Multi-Criteria / Multi-Objective Land Allocation

Land Use Suitability Analysis of Northeastern Washtenaw County, Michigan

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Introduction

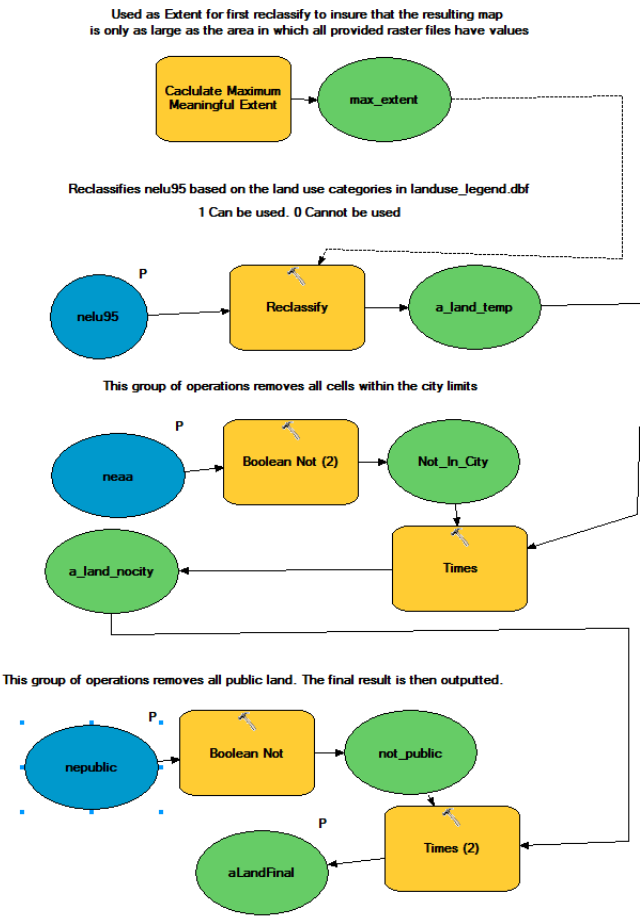
For a city to expand, neighboring areas must be developed in order to grow the city limits. However, land is a precious resource and should be allocated appropriately. If land is developed upon randomly, there can be grave consequences; such as erosion damaging building foundations or agricultural land which refuses to grow crops. Therefore careful planning is a requirement for the successful expansion of a city. The first step of this process is a suitability analysis on the area you wish to develop.

Northeastern Washtenaw County, Michigan, is a place facing this exact problem. It is located near the city of Ann Arbor and the Detroit Metro area, and boasts easy access to the highway. The Southeastern Michigan Council of Governments (SEMCOG) has finally decided that it is time to expand. However, they want to minimize the harm done to the environment during the development of the area.

This report analyzes the surrounding landscape and divides the usable land into 3 sections: developed land, agricultural land and nature preserve land. This report explains the methodology of the accompanying maps and Model Builder files, to illustrate the thought process behind the creation of our suitability models. In addition, attached to this report is a sample land use map which shows, according to our models, the best way to allocate the available land according to the criteria given by SEMCOG.

Separating Land Equally

Our first step was to identify the land which was available for use. To visualise the available land, we created a binary raster file in which 1s represented land available for allocation and 0s represented land unavailable for allocation. In order to do this, we used 3 of the raster files provided to us by SEMCOG: nelu95 (land use in 1995), neaa (the Ann Arbor city limits) and nepublic (a map of public land). Firstly, based on the nelu95 raster, we marked developed land, cemeteries, water features and wetlands as unavailable for use. Areas that were currently in use for extractive purposes, outdoor recreation, agriculture and forested land were marked as available for use. We then used the neaa raster file to mark all land inside of the Ann Arbor city limits as unavailable for use. We did this because we were hired to determine the suitability of Northeastern Washtenaw County, an attractive area to develop partly due to its proximity to Ann Arbor, we assumed that this meant Ann Arbor was not included in the study area. Finally, we used the nepublic raster to mark all public land as unavailable for use as directed in the materials provided by SEMCOG. After performing these operations, we determined that 281 660 raster cells were available for use. The raster's have cell sizes of 30m^2, meaning that roughly 8 449 800m^2 are available for use. SEMCOG wishes to allocated 10% of this space to developed land, 36% to agricultural land and 54% to nature preserve land. This would be 28 166 cells or 844 980m^2 of developed land, 101 398 cells or 3 041 940m^2 of agricultural land and 152 096 cells or 4 562 880m^2 of nature preserve land.

