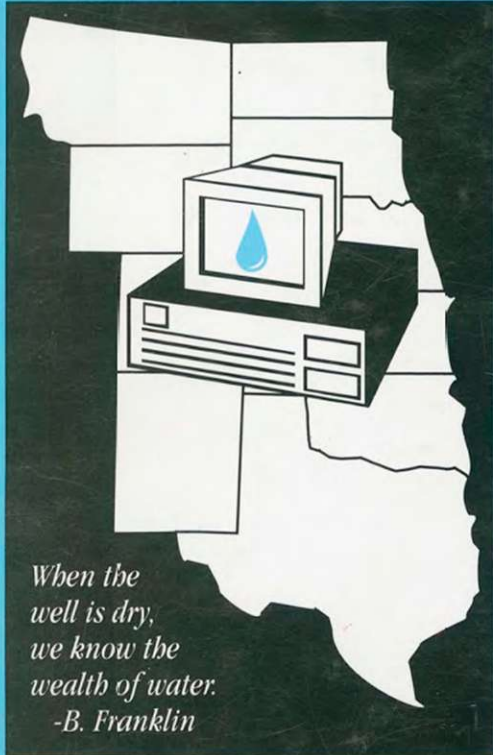# PROCEEDINGS

When the
well is dry,
we know the
wealth of water.
-B. Franklin

WORKSHOP ON COMPUTER APPLICATIONS IN WATER MANAGEMENT

May 23-25, 1995
Fort Collins, Colorado

Sponsored by:
Great Plains Agricultural Council
USDA, NCRS and ARS
Colorado State University,
 Department of Soil and Crop Sciences
 and Water Resources Research Institute
University of Wyoming,
 Cooperative Extension Service
 and Water Resources Center
University of Nebraska,
 Water Resources Center

COLORADO WATER RESOURCES RESEARCH INSTITUTE

Information Series No. 79

GPAC Publication No. 154

WORKSHOP ON

COMPUTER APPLICATIONS IN

WATER MANAGEMENT

Proceedings of the 1995 Workshop
May 23-25, 1995
Colorado State University
Fort Collins, CO

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PREFACE

The Great Plains Agricultural Council (GPAC) is an organization made up of the Land Grant Universities in the Great Plains States and the GPAC member USDA Agencies. The GPAC provides information on problems and issues relating to agriculture, resource use, and rural development in the Great Plains region.

Responding to a 1992 recommendation from its Water Committee, the GPAC Executive Committee approved the formation of a Task Force on Computer Applications in Water Management. For this Task Force, we are pleased to have the participation of the Bureau of Reclamation, USDI as well. The Task Force was organized in the spring of 1993 to plan and conduct a workshop which would provide a forum for model developers and users to discuss successes and failures of computer-based tools in water management. The Executive Committee charged the task force to:

- Identify specific needs of water quantity and quality managers that can most appropriately be met with computer simulation models.
- Identify specific computer simulation models or other appropriate methodologies which are actually used or have the immediate potential for use by water managers.
- Develop a subject matter scope for the workshop.
- Identify groups of computer simulation model developers and users, especially within state agencies, who would benefit from the workshop.
- Identify potential members and provide guidance for program and editorial committees to be charged with siting, program development and conduct of the workshop, and production of the proceedings.

At the initial meeting of the Task Force, it became apparent that computer-based data and information systems must be an integral part of the workshop. These systems were added to the subjects to be addressed by the workshop. At the second meeting of the Task Force, the purpose of the Workshop was formulated as:

The purpose of the Workshop is to familiarize State and Local mid-level water resource managers in the Great Plains with computer models, information exchange networks, and computer-assisted automation technology, available for the analysis and solution of complex water quantity and water quality issues. While examples will relate to Great Plains water management issues, the Workshop will also be of interest to water managers from other regions. The focus will be on illustrating the use and limitations of a variety of computer models related to water quantity and quality management by way of four or five test cases. The Workshop will bring together model developers and potential users in state and local applications to exchange user needs and potential methods of issue resolution.

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The Workshop has been organized around applications of:

-- Information Technology
-- River Basin Scale Models
-- Watershed Scale Models
-- Field Scale Models

and supported by:

-- A General Session
-- Poster and Computer Demonstrations
-- Commercial Exhibits

On behalf of the Great Plains Agricultural Council and the Task Force organizing the Workshop, we hope you find the proceedings of this Workshop to be useful in your efforts to serve the people involved with water management.

Lajpat R. Ahuja
USDA-ARS
Task Force Chair

Duane L. Johnson
USDA-NRCS
Task Force Administrative Advisor

Melvin D. Skold
Colorado State University
GPAC Executive Director

CONFERENCE ORGANIZING COMMITTEE

The members of the Task Force and their responsibilities for organizing this Workshop are:

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MODEL SELECTION AND USE - INCREASING THE CHANCES FOR SUCCESS: DEVELOPER'S VIEWPOINT

D. L. Nofziger[1]

ABSTRACT

Computer models have been developed to assist decision-makers manage and protect our water resources. Those models provide one method of extending experimental findings to new locations, chemicals, and management systems. However, the decision-maker and model user have a major role in selecting, using, and interpreting model results. Guidelines are presented for the use of models as a decision aid. Those begin with having a clear understanding of the information desired and the processes deemed important. Other points include recognizing that models incorporate simplifications of reality and provide different outputs. Model selection must match processes, simplifications, output requirements, scale of time and space, available input data and computer resources to the needs of the decision-maker. The user must incorporate issues related to non-uniformity and uncertainty in model inputs along with model sensitivity into decisions based on model output. Models can be useful, but they must be used with care.

INTRODUCTION

A model is a representation of an object, process, or collection of objects and processes which is useful for a specific purpose. Many forms of models exist. For example, we have physical models of trains, cars, people, houses, cities, aquifers, the world, and the solar system. We also have conceptual models of molecular structure, our nervous system, and simple and complex biological, physical, and chemical processes and systems. Scientists formulate statistical models summarizing and interpreting data as well as mathematical models for describing processes of interest. Sometimes the mathematical models are simple enough to be used with only a pencil or calculator, but many models require computers to perform the calculations or to present the results in a form we can use.

In this conference, we will focus on computer models relating to management and protection of our water resources. In this context, the computer models can be sources of information as we make decisions. Making informed decisions requires (1) a clear understanding of the decision to be made, (2) identifying important issues involved, (3) finding sources of information dealing with these issues, (4) collecting information, and (5) critically examining and assimilating the information as it relates to the decision at hand. We often

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need to repeat some of these steps based on information gained in the process. These steps are required whether or not we use models. In fact, models serve primarily in step 4. So although models can be a great source of information, they constitute only part of one step in the decision-making process. We decision-makers still carry most of the responsibility. By recognizing this, we greatly increase our chances of making wise use of models. In this presentation, I will present concepts which we must keep in mind as we use computer models as decision aids.

MODEL SELECTION

Models are developed for specific purposes and evaluated for that purpose. They always involve simplifications of the real systems. When the simplifications incorporated into a model are consistent with the purpose of the model, the usefulness of the model is enhanced because we can focus on the most important aspects of the system. However, because the model developer made the simplifications with a specific purpose in mind, we must be certain our use of the model is consistent with that purpose. Model developers have a major responsibility to inform users of the purpose and limitations of the model. Model users must examine this information in light of the information desired. If documentation of this type is not available, I would search for another model.

A review of literature is often useful when selecting models. This review can provide insight into how specific models have been used, what was simulated and under what conditions, and how the model output compared with experimental measurements. Publications such as Pennell et al (1990) and Bergström and Jarvis (1994) provide comparisons of predictions from several models with experimental measurements. Those comparisons provide a measure of the ability of a model to duplicate experimental results for the specific conditions used. The literature review can provide an assessment of the ability of any of the models to match experimental measurements. In addition, measurements at different sites and for different years, provide insight into the natural variability of the processes. All of this information is useful in choosing appropriate models and interpreting results.

Many models for estimating water quality or water use are process oriented. That is, scientists have studied the physical, chemical, and biological processes involved in these systems and have formulated mathematical models of each component. The computer model developer combines selected component models to form the larger model of the entire system.

Models do not include all processes known to be active in the large system. So a model user will want to be aware of the processes included in the composite model. If specific processes believed to be important are omitted, a different model may need to be used or the results interpreted in light of this limitation. For example, if I am concerned about the impact of a benzene spill upon ground water quality and the model I am considering does not incorporate

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loss of chemical by volatilization, that model will likely overestimate leaching. If the chemical of concern had been one with little tendency to vaporize, omitting that component could have been insignificant.

The quantities computed and the way they are displayed differ from model to model. This means we must make certain the model produces output which we can use in the decision-making process. Related to that is the scale of time and space which is of interest. For example, the model may calculate the flux and concentration of sediment entering a stream or the flux and concentration of a pesticide entering the ground water. Does the decision being made require this information every second or are we interested in average values over time periods of days, weeks, months, or years? Similar questions must be addressed in terms of space. Are point or areal averages of interest? We must select a model capable of providing the output of interest at the scales of interest.

The selection of a model must incorporate the data requirements of it. Good data are needed for good predictions using any model. Models require different numbers and types of parameters. When possible, the models should be selected to meet the current purpose and then the parameters obtained. In many cases, budgets, time, and expertise prevent experimental measurement of these properties so only known properties can be used. These limited data may restrict the choice of model.

A final item to consider is the amount of computer resources required to carry out the simulations. Detailed models which incorporate many processes and provide great detail at small time intervals can require large computing power when used to simulate large times. Two and three dimensional models require even larger computer resources. Computing times for flow and transport models can be as low as a few seconds per year simulated or as high as many days. These considerations can be very important when we incorporate soil variability and parameter uncertainty into the analysis.

MODEL USE

Using models as a source of information for making decisions is different than using a reference book in that we users have a great deal of control over what comes out. Since models require input parameters, we model users must make wise choices for those to get meaningful output. High quality input data are needed to get reliable model output. Those data will likely need to be gathered experimentally. Soil data stored in national databases will probably not be adequate for site specific modeling of water flow and chemical transport. However, that will depend upon the decision to be made and the sensitivity of the output to the parameters.

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Sensitivity: Soil, chemical, site, and environmental properties are rarely known with certainty so values we enter into models contain some error. It is important to know the impact of this uncertainty upon the output which is of interest to us. The change in model output resulting from a specific change in an input parameter is known as the sensitivity for that parameter. Knowledge of this sensitivity is useful in determining the quality of input data required in the model. The sensitivity can be determined by making simulations with different values for the parameter of interest and observing the change in output. By carrying out these simulations for the expected range of each parameter, we can gain insight into the impact of uncertainty in each parameter upon the quality of the model output. If we will be experimentally measuring the parameters, this can help us decide how accurately we must measure each one.

Non-Uniformity: Many times we need to model flow and transport in non-uniform regions. These non-uniformities may arise from soil variability over space and depth. Jury (1986) summarizes the extent of these differences reported in the literature. A common approach for incorporating non-uniformity in soil properties into the analysis is to find a set of parameters which can be used in the model to provide one set of results which are assumed to apply to the entire area of interest. Usually these inputs are mean values for the parameters in the area. A second approach is to make simulations using soil properties from different sites in the area of interest and to combine the model outputs to get the value for the entire region. Since most models of flow and transport are not linear, the two methods will not give identical results. I urge model users to use the second approach for two reasons. First, the averaging is done on the model output of interest. Second, the results for the different sites provides the user with information on the range of behaviors expected in the area. Knowledge of that range in output may be important when making decisions.

Weather: Weather is an important component in many water management models. It is often highly variable at a site. For some purposes, average annual values can be used so daily and seasonal variations are not important. In other cases, the daily (or even hourly) distribution is critical. Haan et al (1994) have shown that uncertainty in future weather can have large impacts upon chemical leaching. One way to deal with that is to make many simulations for different weather records. We can then think in terms of the probability of some condition being satisfied, recognizing that in any given year, it may or may not be satisfied. Nofziger and Hornsby (1994) have incorporated this capability into CMLS94.

MODEL OUTPUT EVALUATION

Once model output is available, it must be examined carefully. If any results are unexpected, they should be examined further. Were the parameters used in the model the values we intended to use? Can we see how this surprise came about by examining the model of the system we have in our mind? What process in the model could have produced this result? Could it arise from bad data or estimated input parameters? Would any assumptions made in the model produce this result? If we cannot resolve the issue, we will likely want to discuss

the situation with the model developer or another knowledgeable person. If this part of the information is critical to the decision, I would recommend that the analysis be carried out with an additional model.

If the results seem reasonable in light of other knowledge and literature, these findings can be assimilated into the decision making process. It is important that the knowledge gained about model limitations and assumptions and parameter sensitivity and variability be used in the assimilation process as well.

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MODEL SELECTION AND USE - INCREASING THE CHANCES FOR SUCCESS - A USER'S VIEWPOINT

Barbara M. Vining and Mary K. Brodahl[1]

ABSTRACT

Models have moved from the research arena into private, state and federal sectors. As decision-making tools they are being used to analyze current federal and state legislation constraints on the economy and environment and to assist producers in making decisions on issues such as environmental benefits and the accompanying costs. Successful model application depends on good model documentation and support imparting an understanding of the system being simulated and the technology used in the simulation; an understanding of how to get appropriate data; the user's ability to comprehend and interpret model output; and an understanding of how the model can be used as a decision-making tool.

INTRODUCTION

As we approach the next millennium, the public is demanding more decision-making tools. That is, the public wants to know more about the risks of certain practices or management decisions. These probabilities may be tied into human health risks or strictly economic decision-making processes. Nevertheless, we are at a crossroads where computer models are no longer only research tools. Instead, policies are being evaluated and even written with the outcomes of "what if" scenarios that are being input into many of the environmental models.

Models have come off the research bench and into state and federal agency hands for analyzing current federal and state legislation constraints on the economy and environment. Private consulting firms are using models to assist their clients in making decisions on issues such as what environmental benefits might be gained by instituting various measures and analyzing the costs that goes along with those measures. The key issue at stake is who will provide the support for data input, appropriate application of the model and proper interpretations of the output.

Successful model selection and use depends on good model documentation and support which imparts an understanding of the system being simulated and the model technology used to do this; an understanding of how to get appropriate data for implementing the model; user ability

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to comprehend and interpret model output; and, importantly, an understanding of how the model can be used to address "real life" issues. We will expand on these in the rest of the presentation.

MODEL DOCUMENTATION

Many users of software go to their local bookstore to look for simplified documentation about software that they are learning to use. "MS Word for Dummies" might be a typical title that sells well. Why is it that documentation that comes along with the software is not always consulted? And why would people want to purchase extra documentation above the cost of the original software? The message is the same one that should be understood by model developers. Many users of computer models are looking for a decision-making tool or a bridge to the decision-making process. They want something that is easy to read, that is thorough and which can assist them them in being able to intelligibly use the model for its appropriate uses. Case studies or examples of short runs of the model applied to real situations are perhaps the best instructional tools. Think of how we learn math. Most math text books start out with examples of the situation or theorem that is being studied. Several problems are solved for the student before he or she is asked to solve problems on their own. There is a foundation that must be laid and built on to achieve a firm understanding. Computer model use requires these same steps.

Documentation goes beyond user manuals. It is a major component of the user-model interface design. The interface's organization of data entry, simulation summaries and other information presented to the user can facilitate an understanding of the data requirements, simulations, and interpretation of model output.

THEORIES AND RESEARCH SUPPORTING MODEL

How many of us would believe that we could understand differential calculus without having first understood limits, derivatives or integrals? Likewise, model users range from the expert university user who requires a model to describe or study a situation to a novice user, who needs a model to make decisions regarding appropriate nutrient and pesticide management for a farmer that does not pose a large risk to ground or surface water quality.

The foundation of understanding the model begins with the underlying theories and research that support the model. Instruction from cited literature coupled with a discussion of the appropriateness of algorithms chosen for the model build an understanding of how the models will work in different scenarios.

DATA REQUIRMENTS

Many developers of models may include an initial database for soils and climate for the state that the user lives in but they may not teach or document where to go to get data and how to get measurements off the land. Without actual flight training, ground school does no good to develop skills of a pilot. Without actual data gathering experience in the field, documentation doesn't develop data gathering skills.

INTERPRETATION OF MODEL OUTPUT

Interpretation of computer model output is a general weakness in most documentation and in most workshops on computer models. Users need to discuss and understand when models are more appropriate for relative difference comparisons and where some success has been gained in using actual output. Users may need to be taught appropriate statistical analyses of output. Model developers could indicate what statistical approaches are applicable to the output in their model documentation .

MODEL APPLICATION: INNOVATIVE USES OF MODELS

Although it is important to know whether or not a model is a point model or a watershed model or something else, this should not stop a user from exploring new uses of a model, while keeping in mind restrictions that influence the interpretation of the output.

An example of a successful adaption of a point tool to a regional scale was the use of SEEPPAGE (A System for the Early Evaluation of the Pollution Potential of Agricultural Groundwater Environments; USDA-SCS, 1988) for developing ground water site sensitivity maps for the 15 county Mid-Nebraska Demonstration Project. Project workers wanted a tool which could give them an idea of the variation in ground water site sensitivity to nitrates throughout the 15 county project. The soil mapping unit was chosen as the "site." SEEPPAGE site index numbers coupled with coarse knowledge of irrigated vs. dryland cropping were reasonably related to detections and concentrations of nitrate identified by monitoring data. A tool such as this GIS application of SEEPPAGE can be used to help identify potential areas of high ground water contamination.

MODEL APPLICATION: DECISION-MAKING TOOLS

The model as a decision-making tool is an emerging concept that has thrust modelling from the role of studying processes to giving people tools to make decisions. Whose role is it, then, to take these models and turn them into decision-making tools? The answer may not be the same for every model that has been developed. Model developers could assure appropriate uses of models if they engage in an on-going dialogue with model users and

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develop innovative means of communicating model applications to the user. If the developer asks "what questions are the users trying to answer?", then, he or she can provide some initial guidelines for appropriate use. In the end, the greater the need for decision-making tools, the more the user will look for innovative ways of utilizing tools that are currently available or will seek out other tools.

Adaptations of models range from the development of site sensitivity maps using SEEPPAGE to using NAPRA (National Agricultural Pesticide Risk Analysis; USDA-SCS, 1993), which incorporates GLEAMS (Groundwater Loading Effects of Agricultural Management Systems; Leonard et al., 1987), as a risk assessment tool. The NLEAP (Nitrogen Leaching Economics Analysis Package) model was used in Weld County, Colorado in conjunction with ground-water monitoring data (Wylie et al., 1994). This very application is readily applicable to states like Nebraska, particularly where the vadose zone material is somewhat homogeneous as in sands over shallow aquifers.

A question, then, is what is the most effective means of communicating to decision-makers the successes of innovative applications of computer models. How would Nebraska state agency employees or even federal employees in Nebraska know that the NLEAP application in Weld County might work for them along the Platte River and other places in the state? How do we ensure that information about successful applications is available to decision-makers when they are trying to identify the appropriate approaches for answering their questions?

Should the developer have a one-page executive summary or fact sheet on each application of their model in the event they receive a call they could send it immediately? Should decision-makers search the literature to find documents that probably don't exist? Who will be the keeper of the information?

The answer is through partnerships that rely on continual dialogue. Partnerships based based on mutual interests in answering environmental and economic questions require periodic communication among partners. Successful communication avenues include meetings, newsletters from the modelers, surveys to the users, computer bulletin boards, etc. The main point is that communication occurs and that it does so with regularity. The model user needs access to someone or some communication conduit to express his or her needs.

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MODELS AND DECISION MAKING IN UNCERTAIN ENVIRONMENTS

C. T. Haan[1]

ABSTRACT

The natural environment is uncertain and heterogeneous. Most environmental models are deterministic and treat heterogeneity as an aggregation of homogeneous units. We know future weather, which will be a major forcing function for water and water quality events, only in a stochastic sense. This paper discusses the treatment of these sources of uncertainty in a modeling effort. Other topics discussed in the paper are: the impact of uncertainty in knowledge of model input parameters on model predictions; estimating confidence limits on model predictions without observed data on model responses; interpretation of model results based on future and thus uncertain weather; and the interaction between scale, spatial variability and uncertainty. A basic thrust running throughout the presentation is an emphasis on the difference in the use of models in situations where observed data on quantities predicted by models exists and where such data do not exist. The later case is much more prevalent in the user arena and the former in the research arena. Model accuracy shown in the research arena is not directly transferable to the user arena. Space does not allow a thorough coverage of these topics in this brief written version of the presentation.
Keywords: Models, Hydrology, Uncertainty, Decisions

INTRODUCTION

In the space allocated for this written presentation, only briefly mention can be made of what will be covered in the detail during the General Session of the Workshop. My topic is very broad requiring a discussion of models, decision making, uncertainty and environments. Thus all of the words in the title are key words. They are also words that everyone is familiar with and everyone understands. Unfortunately, the understanding generally varies from individual to individual making it necessary to define the terms as I will be using them. Again space limitations preclude exhaustive treatments of the terms.

After defining the terms, I will discuss how these elements come together to challenge the model developer, the model user and the decision maker. Recognizing uncertainty incorporates an element of intellectual honesty into a modeling effort that might otherwise be missing. It adds realism to the decision making process in that decisions are always made in uncertain environments. It also shifts some responsibility for decisions from the model to the decision maker - the point where this responsibility should lie. Ultimately all decisions are

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made in the political arena. Hydrologic models provide information to this arena as do economic and social analyses. Hydrologic models can help us in understanding what will happen in the physical world if we adopt a certain decision strategy - they cannot tell us, independent of political, social and economic considerations, what decision strategy to adopt.

MODELS

Hydrologic/Water Quality (H/WQ) models may be defined as:

> "A collection of physical laws and empirical observations written in mathematical terms and combined in a way that produces a set of results (outputs) based on a set of known and/or assumed conditions (inputs)."

Models may be physically based, conceptual or correlative. Regardless of how models are classified, they can be represented as

$$O = f (I , P , t) + e \tag{1}$$

where O represents the H/WQ responses, f represents a collection of functional relationships (composing the model), I represents model inputs, P represents the parameters of the model, t is time, e represents errors in the estimation of O. In general there may be n observations (data points) to model using several model inputs and producing several model outputs or responses. Model responses may be runoff, sediment concentration, nitrate or phosphorus concentration, and/or other quantities of interest. The classification as to type of model is dependent on the nature of f. The distinction between inputs and parameters may not be clear in all cases. For our purposes clarity on this point is not required. I generally think of inputs as those quantities that are essentially independent of the model and include rainfall, temperature and other driving functions. Parameters are quantities that must be estimated for the model to function. The parameters are dependent on the specific site that is being modeled. Procedures for determining the parameters are very much a function of the type of model and data availability.

UNCERTAINTY

Sources of uncertainty in the modeling process include the algorithms used to represent the various processes being modeled, the parameters used to specify the particular physical setting under study, the environmental conditions (i.e., land use and weather) that exist during the period of interest, and the observations (if any) used in tailoring the model for the application. One of the major differences between the use of models in research and practice is the availability of data. Research settings generally are selected because of the availability of data or a data collection program is initiated. These data includes data on the response variables being modeled. Most practical applications of models are made in situations where there is a general lack of data, especially data on the response variable.

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If observed data are available on the response variables of interest, model parameters can be adjusted to improve the match between predictions and observations. Without these observed data, parameters must be estimated based on experience with the model in other settings. This, of course, introduces considerable uncertainty in that one does not have a very satisfying measure of the model's performance in the setting of interest.

One of the first things that must be done in evaluating the effect of parameter uncertainty is to conduct a sensitivity analysis on the model outputs with respect to each parameter of interest. If a model response is not sensitive to a particular model parameter, uncertainty in that parameter would be of little concern since the model response would change little over a range of values of the input parameter. Sensitivity analyses may be done using either absolute or relative sensitivity coefficients.

Uncertainty in model parameters can be summarized as probability density functions (pdfs). One, two or three parameter distributions might be used. Generally the scarcity of data available for distribution selection and parameter estimation precludes the use of pdfs with more than two parameters. H/WQ models will not accept pdfs of model parameters. Single values or point estimates are used. Single or point estimates of responses are produced. One way to introduce parameter uncertainty into a model is via Monte Carlo Simulation (MCS). In MCS parameter pdfs are sampled and the resulting set of parameters used in the model to produce a single estimate of model response. By repeating the process many times, many possible model responses are produced. These model responses can be analyzed probabilistically (using pdfs) and confidence intervals on the responses found based on the output pdfs.

A second method of evaluating the uncertainty in model outputs is with First Order Analysis (FOA) to estimate the variance of model outputs. The variance of outputs found through FOA is a function of the variance of the model parameters and the sensitivity of the model output to the parameters in question. The validity of a FOA is dependent on the variability in the model parameters and the linearity of the model with respect to the parameters.

Regardless of whether MCS or FOA is used, any significant correlations among the model parameters must be preserved. If parameters tend to vary together in some joint manner, then this joint behavior must be incorporated into the analysis.

For weather uncertainty caused by the natural stochastic behavior of weather, many individual and equally likely weather sequences can be used in the model. Each weather sequence will produce an output or an output sequence. The entire collection or ensemble of outputs can then be analyzed to find the probability of some predetermined output.

Distributed parameter models are especially challenging in that there is generally not a unique set of model parameters that will produce a given model response. There are often several parameter sets that will yield the same or very nearly the same model responses. This is generally caused by the large number of parameters that must be estimated and the very

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limited information on which to select among all of the possible parameter sets. It would not be unusual to have a distributed model requiring 20 parameters for each individual cell applied to a watershed having 50 cells. The net result is the need to estimate 1000 parameter values! Likely only a few observations of model response are available making the number of unknown parameters far greater than the number of known conditions.

DECISIONS

If one has bought into this idea of uncertainty and probability distributions of model outputs, one can quickly grasp the difficulty of making environmental management decisions. A particular management decision does not result in a single environmental response to be realized year after year but a whole range of responses to which probabilities can be attached. Hydrologists and flood control specialists have recognized this for years in the design criteria they use based on the probability of a more severe flood. This is stated in terms of a return period the reciprocal of which is a probability.

A flood control effort is not designed to control all possible flooding. It is designed to control flooding up to certain level of probability of being exceeded - typically 0.10, 0.05 or 0.01 or even smaller. These probabilities translate into return periods of 10, 20, and 100 years, respectively. It is implicitly recognized that no matter how large a flood control project is, there is a finite probability that the project design will be exceeded. Generally this probability decreases as the size of the project and consequently the cost increases.

These same ideas have a role to play in environmental protection. Do we want to regulate chemicals and waste management systems so that there is no possibility of any contaminants getting into surface or ground water? If so that implies that we want a probability of zero of a pollutant entering the hydrologic cycle - a probability that may only be achieved by a complete ban in the case of field applied pesticides and nutrients! If we adopt this mentality, we don't need models. Models properly used over the entire range of potential weather and management practices in most physical settings will predict a finite probability, maybe extremely low, of some contaminant entering the hydrologic cycle. Long term monitoring programs with the proper instrumentation will show the same thing.

What we need are enlightened decision makers and environmentalists that understand the above ideas and can adopt regulatory policies in their light. After all, the very same ideas apply to undisturbed, natural systems. The nutrients and sediments contributed to hydrologic systems because of agricultural practices are also contributed naturally. Indeed our lakes and streams would be very sterile without them. We are approaching the point where, as modelers, we can provide probabilistic estimates to decision makers. The challenge is to incorporate into environmental policies a recognition of the stochastic behavior of natural systems.

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RESERVOIR AND RIVER SYSTEM MODELS

G. L Aycock, E. Eberaert, A. Mackichan, N. Parker, M. Brewer, D. Frevert, and D. King[1]

ABSTRACT

Reservoir and river system models are very useful in assisting with water management issues on larger scale systems such as river basin. This paper provides an overview of several different models that can be used for managing single or multiple reservoirs within a river basin. Five models are discussed comparing their strengths and weaknesses (ROMS, CALIDAD, HYDROSS, MODSIM and PRSYM). The ability to balance water use between agriculture, municipal, industrial, recreation, fish and wildlife, and other competing needs is an important benefit that can be gained from use of reservoir and river system models.

A case study is also presented for the Rapid Creek Basin located in South Dakota. The River Operations Modeling System (ROMS) was used to assist with reservoir and river operating decisions and to evaluate the allocation of stored water between the various beneficiaries of this Unit. The model is also assisting with the negotiation process necessary for renewing storage contracts between the Bureau of Reclamation (Reclamation), Rapid City, and the Rapid Valley Water Conservancy District (RVWCD).

RAPID CREEK CASE STUDY

Brief Description/Purpose: Deerfield and Pactola reservoirs are part of the Bureau of Reclamation's Rapid Valley Unit located in the Black Hills in western South Dakota. Deerfield Reservoir is located on Castle Creek, a tributary of Rapid Creek and Pactola Reservoir is located downstream on Rapid Creek (see Figure 1, System Diagram). These two reservoirs furnish a supplemental irrigation supply to about 8,900 acres in the RVWCD and also furnish a portion of the municipal supply for Rapid City and the Ellsworth Air Force Base. These reservoirs also provide water to maintain desired fishery flows in Castle Creek and Rapid Creek and provide significant flat water recreation for the area.

The existing water service contract for water supplies from Pactola Reservoir between Reclamation and Rapid City was up for renewal in October, 1992. The water service contract for RVWCD from Pactola is not scheduled for renewal until the year 2000. However, RVWCD is a party to these contract negotiations because they also have an opportunity to negotiate a new contract at this time. Rapid City and RVWCD have expressed an interest in changing from a water service contract to a water storage contract. Reclamation supports this change as a water storage contract enhances water conservation as each entity manages a

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storage pool of water versus using preset contracted amounts of water with no benefit from conservation efforts on individual carryover storage. Instream flows for fishery habitat are also a concern.

The ROMS Model for the Rapid Creek Basin was developed to assist with reservoir and river operating decisions and to evaluate the allocation of stored water for the various beneficiaries of this project to negotiate the proposed water storage contract between Reclamation, Rapid City, and RVWCD. The model allocates both native flow based on water right priorities and stored project water based on contractual rights and reservoir and river operating criteria. The model is also used to develop operating plans based on forecasted water supplies and expected operational needs.

Overview of Model: This is an interactive model which allows the users to quickly change a number of operating parameters and input values though a series of user friendly menus. The user can then evaluate the effect of certain changes in operating criteria or water demands. The model first operates the physical system, then determines the storage ownership accounts. Ownership computations are done after the fact, and do not constrain the physical operations.

The model examines the reach gains and demands below Pactola to determine the required Pactola release for each month. The model then looks at the Deerfield inflow, and determines the total release necessary to meet the target reservoir content and provide minimum fishery flows. The model next looks at Pactola and uses the water demands, the Deerfield-Pactola gain, and the Deerfield release to determine the end-of-period content and any need to release surplus water. Pactola demands are based on water needs adjusted for accretions below Pactola Dam and fishery needs.

Hands on Operation of Model: The model operates on a IBM compatible Personal Computer (PC) using the Windows operating platform and a Windows compatible spreadsheet software package such as Quattro Pro or Excel. The model can also be run on a Laptop PC which allows hands on interactive use with the various water users.

Hydrologic Analysis: The original proposed reservoir allocations for Pactola Reservoir (total active capacity of 55,000 acre-feet (A.F.)) for a new repayment contract were:
Rapid City 35,000 A.F.; RVWCD 16,000 A.F.; and Fishery 4,000 A.F.

Model runs were conducted utilizing these pool allocations and the results were presented to Rapid City and RVWCD. The firm yield for RVWCD from storage water from Deerfield and Pactola Reservoirs and their native inflow rights was 16,200 A.F. This provides RVWCD with a full irrigation supply of 1.8 A.F./acre to irrigate approximately 8,900 acres. The fishery pool of 4,000 A.F. was proposed by Rapid City to meet the instream flow requirements for fishery habitat below Pactola Reservoir. Minimum flows in Rapid Creek would be in the 12.5 to 20 cubic-feet-per second range to protect the creek's fisheries.

Rapid City has stated that, as the city grows, irrigated land will be purchased and taken out of production. RVWCD has now accepted that as Rapid City expands, irrigated land within the District boundaries will be taken out of production for municipal development. The storage accounts currently proposed in the basis for contract negotiation are: Year 1995 - Rapid City 27,000 A.F.; RVWCD 24,000 A.F.; and Fishery 4,000 A.F.; Year 2030 - Rapid City 27,000 A.F.; RVWCD 24,000 A.F.; and Fishery 4,000 A.F. The total active storage in Pactola Reservoir is 55,000 A.F.

The ROMS model runs from 1995 through year 2030 on a monthly time-step. The increase in Rapid City's and decrease in RVWCD's pool allocations over time would be accomplished in 5 year increments or tied to water usage. The ROMS model for the Rapid Creek Basin has the capability for the user to select different storage pool allocations on a monthly time-step. The historical inflow record was repeated with gains and depletions being accounted for. Rapid City's demand increases linearly from 10,800 A.F. in 1995 to 22,000 A.F. in 2030. RVWCD's demand ranged from 6,800 A.F. to 16,200 A.F. based on historical diversions. Studies made using the model show that Rapid City's and RVWCD's demands are fully met in all years of the study period but the fishery pool is short by 1,300 A.F. during one year. Rapid City, which manages the fishery pool, could choose to release water from their storage pool to meet the fishery demand shortage. Instead of the model managing storage accounts for shortages, the ROMS model allows the various water users and managers to make water resource management decisions as to how the shortages are dealt with. The ROMS model is being used as a water management tool for planning long term water resource management strategies for the Rapid Creek basin such as these contract negotiations as well as short-term annual operating plans. (Contact person: Ed Eberaert, 406-247-7747).

MODELS

ROMS: ROMS is an user interactive computer model that simulates the operation of reservoirs and stream flow in a given river basin. The model is designed for site specific applications and simulates the operation of one or more reservoirs, reservoir releases for irrigation, municipal and industrial supply, river fishery flood control and power generation. The model is primarily intended as a operation model to assist with developing reservoir and river operating plans for the near and foreseeable future. The model allows the user to evaluate a number of "what -if" situations to determine the effects of various operational criteria on river flow, water supply and reservoir levels. The model operates in a PC environment and utilizes all of the user friendly features of Microsoft Windows and interfaces readily with spreadsheet programs such as Excel. (Contact person: A. Mackichan, 406-247-7850).

CALIDAD: CALIDAD is a general purpose, object-oriented, rule based modeling framework which links mass balance computations to user defined institutional constraints and management objectives to determine reservoir release and diversion schedules. The object-oriented approach allows each river basin feature, such as reservoirs, outletworks, demands,

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hydropower plants, and inflows to be treated modularly. The Rapid Creek Basin was used as a test case for the application of CALIDAD to storage ownership accounting and water right priorities. A network schematic was created for Rapid Creek from the available river system objects, and a new object was developed to perform the system's specific storage and water right accounting aspects.

This site-specific object follows the logic of the ROMS model application, "hard-wiring" its calculations of deliveries to water rights and storage ownership accounts, and performing the re-initialization of all accounts in May. These are aspects of this particular river basin system which could not be handled by any existing object or by creating management rules. Changes to the way the accounts are computed will require changes to the Rapid Creek object and recompilation of the program. These accounting procedures can be viewed as "physical" rules in the same sense that the top of a dam is a physical rule in a reservoir object. It is a behavior which is programmed in the object code and which would have priority over any rule entered by the user through the rule editor. Each account, however, is a Rapid Creek object variable, and individual management rules can be written for them.

Developing a separate object to handle ownership accounts works well still allows for the other CALIDAD functionality to be used in modeling the river basin. But the functionality needs to be generalized to eliminate the necessity of writing a new object for each new application. multiple ownership characteristics of storage facilities must be generalized in a new type of reservoir object which can dynamically model this aspect of river basin management. In addition, using rules to address water rights will be cumbersome for any system with more than a handful of demands. The performance issues of the search algorithm must be addressed before CALIDAD can be realistically applied as a water resources management tool in basins larger than Rapid Creek. CALIDAD operates on a Sun SPARCstation, Data General Aviion, and DECstation platforms (work stations). (Contact person: N. Parker, 303-236-0123, Ext. 214).

MODSIM: MODSIM is a priority driven reservoir and river system model. The model uses a system of links simulating channel reaches, canals and other conveyance features along with a series of nodes to simulate reservoirs, diversions, and minimum flow locations. Sophisticated treatments of multiple storage priorities in reservoirs have been developed to deal with exchanges, rent pools, and other common water use arrangements. Subsurface return flow, groundwater withdrawals and hydroelectric generation can also be modeled. The model is run interactively primarily using monthly time steps, but daily or weekly time steps can also be used. MODSIM can be run on IBM compatible PCs as well as most work stations. (Contact person: D. Frevert, 303-236-0123, Ext. 225).

HYDROSS: The Hydrologic River Operation Study System (HYDROSS) model is a system of computer programs written in FORTRAN-77. This model is used to conduct monthly water supply studies for evaluating existing and proposed water demands in a river basin based on water right priorities. The physical system modeled is characterized by a flow network. The network includes nodes called stations in HYDROSS, which represent

reservoirs, demands points, river confluences, and points of know flow. Arcs between nodes represent river reaches and canals. The basic input into HYDROSS includes flow data, demand data, and reservoir data. Water allocation in HYDROSS is structured so that flows are spatially and temporally allocated in accordance with water right priorities. Instream flow, power, diversions, and storage are the four types of demands described in HYDROSS. Each of these demands can be assigned a water right. The operation of reservoirs is performed using five reservoir content levels. The physical limits of the reservoir are described using absolute maximum and minimum storage contents. Reservoir operations are simulated using desired maximum and minimum limits which can vary from month to month. A pool maintenance routine is available to balance storage among a system of reservoirs. (Contact person: M. Brewer, 303-236-0123, Ext. 227).

PRSYM: PRSYM (Power and Reservoir System Model) is a general purpose river system model that can be used for river-basin planning and operation. PRSYM is object-oriented with objects that are analogous to river-basin features such as diversions and reservoirs. This approach is data-centered in that a reservoir and river system and it's operating policies are defined by the data supplied to the model. PRSYM can currently be run in three modes: 1. Simulation mode which uses only physical constraints such as maximum content at a specified period, 2. LP/Goal Programming mode which uses institutional constraints and goals expressed as economic values to determine operations, and 3. Rule Processor mode which enables modeling of institutional rules and policies such as law of the river limitations. In addition, a network solver mode that will enable processing of water rights and ownership, will be available in late 1995. (Contact person: D. King, 303-236-0123, ext. 225).

Fact Sheets, providing more in-depth information, are available for each of these models.

HYDROSS SIMULATION SUPPORT SYSTEM

Mike S. Brewer and Warren L. Sharp[1]

ABSTRACT

A generalized surface water network flow model called HYDROSS has been coupled with a graphical user interface (GUI) and a relational database management system to create a simulation support system on a UNIX workstation. HYDROSS is a surface water supply model developed by the U.S. Bureau of Reclamation to assist in planning studies for evaluating existing and proposed demands on a river system. HYDROSS operates over a discrete period of record, simulating the effects of factitious development on historical pristine flows. The X windowing system was used to develop the GUI which includes an interactive network builder to schematically define a river network for calibrating, verifying, and interpreting model results. The Ingres relational database management system was used to manage a hierarchical scenario database for further analysis and comparison.
Keywords: Surface Water, Simulation, Water Rights, Network Model.

INTRODUCTION

Managing the development and operation of river basins requires an understanding of many different aspects and interests associated with these basins. In addition, planning for future development implies an interactive process where varying levels of potential river basin development are analyzed to determine if conflicts result. To overcome existing difficulties in using complicated river system models, the U.S. Bureau of Reclamation (Reclamation) has developed a simulation support system which includes a river basin simulation model, a GUI that symbolically and graphically displays all simulation activities, and a relational database for managing model input and output. This paper presents an introduction to HYDROSS and its ancillary Graphical User Interface.

WATER SUPPLY MODEL

Background
The Hydrologic River Operation Study System (HYDROSS) model was selected for simulating the operation and management of a river basin (Bureau of Reclamation, 1991). HYDROSS is a system of computer programs written in FORTRAN-77; it is used to conduct monthly water supply studies for evaluating existing and proposed demands in a river basin.

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HYDROSS was originally developed on a Control Data Corporation Cyber computer in 1977 by Reclamation. The programs were converted to the DOS operating system in 1991. The physical system modeled is characterized by a capacitated flow network. The network includes nodes, called stations in HYDROSS, which represent reservoirs, demands, river confluences, and points of known flow. Arcs between nodes represent river reaches and canals. The basic input into HYDROSS includes flow data, table data, and network data. Flow data represents pristine monthly flows at each station in the network. Table data includes operational parameters needed to perform simulations. Network data provides information about the physical relationship between stations and arcs.

Allocation of Water Supplies

Water allocation in HYDROSS is structured so that flows are spatially and temporally allocated in accordance with water right priorities. Within a river basin, two types of flow are allocated, including natural flow and project flow. Natural flow is the flow which would occur in the absence of factitious development. Project flow is the water which has been stored in a reservoir or previously allocated through water right procedures. Natural flow is first used to satisfy demands with natural water rights; then, demands with project water rights are satisfied if remaining natural flow exists. Project flow is used to satisfy project demands when natural flow cannot. The above definitions contain a dichotomy in that a **project** water right may be satisfied using **natural** water, but project water cannot be used to satisfy natural water right demands.

Demands and Water Rights

Instream flow, power, diversions (six types), and storage are the four types of demands described in HYDROSS. An instream flow is a demand that requires flow to be maintained in the stream at a given station. Water flowing through a station with an instream flow demand is available for use below the station. A power demand is the flow required at a power plant. Power plants can only occur at reservoirs. The actual flow volume is calculated from the reservoir content (head) and efficiency data. Water used to satisfy power demands is not withdrawn from the stream. A diversion demand depletes water from the stream and potentially denies water to other users with junior water rights. A diversion can have a natural water right and a supplemental project right. A storage demand is similar to a diversion except that HYDROSS automatically assigns the lowest priority to the storage facility. Return flows from diversions can originate from both diversion sites and canal losses. Return flows re-enter the network at any station and may be delayed up to eleven months.

Reservoir Operations

The operation of reservoirs is performed using five reservoir content levels. The physical limits of the reservoir are described using levels for absolute maximum and minimum content. Reservoir operations are simulated using maximum and minimum levels which can vary temporally. A pool maintenance level is used to balance storage among a system of reservoirs. Power at a reservoir is computed at the downstream end of a station using discharge, head, and efficiency data.

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<u>Output</u>
HYDROSS creates one output file called ODS (Output Data Summary) which contains the results of a given run. A separate HYDROSS program is used to generate reports about the run, and these reports are selected by the user. The units used to display values and the number of decimal places displayed can also be controlled by the user.

GRAPHICAL USER INTERFACE

A portable GUI to carry out simulations and generate graphic displays of data from the simulations was developed using the X Window System (X11) and Motif. The GUI used in this system was segregated into canvas, menu, and message areas. The canvas area is used for building a network representation of the river basin. The menu area provides pull-down menus required to edit input and output data and for HYDROSS run control. The message area provides feedback to the user as a sequence of tasks is competed.

The Ingres database management system, based on the relational model (Malamud, 1989), was used to support the storage and retrieval of data necessary to operate HYDROSS. A hierarchical scenario database was developed using Ingres to overcome the difficulties of keeping these scenarios well organized and to provide for a mechanism necessary to compare the results of multiple runs. The philosophy behind this hierarchical database is similar to the Revision Control System (RCS) discussed by Tichy (1991) and available for many Unix workstations. The database arranges scenarios into an ancestral tree. The tree has a root scenario which is the HYDROSS data initially used to populate the database.

Basic input into HYDROSS, including flow data, table data, and network data, are stored in the database. A separate utility can be used to populate the database with existing HYDROSS input files. Input editing tools are provided to view, plot, and edit input data.

GREAT PLAINS APPLICATIONS

HYDROSS has been used to simulate the hydrology of the entire *Missouri River Basin* upstream of Fort Peck Reservoir in Montana. The primary purpose of this study was to identify the volume of water available in the basin which may be marketable by Reclamation. The entire *Milk River Basin* in Montana has been modeled using HYDROSS. This study was used to negotiate water rights settlements in the basin. The model was also used to improve water management. In a cooperative effort with the State of Montana and irrigators, the *Musselshell River Basin* has been modeled using HYDROSS. The purpose of this study was to identify changes in reservoir operations and water delivery practices which will improve the overall efficiency of water management in the basin and help to eliminate water shortages. HYDROSS has also been applied to the *Marias River basin* in Montana to assist the State of Montana and Indian Tribes in assessing Tribal water rights.

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SUMMARY

HYDROSS has been used successfully over the past ten years as part of a variety of water resource planning studies within the Great Plains Regions. However, water right allocation practices have changed during this tenure, and HYDROSS should be modified to reflect these changes. In particular, HYDROSS should be modified to 1) directly account for multiple ownership of water stored in reservoirs and 2) allow complicated water right exchanges within river basins.

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DECISION SUPPORT FOR WATER RESOURCES MANAGEMENT IN THE COLORADO RIVER REGIONS

T.J. Fulp, W.B. Vickers, B. Williams, D.L. King[1]

ABSTRACT

The US Bureau of Reclamation (USBR), once primarily a water project construction agency, is now focused on the effective management of water resources to meet multiple objectives. These management decisions tend to be complex, with sometimes uncertain consequences and with significant long-lasting impacts. It is our premise that decision support systems (DSS) can aid water resources engineers and managers in the analysis of these decisions.

To this end, the USBR and US Geological Survey (USGS) are involved in a joint initiative to develop and implement decision support tools for integrated basin management. There are three key components to the software being developed: an integrated, relational database (Hydrologic DataBase or HDB), a precipitation-runoff model (the Modular Modeling System, or MMS), and a water and power system model (the Power and Reservoir System Model or PRSYM). These tools are currently being implemented in several USBR offices including Salt Lake City, Albuquerque, Durango, Boulder City, and Hoover Dam.

In this paper, we focus on the water and power system model, PRSYM. Further information on any of the components may be obtained by contacting the authors. Detailed information concerning MMS may be obtained from the USGS.

DATA-CENTERED DSS

Previous developments of DSS for water and environmental systems have concentrated primarily on modeling (Fulp, et al, 1991, Reitsma and Sieh, 1992). Reitsma and Sieh make the argument that a data-centered approach provides a much better foundation to support decision making within an organization. The data-centered approach simply states that the data is the "center of the DSS universe" -- all components (including models) "revolve" around the database.

The Upper and Lower Colorado Regions have adopted this approach to decision support (Ryan and Sieh, 1993). Figure 1 shows the configuration that is currently being installed at

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each office. Using existing relational database and wide-area-network technology, we are able to share data on a near real-time basis. Models, such as the mid-term Colorado River operations model (the 24-month study model) will be able to access data directly through Data Management Interfaces (DMI's). The DSS will present a consistent view of both historical and model-projected data through a graphical user interface (GUI).
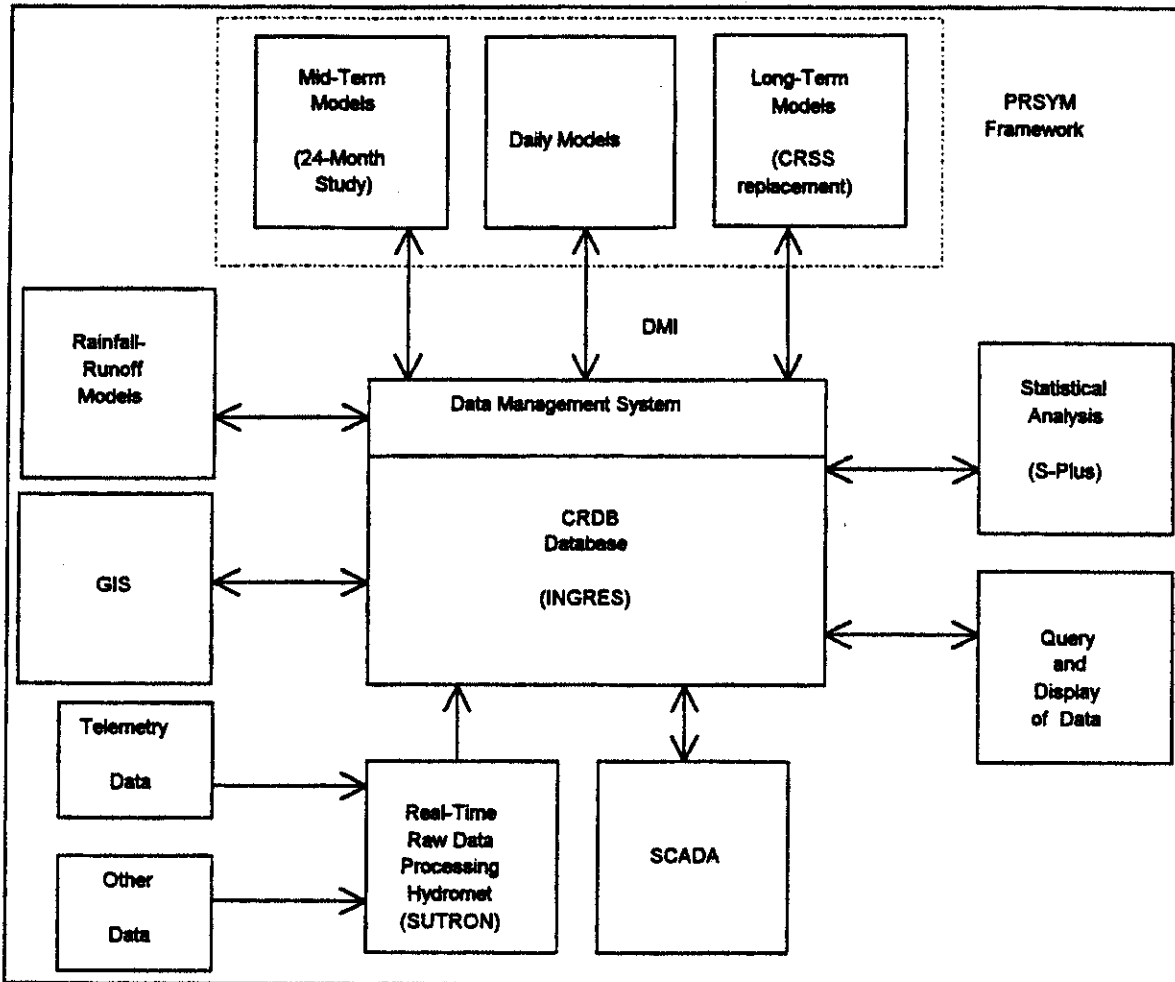
Figure 1 Data-centered decision support system currently being implemented in the Upper and Lower Colorado Regions.

PRSYM

Recent advances in software engineering technology have made it possible to develop *general-purpose modeling frameworks* that are easier to develop, maintain, and use. These frameworks have much greater flexibility with respect to the representation of the physical principles, and therefore, the types of systems that they can model. Such frameworks can provide a full suite of modeling services to the user. These services include the ability to interactively:

- build and edit the model
- choose the time step and horizon for which the model should run
- choose the source of data that is required for the model (invoke the particular DMI's)
- choose the behavior of the individual objects that make up the model
- choose the controller or mechanism which drives the model solution

The advances that make this possible are encapsulated in the object-oriented approach to software development. The key concept is that we can represent the behavior and relationships of the real-world system in a much more natural way in the software. A detailed discussion of this technology is beyond the scope of this document so we refer the interested reader to the excellent book by Taylor, 1990.

PRSYM is a general-purpose modeling framework developed through a collaborative program between USBR, Western Area Power Administration (WAPA), the Tennessee Valley Authority (TVA), and the Electric Power Research Institute (EPRI). The primary contractor for this work is the University of Colorado's Center for Advanced Decision Support (CADSWES).

The user constructs a model by selecting reservoir, reach, confluence, and other objects from a palette, naming the objects, and linking them together to from the basin network topology. Particular methods for modeling the physical processes associated with each object (i.e., river reach routing, hydropower calculation, etc.) are then selected from a menu for each object type. This methodology allows users from each sponsoring agency to add new methods as needed to customize behavior of particular objects without sacrificing portability. All computations are done in standard metric units, but users can specify particular units for importing, exporting, and displaying purposes, as well as dynamically define new unit types. Operational policy is either added through a constraint editor or through the rulebase editor, depending on which controller the user wishes to use.

