농촌계획
Vol. 10, No. 4, 2004 (55-64)

Application of NAPRA WWW for Modeling Surface Water Quality

Kyoung Jae Lim · Bernard A. Engel* · Ki-Sung Kim · Joong-Dae Choi
Department of Agricultural Engineering, Kangwon National University
**Department of Agricultural and Biological Engineering, Purdue University*

지표수질 모의를 위한 NAPRA WWW 시스템의 적용

임경재 · 버나드 엥겔* · 김기성 · 최중대
강원대학교 농업공학부 · *퍼듀대학교 농업생명공학과

ABSTRACT : National Agricultural Pesticide Risk Analysis (NAPRA) WWW 시스템 (http://pasture.ecn.purdue.edu/~napra)은 각기 다른 영농방법이 지표수질, 유사, 그리고 지하수질에 미치는 영향을 평가하기 위하여 개발되었다. 이 NAPRA WWW 시스템은 Total Maximum Daily Loads와 같은 수질 요건을 만족시킬 수 있는 최적영농 방법이 무엇인지 찾는데, 그리고 수질 측면에서 취약한 지역을 찾아내는데 매우 효율적인 시스템이다. 이 NAPRA WWW 시스템을 이용하여 미국 인디애나주의 수계에 대해서, NAPRA 모의 Nitrogen과 Atrazine 결과를 실측치와 비교하였다. 18개 수계에 대해서 NAPRA 예측 질소값과 실측 질소값을 비교한 결과 R^2 값은 0.51이고, 6개 수계에 대해서 NAPRA 예측 Atrazine값과 실측값을 비교한 결과 R^2 값은 0.87이었다. 이 연구에서 보여지는 바와 같이 NAPRA WWW 시스템은 수계내에서 질소와 Atrazine에 따른 오염지역을 찾아내는데 효율적으로 사용될 수 있는 시스템이다.

Key words : Decision support system, Geographic information systems, NAPRA WWW, Nonpoint source pollution, Water quality model

I. Introduction

Nonpoint source (NPS) pollution problems cause tens of billions of dollars in damage in the U.S. every year (Lovejoy et al., 1997). Nutrients, pesticides, sediment, animal wastes, bacteria, and salt are the primary NPS pollutants from agricultural activities. Fertilizer and livestock waste applied to agricultural fields are the primary causes of nitrate-nitrogen contamination within Indiana (IDEM, 1989). The hypoxia region in the Gulf of Mexico has been a concern, and it was found that NPS pollution is the primary cause of hypoxia. Although the nitrate concentrations in streams in the Indiana White River basin don't exceed 100 mg/L, it plays important roles in eutrophication of lakes in Indiana and in the Gulf of Mexico (U.S. EPA, 1997). Thus, we need to design short-term, intermediate, and long-term plans to reduce nutrient loadings to the Gulf of Mexico. Also, pesticides lost in runoff and shallow groundwater can impair surface and subsurface water quality. A variety of pesticides were commonly found in streams in the Indiana White River basin (Fenelon, 1998). Pesticides behave differently depending on their properties, such as sorption, soil and water half-life, and water solubility. Highly soluble pesticides usually move with runoff or leach to shallow groundwater, while some pesticides having higher sorption coefficient adsorb onto the soil and results in low concentrations in water, but in high concentrations on soil particles (Bicknell et al., 1996).

Identification of regional NPS pollution problem areas is important to farmers, extension agencies, and action agencies because their success is dependent on development and implementation of appropriate management strategies. To identify the severity of NPS pollution and methods for its control, many models have been developed and tested over the years (Beasley et al., 1980; Knisel and Davis,

Corresponding author : Ki-Sung, Kim
Tel : 033-250-6466
E-mail : kskim@kangwon.ac.kr

1999; Arnold et al., 1993). However, preparing input data for these models is often difficult for model users. The Geographic Information Systems (GIS) are often used in preparing these data for hydrologic and water quality models. The GIS can be used to map, compare, and spatially analyze the input data and output which can be useful in understanding and interpreting the results (Stallings et al., 1992).

Hydrologic models integrated with GIS have the advantage of ease and efficiency of storing, retrieving, and formatting the many types of spatial and tabular data required for hydrologic/water quality modeling (Stallings et al., 1992). Examples of GIS integration into physically-based hydrologic and water quality models and rank-based groundwater models include ANSWERS (Rewerts and Engel, 1991), AGNPS (Engel et al., 1993; Engel, 1996), SWAT (Srinivasan and Arnold, 1994), DRASTIC (Engel et al., 1996), SEEPAGE (Engel et al., 1996), SPISP (Engel et al., 1996), NAPRA WWW (Engel and Manguerra, 1998; Engel and Lee, 1998), Nutrient Enabled NAPRA WWW (Lim and Engel, 1998), and L-THIA (Lim et al., 2001). However, even models integrated with GIS still require experienced people to prepare input data, make the appropriate assumption, and interpret the output (Engel and Lee, 1998, Lim and Engel, 1998). Thus, the NAPRA WWW system was developed to enable the users having no scientific backgrounds on hydrology and water quality to simulate the effects of pesticide managements on hydrology and pesticide losses (Engel and Lee, 1998), and the nutrient component of Groundwater Loading Effects of Agricultural Management Systems (GLEAMS) was added to the NAPRA WWW system (Lim, 1998 Lim and Engel, 1998; Lim and Engel, 2003) for the simulation of nutrient component. This NAPRA WWW system is useful to estimate the effects of agricultural management on surface and subsurface water quality, and it can also be used to determine the appropriate rates of pesticide and nutrient applications to meet water quality specifications such as Total Maximum Daily Loads.

