Cartographic Modeling for Site Selection

Using Vector and Raster Analyses to Determine Land Suitability for Biosolids Application in the Gun River Watershed based on Michigan Department of Environmental Quality (MDEQ) Criteria

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Abstract

The application of biosolids (sewage sludge) to agricultural lands provides numerous benefits. When applied directly to the land or incorporated into the soil, biosolid material can provide essential nutrients for plants and ultimately improve soil richness and soil productivity. Sewage treatment plants use landfills or incineration as disposal methods; land-applying biosolids is increasing as a more cost effective and environmental-friendly method of disposal. The purpose of this exercise is to use a Geographic Information Systems (GIS) model for determining site-specific application of biosolids to agricultural lands in the Gun River Watershed, southwestern Michigan. Suitability is based on guidelines provided by the Michigan Department of Environmental Quality (MDEQ). The criteria for suitability includes slope, land cover, and isolation distances to hydrology, roads, and domestic wells. Additional research should be considered to include other factors, such as soil characteristics, biosolid properties, and isolation distances to groundwater, municipal and noncommunity public wells, and commercial buildings and homes.

Introduction

Millions of tons of sewage sludge (biosolids) are generated annually from wastewater treatment plants across the United States and Canada (Francek et al. 1999). Historically, sewage sludge materials were sent to landfills, incinerated, or even diluted into local waterways; methods that were costly and detrimental to the environment. The Clean Water Act provided the necessary “backbone” to improve wastewater treatment plant facilities and operations, therefore putting a stop to improper disposal practices.

A disposal option of sewage sludge that is getting research attention is application to crop fields, disturbed lands, and forested areas. Utilization of sewage biosolids on agricultural land as crop nutrient input is a common practice in Ontario (Payne et al. 2001). The application of this material returns nutrients to the soil for healthier plants and is an excellent source of organic material. Biosolids can improve soil texture, water holding capacity, and provide food to soil microorganisms. The material from the wastewater treatment plant contains total nitrogen, organic material, and elemental phosphorus; other nutrients will be present as well. Chemical analysis is required to determine nutrient and heavy metal content, as well as calculation of agronomic rates (Payne et al. 2001).

Proper application of this material to agricultural land is essential. Heavy metals, disease-causing agents, therapeutic agents, and eutrophying nutrients are found in sewage sludge that makes this material a safety concern. Heavy metals commonly found in sewage sludge include arsenic, cadmium, chromium, cobalt, copper, lead, mercury, molybdenum, nickel, selenium, and zinc. The quality and application rate is determined by the amount of available nitrogen and the quantities of these metals (Payne et al. 2001).

How do we determine suitable land for sewage sludge (biosolids) application? This can be challenging because of the complex social and environmental issues related to inadequate or excessive application of biosolids to agricultural lands. When spatial data is available, geographic information systems (GIS) can aid in proper identification of suitable and unsuitable sites in a timely and cost-effective manner. GIS allows us to input spatial and attribute data and perform calculations that meet certain criteria.

Michigan does allow the application of biosolids to agricultural land. Before sewage biosolids can be used for land application in Michigan, the material must meet the criteria (Table 1) outlined in the Michigan Department of Environmental Quality (MDEQ) Administrative Rules Part 24. Land Application of Biosolids. This document provides the necessary criteria to apply biosolids to agricultural land. The person land applying material must also obtain a general permit authorizing land application of biosolids; a requirement under the MDEQ National Pollutant Discharge Elimination System (NPDES). According to MDEQ, the following factors and criteria are used for determining site suitability of land applying biosolids.

- Agricultural land, forested land, barren land, and reclaimed land are typical land types used for land application of biosolids.
- A person shall not apply bulk biosolids to agricultural land having a slope of more than 6% for surface application or more than 12% for subsurface injected biosolids.
- Isolations distances for hydrology and domestic wells are provided in Table 1. The isolation distance to roads was imposed as an additional layer, but not included in the MDEQ guidelines.

Table 1. Criteria for Land Application of Biosolids

Criteria	Injection or surface application with incorporation (Raster Analysis)		Surface application without incorporation (Vector Analysis)	
	Suitable	Not Suitable	Suitable	Not Suitable
Slope	0 – 12%	> 12%	0 – 6%	> 6%
Land Cover	Agriculture	Not Agriculture	Agriculture	Not Agriculture
Hydrography	> 50'	< 50'	> 150'	< 150'
Transportation	> 100'	< 100'	> 100'	< 100'
Domestic Well	> 100'	< 100'	> 150'	< 150'

Study Area

The purpose of this exercise is to use existing vector and raster data to identify suitable land for the application of biosolids, an end product from the wastewater treatment facility. The study area for this project is the Gun River Watershed (Watershed), located in southwest Michigan (Figure 1). The Watershed encompasses an area of 73,272 acres (114 square miles) in Allegan and Barry Counties, Michigan. The Gun River flows from Gun Lake through agricultural land into the urbanizing area of Otsego Township, Allegan County, where it joins the Kalamazoo River. The Watershed encompasses portions of Wayland, Martin, Gun Plain, and Otsego Townships in Allegan County, and portions of Thornapple, Yankee Springs,