As of March, 1995, controllers supported include basic simulation, linear programming/goal programming, rulebased simulation, and simulation plus water quality (temperature and salinity). Computational time steps supported are hourly, 6-hourly, daily, weekly, and monthly.

Data associated with an object can be entered through the Graphical User Interface (GUI), imported and exported from ASCII files, or automatically imported and exported through DMI's. Users can write customized DMI's in any standard programming language to access data from a variety of sources including relational databases. PRSYM also provides a utility whereby the user can set up and automatically execute many PRSYM runs using one of the controllers (multiple run management). Results of single or multiple runs can be viewed graphically or by setting up a control table which provides a spreadsheet format view of user-selected variables. Any number of views can be configured, saved and used by the user.

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As of March 1995, PRSYM does not support water rights allocation and accounting. Development plans for 1995, however, include this functionality.

PRSYM is being developed primarily in the C++ programming language, an object-oriented language that is based on the C programming language. The GUI is being developed with the Galaxy Application Environment, a cross-platform tool that allows the program to run under several common operating and windowing systems. PRSYM currently is supported on Sun workstation running the Solaris operating system (Unix). Plans for 1995 include support for HP and Silicon Graphics workstation.

MMS

As with PRSYM, the Modular Modeling System is a general-purpose precipitation-runoff modeling framework that has been developed to enable a user to selectively couple the most appropriate physical process algorithms from applicable models to create a model for the desired application (Leavesley, et al, 1992). Where existing algorithms are not appropriate, new algorithms can be developed and easily added to the system. This modular approach to model development and application provides a flexible method for identifying the most appropriate modeling approaches given a specific set of user needs and constraints.

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WATERSHED SCALE WORKSHOP
INTRODUCTION AND OVERVIEW

Stephen (Bernie) Owen[1]

Welcome to the watershed scale session. Presentations will be made in this session to familiarize you with some of the tools currently being used in the water quality arena to address watershed scale problems and solutions. Presentations will be made by representatives from two agencies of the United States Department of Agriculture: the Agricultural Research Service (ARS) and the Natural Resources Conservation Service (NRCS), formerly the Soil Conservation Service (SCS).

This session will last approximately three and a half hours and will describe two watershed scale models and a tool utilizing GIS that incorporates these two models plus two field scale models. Personnel from ARS and NRCS will be introduced as they start their presentations. Presenters are from Texas, Minnesota, and Fort Collins. We also have available fact sheets on each of the four models plus a fact sheet on the tool - Hydrologic Unit Water Quality (HUWQ). These fact sheets were recently updated (March, 1995), so you will be receiving current information. We also have a representative from Seco Creek, Texas, an area where these models and tools have been used.

The last item on the agenda will be a panel discussion by all presenters. You will be provided the opportunity to ask questions of any and all the presenters during this panel discussion. We are looking forward to an informative and interesting session. I encourage your attention and participation.

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THE SECO CREEK WATER QUALITY DEMONSTRATION PROJECT

PHILLIP N. WRIGHT[1]

ABSTRACT

The Seco Creek Water Quality Demonstration Project (WQDP) is a USDA cooperative project involving the Natural Resources Conservation Service (NRCS), Texas Agricultural Extension Service (TAES), Consolidated Farm Service Agency (CFSA), and the Texas State Soil and Water Conservation Board (TSSWCB) working with twenty-two other local, state, and federal agencies, groups, and universities.

The primary objective of the project is to work with landowners and operators on a voluntary basis to apply Best Management Practices (BMP's) within the watershed that will maintain or improve water quality and quantity of the surface and groundwater.

The Seco Creek Water Quality Demonstration Project, located approximately fifty miles west of San Antonio, Texas and established in April 1990, covers 170,670 acres in Bandera, Medina, and Uvalde Counties. The project area contains 32,500 acres of recharge zone for the Edwards aquifer. Two recharge structures constructed by the Edwards Underground Water District within the project area provide approximately 8 percent to 10 percent of the annual recharge of the Edwards aquifer, the sole source of water for 1.5 million people.

The Best Management Practices developed and installed in the Seco Creek Water Quality Demonstration Project will have a significant impact on the water quality and quantity of the Edwards aquifer. They will have even greater effects if expanded across the entire catchment and recharge zone of the aquifer.

BMP's such as filter strips, nutrient management, irrigation water management, and integrated crop management are being implemented on cropland within the watershed. These practices have currently been applied to 70 percent to 85 percent of the cropland and pasture land in the project area.

The Seco Creek Water Quality Demonstration Project is the only national demonstration project that is predominantly rangeland; 85 percent of the project area is occupied by this land use.

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Therefore a large portion of the work is directed at rangeland management practices that have direct effect on water quality and quantity. The primary BMP's being applied to rangeland are grazing management, riparian area management, critical area treatment, brush management, spring enhancement, and wildlife habitat management. These practices have been applied to approximately 80 percent of the rangeland within the project area.

Currently there are 56 demonstration sites established on privately-owned land within the project area. On these demonstration sites landowners and operators have voluntarily installed over 350 applications of fifty different BMP's. In some cases, cost share assistance from project agencies has been used to assist with the installation of BMP's; however, much of the work has been completed with technical assistance from staff member to landowners.

The success of this project is attributable to three major points: (1) overall respect for private landowner rights, (2) excellent cooperation between the agencies involved, and (3) an excellent information and education program.

Land within the Seco Creek Water Quality Demonstration Project area is 100 percent privately owned. The understanding of and respect for private landowners rights has allowed the project staff to work very effectively. The lead USDA agencies have no regulatory authority and therefore rely on a working relation with landowners built on trust and mutual respect.

Cooperation between the lead agencies is excellent at all levels. Representatives from the Natural Resources Conservation Service and Texas Agricultural Extension Service are housed in the Seco Creek Water Quality Demonstration Project Office. The office set up and agency cooperation allows quick and efficient assistance to landowners.

The information and education program varies from news articles, videos, field days, and tours to presentations and youth camps. At the beginning of the project, a local coordinating committee of local leaders was established. Landowner meetings were conducted to establish local involvement. Annual meetings of these groups are conducted to keep individuals informed on progress. More than 250 tours, field days and programs have been conducted since April 1990. Further, more than 50,000 people nationwide have participated in information activities of the project. Two youth camps have been conducted to provide natural resource and ecosystem management education to 50 area youth. Current plans are to expand this education program to include a teachers workshop in 1995.

Ongoing studies on cropland within the project area include monitoring of nutrient and pesticide runoff from cropland. Monitoring chemical build up in the soil profile. The evaluation of LEPA (Low Energy Precision Application) irrigation and soil moisture monitoring is also being conducted. We are currently evaluating the effectiveness of filter strips at increasing infiltration and reducing sediment movement.

Studies on rangeland involve herbicide movement from broadcast chemical brush management. The evaluation of alternative brush management techniques that reduce or eliminate chemical use. Enhancement of wildlife habitat through the removal of undesirable woody plant species and establishment of wildlife watering facilities.

Increasing water yield from rangeland watersheds is being evaluated in three separate studies. The first study, conducted by Dr. Bill Dugas, Blackland Research Station, Temple, Texas compares the evapotranspiration from a site where the brush has been removed to a site infested with brush. Data from three years of study shows an increase in available water yield. This increase is estimated to be approximately 55,000 gallons per acre per year following removal of regrowth Ashe Juniper. A similar study has evaluated methods of enhancing spring flow. After four years of data collection, an increase of approximately 60,000 gallons of water per acre per year is calculated following removal of regrowth Ashe juniper. The third study involves the use of stem flow gauges and leaf area index reading to calculate water use by woody plant species on a per acre basis. The preliminary results from the first year of data collection parallel the result of the first two studies discussed.

Surface and ground water quality and quantity in the project area being monitored by the U.S. Department of Interior - U.S. Geological Survey, through a cooperative agreement with the Texas State Soil and Water Conservation Board. Approximately 30 years of historic water quality data were available from one site on Seco Creek; therefore, a baseline was established. Currently a monitoring network of seven precipitation stations, nine stream gauges, four automatic stream samplers, and one independently sampled surface water site provide water quality and quantity data. Discharge measurements and stream gains and losses are measured between the stream gauges. Water quality samples are taken at the rise, peak, and recession flow components of the flood hydrograph at the five gauging sites. Ground water samples have been collected from twenty-five shallow ground water wells from the Leona and Escondido formations and from eight deeper Edwards aquifer wells.

Stream flows in the project area are rainfall event oriented and typically of short duration with large magnitude. There is no sustained flow in the central or lower parts of the watershed due to the recharge zone of the Edwards aquifer. The only time the flow is sustained in the main stem of the Seco Creek is during flood flows.

Water quality samples are collected by U.S. Geological Survey and analyzed for more than 70 properties or constituents that effect the suitability of water for domestic use. The purpose of this sampling is to outline the effects of best management practices applied within the Seco Creek Water Quality Demonstration Project on water quality and quantity and describe its interactions with ground water in the area. Water quality sampling within the project area shows no major surface water quality problems. Water samples collected from February 1990 to present show no contaminates in excess of the EPA drinking water standards.

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The Seco Creek project has been involved in the use of four water quality models to evaluate the effects of BMP application on field and watershed scale areas. Models which have been utilized are EPIC, SWRRBWQ, AGNPS, and SWAT. The AGNPS model is being utilized as part of the HU/WQ tools development which is a interface between the model and the GRASS GIS system.

In the use of these models and the development of the GRASS data base the most critical step is the initial data collection. It is very time consuming; however, if not done correctly it will cost you more time in the long run. Knowledge of the model requirements is essential to insure that adequate information is collected for the data base. In the use of HU/WQ, recent developments in data formatting have made it much simpler to determine what data is needed to run a specific model.

The Seco Creek Water Quality Demonstration Project is an example of how voluntary cooperation at all levels from the individual landowner to governmental agencies can be used to establish best management practices that protect water quality and quantity. The best management practices developed and used in the project area will have major impact on the water resources of Texas.

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AGNPS - AGRICULTURAL NONPOINT SOURCE MODEL

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ABSTRACT

AGNPS is a well-known distributed parameter nonpoint source agricultural pollution model that has been modified recently to include pesticides, point source sediments, source accounting, and different types of erosion. Hydrograph shape can be altered, nutrient decay has been added, and an option for channel geometry is included. A continuous simulation version is currently under development.
Keywords: Water Quality, Models, Agricultural Nonpoint Source Pollution

MODEL FEATURES

AGNPS is a distributed parameter, event-based model. It simulates the behavior of runoff, sediment, and nutrient transport from watersheds that have agriculture as their prime use. The nutrients considered include nitrogen (N) and phosphorus (P), both of which are essential for plants and are major contributors to surface water pollution. AGNPS also considers chemical oxygen demand (COD), which is a measure of the oxygen required to oxidize organic and oxidizable inorganic compounds in water. As such, it is used as an indicator of degree of pollution. Basic model components include hydrology, erosion, and sediment and chemical transport. In addition, the model considers point sources of sediment from gullies, streambanks, construction sites, etc., and inputs of water, sediment, nutrients, and COD from animal feedlots, springs, and other point sources. Water impoundments, including reservoirs and tile-outlet terraces, also are considered as depositional areas of sediment and sediment-associated nutrients.

The model operates on a cell basis. Cells are uniformly square areas subdividing the watershed and allowing analyses at any point within it. Potential pollutants are routed through cells from the watershed divide to the outlet in a stepwise manner so that flow at any point between cells may be examined. All watershed characteristics and inputs are expressed at the cell level. A separate routine also permits the use of variable cell sizes to allow detailed characterization and analysis of critical areas. For watersheds exceeding 2,000 acres, cell sizes of 40 acres are generally recommended. Smaller cell sizes are recommended for smaller watersheds. Accuracy of results can be increased by reducing the cell size, but this increases the time and labor required to run the model.

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Conversely, enlarging the cell size reduces time and labor, but the savings must be balanced against the loss of accuracy resulting from treating larger areas as homogeneous units.

Inputs to the model include information on precipitation, soils, land use, upland and channel drainage, agricultural management, and point sources. Runoff volume is calculated based on the NRCS curve number method (USDA, 1972). Peak flow rate is calculated either by the empirical relationship of Smith and Williams (1980) used in the CREAMS model (Knisel, W.G., 1980) or by a method based on SCS-TR55 (USDA, 1986) which is a simplified procedure for estimating runoff and peak discharges in small watersheds. The peak flow rates calculated from either method are used to generate a triangular hydrograph for each cell. The shape of the hydrograph can be user defined by partitioning it into at least three uniform increments on the rising limb. Flow rates are calculated for each increment using the average time to peak, the flow duration, and the increment duration.

The well-known Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978), modified by an adjustment for slope shape, is used to estimate upland erosion for single storms. Soil loss is calculated for each cell of the watershed, and eroded soil and sediment yield are subdivided into five particle size classes--clay, silt, small aggregates, large aggregates, and sand. Multiple gullies and channel erosion types can be entered.

After runoff and upland erosion are calculated for each cell, detached sediment is routed from cell to cell through the watershed to the outlet using sediment transport and depositional relations described by Foster et al. (1981) and Lane (1982). Effective transport capacity is computed using a modification of the Einstein equation. Sediment load for each of the five particle size classes leaving a cell is calculated. The sediment transport calculations allow for deposition and/or scouring of all particle sizes during channel flow based on transport capacity and sediment availability. However, the user has the option of not allowing any scouring, as in the case of a non-erodible channel bed, or allowing only specific particle sizes to scour, as might be the case in a relatively stable channel bed.

The model estimates the transport of N, P, pesticides and COD throughout the watershed. Relationships used to calculate chemical transport have been adapted from CREAMS (Frere et al. 1980) and a feedlot evaluation model (Young et al. 1982), with modifications for the effects of variations in soil texture. Chemical transport calculations are divided into soluble and sediment adsorbed phases. Soluble nutrient estimates consider the effects of nutrient levels in rainfall, fertilization, and leaching. COD in the model is assumed soluble. Pesticides, soluble nutrients and COD are allowed to decay with time once they enter a channel.

The model treats nutrient and COD contributions from animal feedlots as point sources and routes them with contributions from diffuse sources. Chemical contributions from

feedlots are estimated using a separate feedlot pollution model (Young et al. 1982) as a subroutine. This model estimates nutrient concentrations and mass at both the feedlot edge and at a receiving body of water. Other point-source inputs of water and nutrients, such as springs, wastewater treatment plant discharges, etc. are accounted for by inputting incoming flow rates and concentrations of N, P, and COD to the cells in which they occur.

Erosion from streambanks, streambed, gullies, and other sediment sources are accounted for using estimated values as point sources. Sediment from these sources is added to upland sediment and considered in the transport phase of the model. Nutrients from these sources are added to other nutrient inputs to a cell and routed accordingly.

Sediment and runoff routing through impoundments is accomplished using relationships described by Laflen et al. (1978). These relations were developed for impoundment terrace systems having pipe outlets.

Various output options are available with the model. Preliminary output given for all watersheds being analyzed includes watershed area and cell size, storm precipitation and erosivity (EI), estimates of runoff volume and peak flow rate at the watershed outlet, and area-weighted erosion, both upland and channel. Also given are estimates of sediment delivery ratio, sediment enrichment ratio, mean sediment concentration, and total sediment yield for each of five sediment particle size classes. Also available is a nutrient analysis, which includes N, P, and COD mass per unit area for both soluble and sediment adsorbed nutrients, and N, P, and COD concentrations in the runoff.

A more detailed output can be obtained for any or all cells if desired, and includes runoff volume, peak flow, upland erosion, channel erosion, sediment yield by particle size, deposition, soluble N, P, and COD (both concentration and mass load), and sediment attached N and P (mass load). Cell selection for output depends on the problem. For example, if a stream reach needs to be protected for fish habitat, those cells having outlets to the stream may be the only ones that need to be examined. If an impoundment at the watershed outlet needs protection, then only the output at the outlet of the watershed may need to be examined. If a potential problem is shown to exist, upland cells may be selected and examined to identify and prioritize problem areas where management alternatives can be implemented in order to correct the problem.

If the chosen cell size is too large to adequately reflect conditions in a certain area of the watershed or, if upon examination of the output, a cell is considered to have a problem which requires more detailed examination, a cell division capability allows for the division of any cell from the original grid into fourths. This division process can be repeated three times, resulting in cells 1/64th the size of the original cell. This process enables a more detailed analysis of critical areas within a watershed.

MODIFICATIONS

At present, the model can be used for estimating results of specific hydrologic events. However, it is currently being modified so that it can also be used in a continuous simulation mode for providing average annual response of a watershed to a representative annual distribution of rainstorms for and area. Integrating continuous simulation to the existing distributed spatial abilities anables an even more representative description of the stochastic physical processes controlling the movement of sediment and agricultural chemicals from the field into the surrounding environment.

While the basic components of the model will remain the same, the continuous simulation mode involves several modifications to the model as it now exists. These include incorporation of a weather generator (Nicks and Lane, 1989) to generate a representative sequence of storms for the area of interest and the annualization of most of the localized time dependent factors in the model representing specific vegetative and soil conditions. Input parameters will be initialized for a certain point in time. The weather generator generates daily weather for the desired period of time and the model, operating on a daily time step, calculates daily changes in soil, vegetative, and soil moisture conditions and keeps a running balance of water, sediment and nutrient movement in each cell. Also, upland erosion is estimated using techniques adapted from the revised universal soil loss equation (RUSLE) (USDA, In press). Output results can be viewed for any single cell within the watershed, a sub-basin within the watershed, or for the entire watershed in either tabular or graphical mapped format. Runoff events taking place within the simulation can be viewed individually, as a monthly or yearly accumulation of storm results, or as an average annual value derived from a multiple-year scenario.

Because the continuous simulation model requires calculations to be made over an entire year, a set of winter routines has been incorporated into AGNPS to deal with snowmelt runoff and runoff from frozen soil conditions. The snowmelt-frozen soil procedure is composed of three separate components which interact with each other on a daily basis. These components deal with soil frost, snowmelt, and snowdrifting. The frost component estimates the extent of frost development and thawing over the winter period as well as changes in soil water content and infiltration capacity. The snowmelt component estimates the amount of snowmelt occurring and how much snowmelt water is available for runoff in the spring. The snowdrift component estimates the depth, density, and distribution of snow cover over the watershed. Prediction of the effects of soil frost and snowmelt on runoff and soil erosion at any point within a watershed is achieved by allowing the three components of the snowmelt-frozen soil process to interact on a daily basis.

In summary, the AGNPS model is a distributed parameter, event- based model developed to analyze and provide estimates of runoff water quality from primarily agricultural watersheds. The model is relatively easy to use and is flexible in its capability to

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address a wide range of problematic conditions within watersheds. The outputs help describe: 1) the extent of NPS problems--how much sediment and nutrients are being generated and transported throughout a watershed, 2) the source of such problems--"hot spot" cells and/or drainages delivering substantial levels of NPS pollutants to waterways, and 3) the potential environmental impacts of alternative land uses, conservation treatments, and management scenarios involving crops, tillages, and various management practices and control measures. These outputs allow the user to evaluate the impact of applying alternative management practices at any point within the catchment. Such a procedure enables the user to rate upland catchment areas in priority order to remedy a downstream problem.

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SIMULATOR FOR WATER RESOURCES IN RURAL BASINS-WATER QUALITY

J. G. Arnold and C. E. Drungil[1]

ABSTRACT

Simulator for Water Resources in Rural Basins-Water Quality (SWRRB) was developed to predict the effect of management decisions on water, sediment, nutrient, and pesticide yields at the subbasin or basin outlet. The model was developed by the USDA-Agricultural Research Service at Temple, Texas and diskettes, documentation, and technical support are available through the Water Quality Coordinators at each of the USDA-National Resources Conservation Service National Technical Centers. Recent developments include a new model called SWAT (Soil and Water Assessment Tool). SWAT was developed by modifying SWRRB to simulate hundreds or thousands of grid cells or subwatersheds and by developing a new reach routing structure. Other advancements include improved subsurface flow models, water transfer, CO_2 submodels, and the ability to simulate animal waste.

Keywords: Hydrology, watershed, river basin, erosion/sedimentation, nutrients, pesticides

INTRODUCTION

Simulator for Water Resources in Rural Basins-Water Quality (SWRRB) (Arnold et al., 1990) simulates hydrologic and related processes in rural basins. SWRRB is a comprehensive, continuous simulation model covering aspects of the hydrologic cycle, pond and reservoir storage, sedimentation, crop growth, nutrient yield, and pesticide fate. The objective of the model is to predict the effect of management decisions on water, sediment, nutrient, and pesticide yields at the subbasin or basin outlet. A basin can be divided into a maximum of 10 subbasins to subbasins to account for differences in soils, land use, crops, topography, vegetation, or weather. SWRRB allows for simultaneous computation on each subbasin and routes the water, sediment, and chemicals from the subbasin outlets to the basin outlet. It also has a lake water quality component that tracks the fate of pesticides and phosphorus from their initial application on the land to their final deposition in a lake. SWRRB can model the effects of farm level management systems such as crop rotations, tillage, planting date, irrigation scheduling, and fertilizer and pesticide application rates and timing. The effect these management systems have on the movement of contaminants can be tracked to the watershed outlet. The model partitions nitrate loss between runoff, lateral subsurface flow, percolation, and crop uptake. Soluble and sediment attached phosphorus is calculated. The amount of pesticide lost with runoff and leached through the root zone is computed.

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Sediment yield is calculated using the Hydrogeomorphic Universal Soil Loss Equation (HUSLE). Nutrient, pesticide, and sediment yields at the basin outlet are determined after accounting for channel transmission losses and deposition.

Advantages/Limitations
SWRRB was developed for specific watershed management applications and has many unique features and limitations. Selected features include:

- The UTIL data assembly system provides for interactive data entry and editing. Help screens are provided. UTIL also has a routine that checks data parameters to ensure they fall within a specified range.
- Parameters from the Soils-5 data base and a pesticide data base are housed internally in the model.
- Peak discharges are determined using the SCS TR-55 unit peak discharge equation methodology.
- Sediment yield originating from cropland is determined independently from stream bed and bank sources.
- The curve number can be adjusted at planting and at harvest.
- Automatic or manual irrigation and furrow irrigation are options.
- Measured monthly water and sediment yields can be input by the user. The model will make a statistical comparison on the measured and predicted values.
- The usefulness of ponds or reservoirs to trap sediment at the subbasin or the watershed outlet can be determined.
- Run-time graphics allow the operator to see selected processes being graphed as the model is executing. Any of the output variables can be plotted with respect to time (years). Eight graphs can be displayed on the screen simultaneously.
- Input is in English or metric units.

Currently, SWRRB has several limitations that include:
- Time of concentration determinations are not consistent with SCS methods.
- A maximum of 10 subareas per analysis is allowed.
- Organic waste applications are not modeled.
- As nutrients and pesticides flow from each subbasin to the basin outlet, no degradation occurs.
- Hydraulic residence time is not considered by the lake water quality module.

CURRENT DEVELOPMENTS

The SWAT Model
SWAT (Soil and Water Assessment Tool) was developed by modifying the SWRRB model for application to large, heterogeneous river basins. Major changes to SWRRB include: (a) expanding the model to allow simultaneous computations on several hundred subwatersheds (the upper limit is 2500 subbasins) and (b) adding components to simulate lateral flow from the soil profile (0-2m), groundwater flow from the shallow aquifer (2-25m), reach routing transmission losses, and sediment and chemical movement through ponds, reservoirs, streams

and valleys. SWAT operates on a daily time step and is capable of simulating 100 years or more. Major components of the model include surface hydrology, weather, sedimentation, soil temperature, crop growth, nutrients, pesticides, groundwater and lateral flow, and agricultural management.

The SWAT model offers significant advantages over SWRRB. SWAT offers distributed parameter and continuous-time simulation, flexible watershed configuration, irrigation and water transfer, lateral flow, groundwater flow, animal waste simulation, and CO_2 submodels. The distributed parameter, continuous-time feature was achieved by developing a new routing structure. SWRRB routes from subbasin outlets directly to the basin outlet for simplicity. The new routing structure in SWAT is required to allow large basins to be simulated, provide more realistic routing, allow for more subbasins to be easily added, and simplify GIS linkages and database management. A detailed description of the model and model inputs is found in Arnold et al. (1993).

Seco Creek Application

SWAT was applied to the upper portion of Seco Creek watershed (Fig. 1), located in south central Texas (Srinivasan and Arnold, 1994). The basin is approximately 114 sq. km. The Seco Creek watershed is predominantly rangeland (98% of the area). The base GIS layers were digitized by the Soil Conservation Service (SCS)-Fort Worth GIS center. The elevation contours were digitized at the 1:24000 scale from USGS 7.5 minute maps. The field boundary map and soils map were also digitized at 1:24000 scales from county records. The soils in the watershed are primarily the Tarrant soil series, which has a high clay content. The basin has been monitored by the USGS since 1966; however, water quality data were sampled once every 90 days. Consequently, only simulated streamflow was compared to USGS average daily flow records. SWAT output has been validated against measured nutrient pesticide yields at other watersheds (Blasland and Bouck, 1992; Engel et al., 1993). Measured daily rainfall and temperatures were obtained from January 1991 through August 1992 from unpublished data for the watershed. Thus, monthly simulated streamflow data from SWAT was compared to monthly measured streamflow data from the 20-month run.
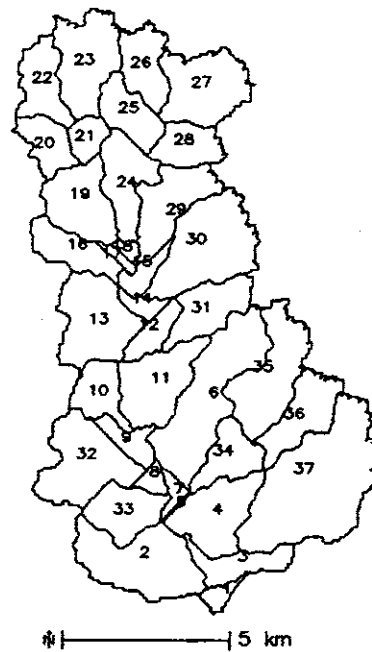
Figure 1. Basin and Subbasin Map of Upper Seco Creek Watershed

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Generally, simulated values compared well with measured values, with average monthly predicted flows 12 percent (Fig. 2) lower than measured flows. Measured and predicted standard deviations compared well (within 8 percent) (Fig. 2). An R^2 of 0.86 (Fig. 3) also indicated a close relationship between measured and predicted values. Statistics are valuable criteria, but a graph often sheds considerable insight to the goodness-of-fit. Measured versus predicted monthly streamflow are plotted in Fig. 2. A regression line and line-of-perfect-fit (1: 1) are plotted with the regression points. Seasonal trends can easily be visualized by plotting measured and predicted monthly values against time. The measured and predicted monthly
surface runoff for the 20-month period (Fig. 3) showed that there were no general tendencies to over or underpredict during certain seasons of the year.
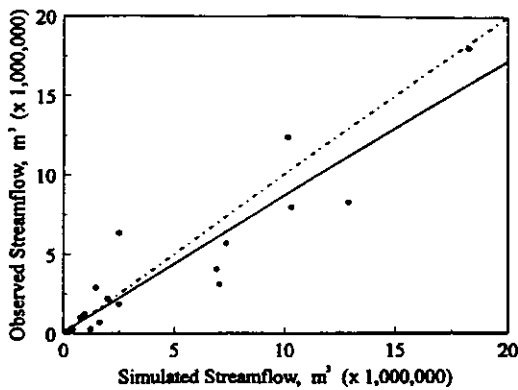
Figure 2. Observed vs. Simulated Average Monthly Streamflow Regression Chart for the 20-month Period (January 1991 to August 1992).
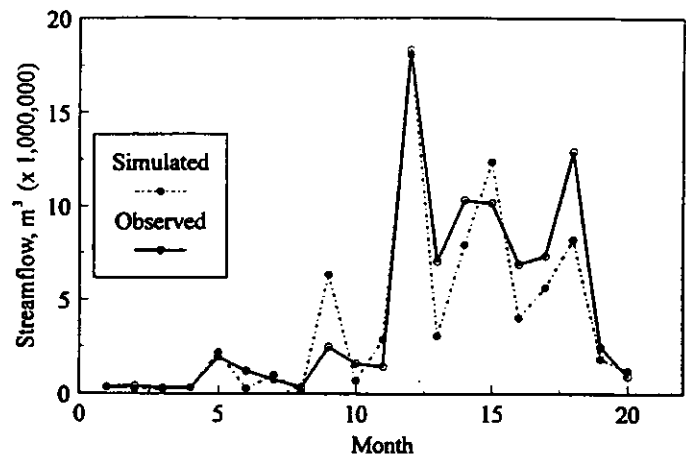
Figure 3. Observed and Simulated Average Monthly Streamflow in Cubic Meters for 20-Month Period (January 1991 to August 1992).

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HYDROLOGIC UNIT WATER QUALITY MODEL GIS INTERFACE TO FOUR ARS WATER QUALITY MODELS FOR USE BY THE NATURAL RESOURCE CONSERVATION SERVICE

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ABSTRACT

The Natural Resorce Conservation Service (NRCS) is developing a decision support tool for ecosystem planners that integrates GRASS GIS, INFORMIX DBMS and ARS pollutant loading models. A Graphical User Interface (GUI) provides a framework for entering data, running pollutant loading models and analyzing simulation results. Version 1.4 of the tool supports AGNPS version 4.03. Planned future versions will integrate SWRRBWQ, EPIC and GLEAMS. Use of the interface results in standardized and consistent input data across the suite of pollutant loading models because many model input parameters are derived by aggregation, compositing and derivation techniques from base attribute and spatial input data. All model output is partitioned back into the database so that model results can be analyzed through tables, graphs and maps.
Keywords: GIS systems, Watershed planning, Watershed modeling, Water quality, AGNPS, GLEAMS, EPIC, Interface

BACKGROUND

The Hydrologic Unit Water Quality Model GIS Interface (HU/WQ Tool) to four ARS water quality models is designed for use by NRCS State Office personnel as a decision support tool and in formulating water quality project plans for impaired watersheds and evaluating the impacts of conservation and management practice implementation (Drungil, et al., 1993, 1994).

NRCS began work on the HU/WQ Tool in April of 1992 by developing four character based prototypes, one for each of the four water quality models: AGricultural Non-Point Source (AGNPS, Young, et al., 1987), A Basin Scale Simulation Model for Soil and Water Resources Management (SWRRBWQ, Arnold, et al., 1990), Erosion Productivity Impact Calculator (EPIC, Sharpley and Williams, 1990), Ground Water Loading Effects of Agriculturral Management Systems (GLEAMS, Knisel, et al., 1992). The purpose for developing the prototypes was to demonstrate the technical feasibility of interfacing each of the ARS models with GIS spatial data linked to basic attribute data describing fields, management practices, soils, etc. The prototypes for AGNPS, SWRRBWQ and EPIC were completed and tested in the summer of 1993. The prototype for GLEAMS was also coded but due to time constraints was not tested. In August of 1993, the NRCS sponsors decided to continue with the development of the HU/WQ Tool by

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combining the developmental prototypes with a GUI common user interface. In May of 1994, the first common user GUI interface to AGNPS was released to the eight test states for evaluation. Version 1.3 of the AGNPS HU/WQ Tool was released in the November 1994 and version 1.42 in February of 1995 to eight test states. The HU/WQ Tool that will include AGNPS and SWRRBWQ is currently planned to be released in July of 1995.

HU/WQ TOOL PURPOSE

HU/WQ Tool will assist NRCS State and Project Office personnel in planning water quality projects. The NRCS has a nine step planning process that goes from problem identification through to final project evaluation. The HU/WQ Tool tool is most usefull in the following planning steps:

- **Inventory Resources** - Although the HU/WQ Tool does not produce an inventory, the tool does provides a consistent direction and methodology for collecting, storing and managing watershed data.

- **Analyze Resource Data** - The HU/WQ Tool can aid in the analysis of resource data. Modeling allows evaluation of resource interactions to compare pollutant loadings under a different land management scenario.

- **Formulate Alternative Solutions** - Knowledge of how the HU/WQ Tool derives model input parameters and the internal process within the water quality models can help the planner gain a better understanding of the processes involved and their interrelationships.

- **Evaluate Alternatives** - The HU/WQ Tool is primarily designed to facilitate the evaluation of alternatives management strategies. Alternatives can be formulated by modifying either the spatial or base attribute data and then running the model(s). The tool manages input and output data so that alternatives can be evaluated by comparing simulation results spatially in maps, in tables and graphs.

There were two primary reasons for devloping the HU/WQ Tool:

1. To reduce the effort required in gathering model input data to run multiple simulation models. The tool allows the user to collect 'base' resource data such as primary soil and field information. The tool then derives the necessary model input data from the base data.
2. To provide a methodology where model input parameters are derived from base data in a documented, technically approved, consistent and repeatable process thereby eliminatimg personal bias in the development of model input parameters.

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HU/WQ TOOL SOFTWARE STRUCTURE

The HU/WQ Tool software is designed to facilitate the management of multiple water quality projects, each with its own set of alternative simulations. The user first creates a project and then inputs the base attribute data and creates the necessary GRASS GIS maps. After the spatial and attribute data have been entered, the user can create an baseline simulation by selecting the model of choice and entering a name for the simulation. At this point a complete copy of the base collected data is copied to the new simulation. To make an alternative data set, the user edits a copy of the original data thereby preserving the integrity of the original data. It is important to note that the user edits 'base' data such as the rotation/tillage data and not actual model input. If the user desires, the tool does provide the capability to edit model input data although it is generally not recommended. Figure 1 is a simplistic hierarchy of the HU/WQ Tool.
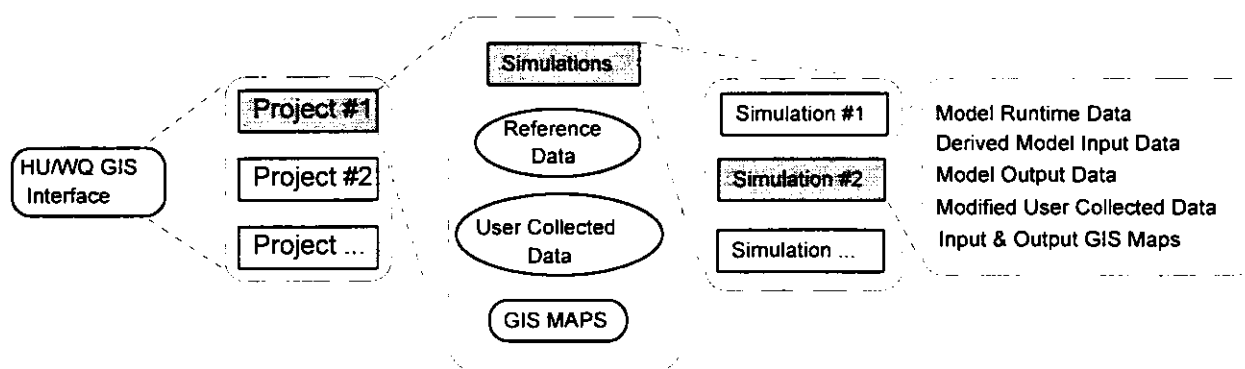
Figure 1

DATA REQUIREMENTS

Spatial Data: Spatial data required by the HU/WQ Tool consist of a set of raster maps in the Geographic Resource Analysis System (GRASS) format. Primary input GRASS maps are developed outside of the HU/WQ Tool. Five GRASS raster maps are required: 1. Soil; 2. Fields; 3. Geomorphic Areas; 4. Point Sources; 5. Digital Elevation; 6. Subwatershed; 7. Watershed data. The GRASS category label in each of the maps links the spatial area to the collected attribute data.

Collected Attribute Data: Information about each field, watershed, subwatershed etc. is entered through the HU/WQ Tool. Data are primarily entered into tables in a spreadsheet format. For many data elements, range checking and referential integrity is checked immediately after a data element is entered and warning messages displayed if values are out or range of reference non-existent data. There are sixteen tables that must be filled out by the user:

1. Field Table	7. Gully Table	13. Sink Source Table
2. Rotation Tillage Table	8. Pond Table	14. Watershed Table
3. Fertilizer Table	9. Reservoir Table	15. Subwatershed Table
4. Pesticide Table	10. Terrace Table	16. Geomorphic Table
5. Irrigation Table	11. Feedlot Table	
6. Non-Cropland Table	12. Point Source Table	

MODEL INPUT AND OUTPUT EVALUATION

All model input and output data can be viewed in tables, graphs and maps. Graphs would pertain only to time variant output such as daily rainfall amount. Tables and maps would apply to all non-time variant input and output information. The user can display multiple maps, graphs and tables simultaneously. The tool also has the capability of showing the difference between the non-time varient output of any two simulations in form of tables or maps.

Time variant model output data will be displayed as either static or dynamic graphs. Dynamic graphs are scrollable graphs where the user can use the mouse to move from the beginning to end of the simulation. Multiple dynamic graphs will be linked so that as one graph scrolls the rest automatically scroll with it. Static graphs show the entire simulation period in one graph.

CONCLUSION

The NRCS HU/WQ Tool to the water quality models will provide a platform in which NRCS State and Project Office personnel can plan and evaluate water quality projects. The interface will help standardize input data are collection and derive model input data in a consistent, repeatable manner. Use of the interface will facilitate the use of water quality models at the NRCS State office level.

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WATER MANAGEMENT WITH THE SOYBEAN CROP MODEL GLYCIM

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ABSTRACT

GLYCIM is a dynamic simulator of soybean crop growth that is mechanistic at the level of the physical and physiological processes involved in the transfer of materials in the soil, plant, and atmosphere. The model is equipped with a two-dimensional soil process model in which the soil profile at right angles to the row is divided into rectangular cells. Carbon made available for root growth by the plant is allocated first to cells that are most desirable for root growth. When the root is long enough, growth of the root in a particular cell is distributed between that cell and adjacent cells based on their desirability for root growth. Water is taken up from those soil cells in which it is most freely available. The soil and plant resistances are taken into account in the calculation of water uptake. The model provides soil water potential from the root zone for the calculation of root turgor levels and leaf water potentials. The leaf water potentials, in turn, are used to estimate reductions in growth and photosynthesis induced by water stress and for managing the frequency and amount of irrigation applied. Sprinkler, furrow, and flood irrigation can be simulated.

WINGLY is the Windows™ interface to the soybean model GLYCIM. Since the 1990 growing season GLYCIM-WINGLY has been used by farmers for crop management and input optimization. In addition to water management, the model is being used for selecting cultivar, row spacing, plant density and planting date prior to planting, and for post-planting decisions such as insect control, harvest timing and forecasting of final yield. The model helps farmers to optimize inputs, maximize profits, and minimize environmental pollution. In a recent survey by Mississippi State University, the soybean growers using GLYCIM for crop management reported a 14 - 29% increase in yields and a 400% increase in irrigation efficiency.

INTRODUCTION

Crop simulation models are farm management tools capable of bringing new research information on crop physiology, genetics, soil science, entomology, and pathology from the scientist to the farmer in a usable form. These models offer great potential for improvements in crop production

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efficiency and crop management. New knowledge can arrive in a farmer's computer long before it is published in research journals by using the models for direct research information transfer. Crop simulation models can predict the growth of a crop from emergence to maturity, account for major physiological and morphogenetic processes, and describe the primary relationships in the soil-plant-atmosphere system. Models are also being used for hypothesis testing and research planning.

The soybean simulation model GLYCIM was developed by Acock et al. (1985) and was initially validated using data collected on cultivar 'Forest' at the Plant Science Farm at Mississippi State University (Acock et al., 1985; Gertis, 1985; Aung, 1989). Since the 1991 growing season GLYCIM has been used by farmers for crop management and input optimization.

The model is being used for selecting cultivar, row spacing, plant population and planting date prior to planting, and for post-planting decisions such as irrigation scheduling, insect control, harvest timing, and forecasting of final yield. The model helps farmers to optimize inputs, maximize profits, and minimize environmental pollution. In a recent survey by Mississippi State University, the soybean growers using GLYCIM with new cultivar parameters, for crop management reported a 14-29% increase in yields and a 400% increase in irrigation efficiency (Whisler et al., 1993).

MATERIALS AND METHODS

General Description of GLYCIM. GLYCIM is a dynamic simulator of soybean crop growth that is mechanistic at the level of the physical and physiological processes involved in the transfer of materials in the soil, plant, and atmosphere. It is organized into modules in accordance with a generic modular structure and runs in hourly time steps. Documentation, including the FORTRAN listing, definition of variables, description of theory, and details of input and output files, has been published (Acock et al., 1985; Acock and Trent, 1991). Mechanisms involved in the physical and physiological processes in the plant and its environment are mathematically described in the model. These processes include light interception, carbon and nitrogen fixation, organ initiation, growth and abscission, and flows of water, nutrients, heat, and oxygen in the soil. All of the important factors known to influence these processes are included in the model along with information about how the factors interact. Carbon dioxide concentration in GLYCIM has a direct effect on gross photosynthetic rate and on photorespiration rate. Carbon availability affects the expansion and dry weight gain of all the organs on the plant. Root growth influences water uptake, plant water relations, and stomatal conductance. Since the model was originally designed to examine the interactions between CO_2 and other environmental factors, all the processes in the model have been brought to approximately similar level of mechanistic detail.

The environmental inputs necessary to run GLYCIM are solar radiation, maximum and minimum air temperature, rainfall, and wind speed. The model also uses wet and dry bulb temperature if available. The program has the capability to use either hourly or daily environmental input data. GLYCIM also needs information on the physical and hydraulic properties of the soil, maturity

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group of the variety, latitude of the field, date of emergence, row spacing, plant population within a row, row orientation, irrigation amount, method and date, and CO_2 concentration of the atmosphere.

The model has been designed to simulate the growth of plants of any maturity group on any soil and at any location and time of year. All soil processes in the model are mechanistic, and soil characteristics by horizon are required. Simulations are initiated at the cotyledonary stage with appropriate data on the number, size, and weight of organs on the plant. Plant growth in size and phenological stage are all predicted by the model. During simulation, the model provides predicted values for most of the physiological variables. It also simulates nitrogen concentrations of various organs on the plant and water and nitrogen status of the soil. The model provides the dry weights of all plant parts and final seed yield.

A brief description of different modules in GLYCIM is as follows: The module SOILIN uses data on the characteristics and initial conditions of soil in the various horizons of the profile to calculate characteristics and initial conditions in each cell of the soil profile. The module LYTINT calculates hourly values of the total photosynthetically active radiation that would be intercepted by the crop canopy. Volumetric water content, water potential, hydraulic conductivity, oxygen concentration, temperature, and concentrations of ammonium and nitrate in each cell in the soil profile are calculated in SOILEN.

The vegetative and reproductive developmental rates are calculated in module PHEN. PNET uses single-leaf photosynthetic characteristics to calculate crop canopy characteristics and canopy gross photosynthetic rate. Photorespiration rate and maintenance respiration rate are calculated and subtracted to get net photosynthetic rate, which is corrected for stomatal closure caused by water stress. The net carbon fixation rate and the rate of carbon translocation out of the leaves are also calculated in PNET. The module POTGRO calculates potential rates of growth for all organs on the plant at a given air temperature assuming that carbon, water, and nutrients are plentiful. PARTIT calculates an initial partitioning of carbon to various organs based on priorities that change with stages of growth. WATERS maintains a functional balance between root and shoot by growing roots as necessary to meet transpiration demand. It calculates potential root water uptake for a number of key shoot water potentials and compares these with the potential transpiration rate to estimate shoot water potential. Depending on shoot turgidity, the shoot or root, or both, may grow. Stomatal conductance is a function of shoot turgidity.

GLYCIM-WINGLY system provides an 'Irrigation required' message when deep water stress in simulations occurs three days in a row. Sprinkler, furrow, and flood irrigation can be simulated. Being alerted, the user can make several runs with projected weather, varying amounts of irrigation water applied and delays in irrigation start. The user selects the irrigation schedule using results of the model's runs and availability of resources to irrigate. Results of the runs can be seen both in tabular and in graphical forms.

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GPFARM DECISION SUPPORT SYSTEM FOR WHOLE FARM/RANCH MANAGEMENT

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ABSTRACT

The conceptual basis and recognized need for a systems approach for agricultural research and development in the Great Plains dates back at least 10-15 years. Sustainable agriculture in the Great Plains has become a complex problem that demands consideration of many interrelated factors, processes, and institutions. Across the Plains, agriculture is challenged by the availability of water and nitrogen. Central to meeting this challenge, a need was identified to develop the Great Plains Framework for Agricultural Resource Management (GPFARM) PC-based decision support system (DSS). GPFARM will provide management support at the whole farm/ranch level with emphasis on cropping and ranching systems, water and nutrient management, pest management, economics, environmental impacts, and risk analysis. GPFARM is targeted for use by agricultural consultants, computer-oriented producers, action agencies, federal and state extension personnel, and research scientists.
Keywords: Decision support system, Models, Modeling

GPFARM OBJECTIVE AND APPROACH

The general purpose of GPFARM is to provide an operational framework for a whole farm/ranch decision support system across the Great Plains including site-specific management, socio-economic analysis, and environmental impacts; site database generation; and risk analysis from which alternative agricultural strategies can be developed and tested. GPFARM will implement the concepts of a systems approach to address the problems of Great Plains agriculture today and in the future and will result in

The development of a decision support system that is capable of analyzing 1-10 year farm/ranch level, management plans based on the predicted productivity of selected management options and associated environmental and economic risks.

GPFARM will include soil-crop-animal simulation modules, all appropriate databases, an economic analysis package, and an environmental risk assessment module that will evaluate various preselected management options. Figure 1 shows the information the user will input and the flow of information between the soil-crop-animal, economic, and environmental modules.
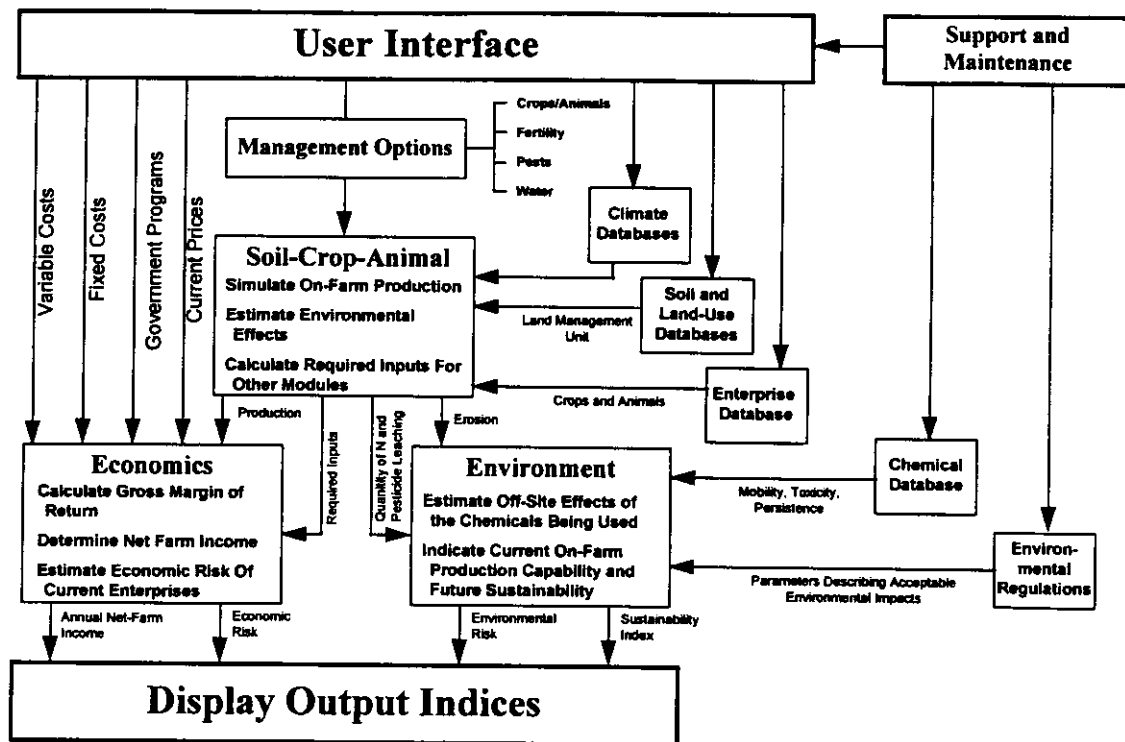
Figure 1. Modules within GPFARM

Actual development of GPFARM will be done using object-oriented design, layout, and programming techniques where feasible. A preliminary schematic of the object content and relationships for GPFARM is shown in Fig. 2.

Management options to be considered include integrated crop-livestock production, crop rotation, grazing, nutrient, water, plant and animal pests, residue cover, tillage, and snow-water conservation. The databases will include soils, land use, climate, and various management options. Climatic data will either be obtained from the GPFARM climate database, entered by the user, or estimated using a weather simulator for typical wet, average, and dry years, or any desired combination.

The soil-crop-animal simulation modules mathematically describe the various biological, physical, and chemical processes involved in crop-animal production systems; e.g. nutrient cycling, infiltration, evapotranspiration, runoff, and deep percolation, nutrient uptake, etc. Module input parameters will be contained in a separate database that can be accessed by users through the Microsoft Windows-based Graphical User Interface (GUI). Land Management Units (LMU's)

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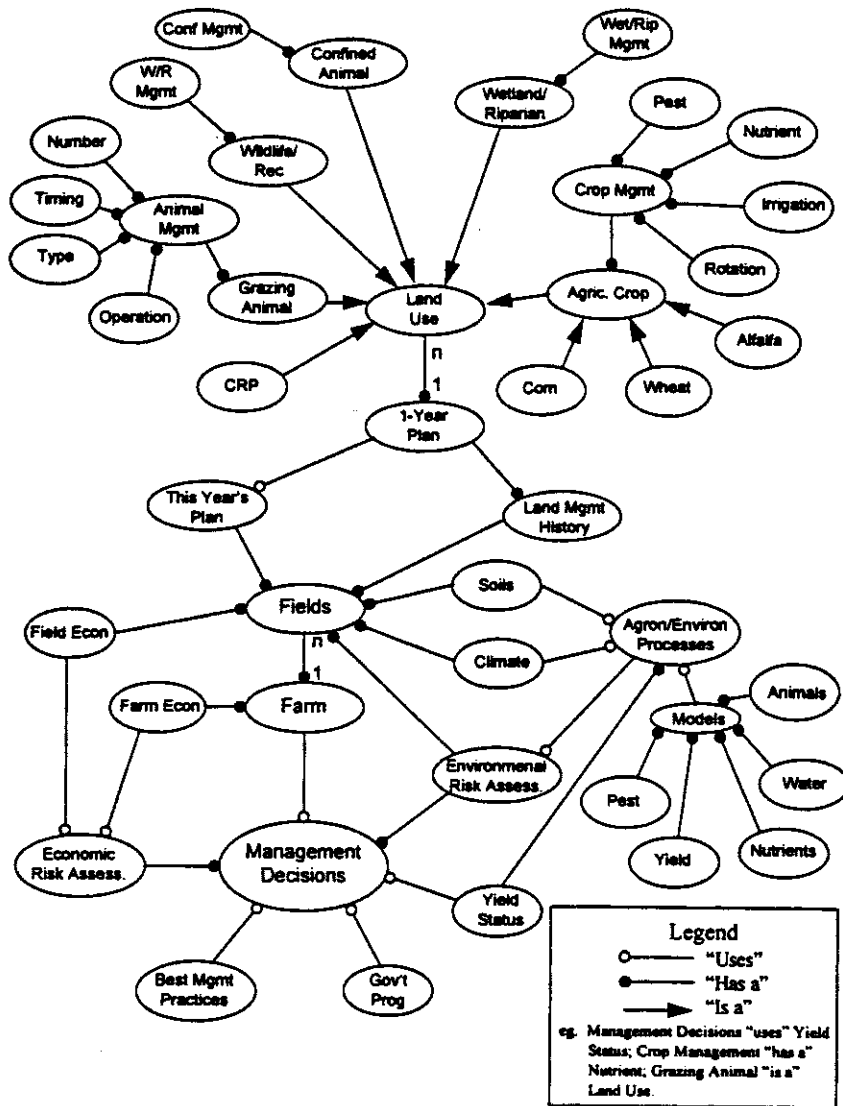
Figure 2. Objects and relationships for GPFARM

will be defined in each field and include multiple soil series and associated land use (e.g., cropland, grazinglands, wetlands, etc.). Intra-farm transfers of resources will be allowed between LMU's. Based on the selected management options and data from the various databases, the model will predict crop and animal production, water use, nutrient uptake, erosion (water and wind), and quantities of nitrate and pesticides leached. These quantities will be used for both the economic and environmental risk analyses.

