ASSESSMENT OF SUBSURFACE DRAINAGE MANAGEMENT PRACTICES TO REDUCE NUTRIENT LOADINGS USING AnnAGNPS

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Abstract

The goal of the Future Midwest Landscape (FML) project is to quantify current and future landscape services across the region and examine changes expected to occur as a result of two alternative drivers of future change: the growing demand for biofuels, and hypothetical increases in incentives for the use of agricultural conservation practices to mitigate the adverse impact caused by the growing demand for biofuels. The overall objective of this study is to assess the agricultural management alternatives for nutrient loading reduction. To achieve the overall objective of this study, the USDA Annualized Agricultural Non-Point Source Pollution (AnnAGNPS) model was applied to the Ohio Upper Auglaize watershed, which is located in the southern portion of the Maumee River Basin. This watershed is also part of the USDA-NRCS Conservation Effects Assessment Project (CEAP) Special Emphasis effort with the objective to assess the effects of agricultural conservation practices on water quality. In this study, AnnAGNPS model was calibrated using USGS monitored data; and then the effects of various subsurface drainage management practices on nitrogen loadings were assessed. Wider drain spacing and shallower depths to drain can be used to reduce nitrogen loadings. In addition, nitrogen loadings could be significantly reduced by plugging subsurface drains from November 1 to April 1 of each year.

ENVIRONMENTAL ISSUE

Nitrogen (N) losses to surface waters are of great concern on both national and regional scales. Scientists have concluded that large areas of hypoxia in the northern Gulf of Mexico are due to excessive nutrients derived primarily from agricultural runoff via the Mississippi River (1999; USEPA, 2007). Excessive N loading is also responsible for algal blooms and associated water quality problems in lakes and rivers in other locations, such as the Lake Erie of the great lake systems in Northern Ohio (Ohio EPA, 2008). Loss of N to surface waters is also a problem on a local level. Excess nitrate in drinking water can be toxic to humans, and treatment is expensive when nitrate in surface water supplies exceed EPA threshold levels (USEPA, 2008).

Nitrogen losses from drained cropland have been identified as one of the major sources of N in streams and estuaries. There is strong evidence that artificial drainage, installed in many regions of the Midwest, improves crop production and increases N losses to surface waters (Gilliam et al., 1999; Dinnes et al., 2002; Kalita et al., 2007). Scientists have proposed ways of reducing N loads to the Gulf of Mexico and other water bodies. They include the reduction of N fertilization rates and creation of wetlands and riparian buffers (Mitsch et al., 2001; Crumpton et al., 2007). Others have recommended cessation of drainage of agricultural lands and/or conversion of agricultural lands back to prairie or wetland. However, with the growing demand for biofuels, more agricultural production is required. Over 40 million ha, or about 25% of the cropland in the U.S., requires improved drainage for agricultural production (Jaynes and James, 2008). These lands are among the world's most productive soils, and they make up an extremely important part of corn/soybean production. Therefore, there is an urgent need to develop methods to allow the continued high agricultural productivity of these naturally poorly drained soils while reducing N losses to surface waters.

RESEARCH GOAL

Research results indicate there might be a potential for reducing N loads to surface waters through management of drainage systems (Drury et al., 2009). However, the functional relationships have only been documented for a few soils and conditions. There have been few studies reporting the effects of drain spacing and depth on N losses. Given the expensive nature of long-term monitoring programs which are often used to evaluate management effects on non-point source pollution, models developed over the past years may be used as an alternative to simulate movement and fate of nutrients in drained soils, and evaluate effects of drainage system design and management on nutrients losses to surface waters. Therefore, the overall goal of this study is to explore the long term effects of drainage management on reducing nitrogen losses within the Upper Auglaize watershed in Ohio using AnnAGNPS.

METHODS AND PROCEDURES

AnnAGNPS Model Description

AnnAGNPS is an advanced simulation model developed by the USDA-ARS and NRCS to help evaluate watershed response to agricultural management practices (Bingner et al., 2003). It is a continuous simulation, daily time step, pollutant loading model designed to simulate water, sediment and chemical movement from agricultural watersheds (Bingner et al., 2003). The spatial variability of soils, land use, and topography within a watershed can be determined by dividing the watershed into many user-specified, homogeneous, drainage-area-determined cells. From individual cells, runoff, sediment and associated chemicals can be predicted from precipitation events that include rainfall, snowmelt and irrigation. AnnAGNPS simulates runoff, sediment, nutrients and pesticides leaving the land surface and being transported through the watershed channel system to the watershed outlet on a daily time step basis. The model routes the physical and chemical constituents from each AnnAGNPS cell into the stream network and finally to the watershed outlet and has the capability to identify the sources of pollutants at their origin and track them as they move through the watershed system. The complete suite of AnnAGNPS models, which include programs, pre-and post-processors, technical documentation, and user manuals, are currently available at http://www.ars.usda.gov/Research/docs.htm?docid=5199.