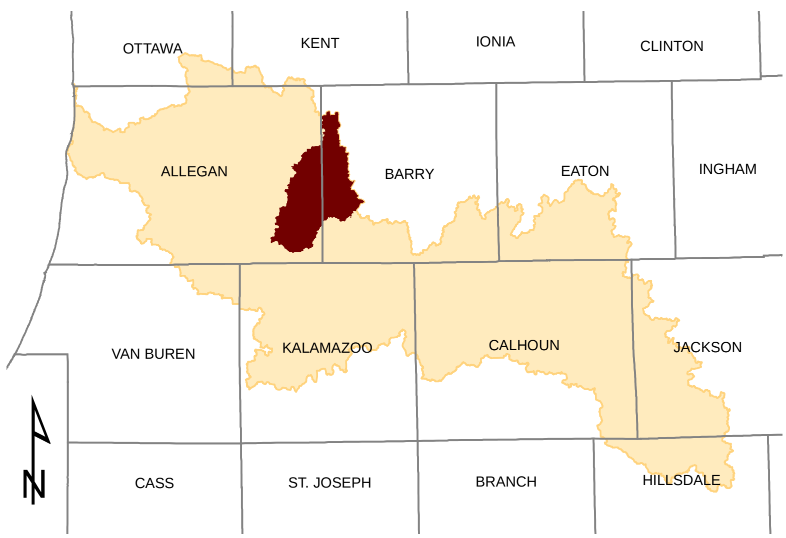


Figure 1. Gun River Watershed Location

Orangeville, and Prairieville Townships in Barry County. The eastern half of the Village of Martin and the northeast section of the City of Plainwell (both within Allegan County) are also within the Watershed. The majority of Gun Lake lies in Barry County. The distance between the outlet at Gun Lake and the mouth of the Gun River where it enters the Kalamazoo River is about 12 miles.

Agriculture is the predominant land use (approximately 55%) in the Watershed, however large portions of land in the eastern part of the Watershed are included in the Barry State Game Area and the Yankee Springs Recreation Area, which are, and will remain, as woodlands. The agricultural production in the area includes corn, soybeans, wheat, and oats. A large amount of farmland is also used for pasturing and growing alfalfa.

Data

The data used for geographic information system (GIS) analysis comes from the Michigan Center for Geographic Information (www.michigan.gov/cgi). The factors that I plan to use during the analysis to determine land suitable for biosolids application includes slope (digital elevation model), land cover, hydrography (surface water features), transportation, and drinking water wells. Because the Gun River Watershed splits Allegan and Barry Counties, I downloaded feature files for both jurisdictions.

The Michigan Center for Geographic Information provides a geographic framework (updated to Version 6b on July 20, 2006) for the entire State of Michigan. This framework includes such layers, as roads, rivers, lakes, streams, political boundaries, school district boundaries, and census area boundaries. The framework geography is maintained in the Michigan GeoRef projection system, a form of an Oblique Mercator projection. For additional information, refer to Michigan Geographic Framework metadata file available at www.michigan.gov/cgi.

Land cover used for analysis was provided by the Michigan Center for Geographic Information. The United States Geological Survey (USGS) created the National Land Cover Data (NLCD) in 1992. Each grid cell represents land cover and has not been modified or updated by the Michigan Center for Geographic Information. For additional information, refer to the NLCDmeta.txt file, which contains the metadata as created by the USGS.

