

GIS Based AGNPS Assessment Model in a Small Watershed

Yongsheng Ma, Jon Bartholic

Institute of Water Research, Michigan State University, Michigan 48823, USA,
ysma66@yahoo.com.cn, yongshengma@hotmail.com

Abstract: AGNPS, which is an agricultural non-point source pollution model, was used in combination with GIS tools to assess the feasibility of water quality effluent trading for phosphorus, in Morrow Lake sub-watershed, Kalamazoo, Michigan, USA. GIS software packages (Arc/Info and ArcView) were used to prepare data input for the model and post process the results. The sensitivity of AGNPS parameters was evaluated to determine which most influenced phosphorus sediment loading. Evaluations were conducted to determine whether calculation processes could be simplified for rapid pollution forecasts. The results showed that pollution could be predicted by varying temporary model data (i.e. precipitation etc.) in the AGNPS model. Lastly, parameter sensitivity showed that phosphorus sediment is most sensitive to soil texture while sediment loss is most sensitive to the SCS curve number. [Nature and Science 2003;1(1):50-56].

Key words: watershed; AGNPS model; phosphorus; sedimentation; Michigan

1. Introduction

Agricultural non-point source (NPS) pollution has risen to the leading cause of surface water degradation due to agricultural pollution in last few decades. NPS pollution from agricultural activities contributed to 72% of the impaired stream miles in 48 states reporting sources (Yagow, 1999). Morrow Lake watershed was studied using Arc/Info 7.0 and ArcView 3.0 to generate cell data, and using AGNPS 5.0 to integrally analyze water and nutrients runoff and sediment of the watershed.

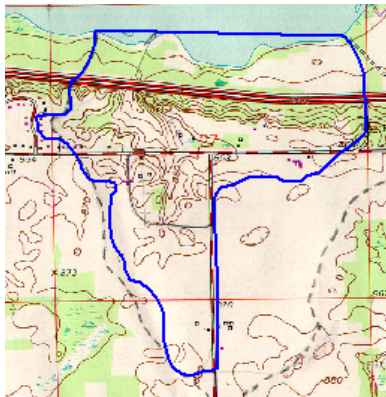


Figure 1. Morrow Lake Watershed Map

Morrow Lake Watershed (Figure 1) is located in southwest corner of the state of Michigan, and has an area of 400 acres. It belongs to Kalamazoo phosphorus trading project (Figure 2). The surface



Figure 2. Kalamazoo Watershed

Symbol	Soil Name	Group
KaA	Kalamazoo Loam, 0 to 2 percent slopes	B
KaB	Kalamazoo Loam, 2 to 6 percent slopes	B
KaC	Kalamazoo Loam, 6 to 12 percent slopes	B
CoB	Coloma loamy sand, 0 to 6 percent slopes	A
CoC	Coloma loamy sand, 6 to 12 percent slopes	A
CoD	Coloma loamy sand, 12 to 18 percent slopes	A
OsB	Oshtemo sandy loam, 1 to 6 percent slopes	B
OsC	Oshtemo sandy loam, 6 to 12 percent slopes	B
OsD	Oshtemo sandy loam, 12 to 18 percent slopes	B
OsE	Oshtemo sandy loam, 18 to 35 percent slopes	B
SpB	Spinks loamy, 0 to 6 percent slopes	A
SpC	Spinks loamy, 0 to 6 percent slopes	A
SpD	Spinks loamy, 0 to 6 percent slopes	A

Table 1. Soil Types in Morrow Lake Watershed.

water flows from south to north and then leads to the lake. The soil in the watershed is composed of Kalamazoo loam; Coloma loam sand; Spinks loamy sand and Oshtemo sandy loam (Table 1).

In the watershed, the land is primarily cultivated with pasture, corn, soybean, alfalfa, hay and wood. There is a village located in western area of the watershed, and a horse yard feedlot (30 horses) in the eastern area of watershed. Freeway 94 passes through the watershed from east to west. Due to steep land slopes over of 8%, and combines with agricultural activities, the soil erosion and fertilizer runoff pollution problems are very significant.

