FIFA World Cup Stadium Suitability in the Montreal Metropolitan Area

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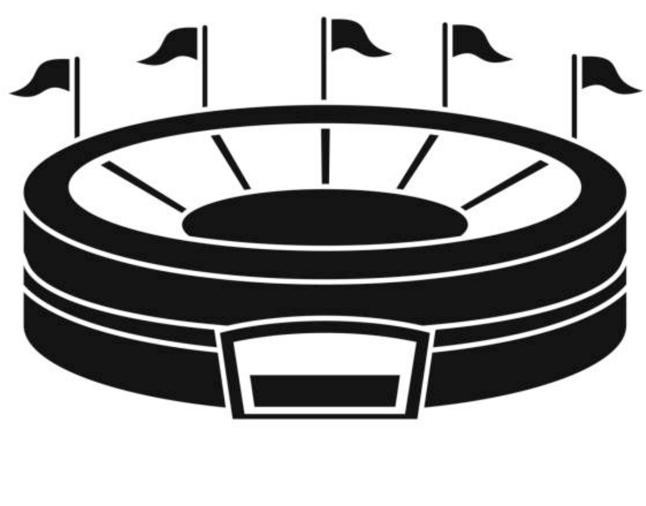

Abstract

While Montreal, Quebec, has the capability to host global-scale events, its bid to host the 2026 FIFA World Cup was withdrawn due to financial concerns. In the future, when debt accrued from handling COVID-19 is no longer constraining the city's ability to hold the games, the construction of a stadium capable of supporting all stages of the tournament should be considered to increase Montreal's chances of being selected by FIFA. This project aimed to identify the most suitable location for a World Cup stadium large enough to support the finals in the Greater Montreal Area through the use of Multi-Criteria Evaluation. Open area, gentle slope, sand and loam soil types, proximity to population centers, and transportation accessibility are factors that increase the suitability of the proposed stadium, whereas areas that have pre-existing use, poor soil, steep slope, or far distance from population hubs and transportation systems are deemed unsuitable. The study further excludes the stadium's ability to be located on water bodies, highway networks, and protected areas. The suitability model was constructed using ArcGIS Pro software and weighted using the Analytic Hierarchy Process (AHP) with a pairwise comparison matrix. The model, after running it with the inclusion and exclusion of land soil type, returned 5 potential locations. A single location was selected as the most suitable with it being situated just north of Montreal island. The location was on flat, open land, sand soil, within 25 kilometers of the city center, and close to a train station and highway exits. The proposed location was not placed on water bodies, major roads, protected areas, or any land use or soil type deemed unsuitable. Overall, the study will serve as a framework for large-scale site selection projects using GIS and provide suggestions on ways in which similar studies using MCE could be improved.

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Introduction

The FIFA World Cup is a quadrennial event that garners continuous record-breaking spectator numbers with each passing of the tournament (FIFA, December 2022). Hosting the tournament is enticing to local governments and investors as the games can attract nearly 1.5 million tourists as well as the general attention of the world (Supreme Committee for Delivery & Legacy, 2022). The next World Cup tournament in 2026 is to be played in North America, split between the joint hosts of Canada, United States, and Mexico. Montreal, despite showing initial interest in hosting the 2026 games, ultimately withdrew its submission in 2021 after the province declared it would not financially support the project (Lau, 2021). This decision may have been influenced by the presence of COVID-19 in Canada, as Quebec was hit hardest in the country, costing the province a total of $28 billion; Montreal being at the forefront of the pandemic (Bergeron, 2023). As global rates of the virus continue to drop, Montreal should consider itself a FIFA candidate once again.

Any city selected by FIFA must have the necessary infrastructure to support such a spectacle, such as an expansive transportation system and a comprehensive hospitality industry, as well as having a large population with a distinct and lively culture (FIFA, 2018). Considering the Greater Montreal Area is the second largest population in Canada that is known for its unique North American-European blended culture (FIFA, 2018), and its ability to host large global events such as the Canadian Formula One Grand Prix is on display every year (Tourisme Montréal, 2022), the city can be said to exceed the standards FIFA places on World Cup hosts. The concerns arise, however, with the physical ground on which games would be played in Montreal as the city, according to FIFA guidelines, does not have a stadium capacity large enough to host matches deeper in the tournament than a quarter-final game (FIFA, 2018). While local governments and other financial stakeholders may be hesitant to commit to building a mega-stadium due to the risk of becoming a financial loser, mega-stadiums, when planned accordingly, can be effectively used after their original purpose has passed, revitalize or redirect tourism to a new part of the city, and be a net financial positive for those involved (Sroka, 2021). Therefore, to effectively plan for the short and long-term success of the proposed stadium by finding an appropriate location, a Multi-Criteria Evaluation (MCE) was carried out to determine a site within the Greater Montreal Area where an 80,000 person capacity stadium (one large enough to host the finals) would be suitable. Within an MCE, there are several social, economic, and environmental variables and constraints that shape where the stadium can be located. A variable is deemed a factor that contributes towards suitability, whereas a constraint represents land that is deemed unsuitable. Variables that will be used to shape criteria of suitability have differing weights to determine the influence they have on site selection.

Covering approximately a 120,000m^2 plot of land, Montreal's 1976 Olympic stadium is of a similar physical size to the proposed FIFA stadium, however there is little reported information behind how the city selected its site. Thus, reports on stadium construction of similar seating capacity were used, such as the Mercedes-Benz NFL stadium in Atlanta. Its 80,000 capacity stadium's master plan highlights the need of stable soils and the importance of having a stadium within a reasonable distance to the airport (Populous & Rider Levett Bucknall, 2011). FIFA also provided further detail into the process of selecting stadiums for the World Cup, such as the importance of proximity to public transportation and city centers (FIFA Site Selection, 2022). Other variables and constraints for the MCE are based on protected provincial land outlined by the Quebec government under the Conservation on Biological Diversity strategy (Ministère de l'Environnement, 2023), and the general desire to build on flat land without having to demolish pre-existing infrastructure. While this project is specifically focused on finding a suitable location for a stadium in the Greater Montreal Area, the operations of this project are applicable outside of the study. Due to the lack of accessible research on the subject, this Multi-Criteria Evaluation is therefore just as much about creating a standardized framework for stadium suitability mapping as it is about finding an ideal location in Montreal.

To carry out the Multi-Criteria Evaluation, the use of Geographic Information Systems (GIS) is highly valuable since the task of locating a suitable location for a stadium is entirely a spatial problem. World Cup stadiums are enormous structures that require an abundance of open space to be constructed. Using the area measurement tool in Google Earth to determine the dimensions of pre-existing stadiums such as the Mercedes-Benz Stadium and the Mile-High Stadium, which both have a seating capacity similar to the proposed seating capacity of 80,000, it is estimated that the plot of land needed for the Montreal stadium will take up an area of 150,000m^2 in the shape of an ellipse. This surface area is inclusive of parking lots and walkways around the outside of the stadium for spectators, as well as the stadium itself.

The purpose of this project is to use a GIS-based Multi-Criteria Evaluation approach to find a suitable location for a FIFA World Cup Stadium in the Greater Montreal Area. This research does not only serve to benefit stakeholders in Montreal, such as fans and investors of the project, but also act as a guideline of how to approach stadium site suitability for future World Cup host nations.

Research Objectives

1. Identify important variables and constraints related to selecting a location for a FIFA World Cup stadium in the Greater Montreal Area.

2. Process data in order to acquire two suitability rasters for the study area: one from running the MCE model *with* the soil type raster, and one from running the MCE model *without* the soil type raster.

3. Acquire five total locations by running the suitability model twice and manually determine which output is the best suited location for the World Cup stadium in Montreal.