Preliminary plans are to use farm enterprise budgeting procedures to determine farm profitability in terms of net farm income. The economic analysis module will use crop and animal production for each LMU from the simulation module and user supplied or database commodity prices to determine the gross income of each enterprise. An economic indicator that is understood by most of the users will be used to characterize changes in financial risk for the various scenarios.

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The environmental module will use leachate results from the simulation of each LMU to calculate environmental indices and a composite environmental index reflecting off-site vulnerability and the quantity, toxicity, mobility, persistence to breakdown, etc. of each chemical leached as well as amount of erosion. These indices will represent the potential off-farm impact on the environment. Consideration will be given to a composite index calculated from the simulation results for each LMU to reflect changes in the long-term sustainability of the farm. GPFARM will not recommend a single management scenario for maximizing profitability and minimizing adverse environmental impacts. Instead several economic and environmental indicators will be displayed to allow the user to compare different management scenarios based on the relative values of the various indicators.

GPFARM DEVELOPMENT PHASES

The development of GPFARM will progress in three distinct phases:

Phase 1 - The objective of Phase 1 is to build a prototype of GPFARM for strategic planning and analyzing 1-10 year farm level management plans based on the predicted productivity of selected management options and associated environmental and economic risks. The region of emphasis will include only selected operations of Eastern Colorado.

Phase 2 - The objective of Phase 2 is to enhance the prototype of GPFARM to include improved and expanded scientific information, to extend the geographical area of consideration from specific areas of Colorado to the entire Great Plains, to increase the number of crop and animal species represented by the system, and to offer more management options and government programs.

Phase 3 - The objective of Phase 3 is to develop a DSS useful for short-term management of crop and animal production systems by providing management recommendations with sufficient detail to manage individual subareas and soils within fields.

GPFARM PROGRAM MAINTENANCE

GPFARM will be developed over several years with a strong potential for extension to agricultural management support on a national basis. Based on the current rates of advancement of computer technology (both hardware and software), the life expectancy of GPFARM is approximately 10 years. Technology transfer and maintenance of GPFARM should be a joint interagency effort between ARS, NRCS, and Extension. ARS will maintain technical support for program bugs and extensions that may be become necessary and will also provide training for NRCS and Extension instructors. NRCS and Extension could subsequently provide training on the use and application of GPFARM within their organizations, and training of producer and other groups.

THE STREAM NETWORK TEMPERATURE MODEL (SNTEMP): A DECADE OF RESULTS

John M. Bartholow[1]

ABSTRACT

The National Biological Service's Stream Network Temperature Model (SNTEMP) is described briefly and some study applications are referenced.

Keywords: Water temperature model, SNTEMP, SSTEMP, Mathematical models, Thermodynamics

INTRODUCTION

The Stream Network Temperature Model (SNTEMP) was developed to help aquatic biologists and engineers predict the consequences of stream manipulation on water temperatures. Water temperatures may affect aquatic systems in many ways, ranging from acute lethal effects, to modification of behavioral cues, to chronic stresses, to reductions in overall water quality. Manipulations may include reservoir discharge and release temperatures, irrigation diversion, riparian shading, channel alteration, or thermal loading. The model has been used to help formulate instream flow recommendations, assess the effects of altered stream flow regimes, assess the effects of habitat improvement projects, and assist in negotiating releases from existing storage projects.

SNTEMP's development was a cooperative effort between the Soil Conservation Service and the U.S. Fish and Wildlife Service as one component of the Instream Flow Incremental Methodology (IFIM; Stalnaker et al., 1995). The design criterion was to produce reasonable predictions with readily available data; the result was the SNTEMP (Theurer et al., 1984). Later, an offshoot of SNTEMP, the Stream Segment Temperature Model (SSTEMP) was developed by Bartholow (1990).

DATA REQUIREMENTS

SNTEMP is a mechanistic, one-dimensional heat transport model that predicts the daily mean and maximum water temperatures. Net heat flux is calculated as the sum of heat to or from long-wave atmospheric radiation, direct short-wave solar radiation, convection, conduction, evaporation, streamside vegetation (shading), streambed fluid friction, and the water's back radiation. SNTEMP requires that the spatial layout of the hydrologic network be defined by subdividing it into stream segments with homogeneous characteristics such as flow, width, and

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shading. Each homogeneous stream segment is described by its length, top width, slope, channel roughness (Manning's n) or travel time, and shading characteristics. The meteorological influences are described by air temperature, relative humidity, wind speed, percent possible sun (inverse of cloud cover), and ground-level solar radiation. The flow of surface and ground water into each stream segment, along with their respective water temperatures, are also required inputs. The full list of data requirements is given by Bartholow (1989).

SNTEMP APPLICATIONS

SNTEMP has been used in a variety of applications. Theurer developed SNTEMP using two case studies to ensure model applicability and match with the development objectives (Theurer et al., 1982, 1985). These ranged over two scales: the vast upper Colorado River basin and the smaller Tucannon River. Since maturation, the model has been used widely, especially by consultants dealing with biological flow requirements in bypass reaches below hydropower facilities (Lifton et al., 1985, 1987; Voos et al., 1987). SNTEMP has been used in a broad range of applications, from the cold water of Alaska (Meyer et al., 1983) to the much warmer water of Nebraska (Dinan, 1992). The model has also been applied in less conventional situations, such as evaluating standards for streamside timber removal (Sullivan et al., 1990), revegetation requirements to increase shading and channel restoration (Bartholow, 1991, 1993), and channel manipulation to increase salmon rearing habitat by removing vegetated berms (Zedonis, 1994). SNTEMP has even been used below a peaking hydro facility (Waddle, 1988), something it was not designed to do. Increasing use of SNTEMP in conjunction with fish population models seems to be a recent trend (Bartholow et al., 1994).

SSTEMP, the offshoot model, is extremely easy to use because of its similarity to commonly available spreadsheet applications. The ability of both models to calculate solar radiation and streamside shading has also proven to be a strength; many other water temperature models do not have this capability. Even if the heat flux and heat transport components of SNTEMP are not used in a specific application, the solar and shade submodels may be used with other temperature modeling approaches (Sullivan et al., 1990; Tu, 1991; J. Risley, U.S.G.S. Portland, personal communication). Components of the models have been well validated (Theurer and Voos, 1982; Theurer, 1985; Mattax and Quigley, 1989; Bartholow, 1993), and their performance has compared favorably in side-by-side evaluations with other water temperature models ranging from simple to more complex (Sullivan et al., 1990, Tu and Liu, 1992).

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IRRIGATION SCHEDULING WITH CLIMATIC DATA

Gerald W. Buchleiter, Dale F. Heermann, Harold R. Duke[1]

ABSTRACT

SCHED is a simple soil water budget model developed to help farmers improve water management under center pivots. Two options are available for calculating evapotranspiration. Soil water depletions are used to recommend a range of dates for the next irrigation. Data requirements are small and becoming more widely obtainable by farmers.
Keywords: irrigation scheduling, evapotranspiration, center pivot

INTRODUCTION

Jensen et al. (1971) developed many of the original irrigation scheduling concepts based on the assumption of an adequate water supply. Heermann et al. (1976) extended the irrigation scheduling concepts to center pivots by recommending a range of dates rather than a single date for the next irrigation. The computerized irrigation scheduling program, SCHED, uses these basic concepts to help farmers improve irrigation management of center pivots at the field level.

MODEL DESCRIPTION

The irrigation scheduling program is based on a simplified daily soil water budget of the root zone during the growing season. Because of the desire to minimize the complexity of modeling all of the processes and associated data requirements, the program does not partition applied water into infiltration and surface runoff or handle specialized situations such as salinity or high groundwater tables. The assumption is made that the center pivot system is reasonably well designed and managed so runoff potential is minimized by matching water application with the soil's infiltration capability and temporary surface storage. The growing season is defined in terms of four dates - *planting, root development, effective cover* and *harvest* - which are either known or can be readily estimated by the farmer. *Planting* is the date when the seed is planted or the breaking of winter dormancy in the case of a perennial crop. *Root development* is the date when roots begin expanding usually 10-14 days after planting. *Effective cover* is the date when the crop reaches the maximum vegetative state and water use rate. *Harvest* is the date when crop water use ends either because of physical removal of the crop or a killing freeze.

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Soil water budget

The simplified soil water budget that expresses depletion of available soil moisture in the root zone is given by:

$$\text{Depl} = \text{Depl}_{\text{Prev}} + \text{Et}_a + \text{E}_{ws} - \text{I} - \text{R} + \text{Perc} \tag{1}$$

Depletion is the difference between the total water available and the actual water in the root zone. Total water available is the product of the water holding capacity and the rooting depth plus any transient, free-draining water moving through the root zone. The rooting depth is assumed to increase linearly as a function of time from a user specified minimum root depth at the *root development* date to a maximum root depth at *effective cover* date. Prior to the *root development* date, a minimum depth of soil assumed necessary for germination and emergence is specified. After the *effective cover* date, the root depth is assumed to remain constant at the specified maximum root depth. $\text{Depl}_{\text{Prev}}$ is depletion in the root zone for the previous day.

Crop water use is modeled as a two step process. The first step is to calculate the maximum water use of an actively growing reference crop, Et_{ref}, such as alfalfa. Of the two methods provided, the modified Penman equation does the best overall job in calculating ET, especially in semi-arid areas which have large amounts of wind. The modified Penman equation requires daily data on maximum and minimum temperatures, solar radiation, vapor pressure, and wind run. Automatic weather stations, which record and store data electronically, typically collect these data. If all of these data are not available, the user may select the Jensen-Haise equation, which requires only maximum and minimum temperature and solar radiation data, to calculate Et_{ref}.

Actual crop water use, Et_a, is calculated by multiplying Et_{ref} by an empirically determined, basal crop coefficient, based on the stage of crop growth and a moisture stress coefficient based on the depletion level of the root zone. Two sets of third degree polynomial coefficients are required; the first set is applicable from *planting* to *effective cover* and the second set is applicable from *effective cover* until *harvest*. Computed crop water use assumes a dry soil surface. Evaporation, E_{ws}, occurs from the soil surface for several days following rainfall or irrigation, particularly while the crop is small. An exponential function approximates field observations about the duration of a wet soil surface following a precipitation event. For sandy soils, the soil surface usually dries out in 1 or 2 days while in heavier clay soils, the soil surface remains wet for 3 or 4 days.

Water is applied either by rainfall, R, or irrigation, I. Since it is difficult to obtain infiltration and conductivity parameters representative of an entire field in order to model water movement through the root zone, a simplified, empirical approach is used. A separate component is maintained for transient water assumed to infiltrate in excess of the field capacity. An exponential function, based on the water holding capacity of the soil, determines the fraction of the transient component available for crop use. The remainder of the transient water is considered percolation, Perc, below the root zone. Soil water budgets are

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maintained at two points in each field. The first point is where the irrigation normally begins and the second point is where the irrigation normally ends. Depletions are updated periodically using measured values for weather, rain and irrigation data. Based on expected crop water use rates, depletions in the root zone are projected into the future to determine how much water can be applied without overfilling the root zone. Based on these projected depletion levels, a range of dates for the next irrigation is recommended, giving the farmer some leeway in coordinating irrigations with other cultural practices. Assuming that soil water depletions are reasonably consistent around the field, the depletion at the starting point determines the *earliest date* to irrigate without overfilling the root zone, while the depletion at the ending point determines the *latest date* that irrigation must begin to avoid exceeding the allowable depletion. Generally this approach works well except in some situations early in the growing season when the intended irrigation depth exceeds the maximum allowable depletion of the minimum root zone. In this case, a single date determined by the *latest date* is recommended and usually causes some overirrigation at the beginning of the irrigation. This overirrigation can be reduced by increasing the system speed and applying smaller depths until the root zone has increased sufficiently to hold larger irrigation depths.

MODEL OPERATION

The irrigation scheduling program, SCHED, is written in QuickBASIC for use on microcomputers with MS-DOS 2.0 or higher. It is menu driven with prompts to explain the options available. Details about operating the program are given in the User's Guide which is distributed with the program.

Model Inputs
During the initial startup, data files are automatically created for weather, rainfall, irrigation, field, and crop coefficient data. Although default values are provided for the various parameters, these files must be edited with the specific information for each field and crop grown. Ranges of values for the water holding capacity, the main soil parameter, can be found in soil surveys, agronomy textbooks or the User's Guide. Water holding capacity can also be computed from 1/3 and 15 bar water retention tests done in the lab. Required crop information includes the planting, root development, effective cover, and harvest dates, and minimum and maximum rooting depths. Usually the farmer knows these dates, but general guidelines are given in the User's Guide for determining effective cover dates in temperate regions in the western United States. Local experience should be used when possible to estimate effective cover, which usually occurs at the time of about 80-90% of ground cover. Unusually cool weather may slow crop development, necessitating adjusting the apparent planting and effective cover dates to match the computed with actual ET rates. Polynomial coefficients for computing the basal crop coefficient for many of the prevalent crops in the Central Plains of the U.S. are given by Duke et al. (1987) as well as in the User's Guide. Third order polynomial coefficients for additional crops can be developed by simple regression analysis of published crop coefficients. If these crop coefficients use a different reference crop, additional adjustments must be made to account for the different reference

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crop. The irrigation system data includes the irrigated area, discharge, minimum time to complete a revolution, pivot speed and application efficiency. These data, except for application efficiency, are usually known by the farmer or obtainable from the center pivot dealer. In the absence of more reliable data, 0.85 is a reasonable estimate of application efficiency for center pivots.

After the initialization has been completed, data entry consists of weather data, rainfall and irrigation amounts for each field on a daily basis. If depletions were measured in the field during the update period, they are also entered. Weather data can also be imported electronically with the use of a modem and appropriate telecommunication software. Rainfall is measured with a raingauge in the vicinity of the field. Irrigation can either be measured with a raingauge above the crop canopy or it can be calculated on a net basis from the flow rate, time to complete a revolution, irrigated area, and application efficiency.

Model Output

Although daily input data are required, the user can choose the update date for producing an irrigation schedule. Soil water budgets are projected for 10 days in the future from the update date using the same budgeting procedures but with an average Et_{ref} based on an exponential function fitted to historical data. If the evaporative demand is expected to differ significantly from normal, the user can either increase or decrease the forecasted Et_{ref} by 10%. The *earliest date* is when the projected depletion exceeds the irrigation depth that the farmer intends to apply. The *latest date* is when irrigation must begin so the maximum allowable depletion is not exceeded when the irrigation is completed.

Three choices of printed output are available depending on the degree of detail desired by the user. The simplest output prints the actual crop water use on a daily basis for the update period and the estimated crop water use for the next 10 days. Typically this output choice is used by action agency personnel who provide general water use information for various crops in a region. No soil water budgeting is performed, so farmers must devise their own ways for recording and utilizing this information. The second choice, which is the most detailed, provides a daily accounting of the various components of the soil water budget, projected soil water depletions for the next 10 days, and a recommended range of dates for the next irrigation assuming three different rainfall amounts. The third choice provides an abbreviated form of the second choice. The cumulative amounts of the various water budget components for the entire update period and the recommended range of dates for the 'no rainfall' condition are printed out.

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BASIN-SCALE ASSESSMENT OF A NON-POINT SOURCE POLLUTANT IN THE VADOSE ZONE

D.L. Corwin, P. J. Vaughan, J. D. Rhoades and D. G. Cone[1]

ABSTRACT

A one-dimensional, solute transport model TETrans has been integrated into the geographic information system ARC/INFO for the purpose of determining areal distributions of salinity in the soil profile and of estimating salt loading to the groundwater. Approximately two-thirds (2396 hectares) of the Broadview Water Distict located on the westside of the San Joaquin Valley of central California was used as the test site to evaluate the coupled GIS/solute transport model. Results of the TETrans calculations are presented for a single growing season (1991). Display maps show calculated estimations of salt-loading to groundwater and predictions of potentially salt-affected soils. The maps provide the visual information essential for formulating irrigation management strategies to minimize groundwater pollution, reduce water usage, lower shallow water tables, and reclaim deteriorating soils without adversely impacting crop productivity.

INTRODUCTION

The objective of this study was (1) to integrate a functional solute transport model for the vadose zone into a GIS for the basin-scale (thousands of hectares) assessment of a non-point source pollutant (i.e., salinity) and (2) to demonstrate the utility of this approach by producing maps of salt accumulation in the soil and salt-loading to the groundwater for a representative water district on the westside of the San Joaquin Valley known to have shallow water tables and salt-affected soils.

The functional solute transport model TETrans, introduced by Corwin and Waggoner (1990 and 1991) and Corwin et al. (1991), has been integrated into the ARC/INFO geographic information system. A detailed description of the coupling of TETrans to ARC/INFO can be found in Vaughan et al. (1993), and Vaughan and Corwin (1995).

TETrans is a mass-balance, layer-equilibrium model often referred to as a "tipping-bucket model". It defines nonvolatile solute transport as a sequence of events or processes: (i) infiltration and drainage to field capacity, (ii) instantaneous chemical equilibration for reactivesolutes, (iii) water uptake by the plant roots resulting from transpiration, (iv)

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evaporative losses from the soil surface, and (v) instantaneous chemical reequilibration. Each process is assumed to occur in sequence as opposed to the collection of simultaneous processes which actually take place in nature. Furthermore, each sequence of events or processes occurs within each defined soil layer of a finite collection of discrete soil layers forming the soil profile. From a knowledge of water inputs and losses, and of soil-solute chemical interactions, TETrans predicts the average solute concentration for each defined soil layer through the vadose zone.

RESULTS AND DISCUSSION

Display maps showing areal distributions of irrigation efficiency (i.e., leaching fraction), soil salinity concentration profiles (for 0-0.30, 0.30-0.63, 0.60-0.90 and 0.90-1.20 m depth increments), total drainage, and total salt loading to the groundwater were created. A detailed discussion of all maps has been previously given by Corwin et al. (1994).
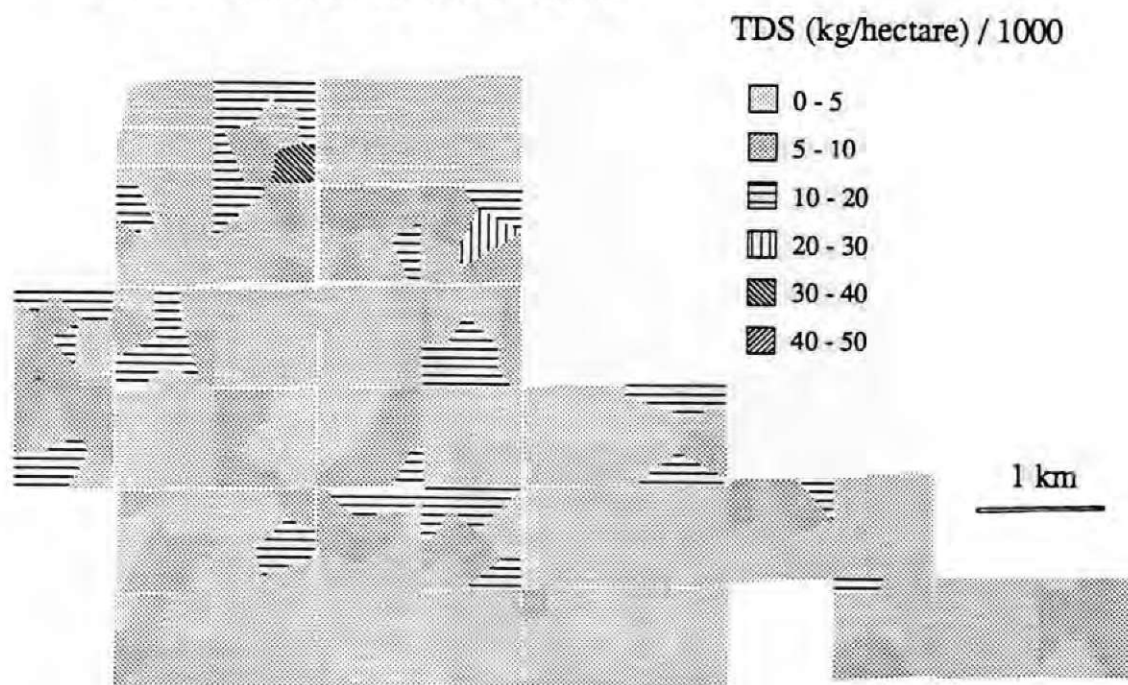
Figure 1. Spatial distribution of the simulated amount of salt draining beyond the root zone.

Figure 1 illustrates the amount of salt which has drained beyond the root zone and will ultimately enter the groundwater. Most of the area shows very little salt loading because a

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significant portion of the study area was fallow for the time period simulated (i.e., April to September, 1991). Nevertheless, the map clearly shows areas in the north where considerable salt-loading is occurring. To reduce the downward movement of salts into the groundwater in these areas a reduction in the amount of applied irrigation water is needed. However, these areas are also high in soil salinity within the root zone (see Figure 1); consequently, reducing the leaching fraction may elevate the salinity in the root zone to a level which is detrimental to crop grow. An alternative would be to select a more salt tolerant crop.

Figure 2 provides an inventory of salt-affected soils for the study area. Areas of high, medium and low simulated salinity development are shown. This map provides a visual means of quickly assessing areas of potential concern for crop productivity purposes. Areas high in soil salinity either require increased leaching to remove salts and the addition of a drainage system to prevent groundwater degradation, or the selection of salt tolerant crops. Areas of moderate and low salt accumulation require less drastic strategies allowing the irrigation manager to select less salt tolerant crops and to consider the option of using a lower quality irrigation water without detrimental effects.

Soil Salinity Inventory (9/30/1991)

EC$_e$ (dS/m)

- 0 - 2 (low salinity)
- 2 - 4 (moderate)
- >4 (saline)

1 km
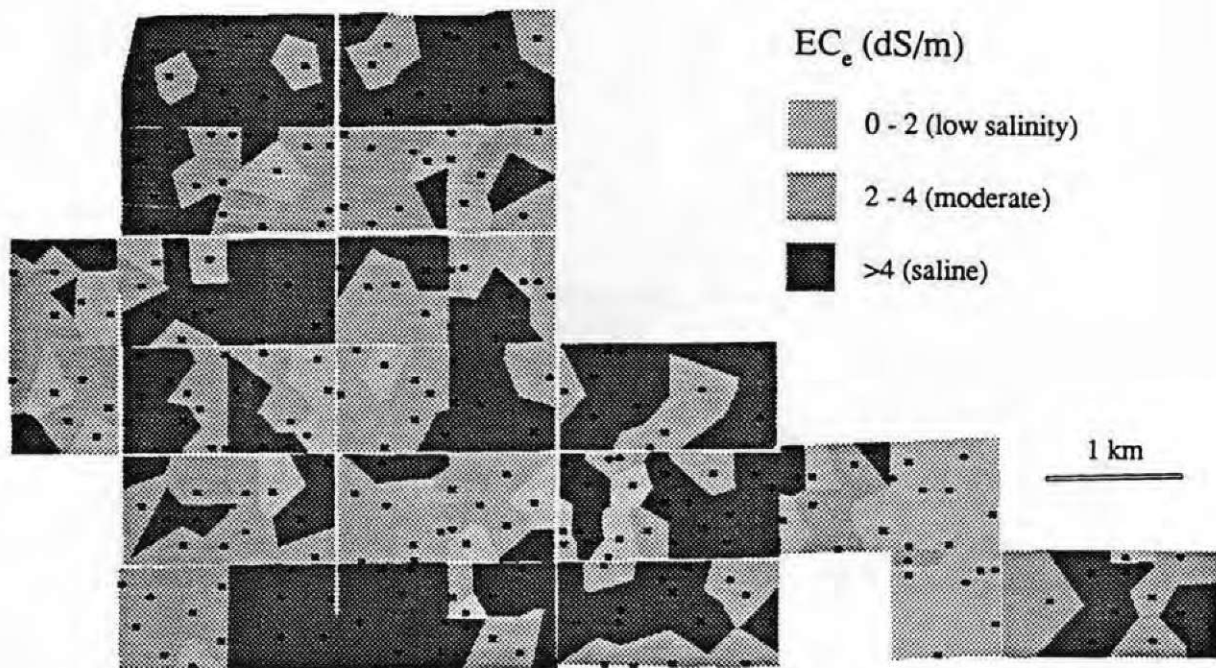
Figure 2. A real distribution of the calculated depth-averaged soil salinity (top 1.2 m of soil) for the preliminary 6-month study period of the Broadview Water District study area.

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AGRICULTURAL METEOROLOGICAL INFORMATION SYSTEMS

Paul Davidson and Monte McVay[1]

ABSTRACT

The Bureau of Reclamation, in cooperation with the Bonneville Power Administration (BPA), has developed a real time data collection and information system called "AGRIMET." This system promotes energy and water conservation through expanded data support for irrigation management and scheduling programs.

AgriMet field stations automatically collect site-specific weather data and translates that data through crop models into local crop water use information. The primary emphasis is on irrigation management -- applying the right amount of water at the right time. While the original purpose was prediction of evapotranspiration (the amount of water used by a crop), other uses are being recognized as AgriMet expands. Other uses that have already been included are integrated pest management, frost protection, and other crop management activities.

AGRIMET

Brief Description/Purpose: AgriMet has expanded from the initial partnership between Reclamation in the Pacific Northwest and Bonneville Power Administration. Cooperative sponsorship now includes public and private electric utilities, land grant universities, Cooperative Extension Systems, Natural Resource Conservation Service, local conservation districts, the Agriculture Research Service, irrigation districts, and other state and local water resource agencies and organizations.

To model local crop consumptive use, AgriMet stations automatically monitor and "phone home" by satellite (Geostationary Operational Environmental Satellite, GOES) the climatic parameters required to calculate a daily reference ET based on the 1982 Kimberly-Penman equation. AgriMet stations are located in irrigated agricultural settings to monitor weather parameters representative of the evaporative demand on irrigated crops. Each AgriMet station monitors air temperature; relative humidity; solar radiation; precipitation; and wind "run," speed, and direction. The stations are powered by a solar charged 12-volt battery. A data collection platform (DCP) located inside a weather-tight box interrogates the sensors at programmed intervals -- every 15 minutes or hourly, depending on the parameter. The DCP transmits the data every four hours via the GOES satellite to Reclamation's downlink in

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Boise, Idaho. The data is transferred to various Reclamation Offices and is decoded, quality checked, and incorporated into Reclamation's main computer database. Crop water use models are run daily to translate the local climatic data into daily ET information for crops at each station.

The AgriMet system is very economical when compared to more conventional remote collection systems (i.e., line-of-sight radio or phone systems). Field stations require little maintenance, are self-contained, require no external power source, and normally need only one "tuneup" visit per year. Reclamation's use of the GOES satellite system provides AgriMet the ability to place a station anywhere in the western United States. The economics of the system is appealing to many of Reclamation's partnerships because it allows them to concentrate more of their financial resources in developing their out-reach programs.

Anyone with a computer, modem, and an AgriMet user account can gain access to weather data or site-specific daily crop water use information. Local program coordination, quality control, and model calibration is handled through cooperative arrangements with Natural Resources Conservation Service field offices, Cooperative Extension agents, water resource agency specialists, and private consultants. Through their technical assistance, AgriMet is providing site-specific crop water use information in support of on farm irrigation management and scheduling programs.

Evapotranspiration: ET is one of the primary elements of the hydrologic cycle. It represents the primary use of water by a growing crop or vegetation and is strongly influenced by the nature and amount of canopy, water content of the root zone, and local weather conditions.

Plants extract water from the soil to satisfy an evaporative demand in the atmosphere. Evaporative demand is characterized by both atmospheric variables and the aerodynamic and radiative properties of the particular plant and soil environments. Solar radiation is the most significant climatic factor affecting evaporative demand in that it is the driving source of energy necessary to transfer water from a liquid to the vapor phase in plants and at the soil surface.

In all actively growing plants, there is a liquid phase continuity from the water in the soil through the plant to the liquid-gas interface at evaporation sites in the leaves. Water moves in the liquid phase of the soil-plant system in response to differences in the potential energy of water in the system. For water to move from the soil into the plant, the potential in the plant must be lower than that in the soil. The potential gradient in the soil-plant system results from water losses by transpiration at the plant leaf surfaces. As transpiration progresses, plant water must be replenished by water uptake from soil through the roots.

The loss of water through plants is mainly by transpiration through stomates, although evaporative demand also results in some direct evaporation of moisture from leaf and soil surfaces. The relationship between transpiration and evaporative demand is dynamic and

complex. Basically, when the soil water content reaches approximately 50 percent of the available water holding capacity in the root zone, then the available water begins to govern ET rather than atmospheric demand.

Parameters affecting the relationship between transpiration, evaporative demand, and the soil water status include such things as root distribution and density, soil water potential and aeration within the crop root zone, soil hydraulic conductivity, stomatal sensitivity to leaf water potential, and internal plant resistance. The quantitative response of evapotranspiration to evaporative demand is not a straightforward prediction due to the complicated feedback between the atmosphere, the crop canopy, and the soil reservoir. As a result, many empirical relations between evapotranspiration and evaporative demand have been developed to characterize crop water use.

Crop Water Use Modeling: While agricultural water requirement information has always been essential in the planning, design, and operation of irrigation projects, it has seldom been practical or cost-effective to obtain such data directly through local field measurements. Consequently, numerous predictive equations utilizing meteorological data have been proposed to estimate crop evapotranspiration demand. Most of these are empirical, based on the correlation of measured ET (usually with weighing lysimeters) with calculated relationships involving one or more climatic factors.

It is important to note that none of the equations to predict crop water use are universally accurate, and the use of each for particular applications depends upon such things as the availability of data, the ease of computation, user acceptance, and the time increment of interest. Generally, the equations which use only temperature or temperature and solar radiation are simpler and require the least data input. The "combination" equations are more complex and require more extensive data since they attempt to model the plant's complete evaporative demand environment. The combination equations generally perform better, particularly for short time increments such as daily. The term "combination method" is from the combining of net radiation (the "heat function") and advective energy transfer (the "wind function") into one equation. In essence, they are attempts to quantitatively model, through an overall energy balance, the complicated evaporative demand feedbacks between the atmosphere, the crop canopy, and the soil reservoir.

While an energy balance concept was applied to evaporation from water surfaces in the 1920's and 1930's, it was first applied to cropped surfaces by Penman in 1948. Throughout the intermountain west a modified form of the original Penman equation, the 1982 Kimberly-Penman, has been used for crop water use modeling. It was adapted from research work conducted by the Agriculture Research Service (ARS) at Kimberly, Idaho. The 1982 Kimberly-Penman equation requires meteorological inputs that include maximum and minimum daily temperatures, relative humidity, daily solar radiation, and daily wind movement. These parameters are all available from any AgriMet station.

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A full report detailing the different equations as they are applied in AgriMet is available from Reclamation. A report which describes the crop curves used to convert reference ET into specific crop ET is also available. For additional information about Reclamation's AgriMet network, contact either Paul Davidson in Billings, Montana, at 406-247-7758 or Monte McVay in Boise, Idaho, at 208-378-5282.

THE MONTANA MISSOURI RIVER MODEL AND ITS USE IN A BASIN-WIDE WATER ALLOCATION PROCEEDING

Larry S. Dolan[1]

ABSTRACT

The Montana Department of Natural Resources and Conservation developed a hydrologic model to analyze water allocations in the Missouri River basin. The model is a FORTRAN program which uses a mass-balance approach to compute monthly streamflows, reservoir operations, hydropower production, and irrigation and municipal water uses for a 59-year base period. The model uses a monthly time step, and simulation results are presented as monthly mean and percentile-exceedence values. Results from the model were used to develop two environmental impact statements (EISs), addressing applications to use basin waters for consumptive and instream purposes. The EISs assessed potential impacts to water quantity and distribution, water rights, water quality, stream channel form, fisheries, wildlife, recreation, hydropower production, and economics. (KEY WORDS: water policy and decision making, water planning, hydrologic modeling, Missouri River, environmental impact statements).

MISSOURI BASIN WATER RESERVATION PROCEEDING

In 1985, the Montana Legislature directed the Montana Department of Natural Resources and Conservation (MDNRC) to initiate and coordinate a water reservation proceeding in the state's Missouri River basin. During the proceeding, public entities were encouraged to apply to set water aside for future consumptive and existing instream uses. The legislature initiated the process for two reasons. First, it believed the proceeding would encourage a balanced approach to the development and protection of water resources in the basin. Second, water reservations were regarded as a way to build a strong legal basis for protecting Montana's share of Missouri River water from downstream states.

Due to the vast size of the basin, the proceeding was split at Fort Peck Dam, with applications in the upper portions of the basin acted on first. The applications received in both portions of the basin are summarized in Table 1.

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[1] Department of Natural Resources and Conservation, Helena, MT

Table 1. Summary of Applications to Reserve Water in the Missouri Basin of Montana.

Applicant	Purpose
22 Cities	Water for future growth
29 Conservation Districts	Irrigation of about 250,000 acres
MT Department of Fish, Wildlife and Parks	Instream flow protection for fish, wildlife and recreation on 304 streams
MT Dept. of Health and Environmental Sciences	Instream flows on the Missouri River to maintain water quality
US Bureau of Land Management	Instream flows on 35 headwater streams
US Bureau of Reclamation	Trans-basin diversion of water from Missouri River to Milk River

MISSOURI RIVER MODEL

The Missouri River model is a water mass-balance program written in the FORTRAN computer language. The model computes monthly streamflows, reservoir operations, hydropower production, and irrigation and municipal water uses. In general, the basin's monthly water budget is simulated by estimating gains and losses to streamflows above or between each of the 40 locations or "nodes" depicted in the model schematic (Figure 1). The model is made up of four major components: (1) the irrigation component, (2) the municipal component, (3) the dam and reservoir operation components, and (4) the streamflow component.

Irrigation Component

The irrigation component of the model computes monthly irrigation diversions, crop consumption, losses, and return flows for existing and proposed irrigation within each node basin. This component of the model also adjust irrigation depletions to a "baseline" level. Depletions computed in the irrigation component are then passed on to the streamflow component of the model.
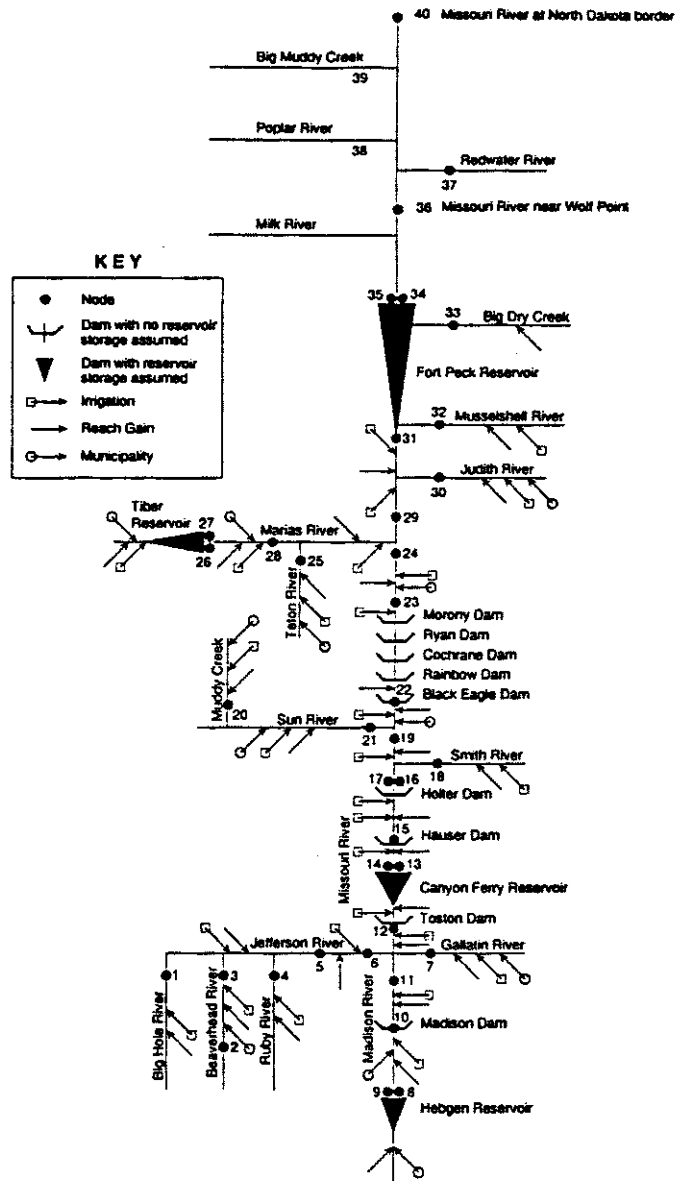
Figure 1. Missouri basin model schematic

Municipal Component

The municipal component of the model was used to account for new municipal uses. Monthly municipal depletions by node are computed based on diversions, system leakage, consumption, evaporation, infiltration, and surface discharges for each municipal water system. Gains or losses in streamflows from the municipal component are passed on to the streamflow component.

Dam and Reservoir Components

The dam and reservoir components of the model simulate the operation of 13 dams and reservoirs. Nine of these dams are simulated as run-of-the-river hydropower facilities. The model computes monthly power production at these dams using streamflows calculated in the streamflow component of the model, along with turbine capacities, generator ratings, and reservoir water levels. The remaining four reservoirs have sufficient storage to alter monthly streamflows. The subroutines used to simulate operations at these dams compute monthly reservoir outflow, storage, water level, spillage, and power production.

Streamflow Component

Monthly streamflows at each node are simulated in this component of the model by combining estimated and recorded historical monthly streamflows (USGS, 1989) with results from the irrigation, municipal, and reservoir components of the model.

Model Results

The simulated monthly streamflows and reservoir operations for the 59-year base period are summarized by the model as monthly mean and percentile exceedence streamflows, reservoir levels, storage volumes, spillage, and power production values.

DEVELOPING THE ENVIRONMENTAL IMPACT STATEMENTS

The Montana Board of Natural Resources and Conservation (Board) was responsible for deciding on whether to grant, deny, or modify the reservation requests. Two EISs were prepared by MDNRC--one each for the upper and lower portions of the basin (MDNRC 1991-1992, and 1994)--to inform the Board, and the public, of potential impacts that could occur as a result of a Board decision. In the EISs, MDNRC assessed the impacts of hypothetical "alternatives" which encompassed a range of Board decision scenarios.

The model was used to simulate basin streamflows and reservoir operations under the various alternatives, and to compare these to baseline conditions. The information was then summarized and distributed to all the MDNRC staff resource area specialists working on the

EISs. Resource areas examined included water quantity and distribution, water rights, water quality, stream channel form, fisheries, wildlife, recreation, hydropower production, and economics.

For some resource areas, potential impacts could be quantified using the model results. To assess impacts to hydropower, electricity production at each facility under each alternative was compared to baseline conditions, and estimated hydropower losses in Gigawatt hours calculated. These losses were then multiplied by their dollar value to compute costs. Another concern was potential losses to recreation values if streamflows and reservoir levels were decreased as a result of new consumptive-use development. To address this concern, the value of an acre-foot of water for recreation at different locations in the basin was estimated (Duffield et al., 1990). Then, for each alternative, modeled streamflow reductions were multiplied by the recreation value of the water to estimate these costs.

For resource areas where impacts could not be directly quantified, for instance to fisheries and wildlife resources, model results were used qualitatively. Here the simulation results provided the staff specialists with an idea of the magnitude of flow changes that would occur at a particular node, under each alternative. The specialists then used this information to estimate impacts to the resource.

Model results and summary figures presented in the EISs illustrated to the general public and decision makers the magnitude of streamflow reductions that could occur under each alternative.

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MODELING OF IRRIGATED AND DRYLAND CORN PRODUCTION SYSTEMS IN EASTERN COLORADO

H.J. Farahani, L.R. Ahuja, G.A. Peterson, G.W. Buchleiter and L.A. Sherrod[1]

ABSTRACT

Mathematical modelling of agricultural systems is an effective way to synthesize knowledge regarding the effects of alternate management practices on crop production, soil and water conservation and water quality. We assessed the ability of the USDA/ARS Root Zone Water Quality Model to simulate irrigated and dryland corn production systems in eastern Colorado. The intentions were to gauge model usefulness to: 1) evaluate ground water contamination of nitrate on vulnerable sprinkler irrigated sandy soils, and 2) to assess the effects of residue management on water conservation in dryland/no-till farming. Results from seasonal simulation runs were compared to field measurements of soil water and nitrate, crop yield/biomass production, crop water and N uptake, and water and nitrate leaching below the root zone. The overall performance of the model was satisfactory considering the wide range of crop water availability between irrigated and dryland sites. The model suggests that under dryland/no-till farming in semi-arid eastern Colorado with in-frequent rainfall, retardation of soil evaporation by a flat surface residue is minimal. In regard to ground water quality, the model identified irrigation scheduling as a major factor affecting water and nitrate leaching on irrigated sandy soils. For instance, model simulation of a typical practice of 40% over-irrigation (above crop water use) resulted in a 250% increase in water and nitrate leaching. The model was found to have educational utility and provided a research tool to synthesize knowledge, identify knowledge gaps, and enhance transfer of technology.
Keywords: Soil Evaporation, Nitrate Leaching, Residue

INTRODUCTION

Considerable time and effort is needed to experimentally study the impacts of alternate agricultural management practices on production and the environment. This limitation necessitates the use of system-wide mathematical models to synthesize and enhance our understanding of complex and highly interrelated processes in the natural environment. Models which adequately describe the system can be used to quickly and efficiently evaluate the effects of management practices on production and the environment, aid in identifying knowledge gaps for future research, and facilitate transfer of management technologies to

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other sites with less need for expensive and timely measurements. The USDA/ARS Root Zone Water Quality Model (RZWQM) is a prime example of such a system-wide agricultural model. Assessment of RZWQM performance for a variety of soil, crop, climatic conditions and management practices is needed to gauge model usefulness.

Our main objective was to evaluate the ability of RZWQM to simulate center-pivot irrigated and dryland/no-till corn production systems in semi-arid eastern Colorado by comparing field measured with model predicted values for crop yield/biomass and important components of the soil water and N budgets.

Numerous studies have documented the vulnerability of sandy soils to leaching of nitrates and emphasized the need for sound water and nitrogen management practices to reduce nitrate leaching and the potential for groundwater degradation (Smika and Watts, 1978; Hergert, 1986). The site selected for model evaluation of irrigated corn production and groundwater contamination was extensively monitored during the 1970's (Duke et al., 1978). The coarse textured soils in the area are easily adapted to sprinkler irrigation, but their low water holding capacity coupled with frequent irrigation to safeguard against mechanical breakdown and crop failure provide a relatively high potential for deep percolation of water and solutes below the root zone.

The experimental data from the on-going "agroecosystem management project" of Peterson et al., (1993) provided the measurements for model evaluation of dryland/no-till farming. In the dryland study, crop production is mainly limited by water availability and surface residue management is considered as the key to efficient use of precipitation by reducing soil evaporation and enhancing soil intake characteristics. While these effects enhance soil water storage, their relative dominance is not clearly understood. In order to better understand the effectiveness of residue on soil evaporation, we utilized RZWQM along with it's newly revised evapotranspiration (ET) model that partitions ET into bare and residue covered soil evaporation and crop transpiration (Farahani, 1994).

RESULTS

Prior to evaluation, model parameterization is needed to ensure proper model behavior for the particular crop and site. We parameterized the corn plant growth using seasonal field data from 1972 for the irrigated site and 1991 data for dryland. Evaluation runs, using the parameterized model, were conducted comparing model results with measurements from the subsequent year (irrigated) and from different soils and sites (dryland).

For the irrigated system, seasonal comparison of model output against measured soil water, crop water use, grain yield/biomass, and nitrate and water leaching below root zone were in good agreement, deviating by 5 to 22% from measured values. We feel that RZWQM can be used to simulate sprinkler irrigated corn growth and evaluate the effects of various management practices. A simulation run was made to predict the impact on water quality if

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the corn field were over-irrigated by 40% above crop water use which is a typical scenario in this alluvial aquifer area where soils are sandy, water is relatively abundant, pumping depths are shallow, and few irrigators schedule irrigation based on crop needs. Deep percolation of water and nitrate below the root zone increased by 250% that could potentially reach the alluvial aquifer 65-100 ft below the soil surface. Model suggests that successful BMP strategies must consider irrigation management on these sandy soils with low water holding capacities. Currently, RZWQM is being used to evaluate long-term effects of various combinations of irrigation water- and N-scheduling on nitrate loading and leaching.

In each of the two dryland sites, the treatment plots have three soil types relating to three slope positions (summit, side, and toe). The particular system selected for simulation was the 1991 corn phase of the wheat-corn-fallow system. This included six different data sets with each representing the mean of two replicated plots. It is well established that runoff water from the upland positions contributes to the lowland toeslope positions resulting in significantly greater productivity. RZWQM was found to respond to changes in available water between slope positions and site locations as reflected in yield/biomass and crop water use. However, production was under-predicted on toeslopes due to inadequate available soil water caused by under-predicting runoff contribution from the upslope positions. The physically-based rainfall/runoff process in the model predicted very small runoff because of dampened rainfall intensity data given as hourly totals. Actual rainfall intensity/duration data is needed to adequately describe runoff in the model. These results suggest that model has the capability of simulating rather extreme conditions encountered in dryland agriculture where crop production occurs under moderate to severe water stress conditions. However predicting the economic consequences (i.e., grain yield) and water use efficiency of cropping sequences require adequate runoff estimates since every unit of stored water translates to additional yield and thus profit. This is particularly important in the case of the highly productive toeslope positions.

Utilization of the model as a research tool suggests that residue contribution to decreased evaporation of water from the soil is minimal in this region. This was determined based on simulation results from two management scenarios: 1) the actual no-till residue cover system from corn planting in May/1991 to wheat planting in Sep/1992, and 2) the same system as in 1, but with no surface residue (i.e., bare soil). The total increase in soil water storage due to residue was only 0.8 inch of water for the entire simulation period. Under high evaporative demands coupled with infrequent rainfall in eastern Colorado, most soil evaporation occurs at rates well below potential due to the self-mulching effects of a dry soil surface layer. The fundamental question remaining to be answered is "What are the dominant residue-related mechanisms that contribute to enhanced soil water storage during the fallow periods in semi-arid climates?" Perhaps, an even more fundamental question is "Is enhancement of soil water storage under no-till management a residue-related process, or merely the consequence of not stirring the soil?"

Technology Transfer: Results show that RZWQM has the potential to assess the environmental impact of sprinkler irrigated sandy soils and the water conservation impacts of

dryland/no-till farming. The complexity of the processes and the need to interpret model results favor the technical staff of most action agencies as model users. The model can be a research and educational tool in the hands of specialists in research, industry and academia. We currently have many collaborators at various research institutes using the model for predicting the fate of agrochemicals under a wide range of management practices. The Management System Evaluation Area (MSEA) project is using RZWQM to help quantify their experimental results and evaluate alternative practices. These activities should provide important findings that can be used by farmers, agricultural consultants and various government, state and local agencies directly involved with agriculture.

Public Affairs Activities: More information on the model is available from the Technical Documentation, which can be obtained upon request from USDA-ARS GPSR. Detailed model evaluation results were presented at the International Symposium on Water Quality Modelling in Florida as listed below.

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THE WATER EROSION PREDICTION PROJECT (WEPP) MODELS FOR USE IN NATURAL RESOURCE MANAGEMENT

D. C. Flanagan, J.C. Ascough II, M.A. Nearing, J.M. Laflen and S.J. Livingston[1]

ABSTRACT

A new and exciting set of tools will soon be available to natural resource managers and others with interests and/or responsibilities in soil and water conservation. The United States Department of Agriculture is nearing completion of the Water Erosion Prediction Project (WEPP) models, which provide state-of-the-art hydrologic and erosion predictive science in an easy-to-use package of computer programs. Comprehensive databases for climatic, soil, crop and tillage operation parameters are provided with the models, which will allow application in every county within the United States. In addition to estimating erosion and sediment loss due to rainfall, WEPP also predicts runoff and soil loss due to snow melt, stationary sprinkler irrigation, or furrow irrigation. This paper will briefly present some typical applications of WEPP in managing soil resources and advantages which WEPP has over other erosion prediction technology.

INTRODUCTION

The WEPP models are continuous simulation, distributed parameter, erosion prediction computer programs that are used on personal computers (PCs). In a WEPP simulation, daily water additions (from rainfall, snow melting, or irrigation) may be estimated to cause runoff, which can then cause erosion and sediment loss from a field or small watershed. The individual daily values for runoff and erosion are summed to produce totals and then average values. Daily climate for WEPP simulations is created using a weather generator which accesses long-term weather station statistics. The WEPP hillslope profile erosion model contains components which allow simulation of winter processes, irrigation, surface hydrology and hydraulics, subsurface hydrology, erosion, impacts of management on the soil, plant growth and management, and residue management and decomposition. The WEPP watershed erosion model contains all of the hillslope profile model components and additional routines to compute hydrology and erosion in channels and impoundments. Further information on the science in the WEPP models can be found in other literature (e.g. Lane and Nearing, 1989; Ascough et al., 1994). The WEPP models allow the user to describe hillslopes and/or watersheds having nonuniform slopes, soils, and cropping/management.

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The WEPP models are intended to be used in all situations in which current (such as USLE (Wischmeier and Smith, 1978) and RUSLE (Renard et al., 1991)) erosion prediction technologies are applied. A major application will be in assessing the erosion potential of various management alternatives. For example, will use of a particular conservation tillage system such as no-till production of corn and soybeans sufficiently reduce the erosion hazard on a specific parcel of land having a certain slope configuration, soil composition, and geographic location (climate)? Another example would be comparison of the effects of various cattle grazing levels on the erosion hazard from a rangeland site. In forested areas, WEPP can be used to determine how different management of forest roads will impact the amount and types of sediment reaching nearby streams and fish populations.

In addition to providing total and average estimates of soil loss, the WEPP models can provide extremely detailed information, including spatial and temporal distributions of soil loss and sediment deposition, as well as the impact of various management practices on sediment delivery and sediment characteristics, both of which are important to off-site water quality. One of the main outputs of WEPP is the soil loss and/or sediment deposition at a minimum of 100 points on a hillslope profile (Figure 1). The user can visually determine where excessive erosion will most likely occur, and if necessary, pinpoint application of suitable conservation practices.
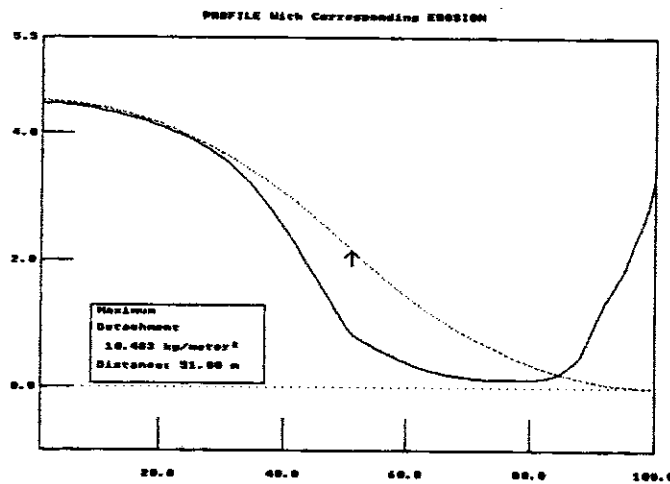
Figure 1. Graphical output from the WEPP model depicting soil detachment and sediment deposition on a hillslope profile. The upper dotted line depicts the soil profile surface, and the solid line represents soil detachment when below the profile line and deposition when above the profile line.