The goals of this paper were to evaluate the predictive abilities of the NAPRA WWW system from nutrient and pesticide perspectives. In this study, the NAPRA WWW system was run for 18 study watersheds and six watersheds in Indiana to examine the nutrient and atrazine losses in runoff, respectively.

II. Review of Literature

Hamlett et al. (1992) identified the NPS pollution potential of 104 watersheds in Pennsylvania and prioritized them based on watershed NPS pollution indices. GIS data were used to compute the watershed NPS indices by combining four other indices a runoff index, a sediment production index, an animal loading index, and a chemical use index. The 104 watersheds were ranked based on these indices and the watersheds vulnerable to NPS pollution were identified for more intensive managements to mitigate the water quality degradation (Hamlett et al., 1992). Choi et al. (2000) also identified the NPS pollution potential in subwatersheds of the Soyang Dam basin in Korea based on the same NPS indices as those considered in the study by Hamlett et al. (1992). However, Choi et al. (2000) used the Long-Term Hydrologic Impact Assessment (L-THIA) GIS system (Lim et al., 2001) and Revised Universal Soil Loss Equation (RUSLE) integrated with ArcView GIS. Choi et al. (2000) also developed a Vulnerability Index map generator to create vulnerability index maps with different weights for each index. The Hamlett et al. (1992) and Choi et al. (2000) approaches don't predict pollutant transport, but rather provide indices that reflect the expected magnitude of NPS pollution. The model results in these studies were not compared to water quality data.

Better techniques than the Hamlett et al. (1992) and Choi et al. (2000) watershed indices approaches are needed to enable a user to examine the site-specific effects of management practices, and nutrient and pesticide application date and rate on nutrient and pesticide losses in runoff, to sediment, and to shallow groundwater. The NAPRA was developed by Natural Resources and Conservation Service (NRCS) and the University of Massachusetts to evaluate the complex environmental risks of pesticide use (Bagdon et al., 1994).

The Web-based NAPRA approach (Engel and Manguerra, 1998; Engel and Lee, 1998) was developed to estimate the site-specific effects of land use and management on water quality with respect to pesticides. The nutrient component of the GLEAMS was added to the NAPRA WWW system to simulate the effects of agricultural management on nutrient water quality (Lim, 1998; Lim and Engel,

1998). Pesticide data from the GLEAMS User's Manual and USDA database was incorporated in the NAPRA WWW database to facilitate selection of valid pesticide names by either trade name or common name (Lim and Engel, 1999; Lim and Engel, 2000). Pesticide properties, such as water solubility, organic carbon partitioning coefficient (Koc), half life, and washoff fraction, are extracted from the database and used in the pesticide input parameter file. The GLEAMS hydrologic/water quality model within NAPRA WWW system requires numerous soil properties, pesticide properties, and daily weather data. The soil parameters were obtained from State Soil Geographic Database (STATSGO) or National Soil Information System (NASIS). Relevant soil parameters, such as porosity, field capacity, wilting point, organic matter content, soil erodibility, and sand, silt and clay content are extracted from a relational database to create GLEAMS input parameter files (Engel and Manguerra, 1998; Lim and Engel, 2003).

The overview of the NAPRA WWW system is shown in Figure 1. The NAPRA WWW system uses the GLEAMS model as the core model to estimate the effects of farm management changes on surface and subsurface pesticide water quality (Knisel and Davis, 1999). The pre- processor in NAPRA WWW system constructs input files for GLEAMS (Knisel and Davis, 1999) from user-provided management, pesticide, and nutrient data in the input interface, by querying databases and by running weather generator models. The main input interface of the NAPRA WWW system, shown in Figure 2, can be divided into four major categories: 1) field input, 2) management input, 3) pesticide input, and 4) nutrient input. Crop rotations and multiple pesticide and nutrient applications for each crop can be simulated. Once the input parameter files are created, the GLEAMS is run with the input files and its results are summarized in the form of graphical output plots and GIS maps. These results are displayed in the user's Web browser (Engel and Manguerra, 1998; Lim and Engel, 2003). The NAPRA WWW approach is designed to be easy to use and widely accessible through the Internet.

