

1. INTRODUCTION

This research is focused on the transport of nutrients and herbicides in surface waters of the Midwestern United States and it examines the extent to which Geographic Information System (GIS) technology can be used to automate and improve the computation of spatio-temporal distribution of selected agricultural chemicals. Up to now, there have been elaborate flow models and pollutant transport models in use at the watershed scale. The application of the most widely used deterministic models such as ANSWERS or SWRRB is limited to agricultural basins of about 200 km² and 800 km² respectively. An extended version of SWRRB, SWAT model, has been applied to study the hydrology and crop conditions for the conterminous U.S. Deterministic models focus mainly on the detailed description of small-scale physical phenomena and they require huge computer and data resources if implemented on the scale considered here. In the light of the existing projects, the aim of this project is to develop a procedure of estimating the distribution of agricultural chemicals over a region which size is limited only by data availability.

This work proposes a statistical-GIS methodology of determining the amount of selected agrichemicals (nitrate plus nitrite as nitrogen and atrazine) in the rivers of the Upper Mississippi-Missouri River and the Ohio River basins, which have a total drainage area about $2.4 \cdot 10^6$ km² (data used for model parameter calculations were collected in sites scattered over this region). Since the agrichemical transport model requires spatially distributed flow, a technique of spatial redistribution of the discharge recorded in USGS gauging stations, as well as the application of an agrichemical transport model is presented here for the Iowa -Cedar River watershed, Iowa and Minnesota, which has an area of about 32,000 km².

1.1 Motivation

It is commonly known that agricultural activity endangers the quality of surface waters. Farmers apply chemical nutrients to increase soil fertility and use pesticides to control unwanted plants and destructive insects. About 60 percent of pesticides (Gianessi and Puffer, 1990) and nitrogen fertilizers (Kolpin, et al., 1991; US Environmental Protection Agency, 1990) used in the USA are applied to cropland in twelve Midcontinental States (Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, Wisconsin). Four major herbicides: alachlor, atrazine, cyanazine, and metolachlor, account for about 73 percent of the pesticides applied (Gianessi and Puffer, 1990).

Numerous studies have been performed on a small watershed scale. But until recently, few studies have been conducted to evaluate the contamination of rivers in the Upper Mississippi-Missouri and Ohio River basins.

In 1990, the United States Department of Agriculture (USDA) initiated a Management System Evaluation Areas (MSEA) program. The major purpose of this program is to determine the influence of agricultural practices on water quality in the Midwest and to identify management systems that protect water quality. Ten study areas were established to gather data for a better understanding of the factors and processes that control the fate and transport of agricultural chemicals (Hatfield, et al., 1993). Also, the United States Geological Survey (USGS) conducts observational studies to determine the distribution, transport and persistence of selected herbicides, insecticides, and inorganic nutrients in the Mississippi River and its tributaries (Battaglin, et al., 1993).

The Geographic Information System (GIS) offers a unique technology to formulate more objective and consistent methods to synthesize collected data and to assess water quality over large areas (Maidment, 1996). This work explores the applicability of GIS technology to regionalize to large basins the results of small watershed scale water quality studies, and to evaluate the temporal and spatial distribution of the loads and concentrations of selected agricultural chemicals in the surface waters of the Upper Mississippi-Missouri and Ohio River basins.

1.2 Objectives

The general objective of this research is regionalization of watershed scale measurements. This general objective can be divided into the following goals:

- 1) To formulate statistical models capable of representing the spatio-temporal variability of agricultural chemicals in surface waters;
- 2) To evaluate the applicability of the GIS technology for deriving stream and watershed characteristics that influence chemical transport processes;
- 3) To develop a methodology for calculating time series of monthly average flow rate in ungauged streams;
- 4) To build a model for predicting concentrations and loads under different hydrologic conditions and for different agricultural chemical application rates than those historically observed.

