ASSESSMENT OF SUBSURFACE DRAINAGE MANAGEMENT PRACTICES TO REDUCE NITROGEN LOADINGS USING ANNAGNPS

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ABSTRACT. *The goal of the Future Midwest Landscape project is to quantify current and future landscape services across the Midwest 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. Nitrogen losses to surface waters are of great concern on both national and regional scales, and nitrogen losses from drained cropland in the Midwest have been identified as one of the major sources of N in streams. With the growing demand for biofuels and potentially increased corn production, measures are needed to allow the continued high agricultural productivity of naturally poorly drained soils in the Midwest while reducing N losses to surface waters. Therefore, the objective of this study is to examine the long term effects of drainage system management on reducing N losses. To achieve the overall objective of this study, the USDA Annualized AGricultural Non-Point Source (AnnAGNPS) pollutant loading model was applied to the Ohio Upper Auglaize watershed located in the southern portion of the Maumee River Basin. 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 spacings and shallower depths to drain can be used to reduce nitrogen loadings. Nitrogen loading was reduced by 35% by changing drain spacing from 12-m (40-feet) to 15-m (50-feet); and 15% nitrogen was reduced by changing the drain depth from 1.2-m (48-inch) to 1.1-m (42-*

inch) and an additional 20% was reduced by changing the drain depth from 1.1-m (42-inch) to 0.9-m (36-inch). In addition, nitrogen loadings could be significantly reduced by plugging subsurface drains from November 1 to April 1 of each year. About 64% nitrogen was reduced by completely controlling subsurface drainages for a drainage system with drain space of 12-m (40-feet) and drain depth of 1.2-m (48-inch).

Keywords: *AnnAGNPS watershed modeling; Ohio Upper Auglaize watershed; Midwest; drainage management practices; water quality.*

INTRODUCTION

The Future Midwest Landscape (FML) study is part of the US Environmental Protection Agency (EPA)'s new Ecosystem Services Research Program, undertaken to examine the variety of ways in which landscapes that include crop lands, conservation areas, wetlands, lakes, and streams affect human well-being. The goal of the FML 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 (increased corn production particularly).

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 (Rabalais et al., 1996, 1999; Aulenbach et al., 2007; USEPA, 2007). Excessive N and phosphorus 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. 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 such as the United States Department of Agriculture (USDA)-Natural Resources Conservation Services (NRCS) Conservation Reserve Program. However, with the growing demand for biofuel, more agricultural production is required. 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 indicates there might be a potential for reducing N loads to surface waters through management of drainage systems (Drury et al., 1996; Mitchell et al., 2000; Drury et al., 2009). However, functional relationships have only been documented for a few soils and conditions (Gilliam and Skaggs, 1986; Kladivko et al., 1999). There have been few studies reporting the effects of drain spacing and depth on N loss (Kladivko et al., 1999; Sands et al., 2008). Given the expensive nature of long-term monitoring programs, which are often used to evaluate management effects on non-point source pollution, computer models have been developed as an acceptable alternative for simulating the fate and transport of nutrients in drained soils, and for evaluating the effect of drainage system design and management on nutrients losses to surface waters. Skaggs and Chescheir (2003) simulated the effects of drain spacing on N losses for soils in North Carolina and Luo (1999) for soils in Minnesota using DRAINMOD-N (Breve et al., 1997), which is based on a simplified N balance in the profile. Both studies indicated a potential for reducing N loads to surface waters by increasing drain spacing as reported in field experiments done by Kladivko et al. (1999). However, a simulation study done by Davis et al. (2000), using the ADAPT (Chung et al., 1991; Chung et al., 1992; Desmond et al., 1995) model to analyze the effects of drain spacing and depth and fertilization rates on N losses from a Minnesota soil, had contrary results. Davis et al. (2000) concluded that drain spacing had little effect on nitrate nitrogen loss through drains and that the best method of reducing N loss was to reduce fertilization rates. Zhao et al. (2000) also concluded, based on 25-year DRAINMOD-N simulations for the April-August months, that drain spacing had little effect on N loss to drainage water. Therefore, more evaluations of the impact of drainage management on N loss to surface waters for soils in other states are needed. In addition, the previous evaluations were all performed on field scales. Evaluations on a watershed scale, which are more complex and difficult to monitor, is also needed for various soil conditions. Furthermore, evaluation on a watershed scale is very important for targeting critical areas that caused serious problems to achieve the maximum environmental benefit.

The objective of this study is to examine the long term effects of drainage system management on reducing N losses within the Upper Auglaize watershed in Ohio using AnnAGNPS.

METHODS AND PROCEDURES

AnnAGNPS model description

Annualized AGricultural Non-Point Source (AnnAGNPS) pollutant loading model is an advanced simulation model developed by the USDA-Agricultural Research Service and NRCS to help evaluate watershed response to agricultural management practices (Bingner et al., 2009). 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., 2009). The AnnAGNPS model evolved from the original single event AGNPS model (Young et al., 1989), but includes significantly more advanced features than AGNPS. The spatial variability of soils, land use, and topography within a watershed can be determined by discretizing the watershed into many user-defined, 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 their transport through the channel system to the watershed outlet on a daily time step. Since the model routes the physical and chemical constituents from each AnnAGNPS cell into the stream network and finally to the watershed outlet, it has the capability to identify pollutant sources at their origin and to track those pollutants as they move through the watershed system. The complete AnnAGNPS model suite, 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 hydrology components considered within AnnAGNPS are rainfall, interception, runoff, evapotranspiration (ET), infiltration/percolation, subsurface lateral flow, subsurface drainage and base flow. Runoff from each cell is calculated using the SCS curve number method (Soil Conservation Service, 1985). The modified Penman equation (Penman, 1948; Jenson et al., 1990) is used to calculate the potential ET (PET), and the actual ET (AET) is represented as a fraction of PET. The AET is a function of the predicted soil moisture value between wilting point and field capacity. Percolation is only calculated for downward seepage of soil water due to gravity (Bingner et al., 2009). Lateral flow is calculated using the Darcy equation, and subsurface drainage is calculated using Hooghoudt's equation (Freeze and Cherry, 1979; Smedema and Rycroft, 1983). A detailed methodology of subsurface drainage calculations are described in Yuan et al. (2006). Briefly, for a given time step, the depth of saturation from the impervious layer is calculated first based on the soil moisture balance of the root zone layer; then the amount of drainage is calculated based on boundary conditions (e.g. depth of drain for conventional systems or weir height if in controlled drainage). The reader is referred to Yuan et al. (2008) for methods of predicting baseflow for AnnAGNPS simulations.

