Identification of Lost Urban Wetlands Using Remote Sensing Techniques and Historical Maps

Alexander Rabine
Department of Resource Analysis, Saint Mary's University of Minnesota, Minneapolis, MN 55404

Keywords: Urban Wetlands, GIS (Geographic Information Systems), LiDAR (Light Detection and Ranging), Remote Sensing, Photo Interpretation, DEM (Digital Elevation Model), GLO (General Land Office) Maps

Abstract

Wetlands are an important component of Minnesota's landscape. They provide habitat for a variety of species, act as a scrubber to eliminate pollutants before toxins get into drinking water, provide a heatsink to help mitigate climate change, and act as a sponge when water levels rise, to name a few wetland benefits. Wetlands are disappearing at an alarming rate and measures need to be taken to protect them. There are a multitude of governmental and private organizations working to do so, but their focus is on existing wetlands and not on wetland areas that have been drained for agriculture or urban development. This study focused on identifying lost urban and suburban wetlands in the northern part of Hennepin County, which is the fastest growing and most populated county in Minnesota. Remote sensing and image analysis techniques were used to identify prior wetlands that were developed over or drained. This identification would support efforts to reestablish or rehabilitate these lost wetlands. Many data layers were created from raw LiDAR data, and third-party tools were used to further enhance the creation of the data layers. These layers were then overlaid to identify areas that were once wetlands but have since been developed over. Overall there were about 2,311 acres of lost wetlands that were identified, digitized, and attributed. With more people now seeing the importance of wetlands, there are more initiatives to identify wetland areas that can and should be protected from development. This study employs only a few of many methods available for wetland identification.

Introduction

According to the U.S. Fish and Wildlife Service (USFWS, 2018), wetlands "are lands where saturation with water is the dominant factor determining the nature of soil development and the types of plant and animal communities living in the soil and on its surface." Ancog and Ruzol (2015) define a wetland as an "aquatic to semi-aquatic ecosystem where permanent or periodic inundation or prolonged waterlogging creates conditions factoring the establishment of aquatic life." It is estimated that Minnesota has 10.6 million acres of wetland cover, comprising about 20% of all of the state's land cover (Minnesota Pollution Control Agency, 2017). But according to Kloiber (2018) of the Minnesota Department of Natural Resources, it is estimated that Minnesota has lost nearly half of its wetlands since pre-settlement. Additionally, up to 60% of wetlands across the United States have been lost according to some studies (Sikora and Cieśliński, 2016). Two of the

Rabine, Alexander. 2018. Identification of Lost Urban Wetlands Using Remote Sensing Techniques and Historical Maps. Volume 21, Papers in Resource Analysis. 11 pp. Saint Mary's University of Minnesota University Central Services Press. Winona, MN. Retrieved (date) from http://www.gis.smumn.edu

biggest contributing factors in wetland loss in Minnesota are drainage for farmland and urban sprawl. Some Minnesota residents might welcome this loss, as mosquitoes tend to breed in areas around wetlands. So why protect them? Ancog and Ruzol (2015) state that wetlands play an important part in a healthy ecosystem. Wetlands provide flood mitigation, water regulation, sediment retention, and habitat for different species (Ancog and Ruzol, 2015). Urban sprawl has played an important role in wetland loss and finding areas where wetlands can be rehabilitated and/or restored in urban and suburban areas can help mitigate some of these losses.

Hennepin County

This research will focus on Hennepin County, Minnesota, which is the most populated county in Minnesota. Hennepin County had a population of 1,152,381 in 2010 and an estimated population of 1,252,483 in 2017, an increase of 8.6% (U.S. Census Bureau, 2018). The county is 602 total square miles and contains the city of Minneapolis, which is the county seat and most populated city in Minnesota. The study area for this project is located in the northern part of the county (Figure 1).

Study Area

Because of the size of Hennepin County and the computing power available to do the analysis, a smaller study area was chosen based on the greatest population change by block group between 2010 and 2017 (Figure 2).

