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地理資訊系統應用於集水區管理非點源模式之研究

A Study of GIS Application with Nonpoint Sources Modeling for Watershed Management

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摘　要

以地理資訊系統（GIS）作爲非點源模式之前處理模組可提昇該模式應用於集水區經營管理上之效率。非點源模式係一具有物理基礎之分散式（distributed）模式。因其於集水區管理上之使用日漸頻繁，規劃者必需熟悉、維護和使用大量具有空間性分佈之資料，以滿足模式應用之需求。而GIS因能有效處理空間資訊並具有強大之空間展示能力，與非點源模式聯合運用除能迅速提供各種所需之資料，並能展示模擬之結果，以突顯問題之所在。本文係利用非點源模式與PC版之GIS結合，開發模式輸入與輸出資訊自動化程式，可藉GIS之功能完全自動產生模式之輸入資料，展示經由模式模擬之結果。該系統應用於德基水庫上游一小集水區，以模擬不同土地利用經營管理策略之影響。由成果顯示，本研究所發展之系統乃爲一非常有效之工具，可資應用於集水區土地利用與管理經營。
關鍵詞：地理資訊系統，非點源，模式，管理經營。

ABSTRACT

Using geographical information systems (GIS) technology as a preprocess platform for nonpoint sources models provide an effective mechanism for performing watershed management studies. Increasing use of distributed, physically based nonpoint sources model for watershed management requires planner to acquire, maintain, and utilize the extensive, spatially referenced data base necessary to support these efforts. GIS is ideally suited to preparing, storing, updating, analyzing, and displaying these data in conjunction with nonpoint sources modeling. In this paper, a nonpoint sources model is employed to link with a PC-based GIS package to facilitate preparing, examination, and analysis of spatial distribution model input and parameters. Impact of watershed management strategies are performed for a small watershed of Techi reservoir in Taiwan. Linked with an interactive facility to evaluate spatial distributed data and managing scenarios, the result is a powerful tool for watershed-wide land use management.
Keywords：GIS, Nonpoint sources, Model, Management.

INTRODUCTION

Effective watershed management is highly relied on appropriate consideration of spatial variability of watershed characteristics. This realization has prompted increasing use of physically based watershed models such as Agricultural Nonpoint Sources Pollution Model (AGNPS) (Young et al., 1987). The use of spatially distributed,physically based models enhances the ability to simulate the runoff response of sediment yield, chemical and nutrient loading of catchment. In addition,physically based models provide a stronger basis for evaluating impacts of watershed management strategies of land use pattern. With this enhanced technical capability, however , as well encounters an increased burden on planner to satisfy the spatial data base requirements associated with more realistic,physically based modeling.

GIS currently provides powerful capabilities for supporting the spatial data base requirements of watershed management. This technology has been widely utilized for several years in natural resources management for digital mapping,cartographic modeling, and analysis of spatially referenced data. Several authors have applied GIS in watershed modeling including Bondelid et al. (19 82),Berry and Sailor (1987), Goulter and Forrest (1987), White (1988), and Stuebe and Johnston (1990). Remote sensing techniques have been applied to watershed modeling as well by Kuittinen and Suchsdorff (1987). Shamsi et al. (1991) combined remote sensing and GIS to develop information layers at a 10 m resolution from satellite and high altitude aerial photography for assessing a storm sewer master plan. Meyer et al. (1993) employed GIS to evaluate urban storm water management strategies.

Watershed impact management studies require significant effort in terms of data organization, development and calibration of model parameters, and presentation of results. When land use patterns in the study area are changing rapidly, the problem become even more complex. To counter these difficulties, GIS was applied to organize, store, and display spatial and nonsptial data for the study. The capabilities of the GIS and the distributed process watershed model, AGNPS, are exploited in this paper to show the effectiveness in assembling model input data and storing model output for later analysis and display.

A procedure is presented for linking a commercially available GIS package call ARC/INFO with a physically based, spatially distributed watershed model, AGNPS,for watershed land use management. A descriptive preprocessing GIS utilizes digitized base map to prepare derived spatial data for model computation.Watershed runoff , chemical constituents, and sediment yield are then computed by AGNPS. Using derived maps of the most sensitive model parameters, model results are incorporated into a post processing GIS for examining consequences of varies land use management strategies. This procedure was applied to the Chichiawan and Yosheng stream watershed of Techi reservoir located in Taichung county, Taiwan.

