Suitability Analysis for a New Maple Syrup Farm in Eastern Township, Quebec

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GDAA 2020: Location Analytics

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Purpose of the Project

The purpose of this suitability analysis is to locate the optimal site for a new maple syrup farm in the Eastern Townships of Quebec.

Criteria & Constraints

Based on the goal of our suitability analysis, and a discussion among the team members, the criteria were identified and organized into three primary objectives as follows:

1. Environmental Conditions
2. Accessibility
3. Climatic Conditions

Physical constraints were also established to prevent the selection of areas unsuitable for the placement of a maple syrup farm.

Environmental Conditions

Sub-Model: Environmental Conditions

Table 1: Criteria used in assessing suitability for environmental conditions.

Criteria	Required Data	Layer Name	Source	Weight
The maple syrup farm must be within an existing wooded area composed of mature maple trees that are at least 40 years old, preferably sugar maple.	Primarily sugar maple tree forests	“Trans_MapleExtent”	Ecological classification of Quebec Territory	1.5
Sugar Maple can tolerate a soil PH of 3.7 to 7.5 but grow best in 5.5-7.3.	Soil PH data	“Reclass_Soil_PH”	ESRI	1
Full sun exposure in spring and summer is required for tree growth.	Total solar energy input from Mar-Aug.	“Trans_SolarEnergy”	WorldClim V2.1, Climate Data for 1970-2000	1
Healthy trees have more stored energy (in the form of starches) to fuel sap production, and are more resilient against pests, diseases, and environmental stressors.	Tree canopy cover	“Trans_TreeCanopyCover”	NASA Global Forest Cover Change Tree Cover Multi-Year Global 30m, retrieved from Google Earth Engine	1
To facilitate the sap collection process a slope of less than 10 degrees is preferred	Slope	“Slope_Trasformed”	NRCan	1

Soil Ph

Sugar maples can thrive in various soil types, although they exhibit a preference for slightly acidic conditions ranging from 5.5 to 7.3 and can tolerate pH levels within the range of 5.7 to 7.5 (Chamberlain, 2020; McIsaac, 2012). In this project, soil pH data sourced from ESRI indicated a pH range of 4.3 to 6.9 within the study area. Given that this range falls within the acceptable pH conditions for sugar maple growth, we categorized values falling within the preferred range as most suitable. Specifically, the midpoint of the preferred pH range was designated with the highest suitability value of 10. Suitability values were then adjusted downward as pH values deviated from this midpoint, with lower values assigned to lower pH levels.

Slope

Maple syrup farms commonly utilize tubing systems to gather sap, connecting taps from various trees to a central collection point usually located in the sugar shack. Ensuring the proper functioning of these tubing systems demands regular inspections and maintenance by personnel. Consequently, forests with gentler slopes are favored to enhance working conditions and streamline farm upkeep operations. Slopes exceeding 10 degrees are typically deemed less desirable due to the increased challenges they pose. As a result, slope values have been reclassified to assign greater suitability to lower slopes, aligning with the practical needs of maple syrup farming operations.

Tree Canopy Cover

Tree canopy cover is crucial for selecting a maple syrup farm due to its direct impact on sap production, tree health, and resilience to environmental stressors. A dense canopy facilitates optimal photosynthesis, ensuring higher sap yields during the sugaring season, while also providing shade and moderating soil moisture and temperature, promoting tree health and stress resistance. Moreover, healthy trees with ample foliage are better equipped to defend against pests and diseases, contributing to the sustainability of syrup production. Furthermore, a diverse and thriving canopy supports a rich ecosystem, benefiting biodiversity and ecosystem health. Therefore, selecting a maple syrup farm with a dense and healthy tree canopy is essential for maximizing syrup yields, ensuring long-term sustainability, and maintaining the overall health of the forest ecosystem.

Solar Energy

Exposure to sunlight is required for foliage to develop and aid in tree growth as well as sap yield. According to Environment Canada’s report on Atmospheric Influences on the Sugar Maple Industry in North America, the distinct red colour of the sugar maple leaves is generated by a pigment known as anthocyanin. Anthocyanin is associated with high sugar levels in the fall season and develops best on days where the warm sun provides heat that keeps the surface temperature of the leaves above freezing. The Topography of the eastern township of Quebec consists of higher elevation providing stronger intakes of solar energy, while forest stands in the western regions experience more exposure and this exposure dwindles as you move towards the east. Pockets of forests within these preferred areas can suffer from competitive tree coverage and other obstructions.