The study area is 146 square miles and contains five major cities: Rogers, Champlin, Osseo, Corcoran, and Maple Grove. The study area was also chosen because Rogers is the fastest growing city in Minnesota with a 44% change between 2010 and 2015. In addition, Maple Grove added 3,588 residents, ranking it in the top 17 Minnesota cities that have added residents between 2010 and 2015 according the Minnesota State Demographer's Office (Hibbs, 2016).

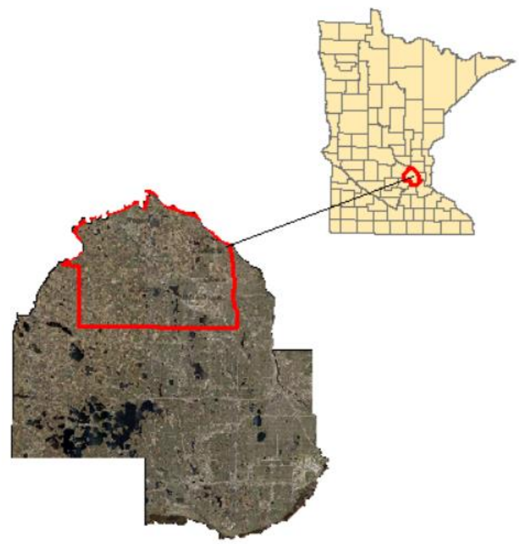

Figure 1. Image of Hennepin county. The study area is outlined in red.

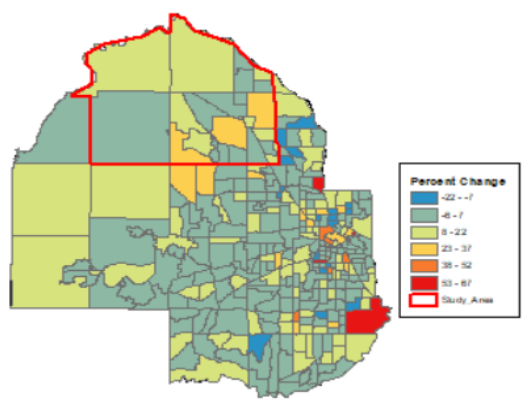

Figure 2. Population change map of Hennepin County. The study area saw an average increase in population of 9.5 percent between 2010 and 2015.

Methods

This study focused on identifying lost wetlands that have been drained for agricultural purposes and urban development by using historical General

Land Office (GLO) maps, remote sensing techniques, and image analysis to indicate and attribute where wetlands were located.

Data

GLO maps are a web service obtained through the Minnesota Geospatial Commons website (Figure 3). These maps are digital scans of the original public land survey plat maps. The GLO maps date between 1848 and 1907 during the first government land survey of the state (Minnesota Geospatial Office, 2018). The wetland features within the study area were manually digitized for further analysis.

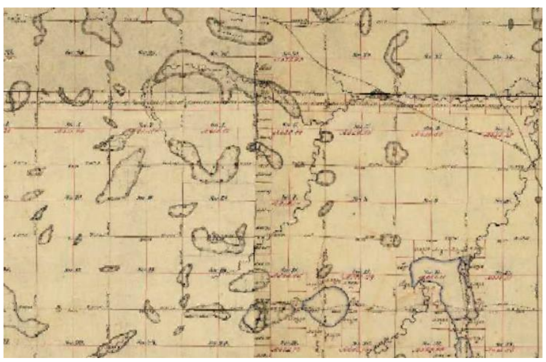

Figure 3. GLO map retrieved from the Geospatial Commons website. Map dates vary between 1848 and 1907.

LiDAR

The National Oceanic and Atmospheric Administration (2012) defines LiDAR (Light Detection and Ranging) as "a remote sensing method that uses light in the form of a pulsed laser to measure ranges (variable distances) to the Earth." These points are then used to generate a multitude of different maps, including 3D representations of the earth's surface and, more commonly, digital elevation models (DEMs).

Raw LiDAR data was downloaded from the Minnesota Geospatial Commons. Because LiDAR files tend to be quite large, data is commonly stored in a compressed file named .laz, or laser file. These files were downloaded using a tool called Filezilla. To use LiDAR files in ArcMap, the .laz files need to be decompressed. ArcMap does not have the capability to decompress .laz files. A tool called LAStools was downloaded to decompress the .laz files to .las files and create a bare earth LAS dataset. ArcMap was used to visualize the bare earth returns of the study area (Figure 4).