GEOGRAPHICAL INFORMATION SYSTEMS

Geographical information systems (GIS) are a set of computer tools for collecting,storing, retrieving, transforming, and displaying spatial data about geographical objects and their nonspatial attributes (Burrough, 1986). Geographical objects include natural phenomena (such as lakes, rivers, and forests), manmade structures(such as dams, building, roads, agricultural fields and municipalities), and other objects that may define the location and extent of a geographical phenomenon(such as a special soil type, or geological formation).

Spatial data specify the location and relative position of objects. A vector representation uses points, lines, and areas or polygons, and a raster representation uses an x-y grid to define spatial location and the relative position of objects (Parker, 1988).

Nonspatial attributes, such as the population of a municipality, the average water level in a lake, or the hydraulic conductivity of a particular type of soil, are associated with objects. In a vector based GIS, nonspatial attributes are linked with a point, line, or polygon that is used to represent the object of interest. Spatial information and nonspatial attributes are stored in separate data bases within the GIS. The database allows the attributes to be queried,and objects linked with the attributes, to be displayed. The database concept is central to GIS, and is the main difference between GIS and drafting or computer mapping systems, which can only provide a good graphic output. Essentially,GIS give one the ability to associate information with a feature on a map, and to create new relationships that can determine the suitability of various sites for development, evaluate effects on the environment, identify the best location for a new facility, and so on. The relationship between spatial objects and their related attributes, gives GIS powerful capabilities for analyzing land and water resources problems.

Several components constitute GIS:its software tools and database, are two of the major modules within the system. The user becomes part of GIS whenever complicated analyses, such as spatial analyses and modeling, have to be carried out. These usually require skill in selecting and using tools from the GIS toolbox, as well as intimate knowledge of the data being used. At present, and in the foreseeable future, general-purpose GIS will require skilled and informed users; pressing a button will not enough.

For applications in water resources, GIS technology in general must handle data coverage relating to land use, land cover, geology, and soils. Network-oriented data (streams, water distribution systems, sewer systems) and terrain information are very significant. Frequently, subsurface information is important (e.g. for groundwater modeling). In the field of water resources, the major spatial data base was EPA's STORET water quality data base, storing stream quality information that could be referenced by location primarily by river mile index or latitude-longitude). EPA also maintains the reach file, a data system initiated in the 1970's, that is organized by hydrologic structure and has significant spatial data retrieval and analysis capabilities organized by hydrologic units (Horn and Grayman, 1993).

Prediction of surface runoff is one of the most useful hydrologic capabilities of a GIS system. The prediction can be used to assess or predict aspects of flooding, aid in reservoir operation, or to predict the path of pollutants. De Vantier and Feldman (1993) reviewed the GIS application in hydrologic modeling and described several applications in flood plain hydrology, erosion prediction, and water quality prediction.

In considering the many spatial parameters affecting non-point pollution that led to the development and use of a number of geographical information systems, Grayman (1975) presented an application of water quality planning for the James River Basin. Using ADAPT (Areal Design and Planning Tool) he modeled waste water treatment discharge and the waterborne wastes from land development and pollution from an unknown source. The system used a TIN (Triangular Irregular Network) data structure for both the spatial data and model. Applying ADAPT to urban runoff analysis, Grayman demonstrated the cost effectiveness of automated spatial data analysis, (Grayman et al., 1982). Recently, efforts have been directed toward the development of models that utilize spatial data more fully. Needham and Vieux (1989) presented the application of a vector based GIS, using ARC/INFO to generate an input file for AGNPS (A gricultural NonPoint Source pollution model)and displayed a model output for a small watershed in Michigan. Vieux (1991)reviewed the application of GIS in water quality and quantity modeling and presented an application using TIN supplied nodal land surface slopes to the finite element model for the direct surface runoff simulation.

