Land Use Planning Exercise Using Geographic Information Systems and Digital Soil Surveys

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ABSTRACT

Geographic information system (GIS) technology has become a valuable tool for environmental science professionals. By incorporating GIS into college-level course curricula, agricultural students become better qualified for employment opportunities. We have developed a case study–based laboratory exercise that introduces students to GIS and the Natural Resource Conservation Service soil survey geographic database for evaluating land use issues associated with septic systems. The primary objective of this laboratory exercise was to teach students how GIS and digital soil surveys can be used as tools to make environmentally based land use decisions. Before the start of the course, all students indicated that they knew little about GIS and were interested in learning more. Using information they acquired in lecture concerning soils and the requirements for the installation of septic systems, students completed an exercise in which they evaluated land development possibilities on a 42-hectare site. All students indicated that the laboratory exercise enabled them to understand the functions of GIS, with respect to land use decisions. They were enthusiastic about their results and indicated that the laboratory provided an adequate summary of the material presented throughout the course.

GEOGRAPHIC INFORMATION SYSTEM (GIS) technology has recently attracted increased interest within the environmental sciences profession (Brilis et al., 2001). For example, GIS has been used in conjunction with soil surveys to monitor land use changes (Wu et al., 2001), site future landfill locations (Baban and Flannagan, 1998), and predict necessary types of onsite wastewater treatment systems. Students had also attended lectures on uses and limitations of soil surveys in conjunction with soil suitability for septic systems. The GIS exercise was taught in a laboratory equipped with personal computers for each student (Pentium IV, 2.4 GHz). The GIS software installed on each computer was ArcView 3.2 (ESRI, Redlands, CA). The name of this software package is provided for information purposes only and does not represent an endorsement of this product by the authors or Purdue University.

Prospective employers expect agricultural students to have computer skills (Johnson et al., 2000). By incorporating GIS into course curricula, agricultural students become more qualified for employment. The GIS skills allow students to solve current environmental problems by using creativity and inductive reasoning while generating digital maps (Lemberg and Stoltman, 2001).

Incorporating soil surveys into environmental courses encourages students to apply soil information to land use planning, rather than the more common use for agricultural practices (McCallister et al., 2002). Digital soil databases, such as the Natural Resources Conservation Service (NRCS) soil survey geographic database (SSURGO), can be used to estimate soil characteristics based on known relationships to other soil physical and chemical properties (Nielsen et al., 1996);

SSURGO provides information regarding soil characteristics at specific locations, at scales ranging from 1:12,000 to 1:63,360.

To increase the students’ educational experience, the teaching style of a course should be based on the interests of the students (Torres and Cano, 2000). Students have responded in the past with enthusiasm and interest when GIS and digital soil surveys were incorporated into soil science and land use planning courses (Lee et al., 1999; McCallister et al., 2002). Interactive learning and hands-on exploration has proved to be successful in getting students actively engaged in science courses, and it has increased their confidence and experience (Haskett, 2001).

The objectives of this laboratory exercise were to enable students to use GIS and digital soil surveys to evaluate soil properties and soil variability, and use these tools for making land use decisions.

LABORATORY ASSIGNMENT

Course Background

Agronomy 399, Soils and Land Use Planning, is a 2-credit course in the Department of Agronomy at Purdue University, West Lafayette, IN. A professor is responsible for the lecture, and a graduate teaching assistant oversees the laboratory. To provide students with more hands-on opportunities and promote student–teacher interaction, maximum capacity of the laboratory is currently limited to 10 students. Most of the students are Natural Resources and Environmental Science majors and many express interest in learning GIS and additional information about soils. The course consisted of a 1-hour lecture followed by a 3-hour laboratory each week.

The course objectives were to broaden students’ background in soil science, including the suitability of soils for urban land uses. The course was designed to expose students to land use decision-making and how regulations at the county and state level incorporate soils information to determine housing development suitability.

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Prior to this GIS land use planning exercise, students attended lectures on uses and limitations of soil surveys including soil suitability for septic systems. Students had also completed five independent exercises using GIS to familiarize them with basic operations, including linking and joining

Abbreviations: DOQ, digital orthophotoquad; GIS, geographic information system; NRCS, Natural Resources Conservation Service; SSURGO, soil survey geographic database; TIGER, topologically integrated geographic encoding and referencing system; USGS, United States Geological Survey.
tables, geocoding addresses, and querying data (Breslin et al., 1999).