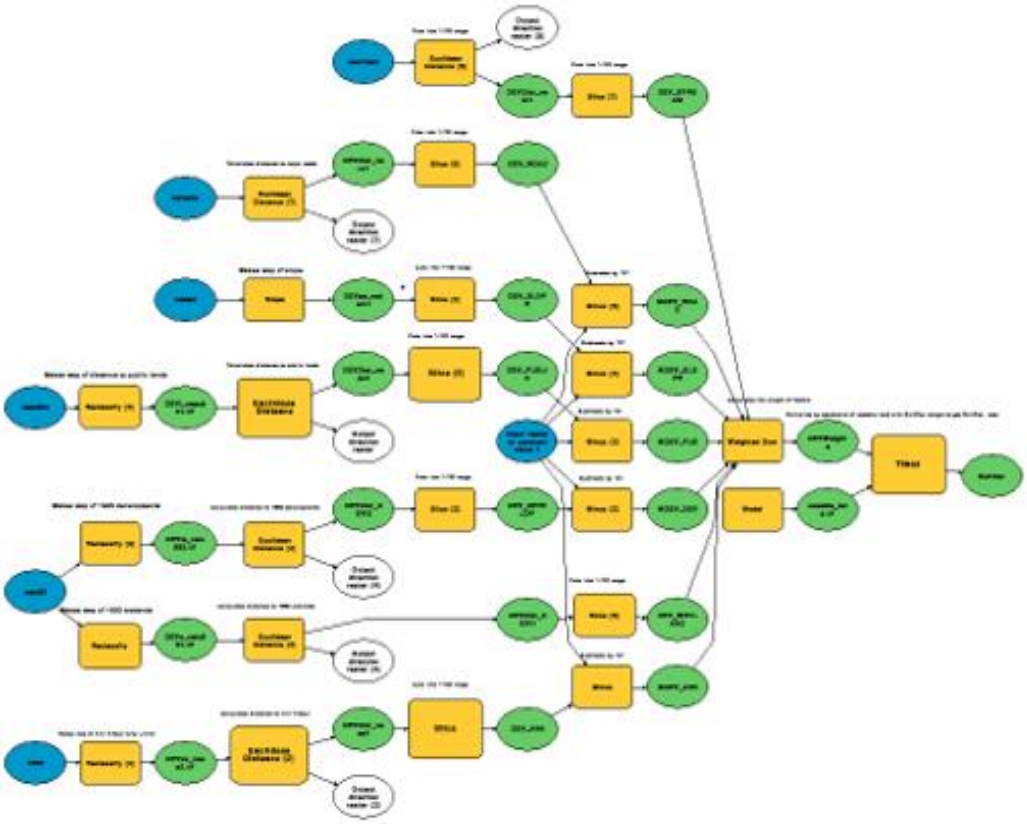


Methods

Developed Land Suitability

The developed land suitability map is used to show what areas in Northeastern Washtenaw County, Michigan, can undergo development projects with respect to the natural and agricultural lands. In order to create the developed land suitability map we needed to look at its seven main criteria which were distance to major roads,public lands, Ann Arbour, 1995 development , 1995 wetlands , lakes/streams and the slope calculations.

Model Builder Diagram



In my ArcGIS model builder we created maps for each criteria using the reclassify tool. Then we used the Euclidian distance tool to calculate the distance for all the map criteria except for slope and afterwards cut them into a 1-100 range using the Slice tool. After that we subtracted 101 using the Minus tool for the negative factors which explains the criteria that the development suitability map should be close to. Lastly, we calculated the weighted factors of each criteria using the

Weighted Sum tool and multiplied the constraints of useable land with the SuitDev weight tool to get the final development suitability map.

AHP File

RECIPROCAL MATRIX

Criteria	e to Majo	e to Publi	ce to Ann	1995 dev	Slope	lakes ar	to 1995 wetlands
Distance to Majo	1.00	1.00	0.78	3.00	5.00	5.00	3.00
Distance to Publi	1.00	1.00	0.56	0.78	3.00	3.00	1.00
Distance to Ann	1.28	1.79	1.00	5.00	7.00	5.00	3.00
Distance to 1995 dev	0.33	1.28	0.20	1.00	3.00	1.00	3.00
Slope	0.20	0.33	0.14	0.33	1.00	0.56	0.78
Distance to lakes ar	0.20	0.33	0.20	1.00	1.79	1.00	0.78
Distance to 1995 w	0.33	1.00	0.33	0.33	1.28	1.28	1.00
SUM	4.35	6.73	3.22	11.45	22.07	16.84	12.56

Table 8. Random Consistency Index (RI)

n	RI
1	0.00
2	0.00
3	0.58
4	0.90
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45
10	1.49
11	1.51
12	1.48
13	1.56
14	1.57
15	1.59

NORMALIZED MATRIX

								SUM	Priority Vector
	0.230	0.148	0.243	0.262	0.227	0.297	0.239	1.645	0.24
	0.230	0.148	0.174	0.068	0.136	0.178	0.080	1.014	0.14
	0.295	0.265	0.311	0.437	0.317	0.297	0.239	2.161	0.31
	0.077	0.190	0.062	0.087	0.136	0.059	0.239	0.851	0.12
	0.046	0.049	0.044	0.029	0.045	0.033	0.062	0.310	0.04
	0.046	0.049	0.062	0.087	0.081	0.059	0.062	0.447	0.06
	0.077	0.148	0.104	0.029	0.058	0.076	0.080	0.572	0.08
SUM	1.000	1.000	1.000	1.000	1.000	1.000	1.000	7.000	1

n= 7

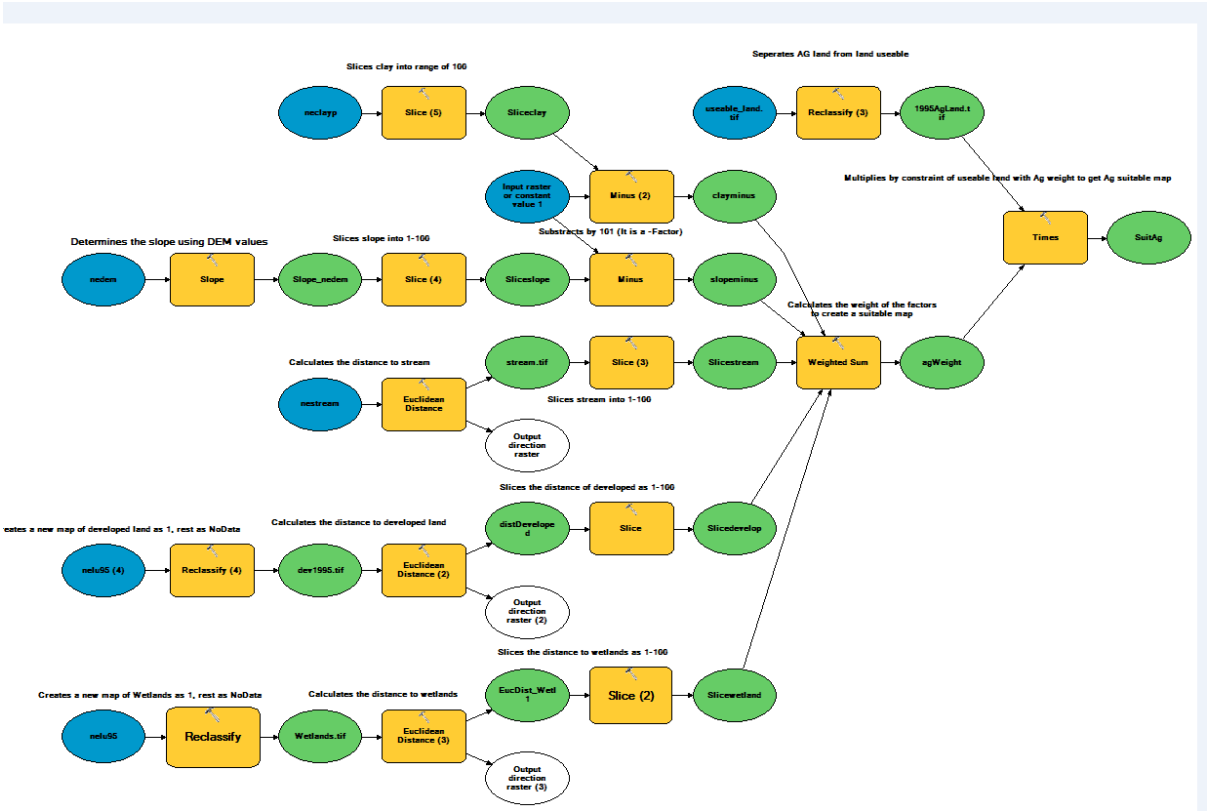
Lambda max	7.4607
Consistency Index (	0.076779
Consistency Ratio (	0.06