The US Army Corps of Engineers has had a long involvement with GIS technology,beginning with their sponsorship of research on resource analysis methods by Steintz et al. (1969). The Honey Hill study using this methodology (Corps of Engineers, 1971) was followed by the Santa Ana River Basin Study (Corps of Engineers, 19 75) which used gridbased methods for river basin planning. The study which utilized an approach that combined GIS and hydrologic modeling technology, is notable. Because the modeling wasn't simplified or subordinated to the GIS aspects of the study, GIS served as a database to feed the models used. The Corp's Hydrologic Engineering Center (HEC) has continued to use spatial analysis technology and has produced a variety of computerized tools that make use of spatial databases. HEC is currently working on the development of the next generation of these tools using GIS and database technology (Males and Grayman, 1992).

Geographical information systems are gaining widespread acceptance as important tools for decision support in land, water resources, environmental management and spatial analysis. GIS, aid in the preparation, analysis, display, and management of geographical information. Clearly, GIS could improve the modeling capability of water resources models, and such models would also benefit from the spatial analysis and display capability of GIS. Combining the strengths of each, will result in more powerful tools for dealing with water resources planning and management problems.

NONPOINT SOURCES MODEL

Nonpoint sources models as Vieux and Needham (199 3) mentioned, that address agricultural pollution sources, range from statistically derived loading factors and delivery ratios to more complex models. Examples of field scale water quality models are CREAMS (Chemicals, Runoff, and Erosion from Agricultural Management Systems by Knisel, 1980), ACTMO (Agricultural Chemical Transport Model by Free et al., 1975), HSPF (Hydrologic Simulation Program Fortran by Barnwell and Johanson, 1 981), and NPS (Nonpoint Simulation Model by Donigian and Crawford,1976). Watershed scale nonpoint models have not been widely developed as field scale models. However, two models for nonpoint sources pollutant distributed throughout a watershed are ANSWERS (Areal Nonpoint Source Watershed Environment Response Simulation by Beasley et al., 1980) and AGNPS (Agricultural Nonpoint Source Pollution Model by Young et al., 1 987). Both models are based on grid cell structure to represent the conditions of watershed. The model is computed at the grid cell scale but distributed at the watershed scale.

The distributed process model, AGNPS, computes runoff, sediment yield, and chemical substance within each grid cell. The model then routes the water,sediment yield, and chemical constituents downslope from one cell to the next until reaching the outlet of watershed. Sediment yield and attached phosphorus may be deposited or transported to the next cell depending on hydrologic characteristics of each cell. As such, the model applicability extends beyond the edge of field to the watershed basin scale (Vieux and Needham, 1993).

PROCEDURE

The options for development of integrated GIS and nonpoint sources model for watershed management include: an integrated approach, an embedded approach, and an interfaced approach (Horng, 1994).

Integrated approach

The integrated development approach, use customized programs to assemble urban watershed model routines, and GIS package modules, into an integrated environment. Efforts such as these are programmatically intense, and typically use an efficient data exchange, at the function level, with a structure/array passing or dedicated file exchange, for rapid system response (Meyer et al., 1993). An example of this approach, would be utilization of a public domain, GIS package such as, GRASS (Construction Engineering Research Laboratory, U.S. Army Corps of Engineers, Champaign, IL), along with an interactive screen and graphic tools, for decision support system development. Implementation of these systems is not yet a common engineering practice, because of the initial computer hardware/software investment and the need for skilled staff.

Embedded approach

GIS doesn't yet have the complete analytical capabilities necessary to conduct calculations currently available in traditional models. It is likely, however,that the analytical capabilities of many available GIS packages will continue to improve, in both scope and computational efficiency in the future. This will allow realistic simulation modeling within the GIS. Many popular GIS packages, mentioned by Meyer et al. (1993), include dedicated language interfaces that facilitate embedded modeling: ARC/INFO (Environmental Research Institute (ESRI) Inc ., Redlands, CA)provides AML and SML languages; PMAP (Spatial Information Systems, Inc. Arlington, VA) supports marco playback; and GeoSQL (Generation 5 Technology, Inc., Westminster, CO) offers programming in AutoLISP within the AutoCAD architecture (Autodesk ,Inc., Sausalito, CA). These various environments, however, are primarily intended to provide interactive control of the GIS, rather than serve as modeling platforms.