Input data sections utilized within the AnnAGNPS model are presented in figure 1. Required input parameters include climate data, watershed physical information, and land management operations such as planting, fertilizer and pesticide applications, cultivation events, and harvesting. Daily climate information is required to account for temporal variation in weather and multiple climate files can be used to describe the spatial variability of weather. Output files can be generated to describe runoff, sediment and nutrient loadings on a daily, monthly, or yearly basis. Output information can be specified for any desired watershed source location such as specific cells, reaches, feedlots, or point sources.

The Upper Auglaize Watershed

The Upper Auglaize (UA) watershed is located in portions of Auglaize, Allen, Putnam, and VanWert counties, Ohio in the southern portion of the Maumee River Basin (fig. 2). The watershed encompasses 85,812 ha upstream of an outlet located at the Fort Jennings (04186500) U.S. Geological Survey (USGS) stream gage station (fig. 2). 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 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 (Fine, illitic, mesic Aeric Epiaqualfs) and Pewamo (Fine, mixed, active, mesic Typic Argiaquolls) are the major soil series 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. Common conservation practices applied in the watershed include grassed waterways, subsurface and surface drainage, conservation-tillage and no-tillage, grass filter strips, and erosion control structures.

Input Preparation of Existing Watershed Conditions

Using Geographical Information System (GIS) data layers of elevation, soils, and land use, a majority of the AnnAGNPS data input requirements were developed by using a customized ArcView GIS interface (Bingner, 2009). Inputs developed from the ArcView GIS interface include physical information of the watershed and subwatersheds (AnnAGNPS cells), such as boundary location, area, land slope and slope direction, and channel reach descriptions. The ArcView GIS interface was also used to assign soil and land-use information to each subwatershed cell based on soil and land-use data layers. Additionally the AnnAGNPS Input Editor (Bingner, 2009), a graphical user interface designed to aid users in selecting appropriate input parameters, was used for developing the soil layer attributes to supplement the soil spatial layer, establishing the different crop operation and management data, and providing channel hydraulic characteristics.

Soil information was obtained from the USDA-NRCS Soil Survey Geographic (SSURGO) Database (Natural Resources Conservation Service, 2009). SSURGO provides most of soil parameters required for an AnnAGNPS simulation, such as soil texture, erosive factor, hydraulic properties, pH value, and organic matter content. Information on soil N was estimated based on soil organic matter (Stevenson, 1994). GIS soil maps were used in conjunction with the subwatershed maps to determine the predominant soil assigned to each AnnAGNPS cell.

The characterization of the UA watershed land use, crop operation, and management during the simulation period was critical in generating estimates of the runoff, sediment and N loadings. AnnAGNPS has the capability of simulating watershed conditions with changing land use and crop management over long simulation periods. However, at the UA watershed scale, it was very difficult to characterize the long-term annual changes, including land use and field management practices, occurring in the watershed. Inputs for existing watershed conditions were established by using 1999-2002 LANDSAT imageries and a 4-year crop rotation derived from 1999-2002 field records (Bingner et al., 2006). A summary of the most prevalent crop rotations determined for the four-year land use data are shown in table 1. Rotation components are C (Corn), S (Soybeans), W (Wheat) and F (Fallow meaning permanent grass). The table combines four-year crop sequences that are equivalent except for the year in which they start. In other words, a rotation of CSCS is the same as SCSC for the sake of identifying existent crop rotations despite the fact that the sequences are offset by one year (the AnnAGNPS model keeps them separate by using an offset parameter). More details on development of land use and rotation sequences can be found in Bingner et al. (2006). Because actual tillage information was not available for each field within the UA watershed, tillage type was applied on a random basis to each field such that the accumulative percent area of conventional, mulch, and no-till simulated for the 1999-2002 period was consistent with known percent areas for each tillage type for the same time period at the watershed scale. Percentages of tillage and land use for the UA watershed during 1999-2002 are summarized in table 2. AnnAGNPS allows for subsurface drainage systems to be simulated or not to be simulated for any given field during the model simulations. Since detailed information on subsurface drainage system location and drain diameter/spacing were not available, it was not possible to differentiate areas where subsurface drains were installed or the depth and spacing of any existing drainage system. Local experience substantiated that most fields in the watershed were subsurface drained to a very large extent. Therefore, the AnnAGNPS simulations were conducted with subsurface drainage conditions in all cells containing agricultural crops. Model inputs of fertilizer application such as rates and extents were estimated based on interviews with four custom applicators operating in or near the UA watershed (table 3). Fertilizer reference information was input based on AnnAGNPS guidelines and databases. Plant uptake was chosen through literature investigation (Yuan et al., 2003).

Runoff curve numbers were selected based on the National Engineering Handbook, section 4 (SCS, 1985). Crop characteristics and field management practices for various tillage operations were developed based on RUSLE (Renard et al., 1997) guidelines and local RUSLE databases. Climate data for an AnnAGNPS simulation can be historically measured, synthetically generated using the climate generator program (Johnson et al., 1996; Johnson et al., 2000), or created through a combination of measured and synthesized. Due to the lack of measured long-term weather data for the UA watershed, a one-hundred-year synthetic weather dataset was developed and used for all simulations in this study.