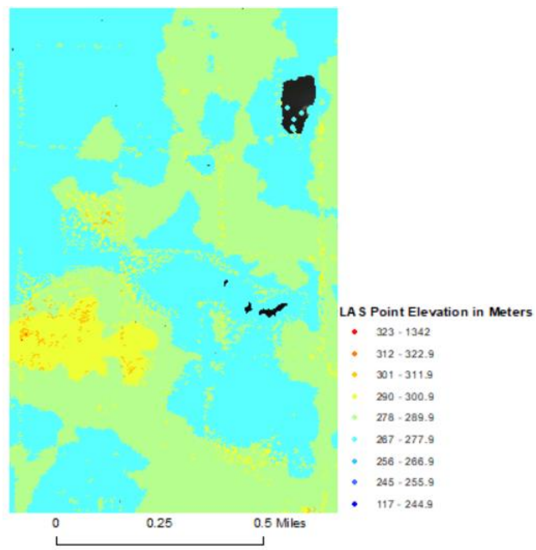

Figure 4. LiDAR returns downloaded and decompressed from the Minnesota Geospatial Office FTP site. Each color represents a different range of elevations with blue points representing lower elevation and red points representing higher elevations.

From the bare earth LAS dataset, a DEM was created using ArcMap. The DEM is a representation of the earth's surface (Figure 5).

From the DEM, a hillshade was created to visualize elevation. A multi-directional hillshade function was downloaded from Saint Mary's University of Minnesota Geospatial Services office and used to further enhance the hillshade (Figure 6). According to Nagi (2014), normal hillshades are created by illuminating light from the northwest direction, which can cause the hillshade to look overexposed and hide details of the terrain. The multi-directional hillshade illuminates from six different sources which more realistically represents the surface of the earth. The multi-directional hillshade was created using the Image Analysis window's Add Function ability in ArcMap.

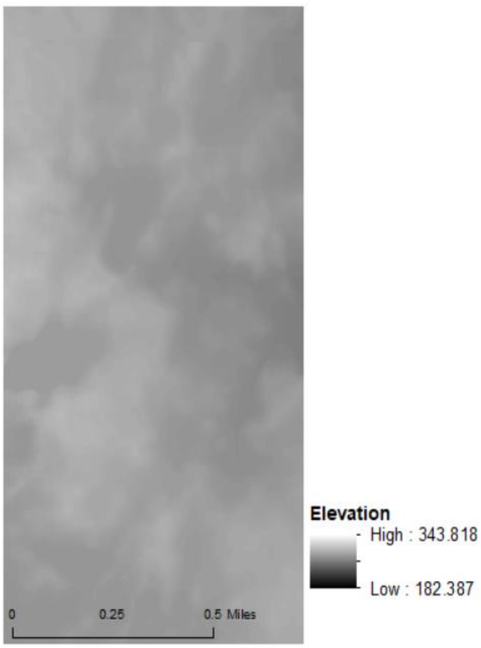

Figure 5. DEM created from the LiDAR point returns. Darker areas indicate lower elevation while lighter areas represent higher elevation.

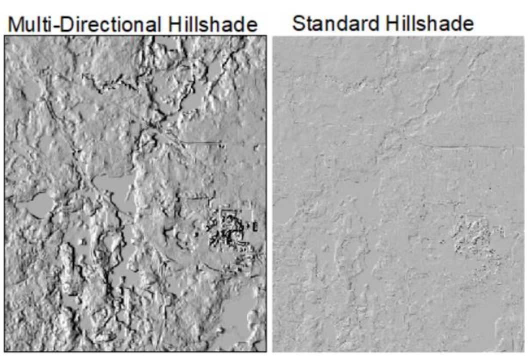

Figure 6. Image comparing the multi-directional hillshade (left) to the standard hillshade (right). The multi-directional hillshade shows more detail in visual elevation changes.

HPI

A hydro positioning index, or HPI, was created from the DEM (Figure 7). Vaughn (2018), states that an HPI is a product created "to visualize and map land formations associated with water features on earth's surface." The HPI was created by processing the DEM through the Focal Statistics tool. That output was then processed through the Minus tool, which subtracts the Focal Statistics tool output from the original DEM on a cell by cell basis.

