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Detecting subsurface drainage systems and estimating drain spacing in intensively managed agricultural landscapes

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ABSTRACT

Detailed location maps of tile drains in the Midwestern United States are generally not available, as the tile lines in these areas were laid more than 75 years ago. The objective of this study is to map individual tile drains and estimate drain spacing using a combination of GIS-based analysis of land cover, soil and topography data, and analysis of high resolution aerial photographs to within the Hoagland watershed in west-central Indiana. A decision tree classifier model was used to classify the watershed into potentially drained and undrained areas using land cover, soil drainage class, and surface slope data sets. After masking out the potential undrained areas from the aerial image, image processing techniques such as the first-difference horizontal and vertical edge enhance filters, and density slice classification were used to create a detailed tile location map of the watershed. Drain spacings in different parts of the watershed were estimated from the watershed tile line map. The decision tree identified 79% of the watershed as potential tile drained area while the image processing techniques predicted artificial subsurface drainage in approximately 50% of the Hoagland watershed. Drain spacing inferred from classified aerial image vary between 17 and 80 m. Comparison of estimated tile drained areas from aerial image analysis shows a close agreement with estimated tile drained areas from previous studies (50% versus 46% drained area) which were based on GIS analysis and National Resource Inventory survey. Due to lack of sufficient field data, the results from this analysis could not be validated with observed tile line locations. In general, the techniques used for mapping tile lines gave reasonable results and are useful to detect drainage extent from aerial image in large areas. These techniques, however, do not yield precise maps of the systems for individual fields and may not accurately estimate the extent of tile drainage in the presence of crop residue in agricultural fields and/or existence of other spatial features with similar spectral response as tile drains.

1. Introduction

Subsurface drainage (popularly known as ‘tile drainage’) systems have been a common practice for decades in the Midwestern U.S. to transform the poorly drained soils into productive cropland. Although subsurface drainage provides many agronomic and environmental benefits, subsurface drainage systems have important implications for surface water quality and hydrology such as accelerating the transfer of nutrient pollutant to surface water (Strock et al., 2004). Due to limited information on subsurface drainage installations, it is difficult to understand the hydrology and nitrate dynamics

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of intensively tile drained watersheds and plan effective mitigating polices to reduce the nitrate load to downstream water bodies (Sugg, 2007). Information on tile line locations is also useful for identifying the areas where tiles are damaged and the areas where there is a need to increase the drainage intensity. In addition, the analysis of hydrological effects of subsurface drainage systems using hydrologic models is complicated because of limited information on the locations of historic tile drains (Zucker and Brown, 1998). Many of the hydrology models, such as DRAINMOD, require drain spacing as an important input to the model in order to estimate drain flow from a field or watershed (Skaggs, 1982).

Traditionally, manual tile probing techniques were used to locate tile lines in the fields. These methods are time consuming and labor intensive and cannot be applied to large areas. The most recent survey in the United States that included information on the drainage at county-level is the 1992 National Resource Inventory (NRI). The NRI was a statistically based survey in which subsurface drainage information were collected for those areas which were part of government-recognized conservation practices (Sugg, 2007). Many attempts have been made recently to estimate tile drained areas in the Midwest (Sugg, 2007; Sui, 2007) based on available cropland and basic soil map layers. For example, the Soil Drainage Class (SDC)-based data set developed by the World Resources Institute (WRI) used the 1992 National Land Cover Dataset (NLCD) and State Soil Geographic (STATSGO) data to create tile drainage estimates for Midwestern States. Some county estimates were adjusted based on 1992 NRI estimates and expert advice (Sugg, 2007). The WRI study concludes that although the Geographic Information System (GIS)-based analysis using soil and land cover characteristics provides an approximate estimate of tile drained extent, in the absence of more recent actual county-level drainage data, it is not possible to know currently existing tile drained land. This study also suggests the use of more detailed Soil Survey Geographic (SSURGO) digital soil maps to produce more accurate estimates of drained area. Similarly, Sui (2007) used a GIS-based analysis of land use, soil and topography datasets to classify the tile drained areas in Indiana for all cropland where the soils are poorly drained, and the slope is less than 2%. This study used information on cropland from the 2001 NLCD dataset and soil drainage properties from the STATSGO data.

Naz and Bowling (2008) used a Decision Tree Classification (DTC) for mapping potential tile drained areas in Purdue University's Agronomic Center for Research and Education (ACRE) by utilizing multiple data sets such as land cover from the National Agricultural and Statistics Service (NASS), and soil drainage and surface slope from the SSURGO database to locate areas where the tile drains may be installed. They suggest that DTC can be a very effective tool in quantifying an approximate estimate of tile drained agricultural fields over a large area, which could be used as a preliminary classification in the studies where a more detailed map of individual tile lines is required (Naz and Bowling, 2008).

While the techniques based on soil physical properties and land cover data can give an approximate estimate of tile drained areas at large scale, a combination of GIS-based analysis with remotely sensed data from aerial images can provide more accurate information for mapping of individual tile lines. The automated feature extraction tools such as edge detection filters, available in remote sensing software can be used to generate the tile line location map for an area using high resolution remotely sensed data. The tile drain mapping procedure is based on the fact that the soil over subsurface drains has higher reflectance in the infrared regions of the spectrum because it dries faster than the soil at other locations in the field (Verma et al., 1996). Previous studies concluded that the best time for taking imagery that could be used for tile delineation is 2–3 days after 2.54 cm of rain on the field sites (Verma et al., 1996; Varner et al., 2002; Northcott et al., 2000). In these studies, high resolution color infrared and panchromatic aerial images and additional GIS data such as surface moisture, surface slope and drainage class were used to facilitate the easier detection of tile lines. They used multiple image processing techniques to identify the most effective method for mapping drainage tiles. Naz and Bowling (2008) used directional first-difference horizontal and vertical filters to detect the tile lines from aerial images at the ACRE. Other edge detection algorithms such as gray level gradient, Sobel, Laplacian, Prewit, Robert, Kirsch and Rosenfeld threshold operators are also designed to process every pixel on the original image using the gray level variation to make decisions about edge existence using first or second order derivatives (Sun, 2003). The major drawback of these techniques is their sensitivity to noise, particularly for high resolution images which leads to low accuracy of edge detection. Although the automated tile mapping has been successfully done at field scale (Verma et al., 1996; Naz and Bowling, 2008), automated feature extraction techniques have not been used to map the tile lines at watershed-scale.

The purpose of the present study is to use a combination of GIS-based analysis of land cover, soil and topography data and analysis of high resolution aerial photographs to map individual tile drains and estimate drain spacing within the Hoagland watershed in west-central Indiana. The specific objectives of our study are to (1) identify potential tile drained areas based on land cover, soil drainage and soil slope data using DTC, (2) map tile line locations using image processing techniques and (3) estimate drain spacing in the watershed based on the predicted tile line map.

2. Methods

In order to achieve the stated objectives, the Hoagland watershed area was classified into potentially drained and undrained areas using DTC. The potentially undrained areas in the watershed were masked out from the aerial image in order to map tile lines using image processing techniques. Statistical processing was done to remove erroneous lines that were identified as tile lines and to estimate the drain spacing within the watershed. The primary assumptions of this analysis are summarized in Table 1, and described in the following sections.

2.1. Study site

The Hoagland watershed ($202\ km^2$ in area) is located in White, Benton and Jasper Counties in west-central Indiana (Fig. 1). It