Growing Switchgrass in Unused Urban Parcels:

A Site Selection Analysis

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Introduction

In 2008 petroleum products accounted for 94 percent of all energy consumed by the transportation sector in America. Contrast this to renewable biofuels, such as ethanol, which only accounted for 3 percent of energy consumed. This reliance on petroleum to power transportation is not likely to change significantly in the near future. However, as concerns grow over carbon dioxide emissions, supporting hostile governments by importing oil and the environmental impacts of oil production – recently highlighted by the BP oil spill in the Gulf of Mexico – sources of cleaner, sustainable and domestic energy will be sought out and become profitable.

One potential source of ethanol is switchgrass, a perennial grass that grows in a wide variety of climates and land conditions. Since switchgrass is able to grow in less than ideal conditions, marginal crop land or other non agricultural land is able to support it, rather than prime agricultural land normally used for food production. Another possible location for growing switchgrass is unused urban areas. Undeveloped or vacant parcels do not provide any benefit to cities. Using these parcels to grow switchgrass generates economic benefits and also can revitalize polluted or contaminated land.

The goal of this project is to perform a site suitability analysis using GIS to determine if unused or vacant parcels in Tacoma, Washington are feasible locations to grow switchgrass. Additionally, the process developed will be modeled using ArcGIS ModelBuilder so that the analysis can be applied to any region, given the appropriate data.

Research

The Energy Independence and Security Act of 2007 mandated the use of 11 billion gallons of renewable fuel for motor gasoline by 2009, with the mandate growing to 36 billion gallons by 2022. Ethanol is currently the primary source of renewable fuel, with the majority of ethanol being produced from corn. Producing ethanol from corn is a relatively simple process because the materials are easily broken down into fermentable sugars, which are then converted to ethanol. Drawbacks to corn based ethanol are high water and energy requirements and using prime agricultural land for fuel rather than food (Cherubini, 2010). Producing ethanol from cellulosic feedstocks, such as grasses, trees, agricultural and forestry residues and even municipal waste, is a more complex process but is more efficient, less resource intensive and generates fewer emissions. Cellulosic ethanol technology is still expensive and maturing, and has not yet become cost effective enough to produce commercially. Switchgrass is currently one of the primary sources of cellulosic ethanol, and has been identified as a model biofuel crop by the US Department of Energy (Khanna, 2008).

A major advantage of switchgrass over corn as an ethanol feedstock is its ability to thrive in marginal land conditions, making competition with the food supply for prime agricultural land unnecessary. A study evaluating marginal land resources such as roadway buffer strips, brownfield sites, and marginal agricultural land found that these land types could support a productive switchgrass growing operation. Estimates for switchgrass production range from 5 to 10 tons per acre, and approximately 100 gallons of ethanol can be produced per ton of switchgrass with current technologies (Gopalakrishnan, 2009).

Haddad and Anderson performed a GIS based site suitability analysis to determine ideal locations for collection and storage of corn stover for use as an ethanol feedstock. Production potential, environmental impact and a transportation network analysis were the three major criteria. The production potential criteria were: corn suitability rating, estimated yield, land capability classification, and farmland designation. Each category was weighted equally and the layers were combined. The resulting layer was reclassified, with 1 indicating low suitability, 2 indicating moderate suitability and 3 indicating high suitability. The same process was followed with the environmental impact assessment. Criteria considered included habitat, soil erosion and proximity to water bodies. The layers were weighted equally, combined and reclassified, with 1 indicating high environmental impact, 2 indicating moderate impact and 3 indicating low impact. A network analysis was also conducted which created service areas for railroads and major roads (Haddad, 2008).

Planning

The spatial extent of the project is the city of Tacoma, Washington. With a population of 200000 and an area of 50 square miles, Tacoma provides a diverse array of land uses and has a well developed industrial sector, which should provide an ample amount of vacant parcels for analysis. The data required for the project is the following: a land use/parcel layer, an impervious surface raster layer and an elevation raster layer. The basic criteria for evaluating the suitability of a particular parcel is appropriate land use designation, appropriate distance from residential parcels, area of the parcel, impervious surface coverage and slope. A smaller set of criteria was chosen to keep the process relatively simple, with the intent of building a model. If no model was being created, a more complicated analysis could include proximity to major roads or railways, an economic analysis that includes the cost of developing the land for agriculture as well as expected profits based on land area and a network analysis to determine a theoretical collection route and transportation costs.