Before exposure to GIS within this course, an informal prelaboratory survey was used to assess student computer skills. All students felt comfortable using a computer (web-browsers, email, spreadsheet, and word processing software). All students used a computer at least once a week and expressed interest in learning more about GIS. Most students indicated they would eventually like to live in rural areas. Although this would require use of a home septic system, less than half indicated that they would need soils information at the house location before purchase.

**Case Study**

This exercise was based on a land use issue in Tippecanoe County, Indiana. In a single subdivision developed in the early 1990s, numerous septic system failures occurred prematurely. On one street, 10 out of 14 septic systems failed within the first 10 years after installation. Soils within the individual subdivision lots were approved for conventional septic systems under the residential sewage disposal systems rule 410 IAC 6-8.1 (Indiana State Dep. of Health, 1990), which requires a soil morphologic description for each lot. However, the soils were disturbed during road construction the following year after the original soil evaluation was completed (Stout, 2003). Thus, many of the septic systems were designed for natural soils but were installed in fill material deposited on top of the original soil surface. Disturbed soils such as this fill material will not have the natural soil structure and microporosity needed for septic systems to function properly. The entire subdivision consists of 83 homes, with lot sizes approximately 0.2 to 0.4 hectares (Fig. 1). The large number of premature septic system failures illustrates the need to preserve soils in their natural state until the septic system soil absorption field is constructed.

We used this scenario to expose students to the utility of GIS and SSURGO for land use evaluation.
Materials and Methods

The laboratory exercise was broken down into four sections: (i) adding data layers and assessing land suitability based on SSURGO data, (ii) determining current land use from digital orthophotoquads, (iii) geocoding septic system permit data, and (iv) analyzing septic system performance based on number of repaired systems.

Soil Survey Geographic Database (SSURGO)

The SSURGO data used in this laboratory was obtained from the NRCS soils database website (www.ncgc.nrcs.usda.gov/branch/ssb/products/ssurgo; verified 20 Jan. 2004). For reference, the students were provided a copy of the SSURGO Data Use Information Handbook (Soil Survey Staff, 1995). The SSURGO data was from an order 2 soil survey, at a scale of 1:15 840, designed for natural resource planning and management. Soil map units in the database were delineated by field traverses and transects (Soil Survey Staff, 1995).

The SSURGO data was provided in spatial and attribute formats. The spatial data, or polygons of map unit boundaries, are provided as a shapefile and with associated attribute table. A shapefile contains the boundaries of a particular soil map unit, whereas the attribute table, which is linked to the shapefile, contains the data concerning each map unit. This link between attribute table and shapefile allows users to determine which soil series are within a specified polygon. Additional data tables that contain soil interpretations for use and management are provided and can be imported into the GIS and linked to the shapefile attribute table. The interpretation tables contain additional information about each soil map unit and can be linked or joined to the attribute table.

To save time, the students were not required to download or unzip the SSURGO data themselves. The database was downloaded and stored before the lab exercise and made available to them through a network computer drive. The interpretation data table from SSURGO was necessary to obtain soil ratings for septic system utilization. Step-by-step procedures were provided to students for joining the SSURGO interpretation table with the attribute table. Students edited the map legend in order to view the soil suitability ratings for septic systems: slight, moderate, or severe (Fig. 2). Instructor-designed questions were used to get students to interpret the soil ratings at the site location using GIS data queries and septic system regulations.

Digital Orthophotoquad

In addition to SSURGO, a U.S. Geological Survey (USGS) digital orthophotoquad (DOQ) was included in this laboratory to allow students to see an aerial view of the site (USGS, 2000). The DOQ was preprocessed to include only the study site (Fig. 1).

By adding the DOQ data layer to the GIS view, students could compare how they envisioned the future development of the subdivision with the current layout of individual home lots (Table 1). By counting the number of houses visible on the aerial photograph, students could compare the current housing density with the proposed density from their design, to assess the development of the subdivision compared with current recommendations of the local county plan commission, one house every 0.81 hectares (2 acres).