Sugar Maple Stands

The ecological classification of Quebec's territory delineates various polygons across the province providing information on the primary species of trees for each. These polygons were filtered to identify regions where the predominant species were either "sugar maple groves" or "yellow birch groves with fir and sugar maples." Polygons dominated by sugar maple trees were designated a priority value of 10 for further analysis, signifying their significance in sap production. Mixed polygons, encompassing a blend of species such as yellow birch, fir, and sugar maples, were assigned a value of 5. This approach recognized that sap production is influenced by multiple factors beyond mere species dominance, such as canopy cover, a proxy for tree age. Consequently, areas with a lesser abundance of sugar maples but possessing other favorable characteristics, such as mature canopy cover, were deemed crucial for consideration in the analysis.

Accessibility

Table 2: Criteria used in assessing suitability for accessibility conditions.

Criteria	Required Data	Layer Name	Layer Source	Weight
Tourists and local customers prefer ease of access rather than travelling to remote locations.	Proximity to highways	“Trans_Dist_Highways”	Canada National Highway System	1
Products are transported to storage facilities. Shorter travel time reduces transportation costs.	Drive time to storage facilities	“Trans_Dist_Storage”	Québec Maple Syrup Producers (QMSP)	2
Streamline and modernize sap production require stable power supply.	Distance to powerline	“Trans_Dist_Powerlines”	CanVec	1.25

Power Supply

Access to electricity is paramount for the efficient operation of a maple farm, facilitating essential processes and enhancing overall productivity. Being near power lines offers numerous advantages in terms of infrastructure and operational efficiency. Electricity powers critical equipment and machinery integral to maple syrup production, including evaporators, vacuum pumps, lighting systems, and heating equipment. Moreover, modern technology and automation systems reliant on electricity help streamline operations, ensuring consistency and quality in syrup production.

Beyond operational needs, electricity infrastructure supports safety measures such as alarm systems and temperature control mechanisms, contributing to quality assurance and farm safety. Additionally, reliable access to electricity fosters the potential for expansion and growth by providing a dependable power supply for scaling operations and investing in new equipment. However, in situations in which connecting to power lines is not feasible, alternative power sources like solar, wind, hydroelectric, biomass, or microgrid systems offer viable options for generating electricity onsite, albeit with varying considerations regarding cost, sustainability, and reliability. Ultimately, the availability of electricity infrastructure plays a crucial role in shaping the efficiency, sustainability, and growth potential of maple farms.

Storage Facilities

In Quebec, where a substantial portion of the world's maple syrup is produced, major storage facilities play a pivotal role in the maple syrup industry's infrastructure. These facilities serve as central hubs for storing, processing, and distributing maple syrup, acting as crucial intermediaries between maple syrup producers and buyers worldwide. For maple syrup farms, proximity to these storage facilities holds great importance, offering several strategic advantages.

First and foremost, being situated near major storage facilities provides maple syrup farms with convenient access to markets and buyers. By reducing transportation costs and logistical complexities, farms can streamline the distribution process, ensuring the timely delivery of their products to customers. This proximity fosters stronger connections with buyers and enables farms to respond promptly to market demands, enhancing their competitiveness in the industry. Moreover, proximity to storage facilities offers maple syrup farms opportunities for collaboration, knowledge sharing, and industry networking. By being part of a vibrant maple syrup ecosystem, farms can benefit from shared resources, expertise, and best practices, driving innovation and continuous improvement in syrup production techniques. Collaborative efforts within close-knit maple syrup communities can also lead to collective bargaining power and advocacy for industry interests. Furthermore, proximity to storage facilities offers maple syrup farms access to essential support services and infrastructure, such as quality control testing, packaging facilities, and transportation logistics. Farms can leverage these services to ensure the consistent quality of their products, comply with regulatory standards, and efficiently package and distribute syrup to customers worldwide.

Highways

The maple syrup farm primarily earns revenue through exports; however, visitation is often supplementary return and can create exposure and personality to a brand. Sherbrooke, Quebec's 6th largest municipality, gets quite a bit of traffic. To a traveler, proximity to a central highway is enticing enough to make a stop worthwhile. Customers might think twice about venturing an hour or further into rural Quebec along their travels to visit and experience a tasting/excursion. Highway 112 is the secondary path of transformation between Montreal and Quebec City, behind the Trans-Canada Highway. Sherbrooke also links to Highway 55 that borders Vermont, 1 of 15 Vermont border crossings to Canada.

Climatic Conditions

Table 3: Criteria used in assessing suitability for climatic conditions.