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In addition to having output available of the runoff, erosion, and sediment yield for each simulated storm event, the WEPP models also can provide a wealth of other information concerning the moisture status of the soil, the growth status of the plants, or the amount of plant residue materials. A large output data file containing daily values of approximately 100 different variables can be created, and any of the variables can be plotted against another using a WEPP utility graphics viewer. Up to six graphs can be displayed at one time on the screen, and data from any available graphics data files may be plotted and also saved as a .PCX file. Figure 2 shows an example of one of these graphs, in which interrill ground cover fraction is plotted versus the day in the simulation. The peaks and valleys in this graph are due to the impact of tillage operations and harvest operations through the simulation on ground cover amounts. The simulation used in this example was a corn-soybean crop rotation under a conventional management system.
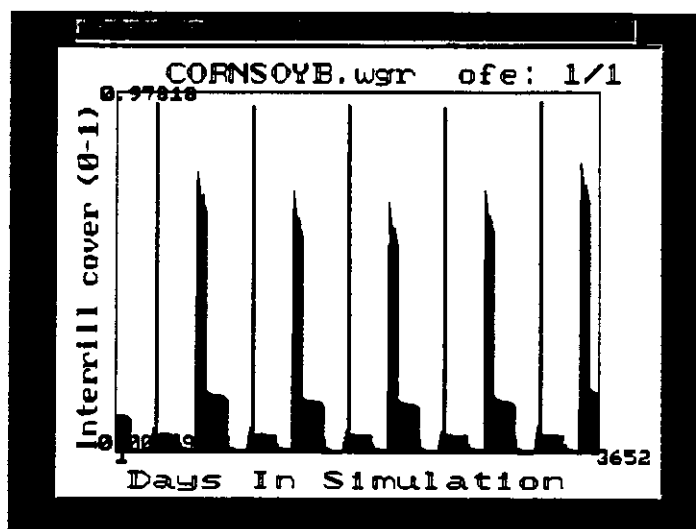
Figure 2. Graphical output from the WEPP model depicting the impacts of tillage, harvest, and residue decomposition on interrill ground cover over a 10 year simulation period.

WEPP APPLICATION EXAMPLE

For the purposes of demonstrating the capability of the WEPP model at comparing various practices for their impact on natural resources, six 50 year simulations were performed with WEPP version 95.1 which represented a range of management systems for growing continuous corn near Indianapolis, Indiana on a Miami silt loam soil. The profile was 100 meters (328 ft) long and S-shaped, with a slope steepness of 0 % at the top of the hill, 9 % at the center of the hill, and 0% at the bottom of the hill. Systems simulated were tilled-fallow, fall moldboard plow (MP) corn, spring MP corn, spring chisel plow (CP) corn, no-till corn, and a fall MP corn with sprinkler irrigation. Table 1 shows some of the major results from these simulations. Average annual precipitation for all simulation trials was 1054 mm (41.5 inches). An annual average of 285 mm (11.2 inches) of irrigation water was applied in the simulation having stationary sprinkler irrigation with depletion level scheduling.

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The results in Table 1 show that in these WEPP simulations, runoff, soil loss, and sediment yield were reduced as the amount of tillage in a system was reduced, and increased amounts of surface residue were available to protect the soil from erosion. For this example, the no-till system almost completely controlled erosion at the site. The sprinkler irrigation system increased runoff, crop yield, soil loss, and sediment yield when compared to the same system without irrigation. One reason for the relatively large amount of runoff from the irrigated example was due to the tendency of a Miami silt loam soil to form a surface seal and have a very low effective hydraulic conductivity. This resulted in many irrigations being applied to the soil, with not much of the applied water infiltrating into the soil. On a soil which does not form much of a surface seal (sand), the impacts of irrigation on runoff, erosion, and sediment yield would be much less.

Table 1. Results of WEPP 50 year simulations for various management systems for a Miami silt loam soil near Indianapolis, Indiana.

Management System	Avg. Annual Runoff mm (in)	Avg. Annual Crop Yield kg/m^2 (bu/A)	Avg. Annual Detachment kg/m^2 (tons/A)	Avg. Annual. Max. Detach. kg/m^2 (tons/A)	Avg. Annual Sedmt. Yld. kg/m (lbs/ft)
Tilled Fallow	109 (4.3)	0.00 (0)	13.7 (61.2)	35.7 (159.2)	570 (383)
Fall MP/ Irrigate	295 (11.6)	0.80 (128)	9.0 (40.3)	25.7 (114.6)	454 (305)
Fall MP Corn	88 (3.5)	0.75 (120)	7.0 (31.1)	17.7 (79.1)	321 (216)
Spring MP Corn	90 (3.5)	0.75 (120)	6.0 (26.9)	15.3 (68.2)	283 (190)
Spring CP Corn	80 (3.1)	0.75 (119)	3.3 (14.9)	7.8 (34.6)	194 (131)
No-till Corn	64 (2.5)	0.71 (114)	0.03 (0.13)	0.03 (0.13)	3 (2)

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DECISION SUPPORT SYSTEM FOR STREAM-AQUIFER MANAGEMENT IN THE SOUTH PLATTE RIVER BASIN

J. W. Fredericks, J. W. Labadie, J. Altenhoffen[1]

ABSTRACT

A stream-aquifer management decision support system (SAMDSS) links a finite difference groundwater model (MODFLOW) with a river basin network flow water rights model (MODSIM) using geographic information system (GIS) and database management system (DBMS) technology. AUTOCAD and a powerful, low-cost, raster GIS package, IDRISI, are used for preparing grid-based spatial data for input into MODRSP (a discrete response function generator for MODFLOW) to compute numerical groundwater response coefficients. MODSIM utilizes the response coefficients to simulate spatially varied and time-lagged stream-aquifer return/depletion flows under river administration based on the prior appropriation doctrine. Integration of GIS, DBMS, MODRSP, and MODSIM allow analysis of conjunctive use plans which include decreed flow and storage rights, river calls, exchanges, trades, and plans for augmentation. SAMDSS is applied to the Lower South Platte River Basin between the Kersey and Balzac gaging stations. The Bijou Augmentation Plan is simulated, along with its effects on daily administration of South Platte Water District #1 by the Office of the State Engineer. Results are contrasted with current use of lumped stream depletion factors. A prototype graphical user interface effectively communicates important augmentation plan and daily administration information to decision makers.

Keywords: Water rights, River basin management, Stream-aquifer systems, Geographic information systems, Decision support systems.

STREAM-AQUIFER MANAGEMENT DECISION SUPPORT SYSTEM

Decision support systems, as an appropriate methodology for water resource planning and management, have been described by Armstrong (1987), and Labadie, et al. (1989). The classic definition of decision support systems (DSS) provided by Sprague and Carlson (1982) describes a DSS as *"an interactive computer-based support system that help decision makers utilize data and models to solve unstructured problems."* The DSS includes three subsystems: (i) model base management software); (ii) data base management software; and (iii) dialog generation and management software for managing the interface between the user and the system.

The structure of the stream-aquifer management decision support system (SAMDSS) is shown in Fig 1. SAMDSS is constructed around an open architecture permitting access to input and output data and allowing modification and verification at all levels of the modeling process.

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Data Base

Relational (DBASEIV)	
Spatial (AUTOCAD,IDRISI)	
Time Series (DBASEIV)	
Summary (DBASEIV,Quattro Pro)	

Model Base

Return Flow Calibration (USBR PTFLOW)
Geographical Analysis (IDRISI,AUTOCAD)
Irrigation Demand (CROPWAT)
Water Quality (MODPATH)
Network Flow (MODSIM)
River Routing (MODSIM)
Surface Runoff (SEAMOD/HEC1/TR20)
Ground Water (MODFLOW,MODRSP,MODSIM)
Water Rights (MODSIM)

Dialog

Data Base Management System	Model Management System
User Management System	

Command & Control (WINDOWS/MAPINFO)	
Input	Output

* Implemented

Figure 1. Components of Stream-Aquifer Management Decision Support System

The stream-aquifer management decision support system is designed to:

■ Assist in long term river basin planning activities, daily river administration, and river management options such as groundwater augmentation.

■ Incorporate appropriation water right features such as decreed diversions, direct releases from a reservoir to a downstream diversion point, diversions at alternate points, exchanges, trades, recharge and augmentation plans.

■ Represent a complex river basin system as a flow network for which highly efficient solution methods are available.

■ Consider reservoir seepage, irrigation infiltration, channel loss, well pumping, return flows, river depletion due to pumping, and aquifer storage.

■ Consider the spatial distribution of return/depletion flows along a stream, and track over time, from source to destination, individual return/depletion flows due to various geohydrologic activities.

- Efficiently allocate river basin water resources according to user specified operational rules and demand priorities.
- Use geographical information (GIS) and data base management (DBMS) system technology for preprocessing and postprocessing of data.

BIJOU AUGMENTATION PLAN CASE STUDY

A groundwater augmentation plan for the Bijou Irrigation Company was prepared by HRS (1983) to replace depletions that would otherwise accrue to the South Platte River as a result of well pumping to meet irrigation demands. The plan originally involved 196 individual wells and a groundwater recharge program that includes recharge from Bijou Canal, Bijou Reservoir #2, several creeks, and a number of small recharge ponds (Fig. 2). A water right augmentation account is currently prepared for the Bijou system on a monthly basis by the Northern Colorado Conservancy Water District (NCCWD). The account is submitted to the Office of the State Engineer (SEO) for use in administering water in the South Platte River.

The current calculation procedure for the Bijou Augmentation Plan uses SDF recharge site values (Hurr, et al., 1972), measured channel inflow and outflow, and estimates of surface area evaporation to calculate monthly recharge credits. Account debits due to well pumping are estimated based on calculated irrigation crop demands minus irrigation water supplied through measured surface

Figure 2. Bijou Irrigation Company Augmentation Plan Network

diversions. If there is a call for water by a senior water right owner, and the Bijou Augmentation account for the month shows a negative balance, then the Bijou Irrigation Company must provide supplemental water to offset the negative balance or face the possibility have having its member

wells temporarily shut down. Supplemental water can come from exchanges, trades, and upstream reservoir releases.

GENERATING RESPONSE COEFFICIENTS USING MODRSP

MODRSP/MODFLOW (McDonald and Harbaugh, 1988) was used to generate stream-aquifer response coefficients for each of the 196 wells and 32 recharge sites identified in the Bijou Augmentation Plan. The alluvial aquifer is unconfined but water table fluctuation compared with the depth of saturated thickness is sufficiently small (Romero, 1990) so transmissivity can be treated as independent of head. Sets of coefficients for each well and recharge site were developed to simulate the effects of the groundwater pumping and recharge on the South Platte River and major tributaries. The Lower South Platte River was divided into 29 reaches with 11 separate tributaries.

The network for the finite difference groundwater model was set up to cover all of Water District #1 located within the South Platte alluvial aquifer (Fig. 3). The aquifer boundary was taken from the USGS maps prepared by Hurr, et al. (1972). A 370 by 140 groundwater grid network with each cell having dimensions of 1000 ft x 1000 ft. was developed using GIS techniques. MODRSP transmissivity, boundary condition, river, and well data input files were also developed using the GIS and database procedures. Hydrography for the study area was read into AUTOCAD (Autodesk, Inc.) from Bureau of Census (1989) TIGER Files. The USBR Point Flow Study schematic, USGS 1:100,000 County maps, State Engineer's Diversion Structure computer database for District No. 1, and South Platte Straight Line Diagram for Irrigation Division No. 1, Water District #1 (Wheeler, 1985) were used to identify individual river reaches, drains, canals, and reservoirs.

Transmissivity data were digitized from the Hurr, et al. (1972) transmissivity maps for Greeley, Weldonna, and Brush reaches of the South Platte River. IDRISI was used to develop a raster grid file from the contour data for input into MODRSP. Well data were digitized into AUTOCAD using the Bijou Irrigation Company Plan for Augmentation Irrigation Well Location Map (HRS, 1983). The associated grid cell along with the groundwater grid row and column number for each well was directly calculated from the well x,y locations provided in AUTOCAD. For implementation of the Bijou Augmentation Plan, the Bijou Canal, Kiowa Creek, and Bijou Creek recharge sites were subdivided into 26 separate recharge sites. Locations of the Bijou Augmentation Plan recharge drains and canals were available from TIGER hydrography data; however, for the demarcation of individual reaches, it was necessary to digitize this information using the Bijou Irrigation Company Plan for Augmentation Recharge Site Stream-Depletion Factor Contour Map (HRS, 1983). This reach information was then overlaid on the hydrography data. QUATTRO PRO was used to calculate the finite difference groundwater model grid cell row and column locations for each site, with the 26 recharge sites defined by 246 grid cells.

MODSIM AUGMENTATION NETWORK

The monthly water account for the Bijou Irrigation Augmentation Plan was simulated using MODSIM for a period of seven years from 1985 to 1991. The MODSIM network for the system is presented in Fig. 3. The network includes 281 nodes, 8 reservoirs, 232 demands and 81 links. A total of 196 member wells are covered in the Bijou Plan, along with recharge sites at the Bijou

Canal, Bijou Creek, Kiowa Creek, Bijou #2 Reservoir, Milliron Draw, Chase Pond, Weingarde Pond, Kiowa Creek, Lost Creek East Pond, Lost Creek West Pond, and Weimer Pond

COMPARISON OF SIMULATION RESULTS

The first simulation run used stream depletion factors (SDF) (Jenkins, 1968) for well and recharge sites given in the Bijou Augmentation Plan Report. Groundwater response coefficients were generated using the Glover model (Glover, 1978) within MODSIM. No deficit accounts occurred in any of the 84 months. The second simulation run used the response coefficient file generated using MODRSP. Deficit accounts occurred in seven out of 84 months. A comparison of the two simulation runs shows is presented in Fig. 4. The finite difference method using MODRSP results in a larger credit account. Total net account for the
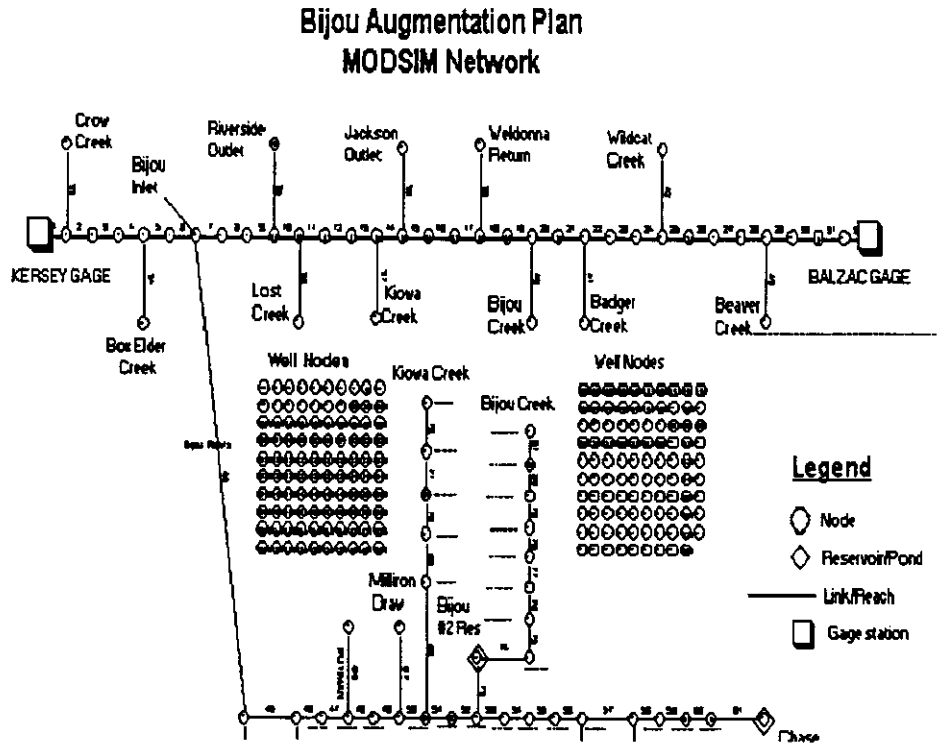
Figure 3. Bijou Augmentation Plan MODSIM Network
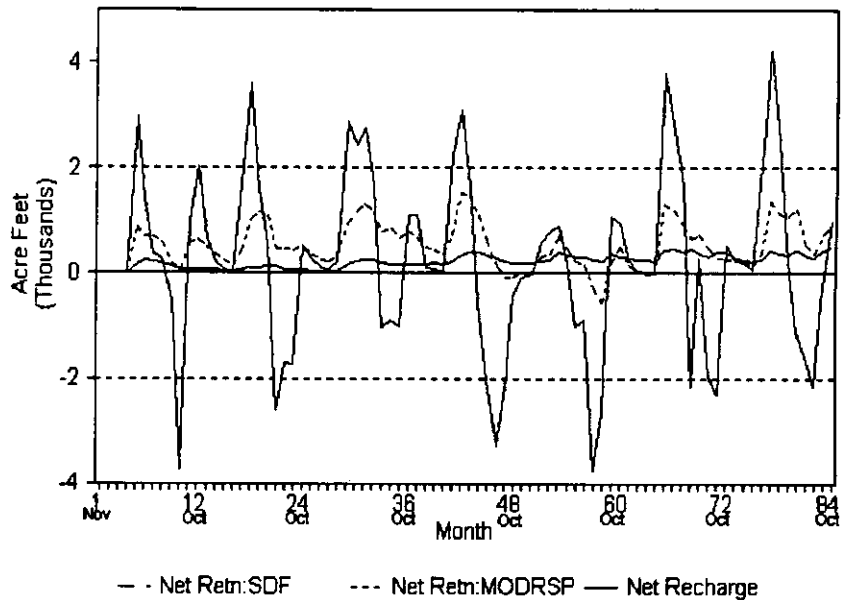
Figure 4. Comparison of Augmentation Plans (SDF versus MODRSP)

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seven years for the SDF method was 18,900 ac-ft, as compared with 44,200 ac-ft for the finite difference method. During the critical irrigation months of July, August, and September, the SDF method results in an average of 235 ac-ft/month, whereas the finite difference method produces an average of 762 ac-ft/month.

GRAPHICAL USER INTERFACE FOR SAMDSS

An interactive format was prepared in MAPINFO (MapInfo Corp.) to demonstrate procedures for displaying spatial data output using DSS techniques. Three types of output display are used: interactive maps, graphs, and data tables. The DSS is designed to assist in daily administration for Water District #1 and to consider the effects of the Bijou Augmentation Plan. MODSIM can be executed from within the DSS, with MAPINFO software used to display output results. Menu options are included to simplify data entry and for output display. Input and output files used by MODSIM, QUATTRO PRO and MAPINFO are prepared internally by the DSS. The user is able to interactively view daily administration diversion results on a river diversion map of the Lower South Platte River Basin. The canals and ditches diverting surface flows are automatically highlighted in color, with the most junior canal or ditch receiving water is shaded in another color.

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DISTANCE EDUCATION THROUGH TECHNOLOGY TRANSFER USING KU BAND SATELLITE SYSTEMS

Bob Hamblen[1]

ABSTRACT

This report is prepared and submitted by Dr. Bob Hamblen on behalf of the distance education team working with D.T.N. and Farm Dayta satellite systems. This project has been headed up by Dr. Bob Hamblen, Dr. Bruce Bainbridge, Dr. Howard Schwartz, and Mark McMillan but the input into the project both from a monetary and informational source has been extremely broad based. Those involved in the project from a direct monetary basis are: Cooperative Extension component, Agricultural Experiment Station component, Agricultural Research Service, the Colorado Corn Growers Association, and the Colorado Dry Bean Administrative Committee. The two companies of D.T.N. and Farm Dayta have provided in kind contribution through the use of pages on the systems that total over $100,000 per system per year.

Scope of the project

This project started with an iniative grant in 1992. At that time there were 850 total subscribers to the systems. It is now received daily by over 2,000 subscribers in the state of Colorado. In addition to farmers and ranchers having the systems there are systems installed in coffee shops, banks, Cooperative Extension offices, Coops, and other locations were there are multiple viewers. Presently there are 20 pages of information that are updated at varying times. The eight pages of information dealing with weather, growing degree days, and crop water E.T. are updated daily. Information on the major crops of corn, wheat, dry edible beans, and other crops are updated Mondays, Wednesdays, and Fridays. This includes production practices, disease and insect information. Five pages on the color D.T.N. systems are used to project color graphics images off C.D. Roms that have been developed by the project and are changed once per week in the summer. The Commodity groups have two pages to update their members on information. In the fall, winter and spring months information related to marketing, policy, livestock and other agricultural issues are to be broadcast.

D.T.N. has just reached it's 75,000 th subscriber nationwide and Farm Dayta has over 30,000 subscribers nationwide.

Impact of the program:

Progress Report:

The survey results for 1994 based on the combination of the mail returned surveys and the phone follow-ups to date we have a 50 percent return. Off these preliminary results we have the following data:

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1. Age distribution was as follows for the respondents:
    25 and under - 2%, 26-35 - 27%, 36-45-43%, 46-55-22%,
    56-65-2%, and over 66-4%

2. Educational level was distributed as follows:
    high school-44.4%, Associate of Arts-11.2%, Some
    college-4.4%, Bachelors degree-35.6%, Master degree-
    2.2%, Doctorate-2.2%.

3. Gross sales of crops off the operation was as follows:
    Less than 50,000-10.25%, 50,000-150,000-25.6%, 150,001-
    250,000-20.5%, 250,001-350,000-15.4%, 350,001-450,000-
    12.8%, 450,001-550,000-2.6%, 550,001-650,000-2.6%, and
    over 650,001-10.25%.

4. Gross sales from livestock off the operation was as follows:
    Less than 50,000-10%, 50,001-150,000-33.3%, 150,001-250,000-20%,
    250,001-350,000-6.7%, 350,001-450,000-6.7%, 450,001-550,000-3.3%,
    and over 650,001-20%.

5. The percentage of respondents to the survey that said they utilized
    at least one of the five segments from Colorado Information to make
    management decision was as follows:
    > Seventy nine percent of the respondents for both D.T.N. and Farm Dayta
    > said they utilized at least one of the five segments to make management
    > decision.

6. The value that the respondents placed on the Colorado Information segment
    was as follows:
    > The average value place on the Colorado Information segment by respondents
    > was $1,998.42. This would extrapolate to approximately 3.7 million
    > value for all subscribers.

Both D.T.N. and Farm Dayta systems have held Colorado State University up as the model for other land grant universities for development of their programs. When you have calls from universities like University of Nebraska, Michigan State University, and the University of Illinois asking how to establish their systems it is a very positive position for Colorado State University. No other university at the present time provides as many pages of information or updates that information as often or provides color images as the Colorado Information does put up by Colorado State University. We are one of the leaders in the utilization of this type of information.

SIMULATIONS OF SNOW DISTRIBUTION AND HYDROLOGY
IN A MOUNTAIN BASIN

Melannie D. Hartman, Jill S. Baron, Dennis S. Ojima[1]

ABSTRACT

Understanding of interactions between atmosphere and land surface processes is critical to understanding water basin hydrology. Terrestrial biospheric processes and terrain heterogeneity control fluxes of water, energy, and CO_2, and these perform an important role in determining hydrologic processes such as snowpack accumulation and melt, soil water storage and rates of discharge. Increasing simplification of the representation of major processes in atmosphere, biosphere and hydrosphere based on sound scientific understanding allows us to explore these interactions, and this research will develop the interface between simplified representations of biologic and hydrologic processes. We examine the capacity of the ecological-hydrological simulation system RHESSys to model land surface processes in a mountain basin.
Keywords: Snow redistribution, Discharge, Mountain Basins.

INTRODUCTION

Land surface heterogeneity strongly affects hydrosphere land linkages through variability of the radiation environment, precipitation and temperature conditions, and soil water drainage (Band et al., 1991, Nemani et al., 1991). Biospheric processes exert an important role in determining reciprocal interactions between the hydrosphere and the land surface (Schimel et al., 1991). We define land surface processes explicitly as combined hydrologic and ecosystem processes. Changes in regional or global precipitation patterns or temperature will have dramatic long-term consequences to terrestrial ecosystems and regional scale hydrology (Rango and van Katwijk 1990). Biological parameters, such as vegetation structure and physiology that influence hydrological fluxes, are influenced by biogeochemical processes (e.g. production and nutrient cycling) abiotic conditions (e.g. hillslope position and soil drainage), human disturbance, and episodic natural events such as fire and grazing. In preparation for looking at the link between atmospheric, hydrologic, and biologic processes we are currently applying RHESSys to understand land surface processes over heterogeneous mountain terrain. The objective of this paper is to illustrate simplified relationships that allow sufficient representation of the ecosystem-hydrological processes linkage.

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STUDY AREA

In this paper we will focus on the Loch Vale Watershed (Baron et al. 1991), at the headwater of the South Platte River Basin. Loch Vale Watershed (LVWS) is a high relief, 660 hectare basin located in Rocky Mountain National Park. More than 80% of the basin surface consists of bedrock outcrop and active talus slopes. Several permanent snow fields and an active rock glacier are also present in the upper reaches of LVWS. The basin is divided into distinct alpine and subalpine elevational terraces. Alpine vegetation in LVWS consists of low herbaceous, dwarf-shrubs, and lichens. Subalpine vegetation consists of old-growth subalpine-fir/Englemann spruce forest. Snow accumulation and melt dominate the hydrologic cycle of LVWS.

METHODS

RHESSys is a data and simulation framework within which ecosystem process models and hydrologic models are linked in order to represent the distributed feedbacks between ecological and hydrologic processes at the watershed scale (Band et al., 1991, Nemani et al., 1991). RHESSys incorporates a set of geographic information processing techniques to combine information drawn from digital terrain data, remote sensing and digitized soil maps into a distributed parameter set along with the algorithms necessary to operate the hydroecological models. The distributed framework is based on a terrain partition in which each terrain object (hillslopes, stream reaches, and contour bands) comprising the watershed is explicitly represented while the internal variability of each object is represented as a joint parameter distribution. The GIS/remote sensing approach to parameterization is required for simulation of large watersheds; manual methods are inefficient and impossible to implement on larger, regional to subcontinental scales (Band et al., 1993). Daily climatological data are imposed across the landscape from surface meteorological stations.

For our simulations we use a version of RHESSys that implements snow redistribution and elevational banding. In high relief areas such as the Loch Vale Watershed, snow is redistributed by wind. Explicit modeling of the interaction of wind and small scale topography is complex and requires intensive data not available for LVWS. RHESSys implements a surrogate redistribution of incoming snow which is based the distribution of $\ln(\alpha/\tan\beta)$, the topographic similarity index. In our experiments we show the effect of elevational banding and snow redistribution in the Loch Vale Watershed.

RESULTS

For the simulations, we partitioned the watershed into 24 hillslopes. Each hillslope is further divided into elevational bands of specified width. We ran RHESSys for two consecutive years, with elevational bands of 100, 200, 500, and 5000 meters, and snow redistribution parameters of 0.002 and 0.0. Essentially, a 5000 meter elevation band in LVWS is equivalent to running the model without elevational banding. We turn off snow redistribution by setting the snow redistribution parameter to 0.0.

Snow redistribution maintains snowpack depth throughout the year, as is observed in the Loch Vale Watershed. The depth of the snowpack differs according to elevation band width; smaller bands maintain deeper snowpacks throughout the year, but the difference is only 1-2 cm of snow water equivalent per elevation band. Snow redistribution also lengthens the melt period. When no snow distribution is applied, summer peak flows are overestimated along with total annual discharge. The snowpack also melts off completely in the summer.

The simulated hydrograph in 1986 shows a good estimate of discharge timing and magnitude for most of the year (Figure 1). Snow redistribution made a big difference in the predicted runoff, whereas banding did not. Total annual discharge (observed at 92.4 cm) was estimated (using 100 m elevation bands) at 103.0 cm when snow redistribution was implemented, 112.9 cm when it was not. The spike of 2.7 cm at julian day 92 is troublesome. We believe there was a rain on snow event this day of 6.0 cm in the Loch Vale Watershed. RHESSys does not give a water holding capacity to the snowpack and thus rainfall will not infiltrate the snow but go directly to the soil and then to runoff.

Results for 1987 show that applying 100 m elevation bands, and using snow redistribution gives a good estimate for total annual discharge (Figure 1). Total annual discharge (observed at 74.7 cm) was estimated (using 100 m elevation bands) at 74.9 cm when snow redistribution was implemented, 78.1 cm when it was not. Although the timing and magnitude of spring discharge is well estimated, summer peaks for this year are too high, and late summer discharge estimates are too low. We believe this phenomena could be due to the changing characteristics of the snowpack throughout the melting season; currently RHESSys applies a single melting rate throughout the year. Possible biological influences on evapotranspiration that affect discharge are also under investigation.
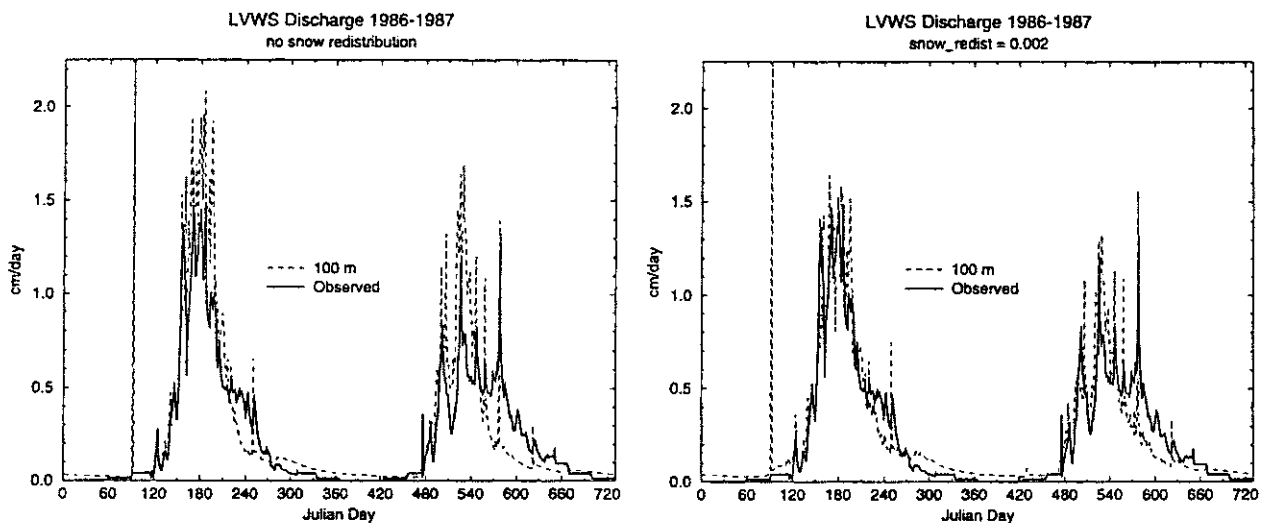
Figure 1. Observed and simulated discharge.

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DISCUSSION

Results are inconclusive as to whether elevational banding is advantageous in Loch Vale simulations. The differences in the timing and volume of peak flows is slight when comparing hydrographs of different elevational bands. We suspect elevational banding is more useful when applied to larger basins with more elevational difference as is evident in runs for the South Platte Basin (63,000 km^2) performed by Tague (1994).

Although the total annual discharge matches well with observed annual discharge, the timing of snowmelt is a bit off. Too much snow melts in the summer time. Currently one melting rate is applied to the entire year. This is not realistic since the properties of snow and glaciers, including albedo and snow density, vary throughout the year. Glaciers also have different melting properties than seasonal snowpacks. Currently RHESSys does not treat glaciers differently than snow.

We are currently testing a version of RHESSys which will allow us to specify parameters related to snowpack depth (e.g. melting rates, initial snowpack, latent heat transfers, water holding capacity) and vegetation parameters (e.g. aerodynamic resistance) by elevation terraces. Thus we could specify separate properties for the alpine tundra and the subalpine forest. Future modifications may include spatial descriptions of vegetation and snow properties at the hillslope level.

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IRRIGATION DEMAND UNDER CLIMATE CHANGE DETERMINED BY REGIONAL SIMULATION

J. D. Haskett[1], Y. A. Pachepsky, B. Acock

ABSTRACT

A key concern about projected climatic changes is the effect on the demand for irrigation water. To understand how this demand will change it is necessary make regional estimates. The soybean physiology model GLYCIM (Acock and Trent, 1991) has been adapted for the simulation of soybean production at the state level, and provides estimates of irrigation demand under realistic weather conditions. This regional version of the model includes scaling methods that incorporate complex soil hydrologic information crucial in predicting crop water availability. These methods rely on frequency distributions that represent the soil properties of the constituent soils of the agricultural soil associations within a county. State specific data from the General Circulation Model (GCM) created by the Goddard Institute for Space Studies (GISS) is used to create weather scenarios for particular weather sub-regions or centroids. Statewide simulations can be constructed that estimate crop and irrigation response under climate change with an accompanying increase in atmospheric $[CO_2]$. In this study soil and weather scenarios for the state of Iowa were collected and irrigation demand for the years 1991 and 2051 was simulated. Little sub-regional or state-wide change in irrigation demand was found . It is likely that this is the result of an increase in precipitation that parallels the increase in temperature in this climate change scenario, and that both of these increases were moderate.

INTRODUCTION

Changes in climate and in atmospheric $[CO_2]$ have raised concern about agriculture, with particularreference to the demand for irrigation water (Postel, 1990; Waggoner et al., 1992). Changes in evapotranspiration induced by changes in temperature, precipitation, and plant water use efficiency could have a significant effect on the need for irrigation both in areas already dependent on irrigation and areas not currently using significant amounts of irrigation water. The scale of interest for irrigation demand is regional, since irrigation water either from groundwater or surface sources is often managed on a regional basis. The crop physiology model GLYCIM, that can mechanistically simulate plant response to environmental variables such as temperature, and $[CO_2]$ has been extended to include large (county level) areas. This extension allows the inclusion of the complexity of the soil landscape that can be critical in determining water availability.

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Aggregation methods applied to both soil and weather data are pivotal in making realistic regional estimates and have been applied extensively in this study.

MATERIALS AND METHODS

The state of Iowa is divided into nine Crop Reporting Districts (CRDs). In order to make regional estimates for Iowa two counties within each CRD were selected on the basis of the availability of a county soil survey completed after 1980. It has been determined that the average of soybean yields in these 18 counties is a good predictor of yields for the state of Iowa (Haskett, unpublished data). In this study, estimates of CRD irrigation demand were based on averages of the demand in the selected constituent counties, while the average demand of all 18 selected counties was used for the statewide estimates.

Soil Aggregation

In each selected county soil association files were created by sampling from frequency distributions of the soil properties of the constituent soils derived from their percent areal extent within the association. Estimates of soil hydraulic properties were then made based on these soil files using empirical equations developed by Rawls and Brakensiek (1982). Simulations for each soil association were run and the results were combined to produce county level estimates by taking a weighted average based on the areal extents of the associations within the county.
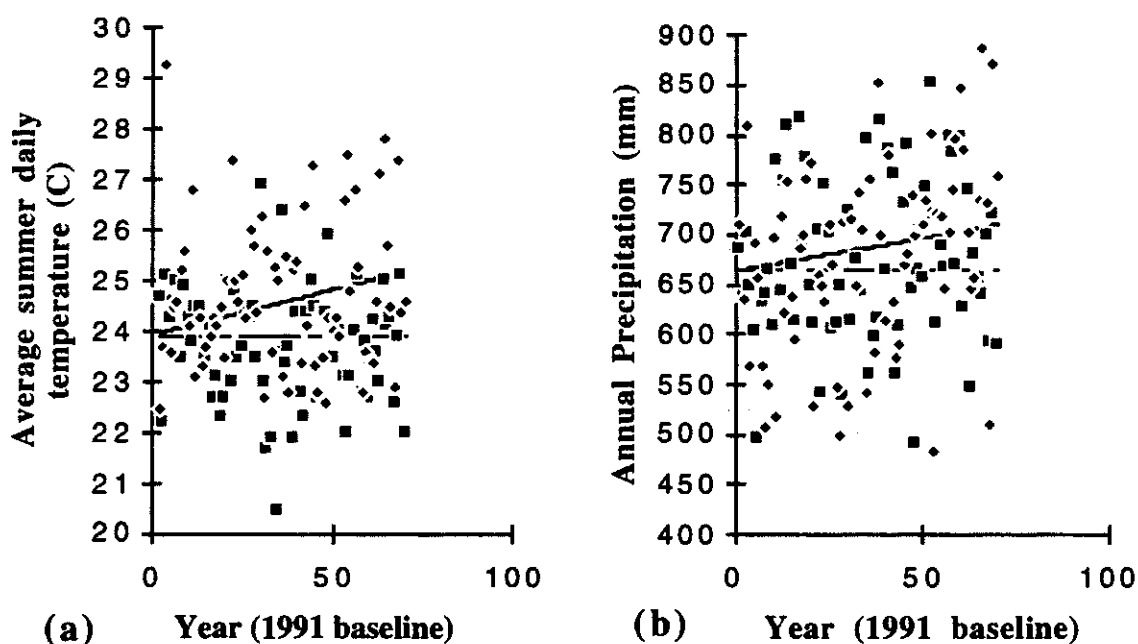
Figure 1. Average summer daily temperature (a) and annual precipitation (b) weather data points from Goddard Institute for Space Studies based on changed [CO_2](■) and unchanged [CO_2](◆)with corresponding regression lines (--- unchanged [CO_2], — changed [CO_2]).

Weather Aggregation

In order to generate weather for use in the simulation climate files the grid cell containing Iowa were obtained from the Goddard Institute for Space Studies (GISS) General Circulation Model (GCM). Starting with a base year of 1991 and an atmospheric $[CO_2]$ of 350 ppm this scenario includes an increase in $[CO_2]$ of 1% per year, rising to 660 ppm by 2051. The Wilks (1992) method was used to prepare 5 replicate weather data sets for each of two sample years, 1991 and 2051. In this method monthly grid cell values from the GCM were transformed into daily values for temperature, solar radiation and precipitation. This was done by applying climate parameters derived from regression of climate change predictions of the GCMs (Fig. 1) to weather files of current values specific to each CRD. The resulting file sets then represent replicate weather samples having the characteristics of the year in question.

Plant and Cultural Practice Parameters

A standard set of parameters for soybean characteristics were used in all simulation runs of the model. These specified an indeterminate cultivar of maturity group 3, with Julian day 151 as the date emergence date, planted with a row spacing of 76.5 cm and 26.2 plants per meter of row.

Irrigation Control

In designing irrigation control for the simulation the authors have followed the parameters laid out by Curry et al. (1990) for their simulation of soybean response to climate change in the southeastern United States. Under these specifications the GLYCIM model was set up such that irrigation water was applied to fill the soil profile to field capacity when the available soil water in the upper 0.5m of the profile dropped to 40%. The application efficiency was set at 75%.

RESULTS AND DISCUSSION

Irrigation demand in the 1991 scenario was low for all CRDs and remained low for all CRDs in the 2051 scenario after climate change and increases in atmospheric $[CO_2]$ (Table 1). The same trend was found at the state level (Table 1).

Although changes in demand occurred, the overall level of demand is so low as to be considered negligible as compared with water from precipitation. For example, in CRD 1 average yearly precipitation during the growing season (Julian day 130-284) was in excess of 400 mm yr^{-1} for both 1991 and 2051 scenarios. In this study increases in crop growth resulting from increased $[CO_2]$ did not result in increased demand for irrigation water, precipitation was still adequate in the changed climate scenario.

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Table 1. Irrigation water applied (mm yr-1) in the crop reporting districts and state of Iowa for 1991 and 2051 climate X CO_2 scenarios.

Crop Reporting District	1991 (350 ppm)	2051 (660 ppm)
CRD 1	10.8	11.8
CRD 2	4.4	2.2
CRD 3	8.8	3.2
CRD 4	4.7	2.1
CRD 5	3.2	8.6
CRD 6	13.4	14.8
CRD 7	9.0	9.1
CRD 8	0.4	0.0
CRD 9	3.9	14.0
Statewide	6.5	7.3

The lack of increased demand for irrigation water under the scenarios tested is a result of the global climate change scenario selected. The GISS GCM predicts small changes in climate accompanying increases in atmospheric $[CO^2]$, these take the form of moderate increases in temperature and precipitation (average summer temperature increases 0.76°C, and average annual precipitation increases of 7%) during the growing season in Iowa. This trend is not corroborated by other GCM results, for example, Ritchie et al. (1989) found that while the GISS GCM predicted increasing temperatures and precipitation under climate change in the mid-west during the growing season, the Geophysical Fluid Dynamics Laboratory (GFDL) GCM predicted increasing temperature with decreasing precipitation, during the growing season. Under the GFDL scenario it seems likely that significant increases in irrigation demand could occur.

CONCLUSIONS

By using soil and weather aggregation techniques it is possible to make regional estimates of irrigation demand that take into account the complexity of soil hydraulic properties while maintaining a tractable level of computation.

Under the GISS GCM climate scenarios in which changes in temperature and precipitation are small and increase slightly, there is no important change in irrigation demand in soybean production for the state of Iowa.

In order to get a realistic picture of the full range of possibilities for irrigation demand under climate change, it will be necessary in the future to do regional simulations using climate predictions from other GCMs, that are substantially different from those of GISS.

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RESPONSE SURFACE METHODOLOGY AS A MEANS OF REDUCING THE COSTS OF BIOPHYSICAL SIMULATION

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ABSTRACT

Biophysical simulation models are powerful decision support tools that can aid agricultural researchers in their analyses. While these models are relatively cheaper than conducting site specific field experiments, they are by no means cost-free to operate. Resources, such as analyst and computer time, must be allocated to the calibration, repetitive execution, data collection and data interpretation processes. To further reduce the costs of conducting biophysical research, response surface methodology (RSM) is proposed. RSM in essence expresses the relationships in biophysical simulation models with relatively simpler models. RSM can be very useful in reducing the computational efforts in water management modeling as well as making model results easier to understand.

Keywords: Response Surface Methodology, Biophysical Simulation.

ESTIMATING RESPONSE SURFACES

"The response surface procedures are a collection involving experimental strategy, mathematical methods, and statistical inference which, when combined, enable the experimenter to make an efficient empirical exploration of the system in which he is interested." (Myers, 1971, p. 1). RSM is a synthesis of techniques which help a researcher quantify the response of some chosen variable, such as nitrate leaching, to changes in the levels of a set of influencing factors, such as nitrogen (N) fertilizer and irrigation water. RSM requires the researcher to choose a response variable, choose the factors that most likely influence the response variable, identify an experimental design, execute the experiment, estimate response surfaces with regression analysis, and, finally, determine the optimal point on the estimated surface (Cornell, 1984).

RSM is a form of metamodeling. A metamodel is a simplification of the input-output relationship of a much more complex system (Bouzaher et al., 1993). It is a model of a model. Using RSM a researcher can run a biophysical simulation model a selected number of times over a range of realistic operation and then infer system behavior through the estimated coefficients of the influencing factors. This process eliminates the need to run the biophysical simulation model exhaustively for all combinations of levels of the influencing factors for each scenario of interest.

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Root Zone Water Quality Model (RZWQM) (DeCoursey and Rojas, 1990) was chosen to simulate the biophysical characteristics of a site in Crook, CO (Duke, Smika and Heermann). The twelve month period from April 9, 1972 to April 8, 1973 was simulated. Corn grain yield (Q), residual NO_3-N in the crop root zone (LI1) and NO_3-N escaping the bottom of the crop root zone (LB1) were chosen as the response variables. LI1 and LB1 were measured as of the end of the simulation period or day 4/8/73. N fertilizer applied (N), irrigation water applied (W) and residual NO_3-N in the crop root zone (LI0) were chosen as the influencing factors. LI0 was measured as of the beginning of the simulation period or day 4/9/72. All other RZWQM variables were fixed to the site characteristics of Crook, CO.

The real cost savings from using RSM are associated with the central composite design (CCD). The CCD minimizes the number of computer runs required to capture the underlying structure of a model. The CCD is a 2^k+2k+1 factorial experimental design where k represents the number of influencing factors. The CCD accommodates nonlinear relationships between the influencing factors and the response surface. Table 1 compares the CCD to the most common nonlinear experimental design or the 3^k design. For eight factors, the CCD requires 273 simulation runs while the 3^k design requires 6,561 runs.

The process of establishing an experimental design requires the researcher to define the range of realistic operation for the variable levels of the influencing factors. This process often helps clarify and focus the original purpose of the biophysical research. For N, the low and high values were 144.4 kg/ha and 224.4 kg/ha, respectively. For W, the low and high values were 27.4 cm and 64.0 cm, respectively. The low and high levels for LI0 were 2.8 ppm and 15.0 ppm, respectively. The midpoint (M) of each range was determined for each factor. Finally, the axial points (AP), or extreme points which lie slightly below and above the low (L) and high (H) levels, were calculated using Eq. (1):

Table 1. Number of Simulation Runs Required under Different Experimental Designs.

Factors	3^k	CCD
1	3	5
2	9	9
3	27	15
4	81	25
5	243	43
6	729	77
7	2,187	143
8	6,561	273

AP = [M ± α(H-M)] = [M ± α(M-L)(1)

where, $\alpha=[((FN)^{-5}-F)/2]^{-5}$ and $F=2^k$ and $N=2^k+2k+1$ (Khuri and Cornell, 1987).

To ascertain the values of the response variables associated with each point in the CCD, the RZWQM biophysical simulator was run fifteen times. Linear regression was used to fit response

surfaces to the data. A quadratic parametric form was used for the Q and Ll1 response surfaces. while a Cobb-Douglas parametric form was used for the LB1 response surface. The final response surfaces are summarized in Table 2. Most of the parameters were statistically significant at the 95% level of confidence. The statistical fit of each equation was very good indicating that little was lost from the algebraic representation or the metamodel of RZWQM.

Table 2. Estimated Response Surfaces. [a]

$Q = 1312.6 + 84.3N - .21N^2 - 3.9W^2 + .61NW - .10NLI0 + .83WLI0$

        (1.2)   (-1.1)   (-7.5)   (2.5)   (-3.5)   (7.1) $R^2 = 97.7$

$LI1 = -47.1 + 7.0W - .09W^2 + .001LI0^2 + .002NLI0 - .01WLI0$

        (4.1) (-4.7) (1.7)   (3.9)   (-3.7) $R^2 = 94.8$

$\ln LB1 = -6.4 + 2.41\ln W + .41\ln LI0$

        (11.8)   (4.3) $R^2 = 92.9$

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a. The t-statistics for the estimated coefficients are in parentheses.

An interesting and appealing aspect of RSM is its visual emphasis. The graphs for Q and Ll1 are presented in Fig. 1 and Fig. 2. The LI0 dimension was collapsed by fixing it to a level near the midpoint in the experimental design range.
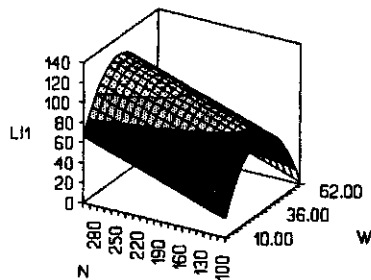
Figure 1. Q Response Surface.   Figure 2. Ll1 Response Surface.
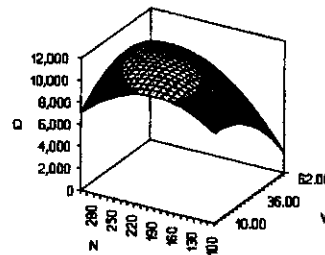
When N (W) is fixed and W (N) increases, Q increases, reaches a maximum and then decreases. When N is fixed and W increases, LI1 increases, reaches a maximum and then decreases. When W is fixed and N increases, LI1 increases. While the response surface for LB1 was not graphed, for any fixed level of LI0 the variable LB1 increases as W increases. The salient behavior of the underlying biophysical system is captured with relatively few variables. Fewer variables are not only easier to manage from a practical standpoint, but also facilitate the understanding and usability of the information. Researchers can then use this insight to develop and test alternative hypotheses. This sequential process of hypothesis formulation and experimentation in the development of knowledge has great practical appeal (Khuri and Cornell, 1987).

The final step in RSM of finding the optimum value of each surface was omitted as the estimated response surfaces were simultaneously incorporated into a dynamic economic model to find the economic optimum of the system. This economic optimization problem is far beyond the scope of simply finding the physical optimum on a single surface as RSM requires.

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USE OF THE SCS-SCHEDULER PROGRAM — SOUTHERN HIGH PLAINS

Terry A. Howell[1], Karl Johnson[2], and Donald A. Dusek[3]

ABSTRACT

The SCS-Scheduler can improve irrigation water management but has not been evaluated widely in the Western U.S. The SCS-Scheduler program was evaluated on a farm in the Southern High Plains since 1991. The program provided useful information to the grower to schedule irrigations for winter wheat, corn, and sorghum. Field yields from scheduled fields were considerably above county-wide average irrigated yields and water use efficiency values indicated good irrigation management. Crop coefficients were determined for use in the SCS-Scheduler for wheat, corn, sorghum based on measured evapotranspiration at Bushland. The SCS-Scheduler PET (potential evapotranspiration) method was found comparable with the NP-PET values based on the Penman-Monteith equation but slightly higher than those estimated using Ref-ET based on ASCE Manual No. 70.

Keyword: Corn, Evapotranspiration, Irrigation scheduling, Management, Sorghum, Wheat

INTRODUCTION

The SCS-Scheduler program (Shayya and Bralts, 1994 and Shayya et al., 1990) for irrigation scheduling was evaluated for the Southern High Plains for corn, sorghum, and wheat. Crop coefficients for these crops were determined based on lysimeter measured evapotranspiration values, and the potential evapotranspiration (PET) method used in the SCS-Scheduler was compared to other programs to facilitate other crop coefficient transfers.

METHODS

Research and evaluation of the SCS-Scheduler program was started in 1991 on the Johnson Farm south of Morse, TX in Hutchinson County. The soil type on the farm is classified as Sherman

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silty clay loam. A Campbell Scientific 012 weather station was installed on the farm to provide the necessary weather data for the program. The station was situated over native grass in an isolated corner of the equipment yard about 500 to 1,000 ft from any obstructions. Irrigations were scheduled using the SCS-Scheduler for graded furrow
irrigations (some fields used surge methods) applied to winter wheat, corn, and sorghum, and soil water was routinely monitored with gypsum soil blocks installed at 1, 2, 3, and sometimes 4 ft depths using a Delmhorst KS-1 meter. Other comparisons were made with irrigation experiments conducted at Bushland, TX in Potter County using weighing lysimeters and sprinkler irrigation on winter wheat, corn, and sorghum. Weather data for Bushland were obtained from the ET weather station located over irrigated grass using a different but similar set of instruments. The soil type at Bushland is classified as Pullman clay loam and is similar to the Sherman silty clay loam soil at the Johnson Farm.

In the 1991 season, initial runs were made using weather data obtained from the nearby weather station (about 15 mi. away) operated by the Texas Agricultural Experiment Station at Etter, TX in Moore County. Initial operation encouraged further program use. In 1992 a weather station was installed on the Johnson Farm, and its data were used from March 3 for the remainder of the 1991-92 wheat season to the present. The SCS-Scheduler was used for wheat and corn in 1991 and 1992 and sorghum in 1993. Generally, irrigations were timed to maintain 75% of the available field capacity with wheat irrigations generally avoided until after March and corn not irrigated until the 6-leaf stage. Corn irrigations were stopped when the starch line progressed about half way down the kernel.

RESULTS

The farm yield results are presented below and generally indicated that crop yields of the fields managed with the SCS-Scheduler exceeded comparable mean county irrigated yields (Amosson et al, 1995). Since winter wheat and sorghum are widely produced under limited irrigation in this region, county average yields may be lower than yields expected for full irrigation. However, corn is usually fully irrigated in this region. Yields exceeded county average yields by over 25% for corn, over 50% for sorghum, and over 30 to 40% for wheat.