In our AHP file we created a weighing criteria method through the reciprocal matrix that used a scale where two criteria are compared against each other using a nine point scale. That reads as followed , 9 = extremely favours, 7 = very strongly favours, 5 = strongly favours, 3 = slightly favours and 0 = Equal. As a result this created the normalized matrix which outputted priority vectors based on the importance of each criteria out of 1 . A lambda max value of 7.46 was generated which illustrates the reciprocal matrix sum plus the priority vector multiplied by the each pair and then are added to other pairs. While the consistency index and ratio are below 10 % because it showcases uniformity in our ranking of the criteria. The consistency index represents the overall operation behind the AHP hierarchy system and the consistency ratio displays the comparison between the consistency index over the random consistency index. For our comparison matrix of development suitability we chose seven criteria to compare and can be seen in the n=7 part of the file. Our way of choosing the importance was based on which criteria benefited the development suitability map. The most vital criteria was therefore the distance to Ann Arbour as we wanted the developments to be close to a city so that people could travel less for other business and recreation. Distance to major roads was ranked second because we wanted to have close transportation access. Distance to public lands was ranked third to mitigate environmental loss in the Michigan area. 1995 developments and wetlands were placed in the middle as we wanted to stay further away from those unfriendly development regions. Bodies of water

and slope had the least importance as they did not play a huge role in the development suitability map because of their little impact to urban sprawl.

Agricultural Land Suitability

Agricultural land has one of the largest plannable land, thus, most of ‘useable land’ was constrained under Ag Land Use 1995. We used 5 criterias: clay content, distance to 1995 development, slope, distance to lakes and streams and distance to wetlands for the agricultural land suitability map.



Model Builder Diagram

My group and I started by creating the maps of each criteria using the reclassify tool. After that we calculated the euclidean distance for all the criteria except the clay content and slope. Afterwards each criteria data was sliced into a range of 1-100 using the slice tool. The minus tool allowed us to subtract 1001 from the slope and clay content as they were negative factors.We then used the weighted sum tool to calculate the weights of the factor to create a suitability map. Finally we multiplied the constraints of useable land with Ag weight to get the complete Ag suitable map.

AHP File

RECIPROCAL MATRIX

Criteria	Clay Content	Slope	to 1995 Deve	to lake and	ance to wetlands
Clay Content	1.00	3.00	9.00	7.00	7.00
Slope	0.33	1.00	7.00	5.00	5.00
Distance to 1995 Development	0.11	0.14	1.00	0.33	0.33
Distance to lake and streams	0.14	0.20	3.00	1.00	1.00
Distance to wetlands	0.14	0.20	3.00	1.00	1.00
Sum	1.73	4.54	23.00	14.33	14.33

NORMALIZED MATRIX

						Sum	riority Vector
	0.578	0.660	0.391	0.488	0.488	2.606	0.52
	0.193	0.220	0.304	0.349	0.349	1.415	0.28
	0.064	0.031	0.043	0.023	0.023	0.186	0.04
	0.083	0.044	0.130	0.070	0.070	0.397	0.08
	0.083	0.044	0.130	0.070	0.070	0.397	0.08
Sum	1.000	1.000	1.000	1.000	1.000	5.000	1.00

Lambda max	5.3150	n =	5
Consistency Index (CI)	0.08		
Consistency Ratio (CR)	0.07		

Table 8. Random Consistency Index (RI)

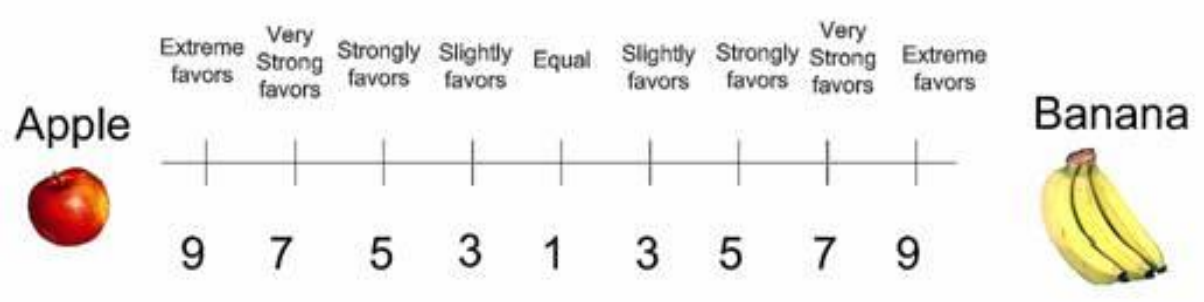
n	RI
1	0.00
2	0.00
3	0.58
4	0.90
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45
10	1.49
11	1.51
12	1.48
13	1.56
14	1.57
15	1.59

The AHP file for agricultural suitability was made to compare the five different criteria amongst one another. We utilized the reciprocal and normalized matrix to show the hierarchy of importance for each criteria and how they stacked up in relation the agricultural suitability map. Clay content was ranked number one in importance as it directly impacts the crop yield depending on the richness of the soil and nutrients. Slope was put right after as it corresponds to the water runoff from the elevation. Our third most important criteria was tied with distance to streams/lake and wetlands for the reason that too much water may cause soil erosion which will kill the plants. The least important criteria was distance to 1995 developments as the pollution and chemical used in the buildings would ultimately lead to stagnant plant growth.

