**Applying a Model to Predict the Location of Land Drained by Subsurface Drainage Systems in Central Minnesota**

Derrick Chip Brown
*Department of Resource Analysis, Saint Mary's University of Minnesota, Winona, Minnesota 55987*

*Keywords:* Agricultural Drain Tile, Subsurface Drainage Systems, Decision Tree Classification, GIS, Land Use, Soil Characteristics, SSURGO, NLCD, NASS, Kandiyohi County, Meeker County, Renville County, Minnesota

## Abstract

Agricultural drain tile systems are a significant influence on the condition of wetlands and waterways. The influence of these systems is often difficult to determine since installation records are incomplete or were never kept. Using a modified decision class tree and raster analysis in ArcGIS, a model for predicting the location of land drained by subsurface systems was evaluated. The three-county study site in the agricultural region of central Minnesota provided an area of known drain tile systems so that the model predictions could be compared to locations of existing systems and drained land. The model criteria incorporated publically available data including agricultural land use data identified by the National Land Cover Dataset (NLCD) and the National Agricultural Statistics Service (NASS), soil characteristics obtained through the Soil Survey Geographic Database (SSURGO), and slope characteristics developed from the National Elevation Dataset (NED). Results indicate that with the best combination of criteria the model predictions correspond nearly 80% with the actual drain tile data. The potential to incorporate the influence of drain tile areas into land-use based assessments of wetland and waterway health is an important outcome of being able to identify land drained by artificial subsurface drainage features.

## Introduction

Subsurface drainage systems, also called agricultural drain tile, have been installed throughout the Midwestern United States since the early 1900's. (Jaynes and James, 2004; Hubbard, 2005). Zucker and Brown (1998) reviewed the potential benefits of drain tile installation to agricultural production. Reductions in soil erosion, improvements in nutrient uptake by roots, and allowing farmers to access to fields earlier in the planting season were cited as benefits.

The use of agricultural drain tile also has adverse effects. For example, nitrogen and nitrate losses to surrounding waterways are increased in areas where subsurface drainage exists (Zucker and Brown, 1998). This increase in nitrogen runoff raises the nitrogen levels in major riverways such as the Mississippi River, thereby contributing to the hypoxic zone in the Gulf of Mexico (Petrolia, Gowda, and Mulla, 2005).

Other negative effects of drain tile systems include loss of wetland habitat, decreases in water quality, exacerbating flood events, altering hydrology, and lowering the water table

Brown, Derrick Chip. Applying a Model to Predict the Location of Land Drained by Subsurface Drainage Systems in Central Minnesota. Volume 11, Papers in Resource Analysis. 14 pp. Saint Mary's University of Minnesota Central Services Press. Winona, MN. Retrieved (date) from http://www.gis.smumn.edu

(MTWS, n.d.; Hubbard, 2005.).

Given the significant impact that subsurface drainage systems have on wetlands and waterways, the identification of land that is drained by these systems is important (Bourdaghs, Campbell, Gernes, and Brandt-Williams, 2007; Naz, Ale, and Bowling, 2009).

Prior research has focused on two areas: 1) making estimates of the number of acres drained by the systems and 2) locating specific drain tile systems.

Several estimates of the number of acres of land drained by subsurface drainage systems exist. The 1978 Census of Agriculture conducted by the National Agricultural Statistics Service used a survey completed by farmers to gather information about the numbers of acres of farm land with drain tile (Jaynes and James, 2004). In 1992, the Natural Resource Conservation Service as part of its Natural Resource Inventory also created an estimate of drained agricultural land. The results of these surveys vary and are thought to be unreliable because of the inconsistent survey methods employed (Jaynes and James, 2004). Furthermore, these estimates were made for the state level, a scale at which the direct effects on local and regional wetlands and waterways cannot be resolved.

More recently, researchers have attempted to improve estimates of the acreage of land drained by tile systems using geographic information systems (GIS). For example, Jayne and James (2004) employed land use and soil characteristic data to make an estimate of tile-drained land that closely matched earlier survey-based estimates. But again, the resulting estimate was at a state-wide scale.

Sugg (2007) utilized similar methods with updated data which resulted in different estimates at the county level. The estimates were unverifiable since the locations of subsurface drainage systems are generally unknown. The result is likely to be an over estimate of the land influenced by subsurface drainage (Sugg, 2007).

While these estimates are linked to geographical regions such as counties, they are still not specific enough for use to assess the conditions of wetlands in a particular area.

The second body of research focused on agricultural drain tile employs aerial imagery, remote sensing, and automatic feature recognition to locate drain tile systems (Naz et al., 2009). The exact locations of drain tile systems are incomplete since records of installations have been lost or were never kept. Without these records, the subsurface drainage systems are difficult to locate (Jaynes and James, 2004; Naz et al., 2009). Knowing the location is important for wetland restoration planning and to prevent damage to existing systems when additional drainage systems are installed (Naz et al., 2009).

However, knowing the exact location of subsurface drainage systems is not necessary to incorporating the influence of these systems into an assessment of the condition of the wetlands and waterways. What is important is to identify agricultural land that is likely to be drained by tile systems so that when land use is used as a variable in judging the health of a wetland or waterway, the influence of the drainage system can be taken in to account (Bourdaghs et al., 2007).

