TEACHING SOIL CONSERVATION AND NON-POINT SOURCE POLLUTION

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Abstract

Several non-point source pollution models have are used in the undergraduate and graduate teaching programs at the University of Guelph to simulate watershed behavior in southern Ontario. In particular, the simulation of soil conservation measures (e.g., conservation tillage, crop rotation, grassed waterways), and of various strategies for implementing such measures (e.g., random implementation over an area, targeted remediation) has greatly enhanced the learning environment. Examples of simulation exercises are presented and discussed from a teaching perspective.

Introduction

In recent years numerous soil conservation and agricultural non-point source (NPS) pollution simulation models have been developed, e.g. AGNPS (Young et al., 1985), ANSWERS (Beasley et al., 1980) and WEPP (Foster, 1987). As these models have become more convenient to use (i.e., user-friendly software has been developed for microcomputer applications, and the microcomputers themselves have acquired more storage and are faster), many are seen to be state-of-the-art tools for planning soil and water management systems, e.g. CREAMS (Knisel, 1980) and GAMES (Dickinson et al., 1987). Further, there has been considerable effort devoted to the review and evaluation of agricultural NPS models in an attempt to clarify their application strengths and weaknesses (Leavesley et al., 1988; Rose et al., 1988).

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The development and application of NPS models have coincided with the more broadly based advocacy for using computer software for teaching purposes. As a result, many of these simulation models are now presented in textbooks (Novotny and Chesters, 1981; Haan et al., 1982; Lal, 1988) and incorporated into classroom projects (Rudra et al., 1987a and 1987b; Dickinson et al., 1988).

Although the use of computer simulation models in the educational environment is a recent phenomenon, the classroom use of other types of simulation models is not new. Iconic models involving pipe networks, water flumes, soil erosion flumes and rainfall simulators have been used for demonstration and experimentation purposes for some time. Also physical and electrical analogs, e.g., the Hele-Shaw apparatus (Todd, 1954; Todd, 1955; and Marino, 1967) and resistance paper models (Luthin, 1952; Karplus, 1958; and Bouwer, 1962) have proven to be popular teaching aids. With the increased familiarity, popularity, and availability of digital microcomputers _ and with economic pressures on campuses leading to less physical laboratory space, time and equipment _ there has been a noticeable shift away from the more physically based simulation teaching devices to computer based models. The move to using NPS models in the classroom, therefore, can be viewed not so much as a change in philosophy of approach as a change in the means of taking

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thinking so students may attack the ill-structured problems they will face in real life, personally and professionally. Improving thinking skills may be a more important educational function than disseminating knowledge in the classroom.

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an approach to simulation.

In light of the developments and observations noted above, it seems appropriate now this time for educators to recall what a simulation model is, and to clarify the rationale for using NPS models for the teaching of soil conservation. These recollections provide a background for considering examples of two models presently used in courses at the University of Guelph.

Simulation Model

A simulation model is a simplified, integrated representation of a system that can reproduce some but not all of the particular aspects of behavior for which understanding or prediction is required. It also may be considered to mimic the dynamic behavior of a system over time; to be a surrogate of its real world prototype; or to be a caricature of nature, exaggerating or distorting selected features of the original system (yet not producing such a badly distorted likeness as to create absurd effects). An agricultural NPS simulation model provides a structure that interrelates facts and observations regarding rural fields and/or watersheds, focussing on the joint function of variables of concern at successive time steps for time varying inputs.

Classroom Use of NPS Models

There is now little question that agricultural NPS models have proven to be extremely useful as research tools and for management purposes (Seip and Botterweg, 1988; Leavesley et al., 1988; Rose et al., 1988). There has been less said about their use and usefulness in the classroom. However, it is now abundantly clear that the availability of detailed, well-structured, integrated non-point source models that are rapid, inexpensive and extremely versatile to use has provided a rich teaching and learning resource. These models serve to:

❶ integrate and clarify existing knowledge regarding soil conservation and agricultural NPS pollution. In a concise, well-structured fashion, they capture and record what we know.

❷ facilitate the acquisition of knowledge regarding fundamentals and the rural NPS system as a whole. Understanding is easiest to acquire in those areas where knowledge has been structured and well-organized. With a formal model, our mental image of the system is clearly exposed, allowing for a more coherent, orderly image to emerge. This clear mental mapping serves as a mnemonic device -- a means to structure, store and retrieve knowledge.