4. Assess the strengths and limitations of the model and suggest improvements for future studies related to stadium site selection.

Study Area

The location utilized for carrying out the Multi-Criteria Evaluation to determine the suitability of a new FIFA World Cup stadium is the Greater Montreal Area. With an area of approximately 150,000 km^2, the rectangular shape that represents the study area, seen in Figure 1 below, was selected as it contains the largest populations of the region while still being within a one hour's drive of Montreal's downtown center. The one hour drive time from downtown Montreal was identified using the third party time-distance analysis tool, *TravelTime API*. This tool returned a polygon shape with anywhere inside the borders of the polygon being a one hour drive from downtown. The rectangular study area was plotted inside the time-distance polygon to ensure anywhere inside the rectangle is within the one hour max driving time from downtown Montreal. Proximity to host city centers is a typical requirement for World Cup stadiums as all eight of the stadiums utilized by Qatar in 2022 were within a one hour drive of Doha. (Supreme Committee for Delivery & Legacy, 2022). The site for the proposed stadium will be a 150,000 m^2 ellipse plot of land, which is ample space for the desired size of the structure and its amenities for spectators, staff, and parking.

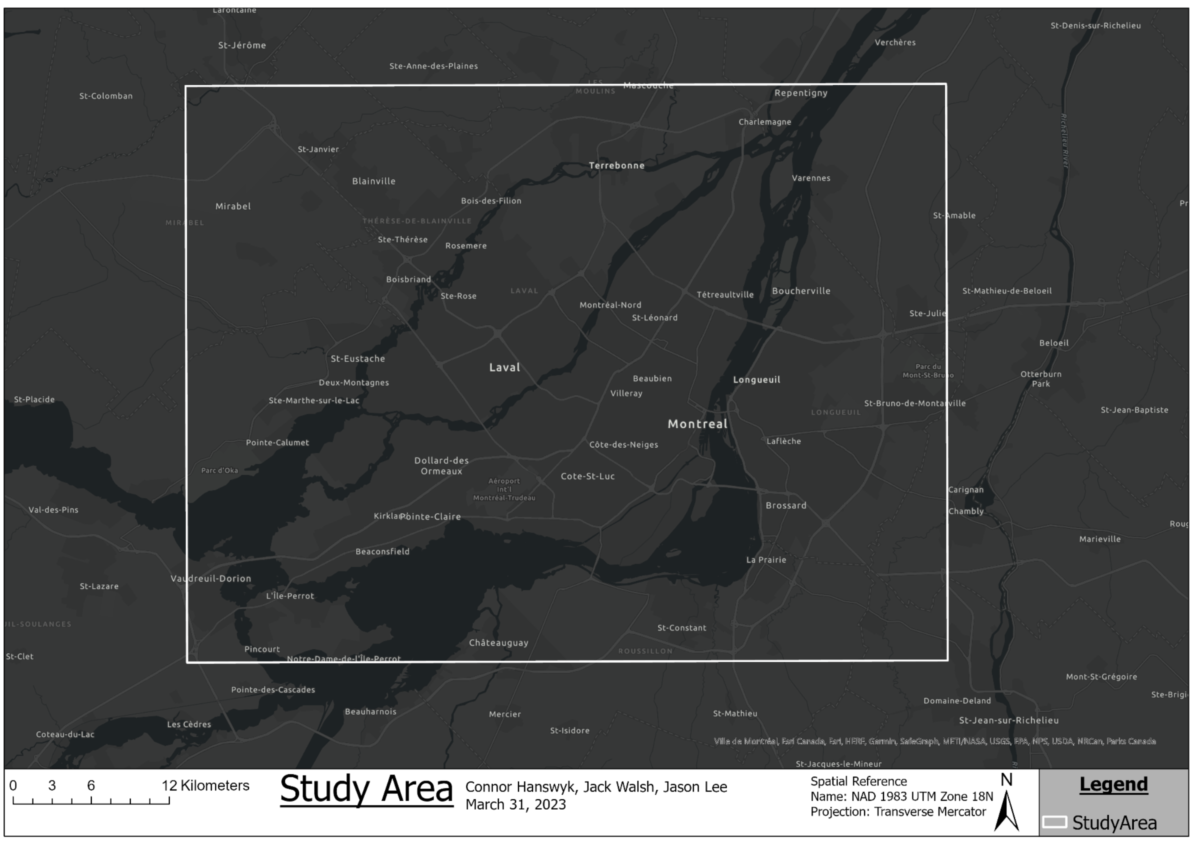

Figure 1. *Map of study area incorporating the Greater Montreal Area and surrounding region.*

Data

Table 1. Data collected for Suitability Modeling within the Greater Montreal Area.

Variable	Title of Dataset	Data source	Date Created or Last Modified	Resolution Before Resampling
Land Use	Land Use (LUR) - 2014	DMTI Spatial Inc.	April 07, 2015 (Last Modified)	N/A Vector Data
Slope	SRTM 1 Arc-Second Global	USGS	September 29, 2014 (Date Created)	30m Raster Data
Soil Type	Quebec Soil Studies	Research and Development Institute for the Agri-Environment	Sep 13, 2021 (Last Modified)	N/A Vector Data
Distance from Population Centers (Montreal)	Municipal Zones	Ville de Montreal, Quebec Data Partnership	Oct 18, 2021 (Last Modified)	N/A Vector Data
Distance from Population Centers (Laval)	Electoral District Boundaries	Ville de Laval, Quebec Data Partnership	Oct 18, 2021 (Last Modified)	N/A Vector Data
Distance from Population Centers (Longueuil)	Electoral Districts	Ville de Longueuil, Quebec Data Partnership	May 2, 2022 (Last Modified)	N/A Vector Data
Distance from Railway Stations	Exo Train Stations	Exo Quebec	Dec 09, 2021 (Last Modified)	N/A Vector Data
Distance from Highway Exits	Highway Exit	Quebec Ministry of Transport and Sustainable Mobility	Jan 27, 2023 (Last Modified)	N/A Vector Data

Variable	Title of Dataset	Data source	Date Created or Last Modified	Resolution Before Resampling
Distance from International Airport	Point Vector Layer	Ourselves	Feb 15, 2023	N/A Vector Data
Protected Area Constraint	Register of Protected Areas in Quebec	Quebec Ministry of the Environment	Jan 27, 2023 (Last Modified)	N/A Vector Data
Highway Lines Constraint	Major Roads Line	DMTI Spatial Inc.	Sept 15, 2020 (Last Revised)	N/A Vector Data

Methods

Objective 1

The first step in determining a suitable location for a stadium within the Greater Montreal Area capable of supporting a World Cup finals match was to derive input variables and constraints. The five variables identified are land use, slope, soil type, distance from population centers, and distance from transportation infrastructure, with the latter being split into three variables. Constraints affecting the suitability of the site location are water bodies, protected area, major road network, and unsuitable classes within the land use and soil type datasets. Therefore, land use and soil type act as a variable-constraint hybrid, which is further discussed below.

1.1 Land Use

The city of Montreal is a significantly developed region, meaning there are areas where it is impossible to build a structure of such magnitude due to pre-existing development and zoning requirements. The land use dataset, as seen in Figure 2 below, is broken into six categories: Open Area, Parks and Recreation, Resource and Industrial, Commercial, Residential, and Government and Institutional. Open Area was identified as the only suitable land use class as it does not require any demolition of pre-existing infrastructure. Therefore, all other land use classes were considered constraints for suitability and were not favored for site selection.