The parcels desired as switchgrass sites are vacant commercial and vacant industrial land. The ideal parcel should be located at least 0.1 miles away from residential parcels to minimize noise and view impacts. Placing a buffer around residential parcels should insure that any available parcel is near a major road. A parcel of at least 0.5 acres in size is desired to ensure that an adequate amount of ethanol can be produced to be cost effective. A 0.5 acre parcel can produce 250 to 500 gallons of ethanol per year. For reference, approximately 1 to 2 acres of land can theoretically produce enough ethanol to power one vehicle for an entire year.

Once the unused parcels have been filtered by the residential parcel buffer and area, the raster data can be analyzed. An ideal parcel will have a low percentage of impervious surfaces and also minimal slope changes. The slope will be calculated from the elevation data. The impervious surface and slope rasters will be reclassified to provide easier interpretation of the data. After reclassification of the rasters the remaining available parcels can be evaluated based on the average impervious surface coverage and slope within each individual parcel. If a parcel meets the desired slope and impervious surface criteria it is considered suitable as a site to grow switchgrass.

Methods and Implementation

<u>Manual Analysis</u>

The initial analysis was conducted using ArcMap and ArcCatalog. A file geodatabase was created to contain all final rasters and data tables, and a feature dataset was created within the geodatabase to store all vector data created. The coordinate system used for the feature dataset was NAD_1983_HARN_StatePlane_Washington_South_FIPS_4602_Feet. The Tacoma parcel layer was obtained from the Washington State Geospatial Data Archive (WAGDA). The attribute table for the parcel layer contains many fields, but the three needed for the analysis were tax parcel number, land use designation and the area of the parcel in acres. Using the 'Select by Attributes' tool and selecting the appropriate land use designation types, the unused parcel and residential parcel layers were created. Using the 'Select by Location' tool, any unused parcel located within 0.1 miles of a residential parcel was eliminated from the selection. Using the 'Select by Attribute' tool again, any unused parcel less than 0.5 acres was removed from the selection.

The impervious surface and elevation rasters were obtained from the USGS Seamless Server. Both rasters have a 30 meter cell size. The impervious surface raster measures the percentage of the cell covered by impervious surfaces. The elevation data provides the elevation of the cell in meters. Both rasters were reprojected into the same coordinate system as the feature dataset. Using the 'Slope' tool in the Spatial Analyst toolbox a raster measuring slope as a percentage was created from the elevation raster. The 'Extract by Mask' tool in the Spatial Analyst toolbox was used to clip the slope and impervious surface rasters using the remaining parcels after the buffer and area filter as the mask. This significantly reduces the size of the raster layers and decreases the processing necessary to run reclassification and zonal statistics. The Spatial Analyst 'Reclassify' tool was used to convert the raw raster data into more usable categories. The reclassification intervals are below:

Impervious Surface

0.0001-10%	1
10.0001-20%	2
20.0001-30%	3
30.0001-40%	4
40.0001-50%	5
50.0001-60%	6
60.0001-70%	7
70.0001-80%	8
80.0001-90%	9
90.0001-100%	10

Slope

0-1%	1
1.0001-2%	2
2.0001-3%	3
3.0001-4%	4
4.0001-5%	5
5.0001-10%	7
>10%	10

Classifying the impervious surface data in 10% intervals allows for a simple query when evaluating potential parcels. For this project a suitable parcel will have less than 30% impervious surface coverage and have less than 4% slope. Slopes of over 5% were given higher values to make those cells more “costly” to use. Once the reclassification was complete the ‘Zonal Statistics as Table’ tool was used with the available unused parcels as zones. This determined the average impervious surface coverage and slope of each remaining unused parcel. The resulting tables were then joined to the available parcels layer, using tax parcel number as the join field. A final ‘Select by Attributes’ was performed, which selected every parcel with less than 4% slope and 30% or less impervious surface coverage.