Complete information on weather generation can be found at the AnnAGNPS web site (http://www.ars.usda.gov/Research/docs.htm?docid=5199).

Model Calibration

Annual average flow and suspended sediment data collected at the Fort Jennings USGS stream gage station for the period of 1979-2002 (24 years) were used to calibrate AnnAGNPS simulated long-term annual average runoff and suspended sediment loss. The long-term average annual data were chosen for calibration for the following reasons: 1) long-term average annual information is needed for evaluation of the drainage management practices; 2) historical weather data were not available, and 100-year synthetic weather data were used for simulations (while synthetic weather data would not match 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 annual changes occurring in the watershed was not fully characterized by AnnAGNPS because of lack of information. The land use and management practices of 1999-2002 (tables 1 and 2) were considered to represent the existing situation of the watershed (Bingner et al., 2006). For simulations of existing watershed conditions, 100-year synthetic weather data were used, with the 4-year land use and tillage operation listed in tables 1 and 2 repeated for a 100-year period during simulations. However, the spatial distribution of actual tillage practices was not available for each crop field. From representative tillage transect data, the overall percentages of tillage types were known while the exact field-by-field values were not. 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 reported for the counties in the watershed (Bingner et al, 2006).

Land use and field management for the existing conditions were assumed to represent the calibration period of 1979-2002. Trial and error were performed to adjust AnnAGNPS parameters of drainage rate, curve numbers, amount of interception and sediment delivery ratio to produce the long-term average annual runoff and sediment loading close to that measured at the Fort Jennings USGS stream gage at the outlet. The maximum drainage rate was set to 12.5 mm/day (0.5 inches) based on local experience. The curve number was selected from the table 9 of the National Engineering Handbook-section 4 (SCS, 1985). The curve numbers used in model simulations after calibration are listed in table 4. For example, after calibration, row crop contoured and terraced with good condition was used for row crops with no tillage; row crop contoured with crop residue and good condition was used for row crops with mulch tillage; and row crop straight row with poor condition was used for row crops with conventional tillage (table 9 of the National Engineering Handbook-section 4; SCS, 1985). By default, AnnAGNPS assumes that interception is zero. A literature review suggests that interception varies between 1.2 mm and 2.5 mm. A value of 1.5 mm was used. For sediment, the only parameter adjusted was the sediment delivery ratio and a value of 0.4 was used. More details on calibration can be found in Bingner et al. (2006).

Following the calibration and simulation of existing conditions' runoff and sediment loading, N loading from the watershed was simulated. No further calibration was performed for N loading because information on N loading was not available at the Fort Jennings USGS stream gage station. However, water quality data were available from the Maumee River at Waterville USGS stream gage station (figure 2). Water and pollutant loadings from the UA watershed go through the Waterville stream gage station before they enter the Lake Erie (figure 2). Thus, AnnAGNPS simulated long-term average annual N loading was compared with average annual (1996-2003) N data collected at the Waterville stream gage station. As discussed in runoff and sediment calibration, the long-term average annual N loss information is needed for evaluation of the impact of drainage management practices on N loss.

Evaluation of Drainage Management Practices on Nitrogen Loading

Controlled drainage, the process of using a structure (weir or "stop log") to reduce drainage outflow (water is held at certain level in the field through this control structure), has been widely studied for crop production and environmental benefit (Evans and Skaggs, 1989; Evans et al., 1995).

Research has shown that controlled drainage conserves water and reduces nitrate loss from agricultural fields (Gilliam et al., 1979, 1999; Evans et al., 1995; Skaggs and Chescheir, 2003). Therefore, this is accepted as a best management practice in some states because of the benefit to water quality. Thus, it is very important for AnnAGNPS to be able to simulate the impact of controlled drainage on N loading.

Using the calibrated model, the effects of drain spacing and depth on N loading were evaluated. Drain spacings of 9.1-m (30-feet), 12.2-m (40 feet) and 15.2-m (50-feet) and depths of 1.2-m (48-inch), 1.1-m (42-inch), 0.9-m (36-inch), 0.8-m (30-inch), and 0.6-m (24-inch) were selected and analyzed based on local experience. Following the simulations on drain spacing and depth, drains turned completely off (the weir levels were set at the surface) during the dormant season (November 1 to April 1 the second year) were simulated to evaluate the impact of keeping water in the field during the dormant season on N loading.

RESULTS AND DISCUSSIONS

Model calibration results are presented in table 5. Results of N loadings from different drainage management scenarios are displayed in figures 3-5.

Model Calibration

Annual average runoff (1979-2002) observed at the Fort Jennings USGS stream gage station was 254 mm. After calibration, the simulated 100-year annual average runoff was 254 mm, which consisted of 163.6 mm from direct surface runoff and 90.4 mm from subsurface quick return flow (table 5). Subsurface drainage flow was the major component of subsurface quick return flow. Annual average sediment loading (1979-2002) observed at the Fort Jennings USGS stream gage station was 0.753 T/ha/yr. After calibration, the simulated 100-year annual average sediment loading was 0.771 T/ha/yr (table 5). More details on runoff and sediment calibration and their changes from different management scenarios can be found in Yuan et al. (2006). Runoff and sediment calibration is important for this study because parameters used during calibration are the basis for N loading and additional alternative management scenarios evaluation.

Evaluating and calibrating the model in a more intensive way, such as comparison of annual runoff and sediment, was not possible because historical weather data were not available for the study site (Yuan et al., 2006). In addition, when and where land use changed and how field management operation (including planting, harvesting, and tillage operations) changed during 1979-2002 were not known. The 4-year land use and management practices of 1999-2002 (tables 1 and 2) were assumed to represent the condition for 1979-2002 calibration period, and they were repeated during the simulation period. Therefore, the calibration of the model is limited to average annual. The average annual reflects the long-term situation that occurred in the watershed over the years; thus, the critical parameters impacting runoff and sediment loadings from the watershed can still be calibrated to better reflect the actual conditions of the watershed.