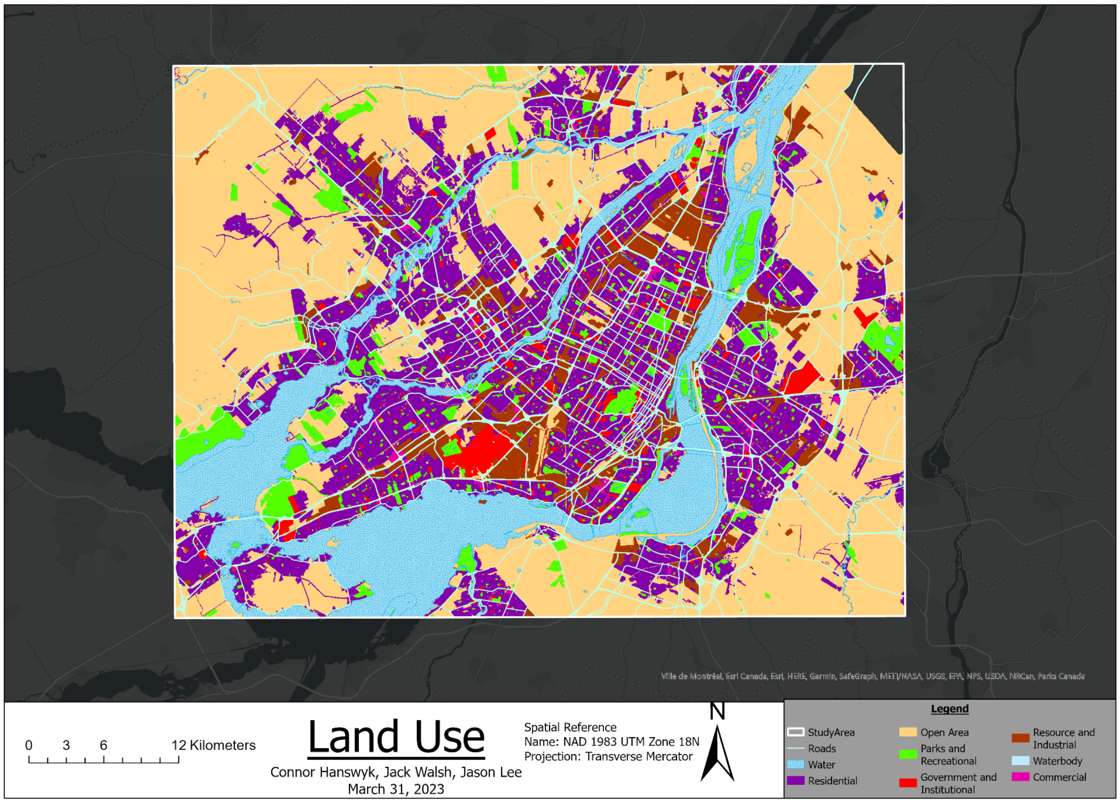

Figure 2. *Map of land use classification of the Greater Montreal Area and the surrounding region.*

1.2 Slope

Slope is another important variable within the MCE. Building on land with a high grade increases excavation costs and labour expenses. Furthermore, building on top of a steep slope subjects the structure to the risk of slope failure (Goh et al., 2020). Therefore, an inverse relationship is displayed, where low gradient areas were deemed the most suitable, and suitability decreases as slope increases.

1.3 Soil Type

Soil type is another important factor to consider when undertaking any construction project as soil types have different chemical and physical properties that impact the strength and stability of the ground (Sindelar, 2015). Unstable soil can result in cracking or shifting of a foundation over time and can cause catastrophic structural failures (Sindelar, 2015). The soil categories of the Greater Montreal Area are Loam Soil, Sand Soil, Gravel Soil, Glacial Till, Organic Soil, Clay Soil, and Diverse Soil. The dataset also included water bodies, major highways, and unmapped areas within regions of significant urban development. Clay soil is unsuitable for building because it has poor drainage. Also, when it becomes saturated with water, it expands greatly, but later when it dries out, it shrinks dramatically, thus proving it highly unstable (Mokhtari & Dehghani, 2012). Another soil unsuitable for building on is organic soil, which is susceptible to high rates of compaction over time and has low soil strength (Baker et al., 1988). Furthermore, gravel soil and glacial till are the product of glacial deposition resulting in soils that are spatially variable in composition, structure, and properties, making them unsuitable for construction (Clarke, 2018). On the other hand, loam and sand soils are highly suitable for construction. Loam soil has a high mixture of particle sizes which interlock when compacted, maximizing soil strength and drainage. Sand particles are uniform and consistent in size which gives them similar properties to loam soil (Sindelar, 2015). Therefore, literature review has shaped soil type as a constraint, only allowing building to occur on the two suitable types, sand and loam soils.

1.4 Distance from Population Centers

Fan accessibility is an important piece of criteria that shapes where an ideal site for a stadium will be because it influences attendance and therefore overall revenue return (Penning, 2012). Considering the surge of people who visit World Cup host cities during the games, the proposed stadium should be located within a close distance to the hotels in which these visitors are staying. In Montreal, 58% of the hotel rooms are located in the downtown area, emphasizing the need for the stadium to be close to the city (FIFA, 2018). It is also important to consider permanent residents of the area, as they will influence both the short- and long-term success of the stadium. According to 2021 census data, 2,455,798 of the 3,002,910 living in the Greater Montreal Area reside in Montreal, Laval, and Longueuil (Statistics Canada, 2023). Therefore, this variable determines the ideal stadium location as a place within the city borders of the three population centers, with Montreal being significantly more important as it holds the majority of the population in the region.

1.5 Distance from Transportation Infrastructure

Transportation infrastructure is further broken down into three sub-categories: Distance from Railway Stations, Distance from Highway Exit Points, and Distance from International Airport. While each criterion has varying weight in the suitability model, which is described within Objective 2 below, the reasoning behind the importance of a stadium being in close proximity to transportation infrastructure is similar. Fans visiting from outside of the country will likely arrive though Pierre Elliott Trudeau International Airport (YUL), thus it is preferred for the stadium to be within a reasonable distance of the airport. In most cases, FIFA stadiums are located less than 25 kilometers from the city's airport (FIFA Site Selection, 2022). Once visitors have settled amongst residents in the city, railway stations and highway exit points are the variables that make up the "modal split", which is the term FIFA uses to describe a location's accessibility by car and public transportation (FIFA Site Selection, 2022). Exo, officially known as Réseau de transport métropolitain, is a five-line commuter rail with 59 stations serving the Greater Montreal Area (Exo, 2023). Highway exit points, which represent the other side of the modal split, are also an important variable to consider as they are used by players, employees, local fans, and a portion of visiting fans as well (FIFA Site Selection, 2022).

1.6 Suitability Constraints

The three constraints within the study area which were deemed completely unsuitable for the stadium are water bodies, protected area, and major road networks. Protected areas were a constraint because they are lands that the Government of Quebec prohibits any activity that alters basic biological characteristics for the purpose of conserving nature in the province (Ministère de l'Environnement, 2023). A 100 m buffer has been added to the layer to further protect wildlife and limit the possibility for pollution to enter and contaminate delicate ecosystems. Finally, major road networks were a separate constraint because they were incorrectly included in the "Open Area" category of the land use dataset, and thus needed their own layer to specify them as not Open Area. A 50 m buffer was added to the major road network layer to protect the people on the grounds on the outside of the stadium and to make the outside area of the stadium in general more pleasant for fans.