Interfaced approach

Perhaps the easiest method of exchanging information is by flat data file transfer. Dissimilar data file formats may be converted by utility programs,which are significantly less complex than those required in the integrated approach. As the applications of GIS increase, the availability and capability of a conversion program will increase as well. The main drawback, is that flat file exchange may be more time consuming than integrated, or embedded approach. In spite of the disadvantages, the interfaced approach using model/GIS data file linkage is considered to be the most effective one for this study.

The procedure for linking GIS and the AGNPS for watershed management,involves the following steps:

1. Acquisition and development of base map data layers and the coverage required for AGNPS modeling.
2. Preprocessing of the model input data and parameters and the development of GIS techniques suitable for input of spatial information into the AGNPS model.
3. Interfacing GIS to the AGNPS model through the development of a program for converting GIS coverages to AGNPS model input paramenters.
4. Simulating runoff, sediment yield, and chemical substance distribution, of the study basin, by the AGNPS model.
5. Postpossessing of AGNPS model output, by returning total amount to the GIS, for spatial display and analysis.
6. Analysis of Scenarios, including a change in land use, and spatial distribution maps with different sediment yield for the basin within the GIS.

The risk zone maps, can be produced based on related criteria and previous prepared coverage including, land use, and catchment boundary.

In this approach, the model and GIS operate independently and are linked through jointly shared data files, such as these listed in Table 1, that show the model used the curve number of the corresponding hydrological soil type,combined with different land use, in GIS database. Again, smoother linkages may be envisioned, such as link integration and structure passing; however,proprietary rights of commercial software, limit the feasibility of these approaches.

Table 1. Curve number of corresponding soil type for dif ferent land use

Land use code	Hydrologic soil type			
	A	B	C	D
1	89	92	94	95
2	77	85	90	92
3	77	85	90	92
4	77	85	90	92
5	81	85	91	93
6	81	85	91	93
7	77	85	90	92
16	62	71	78	81
19	72	81	88	91
20	39	61	74	80
25	100	100	100	100

CASE STUDY

Study area

The study area, Chichiawan and Yosheng stream watershed as shown in Fig. 1, is a 10858 hectare (ha) watershed operated by the Techi reservoir watershed conservation commission of Taiwan. The land use in the catchment area is mainly forested land with some agricultural activities. Digitized soils, land use/cover,river system and topography for the watershed were used to build the AGNPS input parameter database. Using DTM data from Agricultural Aerial Survey Institute, a topography of watershed at a scale of 1:25,000 can be produced. Soil types coverage was digitized from Soil Conservation Bureau at a scale of 1:25,000. The land use/cover maps were digitized from Building and Construction Administration at a scale of 1:25,000 and modified with field investigation. The model parameter which must be compiled for watershed and each grid cell are given as:

Watershed

1. Watershed idèntificaiion
2. Area of each cell
3. Number of cells
4. Precipitation
5. Energy-intensity value
6. Description

Grid cell

1. Cell number
2. Receiving cell number
3. SCS curve number
4. Land slope
5. Slope shape factor
6. Field slope length
7. Channel slope
8. Channel sideslope
9. Manning roughness coefficient for the channel
10. Soil Erodibility factor
11. Cover and management factor
12. Support practice factor
13. Surface condition constant
14. Aspect
15. Soil texture
16. Fertilization level
17. Fertilizer availability factor
18. Point source designator
19. Gully source level
20. Chemical oxygen demand factor
21. Impoundment factor
22. Channel indicator

Many parameters are not necessarily related to any of the spatial information contained in the digitized database. To generate input data for AGNPS, parameters are grouped as they related to the availability within the spatial database with proper format. A short description of each parameter follows as it relates to the model parameter extraction using GIS.

