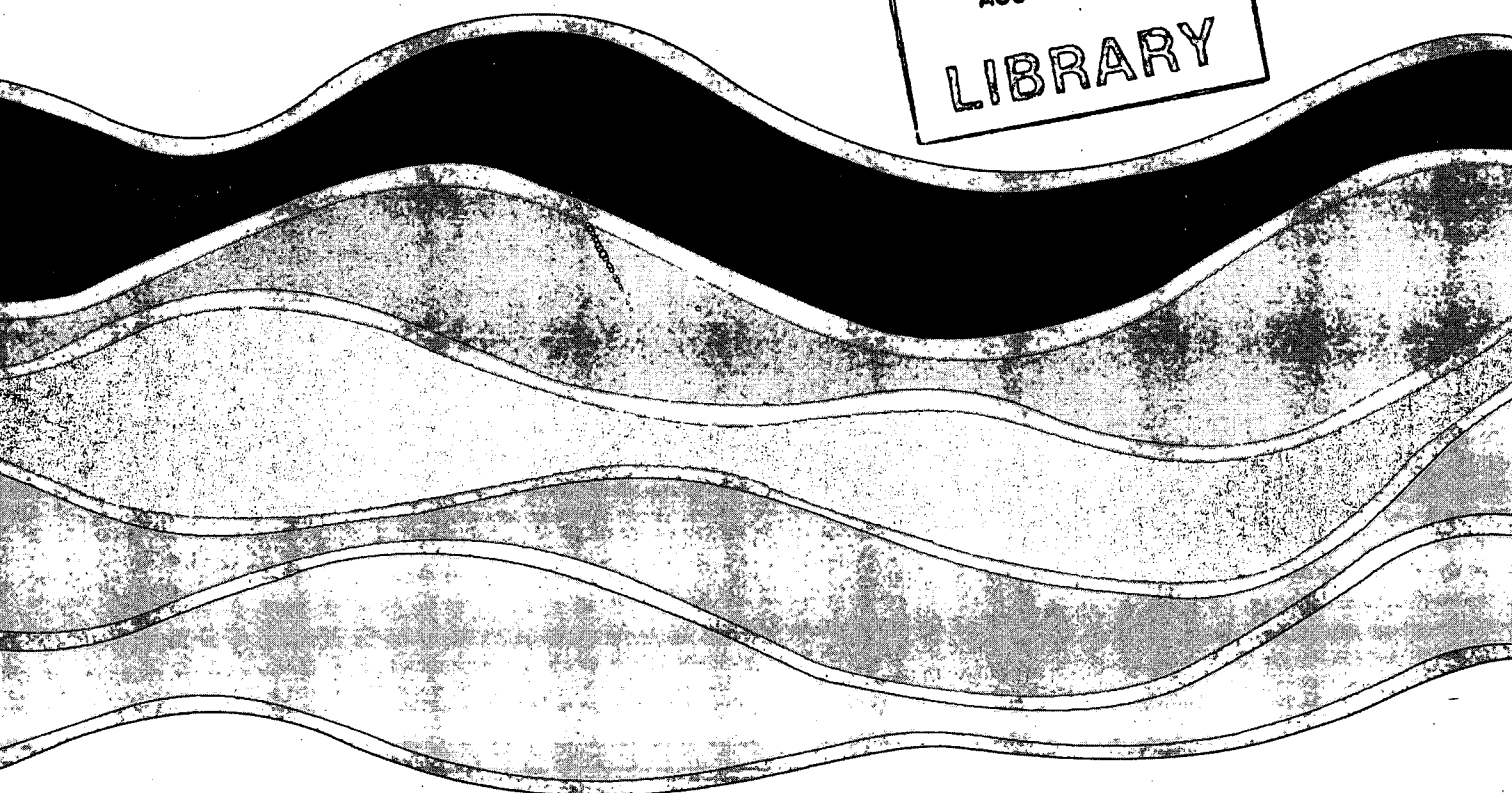
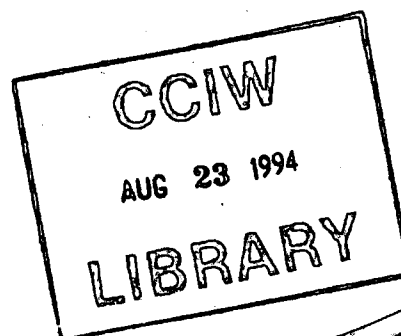
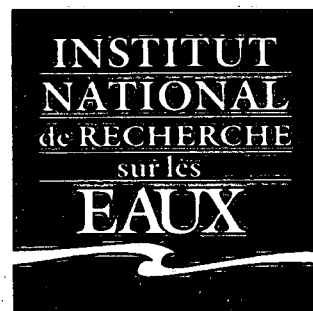
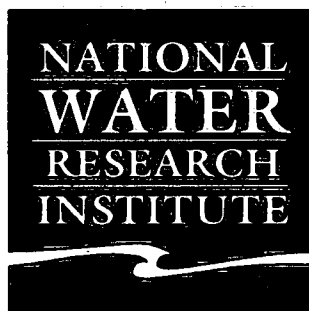


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**SIMULATION OF NON-POINT POLLUTANT  
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**NWRI Contribution No. 94-65**

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**SIMULATION OF NON-POINT POLLUTANT LOADS TO LAKE CHAOHU  
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**A Technical Note**

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**NWRI Contribution No. 94-65**

## MANAGEMENT PERSPECTIVE

This work evaluates a non-point source simulation model to determine its applicability to a watershed with multiple land uses and with different agricultural practices in different geographic zones. The model demonstrates fairly good agreement between simulated and measured nutrient loadings. The procedures used and the results presented in this report are useful for development of watershed modelling methodology.