Figure 7. HPI layer created to visualize ways water travels over the surface. Yellow areas represent water flow, while darker areas represent roads and depressions.

Break Line Editing

LiDAR is a very powerful and useful tool, but it is not perfect. Because the laser cannot penetrate through ground, flow patterns can be inaccurate. These errors occur when water flows underground through a culvert (Figure 8) or under a bridge where the laser cannot penetrate.

Using the Agricultural Conservation Planning Framework watershed planning tools, culvert locations were identified by creating a flow impediment layer to identify areas of pooling water (Figure 9).

Figure 8. Aerial image of culvert.

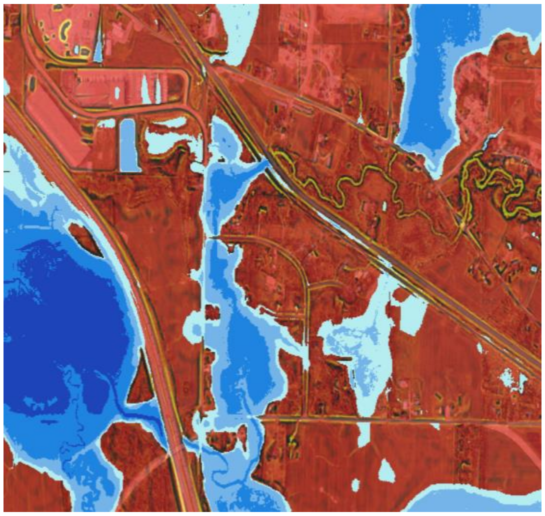

Figure 9. Impeded flow layer was created to show areas of pooling water.

These "digital dams" were broken by digitizing break lines to continue the flow of water through the culvert (Figure 10). After all the digital dams were digitized, the break lines were added to the DEM and a new hydro conditioned DEM was created. A new HPI was also created as a more accurate representation of hydrological features in the study area.

Aerial Imagery

Two sets of aerial imagery were used in this study and mosaiced individually. 2010 1ft resolution imagery was obtained in individual .tiff files from the Minnesota Geospatial Office (MNGEO). The 2017 NAIP imagery (Figure 11) was also obtained from MNGEO and was symbolized as color infrared to help identify and classify lost wetlands.

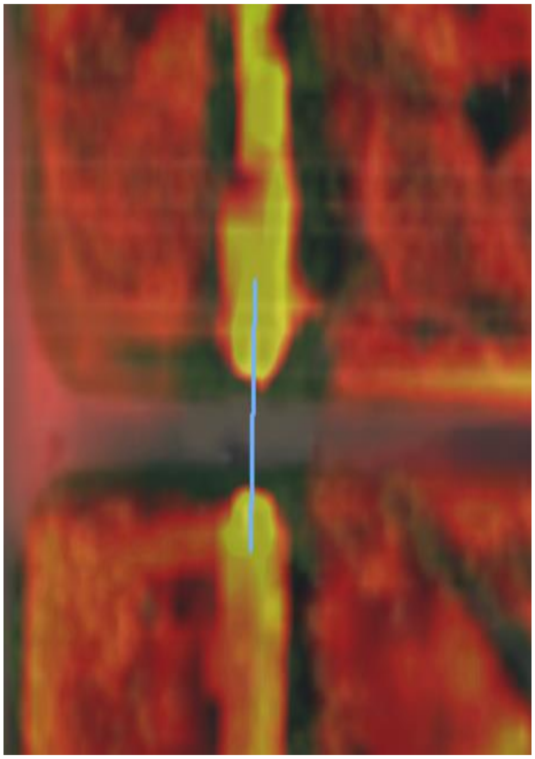

Figure 10. A break line manually digitized to continue flow through a culvert.

Figure 11. Color infrared aerial imagery. Red areas represent vegetation while blue tinted areas represent roads and blacktop.

