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Nutrient Enabled National Agricultural Pesticide Risk Analysis (NAPRA) WWW Decision Support System for Agricultural Best Management Practices

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최적관리기법을 위한 웹기반 NAPRA 의사결정 지원시스템

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요약 : National Agricultural Pesticide Risk Analysis (NAPRA) World Wide Web (WWW) 시스템 (http://danpatch.ecn.purdue.edu/~napra)은 다양한 영농방법에 따른 농약과 영양물질의 지표수/지하수 유실량을 웹에서 모의하고자 개발되었다. 단일 토양에 대해서 모의할 수 있는 Single Field 버전의 많은 기능이 개선되었고, 행정구역/수계 경계에 대해서 모의할 수 있는 County/Watershed 버전을 확장시켜, Web Geographic Information Systems (GIS) 버전의 NAPRA 시스템을 개발하였다. Web GIS 툴을 이용하면, 모의하고자 하는 지역을 마우스로 디지타이징 한 후, 그 지역에 대해서 영농방법에 따른 영향을 모의할 수 있다. 모의결과를 웹브라우저를 통해서 지도로 보여줄 뿐만 아니라, 그 결과를 데스크탑용 GIS에서 사용할 수 있는 포맷으로 제공한다. 모델을 운영하기 위하여 방대한 양의 입력자료가 필요하고, 일반 사용자가 준비하기 힘든 데이터들이 있는데, NAPRA WWW 시스템은 이러한 입력자료를 서버측 GIS 데이터 베이스, NAPRA 데이터 베이스, 강우 및 온도 모델 예측치 에서 추출하여 모델을 운영한다. 또한, 모의결과를 방대한 양의 텍스트 파일이 아닌, 차트나, 테이블, 또는 지도형태로 보여주기 때문에, 농부와 같이 전문지식이 없는 사람이 이 시스템을 이용하여 여러 가지 영농 방법 중에서 환경 친화적이면서 경제성을 유지 할 수 있는 최적관리기법을 찾아낼 수 있다.

Key words : Decision support system, GLEAMS, NAPRA, Nutrient, Pesticide, WWW

I. 서 론

Approximately 6.5 million tons of nitrogen are produced from 11.5 million tons of nitrate fertilizer and 7 billion farm animals every year in the U.S. (Puckett, 1994). Nonpoint source (NPS) pollution problems are the primary concerns of water quality degradations for many locations and have caused tens of billions of dollars in damage in the U.S. every year (Lovejoy et al., 1997). Fertilizer and livestock waste applied to agricultural fields are the primary causes of nitrate-nitrogen contamination in Indiana (IDEM, 1989). It was also found that the primary cause of the Hypoxia in the Gulf of Mexico is the NPS pollutants coming from the upstream areas (U.S. EPA, 1997).

In addition to nutrients, pesticides applied to the field can impair surface and subsurface water quality through runoff and leaching to the shallow groundwater. A variety of pesticides were commonly found in streams in Indiana (Fenelon, 1998) and some pesticides were reported exceeding U.S. EPA's Maximum Contaminant Levels in several surface water supplies (Goolsby and Battaglin,

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1995). Every pesticide behaves 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 result in low concentrations in water but in high concentrations on soil particles (Bicknell et al., 1996).

Many NPS models, such as Area Nonpoint Source Watershed Environment Response (ANSWERS) (Rewarts and Engel, 1991), Agricultural Nonpoint Source (AGNPS) (Engel et al., 1993), and Soil and Water Assessment Tool (SWAT) (Srinivasan and Arnold, 1994), have been developed and integrated with Geographic Information Systems (GIS) to reduce water quality degradation due to NPS pollution. GIS assist in developing and analyzing data required by these models. GIS tools extract the spatial data and run model after the GIS data are ready. Thus, model results are used by the tools to build GIS data layers. Results can be analyzed using GIS tools to help the user understand and analyze the model results easily. However, GIS integrated models require expertise to operate. So, these models have been used by primarily scientific researchers, and are too difficult for novice users (Mohtar et al., 2000).