This task is part of the exercises undertaken by Madam Xu during her six month stay at the National Water Research Institute, Burlington, Ontario under the Lake Chaohu Remedial Program sponsored by Canada-China Environmental Cooperation Program.

## SOMMAIRE À L'INTENTION DE LA DIRECTION

On évalue ici un modèle de simulation d'une source non ponctuelle pour déterminer si on peut l'appliquer à un bassin hydrographique à multiples utilisations du sol et diverses pratiques agricoles dans des zones géographiques distinctes. Le modèle permet d'obtenir une concordance relativement bonne entre les apports mesurés en éléments nutritifs et les résultats de la simulation. Les techniques utilisées et les résultats présentés ici seront utiles pour l'élaboration d'une méthode de modélisation des bassins hydrographiques.

La présente étude fait partie des activités entreprises par Madame Xu durant son séjour de six mois à l'Institut national de recherche sur les eaux, Burlington, Ontario, dans le cadre du programme de mesures correctrices du lac Chaohu, parrainé par le programme Canada-Chine de coopération environnementale.

## ABSTRACT

For remedial measures of Lake Chaohu, Anhui, China, modelling is needed in order to evaluate the pollutant loads originating from various sources within the Lake Chaohu watershed. The Agricultural Non-point Source Pollution Model (AGNPS) was assessed for possible use to predict non-point nutrients input to Lake Chaohu from the watershed. The AGNPS is a single event steady state model to simulate runoff, erosion, sediment yield and agriculture related water quality components. The model was evaluated by using storm events with various rainfall distributions to simulate the water quality components. The simulated water quality was then compared to water quality observed in the field. The results of this assessment are discussed.

## RÉSUMÉ

Afin de déterminer les mesures correctrices nécessaires au lac Chaohu à Anhui en Chine, il faut utiliser une modélisation pour évaluer les charges en matières polluantes provenant des diverses sources du bassin hydrographique de ce lac. On a évalué le modèle de pollution agricole non ponctuelle afin de déterminer s'il est utile pour prévoir les apports non ponctuels en éléments nutritifs au lac Chaohu en provenance du bassin hydrographique. Ce modèle, à l'équilibre et événement unique, sert à simuler le ruissellement, l'érosion, les charges sédimentaires et les composantes de qualité de l'eau liées à l'agriculture. On a évalué le modèle au moyen d'averses dont les distributions de précipitations sont variées pour simuler les composantes de qualité de l'eau. La qualité de l'eau simulée a ensuite été comparée à la qualité de l'eau observée sur le terrain. On discute ici des résultats de cette comparaison.

## **1.0 INTRODUCTION**

The trophic state of Lake Chaohu of Anhui, China has been identified as eutrophic to hyper-eutrophic in the Study of Eutrophication of Lakes of China (Tu et al. 1990). Nonpoint pollution has been identified as one of the sources contributing to the lake's eutrophication. Consequently, nonpoint source pollution is a spatially related and multi-constituent water quality problem. Pollutant sources are often distributed over different geographic areas and are not readily identifiable. Field data alone are not sufficient to evaluate all possible control schemes at source and during transport and deposition processes. For this reason, watershed modelling for hydrologic system synthesis, prediction and optimization is considered as one of the feasible approaches. In this connection, a non-point source simulation model together with a subwatershed from the Lake Chaohu watershed were selected for the purpose of studying the non-point pollutant loads to Lake Chaohu. Due to data availability and the time necessary to conduct the study, the Nanfei-Dianbu subwatershed was selected for this activity. The objective of this work is to assess the model's applicability to the subwatershed, with possibility to extend the model to basin-wide prediction of pollutant loads. This model was chosen because of the model's simplicity and ease of use. The Nanfei-Dianbu subwatershed contributed a large percentage of pollutant loads to Lake Chaohu (about 27% of total P and 36% of total N) as compared to other subwatersheds within the Lake Chaohu watershed. In addition, Nanfei-Dianbu subwatershed comprises multiple land uses. The report which follows describes the simulation procedures and simulation results.

## **2.0 SIMULATION PROCEDURES**

### **2.1 Simulation Model**

The estimation of non-point pollutant loads was carried out by

the Agricultural Non-Point-Source Pollution Model (AGNPS), version 3.65.5, January 1993. AGNPS was developed by the U.S. Department of Agriculture - Agricultural Research Service, University of Minnesota, in cooperation with the Minnesota Pollution Control Agency and the Soil Conservation Service. AGNPS is a single-event steady state model designed to simulate sediment and nutrient transport primarily from agricultural watersheds (Young et al., 1987). In the model, while water proceeds from the headwaters of the watershed to the outlet, pollutants are routed in a stepwise fashion so that flow at any point may be examined. The model works on a cell basis. These cells are uniform grid squares that divided up the watershed. The watershed can be divided up to a maximum of 1900 cells with a maximum area of 404 ha per cell. The cells are interconnected according to stream drainage patterns. The division of the watershed into small square areas makes it possible to analyze any subarea in the watershed. The basic components of the model deals with hydrology, erosion, sediment transport, transport of nitrogen, phosphorus, and chemical oxygen demand.

## **2.2 Description of the Lake Chaohu Watershed**

A brief description of the watershed follows.

The drainage area of Lake Chaohu, covering ten cities and counties, is located in central Anhui province, at 30° 58' 40" - 32° 06' 00" N and 116° 24' 30" - 118° 0' 00" E. The lake itself is located at 31° 25' 28" - 31° 43' 28" N and 117° 16' 54" - 117° 51' 46" E. The catchment has a total area of 9130 km<sup>2</sup> (upstream of the Lake Chaohu outflow control gate (Figure 1)) including 783 km<sup>2</sup> of the surface area of Lake Chaohu. There are seven major subwatershed systems (Figure 1).