CROP	FIELDS	AVG. YIELD bu/ac	COUNTY AVG. YIELD bu/ac	YIELD COMPARISON % above County Yield
Winter Wheat				
1991-92	2	88	59	49
1992-93	7	79	60	32
Corn				
1992	2	240	190	26
1993	5	199	157	27
Sorghum				
1993	1	143	92	55

A freeze on 10 March 1992 killed 18 to 42% of the wheat tillers. No adjustment was made to the SCS-Scheduler for the reduced tillers. The soil water sensors and program computed ET indicated similar water use trends despite the heavy tiller reduction. By monitoring both sources of information, the need for irrigations in late March was anticipated even though the crop appearance did not warrant irrigation yet. The value of the growing degree day (GDD) time scale available with version 3.0 improved corn irrigations in 1992. The GDD accumulation in June indicated more rapid crop development than the simpler time scale, and a mid June irrigation avoided a potential yield reduction. In 1993, wheat yields were a little better than in 1991-92 while corn yields suffered from heat stress that reduced yields. Water use efficiencies (grain yield per unit irrigation plus rainfall) averaged about 3.2 and 3.4 bu/ac-in. for wheat in 1991-92 and 1992-93, respectively, and 6.8 and 6.5 bu/ac-in. for corn in 1992 and 1993, respectively, and 8.2 bu/ac-in. for sorghum in 1993 indicating the efficient use of irrigation and rainfall with the SCS-Scheduler.

Mean crop coefficients were determined for ET data from fully irrigated crops at Bushland. These values represent only single seasons, but should be representative for other conditions. The SCS-Scheduler K_c values are mean crop coefficients and input based on growing season days (time scale) or on growing degree days (thermal time scale). GDD is computed by the SCS-Scheduler using the mean air temperature less the lower base temperature. Most K_c values are reported in different time scales (% time from emergence to full cover and days after full cover) (see Jensen et al., 1990), so some adaptations are necessary to use previously published K_c values.

% of Time	GDD Time Scale			Season Days Time Scale		
	Corn K_c	Sorghum K_c	Wheat K_c	Corn K_c	Sorghum K_c	Wheat K_c
0	0.26	0.20	0.40	0.26	0.20	0.40
10	0.26	0.30	0.60	0.27	0.35	0.50
20	0.40	0.48	0.40	0.38	0.45	0.70
30	0.90	0.72	0.45	0.80	0.60	0.45
40	1.15	1.08	0.85	1.10	0.90	0.40
50	1.20	1.05	1.20	1.15	1.15	0.90
60	1.20	1.05	1.30	1.15	1.10	1.10
70	1.25	0.95	1.30	1.20	1.05	1.20
80	1.30	0.80	1.35	0.95	0.70	1.30
90	1.10	0.60	0.80	0.60	0.60	0.80
100	0.60	0.40	0.55	0.26	0.40	0.45
Base Temp (°F)	50	50	35			
Max. Temp. (°F)	86	100	79			
Total GDDs (°F-days)	3,000	3,300	5,000			
Total Days				180	150	310

In addition, K_c values are specific to a "reference ET" or PET method. The PET method used in the SCS-Scheduler was compared to the REF-ET (v2.1) program and to the grass reference

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ET equation used in the NP-PET (North Plains-PET) network. The resulting linear regressions indicate the corrections needed to compare K_c values for the SCS-Scheduler to other published K_c values using other PET methods. The Penman-Monteith (Allen, 1990) based on REF-ET (v2.10) was similar to the Kimberly Penman equation (corrected to grass) and the NP-PET Penman-Monteith equation. The SCS-Scheduler was about 10% higher than the Penman-Monteith (REF-ET) equation, while the REF-ET FAO Penman equation was about 21% lower than the Penman-Monteith (REF-ET) equation. The SCS-Scheduler PET method agreed well with the NP-PET method, except it was slightly higher during the wheat season. These regressions can be used to translate K_c values from one base PET equation to another base PET equation.

METHODS	CORN in 1994 N = 168			SORGHUM in 1993 N = 131			WHEAT in 1991-92; N=287		
	INT. in./d ----	SLOPE ----	r^2 ----	INT. in./d ----	SLOPE ----	r^2 ----	INT. in./d ----	SLOPE ----	r^2 ----
Kim. Pen.	0.00	1.04	0.96	-0.01	1.11	0.98	0.00	1.01	0.96
Corr. FAO Pen.	0.02	1.14	0.93	0.00	1.18	0.94	-0.01	1.28	0.95
NP-PET (PM)	0.02	0.95	0.93	0.01	0.99	0.97	0.02	0.96	0.99
SCS-Scheduler	0.04	0.93	0.90	0.04	0.95	0.92	0.03	0.86	0.94

All methods were expressed as Y(ET method; dependent variable) = Int. + Slope * X(Penman-Monteith REF-ET method; independent variable).

Penman-Monteith Equation (REF-ET for grass)
Kimberly Penman (REF-ET corrected for grass)
Corrected FAO Penman (REF-ET)
NP-PET (North Plains PET Network Penman-Monteith equation for grass)
SCS-Scheduler (modified FAO Penman equation for grass)

SUMMARY

Overall, the SCS-Scheduler program performed rather well. Obtaining representative input data (crop, soil, and climate data) remains somewhat problematic. Future updates to the SCS-Scheduler Package will address several shortcomings of the program and facilitate easier use by growers and specialists.

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PIT-RESERVOIR DESIGN FOR STORAGE OF DRIFTING SNOW

R. L. Jairell and R. A. Schmidt[1]

ABSTRACT

Accumulating drifting snow in pit reservoirs is a proven method of providing stockwater for early-season pastures on the northern Great Plains. Combining a snow fence with the pit and berm greatly increases the efficiency of drift accumulation. A computer model that balances the earthwork and snow fence size to the seasonal snow transport provides a sound cost/benefit estimate for this technique.

Keywords: Snow, Drifting Snow, Blowing Snow, Ponds, Pit-reservoirs, Stockwater.

DESIGN OVERVIEW

This snow-harvesting design matches drift storage to the expected annual snow transport by wind. The area upwind of the storage site that contributes drift snow is the fetch. Snow transport is the volume of snow water blown from the fetch to the site during the winter. The procedure balances storage volumes with drift on a unit width of fetch--that is, for a lane extending upwind that is one unit wide, a foot or meter. One unit width of pit must hold all the melt water from snow transported off a unit width of fetch. Together, the snow fence and the pit must have sufficient capacity to capture the winter's drifting snow. Figure 1 illustrates the design concept.
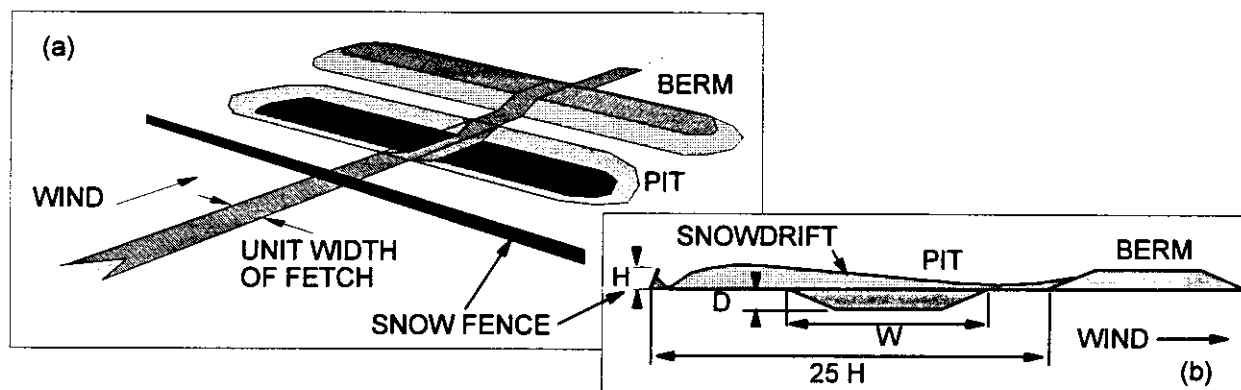
Figure 1. An oblique perspective (a) of the snow fence-pit-berm combination that maximizes snow drift storage. Design computations are for a unit width across the wind (after Jairell and Schmidt, 1992). Cross section (b) shows the optimum snow fence placement, 25 H upwind of the berm. (H is fence height.)

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ANNUAL SNOW TRANSPORT

The design procedure begins with an estimate of the average winter snowfall. During relocation by wind, part of this precipitation returns to vapor by sublimation. The greater the fetch distance, the larger the fraction vaporized. Tabler (1975, 1994) developed a method to estimate the amount of drift snow available for harvest, reducing snowfall estimates by the amount sublimated in transport. His method is based on a conceptual transport distance
T (m), in which an average-sized drifting snow particle completely sublimates. The empirical value, T = 3000 m (10,000 ft), applies in a wide range of northern latitudes (Tabler, 1994).

For this design, we assume that all winter snowfall is relocated (drift storage by vegetation on the fetch is zero). Equation 1 estimates total seasonal snow transport Q_t (kg/m) for relocated winter precipitation, S_{rwe} (m), and fetch distance F (m).

$$Q_t = 500 \ T \ S_{rwe} \ (1-0.14^{F/T}) \tag{1}$$

SNOW FENCE, PIT, AND BERM DIMENSIONS

Jairell and Tabler (1985) explored the trapping of drift snow by several combinations of snow fence, pit reservoir, and embankment, using small-scale modelling techniques (Tabler, 1980; Tabler and Jairell, 1980; Jairell and Schmidt, 1987). Observed snow drifts in full-scale pit reservoirs (Jairell and Schmidt, 1990) confirmed the model predictions, that the optimum snow-trapping combination was a snow fence upwind of the pit, with the berm placed downwind (Fig. 1). Snow storage volume was the sum of pit volume plus normal storage behind the snow fence. Placing the berm near the downwind tail of the drift also added storage volume to that expected for the fence on a horizontal surface (Fig. 1b).

The pit cross-sectional volume should hold all melt water estimated from Eq. 1. Several considerations determine the shape of the pit cross section, including ease of animal access, slope angles that avoid soil slumping, minimizing leakage and evaporation, and draining all meltwater into the pit. A trapezoidal pit cross section (Fig. 1b) with 1:3 bank slopes is used to compute storage volumes.. Dimensions of the pit cross section are selected so the capacity matches the water volume estimated by Eq. 1.

By assuming upwind storage is zero, a higher snow fence is designed, compensating for the reduction in trapping efficiency that occurs as the drift behind the fence approaches maximum volume (Tabler and Jairell, 1993). We assume snow stored in the pit will be 50% water. This density is slightly higher than the average (45%) for the expected snow depths in the pit (Tabler, 1994, p. 58). However, with that assumption, a pit will store one-half the snow drift in the design winter, estimated from Eq. 1. The snow fence must be of sufficient height to trap the other one-half of the annual snow transport. Equation 2 (Tabler, 1994 p. 103) gives the volume of snow water storage Q_c (metric tons/m) provided by a unit length of snow fence, as a function of fence height H (m).

$$Q_c = 8.5 \ H^{2.2} \tag{2}$$

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STORAGE LOSSES

Evaporation and seepage reduce available water. Sturges (1989) demonstrated that leakage equaled the snowmelt rate during April and May at one stockwater pond. Evaporation losses were much less than seepage. Plastic lining is essential to an effective system if seepage is a significant fraction of snowmelt rate. For pits lined with plastic, restricting animal access to a small corner of the pit will minimize damage to the liner.

COSTS

Snow harvesting costs include costs of excavation, snow fence, and optional pit liner. Maintenance costs are not included in the present version of design computations. The expected useful life of the system is 25 years. An example cost analysis (Jairell and Schmidt, 1992) shows that harvesting drift snow is often less expensive than developing wells.

COMPUTER-AIDED DESIGN

This design procedure is available as a spreadsheet computer program. The designer enters an estimate of winter precipitation and fetch distance at the site. The program estimates the volume of water available from drifting snow. Pit depth (D in Fig. 1b) is entered by the user, allowing soil profile information to be used to minimize seepage loss. The program computes pit width W (Fig. 1b) to provide the necessary water storage. Assuming the deposited snow is 50% water, the program selects a fence height H that will add sufficient drift storage capacity. Finally, costs are computed for the system, with and without a pit liner. Computations are for a unit width of fetch and system (Fig. 1a). The designer selects a system length that provides the required total water volume. The system of units may be either metric or English.

CONCLUSION

In regions of the central and northern Great Plains where much of the winter snowfall is relocated by wind, snow fences with pit reservoirs are a proven method of obtaining livestock water. Properly designed, with fence upwind, berm downwind, and storage capacity to match annual snow transport, such systems are a cost-effective alternative to wells. At locations where existing wells become unreliable in drought years, snow harvesting can augment existing water developments at a reasonable cost.

Designing a snow fence-pit-berm water source begins by estimating available snow transport, from average winter snowfall and fetch distance along the drifting wind direction. Pit excavation must match this volume of water. The pit will then trap one-half the snow transport. A snow fence height is chosen to provide storage for the one-half of snow transport not stored by the pit and berm. The snow fence, pit, and berm are extended across the wind to match the water requirements (number of animals, number of days of use, and losses to seepage and evaporation). Initial construction cost per unit width of system is multiplied by length of fence and pit to estimate total cost.

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USING NLEAP TO ESTIMATE CROPLAND NITRATE LEACHING LOSSES IN THE CENTRAL WISCONSIN SAND PLAIN

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ABSTRACT

Excessive nitrate has been documented as the major groundwater contaminant in the sandy, intensively agricultural 108 sq. mi. Stevens Point-Whiting-Plover (SWP) wellhead protection area of the Central Wisconsin Sand Plain. Groundwater is typically within 10 to 20 feet of the surface. About 25% of rural domestic wells exceed the nitrate-N standard of 10 mg/l.

We used the Nitrate Leaching and Economic Analysis Package (NLEAP) model to estimate nitrate leaching from three sandy soils under specific cropping, management, and environmental conditions. The model simulated production of irrigated potato, sweet corn and snap bean, dryland corn and dryland alfalfa on three soils with two N management systems under average rainfall. The data showed that nitrate leaching (NL) increased as applied N increased, cropping intensity increased and soil coarseness increased. Plainfield loamy sand was very susceptable to large NL losses. Integrated Crop Management (ICM) reduced applied N and NL by 20-45 and 3-41 lb N/a respectively, compared to conventional management (CON). For vegetable crops, ICM included proper irrigation scheduling which reduced irrigation and leachate water 13-50% compared to CON. NLEAP results suggest management and land use alternatives exist which could reduce NL losses and improve water quality.
KEYWORDS.Water quality,groundwater,nitrate leaching, NLEAP, integrated crop management.

INTRODUCTION

The Stevens Point, Whiting, Plover (SWP) Wellhead Protection Project Hydrologic Unit Project is designed to protect the groundwater recharge area of municipal wells serving more than 40,000 people in three communities. The 108 sq. mi. groundwater recharge area is located in the dominantly agricultural Central Wisconsin Sand Plain of Portage County (Fig. 1). The project's main goal is to encourage voluntary adoption of Best Management Practices (BMPs) to reduce nitrate and pesticide contamination of groundwater. Agriculture includes a mixture of intensively managed irrigated vegetable farming, and less intensive dryland and irrigated corn-alfalfa-dairy farming. Land use (Fig. 1) consists of 38% cropland, 36% woods and wetland areas, and 26% urban and all other uses (Ebert and Moberg, 1992). About 38% of the cropland or 10,000 acres is sprinkler irrigated, mostly with center pivots. In a typical year, vegetables are grown on 7,100 acres (71%) of the irrigated cropland. Potato makes up about 3,600 acres which is 5% of the basin area and 5% of the state's potato acreage.

The basin is sensitive to groundwater problems because sandy soils overlie a sand and gravel aquifer which is typically within 10 to 20 ft. of the surface (Ebert et al., 1993). Irrigated agriculture is concentrated in the southern part of the SWP near urban areas and municipal wells (Fig. 1).

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Figure 1. Stevens Point, Whiting, Plover
Wellhead Protection Project Area

Direction of Groundwater Flow
☐ Agriculture
◼ Irrigated Agriculture
▨ Grassland/Undeveloped
▨ Forest
☐ Urban/Sports Area
◼ Commercial/Industrial
☐ Airport
◼ Water
● Municipal Well Location

Portage County

Stevens Point
Recharge Area

Whiting
Recharge Area

Wisconsin

Plover
Recharge Area

Source: Portage County Planning and Zoning
Digitized by Golden Sands RC&D, 1992

Water Resources Planning Staff, 1993
State Plane Coordinate Projection, Zone 5726

Table 1. NLEAP Predicted Annual Nitrate-N Leached (NL) to Groundwater from 3 Soils and 5 Cropping Systems with Integrated Crop Management (ICM) and Conventional Management (CON) and Average Rainfall in Portage Co., WI

Cropping System (yield/acre)	N Appl.		Nitrate-N Leached					
			Plainfield ls		Billitt sl		Rosholt l	
	ICM	CON	ICM	CON	ICM	CON	ICM	CON
				-----lb N/acre-----				
3 T dryland alfalfa	0	0	0	0	0	0	0	0
100 bu. dryland corn	130	170	46	83	8	11	8	13
4.5 T irrigated snap bean	70	110	37	48	11	14	18	23
6.5 T irrigated swt. corn	150	175	55	87	18	37	30	55
20 T irrigated potato	220	265	120	138	69	110	95	133

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Table 2. Estimated Irrigation Water Applied (IWA) and NLEAP Projected Leachate Volume (PLV) from 3 Soils and 3 Cropping Systems With Integrated Crop Management (ICM) and Conventional Management (CON) and Ave. Rainfall in Portage Co., WI.

Cropping System (yield/acre)	Plainfield ls				Billitt sl				Rosholt l			
	IWA		PLV		IWA		PLU		IWA		PLV	
	ICM	CON	ICM	CON	ICM	CON	ICM	CON	ICM	CON	ICM	CON
					----in./year----							
4.5 T snap bean	4.5	5.2	10	11	4.2	4.8	5	6	4.2	4.8	4	5
6.5 T swt. corn	6.1	7.5	7	8	6.6	7.8	3	4	6.6	7.8	3	4
20 T potato	8.6	12.4	9	12	7.2	12.0	5	10	7.2	12.0	5	10

Groundwater moves south and southwest from these areas toward the urban areas. The villages of Plover and Whiting have installed nitrate removal systems costing $2.7 million because their wells have exceeded the 10 mg/l NO_3-N drinking water standard. About 25% of rural domestic wells now exceed the nitrate standard (CWGC, 1994).

NLEAP ANALYSIS AND DISCUSSION

The Nitrate Leaching and Economic Analysis Package (NLEAP) model developed by Shaffer et al. (1991) was used to estimate nitrate leached (NL) from three typical soils under specific cropping, management, and environmental conditions. Under ideal conditions, crops take up about 50-70% of available N with the rest subject to NL or other losses (Stanford, 1973). Table 1 shows estimated NL from two dryland and three irrigated cropping systems with integrated crop management (ICM) and conventional (CON) management under average rainfall conditions. NL increased as cropping intensity increased, applied N increased, and soil coarseness increased. Irrigated long season potato had the highest fertilizer N requirement and the highest NL losses (Table 1). Potato averaged nearly 140 lb N/a NL when fertilized with 265 lb N/a on sand. NL was more than 50 lb N/a greater with potato compared to other crops under similar management. For row crops, ICM reduced applied N by 20-45 lb N/a and NL by 3-41 lb N/a as compared to CON. NL losses were only 8 lb N/a for dryland corn with ICM on the two loam soils. Dryland alfalfa received no applied N and showed no NL losses.

For vegetables, Univer. of WI-Extension irrigation scheduling component of ICM reduced irrigation water applied (IWA) by 0.6-4.8 in./year and NLEAP projected leachate volume (PLV) losses from the root zone by 1-5 in./year compared to CON (Table 2). For irrigated crops, ICM reduced NL by reducing applied N (Table 1), IWA (Table 2) and PLV (Table 2). ICM reduced PLV by 3-5 in. of water or 25-50% for potato and by 1 in. or 13-25% for snap bean compared to CON. Irrigation scheduling is vital to minimize NL due to over-irrigation.

The high NL values generated by NLEAP for irrigated vegetable crops is in agreement with a the results of a recent N mass balance study conducted in the wellhead area. Using 1991-92 cropping and land use data, Kaap et al. (1993) estimated potentially leachable nitrogen (PLN) of 66 lb N/wellhead area acre, 100 lb N/cropland acre, and 160 lb N/row crop (vegetable and corn) acre. PLN represents excess available N potentially subject to NL after accounting for N imputs and losses from the system, including crop and animal uptake and removal from the area. The data suggests that irrigated vegetable farming is a major source of PLN.

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NL was much greater for crops grown on the sandier Plainfield soil than on the finer textured loams. For example on dryland corn, NL was nearly six times greater on the sand than on the two loams (Table 1). These results agree with past UWEX research showing that coarse Plainfield soils are subject to rapid NL losses (Olsen et al., 1970; Endelman et al., 1974). In a corn-soybean study of "carryover" N, Bundy et al. (1993) found that early spring residual soil profile nitrate contents were much less in the top 3 ft. of Plainfield soil than in silt loam soils.

CONCLUSIONS

NLEAP results suggest that some management alternatives exist which could reduce NL losses. First, growers need to adopt ICM practices to utilize applied N and irrigation water more efficiently. Second, irrigated crops may need to be grown only on finer textured soils, not on the extremely leachable Plainfield and other sands. Unfortunately, Plainfield loamy sand is the dominant irrigated soil in the SWP area. SWP staff estimated that 20% to 40% of irrigated crops are grown on sands, which are ideal for potato production. Therefore, this alternative becomes very difficult to implement. An even more drastic alternative would be to ban irrigated agriculture from the wellhead area.

These and other NLEAP modeling results were used in a followup study to correlate annual nitrate loading to the aquifer and nitrate concentrations in municipal wells (Kaap et al., 1995). From this, quantified reductions in nitrate loading were targeted and addressed through ICM implementation and changes in cropping and land use. These actions may be the first steps in reducing nitrate concentrations in public drinking water supplies to safe levels.

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MONITORING SOFTWARE FOR POLLUTANT COMPONENTS IN FURROW-IRRIGATION RUNOFF

R.D. Lentz and R.E. Sojka[1]

ABSTRACT

Non-point source pollution from furrow-irrigated agriculture threatens surface water quality throughout irrigated regions of the world. For example, sediment or dissolved chemicals contributed by irrigation return-flows can degrade habitats and increase user costs downstream. The threat from these pollutants has been fully appreciated only recently, resulting in an increased interest in runoff monitoring. However, analysis of runoff data from furrow-irrigation is cumbersome and time consuming. Calibration functions relating measured quantities to desired water-component concentrations must be obtained for each treatment (e.g. a calibration function relating measured component volumes to runoff component concentration). It is awkward and tedious to plot or analyze constituent runoff data by treatment. The PASCAL program described here reads inflow and runoff data from an ASCII text file and derives, displays, and statistically compares calibration functions for treatments or any other user-defined furrow group. It employs the computed or a user-supplied function to calculate infiltration, runoff, and component loss for each furrow. In addition, the software computes and plots group-averaged values for inflow, outflow, infiltration, runoff constituent loss, and outflow constituent concentration as a function of irrigation duration.
Keywords: Furrows, Irrigation, Runoff, Sediment discharge, Field losses, Infiltration.

INTRODUCTION

Several field constituents are lost from furrow-irrigated fields in tailwater, including eroded sediment (Berg and Carter, 1980, mineral and fertilizer salts (Carter, et al., 1973), pesticides (Hall, et al., 1991), weed seeds, and disease organisms (e.g. nematodes). When these displaced materials enter the return flow, the stream becomes a potential non-point pollution source of surface waters.

Some 1.5 million ha of highly erodible soils are furrow irrigated in the Pacific Northwest. Soil-losses ranging from 5 to 50 t ha^{-1} yr^{-1} occur on many ha in South-Central Idaho (Berg and Carter, 1980). Soil erosion is a critical process because other field components such as total phosphate and pesticides are closely associated with fine soil particles, hence, phosphate or pesticide losses are directly related to amount of sediment removed from fields in irrigation runoff.

WASHOUT is a comprehensive Pascal program that may be used to compute and plot irrigation inflow, runoff, and infiltration values, and ongoing pollution-component-losses (e.g. sediment) in furrow tailwater. Calibration functions relating measured component indexes to runoff component concentration (e.g. functions relating volume of settled sediment in Imhoff cones to mass of sediment per unit volume runoff) are computed by WASHOUT. Calibration functions can be computed separately for different furrow conditions and statistically compared to determine whether the individual functions are required to compute field component losses. Net infiltration is calculated, and calibration functions are employed to estimate the runoff constituent and its net loss for each furrow. WASHOUT computes and plots group-averaged values of cumulative constituent loss, outflow constituent concentration, and flow rate as a function of irrigation duration.

USING *WASHOUT* TO MONITOR FURROW SOIL LOSSES

We used WASHOUT to monitored furrow-irrigation induced sediment losses in Southern Idaho. Sediment content in furrow tailwater was measured using the Imhoff cone method. The technique employs a calibration function that correlates the sediment volume settled in an Imhoff cone after 30 min, with sample sediment concentration (weight per unit volume runoff).

Field measurements were made on each experimental furrow. These included irrigation inflow, out-flow, and settled sediment volumes from 1-L runoff samples collected in Imhoff cones. Identifying codes, furrow spacing and length were noted for each furrow. Time and inflow rate were recorded whenever furrow inflow was adjusted. Time, outflow rate, and sediment volume were recorded at each sampling interval. Outflow rate and sediment volume were measured at 5 and 15 min after furrow advance, then every 30 min during the next 3 h. From then on, measurements were made hourly, with a final appraisal made just prior to inflow shut off. Four to ten runoff samples, representing the sampling range were collected from Imhoff cones for each treatment. These were filtered in the laboratory and sediment mass was used to compute calibration functions (see following section). Details on furrow monitoring and filtering techniques were reported previously (Lentz and Sojka, 1994).

WASHOUT reads the raw data from an ASCII text file. Information for each furrow is entered as a block, beginning after the initial data file title record. Computer data entry is simplified because the field data sheet format closely matches that of the input file (e.g. see Sojka et al., 1994).

Imhoff Cone Calibration Functions

The program computes Imhoff cone calibration functions for up to 20 different groups defined by one or more of the furrow identifiers. The ability to declare group types permits one to determine those treatments or factors that require unique calibration functions. Sediment mass of collected calibration samples are regressed on the corresponding Imhoff settled-sediment volumes using the least squares method. Sediment concentration ($SCONC_i$), in g L^{-1} for each irrigation interval (i) , is estimated from the calibration equation: $SCONC_i = B \cdot SVOL_i + C$, where B is the slope, C is the Y-intercept, and $SVOL_i$ is the Imhoff cone settling volume (mL).

WASHOUT then tests for similarity among calibration functions using an ANOVA F-test . Up to four of any of the groups can be tested at one time. After defining groups to be employed in the analysis, WASHOUT asks for the number and identification of groups to analyze. Regression functions for each group are computed and both lines and data points are displayed (Fig. 1), permitting a rapid graphic assessment of regression fit. Next, a statistical comparison between group calibrations is completed; and the functions are displayed on screen, along with F-test statistics (Fig. 2). This analysis determines whether unique calibrations are required for each group.

Infiltration and Sediment Loss Calculations

When calibration function analysis is complete, the program requests the user to specify which calibration function to apply to each of the previously selected furrow groups. Output values are then calculated for all furrows in each group. At this point a program prompt permits the user to request a data display for individual furrows (Fig. 3).
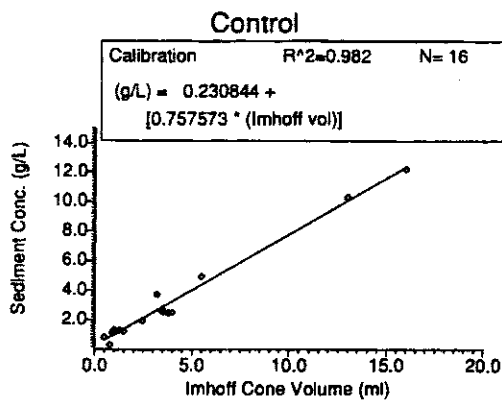
Fig. 1. Calibration function and data points. Four functions per page.
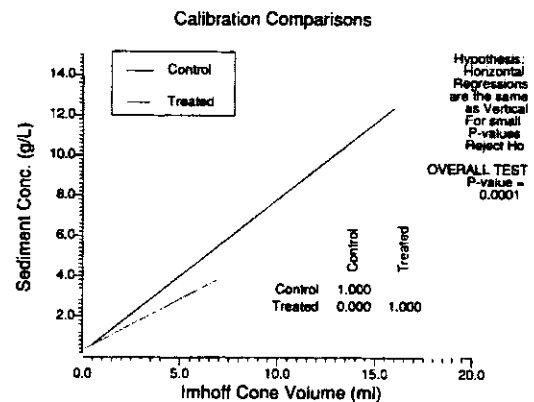
Fig. 2. Display of compared calibration functions and F-test statistics.

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The software outputs computed values to an ASCII text file, which is readily imported into statistical or graphics software. Furrow identifiers are included to aid in sorting data. Each data column in the output file is labeled. Calculated outputs include mean outflow in L min^{-1}, total sediment loss in kg/ha, total inflow in mm, total outflow in mm, total infiltration in mm, mean sediment concentration in g/L, depth of soil loss in mm, infiltration in inches, and furrow advance time in minutes (time required for the water to traverse the dry furrow).
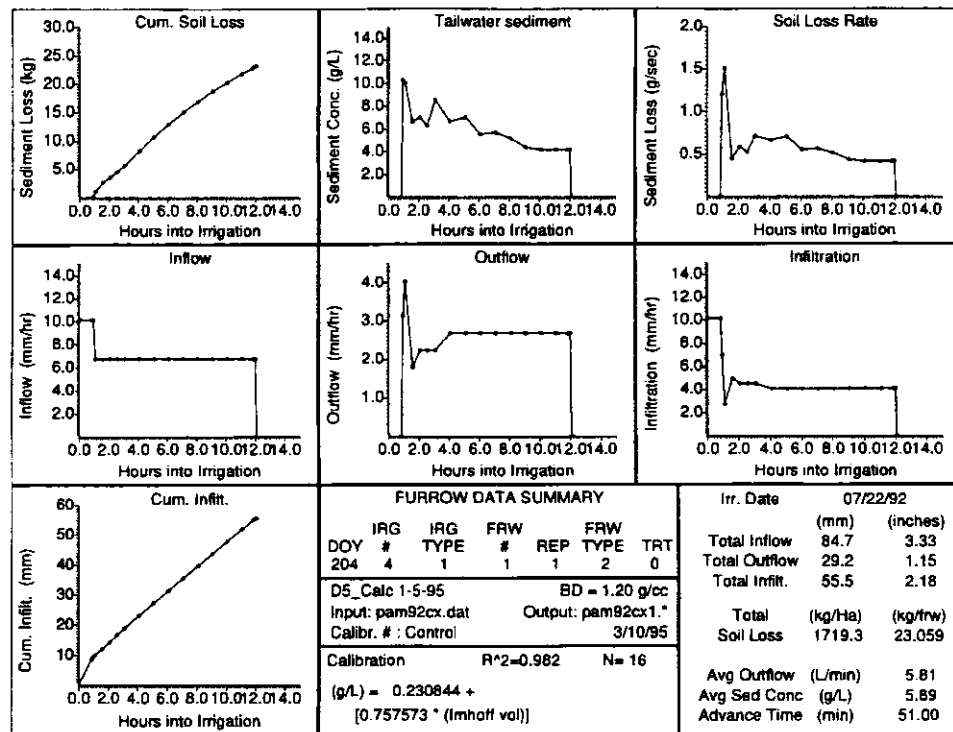
Fig. 3. Display option for individual furrow output.

The program also outputs a second file, which contains irrigation duration data. WASHOUT can tabulate furrow data based on group or furrow identifier. Compiled irrigation parameter values, cumulative soil loss, runoff sediment concentration, and outflow rate are averaged within the defined groups and plotted as functions of irrigation duration (Fig. 4).

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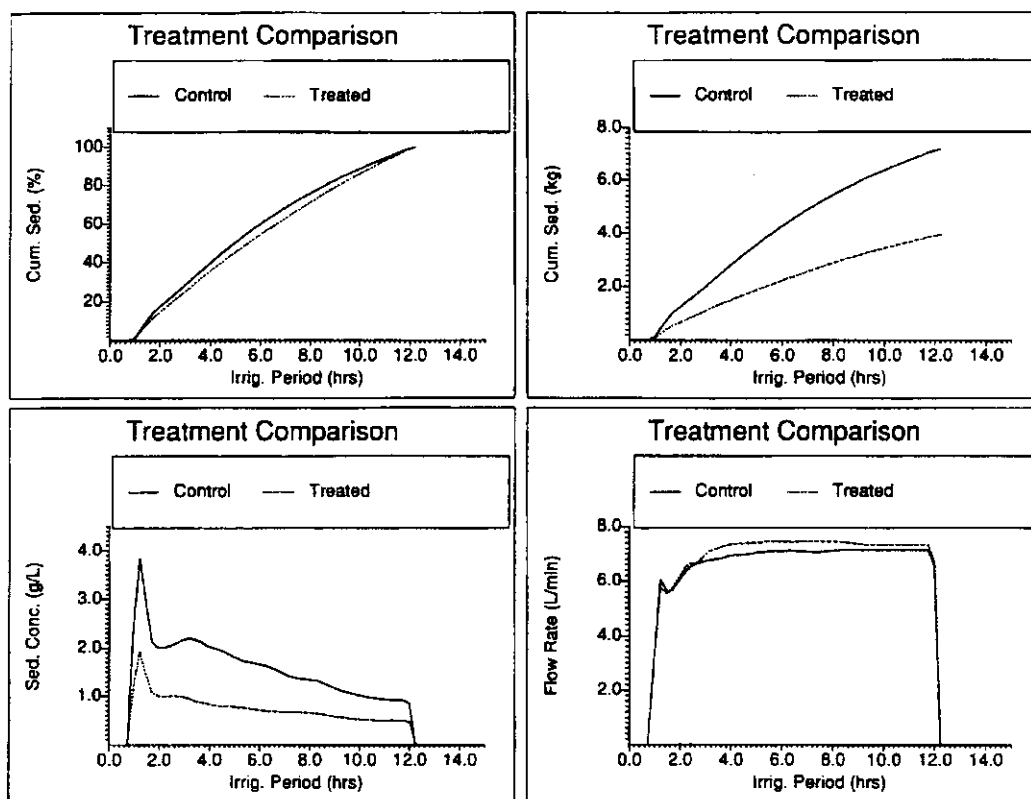
Fig. 4. Display of group-averaged irrigation parameter values plotted as a function of irrigation duration.

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MODELS FOR ESTIMATING GROUNDWATER CONTAMINATION POTENTIAL FROM AGRICULTURAL PESTICIDES

Shiping Liu and Dana Hoag[1]

ABSTRACT

Agricultural chemicals are significant contaminants of groundwater. Many indices and models have been developed to estimate their contamination potential. Policy makers and their agents have a difficult time assessing which models to use. This study used a rank test to compare ranking results between alternative approaches. The rank tests indicate that the contamination potential is strongly correlated for all approaches considered. We suggest that simplified guidance from technical specialists would help policy makers make better decisions.
Keywords: Groundwater contamination, ranking, policy

INTRODUCTION

Public concern has increased over groundwater contamination. Precise estimates of the extent of groundwater pollution are difficult to make. The USEPA, U.S. Department of Agriculture, and other agencies have devoted considerable resources to understand and quantify pesticide leaching and subsequent groundwater contamination. Consequently, many indices and computer simulation models have been developed to estimate pesticide leaching potential or to simulate leaching through the soil profile. Most are intended to be used by persons with experience in the field. However, they are often used by or for policy makers with little understanding of how they work or what they mean.

The purpose of this study is to compare the relative differences in leaching potential estimates for alternative indices, screening tools, or models from a policy maker's perspective. Modelers have made such comparisons (Harter and Teutsch, 1990; Rao, Hornsby and Jessup, 1985). But these have been technical in nature. A policy maker is faced with many choices and is interested in only one "simple" question: which chemical leaches the most? The actual answer is best characterized by "it depends," and a communication gap is thus born. We review five approaches for estimating groundwater contamination potential, and compare predictions across the approaches by applying them to the Walnut Creek watershed in Iowa. Our approach is to compare only the end results of the models. That is, we contend that the process is not of interest to policy makers, only the results. Therefore, we compare the ordinal rankings indicated by different approaches. We offer our limitations as economists as further evidence as to why modelers need to assist users such as us with modeling choices, since we will not have the

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expertise to judge the process that generates the results. In addition, we expect the results to be specific to the data choices made for the example, and do not mean to imply any generalization of our results.

MODELS AND INDICES FOR ESTIMATING
GROUNDWATER CONTAMINATION POTENTIAL

Several simulation models have been developed to estimate groundwater contamination potential: Groundwater Loading Effects of Agricultural Management Systems (GLEAMS), Chemical Movement in Layered Soils (CMLS), the Pesticide Root Zone Model (PRZM), and the Leaching Estimation and Chemistry Model (LEACHM). These field-scale simulation models provide quantitative estimates of water and solute movement but also require extensive data inputs for the system that is being simulated. Another class of screening tools is indices (Rao, Hornsby, and Jessup, 1985). The main advantage of indices is that they have low data demands and are designed to be relatively easy and inexpensive to use.

Already the policy maker is faced with the question of precision over simplicity. But do the different approaches yield different results? We focus on four indices, the GUS index, the HLP/SLP Matrix, the GWCP, and the Jury "screening" model, and one simulation model, PRZM.

GUS. The GUS (groundwater ubiquity score) index (Gustafson, 1989) is a measure of the potential for a pesticide to reach the groundwater. The GUS index depends on two chemical properties of pesticides: soil half-life (T1/2) and partition coefficient (Koc). A higher GUS index is correlated with a higher tendency for a chemical to leach into the groundwater. The GUS score is independent of soil properties.

HLP/SLP Matrix. Weber (1991) developed a herbicide leaching potential (HLP)/soil leaching potential (SLP) matrix to help farmers select the best herbicide and reduce the chance of herbicides getting into their groundwater. The SLP for a given soil series is computed by summing the products of ratings and the appropriate weighting factors for pH, texture and organic matter. The HLP uses Koc (partition coefficient), $T_{1/2}$ (half-life), rate of herbicide applied, and the fraction of herbicide hitting the soil, which depends on canopy size. A matrix indicates the potential risk of applying a given herbicide on a given soil series based on the combined HLP/SLP scores.

GWCP. A relative county groundwater contamination potential (county GWCP) was developed based on HLP/SLP values. The index was adjusted by accounting for the market share of each pesticide in the county being evaluated (Liu, 1993). The revised index provides continuity and adds the ability to generalize to a county level. It maintains all of the properties of the HLP/SLP index.

<u>Jury Screening Model</u>. Jury et al. (1983) recommend using a screening model that includes the influence of mobility and biochemical half-life to assess the potential for contamination.

COMPARING PESTICIDE LEACHING POTENTIAL ESTIMATES

To test the potential difference in model estimation, the five measurement approaches were applied to Walnut Creek Watershed. There are 13,100 acres of cropland and 760 acres of timber and pasture in the watershed, which receives an average of 849 mm of annual precipitation. The two major crops are corn and soybeans which account for more than 90 percent of the total cropland. More than 95 percent of corn acres are treated with herbicides by more than one treatment (1.8 on average). The major herbicides used in this watershed are Atrazine (AAtrex), Cyanazine (Bladex), EPTC (Eradicane) and Metolachlor (Dual), which account for about 75 percent of corn acres treated with herbicides. Half-life and K_{oc} values for the most frequently used herbicides in the watershed are listed in Table 1, along with the corresponding GUS and HLP scores.

<u>Pesticide Leaching Potential</u>
GUS and HLP were estimated for the nine herbicides listed in Table 1. Based on GUS index, Dicamba (Banvel), Atrazine, and Bentazon (Basagran) were indicated as most likely to leach (Table 1). HLP scores for these nine herbicides indicate that the herbicides Dicamba, Atrazine, and Bentazon are most likely to leach.

From Table 1, it is clear that relative leaching potentials estimated using HLP and GUS for the nine herbicides are very similar because both use Koc and $T_{1/2}$ as major characteristics to indicate a herbicide's leaching potential.

Table 1. Major herbicides and their characteristics

Chemical Name	Trade Name	Half Life (days)	Koc	GUS	HLP
Niscosulfuron	Accent	26	450	1.9057	0.0002
Atrazine	AAtrex	60	100	3.5563	0.5580
Bentazon	Basagran	35	20	4.1674	0.4025
Bromoxynil	Buctril	5	190	1.2031	0.0071
Cyanazine	Bladex	14	190	1.9728	0.0597
Dicamba	Banvel	14	2	4.2395	2.3800
Metolachlor	Dual	20	200	2.2104	0.2220

The other indices or models require more information. To be complete, a fifth measurement, the PRZM model, is also added. Simulation runs were performed with the PRZM module of the Risk of Unsaturated/Saturated Transport and Transformation of Chemical Concentrations (RUSTIC) model, a linked modeling system developed for the USEPA.

RANK TEST RESULTS

The Spearman's coefficient of rank correlation was used to assess whether the different models and indices give consistent estimates of relative risks for different herbicides or soils. The GUS and HLP correlation coefficient is 0.93651 and T value is 7.06628. This is significant at the 0.1 percent level, indicating that the relative potential of the different herbicides to leach as estimated by the GUS and HLP scores is consistent.

The pesticide leaching potential or the amount of pesticide leached as estimated by the remaining three models, Jury, PRZM and GWCP, depends on both herbicide characteristics and soil characteristics. Test results indicate that the estimates provided by each model are strongly correlated and therefore, at least the results made by each of the three models are very similar.

Table 2. Rank tests of four estimations[a]

Model	GWCP	JURY
Jury	(0.850, 14.34, n=54)	
PRZM	(0.832, 10.82, n=54)	(0.870, 12.73,n=54)

[a]The first number is the estimated correlation coefficient, the second number is t value, and n is the number of pairs. They all are significant at 0.1 percent level.

CONCLUSIONS

There are many different indices and models that have been developed to estimate pesticide leaching and or pesticide leaching potential. These different indices and models range greatly in the types of data that are required and the output that is provided. Based on a simple ranking of results from these models or methods, there are little differences in the message they are sending to policy makers and other decision makers. Less sophisticated users could benefit by guidance from modelers based on results instead of technical comparisons about model process.

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THE PHYSICAL HABITAT SIMULATION SYSTEM: STRUCTURE AND LOGIC

Robert T. Milhous[1]

ABSTRACT

The Physical Habitat Simulation System (PHABSIM) was developed to determine how the instream physical habitat for aquatic animals changes as the discharge in the stream changes. The system is designed to work with information about a specific stream and about a specific species of aquatic animal (fish, aquatic invertebrate, and so forth). The system simulates the habitat using user supplied data for the stream and for the species of animal. The system first simulates water surface elevations (depths are calculated from the water surface elevations); second, the velocities; third, the physical habitat versus streamflow relationship; and fourth, the physical habitat when combinations of flows or species are involved.

INTRODUCTION

The Physical Habitat Simulation System (PHABSIM) simulates the relation between physical habitat for various life stages of a species of fish or a recreational activity and the instream discharge. The objective of physical habitat simulation is to obtain a biological representation of the physical charateristic of a stream. In water allocation decisions, knowledge of the relationship between benefits and streamflow for the various uses is desirable. In general, the benefit of an out-of-stream use can be quantified in terms of some type of production function relating the quantity of water used to the benefits produced. In order to have the ability to make measurable tradeoffs between the various uses, a simulation system called PHABSIM has been developed to analyze and display the relationship between streamflow and physical habitat, or between streamflow and recreational river space. This relationship is a continuous function between the physical habitat and the streamflow. It can be used to examine the tradeoff between the value of water used instream with the water used out-of-stream. Therefore, tradeoffs can be made between alternative uses and mutually acceptable management criteria developed. The decision as to the "best" allocation of the available water is a matter of negotiation among various interest groups. Examples of the application of PHABSIM to water allocation problems are presented in Milhous, R.T. (1986) and in Nestler, Milhous, and Layzer (1989).

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The basic equation used in physical habitat simulation is:

$$WUA(Q) = \int_A f(v,d,CI) \, dA \tag{1}$$

where WUA(Q) is the physical habitat at the streamflow Q (usually called the weighted usable area), dA is an incremental area, A is the total area at the streamflow Q, v is the velocity, d is the depth, CI is an index to the channel characteristics and is usually after a combination of a substrate index and a cover index, although other forms of a channel index are possible.

The equation above can also be represented as the sum of areas within a larger reach of stream. In this case the sum is:

$$WUA(Q) = \sum_{i=1}^{n} f[v(i), d(i), CI(i)] \tag{2}$$

in which the reach has been divided into n cells and v(i), d(i), CI(i) are the average values for the variable within a specific cell (cell i in this case).

The usual functions, f( ), is:

$$f(v,d,CI) = g(v) * h(d) * k(CI) \tag{3}$$

where g( ) is some function of the velocity as related to the habitat needs of the aquatic animal, h( ) is some function of the depth, and k( ) is some function of the stream channel index, usually substrate and/or cover. The velocity and depth vary as the streamflow changes, but it is assumed the channel index does not. Other functions are available as options in the habitat simulation models. See Stalnaker (1980) and Bovee (1986) for additional information on the development of the functions g, h, and k (also called species criteria).

Temperature can also be considered in the physical habitat simulation if the suitability of habitat as a function of temperature is available. The function for temperature is used in the equation below:

$$WUA'(Q) = WUA(Q) \times m(T) \tag{4}$$

where WUA'(Q) is the weighted usable area modified for temperature effect, m( ) is a function of temperature, and T is the temperature.

STRUCTURE OF PHABSIM

The PHABSIM system is a library of programs that can be collected in to three major groups and a fourth group that is used to support a user of the system in the application of the system. The three major groups are: 1) programs used for the simulation of velocities and water surface elevations (hydraulic simulation); 2) programs used to simulate the habitat in the stream using the simulated velocities and water surface elevations (used to calculate depth), an index to the substrate and cover(channel index), and criteria relating the quality habitat for a species of aquatic animal to the velocity, depth, and channel index; 3) programs that use either multiple species or different times to arrive at the physical habitat (combined habitat).

The hydraulic simulation programs assume the shape of the channel does not change with streamflow over the range of flows being simulated. The results of the hydraulic calculations are water surface elevations and velocities. The water surface elevations are one dimensional in that the same value is used for any point on a cross section. In contrast, the velocity varies from point-to-point across any cross section. The hydraulic models also assume the water surface elevations are effectively independent of the velocity distribution in the channel.

The structure of PHABSIM is given in Fig. 1. Information on the simulation of habitat considering time or multiple species is given in Nestler et al (1989). The reference manual for the system is Milhous et al (1989).
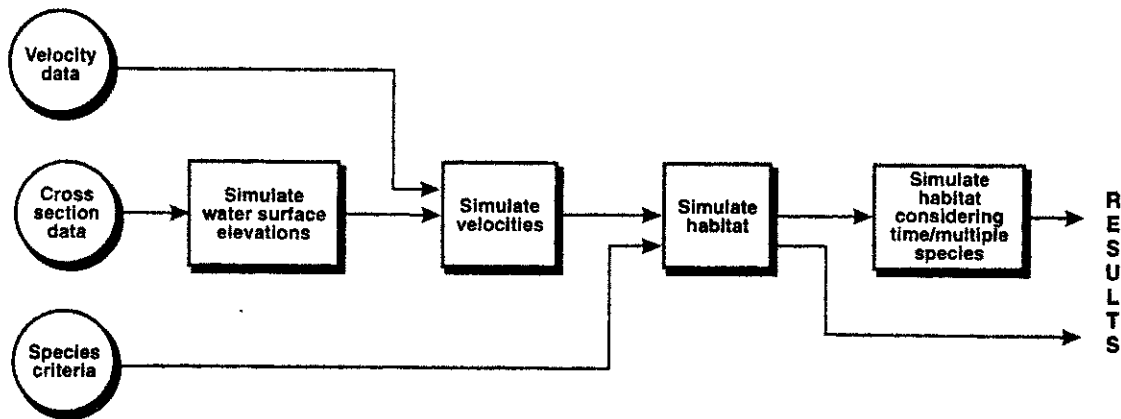
Figure 1. Structure of the Physical Habitat Simulation System (PHABSIM). The User supplies the information on the right of the diagram.

APPLICATION

An example of the habitat versus streamflow function developed using PHABSIM is given as Figure 2.
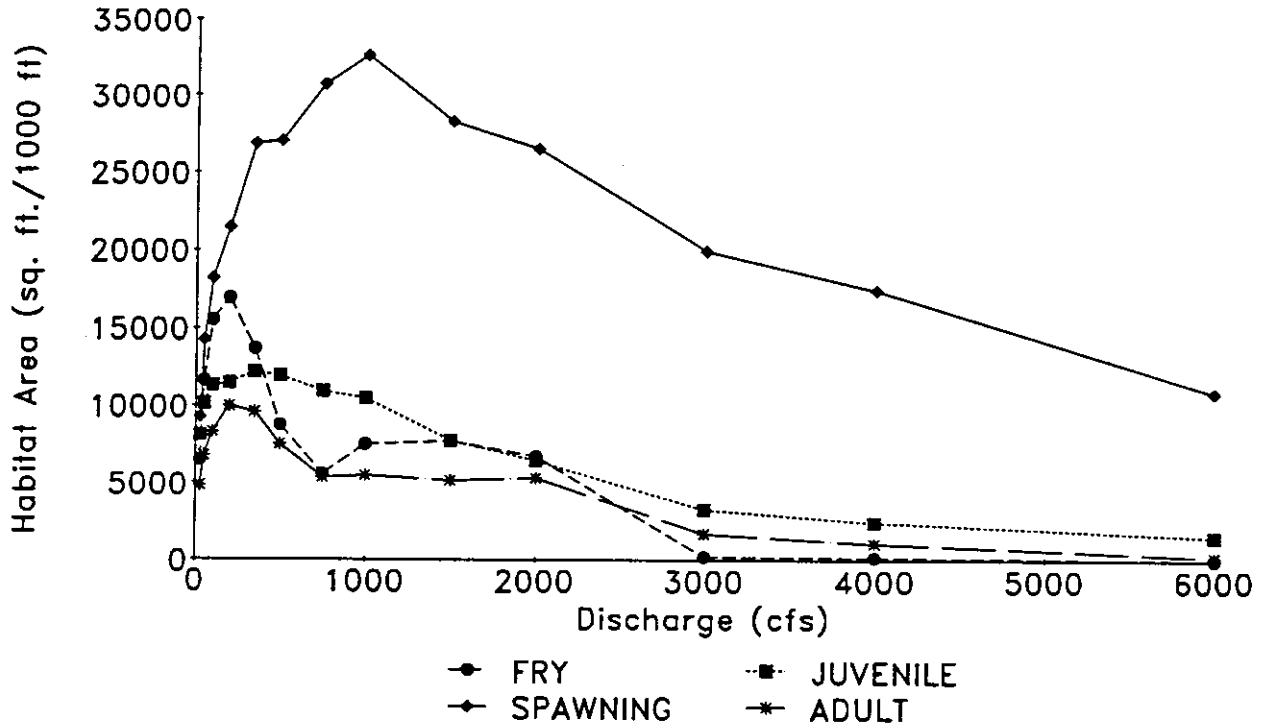
Figure 2: The Smallmouth Bass Habitat Versus Streamflow Function for the Pinedale Reach of the Salmon River in Northern New York.