AGNPS model was developed at United State Department of Agriculture – Agricultural Research Service (USDA – ARS) for evaluation of alternative agricultural management. AGNPS is a grid-based model where spatial variability is a function of cell size. AGNPS has characteristics of multipurpose use and strong calculating functions with three basic components: hydrology, soil erosion, and nutrients.

The hydrology component of AGNPS uses the Curve Number method that developed by USDA Soil Conservation Service (SCS) to compute the runoff for each cell. The runoff equation (Kang, 1998) is:

$$Q = (P - I_a)^2 / (P - I_a) + S \quad \text{or} \quad Q = (P - I_a)^2 / (P + 0.8 S) \quad (\text{when } I_a = 0.2S) \quad (1)$$

Where: S = potential maximum retention after runoff begins, (in)

$$S = 1000 / CN - 10 \quad (2)$$

Q = runoff, (in),
 P = rainfall, (in), and
 I_a = initial abstraction, (in).

The erosion and sediment component of AGNPS adopted the Universal Soil Loss Equation (USLE) model for calculating on-site soil erosion, in equation (3) (Kang, 1998):

$$A = RKLSPC \quad (3)$$

Where: A = annual soil loss
 R = rainfall factor
 K = soil erosion factor
 L = field slope length factor
 S = field slope factor
 P = supporting practice factor
 C = cover and management factor

The nutrient components of AGNPS are based on Pollutant Loading (PL) computer model. The PL's predicted are: (1) water; (2) sediment by particle

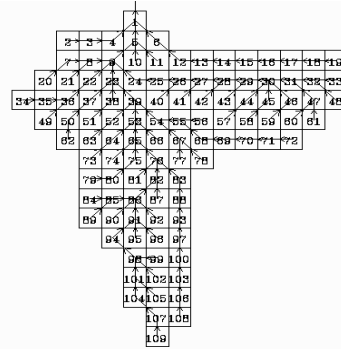


Figure 3. The AGNPS Model Grid Layout and Flow Net

size class & source of erosion; and (3) chemicals-nitrogen, phosphorus, organic carbon, & pesticides. PL's are generated from land areas (cells) and routed through stream systems on a daily basis. Special land use components such as feedlots, gullies, field ponds, and point sources are included (USDA/AGNPS, 2001).

Geographic Information System (GIS) is “an organized collection of computer hardware, software, geographic data, and personnel designed to efficiently capture, store, update, manipulate, analyze, and display all forms of geographically referenced information.” (US Army Corps of Engineers, 2000). In this study, GIS tools are used to divide Morrow Lake watershed into 109 cells as grid data format, each cell area equaling 3.2 acres. GIS generated flow net, soil, and pollution loading provides input data for the model.

2. AGNPS Model Input Data

2.1 Input Data Preparation

The AGNPS 5.00 is designed for watersheds where over land flow dominates. The input data are composed of initial data of whole watershed and each cell.

The initial data are general information that are required for the whole watershed, including Area of each cell, Cell Number, Precipitation and Storm type. Storm type (there are 4 classes of storm type: I, IA, II, III) is used to calculate the peak discharge at a location in the watershed and also to determine the Energy Intensity (EI) for a storm to calculate sediment yield. Michigan is in the Type IA region. The value of Energy Intensity (EI) is the rainfall erosion index for the storm event used in universal soil loss equation (USLE).

There are 22 input data required for each cell. In the project, the watershed is divided into 109 grid cells.

The flow-net, flow direction, land slope and slope length are generated by means of Arc/Info and ArcView.