To overcome these limitations of GIS integrated models, the National Agricultural Pesticide Risk Analysis (NAPRA) World Wide Web (WWW) system was developed to provide an easy-to-use interface to the model, and to help the users understand the model results by providing the output in tabular, graphical formats. There have been needs to enhance the NAPRA WWW system to simulate the more complex agricultural management system. Also, it was not possible to define the spatial location of interest within the county or watershed boundary with the old version of the NAPRA WWW system. Thus, many features have been enhanced in the NAPRA WWW system and Web GIS version of the NAPRA system was developed in this study. The NAPRA WWW system has been applied to many study watersheds in Indiana and has been found that it has a potential to identify vulnerable areas to NPS pollutants (Lim and Engel, 1999; Lim and Engel, 2000, Lim et al., 2001). Thus, the accuracy of the NAPRA WWW system will not be discussed in this paper.

II. GLEAMS and NAPRA WWW SYSTEM

The NAPRA WWW system uses Groundwater Loading Effects of Agricultural Modeling Systems (GLEAMS) (Knisel and Davis, 1999) as a core model to simulate hydrology, erosion, pesticide losses, and nutrient losses. The GLEAMS model is a field scale, physically based continuous time step computer model created from the modification of Chemicals, Runoff and Erosion from Agricultural Management System (CREAMS) (Knisel et al., 1992). The model has four components: hydrology, erosion, pesticide and nutrient. The pesticide and nutrient components are optional, and hydrology and erosion parameter files are required to run GLEAMS (Knisel et al., 1992). Hydrology processes are responsible for providing the transport medium for sediment and agricultural chemicals and nutrients (Knisel et al., 1992), and the hydrology output is the input of the other three components and sediment yield and silt/clay/organic matter output are also used in the pesticide and nutrient components (Mamilapalli and Engel, 1994). GLEAMS is used to estimate the effects of farm management changes on surface water and shallow groundwater quality - sediment, pesticides, and nutrients leaving the bottom of the root-zone or edge of the field (Leonard et al., 1987) and predicts surface runoff and sediment yield from agricultural fields. Percolated water may transport many contaminants beyond the root zone and thus, groundwater in areas of saturated soil profiles and high water tables may be particularly vulnerable to contamination by plant nutrients and pesticides (Sichani et al., 1991). GLEAMS nutrient component incorporates processes to estimate surface and subsurface fate of edge-of-field and bottom-of-root-zone loading of plant nutrient nitrogen and phosphorus. The processes considered are mineralization from crop residue, soil organic matter, and animal waste. immobilization to crop residue, and crop uptake for both N and P, In addition to these, nitrogen fixation by legumes, denitrification, nitrogen in rainfall and ammonia volatilization from animal waste and two stage mineralization of nitrogen-ammonificatioon and nitrification are also considered (Knisel et al., 1992). GLEAMS model was applied to an experimental drainage field at the

Southeast Purdue Agricultural Center near North Vernon, Indiana by Sichani et al. (1991). It was found that the field-scale simulation were close to the field observations for masses for pesticides leached from the root zone and for timing of pesticide detection in the drain tile flows (Sichani et al., 1991).

NAPRA (USDA NRCS, 1995) is an automated pesticide risk screening process that utilize the USDA-Agricultural Research Service (ARS) environmental fate model GLEAMS (Knisel et al., 1992). The Web-based NAPRA system was developed (Engel and Manguerra, 1998) and nutrient enabled NAPRA WWW system was developed by Lim and Engel (1998). With the information provided in the NAPRA input interface and data from NAPRA database, the NAPRA system builds input parameter files for GLEAMS model. The GLEAMS simulated results are used in preparing hydrology output, pesticide and nutrient loss and probability of exceedance curves, and tabular pesticide and nutrient probability of exceedance data. The NAPRA WWW system is constructed using Java script, Java, HTML, Dynamic HTML, Cascading Style Sheets (CSS), C language, CGI using the PERL language, and the Mapserver (Mapserver, http://mapserver.gis.umn.edu) GIS tool.