The environmental conditions of the watershed are affected by urbanization, industrial and agricultural activities. Utilization of land in the watershed is 57%, 16%, 19% and 8% respectively for agriculture, forestry, urban and suburban, and others. There are

about 1050 tonnes of phosphorus and 18,368 tonnes of nitrogen coming into Lake Chaohu annually from the watershed, of which 34% of TP and 40% of TN are retained by the lake. Increase in population brings ecological pressure on Lake Chaohu. The Lake Chaohu watershed has a population of 6 million of which 1.2 (20%) million are urban settlers.

The flushing time of the lake is estimated to be 1.1 years by dividing the water volume of the lake by the outflow rate (1987/88 data) of the lake.

### **2.3 Description of the Studied Subwatershed**

The studied subwatershed has an area of 1668 km<sup>2</sup>. The main tributaries in the watershed are the Nanfei and Dianbu rivers. The Dianbu tributary drains to Nanfei, and Nanfei drains to Lake Chaohu (Figure 2). The combined annual runoff volume of the two tributaries to Lake Chaohu is  $768 \times 10^6$  m<sup>3</sup>. The average yearly rainfall in the subwatershed is 1067 mm. Thus, the annual runoff coefficient is 0.43. Major land use included urban and suburban, (the City of Hefei, capital of the Province of Anhui, with a population of 927,000, is located in this subwatershed, upstream of the Nanfei tributary, and it has urban area of 158 km<sup>2</sup>), electric power generation station, lumber mill, beer and wine brewing, agricultural chemical plant, bicycle factory, packaging factory, meat processing plant, steel refinery and finishing plants, paper mill, hide processing plant, tannery, printing plant, pharmaceutical production plant, forest and agricultural lands. Area of each category of land use is not available. Consequently, some catchment parameters had to be estimated on the basis of incomplete information. Also, there are two large reservoirs located in this subwatershed (Figure 2).

## 2.4 Subwatershed Data File

The Nanfei-Dianbu subwatershed was divided into grid cells. The grid cell division was prepared by using a 1:206,000 map enlarged from a 1:500,000 map (the only source available). (If higher resolution maps had been available, the recommended map scale for preparing the grid cells data should not be greater than 1:50,000.) The aerial map was then reproduced by using RAISON's graphic module for visual convenience. The cells are numbered consecutively from 1 to the total number of cells, beginning at the cell in the northwest corner of the subwatershed and proceeding from west to east southward. The watershed drainage pattern was established by overlying the river systems over the cells. The total area (1668 km<sup>2</sup>) of the subwatershed was divided into a total of 482- and 346-ha grid-cell sizes for input to the AGNPS model. The connectivity of flow paths of cells is shown in Figure 3. Subsequently, twenty-two input parameters (Table 1), covering a wide range of physical and chemical characteristics, were assigned to each cell. Sediment and nutrients are routed through the watershed; their concentrations in each cell being a function of upstream loading and the unique cell attributes, which can either increase or diminish the non-point pollutant load.

## 3.0 APPROACH

For the Nanfei-Dianbu subwatershed study, the AGNPS model was tested by (1) comparison between predicted and observed nutrient unit loads and concentrations data and (2) comparison of predicted and observed annual nutrient loadings at the outlet of the subwatershed, i.e. the outflow of Nanfei River as it enters Lake Chaohu.

The input to the AGNPS model for simulation was obtained by varying the rainfall events from 1.8 mm to 98 mm for a 4-hour duration, which were estimated from the report by Tu et al., 1990

corresponding to frequencies of five-times-a-year to once-in-98-years events. The report by Tu et al., 1990 was very helpful in selecting the parameter values.

#### 4.0 RESULTS AND DISCUSSION

##### 4.1 Comparison of Model-Predicted Results and Field Observed Data

Basically, most of the model input data is physically-based, and very little parameter calibration is required. For this reason, after the establishment of the data file, comparison of the model results with field data is essential.

There are three ways how to compare modelling results with field data. The first way, for a single event, is to prepare the single event input data for all the cells in the AGNPS model so as to duplicate the actual field condition. Lack of measured single rain event data and land management information from the Nanfei-Dianbu subwatershed made such a comparison unachievable.

The second way is by sensitivity analysis. The sensitivity analysis is performed by varying the value of input parameters. Such results may not represent the actual field conditions. However, the sensitivity analysis provides information on which parameter is the most significant in the modelling processes.

The third way is by using the average annual conditions of water quality loads with field monitoring data. This approach is generally acceptable for planning and management practices and was adopted here. In this approach, the grid-cells of the Nanfei-Dianbu subwatershed were set to depict 1987/88 watershed conditions which closely represent the field data collection period.

#### 4.2 Comparison of Predicted and Observed Nutrient Unit Loads and Concentrations

The nutrient unit loads and concentrations predicted by the model and the corresponding data observed in the Nanfei-Dianbu subwatershed are given in Table 2.

