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FOREWORD

This publication consists of papers presented at a Bouyoucos Conference held under the sponsorship of the Soil Science Society of America. Funds supporting the Bouyoucos Conferences came from a generous donation by Dr. George Bouyoucos in 1972. The fund was originally set up to recognize and award outstanding research careers in soil science. Dr. Bouyoucos has had an outstanding career in soil science himself, devising instruments and establishing methods that have been adopted worldwide for managing irrigation water purposes. In 1992, SSSA decided that the Bouyoucos Funds would be more effectively used to sponsor research conferences devoted to in-depth discussions on certain aspects of soil science, and to foster creative interactions among soil scientists as well as with those in other disciplines. This publication is a fine example of the results from such a conference.

This conference addressed one of the major issues challenging soil science today; that is, how to quantify the distribution and magnitude of non-point source pollutants in terrestrial ecosystems across a landscape and to develop appropriate methodology for cleaning up the pollutants. Conceptually, there is an increasing volume of basic knowledge on most of the processes involved in pollutant behavior and fate in the soil environment. Until recently, there has been a lack of tools to extrapolate and apply knowledge gained from studies at laboratory and field plot scales to explain behavior at the landscape scale. The challenge to soil science is how to establish a meaningful database that quantitatively describes the conceptual framework of pollutant behavior in soils at the landscape scale.

The computer-based GIS (geographic information system) has been shown to be an cost-effective means to collate remotely sensed soil and landscape data and organize them in a meaningful way at the landscape scale. When the GIS is combined with models applicable to simulate processes at landscape scale to produce an integrative spacial databases characterization of interactive factors within a whole watershed can now be possible. Advances in this knowledge area can lead to realistic management solutions for controlling pollution and for mediating contaminated environment.

PREFACE

Because of their ubiquitous nature and potential chronic health effects, non-point source (NPS) pollutants have become a focal point of attention worldwide, particularly with regard to the pollution of surface and subsurface sources of drinking water. The ability to model NPS pollutants provides an assessment tool for optimizing the utility of the environment by sustaining its use with minimal detrimental consequences while preserving the esthetic qualities that serve man's spiritual needs. This preface provides a brief introduction and general discussion of the papers presented at the 1995 ASA-CSSA-SSSA Bouyoucos Conference entitled *Applications of GIS to the Modeling of Non-Point Source Pollutants in the Vadose Zone*.

The world faces a wide variety of complex environmental threats: the loss of biodiversity; the depletion of the ozone layer; global climate change; the degradation of soil and water resources essential for food production; and the accumulation of widespread, health-threatening pollution. These problems are even further exacerbated by the basic trend in world population, which has doubled since 1950 and is expected to double again by the middle of the next century. The foremost global issue facing mankind is how to satisfy the ever-growing need for natural resources to meet food and living standard demands, while minimizing impacts upon an environment that already shows signs of serious levels of biodegradation.

During the past 20 years, since the Stockholm Conference on the Human Environment, the world has started to recognize that environmental problems are inseparable from those of human welfare and from the process of economic development, and that many present forms of development erode the environmental resources on which human livelihood and welfare ultimately depend. This awareness has fostered the concept of sustainable agriculture as a means of meeting the world's future food demands. Sustainable agriculture is based upon a delicate balance between crop production, natural resource use, environmental impacts, and economics. The goal of sustainable agriculture is to meet the needs of the present without compromising the ability to meet the needs of the future. Ideally, it strives to optimize food production while maintaining economic stability, minimizing the use of finite natural resources, and minimizing environmental impacts. This presents a formidable dilemma because agriculture remains as the single greatest contributor of non-point source (NPS) pollutants to soil and water resources (Humenik et al., 1987).

Point source and NPS pollutants differ solely in the scale of the areal extent of their source. Point source pollutants are those isolated to a single point location such as hazardous waste spills or dump sites. The characteristic feature of a point source pollutant is the high level of toxicity that can result in acute toxicity to plants and animals including man. In contrast, NPS pollutants are spread across broad areas encompassing hundreds, thousands, or even millions of hectares of

soil; millions of liters of water; and/or millions of cubic meters of air. Characteristically, NPS pollutants are ubiquitous, but are generally low in concentration; consequently, their impact upon human health, plants, and animals is chronic in nature.

The focus of the public's attention in the past has been primarily upon point source pollutants because of their high level of toxicity; however, as chemical analysis techniques and instrumentation have improved the ability to detect smaller and smaller quantities of contaminants in all compartments of the environment, the ubiquitous nature of some contaminants has been documented. Furthermore, long-term toxicological studies have revealed the chronic health effects associated with prolonged exposure to low levels of some NPS pollutants. Even though point source pollutants are more toxic, they actually pose less of a health threat because they are readily identifiable and once identified they are more easily controlled. On the other hand, NPS pollutants are so diffuse and at such low concentrations that identifying the extent of their presence is an onerous task only exceeded by the virtually impossible task of their control, isolation and clean up. Remediation of point sources of pollution is expensive, but the costs associated with NPS pollutant clean up are staggering. Their ubiquitous presence and costly clean up combined with the recognized chronic health effects associated with long-term exposure has refocused the public's attention from point source to NPS pollutants.