Objective 2

2.1 Processing

The coordinate reference system used for this study was NAD 83 UTM Zone 18N. This was established in the *environments* window in ArcGIS Pro so any new layers with data transformation or conversion would remain projected on the same coordinate system. Each of the raw datasets, when acquired from their sources (listed in Table 1), came in the form of vector data. The only exception to this was the SRTM 1 Arc-Second Global DTM dataset, which already came in the form of raster data. As the suitability modeler only accepts raster layers as criteria, all vector datasets were first transformed to rasters either using the *Distance Accumulation* tool for the population and transportation infrastructure datasets, or the *Polygon To Raster* tool for the land use and soil type datasets. Once all the variables were converted to their raster form, resampling was done to apply a universal pixel resolution. This resolution was 30m x 30m as this was the default resolution of the DTM dataset and was spatially applicable to our study requirements. Furthermore, any layer that had not already been projected to the desired coordinate reference system was done so here. With all variables converted to raster form and resampled appropriately, the *Clip Raster* tool was used to make the extent of all variables remain only within the study area. For a visualization of the workflow process, see Figure 5 below.

2.1.1 Land Use

The land use raster was further processed and reclassified into a land use constraint raster. Open Area was the only category considered suitable for the site location model. All other categories were reclassified as a constraint. Reclassification was done with a simple python function using Boolean logic to assign a value of 1 to anything within the land use dataset that had the classification of Open Area. All other land use types got a value of 0 (unsuitable for construction). The derived land use constraint map was then combined with both the major road network raster and the protected area raster using the *raster mosaic* tool. This produced a final constraint map which displayed only suitable or unsuitable land.

2.1.2 Slope

Slope was calculated using ArcGIS Pro's *Slope* Tool with inputs being elevation data from the SRTM1 Arc-Second Global DTM. Flat areas of land with zero degrees slope were given maximum suitability. Low gradient areas were still deemed suitable, but as slope increased, suitability decreased accordingly.

2.1.3 Soil Type

The soil data was initially categorized too specifically for the scale of our project using specific codes for each plot of land. Using the soil legend provided by the data source, the data was manually reclassified by adding each code to a python dictionary script which categorized each soil code into the seven soil categories and three non-soil categories. After classifying the data with the python script, a soil constraint raster was derived, and the categories were reclassified into two classes: suitable soil (loam and sand) and unsuitable soil. Reclassification of this dataset occurred in the same fashion as land use where a Boolean logic python function was used to assign suitable soil types a value of 1 and unsuitable types a value of 0. Figure 3 below shows the Greater Montreal Area as either land with suitable soil (sand and loam soils) and land with unsuitable soil types.

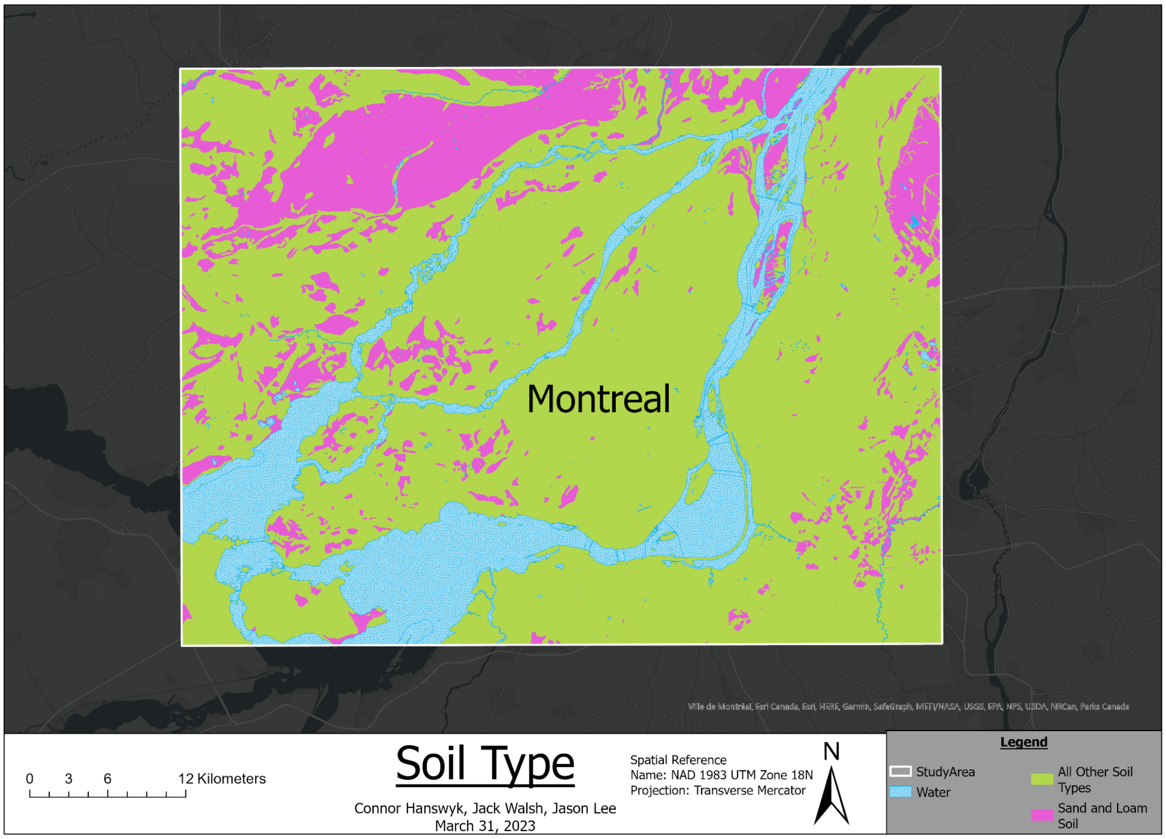

Figure 3. *Map of suitable and unsuitable soils within the Greater Montreal Area and surrounding region.*

As a result of reclassifying the soil type data set to only allow for sand and loam soil types to be suitable, an updated soil raster was produced, as seen above in Figure 3. This figure shows the reclassified soil categories, where pink areas are pertaining to sand and loam, while green classifies all of the unsuitable soil types. However, the Quebec Soils Studies data shows the majority of the island of Montreal, which is heavily developed land, as non-sand or loam soil grounds despite literature review suggesting against building on these other soils (gravel soil, glacial till, organic soil, clay soil, and diverse soil). To compensate for the fact that construction on these other soils has been accomplished in the Montreal Metropolitan Area, the suitability model has been run twice: once with the inclusion of soil type as a variable and once without the inclusion of soil type as a variable.

2.1.4 Population Centers

After distance accumulation was run from the borders of the three population centers (Montreal, Laval, and Longueuil), the three rasters were then combined in their own suitability model and weighted by the percentage of population each city has compared to the three populations combined (i.e., Montreal = 71.79%). A suitability layer was generated indicating increased suitability as one moves closer to the main population centers with Montreal being the most suitable, Laval being the second, and Longueuil being the third most suitable. Suitability is greatest on the island of Montreal, between Laval and Longueuil, but is also high across the entire island because it held such a high percentage of the population. Any location within the study area that was not close to the three population centers (especially Montreal) was indicated as being not suitable. This suitability map, along with the transportation distance accumulation maps, are displayed below in Figure 4.

