Sugarbush Site Suitability in Ojibwe Ceded Territory of Northern Wisconsin

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GEOG578 Capstone Project

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I. Capstone Statement / Project Goals

The Ojibwe people maintain usufruct rights on public lands, including the right to tap sugar maples for syrup and sugar, in ceded territories of Wisconsin. Maple sugar plays an invaluable spiritual and cultural role in the Ojibwe economy, and knowing the optimal locations for sugarbush stands would allow the Ojibwe to further manage, develop, and utilize this resource. Thus, we plan to conduct a site suitability analysis using climatic, habitat, and socioeconomic factors to locate sugarbush sites in Ojibwe ceded territories of northern Wisconsin.

II. Introduction & Background

Our objectives are to locate the healthiest, most tappable, and therefore most profitable stands of sugar maples in Ojibwe ceded territory (as defined by the treaties of 1837 and 1842), within the Wisconsin state boundary. In the U.S., the Ojibwe currently spread across Wisconsin, Minnesota, Michigan, Montana, and North Dakota (Roy 2018). In Canada, as the second-largest First Nations population, they make up a significant portion of the populace. Our Wisconsin-focused model will serve as a starting point for finding suitable maple sugarbushes; eventually, we can expand the model to find sugarbushes throughout Ojibwe territory.

The Ojibwe people were likely tapping sugar maples long before European settlers arrived in the United States (Holman & Egan 1985, Munson 1989). Families returned to the same sugarbush (stand of sugar maples) spring after spring. To the Ojibwe (and other native tribes) sap is not just sap; it is a precious gift signaling the end of winter – the Ojibwe word for spring, *ziig-wan*, incorporates the idea of sap starting to flow from the maple trees (Erickson 2006). Maple sugar and (more commonly today) maple syrup play an integral role in Ojibwe culture.

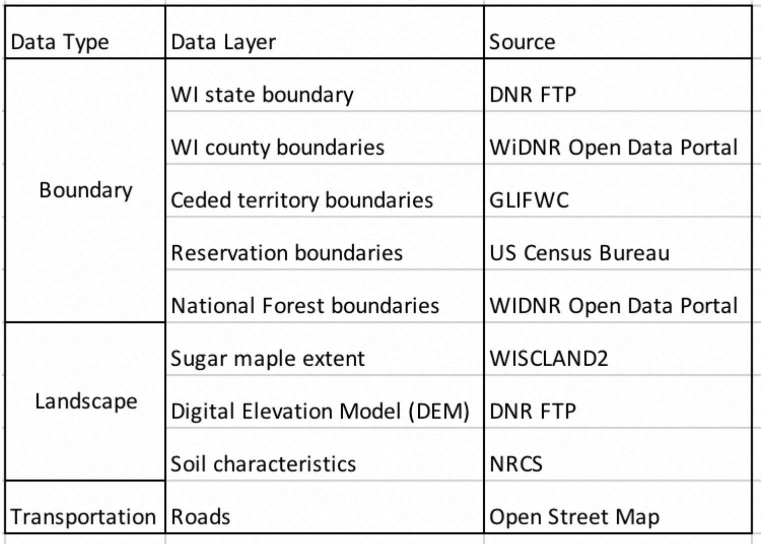
Beyond culture, maple products contribute substantially to the Ojibwe economy (Keller 1989). Families who produce more syrup than they need can sell to stores, or directly to friends and neighbors (Science Museum of Minnesota, 2018). In 1866, the Keweenaw Bay Indian Community sold 453,252 pounds of maple sugar to Mackinack Indian agents (Wyckoff 1999). That requires tapping 151,804 trees and boiling down 2,266,260 gallons of sap. And as maple products have gained mass appeal, more and more sellers aim to increase their yearly production. But finding a sugarbush takes time (hence their generational aspect in Ojibwe culture). Most of Wisconsin's sugar maples remain a truly "untapped" resource. Our model uses environmental and socioeconomic parameters to find the sugarbushes of the next generation.

We already know the ideal growing conditions for a maple sugarbush (Brown et al. 2015; Tirmenstein 2018; Farrell 2012; Stults et al. 2016; United States Forest Service 2018). These soil nutrient, drainage and texture characteristics make up one set of layers of our optimization model. Road networks and access make up the second set. Finally, we know the current spread of sugar maples across Wisconsin. By overlaying all of these layers, we can select out just those areas that would support a profitable, sustainable sugarbush.

III. Methodology

Sugar maples are capable of growing in a wide range of conditions, which made it necessary to differentiate between the many variables that affect sugar maple growth and distribution. Our analysis relied on multi-criteria decision making (Brown et al. 2015) and weighted sum analysis to produce a site suitability output map that incorporated both environmental and socioeconomic factors.

Our input data layers initially fit into two categories: climate data and landscape data (Table 1). We identified these data layers after reviewing the literature on sugarbush sites and sugar maple growing conditions (Brown et al. 2015; Tirmenstein 2018; Farrell 2012; Stults et al. 2016; United States Forest Service 2018). However, after examining climate data across the project extent, we determined that due to the size of our extent, climate was constant and could be eliminated from the analysis (Figure 1). Instead, we focused heavily on soil characteristics, which are much more variable across northern Wisconsin. Each layer was imported into ESRI ArcMap 10.5 and clipped to the study area boundary of the ceded territory.



Data Type	Data Layer	Source
Boundary	WI state boundary	DNR FTP
	WI county boundaries	WiDNR Open Data Portal
	Ceded territory boundaries	GLIFWC
	Reservation boundaries	US Census Bureau
	National Forest boundaries	WIDNR Open Data Portal
Landscape	Sugar maple extent	WISCLAND2
	Digital Elevation Model (DEM)	DNR FTP
	Soil characteristics	NRCS
Transportation	Roads	Open Street Map