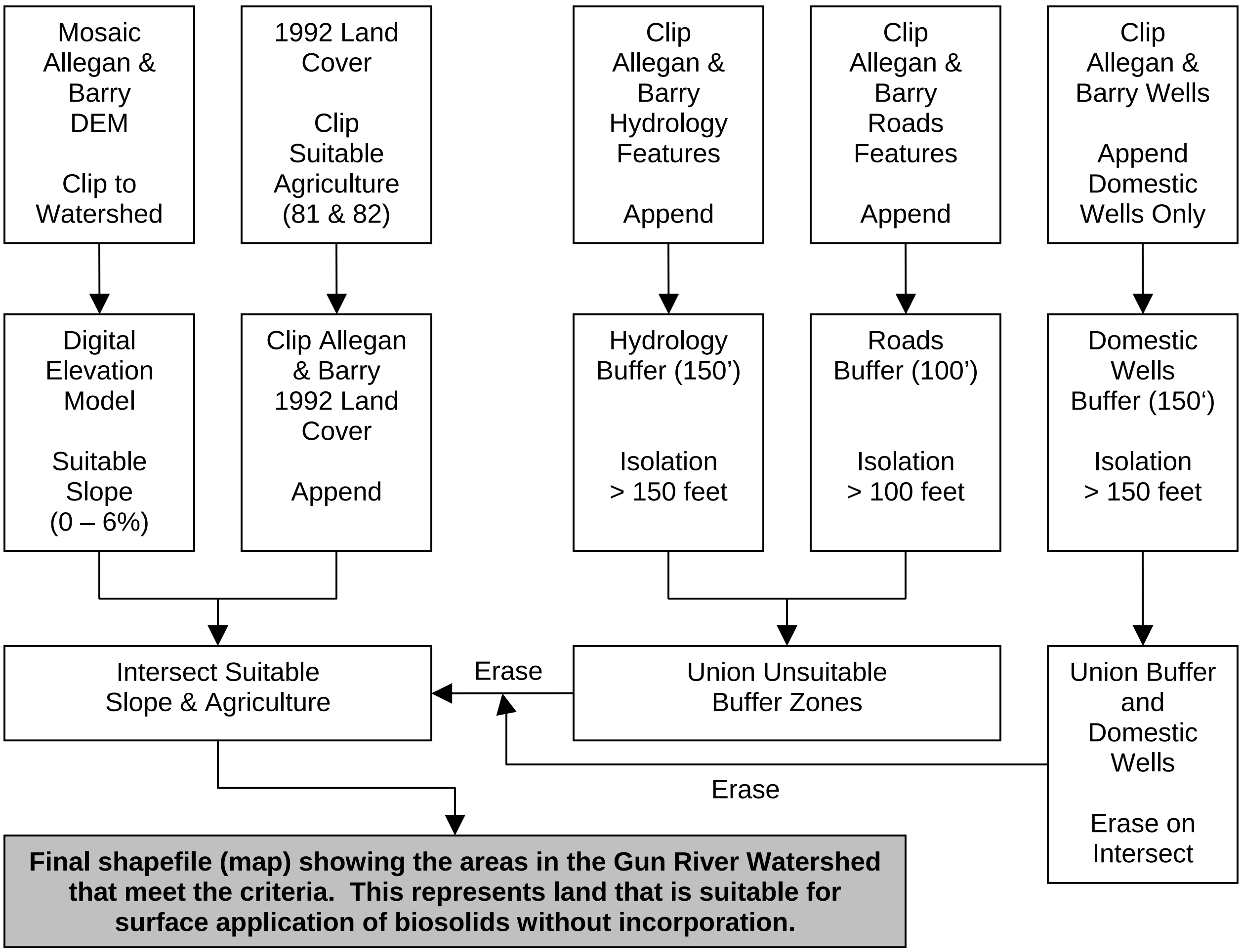
Methods

Site selection is a spatial problem that requires inputs of large volumes of biophysical, environmental, and sociopolitical data (Basnet et al. 2001). There are two types of application methods for biosolids in Michigan: (1) injection or surface application of material with incorporation into the soil and (2) surface application of material without incorporation into the soil. I chose to conduct two separate GIS analyses to determine suitability for both methods using vector and raster analyses.

Vector Analysis

Vector analysis included uploading the applicable layers and completing map overlay functions as described in Flow Diagram 1. All features were clipped to the two counties and then each feature was appended to form the data within the watershed boundary. Spatial analysis of the digital elevation model (DEM) was conducted to determine areas of 0-6% slopes, the criteria set for surface application of material without incorporation into the soil. The raster was converted to a feature for map overlay analysis. Areas of agriculture were selected from the land cover dataset.