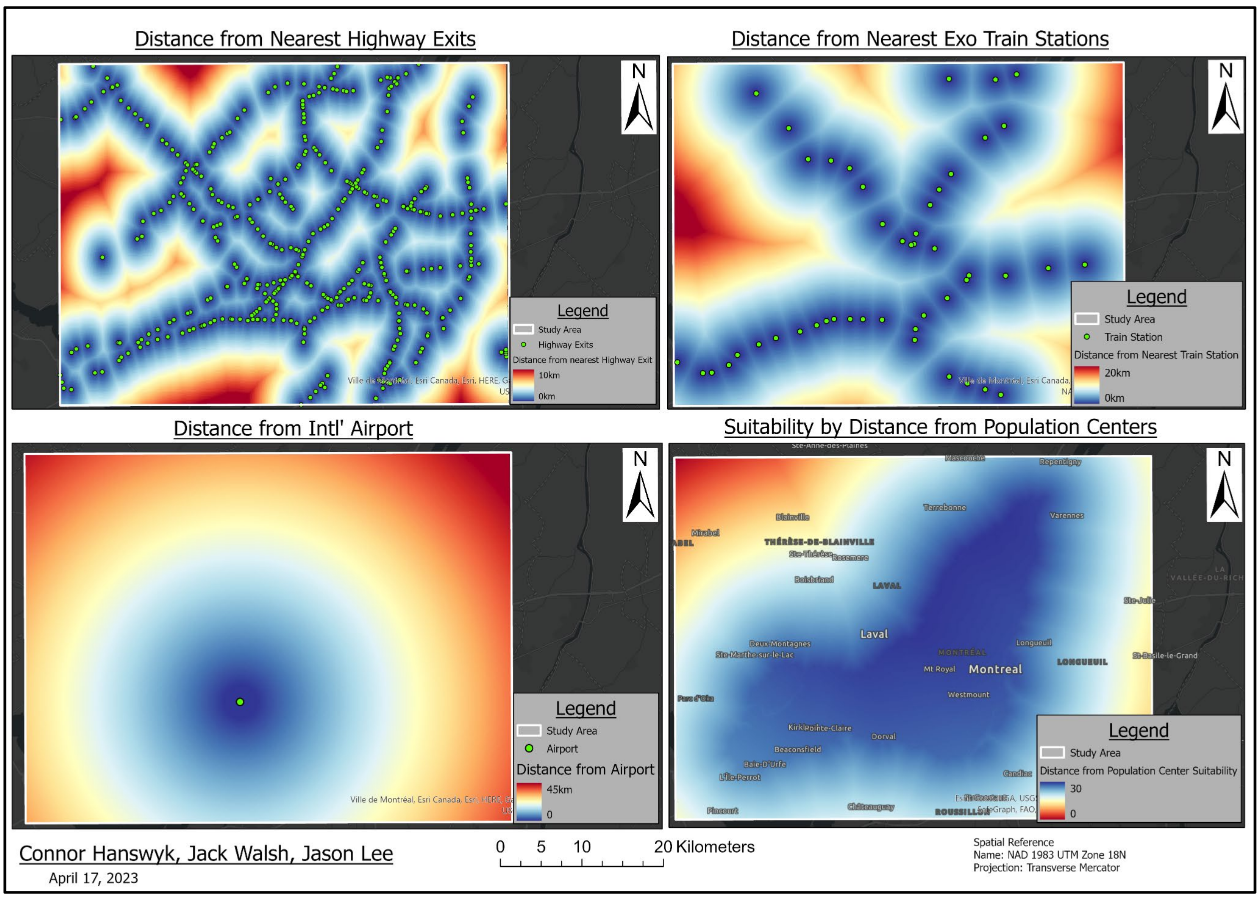

Figure 4. *Distance accumulation maps of transportation and population center variables within the Greater Montreal Area and surrounding region.*

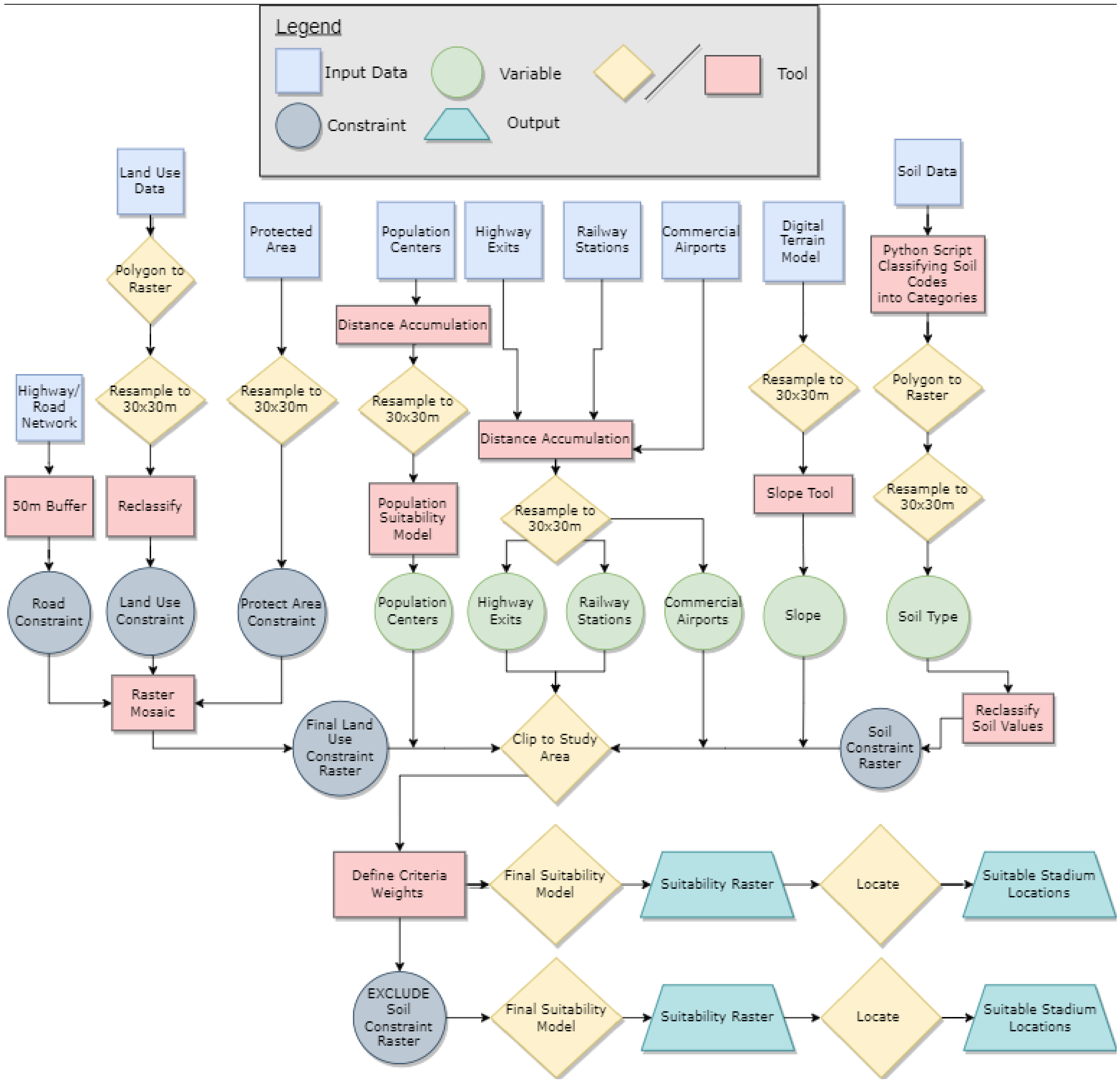

Figure 5. *Flowchart describing the overall workflow and GIS techniques used to derive the suitable stadium location.*

2.2 Weights

A pairwise comparison matrix was utilized to rank the aforementioned criteria in order of importance. Table 2 below describes the 9-point suitability scale used to distinguish the preference of a variable and its corresponding numerical rating. All of the variables were then compared to one another, row to column, and assigned a preference rating, based on what was identified as the most important in the literature. Table 3 shows the numerical rating of preference assigned to each variable.

Table 2. 9-point pairwise comparison scale used to establish the weights of each MCE criterion.

Numerical Rating	Preference
9	Highly Preferred
7	Strongly Preferred
5	Moderately Preferred
3	Slightly Preferred
1	Equally Preferred
1/3	Slightly Less Preferred
1/5	Moderately Less Preferred
1/7	Strongly Less Preferred
1/9	Highly Less Preferred

Table 3. Pairwise comparison matrix of the seven influential site selection variables. Relative importance was assigned from row to column based on a 9-point scale.