Criteria	Required Data	Layer Name	Source	Weight
Regions with low wind speed during the spring is preferred.	Average wind speed in Spring (Mar-June)	"Trans_WindSpeed_Spring"	WorldClim V2.1, Climate Data for 1970-2000	1
Regions with lowest temperature and highest amount of snow cover in December is preferred.	Average lowest temperature in December. Average precipitation in December.	"Trans_Dec_Temperature" "Trans_Dec_Precip"	WorldClim V2.1, Climate Data for 1970-2000	1
Below freezing at night and above freezing during the day from February and March lead to higher production.	Water vapour pressure in February and March as indicators of snow melt and temperature variation during daytime. 14	"Trans_WaterVapour_Feb" "Trans_WaterVapour_Mar"	WorldClim V2.1, Climate Data for 1970-2000	1
Dry August or wet May can affect sap quantity/quality in the upcoming year.	Average precipitation in May Average precipitation in August	"Trans_May_Precip" "Trans_Aug_Precip"	WorldClim V2.1, Climate Data for 1970-2000	1
Flood and drought can affect overall tree health.	Precipitation in the driest quarter. Precipitation in the wettest quarter.	"Trans_Precip_Driest_Qtr" "Trans_Precip_Wettest_Qtr"	WorldClim V2.1, Bioclimatic Variables for 1970-2000	1
Heat stress in the summer can affect sugar maple's ability to produce starch.	Mean Temperature of the Warmest Quarter	"Trans_MeanTemp_Warmest_Qtr"	WorldClim V2.1, Bioclimatic Variables for 1970-2000	1

Wind Speed

Sugar maple trees are particularly vulnerable to strong winds due to their shallow, wide-spreading root systems, which offer less anchorage compared to trees with deep taproots like oaks or hickories. Additionally, their dense canopy acts as a large sail, while this give them great advantage in the summer in absorbing sunlight and carbon dioxide, they are extremely vulnerable to harsh weather and strong wind in the early spring. Furthermore, the process of sap collection involves tapping the trees, resulting in small wounds on the tree body. In windy conditions, this can lead to the dislodging of taps, tearing of tubing, and overturning of collection buckets, disrupting the sap flow. Wind-related damage such as broken branches and fallen trees can also restrict access to roads, further complicating sap collection, especially when compounded with extremely cold weather during early spring.

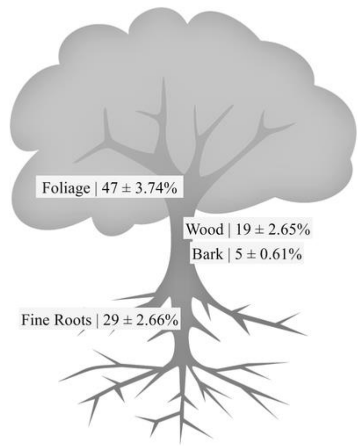

Figure 1: Illustration of the Sugar Maple's tree root system (Welp, L.R., et al. (2017)

Thermal Window

The optimum thermal window for maple sap production typically ranges from approximately. This temperature range is crucial for the sap to flow within the maple tree. When temperatures fluctuate around freezing point, typically during late winter and early spring, pressure changes within the tree's vascular system cause sap to move upward from the roots to the branches, facilitating sap collection. Temperature fluctuations outside of this range can either inhibit sap flow or lead to premature leaf development, which can either lead to bitterness or reduced production.

Air Temperature and Precipitation in December

December is a critical time period for ensuring high quality sap production in the upcoming spring. Low air temperature in December is crucial for maple trees in two ways, one is dormancy, and the other is the development of a thick snow cover. In late autumn and early winter, Sugar Maple enters a state of metabolic slowdown, conserving energy, and resources to withstand harsh winter conditions. Dormancy triggered by low temperature helps synchronize internal processes, including bud formation, setting the stage for healthy growth in the upcoming spring season.

Thick and stable snow cover (30+cm) in the winter can act as an insulator that prevents soil freezing and provides sufficient root moisture for mature sugar maples. When temperatures drop below freezing, any precipitation, whether snow or sleet, will accumulate and form snowpack on the ground. Having low air temperature in early December also prevents the snow from melting too quickly and ensuring that the snowpack remains intact until the next precipitation.

Vapour Pressure

For sap flow in sugar maple trees during February and March, air temperatures are required to be below freezing at night and above freezing during the day, the ideal daily temperature range is +5°C and -5°C. While it's difficult to get temporally aggregated temperature measurements in the field, water vapour pressure (measured in kPa) is an alternative indicator for daily temperature variations in an area by measuring the fluctuation of water being evaporated from the surface.

As temperatures rise during the day, the air's ability to hold moisture increases, leading to higher water vapor pressure. Conversely, as temperatures drop at night, the air's capacity to hold moisture decreases, resulting in lower water vapor pressure. Therefore, the highest the water vapour pressure in an area, the greater the daily temperature change.

For sugar maples, warm daytime temperatures cause the tree's wood to expand. The sap in its branches would be subjected to strong pressure, forcing it to flow into the trunk, and eventually dripping out through the taps. When it gets frigid at night, the wood contracts, squeezing off the flow, and more sap rushes up the tree from its cache in the roots.

