Using GIS to Detect Changes in Land Use Land Cover for Electrical Transmission Line Sitting and Expansion Planning in Winona County, Minnesota, USA

Charles U. Uzoukwu
Department of Resource Analysis, Saint Mary's University of Minnesota, Winona, MN 55987

Keywords: LULC, NLCD, USGS, GIS, ArcGIS, Cell Statistics, Corridor, Sitting, Transmission Line, Change, Detection, Least Cost Path, DEM, Route

Abstract

Winona County, Minnesota has experienced urban growth and in the last decade this has caused a rapid loss of farm and open space land. These changes in land use and land cover have occurred mostly, with the conversion of forest, crop land and wet area to low density urban use. The development has been mostly residential. As a result, altered land surface characteristics have developed. This project used GIS to assess land use land cover (LULC) changes between 1991 and 2001, and to use this knowledge for the purpose of determining the least cost path for electrical transmission line siting from Minneiska to LaCrescent in Winona County. Sitting an electrical transmission line is more difficult than siting other public infrastructure. Designing the shortest path involved several information layers, these being LULC, elevation/slope, roads, sewer, and utility lines. Each layer was reclassified, ratings applied and combined to create a suitability raster in order to model the final path. In an actual siting, GIS can also help to enhance public involvement, reduce opposition from stakeholders, and increase the probability of acceptance of a project.

Introduction

Winona County is located in south-eastern Minnesota with its county seat located in Winona. The 2000 census listed the population at 49,985 with a total area of 642 square miles (1,662 km^2), of which, 626 square miles (1,622 km^2) was land and 15 square miles (40 km^2), (2.38%) was water.

Today, about 47% of the world's populations are living in urban areas and this number is expected to rise to 60% by 2030. This urban growth has profound impacts on water resources, agricultural land, energy consuming distribution, and the limited remaining open space. A spatiotemporal analysis of growth patterns is essential in order to develop sufficient infrastructure (Li and Zhao, 2003). To determine the most suitable site and shortest path for an electrical network extension, presently network planners work manually, using maps and aerial photographs to find optimal routes. The more factors considered, the longer it takes to evaluate and determine the shortest path. Electrical utilities and other route planners are turning more and more to using GIS as an effective alternative (Barnard, 2006).

Transmission line siting provides an important benchmark for siting problems facing new renewable energy development projects. Therefore, one way to evaluate this challenge is to compare areas with different levels of renewable resource potential in conjunction with the study of areas of

Uzoukwu, Charles, U. 2010. Using GIS to Detect Changes in Land Use Land Cover for Electrical Transmission Line Siting and Expansion Planning in Winona County, Minnesota USA. Volume 12, Papers in Resource Analysis. 11 pp. Saint Mary's University of Minnesota Central Services Press. Winona, MN. Retrieved (date) from http://www.gis.smumn.edu

anticipated transmission line siting difficulty (Vajjhala, 2007).

Since they are not aesthetically pleasing, the process of transmission line routing is highly complex. People are also concerned about health issues like Electromotive Force (EMF). This may create a high level of public opposition (Gill, 2005). Using GIS, a model can be created to overlay any number of requirements into one multi-criteria analysis which is created by reclassifying layers using relevant scores that are spatially added together. In the case of an electrical network, the best route would run along the least slope, avoid forests, wetlands and other ecologically sensitive areas, be routed near to roads, and avoid households while running near densely populated areas in order to easily supply them with electricity (Barnard, 2006).

GIS is increasingly being used to manage electrification, ranging from basic planning to models developed for the full range of information management. Ground breaking practices using GIS and sharing information with other service providers and cities are gaining momentum. In fact, GIS is capable of improving the corridor planning process for anything. Highway and transmission line siting have similar processes and the technology allows planners to solicit, gather, analyze and document information from stakeholders. It introduces transparency and satisfaction for both the public and planners.

This paper develops a Geographic Information System (GIS) based methodology that enumerates various changes that occurred in the Land Use/Cover in the project area (Winona County) within a period of 10 years. It uses available data including roads, sewer, utility lines, zoning, and slope, with the primary goal of analyzing areas suitable for proposed expansion and design of the shortest and least cost path and corridors for electrical transmission lines.

Methodology

Data Collection

For this research, several datasets were required. Data themes including zoning, sewer lines, utility lines, and roads were obtained from the Winona County's Planning Department.