As expected with such coarse-scale information used in the model, the predicted unit load of N in sediment and runoff are 3 times underestimated and 8 times overestimated, respectively, by the model. The predicted soluble N concentration and the ranges of concentration (Table 2) in runoff agree fairly well with the observed values. It is of interest to further examine the discrepancies respectively between predicted and observed N loads in sediment and in runoff. Such discrepancies were probably due to the types of agricultural practices (the AGNPS model assumed agricultural practices, principally on dry land) in the subwatershed since the discharge from industrial sources and sewage from the urbanized areas were relatively stable while those from other sources were determined by rainfall and pollutants transported by runoff. It was estimated that about 70 % of the subwatershed was occupied with rice paddies. Paddy rice is grown with a layer of impounded water on the surface of the field during growing season. Impounding combined with silt-loam soil type in the paddy field would increase organic materials available for transport by runoff. It was noted that on the average, 86% of the total N (Tu, et al., 1990) transported by the Nanfei River to Lake Chaohu was in particulate form. The model prediction showed less N loads in sediment than in runoff, whereas the observed data showed the opposite. However, these discrepancies can be reduced by adjusting the input agricultural practice parameters and further verification by observed data. Improvement of the agreement depends on the availability of detailed data for the study area.

The P loads in sediment and in runoff were higher, respectively, by a factor of 2.6 and 24, between predicted and observed values (Table 2). The predicted P load in sediment and in runoff had a similar trend as for N. This may be further interpreted as the model was designed primarily for application in north American agricultural practice. The water quality and physical parameters used in the AGNPS were based on dry land environment. The observed P load in sediment was much higher than the P load in runoff. Again, this may be explained by the same reason as discussed earlier for N loads. The ranges of predicted P concentration in runoff are comparable to those of observed ranges.

Both predicted COD load and concentration in runoff were higher than the observed values. The model-predicted results with monitoring data for average conditions indicated varying degrees of accuracy for COD.

There is no data available for comparison of the ranges of load for observed N, P, and COD between the predicted and field measured data. From the average values (note that both units of load and concentration are entered in the average), the model overestimated by a factor of 1.8 times over the field values. In this context, considering the limitation of data input and the uncertainty of water quality in a complex soil-water environment, it was generally acceptable that the model demonstrated the ability of prediction within an order of magnitude of accuracy.

#### **4.3 Comparison of Average Annual Nutrient Loadings**

Results of model predicted and observed annual nutrient loads transported by the Nanfei River to Lake Chaohu are presented in Table 3. The predicted total suspended solids load was 29,870 tonnes per year and compared very well with the monitored load (1987/88) of 24,400 tonnes per year. The predicted total nitrogen load was 4,480 tonnes per year which underestimated the observed

load. The predicted total phosphorus load was 580 tonnes which exceeded more than twice the observed load. The COD was underpredicted by 25% of the observed load. This is probably due to the fact that 1987/88 was a wet year where streamflow volume was higher than the long term average. It may be a deficiency of the model or it may be due to the inadequacy of the monitored data.

In general, the model predicted COD concentration was high when the runoff volume was small or vice versa. The model predicted sediment load fairly accurately. Similar results were reported by Koelliker and Humbert (1989).

The average ratio between model predicted and field observed annual nutrient loads is 1.01 (Table 3). This ratio shows almost a perfect match. This suggests that the model is able to predict fairly accurately the total loading of nutrients from the subwatershed, regardless of the variations of individual nutrient loadings within the component.

#### **4.4 Runoff Coefficient of the Subwatershed and Application**

The model predicted runoff coefficient (runoff volume/rainfall volume) for the Nanfei-Dianbu subwatershed was 0.43 compared to the observed runoff coefficient of 0.42, with a difference of 3%. The runoff coefficient for the Nanfei-Dianbu subwatershed appeared to be higher than a typical rural watershed and lower than a typical urban watershed. This may suggest that the subwatershed is undergoing urbanization (Walesh, 1989).

To illustrate the application of the model to the Nanfei-Dianbu subwatershed, the simulation results showing the critical area of sediment yield are plotted in Figure 4.

## 5.0 SUMMARY AND CONCLUSION

The nutrient simulations produced annual unit load and concentrations which were comparable to the observed average annual unit loads for the Nanfei-Dianbu subwatershed. The predicted N load in sediment was lower than the observed N load in sediment, and the predicted N load in runoff was higher than the observed N load in runoff. Both predicted P loads in sediment and in runoff were higher than the observed P loads in sediment and in runoff. The predicted ranges of nutrient concentrations were comparable to the observed ranges of nutrient concentrations.

The overall average of the total annual nutrient loads attained a high degree of agreement suggesting that the model can be extended to simulate the non-point source pollutant loads for the whole watershed of Lake Chaohu.

In spite of the coarse resolution and limited data used in the model, the modelling approach shows good promise for designing better monitoring systems and for model improvements when more accurate information is available.

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- Young, R.A., C.A. Onstad, D.D. Bosch, and W.P. Anderson. 1987. AGNPS: A non-point source pollution model. A watershed analysis tool. USDA, ARS, Conservation Research Report No. 35. National Technical Information Service, VA.

Table 1. Input Parameters used in the AGNPS model

| <u>TITLE</u>      | <u>DESCRIPTION</u>                               |
|-------------------|--|
| Cell Number       | ID of current cell                               |
| Receiving Cell    | ID of cell receiving outflow from current cell   |
| SCS Curve Number  | Relates runoff mass to rainfall mass             |
| Field Slope       | Mean slope of fields (%)                         |
| Slope shape       | Indicates concave, convex or uniform slope shape |
| Slope Length      | Indicates average field slope length             |
| Channel Slope     | Mean slope of stream channel (%)                 |
| Side Slope        | Mean slope of stream channel banks (%)           |
| Roughness         | Manning's Roughness Coefficient for channels     |
| Soil Erodibility  | K-Factor from Universal Soil Loss Equation       |
| Crop Practice     | C-Factor from Universal Soil Loss Equation       |
| Support Practice  | P-Factor from Universal Soil Loss Equation       |
| Surface Condition | Indicates degree of land surface disruption      |
| Aspect            | Principal drainage direction                     |
| Soil Texture      | Indicates sand, silt, clay or peat               |
| Fertilization     | Indicates level of added fertilizer              |
| Incorporation     | Indicates % fertilizer left on soil after storm  |
| Point Source Flag | Indicates presence of any point source           |
| Gully Source      | Override estimate of gully erosion magnitude     |
| COD               | Level of chemical oxygen demand generated        |
| Impoundment Flag  | Indicates presence/absent of terrace systems     |
| Channel Flag      | Indicates presence/absent of defined stream.     |

