). There were 1,293 forested wetlands identified.

As with the Rum River Central Park data, the analysis was refined by reducing the size of the wetlands (Figures 14 and 15). These results indicated where there was a high potential for ephemeral wetlands to occur.

Figure 11. Step 1 model analysis - Potential Wetland Areas within Bunker Hills Park - aerial photo base map.

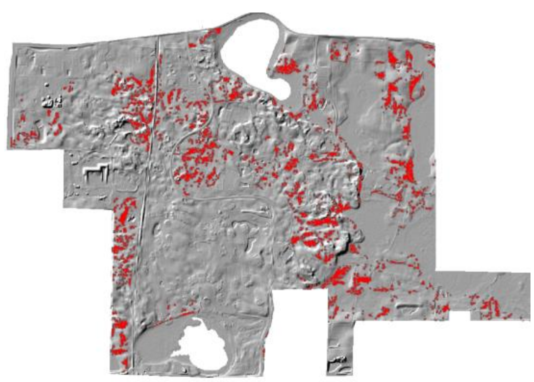

Figure 12. Step 2 Model Analysis - Potential Wetland Areas in forested areas within Bunker Hills Park - lidar base map.

The forested wetlands identified in Step 2 were further reduced to those areas that were less than 1000 square meters. Approximately 806 forested wetlands were found. The total area was 270,852 square meters. This equates to an estimated 4 % of the total park area.

Figure 13. Step 2 Model Analysis - Potential Wetland Areas in forested areas within Bunker Hills Park - aerial photo base map.

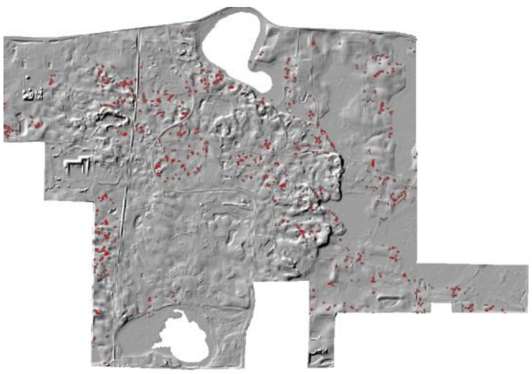

Figure 14. Reduction of Potential Wetland Areas on lidar basemap within Bunker Hills Park.

Figure 15. Reduction of Potential Wetland Areas on aerial basemap within Bunker Hills Park.

As with the Rum River Central Park field observations of selected sites were conducted to confirm the presence or absence of wetland in the areas identified by the model (Figure 16). Two sites were randomly selected and observed to have had ephemeral wetlands present.

Figure 16. Photos of observations of two wetland locations identified from the model in Bunker Hills Park.

Discussion

The objective of this study was to create a model that could predict locations of forested (woodland) ephemeral wetlands. These types of wetlands are jurisdictional (regulated), are isolated and depressional in nature, and often dry up in mid-late summer.

There have been few if any published ephemeral wetland studies conducted using lidar. The model used here was developed to identify playa lakes (similar to pothole wetlands in the upper Midwest) in the southern plains. Playa lakes are found in the southern prairie. However, this model had not been tested in the upper Midwest and clearly not used to identify ephemeral wetlands in forested areas.

The model required modification to account for forested conditions and soil characteristics. Both the forested and soil characteristics are important in identifying woodland ephemeral wetlands. The forested condition was part of the land use component within the model. The forested areas were further reduced by selecting those forested areas that were identified from the Minnesota Land Cover Classification System (MLCCS) dataset. Soils selected had a Bt horizon and provided a confining layer. Other soils were selected that had some type of confining layer so the forested condition was associated with one of these soil types.

The model identified more than 25% of each park analyzed as having potential wetlands. Anoka County is relatively level lying within the Anoka Sand Plain. This indicates that there are many low lying areas within the County. It would be expected that once the size of the wetlands was reduced (defining the ephemeral wetlands) the percentage of wetlands within each park would decrease significantly. An interesting note on the Rum River Central Park data, the number of forested wetlands actually increased from the PWA wetland data from Step 1. This was unlikely as the total number of wetlands identified in forested conditions should decline, as there is less forested area in the total area of the park.

A review on the accuracy of the model in locating wooded ephemeral wetlands was done with a random field check of each park. Two wetland areas were randomly selected within each park that had relatively close proximity to road way access. Each area identified from the model did in fact contain ephemeral wetlands.

Even though the model did identify wooded ephemeral wetlands based on field observations of selected sites, there may be additional wetlands that were not identified from the model (false negatives) and wooded wetlands that were identified as wetland but were not wetlands (false positives).

It would be possible to check the entire park and wetlands identified however, time constraints did not make this a viable option for this study. It is also important to note that some areas that were identified from the model may no longer exist due to natural or anthropogenic disturbances.

Conclusions

The lidar model did appear to predict where wooded ephemeral wetlands may occur within Anoka County as evident by the positive field checks of the actual locations predicted. Since much of the soil in Anoka County is sandy in nature and which are typically well drained, it would be an interesting study to see how well the lidar model would work with finer-grained soils.

The model needs additional parameters that were included as part of this study in order to be refined to be used as predictive model for determining wooded emphemeral wetlands. Additional research using this lidar model could also be done to determine ephemeral wetlands status in woodlands on other soil types.

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