Nature Preserve Land Suitability

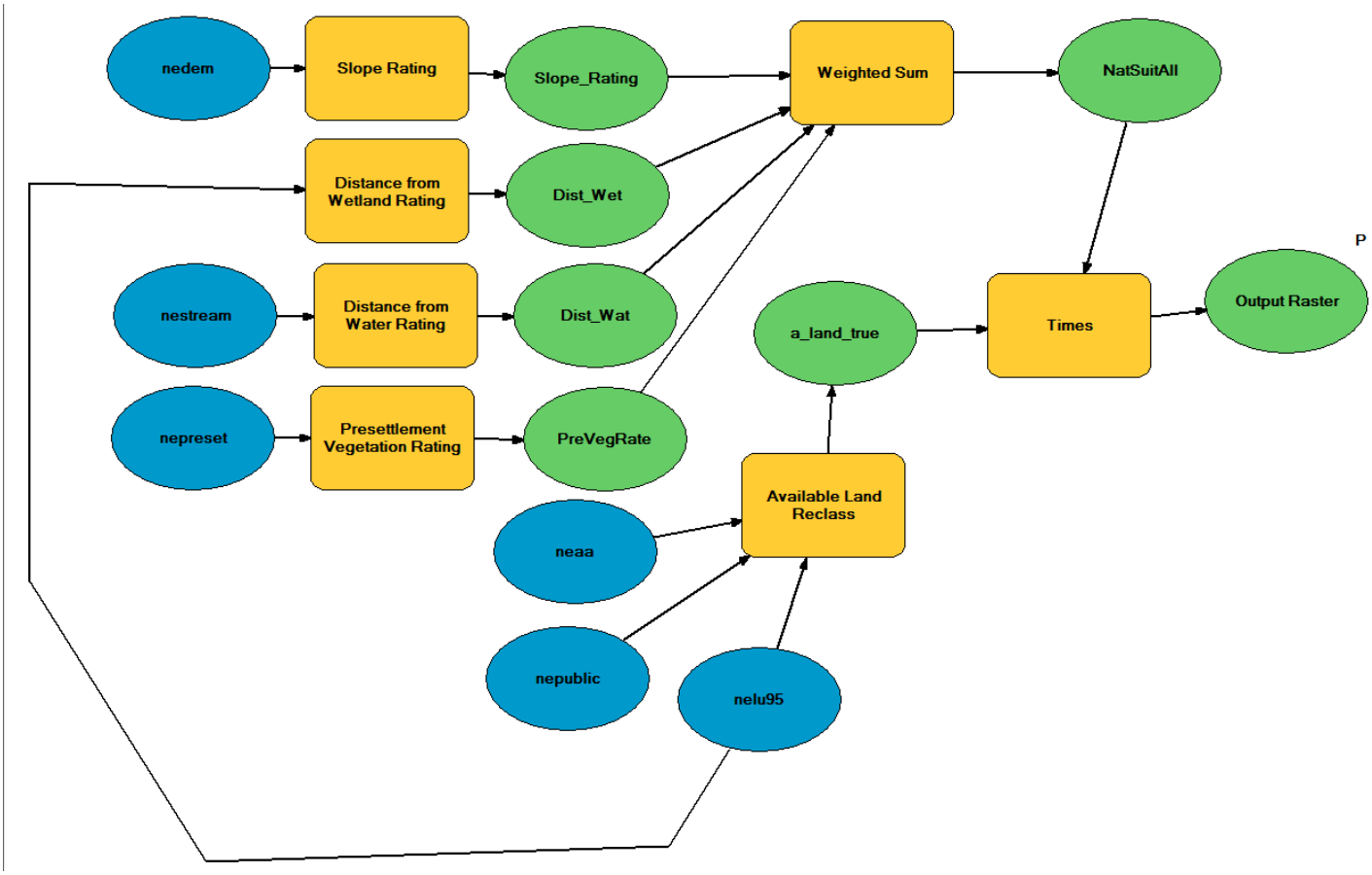
To determine the suitability of a cell to act as nature preserve land, we evaluated each cell based on the following 4 criteria: the slope of the cell, the distance to the nearest wetland, the distance to the nearest water feature and the type of presettlement vegetation, if any, the cell contained.

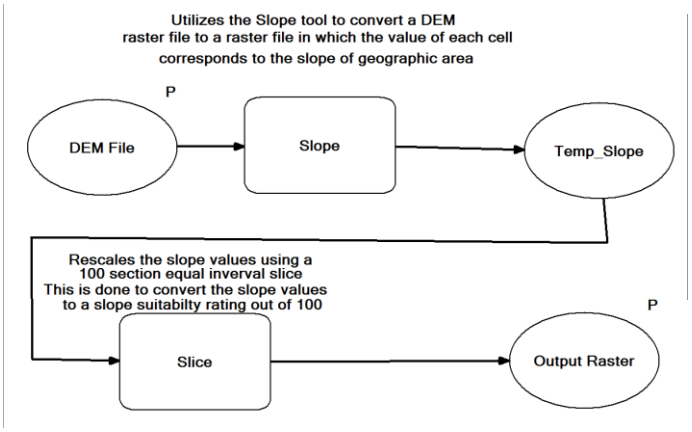
Firstly, we used the Analytic Hierarchy Process (AHP) to determine how much we would weigh each factor in our nature preserve land suitability model. The AHP consists of comparing each criteria with one another using a numeric scale, typically from 1 to 9. Below is an example of an AHP preference scale taken from from the AHP tutorial on Kardi Teknomo's website.