Flow Diagram 1 ◆ Vector Analysis

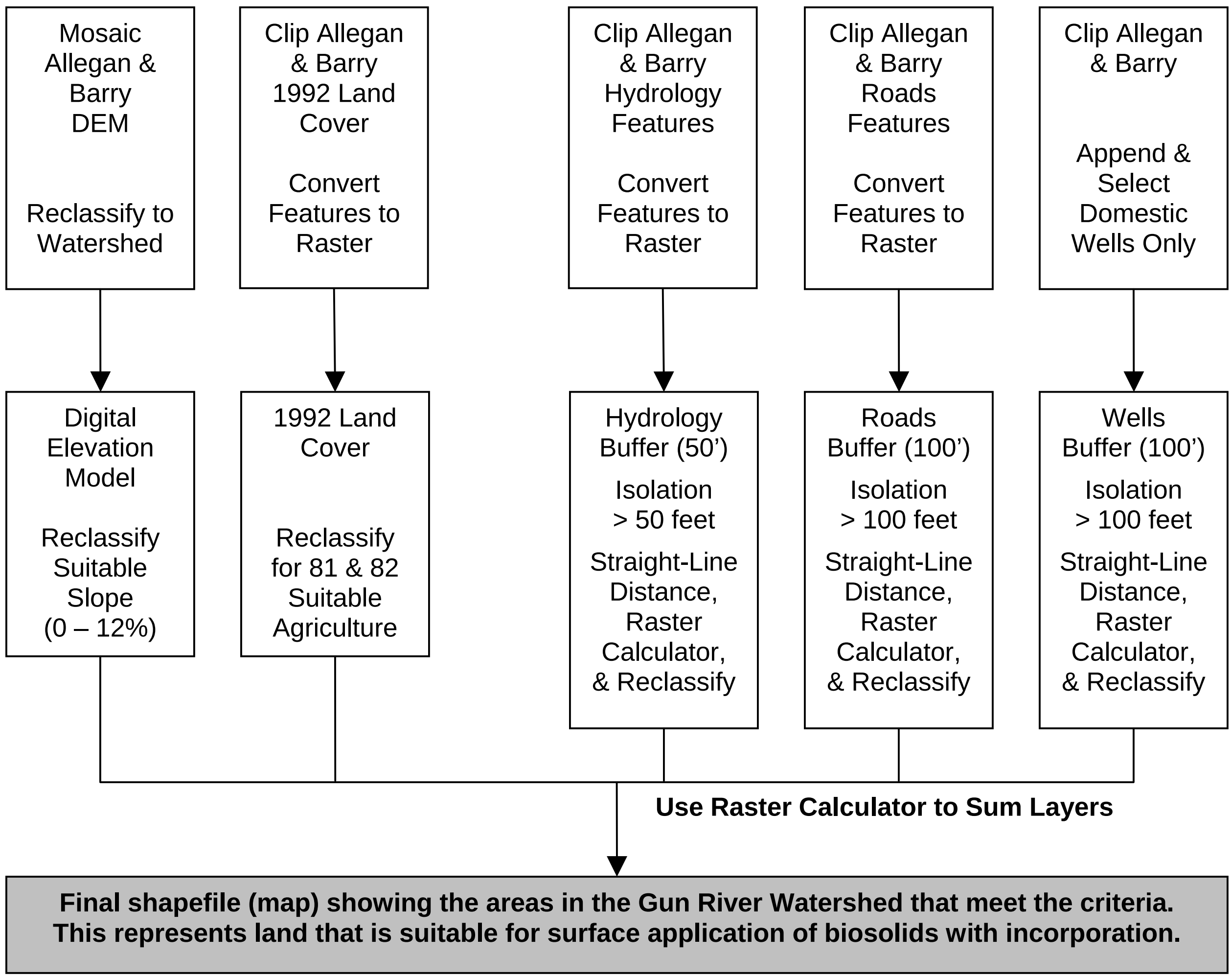


Buffers with the appropriate isolation distances were placed and extracted for hydrology, transportation, and domestic wells. By performing map overlay functions, a final suitability map was created.

Raster Analysis

Raster analysis included uploading the applicable layers and completing reclassification of the watershed boundary, as to represent the “clip” layer. The land cover, hydrology, and roads layers were converted to raster. Spatial analysis of the digital elevation model (DEM) was conducted to determine areas of 0-12% slopes, the criteria set for injection or surface application of material with incorporation into the soil.

Flow Diagram 2 ◆ Raster Analysis



The buffers for hydrology, roads, and wells were calculated by using the straight-line distance function under the spatial analyst toolbar. All layers were summed using the raster calculator to determine land application suitability.

The data retrieved from the Michigan Center for Geographic Information is projected in Michigan GeoRef and the units of measurement are in meters. The grid size (pixel size) is 30 meters by 30 meters. For the purpose of this exercise I used the resample tool to adjust the cell size of the raster datasets to meet the isolation distance criteria. The grid sizes for the raster datasets are 15.24 meters by 15.24 meters, which is equal to 50 feet by 50 feet, an applicable isolation distance to the aforementioned criteria.

Results/Discussion

The digital elevation model was used to determine those areas within the watershed that meet suitability criteria. Any biosolids land applied without incorporation into the soil (surface application only) must be on slopes no greater than 6% (Figure 2). Primarily the land on both sides of the Gun River represents this area. The areas on the east side of the watershed are very steep slopes, heavily forested, and make up part of the Yankee Springs recreation area and the Barry State Game Area.

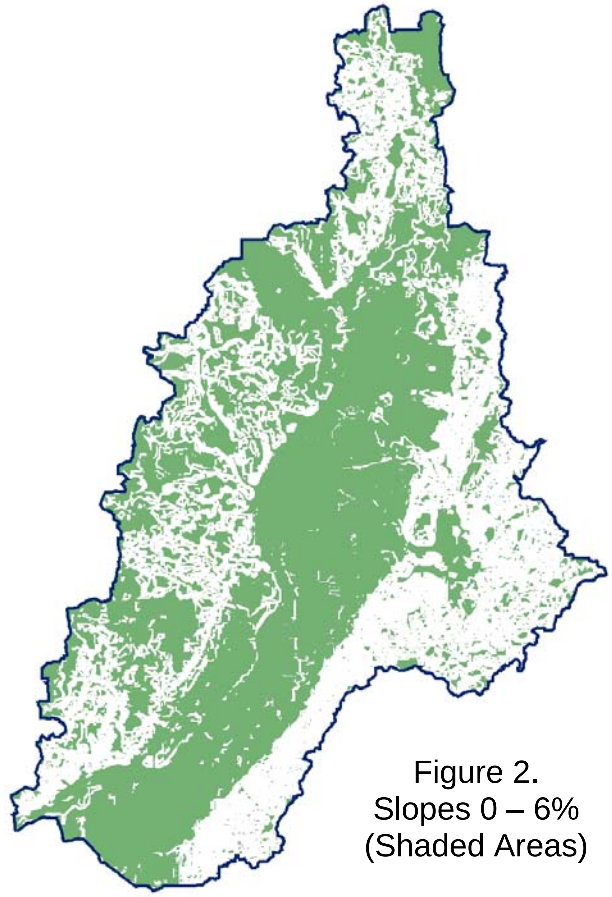


Figure 2.
Slopes 0 – 6%
(Shaded Areas)

Biosolids material that are injected or applied on the surface and incorporated into the soil can be land applied on slopes no greater than 12% (Figure 3). We still see steeper slopes on the east side of the watershed, areas concentrated primarily by forested land.