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MODELING THE RIPARIAN ZONE

Robert T. Milhous and Gregor T. Auble[1]

ABSTRACT

The relation between riparian vegetation and streamflow is complex. Furthermore, the present state-of-the art in modeling the link between riparian vegetation and flows in the river is rudimentary. Two simple models are presented in this paper. The first links streamflows to the potential for establishment of cottonwood trees and is applied to the Bosque del Apache reach of the Rio Grande in central New Mexico. The second model links herbaceous species composition at a point on an elevational gradient to the frequency that the point is inundated. This model is applied to the canyon bottom of the Black Canyon of the Gunnision River in western Colorado.
Keywords: Riparian vegetation, cottonwood, streamflow

COTTONWOOD ESTABLISHMENT INDEX

Over the last 150 years the riparian cottonwood forests of the Middle Rio Grande Valley have changed significantly. The native cottonwoods are adapted to the natural pattern of a snow melt hydrograph characterized by spring floods in late May or early June, followed by gradually receding streamflows throughout the remainder of the summer. The natural pattern of streamflows has been significantly modified by water management activities in the Rio Grande basin and reduction in peak flows have been suggested as a cause of changes in riparian forest.

An index model of establishment suitability was developed to test the potential importance of flow alterations on cottonwood regeneration in the Bosque del Apache reach of the Rio Grande between San Acacia and San Marcial, NM, using streamflow data from gages near San Marcial (Milhous, 1994). Suitable conditions for cottonwood seedling establishment include a bare, moist substrate during the time the seeds disperse, followed by flows that do not destroy (usually by erosion or overtopping) the small plants. The first assumption of the index model is that the clean substrate results if flows cover an area during the period 1 April thru 15 July. The next assumption is that young seedlings survive if subsequent flows during the rest of the water year and through the next year do not exceed the flows during the initial germination window. If the flows during the rest of the water year or during the following water year are greater than the cleansing flow, the establishment index is zero. The model determines areas suitable for establishment by assuming the width of a river can be calculated using the simple power law, $W = A*(Q**B)$, (1)

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where W is width, Q is streamflow, and A and B constants. If the streamflow available to prepare an area for cottonwood establishment is QEST, and the flow following the establishment period limiting the area available for establishment is QDES, then the width available for establishment (WEST) is

$$WEST = A*((QEST**B) - (QDST**B)). \qquad (2)$$

The objective is an index to establishment; therefore, we assume the value of A is 1. The establishment index (ESTI) is thus

$$ESTI = (QEST**B) - (QDST**B). \qquad (3)$$

The width versus discharge relation (discharge in cms, width in meters) for the San Marcial gage is

$$W = 18.75 \, Q^{0.34} \qquad (4)$$

QEST is the maximum average 5-day discharge in the period 1 April thru 15 July. QDST is the maximum average daily discharge in the rest of the water year and the following water year. The results are given in Fig. 1. Note that there have been periods available for cottonwood establishment during all of the record, although the construction of upstream reservoirs has probably caused a reduction in the amount and the frequency. Thus, the establishment index model suggests that a moderate increase in peak flows would not improve the establishment of cottonwood in the Bosque del Apache reach.
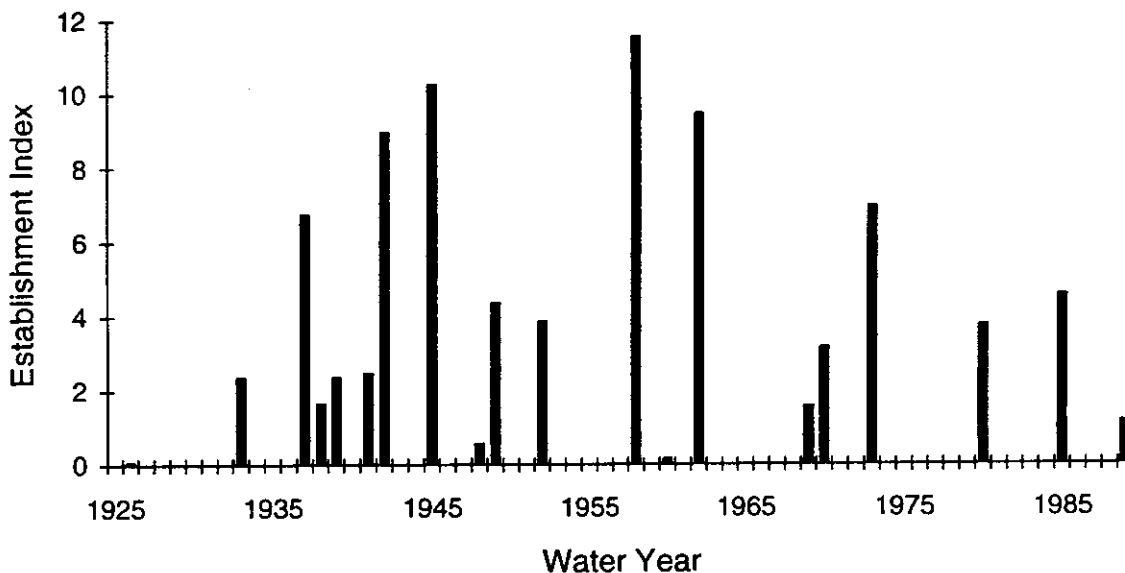
Figure 1. Annual Establishment Index based on seedling survival for the Rio Grande River near San Marcial, New Mexico. Water years 1925 thru 1989. Streamflow data from the records of the U.S. Geological Survey.

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This model employs a direct gradient analysis of existing vegetation to locate cover types along a gradient of hydroperiod, or fraction of time inundated as indicated diagrammatically in Fig. 2. The model has been applied to the largely herbaceous riparian vegetation of the Black Canyon of the Gunnison National Monument along the Gunnison River in Colorado (Auble et al., 1994). The model was calibrated by measuring the existing distribution of vegetation along a hydroperiod gradient. Randomly located plots were censused and four cover types were defined. A hydraulic model for the reach was calibrated and used to estimate the hydraulic position or discharge required to inundate each plot. Each plot was assigned to one of the cover types, and the hydroperiod determined for each plot based on the discharge required to inundate the plot and the historical flow exceedance curve. The hydroperiod gradient was broken into 12 classes and the proportion of plots in each cover type was calculated for each hydroperiod class (Fig. 3). These proportions were then used as probabilities to estimate the future cover type of a plot from its future hydroperiod.
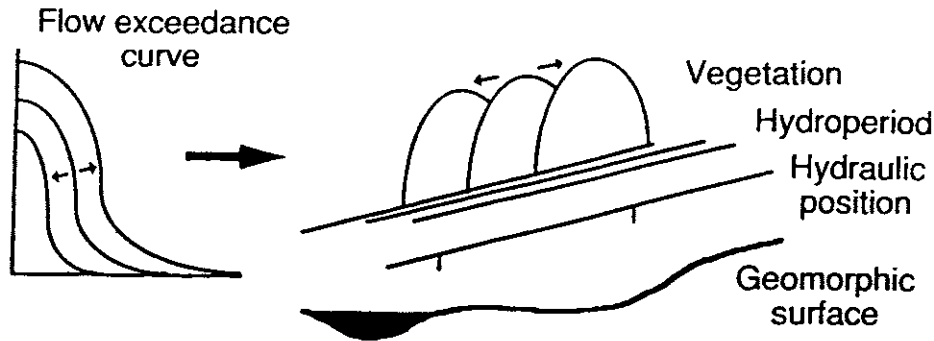
Figure 2. Diagrammatic application of direct gradient model (from Auble et al., 1991).
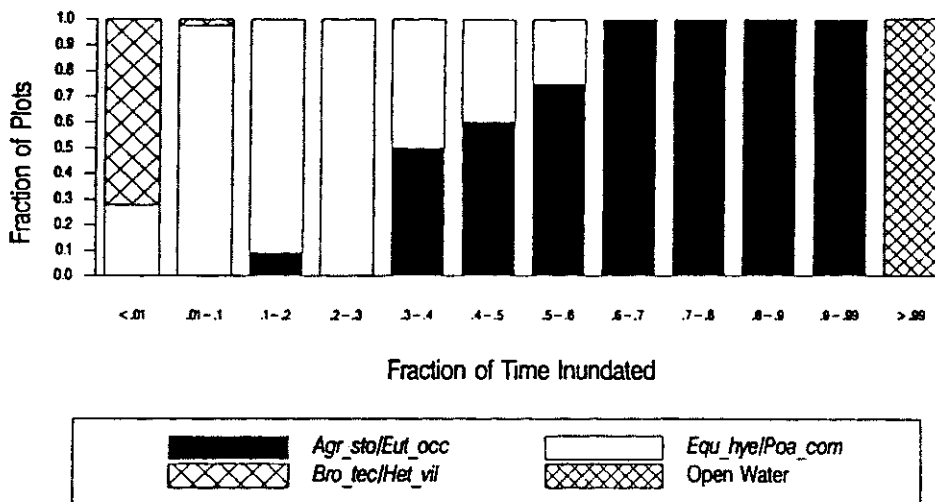
Figure 3. Observed distribution of riparian cover types used to calibrate direct gradient model (from Auble et al., 1991).

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Flow exceedance curves describing different hydrologic alternatives were used to produce plot hydroperiods associated with each alternative. Applying the cover-type probabilities to plots with new hydroperiods produced an estimate of the expected value of the new number of plots in each cover type as follows:

$$n(i,j) = P(i,j) * T(j), \tag{5}$$

where $n(i,j)$ = number of plots in cover type i and hydroperiod class j, $P(i,j)$ = probability that plot in hydroperiod class j is in cover type i, $T(j)$ = total number of plots in hydroperiod class j.

DISCUSSION

The complexity of riparian systems and the current state of the art of models relating streamflow to riparian vegetation do not permit development of a general model that can be reliably applied to a wide range of assessment problems. Rather, we are in the position of carefully matching the restrictive assumptions of available models to answering limited questions about particular riparian systems. The principal advantages of the cottonwood establishment index and direct gradient models are their simplicity and reliance on relatively standard aspects of plant community ecology and hydrology. Their most serious limitations are centered on unrealistic assumptions about stationary channel geometry. The direct gradient model may work reasonably in a bedrock controlled canyon, but where the channel is meandering the hydroperiod of points in the riparian zone is changing as the discharge to inundate those points changes. Likewise, the cottonwood establishment model may be doing poor job of estimating long-term cottonwood regeneration by failing to account for whether or not the suitable area is in the same or different locations over time. Seedlings established in the same location as last year's seedlings do not produce the same replacement of trees as seedlings established on a newly accreting point bar that will be less subject to future disturbance as the river moves away from the establishment site. Effectively incorporating fluvial geomorphic processes into the relation between flow and vegetation is the challenge of the next generation of riparian models.

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WATERSHED HYDROLOGY AND BIOGEOCHEMISTRY: SIMULATION OF STREAMFLOW QUANTITY AND QUALITY BY THE CENTURY MODEL

William M. Pulliam and William J. Parton[1]

ABSTRACT

Century is a linked hydrologic-biogeochemical simulation model with interconnected submodels for water flow and storage, primary production, and decomposition. It simulates biotic effects on water loss and streamflow chemistry explicitly and interactively. Thus, it can be used to provide dynamic simulations of streamflow amount and the export of organic and inorganic solutes from natural and managed ecosystems. The hydrologic submodel is based on a monthly water balance, driven by precipitation, temperature, simple soil physical properties, and biomass controls. Water losses (evaporation, transpiration, sublimation, drainage) and storages (soil water and snowpack) are simulated from these drivers. This model realistically predicts monthly water loss and streamflow for a suite of ecosystems including grassland, forest, and tundra. Leaching and streamwater export of organic C, N, and P and inorganic N and P are simulated by simple relationships between water flow, soil texture, and sizes of labile soil organic matter (SOM) and inorganic nutrient pools. The SOM and nutrient pools are in turn simulated dynamically by the linked production-decomposition biogeochemical submodels. *Century* has shown the ability to realistically predict changes in streamwater chemistry in response to natural and human-caused disturbances.

THE CENTURY MODEL

Estimates of hydrologic budgets and biogeochemical fluxes are vital to studies of ecological effects of climate change. We here present evaluations of the performance of *Century, an* ecosystem biogeochemical model linked to a monthly water balance model. In this model we have linked key hydrologic and ecosystem processes that can vary over time, providing a dynamic simulation of interplays between abiotic and biotic phenomena. *Century* is designed for general applicability to any upland ecosystem, including forest, grassland, cropland, shrubland, or tundra. After site calibration, the only climate data needed for deriving these estimates are simple monthly mean values for precipitation and air temperature.

The hydrologic system is simulated by a monthly water balance model. Models of this class are frequently used in such applications. Their utility has been widely demonstrated, and the application of monthly water balance models to ecosystem and climate change studies has been discussed by Leavesley (1994). Monthly water balance models have demonstrated great versatility, being applied successfully in numerous diverse situations. A major weakness of

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most water balance models, however, is an inherent assumption that properties of the simulated region that control its hydrologic response are constant over time. This is potentially a problem when these models are used over long time periods encompassing significant environmental change. In the case of *Century*, however, the hydrologic model is tied interactively to an ecosystem model, providing simultaneous simulations of responses and feedbacks of ecological and hydrologic processes to environmental change.

Model description
Century is a linked production-decomposition biogeochemical model. It accounts for inputs, transformations, and losses of carbon (C), nitrogen (N), and other mineral elements in terrestrial ecosystems, and has been described extensively by Parton *et al.* (1993). Primary production in *Century* is driven by environmental controls (such as temperature and moisture) and nutrient availability, with modifiers for shading, leaf area, and human management effects. Decomposition is a function of physical environment (soil texture, moisture, temperature) and litter quality. Nutrient mineralization and immobilization are controlled by carbon flows and changes between carbon:nutrient ratios in different litter and soil organic mater storage pools.

The water balance model within *Century* simulates inputs, storage, and loss of water within a soil column at a monthly time step. Evapotranspiration is calculated based on potential evapotranspiration (PET) as estimated by the Linacre (1977) approximation to the Penman (1948) equation. The Linacre formulation requires only monthly precipitation, maximum and minimum air temperatures, and site latitude as drivers. Evaporation is calculated as the sum of canopy, litter, and bare soil interception and/or snowpack sublimation. Canopy, litter, and bare soil interception are estimated as functions of biomass and litter mass. Transpiration is a function of PET and water availability, and is reduced when leaf biomass is low. Storage terms are snowpack, soil water, and groundwater. Precipitation that falls when air temperatures are below freezing is added to the snowpack. Snow is melted and passed to the soil column as a function of mean monthly air temperature. The soil column is simulated with a multilayer "tipping bucket" approach. After all transpiration and evaporative demands are met, any remaining water is added to the topmost soil layer. Water in excess of that needed to bring this layer to field capacity is drained to the next soil layer. Excess water from this layer is then tipped to the next layer, continuing until either there is no excess water or the excess drains through the bottom of the simulated soil profile.

Drainage water leaving the soil column is divided between stormflow that exits the system during the current month and groundwater storage that supports baseflow in future months. This type of simple baseflow/stormflow separation has been widely used to approximate watershed hydrograph dynamics. Organic and inorganic nutrients are leached from soil by excess water flowing through the soil column. The leaching is a function of soil texture, amount of water flow, and the size of the inorganic and labile organic nutrient pools, which are in turn predicted by the nutrient cycling portion of the model. Leached nutrients are then apportioned with stormflow and baseflow to yield monthly watershed biogeochemical exports.

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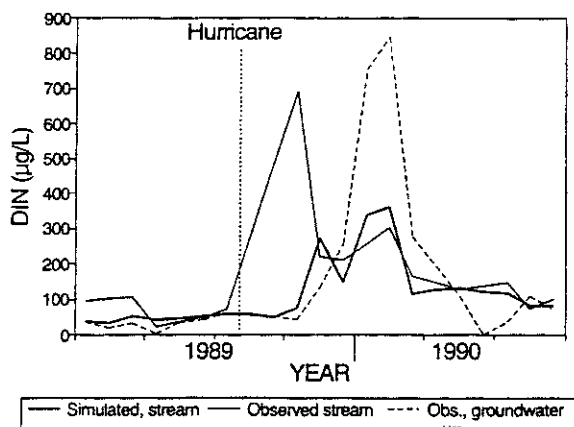
Figure 1. Observed streamwater and riparian groundwater dissolved inorganic N (DIN) concentrations and simulated streamwater DIN for a watershed in the Luquillo Experimental Forest, Puerto Rico. Hurricane Hugo extensively damaged this forest in late 1989.
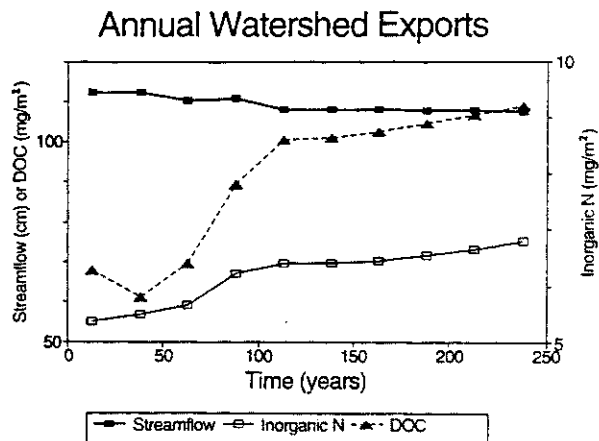
Figure 2. Simulated streamflow, DIN, and dissolved organic C (DOC) export from a watershed at the Coweeta Hydrologic Laboratory, North Carolina, over a 250 year period with climate change driven by doubled atmospheric CO_2. Each point is an average of 25 consecutive years.

Model validation

The ability of *Century* to realistically simulate rates of primary production, decomposition, and nutrient cycling in grassland, cropland. and forest ecosystems has been documented innumerous studies (e.g. Ojima *et al.* 1993, Zimmerman *et al.* 1995). The performance of *Century's* water balance model has been tested at numerous sites as well. Pulliam et al. (in prep) evaluated its behavior at six sites within the United States, including grassland, alpine, and temperate and tropical forest systems. In all cases, the model was able to realistically reproduce observed water loss or streamflow, with correlations (r) between monthly observed and simulated values ranging from 0.79 to 0.91.

APPLICATIONS

Century has been used in many implementations to investigate the effects of environmental change on ecosystem biogeochemistry (e.g. Parton *et el.* 1987, Ryan et al. 1995). Two examples of its use to simulate streamflow and water quality effects are presented here.

Nitrogen leaching after hurricane disturbance

At the Luquillo experimental forest in Puerto Rico, export of dissolved inorganic N (DIN) was greatly elevated after hurricane Hugo extensively damaged the forest. There was an almost immediate spike of DIN in streamwater, probably due to leaching from litter deposited directly in the stream channel (Fig. 1). This was followed by a lower but more sustained pulse of high DIN concentrations in both streamwater and riparian groundwater. *Century*

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simulations of hurricane impacts at this site closely matched the long-term pulse of DIN export. They did not predict the initial brief streamwater pulse caused by within stream-channel processes. This points to both *Century's* ability to provide rates of watershed N loss via soil leaching, and the limitation that it does not represent within stream channel processes.

Streamflow and streamwater N and P in response to long-term climate change
Figure 2 presents simulations of exports of water, DIN, and dissolved organic C (DOC) from a watershed at the Coweeta Hydrologic Laboratory in North Carolina in response to climate change over a 250 year period. The climate change scenario was based on simulations of the GFDL Global Climate Model for doubled atmospheric CO_2, and was applied gradually over a 50 year period beginning at year 50 of the simulation. While simulated streamflow changed only slightly (decline of 5%), predicted DIN export rose by over 25% and DOC export nearly doubled in response to simulated climate change.

CONCLUSIONS

Century provides a versatile tool for simulating the effects of many types on environmental changes on watershed hydrology and biogeochemistry. Its linkages between hydrologic and biotic processes make it especially suited to long-term forecasts where the environment can be expected to change substantially.

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FARM*A*SYST DECISION SUPPORT SYSTEM[1]

P.C. Robert and J.L. Anderson[2]

ABSTRACT

The Farm*A*Syst Decision Support System (FADSS) developed by the University of Minnesota Farm*A*Syst program in collaboration with the National Farm*A*Syst staff, is a computerized version of the Farmstead Assessment System. The user-friendly computer software provides access to Farm*A*Syst worksheets and fact sheets. The main objective of FADSS is to assist users in developing plans of actions to address problems found during an assessment. FADSS is a complete and integrated software that facilitates the use of Farm*A*Syst worksheets. It provides a user-friendly environment to select risk rankings for each category assessment, store selections, compute worksheet overall risk rankings, access fact sheets,a nd view and print a table showing high risk categories and farmstead action plans. The plan of action lists recommendations for all high risk categories found during the assessment process. Farm*A*Syst project managers can create individual project files; perform various queries on risk rankings by project(s), by selected farmstead(s) or group of farmsteads, by year(s), and by all or selected assessment categories; view query results; and modify plan of actions. A password is required to modify the action plan recommendations. The system runs under the Microsoft Windows® environment and uses standard features such as dialog windows, data entry dialog bars, and action buttons. Automatic installation of the software on the computer hard disk is provided. Error checks are imbedded in the software. Helps are provided for most software options. A user's guide is available for new users. FADSS computer requirements are similar to Microsoft Windows requirements.

INTRODUCTION

The purpose of the Farmstead Assessment System (Farm*A*Syst) program is to prevent pollution through a voluntary pollution risk assessment. The program is designed to:

- create awareness of farm activities and structures that may cause drinking water contamination and other environmental problems;
- promote an understanding of pollution prevention and clean-up actions;
- identify sources of technical, educational and financial assistance;
- aid in developing personal, voluntary action plans.

This is accomplished by integrating complex national and state environmental policies and programs of numerous agencies into an applied decision-making framework for farmers,

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ranchers, and rural residents (Jones and Jackson, 1990). The framework uses a series a step-by-step worksheets that evaluate rural activities and structures posing risks to groundwater. Information on available financial, technical and educational assistance is also provided through fact sheets developed to coincide with each worksheet (Jackson and Anderson, 1993). Farmers and rural residents can use Farm*A*Syst on their own, or in consultation with local experts. The system is designed as a confidential service to concerned farmers and rural residents (MES, 1991 and UWEX, 1991).

FARM*A*SYST DECISION SUPPORT SYSTEM

The Farmstead Assessment Decision Support System (FADSS) is computer software developed to facilitate the use of the Farm*A*Syst worksheets and provide action recommendations to solve problems associated with current farmstead activities. Major components of the software are:

- user-friendly data entry windows to record farmstead rankings for all assessment worksheets and categories;
- computation of average risk rankings for each worksheet and computation of overall farmstead risk rankings;
- display all high ratings from individual farmstead assessments and action recommendations to reduce high risk factors;
- capability to modify action recommendations for high-risk factors by authorized information managers;
- search capability by sheet categories and risk rankings, computation of risk factor frequency, and display of summary statistics;
- display fact sheet information;
- print action recommendations and summary statistic reports;
- Microsoft Windows based system.

FUNCTIONS OF THE DECISION SUPPORT SYSTEM

File management. A file contains farmstead assessments (records) corresponding to a geographic or administrative division such as project, watershed, region, county, or township. A file is created by selecting the command [File] available from the menu bar. When selecting [File] a drop box window shows the options Open/Create, Close, Copy, Delete, Combine, and Exit. Choosing the command [File|Open/Create] creates the dialog window that provides tools to create a new file or recall an old file in a selected directory. Files can be closed, copied, deleted, and combined. Farmstead records already in the database can be retrieved by using the options [FarmsteadRecord|Old|First] or Last, Next, Previous, and Locate. A new farmstead record is created by choosing the option [FarmsteadRecord|New] from the same menu bar option. This displays the General Information window where mandatory and optional information are entered. Code numbers can be used in the mandatory section containing Project ID and Farmstead ID to preserve the confidentiality of the information. In the same menu bar option the command [Save] is used to store in the file all farmstead information entered before closing FADSS or during a data entry session for

precaution reason. If a user forgets to save the information in the file before leaving the software, a warning message is displayed on the screen to remind the user to save the data.

Input of risk assessments. Data input is accomplished by calling the worksheet dialog windows from the menu bar. There are two ways to enter the ranking data. One is to use completed worksheet forms from the Farm*A*Syst folder (MES, 1991 and UWEX, 1991) and type rankings (1,2,3 or 4) in the input boxes of worksheet dialog windows. Second is called direct data input and is performed by displaying the ranking descriptions for each worksheet category after pressing the little button i located on the left side of each category input box (Fig. 1) and clicking in one of the round button corresponding to the four risk rank. Clicking the Next button closes the [Ranking Description] dialog window, transfer the ranking value to the corresponding input box in the worksheet dialog window, and bring up the next [Ranking Description] worksheet category dialog window. The keyboard tab key can be used to go to the next feature of the worksheet dialog window such as the next input dialog box, the next i button or the next R button. A specific input box or button can be selected by pointing and clicking the mouse of an equivalent device.
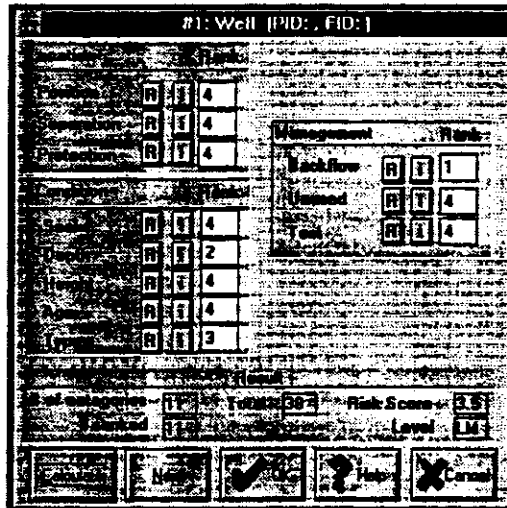
Figure 1. Worksheet risk assessment dialog window
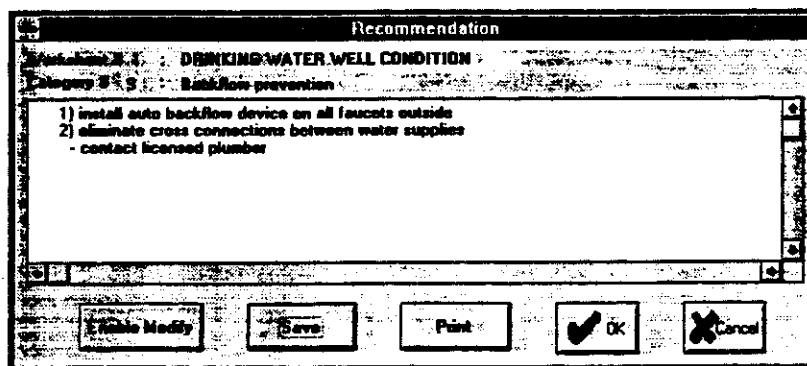
Figure 2. Action recommendation window

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Action recommendations. Each worksheet category within worksheet dialog windows has a corresponding recommendation button R for high risk ranking located to the left of the i button (Fig. 1). Clicking over the button displays the action recommendations for the selected category (Fig. 2). A hard copy can be made by clicking the Print button. Authorized Farm*A*Syst program managers can modify the recommendations after entering a password. A printed list of recommendations can be obtained from one option of the [Query] menu bar.

Query. The [Query] option of the menu bar provides the capability to search risk assessment classes from all records included in a file or from selected records (farmsteads) comprised in a project or a geographic or administrative entity. Records can be sorted by date, project, farmstead, and worksheet. All records or sorted records can be displayed in tabular or graphical forms. All screen outputs can be printed using the Print button.

Help. [Help] provides information about the software and menu bar options, and access to the fact sheets.

CONCLUSIONS

Major benefits of the Farm*A*Syst Decision Support System include:
- ability to provide action plan recommendations to solve or avoid potential pollution problems for individual farms;
- capability to adapt action plan recommendations to local conditions by authorized Farm*A*Syst program managers;
- tool to keep track of assessments and ascertain what are the most prevalent problems in project areas;
- fast and simple way to provide clientele with recommendations about what they can be to address identified problems.

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SEASONAL TRANSPORT OF SNOW BY WIND

R. A. Schmidt and R. L. Jairell[1]

ABSTRACT

In colder, treeless regions--plains, alpine, or in polar latitudes--relocation of snow by wind is often a large component of the winter water balance. Recognizing this redistribution as a resource, like streamflow, leads to water conservation practices--stubble management, for example. Estimating evaporation of snow during drifting is the key to designing effective conservation practices. Successful snowdrift control projects, such as the snow fence system on Interstate-80 in southeast Wyoming, have validated the computational model.
Keywords: Snow, Drifting Snow, Blowing Snow, Snow Drifts, Water Conservation.

OVERVIEW

The quantity of snow that wind removes from a surface area, or fetch, is equal to the snowfall minus storage on the fetch (Fig. 1). The amount of this relocated precipitation that arrives at some downwind point of interest depends on how much is revaporized during transport. The fact that revaporization is significant, even under blizzard conditions, results primarily from the extremely large surface area exposed by the drifting ice particles. The greater the fetch distance, the larger the fraction of drifting snow vaporized.
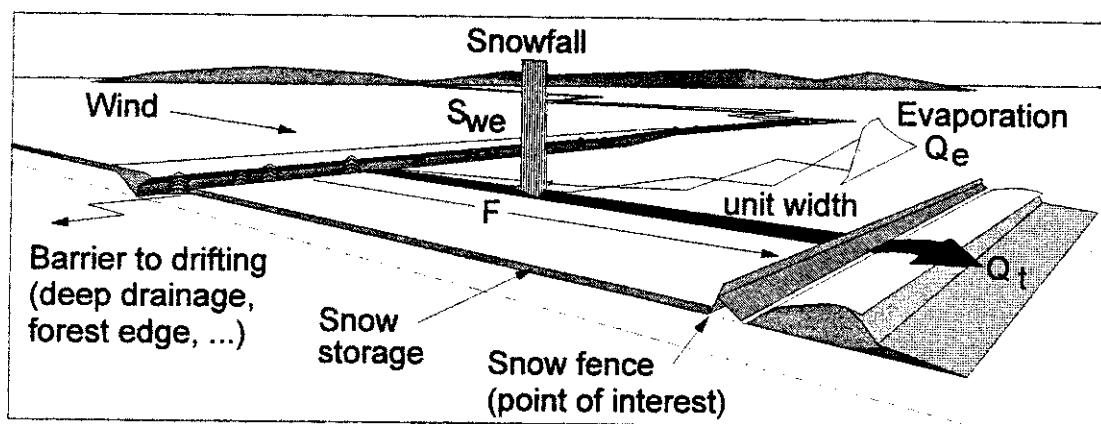
Figure 1. The snow quantity Q_t delivered by wind at the point of interest is computed for a unit width across the wind. The amount relocated is snowfall S_{we} less storage on the fetch. Quantity Q_e that evaporates during relocation will depend on fetch distance F, measured from some point of interest to the nearest upwind barrier to drift transport (Tabler, 1975, 1994).

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ESTIMATING SNOW TRANSPORT

Computing seasonal transport of wind-blown snow must begin with some value for the winter snowfall water-equivalent, S_{we} (following notation in Tabler, 1994). Estimating the average winter snowfall in windswept regions is confounded by problems of measurement inaccuracy in reported data. Tabler (1994) suggests various sources and estimation techniques. Reducing this winter snowfall value by an estimate of snow water-equivalent held on the fetch determines S_{rwe}, the amount relocated. Topography, vegetation, and the winter weather history, all influence fetch storage (Tabler and Schmidt, 1972, 1986).

Tabler (1975) developed a method for estimating revaporization during transport, from an analysis of the sublimation of drift snow particles (Schmidt, 1972), . The procedure defines a conceptual transport distance T (m) in which an averaged-sized drift particle completely sublimates. Distance T should vary within and between storms, depending mostly on humidity and temperature. However, empirical determinations of T averaged over a winter season cluster near T = 3000 m (10,000 ft) for a wide range of latitudes (Tabler, 1975, 1994).

The actual fetch distance F, from which drift snow arrives, may be greater than T because the distribution of drift particle sizes includes classes larger than the average. Often F is limited by some barrier to drifting, as in Fig. 1. Equation 1 (Tabler, 1975) estimates seasonal evaporation Q_e (kg/m) from relocated winter snowfall, S_{rwe} (mm), blown from a unit width extending upwind for fetch distance F (m) . Evaluations of Eq. 1 are plotted in Fig. 2a.

$$Q_e = F\ S_{rwe} - 0.5\ T\ S_{rwe}\ (1-0.14^{F/T}) \tag{1}$$

The second term on the right in Eq. 1 is the residual mass of drifting snow that arrives at some point of interest. Equation 2 (Tabler, 1994) provides the desired estimate of seasonal drift transport Q_t (kg/m). Figure 2b gives example evaluations, assuming uniform snow storage on the fetch.

$$Q_t = 0.5\ T\ S_{rwe}\ (1-0.14^{F/T}) \tag{2}$$

VERIFICATION AND APPLICATIONS

This procedure was initially developed and tested in southeastern Wyoming (Tabler and Schmidt, 1972). Snow drifting problems along Interstate-80 between Laramie and Walcott Junction provided opportunity to verify the concept at many locations, over a range of precipitation and fetch storage situations (Tabler, 1975; Tabler and Furnish 1982). Success at all stages of this large drift control project led to other applications of the method (Tabler and Sturges, 1986; Tabler and Schmidt, 1986). Application to pit-reservoir design is included in a companion paper in this volume (Jairell and Schmidt, 1995). Several drift control applications on the Alaskan North Slope support the assumption of the constant value, T = 3 km, as a first approximation (Tabler 1994). Schmidt and Hartman (1986) applied the procedure to estimate avalanche loading, where storage on the alpine fetch was large.
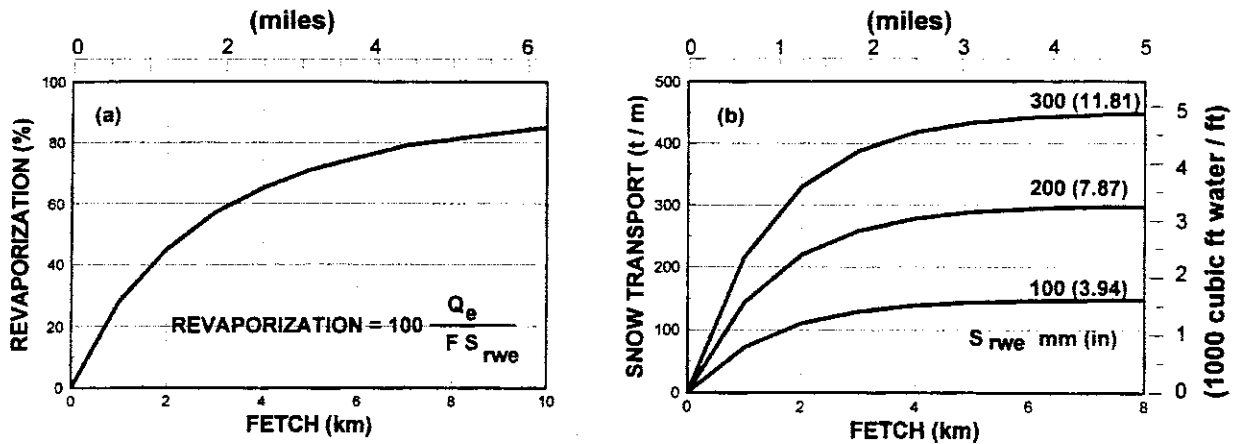
Figure 2. (a) The fraction of wind-transported snowfall S_{rwe} that revaporizes during the drift season depends only on fetch distance, when distance T in Eq. 1 is assumed constant (Tabler, 1994). (b) Evaluation of Eq. 2 gives the volume of water available from seasonal snow transport by wind.

COMPUTATIONAL PROGRAM

A spreadsheet program provides computer solutions of this procedure. The user enters an estimate of winter precipitation, the fraction of snowfall relocated, and fetch distance at the site. The program computes the volume of water available from drifting snow, and the estimated amount evaporated during drifting. The system of units may be either metric or English.

CONCLUSION

The snow relocated by wind during a winter season is a significant resource in large regions of the globe. Conserving and managing this water requires estimates of quantities available. The key to such estimates is a computation of the seasonal amounts of snowfall that revaporize during transport, primarily because of the large surface area exposed by drifting particles. The computational procedure outlined above has provided cost-effective snowdrift control and water conservation project designs in a wide range of latitudes.

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NLEAP MODEL FOR IDENTIFICATION AND MITIGATION OF REGIONAL NITRATE LEACHING HOT SPOTS

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ABSTRACT

Improved methods are needed to assess areas where potential NO_3-N leaching may be occurring from agriculture and suggest management alternatives that minimize the problem. Regional studies in eastern Colorado show the NLEAP NO_3-N leaching model in conjunction with GIS technology can be used to identify potential NO_3-N hot spots in shallow alluvial aquifers under irrigated agriculture. The same combined technology also shows promise in identifying Best Management Practices (BMP) that help minimize NO_3-N leaching in vulnerable areas. Case studies using NLEAP/GIS are presented for the South Platte River basin in eastern Colorado. These studies suggest that the nitrate leaching problems in the region should be managed based on recommendations for specific hot spot areas rather than broad basin-wide management scenarios.
Keywords: NLEAP, Nitrate, Leaching, Nitrogen Management, BMP

INTRODUCTION

Recent research has shown a strong correlation between NO_3-N concentrations in the underlying unconfined aquifers along the South Platte River in northeastern Colorado and associated agricultural variables such as cropping and irrigation practices, soil properties, and fertilization methods (Wylie et al., 1994; Shaffer and Wylie, 1994). This research shows that use of simulation models which provide estimates of NO_3-N leaching based on environmental and agricultural management variables can provide estimates of groundwater NO_3-N hot spot locations which are more reliable than estimates based only on knowledge of system physical properties. Specifically, the Nitrate Leaching and Economic Analysis Package (NLEAP) model is being successfully used in conjunction with GIS mapping to predict the distribution of these hot spots (Wylie et al., 1994) across a broad geographical region.

The NLEAP model (Shaffer et al., 1991) was developed as part of a national effort to consolidate knowledge about managing nitrogen in agriculture, provide a screening tool to assess potential NO_3-N leaching, and suggest alternative management techniques (Follett et al. 1991). NLEAP has received extensive field validation testing by its authors and independent

researchers (Shaffer et al., 1991; Khakural and Robert, 1993; Crookston and Hoffner, 1993; Shaffer et al., 1994a; Shaffer et al., 1994b; Follett et al., 1994; Beckie et al., In press). Initially, NLEAP was used to estimate NO_3-N leaching indices at the field scale. However, recent research efforts by Wylie et al. (1994) have shown that NLEAP leaching indices can be extended to a watershed or regional scale by combining NLEAP simulations with GIS technology.

SOUTH PLATTE CASE STUDIES

A GIS database was assembled for the irrigated agricultural region overlying the alluvial aquifer of the South Platte and its major tributaries within Weld and Morgan Counties in Colorado. The database contains information layers for soils, groundwater concentrations, irrigated agriculture coverage, and feedlot locations. NLEAP simulations were conducted for the Weld County portion of the study area for each unique combination of soils, irrigation type, and location relative to feedlots. The simulations show that NLEAP leaching estimates using reasonable regional assumptions of management practices and NRCS soil survey data can identify major spatial patterns of groundwater NO_3-N concentration (Wylie et al., 1994, Wylie et al., 1995). Strongest correlations were obtained with the NLEAP Nitrate Leached Index (NL) using a long term steady state simulation including inorganic and manure fertilizer sources (Wylie et al., 1994; Shaffer et al., 1994a; Wylie et al., 1995). Proximity to confined animal feeding operations, which corresponds to an increased likelihood of manure applications and generally higher simulated leaching rates, was found to be strongly correlated with high concentrations of NO_3-N in the groundwater.

An objective of the S. Platte project is to determine the extent to which the NLEAP model can be used to test alternative management practices that may reduce NO_3-N leaching from irrigated agriculture. To this end, alternative management
practice evaluation has been established at three cooperating field sites. At each location, a portion of the field is managed using one or more recommended best management practices, and the remainder of the field is managed using the cooperators' conventional practices . These sites were intensely monitored during the 1994 growing season to establish pre- and post-season nutrient levels, water budget, crop yield, crop nitrogen uptake, tillage practices, soil properties, and nitrogen mineralization rates. Laboratory analysis of field samples is currently underway, and NLEAP simulations will be conducted to evaluate the ability of NLEAP to simulate the effects of the different management practices at each site. Monitoring of these fields will continue through the 1995 growing season.

As part of the technology transfer objective of the current project, reports on project progress have been presented at numerous local, regional, national, and international events and published in media targeting a range of interested groups (Schuff, 1992; Shaffer et al., 1994a; Shaffer et al., 1994b; Shaffer and Wylie, 1994; Wylie et al., 1995). Local meetings have been held to present results of this research and information about management alternatives to producers and action agency personnel in each county within the study area. Results from

this research have drawn attention to areas of concern and have helped to begin constructive dialogue on reasonable solutions. The research has provided:

- demonstration of the utility of using the NLEAP model to identify regional NO_3-N hot spots.
- valuable validation data that have established confidence in NO_3-N leaching estimates made by the model.
- convincing evidence that groundwater NO_3-N concentrations are closely related to the agricultural activities occurring on the overlying land surface.
- support for the use of NLEAP as a tool in comparing alternative management practices for reducing NO_3-N leaching.

FUTURE PLANS

Discussions with project collaborators, local producers, action agency personnel, and other researchers have indicated a need to establish a mechanistic in addition to a correlative linkage between NO_3-N leached from the root zone and the NO_3-N hot spots in the alluvial aquifer. Also, producers and regulators tell us that they want to know the relative impact on the aquifer of current and future animal manure versus commercial fertilizer applications. Everyone involved wants increased confidence that proposed BMP's will effectively reduce groundwater NO_3-N levels within a stated time frame.

These discussions and careful study of the results of research so far have identified a number of key questions which must be addressed to generate confidence in the choice and effectiveness of BMP implementation. Some of these recurring questions are:
- what are the mechanisms for buildup and apparent stability of these NO_3-N hot spots?
- what is the role of groundwater transport in formation of the hot spots?
- what are the relative roles of water management and nutrient management in affecting groundwater contamination?
- what are the relative contributions of inorganic fertilizers and manures?
- will implementation of alternative management practices improve groundwater quality?
- what management practices will effect the most incremental improvement in the groundwater quality?
- over what time scale will effects of BMP's, if implemented, be seen in the groundwater?
- are other below-root zone processes (e.g. denitrification in the vadose zone or saturated zone) important factors?

The proposed future research is designed to help answer these questions by looking at combined crop, soil, deep vadose, and groundwater systems as well as providing longer term support for testing of proposed BMP's and the modeling approaches. The complexity of the agricultural activity in this region requires that the total agricultural system be considered. The activities of all components of the agricultural management system must be linked with the geo-physical system components to balance nutrient inputs and outputs and achieve a sustainable resource base.

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We propose to intensively study three prominent NO$_3$-N hot spots in the S. Platte alluvial aquifer in Colorado, and use knowledge gained in these intensive studies to develop an accurate picture of the regional system. Monitoring of field-sized plots in the study areas will be used to support development of a modeling system for simulation of NO$_3$-N leaching, transport to the groundwater, and subsequent accumulation and movement in the groundwater. The carefully planned field studies will also supplement model evaluation in terms of selecting alternative management techniques to minimize NO$_3$-N leaching, validating predictions of NO$_3$-N leaching and its contribution to groundwater, and separating potential NO$_3$-N sources.

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THE SWMS_2D CODE WITH A USER-FRIENDLY INTERFACE IN A WINDOWS ENVIRONMENT

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ABSTRACT

A new version (2.1) of the SWMS_2D code simulating water flow and solute transport in two-dimensional variably saturated media was developed. The code was made more effective by implementing an interactive graphics-based user interface which includes data pre-processing and graphical presentation of the output results in a MS Windows 3.1 environment. Data pre-processing involves specification of the flow region having an arbitrary continuous shape bounded by polylines, arcs and splines, discretization of domain boundaries, and subsequent automatic generation of an unstructured finite element mesh. The method used for generating the mesh was based on a Delaunay criterion. We also incorporated an alternative, structured mesh generator for relatively simple quadrilateral domains. A small catalog of soil hydraulic properties was made part of the user-friendly interface. Graphical presentation of the output results consists of simple two-dimensional x-y plots, as well as contour and spectral maps, velocity vectors, and animation of both contour and spectral maps. Graphs along any cross-section are also readily obtained. The versatility of the SWMS_2D code is illustrated by means of an example simulating the two-dimensional infiltration of water and solute from a furrow into a tile-drained soil profile.

Keywords: Solute transport, Water flow, User-friendly interface, Mesh generation.

INTRODUCTION

The past several decades has seen considerable progress in the conceptual understanding and mathematical description of water flow and solute transport processes in the unsaturated zone. A variety of multi-dimensional numerical models based on the Richards' equation for variably saturated flow and the Fickian-based convection-dispersion equation for solute transport are now available to predict water and/or solute transfer processes between the soil surface and the groundwater table. These models have proven to be useful for (1) predicting water and solute movement in the vadose zone, (2) analyzing specific laboratory or field experiments involving unsaturated water flow and/or solute transport, and (3) extrapolating information from a limited number of field experiments to different soil, crop and climatic conditions, as well as to different tillage and water management schemes.

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Even with well-documented multi-dimensional numerical computer models available, one major problem which often prevents the use of such codes is the extensive work required for data preparation, finite element grid design, and graphical presentation of output results. Hence, a more widespread use of multi-dimensional models requires techniques which make it easier to create, manipulate and display large data files, and which facilitate interactive data management. Introducing such techniques will free users from cumbersome manual data processing, and should enhance the efficiency in which programs are implemented for a particular example. To avoid or simplify the preparation and management of relatively complex input data files for two-dimensional applications, and to graphically display final simulation results, we developed an interactive graphics-based user-friendly interface for the MS Windows 3.1 environment. The interface is connected to the SWMS_2D code (Simunek et al., 1994) which simulates two-dimensional variably-saturated water flow and solute transport in a porous medium. Details of the SWMS_2D finite element code are given in the user manual, and are not further discussed here.

AN INTERACTIVE GRAPHICS-BASED USER INTERFACE

The new version 2.1 of SWMS_2D consists of an interactive graphics-based user interface, and the computational FORTRAN application itself. The user interface includes five modules and one dynamic linked library (DLL). All modules except the Fortran application are written in C++.

Brief Description of Particular Modules

SWMS_2D (Fig. 1) is the main program unit defining the overall computational environment of the system. This module controls execution of the program and determines which other optional modules are necessary for a particular application. The module contains both the pre-processing and post-processing units. The pre-processing unit includes specification of all necessary parameters to successfully run the SWMS_WIN Fortran code, a grid generator for relatively simple rectangular transport domains, and a small catalog of soil hydraulic properties. The post-processing unit consists of simple x-y graphics for graphical presentation of soil hydraulic properties, as well as such output as time changes of a particular variable at selected observation points in the domain, and actual or cumulative water and solute fluxes across boundaries of a particular type.

A project manager, POSITION (DLL) (Fig. 1) is used to manage data of existing projects, and helps to locate, open, copy, delete and/or rename the desired projects, or their input or output data.
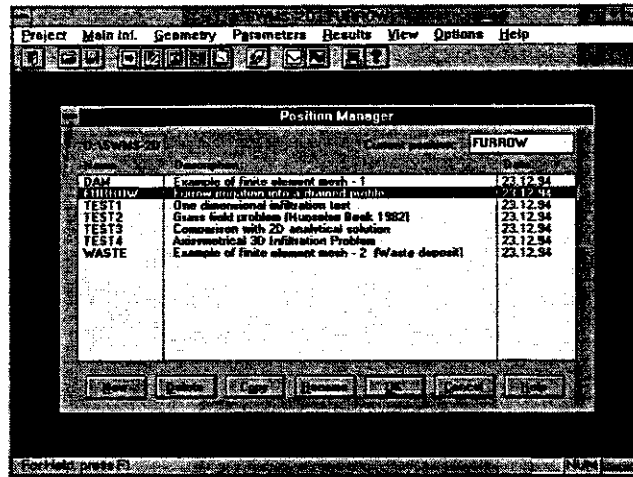
Figure 1. The main window of the SWMS_2D module, including the project manager.

The module GEOMETRY (Sejna et al., 1994) may be used to design boundary curves of virtually any two-dimensional computational domain in a Windows environment. Boundary curves can consist of any number of poly-lines, arcs, circles or cubical splines. The module permits one to specify internal boundaries (e.g., drains, wells, impermeable objects), as well as internal curves. The consistency of the invoked geometry is also checked by this module. Boundary curves can be entered from a keyboard or with a mouse, or by reading an ASCII file.
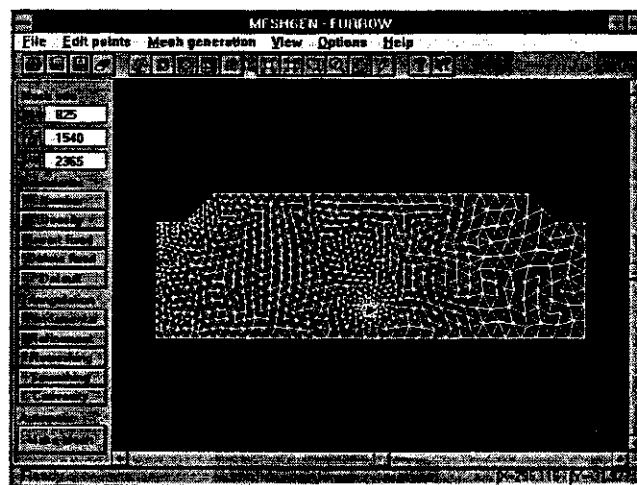
Figure 2. The main window of the MESHGEN module.

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The MESHGEN (Fig. 2) (Sejna et al., 1994) module may be used to discretize a two-dimensional flow region into an unstructured triangular mesh. The algorithm used for this purpose is general and can be applied to virtually any two-dimensional computational domain. The first step of the mesh generation process is discretization of the boundary curves, while the second step involves the generation of the unstructured triangular mesh. The second step consists of five operations: (1) discretization of the flow domain into triangles with vertices in a given boundary nodes (fundamental triangulation), (2) inserting new points in all triangles which do not fulfill a certain smoothness criterion (mesh refinement), (3) implementation of Delaunay retriangulation for the purpose of eliminating all nodes surrounded by more than six triangles, as well as all extreme angles (remeshing), (4) smoothing of the mesh by solving a set of coupled elliptic equations in a recursive algorithm (smoothing), and (5) correction of possible errors which may appear during smoothing of the finite element mesh (convexity check). Operations 2 through 5 are repeated until a prescribed smoothness of the mesh has been achieved.

The BOUNDARY module helps a user in the specification of boundary and initial conditions, as well as the definition of the spatial distribution of other parameters characterizing the flow domain (e.g., spatial distribution of soil materials, scaling factors, root water uptake parameter, and possible hydraulic anisotropy) and/or observation nodes. All parameters in this module are specified in a graphical environment with the help of a mouse.

The SWMS_2D system further involves the FORTRAN application SWMS_WIN which simulates water and solute movement in a two-dimensional variably saturated medium. The SWMS_WIN program numerically solves the Richards' equation for saturated-unsaturated water flow and the convection-dispersion equation for solute transport. The flow equation incorporates a sink term to account for water uptake by plant roots. The solute transport equation includes provisions for linear equilibrium adsorption, zero-order production, and first-order degradation. The flow region itself may be composed of nonuniform soils having an arbitrary degree of local anisotropy. Flow and transport can occur in the vertical plane, the horizontal plane, or in a three-dimensional region exhibiting radial symmetry about a vertical axis. The water flow part of the model considers prescribed head and flux boundaries, as well as boundaries controlled by atmospheric conditions.

The governing flow and transport equations are solved numerically using Galerkin-type linear finite element schemes. Depending upon the size of the problem, the matrix equations resulting from discretization of the governing equations are solved using either Gaussian elimination for banded matrices, or the conjugate gradient method for symmetric matrices and the ORTHOMIN method for asymmetric matrices.

An external module GRAPHICS (Fig. 3) may be used to present results of the simulation by means of contour maps, isolines, spectral maps, velocity vectors, and animation of both contour and spectral maps. Contour and spectral maps may be drawn for the pressure head, water content and/or concentration. Animation of all three variables is also possible. Graphs of all variables at the boundaries, as well as along any selected cross-section, can be readily obtained.