III. TWO VERSIONS OF THE NUTRIENT ENABLED NAPRA WWW SYSTEM

There are two versions of the NAPRA WWW system: 1)Single Field version and 2)County/ Watershed version. The Single Field version can be run for only one component of one Map Unit ID (MUID) in State Soil Geographic Database (STATSGO) or one soil symbol in the National Soil Information System (NASIS) (USDA, NRCS, http:// nasis.nrcs.usda.gov) soil data. The County/ Watershed version runs for the county or watershed of interest. Although it takes more time to run for a county or watershed than running the Single Field version, model users can see the spatial variations of pesticide and nutrient losses in surface and shallow groundwater. The output obtained from the County/Watershed version can be used to prioritize areas by identifying critical watersheds or areas within watersheds from a nutrient loss perspective as well as a pesticide loss perspective.

1. Single Field Version of the NAPRA WWW System

The Single Field version of the NAPRA WWW system can be accessed at http://danpatch.ecn.purdue. edu/~napra/. Three crop rotations and multiple pesticide and nutrient applications for each crop can be simulated with the Single Field version of the NAPRA WWW system. Hundreds of JavaScript functions were written to provide user friendly interface and to check the possible errors by the users. To allow the NAPRA users to select the soil symbol of interest from a map, rather than from pulldown menus, a customized Mapserver (Mapserver, http:// mapserver.gis.umn.edu) WWW interface was developed (Figure 1) using Java, Javascript, and CGIs.

The NAPRA WWW system requires the amount of pesticide active ingredient applied to the crop. Most model users are unlikely to know the exact amount of active ingredient of the pesticide they wish to simulate. Therefore, pesticide information in the Crop Data Management Systems (Crop Data Management Systems, http://CDMS.net) was linked to the NAPRA WWW, and simple pesticide search functions and a simple active ingredient calculator using Javascript were developed for this purpose as shown in Figure 2. The active ingredient information can be obtained from the search output, and the amount of active ingredients of pesticides can be