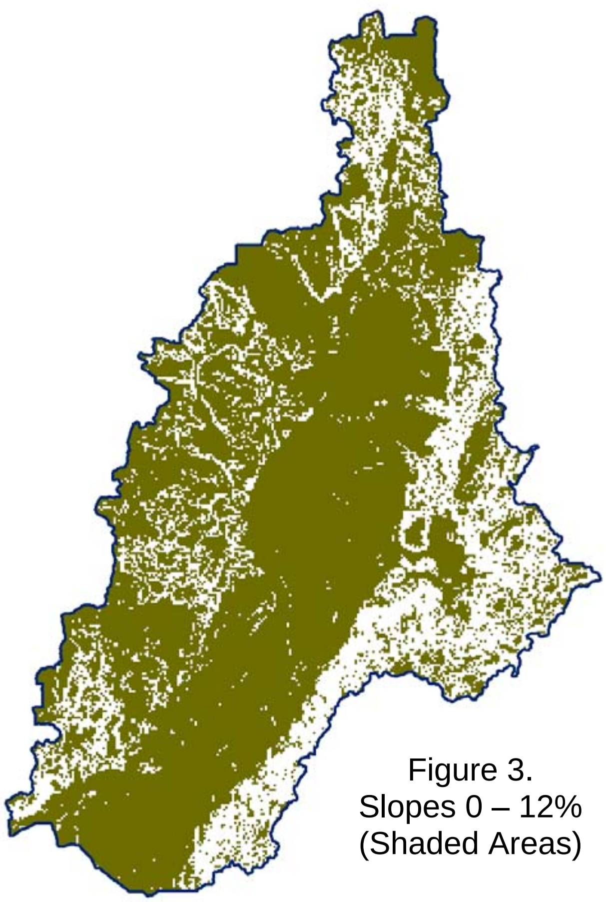


Figure 3.
Slopes 0 – 12%
(Shaded Areas)

Application of biosolids will occur on agricultural land as an added source of plant nutrients and organic material. The Gun River Watershed consists of 57% agricultural land (Figure 4) based on 1992 National Land Cover Dataset (NLCD). The vector and raster analyses for agricultural land are very similar; so one map is illustrated to show the agricultural areas within the Watershed.

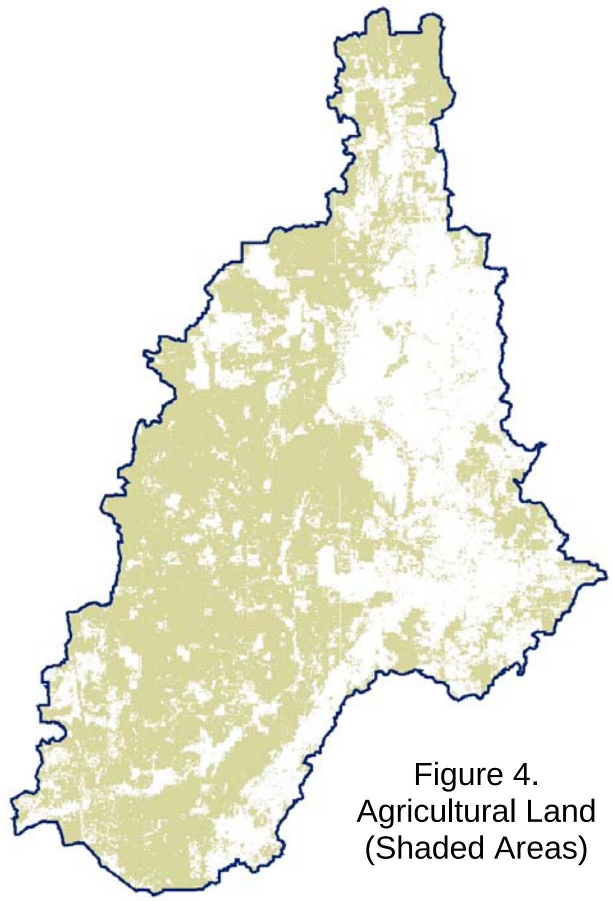


Figure 4. Agricultural Land (Shaded Areas)

The hydrology of the Gun River Watershed includes Gun Lake, smaller lakes, the Gun River, and a network of tributaries and county drains (Figure 5). The Gun River discharges into the Kalamazoo River near Otsego, Michigan. The isolation distance for hydrology depends on the application method. A 50-foot (15.24-meter) buffer was placed on surface water features when material is injected or surface applied with incorporation. A 150-foot (45.72-meter)

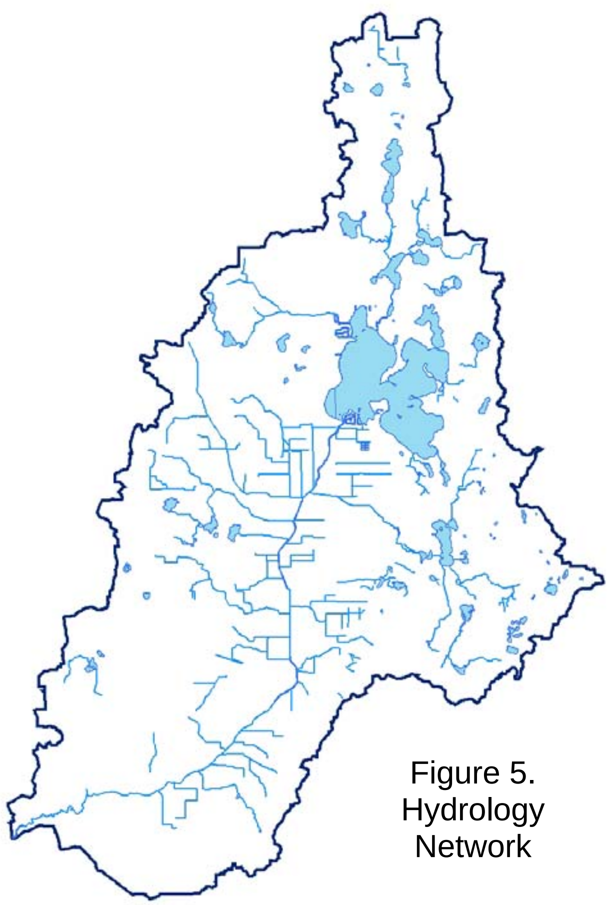


Figure 5. Hydrology Network

buffer was used when material is surface applied without incorporation.