Homes et al. (2001) used stream flow and herbicide concentration data to develop and evaluate a method for estimating comparative watershed contamination potential. U.S. Geological Survey data for five relatively water soluble herbicides were analyzed for 16 Indiana water

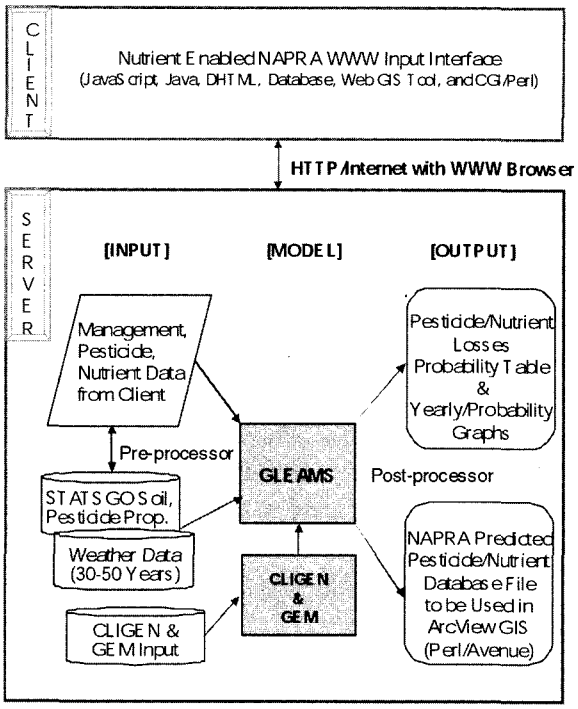

Figure. 1. Overview of the nutrient enabled NAPRA WWW decision support system (Lim and Engel, 2003)

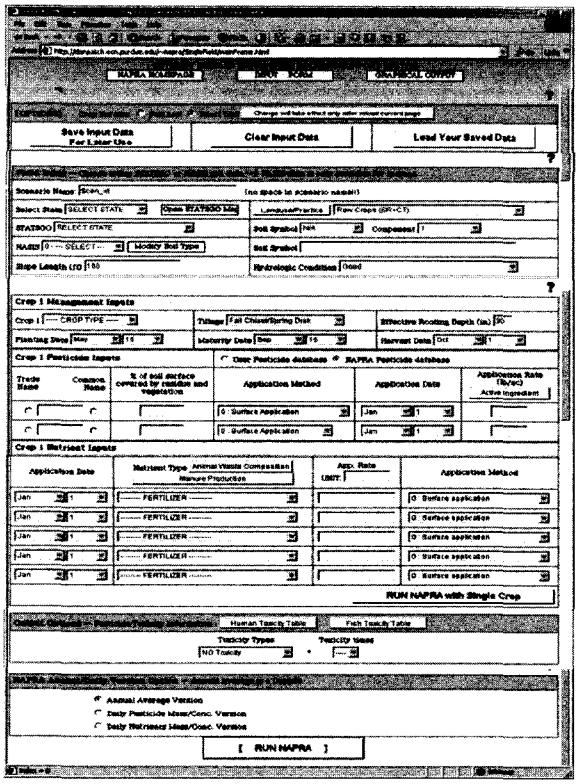

Figure. 2. The NAPRA WWW main input interface (Only a portion of the input interface is shown due to space limitation (Lim and Engel, 2003)

sheds ranging in size from 45 km^2 to 4479 km^2. Correlation was assessed between observed herbicide losses and an herbicide runoff index using GIS-based land use, soil type, SCS curve number, tillage practice, herbicide use, combinations of the factors, and NAPRA WWW predicted herbicide losses. State average pesticide application rate was used in the model runs, although all pesticides, except atrazine, were applied to less than 50% of Indiana. The results were generally poor because all watersheds were assumed as agricultural areas and some pesticides considered might not be applied to some of study watersheds. Thus, the predicted pesticide values were generally higher than measured pesticide values. However, the correlation between runoff curve number and the measured pesticide was high, so the runoff curve number (CN) can be used as a simple water-soluble herbicide contamination susceptibility index (Homes et al., 2001).

III. Methodology

The potential of the nutrient enabled NAPRA WWW system for identifying critical watersheds from nitrogen and atrazine loss perspectives was evaluated by comparing the NAPRA WWW predicted nitrogen and atrazine results with observed water quality data. Eighteen watersheds within Indiana were selected for nitrogen comparison and six watersheds in the Indiana White River Basin were selected for atrazine comparison (Figure 3). The boundaries of the study watersheds were delineated using 1 : 250,000 DEM data from the USGS. The areas of the study watersheds range from 11.50 km^2 to 12,998 km^2. Land uses of the study watersheds are mainly cropland, pasture, and forest based on the USGS land use/land cover map. Slopes within the watersheds are generally flat with average slopes less than 2% in most of the watersheds. Nitrogen and atrazine water quality data were obtained from USGS for the study watersheds in the Indiana.

Indiana Agricultural Statistics data (http://www.nass.usda.gov/in/index.htm) were used to assess the total nitrogen fertilizer applied within each county/watershed and animal waste production from beef cows, milk cows, hogs, chickens, and turkeys for each county. These values were compiled for each county and estimated for each watershed using the area-weighted average of the percentage of the watershed within the county.