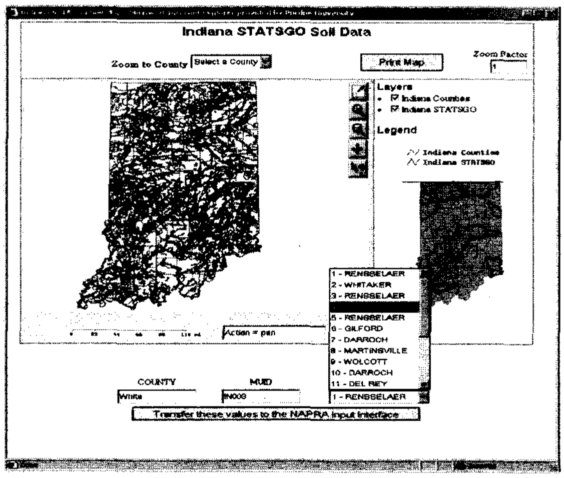

Figure 1. Indiana STATSGO Soil Map using Mapserver CGI Program

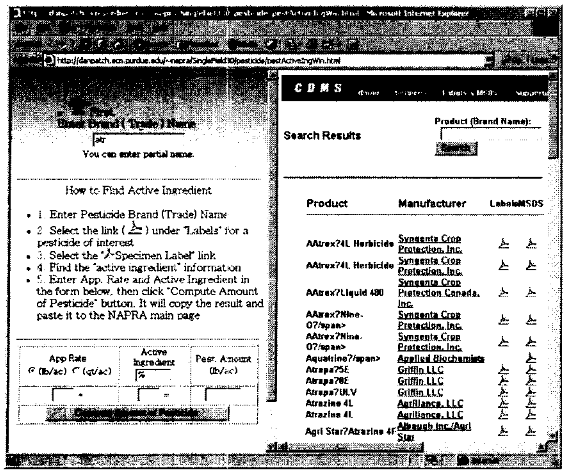

Figure 2. The Pesticide Active Ingredient Computation Window

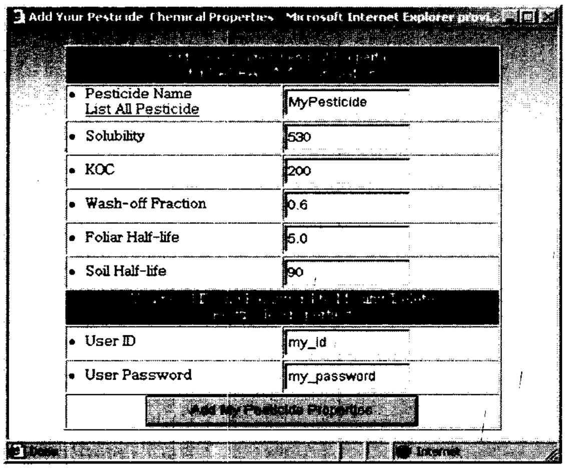

Figure 3. Interface for User Provided Pesticide/ Chemical Properties

computed using the simple calculator provided in this search window. This calculator transfers the amount of active ingredient to the main NAPRA input interface.

The user can enter their own pesticide/chemical properties in a "personal" database on the server-side for use in NAPRA model runs as shown in Figure 3, if the pesticide/chemicals of interest are not included in the NAPRA pesticide database. Users can modify or delete the property value if necessary with their ID and password.

Seventy eight crops can be simulated in the current NAPRA WWW system. Average planting, maturity, and harvesting date for commonly planted crops in Indiana (Indiana Agricultural Statistics Service, 1999) are associated with each county in Indiana, so the interface automatically updates the average date for these inputs depending on the county selected. The user can adjust these dates if desired.

Brief descriptions of animal waste nutrient composition from GLEAMS user manual (Knisel and Davis, 1999) and land use types were linked in the input interface for model users who are not familiar with the terminology used. Human and fish toxicity level information for hundreds of pesticides is also stored in the NAPRA relational database. The level of toxicity information can be selected in the input interface, and levels are displayed on the pesticide loss output graphs. Twenty commonly used fertilizer and 14 animal waste types can be simulated with the NAPRA WWW system. The nutrient composition data for each nutrient type are used in the model runs.

Once the GLEAMS model is run with the parameterized input files using the data from the spatial and relational databases and user-provided information in the NAPRA input interface, a post-processor creates a series of outputs. Probability of exceedance values at the 10% and 50% levels for pesticide and nutrient losses in surface water, shallow groundwater and sediment are provided in a table as shown in Figure 4. Values used in the probability table are interpolated linearly if there are no specific 10% and 50% probability values in the model results. Both mass and concentration of pesticide and nutrient losses are reported in this table in either English unit or Metric unit.

50% and 10% Pesticide and Nutrient Probability of Exceedence Values for Surface, Shallow Groundwater and Sediment Losses

NAPRA Predicted Mass Lost	Runoff		Shallow Groundwater		Sediment	
	50 %	10 %	50 %	10 %	50 %	10 %
Atrazine (g/ha)	5.8741	23.3043	2.9132	11.9740	0.0005	0.0034
Nitrogen (kg/ha)	5.3594	10.3845	9.4068	18.5617	0.0168	0.0704
Phosphorus (kg/ha)	1.1827	1.8910	0.0005	0.0012	0.2173	0.6291
NAPRA Predicted Concentration Lost	**Runoff**		**Shallow Groundwater**		**Sediment**	
	50 %	10 %	50 %	10 %	50 %	10 %
Atrazine (ppb)	3.8021	64.3640	1.7520	7.0011	---	---
Nitrogen (ppm)	4.2831	9.7295	4.7423	6.3168	---	---
Phosphorus (ppm)	1.0172	1.2384	0.0003	0.0005	---	---

Figure 4. Pesticides and Nutrients Probability of Exceedance Table

Table 1. The Graphical Outputs of the Single Field Version of the NAPRA WWW

▶ Graphical Output of Pesticide In Terms Of Probability of Exceedance
- Pesticide Loading in Annual Runoff (g/ha)
- Pesticide Loading in Annual Sediment (g/ha)
- Pesticide Loading Leached Annually (g/ha)
- Pesticide Concentration in Four-Day Runoff (ppb)
- Pesticide Concentration Leached in Four Days (ppb)
- Pesticide Concentration in Annual Runoff (ppb)
- Pesticide Concentration Leached Annually (ppb)
- Annual Runoff (cm)
- Annual Percolation (cm)