❸ enhance understanding of, and skill with, "state-of-the-art" technology with data management and model calibration runs. Exercises can be provided in data management, model calibration, model validation, sensitivity analysis etc. Students gain experience with the software and appreciation for problems of data assembly and processing.

❹ enhance understanding of the basic processes and how they combine with simulation runs. A simulation model provides insight into the nature of the system operation, and facilitates the construction of explanatory theories. Grasping the structure leads to learning about the fundamentals; and understanding the fundamentals makes the system more comprehensible, clearing the road to a more adequate transfer of principles.

❺ enhance understanding of interactions among processes with sensitivity analysis. The interdependence of variables and parameters is clarified and the problems associated with interdependence (i.e. model calibration and interpretation) are exposed. The models aid the development of a more complete understanding of the NPS system, including knowledge of significant processes and important information and data.

❻ enhance understanding of the accuracy of modeling with validation runs. The feasibility of modeling is revealed, along with the need for improvements. Strong and weak modeling components may be clarified.

❼ enhance understanding of possible impacts of remedial measures (and other system changes e.g. climate change) with predictive runs. The models provide a tool for experimentation, facilitating projections, allowing the screening of a large number of alternatives, and enabling students to move beyond the information given.

❽ enhance understanding of possible impacts of social factors such as policy decisions, economics, and adoption patterns in time and space with prediction runs. The models allow exploration and evaluation of not only specific remedial measures but also ramifications of the adoption of various implementation strategies. Such studies open the door to improved communication between students of different disciplines.

❾ enhance understanding of temporal and spatial patterns in inputs and outputs with simulation and prediction runs. The unaided human mind is not adequate for comprehending dynamic models that represent changes through time and space. Simulation models provide a much needed aid for such comprehension.

❿ provide a basis for critical review of the model and its applicability; and provide learning opportunities for students of diverse learning styles. Simulation models provide learning opportunities for the innovator, the concept and model creator, the practical applier of ideas, and the explorer and doer.

With this abundance of possible reasons for using NPS models in the classroom, it is not so much a question of "why" but rather "how" to use them to take advantage of the possibilities. The "how" is illustrated by the following soil conservation and NPS model examples presently used in the undergraduate and graduate student programs of the School of Engineering, University of Guelph.

USLE Tutorial

A tutorial program for estimation of soil losses by sheet and rill erosion (Cook et al., 1986) was developed to facilitate familiarization with basic concepts of sheet and rill erosion, and with alternative soil conservation practices and their effects. It is intended to be self-explanatory and user friendly; and no lengthy procedures need to be memorized before using the package as it is entirely menu driven.

The programs that make up the package include:

- ❑ Information on the Universal Soil Loss Equation,
- ❑ Information on Tolerable Soil Loss Levels,
- ❑ Information on Alternative Soil Management Practices,
- ❑ and, Calculation of Soil Loss from a Field.

The first three programs are tutorials designed to provide background information only and do not involve calculations. For example, the "Information on the USLE" tutorial provides information concerning the use of the USLE and the selection of its parameter values. Upon selection of a particular parameter (A, R, K, LS, C, P), screens of information are presented.

The fourth program allows the student to calculate an estimated annual soil loss for a set of user specified field conditions. Input to the program is by menus, and assistance in the selection of the USLE parameter values is provided on help screens. For example, when a value for the rainfall factor (R) is requested, it can be entered directly if known, or the student can call up a table or map of R values on help screens. Such screens have been developed for Ontario locations, but similar screens can be readily created for other regions. Input is quick and convenient, and the student has the option of correcting errors in input data. Successive trials can be run quickly for a site by changing only one or two parameter values and without re-entering all the input data.