Table 1: Input data layers

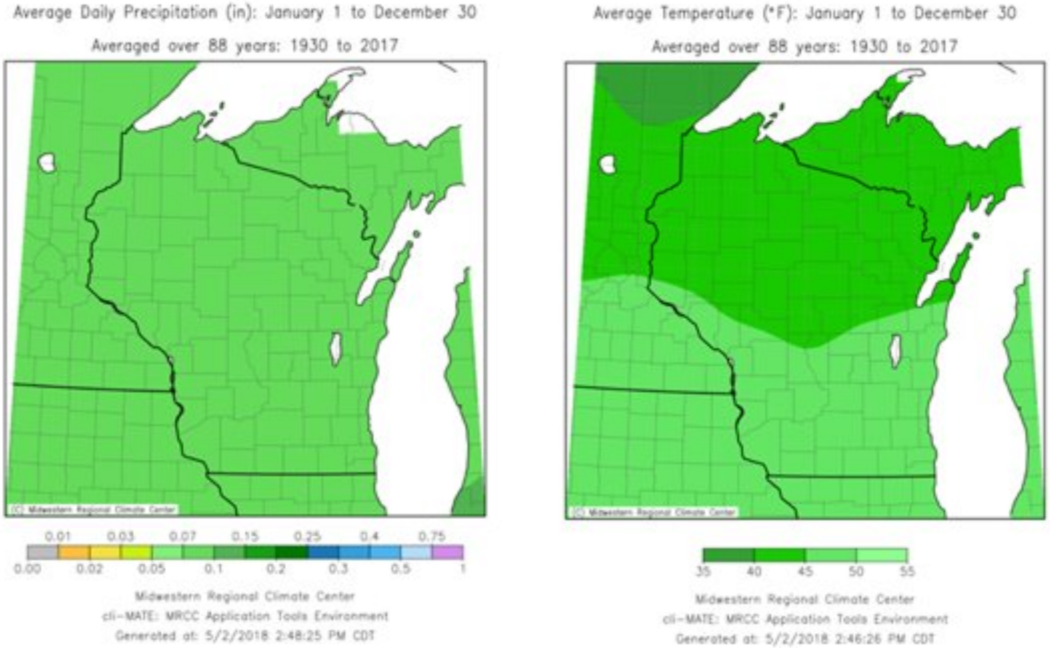
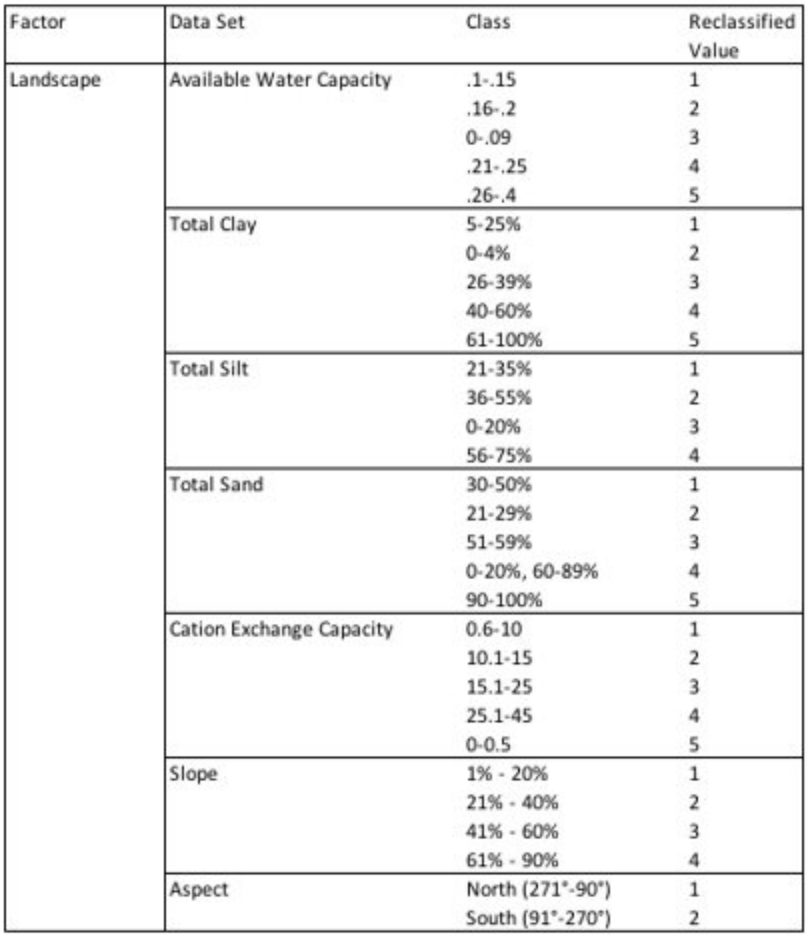


Figure 1: Temperature and Precipitation Averages for Wisconsin (WI Regional Climate Center). Because both temperature and precipitation are constant (on average) across our project extent, they would have negligible impact on our weighted sum analysis, and thus were omitted.

To create the site suitability map we performed a weighted sum analysis of the raster data layers, which required ranking each data layer (Table 2) before multiplying them by an established weight representing their influence on the analysis. We ranked the seven landscape raster layers pertaining to soil characteristics (water capacity, clay, silt, sand, slope, aspect, and cation exchange capacity) on a 1-5 scale, with a rank of 1 representing the ideal (best) conditions for sugar maples and a rank of 5 representing the least ideal (worst) conditions (Brown et al. 2015).



Factor	Data Set	Class	Reclassified Value
Landscape	Available Water Capacity	.1-.15	1
		.16-.2	2
		0-.09	3
		.21-.25	4
		.26-.4	5
	Total Clay	5-25%	1
		0-4%	2
		26-39%	3
		40-60%	4
		61-100%	5
	Total Silt	21-35%	1
		36-55%	2
		0-20%	3
		56-75%	4
	Total Sand	30-50%	1
		21-29%	2
		51-59%	3
		0-20%, 60-89%	4
		90-100%	5
	Cation Exchange Capacity	0.6-10	1
		10.1-15	2
		15.1-25	3
		25.1-45	4
		0-0.5	5
	Slope	1% - 20%	1
		21% - 40%	2
		41% - 60%	3
		61% - 90%	4
	Aspect	North (271°-90°)	1
		South (91°-270°)	2

Table 2: Fuzzy scoring rankings of data layer variables

The entire study area, due to its smaller spatial extent, falls within sugar maples' preferred ranges for the two climatic variables of mean annual temperature (0°C-18°C) and mean annual precipitation (1000mm-1500mm). Sugar maples are generalists; research shows that while the trees prefer to grow in mild areas with "low drought stress," they may still persist if other variables are suitable (United States Forest Service 2018; Tirmenstien 2018; Stults et al. 2016). For these reasons, as well as those discussed above, we felt it unnecessary to include temperature or precipitation in our analysis.

The soil layers are the significant component in this analysis because, though sugar maples can grow in a variety of conditions, the soil conditions and their modification of climate variables such as precipitation are the key factor dictating sugar maple health (Brown et al. 2015; United States Forest Service 2018). The Natural Resources Conservation Service (NRCS) classifies soil drainage in qualitative categories that matched with our review of the literature to produce our rankings of "well drained" as 1 (ideal) and "very poorly drained" as 5 (least ideal) (NRCS 2018; Brown et al 2015; Tirmenstien 2018; Stults 2016). However, after meeting with the NRCS to discuss our project, we chose to use available water capacity (AWC) as a clearer, more measurable metric for soil drainage. Water capacity is commonly measured in centimeters per centimeter (NRCS 2018). Sugar maples prefer soil that does not become too waterlogged, but extremely dry soils would stress the trees. Thus, we ranked the second-lowest AWC range as 1 (most ideal), the third-lowest as 2, and the lowest (ie, driest) as 3. The wettest soils (with the highest AWC) were ranked as 5, least ideal.

Soil texture is another variable for which sugar maples have a wide tolerance range, though they tend to prefer "loamy soils" above other varieties (Brown et al. 2015). Loam is a mixture of silt, sand, and clay, often with equal parts silt and sand, and slightly less clay (Figure 2). Based on this definition, we ranked pure or heavily sand/clay soils as 5, which also reflects those soils' least ideal characteristics of water retention (too little in sand, too much in clay). Heavy-silt soils were only ranked as 4, because silt is more important to loamy soils than sand or clay, so we wanted it to be weighted slightly heavier. To approximate loam, we gave a ranking of 1 to soils that had midrange values of clay, sand, and/or silt to reflect the more equal distribution of each type in loamy soils (Table 2). As each soil type veered away from its middle point, we ranked it lower; e.g., soils with less than 30% or more than 50% sand were ranked as 2, because they are further from loam. Working this way, each of the non-loam soil types (e.g. silt loam, loamy sand, silty clay) were ranked progressively lower in suitability as the texture shifted to more extreme soil types that would impact the soils' ability to meet other criteria preferred by the sugar maples (e.g. drainage, fertility) (Stults et al. 2016; Tirmenstien 2018; United States Forest Service 2018).