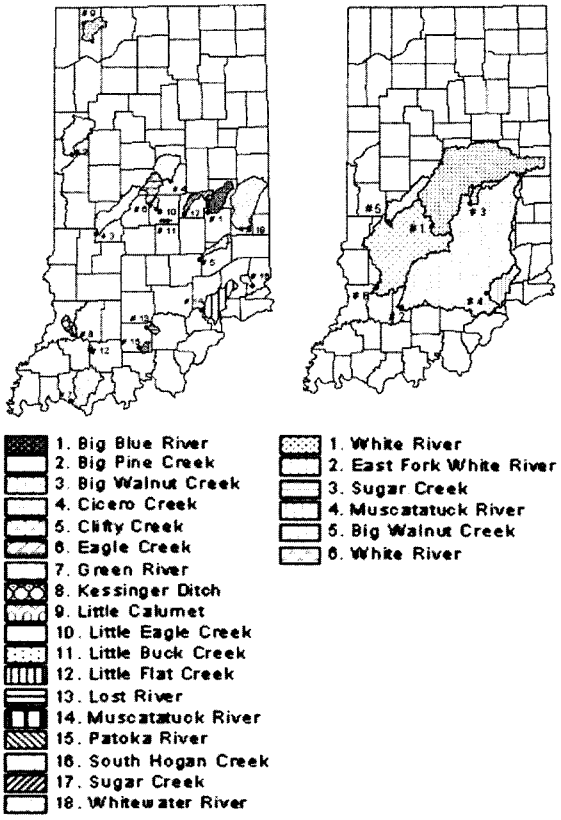

Figure. 3. Eighteen nutrient evaluation watersheds, six pesticide evaluation watersheds, and water quality monitoring stations for each watershed.

The simulations were completed for corn and soybeans, and the total nitrogen losses were computed based on the relative area percentage of corn and soybeans in the counties within watersheds. The area of corn and soybeans planted for each county were obtained from the Indiana Agricultural Statistics Service (http://www.nass.usda.gov/in/index.htm). Corn and soybean percentages assigned to each watershed were estimated based on the percentage of each county within each watershed. The percentages of corn and soybeans planted in each watershed were multiplied by NAPRA WWW predicted outputs for each crop to obtain estimated watershed nitrogen losses for comparison with the observed data.

State average atrazine application rate was obtained from the Indiana Agricultural Statistics Service 1998-1999 Report, and the NAPRA WWW system was run with the state average atrazine application rate, average planting date, average harvest date, the assumption that 35% of the surface was covered with crop residue at the time of pesticide application and "Fall Chisel/Spring Disk" tillage.

The area of subsurface drainage systems for each county (1.5%-53.8%) was obtained from the Census of Agriculture (U.S. Bureau of the Census, 1974). The percentages of drainage systems for each study watershed were computed on an area-weighted basis using the portion of each county in each watershed. These percentages of drainage system were used to estimate the portion of nitrogen and atrazine leached below the root zone that is likely to be intercepted by subsurface drains. Nitrogen and atrazine leached below the root zone multiplied by the drainage system percentage were assumed to move to surface water. Predicted nitrogen and atrazine losses in runoff plus nitrogen and atrazine leached below the root zone multiplied by the drainage system percentages were compared with the observed nitrogen and atrazine loss data.

1. Model Runs

The NAPRA WWW runs with state average nitrogen and atrazine application rates were completed on the study watersheds. Fertilizer in the form of 16-20-0 and anhydrous ammonia was applied on April 25 for corn. Fertilizer was applied on May 5 for soybeans. Atrazine was applied at 1.50 kg/ha for corn at the planting time. For corn, the planting date was May 5, maturity date was September 15, and harvest date was October 1. For soybeans, the planting date was May 15, maturity date was September 1, and harvest date was September 20. It was assumed that the crop remained the same over the simulation period (e.g. continuous corn and continuous soybeans). Overall simulated results were obtained by multiplying predicted results by their area percentages of corn and soybeans in the watershed, then summing. For the comparison of the NAPRA predicted results with the observed data, the predicted values in runoff and the shallow groundwater were summed after multiplying the predicted values leached by the drainage system area percentage in that watershed.

The NAPRA WWW simulation of the entire Indiana was conducted to obtain maps of nitrate and atrazine losses. Corn and soybeans were simulated for the entire Indiana using the state average fertilizer application and animal waste data. The NAPRA WWW was run based on the STATSGO soil and weather combinations, and its output was reported for all components of each of these combinations. The NAPRA WWW was run for the continuous corn with the state average atrazine application data. The average nitrate and atrazine loss values were computed for each STATSGO unit and weather station combination and converted to database files. Annual average nitrate and atrazine concentration in runoff maps were generated to examine the impacts of corn and soybean cropping on Indiana surface quality. These maps can be used to identify the areas vulnerable to the nitrate and atrazine losses.

2. Assumptions of the NAPRA WWW Nutrient System Approach

Many assumptions are made in NAPRA WWW runs. Management practices, such as nutrient application date, application method, application type, application rate, ground disturbing event dates, ground disturbing event types, and USLE C factors are assumed to be the same each year for the 30-50 year simulation period.