EXAMPLE

Figures 1, 2 and 3 show the main windows of three different modules when the program is used to simulate furrow irrigation in a tile-drained soil profile. Calculations were carried out for a period of 100 days. The soil profile was assumed to be initially free of any solute. Every other furrow was flooded with water to a level of 12 cm. The irrigation water contained solute of unit concentration for the first 50 days. Neither root water extraction nor other soil-atmosphere interactions were considered in this example.
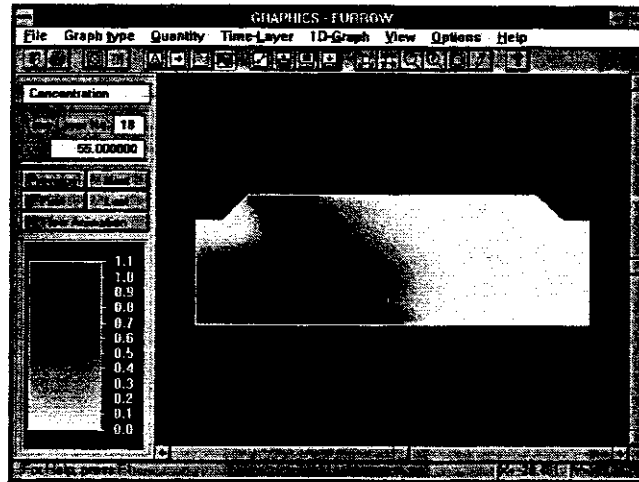
Figure 3. The main window of the GRAPHICS module.

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USING UNSATCHEM WITH USER FRIENDLY INTERFACE, AS A WATER MANAGEMENT TOOL

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ABSTRACT

The UNSATCHEM model is designed as a research/ management model for predicting rootzone Chemistry and water and solute movement in the unsaturated zone. The model simulates one-dimensional variably saturated water flow, heat transport, carbon dioxide production and transport, and multicomponent solute transport with major ion equilibrium and kinetic chemistry. The model also considers major ion cation exchange, anion adsorption, both extended Debye-Hückel and Pitzer expressions for single ion activity coefficients at high ionic strength, as well as root development, plant water uptake, and solution chemistry with complexation. Various multicomponent kinetic expressions are used to describe the precipitation-dissolution of calcite and dissolution of dolomite. The model includes a user-friendly interface which operates within a MS Windows 3.1 environment. The user interface includes data pre-processing with the option of selecting from a table of hydraulic parameters based on soil texture, as well as selection of boundary conditions. The data are output in tabular as well as graphical form. Although developed as a research model the addition of the user friendly interface enables use by agricultural specialists.
Keywords: Multicomponent transport, soil chemistry, unsaturated water flow

INTRODUCTION

Efficient water management under arid and semiarid conditions requires knowledge of the salt content and distribution in the soil profile as well as knowledge of the water budget. Knowledge of these factors in turn requires that we model the transport of major soluble ions in the unsaturated zone. Realistic modeling of root zone chemistry requires consideration of processes in the gas, liquid and solid phases. Many factors may influence the transport and reaction parameters of the chemical system but among the most important are water flow, heat transport, and the dynamic changes in CO_2 concentrations. Water is the transport medium for dissolved chemicals and also significantly affects the production and concentration of CO_2. Soil temperature affects not only the thermodynamic equilibrium constants and reaction rates but more importantly, the production of CO_2. The CO_2 concentration exerts an important control on the biological and chemical processes in the soil and has a direct effect on the solution chemistry of the entire subsurface. Variations in soil CO_2 concentration produce changes in soil pH (for all but acid soils), and thus alters the solubility of many solid phases such as carbonates and oxihydroxides.

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Coupling of hydrological models for water flow and solute transport with detailed chemical equilibrium models is relatively recent, undertaken only within the last decade. The chemical and multicomponent transport models generally use either the total inorganic carbon as a conservative property and/or fixed pH as an input variable. However, in a soil environment the CO_2 concentrations fluctuate, resulting in increases in dissolved inorganic carbon and soil pH when CO_2 increases. The second limitation of these earlier models is that they consider only equilibrium reactions, while published data for natural systems indicate that kinetic reactions often control solution composition.

MODEL DEVELOPMENT

Below, we briefly review the UNSATCHEM model and present an example of its application to a water management problem. The model incorporates the SOILCO2 model Simunek and Suarez [1993], which considers variably saturated water flow, heat and CO_2 transport and biological CO_2 production, with chemical equilibrium and kinetic solute transport submodels. The model treats Darcian water flow in a variably saturated rigid porous medium using a modified form of the Richards equation. Root water uptake is treated using the modified version of the expression proposed by van Genuchten [1987]. Values for the osmotic head are obtained using osmotic coefficients and a modified form of the van't Hoff equation. The partial differential equation governing one dimensional advective-dispersive chemical transport under transient water flow conditions in partially saturated porous media is taken as

$$\frac{\partial(\theta c_k)}{\partial t} + \rho \frac{\partial \bar{c}_k}{\partial t} + \rho \frac{\partial \hat{c}_k}{\partial t} = \frac{\partial}{\partial x}(\theta D \frac{\partial c_k}{\partial x} - qc_k) \qquad k = 1, 2, ..., N_c$$

where c_k is the total dissolved concentration of aqueous component k [ML^{-3}], $\bar{c}_k$ is the total sorbed concentration of component k [MM-1], $\hat{c}_k$ is the total precipitated concentration of component k [MM^{-1}], p is the bulk density of the medium [ML^{-3}], D is the "effective" dispersion coefficient [L^{2}T^{-1}], q is the volumetric flux [LT^{-1}] and N_c is the number of aqueous components.

A detailed development of the one-dimensional carbon dioxide transport model and justification of respective assumptions were given in Simunek and Suarez [1993]. The CO_2 transport in the unsaturated zone is considered to occur in both liquid and gas phases. Furthermore, we considered that the CO_2 concentration in the soil is governed by two transport mechanisms convective transport in the aqueous phase and diffusive transport in both gas and aqueous phases, and by CO_2 production and/or removal. Production of CO_2 occurs by respiration by soil microbes and by plant root respiration. We assume that the CO_2 production by these two processes is additive and that it is possible to superpose the effects of environmental variables that alter production from the reference value.

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The model includes an expanded version of the chemical speciation model CARBCHEM of Suarez [1977]. Details of the chemical model are given in Suarez and Simunek [1994]. The chemical system for predicting major ion solute chemistry of the unsaturated zone includes 37 chemical species. These are divided into 8 chemical components (calcium, magnesium, sodium, potassium, sulfate, chloride, nitrate silica), 12 complex aqueous species, 6 possible solid species (calcite, gypsum, nesquehonite, hydromagnesite, dolomite, sepiolite, and gibbsite), 4 sorbed species, and seven species constituting the CO_2-H_2O system. Partition between the exchanger (solid phase) and the solution is described by the Gapon equation. We consider 4 solid phases that constrain the solution to equilibrium whenever the solids are specified or approached from oversaturation: gypsum, nesquehonite, hydromagnesite, and sepiolite. Precipitation-dissolution of calcite is optionally treated with either equilibrium or kinetic expressions. In the latter case, the equation corresponding to calcite equilibrium is omitted from the equilibrium system and the rate of calcite precipitation-dissolution is calculated from a rate equation. Dissolution of dolomite is always considered to be a kinetic process and never included into the equilibrium system, since true ordered dolomite does not precipitate under earth surface conditions.

The precipitation or dissolution of gypsum, calcite (if considered in the equilibrium system), nesquehonite, hydromagnesite, and sepiolite in the presence of CO_2 is described in terms of the corresponding solubility products KSP The reaction rate of calcite precipitation-dissolution, is treated using a combination of rate equations for surface controlled reactions which consider the inhibiting effect of dissolved organic matter on the reaction rates. The reaction rates of dolomite dissolution, are calculated with the rate equation of Busenberg and Plummer [1982]. Formation of protodolomite, which has been observed in hypersaline environments, can be treated as a mixture of magnesium carbonate and calcium carbonate, both of which are considered in our chemical model.

Calculation of the single ion activity coefficient is specified by using either an extended version of the Debye-Hückel equation or Pitzer expressions. The extended version of the Debye-Hückel equation, is used in the dilute to moderately saline concentration range. At high ionic strength, activity coefficients are no longer universal functions of ionic strength, but are also dependent on the relative concentration of the various ions present in solution. The activity coefficients can then be expressed in a virial-type expansion. This model is considered accurate even for solutions with very high ionic strength (up to 20 molal) and can be used down to infinite dilution.

AN INTERACTIVE GRAPHICS-BASED USER INTERFACE

The software package UNSATCHEM consists of an interactive graphics-based user interface, and the computational FORTRAN application itself. The user interface includes two modules (UNSATCHEM and PROFILE) and one dynamic linked library (POSITION) (DLL). All modules except the Fortran application are written in C++.

Brief Description of Particular Modules

UNSATCHEM (Fig. 1) is the main program unit defining the overall computational environment of the system. This module controls execution of the program and determines which other optional modules are necessary for a particular application. The module contains both the pre-processing and post-processing units. The pre-processing unit includes specification of all necessary parameters to successfully run the UNSATCHEM Fortran code. First the processes (water flow, chemical transport, heat transport, CO_2 transport, root growth, and/or root water uptake) to be simulated are selected, the time and space scales are specified, boundary conditions are entered and so on. A small catalog of soil hydraulic parameters based on the soil texture is part of the pre-processing unit. The post-processing unit consists of simple x-y graphics for presentation of hydraulic properties, time changes of a particular variable at selected observation points in the profile, and actual or cumulative water, CO_2, and solute fluxes across upper and lower boundaries. The water content, pressure
head, CO_2, temperature, concentration (solution, adsorbed, precipitated) and chemical (SAR, EC, pH, pIAP, ...) profiles can be readily obtained.
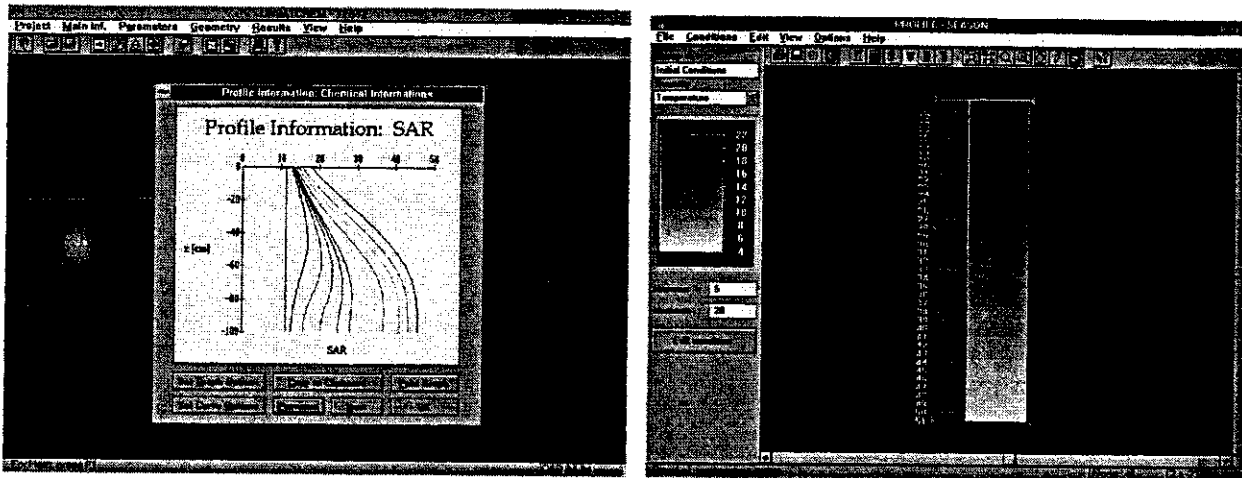
Figure 1. The main windows of the UNSATCHEM and PROFILE modules.

A project manager, POSITION (DLL) is used to manage data of existing projects, and helps to locate, open, copy, delete and/or rename the desired projects, or their input or output data.

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The PROFILE (Fig. 2) module may be used to discretize a one-dimensional soil profile into finite elements. The module also helps a user to specify of initial conditions, as well as the definition of the spatial distribution of other parameters characterizing the soil profile (e.g., spatial distribution of soil materials, root water uptake parameter), and/or observation nodes. All parameters in this module are specified in a graphical environment with the help of a mouse.

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COMPUTER APPLICATIONS USED FOR IRRIGATION WATER MANAGEMENT IN THE SAN LUIS VALLEY, CO.

K.R. Thompson[1]

ABSTRACT

Agro Engineering Inc. is an active participant in improving irrigation water management (IWM) on crops grown in the San Luis Valley. Many different computer tools are used to automate and simplify the field services provided. IWM services include both field water management and irrigation system testing and design.

Computer programs, used to aid in field water management, include a program that prints weather and crop water use summaries for the common varieties grown in the valley. An irrigation scheduling program is available for farmers via modem to aid in forecasting required irrigations on each field. Evapotranspiration is calculated based upon solar radiation, temperature, and wind information obtained from an automated meteorological station and computed using a modified Hargreaves evapotranspiration method.

Irrigation system design tools include a program used to aid in new well design by summarizing test hole results. A can-test program is used to determine system application uniformity on existing systems. In order to renozzle new or existing systems, a nozzling program determines nozzle orifice sizes needed to provide a uniform application of water. Irrigation system testing tools include a program that summarizes pumping plant efficiencies and economics. Another program generates depth-versus-percent charts that reveal the timer settings needed to precisely apply different amounts of water.

OVERVIEW

As water, resources, and food supplies become more scarce and costly, it becomes increasingly important to manage farm systems with greater efficiency. Agro Engineering Inc. (Agro) provides a vital link in transferring technology to the agricultural community through on-farm design, management, and training programs. Agro consults on 40,000 acres of irrigated farm land in the San Luis Valley each year. Primary consultation services include irrigation water management, fertility management, and integrated pest management. Many different computer tools are used to automate and simplify the field services provided. The computer tools pertaining to irrigation water management will be discussed in this paper.

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The San Luis Valley is a high, intermountain valley located in south-central Colorado. The valley has an average altitude of 7,600 feet. The San Luis Valley is surrounded by the Sangre de Cristo Mountains on the east and the San Juan Mountains on the west. The valley floor is relatively flat with an average slope of six feet per mile. It is approximately 50 miles wide east to west, and 100 miles long north to south. The valley is intensively farmed. Around 400,000 acres are currently being irrigated. Potatoes are the main cash crop grown. Some 73,000 acres of potatoes are grown annually. Small grains and alfalfa are the other primary crops with around 110,000 acres of each grown. Secondary crops include canola, lettuce, spinach, and carrots.

The San Luis Valley is part of the Rio Grande basin, bisected by the Rio Grande River. The valley is underlain with a complex system of aquifers in hydrologic connection. The majority of irrigation water is pumped from an unconfined aquifer ranging from 40 to 120 feet thick. Precipitation in the valley averages 7 inches per year with about 80 percent of this precipitation occurring between April and October in the form of localized thundershowers. Consequently, irrigation accounts for nearly 85 percent of the water applied to crops. Center pivot systems are the primary type of irrigation system used. The soils of the valley are sandy loam and loamy sand, with high infiltration rates and low water holding capacities.

METHODS

Agro's irrigation water management services include both field water management and irrigation system testing/design. Field management includes weekly visits to monitor soil moisture, check crop growth, and provide the farmer with an irrigation schedule which advises when and how much to irrigate. Well planned and managed irrigation management programs assure the proper timing and application amounts of irrigation water. At the farm level, irrigation scheduling helps the farmer to maximize crop yields and quality, reduce water and energy consumption, reduce the loss of fertilizer and agricultural chemicals from leaching, and control root zone salinity. The soil water content is determined through the use of tensiometers and the soil-feel method.

Agro uses a set of irrigation scheduling programs to assist in field-scale irrigation management. Agro maintains an automated meteorological station in the central part of the valley. The office computer network queries the weather station hourly and downloads weather summaries. From this data, a program calculates and prints weather and crop water use summaries for the different varieties grown in the valley for use by Agro's field personnel. Crop evapotranspiration is calculated using a modified Hargreaves method. Crop coefficients have been calibrated to the varieties grown in the San Luis Valley.

Agro also provides an irrigation scheduling program that allows clients to call the Agro network via modem and obtain irrigation scheduling and forecasting for each field. This program provides a valuable second opinion and adjusts for rainfall occurring between Agro field visits. The soil water content within the root zone of a given field is modeled by this program using a layered soil moisture model. Wet events, including irrigations and actual rainfall, are entered by the farmer. Crop evapotranspiration is calculated using a modified Hargreaves method with

customized crop coefficients. The model recommends irrigating when it predicts the soil water deficit will exceed management allowable depletion. Future evapotranspiration is forecasted based upon a comparison of current weather to historical meteorological conditions.

System testing is performed as part of the IWM service to quantify system capabilities. Systems are pump tested to determine flow rates, pressures, water levels, and energy demands. A computer program summarizes this informafion and determines loads on motors, pumping efficiencies, and the economics of the pumping plant operation. This allows us to provide the farmer with a summary of the current pumping capabilities and provide recommendations of ways to improve the efficiency and cost effectiveness of the pumping operation. A separate program generates depth-versus-percent charts. These charts provide the farmer with an accurate account of the amount of water applied at different timer settings. Depth-versus-percent charts are crucial, for without an accurate knowledge of the timer setting needed to apply a desired depth, it is pointless to provide the farmer with a precise irrigation schedule.

When new or replacement irrigation systems are warranted, Agro assists clients in obtaining legal water rights and designing the new system. Agro recommends drilling test holes to determine the optimum placement and design of new wells. By sampling soil material and electric logging at different depths at a particular site, Agro can assist in determining the best location to drill a new well to intercept the greatest water bearing material. This information is also used to design well screens and gravel pack material in order to optimize well production. A computer program is used to summarize the sieve analysis of material and the E-logging results to aid in this analysis.

Proper irrigation system design improves irrigation application uniformity and efficiency. Pattern problems are identified with infrared aerial photography and field checking. If a can-test is warranted, a program summarizes water application variations across the length of the system and calculates uniformity. Pattern problems are corrected with new or modified nozzling packages. A nozzling program is used to design nozzling charts, indicating the orifice sizes needed to provide a uniform depth of water across the system. This program uses a mass balance to calculate desired flow across the system. It also calculates head loss due to friction through the main line and down each drop in order to determine the pressure at each nozzle. From this information it can size nozzle orifices appropriately, This program works for all brands of nozzles common to the valley and is applicable for all types and lengths of systems, including systems that are pressure regulated or have flex spans. Drop designs are prepared using CAD software.

These computer applications, developed largely in-house by Agro, have proven to be valuable tools in providing a comprehensive irrigation water management service to the farmers of the San Luis Valley.

COMPUTER CONTROLLED TDR-BASED SYSTEM FOR CONTINUOUS MONITORING OF SOIL WATER CONTENT

D.J. Timlin[1], Ya. A. Pachepsky, and V.R. Reddy

ABSTRACT

Time-domain reflectometry (TDR) is a popular technique for making soil water measurements. To be effective the technique has to provide data on soil water content at different depths and be easily automated.

We developed a system using a set of TDR sensors having different lengths that are installed vertically into the soil from the surface in a cluster. A data logger controls the TDR and records the output signals. The data are downloaded automatically into a laptop computer. A battery and solar panels power the system. A special computer program had been developed that transforms the recorded wave forms and separates the effects of different soil water contents at different depths. Thus the water content measured in the surface soil by the shortest probe is used in the analysis of the wave form from the next longest probe to determine water content in the next layer of soil .

Two seasons of field testing with a soybean crop have demonstrated the reliability of the system and its low maintenance requirements.

MEASUREMENT OF SOIL WATER USING TDR

The movement of water is an extremely variable and complex process, both spatially and temporally. As water moves in soil it carries with it dissolved chemicals and plant nutrients. Measurements of changes of water content are necessary to know the potential for movement of chemicals in soil. Traditionally, soil scientists and hydrologists have tracked the changes in water content by gravimetric sampling, or using neutron probes. These techniques are time consuming and expensive so only a few measurements per day can be taken. Furthermore, critical changes in water content can take place over very small time periods during a rainstorm that, using traditional methods, are virtually impossible to catch.

Recently, soil scientists and hydrologists have applied time-domain reflectometry (TDR) as a method to measure water content in soils. The method is accurate, safe from radiation hazard, causes little soil disturbance and has the potential to be easily automated. The method uses an electronic device known as a Time-domain reflectometer (TDR) to send a voltage signal

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along a coaxial cable that is connected to metallic rods imbedded into the soil. The signal reflects off the end of the rods and returns to the cable tester which records the reflected voltage over time. The time it takes the signal to return to the TDR instrument (travel time) is a function of the water content of the soil surrounding the rods. The travel time is obtained by recording the signal from the cable tester and then marking it at two characteristic points and measuring the distance between them (Fig. 1). A calibration curve that, generally, has to be determined for each location where the method is to be applied is used to obtain water content from the travel time.

There are several methods available to automate the measurements from a TDR device. Automation requires some method to allow the TDR device to switch to one of a number of cables that are connected to probes in the soil. Some cable testers that are commercially available for TDR measurements in soil contain microprocessors that allow them to be controlled from a computer or datalogger. They can be programmed to be turned on, take measurements and then turn off. These setups have been described in the literature (Baker and Allamaras, 1990; Herkelrath et al., 1991).
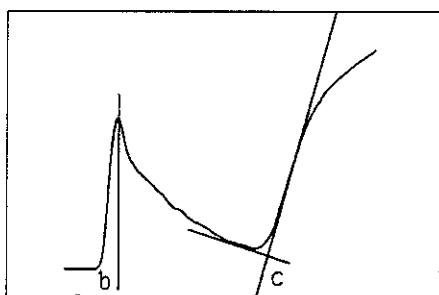
Figure 6 Signal From a TDR Instrument, the Distance 'BC' Is the Travel Time.

One drawback to automation of TDR is the problem of analyzing the signal from the cable tester to obtain the travel time. Often the signal is difficult to interpret with a computer program when there is a wetting front along the soil probe or when using short probes in dry soil. This can limit the use of the data because of the difficulty involved in analyzing a large number of signals by hand. Also it is difficult to obtain an accurate measure of water content for lower depths of soil from probes that are inserted vertically but have different lengths. For example, if there are two probes, one reaching to 5" and another reaching to 10" cm, the water content from 5 to 10" is obtained by subtracting the water contents measured by the two probes. This may result in a large margin of error.

We have developed a method to simulate a TDR signal which can be used to obtain travel time by fitting a simulated signal to a measured one. This is used in conjunction with an automated system of taking measurements of soil water with a TDR device for a number of locations.

MATERIALS AND METHODS

<u>Simulation of a TDR Signal</u>
The simulation method uses the multiple voltage reflection model of Yanuka et al. (1988). The multiple reflection model calculates the reflection and transmission of voltages along a

transmission line and calculates the reflected voltages that ultimately return to the cable tester. The transmission line consists of the coaxial cable from the TDR, and the soil probe, The soil probe has two parts, a 'handle' and waveguides which are metal rods that are inserted into the soil. The 'handle' is the connection between the rods and the cable. A simulated signal is similar to the signal in Fig. 1. A non-linear optimization program will find the travel time that results in a simulated signal that is closest to the measured one. Travel times calculated by the simulation method give calibration curves that are not significantly different from curves that use direct measurements of travel time.

Field Measurements of Water Content using Automated TDR

Two plots planted to soybean measuring 10 ft. by 5 ft. were selected for instrumentation. We inserted three sets of probes in each the interrow and row zones. The probes were made from 3 stainless steel rods 1/8" in dia. connected to a 50 ohm coaxial cable by alligator clips soldered to the end of the cable. They were installed at depths 0-4", 0-10" and 0-16". The alligator clips allowed the use of a hand drill to insert the rods into the soil. There were a total of 12 probes in both plots. A Cambell Scientific[2] CR10 data logger was used to control the Tektronix 1502B TDR. The probes were multiplexed using Cambell Scientific multiplexers. A datalogger program was written to control the TDR to take measurements of all probes once every hour during daylight. The TDR was turned off between measurements. At night, between the hours of 8 pm and 6 am, measurements were taken every three hours to conserve storage space. An 80286 IBM compatible laptop computer was used to download data from the datalogger via a modem every three hours and store the data on a 3.5", 720K diskette. The entire signal of 256 data points was recorded for every probe. The 720K diskette could hold data for approx 3 days. The computer remained on all the time and the only maintenance required was to go out to the equipment to download data and check the cable connections. Power was supplied by a deepcycle 12 volt battery charged by two 18 watt solar panels. The signals were analyzed using the TDR signal simulation program on a desktop computer in the laboratory.

EXAMPLE OF DATA ACQUIRED

Figure 2 shows water content at 0 at 10" as a function of time for the row and interrow positions in the two plots for the period July 26 to 28, 1994. The bars denote
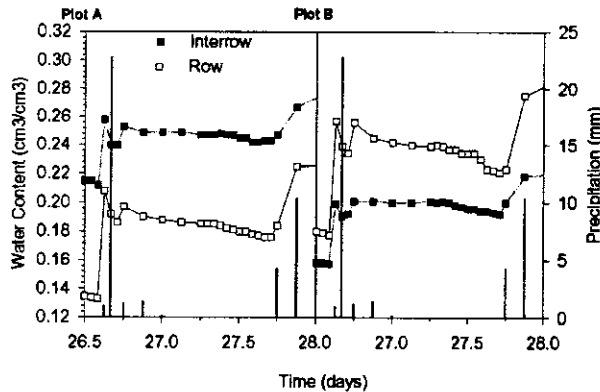
Figure 2 Water content at 0" to 10" as a function of time for the row and interrow positions in the two plots and precipitation for the period July 26 to 28, 1994.

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[2]Cambell Scientific Inc., P.O. Box 551, Logan, UT 84321 (This is not an endorsement of this product by the USDA)

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precipitation. The temporal resolution of the TDR measurements is very high, very small changes in water content are detectable over two to three hours of time. The water contents in the row and interrow zones of the two plots behave differently. The relative increase in water content due to rainfall in the row zone is greater than in the interrow zone. The rate of drainage in the row zone is also more rapid.

Figure 3 shows water contents measured over a period of 16 days in the two plots to 10" in depth. There were two rainfalls that were both at night. Both events were captured in detail by the TDR system. After 3 to 4 hours a large proportion of infiltrated water had drained past the 10" depth in the row zones. The figure also shows changes in water content due to plant water uptake and evaporation. The rate of water loss by evapotranspiration decreases as the soil dries and there is almost no water loss at night. As in Fig. 2 the changes in soil water in the row and interrow zones are similar during evaporation but quite different during infiltration and drainage. This is evidence for different hydraulic properties between the row and interrow zone that can potentially affect chemical transport.

The simulation method is robust and can determine travel times for signals in dry soil and in soils with strongly varying water content. The method can be combined with simpler algorithms and used as a check when the simple algorithm calculates an unreasonable value for water content.
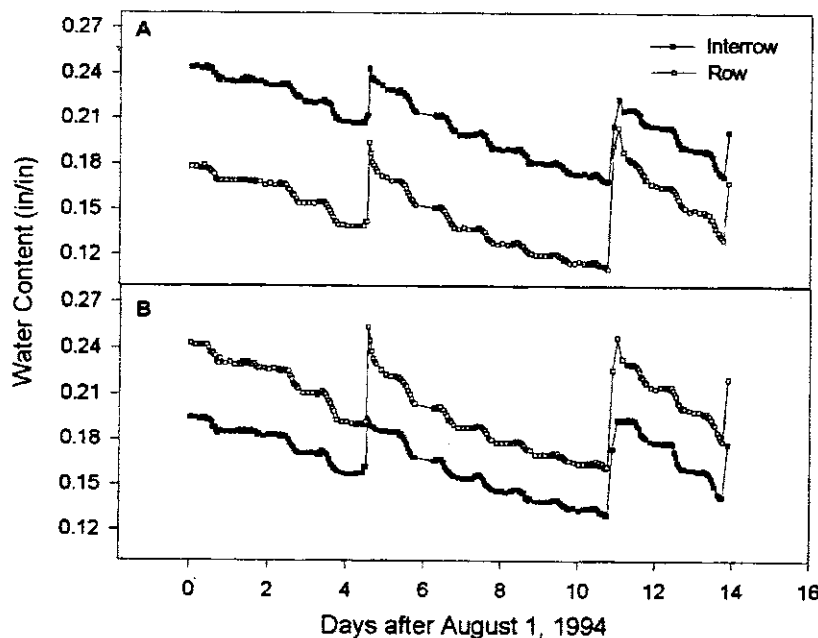
Figure 3 Average Water Contents in the 0 to 10" depth in Plots A and B From August 1 to August 16.

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2DSOIL - A TWO-DIMENSIONAL MODULAR SIMULATOR OF SOIL AND ROOT PROCESSES

Dennis Timlin[1], Yakov Pachepsky, Basil Acock, Hal Lemmon, and Antony Trent

ABSTRACT

The efficiency of many agricultural water management practices depends on the interplay between horizontal and vertical water and solute movement in soils, as affected by soil properties, timing and amount of water supply and chemical application, and root activity. A comprehensive two-dimensional soil and root simulator can be a useful tool to evaluate and compare water management practices, especially for row crops, intercrops, and crops on sloping land. This simulator when interfaced with plant models would give realistic estimates of root water uptake, surface shading, and stemflow. Our objective was to develop such a simulator.

We developed a generic modular design for the two-dimensional soil and root process simulator, 2DSOIL, which can be the basis of a suite of models. Each module corresponds to one or more soil, root or management processes. Modules of 2DSOIL were partly adopted from the most advanced models and partly developed by us. We have built soybean, cotton, and potato models by adding 2DSOIL to the code of existing plant models. We have found that the modular design of 2DSOIL greatly facilitates assembling a model suitable for a particular soil-plant-management combination, since the updating, replacement, and addition of modules is simplified. A user-friendly interface is included in the 2DSOIL design.

SOIL SIMULATORS AS A SOFTWARE

Soil simulators designed to work at different scales and with data of various levels of detail are widely available. The usefulness and flexibility of a simulator in an application depends on (a) the knowledge imbedded in it, (b) its ability to encompass management practices, and (c) its ability to be included in larger models of agricultural systems as a component model. This requires the simulator to be expandable to easily include models of management practices, or to replace process models as new knowledge becomes available, and to be compatible with existing plant and atmosphere models. Replaceable components, an expandable product and compatibility of the product with other products are common issues

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in software development. Since crop simulators designed for specific applications are undoubtedly software, techniques and methodologies of software engineering can be helpful in development of such simulators.

Modularity is an acknowledged principle of software design (Radice and Philips, 1994; Witt et al., 1994). There is general agreement about the desirable attributes of modules: modules have to be testable, they represent one logical self-contained task, modules are closed, are visible, have a single entry point and a single exit point, and have well-defined interfaces. A general guideline is to divide "large aggregates of components into units having loose inter-unit coupling and high internal cohesion.." (Witt et al., 1994).

Ecological modeling has addressed issues of replaceability and expandability in model design. Reynolds et al. (1992) suggested that the goal should be to build a suite of models that are based on general principles derived from structures and behaviors that are fundamentally similar across ecosystems. To accomplish this, they proposed the development of "generic" models that have a similar structure and similar modules . Some of modules may be used in several models with appropriate parameter changes.

DESIGN OF THE GENERIC SIMULATOR

The system requirements for the soil simulator in a crop model consist of providing a proper information exchange between models of soil, plant, atmosphere and management components. To communicate, the models need boundary fluxes, i.e. rates of water, heat, solute and gas transport over soil boundaries, and rates of carbon, water and nutrient exchange between shoot and roots The soil-root model manages soil and root state variables, i.e. distributions of water content, concentrations of solutes, temperature, gas contents, and root densities within a soil domain and receives the boundary fluxes.

To satisfy these system requirements, the soil-root system has been represented as a non-hierarchical system of modules corresponding to real processes. Each process module is composed of submodules that read data and calculate coefficients in models, change soil state variables, and generate time step restrictions for the whole simulator. The data structure of a process module corresponds to the three-level hierarchy shown in Fig. 1. The simulator as a whole has global public variables which are available to all its modules. The set of global variables include soil and root state variables, boundary fluxes, and time/space discretization parameters. The total number of global variables in 2DSOIL is relatively small. Each process module has its own

Global public data:
- temporal/spatial discretization,
- soil and root state variables,
- boundary values

Private data of a module:
- state variables from the previous time step,
- coefficients of the model

Private data of a submodule:
- parameters to calculate coefficients of a model,
- numerical process parameters
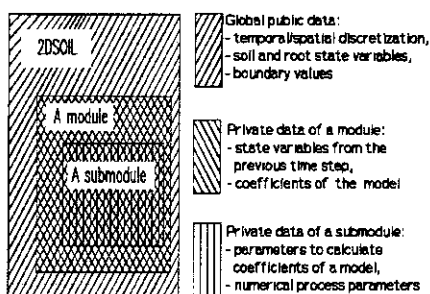
Figure 1 Three Level Hierarchy of Data Encapsulation in the 2DSOIL Simulator

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private data which are not available to other process modules but are available to submodules of this module. Finally, each submodule within a process module has its own protected data which are not available to other submodules or to the process module it serves. Both module and structure hierarchy follow the methodology of modular design known as 'separate specification from design' methodology (Witt et al., 1994). As a part of its specification, each process module has a precisely defined list of global public variables that it must change during invocation. To do it, a process module may use any of the available global variables (and, of course its private variables) as input data. Similarly, the list of the process module's private variables that are subject to change by a submodule within it are defined and documented for each of its submodules ; there are no limitations on which private data the submodule may use.

A permanent spatial grid is used for the spatial reference of soil state variables and boundary fluxes. Modules share data using the grid. At present, the generic simulator is designed to model one- or two dimensional distributions of matter and energy in soils. Transversal spatial grid lines must not cross each other, and this is the only major limitation in grid construction. Soil and root state variables, and boundary fluxes are defined in the nodes of the grid. Both finite-difference and finite-element approximations of mass and energy transport equations can be used in 2DSOIL simulators.

Either a value of a state variable or a value of flux is generated in each boundary node (e.g., a point at the soil surface) for each transport process module included in the simulator. Those values are supplied by plant and atmosphere models which are external to 2DSOIL. A boundary interface module manages the data exchange between the 2DSOIL simulator and other components of a larger model that includes 2DSOIL. Spatial discretization of the soil domain, types of boundary conditions on boundary nodes, information on soil layering, and calculation of time steps are handled by separate control modules. Control modules remain the same for any selection of process modules.

REPRESENTATIVE EXAMPLE OF THE SIMULATOR

The simulator has been developed using FORTRAN. Some modules were adapted from other code, and some developed by us. The adapted modules were rearranged to fit into the general module structure and into the data encapsulation structure of Fig. 1. The simulator includes (a)water transport modules to calculate two-dimensional (Simunek et al., 1992) and one-dimensional (Sherbakov et al., 1986) water flow in variably saturated soil, (b) solute transport modules for two-dimensional (Istok, 1989) and one-dimensional (Pachepsky, 1990) transport of several solutes, (c) heat transport modules for two-dimensional transport of heat (Simunek et al., 1992), (d) gas transport modules for two-dimensional gas transport in air-filled pore space, (e) root water uptake modules describing the trade of carbon and water between shoot and root (Acock and Trent, 1991), (e) root growth dependent on soil water and oxygen contents, soil temperature and root-shoot carbon balance (Acock and Trent, 1991) and water uptake by a

dynamic root system based on the partitioning of the transpiration demand between roots in soil cells according to root mass (Wesseling and Brandyk, 1985), (f) macroelement chemistry modules simulating cation exchange Ca-Mg-Na, dissolution-precipitation of gypsum and carbonates, speciation in solution and dissociation of carbonic acid and water (Pachepsky, 1990), (g) nitrogen transformation modules to calculate mineralization/ immobilization of organic matter in soil, nitrification and denitrification (Bergström et al., 1990), and (h) management modules to simulate soil subsidence after tillage, fertilizer application, and irrigations.

APPLICATIONS

In order to be able to add the 2DSOIL simulator to crop models, we had to create a boundary interface. Interfaces have been written for potato, soybean, and cotton shoot models and for the micrometerological model, WEATHER, implemented in the soybean simulator GLYCIM. We carried out simulations of several example problems to demonstrate the utility of 2DSOIL for water quality issues. These examples have shown that: (a) when alternate furrow irrigation is used instead of regular furrow irrigation, the root distribution is concentrated near the irrigated furrow; this creates favorable conditions for nutrient uptake and will limit leaching of fertilizers if they are placed in the ridge, near the plant, (b) when the subirrigation is being used or the beginning of the growing season is very dry, wide row spacings may cause the leaching of chemicals into deep soil layers; and (c) the development of surface shading which reduces evaporation in the interrow zone and causes soil temperature and moisture differences between row and interrow zones can reverse the ratio of the nitrogen transformation rates in these zones.

Construction of the input data set for two-dimensional simulators is a non-trivial and tedious task if soil layering, unevenness of the surface, localized chemical and water application, and the presence of drainage must be taken into account. To automate the construction of the input data files for 2DSOIL we are developing a visual user interface.

The promotion of code extension and reuse is an essential advantage of the modularity of 2DSOIL. Since each module takes care of its own data, and the functions and data are kept together in the module, the design makes the modules highly independent. A library of modules can be easily accumulated. Development of the representative example is an obvious example of code reuse. We used significant pieces of code written by others and were able to combine them as necessary for a task in hand. The modularity was a necessary precondition of this. We took full advantage of the fact that the codes we used were well-tested, robust and secure.

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LINKING WATER AND GROWTH AND YIELD MODELS TO EVALUATE MANAGEMENT ALTERNATIVES IN SUBALPINE ECOSYSTEM

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ABSTRACT

A modeling exercise is presented linking a subalpine water balance model (WATBAL) with a diameter-class empirical growth and yield model (GENGYM). Simulated outputs of streamflow and vegetative conditions were produced for a 120-year period in a hypothetical forested watershed in the Rocky Mountains. One landscape management scenario was compared to a baseline condition where no management activities occurred. Results indicated water yield would remain stable with no treatment, even though significant shifts in species composition would occur within the watershed. The management scenario increased water yield.

INTRODUCTION

Precipitation received and stored as snow in subalpine ecosystems is the primary source of water for irrigated agriculture and municipal use throughout the West. Research shows management activities that affect vegetation also affect water yield.

Observations made on Fool Creek, as well as other studies at the Fraser Experimental Forest, led to the development of a series of subalpine, water balance models in the mid-1970's. The first of these models, MELTMOD, simulated accumulation and melt of snow in subalpine watersheds. This was followed by the WATBAL model, which simulated a complete water balance for forest vegetation (Leaf and Brink, 1973). The next generation was LUMOD (Leaf and Alexander, 1975), a land use simulator that incorporated output from an even-aged growth and yield model (RMYLD) (Edminster, 1978). All of these early models assumed that clearcutting had the greatest impact upon snowpack accumulation and water yield.

More recently, plot studies were initiated to examine the effect of any stand density on snowpack accumulation. These results, plus a re-examination of studies done over almost 50 years, demonstrated that the increase in snow accumulation was best expressed as a linear function of basal area removed from the stand (Troendle, 1991; Troendle and King, 1987). This thinking has been incorporated in a revised version of the subalpine water balance model WATBAL so that we may now simulate evapotranspiration changes, summer and winter, and project water yields as a function of any forested condition or silvicultural activity (Troendle, 1991).

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In order to simulate the effects of growth, mortality, and silvicultural activities upon water yield, we have manually linked the revised WATBAL model to GENGYM, (Edminster et al., 1990). a growth and yield model capable of simulating growth of subalpine forests under a variety of age distributions and mixed-species compositions (Edminster et al., 1990).

THE MODELING EXERCISE

As an example to demonstrate the technology, we chose to model a hypothetical 500-acre watershed, oriented east-west, with an equal distribution of north and south facing slopes. Elevations range from 9000 ft. at the mouth of the watershed to 11,500 ft. in the alpine zone. All slopes are assumed to be 30%. Climatic data from the Fraser Experimental Forest in central Colorado was used in this exercise. Using a climatic base of 9000 ft. (the actual location of weather data collection), a 30% increase in precipitation was assumed for each 1000-ft. elevation gain. Average temperatures were assumed to decrease 2° F per 1000 ft. elevation increase. South-facing slopes were assumed to be 1° F warmer than the estimate for a given elevation during the growing season, and 2° F warmer in winter. North slopes were assumed to be 1° F colder during the growing season, and 2° F colder in winter. These assumptions were derived from the relationship between weather data collected on the Fraser Experimental Forest.

Forest inventory data from mature, unharvested forests of Engelmann spruce (*Picea engelmannii* Parry ex Engelm.), subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.) and lodgepole pine (*Pinus contorta* Dougl. ex Loud.) were selected to represent the vegetation.

Two scenarios were modeled. In the first, the initial vegetative conditions were projected forward 120 years with no management intervention. This was essentially a baseline scenario that simulated changes in vegetation and streamflow over time in the absence of any vegetation management, or insect and disease attacks (Fig. 1).

A vegetation management alternative was then modeled. It was first assumed that access roads were constructed in the watershed 20 years earlier and that timber was harvested from about 10% of the watershed, in three clearcuts, at that time. In addition, it was assumed that the first entry of a shelterwood cut was also made 10 years earlier in two locations, one in spruce-fir, one in lodgepole pine. This is similar to what has occurred in many subalpine watersheds in the central and southern Rockies.

A more intensive silviculture regime was then simulated to occur on into the future. Treatments included continuing existing management, but added additional clearcut areas to break up the angularity of the original block cuts; applied individual tree selection to spruce-fir stands on 30% of the watershed; and group selection harvest occurred in remaining lodgepole stands. This strategy called for periodic harvest of trees for 100 years into the future from all of the watershed, except for an 8% old-growth set-aside. All treatments are shown on Fig. 2.

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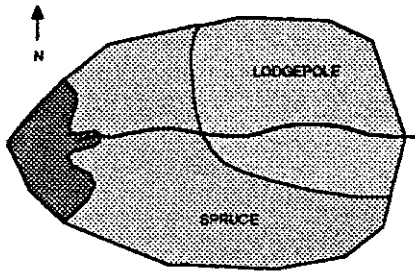
Figure 1. Hypothetical 500-Acre Subalpine Watershed Used in the Model Simulations. Vegetation Consists of Mature Spruce-Fir and Lodgepole Pine Forests, With Alpine at the Upper Headwaters of the Watershed.
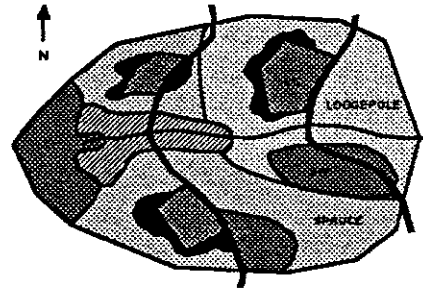
Figure 2. Map of Roads and Past Silvicultural Treatments as Well as Treatments applied in Future Management. Rehabilitation Cuts to Improve Visual Quality of Old Clearcut (CC) Blocks are Shown in Black. Selection Management (SW) was applied to All Forested ARea not Previously Treated, Except that Designated as Old-Growth.

RESULTS

In the baseline simulation of a natural watershed, GENGYM projected slightly different growth trends between north and south slope stands of the spruce-fir type. On north-facing slopes, basal area gradually increases until the end of the projection period (Fig. 3). On south-facing slopes, where initial stocking was somewhat heavier, basal area increased slightly until year 70 and stayed at that level until year 120. In both these cases, the proportion of spruce and fir increased slightly, while pine basal area remained roughly the same throughout the projection period.

A different pattern resulted in the undisturbed lodgepole pine type. Here, overall stocking dropped as the already mature pine naturally died out of the stand and was replaced by spruce and fir (Fig. 4).
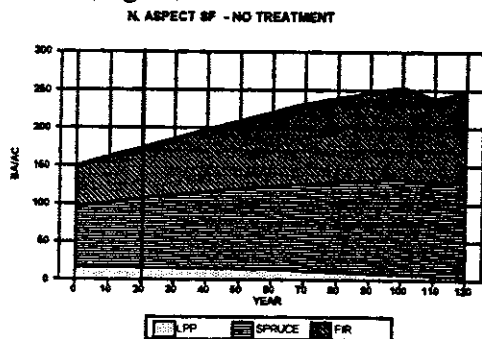
Figure 3. Basal Areas Projected by GENGYM for a 120-Year Simulation of Spruce-Fir on North-Facing Slopes When No Silviculture Treatment was Applied.
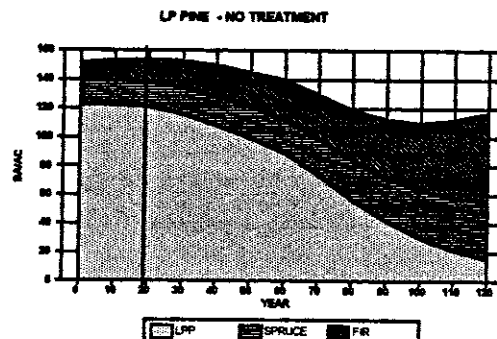
Figure 4. Basal Areas Projected by GENGYM for a 120-Year Simulation of Mature Lodgepole Pine When No Silviculture Treatment was Applied.

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These projected natural changes in species composition and stocking that occurred throughout the watershed had little effect upon streamflow over the 120-year projection period (Fig. 5). Base streamflows remained at a constant 9.3-9.4 in. of water throughout the 120-year model projection.
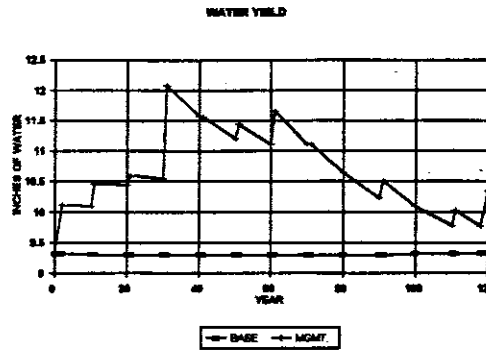
Figure 5. Water Yields Projected by WATBAL for a 120-Year Simulation Period Under the Management and No Management Options.

The effect of management on water yield was very dramatic. Flow increased an average of 15% over the 120-year projection period with periodic streamflow ranging as high as 12 in. of water. The greatest increase in water yield occurred in year 30 of the projection. This coincided with the simultaneous overstory removal cuts of the shelterwood prescriptions and the initial harvests in the individual tree and group selection prescriptions, maximizing the reduction in stand density.

Individual tree selection was the most efficient silviculture system, producing the highest fiber yields per acre, higher than either clearcutting or shelterwood prescriptions. Group selection produced the lowest per acre yields.

DISCUSSION

Several inferences can be drawn from this exercise. First, subalpine watersheds do not have to be managed using intensive clearcutting to significantly increase water yield or maximize fiber production.

Second, water yields appear to be quite sensitive to any silviculture manipulation of subalpine forests. The WATBAL simulations indicate that any significant reduction in basal area, regardless of the method of harvest, will result in an increase in streamflow.

Third, and perhaps most important, the simulations provide a means to view the consequences of combinations of management activities on a landscape scale and allow us to re-think their scheduling prior to implementation.

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USING AVAILABLE SOIL MOISTURE TO DETERMINE PLANTING TIME MANAGEMENT OF GRAIN SORGHUM

R.L. Vanderlip and D.L. Fjell[1]

ABSTRACT

Grain sorghum is normally grown in areas where rainfall is limited and unpredictable. Thus, results from short-term experiments frequently produce erratic results. A computer based decision aid was developed utilizing a sorghum plant growth model to simulate yields for a wide range of planting dates, plant populations, and maturity classes using long term climatic data. Simulations were run for a range of beginning soil moisture conditions to allow the user to make decisions based on long term climatic data and on planting time soil moisture conditions. Results were highly dependent on the location for which simulations were made. Management practices to produce most reliable yields were greatly affected by a starting soil moisture.

INTRODUCTION

The ability of grain sorghum to adapt to adverse conditions has made it a popular crop in the Midwestern United States were rainfall is limited and unpredictable. Unfortunately, this ability to adapt to a wide range of environmental conditions and the variable climate that the crop is grown under make it difficult to determine what management practices should be used to obtain the best economic return.

Given their current soil moisture conditions, management system, economic situation, and the historical climate pattern for their location, producers are often interested in knowing what planting date, planting rate, and hybrid maturity will work best. Also, when sorghum stands are less than desired, producers need to know when to consider replanting.

A decision support model would allow the producer to make informed choices concerning the best management decisions for his situation. Using current soil moisture and economic costs as inputs, the producer could then examine yield and economic returns over a range of historical weather patterns and make adjustments to management to increase return from or minimum risk of the most likely scenario.

Two factors must be considered in choosing management practices for planting or in deciding whether or not to replant an existing stand of grain sorghum. First, the producer needs to

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know the yield expectations of the sorghum crop with the alternative management practices before planting or replanting decisions can be made. A thorough knowledge of optimum planting date, plant population, and maturity classes for a particular location, soil type, and soil moisture condition is essential (Benson, 1990).

Frequently these choices are based on treatment averages of management systems. Although these averages are valuable, they do not allow producers to determine yield expectations over the range of possible practices or perhaps more importantly determine the level of risk associated with each of these practices. This concern for risk is the second factor which producers must face. Anderson et al. (1977) stated that the extension of technological advise will be more effective if due recognition is given to the impact of risk. Ideally, the best management choice would be the one with the highest average return and the lowest variability.

In the Great Plains, the major source of variability is the weather. Therefore, our objective was to produce a computer based system which would take in to account year-to-year variability in yields as affected by both management decisions and weather.

MATERIALS AND METHODS

Experimental Approach
The decision aid was developed by combining an extensive database of simulated yields with an economic module that allows the sorghum producer to input costs and grain prices and thus determine both yield expectations and expected gross returns. Grain yields were simulated using an improved version of the SORKAM (Rosenthal et al., 1989) sorghum growth model. SORKAM has been validated for a number of locations in Kansas and proven to be highly responsive to management and environmental conditions (Heiniger et al., In press).

Using 33 years of climate data, the SORKAM sorghum growth model was used to simulate grain yields for a range of planting dates, plant populations, and hybrid maturities for four Kansas locations: Manhattan, Parsons, St. John, and Garden City. Separate simulations were run assuming either continuous grain sorghum or grain sorghum after fallow, where appropriate, and results from these simulations were considered to be representative of the environmental conditions at each location. Subsequent simulations using the 33 years of climate data and the same combinations of management practices were run for four soil moisture scenarios: a full profile at planting, a three-fourths full profile at planting, a one-half full profile at planting, and a one-fourth full profile at planting.

The economic module was based upon the Kansas State University Farm Management Guides For Grain Sorghum. These provide categories of costs and default values for each input cost. These are all readily accessible by the user to change to whatever input costs are more appropriate for the particular situation being evaluated.

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Results

As expected, the response of grain sorghum to changing management practices varied greatly among locations and in response to available soil moisture conditions. For example, when evaluating replanting decisions there were very few situations in which replanting would be advantageous from a yield stand point and even fewer when it would be economical in the Central and Western Kansas locations. In Eastern Kansas there were relatively more situations were replanting might be appropriate, however, again the tremendous capability of the sorghum crop to compensate for losses in stand indicated that only extremely low plant populations should consistently be replaced.

In each case, the frequency distribution of yields and gross returns are presented in the software so the likelihood of both improvements from changing a management practice on replanting can be balanced against the risks of reduced yields and/or economic losses. Simple frequency distributions for the effects of starting soil moisture on grain yields at Manhattan are shown in Table 1.

Table 1.   Yields from a planting of 75,000 plants/acre of a medium maturity sorghum hybrid at Manhattan with different soil moisture conditions.