Hydric Soils

Following the Minnesota Department of Natural Resources (2012) method of identifying hydric soils, a percent hydric soils layer was created by querying attributes from the United States Department of Agriculture's soil survey geographic database (SSURGO), which identified drainage class, April flooding, April pooling, and August pooling, along with percent of composition soil. Map keys were used to join the tables to a soil grid shapefile to create a percent hydric soils map. The drainage class, April flooding, April pooling, and August pooling values were concatenated in a new field and unique combinations were identified using the Microsoft Excel PivotTable function (Figure 12). These unique values were given attributes based on a water regime table (Appendix A). A table containing the unique values and their corresponding water regime number was then joined back to the original table.

Concat	HydricRegime
,,,	8
Excessively drained	0
Excessively drained,Frequent,None,None	0
Excessively drained,None,None,None	0
Frequent,Frequent	3
Frequent,None,None	3
Moderately well drained	1
Moderately well drained,Frequent,None,None	1
Moderately well drained,None,None,None	0
Moderately well drained,Occasional,None,None	1
Moderately well drained,Rare,None,None	0
Moderately well drained,Very rare,None,None	0
None	0
None,Frequent,Frequent	6
None,None	0
None,None,None	0
Occasional,None,None	3
Poorly drained	2
Poorly drained,Frequent	3
Poorly drained,Frequent,Frequent	4
Poorly drained,Frequent,Frequent,None	4

Figure 12. Sample of a table showing unique concatenated SSURGO attributes and the assigned hydric regime number.

After all the unique combinations were assigned a hydric regime number, a new field was created called percent hydric. A 0 was added to the percent hydric field for all water regimes that equaled 0 and values that were greater than 0 were added based on the soil component percent field. The table was joined to the soils grid in ArcMap and reclassified to show percent hydric soils in the study area (Figure 13).

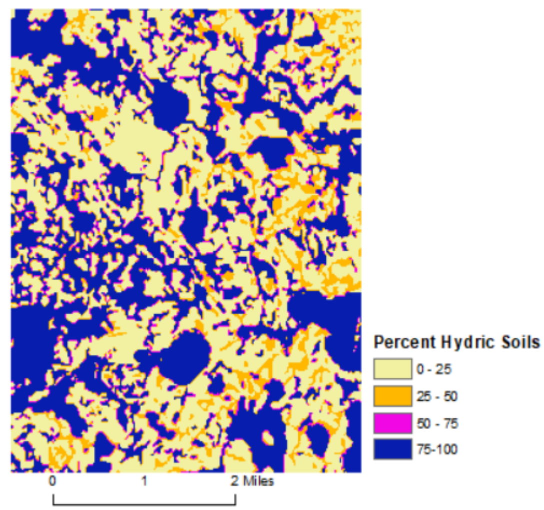

Figure 13. Map showing the percent of hydric soil in a section of the study area.

Wetland Classification

Historic wetlands were classified according to the National Wetland Inventory (NWI) classification system. The NWI is a program implemented by the USFWS to help inform and promote conservation of the nation's wetlands. According to the USFWS (2018), the NWI provides detailed information on the "abundance, characteristics and distribution of US wetlands" (USFWS, 2018).

Wetlands under 0.1 acres were not classified in accordance to the Bureau of Land Management standards. Wetlands were classified using all the discussed layers and attributed accordingly.

The GLO maps were first used to identify wetland areas that were present when these maps were created (Figure 14). The wetland features of the GLO maps were digitized and a shapefile was created.

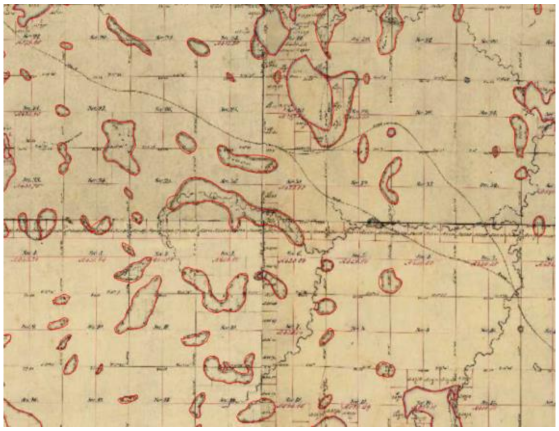

Figure 14. GLO map showing digitized wetland areas in the study area. Wetland areas are outlined in red.