The rules for land application did not have any isolation distances from roads. A 100-foot (30.48-meter) isolation distance was imposed on all roads (Figure 6). Application of this material may shed negative impact on the community; by imposing the isolation distance on the roads, human exposure and social implications may be minimized.

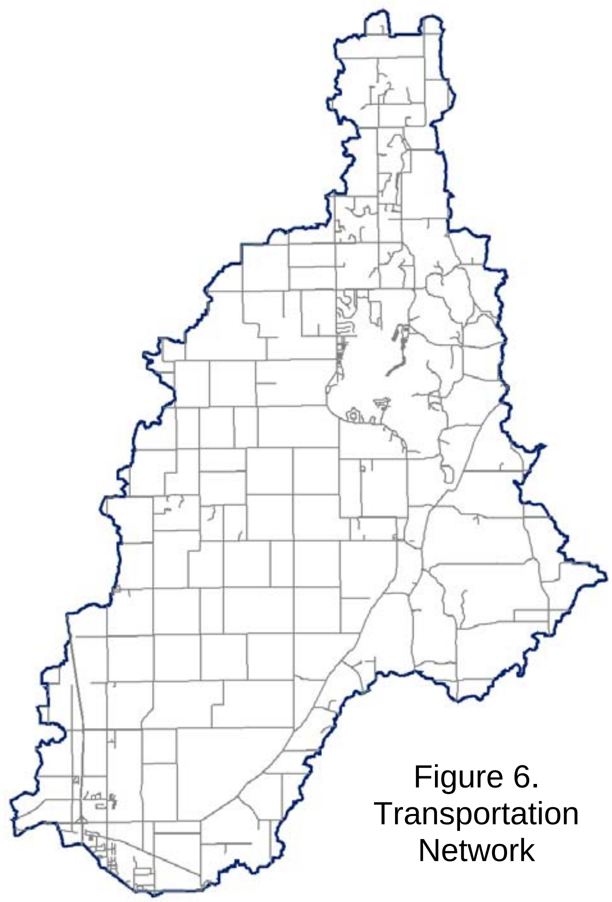


Figure 6. Transportation Network

Most of the people in this Watershed rely on groundwater as the source of drinking water. Protection of the resource is critical. The rules require 100-foot and 150-foot isolation distances to wells for injection and surface application, respectively. Nearly 1200 domestic wells (Figure 7) are found within the Gun River Watershed. For this exercise, municipal and noncommunity public water supplies were eliminated from the dataset.

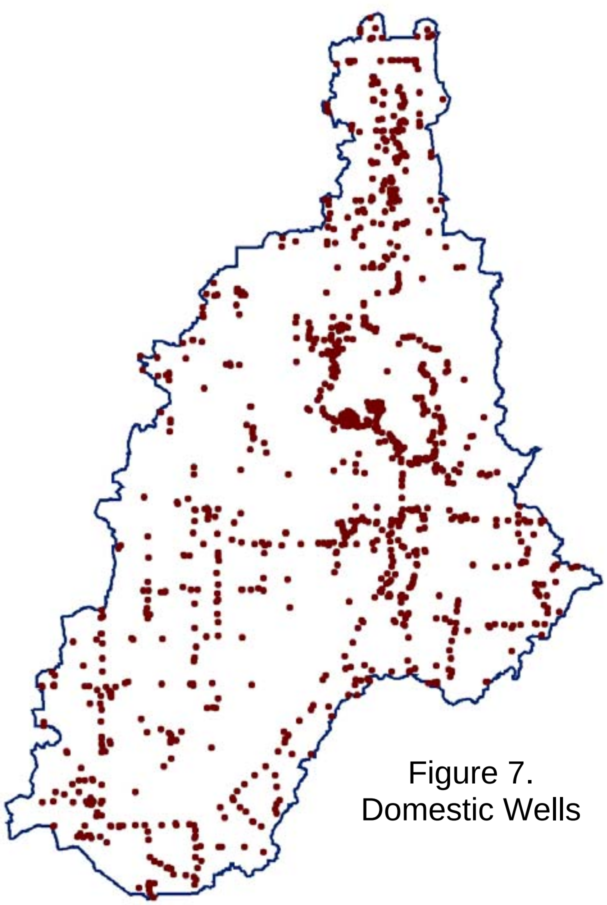


Figure 7. Domestic Wells

Based on the criteria and the map layers produced, two separate products were created depicting the criteria for biosolids application.