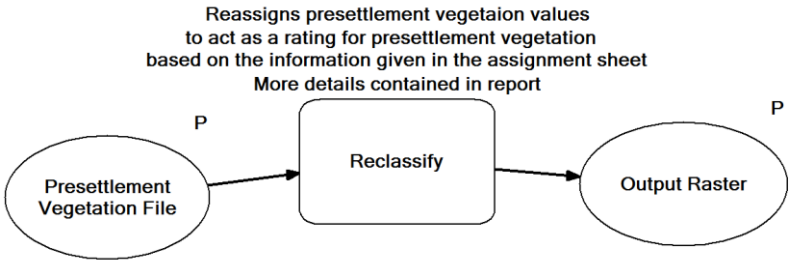


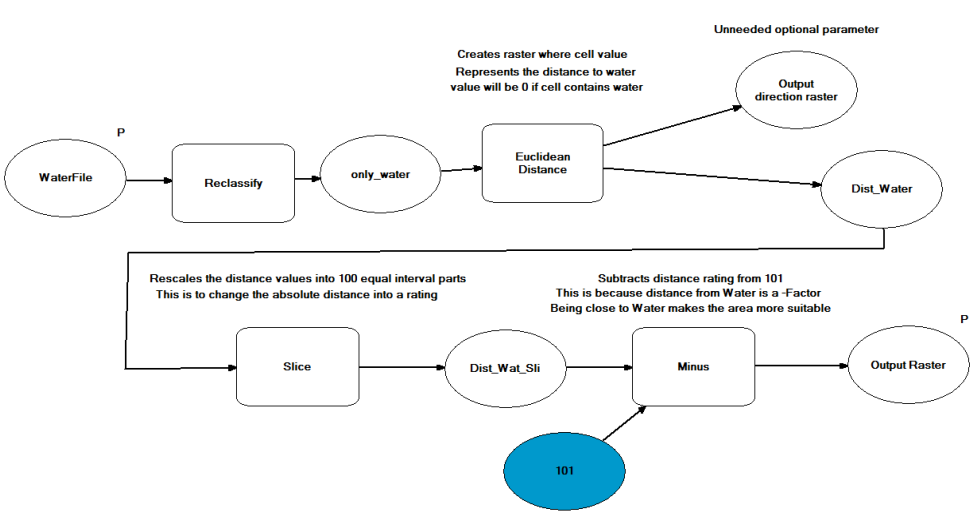
After comparatively ranking all of our criteria, a few mathematical operations are done to determine the weights we will assign to the different criteria. Performing an AHP allows us to retain some structure and objectivity in our weighing of categories while still allowing us to subjectively rank criteria based on what we believe is most important.

Since the goal of nature preserve land is to minimise the damage done to nature, we placed the most importance on being close to existing wetlands. It is important to preserve the wetlands in the area, and setting aside the areas closest to the wetlands for nature preserves will do the most good for the local environment. We believed that the next most important factor was the distance to water features. Preserving the local lakes and streams is yet another way to minimise the impacts of development on the environment. The next lowest weight we assigned was to presettlement vegetation. Areas with more lush presettlement vegetation were prioritised in order to preserve or restore the vegetation. Last but not least is slope, which is important for minimizing erosion, but we believed was less of a priority compared to the other considerations.


nedem
Slope Rating
Slope_Rating
Weighted Sum
NatSuitAll
Distance from Wetland Rating
Dist_Wet
nestream
Distance from Water Rating
Dist_Wat
a_land_true
Times
P
Output Raster
nepreset
Presettlement Vegetation Rating
PreVegRate
Available Land Reclass
neaa
nepublic
nelu95


Utilizes the Slope tool to convert a DEM raster file to a raster file in which the value of each cell corresponds to the slope of geographic area
P
DEM File
Slope
Temp_Slope
Rescales the slope values using a 100 section equal inverval slice
This is done to convert the slope values to a slope suitabilty rating out of 100
P
Slice
Output Raster


Reassigns presettlement vegetaion values to act as a rating for presettlement vegetation based on the information given in the assignment sheet
More details contained in report
P
Presettlement Vegetation File
Reclassify
P
Output Raster


Unneeded optional parameter
Creates raster where cell value
Represents the distance to water
value will be 0 if cell contains water
Output direction raster
P
WaterFile
Reclassify
only_water
Euclidean Distance
Dist_Water
Rescales the distance values into 100 equal interval parts
This is to change the absolute distance into a rating
Subtracts distance rating from 101
This is because distance from Water is a -Factor
Being close to Water makes the area more suitable
P
Slice
Dist_Wat_Sli
Minus
Output Raster
101

Above are some annotated diagrams showing how the nature suitability works. The reclassification done on presettlement vegetation was as follows: wetlands and water features have a rating of 100, oak openings and barrens have a rating of 75 and finally, forested areas have a rating of 50.

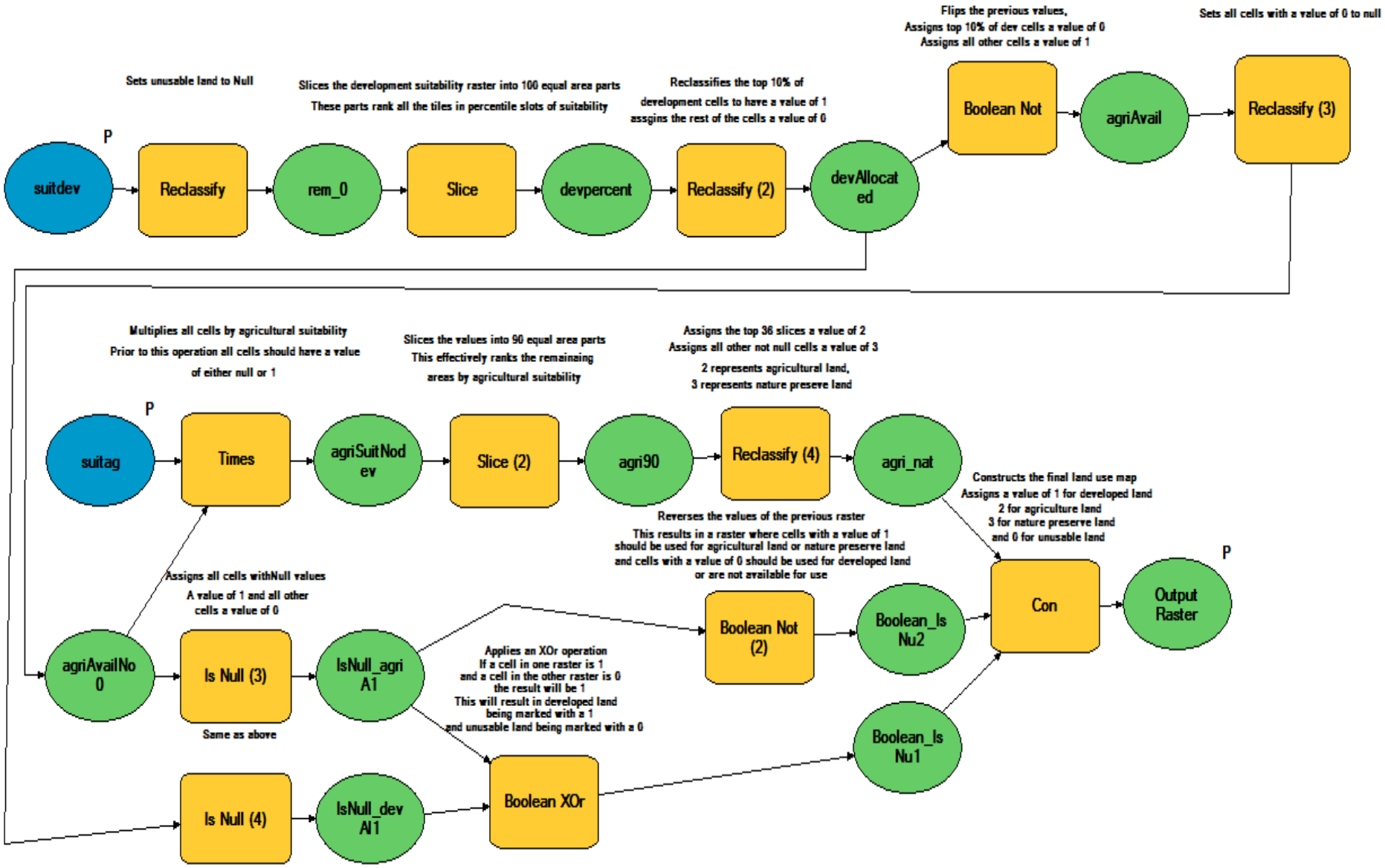
Future Land Use

In order to create the Future Land Use map, we utilised a priority based solution in our model. We thought that this was appropriate because of the request to allocate specific amounts of land to specific categories. A priority based approach allowed our model to come extremely close to the specified allocation goals.