The simulated 100-year average annual agricultural N loading was 12.6 kg/ha/yr, with 12.2 kg/ha/yr dissolved N (table 5) using those calibrated parameters for runoff and sediment. Average annual N loading (1996-2003) observed at the Waterville stream gage station was 18.9 kg/ha/yr which included point source and nonpoint source N loadings. No addition calibration was performed because it is very difficult to separate agricultural nonpoint source N loading from total N loading which includes point source and nonpoint source at the Waterville stream gage station. In addition, the sensitive parameters for N loading such as N fertilizer application rate, soil N concentration and plant uptake (Yuan et al., 2003) were carefully chosen to best represent the watershed condition. Further adjusting those parameters may result in loss of accuracy in representing the watershed condition. For instance, fertilizer application rates were directly obtained from farmer surveys and soil N concentration was estimated based on soil organic matter (Stevenson, 1994). Finally, to evaluate the effects of drainage management practices on N loading, the relative impact of those drainage management practices on N loading is needed. The comparison of their relative impacts could be used for future drainage management planning and decision making.

EVALUATION OF ALTERNATIVE DRAINAGE MANAGEMENT PRACTICES

Long-term AnnAGNPS simulation results indicate a reduction in N loading as drain spacing is increased (figure 3). As the drain spacing increases, the drainage intensity decreases, which reduces the amount of N leaving the agricultural fields. The study done by Gilliam and Skaggs (1986) on several field sites indicated that N losses from drained agricultural fields increased with drainage rates or with the intensity of drainage. Skaggs et al (2005) defined that the drainage intensity is generally associated with drain depth and spacing; and the drainage intensity is assumed to be high with closely spaced drains. Therefore, N losses are expected to be lower with wider drain spacings resulting in decreasing drainage water than with closer drain spacings. Field studies from Indiana done by Kladivko et al. (1999) with three drain spacings (5-m, 10-m and 20-m), all of which provided sufficient drainage for crop production, consistently showed that wider drain spacings resulted in less N losses from agricultural fields than closer drain spacings. Drain spacings of 9-m (30-feet), 12-m (40-feet) and 15-m (50-feet) were used for this study based on NRCS recommendations and other references (Zucker and Brown, 1998; Wright and Sands, 2001). As shown from this study, N loading reduced by about 35% by changing drain spacing from 12-m (40-feet) to 15-m (50-feet) (figure 3). This reduction rate may not be comparable with results obtained from other locations because there are other factors that affect drainage rates and N loading in addition to drain spacing and depth. These include soil physical and chemical properties such as hydraulic conductivity and drainable porosity, the depth of the profile through which water moves to the drains, and soil N level and amount of fertilizer applied. Other factors such as surface depressional storage, which affects surface runoff and hence the amount of water that is removed by subsurface drainage would also impact subsurface drainage rate. Finally, drain diameter and the size and configuration of openings in the drain tube may also affect the drainage rate. The results are useful for drainage management decision making either at the time of drain installation or when producers are considering further drainage improvement. If close drain spacings are shown to be less desirable for water quality, then modification of existing drain lines with water table control structures to have some drain lines turned off might be a practical strategy to mitigate the negative impacts of drainage water.

Results also showed that N loading decreased as drain depth decreased (figure 4). This is because as drain depth decreased, drainage intensity decreased which resulted in less drainage water leaving the agricultural fields (Skaggs et al, 2005). Less drainage water carried less N out of the agricultural fields. Thus, N loadings are expected to be lower with shallower drain depth than with deeper drain depth. Davis et al. (2000) used the Agricultural Drainage and Pesticide Transport (ADAPT) model, a daily time step continuous water table management model, to simulate the impact of fertilizer and drain spacing and depth on N losses for a Webster clay loam near Waseca, Southern Minnesota. Their results showed that N losses decreased as drain depths (1.5-m, 1.2-m and 0.9-m) decreased. Results from Skaggs and Chescheir (2003) with DRAINMOD simulations for a Portsmouth sandy loam at Plymouth, North Carolina also showed that N losses decreased as drain depths (1.5-m, 1.25-m, 1.0-m and 0.75-m) decreased. ADAPT and DRAINMOD are field scale models. Depths of 1.2-m (48-inch), 1.1-m (42-inch), 0.9-m (36-inch), 0.8-m (30-inch), and 0.6-m (24-inch) were used in this study based on the NRCS recommendation. About 15% of N was reduced by changing the drain depth from 1.2-m (48-inch) to 1.1-m (42-inch) (figure 4). An additional 20% of N was reduced by changing the drain depth from 1.1-m (42-inch) to 0.9-m (36-inch) (figure 4). There was only a slight reduction predicted by changing the drain depth from 0.8-m (30-inch) to 0.6-m (24-inch) (figure 4). Thus, drain depths shallower than 0.6-m (24-inch) were not analyzed. This reduction rate may not be comparable with results obtained from other locations because there are other factors discussed previously impacting drainage rate and N loading. The results on drain depths are also useful for drain installation and/or further drainage improvement. If deeper drain depths are shown to be less desirable for water quality, then modification of existing drain depth can be achieved with water table control structures to raise water table (acting as shallow drain) according to crop growth stage. Holding water in the fields will increases the time for denitrification to occur and decreases the transport on N from subsurface water losses to surface waters.