Criteria	Land Use	Slope	Soil Type	Distance Population	Distance Railway	Distance Highway	Distance Airport
Land Use	1	3	5	5	7	7	9
Slope	1/3	1	3	5	5	7	9
Soil Type	1/5	1/3	1	3	5	5	7
Distance Population	1/5	1/5	1/3	1	5	5	7
Distance Railway	1/7	1/5	1/5	1/5	1	3	5
Distance Highway	1/7	1/7	1/5	1/5	1/3	1	5
Distance Airport	1/9	1/9	1/7	1/7	1/5	1/5	1
Total (C)	2.13	4.99	9.88	14.54	23.53	28.2	43

The sum of each numerical rating was calculated and is listed in the bottom row of Table 3. These totals are not representative of the suitability weights as the weights themselves were calculated in the following table, Table 4.

Table 4. Normalized Pairwise Scores. Final weightings of each MCE criterion are listed in the Average Weight column.

Criteria	Land Use	Slope	Soil Type	Distance Population	Distance Railway	Distance Highway	Distance Airport	Average Weight
Land Use	0.4694	0.6015	0.5063	0.3438	0.2975	0.2482	0.2093	**0.3918**
Slope	0.1565	0.2005	0.3038	0.3438	0.2125	0.2482	0.0232	**0.2223**
Soil Type	0.0939	0.0668	0.1013	0.2063	0.2125	0.1773	0.1627	**0.1555**
Distance Population	0.0939	0.0401	0.0338	0.0688	0.2125	0.1064	0.1627	**0.0819**
Distance Railway	0.0671	0.0401	0.0203	0.0138	0.0425	0.1064	0.1162	**0.0774**
Distance Highway	0.0671	0.0286	0.0203	0.0138	0.0142	0.0355	0.1162	**0.0422**
Distance Airport	0.0522	0.0223	0.0113	0.0098	0.0085	0.0071	0.0232	**0.0289**
Total	1	1	1	1	1	1	1	1

To acquire the values for each of the cells in Table 4, Equation 1 was used, where C is the value of a cell in Table 4, x is the value in Table 3 of the same cell as C, and y is the sum of all values in the corresponding column in Table 3.

Eq. (1) $C = \frac{x}{y}$

Average Weight as seen in the rightmost column of Table 4 was calculated by taking the average values of C (found using Eq. 1) for an entire row. These average weights were used directly in the final suitability model; however they were each multiplied by 100 when inputting them into ArcGIS Pro’s suitability modelers as the software does not accept weights less than 1 as a parameter.

Objective 3

After the model was run with and without the soil type raster, the *Locate* tool was then used within ArcGIS Pro's MCE interface to acquire proposed locations for building a new FIFA stadium. The locate tool requires parameters to be specified so the tool knows what size and what shape to locate. The *ellipse* 'shape type' parameter was selected to represent the stadium, its parking, and other amenities. The 'area size' parameter was set to 150,000 m^2 before setting the *shape utility tradeoff* to 100 so the shape and size of a stadium (elliptical) for the proposed sites would not be sacrificed. For the suitability model that included the soil type raster, the number of *output locations* was set to three, with a distance of at least 5 kilometers between the sites so they would provide different locations. On the other hand, the suitability model that did not include the soil type raster had two output locations, also with a minimum distance of 5 kilometers between sites.

Results and Discussion

3.1 Locate Sites With the Soil Type Raster

Upon running the suitability model with each variable and constraint appropriately processed and weighted, the model was successful in returning a suitability raster based on the given weights of each criterion.

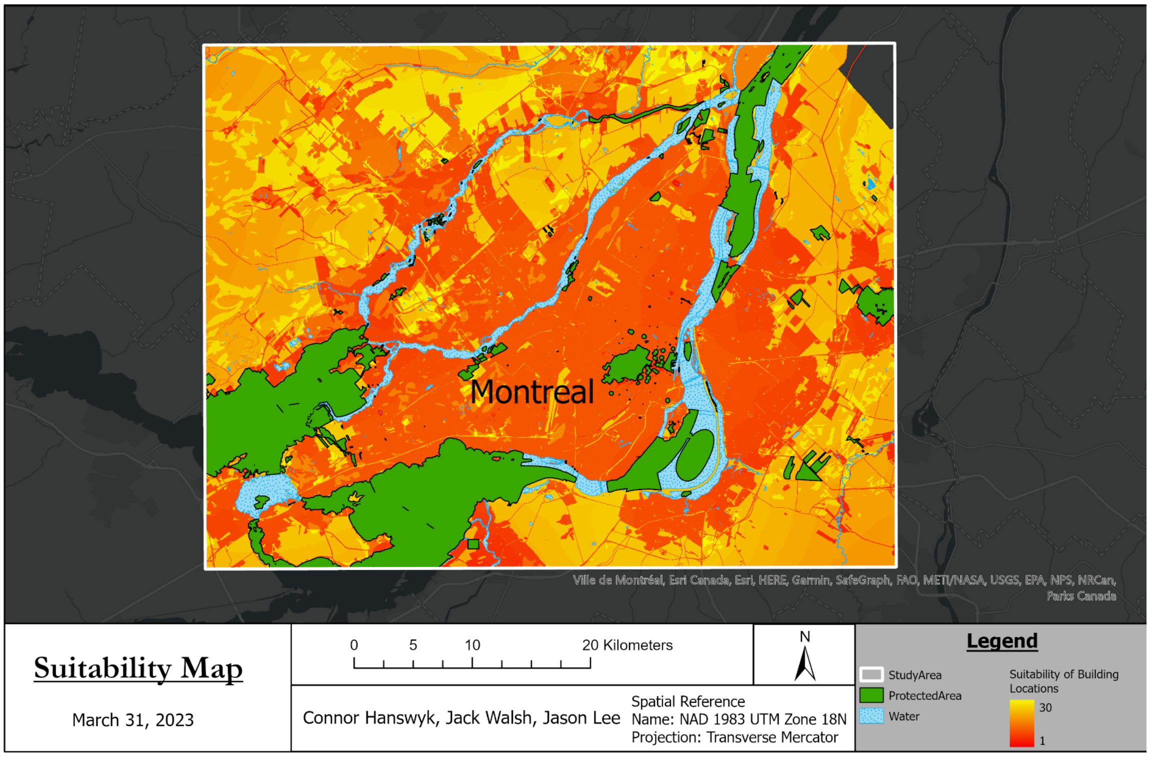

Figure 6. *Site suitability map with soil type included of the Greater Montreal Area and surrounding region.*

Figure 6 displays the suitability for site selection of the entire study area with soil type in consideration. Additionally, the map depicts unsuitable land to build a World Cup stadium such as protected areas and water bodies. Suitability is plotted on a 1 to 30 scale with 1 (dark orange/red) being the least suitable and 30 (bright yellow) being the most suitable. The most unsuitable locations are within the city where significant urban development has occurred and therefore there is a lack of large open areas. Another factor that greatly influenced the site suitability is soil composition, as areas which have sand and loam soil seen in Figure 3 are clearly more suitable than areas that are not in the suitability map. With the suitability raster in Figure 6 being the input, the *locate* tool was then run to generate three potential sites to build a World Cup stadium, seen in Figure 7 below.