The 1991 and 2001 land use land cover datasets were subsetted from the National Land Cover Dataset (NLCD) created by the US Geological Survey (USGS) to the extent of Winona County. The 2000 census data for Winona County were acquired from the United States Census Bureau.

Ground Elevation Data was obtained from the Winona County's Planning Department. Combined, these sources provided the datasets used for the comprehensive analysis of this project. ArcCatalog 9.3 was used to create geodatabases to store datasets and the results of analysis. Coverages were developed in ArcCatalog and exported into shapefile formats.

Projection

The data used for the analysis were all projected using the USA Contiguous Albers Equal Area Conic USGS Version Projected Coordinate System:

Projection: Albers
False Easting: 0.00000000
False Northing: 0.00000000
Central Meridian: -96.00000000
Standard Parallel 1: 29.50000000
Standard Parallel 2: 45.50000000
Latitude of Origin: 23.00000000
Linear Unit: Meter

The coordinate system of the data frame was set from the coordinate system of the land cover 2001 shapefile. All other data layers added to the frame were projected "on the fly" by ArcGIS and were automatically converted into the Projected Coordinate System of the data frame using appropriate mathematical equations.

Data Preparation

Study Area

The census data were downloaded from the Census Bureau as Microsoft Excel tables, classified and merged into groups and saved as a database file. The LULC dataset was subsetted from its original size to represent the study location from the Northeastern quadrant of the United States using the raster 'clip' tool in 'Data Management Tools' within ArcToolbox. Figure 1 shows the study area (Winona County).

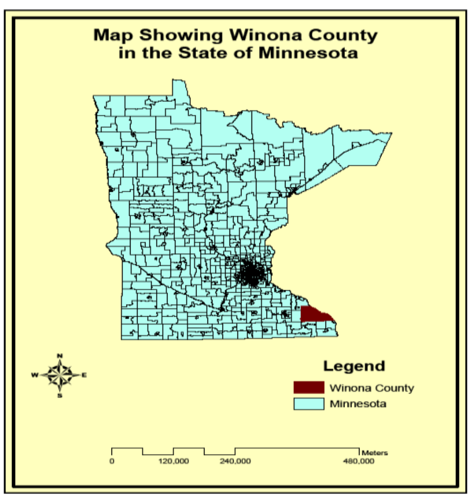

Figure 1. Study area.

The elevation data was scanned creating a Digital Raster Graphic (DRG) and geo-referenced to the UTM Coordinate System based on NAD 27. Datasets (line features) such as roads, utility lines, and slopes (contour lines) were edited to ensure they did not self-overlap with features from the same layer.

Zoning and sewer coverages were already in shapefiles of the study area extent provided by Winona County's Planning Department.

Classification of Land Use Land Cover Categories

For this research, the classification scheme gave a rather broad classification where the land use land cover was identified by specific digits. Table 1 shows the reclassified land use values for 1991. Table 2 shows the reclassified land use values for 2001.

Table 1. Reclassified Land use values for 1991 dataset.

Original Class	**New Class**	**Old Value**	**Reclass Value**
Bare Rock	Barren Land	1	4
Cultivated Land	Agricultural Land	2	2
Deciduous Forest	Forest Land	3	6
Exposed Soil/ Sand Bars/ Dune	Barren Land	4	4
Farmstead/Rural Residence	Agricultural Land	5	2
Grassland	Agricultural Land	6	2
Grassland-Shrub-Tree (Decid)	Agricultural Land	7	2
Gravel Pits/ Open Mines	Barren Land	8	4
Other Rural Development	Built-up Land	9	1
Rural Residential Complex	Built-up Land	10	1
Transitional Agricultural Land	Agricultural Land	11	2
Urban/Industrial	Built-up Land	12	1
Water	Water Bodies	13	3
Wetlands	Wetland	14	5

Both LULC datasets were divided into 14 different pre-determined categories by the USGS. The datasets were converted from polygon features to raster features and then classified using the Reclassify Tool of the Spatial Analyst extension in ArcGIS 9.3.

Table 2. Reclassified Land use values for 2001 dataset.