Nitrogen loading could be significantly reduced by controlling water into subsurface drains from November 1 to April 1 of each year based on model simulations (figure 5). This result is consistent with field observations at various locations (Gilliam and Skaggs, 1986; Drury et al., 1996; Ng et al., 2002; Osmond et al., 2002; Drury et al., 2009). About 64% of N was reduced by completely controlling subsurface drainages (setting weirs at surface) for drain depth of 1.2-m (48-inch) when compared to the conventional drainage system (free drainage from November 1 to April 1) (figure 5). Similarly, 66% of N was reduced for a drain depth of 1.1-m (42-inch), and 59% for a drain depth of 0.9-m (36-inch) (figure 5). As shallower drains, completely controlling subsurface drains (setting weirs at surface) in the dormant season also hold water in the fields which potentially increases denitrification and decreases the amount of subsurface water losses to surface waters which decrease N load to surface water. However, little additional impact was found by completely controlling subsurface drains in the dormant season for drain depths shallower than 0.8-m (30-inch). Therefore, if agricultural producers are adverse to the idea of "completely controlling subsurface drainages or completely turning the drains off" at any time, setting the drainage outlet (depth of drain) at 24-inch or above would achieve the goal of reducing N loading significantly without turning the drains off (figure 5). As indicated in figure 5, nitrogen loading does not change much by completely controlling subsurface drainages in dormant season for drain depths of 30-inch and 24-inch.

Therefore, wider drain spacings and shallow drain depths are recommended to reduce N loading from the fields. In addition, wider drain spacings and shallow drain depths also conserve water. However, information on how crops react to different drainage management practices is also needed to make any final decisions. Completely turning the drains off during the dormant season (November 1 to April 1) appears to be an ideal and very promising approach in reducing N loading because there is not much of a concern for impacting crop productivity for this practice. However, shallow drains such as setting the drainage outlet (depth of drain) at 24-inch or above would achieve the goal of reducing N loading significantly as completely turning the drains off during the dormant season (November 1 to April 1).

Although models are simplifications of the real world and uncertainty is an inevitable part of model simulation, utilization of the AnnAGNPS model can provide evaluation of the relative impact of drainage management practices on N loading, which could be used to provide information needed for future drainage management and planning at the watershed scale. Future watershed modeling work would focus on identify critical areas which should be targeted first for drainage management practices implementation to achieve maximum water quality benefits.

The main focus of this paper was to assess the impact of alternative drainage management practices on N loading and to examine strategies used to reduce N loading from agricultural fields. Since most conservation program assessments would be performed by models, given the difficulties of obtaining long-term monitoring data, application of the AnnAGNPS model for UA watershed drainage management practices assessment provides an excellent tool for this purpose.

SUMMARY AND CONCLUSIONS

AnnAGNPS model was applied to the Ohio UA watershed to evaluate the impact of subsurface drainage management practices on N losses. The model was calibrated using average annual data collected at the Fort Jennings USGS gauging station because historical weather data were not available, and 100-year synthetic weather data were used for simulation. Although significant efforts were spent in characterizing land use, tillage, crop rotation, and management practices during model calibration, the day by day temporal and field by field spatial variations of the information were not fully represented in the model. The synthetic weather data would not match historical weather data for an individual event, long-term synthetic weather statistics should reflect historical weather statistics; furthermore, the average annual reflects the long-term situation that occurred in the watershed over the years; thus, the critical parameters impacting runoff and sediment loadings from the watershed can still be calibrated to better reflect the actual conditions of the watershed.

AnnAGNPS simulation results of drainage management practices showed that N loading was decreased as the drain spacing was increased. Changing drain spacing from 12-m (40-feet) to 15-m

(50-feet) reduced N loading by 35%. Simulation results also showed that N loading was decreased as drain depth was decreased. Changing the drain depth from 1.2-m (48-inch) to 1.1-m (42-inch) reduced N loading by 15%, and an additional 20% reduction can be achieved by changing the drain depth from 1.1-m (42-inch) to 0.9-m (36-inch). Only a slight reduction was predicted by changing the drain depth from 0.8-m (30-inch) to 0.6-m (24-inch). Furthermore, N loading could be significantly reduced by controlling subsurface drains from November 1 to April 1 of each year. Up to 66% of N can be reduced by completely controlling subsurface drainages depending on drain depths. These results are useful for future drainage management and planning at the watershed scale. Although findings from this study are consistent with field observations at other locations, but the actual reductions rates obtained from this study may not be comparable with results obtained from other locations because there are other factors impacting N loading. Future watershed modeling work would focus on targeting critical areas for drainage management practices implementation to achieve maximum water quality benefits.

Notice: Although this work was reviewed by USEPA and approved for publication, it may not necessarily reflect official Agency policy. Mention of trade names or commercial products does not constitute endorsement or recommendation for use**.**

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Table 1. Crop rotations summarized for the 4-year land use, C (Corn), S (Soybeans), W (Wheat) and F (Fallow meaning permanent grass).

Rotation	Area (ha)	Percent of agricultural land use	Accumulated percent
CSCS	16894	21.9%	21.9%
CCCS	10833	14.1%	36.0%
CSSS	6286	8.2%	44.1%
CCSS	5741	7.5%	51.6%
CCSW	5680	7.4%	59.0%
CSWS	4016	5.2%	64.2%
CSCW	3407	4.4%	68.6%
CSSW	3389	4.4%	73.0%
CCFF	1391	1.8%	74.8%
CWSW	1387	1.8%	76.6%
CWSS	1295	1.7%	78.3%
SSSS	1184	1.5%	79.8%
CSWW	1182	1.5%	81.3%
CCCW	1171	1.5%	82.9%
CCWS	1121	1.5%	84.3%
CCCC	1121	1.5%	85.8%
SSSW	1104	1.4%	87.2%
FFWC	1057	1.4%	88.6%
CCSF	575	0.7%	89.3%
CWFW	559	0.7%	90.1%
FFFW	431	0.6%	90.6%

Table 2. Upper Auglaize watershed 4-year crop, tillage, and land-use distribution in percent, the total area is 85,812 hectares.