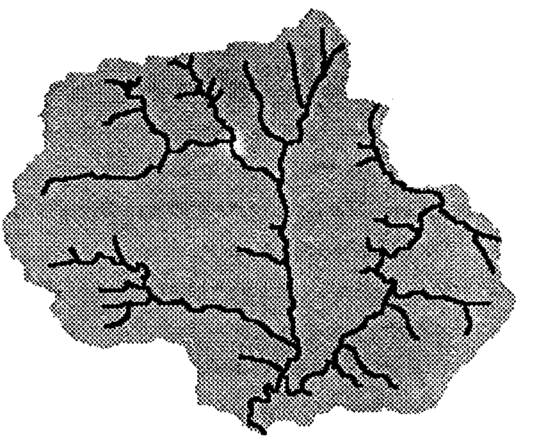

Fig. 1. The catchment of Chichiawan and Yosheng stream watershed

Topography

The Topography affects the flow directions assigned among the cells of the drainage network. Each cell is assigned a unique identifying cell number (CE) which is then used as the receiving cell number (RC) by other cells. This may be done by generating cell coverage of watershed. Aspect (A) which is classified in eight directions (neighboring cells including diagonals), affects the flow path length across a cell and is used in routing sediment yield across the cell. A unique slope direction and magnitude within a single grid cell must be calculated to avoid ambiguous flow directions. Aspect and slope (SL) are computed from digitized elevation contours by overlaying the grid cell coverage onto the TIN representing the land surface. An areally averaging slope is extracted for each AGNPS grid cell. Slope factor (SF) can be generated using aspect and the slope for each grid cell as well.

Soil types

The parameters closely related to soil types are SCS runoff curve number which has to be calculated considering both soil types and land use condition,erodibility factor (K), and soil texture (T). Each of these parameters can be derived from the digitized soil maps by using a lookup table for each soil related to its K-value.

Land Use

The land use classification schemes are often not sufficiently detailed for nonpoint source modeling. Depending on the classification detail model, parameters may not be identified for a particular land use category. Model parameters that are closely related to land use/cover are the cover and management factor (C), surface practice factor (P), surface condition constant(SCC), fertilization level (F), fertilizer availability factor (AF), Manning's roughness coefficient (N), and chemical oxygen demand (COD).

River system

The parameters of channel index (CI), channel slope (CS), and channel side slope (CSS) are calculated from the digitized river system maps by over laying the cell coverage of watershed. Using lookup table, CS and CSS can be assigned for model input.

Field survey

Some factors can only be found through the field survey. These factors, such as point source indicators (PS), which allow the addition of known point sources to a cell ; gully erosion amount (GS);impoundment factor (IF), are best determined in the field. While unlikely, aerial photography or other sources may offer some of this information. Using field information, the spatial data of these parameters can be digitized and overlayed with cell coverage to assign PS, IF,and GS values for model input.

GIS data presentation

The ARC/INFO, a GIS package for PC version is used in this study to offer various software modules with procedures for output from all stored data and analyses, in the form of thematic maps and map-like representations. The following thematic maps in the scale of 1:25,000 for the study watershed have been compiled to visualized the data collected and evaluated during this study of watershed land use management.

Topography

1. Surface system of the study watershed
2. Catchment border of the study watershed
3. Land use of the study watershed
4. Aspect of the study watershed
5. Land slope of the study watershed
6. Soil type distribution

Hydrology

1. Point source location in the study watershed
2. Impoundment terrace location in the study watershed
3. Gully source location in the study watershed

Lookup Table

1. River classification and channel side slope
2. Landuse classification and related its parameters
3. Soil type and related its parameters including T,K
4. Curve number related to land use classification and soil type

LAND USE ANALYSIS

The completed GIS database and linked nonpoint sources model were used to perform land use analysis for the entire watershed. Prior to actual analyses,the AGNPS model was calibrated so that the response would accurately simulate the given condition of watershed. There was gauged flow station to be used for testing three storms occurred in 1987. Because runoff was the only available records in the study area, hydrograph of Typhoon Alex, Jerude, and Linen were used for the model calibration and verification. Using the linkage model and database of GIS,an iterative process was performed to fine-tune selection of routing parameters.The results of runoff calibration and verification are shown as listed in Table 2.

Table 2. The results of runoff calibration and verification

Typhoon	Alex (calibrate)	Jerude (verify)	Linen (verify)
Rainfall (mm)	121.9	201.2	107.4
Duration (hr)	28	55	52
Runoff measured (mm)	26.4	59.7	28.4
Runoff simulated (mm)	26.7	76.20	19.1

For analysis, the study watershed was subdivided into several grid cells with an area of 16 ha as illustrated in Fig. 2. The model parameter database was compiled for a grid-cell size of 16 ha resolution. AGNPS was run for each of six scenarios to evaluate the impact of land use management. The storm used in the simulation was the Typhoon Alex, 28 hours storm with a total rainfall of 12.2 cm. The GIS proved to be advantageous because it could quickly update parameter values related to land use such as CN, F, AF, etc. where they can be easily adjusted for various combination of land use and hydrologic soil group.