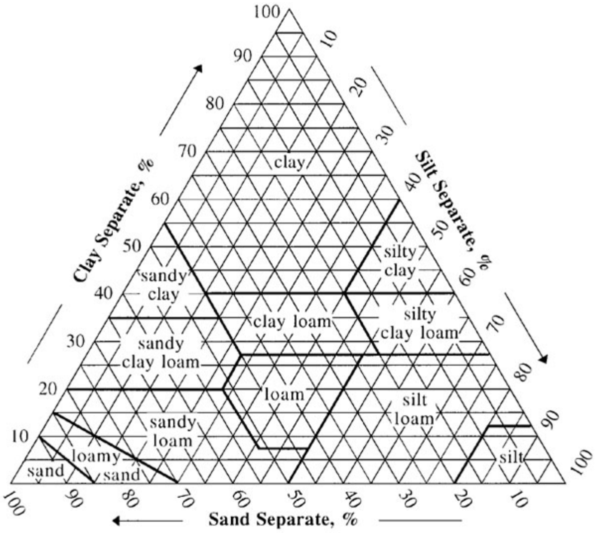
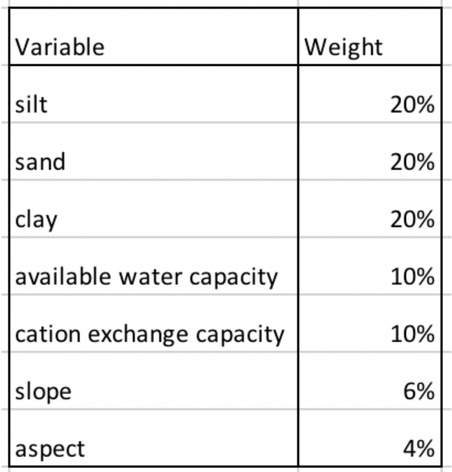


Figure 2: Soil texture definitions used in our ranking scheme. (NRCS)

Sugar maples can grow on a range of slopes given that other variables are ideal, and our ranking reflects this with less slope (1-20%) ranked 1 and sharp slopes (61-90%) ranked 4 (Brown et al. 2015). Somewhat in conjunction with slope is the aspect, or direction the slope is facing. Sugar maples prefer north-facing slopes because the microclimate is cooler in the Summer (Stults et. al 2016; Brown et al. 2015). South-facing slopes are less ideal during summer months but are better for late Winter/early Spring due to their increased sun exposure that helps with early season growth (United States Forest Service 2018). We defined a North-facing slope as any slope oriented 271°-90° and gave it a ranking of 1 to reflect the slightly more ideal nature of the cooler slopes, while South-facing slopes were those oriented 91°-270° and ranked 2.

Sugar maples grow best in nutrient-rich soils but are tolerant of a variety of nutrient loads in soil (Bal et al. 2015). Nitrogen, phosphorous, potassium, calcium, manganese, magnesium, and aluminum are all important nutrients for sugar maple health (Bal et al. 2015). Additionally, sugar maples are found on “Spodisols, Alfisols, Inceptisols, Mollisols, and Ultisols” (Bal et al. 2015, p. 70). In our work with the NRCS, we concluded that the best soil-nutrient proxy for our analysis was cation exchange capacity (CEC), a measure of soil's ability to hold onto essential nutrients (Soil Quality 2018). We ranked soils as 1 if they had a relatively low, but not the lowest, CEC value; high-CEC soils are typically clays and organic matter, both of which can overwhelm sugar maples in large proportions (Brown et al 2015). The lowest CEC value was ranked as 5, because such soils would have too little of the nutrient-rich clays. Those in between were ranked progressively lower in our ranking scheme as their CEC value increased, reflecting the increase in organic and clay matter that is less ideal for sugar maple habitat.

It was necessary to weight each layer according to its importance or influence in the analysis to represent the greater local influence of the landscape variables on sugar maple distribution (Table 3).



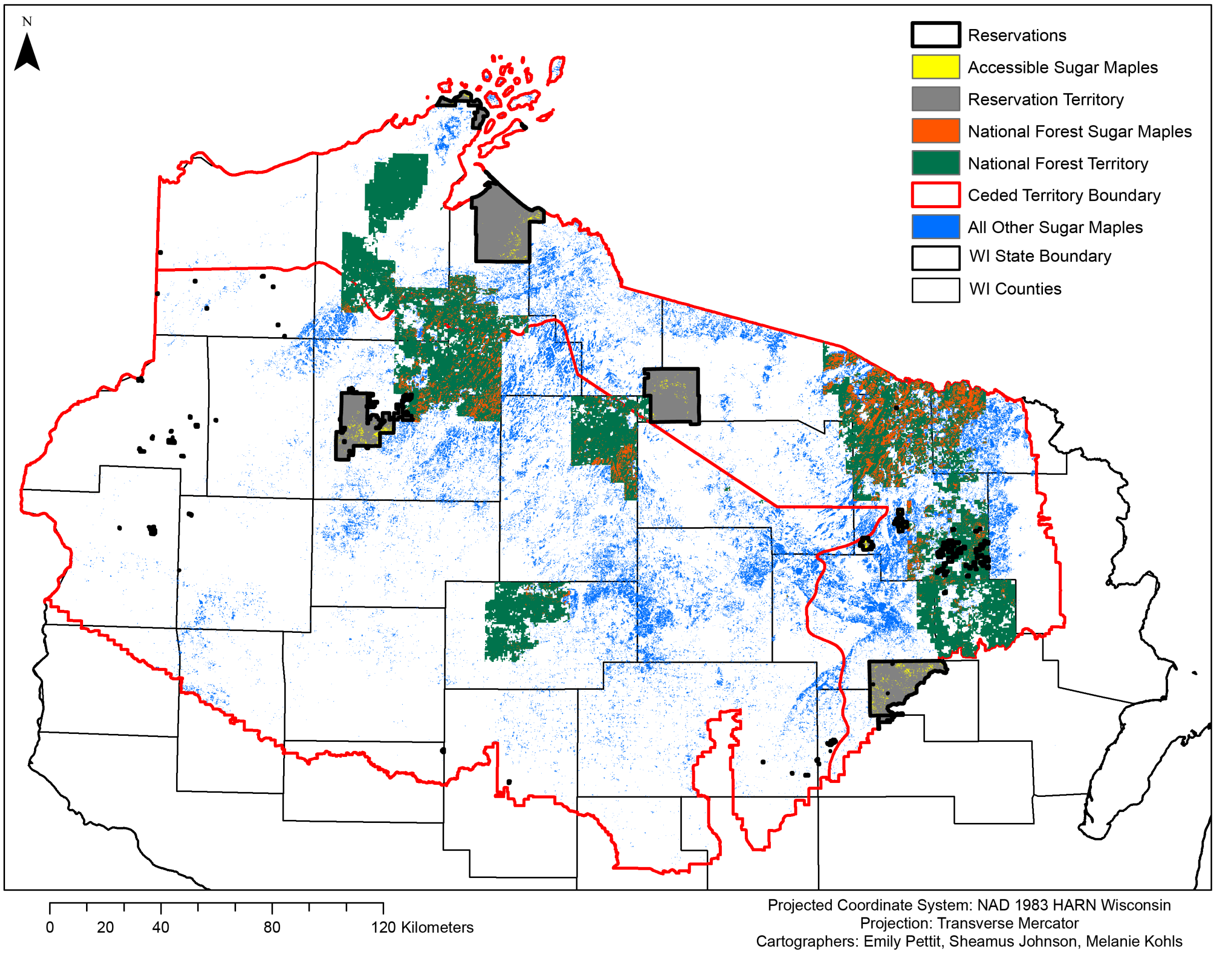
Variable	Weight
silt	20%
sand	20%
clay	20%
available water capacity	10%
cation exchange capacity	10%
slope	6%
aspect	4%