Geocoding Permits

The Tippecanoe County Septic System Permit Database, listing permits issued for new or repaired systems, was obtained from the health department. Within the septic system

| Table 1. Questions assigned to students for land use laboratory exercise. |
| **SSURGO** |
| 1. How many hectares were within the delineated area? |
| 2. If you were the developer of this land: |
| a. Where would you build most of the homes? |
| b. How many houses would you build? |
| c. What would be the average lot size? |
| d. What type of septic systems would you use in various locations (mound or subsurface)? |

| **Land use** |
| 1. What is the actual number of houses within the delineated area? |

| **Geocoding** |
| 2. How many septic system permit locations were located after geocoding? |
| 3. How many were not located? |
| 4. How many permits were issued for new systems? |
| 5. How many permits were issued for repaired systems? |

| **System performance** |
| 1. How many new system permits were issued in the slight rated soils? |
| 2. How many repair permits were issued in the slight rated soil? |
| 3. What system types were used in the slight rated soils? |
| 4. Were all of the absorption fields completely reconstructed, or were some of them just expanded? |
| 5. What were the comments from the inspectors for the cause of failure? |
| 6. How could this have been prevented? |
| 7. What is the main system type installed in the severe soils? |
| 8. Would you like to comment about the system type utilized based on the soil characteristics? |

![Fig. 2. The distribution of the NRCS septic system suitability ratings of the soil within the 42-ha study site.](image-url)
permit database, information regarding the type of permit (new or repair), type of system (conventional or mound), address, and date of installation was available and utilized to geocode the locations of homes within the subdivision. Geocoding is the process of matching an address from the permit database to a particular location on a map.

Students were provided a list containing 83 of the addresses of homes with septic system permits issued within a selected subdivision. Geo-referencing septic system permit addresses is a valuable planning tool to identify challenging areas for development, based on septic system repair rates (Stout, 2003). The locations of households with issued septic system permits were geocoded using the U.S. Census Bureau’s TIGER 2000 (Topologically Integrated Geographic Encoding and Referencing) road map data layer, which contains address ranges and street locations for any specified county (ESRI, 2001). The students were given step-by-step instructions to assist them with the geocoding process and were responsible for determining why some addresses were not identified. Common problems associated with geocoding included misspelled addresses and street names varying between sources (ESRI, 1999). Based on the locations of the geo-referenced septic systems, students performed queries to create two new map layers within their project file for new permits and repair permits (Table 1; Fig. 3).

### Septic System Performance

The students used the SSURGO septic system suitability ratings to determine the number of repair permits issued in the slight, moderate, and severe rated soils. By querying the repair permit table, students were able to determine the type of septic systems installed in each soil suitability class, find out why the systems needed to be repaired, and suggest ways to prevent these problems from occurring in the future. This portion of the exercise allowed students to investigate septic system failures, understand limitations of order 2 digital soil surveys, and express their opinions about the utilization of conventional or alternative design septic system.

### STUDENT RESPONSE

#### Laboratory Completion

All students followed the laboratory exercise without difficulty. Most of the class designed the subdivision to have lot sizes of 0.81 hectares (2 acres). The students were surprised to see that all of the septic systems installed within the subdivision were subsurface, even in the soils rated severe.

Students noted that the soils rated severe had limiting layers and poor drainage, so mound systems should have been installed. System failures where the soils were rated as slight were not so obvious. The septic system inspector suggested that there was “fill on the surface.” Disturbed soils are not suitable for the installation of septic systems, as this displaced soil material can impede vertical water movement. The most common student recommendation for preventing this situation was physically delineating the potential septic system location with flags and/or stakes prior to household construction.

#### Student Feedback

Improved student exam scores over time demonstrated improved understanding of soil influence on land use. All students indicated that this laboratory exercise provided an adequate application of the GIS and septic system information presented throughout the course. All students indicated that the course helped them understand the functions of GIS, with respect to land utilization (Table 2). Many students verbally indicated interest in taking additional GIS courses.

When students were asked how they would change the laboratory exercise, several students suggested more step-by-step instructions including screen capture images of user input windows in the software. Students valued these images because it helped them use the software package more easily when following instructions.

### CONCLUSIONS

Overall, this laboratory exercise was an effective demonstration of how GIS and the SSURGO database could be used
to determine the suitability soils for a particular land use. Students developed their own subdivision plan based on soil characteristics and septic system requirements, and compared their plan to the actual development. This exercise allowed students to generate their own thoughts for land development within regulatory constraints and soil suitability.

We plan to utilize the feedback obtained from the students to improve the course and laboratory exercises by incorporating the following:

1. Include more GIS assignments based on case studies.
2. When possible, provide the students the opportunity to observe the case study sites.
3. Develop additional GIS application assignments prior to this land use laboratory to allow students to become more comfortable with GIS operations and less dependent on step-by-step instructions.

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REFERENCES