- The **SCS Curve Number** is hydrologic soil-cover complex number, is selected by III (wet land) adjusted curve numbers since Michigan is in Great Lake wet moisture condition.
- **K factor** is soil erosion factor, **C factor** is the cropping management factor and **P factor** is the conservation practice factor that all are used in the **universal soil loss equation** (USLE) and can be found in USDA Agricultural Handbook 537.
- The **Surface Condition Constant** is a value based on land use at the time of the storm to make adjustments for overland flow velocity.
- The **Chemical Oxygen Demand (COD)** factor is a value for the COD concentration in runoff, based on the land use in the cell.
- **Overland Manning's Coefficient** is the roughness coefficient for the predominant surface condition within the cell at the time of the storm, is selected according to AGNPS User Manual attached Table.
- The data of **Fertilizer** are input by two Steps: 1) the user puts a **Fertilizer Indicator** 0 or 1 to indicate whether fertilizer has been applied to the cell. 1) 0 indicates no fertilization (such as water or marsh) while 1 indicates fertilization being applied. 2) When the user puts 1, Fertilizer Level screen appears. The user should input a fertilizer level in the screen. The **Fertilizer Level** is a single digit (a value of 1 - 4) indicating the level of fertilization on the field. The number to be input and the associated levels are shown in fertilizer level screen. If user puts a value of 1 - 3 for a fertilizer level, the appropriate Nitrogen and Phosphorus application levels appear. If there is not a fertilization level that fits the amount of fertilization that has actually been applied in the cell. The user can put 4 and then input the amount of Nitrogen and Phosphorus that has actually applied in the cell. In the project, the general fertilizer application levels in Michigan have been considered. In order to test the sensitivity of fertilization level to Nitrogen and Phosphorus in sediment and runoff outputs, two additional trial levels of fertilizer were used. A low level (10% less than normal fertilizer level) and a high level (10% more than normal fertilizer level) have been tested.
- The **Point Fertilizer Source**: in the project, there is only one feedlot, horse yard, with 30 horses. Because the main objectives of the project were assessing of soil and phosphorus sediment, the other analyses such as pesticide were not emphasized.

2.2 AGNPS Data Input Model

AGNPS is a GIS based model. The data must be prepared for all cells of the watershed. It will be difficult to input data by hand for a large watershed. In this study, a data input model - **AGDAT** has been developed. The model can directly utilize AGNPS formatted data from GIS generated database. Figure 4 shows the flow chart of the input data model.

AGDAT can read "*.GIS" files. The files are groups of data that are digitized with GIS methods

and surrounded by **Negative Numbers**, such as Table 2.