**Table 2.****Comparison of Simulated and Observed Nutrient Unit Loads and Concentrations in the Nanfel-Dianbu Subwatershed**

| Parameters                               | Predicted |            | Observed |            |
|--|-----------|------------|----------|------------|
|  | Mean      | Range      | Mean     | Range      |
| Total N load in sediment (kg/ha)         | 0.26      | 0.01-0.58  | 0.77     | n/a        |
| Total soluble N load in runoff (kg/ha)   | 1.19      | 0.02-2.40  | 0.15     | n/a        |
| Soluble N in runoff (mg/L)               | 8.89      | 4.20-19.01 | 4.75     | 8.70-14.70 |
| Total P load in sediment (kg/ha)         | 0.13      | 0.01-0.27  | 0.05     | n/a        |
| Total P load in runoff (kg/ha)           | 0.24      | 0.01-0.48  | 0.01     | n/a        |
| Soluble P in runoff (mg/L)               | 1.33      | 0.68-2.49  | 0.29     | 0.26-1.01  |
| Total soluble COD load in runoff (kg/ha) | 1.51      | 0.10-4.03  | 0.17     | n/a        |
| Soluble COD in runoff (mg/L)             | 18.20     | 7.06-86.65 | 10.97    | 7.60-12.98 |
| Average                                  | 3.97      | -          | 2.15     | -          |

n/a: not available

**Table 3.****Comparison of Model-Predicted and Observed Annual Nutrient Loadings from the Nanfel-Dianbu Subwatershed**

| Parameters                         | (1)<br>predicted | (2)<br>Observed | (3)<br>(2)/(1) |
|------------------------------------|------------------|-----------------|----------------|
| Total Suspended Solids (tonnes/yr) | 29,870           | 24,400          | 0.82           |
| Total Nitrogen (tonnes/yr)         | 4,480            | 6,680           | 1.49           |
| Total Phosphorus (tonnes/yr)       | 580              | 283             | 0.49           |
| Chemical Oxygen Demand (tonnes/yr) | 22,960           | 28,700          | 1.25           |
| Average                            | 14,473           | 15,016          | 1.01           |