By modifying the methods used in previous research, and comparing the results to areas known to have drain tile systems, this study aims to identify the combination of data that best distinguishes agricultural land that is likely to be drained.

## Methods

### *Study Location*

In order to evaluate the ability of the proposed method of analysis to identify land that is drained by subsurface drain tile, choosing a study area where the locations with areas known to have drain tile was necessary. An extensive search for such a location identified three counties in west-central Minnesota in which the locations of county owned drain tile and ditches were digitally mapped.

Figure 1 shows the location of Kandiyohi, Meeker, and Renville Counties in west central Minnesota. According to the 2007 Census of Agriculture, Renville County was the top producer of corn for grain, sweet corn, and vegetables harvested for sale. This highlights the importance of agriculture in this region and the productivity of the land. Though the other counties in the study area were not top agricultural producing counties in the state, the total land in agriculture in the study area was over 549,828 hectares and nearly 89% of the land area in 2007 (USDA, 2009).

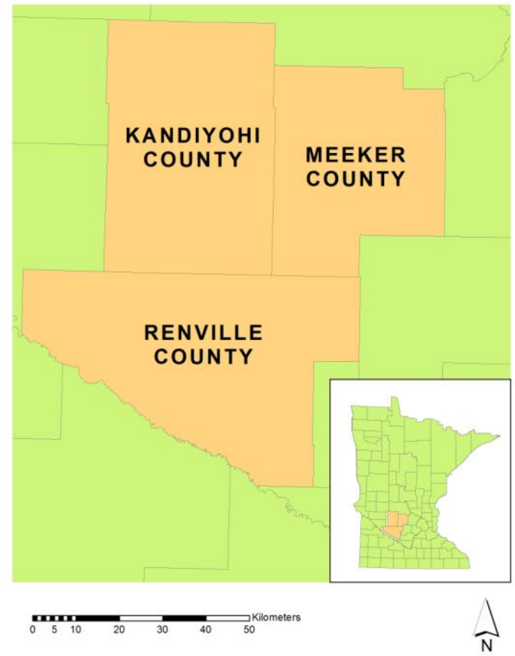


Figure 1. Three-county study area in central Minnesota for applying the subsurface drain tile prediction model.

### *Model Equation*

The methods used to determine the areas influenced by subsurface drainage systems were based on a Decision Tree Classification (DTC) System described by Naz et al (2009). In the DTC, a dichotomous classification was employed to identify progressively the areas likely to be drained based on membership in land use, soil, and slope characteristics. The DTC in this model is represented as Equation 1:

$$PA_{drained} = LU \text{ x } (SC + S)$$

where “$PA_{drained}$” is the a final output of the predicted drained area, “LU” is a reclassified land use raster, “SC” is a reclassified the soil characteristic raster, and “S” is a reclassified slope raster.

The equation in combination with the reclassified data ensured that only agricultural land was considered and resulted in a range of final output values that could be parsed to identify the contributing data sets. See the section “Evaluating the Power of the Model and Criteria” below for a full explanation of the final output values.

### *Model Data*

Table 1 displays data used by other research to make estimates of subsurface drainage systems. For the current study, several variations of the data were compared to identify the combinations that gave the most accurate prediction of drained land. Table 2 shows the criteria used in this study. The drainage class criteria and land capability class criteria were divided into 3 and 4 subcategories respectively for the final analysis.

Before the criteria datasets could be combined using Equation 1, each had to be converted into a raster format and reclassified. In each criteria raster, each cell was assigned a coded value indicating whether it satisfied the parameters of the criteria. The coded values for each data group are shown in Table 3.

County Drain Tile Data

The three counties in the study area provided shapefiles in which drain tile and ditches were represented as lines. The datasets were created by representatives of each county and the Mid-Minnesota Development Commission in 2004. The ditch and subsurface drainage features were digitally mapped using aerial photography, and scanned, georeferenced drainage feature maps provided by the counties (MMDC, 2006). The features in the three

Table 1. Descriptions of previous studies estimating area of subsurface drainage systems.

| **Researchers, year** | **Land Use Data** | **Soils Data source** | **Comments** |
|---|---|---|---|
| Jaynes and James, 2004 | NLCD[1], 1992 | STATSGO[2]<br>Drainage classes,<br>Hydrologic groups,<br>Land Capability Class | Slope also included in some calculations |
| Sugg, 2007 | NLCD[1], 1992 | STATSGO[2]<br>Drainage classes,<br>Hydrologic group | Final estimates used drainage class only |
| Naz et al, 2009 | NLCD[1], 1992 | STATSGO[2]<br>Soil drainage class | |

[1]National Land Cover Dataset

[2]State Soil Geographic Database

Table 2. Criteria for subsurface drainage system identification model.