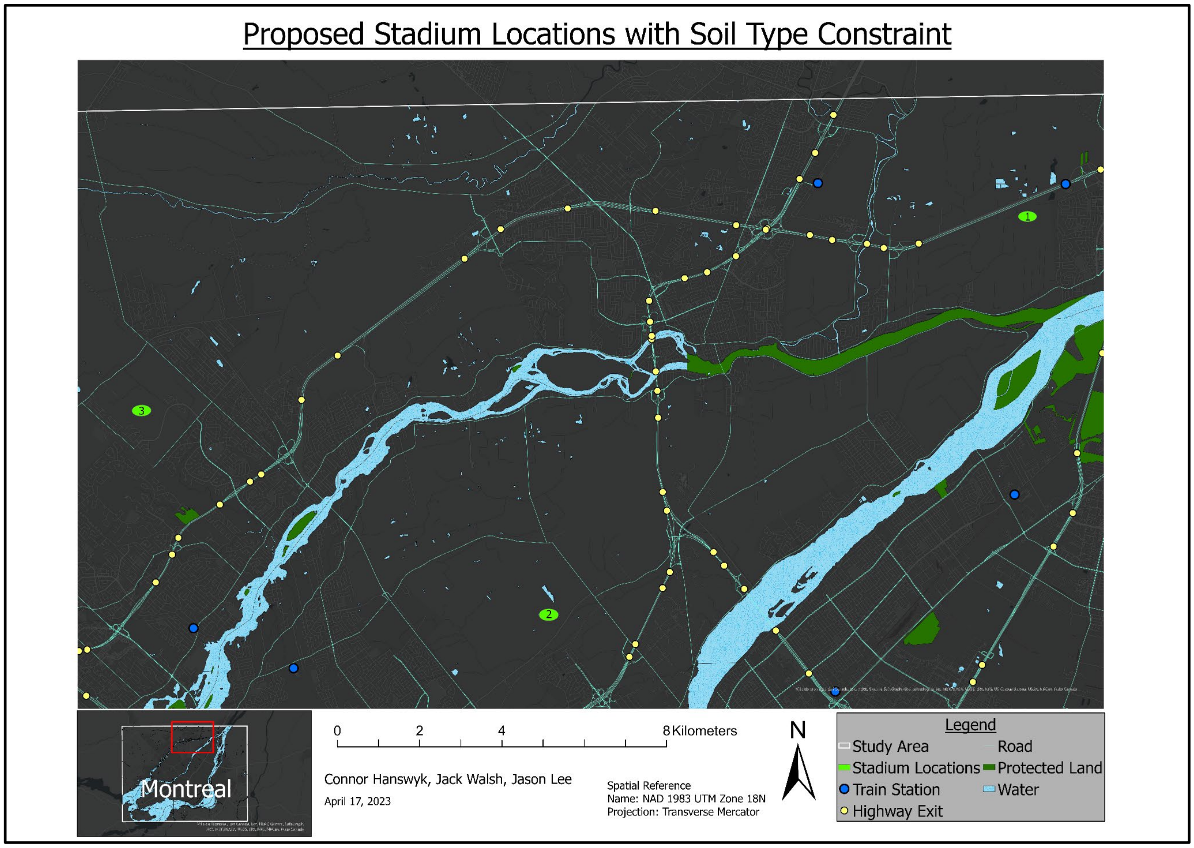

Figure 7. *Map of the proposed sites for stadium construction with soil type in consideration.*

Here, each proposed location has been assigned a number to indicate how it ranks in terms of being the most suitable by the software. The model determined Site 1 to be the most suitable, Site 2 the second most, and Site 3 to be the least suitable. However, since all three sites are free from being situated on a constraint and have high suitability with the variables, each proposed location has the potential for building. Site 1 in the upper right corner of the map has been deemed the most suitable as it, while being on open land and sand soil, is also the closest to a train station and highway exits out of the three sites. Site 2 is located on the island of Laval and therefore most greatly meets the criteria for being close to population centers. However, it is far from the nearest train station, which means less accessibility for fans. Lastly, Site 3 is the least suitable out of the proposed sites because it is far away from train stations and highway exits. While it also meets soil raster constraints and is found in the open area classification, it is the furthest from Montreal's downtown center, which increases its lack of accessibility. Therefore, the manual assessment came to the same conclusion as the model, being that Site 1 is the most suitable of the three proposed locations with the inclusion of the soil type raster.

3.2 Locate Sites Without the Soil Type Raster

As seen below in Figure 8, there is more land deemed highly suitable (yellow) when the soil type raster is excluded. Since a majority of soil in the study area had been previously said to be unsuitable (refer to Figure 3), the removal of soil type as a whole has widely opened up the possible locations where a FIFA stadium can be placed. However, since land use and slope still had the highest impact on suitability, many of the unsuitable locations remained unchanged.

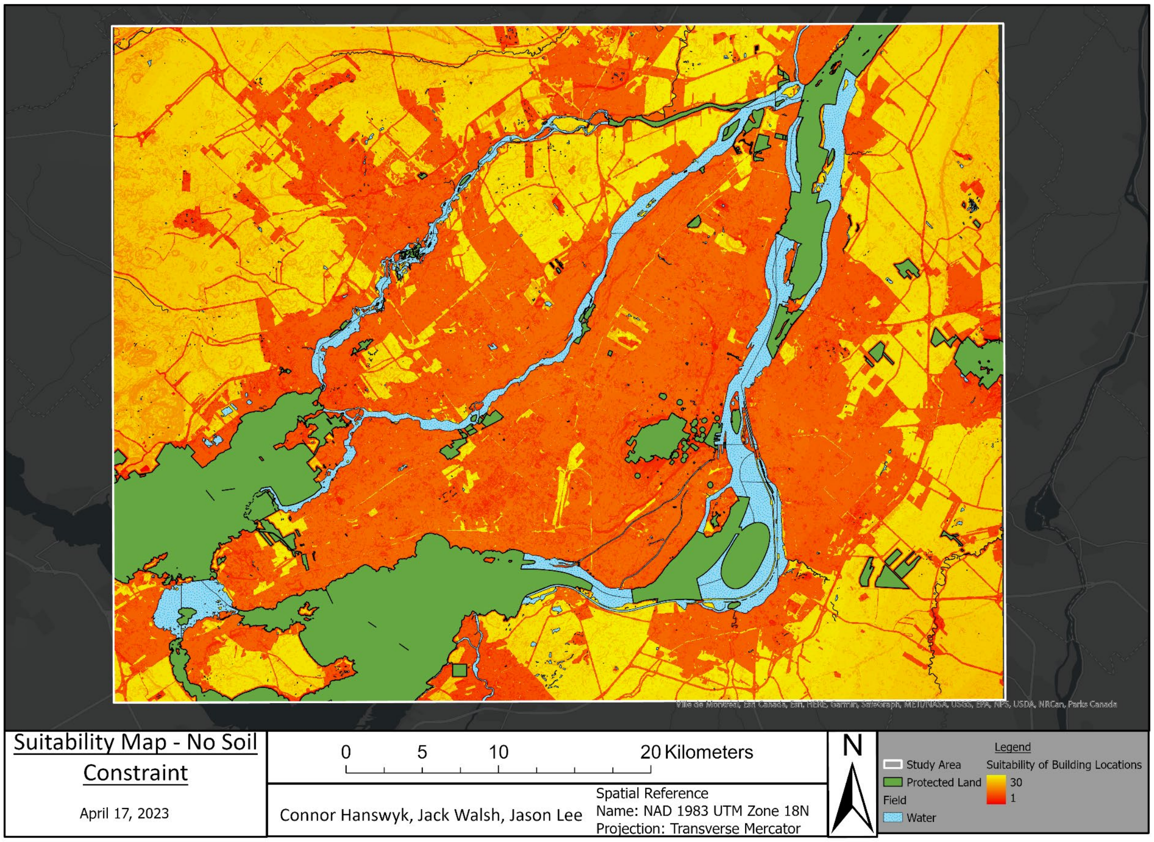

Figure 8. *Site suitability map of the Greater Montreal Area and surrounding region without the soil type raster included.*

Once the locate tool was run after the second suitability map was created, the MCE, when instructed to provide two locations, outputted the results seen below in Figure 9.