Table 3: Weighted variable layers for weighted sum analysis

Our weighting scheme developed out of our review of the literature that highlighted the importance of soil texture (each weighted 20% to produce an equal influence per soil type) to the health of sugar maples (Brown et al. 2015; Bal et al. 2015). Both soil fertility (CEC) and drainage (AWC) were weighted lower (10%) due to their influence on root growth and nutrient uptake. Slope earned a higher weight (6%) than aspect (4%) because of the relationship of slope with drainage/runoff and soil fertility (Stults et al. 2016; Tirmenstien 2018). Both slope and aspect were variables with the widest possible "ideal" value range in our analysis, and thus had least impact on our study area.

For the distance-to-road component of this model we performed a fixed buffer analysis on the road data layer using a 1600m (1 mile) buffer width based on our review of the literature (Farrell 2012). The output layer, when overlaid on the site suitability analysis output, helped to identify those sugarbush sites within tolerable distance for travel to and from roads. In fact, our 1600m buffer encompassed nearly all of the project extent; only one or two very small patches of land were more than a mile from a road. We then ran the model with a smaller (90m) buffer to find the areas that are the most accessible, looking specifically within national forests since those are the areas where the Ojibwe maintain usufruct rights.

IV. Results, Analysis, and Discussion



Projected Coordinate System: NAD 1983 HARN Wisconsin
Projection: Transverse Mercator
Cartographers: Emily Pettit, Sheamus Johnson, Melanie Kohls

Figure 3: Output map showing the most easily accessible sugar maples (yellow) within national forests and reservations, as well as all other sugar maples (orange and blue) within project extent. Both ceded territories are bounded in red.

In Figure 3, all maples inside of reservation boundaries (the gray areas) are coded as accessible, because they are already on reservation land. The yellow pixels represent those sugar maples within the most-accessible 90m road buffer; orange pixels are sugar maples that are within national forests but outside of the smaller road buffer, indicating that they are more difficult to access. We produced this map to better explore how current sugar maple extent compared with the locations of Ojibwe reservations and national forests, with a focus on accessibility to sugar maples within each zone type.

Figure 4 provides a zoomed-in image of one national forest boundary to better illustrate the spatial distribution of accessible and non-accessible sugar maples based on the 90m buffer. The sugar maples on this map are the result of the sugar maple-specific raster layer pulled from WISCLAND2 data. By overlaying this layer with the site suitability analysis (Figures 5 through 7) we can compare current sugar maple distribution with potential future sugarbush locations.