| **Criteria** | **Subcriteria** | **Data** | **Data Source** |
|---|---|---|---|
| Land Use | All agricultural land | NLCD[1], 2001 | http://seamless.usgs.gov |
| | Row crops only | NLCD[1], 2001 | http://seamless.usgs.gov |
| | All agricultural land | NASS[2], 2008 | http://datagateway.nrcs.usda.gov/ |
| | Row crops only | NASS[2], 2008 | http://datagateway.nrcs.usda.gov/ |
| Soil | Drainage class | SSURGO[3] | http://SoilDataMart.nrcs.usda.gov/ |
| | Hydrologic group | SSURGO[3] | http://SoilDataMart.nrcs.usda.gov/ |
| | Land capability class | SSURGO[3] | http://SoilDataMart.nrcs.usda.gov/ |
| Slope | Less than 2% | NED[4], 10m x 10 m cell | http://seamless.usgs.gov |

[1] National Land Cover Dataset

[2] National Agricultural Statistics Service

[3] Soil Survey Geographic Database

[4] National Elevation Dataset

shapefiles were merged into one file and edited to remove any duplicate features. Only the locations of subsurface drainage systems were necessary so the open ditch features were removed from the data. Figure 2 shows the drain tile locations within the study area and a detail of the data in an area in Renville County.

Table 3. File label codes and criteria reclassification values for final raster analysis.

| **Source, criteria** | **File label code** | **Reclass-ification Code** |
|---|---|---|
| Land Use Criteria | | |
| NASS, all agricultural land | lu1 | 1 |
| NASS, row crops | lu2 | 1 |
| NLCD, all agricultural land | lu3 | 1 |
| NLCD, row crops | lu4 | 1 |
| Soil Characteristic Criteria | | |
| Drainage class, very poorly drained soils | dc1 | 100 |
| Drainage class, poorly and very poorly drained soils | dc2 | 200 |
| Drainage class, somewhat poorly, poorly, and very poorly drained soil | dc3 | 300 |
| Hydrologic Groups A/D, B/D, C/D, D | hg | 400 |
| Land Capability Class, Iw-VIIIw | lc1 | 500 |
| Land Capability Class, IIw, IIIw, IVw | lc2 | 600 |
| Slope Criteria | | |
| Slope, less than 2% | s | 1 |
| Subsurface Drainage | | |
| Area with Drain Tile | none | 10 |
| Areas that did not meet criteria | | |
| Criteria not satisfied, in all cases | none | 0 |

Two drain tile area datasets were created to compare the sensitivity of the model in predicting drained land. The first dataset, representing the locations of drain tile, was created by converting the drain tile shapefile to a raster with a cell size of 10 meters. The 10 meter cell size allowed for continuity of the drain tile lines without enlarging the area of tile lines unreasonably.

The second drain tile data set was created by applying a 30 meter buffer to the original drain tile features. This buffered area represented the land area that was potentially drained by the existing drain tile (UMN Extension, 2009; and Sands, 2009). The resulting polygons were then converted to a raster dataset.

The raster data sets were reclassified so a code of 10 was assigned to drained areas and a code of 0 was assigned to undrained areas.

## Model Criteria Data

Data for the criteria used in the model were downloaded from public sources as indicated in Table 2. Raw data from the data sources was clipped to the study area. A reclassification scheme was utilized to prepare data for incorporation into the final analysis and raster calculation (Table 3).

### *Land Use Classification*


Figure 2. Subsurface drainage systems overview (right) and detail (left) in Kandiyohi, Meeker, and Renville Counties, MN. Purple lines indicate the locations of drain tile. The overview is shown at a scale of 1:1,750,000. The detail is shown at a scale of 1:24,000.

Two data sources were utilized to identify agricultural and non-agricultural land. Two variations of selecting agricultural land from each land use dataset were used. Land use code selection followed the methods of previous researchers (Jaynes and James, 2004; Naz et al., 2009; Sugg, 2007).

The 2001 National Land Cover Dataset (NLCD) was reclassified using two schemes to identify agricultural land. The first scheme selected all pasture and hay fields (NLCD, code 81), and cultivated crop (NLCD, code 82) areas. Though drain tile is primarily installed in fields on which row crops are grown (Jaynes and James, 2004; Naz et al., 2009), these systems may have been installed in areas that have changed use from row crops to pasture or hayfields.

The second reclassification scheme using the NLCD selected only areas on which cultivated crops (code 82) were being grown. The NLCD data has a cell size of 30 meters.

Two other land use criteria rasters were created using the National Agricultural Statistics Service (NASS) dataset. One classification selected all field and row crops, pasture and hay areas, and fallow and idle farmland. Again, the non-row cropped land was included in this criteria because of the possibility that drain tile was installed in the past. The other classification included only field and row crops. The NASS dataset had a cell size of 56 meters .

Each land use raster was reclassified so that the land selected as agricultural land received a value of 1 and non-agricultural land received a value of 0.

*Soil Characteristics*

Sugg (2007) and Naz et al. (2009) suggested using data from the more detailed Soil Survey Geographic Database (SSURGO) for an analysis of this type to obtain better estimates of areas drained by subsurface systems. For this reason, the SSURGO database, an extensive listing of soil characteristics and the geographic locations of soil at a county level was utilized. Analysis employing the SSURGO database required joining spatial vector data of the soil type outlines with tabular data that listed soil characteristics.

Based on the methods of developing the soil criteria used in previous research (Table 1), five soil criteria were derived from three soil characteristics (Table 3). In the following cases, the soil characteristics were selected, converted to raster datasets, and then reclassified according to the scheme shown in Table 3.