- A map showing all agricultural land suitable for applying biosolids to the surface of the land and not incorporating into the soil (Figure 8).
- A map showing all agricultural land suitable for injecting biosolids directly into the soil or applying biosolids to the surface of the land and incorporating into the soil (Figure 9).

The result of this process is a graphic display using computer cartography (Geographic Information Systems) of sites that are suitable for land application of sewage waste (Hendrix and Buckley 1992).

Conclusions

There were several factors that were not included in the cartographic site selection model that are equally important. These include soil characteristics (pH, texture, type, etc.), biosolids properties, isolation distance to groundwater, isolation distances to municipal and noncommunity public wells, and isolation distances to commercial buildings and homes. Additional spatial layers and attribute data are needed to build these layers into the model for refinement. Further research applications could include maps that would depict a range of suitable sites for biosolid application from most suitable to least suitable.

Finer grid (pixel) size may be important to achieve greater detail. Because the isolation distances provided in MDEQ guidelines are in increments of 50 feet, I adjusted the grid size to match these distances. This may impose some error do to the resample process in ESRI ArcMap.

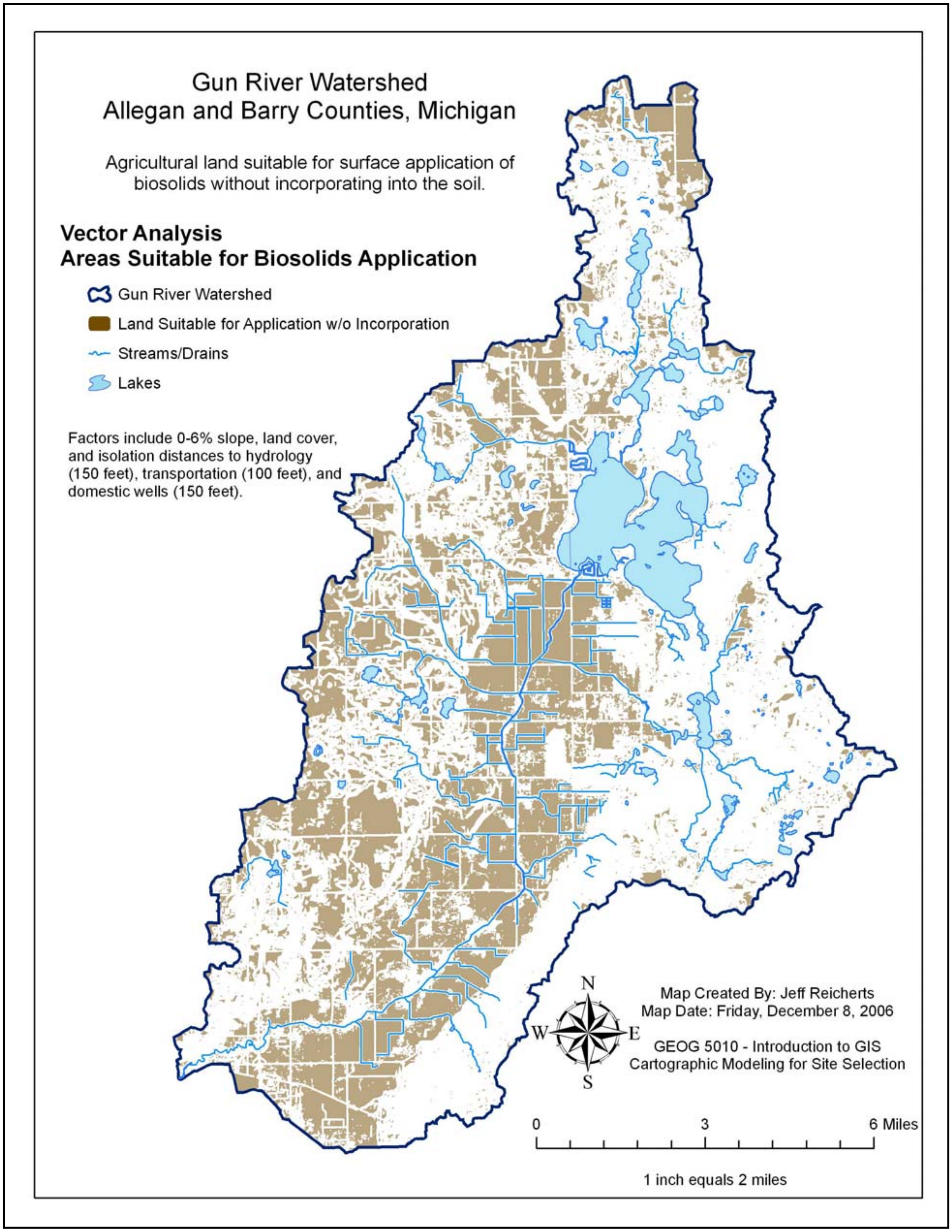


Figure 8. Agricultural Land Suitable for Surface Application of Biosolids without Incorporating into the Soil