The Upper Auglaize Watershed

The Upper Auglaize (UA) watershed is located in the southern portion of the Maumee River Basin (Fig. 1). The watershed encompasses 85,812 ha upstream of the Fort Jennings U.S. Geological Survey (USGS) gaging station at the outlet (Fig. 1). Land use is predominately agricultural with 74% cropland, 11% grassland, 6% woodland, and 9% urban and other land uses. Corn and soybeans are the predominant crops grown in the watershed and together account for an estimated 83% of the agricultural cropland in cultivation and 62% of the total watershed area. Land-surface elevations in the UA watershed range from about 233 to 361 m above sea level. Most soils in the UA watershed are nearly level to gently sloping; however, moraine areas and areas near streams can be steeper. In general, soils in the lower one-third of the watershed tend to be appreciably flatter than those in the upper two-thirds of the watershed. Blount and Pewamo are major soil types in the watershed. These soils are characterized as somewhat poorly to very poorly drained with moderately slow permeability. Therefore, agricultural fields in the watershed are artificially drained to improve crop production. Subsurface drainage (tile drainage) systems have been installed to extend and improve drainage in areas serviced by an extensive network of drainage ditches.

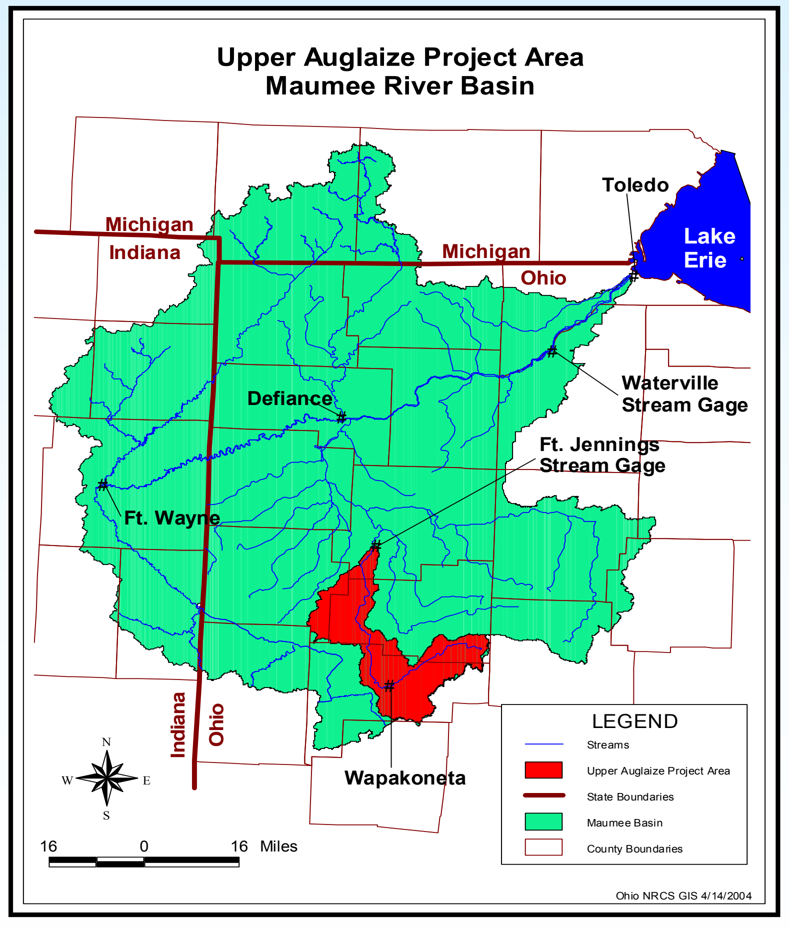


Figure 1. The Maumee River basin drainage network, Upper Auglaize watershed, and the Wapakoneta and Ft. Jennings Gage Station.