The first set of soil criteria were bases on the soil drainage class. The soil drainage class describes the natural drainage conditions of the soil, including the frequency and duration of wet periods (NRCS, 2009b). Because improving the drainage conditions of the soil would allow crops to be grown, the soils with the poorest drainage are likely to possess areas with drain tile systems (Jaynes and James, 2004; Naz et al., 2009).

Three soil drainage class categories in which subsurface drainage are likely to occur include very poorly drained soils, poorly drained soils, and somewhat poorly drained soils (Jaynes and James, 2004; Naz et al., 2009). To create three criteria rasters datasets based on soil drainage class, soils were selected and grouped by drainage class as follows: 1) very poorly drained soils, 2) very poorly drained soils and poorly drained soils, and 3) very poorly drained soils, poorly drained soils, and somewhat poorly drained soils.

Soil characteristics described by SSURGO also include the hydrologic group, defined as "a group of soils having similar runoff potential under similar storm and cover conditions" (NRCS, 2009a). Each soil type is assigned a hydrologic group according to the runoff potential when thoroughly wet. The soils with the highest runoff potential are grouped into the "D" hydrologic group. According to the group description, movement through these soils is restricted or very restricted and could be enhanced by subsurface drainage systems.

While most soils belong to a single hydrologic group (A-D) some soils possessed dual characteristics (A/D, B/D, C/D) and were described as having a "high potential for runoff when left undrained" (NRCS, 2009a).

As with prior research (Jaynes and James, 2004; Sugg, 2007), this study assumed that drain tile exists on agricultural land with soils classified in hydrologic group D. Thus, the second soil characteristic criteria set captured all soils assigned to hydrologic group D and all soils with a dual characteristic that included group D.

A third set of criteria rasters was developed based on the land capability class which describes the ability of the soil to support the production of field crops. The land capability class ranges from I to VIII, with I being few or no restrictions for its use in growing field crops and VIII being severely restricted in its use. Additionally, a descriptive modifier that captures the nature of the limitation may be added to the land capability class. The modifier “w” indicates that the limitation is due to excess water (NRCS, 2009a).

Two criteria representing the land capability class were created: 1) Any soils with the land capability class modifier of “w” were selected as one criteria, and 2) any soils with land capability classifications of IIw (some limitations including excess water), IIIw (severe limitations, including excess water) and IVw (very severe limitations including excess water). These selections were made following the work of Jaynes and James (2004).

In summary, a total of five criteria datasets were created depicting soil characteristics. Table 3 summarizes this information. In each case, the criteria were selected by attribute, converted to raster datasets, and then reclassified by the scheme described in Table 3.

*Slope*

A raster depicting the slope of the landscape in the study area was created from a Digital Elevation Model (DEM) of 10 meter cell size. The slope was calculated as a percent, then was reclassified into areas of less than or equal to 2% slope and areas of greater than 2% slope. This classification was determined following the recommendations of Jaynes and James (2004) and Randall (2009).

*Combining the Criteria*

Once all criteria raster datasets were created and reclassified, they were combined using Equation 1 using the Spatial Analyst Raster Calculator of ArcGIS 9.3. Figure 3 depicts a sample output of a combined criteria raster.

***Evaluating the Power of the Model and Criteria***

To determine the power of the model and criteria to predict areas influenced by subsurface drainage systems, each criteria output raster was combined with the drain tile location raster and the buffered drained tile raster (30 meter buffer of the drain tile locations) separately. The land areas of the resulting raster were classified according to the codes of all the input rasters. An explanation of the resulting codes is found in Table 4. Note that codes represent several permutations of areas of predicted and actual tile as shown in the “Explanation” column.

Table 4. Explanation of the final output results from the model computation.

| Model output Code | Criteria Satisfied | Tile area predicted | Tile area present |
|---|---|---|---|
| 0 | None | No | No |
| 1 | Landuse, slope | No | No |
| 10 | None | No | Yes |
| 11 | Landuse, slope | No | Yes |
| 100* | Landuse, soil | No | No |
| 101* | All | Yes | No |
| 110* | Land use, soil | No | Yes |
| 111* | All | Yes | Yes |

*Note: The hundreds place-holder changed depending on the soil criteria used. The 100-series is just an example.