Landuse	Tillage	1999	2000	2001	2002
Corn	Conventional	10.1%	13.1%	10.5%	10.5%
	Mulch till	18.7%	17.0%	20.3%	17.9%
	No till	10.4%	14.1%	12.2%	14.0%
	Total	39.3%	44.2%	43.0%	42.3%
Beans	Conventional	8.7%	6.0%	7.4%	9.4%
	Mulch till	9.6%	16.8%	11.5%	13.7%
	No till	11.8%	11.1%	13.7%	11.2%
	Total	30.0%	33.9%	32.5%	34.2%
Wheat	Conventional	1.9%	2.6%	3.7%	1.6%
	Mulch till	5.3%	3.8%	4.3%	2.7%
	No till	5.2%	4.6%	3.1%	3.8%
	Total	12.4%	10.9%	11.1%	8.0%
Grass	Conventional	1.4%	0.4%	0.5%	0.6%
	Mulch till	4.2%	0.2%	1.7%	3.7%
	No till	2.7%	0.4%	1.1%	1.2%
	Continuous	0.4%	0.4%	0.4%	0.4%
	Total	8.7%	1.4%	3.7%	5.8%
Forest		5.6%	5.6%	5.6%	5.6%
Residential		2.0%	2.0%	2.0%	2.0%
Roads		1.4%	1.4%	1.4%	1.4%
Commercial		0.5%	0.5%	0.5%	0.5%
Water		0.1%	0.1%	0.1%	0.1%
Grand Total		100.0%	100.0%	100.0%	100.0%

Table 3. Fertilizer application for various crops.

Crop Type	Nitrogen (kg./ha..)	P_2O_5 (kg./ha.)
Corn	157	50
Soybean	0	34
Wheat	65	45
Alfalfa	0	73

Table 4. Curve numbers used for model simulations after calibration

AnnAGNPS land cover	Land cover class from table 9 of the NHD-4 (NRCS, 1985)	Curve Number			
		Hydrological soil group			
		A	B	C	D
Row crop with NT*	Row crop contoured and terraced (good)	62	71	78	81
Row crop with RT*	Row crop contoured with crop residue (good)	64	74	81	85
Row crop with CT*	Row crop straight row (poor)	72	81	88	91
Small grain with NT*	Small grain contoured and terraced (good)	59	70	78	81
Small grain with RT*	Small grain contoured and terraced (good)	60	72	80	84
Small grain with CT*	Small grain contoured and terraced (good)	64	75	83	86
Fallow	Fallow with crop residue (good)	74	83	88	90
Forest	Woods (good)	30	55	70	77
Commercial	Residential (38% impervious)	61	75	83	87
Residential	Residential (38% impervious)	61	75	83	87
Roads	Roads (paved w/ditch)	83	89	92	93

* NT refers to no-tillage, RT refers to reduced tillage and CT refers to conventional tillage.

Table 5. Calibration outputs of runoff sediment and nitrogen as compared to observed values for existing watershed conditions.

Item	AnnAGNPS Simulation	USGS Observation
Watershed annual average direct surface runoff (mm)	162.6	
Watershed annual average subsurface flow (mm)	91.4	
Watershed annual average total runoff (mm)	254.0	254.0
Sediment loading at the watershed outlet (t/ha/Yr)	0.771	0.753
Total N loading at the Waterville gage (kg/ha/Yr)	12.6	18.9