▶ Graphical Output of Pesticide In Terms Of Annual History Values
- Pesticide Loading in Annual Runoff (g/ha)
- Pesticide Loading in Annual Sediment (g/ha)
- Pesticide Loading Leached Annually (g/ha)
- Pesticide Concentration in Four-Day Runoff (ppb)
- Pesticide Concentration Leached in Four Days (ppb)
- Pesticide Concentration in Annual Runoff (ppb)
- Pesticide Concentration Leached Annually (ppb)
- Annual Runoff (cm)
- Annual Percolation (cm)

▶ Graphical Output of Nutrients In Terms Of Probability of Exceedance
- Nitrogen Loading in Runoff (kg/ha)
- Nitrogen Concentration in Annual Runoff (ppm)
- Phosphorus Loading in Runoff (kg/ha)
- Phosphorus Concentration in Annual Runoff (ppm)
- Nitrogen Loading in Sediment (kg/ha)
- Phosphorus Loading in Sediment (kg/ha)
- Nitrogen Loading Leached Annually (kg/ha)
- Nitrogen Concentration Leached Annually (ppm)
- Phosphorus Loading Leached Annually (kg/ha)
- Phosphorus Concentration Leached Annually (ppm)

▶ Graphical Output of Nutrients In Terms Of Annual History Values
- Nitrogen Loading in Runoff (kg/ha)
- Nitrogen Concentration in Annual Runoff (ppm)
- Phosphorus Loading in Runoff (kg/ha)
- Phosphorus Concentration in Annual Runoff (ppm)
- Nitrogen Loading in Sediment (kg/ha)
- Phosphorus Loading in Sediment (kg/ha)
- Nitrogen Loading Leached Annually (kg/ha)
- Nitrogen Concentration Leached Annually (ppm)
- Phosphorus Loading Leached Annually (kg/ha)
- Phosphorus Concentration Leached Annually (ppm)

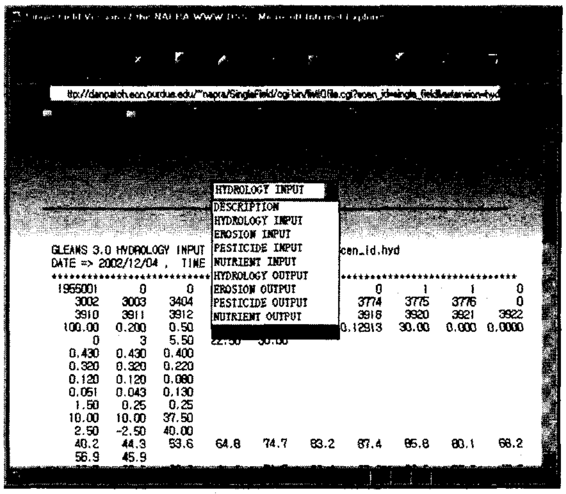

Figure 5. Links to GLEAMS Input and Output Files and Other Simulation Results

The post-processor of the Single Field version of the NAPRA WWW system generates the dozens of graphs as shown in Table 1. As a default, English units are used, but results can be viewed in metric units also. The raw data used in the graphs are provided in tabular format in English and metric units for reporting purposes or further analysis. Human and fish toxicity level information (25%, 50%, 100%, 200%, 500%, and 1000% of the standard value) is provided in the output graphs as water quality guidance.

The output interface also provides access to all GLEAMS input and output files generated during the model runs. Figure 5 shows the interface to access input and output files of the GLEAMS model and other related model results. The description link on the top of the output interface provides a brief description of the NAPRA WWW run. Four GLEAMS input files and four output files are provided, so model users can download and use these data for further analysis if desired.

2. County/Watershed Version of the NAPRA WWW System

The Single Field version of the NAPRA WWW is suitable to examine the effects of agricultural management on single soil with uniform agricultural management information over it. The County/ Watershed version of the NAPRA WWW system was developed to be run for larger areas, such as a county or a watershed. The

STATSGO soil data are used in the County/Watershed version of the NAPRA WWW system. For a County/ Watershed version of the NAPRA WWW runs, the STATSGO soil data, county boundary map, and Thiessen weather polygon networks were intersected in a GIS, and each combination of these three maps were prepared for each county in Indiana. Figure 6 shows the schematic of the County/Watershed version of the NAPRA WWW system. This version is run for each combination, describe as "aMUIDWthrCnty" in Figure 6, of all combinations of soil, and Thiessen weather polygon for each county or watershed, which is described as "allMUIDWthrCnty" in Figure 6, with all other model inputs held constant. Then, it computes the average pesticide and nutrient outputs in surface and shallow groundwater for each of these combinations.