An NWI layer of existing wetlands was downloaded, and any areas where current NWI wetland polygons were present were erased from the GLO wetlands so that only potentially lost wetlands remained. The hydric soils layer was laid over the NAIP CIR imagery, along with the enhanced hillshade and HPI layer, and they were used to aid in attribution of lost wetlands. The swipe tool was used on the soils and imagery layer to show the flow patterns of the HPI layer. Lost wetlands were identified or deleted depending on if they met the criteria of having a high percent of hydric soils, appeared to have a red tint in the NAIP CIR imagery, appeared in wet areas according to the HPI, and did not overlap the current NWI wetland polygons (Figure 15). The lost wetlands that were identified were attributed using all of the collateral data. In areas where the GLO digitized wetlands overlapped areas that were developed, such as parking lots, housing developments or farmland, the hydric soils layer and NWI polygon layer was used to give the best attribution. For example, if the hydric soils layer showed yellow (little to none hydric soils) and the imagery showed development, the polygon was deleted. If the hydric soil layer showed blue or orange (medium to high hydric soils) and the imagery showed development, the wetland was attributed accordingly. The current NWI wetland polygon layer was used to help in the attribution of neighboring lost wetlands where attribution was difficult to determine.

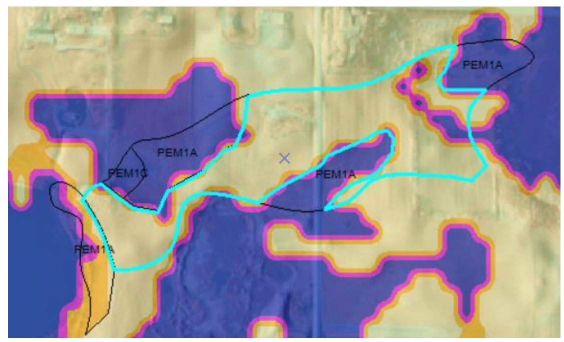

Figure 15. Image of classification procedure. Lost wetlands were identified and attributed based on hydric soils, wet areas, and imagery. Image shows areas with a high percentage of hydric soils (blue and orange); non-hydric soils (highlighted and tan area) were cut out and deleted after determining they were not lost wetlands.

Results

Comparing the original GLO wetlands to the present day, 192 (2,311 acres) were lost since the GLO maps were created. This is in comparison to the 19,702 wetlands (44,526 acres) presently in the study area (Figure 16).

After all the lost wetlands were identified and classified, the acreage of each classification was totaled (Table 1). Palustrine emergent wetlands with an A water regime (PEM1A) had the most acreage with 114 lost wetlands identified and a total of 1665.48 acres. Palustrine emergent wetlands with a C water regime (PEM1C) were the next abundant wetland attribution with 44 wetlands identified and a total of 543.19 acres.

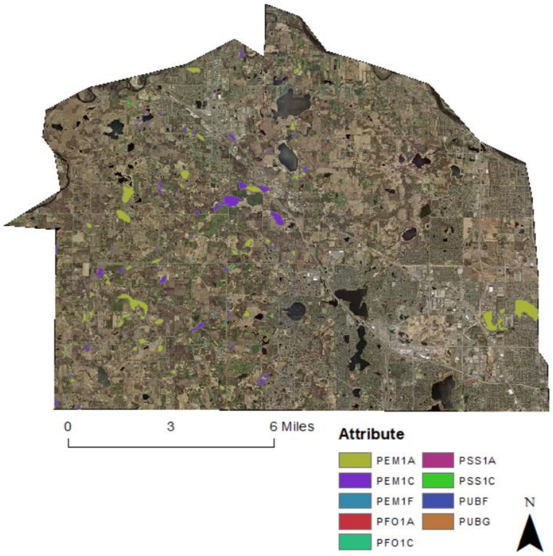

Figure 16. Map of final attributed wetlands.

Table 1. Table representing all attributions of lost wetlands found in the study area reported by attribution and total acreage of each attribute.