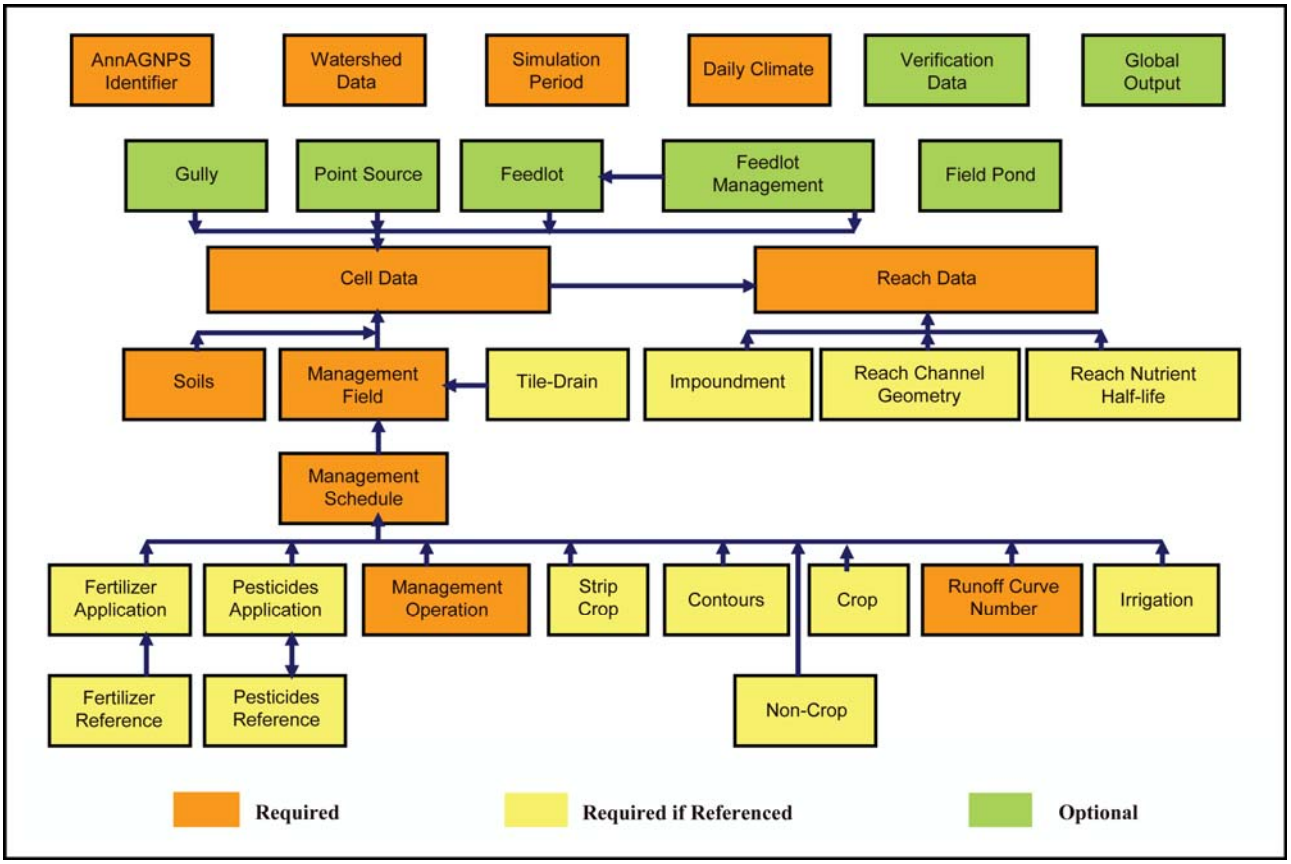

Figure 1. AnnAGNPS input data sections

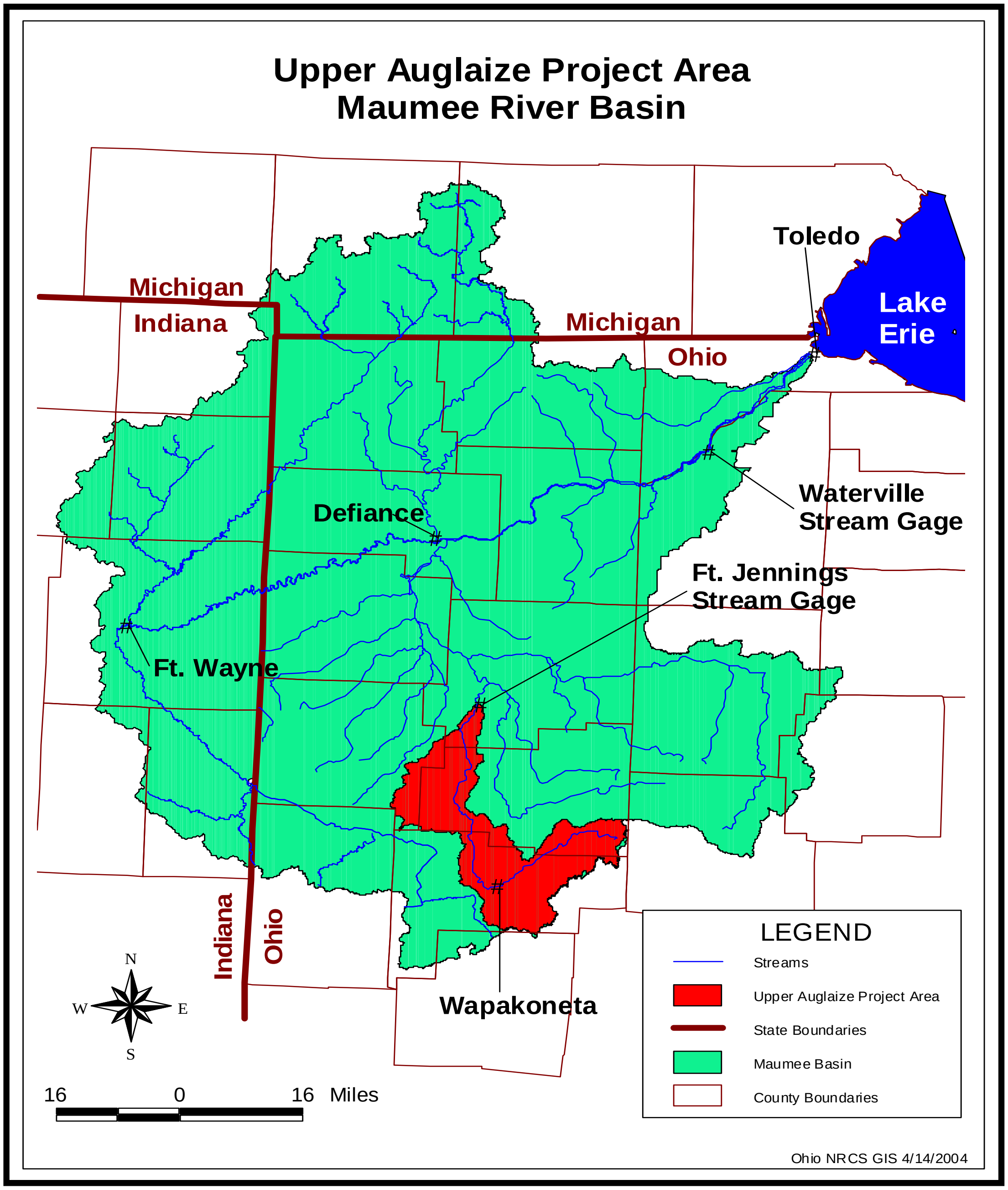

Figure 2. The Maumee River basin drainage network, Upper Auglaize watershed, and the Wapakoneta and Fort Jennings Gage Stations.