The predicted values may vary for the same MUID in the same county with the same agricultural management information if the Thiessen weather station information is different. The County/ Watershed version of the NAPRA WWW predicted nitrate and atrazine concentrations in runoff for the White River basin, Indiana are shown in Figure 7. The NAPRA WWW predicted nutrient and pesticide maps can be used by decision makers to identify the most vulnerable areas or watersheds and to make plans to reduce NPS pollution.

To run the County/Watershed version of the NAPRA WWW system, it may take several hours to complete model runs for a county / watershed of interest. Also, additional efforts are needed to create a GIS map from the simulated results. Sometimes, model users, such as farmers or extension personnel, want to run the NAPRA WWW system for a small area, rather than for a large area. Thus, Web GIS version of the NAPRA WWW system was developed. With this version, model users can simply digitize the area of interest from a map using a mouse with their web browsers, and then run NAPRA WWW for this area. The model predicted pesticide and nutrient output values are provided in GIS map format on the web browser. Also, the output results are available in the ArcView Shape file format, thus model users can download the GIS map for further analysis or reporting purpose. Figure 8 shows the overview of the Web GIS version of the NAPRA WWW system. The easy-to-use NAPRA WWW GIS can be used by novice users, such as farmers, who do not have scientific backgrounds to find the agricultural best management practices for their farm.

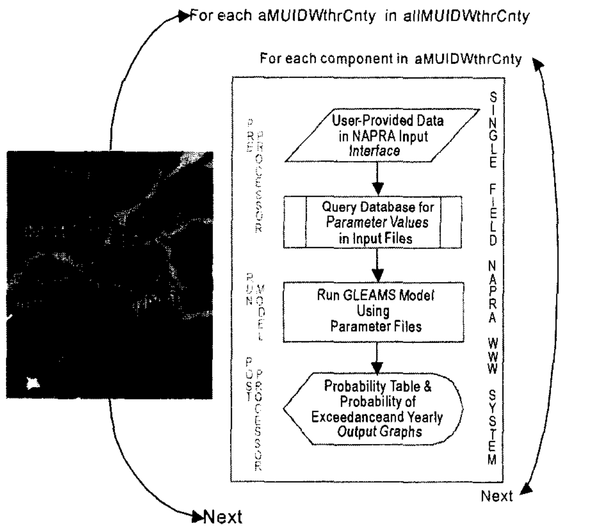

Figure 6. Schematic of County/Watershed Version of the NAPRA WWW System

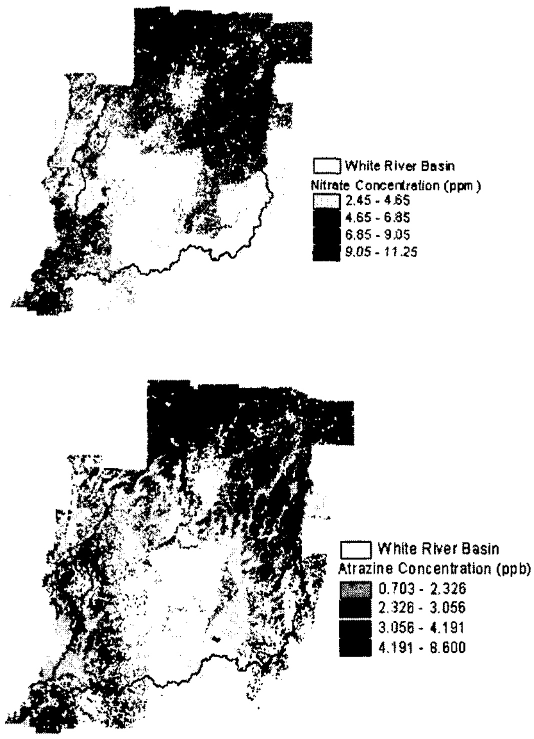

Figure 7. County/Watershed NAPRA WWW Predict -ed Nitrate and Atrazine Concentration in Runoff for the White River Basin, Indiana.