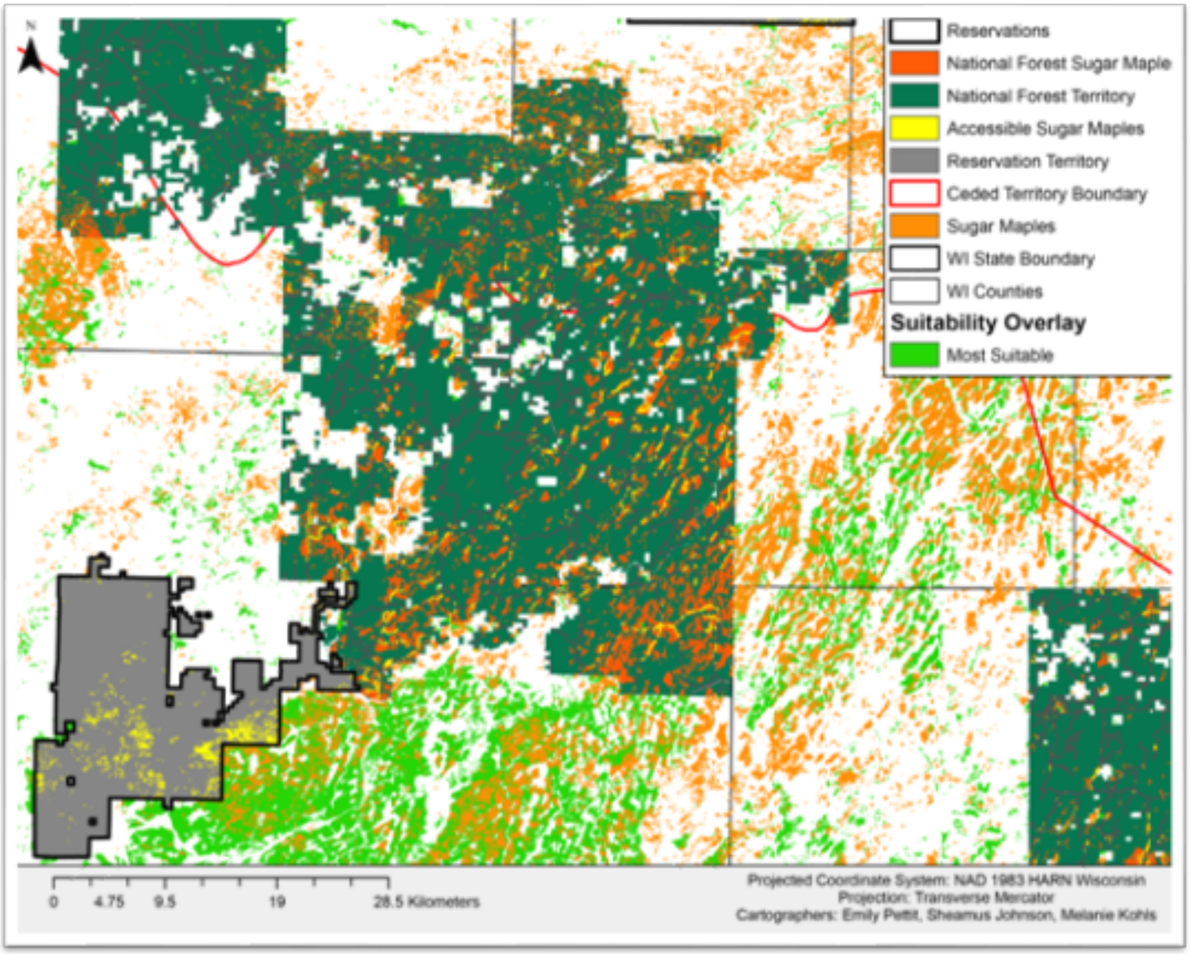
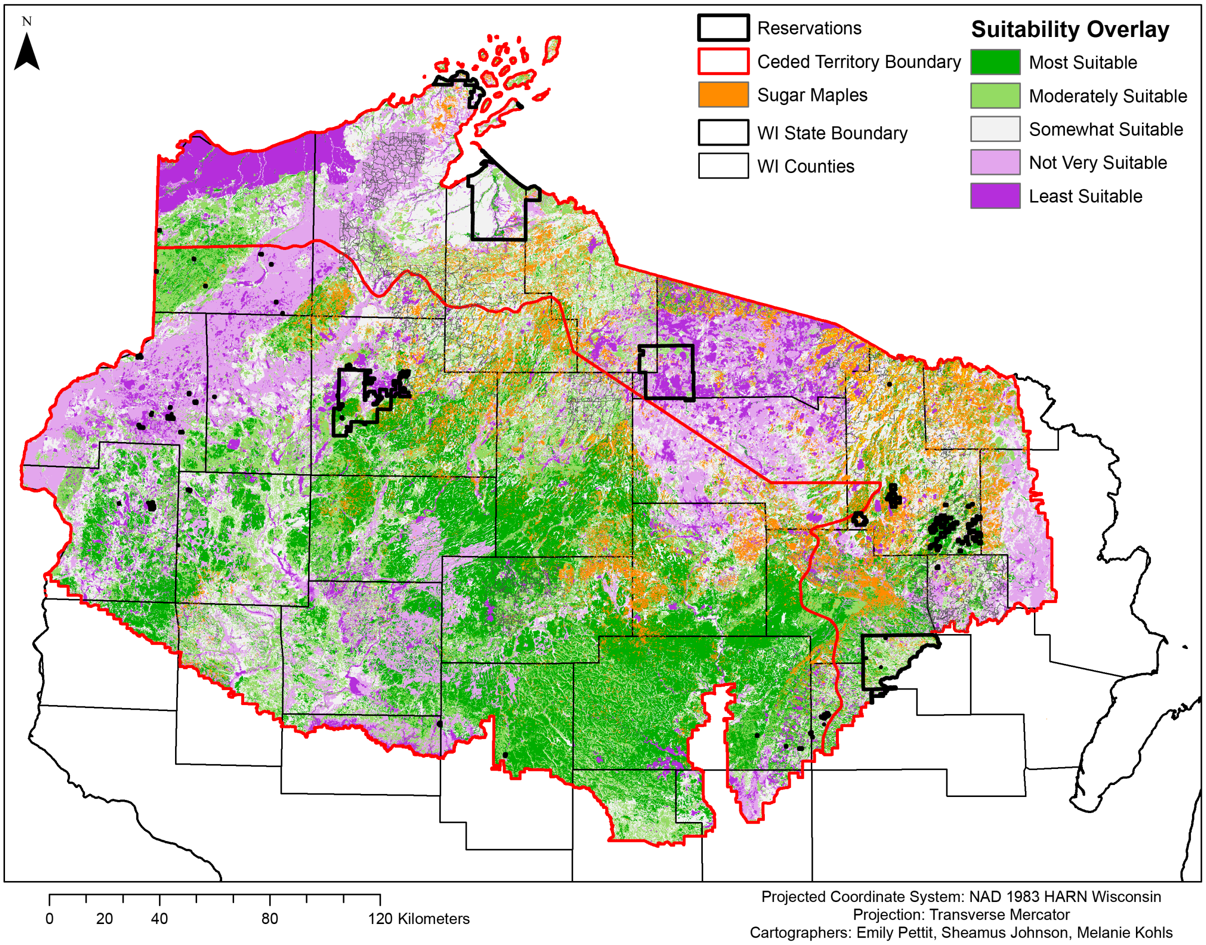


Figure 4: Closeup of the most accessible (yellow) and less accessible (orange) sugar maples within a subset of the overall project extent.

"Less accessible" makes more sense than "inaccessible" here because the orange maples within national forests, though outside of the 90m road buffer, are still included in Ojibwe usufruct rights and may still be within a reasonable distance to travel for tapping. Modern tappers often use tubing to reduce labor and increase efficiency, especially in larger sugarbushes (Jacobson

2017). Tubing could connect farther-off-road trees to nearby trees, thus incorporating trees that fall outside the 90m road buffer. Because of the range of tubing lengths and tapping setups we chose to only analyze the 1600m and 90m buffers, though variations in these distances could provide a more nuanced exploration of accessibility.



Projected Coordinate System: NAD 1983 HARN Wisconsin
Projection: Transverse Mercator
Cartographers: Emily Pettit, Sheamus Johnson, Melanie Kohls

Figure 5: Map of the weighted sum suitability analysis across the project extent: areas least suitable for sugar maple are symbolized with purple. Dark green areas indicate higher suitability, while orange shows current sugar maple extent.

Figure 5 reveals that our analysis identified far more suitable areas than currently have sugar maple on them. This may be due to the fact that sugar maples are generalists in their habitat preference. The variables we selected as "suitable" may be indicative of more general suitability, while the cutoff values we selected in our ranking may have separated equally ideal conditions in reality. Similarly, our analysis did not account for land cover and land use changes that could alter suitability, such as varying forest management regimes and other conservation efforts. Our analysis may also show soil or water capacity conditions that seem suitable for sugar maple but actually constrain their presence due to unaccounted land cover or land use variables. Sugar maples are sensitive to the cation exchange capacity of calcium more than other nutrients (Bal et al. 2015). Our variable of cation exchange capacity is much more generalized and therefore does not account for the exchange capacity of specific nutrients such as calcium. Areas shown as "suitable" on our map may in fact have an average suitability for cation exchange capacity, but not in the nutrients vital for sugar maple health, which results in the discrepancy between suitable areas that contain little-to-no actual sugar maples.