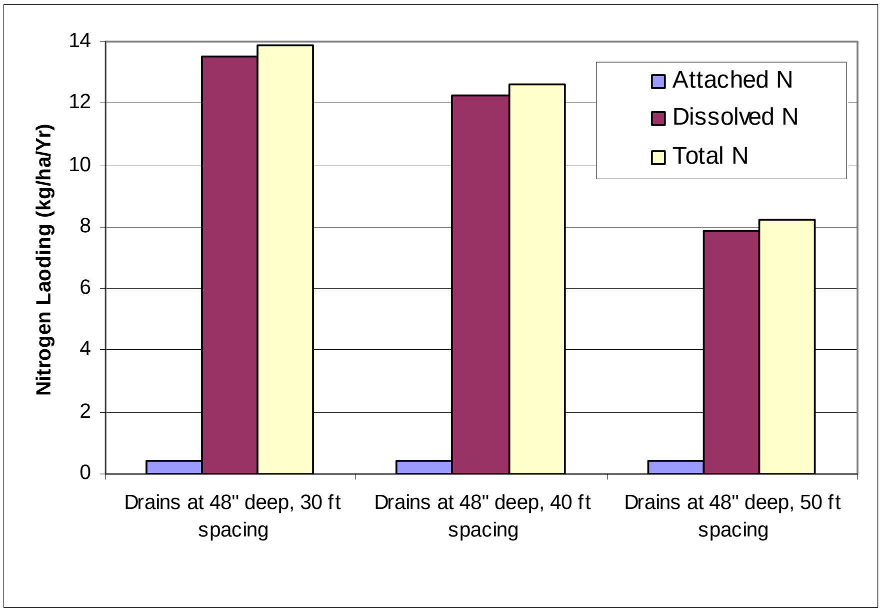

Figure 3. Effects of drain spacing on N loading

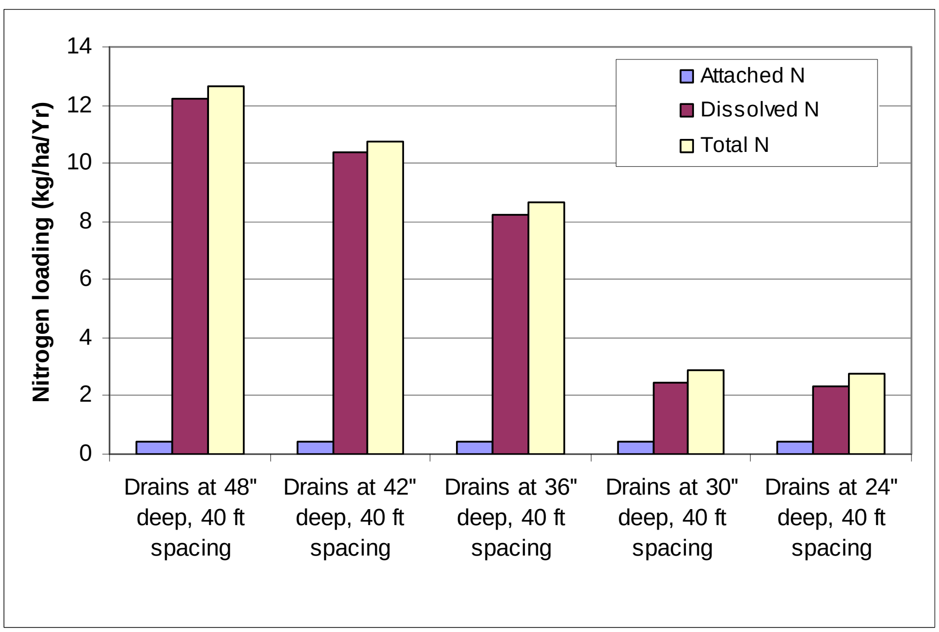

Figure 4. Effects of drain depth on N loading

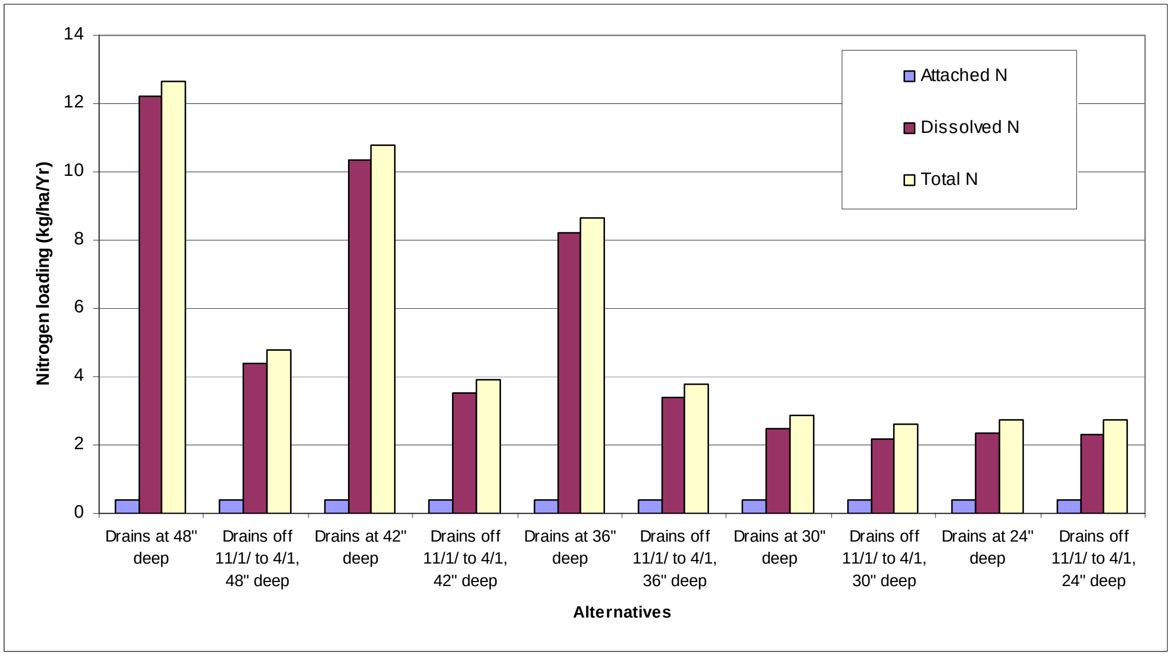

Figure 5. Effects of turning drains off during dormant season (Nov. 1 to Apr. 1) on N loading