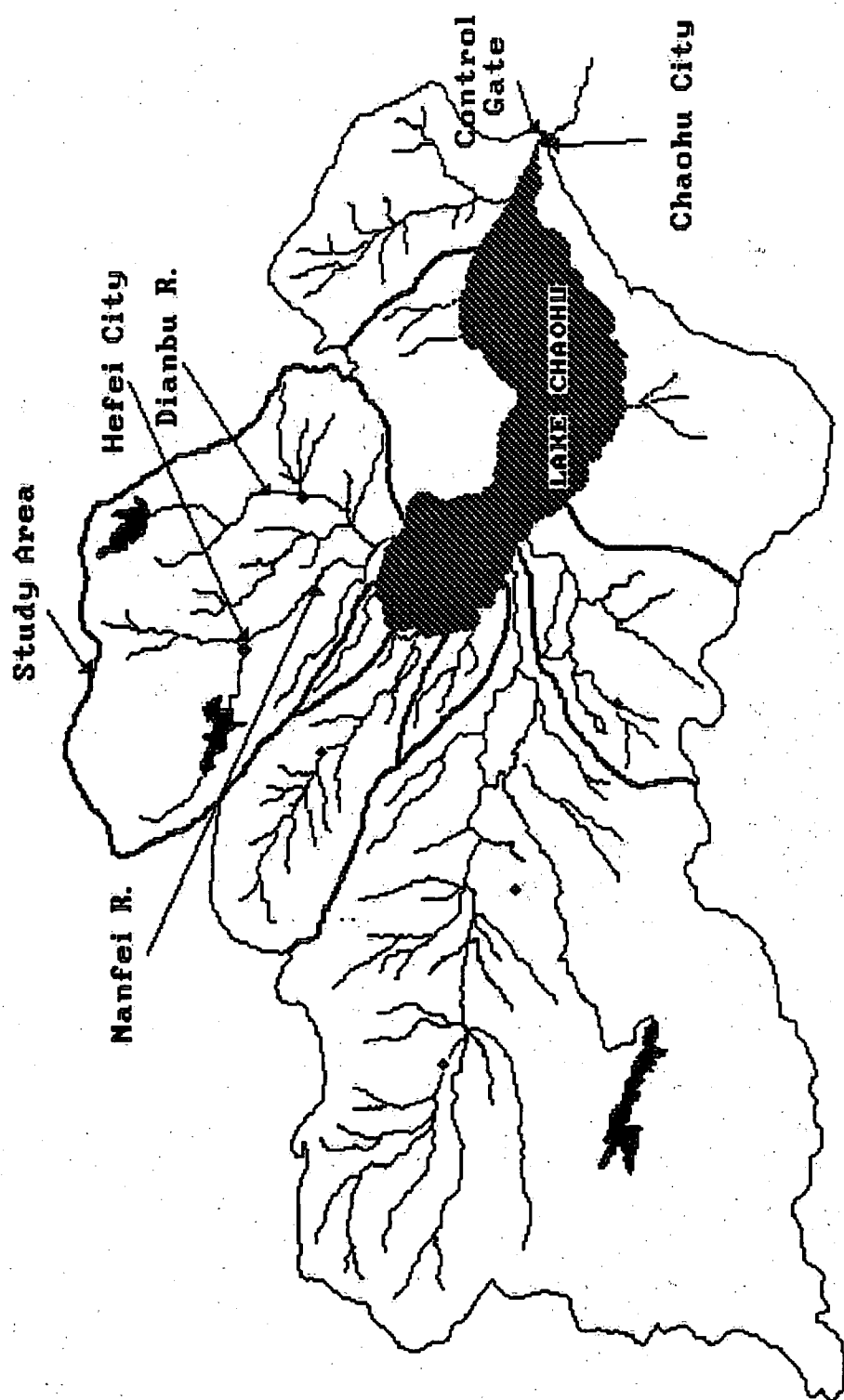


Figure 1. Lake Chaohu Watershed

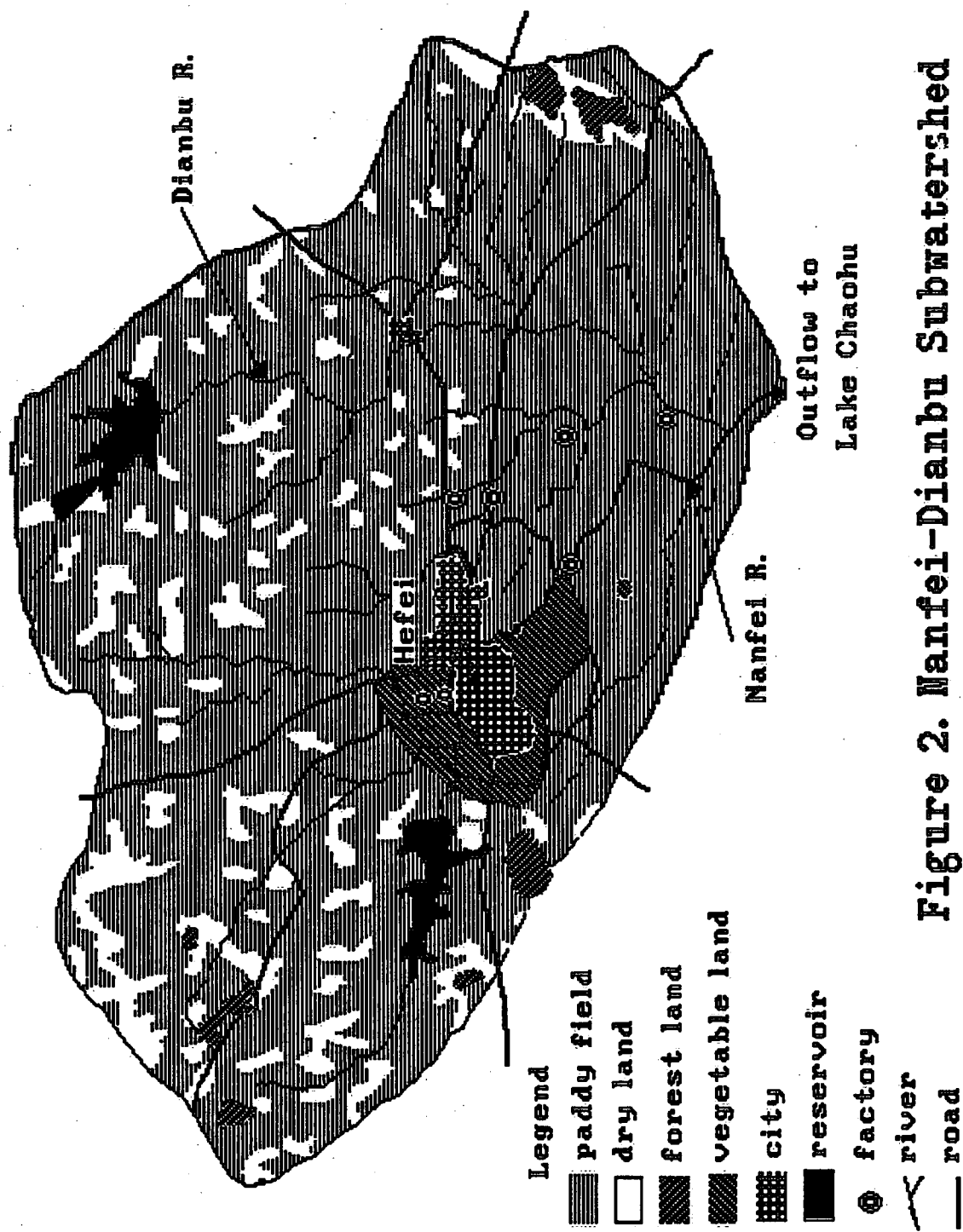
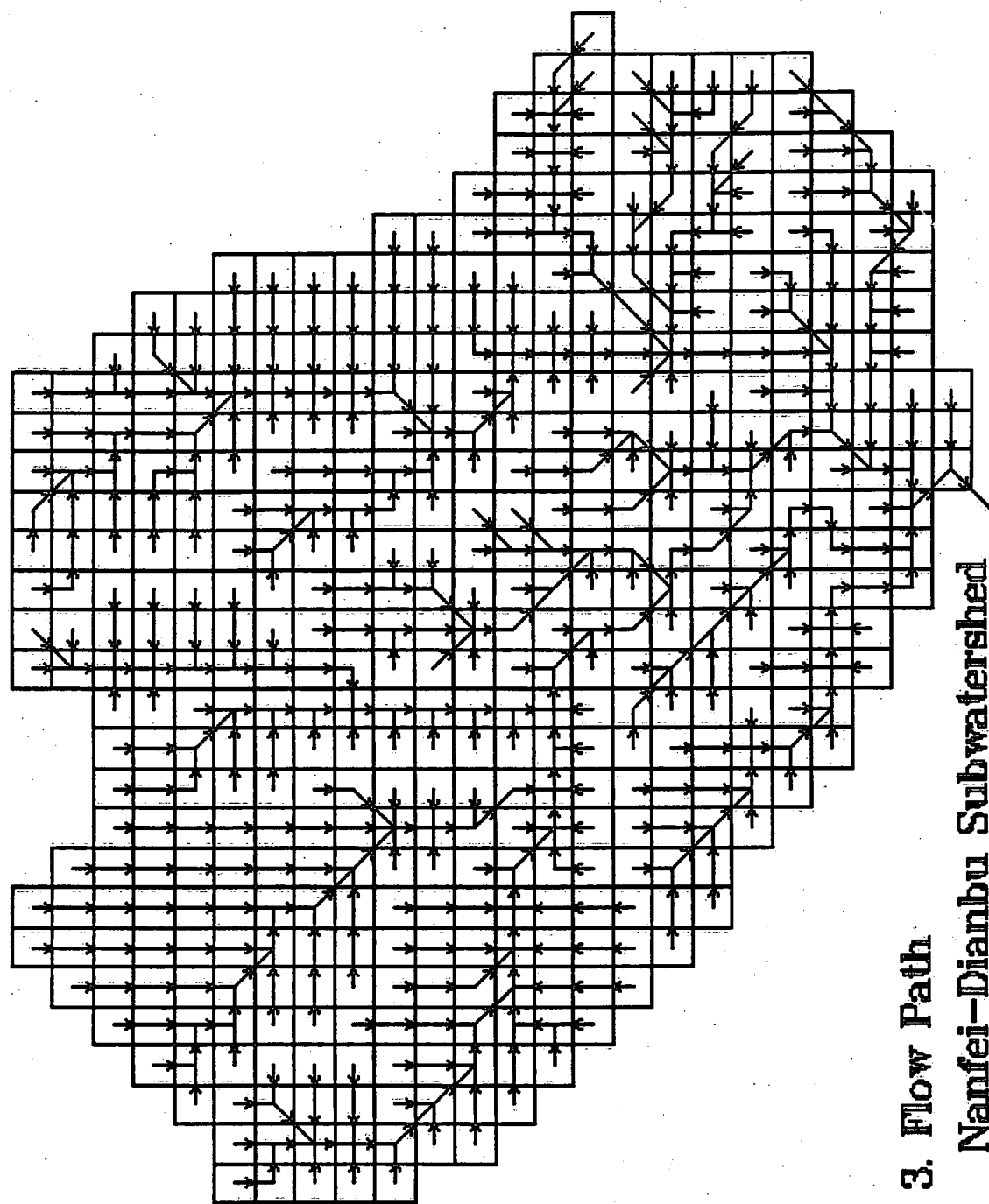