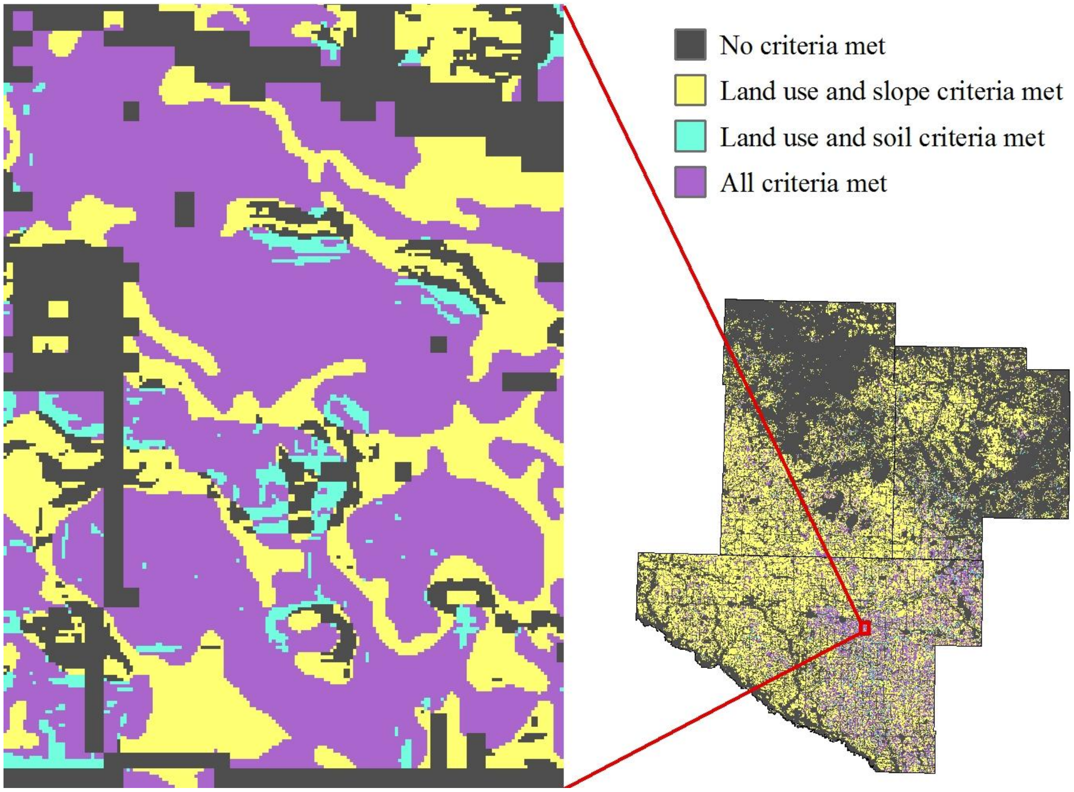


Figure 3. Output of the raster analysis that combined land use criteria, soil characteristic criteria and slope criteria. Reclassification prior to the analysis resulted in four output values that separated the study area into areas where no criteria were satisfied (0), where land use and slope criteria were satisfied (1), where land use and soil criteria were satisfied (100) and where all criteria were satisfied (101). The study area (right) is shown at a scale of 1:1,750,000. The detail (left) is shown at a scale of 1:24,000.

The value attribute table for each raster was exported to a Microsoft Excel file for tabulation and analysis. For calculations, the area of each code category was converted from square meters to hectares.

To evaluate the predictive ability of the model utilizing different combinations of criteria, a ratio of predicted drained area to actual area was calculated as shown in Equation 2:

$$K_{match} = \frac{a^+}{a} \times 100$$

where "$K_{match}$" is the ratio of predicted areas of tile that corresponded with actual areas of drainage tile areas to the actual total areas with drainage tile; "$a^+$" is the area of predicted tile that matched and "a" is the total area with drain tile (Murphy, Ogilvie, and Arp, 2009).

## Results and Discussion

In total, 48 final output raster datasets were created. Of the 48 final output rasters, 24 resulted from combining the final criteria rasters with the drain tile location raster. Another set of 24 final output rasters were produced by combining the final criteria raster datasets with the buffered drained tile raster. Figure 4 shows one of the final output rasters from the analysis.