Input Preparation

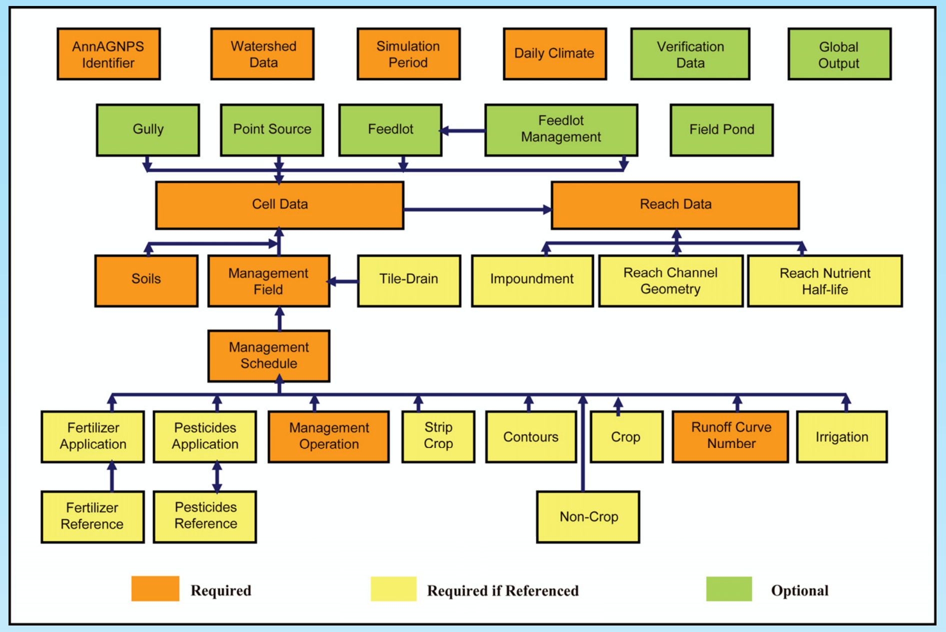


Figure 2. AnnAGNPS input data sections

Figure 2 lists all available AnnAGNPS input data categories. Using the GIS digital data layers of digital elevation model, soils, and land use, a majority of the data input requirements were developed by using a customized ArcView GIS interface (Bingner, 2003). Inputs developed from the ArcView GIS interface include physical information of the watershed and subwatershed (AnnAGNPS cell), such as boundary and size, land slope and slope direction, and channel reach descriptions. The ArcView GIS interface also assigned a soil and land-use type to each cell by using the generated subwatershed and the soil and land-use GIS data layers. Additional steps to provide the model with the necessary inputs included developing the soil layer attributes to supplement the soil spatial layer, establishing the different crop operation and management data, and providing channel hydraulic characteristics. Those inputs can be organized using the AnnAGNPS Input Editor (Bingner, 2003), a graphical user interface designed to aid users in selecting appropriate input parameters.

The characterization of the UA watershed land use, crop operation, and management during the simulation period was critical in providing estimates of the nitrogen loadings. The input for existing conditions of the watershed was established by using 1999-2002 LANDSAT imagery and a 4-year crop rotation derived by summarizing field records from 1999-2002. Tillage type was applied on a random basis to each field to come up with the total amount of conventional, mulch, and no-till percentages implemented in the watershed during 1999-2002 because the overall percentages of tillage types were known while the exact field-by-field values were unknown at this watershed scale. Local experience substantiated that most fields in the watershed were subsurface drained to a very large extent. Therefore, the model was run with subsurface drainage simulated in all AnnAGNPS cells. Model inputs of fertilizer rates and extents were estimated by interviewing four custom applicators operating in or near the watershed.

Table 1. Fertilizer application

Crop Type	Nitrogen (Lb./Ac.)	P_2O_5 (Lb./Ac.)	Yield
Corn	140	45	120 (Bu./Ac.)
Soybean	0	30	40 (Bu./Ac.)
Wheat	58	40	60 (Bu./Ac.)
Alfalfa	0	65	5 tons/Ac.