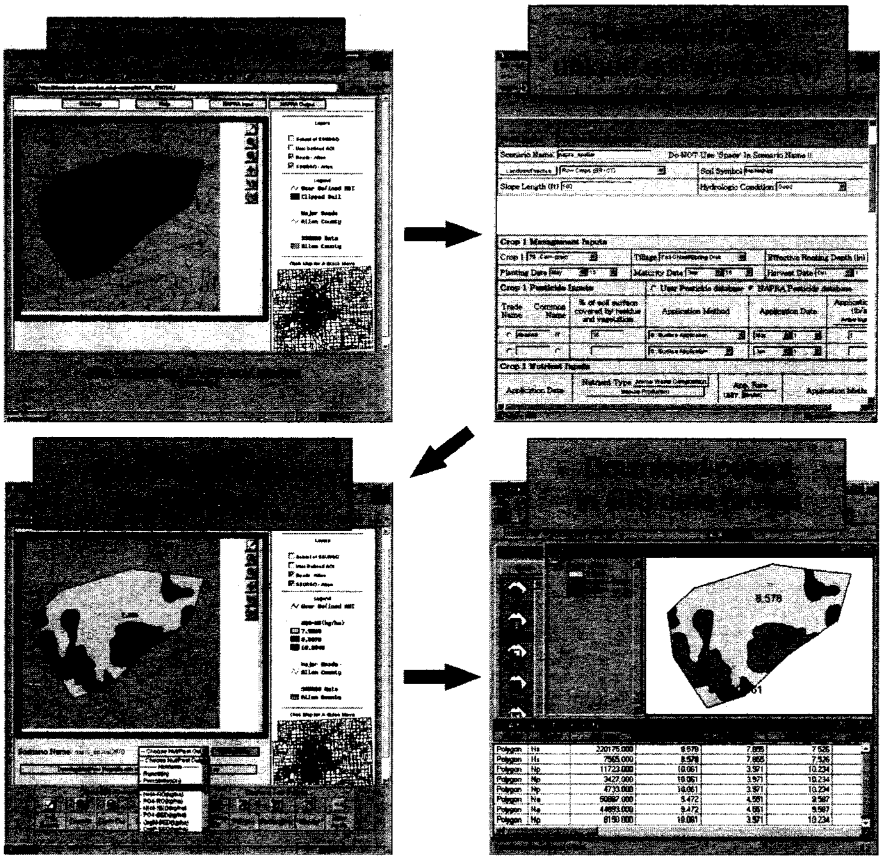

Figure 8. Web GIS Version of the NAPRA WWW System

3. Pros and Cons of the NAPRA WWW System

As stated before, the NAPRA WWW system has many advantages over the conventional GIS integrated models. The model users do not need to purchase expensive GIS software for their desktop computers. It costs too much money and time to obtain the GIS data for the model. Also, it is sometimes difficult for novice users to operate the model without any training. The NAPRA users only need the web browser and the Internet access to run NAPRA WWW system. It can be accessed from any location in the world at any time without any additional costs. However, there are many limitations in the current version of the NAPRA WWW system. It is not possible to change the crop rotations of specific years during the entire simulation period. Also, management information provided in the input interface are assumed to be the same for the entire simulation period. With the current Web GIS version of the NAPRA system, the effects of point source discharges on nutrient losses cannot be simulated.

IV. SUMMARY

Many features of the Single Field version have been enhanced to provide user friendly interface. The County/Watershed version of NAPRA WWW system was further enhanced. The newly developed Web GIS version is an ideal tool for novice users, such as farmers, to simulate the effects of agricultural management for their farms because of its easy-to-use Web GIS interface. The NAPRA WWW system provides an easy to use WWW interface and uses spatial and relational databases to simplify the process of preparing model files. Thus, the NAPRA WWW systems now can be effectively used for nutrient management as well as pesticide management to identify the least impact agricultural management practices.

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