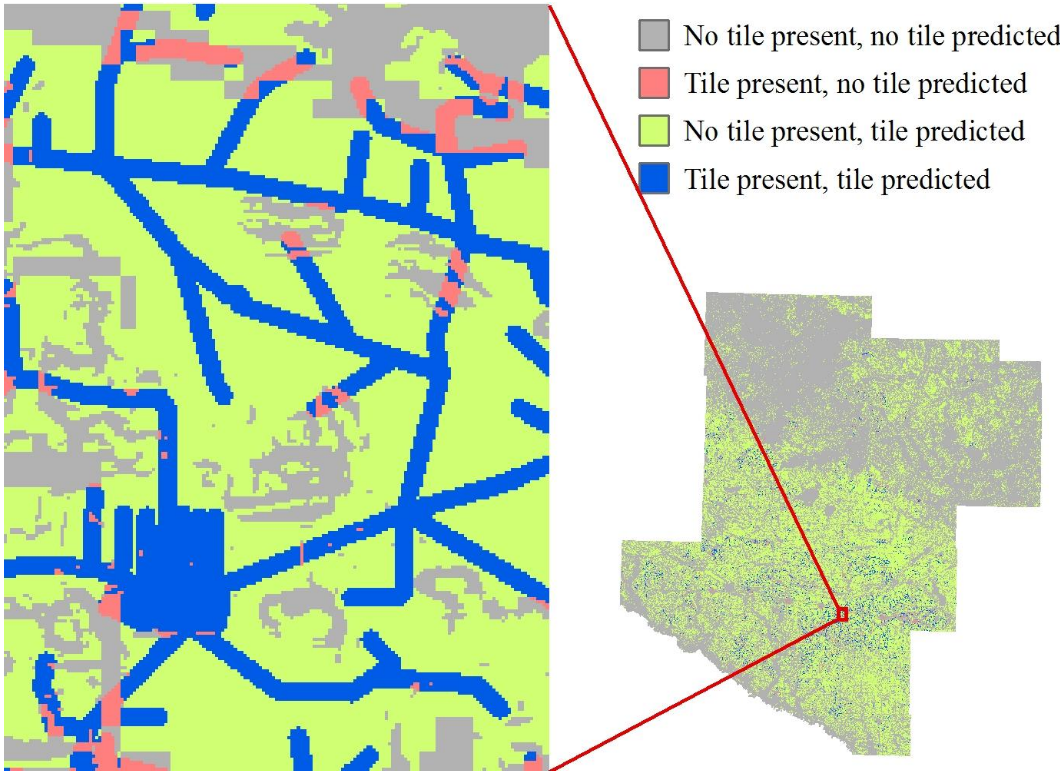


Figure 4. Example output of the final raster calculation using Equation 2. The buffered tile area (30 meters) raster was combined with the final criteria raster resulting in areas classified into the 8 codes that were symbolized into 4 groups according to the presence of tile and the prediction of tile. The 8 codes are listed in Table 4. In this example the final criteria raster represented all agricultural lands (NLCD), soil drainage classes of very poorly drained, poorly drained, and somewhat poorly drained soils, and slopes of less than 2% (criteria raster lu3dc3s). The study area (right) is shown at a scale of 1:1,750,000. The detail (left) is shown at a scale of 1:24,000.

Table 5 shows the criteria combination (file name code), the resulting area of tile predicted that matched the actual tile locations, the total area of drain tile in the study area, and the calculated $K_{match}$ value using Equation 2. The $K_{match}$ values ranged from 38.15 to 78.21, meaning the predicted areas corresponded from 38.15% to 78.21% with the actual tile areas. The criteria raster that yielded the highest $K_{match}$ value combined all agricultural areas as determined using the NLCD 2001 data, the soil drainage classes of somewhat poorly drained soils, poorly drained soils, or very poorly drained soils, and slope of less than 2%. The lowest $K_{match}$ values resulted from combining the soil drainage class of only very poorly drained soils with any land use criteria and a slope of less than 2%.

Table 6 shows the final results when the criteria rasters were combined with the buffered drain tile area. The $K_{match}$ values ranged from 36.39 to 76.12 (36.39% to 76.12% of the predicted tile areas corresponded with the actual tile areas). Again the combination with the highest $K_{match}$ value was the criteria raster that combined the all agricultural land-NLCD dataset, the soil drainage class dataset that included the somewhat poorly drained soils, the poorly drained soils, or very poorly drained soils, and slope of less than 2%. Also, when the soil drainage class of only very poorly drained soils were combined with any land use dataset and a slope of less than 2%, the $K_{match}$ values were lowest.

Interestingly, the $K_{match}$ value did

Table 5. Final results of the raster analysis using the final criteria rasters and the drain tile area raster. Table displays the criteria combination (Table 3 describes the file label codes), the area of tile predicted that corresponded to actual tile, the area of actual tile, and the $K_{match}$ value, the ratio of tile predicted and corresponded to area of actual tile.

| **Criteria Combination** | **Tile predicted and corresponded (hectares)** | **Tile present (hectares)** | **$K_{match}$** |
|---|---|---|---|
| lu3dc3s | 2707.53 | 3462.05 | 78.21 |
| lu4dc3s | 2681.42 | 3462.05 | 77.45 |
| lu1dc3s | 2647.46 | 3462.05 | 76.47 |
| lu3lc2s | 2616.08 | 3462.05 | 75.56 |
| lu3hgs | 2615.16 | 3462.05 | 75.54 |
| lu3lc1s | 2606.13 | 3462.05 | 75.28 |
| lu4lc2s | 2590.4 | 3462.05 | 74.82 |
| lu4hgs | 2589.48 | 3462.05 | 74.80 |
| lu4lc1s | 2581.81 | 3462.05 | 74.57 |
| lu1lc2s | 2558.07 | 3462.05 | 73.89 |
| lu1hgs | 2557.21 | 3462.05 | 73.86 |
| lu2dc3s | 2548.83 | 3462.05 | 73.62 |
| lu1lc1s | 2547.44 | 3462.05 | 73.58 |
| lu3dc2s | 2497.07 | 3462.05 | 72.13 |
| lu4dc2s | 2472.21 | 3462.05 | 71.41 |
| lu2lc2s | 2461.7 | 3462.05 | 71.11 |
| lu2hgs | 2460.84 | 3462.05 | 71.08 |
| lu2lc1s | 2457.87 | 3462.05 | 70.99 |
| lu1dc2s | 2440.77 | 3462.05 | 70.50 |
| lu2dc2s | 2349.68 | 3462.05 | 67.87 |
| lu3dc1s | 1395.13 | 3462.05 | 40.30 |
| lu4dc1s | 1382.95 | 3462.05 | 39.95 |
| lu1dc1s | 1366.63 | 3462.05 | 39.47 |
| lu2dc1s | 1320.82 | 3462.05 | 38.15 |

Table 6. Final results of the raster analysis using the final criteria rasters and the buffered drain tile area raster. Table displays the criteria combination (Table 3 describes the file label codes), the area of tile predicted that corresponded to actual tile, the area of actual tile, and the $K_{match}$ value, the ratio of tile predicted and corresponded to area of buffered tile.