To briefly summarise our model, it attempts to fulfill each requirement one at a time. We prioritise developed land first, because it has the smallest allocation target, followed by agricultural land and finally nature preserve land, since it had the largest allocation target.

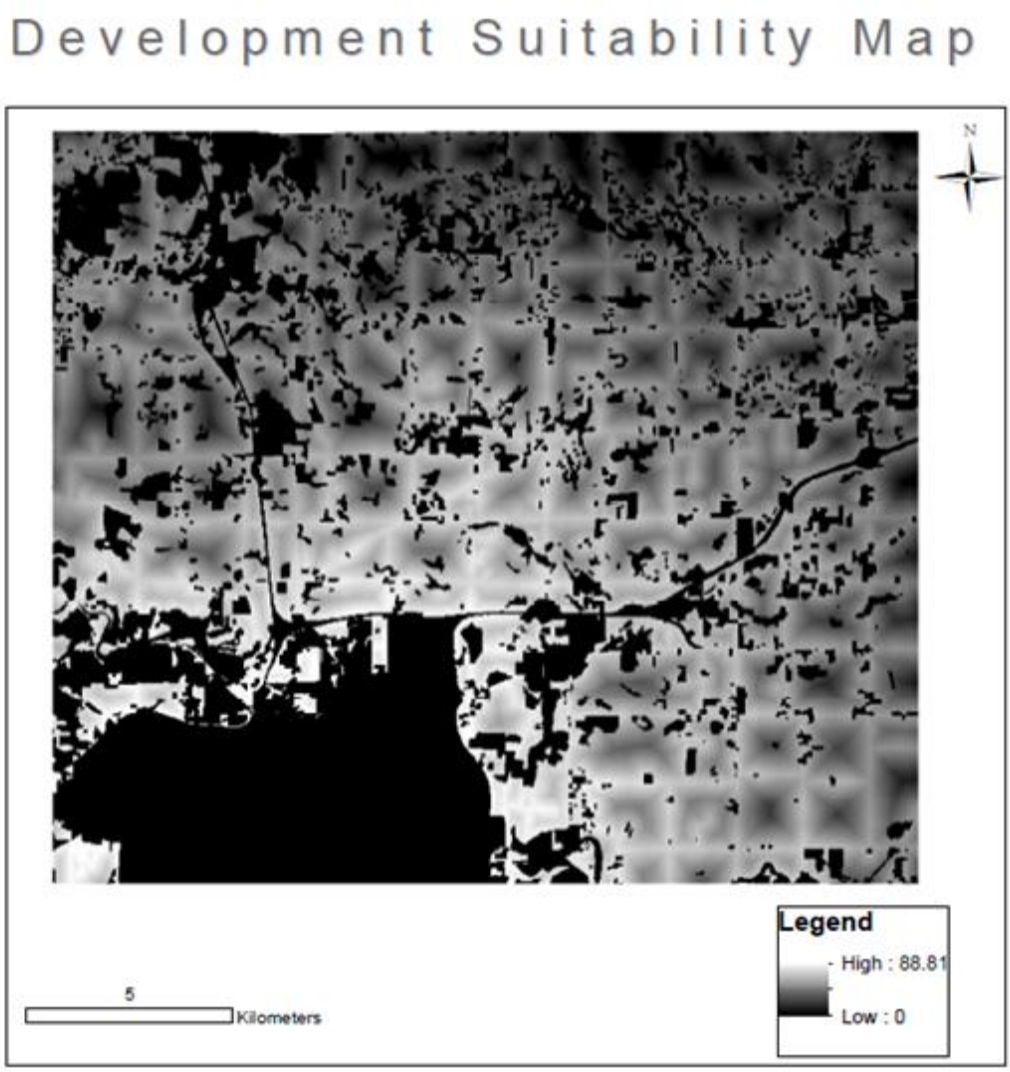
The model works by discarding all unavailable land by setting the cells to noData. If then ranks the cells by development suitability by separating the cells into percentile groups. The highest 10 groups are then selected to be allocated as developed land in the future land use map. The model then does the same thing, but with the agricultural suitability model. After allocating roughly 36% of the usable cells to agricultural land, the remaining suitable cells are then allocated for nature preserve use, because there are no other land types that need to be allocated.

Compared to the highest position method of land allocation, this priority based solution allowed our group to come much closer to the requested allocations. On the next page there is an annotated diagram showing the inner workings of our future land use allocation model.


Sets unusable land to Null
Slices the development suitability raster into 100 equal area parts
These parts rank all the tiles in percentile slots of suitability
Reclassifies the top 10% of
development cells to have a value of 1
assgins the rest of the cells a value of 0
Flips the previous values,
Assigns top 10% of dev cells a value of 0
Assigns all other cells a value of 1
Sets all cells with a value of 0 to null
P
suitdev
Reclassify
rem_0
Slice
devpercent
Reclassify (2)
devAllocated
Boolean Not
agriAvail
Reclassify (3)
Multiplies all cells by agricultural suitability
Prior to this operation all cells should have a value
of either null or 1
Slices the values into 90 equal area parts
This effectively ranks the remaining
areas by agricultural suitability
Assigns the top 36 slices a value of 2
Assigns all other not null cells a value of 3
2 represents agricultural land,
3 represents nature preserve land
P
suitag
Times
agriSuitNodev
Slice (2)
agri90
Reclassify (4)
agri_nat
Constructs the final land use map
Assigns a value of 1 for developed land
2 for agriculture land
3 for nature preserve land
and 0 for unusable land
P
Reverses the values of the previous raster
This results in a raster where cells with a value of 1
should be used for agricultural land or nature preserve land
and cells with a value of 0 should be used for developed land
or are not available for use
Assigns all cells withNull values
A value of 1 and all other
cells a value of 0
agriAvailNo0
Is Null (3)
IsNull_agriA1
Same as above
Applies an XOr operation
If a cell in one raster is 1
and a cell in the other raster is 0
the result will be 1
This will result in developed land
being marked with a 1
and unusable land being marked with a 0
Boolean Not (2)
Boolean_IsNu2
Con
Output Raster
Boolean_IsNu1
Is Null (4)
IsNull_devA1
Boolean XOr