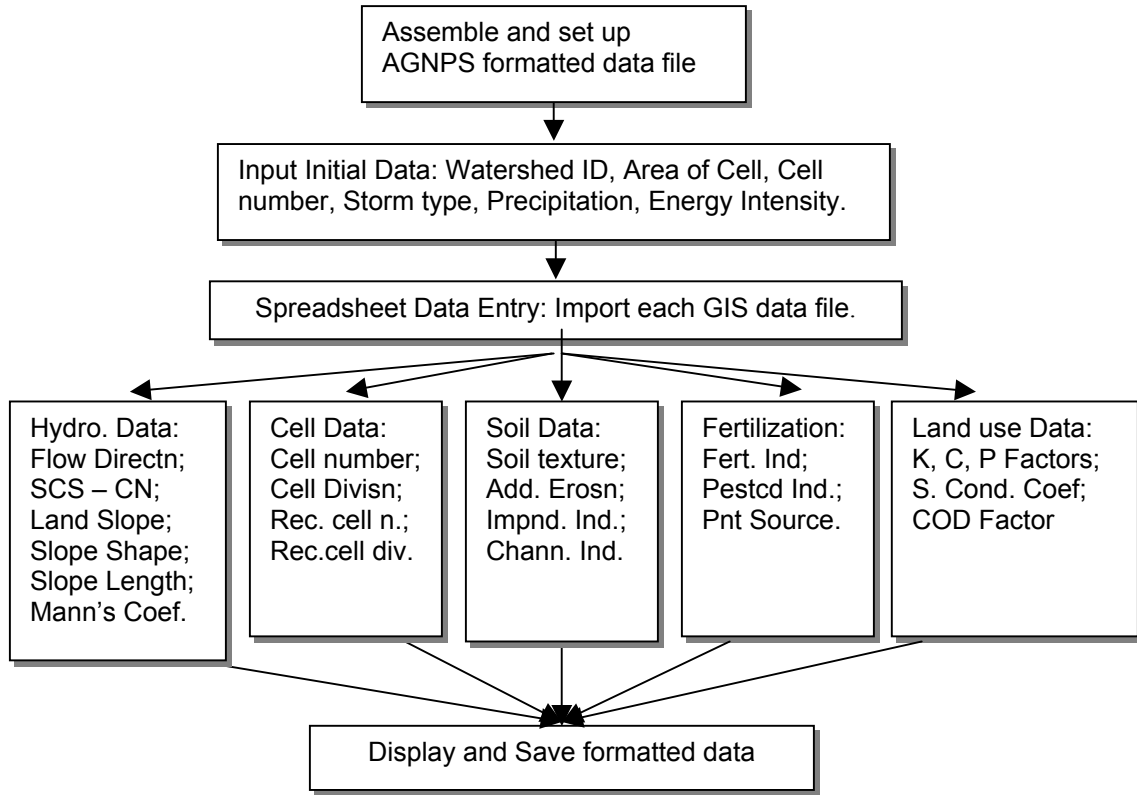


Figure 4. AGDAT Flow Chart

ncols	15
nrows	17
xllcorner	527774.5
yllcorner	526522.5
cellsize	373
NODATA_value	-9999
-9999	780 780 780 780 780 780 780 780 780 780 780 780 780 780 -9999
-9999	790 789.12 784.54 780.12 781.58 780 780 780 782.48 82.77 83.73 784.51 -9999
-9999	814.78 813.07 794.24 804.07 803.00 792.78 792.37 789.54 791.08 788.81 789.83 794.49 792.25 -9999
-9999	850 850 835.96 811.93 841.93 824.81 820.83 813.30 808.81 807.46 805.97 806.00 807.36 813.85 -9999
-9999	859.04 850 840 837.30 823.78 822.76 855.86 860 860 858.78 843.75 842.80 842.68 829.17 843.15 -9999
-9999	860 859.37 860 839.60 830.52 843.77 850 860 864.50 870 870 867.17 868.53 -9999
-9999	870 870 870 846.88 860 856.59 862.29 865.80 870 870 870 -9999
-9999	880 870 860 859.81 879.79 880 -9999
-9999	871.64 870 870.51 877.67 876.19 -9999
-9999	870 870 860 861.79 872.87 -9999
-9999	877.15 870 866.04 870 869.61 -9999
-9999	868.62 869.99 871.31 872.10 -9999
-9999	869.43 873.78 874.58 -9999
-9999	869.32 876.24 877.06 -9999
-9999	873.65 878.69 879.54 -9999
-9999	880 880 -9999
-9999	880 -9999