Original Class	New Class	Old Value	Reclass Value
Water	Water Bodies	1	3
Urban/Industrial	Built-up Land	3	1
Farmstead/Rural Residence	Agricultural Land	4	2
Rural Residential Complex	Built-up Land	5	1
Other Rural Development	Built-up Land	6	1
Transitional Agricultural Land	Agricultural Land	7	2
Cultivated Land	Agricultural Land	8	2
Gravel Pits/ Open Mines	Barren Land	9	4
Bare Rock	Barren Land	10	4
Exposed Soil/ Sand Bars/ Dune	Barren Land	11	4
Grassland-Shrub-Tree (Decid)	Agricultural Land	13	2
Deciduous Forest	Forest Land	14	6
Wetlands	Wetland	16	5
Grassland	Agricultural Land	12	2

The classification scheme developed is shown in table 3, with table 4 showing the class description according to classification developed.

Table 3. Classification scheme developed.

Land Use Land Cover Classes	Value
Built-up Land	1
Agricultural Land	2
Water Bodies	3
Barren Land	4
Wetland	5
Forest Land	6

Table 4. Class description according to the classification developed.

Class	Value	Description of Classes
Built-up Land	1	Rural Residential Complex, Other Rural Development, Urban/Industrial
Agricultural Land	2	Grassland-Shrub-Tree (Decid), Grassland, Farmstead/Rural Residence, Cultivated Land Transitional Agricultural Land,
Water Bodies	3	Water
Barren Land	4	Exposed Soil/ Sand Bars/ Dune, Gravel Pits/ Open Mines , Gravel Pits/ Open Mines
Wetland	5	Wetlands
Forest Land	6	Deciduous Forest

Data Analysis

Area Calculations

This aspect of analysis examined the area and percentage change for each year (1991 and 2001) for each land use land cover type. The ‘count’ field, which represents the number of cells in a particular raster category, was used to calculate area, in acres, for each land use category. In the conversion, one square meter equaled 0.000247 acres. The area calculation was completed using the counts multiplied by the cell size, and then converted to acres. The cell size of the LULC data for 1991 was in feet which were converted to meters by multiplying the cell size by 0.3048 meters. The following results were obtained;

1991
Built-Up Land = 8,564 acres
Agricultural Land = 243,041 acres
Water Bodies = 10,057 acres
Barren Land = 588 acres
Wetland = 1,170 acres
Forest Land = 147,434 acres

Table 5 and 6 show the area and percentage of LULC for both years (1991and 2001).

Table 5. Area and percentage of LULC data for 1991.

Classes	**1991 (Acres)**	**Percent (%)**
Built-up Land	8,564	2.0
Agricultural Land	243,041	59.1
Water Bodies	10,057	2.0
Barren Land	588	0.2
Wetland	1,170	0.4
Forest Land	147,434	36.0
Total	**410,854**	**99.7**

2001
Built-Up Land = 45,974 acres
Agricultural Land = 169,839 acres
Water Bodies = 10,182 acres
Barren Land = 925 acres
Wetland = 1,364 acres
Forest Land = 182,502 acres

Table 6. Area and percentage of LULC data for 2001.

Classes	**2001 (Acres)**	**Percent (%)**
Built-up Land	45,974	11.0
Agricultural Land	169,839	41.0
Water Bodies	10,182	2.0
Barren Land	925	0.3
Wetland	1,364	0.4
Forest Land	182,502	45.1
Total	**410,786**	**99.8**

Analysis to Identify Changes

The most significant changes noted were within the built-up land, and forest land categories. The percentage difference shows a substantial increase in built-up land between 1991 and 2001. The built-up area in 1991 was 2% (8,564 acres) and this increased to 11% (45,974 acres) in 2001, an increase of 437%. There were increases in the urban and in the county townships.

There was an increase in forest land from 1991 (147,434 acres) to 2001 (182,502 acres) with a percentage increase of 44%. This change may be somewhat related to the decrease of agricultural lands within the county. Agricultural land decreased significantly by 30% from 1991 to 2001. Both barren land and wetland exhibited change between the datasets. Barren land increased from 588 acres in 1991 to 925 acres in 2001 representing 57% increase. Wetlands increased by 17% from 1,170 acres in 1991 to 1,364 acres in 2001.

Water bodies exhibited minimal change which weren't significant visually. Figures 2 and 3 illustrate the changes that occurred over the 10 year period. Table 7 gives a tabulated illustration of the percentage change.

Table 7. Percentage change.