| **Criteria Combination** | **Tile predicted and corresponded (hectares)** | **Tile present (hectares)** | **$K_{match}$** |
|---|---|---|---|
| lu3dc3s | 12965.08 | 17032.01 | 76.12 |
| lu4dc3s | 12837.88 | 17032.01 | 75.38 |
| lu1dc3s | 12664.16 | 17032.01 | 74.36 |
| lu3lc2s | 12451.76 | 17032.01 | 73.11 |
| lu3hgs | 12447.97 | 17032.01 | 73.09 |
| lu3lc1s | 12405.36 | 17032.01 | 72.84 |
| lu4lc2s | 12327.15 | 17032.01 | 72.38 |
| lu4hgs | 12323.48 | 17032.01 | 72.35 |
| lu4lc1s | 12286.54 | 17032.01 | 72.14 |
| lu2dc3s | 12184.63 | 17032.01 | 71.54 |
| lu1lc2s | 12162.66 | 17032.01 | 71.41 |
| lu1hgs | 12159.12 | 17032.01 | 71.39 |
| lu1lc1s | 12115.52 | 17032.01 | 71.13 |
| lu3dc2s | 11875.54 | 17032.01 | 69.72 |
| lu4dc2s | 11756.03 | 17032.01 | 69.02 |
| lu2lc2s | 11695.34 | 17032.01 | 68.67 |
| lu2hgs | 11691.8 | 17032.01 | 68.65 |
| lu2lc1s | 11677.17 | 17032.01 | 68.56 |
| lu1dc2s | 11594.66 | 17032.01 | 68.08 |
| lu2dc2s | 11150.56 | 17032.01 | 65.47 |
| lu3dc1s | 6558.7 | 17032.01 | 38.51 |
| lu4dc1s | 6500.8 | 17032.01 | 38.17 |
| lu1dc1s | 6425.88 | 17032.01 | 37.73 |
| lu2dc1s | 6198.67 | 17032.01 | 36.39 |

not improve by expanding the actual drained area by using the 30 meter buffer of the actual tile lines for the final analysis.

Also, when performing the final analysis using only the 4 land use criteria rasters combined with the drain tile area raster, the $K_{match}$ values ranged from 86.2 to 92.0. In other words, according to the data, 8.0% to 13.8% of the drain tile with known locations is not associated with land used for agriculture. Given this information, the amount of drain tile area not identified by the model is reduced from 21.79% to only 15.79% for the land use criteria that had the highest $K_{match}$ value.

**Conclusions**

The results show land area predicted to be drained by artificial subsurface systems corresponded well with areas that are known to have these systems. The best combinations of land use, soil characteristics, and slope criteria resulted in the identification of nearly 80% of the actual drain tile area.

The ability of the model to identify land drained by subsurface tile could be evaluated better if additional data about the locations of existing tile systems was obtained. This study is limited by the drain tile data since it includes only the subsurface drainage features under the jurisdiction of the counties within the study area. It is unknown whether the other areas predicted to be drained in this model actually are drained. But because the model predictions correspond well with the areas that are truly drained, the likelihood that these are drained is good.

The lack of data identifying locations of actual tile lines highlights the need for continued effort to map public and private agricultural drain tile systems and establishing better record keeping of new systems that are installed.

The model and the resulting data establishes a source of information useful to farmers, agricultural scientists, and drain tile specialists interested in locating or installing drain tile systems. The potential for improvements by drain tile installation to areas identified through the analysis could be used to advise farmers interested in installing subsurface drainage.

Also, the potential exists to incorporate this data and method of identifying areas drained by subsurface tile systems into the land use based assessments of wetland condition.

Land use plays a significant role in the health of wetlands and waterways. Human activity such as the installation of drain tile systems, changes the ecology and dynamics of wetlands, rivers and streams through landscape modification and other land use practices (UMN Extension, n.d.; US EPA, 2002; Reiss, 2006; Wang, Brenden, Seelbach, Cooper, Allen, Clark, and Wiley, 2008).

Previous research has employed methods which use land cover and land use as the primary indicator of ecosystem health (Brown and Vivas, 2005; Mack, 2006; Bourdaghs et al., 2007).

These studies have established the effectiveness of these measures, but they have also concluded that localized features such as subsurface drainage systems are not taken into account adequately in these models (Mack, 2006; Bourdaghs et al., 2007).

Having the ability to identify land being drained by subsurface tile systems through GIS methods and incorporate the information into land use based assessments of wetland health, could improve the results of the assessments.

Overall, the model was successful in identifying the areas drained by known subsurface systems and should be considered useful in planning, environmental monitoring, and as a springboard to future analysis of the influence of subsurface agricultural drain tiles.


## Acknowledgements

The author gratefully acknowledges the teachers and mentors John Ebert, Dave McConville, and Patrick Thorsell of the GIS program at Saint Mary's University of Minnesota for their help and direction. County drainage system data was generously supplied by Kandiyohi, Meeker, and Renville Counties. Mark Gernes of the Minnesota Pollution Control Agency, Gyles Randall of the Southern Minnesota Agricultural Research Station, and Gary Sands of the University of Minnesota provided invaluable advice with regards to studying agricultural drain tile systems. April Amman, Ben Johnston, and Nancy Carlin deserve thanks for support and friendship throughout this project.