Scenarios

The land use impact analyses examined existing and future conditions using six modeling scenarios. The base case scenario was based on year 1987 land use condition (see Fig. 3). The results of these scenarios provide an assessment of baseline condition. Through analysis of result, it was possible to identify existing potential erosion area of watershed. Such problem can be managed with a proper land use management scenario through model simulation.

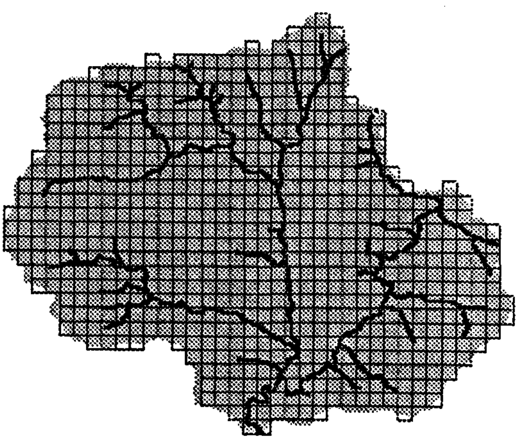

Fig. 2. Grid cell of the study watershed

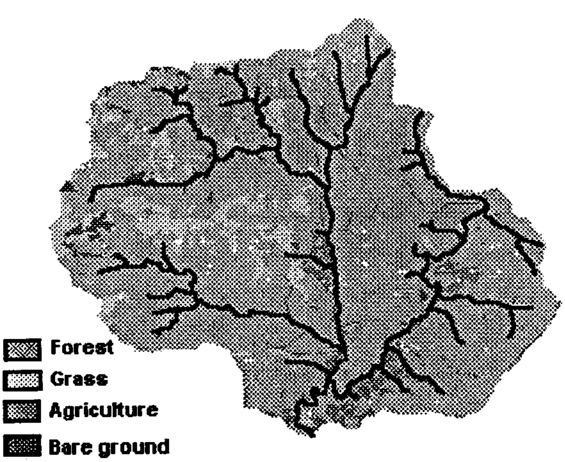

Fig. 3. Land use distribution of year 1987

The analyses of projected land use involved five scenarios as follows:

- Scenario 1: shifted agricultural area with land slope greater than 55% to forest land.
- Scenario 2: shifted agricultural area between stream and T7 road to grass land.
- Scenario 3: employed a combination Scenario 1 and 2. In addition,remaining agricultural area of the watershed was shifted to forest land.
- Scenario 4: shifted all bear ground to grass land.
- Scenario 5: employed a combination of Scenario 3 and 4.

The five scenarios provided a management information for assessing the impacts of land cover shifting measures (see Table 3). AGNPS input data files representing the five scenarios were generated for the study watershed. The simulation results of runoff, peak flow, sediment yield, and chemical constituents for each scenario are summarized in Table 4. It was found that all scenarios in the study watershed reduce the total peak flow, runoff, and sediment yield of watershed.

It was shown that employing design scenario 5 will reduce sediment loading up to 57% compared with base case. Fig. 4 illustrates how these results were presented using the GIS. It was proved that integration of nonpoint source model and GIS technology is a powerful tool for land use management assessment in a watershed.

Table 3. Land use statistics for management scenarios(ha)

Management scenarios	base case	1	2	3	4	5
Land use classification						
Forest	6327.31	6327.31	6327.31	6327.31	6327.31	6327.31
CP	3023.68	3132.01	3023.68	3243.80	3023.68	3243.80
Vegetation farm	142.78	128.83	117.50	61.21	142.78	61.21
Orchard	313.8	219.42	250.50	113.40	313.80	113.40
Bear ground	219.25	219.25	219.25	219.25	-	-
Road	24.11	24.11	24.11	24.11	24.11	24.11
Rock	3.30	3.30	3.30	3.30	3.30	3.30
Waterbody	72.59	72.59	72.59	72.59	72.59	72.59
Total	10858.08					