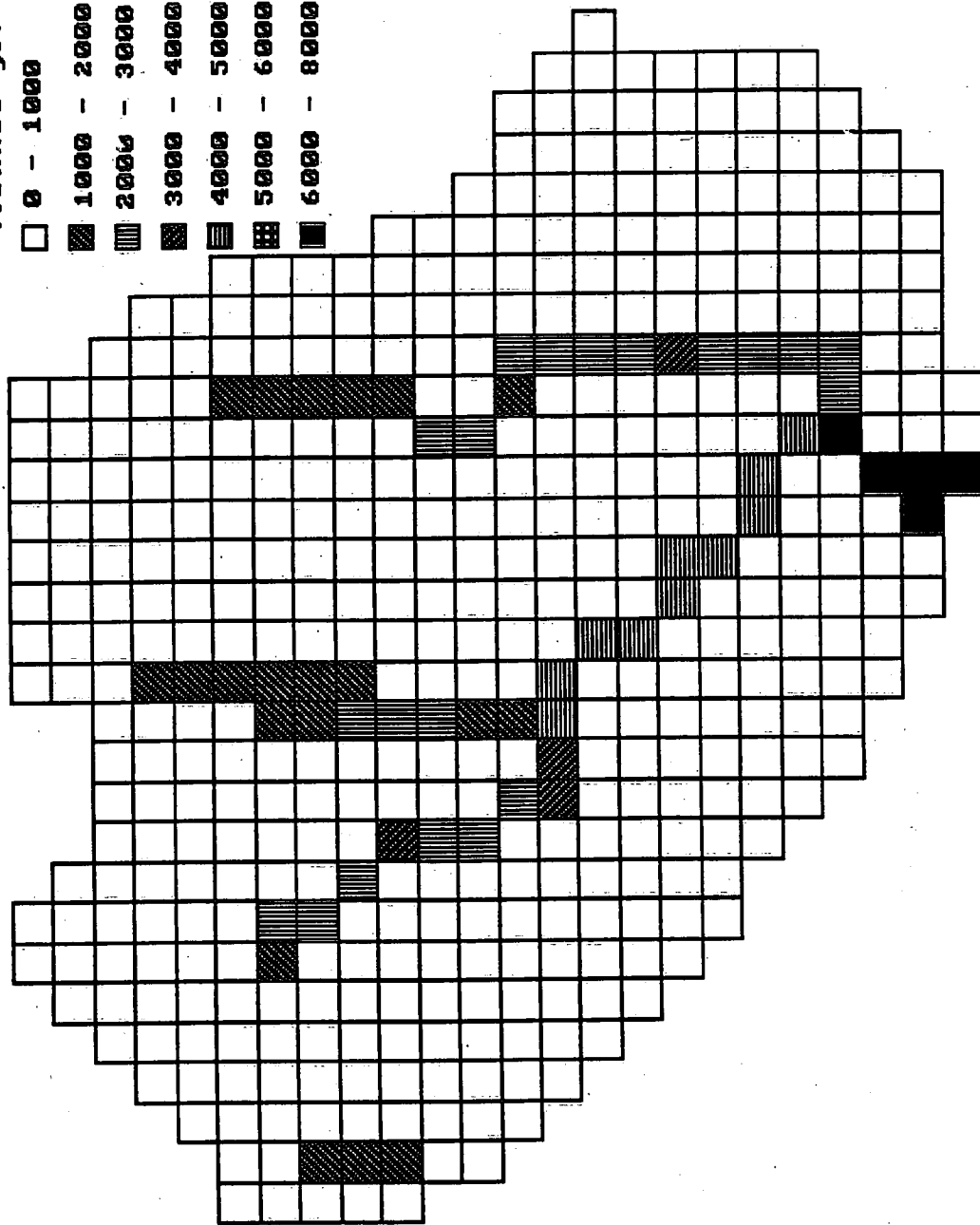
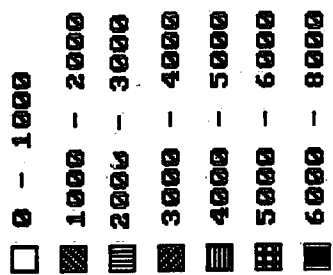
Figure 2. Nanfei-Dianbu Subwatershed