Classes	**Percent (%)**	**Change**
Built-up Land	437.0	Increase
Agricultural Land	30.0	Decrease
Water Bodies	1.2	Increase
Barren Land	57.3	Increase
Wetland	16.6	Increase
Forest Land	23.8	Increase

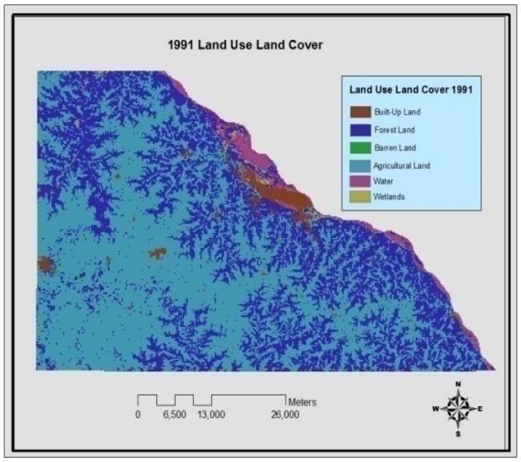

Figure 2. LULC dataset for 1991.

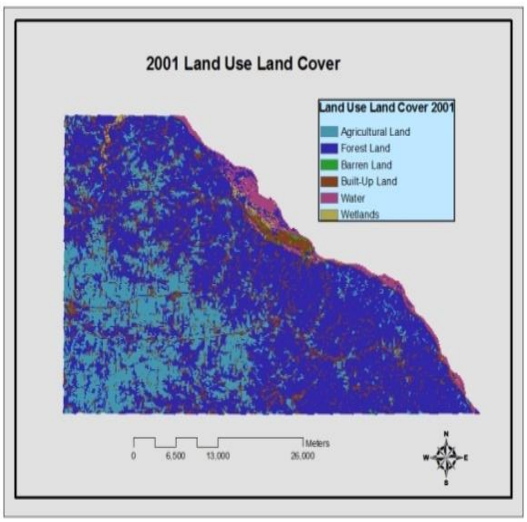

Figure 3. LULC dataset for 2001.

Land Use Land Cover Change Detection Using Cell Statistics

Using the Cell Statistics Function in Spatial Analyst, changes that occurred between LULC 1991 and 2001 were identified. The general setting and raster analysis setting was established in the environment setting. The input rasters used were both the 1991 and 2001 layers. The results and overlay statistics were written to a geodatabase. The output indicated areas where change had and had not occurred using two values 1 and 2.

To isolate areas of change, the CON function from the ArcToolbox was used. The value of 1 indicated areas of no change. Cells with a value of 2 indicated areas where land cover had changed. A new raster was created showing only areas of change. A conditional statement was used indicating that if a cell value was greater than 1, then it should be given a value of 10 in the new raster. One (1) values, were converted to a NoData value. The LULC change raster shows only one value, 10, which are the areas of LULC changes. For this analysis, the cell statistics function was used to detect change in LULC overtime because it operates on multiple rasters. It compares rasters cell by cell, using the variety statistical method (Figure 4).

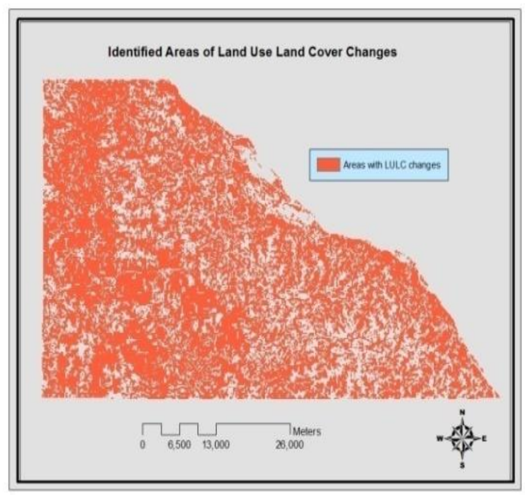

Figure 4. Areas where LULC changes occurred.

Surface Analysis

The Surface Analysis tool “Hillshading” was used in order to create a view of the terrain. Using the DEM (Elevation) dataset, a map of shaded relief was created using the grays in the hillshade to set the lightness of the colors in the thematic layer on a cell-by-cell basis (Figure 5). Hillshading was beneficial as it helps to show the presence of steep slopes (valleys) that exist in the county. It was also used to determine suitable areas for corridor (route) development.