Table 4. Simulation results of management scenarios for study watershed

Scenarios	0	1	2	3	4	5
Runoff (mm)	27.69	26.92	26.92	25.40	27.18	25.15
Peak flow (cms)	50.26	48.99	49.21	46.32	49.53	45.76
Sediment yield (ton)	3134	2374	2352	1376	2613	990
Nitrogen (kg)	5416	4403	4403	3040	4787	2446
Phosphate (kg)	2341	1887	1887	1223	2062	943
COD (kg)	60831	55345	56428	47763	60516	47623

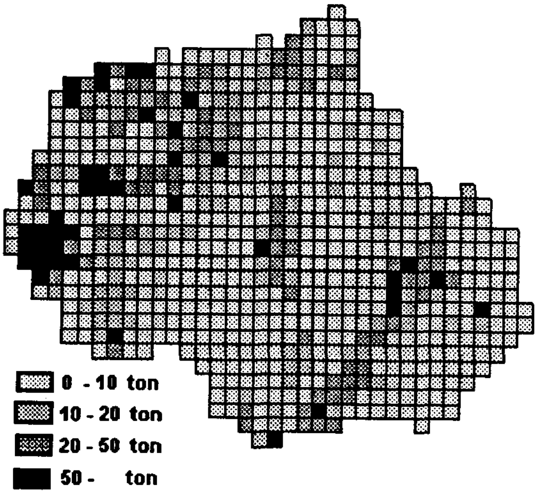

Fig. 4. The distribution of sediment yield for scenario 5

Analysis

The values of model output change due to land cover pattern shifting. Referring to Table 4, most model output including sediment yield, runoff, total peak flow,nitrogen , phosphate, and COD exhibited important variations with different scenarios. Sediment yield and phosphate show an interesting variation with managing scenarios. Sediment yield and phosphate are reduced dramatically to 60% due to the shifting of agricultural and bear ground to forest. Sediment yield is a key issue for watershed management. In this study, the AGNPS is shown as a capable model to simulate the watershed response and evaluated the management scenarios of land use.

SUMMARY AND CONCLUSION

During the case study of this research, the developed GIS has proven to be an extremely efficient tool for data integration of land use management. The relational database of GIS, through dedicated interface, provides a powerful tool in the intermediate graphical data evaluation, as well as the final layout,and data presentation.

Though the GIS development required a major commitment in terms of time and labor, much of the data collection and processing tasks would have been required in any event to conduct the land use management study. The advantage of the GIS was that many of repetitive tasks of number crunching and bookkeeping were automated. Storage and retrieved of the characteristic data in the relational database speeded up the assembly of input data files and execution of modeling runs. Other advantages were that: (1) It was possible to examine the watershed in much finer detail. (2) It was possible to rapidly evaluate the impacts of different managing scenarios; and (3) Calibration of model parameters was efficient and rapid. Analyzing the results of AGNPS, it was possible to identify areas where changing land cover would be detrimental to reduce runoff, total peak flow, sediment yield, and to improve surface water quality.

APPENDIX I: Reference

Barnwell, T. O., and R. Johanson, "HSPF: A Comprehensive Package for Simulation of Watershed Hydrology and Water Quality", Proc. of the Seminar on Nonpoint Pollution Control-Tools and Techniques for the Future, Interstate Committee on the Potomac River Basin, Rockville, Md., 1981.

Berry, J., and J. Sailor, "Use of Geographic Information System for Storm Runoff Prediction for Small Urban Watersheds", Envir. Mgmt., 11(1),21-27,1987.

Bondelid, T., R. McCuen, and T. Jackson, "Sensitivity of SCS Models to Curve Number Variation", Water Resour. Bull., 18(1),111-116,1982.

Beasley, D.B., L.F. Huggins, and E.J. Monke, " ANSWERS User's Manual", Purdue Univ., West Lafayette, Ind., 1980.

Burrough, P.A., Principles of Geographical Information Systems for Land Resource Assessment, Clarendon Press, Oxford, England, 1986.

Corps of Engineers, "Honey Hill: A System Analysis for Planning the Multiple Use of Controlled Water Areas", IWR Report 71-9, October, 1971.

Corps of Engineers, "The Santa Ana Basin: An Example of the Use of Computer Graphics in Regional Plan Evaluation", IWR Contrct Report 75-3, June, 1975.