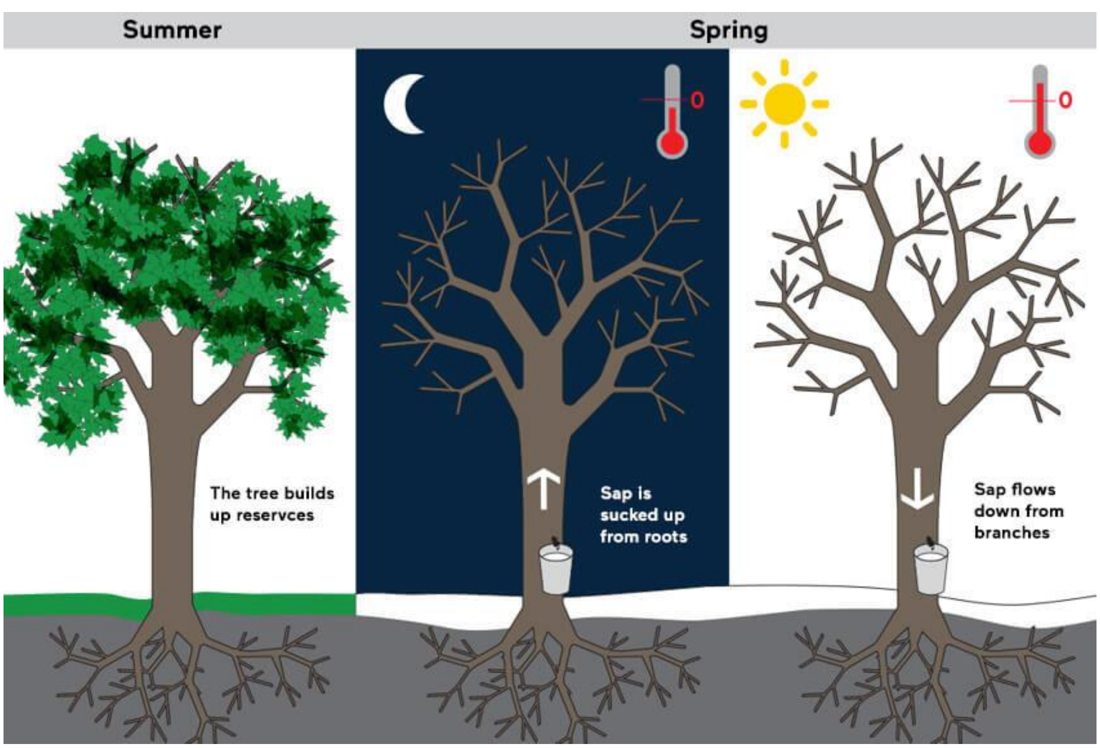

Figure 2: Illustration of how sap collection is done in the optimal temperature range (PPAQ, 2024)

Flood & Drought in the Summer and Spring

Similar to many other deciduous trees, sugar maples are susceptible to the impacts of droughts and flooding during their growing seasons. While their shallow roots aid in efficient nutrient absorption, they also present significant challenges. During droughts, the limited depth of their roots struggles to access dwindling water sources, leaving the trees prone to dehydration and reduced growth. Conversely, flooding saturates the soil, leading to oxygen deprivation and root suffocation in the shallow root system. These natural disasters can compromise the overall health of the trees, resulting in premature leaf drop and diminished starch storage crucial for the following spring's sap production.

Tree canopy and leaf coloration serve as indicators of tree health influenced by flooding and drought. Leaf quantity influences the rate of photosynthesis, while leaf coloration reflects potential starch levels within the tree trunk. The red coloration of autumn leaves is due to a chemical called "anthocyanin," which forms when sugar concentrations are high. Premature leaf drop caused by unpredictable natural events can significantly hinder sugar maple trees' ability to produce the much-needed starch and convert it to sucrose, ultimately leading to poor sap production.

Physical Constraints

In developing a suitability model for a new maple syrup farm in Eastern Township it is paramount to consider not only data that can be scaled and used in our models' calculations, but also identify and exclude areas unsuitable for commercial development beforehand. To take this into consideration our study area was distilled to an appropriate processing extent based on various masked features. This project considered non-forest areas, national parks and conservation areas and water bodies when delineating a processing extent (Table 4). To do this, national parks, conservation areas and water body polygons were erased from a wooded area polygon. Then the resulting wooded area was intersected with polygons with areas that contained sugar maple stands. Figure 1 shows the wooded areas containing sugar maples in green and the masked polygons in red.

Table 4: Criteria excluded from our processing extent.