Many GLEAMS defaults are used for the crop, animal waste, and tillage data because databases related to these are incorporated into GLEAMS. Total nitrogen, nitrate-nitrogen concentrations, total phosphorus, and labile phosphorus concentrations in soil horizons were assumed constant for all of Indiana. These values quickly stabilize for long-term simulations such as those completed in NAPRA WWW, and thus have little effect on the results (Lim, 2001).

The state average atrazine application rate was used. According to a report by the Indiana Agricultural Statistics Service, 1998-1999, atrazine was applied to 86.5% of corn in Indiana. This indicates that atrazine may be applied to only a portion of the corn in the study watersheds. The cropping-management system is assumed the same for the entire area, and only soil parameters and weather vary. In this study, point source nutrient and pesticide values were ignored. Nutrient and pesticide applications were also assumed uniform over the county/watershed of interest during the simulation period.

IV. Results and Discussion

1. Nitrogen Loss Results

Predicted short-term and long-term nitrogen losses were compared with the observed watershed data. A comparison of the short-term NAPRA WWW predicted nitrogen loss

data with the observed nitrogen data for the 18 study watersheds are shown in Figure 4. Short-term predicted results are the average loss for the period of observed water quality data. The observed nitrogen concentration data for the Clifty watershed and Lost River watershed are much higher than observed data for other watersheds. This might be caused by point source pollution in these watersheds. Point source pollution is not considered by the nutrient enabled NAPRA WWW system. Also there may be the possibility of a relatively large amount of nitrate contribution from baseflow in these watersheds compared to the other study watersheds. Thus, SAS software was used to detect possible outliers in measured nitrate concentrations using studentized residual method and Cook's Distance (Schlotzhauer and Little, 1987; Weisberg, 1985). Studentized residual values and Cook's Distance for these two watersheds were higher than those of other watersheds. Thus, these two watersheds were considered as possible outliers. Ignoring these two watersheds, R^2 between short-term predicted and observed data is 0.51, while R^2 between long-term predicted and observed data is 0.41. Short-term predicted and long-term predicted nitrogen concentrations for the 18 study watersheds using state average fertilizer are shown in Figure 5. Based on the results from Figures 4 and 5, the nutrient enabled NAPRA WWW system has reasonable potential for estimating nitrogen loss concentrations from watersheds.

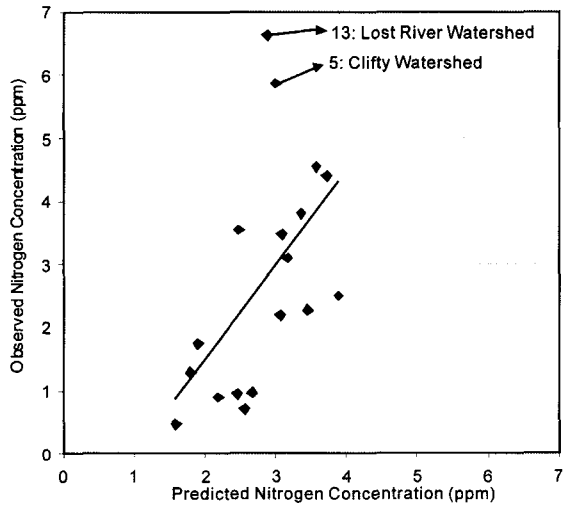

Figure. 4. Comparison of Short-Term predicted Nitrogen concentrations (ppm) vs. Observed Nitrogen Concentrations (ppm). Predicted values were computed using State Average Fertilizer Application.

2. Atrazine Loss Results

The NAPRA WWW predicted atrazine values in runoff and observed data at water quality stations shown in Figure 3 are provided in Figure 6. The NAPRA WWW predicted atrazine losses in runoff are higher than measured data. This can be explained in that degradation occurs when the pesticide travels from fields to the watershed outlet, and dilution occurs due to runoff from other land uses. Also, the date of pesticide application in all fields was assumed to be the same throughout the NAPRA simulation period. The occurrence of rainfall shortly after pesticide application may result in high loss to surface water, because the sorption coefficient (Koc) of atrazine is 100 mL/g, and it is primarily lost with surface

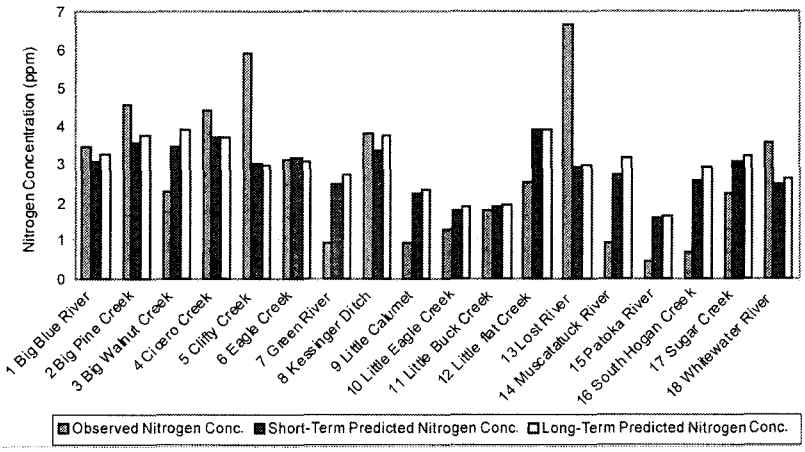

Figure. 5. Comparison of observed, Short-Term predicted, and Long-Term predicted Nitrogen Concentrations (ppm) in runoff. Predicted values were computed using State Average Fertilizer Application.

runoff (Fawcett et al., 1994; Lim, 2001). However, the R^2 value between predicted atrazine concentration values and the observed atrazine concentration values is 0.87.