Donigian, A.S., and N. Crawford, "Nonpoint Pollution from the Land Surface",EPA 600/3-76/083, U.S. Envir. Protection Agency, Washungton D.C., 1976.

DeVantier, B.A., and A.D. Feldman, "Review of GIS Application in Hydrologic Modeling", Water Resources Research, 119(2):246-261, 1993.

Free, M.H., C.A. Onstad, and H.N. Holtan, "ACTMO: An Agricultural Chemical Transport Model", Report No. ARS-H-3, U.S. Dept. of Agric. Engrs. (ASAE),Chicage Ill, 1975.

Goulter, I. and D. Forrest, "Use of Geographic Information System (GIS) in River Basin Management", Water Sci. Technol., 19(9), 81-86, 1987.

Grayman, W.M., "Land-Based Modeling System for Water Quality Management Studies", J. Hydr. Div., ASCE, 101(5):567-580, 1975.

Grayman, W.M., Males, R.M., and Harris, J.J., "Use of Integrated Spatial Data and Modeling Capabilities for Urban Runoff Analyses", Proc. of the Int. Symp.on Urban Hydrology, Univ. of Kentucky, Lexinton, Ky, 1 982.

Horn, C.R., and W.M. Grayman, "Water Quality Modeling with the EPA Reach File System", J. of Water Resour. Plng. and Mgmt, ASCE, 119(2):262-274, 1993.

Horng, M.J., "Integrated Decision Support System for Conjunctive Use Planning of Surface Water and Groundwater in Taiwan", ph.D. Dissertation, Dept. of Civil and Environmental Engrg., UCLA, 1994.

Knisel, W.G., "Creams: A Field Scale Model for Chemicals, Runoff, and Erosion from Agricultural Management System (Manual)", USDA Conservation Res. Report Number 26, U.S. Dept. of Agric., Washington D.C., 1980.

Kuittinen, R. and Y. Sucksdorff, "Invertory of River Basin Characteristics in Finnish Conditions Using Sattelite Imagery", Aqua Fennica, 17(2), 97-114, 1987.

Males, R.M., and W.M. Grayman, "Past, Present and Future of Geographic Information Systems in Water Resources", Water Resour. Update, No. 87, UCOWR, Carbondale,Ill 1992.

Meyer, S.P., T.H. Salem, and J.W. Labadie, "Greographic Information System in Urban Storm-Water Management", Water Resour. Res., 119(2):206-228, 1993.

Needham, S., and B.E. Vieux, "A GIS for AGNPS Parameter Input and Output Mapping", ASAE paper No. 89 -2673, American Society of Agric. Engrs.(ASAE), Chicago, Ill, 1989.

Parker, H., "Unique Qualities of Geographic Information Systems: A Commentary.",Photogram Engrg. Remote Sens., 54(11):1547-1549, 1988.

Shamsi, V., J. Maslanik, and S.McCimsey, "Remote Sensing and GIS to Assess Storm Sewer Master Plan", GIS World, 4(6), 83-86, 1991.

Stuebe, M., and D. Johnston, "Runoff Volume Estimation Using GIS Techniques",Water Resour. Bull., 26(4), 11 1-116, 1990.

Steinitz, et al., "A Comparative Study of Resource Analysis Methods", Department of Landscape Architecture Research Office, Graduate School of Design, Harvard University, July, 1969.

Vieux, B.E. and S. Needham, "Nonpoint-Pollution Model Sensitivity to Grid-Cell Size", J. Water Resour. Plng. and Mgmt, ASCE, 119(2), 141-157, 1993.

Vieux, B.E., "Geographic Information Systems and Nonpoint Sources Water Quality and Quantity Modeling", Int. J. Hydrol. Processes, 5(1):101-113, 1991.

White, D., "Grid-base Application of Runoff Curve Numbers", J. Water Resour. Plng.and Mgmt, ASCE, 1 14(6), 601-612, 1988.

Young, R.A., C.A. Onstad, D.D. Bosch, and W.P. Anderson, "AGNPS, Agricultural Nonpoint Source Pollution Model: A Watershed Analysis Tool", Conservation Res.Report 35, U.S. Dept. of Agric. Res. Service, Morris, Minn. 1987.

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