The USLE Tutorial has been used in conjunction with undergraduate classes at Guelph with regard to exercises such as the following:

❶ **On the basis of your field measurements and the information programs provided with the tutorial, evaluate the USLE parameters for a range of soil and crop management conditions experienced on the Guelph soil erosion plots over their 30+ years of experiments. Estimate the average annual soil loss expected for each set of conditions selected, and compare your estimates with the tables of measured values provided. Discuss your results.**

❷ **Evaluate the USLE parameters and the estimated annual soil losses expected for a range of soil, slope, crop and climatic conditions found in southern Ontario. Compare the ranges of parameter values, the combinations of parameter values, and the soil loss estimates obtained with values in the literature. In light of these comparisons, comment on the nature and likely magnitude of the soil erosion situation in southern Ontario.**

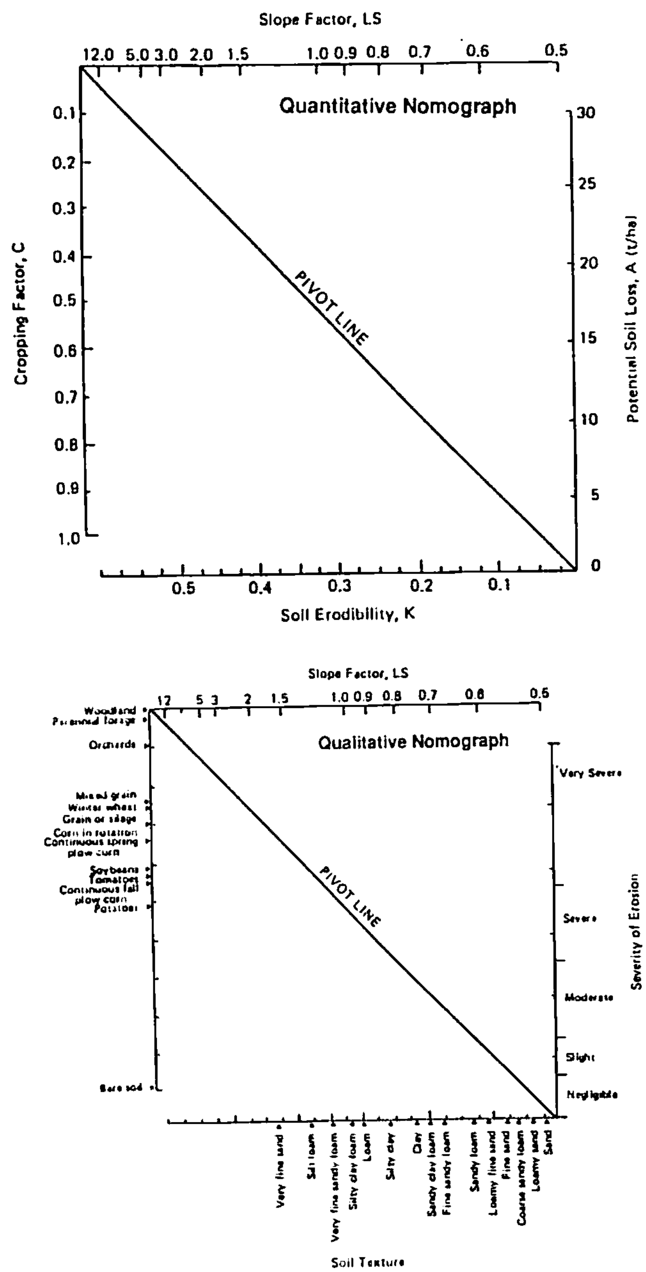
❸ **Consider typical current cropping and soil management scenarios to be found on cash crop farms in Kent and Essex Counties, for cash crop farms in Oxford County, and for mixed farms in Waterloo County. For each farming situation, estimate the expected average annual soil loss for the current conditions and for some alternative "better management practices". What kinds of management changes (if any) would you recommend for these three regions of the province? Justify your recommendations.**

GAMES

The Guelph model for evaluating the effects of Agricultural Management systems on Erosion and Sedimentation (Cook et al., 1985; Rudra et al., 1986; Dickinson et al., 1987) was developed to describe and predict soil loss from water erosion and subsequent delivery of sediment from field to stream and downstream in agricultural settings. The concept of GAMES involves the separation of a watershed into field size elements (irregular shaped if necessary) with homogeneous characteristics of land use, soil type and slope class. The model is normally applied on a seasonal time frame, to allow estimation of potential soil loss and delivery of sediment to vary from winter/spring to summer to fall/winter. In southern Ontario the corresponding, appropriate time intervals are February through May, June through September, and October through January. From the spatial and temporal units chosen, field source areas of erosion and/or fluvial sediment can be mapped seasonally.