3. Nutrient and Pesticide Loss Maps for Indiana

Maps of nitrate and atrazine losses in runoff were created for the Indiana by running the nutrient enabled NAPRA WWW system for regions of the state and aggregating the results. The simulated annual nitrate concentration in runoff for Indiana considering state average fertilizer application is shown in Figure 7. The nitrate concentration classes are based on equal area classification in the data. The cropping management system used is described previously. Based on these results, the northwestern portion of the state is expected to have the greatest nitrate loss in runoff. Annual simulated atrazine concentration in runoff with state average atrazine application is shown in Figure 8. The northern portion of Indiana is expected to have the greatest atrazine losses in runoff. The spatial variations in the predicted nitrate concentration and atrazine concentration in runoff (Figures 7 and 8) were due to the difference in soil properties and climate. The spatial variations are somewhat similar because nitrate and atrazine are both highly water-soluble and easily move with runoff. To examine the pesticide detection in the northeast region of the Indiana, samples were taken from 1996 to 1999 and analyzed to examine the temporal and spatial distribution of pesticide (Wartenberg and Isiorho, 2001). Pesticide contamination, especially atrazine contamination, is severe in this region. These results coincide with the NAPRA predicted atrazine concentration values in runoff as shown in Figure 8.

Advantages of the NAPRA WWW Nutrient Approach

The nutrient enabled NAPRA WWW system approach can be efficiently used to assess how different management practices can improve water quality, and it can also be used to find critical watersheds or areas with respect to nitrogen and atrazine losses. There are several advantages of the NAPRA WWW nutrient system compared to the watershed ranking approach of Hamlett et al. (1992) and Choi et al. (2000). The NAPRA WWW approach considers site-specific weather, soil data, management practices, application rates of fertilizer/manure and other site-specific data. In doing so, it is able to deal with uncer-

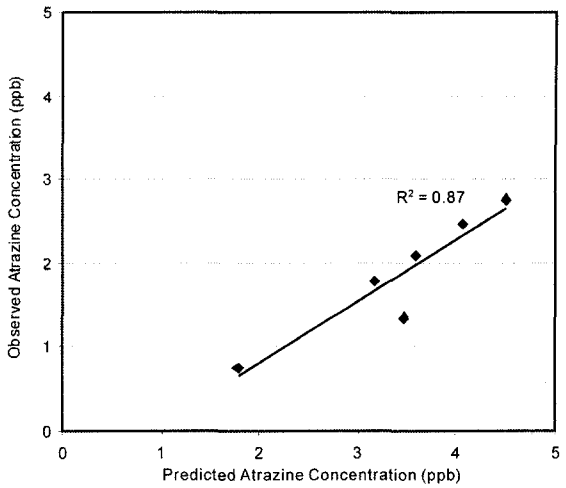

Figure. 6. Comparison of NAPRA WWW predicted atrazine concentrations and observed atrazine concentrations in runoff.

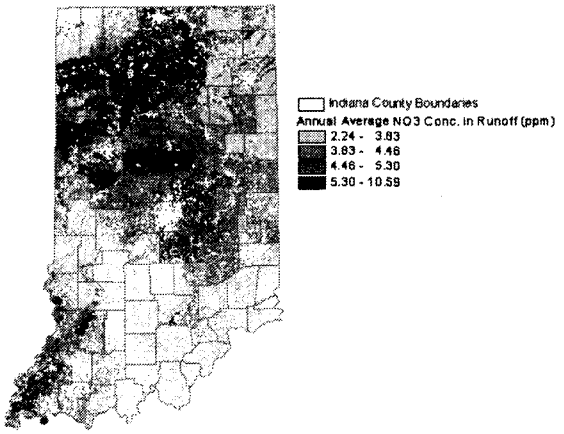

Figure. 7. Annual average NO_3 concentration in runoff for corn-soybean rotations in cropped areas.

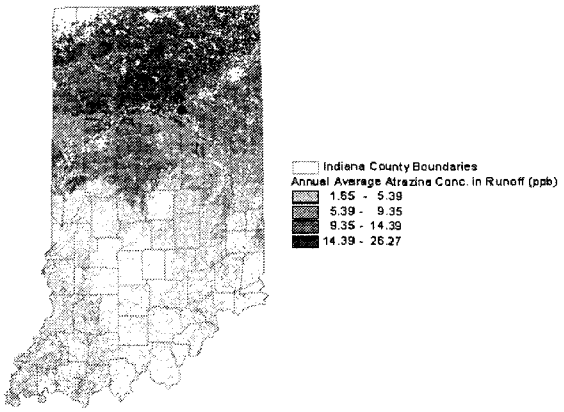

Figure. 8. Annual average atrazine concentration in runoff for continuous corn in cropped areas.

tainty resulting from spatial variability and variations in

weather. In addition, the effects of management changes can also be simulated using the nutrient enabled NAPRA WWW system.