Criteria	Required Data	Layer Name	Source
Cannot be in a National Park	National parks	“Nationa_Parks_GovQC	Quebec Open Data
Cannot be in a conservation area	Other types of conservation areas	“ProtectedPlanet”	Protected Planet
Cannot be in water bodies	Lakes, rivers, ponds	“Water bodies”	Statistics Canada
Cannot be in a non-forested area	Only pre-existing forested areas will be considered	“WoodedAreas”	CanVec
Must be mostly sugar maples	Sugar maple stands	“Final_Maple_Extent”	Ministry of Natural Resources and Forests Quebec

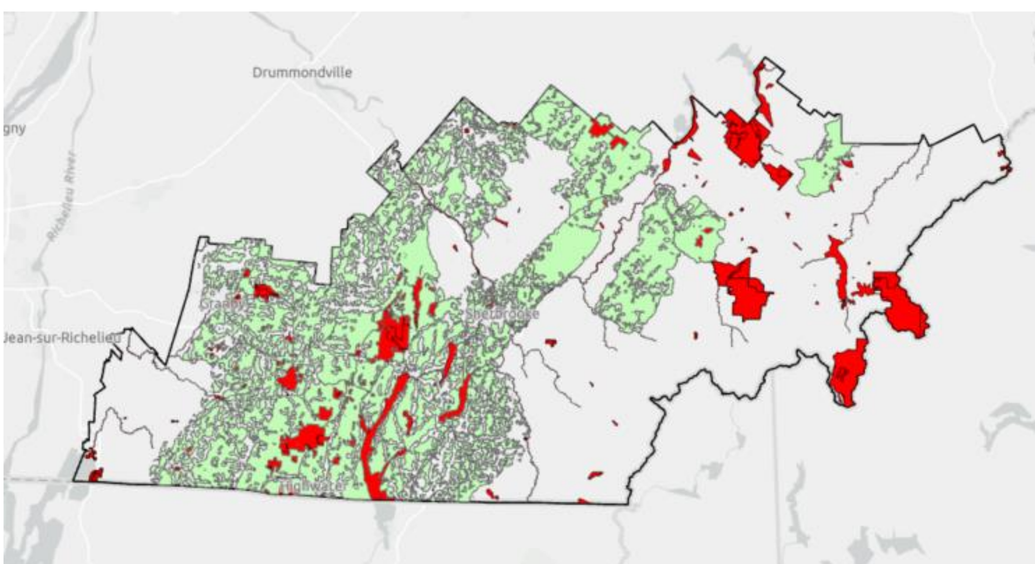

Figure 3: Shows the processing extent in green, the masked-out areas in red, and non-forested areas in grey.

Conservation Areas

Canada is a global leader in conservation, currently offering protection to 13.73% of its total terrestrial areas and 16.8% of Quebec's jurisdiction (UNEP-ECMC, 2024). Agricultural development is strictly limited to areas that aren't being managed for recreation and conservation purposes. 150 of these areas were present in the Eastern Township study area and were removed from the processing extent of our suitability model. Delineation of national parks and conservation areas was done via two sources, the Quebec government and protected planet (Table 4). These sources considered private stewardship areas, national and provincial parks, nature reserves, migratory bird sanctuaries, protected old growth forests, biological refuges, UNESCO Biosphere Reserves and World Heritage Sites, rare ecosystems, and essential habitats for protected species.

Maple Tree Stands and Water Bodies

For our suitability analysis, it was essential to focus solely on pre-existing forested areas while disregarding developed areas, water bodies, and agricultural fields. Additionally, these forested areas should primarily be Sugar Maple stands. To achieve this, we masked out unsuitable areas from our processing extent. Initially, we isolated forested regions from a land classification polygon obtained from *CanVec* ensuring that non-forested areas were excluded. Subsequently, we removed water bodies from this selection, resulting in a refined polygon exclusively comprising forested areas within the Eastern Townships.

We refined our processing extent further by isolating specific locations identified as sugar maple stands, sourced from the Quebec Ministry of Forestry data. These areas predominantly feature sugar maple as the primary species, along with mixed forests containing sugar maple. Subsequently, we narrowed down our processing extent by restricting it to forested regions exhibiting these two distinct forest compositions.

The Suitability Model

Below is the definitive suitability model utilized for generating our site selection output, meticulously crafted through ModelBuilder. The model comprises three distinct sections, each embodying a key objective criterion: Climatic Conditions, Environmental Conditions, and Accessibility. Within each section, a Weighted Sum tool was employed, affording individual sub-criteria the appropriate weightage. Upon the culmination of the weighted surfaces for each primary objective criterion, they were amalgamated using another Weighted Sum tool, yielding our ultimate weighted surface. Subsequently, this weighted surface served as the input for the Locate Regions tool, ultimately identifying five optimal selection sites.