Input data file construction is relatively simple and quick as the model is not overly encumbered with data requirements. Data files can be constructed using any convenient microcomputer wordprocessor or spreadsheet capable of generating ASCII files. Application of the model involves the development of a composite overlay of land use, soils, and slope to divide the watershed area into homogeneous land cells, each of which is characterized by a single land use, soil type, and slope class. Representative values of the soil loss and sediment delivery variables are then determined

Figure 1: Qualitative and quantitative USLE nomograph

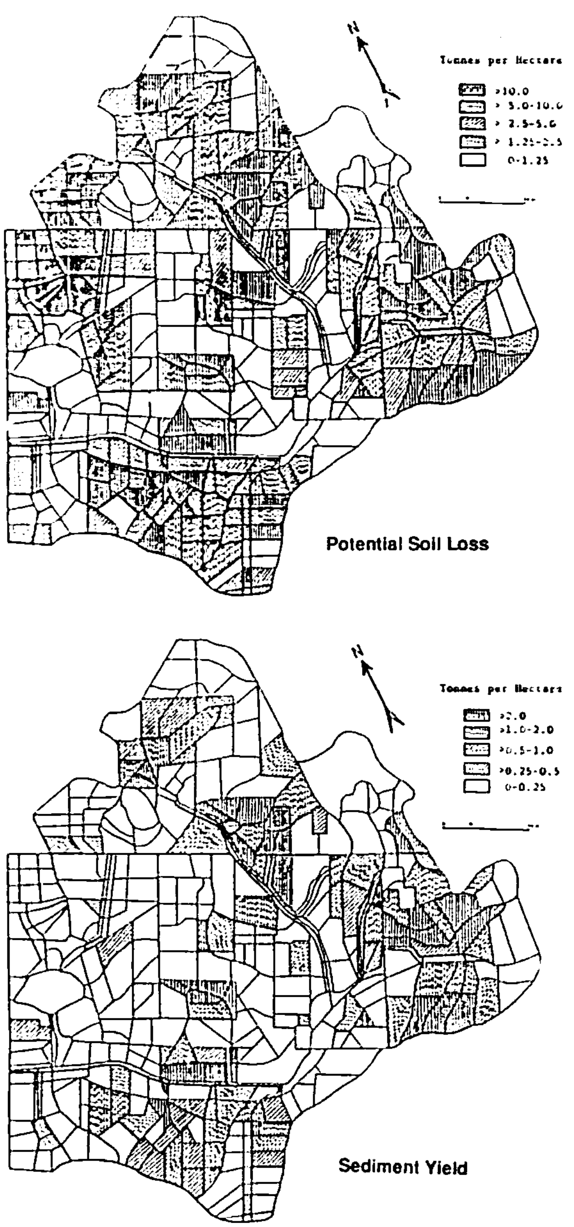


and assigned to each field cell, along with the cell area, across cell flow path length, and proximity to the nearest flowing stream. These initial data sets can be easily modified later for the exploration of soil conservation scenarios.

Calibration of the model involves optimization of just two delivery ratio parameters such that the accumulated watershed seasonal sediment loads estimated by GAMES compare favorable with measured or otherwise estimated loads.

Output is generated on a cell by cell basis for each season being considered, and includes potential soil loss, potential soil loss per hectare, delivery ratio to the adjacent downstream cell, delivery ratio to the nearest flowing stream, sediment yielded to the stream, and sediment yielded per hectare. The output is generally related to a disk file for storage, and editing of output files is readily accomplished by means of a microprocessor or spreadsheet package.

Figure 2: Spatial distribution of soil loss and sediment yield.



With the selection of soil loss and sediment yield tolerance levels, the program also provides for the identification of problem field areas in terms of four categories. Field cells that fall into Category I may be expected to exhibit average soil loss rates above the soil loss tolerance and sediment yield rates above the sediment yield tolerance level. Fields in Category II may be expected to have excessive soil erosion rates, but to yield little sediment downstream. Category III includes those areas expected to exhibit low soil loss rates but excessive sediment yields; and Category IV is the "no problem" category. The mapping of such problem categories provides an extremely valuable basis for the consideration of agricultural and/versus environmental objectives in a watershed.