Model

The above procedure was modeled using the ArcGIS ModelBuilder within ArcCatalog. The model was designed to be as general as possible, so data from any region could theoretically be used as long as the input requirements are met. A screenshot of the user interface is located in the Appendix. The required data inputs are an unused parcel layer, restricted or protected parcel layer, a field in the parcel layer that uniquely identifies each parcel, impervious surface raster and elevation raster. All data must have a defined coordinate system. The user is also able to select the output directory for the data generated, coordinate system used for the feature dataset and reprojection of rasters, the distance and units of the protected parcel buffer and the area requirements for the unused parcels as an SQL expression. If necessary, the user is able to select the input coordinate system of the raster layers and the geographic transformation required for correct reprojection into the chosen coordinate system.

The data generated by the model is a file geodatabase that contains the feature dataset, reclassified impervious surface and slope rasters and the zonal statistics tables for impervious surface and slope. The feature dataset contains the original input vector layers, the final suitable parcels, and vector layers for each process step (residential buffer, area filter and joining zonal statistics tables).

Results

Using the discussed parameters and running the model (0.1 mile residential buffer, >0.5 acre area, slope <4% and impervious surface coverage of 30% or less) resulted in 18 suitable parcels out of 881 possible parcels. Most of the parcels are located in the Port of Tacoma area. The average parcel size is 5.12 acres; total area is 92.25 acres. Assuming maximum crop and ethanol conversion yields and maximum area utilization of the parcels, up to 92250 gallons of ethanol could be produced per year. At the current market price of $2/gallon these parcels could generate a maximum of $184500 per year. The total assessed land value of the parcels $16.8 million. Even before equipment and operating costs are included it becomes clear that this operation is not economically feasible.

The results of the model were satisfactory. Total time to run the model was approximately 5 minutes. Each process ran correctly and the output data was correctly named and located in the proper directory.

Analysis

Improvements to the model would require scripting in Python in order to have more precise control over the inputs and variables. A more thorough model could include the option for the user to input the desired and restricted land use designations and have the model go through the parcel layer and create the desired and restricted layers, rather than requiring the user to provide those layers. Another improvement would be simply to have the user enter the minimum area desired rather than needing a correctly formatted SQL statement, although if the user desires a specific range of areas the SQL statement would be more effective. Enabling the user to specify the output names of the generated data could also be useful, but renaming the files in ArcCatalog may be just as easy.

As mentioned in the Planning section, a more complex site suitability analysis could include proximity to railways and major transportation networks, economic analyses regarding cost of developing the land and a network analysis to determine routing and transportation costs. However, given that the basic analysis showed that a switchgrass operation on small urban parcels in Tacoma is not economically feasible, the extra criteria may not be necessary.