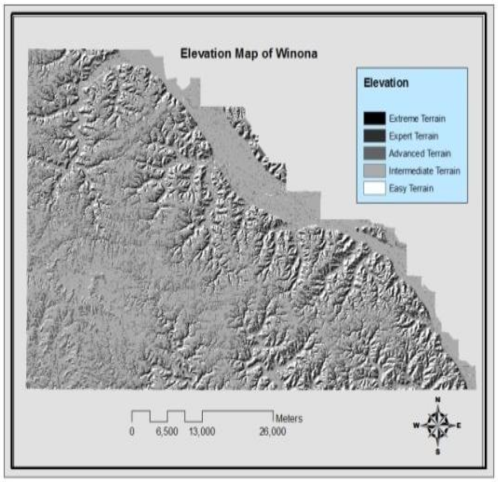

Figure 5. Classified hillshade (DEM) map of the study area.

Surfaces classified as “Easy Terrain” represented more suitable routes while, areas with “Extreme Terrain” would be less suitable.

Least-Cost Path Analysis

To create a line that connects Minneiska (start point) and LaCrescent (end point) with the least resistance, a Least-Cost Path Analysis was conducted. The analysis used the cost-weighted distance and direction surfaces for the study area to determine the most cost-effective route between the start and end points. Figure 6 shows the process developed to find the least-cost path.

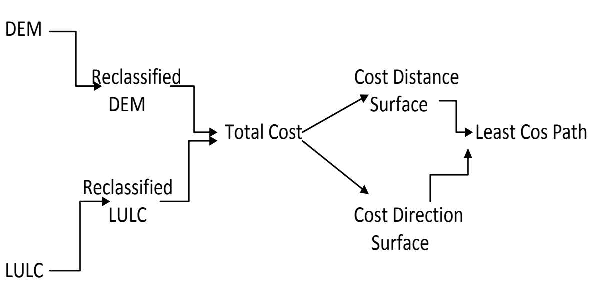

Figure 6. Model showing process involved in finding least-cost path.

Using the spatial analyst tool, a total cost layer was created by adding the DEM and LULC layers. A cost-weighted analysis was performed which created two new surfaces: a Cost Distance (aggregated cost of construction) layer and a Cost Direction (opportunities and obstruction to flow) layer. These were then used as inputs for the least-cost path analysis.

The least-cost path for this research consisted of land with fairly flat terrain, but with consideration of the distance between the two sites. Built-up or developed land (residential, industrial, rural and urban) and water bodies were avoided.

Corridor/Route Identification

With the start and end points identified within a defined area of interest, two datasets (LULC and DEM) were used for the analysis. Both layers were already in raster format and were added together to create a total cost surface. The layers were reclassified with numeric values. Zero values were represented as “NoData” as the spatial analyst will not allow the path to go through NoData cells.

Using the Plus Tool in the math toolset, a total cost layer was created combining the common scale values for the reclassed DEM and the reclassed LULC layers. Data in both layers were ranked using a common scale and then added to create the total cost layer. In order to find the least-cost path for a transmission line, the cost distance and cost direction layers were created using the Cost Distance Tool in the Distance Toolset. The cost distance represents how costs accumulate as you move further away from the start point. The layer takes into account the measured distance from start point and the values of total cost layer for each location cell on the map. The cost direction layer takes into account the total cost layer and determines the bearing to the easiest (least costly) path.

Finally, the Least-Cost Path function was used to create the most suitable corridor avoiding extreme terrain elevation and costly LULC types between LaCrescent and Minneiska. The path followed existing road corridor and avoided edges of water bodies and wetlands. Other considerations could be incorporated into the least-cost path model should they be desired and would be represented as additional input raster layers in the analysis.

Results

This project was based on identifying LULC changes that occurred in Winona County over a period of 10 years between 1991 and 2001. Information was derived to use as input for electrical transmission line siting hypothesized to run from the south-eastern region (LaCrescent) to the north-western region (Minneiska) in Winona County. It was intended to modify and develop a Geographic Information System (GIS) analytical framework to facilitate the choice of route/ corridor selection should one be desired in the future. Criteria's considered for the siting decision making were the rate of change in LULC, elevation, and proximity to roads. The Minneiska area was chosen as it is the closest city to the substation located in Alma, Wisconsin which reiterates its choice as the most logical start point.