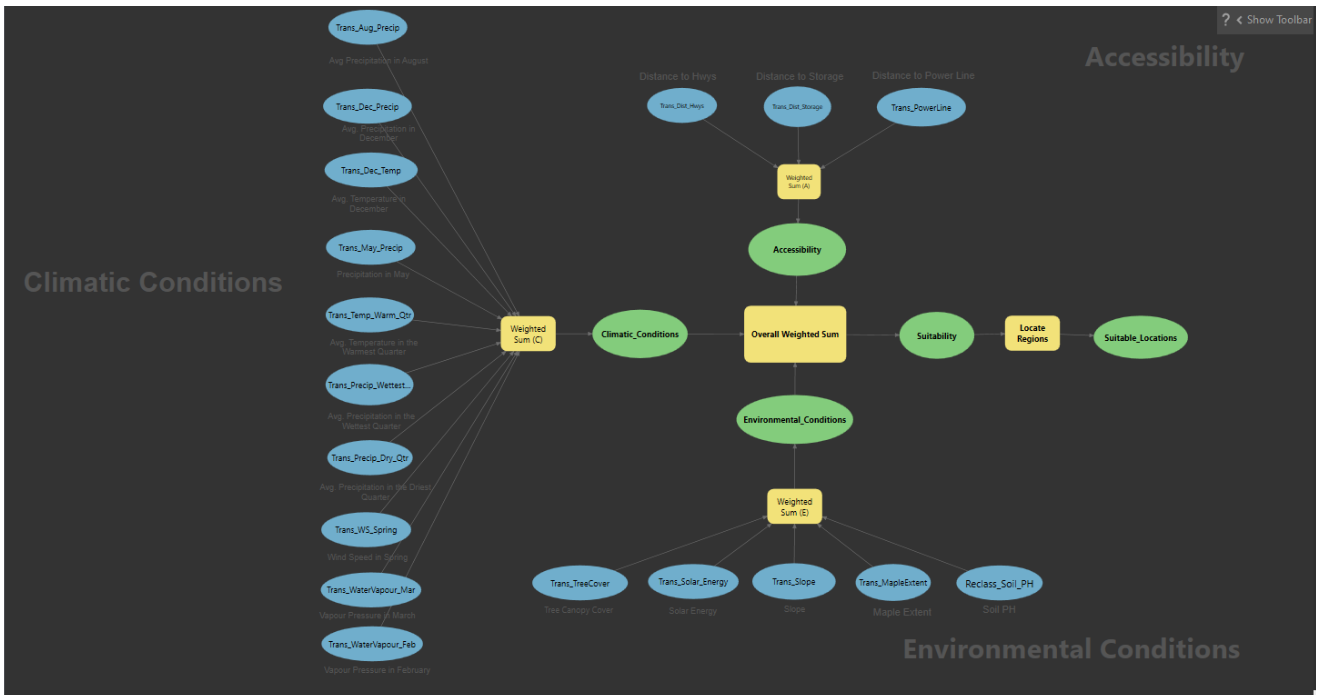

Figure 4: Overview of the Suitability Model

Results

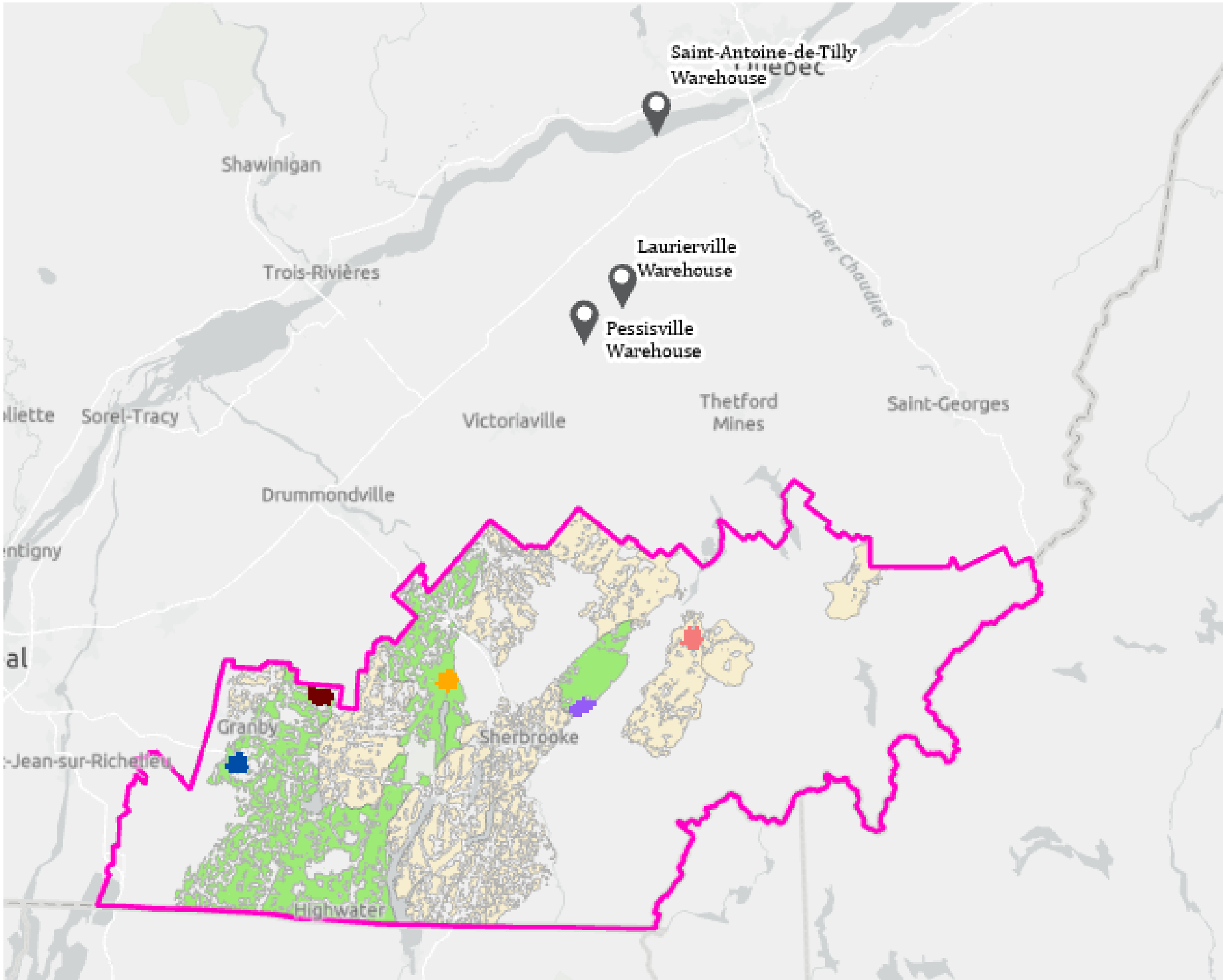

Figure 5: Model Outcomes.

Model Evaluation

The selection criteria for suitable sites generated 5 sites with varied justification for the results. The sites should provide ample space for the acres of forested area and the production site. Investigation of existing maple farms revealed that the largest farms occupy upwards of 800 acres or approximately 3.25km^2. The model allowed for a range of sizes between 1km^2 and 20km^2 of size, most of which exceeded 10km^2. This provides flexibility of location within a suitable site for optimal selection of sugar maple selection.

Sites were restricted to providing a circular shape. The intension was to avoid irregular polygons, as extremities from the center point of the region boundary could result in property line complications. A well-defined property line establishes a clear workplace for employees and reinforces boundaries to avoid accidental trespassing in rural areas. It also allows for equipment to consist of structurally uniform patterns for crop management commonly implemented in the farming industry.