Results

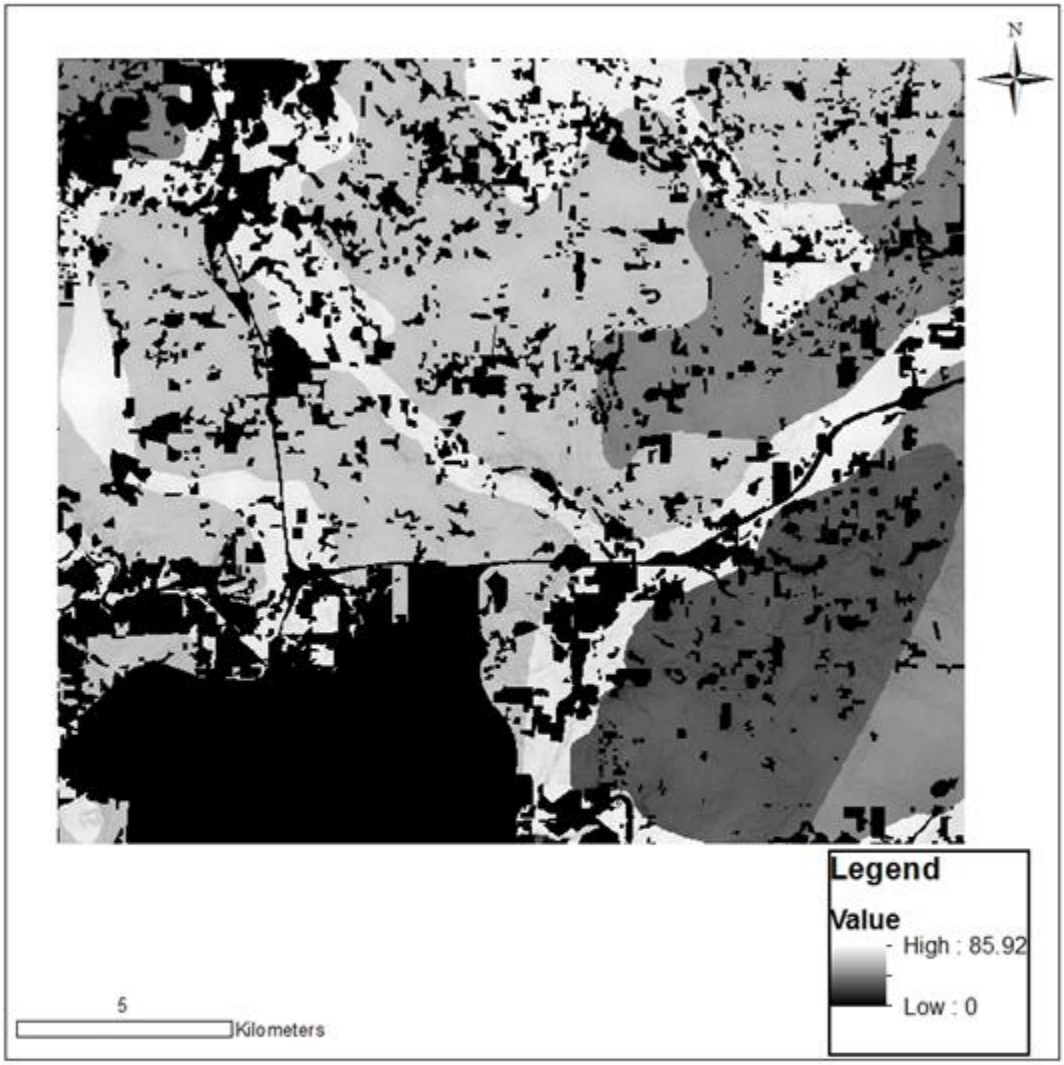
Developed Land Suitability



Map created by: Arjun Chhibbar
May 26, 2016
Instructor: D.T.Robinson
Map Projection: Transverse_Mercator
Data Providers:
MIRIS
SEMCOG
Compiled by SEMCOG
USGS 7.5-Minute quads
Census Bureau TIGER File
SEMCOG MI Natural Features

The development suitability map above depicts the land which can and cannot be developed in. As expected the White-grey areas on the map have a higher value and are closer to Ann Arbour whereas the darker area have lower values and are the least suitable. The black region are undevelopable sites as they are in wetlands or various bodies of water.