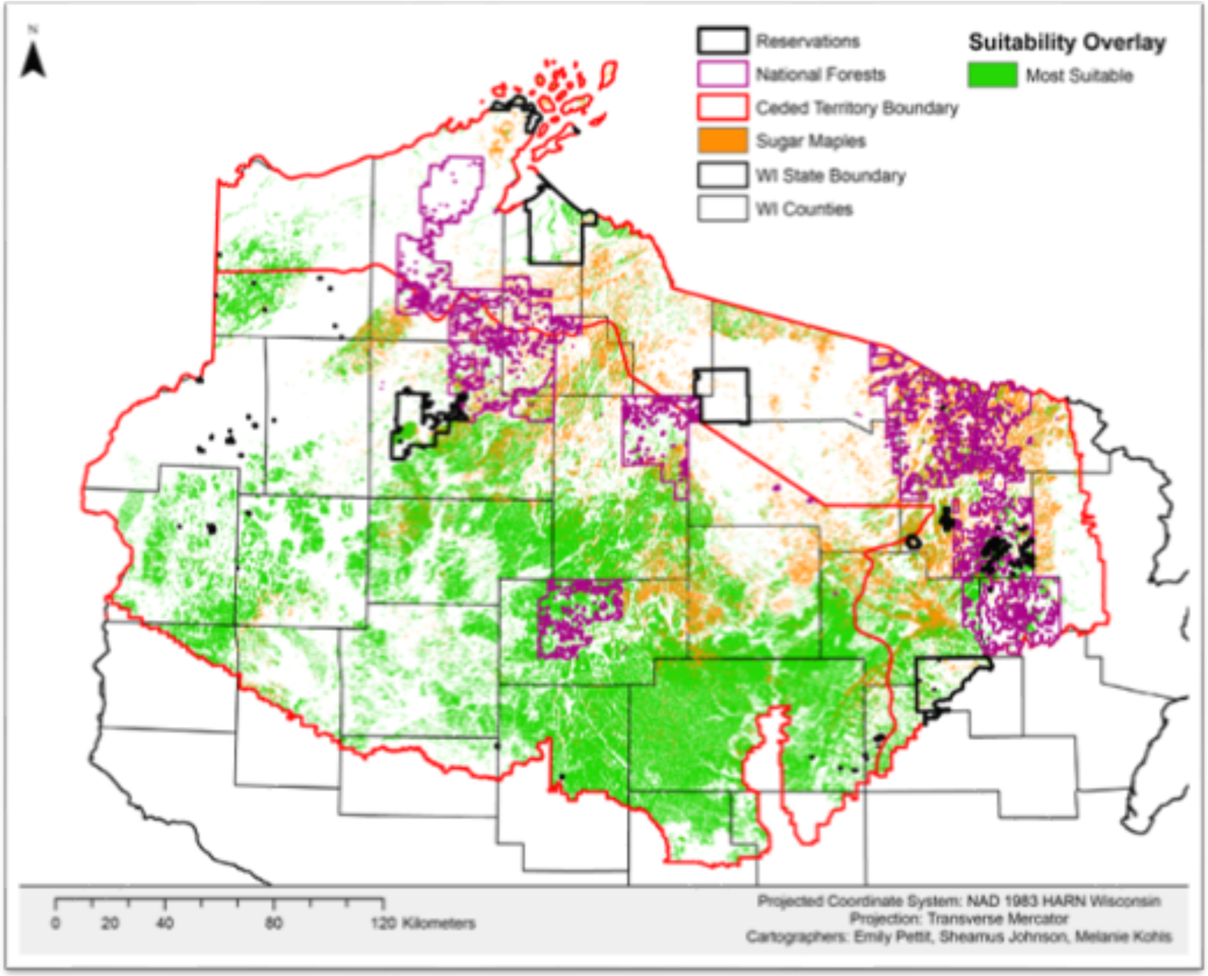


Figure 6: This map shows the most suitable locations identified in our analysis (green) and current sugar maple extent (orange), with the national park boundaries (purple) as our variable for access.

Our analysis shows that while there are suitable sites and current stands of sugar maple within the national park boundaries, the majority of both current sugar maple stands and suitable locations remain outside the park boundaries. There do appear to be suitable areas on the Lac Courte Oreilles and Bad River reservations, which may be suitable locations for future sugarbush plantings.

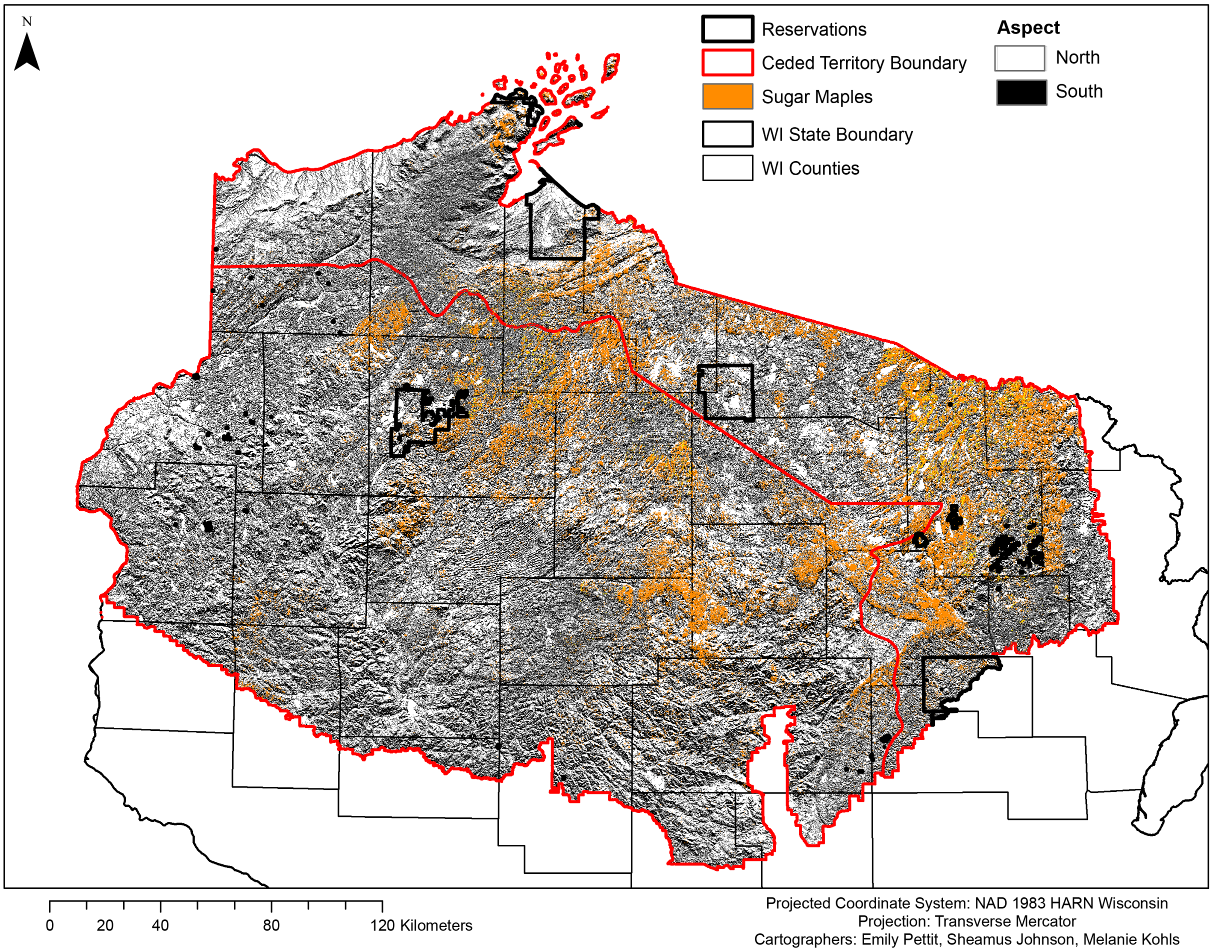


Figure 7: Map showing current sugar maple extent (orange), with aspect (north facing in white, south facing in black).