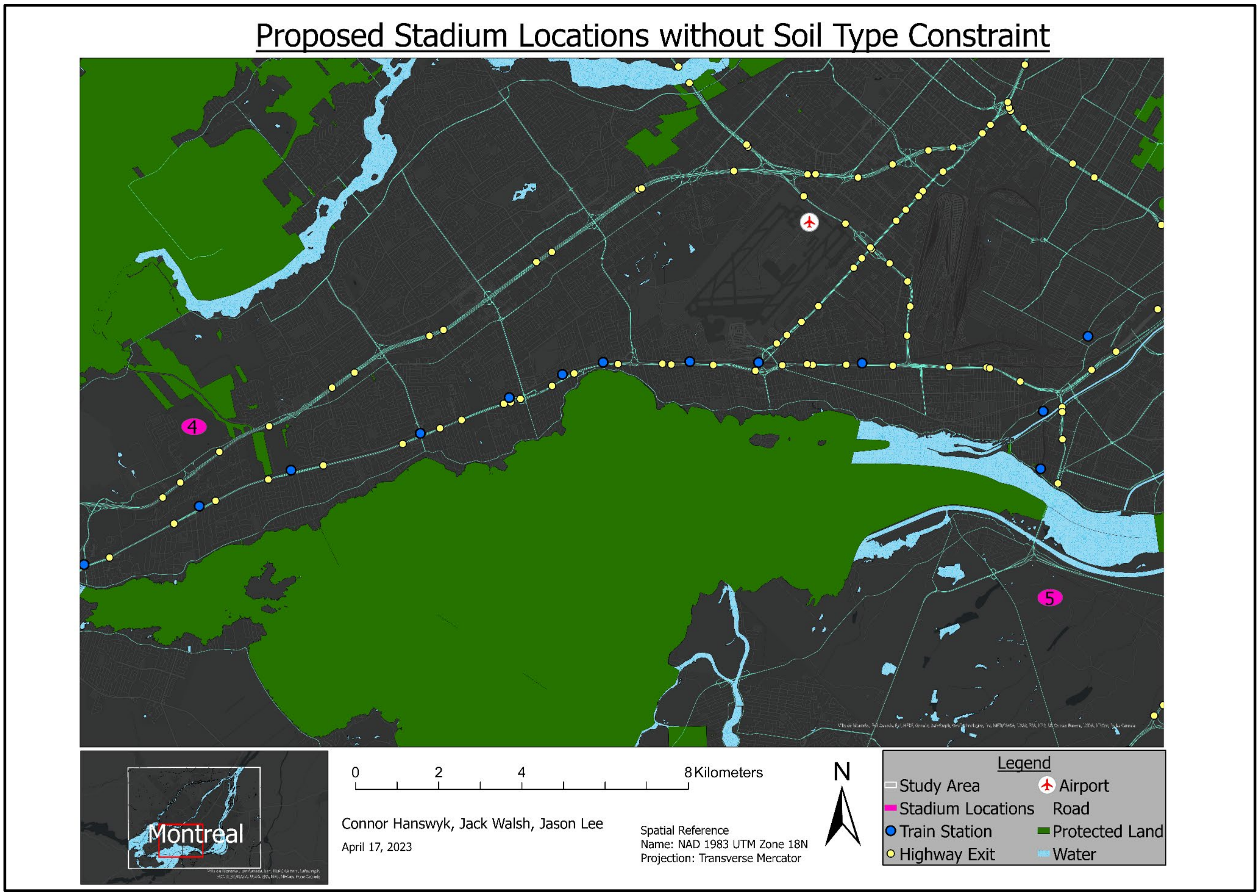

Figure 9. *Map of proposed sites for stadium construction without soil type in consideration.*

The most notable difference between the sites that considered soil type compared to the model that did not is that the non-soil type outputs are located on the island of Montreal or just south of it. Site 4 is close to a highway exit, an Exo train station, and is a reasonable distance from the airport. While Site 5 is closer to Montreal's downtown center, it is generally inaccessible by train and road and not found near a commercial area. Again, the model and the manual assessment have come to the same verdict that Site 4 is the best of these two proposed locations. However, despite Site 4's location on the island, it is still further away from Montreal's downtown center, Laval, and Longueuil than Site 1 is, which decreases its suitability through manual inspection and ultimately ranks it in second place.

3.3 Final Proposed Location

Considering all five of the output sites and the variables and constraints that factor each one, the final proposed location to build a new World Cup mega stadium is Site 1, as seen in Figure 7. The proposed location does not break any of the constraints and furthermore, is located on flat gradient land that is ideal for construction. The location is just north of the northern tip of the Montreal island and is still within a 25 kilometer radius of the city's downtown center. The proposed stadium is in close proximity to numerous highway exits, but more importantly within our criteria, it is located about one kilometer away from an Exo train station. It is also near residential and commercial areas, which is seen as more valuable than being located near no development.

On the other hand, the biggest limitations of the location is that the stadium is found 33 kilometers away from Montreal's international airport which is a greater distance than FIFA's outline desired, and the stadium is also not located as close to population hubs as desired which would increase accessibility and therefore the longevity of the project (Penning, 2012).

Objective 4

4.1 Improvements for the Model

In terms of improvements that can be made to the model itself, one of the most notable would be the addition of a buffer around certain constraints. As mentioned above, a 50 meter buffer was applied to each of the highways in the major road networks raster and a 100 meter buffer was applied to each of the provincially protected areas. The only other buffer that could be utilized to possibly get better results would be a buffer around land classified as residential zones. This would help to ensure that locations, such as Site 3, are placed at ample distance away from residential areas to meet noise and traffic requirements.

4.2 General Improvements for the Study

General improvements that could be made for replicating a similar study in the future would be the use of the most current data available to increase temporal accuracy. For example, the land use dataset used in this project was over five years old, so there was the potential for some land classifications to be out of date and not accurate to what the land is currently being used for. It was observed in one case that Open Area, as classified in the dataset from 2015, is now a Commercial zone. Furthermore, as previously mentioned, the land use dataset also had highways listed as Open Area. This implemented the need for the highways and major roads constraint, so that the suitability model would not consider building on Open Area which highways are in reality. Another improvement to the study would be to consult professionals from relevant fields such as architects, city planners, and FIFA officials to better understand which variables affect site selection the most. This would improve the legitimacy of the study and would help with weighting criteria and knowing what is feasibly possible in terms of building large structures such as stadiums.

Conclusion

The Multi-Criteria Evaluation performed in this study successfully identified a series of suitable locations for a World Cup stadium in the Greater Montreal Area. Through the review of literature, variables and constraints were identified which were then processed and used to shape the criteria of the suitability model. Two suitability maps were then generated, one inclusive of soil type and one exclusive of soil type, and of the five potential locations in total, a single site was proposed that met all criteria while minimizing potential negative impacts. The proposed location was found to be strong in terms of suitability, however, limitations of the project were observed, such as the distance of the proposed site from the international airport and the fact that it is not located closer to population centers for greater accessibility purposes. Future studies could improve upon the model by adding a buffer around residential land constraints, consulting with relevant professionals, and utilizing more current datasets. The proposed stadium location has the potential to be a valuable asset for the city, providing economic and social benefits, but it is important to carefully consider the potential impacts and limitations before moving forward with construction. Variables and constraints identified in this study such as the importance of land use, proximity to population, accessibility by train and highway, and the protection of biologically conserved areas can help shape the criteria used in other site selection projects using the Multi-Criteria Evaluation approach. It also benefits other studies by demonstrating the process of creating and interpreting suitability maps and how the use of these tools can ultimately lead to informed decision-making.

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