Table 2. Arc/Info digitized Contour line data

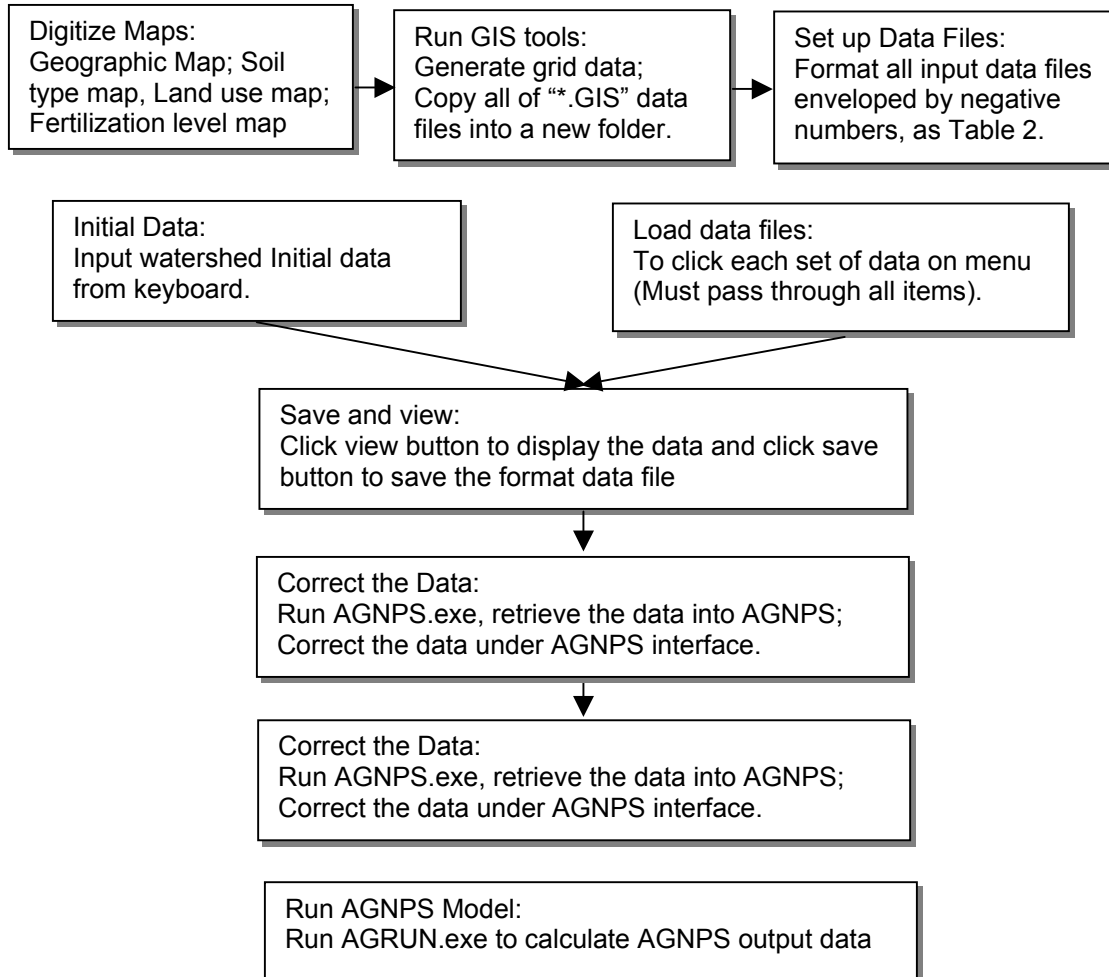


Figure 5. The procedure of running AGNPS

For running the model AGDAT, the user should set up a new folder and copy all of "*.GIS" files into the folder. The process steps are shown in Figure 5.

3. Watershed AGNPS Results

The AGNPS study of Morrow Lake Watershed has been carried out for several conditions. An examination of several model outputs is discussed below.

Phosphorus Concentration and Sediment: As stated in the previous sections, the main problems of Morrow Lake Watershed are nutrient and sediment runoff. The phosphorus in runoff water

occurs due to residual P in soil and P fertilizer applications (Figure 6). Phosphorus sediment loss generated within a cell depends on the total mass of soil erosion, soil phosphorus concentration and enrichment ratio (Baker, 1995).

In Figure 7, there are two zones with high phosphorus sediment. The first zone is located in Cells 51, 52 and 63 (farmland and village). The flow with fertilizer contaminants will converge to the outlet of these cells. The second zone is in cells 46, 60 and 61. This is due to horse yard pollution.