The NAPRA WWW system offers several other advantages in its implementation compared to more traditional methods used within decision support systems (Engel and Lee, 1998; Lim and Engel, 1998; Lim and Engel, 2003). 1) It can be accessed from any location through a WWW browser; 2) Databases and GIS data provide model inputs greatly simplifying use of the system; 3) All model users access the same version of model because it is maintained at a single location; 4) Computationally intensive aspects of the system (County/Watershed version of the NAPRA WWW system) are run on a more powerful computer than available to most model users, 5) The predicted values are interpreted in tabular and graphical format, making it easier for users to understand the results quickly.

V. Conclusions

Eighteen watersheds were used for evaluation of the NAPRA system's potential to predict watershed level nitrogen losses. The comparison of the predicted nitrogen concentration data with the observed data showed the NAPRA WWW predicted similar nitrogen losses as observed data in many cases. The R^2 between the predicted nitrogen loss concentration and the observed data was 0.51 when the state average fertilizer values were used. The NAPRA WWW system was run for six watersheds in the Indiana White River basin. The R^2 value between the predicted atrazine and observed atrazine concentration is 0.87, although the predicted atrazine values were higher than observed data due to limitations in NAPRA model runs.

To identify critical areas from nitrate and atrazine loss perspectives in Indiana, nitrate and atrazine loss to runoff maps were generated. The NAPRA WWW estimates the greatest nitrate losses in runoff to occur in the northwestern portion of Indiana. The atrazine concentration in runoff showed similar patterns. The nutrient enabled NAPRA WWW system shows promise for identifying critical watersheds from nitrogen and atrazine loss perspectives.

Although the data for the NAPRA WWW runs are available for only 48 states in the US, it can be also used in other countries with minimum data preparation. To run the NAPRA WWW system for other countries, such as Korea, local weather data and soil properties are needed. However, these data needs to be uploaded to the NAPRA WWW server for Web-based modeling. Thus, the work is underway to enable users to upload the local GIS soil map with weather data to the NAPRA WWW server for this purpose since the rest of input data for the NAPRA WWW cab be queried from the NAPRA WWW database. The prototype version of the Web GIS-based NAPRA WWW system is available at http://pasture.ecn.purdue.edu/~napra/.

References

1. Arnold, J. G., Engel, B. A., Srinivasan, R., 1993, A Continuous Time, Grid Cell Watershed Model. Proceedings of the Application of Advanced Information Technologies; Effective Management of Natural Resources Conference. ASAE.
2. Bagdon, J. K., Plotkin, S., Hesketh, E. S., 1994, NAPRA Technology Transfer Overview: Introduction. USDA Report, Washington, D.C.
3. Beasley, D. B., Huggins, L. F., Monke, E. J., 1980, ANSWERS; A model for watershed planning. Transactions of the ASAE 23(4) : 938-1238
4. Bicknell, B. R., Imhoff, J. C., Kittle, J. L. Jr., Donigian, A. S. Jr., 1996, Hydrological Simulation Program Fortran User's Manual for Release - 11. Environmental Research Laboratory. Office of Research and Development. Athens, Georgia. U.S. EPA.
5. Choi, K. J., Choi, J., Lim, K. J., Engel, B. A., 2000, Nonpoint Surface Water Pollution Potential in Soyang Watershed. ASAE Paper No. 00-2043, American Society of Agricultural Engineering, Milwaukee, Wisconsin.
6. Engel, B. A., 1996, AGNPS-GRASS Interface.http://soils. ecn.purdue.edu/~aggrass/models/agnps/Index.html
7. Engel, B. A., Manguerra, H. (1998) A WWW-Based Hydrologic and Pesticide Movement Risk Analysis System. Proceedings of International Conference on Geospatial Information in Agriculture and Forestry, 1 : 520-527, Lake Buena Vista, FL.
8. Engel, B. A., Lee, J., 1998, WWW-Based Hydrologic/Water Quality Modeling Decision Support System. In

: Seventh International Conference on Computers in Agriculture. F. Zazueta and J. Xin(eds.), 359-367, St. Joseph, Michigan.