1.3 Scope of Study

The following restrictions define the scope of this research:

- 1) The analysis is limited to two selected agrichemicals - the nutrient, nitrate plus nitrite as nitrogen, and the herbicide, atrazine. These two chemicals were chosen because they are representative of nutrients and herbicides, respectively, and because they are present in measurable quantities in many Midwest streams and rivers. Although the research is performed for only two agrichemicals, a similar procedure could be used for other herbicides and nutrients.
- 2) Since the model is constructed using GIS technology, and since the available data are limited, the concentrations and loads of agricultural chemicals in surface waters are described by regression equations, which have limited application for making predictions.
- 3) Observed loads and concentrations as well as chemical application rates are derived from data published in USGS reports. Watershed and stream parameters are derived from a Digital Elevation Model that is available on Internet. Flow rate and the precipitation data are extracted from CD-ROMs (Compact Disk Read Only Memory) published by Hydrosphere Inc.
- 4) Although the regression equations are estimated from data gathered at 151 sampling sites located in eleven Midcontinental States (Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, Ohio, South Dakota, Wisconsin), the complete GIS model is developed only for the Iowa-Cedar River basin, Iowa.

- 5) Model formulation and model parameter estimation are constrained by the available computer resources (SUN Sparc Station IPX and Sun Ultra).

1.4 Project Summary

This research can be divided into the following steps:

- 1) Preparation of measurement data for statistical analysis. This step involves data entry from printed USGS reports, filling in missing values and data correction, and conversion of data into common units.
- 2) Development of the general forms of equations that can explain spatial and temporal variation of the chemical concentration and load in the Upper Mississippi - Missouri River, the Ohio River and their tributaries.
- 3) For each watershed associated with a measurement point, determining the drainage-basin morphometry, climatic characteristics, and chemical application rate. A 15-second (500 m resolution) digital elevation model is utilized in the following steps:
 - delineation of the stream network from the digital elevation model (DEM);
 - location of stations in which the water samples were collected on the delineated river network;
 - estimation of the drainage area associated to each measurement point;
 - calculating parameters that characterize this drainage area;
 - evaluating the watershed average annual precipitation as well as the average annual temperature; and
 - calculating watershed-averaged chemical application rate.

- 4) Preliminary analysis of the spatio-temporal distribution of the constituent concentrations in the Mississippi-Missouri and Ohio River basins. This step includes development of the regression equations that relate measured agricultural chemical concentrations at a given point to such explanatory variables as the annual agricultural chemical application and the flow rate.
- 5) Formulation and application of the methodology for estimation of monthly flow rate in ungauged streams. This methodology is utilized for a selected watershed, i.e., the Iowa-Cedar River basin. The 3 arc-second (100 m resolution) DEM is chosen as a base map for determining the flow direction and for subdivision of the Iowa-Cedar watershed into small drainage units (mostly 20 - 50 km²). This step is based on the following:
 - constructing a spatio-temporal database of monthly average flow rate and monthly average precipitation rate for period from 1960 to 1992;
 - dividing the Iowa-Cedar River into small drainage units, converting resulting map from raster into vector format, and building “flow” topology among the drainage units;
 - interpolating or extrapolating recorded flow rate over ungauged drainage units using precipitation, estimated flow rate, an average runoff coefficient, and drainage area as input to an estimating equation.
- 6) Estimation of the spatio-temporal distribution of the agricultural chemical concentration and load. In this step the flow rate identified in step 5 is applied in the regression equation developed in step 4.

1.5 Contributions of Study

This research has the following contributions to the knowledge:

- 1) The development of a method for application of the GIS technology to determine factors that influence the process of mobilization and transport of agricultural chemicals over a very large region;
- 2) The estimation of the general temporal (monthly) pattern of the average atrazine and nitrate concentrations in the Upper Mississippi-Missouri and Ohio River basins;
- 3) The application of the GIS technology to store time series of recorded monthly flow rate and precipitation depth (creation of a spatio-temporal database);
- 4) The development of a spatial analysis routine for estimating monthly time series of expected flow rate in ungauged streams;
- 5) The formulation of a GIS spatial model from which concentrations as well as loads of nitrate plus nitrite and atrazine in streams can be calculated for different hydrologic scenarios.

In addition to the contributions listed above, during this research a set of new GIS tools supporting hydrologic modeling has been developed. The following procedures have been constructed:

- 1) Automated watershed division into hydrologic sub-units;
- 2) Improvement of the major flow paths delineated from a digital elevation model (DEM), and therefore enhancement of the delineated stream network and

watershed boundaries by burning in a mapped stream network to the digital elevation model.

- 3) Calculation of a new stream order system to describe the topologic characteristics of a stream network similar to the Shreve or Strahler ordering methods, that makes flow and transport calculations very efficient; and
- 4) Building in ArcView hydrologic modeling tools that do not exist in ArcView for flowaccumulation--accumulating an entity when traveling downstream, determining drainage area upstream of a given location, and identification of transport paths.