Attribute	Number of Wetlands	Acres
PEM1A	114	1665.48
PEM1C	44	543.187
PEM1F	3	8.00786
PFO1A	18	39.8061
PFO1C	3	13.9213
PSS1A	4	22.88788
PSS1C	2	12.9154
PUBF	3	3.4335
PUBG	1	1.03294

Discussion

This study used multiple remote sensing techniques and image analysis methods to identify lost wetlands from historical GLO maps. Multiple layers were created using ArcMap and third-party tools to further enhance the ability to identify and attribute lost wetlands that could potentially be restored. The results of the study were not surprising. This study focused on wetlands that have been mostly drained and/or developed over. This means that many attributes will have a low wetness water regime (A or C). Most of the wetlands were also palustrine wetlands meaning they do not contain flowing water and exist in a more saturated environment. This was also not surprising as the study area's elevation change is relatively flat, so water can settle in areas and develop a wetland environment. The identification of palustrine scrub shrub (PSS), palustrine forested (PFO), and palustrine unconsolidated bottom (PUB) wetlands was surprising as those are clear wetland areas that should have been identified for the current NWI update.

There were areas of the study where potential sources of error could have occurred. Attribution of wetlands is highly based on the editor's opinion, but the opinion must be supported by the data that is present. Error may have occurred during the drawing and attribution of lost wetlands. Another potential source of error was in the drawing of break lines using the HPI layer, impediment layer, and imagery. While drawing break lines, imagery was used to visually confirm break lines. Sometimes the area of a suspected culvert or other digital dam is hidden by tree branches, bushes, or is too small to see. This can cause the final HPI layer to be missing areas where culverts could be located. Another source of potential error is the attribution of PSS versus PFO. Scrub shrub and small forested wetland trees can look very similar in imagery and may be attributed incorrectly.

Suggested Further Studies

Field checking is important in confirming much of the data that was used in this study. Culvert identification from aerial imagery and HPI layers can only go so far in identifying areas of digital dams. A field check could be done to confirm or deny the presence of a culvert, which would make the DEM more accurate. A field check could also be done to confirm the presence and attributes of wetlands.

Another suggestion for further study would be the use of stereo imagery which would visually show a top down 3D perspective. Stereo imagery would clear up the subtle differences between scrub shrub and trees and go as far as helping to identify different species for a more accurate attribution.

Historical aerial imagery could be used to help confirm the presence of wetlands and how the landscape has changed over time. A temporal land use change map could be created from these images, which could prioritize areas of land use change and population change.

Raster analysis is an important part of the identification of wetlands. Even though raster analysis was used in this study, there are multitudes of methods that would further benefit the identification of wetlands in urban areas.

Conclusions

Wetlands are an important part of the Minnesota landscape. With urban development and wetlands being drained for farmland, Minnesota has lost roughly half of its wetlands. It is more important than ever to protect wetlands as Minnesota’s population grows and more wetlands are drained for farmland and urban development.

There are a multitude of private and governmental organizations that are working to map and protect wetlands from being lost to development. The lead organization in this endeavor is the USFWS. The USFWS has developed the NWI, which updates and catalogs wetlands across the country. It is organizations like these which will help planners and policy makers make better decisions regarding wetlands which are vital to the ecosystem overall.

Acknowledgements

I would first like to thank my parents’ house for sinking into the ground, which gave me the idea for this project.
I would also like to thank John Ebert, Greta Poser, and Dr. Dave McConville for their guidance and making my time at Saint Mary’s a wonderful experience. I would also like to thank everyone at the Minnesota Geospatial Office who helped me obtain all the imagery for this project and for also introducing me to many people throughout the State of Minnesota's government whose leadership and expertise have helped me not only with this project but with future endeavors. Lastly, I would like to thank all the staff of Saint Mary’s Geospatial Services Office in Minneapolis, especially Kevin Benck and John Anderson, for talking me through the more challenging analyses in this project.

References

Ancog, R., and Ruzol, C. 2015. Urbanization adjacent to a wetland of international importance: The case of Olango Island Wildlife Sanctuary, Metro Cebu, Philippines. *Habitat International*, 49, 325-332.

Hibbs, J. 2016. Analysis of the 2015 Population and Household Estimates. Minnesota State Demographic Center. Retrieved from https://mn.gov/admin/assets/analysis-2015-population-household-estimates-msdc-nov2016_tcm36-270612.pdf

Kloiber, S. 2018. Verbal Communication. Minnesota Department of Natural Resources.