Both locations used as start and end points were used because of their geographic location and adherence to the research criteria's. The LULC in Winona County was predominantly divided between agricultural land and forest land which shows the significance of the dataset for corridor/route siting for this research. Figure 7, 8, and 9 illustrates different scenario results from Least-Cost Path Analysis carried out using different criteria. Figure 10 is an overlay of all scenarios and criteria's generated from the analysis.

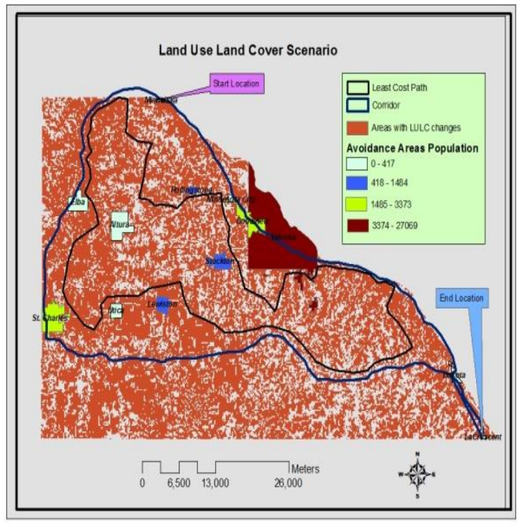

Figure 7. Corridor scenario illustrating LULC criteria.

The DEM was also an important element for determining the route because of the area's undulating terrain characterized by hills and valleys.

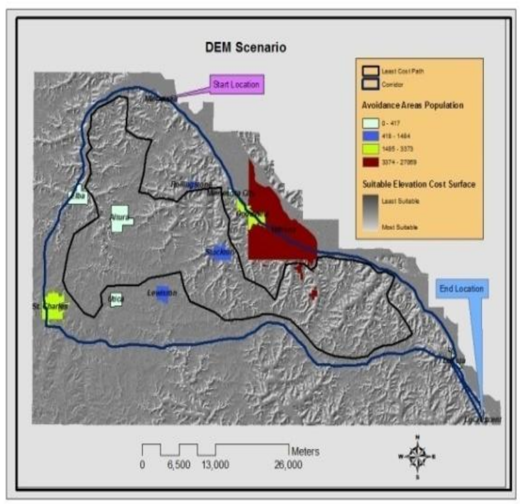

Figure 8. Corridor scenario illustrating DEM criteria.

In Figure 9, the corridor was located near existing road corridors and runs through undeveloped areas (agricultural and forest land). Results were favorable for future planning, and construction.

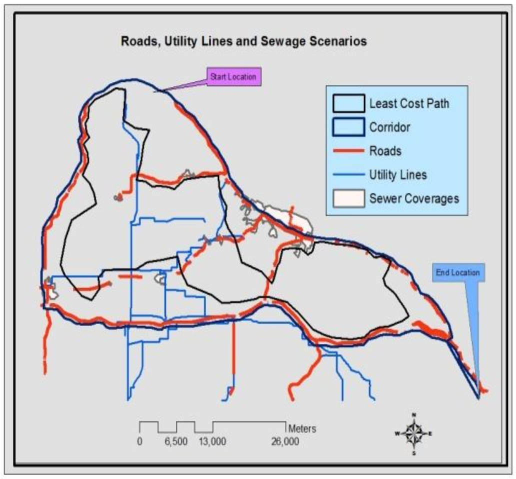

Figure 9. Corridor scenario illustrating road criteria.

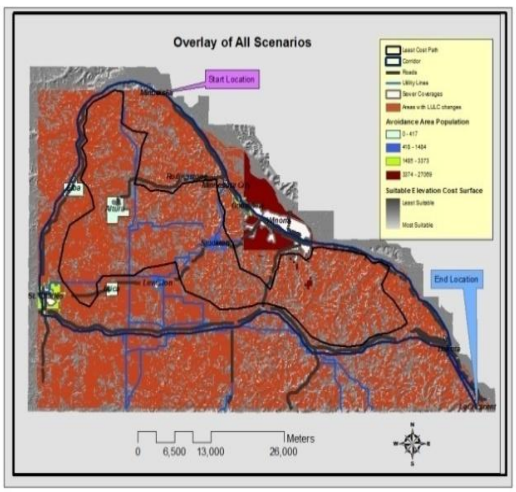

Figure 10. Overlay of all scenarios.