9. Engel, B. A., Navulur, K., Copper, B., 1996, Estimating Groundwater Vulnerability to Nonpoint Source Pollution From Nitrates and Pesticides on a Regional Scale. HydroGIS 96: Application of Geographic Information Systems in Hydrology and Water Resources Management. Proceedings of the Vienna Conference, April 1996, IAHS Publ. No. 235 : 231-237
10. Engel, B. A., Srinivasan, R., Rewerts, C., 1993, A Spatial Decision Support System for Modeling and Managing Agricultural Nonpoint Source Pollution. In: Goodchild, M.F., B.O. Parks, and L.T. Steyart, (eds.) Geographic Information Systems and Environmental Modeling, Oxford University Press, New York, 231-237
11. Fawcett, R. S., Christensen, B. R., Tierney, D. P., 1994, The Impact of Conservation Tillage on Pesticide Runoff into Surface Water: A Review and Analysis. J. of Soil and Water Cons. 49 : 316-325
12. Fenelon, J. M., 1998, Water Quality in the White River Basin, Indiana, 1992-1996. Circular 1150, Indianapolis, Indiana. U.S. Geological Survey.
13. Hamlett, J. M., Miller, D. A., Day, R.L., Peterson, G. W., Bauner, G. M., Russo, J., 1992, Statewide GIS-based Ranking of Watersheds for Agricultural Pollution Prevention. J. of Soil and Water Cons. 47(5) : 399-404
14. Homes, M. J., Frankenberger, J. R., Engel, B. A., 2001, Susceptibility of Indiana Watersheds to Herbicide Contamination. Journal of the American Water Resources Association. 37(4) : 987-1000
15. IDEM, 1989, Indiana Groundwater Protection, A Guide Book, Technical Report, Indiana Department of Environmental Management, Groundwater Section.
16. Indiana Agricultural Statistics Data: http://www.nass.usda.gov/in/index.htm. Last accessed Aug. 15, 2003.
17. Knisel, W. G., Davis, F. M., 1999, GLEAMS Version 3.0 User Manual. USDA-ARS-SEWRL, Tifton, Georgia. Pub. No.: SEWRL-WGK/FMD-050199.
18. Lim, K. J., 1998, An Extension of the National Agricultural Pesticide Risk Analysis (NAPRA) Approach to Include Nutrients. M.S Thesis, Ag. and Biological Engineering, Purdue University.
19. Lim, K. J., 2001, Enhanced NAPRA WWW Spatial Decision Support System (SDSS) with River Water Quality Modeling Capability. Ph.D Dissertation, Ag. and Biological Engineering, Purdue University.
20. Lim, K. J., Engel, B. A., 1998, An Extension of the National Agricultural Pesticide Risk Analysis (NAPRA) Approach to Include Nutrients. ASAE Paper No. 98-3188, American Society of Agricultural Engineering, Orlando, Florida.
21. Lim, K. J., Engel, B. A., 1999, Evolution and Evaluation of Nutrient Enabled NAPRA WWW Decision Support System. ASAE Paper No. 99-2151, Toronto, Ontario, Canada.
22. Lim, K. J., Engel, B. A., 2000, Evolution and Evaluation of Nutrient Enabled NAPRA WWW Decision Support System with GLEAMS 3.0. ASAE Paper No. 00-2173, American Society of Agricultural Engineering, Milwaukee, Wisconsin.
23. Lim, K. J., Engel, B. A., 2003, Extension and Enhancement of National Agricultural Pesticide Risk Analysis (NAPRA) WWW Decision Support System to Include Nutrients. Computers and Electronics in Agriculture. 38(3) : 227-236
24. Lim, K. J., Engel, B. A., Kim, Y., Bhaduri, B., Harbor, J., 2001, Development of Long-term Hydrologic Impact Assessment (L-THIA) WWW System, In: D. E. Stott, R. H. Mohtar, and G. C. Steinhardt, (eds), Sustaining the Global Farm Selected papers from the 10th International Soil Conservation Organization Meeting, May 24-29,1999, West Lafayette, Indiana, International Soil Conservation Organization in cooperation with the USDA and Purdue University, West Lafayette, Indiana. 1018-1023
25. Lovejoy, S. B., Lee, J. G., Randhir, T. O., Engel, B. A., 1997, Research Needs for Water Quality Management in the 21stCentury: A Spatial Decision Support System. J. Soil and Water Cons. 52(1) : 18-22
26. Rewerts, C. C., Engel, B. A., 1991, ANSWERS on GRASS: Integrating a Watershed Simulation with a GIS. ASAE Paper No. 91-2621, St. Joseph, MI.
27. Schlotzhauer, S. D., Little, R. C., 1987, SAS System for Elementary Statistical Analysis. Cary, NC: SAS Institute.
28. Srinivasan, R., Arnold, J. G., 1994, Integration of Basin-Scale Water Quality Model with GIS. Water Resources Bulletin, 30(3) : 453-462

29. Stallings, C., Huffman, R. L., Khorram, S., Guo, Z., 1992, Linking GLEAMS and GIS. ASAE Paper No. 92-3615.
30. U.S. Bureau of the Census, 1974, State and County Data, U.S. Census of Agriculture, 1(14).
31. U.S. EPA, 1997, Proceedings of the First Gulf of Mexico Hypoxia Management Conference, U.S. EPA Report EPA-55-R-97-100.
32. Wartenberg, A., Isiorho, S. A., 2001, Geographic Distribution of Pesticide Contamination in the St. Joseph River Watershed, Northeast Indiana. The Geological Society of America, North-Central Section 35th Annual Meeting, Normal, Illinois. April, 2001.
33. Weisberg, S., 1985, Applied Linear Regression, 2nd Edition, New York, Wiley Pub.