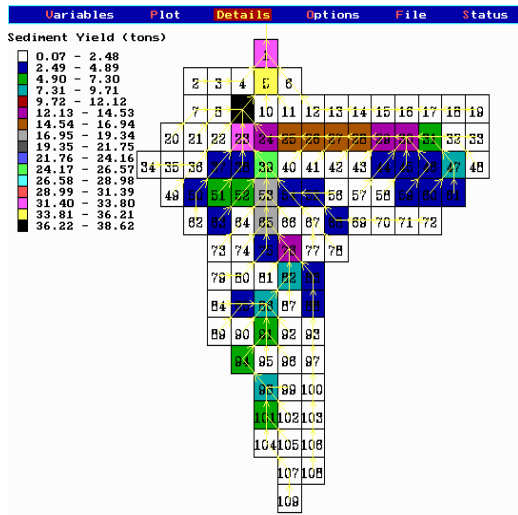


Figure 6. Sediment Yield (tons)

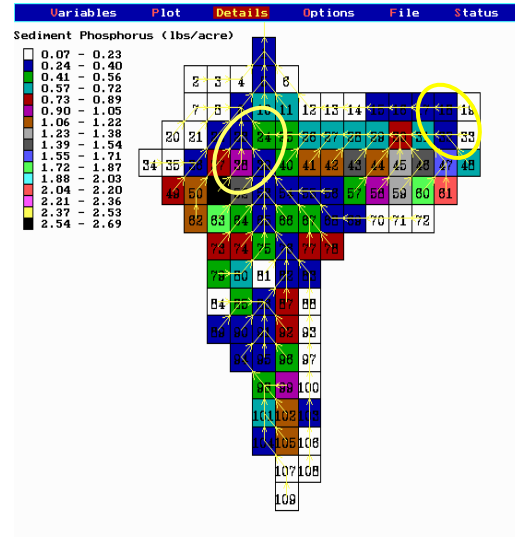


Figure 7. Sediment Phosphorus (lbs/acre)

4. Sensitivity Test and Discussion

In general, AGNPS software can calculate water quality, soil erosion and non-point pollution. However, the reasonableness of calculated results needs to be investigated. Also, simplifying the calculation process of AGNPS input data (i.e. AGDAT) for fast pollution forecasts is another focus in this paper. In order to further analyze AGNPS application for non-point source pollution assessment, several trials with different AGNPS parameters were conducted.

4.1 Soil Sediment and Phosphorus Change Following Precipitation

Both soil and phosphorus sediment increases rapidly with increasing rainfall values. The curves in Figure 8 show that rainfall is a factor strongly effecting soil and phosphorus sediment. The curves are taken in cells 1, 5 and 9 (the out flow cells of the watershed). The curves look like an exponential function. The three curves increase in value following rainfall increases. In Cell 1, phosphorus sediment increases more slowly because there was interval flow added which diluted phosphorus concentration.

4.2 The Sensitivity Test of AGNPS Parameters

In order to test the sensitivity of AGNPS parameters, it is important to re-test following parameter changes. Eight parameters that related to soil and phosphorus sediment including K

factor (Kf), C factor (Cf), P factor (Pf), COD (COD), Fertilizer application level (Fert), SCS curve number (SCS), Soil texture (SITx) and Surface condition constant (Surf) have been tested respectively.

Phosphorus sediment is affected by K, C, P factors, SCS curve number and soil texture (SITx). It is most strongly affected by SITx, as shown in Figure 9.

Soil sediment yield is calculated in AGNPS model with the Universal Soil Loss Equation (USLE). In formula (3), the soil loss is the function of rainfall, soil erodibility, field slope, and land use. It is most

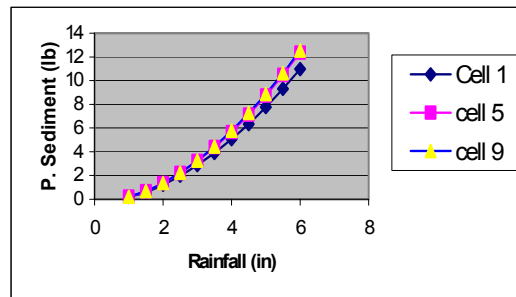


Figure 8. P. Sediment in Different Rainfall (lbs)

sensitive to the SCS curve number (Figure 9).