Model Calibration

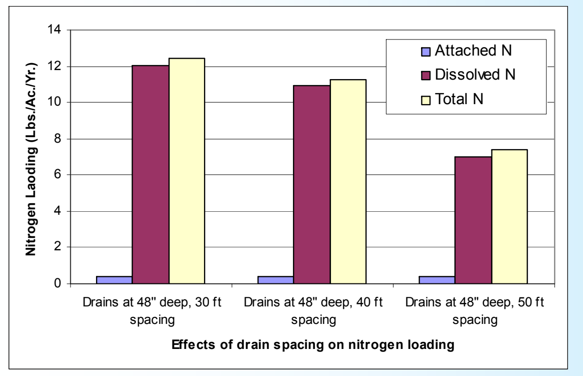
Annual average (1979-2002) flow and sediment data collected at the Fort Jennings USGS gage station were used to calibrate AnnAGNPS simulated long-term annual average runoff and sediment loss. The long-term annual average data were chosen for calibration for the following reasons: 1) long-term annual average information is needed for evaluation of the alternative management scenarios; 2) historical weather data were not available, and 100-year synthetic weather data were used for simulations (while synthetic weather data would not match the historical weather data for an individual event, long-term synthetic weather statistics should reflect historical weather statistics); 3) land use, crop rotation, and management practices during the simulation period changed from year to year, and it was very difficult, at this watershed scale, for AnnAGNPS to characterize the annual changes occurring in the watershed.

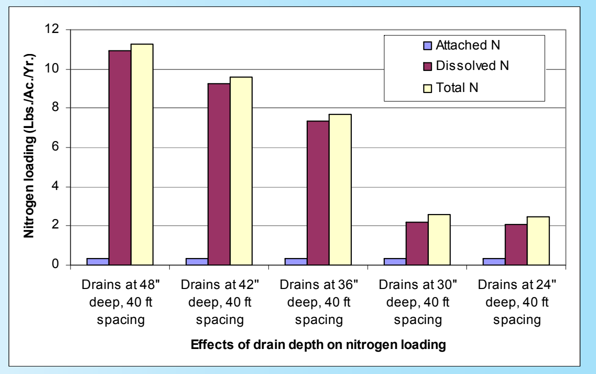
RESULTS

Model Calibration

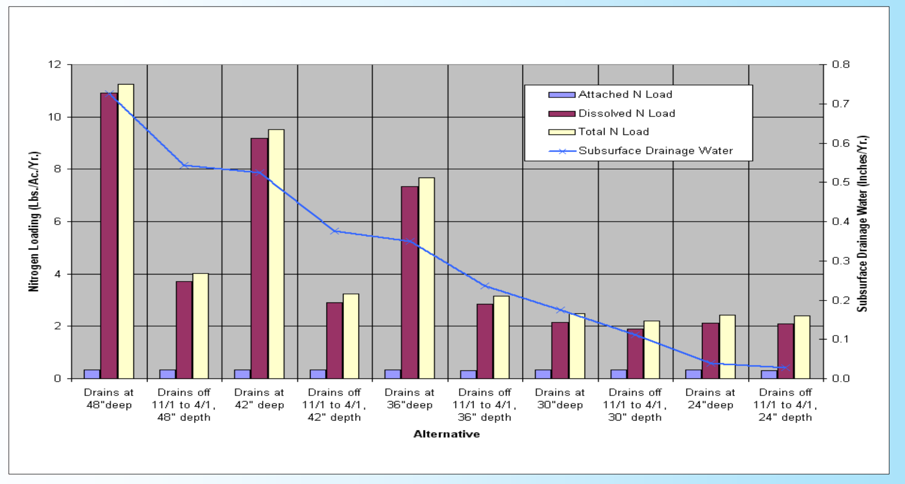
Item	AnnAGNPS Simulation	USGS Observation
Watershed annual average direct surface runoff (Inches)	6.4	
Watershed annual average subsurface flow (Inches)	3.6	
Watershed annual average total runoff (Inches)	10.0	10.0
Sediment loading at the watershed outlet (tons/Ac./Yr.)	0.771	0.753
Total Nitrogen loading at the Waterville gage (Lbs/Ac./Yr.)	12.4	10.8

Effects of drainage spacing and depth on N loading





Effects of controlled drainage on N loading



CONCLUSIONS

Modeling nitrogen with subsurface drainage water management showed: 1) wider drain spacing can reduce nitrogen loadings; 2) shallow depth to drain can also reduce nitrogen loadings; 3) nitrogen loading could be significantly reduced by plugging subsurface drains from November 1 to April 1 of each year.

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