Minnesota Department of Natural

Resources. 2012. Method for Modified Hydric Soil Map Units for the Minnesota NWI Update. Written Communication.

Minnesota Geospatial Office. 2018. Minnesota Original Public Land Survey Plat Maps, Digital Images, Geo-referenced - Minnesota Geospatial Commons. Retrieved July 11, 2018 from https://gisdata.mn.gov/dataset/plan-glo-plat-maps-georef.

Minnesota Pollution Control Agency. 2017. Wetland monitoring and assessment. Retrieved from https://www.pca.state.mn.us/water/wetland-monitoring-and-assessment.

Nagi, R. 2014. ArcGIS Blog: Introducing Esri's Next Generation Hillshade. Retrieved from https://www.esri.com/arcgis-blog/products/arcgis-living-atlas/imagery/introducing-esris-next-generation-hillshade/.

National Oceanic and Atmospheric Administration. 2012. What is LIDAR. Retrieved from https://oceanservice.noaa.gov/facts/lidar.html.

Sikora, M., and Cieśliński, R. 2016. Using GIS to discover changes in the local water cycle of wetlands – case study Poblockie Peatbog. *Limnological Review, 16*(3), 155-164.

U.S. Census Bureau. 2018. QuickFacts: Hennepin County, Minnesota. Retrieved from https://www.census.gov/quickfacts/fact/table/hennepincountyminnesota/PST045217.

US Fish and Wildlife Service (USFWS). 2018. National Wetlands Inventory. Retrieved July 11, 2018 from https://www.fws.gov/ wetlands/.

Vaughn. S. 2018. Hydrographic Position Index. MnIT Services at DNR. Retrieved from http://www.mngeo.state.mn.us/chouse/elevation/HPI_Description_and_Symbolization.pdf.

Appendix A. Table created by the Minnesota Department of Natural Resources (2012) showing the water regime code suggestion for each unique value in the pivot table function.

Water Regime	Description	Example Values for Concatenated Field
0	All excessively drained, somewhat excessively drained, and well drained soils as well as udorthents, udipsamments, pits, and gravel. This water regime level also includes moderately well drained soils and somewhat poorly drained soils that do not flood.	Null-Null-Null-Null (Pits, Udipsamments); Excessively drained-None-None-None; Moderately well drained-None-None-None; Null-None-None-None; Somewhat excessively drained-None-None-None; Somewhat excessively drained-Rare-None-None
1	This water regime level includes moderately well drained soils and somewhat poorly drained soils that do flood at least rarely. (floodplain formations) This is similar to Cowardin's temporarily flooded "A" water regime.	Moderately well drained-Frequent-None-None; Moderately well drained-Frequent-None-Occasional; Somewhat poorly drained-Occasional-None-None
2	Poorly drained and very poorly drained soils that neither flood nor pond. This is similar to Cowardin's saturated "B" water regime.	Poorly drained-None-None-None; Very poorly drained-None-None-None
3	Poorly drained soils that occasionally flood during spring (almost all floodplain formations). Similar to Cowardin's "A" or "C" water regime depending on the length of flooding.	Somewhat Poorly Drained-Frequent-None-None; Poorly drained-Occasional-None-None
4	Very poorly drained soils with frequent spring flooding, but no ponding (almost all floodplain formations). Similar to Cowardin's seasonal "C" water regime.	Very poorly drained-Frequent-None-None
5	Very poorly drained soils with frequent spring flooding and spring ponding (almost all floodplain formations). Similar to Cowardin's seasonal "C" water regime.	Very poorly drained-Frequent-Frequent-None
6	Very poorly drained soils with no flooding, but that do have spring ponding (almost all depressional formations). Similar to Cowardin's seasonal "C" water regime.	Very poorly drained-None-Frequent-None
7	Very poorly drained soils with ponding throughout most, if not all the year (marsh). Similar to Cowardin's "F" or "G" water regime.	Very poorly drained-None-Frequent-Frequent
8	Map units designated as water (non-soil). Similar to Cowardin "H" water regime.	Null-Null-Null-Null (Water)