The impact of NPS pollutants upon soil and groundwater resources is a problem of global importance because NPS pollutants do not recognize boundaries between nations nor are they necessarily isolated by physical barriers whether man-made or natural. As surface water supplies have diminished in quantity and quality, greater demands have been placed upon groundwater supplies to meet domestic, agricultural, industrial and recreational demands. In fact, 50% of the drinking water and 40% of the irrigation water used in the USA come from groundwater supplies. Because of the uneven distribution of available surface water supplies worldwide, the demand is even greater for groundwater supplies in countries such as Mexico. The awareness of the importance of groundwater supplies in meeting drinking and agricultural water demands has brought the concern over the degradation of groundwater to the forefront of public attention particularly in the USA and in European countries. Concomitantly, the degradation of soil resources by man's activities occurs at an unprecedented rate. Currently, an area approximately the size of China and India combined suffers moderate to extreme soil degradation caused by agricultural activities, deforestation, and overgrazing that has occurred during the past half century (Oldeman et al., 1990). This represents 11% of the world's vegetated surface, i.e., 1.2 billion hectares. Of the 1.2 billion hectares, approximately 12% are the consequence of chemical degradation resulting from salinization, acidification, and pollution (Oldeman et al., 1990). Worldwide, faulty agricultural practices account for 29% of the degraded soils with the greatest share occurring in North America (Oldeman et al., 1990).

To address the aforementioned environmental problems, a means of assessing the impact of NPS pollutants upon soil and groundwater resources is needed. One means of assessment aside from real-time measurement is the abil-

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ity to predict the future fate and distribution of NPS pollutants with mathematical models. The capability of predicting the response of a spatially-complex and heterogeneous system such as soil, specifically the vadose zone of soil (i.e., the zone of soil extending from the soil surface to the groundwater table), to the large-scale stresses of NPS pollutants is the consequence of the integration of knowledge from a range of subdisciplines including classical and spatial statistics, remote sensing, geographic information systems (GIS), hydrology, and soil science. Classical statistics is useful for dealing with the problems of data uncertainty, model discrimination, and model verification; whereas, spatial statistics is of value as a means of addressing the problems of spatial variability and spatial structure by modeling both spatial trend and spatial correlation. GIS serves as a means of storing, manipulating, and displaying the tremendous volumes of spatial data associated with NPS pollutants. Remote sensing is a potentially cost-effective means of measuring the physical, chemical, and biological parameters and input data needed by transient-state solute transport models. The water flow and solute transport models developed by soil scientists and subsurface hydrologists are the essential simulation tools used to assess potential temporal and spatial changes in the fate and movement of NPS pollutants within the vadose zone. Integrated methodologies combining all of these essential components are the key to modeling NPS pollutants.

It was the need for a multidisciplinary approach to the modeling of NPS pollutants in the vadose zone that led to the organization of the 1995 ASA-CSSA-SSSA Bouyoucos Conference entitled *Applications of GIS to the Modeling of Non-Point Source Pollutants in the Vadose Zone*. The stated objectives of the conference were to stimulate international interaction between the disciplines of spatial statistics, remote sensing, GIS, and solute transport modeling; to enhance the development of techniques for the assessment of non-point source pollutants in the vadose zone and in subsurface waters; to evaluate the viability of using a GIS-based multidisciplinary approach as a means of assessing the impact of agriculture upon groundwater quality; to promote interest in this newly developing area of applied research; and to explore the positive and negative aspects of the use of a geographic information system as a tool for NPS pollutant modeling.

CONFERENCE OVERVIEW

The 1995 ASA-CSSA-SSSA Bouyoucos Conference *Applications of GIS to the Modeling of Non-Point Source Pollutants in the Vadose Zone* was held in Riverside, CA, from 1-3 May. A total of 55 papers were presented during the three days of the conference consisting of 8 keynote, 9 invited, and 38 volunteered papers. The keynote and invited presenters were assigned topics to their papers with the explicit intention of providing the conference attendees with pertinent background and general information focusing upon the subdisciplines involved with the modeling of NPS pollutants in the vadose zone in a GIS context. Subsequent to the conference, 16 technical papers have been published in a Special Bouyoucos Conference Symposium Issue of the *Journal of*

Environmental Quality (May–June, 1996; Vol. 25, Number 3), and 18 papers are published in this SSSA Special Publication; however, an overview of selected conference papers from both publications that are felt to be worthy of discussion is presented in this preface.