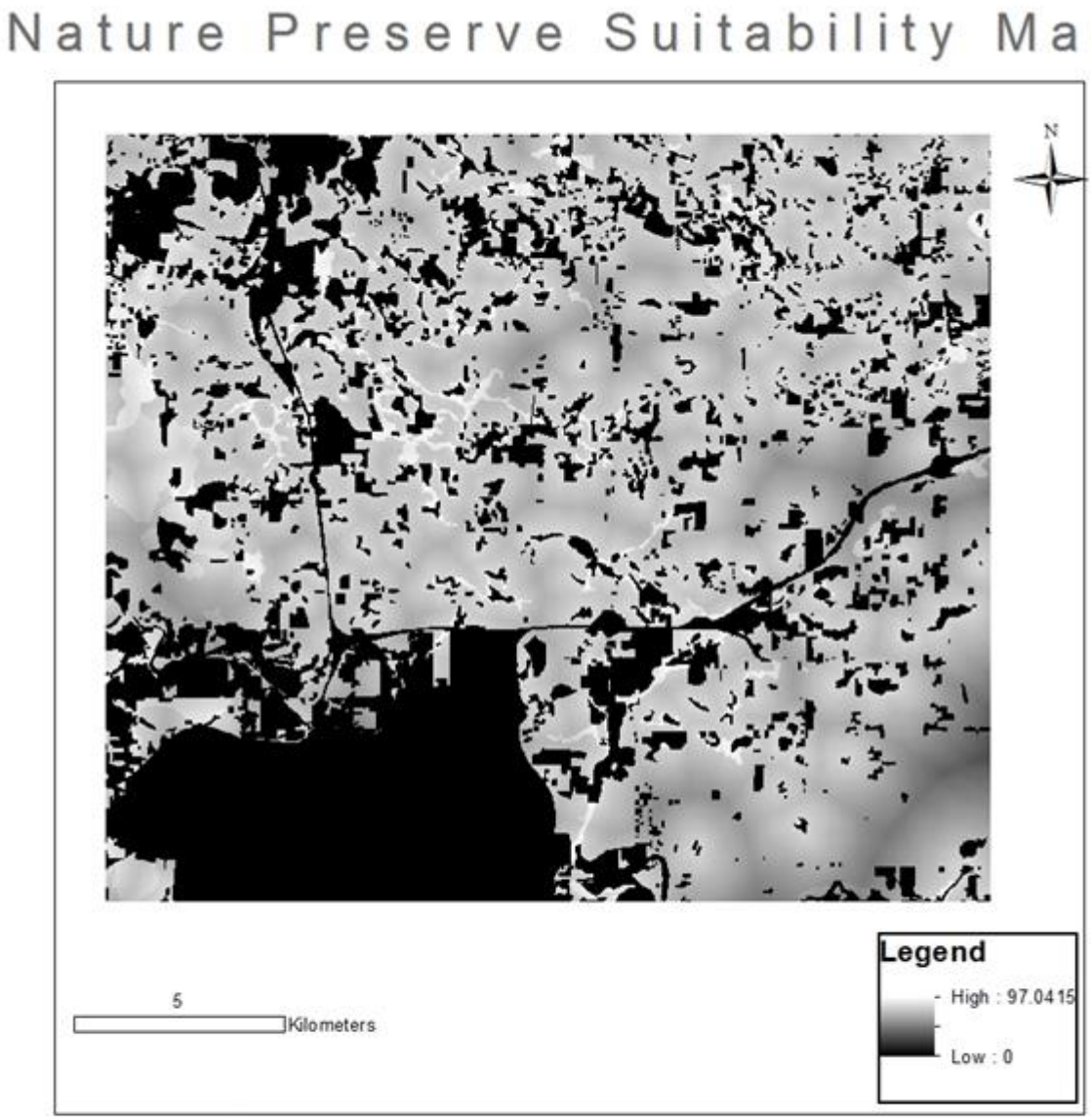
Agricultural Land Suitability



Map created by Shreejan Paudel
May 26, 2016
Instructor: D.T.Robinson
Map Projection: Transverse_Mercator
Data Providers:
MIRIS
SEMCOG
USGS 7.5-Minute quads
SEMCOG MI Natural Features
USDA STATSGO soil database

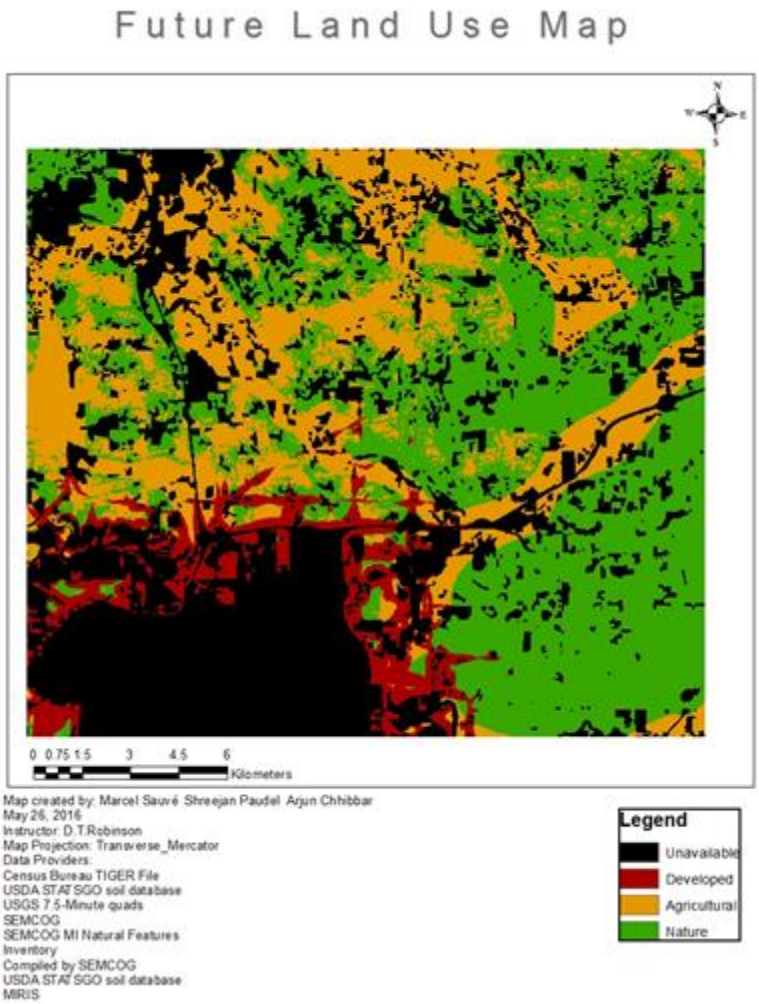
The agricultural suitability map above shows the areas that have arable land against the areas that do not. The lighter coloured areas mean that they have more agricultural farmland while the darker regions display lesser undesirable areas to grow crops.

Nature Preserve Land Suitability



The natural preserve land suitability map above presents the developed land and natural habitats. The lighter coloured areas display the wetlands,lakes and stream while the darker regions are settlements that are not in the natural preserve land.

Future Land Use



Future land use map was generated by combining the suitability maps of Development, Nature Preserve and Agricultural. Our original goal was to get 28 166 cells (844 980m^2) of developed land, 101 398 cells (3 041 940m^2) of agricultural land and 152 096 cells (4 562 880m^2) of nature preserve land. We achieved 25,496 cells (764 880m^2) for developing, 101,724 cells (3 051 720m^2) for agricultural and 154,071 cells (4 622 130m^2) for natural. We managed to get suitable for ~9% of development, ~55% for natural and ~36% for agricultural. We used SLICE, equal area, which states “the input values will be divided into the specified number of output zones, with each zone having a similar number of cells. Each zone will represent a similar amount of area.” (ArcGIS Desktop, n.d.). We believe that this tool caused the representation to not be asexact, thus, creating a minor error on our results.

References

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