The accessibility criteria suggest convenient location qualifications for functionality, customer relations and transportation, however production can resume if a portion of this criteria is not met. The environmental and climatic conditions of the suitability analysis are correlated with the quantity of sap yield from the sugar maple trees. The magnitude of production heavily impacts the success of the farm and so location selection is weighted higher for these two categories.

The overall weighted sum for accessibility, climatic, and environmental conditions are 1, 1.25, and 1.5 respectively. As a result, when deciding the impact of the Environmental sub-criteria, drastic changes occur to the site selection. The rationale for the weight is associated with the dominant tree species throughout the extent, which is weighted as 1.5 within the Environmental criteria.

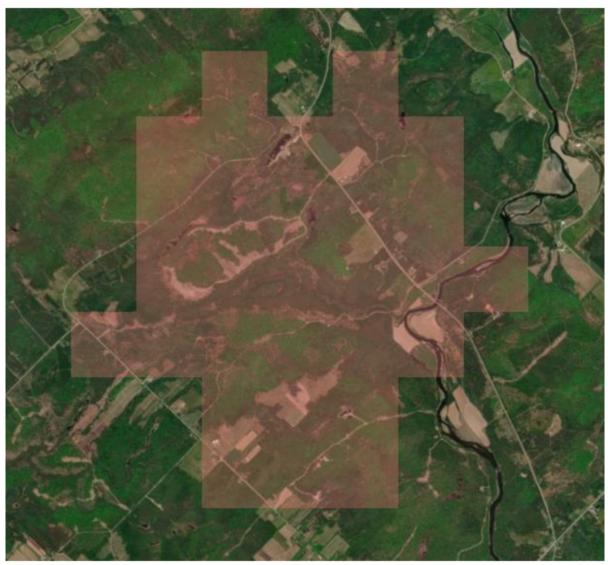

Figure 6: Site 1.

This prioritizes that our site likely exists within the sugar maple dominated region but allows for less dominated regions provided exceptional qualities in other categories. This scenario can be observed in the easternmost site shown above.