**Figure 3. Flow Path**

**Nanfei-Dianbu Subwatershed**

**Sediment Yield  
(tonnes/yr)**

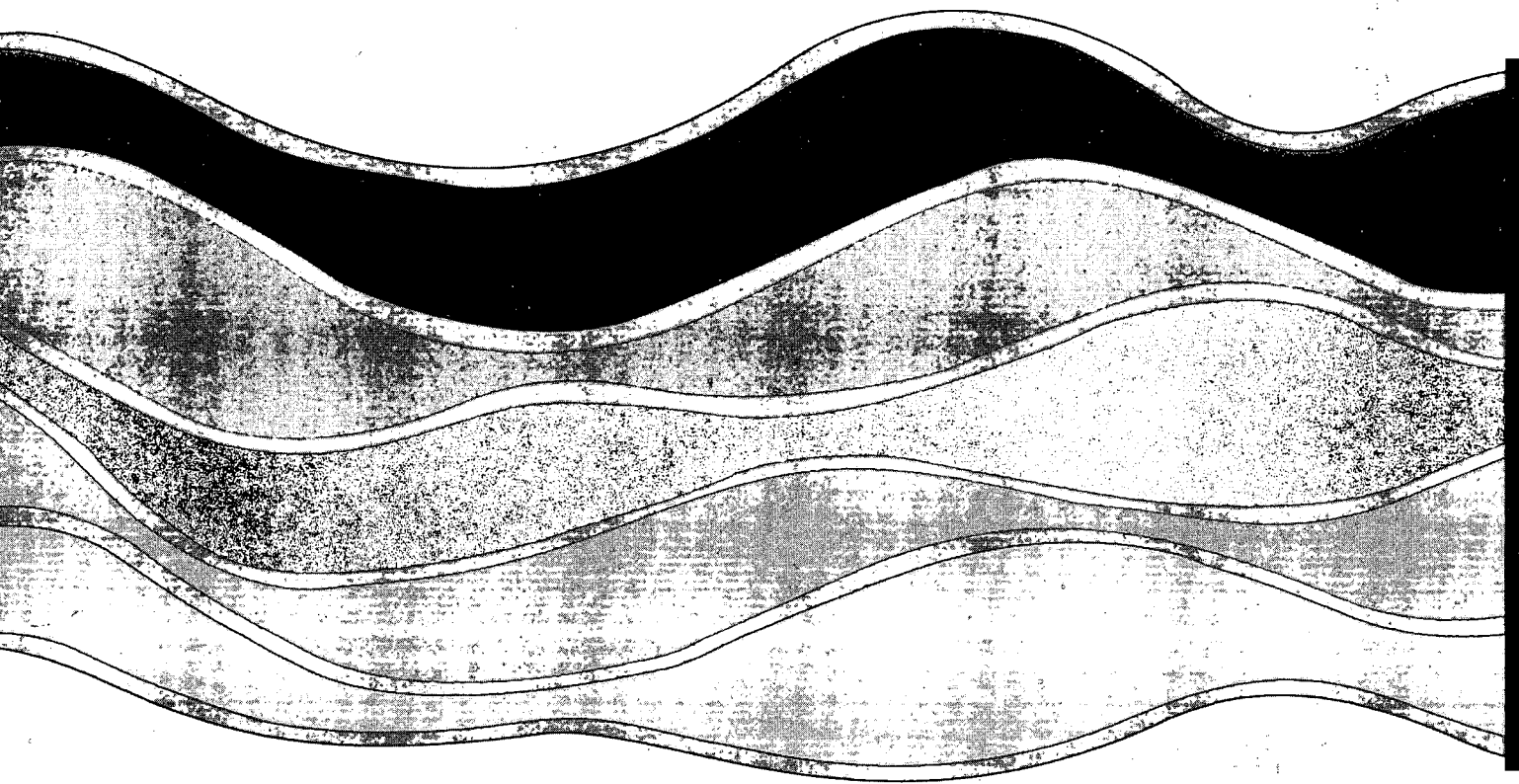


**Figure 4. High Sediment Yield Areas Determined by the AGNPS Model**

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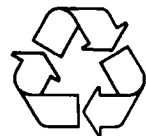
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