## References


Bourdaghs, M., Campbell, D., Genet, J., Gernes, M., and Brandt-Williamset, S. 2007. Testing and Development of the Landscape Development Intensity Index as a Wetland Condition Indicator. *Final Status Report: Development of the Landscape Development Index as a Wetland Condition Assessment Tool*. 5-38.

Brown, M. T., and Vivas, M. B. 2005. A Landscape Development Intensity Index. *Environmental Monitoring and Assessment*, 101, 289-309.

Hubbard, D. 2005. A Review of the Effects of Pattern Tiling on Wetlands and Receiving Waters. Unpublished paper conducted for the U.S. Fish and Wildlife Service obtained from the author.

Jaynes, D. B., and James, J. E. 2004. The Extent of Farm Drainage in the United States. Retrieved March 8, 2009, from http://www.docstoc.com/docs/741030/The-Extent-of-Farm-Drainage-in-the-United-States.

MMDC. Mid-Minnesota Development Commisssion. 2006. Drainage Ditch Inventory for Kandiyohi, Meeker, and Renville Counties. Retrieved on May, 15, 2009 from http://www.lmic.state.mn.us

MTWS. Minnesota Chapter of the Wildlife Society. No Date. Draft Position Statement – Ecological Effects of Tile Drainage. Retrieved on March 7, 2009, from http://www2.crk.umn.edu/tws/MN/downloads/DRAFT-MTWS-TileDrainage.doc.

Murphy, P. N. C., Ogilvie, J., and Arp, P. 2008. Topographic Modelling of Soil Moisture Conditions: A Comparison and Verification of Two Models. *European Journal of Soil Science*, 60, 94-109. Retrieved July 3, 2009 from http://www3.interscience.wiley.com/cgi-bin/fulltext/121642003/PDFSTART.

Naz, B., Ale, S., and Bowling, L. 2009. Detecting Subsurface Drainage Systems and Estimating Drain Spacing in Intensively Managed Agricultural Landscapes. *Agricultural Water Management*, 96(4), 627-637. Retrieved March 3, 2009 from Science Direct, www.sciencedirect.com.

NRCS. Natural Resource Conservation Service. 2009a. SSURGO Metadata – Domains. SSURGO Metadata Version

2.2.3. Natural Resources Conservation Service. Retrieved on July 3, 2009 from http://soildatamart. nrcs.usda.gov/SSURGOMetadata.aspx.

NRCS. Natural Resource Conservation Service. 2009b. SSURGO Metadata – SSURGO Metadata - Table Column Descriptions. SSURGO Metadata Version 2.2.3. Natural Resources Conservation Service. Retrieved on July 3, 2009 from http://soildatamart. nrcs.usda.gov/SSURGOMetadata.aspx.

Petrolia, D. R., Gowda P. H., and Mulla, D. J. 2005. Targeting Agricultural Drainage to Reduce Nitrogen Losses in a Minnesota Watershed. *Staff Paper Series.* P05-2. 1-16.

Randall, G. 2009. Personal Communication. University of Minnesota Agricultural Research Station. Waseca, MN.

Reiss, K. 2006. Florida Wetland Condition Index for Depressional Forested Wetlands. *Ecological Indicators,* 6, 337-352.

Sands, G. 2009. Personal Communication. University of Minnesota. St.Paul, MN.

Sugg, Z. 2007. Assessing Farm Drainage: Can GIS Lead to Better Estimates of Subsurface Drainage Extent? *World Resources Institute*. Retreived March 9, 2009, from http://pdf.wri.org/ assessing_farm_ drainage.pdf.

UMN Extension. University of Minnesota Extension Service. No Date. Agricultural Drainage - Publication Series: Soil Water Concepts. Retrieved March 8, 2009 from http://www. extension.umn.edu/distribution/cropsys tems/DC7644.html.

USDA. United States Department of Agriculture. 2009. 2007 Census of Agriculture. Retrieved on August 1, 2009 from http://www.agcensus. usda.gov/Publications/2007/Online_ Highlights/County_Profiles/Minnesota/ index.asp.

US EPA. United States Environmental Protection Agency. 2002. Methods for Evaluating Wetland Condition: Developing Metrics and Indexes of Biological Integrity. 1-45. Retrieved on February 24, 2009, from http://www.epa.gov/waterscience/ criteria/nutrient/guidance/wetlands/ #modules.

Wang, L., Brenden, T., Seelbach, P., Cooper, A., Allen, D., Clark Jr., R., and Wiley, M. 2008. Landscape Based Identification of Human Disturbance Gradients and Reference Conditions for Michigan Streams. *Environmental Monitoring and Assessment*, 141, 1-17.

Zucker, L. A., and Brown, L. C. 1998. Agricultural Drainage: Water Quality Impacts and Subsurface Drainage Studies in the Midwest. *OSU Extension Bulletin 871.* Retrieved on March 10, 2009 from http://ohioline.osu.edu/b871 /index.html.