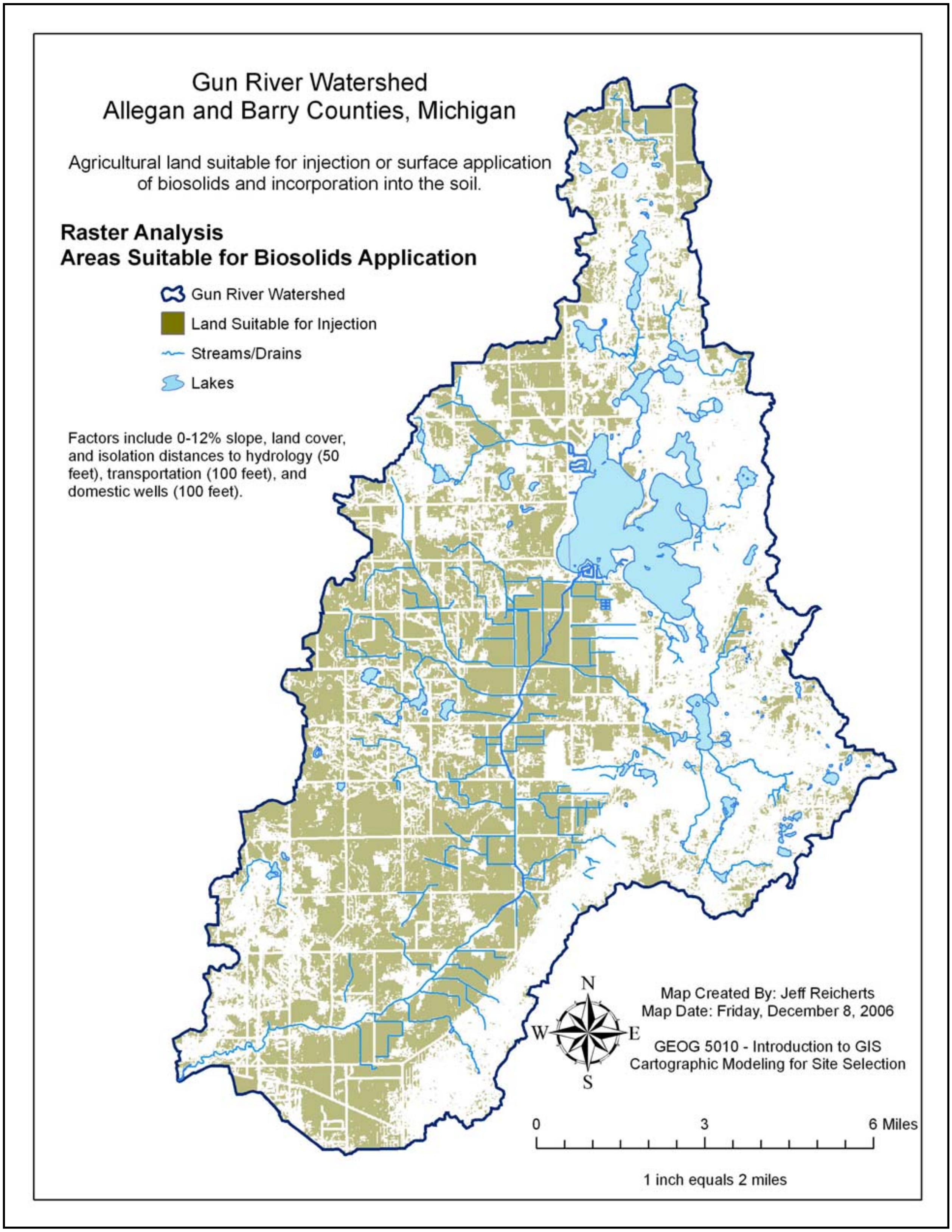


Figure 9. Agricultural Land Suitable for Injection or Surface Application of Biosolids and Incorporating into the Soil

This exercise illustrates the applicability of using Geographic Information Systems (GIS) as a tool for site-specific application of biosolids to agricultural lands in the Gun River Watershed. The influential factors include slope, land cover, and proximity to hydrology, roads, and domestic wells. The model, with further research, could generate maps of greater detail, for example, individual field sites suitable for application within a particular section. Wastewater treatment plants could take advantage of this technology to properly identify potential land application sites. Sewage waste (biosolids) could be land applied in an environmentally sound manner, while at the same time, protect surface water and groundwater resources.

References

Basnet, B. B., Apan, A. A., and S. R. Raine. 2001. Selecting suitable sites for animal waste application using a raster GIS. *Environmental Management*, 28(4), 519-531.

Francek, M., J. Klopcic, and R. Klopcic. 1999. You Can't Put That Here!: GIS Helps Return Sewage Sludge to Soils Where Nutrients Can Be Recycled. Internet. Accessed from http://www.vgin.virginia.gov/documents/articles/localgovt/You_can't_put_that_here.htm.

Giasson, E., Bryant, R. B., and S. D. DeGloria. 2002. GIS-based spatial indices for identification of potential phosphorus export at watershed scale. *Journal of Soil and Water Conservation*, November/December, 57(6), 373-381.

Hendrix, W. G. and D. J. A. Buckley. 1992. Use of geographic information system for selection of sites for land application of sewage waste. *Journal of Soil and Water Conservation*, May-June, 47(3), 271-275.

Michigan Department of Environmental Quality, Water Bureau. Administrative Rules Part 24. Land Application of Biosolids. Effective: November 2, 1999.

Payne, M., M. Janiec, M. Marsh, J. Patterson, R. Stone, and L. Schutt. 2001. Land application of sewage biosolids for crop production. Environmental Science & Engineering. Internet. Accessed from http://www.esemag.org/0901/land.html. September 2001.