The GAMES package has been used in Guelph courses, primarily at the graduate level. Exercises have been of the following sort:

❶ From the current maps and data provided, construct data files for running GAMES for either the Nissouri Creek Watershed or the Big Creek Watershed (half the class should select the Nissouri basin, the other half the Big basin), and calibrate the model for selected load data. Prepare output mappings of expected seasonal soil loss rates, seasonal delivery ratios to the stream, and sediment yield rates for the current land management practices in the watershed. Discuss the seasonal and spatial patterns determined, concerning to available seasonal sediment load measurements and results obtained by students exploring the other basin.

❷ You are advised that the sediment load leaving the basin that you are exploring is too large, and that it should be reduced by more than 30%. Since you have now had considerable experience with data relating to soil erosion and fluvial sedimentation in the watershed, your advice is sought regarding a recommended course of action. For example, should an education and/or financial incentive program be put in place to encourage farmers to implement remedial measures (at random) that might effect moderate or significant levels of control? _ or should a technical assistance program be put into place to target the most critical areas and assist farmers with the implementation of moderate or significant control measures? Explore a few possibilities bysimulating the sequential implementation of 1 or 2 levels of remediation on portions of your watershed, those portions being selected in specified ways (e.g. randomly, "worst first"). Discuss the results, and make (and justify) your recommendations.

Mapped and Graphed Output

It has been found that the preparation of mapped and graphed outputs as a part of the NPS simulation model exercises contributes greatly to the learning situation. (Figures 1 through 3 are included as examples of such outputs). This discovery should not be too surprising, since it has been known for some time that a large amount of information can be displayed and absorbed with graphical means. In fact, maps and graphs tend to show data sets as a whole, allowing us to summarize the general behavior and to study detail (Cleveland, 1985). They lead, therefore, to much more thorough data analysis and more insightful interpretations.

Concluding Comment

We have reasonably good simulation models relating to soil conservation and agricultural NPS pollution, and there is no question that they can be powerful teaching and learning tools. Now it is up to educators to give deliberate thought to learning objectives, and to discover exciting ways in which the models can be used to achieve these objectives.

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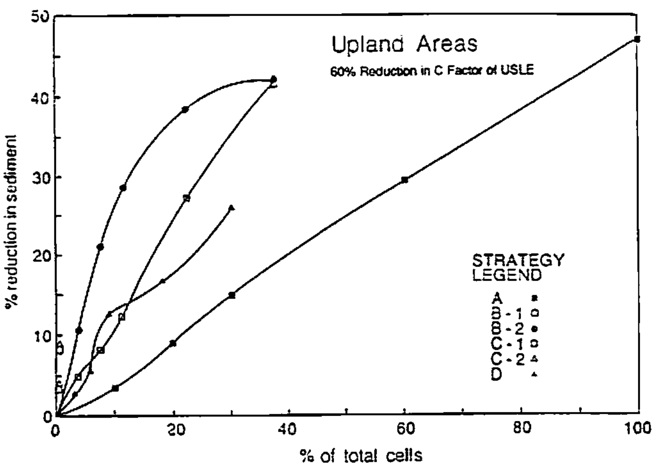
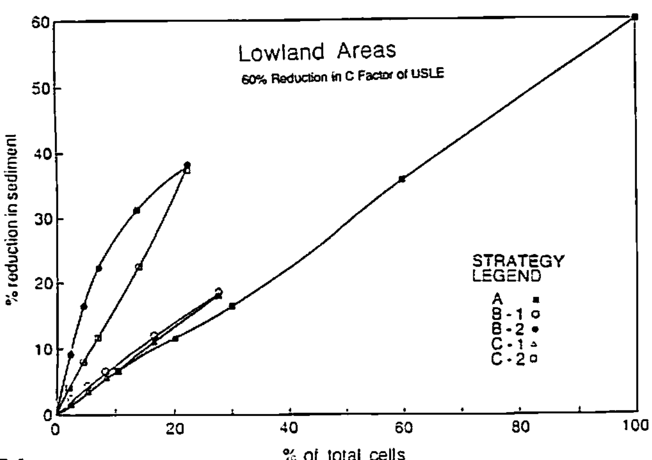
Figure 3: Reduction in sediment yield byt adopting significant changes in cropping pattern in upland and lowland areas.





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