The primary reason for creating a map of aspect (Figure 7) was to explore the distribution of current sugar maple on North and South facing slopes. There are some indications that sugar maples on North-facing slopes may be resilient to changes in the climate, which makes it an important consideration in planting sugarbushes for future use (Stults et al. 2016). Exploring sugarbush distribution in response to climate change was beyond the scope of this analysis, though there remains plenty of work in this area for future study.

V. Conclusion

As a general analysis, our project revealed that though there is discrepancy between our suitable sites and current sugar maples in the ceded territories, there are opportunities for sugarbush plantings in areas not currently used for tapping. The two factors that had the largest influence on our analysis can be broadly categorized as suitability based on access and growing conditions.

We analyzed the proximity of sugar maple stands to existing roads at a buffer of 91 meters and 1600 meters, or approximately one mile. Perhaps the most significant conclusion from this portion of the analysis is that nearly all sugar maples in the ceded territory are within one mile of a road. There were two sections of our study area that both contained sugar maple and were outside of the 1600m buffer, each containing approximately a dozen pixels. This tells us that nearly all sugar maples in our study area are at least within the high limit of accessibility (approximately one mile). It is also significant for future analyses investigating finer-scale access since all sugar maples are within the upper limit of accessibility. A more discrete analysis could produce a finer gradient that assists with locating ideally-accessible stands.

Our suitability analysis for growing conditions (cation exchange capacity, available water capacity, soil component (silt, sand, clay), slope, and aspect) showed far more suitable locations than there were extant stands of sugar maple. Similarly, sugar maple was not present at all locations that our analysis highlighted as suitable. It is likely that, due to maples' generalist habitat preferences, suitable habitat for sugar maples is also appropriate for a host of other plant and tree species. A finer-grain and higher resolution of analysis may provide more accurate results while reducing errors of overgeneralization.

The discrepancy in sugar maple location and identified suitable locations may also be due to a temporal difference. Sugar maple trees can grow to be very old and may be established in locations that were previously more suitable than current soils and other data show. This may also help to explain the rate of crown dieback current stands of sugar maple are experiencing, and is worth further investigation, especially considering future impacts of climate change that were not addressed in this study (Stults et al. 2016).

Our analysis may also have identified more suitable locations for sugar maple than actually exist due to our use of cation exchange capacity as a proxy for soil pH. We chose to exclude pH as a soil variable because it was recorded in a logarithmic scale, which we were unable to modify in time to fit our analysis. Sugar maple are sensitive to a handful of nutrients' cation exchange capacity like calcium (Bal et al. 2015). The NRCS soil data for cation exchange capacity does not specify which nutrients' capacity it is based upon, and therefore is likely an average capacity for all nutrient types. Sugar maple may have stricter preferences in cation exchange capacity than can be captured in the NRCS data, which could be contributing to the larger suitable areas extent we produced. Future analyses may look to specifically include calcium CEC in addition to other suitability parameters, such as pH, for a more refined result. Depending on the soil parameters selected, such an analysis may make up for the lack of specificity in the generalized cation exchange capacity variable.

Lastly, our analysis showed that most of the current sugar maple stands and the majority of suitable locations lie outside of the national park boundaries, which excludes the Ojibwe from access. There are, however, both suitable locations and locations of current sugar maples within the national parks. Figure 4 shows a number of sugar maple stands within the national parks and within the 91m buffer, indicating their accessibility from park roadways. Several more may be considered accessible if a finer buffer analysis is completed. Though our final suitability analysis does not perfectly match current sugar maple extent with suitable locations, the identification of suitable areas without current sugar maples may be useful for selecting potential sites for planting future sugarbushes, thus helping the Ojibwe to maintain access to productive sugarbushes and hopefully helping to secure a valuable economic and cultural resource for years to come.

VI. Appendix A: Diagrams

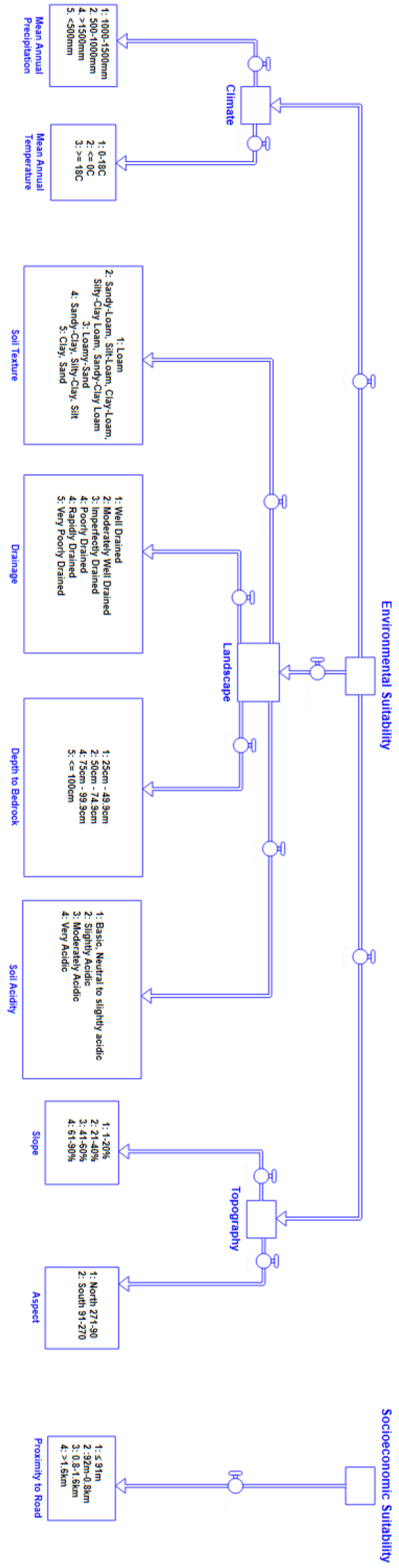


Figure 8: The conceptualization diagram for this study, outlining the key concepts and operationalized variables used to plan and guide the creation of this study.