Project Error

During this project a simple method to improve change estimates by detecting and correcting erroneous changes resulting from positional errors was analyzed. The error inherent in spatial data deserves closer attention and understanding which this project puts into consideration. Because error is inescapable, it should be recognized as a fundamental dimension of data.

Classification Accuracy Assessment

The accuracy of both datasets (1991 and 2001) was fundamental before being used for the analysis to identify changes and area calculation for this project. Classification procedure and scheme developed for this project are likely to have resulted in the identified area of changes in LULC within a period of 10 years as shown in Figure 4.

Change Detection Accuracy Assessment

The LULC change map was a fundamental factor for identifying the most suitable path for siting the transmission line. Knowledge of the accuracy of the change was an important requisite in using the map to determine the least-cost path for siting the transmission line. The detection of LULC change within a period of 10 years for this project was a complex procedure that is incapable of producing consistently accurate results. Potential causes of inaccuracies that may occur in the data for this project include: the lack of sufficient spectral seperability between various categories of land use land cover; and the complexity of the land uses within certain areas in Winona County. Other sources of error that might be associated were the classification system, data conversion, and data generalization. A statistically valid assessment of the accuracy associated with the change detection analysis was an essential element. Since the approach used to measure the accuracy of the original datasets used were unknown, a rigorous accuracy assessment of the change map product was required. Assessing the accuracy of a change map is significantly more difficult than assessing a one point in time classified map and requires extensive consideration and planning.

Conclusions/Recommendations

In general, transmission lines are routed through less populated areas due to aesthetic, health hazards, and socioeconomic reasons. Lack of power is a limiting factor for population growth because population will not grow in areas with insufficient supply of energy. Line siting in areas which are close to wetlands and water bodies are avoided because, if present may affect the habitat and wetland species such as electrocution of bird, and sediment deposition in water bodies during construction among others.

This research shows that routing/siting a transmission line is not only a planning problem but also includes environmental, construction, and safety issues. GIS gives transparency, and an analytical mechanism for comparing values which can be applied to line routing to determine the least cost route between two points. However, the major objective was to identify a route that might be developed with minimum opposition: This work could be extended from the transmission level to the routing of overhead and underground distribution facilities. Using GIS for electrical transmission line siting is a viable tool for planning and network expansion, and ideal for the placement of new substations.

Furthermore, optional criteria could be created for the determination of the shortest path for connecting new customers to existing networks. This would improve performance, expansion, and reducing short and long term costs.

Acknowledgement

My profound gratitude goes to God Almighty who in his infinite love and strength guided me through this research project and entire program. My heartfelt thanks goes to my professors Dr. David McConville, Patrick Thorsell, and John Ebert for their immense contributions towards achieving my educational goal and ensure a tremendous and rewarding experience at Saint Mary's University of Minnesota. Special thanks goes to my classmates for their assistance during the course of my program, to them I remain grateful.

I would like to express my appreciation to the Winona County Planning Department for supplying me with necessary data needed for analysis. Thanks also go to all support staff of the Department of Resource Analysis, and entire Saint Mary's University community for giving me the opportunity to enjoy its wonderful resources and friendly environment. My distinct appreciation goes to my parents for their financial sacrifice and my cousins for their encouragement and everlasting support during my entire program. Finally, I want to say "thank you" to all benefactors who I did not mention specifically.

References

Barnard, J.B. 2006. *An Investigation into Using GIS in Network Planning in Rural Kwazulu- Natal*. Eskom Distribution. Eastern Region. Retrieved on February 8, 2010, from http://www.gisdevelopment.net/application/utility/power/maf06_30.htm.

Gill, R.S. 2005. *Electricity Transmission Line Routing Using a Decision Landscape Based Methodology*. Report. College of Engineering. Wichita State University. Retrieved on January 29, 2010, from http://soar.wichita.edu/dspace/bistream/10057/752/1/t05043.pdf.

Li, J., and Zhao, H. 2003. *Detecting Urban Land Use and Land-Cover Changes in Mississauga Using Landsat TM Images, Journal of Environmental Informatics 2,* Issue 1, 38-47. Retrieved on February 14, 2010, from http://www.iseis.org/jei.

Vajjhala, S.P. 2007. Sitting Difficulty and Renewable Energy Development: *A Case Of Gridlock.* Publication. Resource

Magazine. Retrieved on March 2, 2010,
from http://www.rff.org/RFF-Resources-
164-SitingDificulty.pdf