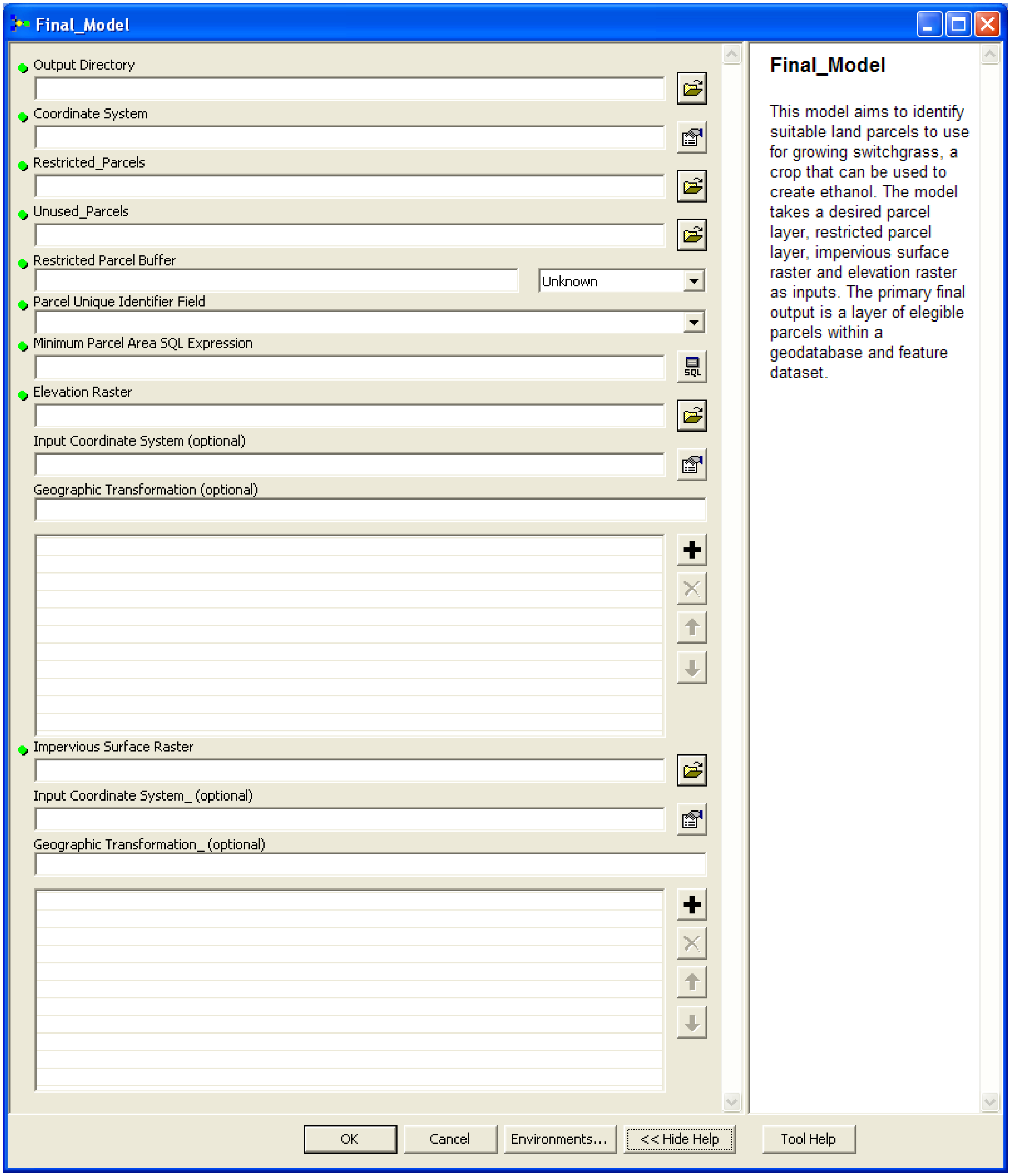
One potential issue with the analysis may occur if the input raster data is clipped to the extent of the region being studied. Originally the analysis was conducted using raster data clipped by a Tacoma boundary layer. After running zonal statistics and joining the tables to the available parcels layer, some parcels had null values in the impervious surface and slope fields. The parcels affected were located at the edge of the Tacoma boundary. In the manual analysis any parcels having null values did not make the final selection. When running the model, however, the null values were replaced with zeros, which satisfies the final selection criteria, even though the actual impervious surface coverage and slope of the parcels is unknown. The solution to this issue is to use raster data that covers a larger extent than the study area. Testing the model with raster data of a larger extent did not result in any null values.

Conclusion

The purpose of this project was to develop a site suitability analysis to evaluate unused urban parcels within Tacoma, Washington as potential sites to grow switchgrass for conversion to ethanol. The process was also modeled so that any region with the appropriate data could run the analysis. Data inputs necessary are a land use or parcel layer, an impervious surface raster and an elevation rater. The model was successfully completed and runs as intended. While the analysis identified 18 parcels in Tacoma that are suitable for growing switchgrass, performing a basic economic analysis reveals that the operation is not cost effective given current ethanol yields and market prices.

Appendix

Screenshot of Model Interface:



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