The eight keynote presentations began with three papers covering the application of GIS as a tool for environmental modeling. Michael Goodchild focused on advanced information technologies useful in assessing environmental impacts including GIS, remote sensing and the global position system (GPS). Peter Burrough discussed the basic principles, advantages, and problems of (i) linking data and models, and (ii) linking models and GIS with particular attention paid to questions of uncertainty, spatial and temporal variation, scaling, model calibration, model validation, and error propagation. Jack Dangermond addressed current commercial applications of GIS to environmental impact analysis indicating a general trend by commercial vendors to develop GIS software that enables the user to customize the application specifically to their needs. The remaining keynote presentations dealt with geostatistics, deterministic and stochastic models of solute transport, the implementation of transport models into GIS, and scale dependency. Andre Journel expounded upon the utility of geostatistics as a means of drawing more useful information from samples at a limited number of points and identified the biggest challenge as facing up to the uncertainties involved with spatial data that become shrouded in definitive answers generated from maps and statistics that do not include probability maps to assess uncertainty. David Maidment outlined an eight step program of describing pollutant transport through the vadose zone and implementing it with GIS. Rien van Genuchten surveyed the current state of deterministic modeling of soil water flow and transport with an emphasis on the use of pedotransfer functions that can parameterize the movement of chemicals. Because Rien van Genuchten was unable to prepare a written manuscript for publication, Dennis Corwin prepared a paper that reviewed the current state of coupling deterministic solute transport models of the vadose zone to GIS from the perspective of the three components comprising GIS-based environmental models: data, GIS, and model. William Jury suggested the use of a stochastic-advective formulation (parallel soil columns) as the most compatible means of coupling a stochastic model of solute transport in the vadose zone to a GIS. The challenge of such an approach is the development of a local-scale model whose parameters can be related to identifiable local-scale features. Jeff Wagenet introduced the issue of scale and aggregation level in leaching models and suggested that there should not be one approach to modeling, but many, each linked to an appropriate combination of physical resolution and intent of the investigator. An understanding of the processes, and the spatial and temporal scales at which they operate is important before choosing to work with any given model to solve any given problem.

The invited papers were intended to provide reviews or specific examples of different aspects of the problems associated with modeling NPS pollution in the vadose zone including parameter and data measurement and estimation methods; sensitivity and uncertainty analysis; spatial variability and spatial structure effects on leaching; regional-scale databases; and the coupling of GIS and solute transport models. The specific topics included the use of NLEAP coupled to a

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GIS to identify and mitigate regional $\text{NO}_3\text{-N}$ (M. Shaffer); the spatial structure of solute transport variability in unsaturated field soil and its influence on parameter estimation and model discrimination (T. Ellsworth); the mapping of the areal distribution of soil organic carbon and sorption potential with electromagnetic induction (D. Jaynes); the estimation of soil hydraulic parameters for regional-scale applications of mechanistic models (D. Timlin); the significance of sensitivity analysis in regional-scale solute transport modeling (T. Addiscott); the use of soil survey data for modeling solute transport in the vadose zone (J. Bouma); the application of soil survey attribute data to GIS pollution transport, fate, and other resource assessment models (R. Nielsen and T. Sobecki); the impact of data uncertainty upon regional-scale leaching assessments of NPS pollutants (K. Loague); and the current state of subsurface modeling in the simulation of global environmental change (L. Steyaert).

The majority of volunteered papers consisted of demonstrations of coupled GIS and deterministic solute transport models. These models ranged from simple statistical regression models to more complex functional models to extremely sophisticated mechanistic models. Several case studies were presented that assessed regional-scale groundwater vulnerability to the leaching of pesticides, nitrates, radionuclides, and salts. Other topics included emerging trends and bottlenecks in coupling vadose zone models and GIS, the effect of input parameter and spatial resolution of data sources upon solute transport predictions, the problem of identifying spatial and temporal variability of soil factors that influence transport, geostatistical analysis of a soil salinity data set, and baseflow mapping as a means of ranking the relative potential for transmitting contaminants through the vadose zone into an aquifer.

The conference culminated with an open forum discussion that allowed the keynote speakers an opportunity to philosophically expound upon the positive and negative aspects for the use of GIS as a tool for NPS pollutant modeling. Both optimism and caution were expressed. The usefulness of applying GIS to the modeling of NPS pollutants was acknowledged with the caution that the users do not abuse the technology by using the sophisticated visualization capabilities of GIS to cloak the reliability of the simulated results so that non-technical decision makers are seduced into accepting the defined map units as absolute entities. As suggested by Loague (1994), associated maps of uncertainties need to accompany groundwater pollution vulnerability maps and soil pollution assessment maps to bring perspective to the risk associated with decision-based maps created from NPS pollution model simulations.

Acknowledgments

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Editors

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