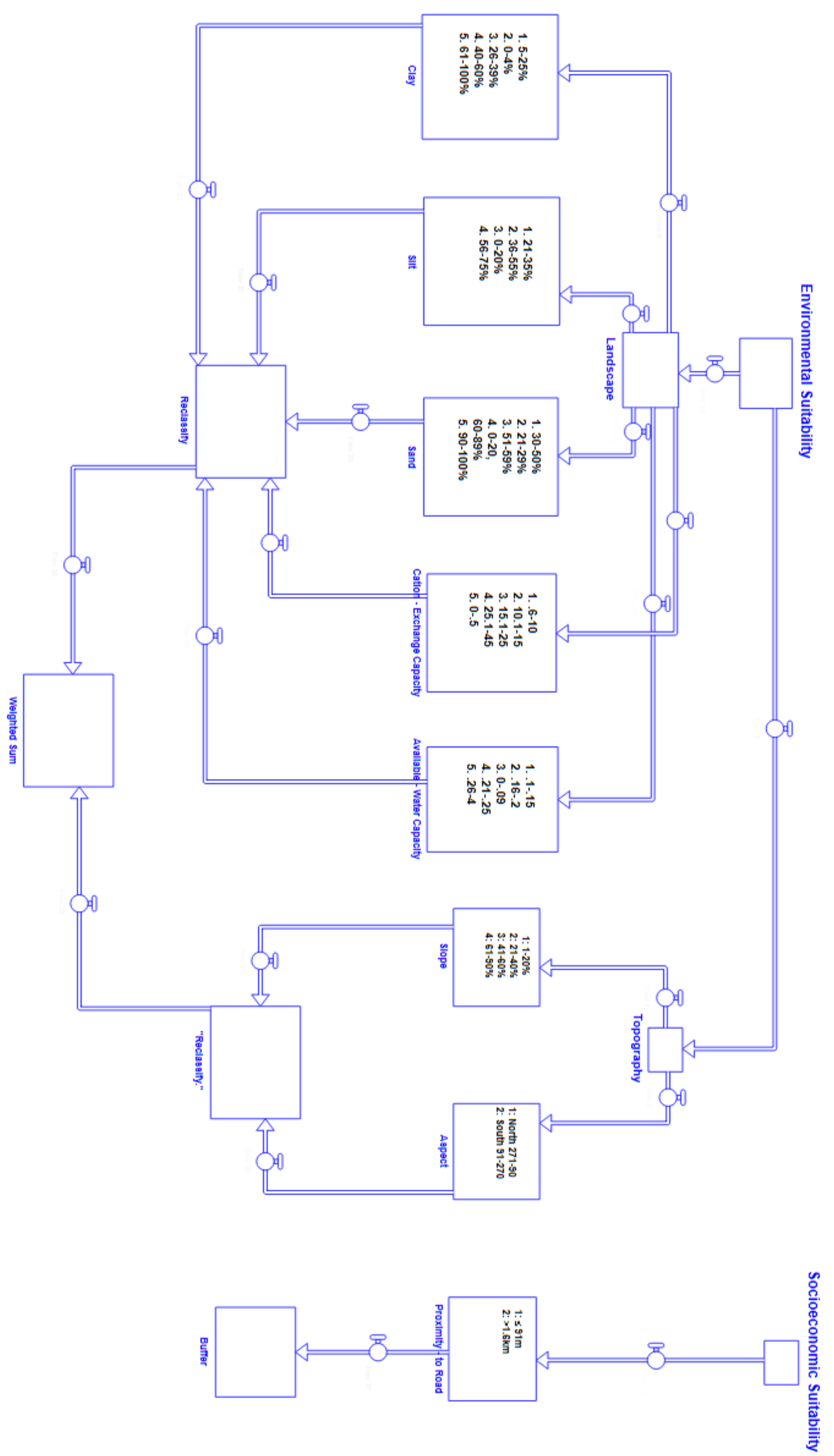


Figure 9: The study implementation diagram, which depicts the work process used in this study to rank, weight and combine the various raster-based variables to produce the weighted sum overlay and accessibility buffers.

Appendix B: FGDC-Compliant Metadata for Soils Data Layer:

Section 1: Identification

Originator: This data set was developed to fulfill the final project requirements for the University of Wisconsin-Madison course 578: GIS Applications by Sheamus Johnson, Melanie Kohls, and Emily Pettit.
Publication_Date: 20180504
Title: Soil Characteristics Profile for Sugar Maple Site Suitability Analysis in the Ceded Territories of Wisconsin from NRCS source data, NAD83 Wisconsin HARN (meters), UWMadison (2018).
Online_Linkage: N/A
Abstract: This GIS data set includes the following soil profile characteristics in attribute table format for 30 counties included in the Ceded Territory of northern Wisconsin: Available Water Capacity, Cation Exchange Capacity, Total Clay, Total Sand, Total Silt.
The 30 counties included in this data set are: Bayfield, Douglas, Ashland, Iron, Vilas, Oneida, Price, Sawyer, Rusk, Washburn, Barnett, Barron, Chippewa, Taylor, Lincoln, Langlade, Forest, Polk, St. Croix, Dunn, Eau Claire, Clark, Wood, Marathon, Portage, Shawano, Menominee, Oconto, Marinette, and Florence.
This data set was compiled in April 2018, using NRCS data published in December 2016.
Progress: Complete.
Theme_Keyword: geoscientificInformation
Theme_Keyword_Thesaurus: ISO 19115 Topic Category
Place_Keyword: Wisconsin, WI, Ceded Territory
Stratum_Keyword: Surface
Access_Contraints: None
Use_Constraints: Must read and fully comprehend the metadata prior to data use; acknowledgement of the Originator when using the data set as a source; data should not be used beyond the limits of the source scale.
Point_of_Contact: Sheamus Johnson, sjohnson65@wisc.edu
Data_Set_Credit: NRCS, specifically Kent Peña and Jason Nemecek
Native_Data_Set_Environment: ESRI ArcMap version 10.5; Windows 10

Section 2: Data Quality

Attribute_Accuracy_Report: n/a
Logical_Consistency_Report: n/a
Completeness_Report: n/a
Positional_Accuracy_Report: n/a
Process_Step: Selection of soil characteristics from the NRCS SSURGO geodatabase; join AWC, CEC, Total Silt, Total Clay, Total Sand to SAPOLYGON shapefile via MUKEY for use in ESRI ArcMap 10.5
Process_Contact: Sheamus Johnson, sjohnson65@wisc.edu
Cloud_Cover:

Section 3: Spatial Data Organization

Indirect_Spatial_Reference: Wisconsin
Direct_Spatial_Reference_Method: Raster

SDTS_Point_and_Vector_Object_Type: n/a

Section 4: Spatial Reference

Horizontal_Coordinate_System_Definition: NAD83 HARN Wisconsin
Abscissa_Resolution/Ordinate Resolution: 30
Planar_Distance_Units: Meters

Section 5: Entity and Attributes

Detailed_Description: This data set is a raster layer (30m) profile of select soil characteristics for the Ceded Territories of northern Wisconsin. The soil characteristics are listed in the attribute table and include the following: Available Water Capacity (percent of capacity available for water to absorb), Cation Exchange Capacity (millequivalents), Total Sand (percent of soil that is sand), Total Clay (percent of soil that is clay), and Total Silt (percent of soil that is silt). This layer also includes the MUKEY values used to join the table during processing and can link this table to other NRCS SSURGO tables via the MUKEY.
Attribute_Domain_Values: Range Domain
Overview_Description: This data set was created to provide a soil characteristics table for the Ceded Territory of northern Wisconsin, and thus all the variables represent only the range of values found in the Ceded Territory. The variables included are Available Water Capacity, Cation Exchange Capacity, Total Sand, Total Clay, and Total Silt.

Section 6: Distribution Information

Distributor_Contact: Sheamus Johnson, sjohnson65@wisc.edu
Distribution_Liability: The distributor of this dataset assumes no liability if the data are incorrect, incomplete, or misused.

Section 7: Metadata Reference

Metadata_Date: 20180505
Metadata_Contact: Sheamus Johnson sjohnson65@wisc.edu
Metadata_Standard_Name: Content Standard for Digital Geospatial Metadata
Metadata_Standard_Version: FGDC-STD-001-1998
Metadata_Access_Constraints: None
Metadata_Use_Constraints: None

VII. Bibliography

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