Figure 8: Site 2.

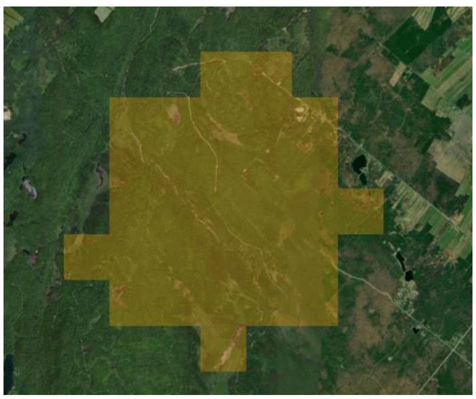

Figure 9: Site 3.

Figure 7: Site 4.

The three sites shown above possess the common qualities of sugar maple forested areas with desirable environmental and climatic properties. The westernmost region, shown below, with further inspection, appears to have existing patches of agricultural land that cannot be used for our maple farm. Fortunately, the region size is large enough that existing tree stands within the region should provide significant capacity for the operation.

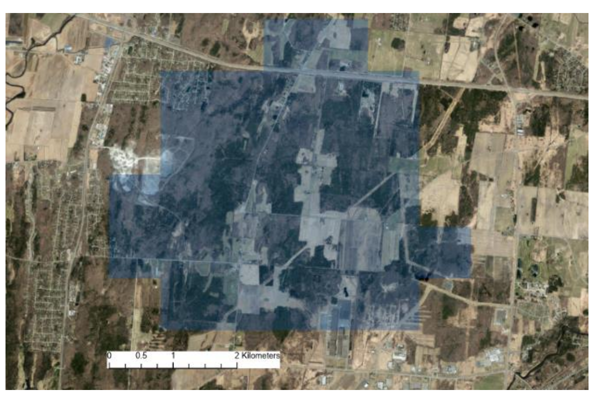

Figure 10: Site 5.

Reflections & Future Improvements

The acquisition of a precise tree inventory dataset continues to pose a challenge. Incorporating a more detailed dataset, such as one that represents trees as individual points, could significantly improve our ability to pinpoint clusters, particularly beneficial for identifying maple tree locations. Additionally, leveraging other biological data such as species, ring circumference, height, and age can enhance our decision-making process. By assigning greater importance to mature trees capable of sap production, we could have refined our selection criteria effectively.

Determining the weighting of criteria presents another challenge. Without insight into the specific preferences of stakeholders involved in this new maple syrup venture, it is difficult to ascertain whether greater emphasis should be placed on syrup quantity/quality or on factors such as site accessibility and cost of transportation. We found that the model outcomes can vary significantly when we have assigned different weights to the different criterion and sub-criterion.

Information regarding existing industrial businesses required follow-up investigations. Simple searches for maple farming operations resulted in not only farms, but also storage facilities, retail locations, equipment manufacturers, maple-themed venues and more. This made the spatial component of competitors and agricultural permits a challenge to accurately acquire. The additional information from this would act as an additional physical constraint when considering masking for the Eastern Township extent.

Conclusions

In conclusion, the suitability analysis conducted for locating the optimal site for a new maple syrup farm in the Eastern Townships of Quebec has identified the five most suitable regions. Through the consideration of environmental conditions, accessibility, physical constraints, and climatic factors, we have outlined key determinants that contribute to the viability and sustainability of maple syrup farming operations.

Environmental criteria, including soil pH, slope, tree canopy cover, solar energy exposure, and the presence of sugar maple stands, were assessed to identify areas conducive to healthy tree growth. By prioritizing regions with favorable soil conditions, gentle slopes, dense tree canopies, ample solar exposure, and abundant sugar maple populations, we located areas were tree quality and health were maximized.

Accessibility criteria such as access to power supply, proximity to storage facilities, and connectivity to highways were highlighted as factors influencing operational efficiency. By strategically locating farms near electricity infrastructure, storage facilities, and major highways, we facilitate streamlined operations, market access, and industry networking, thereby enhancing the competitiveness and growth of the business.

Climatic criteria, encompassing wind speed, air temperature, precipitation patterns, thermal windows, vapor pressure, and flood/drought susceptibility, were incorporated for their impact on sap flow, tree health, and overall production viability. By prioritizing areas with favorable climatic conditions during critical periods such as late winter and early spring, we aim to optimize sap flow and mitigate risks associated with adverse weather events.

This suitability analysis can be modified and adapted for various other purposes such as agricultural site selection, forestry management, renewable energy projects and ecotourism projects. Ensuring the data sources are up-to-date, accurate and comprehensive can improve the model's performance and allow for adaptation for use in other fields. Next steps for improving this suitability analysis could be stakeholder engagement, improvement of tree inventory data and market analysis considering other competitors.

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