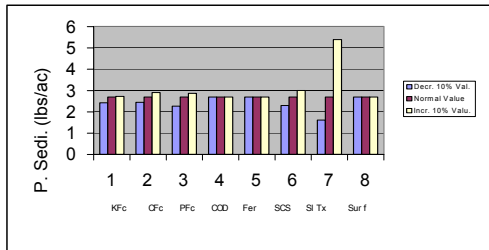


Figure 9. The sensitivity test of P. sediment vs. Parameters change (in Cell #51)

4.3 Establishing a NPS Forecast System

The variables of AGNPS may be divided into 3 categories: 1. Long term data (topography, land scope, soil types), will not change annually. 2. Seasonal data (crops, fertilizer application level, land use) will change according to human activities and will rarely change during a season. 3. Temporary data (precipitation) will change frequently according to rainfall and weather variations.

The evaluations were conducted to determine whether calculation process could be simplified to meet pollution forecasts. The results determined that pollution forecast could be predicted by utilizing temporary variables (i.e. precipitation etc) in the AGNPS model.

5. Conclusions

Non-point source pollution has been identified as the major pollution of water and soil resources environment. Although many efforts have been initiated to reduce agricultural NPS pollution, it remains a problem. The AGNPS model is designed for assessing agricultural non-point source pollution. It can be used to predict water resources runoff, NPS pollution and soil erosion within and from watersheds. AGNPS is a cell-based model for which it is difficult to prepare input data. This study developed an input model AGDAT for AGNPS 5.0. It can directly convert GIS format data into AGNPS data. This study used AGNPS for estimating NPS pollution on Morrow Lake watershed. In order to analyze how the watershed NPS change in different

Situations and conditions, several trials with different precipitation values have been calculated. All of computations provided reasonable results. The results showed that pollution forecast could be predicted by varying temporary variables (i.e. precipitation etc) in the AGNPS model.

Correspondence to:

Yongsheng Ma
 School of conservancy and civil engineering
 Northeast Agricultural University
 Harbin, Heilongjiang 150030, China
 Telephone: 01186-451-5511-7878
 Fax: 011-86-451-5191502
 Email: yasma66@yahoo.com.cn
yongshengma@hotmail.com

Yongsheng Ma is presently working in the School of Conservancy and Civil Engineering, Northeast Agricultural University, Harbin, Heilongjiang 150030, China.

References:

- Dressing SA. Non-point Source Management System Software: A Tool for Tracking Water Quality and Land Treatment, U.S. Environmental Protection Agency, Washington DC, 1999; <http://www.epa.gov/owow/watershed/proceed/dressing.htm>.
- Joubert L. Watershed Non-point Assessment and Nutrient Loading Using the Geographic Information System – Based MANAGE Method, University of Rhode Island, Natural Resources Science, Kingston, RI, 1999; <http://www.epa.gov/owow/watershed/proceed/joubert.html>.
- Kang YT. A Watershed Based Optimization Approach For Agricultural Non-point Source Pollution Management, Institute of Water Research, Michigan State University, East Lansing, MI, 1998;24-30.
- Patwardhan AS. Modeling Nutrients From The Minnesota River Watershed, Publication of Environmental Protection Agency, 1999; <http://www.epa.gov/owow/watershed/proceed/patwardh.htm>.
- US Army Corps of Engineers. Geographic Information Systems (GIS) Definition, 2000; <http://www.nww.usace.army.mil/gis/definition.htm>.
- USDA, National Sedimentation Laboratory AGNPS- Pollutant Loading (PL) Computer Model, 2001; <http://www.sedlab.olemiss.edu/AGNPS.html>.
- Yagow G. Procedures for Indexing Monthly NPS Pollution Loads from Agricultural and Urban Fringe Watersheds, Publication of Environmental Protection Agency, 1999; <http://www.epa.gov/owow/watershed/Proceed/yagow.htm>.
- Young RA. Agricultural Non-point Source Pollution Model, Version 5.00 AGNPS User's Guide, USDA-Agricultural Research Service, 1994:1-5.
- Zhang Y, et. al. Nitrogen Transformation, Transport and Leaching in Drained Land, China university of geo-sciences, Wuhan, China, 1997:45-8.