		Soil Moisture Level			
	Historical	Full Profile	3/4 Full	1/2 Full	1/4 Full
Probability		Yield more than (bu/acre):			
90%	58	77	53	18	11
80%	76	80	74	31	18
70%	80	89	79	51	29
60%	93	97	92	69	37
50%	101	108	100	80	46
40%	109	110	108	89	60
30%	112	113	110	96	71
20%	117	119	117	108	79
10%	130	130	128	117	99

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IRRIGATION ECONOMICS EVALUATION SYSTEM FOR WINDOWS

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ABSTRACT

Irrigation Economics Evaluation System (IEES) is a microcomputer model designed and developed to meet the need for conducting economic evaluation of adjustments to irrigation systems and management techniques to improve the use of irrigated water. IEES can calculate the annual operating costs for seven types of irrigation systems and has five options that can be used to economically evaluate improvements in the pumping plant or the way the irrigation system is used for crop production.
Keywords:irrigation, economics, irrigation system efficiency, irrigation costs, microcomputing.

INTRODUCTION

Establishment of economical irrigation practices is influenced by the knowledge the irrigator has concerning both the economic and technological aspects of irrigation. It is critical for irrigators to know how to estimate irrigation costs under various operating conditions in order to evaluate alternative irrigation techniques. The objective of this manuscript is to report on a model designed to increase the operator's ability to evaluate irrigation system costs. The microcomputer model, Irrigation Economics Evaluation System (IEES), can be used to estimate costs under a variety of operating conditions and to evaluate irrigation systems for economical water use. IEES is designed to utilize user-supplied data to calculate the operating costs for Medium Pressure Center Pivot, Low Pressure Center Pivot, Low Energy Precision Application Center Pivot, Low Drift Nozzle Center Pivot, Furrow Flood Gated Pipe, Surge Furrow Flood Gated Pipe, and Sub-surface Drip irrigation systems that use either natural gas, propane (LP) gas, diesel fuel, or electricity.

MODEL OVERVIEW

IEES is designed to calculate operating costs for eleven items associated with operating irrigation systems and the total annual operating costs on a per acre, per hour and per acre-inch basis. The eleven costs that are calculated on an annual basis in the program are listed in Table 1.

In addition to calculating the annual operating costs, the model has five options that can be used to economically evaluate improvements in the pumping plant or the way the irrigation system is used for crop production. These options are evaluation of pump repair or replacement, evaluation of switching power units from one power source to another, estimates of operating cost changes caused by a falling water table and/or a pump efficiency decline, estimates of operating costs for different levels of water application, and estimates of operating costs under selected fuel inflation rates. Additional components are being constructed that will evaluate switching from a distribution system that is currently in place to a new distribution system, i.e. Furrow Flood Gated Pipe to Sub-surface Drip.

ECONOMIC ANALYSIS

The economic model is basically composed of a budget generator and present value analysis algorithms. Technical data concerning the use of the irrigation system to be evaluated are entered interactively into IEES along with input prices and costs. The program can be used with data collected from a standard well and pumping plant performance test. The equations which comprise the algorithms use the input data along with engineering standards applicable to the specific type of irrigation system and power source to estimate current costs and projected costs under expected future operating conditions. The operator of the model can first estimate annual operating costs or the investment cost for each type of system.

Annual Operating Costs and Investment Cost

The first major component of the computer model estimates eleven annual operating costs for the system being evaluated. Data concerning operating pressure, flow rate, pumping water level, fuel consumption, pump efficiency, fuel prices, and wage rates are entered by the operator in this section. A sample output from IEES is shown in Table 1. The other major component of the model assists in estimating investment costs of the system. This section of the model operates similar to a spreadsheet. Per unit costs and quantities of the distribution system components are entered and compiled into total investment costs.

Optional Evaluations

There are five optional evaluations that can be performed once annual operating costs are estimated. The first optional evaluation involves determining if pump repair or replacement is economically justified. One of the most important parts of this evaluation is predicting the flow rate in gallons per minute of the well when the pump is repaired or replaced. Complete documentation of this procedure can be found in Dvorak et al. (1985a). Once the new flow rate for the repaired pump is estimated, the operating costs of the pumping plant are calculated using the new predicted flow rate and technical pumping efficiency. The flow rate

and technical pump efficiency will be improved, and operating hours and operating costs will be reduced, assuming the same amount of water is applied as before the pump was repaired or replaced.

Total annual operating costs for the system are estimated for a 10-year period with and without improvements. The difference between the two is the savings that can be expected. If the total savings for the 10-year period calculated are negative, the model will terminate the evaluation because it is not economically feasible to make improvements to the pumping plant. If the savings are positive in the evaluation of pump repair or replacement, the model will continue the evaluation by asking for an estimate of the cost to repair or replace the pump or use a computer-generated estimate of the replacement cost. Computer-generated cost estimates are based on 1994 survey data of western Kansas equipment dealers. Annual discounted savings for each year over the 10-year period are summed. If the total discounted savings are less than the estimate to repair or replace the pump, the evaluation is complete. If the discounted savings exceed replacement cost, the replacement cost is subtracted from the total discounted savings to estimate the net savings that can be expected over a 10-year period. The number of years (payback period) required to pay for the repairs is also estimated. An example of the output from this section of the model is provided in Table 2.

The second optional evaluation procedure determines if switching to an alternative power source is economically feasible. When switching power sources, operating conditions associated with the pumping plant are assumed to remain the same. The model uses a procedure developed by Dorn to convert the fuel consumption for the current power source to an equivalent amount of fuel for the alternate power source. Once the model estimates the fuel consumption for the alternate power source under consideration, the total annual operating costs are estimated. The model then estimates the savings if there are any from switching to the alternative power source. The remainder of the economic analysis is similar to that discussed for pump replacement. A complete documentation of the underlying criteria and engineering procedure can be found in Dvorak et al. (1985b).

The third optional evaluation estimates the effect of a falling water table and/or technical pump efficiency decline on operating costs. The user has to enter the expected annual drop in the water table and percentage estimate of the annual technical pump efficiency decline. The model iteratively recalculates the expected flow rate and the pumping water level for each successive annual decline in technical pump efficiency and increase in water table depth so the annual operating cost changes can be calculated.

The fourth and fifth optional evaluation routines calculate and display the annual operating costs for the irrigation system given alternative levels of water application (inches applied per acre) and a user supplied scenario of annual fuel inflation rates for a ten-year period.

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Table 1. Computer Output Format of Annual Irrigation Operating Costs

The following are the operating cost estimates of your system:
All costs are based on 155 acres, 1,477 estimated pumping hours and an estimated 56 water horsepower, 101 brake horsepower and 174 rated horsepower.

Distribution System: Furrow Flood Gated Pipe
Power Unit: Natural Gas

Fuel cost for operation:	$4,154.96
Oil for the engine:	$518.27
Annual electric connect charge:	$0.00
Oil for electric motor:	$0.00
Oil for gear drive:	$103.65
Pumping plant maintenance cost:	$358.74
Repair and maintenance cost for distribution system:	$455.00
Pumping plant maintenance labor cost:	$354.49
Maintenance cost for setup, takedown and operating:	$1,062.00
Costs for reuse on annual basis:	$179.55
Costs driving center pivot on annual basis:	$0.00
Total operating cost:	$7,573.67
Cost per acre:	$48.86
Cost per acre-inch:	$2.71
Cost per hour:	$5.13

Table 2. Computer Output Format of Pumping Plant Repair Evaluation

Projected total cost savings from pumping plant repair are estimated assuming an annual fuel inflation rate of 5%.
Required pump hours are now 1150 to apply 18 inches/acre.

Year	Total Savings	Previous Cost	New Cost
1	$1,163.16	$7,573.67	$6,410.51
2	$1,213.13	$7,800.77	$6,587.63
3	$1,265.61	$8,039.22	$6,773.62
4	$1,320.70	$8,289.60	$6,968.90
5	$1,378.55	$8,552.49	$7,173.94
6	$1,439.29	$8,828.53	$7,389.24
7	$1,503.07	$9,118.37	$7,615.30
8	$1,570.04	$9,422.70	$7,852.66
9	$1,640.36	$9,742.25	$8,101.90
10	$1,714.19	$10,077.78	$8,363.59

The total savings over 10 years is estimated to be = $14,208.10
The total savings with no fuel inflation included is = $11,631.62

Present value analysis:
Estimated costs for pumping plant replacement or refurbishment: $5,190.60
Present value of 10 years of savings: $9,277.58

THIS ANALYSIS INDICATES SAVINGS EXCEED COSTS FROM REPAIR
Discounted savings minus costs: $4,086.98
Number of years to payback repair cost: 6

SUMMARY

Proper use of IEES will provide an irrigator with estimated costs for investment and operation of a specific irrigation system. The model also provides estimates of the costs associated with possible changes to the pumping plant and the amount the system is used. With this information, an irrigator should be able to decide if it is economically feasible to make changes or improvements in the pumping plant to reduce irrigation costs.

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NONPOINT SOURCE POLLUTION MODELING FOR RUNOFF AND SEDIMENT CONTROLS USING CASCADE ROUTING FORMULATION

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ABSTRACT

Nonpoint Source (NPS) pollution problems caused by runoff and sediment from 72,000 acre watershed in south-western North Dakota that drains into the Bowman-Haley reservoir was investigated by using AGNPS (Agricultural Nonpoint Source Pollution) Model. Methodology is described to develop a database for the watershed and to link subwatersheds together in cascade routing model formulation to simulate surface water quality of runoff influxed into the reservoir. Model simulation was used to identify critical areas within the watershed where land treatment should be focused to optimize results. Sensitivity matrix analyses were performed to determine the impact of changing values of various parameters in the model on predicted water quality of the study watershed. These changes in parameter values were related to changing practices on the land to control nonpoint source pollution. Several alternative Best Management Practice (BMP) scenarios were constructed and simulated for various changes in land management and treatment and subsequent changes in water quality reflecting these changes were determined. It was observed that the most effective scenario could reduce sediment and nutrient loading into the Bowman-Haley Federal Reservoir by 62%. Based on the results from simulated scenarios, possible improvements for future water quality management and planning were obtained.
Keyword: Nonpoint Source Pollution, Water Quality, AGNPS, BMP

INTRODUCTION

Agricultural nonpoint source pollution control of water quality in the Bowman-Haley dam located in Bowman County, North Dakota, and Harding County, South Dakota was evaluated by using a distributed parameter hydrologic model, AGNPS (Agricultural Nonpoint Source Pollution Model). The main watershed located in the north of the Bowman-Haley dam, Spring-Cold Turkey-Alkali basin was investigated.

The study watershed has a complex topographic pattern that consists of highly variable land slope patterns and numerous small lakes and wetlands that affects its hydrologic characteristics substantially. For the analysis of such complex topographic features, spatially distributed models are more suitable than conventional lumped models. In that sense, AGNPS is an appropriate distributed parameter model to identify 'critical' areas of high

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sediment and nutrient production in a mainly agricultural watershed, and to estimate the potential benefits of implementing best management practices (BMP) on these 'critical' areas to reduce water quality problems.

OBJECTIVES

The objectives of this study were: (1) To develop a database to apply the AGNPS model to four subwatersheds which make up the Spring-Cold Turkey-Alkali basin which drains into the Bowman-Haley reservoir in south-west North Dakota, (2) To formulate a cascade routing model to link the subwatersheds together to simulate water quality of runoff from a72,000 acre basin with the AGNPS model, (3) To identify critical areas for land treatment to improve water quality using AGNPS model simulations, (4) To conduct sensitivity analyses on AGNPS model parameters to optimize land treatment to improve water quality and (5) To prescribe land management and treatment scenarios for the Spring-Cold Turkey-Alkali basin to improve water quality of runoff entering the Bowman- Haley reservoir based on AGNPS model simulation.

AGRICULTURAL NONPOINT SOURCE POLLUTION MODEL (AGNPS)

AGNPS is an event-based model that simulates surface runoff, sediment, and nutrient transport primarily from agricultural watersheds. The nutrients considered include nitrogen (N) and phosphorous (P), both essential plant nutrients and major contributors to surface water pollution. Basic model components include hydrology, erosion, and sediment and chemical transport. The model has the ability to output water quality characteristics at intermediate points throughout the watershed network. This capability is based on the model's implementation of the 'cell'. Cells are uniformly square areas subdividing the watershed, and all watershed characteristics and inputs are expressed at the cell level.

Model components use equations and methodologies that have been well established and are extensively used by agencies such as the USDA Soil Conservation Service. Runoff volume and peak flow rate are estimated using the SCS runoff curve number method. Peak runoff rate for each cell is estimated using an empirical relationship proposed by Smith and Williams (1980) and which is also used in CREAMS (Frere et al., 1980). Upland erosion and sediment transport is estimated using a modified form of the Universal Soil Loss Equation, USLE (Wischmeier and Smith, 1978). Sediment is routed from cell to cell through the watershed to the outlet using a sediment transport and depositional relationship described by Foster et al. (1981) which is based on a steady-state continuity equation. Chemical transport is calculated based on the relationships adapted from CREAMS and a feedlot evaluation model (Young et al., 1982). AGNPS is a very data-intensive model, the complexities increasing as the size of the watershed increases, but with tools such as geographic information system and database management system, AGNPS has an advantage over other lumped models.

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METHODS

The watershed boundary was delineated and AGNPS was applied to the Spring-Cold Turkey-Alkali subwatershed, which contains 1800 cells (72,000 acres). For data management purpose, the Spring-Cold Turkey-Alkali watershed was further divided into four subwatersheds using a sequential cascade routing model formulation. They are 1)Hart subwatershed with 418 cells (16,720 acres), 2)Bowman subwatershed with 483 cells (19,320 acres), 3)Amor subwatershed with 591 cells (23,640 acres), and 4)Boyessen subwatershed with 308 cells (12,320 acres). Surface runoff flows mainly from the north (Hart and Bowman subwatersheds) to the south and the west (Amor subwatershed) to the east, merged at Boyessen subwatershed. All nonpoint sources including sediment and nutrients are routed sequentially using a cascade routing formulation to the outlet of the Boyessen subwatershed and exit directly to the Bowman-Haley Dam. Thus, based on AGNPS simulation results, degrees of nonpoint source pollution within the Spring-Cold Turkey-Alkali watershed and to the Bowman-Haley Dam are assessed simultaneously.

A 10-year, 24-hour storm event was used in the simulation mainly based on meteorological frequency of the study area. Also, the precipitation value of 3.0 inches with an energy-intensity value of 52.64 which corresponds to 10-year return period and 24-hour duration was selected. The SCS synthetic rainfall type II distribution (USDA SCS, 1986) was applied to the 24-hour storm which represents precipitation characteristics of the watershed in the month of June which is generally the wettest month. The hydrology, sediment and nutrient estimates obtained from AGNPS simulation were then used to assess critical areas of nonpoint source pollution within each subwatershed. For the purpose of this study, critical areas are those in which the pollutant yield exceeded a specific threshold value. The outputs of sediment and nutrient contributions at a subwatershed's outlet were linked to the next subwatershed in a sequential cascade model. The sediment and nutrient routings are performed on a per cell basis proceeding from the headwaters of each subwatershed to its outlet. Thus the estimates of total sediment and nutrient yields at the outlet serve as indicators for developing BMPs to control erosion and nutrient transport from each subwatershed. For the given conditions, the simulated storm produces a peak flow rate of 498 cfs at the outlet of Boyessen subwatershed and the total sediment yield is estimated to be 1507 tons. Substantial amounts of nitrogen and phosphorous discharge were also estimated. Analysis of nitrogen estimates is divided into two components; soluble and sediment-absorbed. Soluble nitrogen includes organic nitrogen (NH_3, NO_3) and soluble Kjeldahl nitrogen. Sediment-absorbed nitrogen consists of exchangeable and fixed NH_3. Phosphorous estimates represent total and dissolved orthophosphate(PO_4^{-3}).

CONSTRUCTION OF BMP SCENARIOS

A total of seven parameter adjustment scenarios was constructed and then combined to create a hypothetical BMP scenario. Seven parameters were selected out of twelve parameters based on their significance in sensitivity to hydrology, erosion and sediment, and nutrient yield

outputs. Overall reduction of nutrient and sediment yields at the watershed outlet were set as the main goal. Care was taken not to significantly alter the current primary land uses such as croplands, water surfaces and wetlands. Alternative land management practice strategies were used instead. Scenarios were constructed such that scenario no. (N+1) was created by adding adjustment of one more parameter to scenario no. (N). For example, scenario no. 7 contained seven parameter adjustments, and so on.

RESULTS OF BMP SCENARIO SIMULATIONS

Scenarios were applied only to the critical areas of a specific nutrient rather than globally applying the scenario throughout the watershed. The results appear to support the idea of adequacy of implementing scenarios to the critical areas only rather than to the entire watershed. Simulated estimates were compared to initial base estimate values to assess improvements made by each practice scenario. Comparison was based on three categorized estimates; hydrology, erosion and sediment and nutrient yields at the outlet of the Boyessen subwatershed.

The final scenario, No. 7 contained parameter adjustments for seven parameters including SCS curve number, Manning's roughness coefficient, cover and management factor, land slope, channel sideslope, practice factor and fertilization availability factor. The scenario No. 7 was most effective in reducing the degree of chemical oxygen demand by 86.5% from the base value of 1.48 lbs/acre. All erosion- and sediment-related nonpoint source pollutants were significantly reduced by 70 to 20% of their base values by altering the cover and management factor (C-factor) and the practice factor (P-factor). Additional reduction was accomplished by adjusting the Manning's roughness coefficient parameter. Upland erosion was reduced by 35%, from 2.8 ton/acre to 1.8 ton/acre. Channel erosion exhibited a pattern similar to the upland erosion. Channel erosion was reduced from 0.09 ton/acre to 0.03 ton/acre which was a 66% reduction. Here, emphasis should be given to the interpretation of the erosion reduction values. Even though the upland erosion had a smaller reduction in percentage value than channel erosion, the reduction of upland erosion is far more significant in nonpoint source pollution control in the study watershed which has highly fluctuating topological characteristics. Total sediment yield was reduced by 68%. C- and P-factors were again the two parameters that made considerable, 1017.8 tons, reduction in total sediment yield from the base value of 1030 tons.

SUMMARY AND CONCLUSION

Sensitivity analysis of the AGNPS model parameters on the study watershed was also conducted so that parameters that have any location-specific and/or significant influence on the output values were identified. Results from the sensitivity analysis were used to construct "what if ," or alternative management scenarios. Results from the sensitivity analysis show that seven AGNPS parameters out of twenty-three were relatively effective in reducing

nonpoint source pollutants from this particular watershed. They were SCS curve number, Manning's roughness coefficient, cover and management factor (C-factor), land slope, channel sideslope, practice factor (P-factor) and fertilization availability factor in descending order of significance. Various rainfall frequencies including 1-, 2-, 5-, 10-, 25- and 100-year return periods were also investigated to determine the effect of various return periods on the watershed response.

After seven simulations, a best management practice (BMP) scenario was formulated and then simulated to evaluate potential improvements in current water quality problems. Simulated results showed that the BMP scenario achieved an average reduction of about 62% from current nonpoint source pollutant levels. The final BMP scenario No. 7 was most effective in controlling the erosion and sediment yield.

It was also observed that the scenario No. 1 alone reduced sediment and nutrient loading by 48%. Thus, by implementing the scenario No. 1 alone, the current goal of the Bowman-Haley project of reducing sediment and nutrient delivery to the Bowman-Haley reservoir by 20% can be attained. It is recommended that single or combination of BMP scenarios should be implemented on the study watershed to improve current water quality problems. Based on the results from the constructed scenarios, possible improvements for future water resources management and planning were obtained. Although this study emphasizes the application of the methodology to the Bowman-Haley watershed in North Dakota, the methodology is applicable to any watershed in general.

The results of this investigation should have direct applications in understanding the topological and physical behaviors of the Bowman-Haley watershed more adequately and constitute a contribution to the future resources management and planning processes by providing guidelines for a long-term phased automation of information management. Also, results from this investigation will lead to easier and better information management of various watershed related data, and more effective and flexible methods for resources planning and management. Furthermore, the developed methodology would be advantageous when study areas are large or numerous, analysis and modeling are performed repeatedly, or alternative land use/landcover scenarios are explored.

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MODELING PESTICIDE TRANSPORT UNDER FIELD CONDITIONS

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ABSTRACT

The impact of pesticides on groundwater quality was studied in a two-year field experiment to determine the movement and fate of two pesticides, picloram and dicamba, in a rangeland soil. Computer models were used to simulate pesticide transport under field conditions. Soil water content and pesticide concentrations were utilized to validate the mathematical models and to describe field-scale transport processes. The computer models were applied to simulate various physico-chemical processes in layered soils, including infiltration due to rainfall and irrigation, evaporation, root uptake, convection, dispersion, adsorption, and degradation. The computer models provided reasonable predictions of average water flow and solute transport under field conditions. However, it was very challenging to simulate the three-dimensional transport processes due to the soil heterogeneity and spatial variability.
Keywords: Numerical models, Pesticide transport, Soil heterogeneity

INTRODUCTION

Pesticides used extensively in agricultural and rangeland soils have the potential for leaching into the soil/substrata environment resulting in the possible contamination of groundwater. Many pesticides have been detected in water supplies throughout the United States; pesticide contamination of water supplies has become a national issue (Moody, 1990). Some pesticides, such as dicamba and picloram, have been listed by the EPA for restricted use due to their high potential for leaching in soils and for their persistence in groundwater (U.S. EPA, 1987). Very few studies have had direct applications in semi-arid and arid states, where a combination of persistent or mobile pesticides and their use on extensive areas of rangeland and irrigated crops may potentially lead to groundwater contamination.

Modeling is increasingly being used as a tool for evaluating the transport and fate of pesticides in soil-water systems. An extensive review of pesticide simulation models was performed by Wagenet and Rao (1990). These models were evaluated and categorized according to their purpose and complexity as research, screening, management and instructional models.

The focus of this study was to use computer models to simulate pesticide transport and fate in semi-arid and arid agricultural and rangeland soils. Data from a field experiment were used to validate various computer models. Predictions of solute transport based on computer models were compared with the experimental data.

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MATERIALS AND METHODS

A two-year field experiment was conducted during 1993 and 1994, at the Agriculture Experimental Farm, University of Wyoming. Two pesticides, picloram and dicamba, were applied at different application rates. Soil solutions were collected by applying soil water collectors. Neutron probe access tubes were installed to estimate water flux and moisture profiles. The hydrological conditions of the experimental site were checked by measuring soil water using a neutron probe before and after irrigations. Soil and water samples were analyzed to determine the concentrations of picloram and dicamba. Soil samples collected from the study site were used for standard batch adsorption studies. Adsorption isotherm parameters for the pesticides were calculated from the Freundlich equation. Soil hydraulic properties, such as soil water retention and hydraulic conductivity, were also determined from the soil samples. Saturated conductivity in the field was measured using the auger-hole method and ring infiltration test.

Two numerical models, LEACHP (Hutson and Wagenet, 1992) and SWMS_2D (Simunek et al., 1992), were used to simulate water flow and pesticide transport under field conditions. LEACHP is a one-dimensional finite difference model, while SWMS_2D is a two-dimensional finite element model. Both can be used to simulate water flow, root uptake, and solute transport in variably saturated soils. The chemical processes simulated by the models include convection, dispersion, diffusion, adsorption, and first- and/or zero-order decay. Physical and chemical parameters required by the models were obtained from the field and laboratory experiments, and batch studies (Krzyszowska et al., 1994). Meteorological data, such as rainfall and evaporation data, were obtained from a weather station nearby the experiment site.

RESULTS

Modeling Results of LEACHP: LEACHP was used to simulate the average pesticide movement in the soil profile. The modeled profiles were assumed one-dimensional two-layer soil columns. LEACHP simulated water flow processes of infiltration, redistribution, and drainage of soil water, incorporating information of irrigation, rainfall, and evapotranspiration. Solute transport processes simulated with LEACHP included convection, dispersion, molecular diffusion, decay, non-linear adsorption, and reaction. As shown in Fig. 1, the concentration distributions simulated by LEACHP had a relatively close agreement with the measured mean concentration profiles in both the general shapes and in the magnitude of concentration peaks. However, the modeling results became less comparable with the measured data as the depth increased.

Modeling Results of SWMS_2D: A two-dimensional model, SWMS_2D, was also used to simulate the average pesticide concentration and transport in the soil profiles. Again, the three-dimensional field was simplified as a one-dimensional problem. Figure 2 compared the simulated breakthrough curves with measured picloram concentrations vs. time at the depths of 15 and 60 cm. The simulated results were comparable with the measured data at the 15 and 30 cm depths, while the simulated results became less satisfactory as the depth increased.
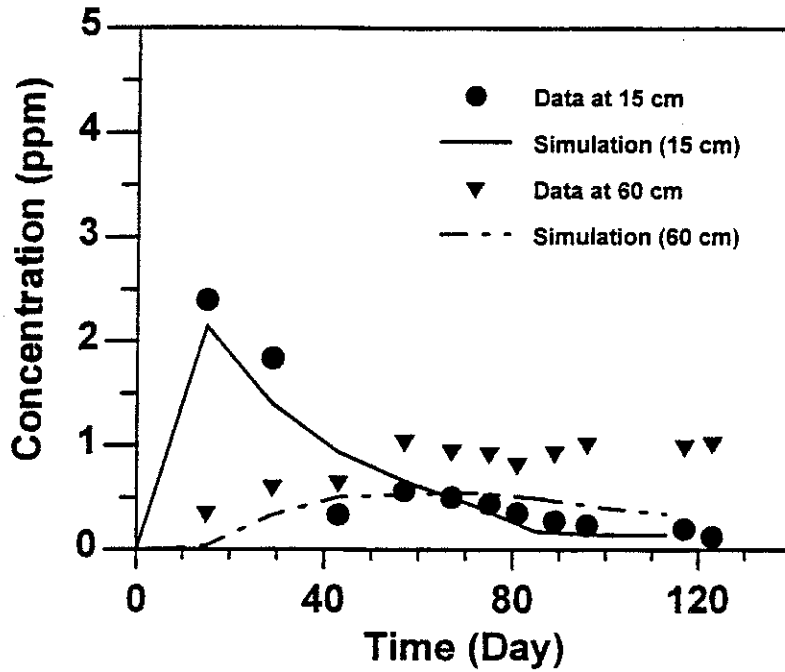
Figure 1.   Measured and LEACHP-simulated picloram concentration distributions at the depths of 15 and 60 cm.
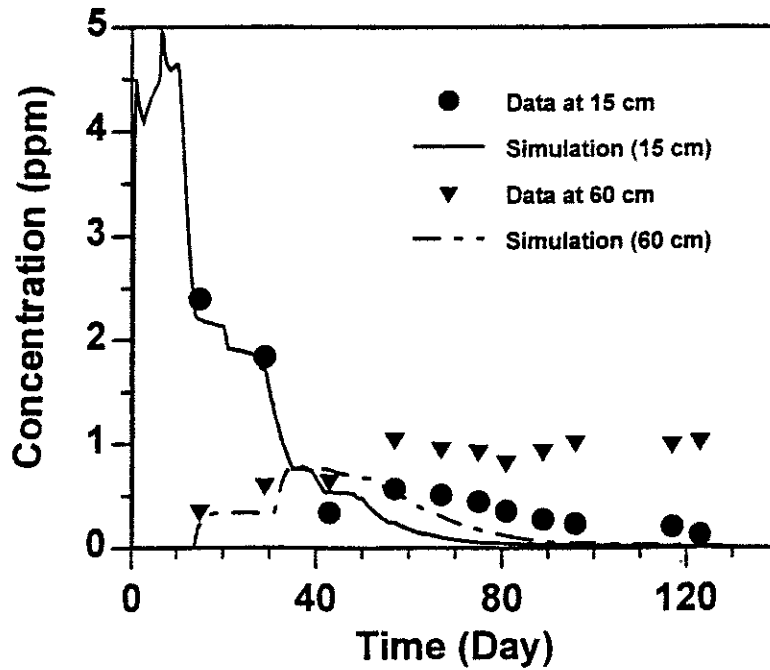
Figure 2.   Measured and SWMS_2D-simulated picloram concentration distributions at the depths of 15 and 60 cm.

Because of soil heterogeneity, it is expected that the dispersivity may be a scale-dependent variable with travel time and travel distance. We used two approaches to model the scale-dependent problem. First, we used different dispersion values at different depths. At a shallow soil depth, the travel time of solute should be longer than that at deeper soil; therefore, a larger dispersivity value was used. Second, we treated the dispersivity as a function of simulation time and a decreasing function with depth. Such numerical strategies resulted in a significant improvement in the simulation results.

DISCUSSION AND SUMMARY

LEACHP is a relatively simple model which can be used to simulate one-dimensional problems. The model is comprehensive enough to describe most of transport processes of water flow and solute movement in soils. Simulation results using LEACHP were in a general agreement with the field measured data. Nevertheless, the one-dimensional model may oversimplify multidimensional physical problems.

SWMS_2D can be used to simulate two-dimensional problems. Therefore, spatial variability of hydraulic properties are readily incorporated into the simulation processes. Simulated results can be significantly improved if spatial information on hydraulic properties are available. Unfortunately, detail hydraulic data are usually rare. Thus, SWMS_2D does not necessarily provide better results than LEACHP.

Modeling strategies were utilized to take into account the scale-dependent hydrodynamic dispersion. Preliminary modeling results illustrate a high degree of spatial variability in pesticide movement. Hydraulic conductivity was found to have the greatest effect on modeling pesticide transport.

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Fact Sheet — AGNPS

Agricultural Non-Point Source Pollution Model
Version 4.03bSCS95a

March 1995

Developer

U.S. Department of Agriculture, Agriculture Research Service, North Central Soil Research Laboratory, Morris, Minnesota.
Contact person: Lyle Steffen, sedimentation geologist, Midwest National Technical Center, 100 Centennial Mall North, Room 152, Lincoln, Nebraska 68508-3688. Questions about AGNPS and requests for copies of the model and model documentation should be directed to Lyle at the aforementioned address or at (402) 437-5318, FAX: (402) 437-5381.

Description

Agricultural Non-Point Source pollution model (AGNPS) is a single-event program. An NRCS version was developed to simulate sediment and nutrient transport from agricultural watersheds. The basic components of the model are hydrology, erosion, sediment, nutrient, and pesticide transport, and chemical oxygen demand. The model is based upon a square grid (cell) geometric representation of the watershed. Each cell homogeneously represents the landscape within the respective grid-cell boundary; e.g., only a single runoff curve number and set of Universal Soil Loss Equation (USLE) parameters are permitted for any individual cell. The physical or chemical constituents are routed from their origin within a cell and are either deposited within the stream channel system or at the watershed outlet. A recently added feature is source accounting, which allows pollutants to be tracked as they move through the watershed.

Uses

AGNPS can be used to evaluate nonpoint source pollution from agricultural watersheds. It can compare the effects of implementing various conservation alternatives within the watershed. Cropping systems, fertilizer application rates, point source loads, nutrient contributions from feedlots, and the effect of terraced fields can be modeled. The model partitions soluble nitrogen and phosphorus between surface runoff and infiltration. Chemical oxygen demand and soluble nutrient contributions from feedlots are transported with runoff. Soluble pollutants are transported with decay functions. Sediment transported nitrogen and phosphorus are also determined. The Universal Soil Loss Equation, adjusted for slope shape, predicts local sediment yield within the originating cell. An estimate of gully erosion occurring in a cell can be input by the user and will be added to the total amount of sediment yield in the cell. Sediment and runoff routing through impoundment terrace systems can also be simulated. Output parameters can be examined for a single cell or for the entire watershed. The user can identify cells of concern in the watershed, rank these areas based on their yield to the edge of their respective cells, estimate total yield to the outlet, and model the effect of conservation alternatives at the edge of the respective cell and at the outlet.

Features	● A spreadsheet style editor facilitates data input and revisions. Help screens are provided.
	● Any precipitation amount, 24-hour storm duration can be stimulated using NRCS rainfall types I, Ia, II, or III.
	● Peak discharges are determined using NRCS TR-55 methodology.
	● The program can analyze as many as 30,000 cells depending upon the availability of extended or expanded memory (or free-space on the hard drive) and the complexity of potential pollution within the watershed.
	● The ability to trap sediment is available.
	● Global geomorphic parameter input capability is permitted for hydraulic channel geometry and/or stream length.
	● A check data utility scans the input for ordinary data input errors.
	● A Grafix Display utility provides a graphical display of the model input and output allowing the user to view up to 14 different parameters simultaneously.
	● Data output can be saved in a new file with columnar ASCII format allowing for import into a GIS.
	● Additional graphical features include output value gradation mapping, channel mapping, tagging, directory display, enhanced on-line help, output to a file, mouse support, and other conveniences.
Limitations	● Continuous simulation is not an option.
	● Nutrient transformations necessary to account for organic waste applications are not modeled.
Future Developments	● Continuous simulation is being developed and will include snowmelt and frozen soil components. The new version will include the Revised Universal Soil Loss Equation to estimate erosion and sediment yield. Ground water and lake modules are complete and awaiting linkage with the continuous simulation model. A weather generator to compute individual storm characteristics for a chosen location will eventually be added.

- Current erosion components may be replaced with Water Erosion Prediction Project technology. The sediment transport and deposition subroutines are being improved.

- Improvements to the feed lot and chemical transport modules are being developed.

**System
Requirements**

AGNPS 4.03bSCS95a minimum system requirements are an IBM compatible computer, MS-DOS 3.0, 2Mb memory, 3 Mb of hard-disk storage, 80286 processor, and a graphics adaptor (CGA minimum). High resolution graphics, math co-processor, and laser printers are supported. The program uses the DOS Protected Mode Interface (DPMI) and the Phar Lap DOS extender, which increase RAM usage. Thus, changes in the config.sys and autoexec.bat files may be necessary for DOS versions prior to 6.0. With a 486-level computer, you may only need to set DPMI MEM at its proper level for your RAM and ensure that you have at least 400K memory available for AGNPS to run.

Boyle Engineering Stream Simulation Model

March 1995

Developer   Boyle Engineering Corporation, Lakewood, Colorado.

Description   BESTSM is a water allocation and accounting model developed to simulate
surface and ground water resources for complex river basins. The model was
designed to help water resource managers make comparative analyses for the
assessment of various historic and proposed river basin management policies.
The model is capable of simulating very complex physical systems operating
under the water rights provisions of legal systems such as the Prior
Appropriations Doctrine. BESTSM's user-friendly data input structures,
accompanied by thorough documentation and report-writer capabilities, make
application of the model simple and efficient.

Water Quality
Applications   BESTSM is capable of tracking conservative water quality components in a
stream basin. This feature of the model has been successfully applied to a river
basin in the San Diego, California, area to evaluate various management
alternatives to control TDS levels in reservoirs and streams.

Features
- Uses system of "linked nodes." Each node or measurement point
  represents a diversion, a stream gage, a reservoir, a point requiring a
  minimum in-stream flow, or any other location where information is
  known or needed. The nodes in the system are "linked" by river channels,
  canals, pipelines, or aqueducts.

- Performs all basin accounting and flow routing between the river nodes.
  The model can easily represent complex networks consisting of multiple
  stream branches with complex cross linkages and off-channel facilities.

- Simulation function is primarily controlled by the water rights input to the
  model. Using water allocation priorities, the model will simulate direct
  flow rights, reservoir storage rights, in-stream flow rights, and operational
  rights.

- BESTSM can simulate complex reservoir operations, as well as the
  allocation of streamflow. Any number of reservoirs can be simulated
  within the basin node network. Reservoirs can be located on a main
  channel or off-channel. And for each reservoir, multiple pools or accounts
  with multiple owners in each type of account can be operated. Examples
  of different pools or accounts include flood pool, recreation pool, storage
  for irrigation, and storage for municipal water supply.

- BESTSM's efficient report writer feature allows the user to select the desired information, locations, and period, then present the information in the form desired—all as a post-processing function. This is accomplished by having all of the model output stored in a binary file. This feature allows for the efficient management of information for analysis, and eliminates the need to re-run the model when the required option is not known in advance.

- Graphical User Interface allows easy visualization of model input/output data.

Limitations
- Extensive data collection required to use model on a daily basis.

- Relatively simple ground water accounting using a Glover-type analysis.

Support
A comprehensive user's manual and technical support are available from Boyle Engineering.

Future Developments
- Improved detail for water quality modeling.

- Direct linkage to a ground water model such as MODFLOW.

Resource Requirements
Designed to run on an IBM-compatible 486 PC with approximately 4MB of RAM and 20 MB of free harddisk space.

An Object-Oriented, General Purpose Decision Support System
for River Basin Management

March 1995

Developer   United States Department of the Interior, Bureau of Reclamation, Denver, CO

Description   The Bureau of Reclamation and other water resources management organizations must often consider the impacts of their decisions from a basin-wide perspective, and planning and operations models are used to assist with this task. Many such models are inextricably tied to a particular river basin (i.e. hard coded) to adequately address the specific institutional and management aspects of the system. It can be difficult to make additions or modifications to these models because this often involves substantial computer code changes which require a detailed understanding of both the model and the physical and institutional aspects of the river basin system. Reclamation recognized the need for a general purpose modelling approach which would resolve these issues, and the result is the object-oriented modelling framework called CALIDAD.

Physical and Institutional Aspects CALIDAD has two fundamental components - the physical simulation and the management objectives (called rules). The physical simulation computes the movement, or mass balance, of water and salinity in the river basin system. Rules are established to express aspects of river management which are not physically based but rather the result of decisions on how to operate the system to achieve certain objectives. Examples include required minimum streamflows, reservoir storage targets for flood control or recreation, and hydropower generation goals. Conflicting rules are handled by assigning weighting factors so that the most important rules will be met before the less important ones. CALIDAD ties rules to the physical features of the river basin through the use of a search technique which examines the results of the physical simulation to see if the specified rules have been met. If not, decision variables in the physical system (reservoir releases and diversions) are changed and the simulation is run again. This process continues until a physical state has been found which better satisfies the rules. Ultimately, CALIDAD's objective is to determine the set of reservoir release and diversion schedules which results in a physical state of the system that meets the management rules.

Object-oriented programming techniques have been employed in the development of CALIDAD, enabling each river basin feature (e.g. reservoir, hydropower plant, irrigation site) to be treated in a modular fashion. This makes additions and modifications to the river basin system easy for the end user, and changes to the code easier for the programmer. Each object type has unique algorithms which govern its behavior. The user builds the river

basin system to be modelled from the available objects, linking them together to create a schematic network representation of the basin. Each object in the schematic network is then explicitly defined with data entered by the user, thus giving them the actual characteristics of the features being modelled. If none of the available object types can adequately model a certain feature of a river basin, a new object can be written and incorporated into the modelling framework.

Decision Support for Water Managers A principal goal in developing the CALIDAD framework was to create a decision support tool that water resources planners could use to model and make changes to the physical and institutional river basin system without requiring computer programming proficiency. Site-specific, procedural models follow operating rules as defined in the model code, usually with "if-then-else" logic and direct computation of model output. To change a rule, the code must be changed. Some models are very complex, and changing or adding functionality can require major alterations. In enabling the creation of the river basin network and the entry of rules through a graphical interface rather than through coding changes, CALIDAD alleviates this need.

Storage and Water Rights Reclamation has investigated the applicability of this object-oriented, rule-based model to issues of storage ownership and water rights priorities. It was determined that development of an object which performs the site specific accounting and allocation procedures would be most efficient. CALIDAD does not have a reservoir object which can dynamically handle multiple storage ownerships. A two-ownership reservoir object developed for a particular application required that each ownership be supplied from a unique source and have a unique release point. This functionality could not be generalized to accommodate the more common situation where total runoff to a reservoir is allocated to multiple accounts in some order of priority with releases to all owners made from the same outletworks. The development of a site-specific object which performs the storage accounting still allows rules to be written for variables representing each account.

Handling water rights for demands requires careful rule crafting. Because of the nature of the simulation algorithm, CALIDAD will try to divert water in the amount of target deliveries in an upstream to downstream order. Relative priorities could be assigned to demands by making each diversion a decision variable and writing weighted rules for each demand object that has a priority. The rule would read "VIP_Demand inflow >= filename" where the file contained the demands. The weight of the rule would indicate the relative priority of the demand. In the event that a shortage occurs and not all of the target flows are met, a rule would be broken. In this case, the search algorithm will try to change the decision variables to meet the rules. Obviously not all of the rules will be met, but the search algorithm will follow the weighting scheme to satisfy the most important rules (the higher priorities) before the lower weighted rules.

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Features

Graphical User Interface - includes the following functionality:

- a network editor/builder which allows the user to create and change the river basin network, edit object data, and customize the basin display
- a rule editor enables the entry of management objectives and institutional constraints in a clear straightforward manner
- output from different scenarios can be combined for custom reports and graphs
- output can be displayed graphically, written to tabular reports, or saved in spreadsheet readable format
- the search results can be tracked during the simulation

Rule Types - the search technique can consider a variety of rule types including:

- system wide rules (e.g. total storage in the basin must be greater than X)
- conditional rules (e.g. IF the level of reservoir A is less than X, THEN demand 1 should receive Y acre-feet)
- rules that span time

Time Step Options - CALIDAD can operate on monthly and daily time steps. Fractions of a month (halves, thirds, quarters) may also be used as a time step.

Limitations

The search space used by the search technique in CALIDAD increases exponentially with the number of decision variables in the system. Therefore, the time required for execution increases significantly with an increase in the number of reservoir releases and varying diversions. Functionality problems have also been noticed with conditional rules. Research is currently ongoing to investigate the resolution of these issues.

Resource Requirements

Hardware: Reclamation has versions of CALIDAD running on Sun SPARCstations, Data General Aviion, and DECstation platforms. The software can be ported to other platforms running X windows and Motif. A minimum of 24 MB of memory is required. CALIDAD also requires 15 MB of disk space for the executable, data, and results files, and an additional 30 MB of disk space are required to accommodate source code files, object files, and local libraries for compilation.

Software: CALIDAD has been compiled and tested under 1) SunOS 4.1.3, 2) DGUX 5.4, and 3) DEC ULTRIX 4.2. It should run under any System V or BDS 4.3 compatible version of UNIX. CALIDAD requires an X Windows environment.

Compilation Requirements:
- X11 Release 4, OSF/Motif version 1.1.x (or X11 Release 5, OSF/Motif version 1.2)
- Stepstone Objective-C compiler 4.3
- C compiler (cc on the SUN and DEC, Green Hills C version 1.8.6 on the DG)

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The Century Ecosystem Simulation Model
Version 4.0

May 1995

Developer   Colorado State University, Fort Collins Colorado and U.S. Department of Agriculture, Agricultural Research Service.

Description   Century is a linked production-decomposition-hydrologic ecosystem simulation model. The biogeochemical portions of the model have closed nutrient cycles with complete accounting for inputs, outputs, and internal transformations of C and N (as well as P and S if desired). Primary production and decomposition are controlled by environmental parameters such as temperature and moisture, and by biological effects such as leaf area and litter quality. Century has been implemented and validated for grassland, cropland, forest, and tundra ecosystems.

The hydrologic submodel is a monthly water balance model with a multilayer tipping bucket soil model. PET is calculated from a simplified Penman representation. Ecosystem effects on canopy, litter, and bare soil interception and transpiration are implemented. Snowpack accumulation, sublimation, and melting are simulated.

Watershed biogeochemistry routines provide for simulation of monthly streamflow and nutrient exports. Nutrient and organic matter leaching are functions of rate of water flow, soil texture, and sizes of labile organic and inorganic nutrient pools. The organic matter and nutrient pools are simulated dynamically by the ecosystem biogeochemistry modules.

Century is a point model with no explicit spatial scale. It can be used to represent a plot, stand, or watershed. It has been linked to spatially explicit databases in the past using various techniques; however, no standard method for using Century in this context has yet been developed.

Water Quality
Applications   Century can simulate the effects of management and natural disturbance or climate change on streamflow and nutrient exports from terrestrial ecosystems. Management practices that can be simulated include tillage, fertilization with organic or inorganic fertilizers, irrigation, fire, harvest of biomass from croplands or forests, and grazing. Natural disturbances can be simulated including fires, windstorms, and pathogen outbreaks. Changes in species composition are not simulated explicitly and must be prescribed by the user.

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Features	• Graphical interface (Time Zero (c)) for viewing output.

Features

- Graphical interface (Time Zero (c)) for viewing output.

- Multiple parameter file structure with utilities for manipulating parameterizations.

- Run-time events (such as planting, harvesting, disturbances, changes in ecosystem type) are defined in schedule files, allowing for easier manipulation and repetition of scenarios than in earlier model versions. Complex land use histories and scenarios can be constructed.

- Can be used to simulate a wide range of terrestrial ecosystems, including croplands, managed and unmanaged grasslands and forests, tundra, shrubland, and savannah. Ecosystem types can be changed within a single simulation, such as a forest to pasture conversion.

- Complete mass-balance accounting of nutrient cycles.

- Enhanced detail and flexibility in crop simulations than in earlier versions.

- Tightly constrained semi-empirical equations for primary production and decomposition generally keep model behavior within realistic bounds even in cases of extreme environmental change.

Limitations

- The simplified PET algorithm sometimes functions poorly in high latitudes; this can be corrected on a site-specific basis.

- There is no explicit representation of species composition; this is represented only by aggregated biomass allocation and tissue chemistry parameters and must be prescribed by the user.

- Parameterization often requires more extensive data than are likely to be available at all sites; in these cases parameters are estimated from data for similar sites and/or ecosystems.

- Most mathematical relationships are approximately linear, which tends to dampen responses to environmental change as compared to some other ecosystem models.

Support

Diskettes and documentation may be purchased through the Natural Resource Ecology Laboratory of Colorado State University, Fort Collins, CO 80523. Contact Bill Parton or Becky Techau.

Future
Developments
- Several enhancements to the forest model are underway, including better representation of forest floor dynamics, soil temperature regimes, and controls on primary production.

- The PET algorithm is being replaced with a more detailed scheme that will behave more realistically over all latitudes.

- Estimations of solar radiation and net radiation balance are being developed to improve prediction of PET and primary production.

Resource
Requirements

Century is usually installed on a MS-DOS compatible system, requiring 512K of RAM. At least 3 megabytes of disk storage are recommended. A 386 or faster processor is recommended but not required. Century is also implemented for UNIX systems, although the documentation and installation support are less extensive for this platform.

Fact Sheet -- CMLS

Chemical Movement in Layered Soils

1994 Release

Developer   D. L. Nofziger, Department of Agronomy, Oklahoma State Agricultural Experiment Station, Oklahoma State University, Stillwater, OK 74074 and A. G. Hornsby, Dept. of Soil & Water Science, University of Florida, Gainesville, FL 52611.

Description   CMLS94 is an update to the original CMLS model of Nofziger and Hornsby written to serve as a management tool and a decision aid for the application of organic chemicals. CMLS can be used to estimate the movement of chemicals in soils in response to downward movement of water. The model also estimates the degradation of the chemical and the amount remaining in the soil profile. CMLS was specifically formulated for ease of use. All of the parameters required by the model are relatively easily obtained. CMLS94 includes routines to estimate daily infiltration and evapotranspiration values from historical weather records.

A new feature of CMLS94 is the ability to assess uncertainty in leaching estimates due to unknown future weather at a site, spatial variability of soils, and uncertainty in chemical properties. This additional capability provides the decision-maker with insight into the range of leaching expected or the probability of leaching more than a specified amount of chemical past some critical depth. Sixteen types of graphs and various forms of tables are provided to view results. Extensive data entry and editing capabilities are also provided. The model is written for MS-DOS computers and is available on the Internet.

Water Quality Applications

●   Examine the position and amount of pesticide in the vadose zone as a function of time for specific soils, application dates, application depths, weather and irrigation regimes, and other site specific conditions.

●   Obtain probability distributions for the amount of chemical leaching beyond a critical depth, the depth of chemical at a specific time, and the time required for a chemical to reach a specified depth.

●   Compare the leaching potential of different pesticides for a specific soil-management system.

●   Rank pesticide leaching for different pest management systems.

●   Estimate the current depth of an applied pesticide to determine if an additional application is needed.

● Educate people about principles of pesticide transport in soils and the impact of specific soil properties, chemical properties, weather, and management practices.

Features

CMLS94 is an interactive model in which the user defines the soil - chemical - management system using pull-down menus and interactive screens. Context-sensitive help messages are available to aid the user. A batch version of the software (CMLS94b) is available for large studies and GIS work.

● The effect of unknown future weather at a site upon leaching estimates can be determined using a built-in Monte Carlo simulator and the WGEN weather generator of Richardson and Wright.

● Soil and chemical properties required in the model are easily obtained.

● Sixteen types of graphs and numerous types of tables are provided so the user can easily examine the results of simulations. These include histograms and probability distributions for examining uncertainties due to weather and soil and chemical properties.

● A soil profile can be made up of up to 20 layers with different soil properties. Sorption coefficients and degradation rates of chemicals can change from layer to layer.

● Supplemental irrigation can be read from a file, applied on a periodic basis, or scheduled by depletion of water in the root zone.

● The impact of soil management upon leaching can be estimated by simulating transport using different curve numbers appropriate for the management system.

● Extensive database management capabilities are built into the software to enable the user to define and reuse soil and chemical properties for their sites.

● Daily infiltration amounts can be provided by the user or estimated from daily weather records. Daily evapotranspiration can be read from user-provided input files or estimated from daily weather data using one of several built-in estimators.

● English or metric units can be used.

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Limitations   The CMLS94 user's manual describes in detail all of the processes incorporated into the model and the assumptions made in it. In some cases the assumptions may be limitations, but in many cases they represent useful simplifications based on comparisons with research models.

- CMLS94 does not attempt to estimate pesticide concentration profiles, only the location of the center of mass and total amount of pesticide.

- CMLS94 does not track the production, transport and fate of chemicals produced during degradation of the applied pesticide.

- Upward movement of pesticide in the profile is ignored. This may lead to overestimating leaching in very dry regions.

- The degradation rate is not adjusted for temporal changes in temperature or soil water content.

- CMLS94 does not attempt to estimate preferential pesticide movement through large soil pores and cracks.

Support   CMLS94 software, manuals, and sample databases are available free of charge via Internet. Contact dln@soilwater.agr.okstate.edu for details. The software with printed manual is also available for $50 from the Department of Agronomy, Oklahoma State University, Stillwater, OK 74078. User support is available by e-mail.

Future Developments

- Improved pesticide degradation algorithm incorporating soil water content and temperature.

- Additional educational material.

Resource Requirements   CMLS94 requires an MS-DOS compatible computer with at least 640 K bytes of random access memory, a graphics monitor (VGA or better preferred), and 3-10 MB of disk space. A 386, 486 or pentium processor is desirable for Monte Carlo simulations, but slower processors can be used. CMLS94b, the batch version of the software, can be used on any platform Supporting ANSI C, such as MS-DOS PCs, and Sun workstations.

Fact Sheet -- EPIC

Environmental Policy Integrated Climate

March 1995

Developer

U.S. Department of Agriculture, Agricultural Research Service, and Texas Agricultural Experiment Station, Temple, Texas.
Contact Person: Bill Boyd, environmental engineer, Midwest National Technical Center, 100 Centennial Mall North, Room 152, Lincoln, Nebraska 68508-3688. Questions about EPIC and requests for copies of the model and model documentation should be directed to Bill at the aforementioned address or at (402) 437-5318, FAX: (402) 437-5381.

Description

Environmental Policy Integrated Climate (EPIC) is a continuous simulation computer model that determines the effect of farm-level management alternatives on water quality constituents leaving the edge of the field and the bottom of the root zone. The area considered is a field-sized area where weather, soils, and management systems are assumed to be homogeneous. The major components in EPIC are hydrology, erosion, sedimentation, nutrient cycling, pesticide fate, plant growth, soil temperature, tillage, economics, and plant environment control. EPIC estimates the long-term relationship between soil erosion and soil productivity and the fate of pesticides and nutrients.

Uses

EPIC can be used to compare management systems and their effects on nitrate, phosphorus, pesticides, and sediment leaving the edge of the field and the bottom of the root zone. The management components that can be changed are crop rotations, tillage operations, irrigation scheduling, and nutrient and pesticide application rates and timing.

The model partitions nitrate losses among surface runoff, subsurface lateral flow, leaching below the root zone, crop uptake, denitrification, and transport by soil evaporation. Other nitrogen processes modeled include mineralization and organic N transport with sediment. Soluble phosphorus in surface runoff and phosphorus transported with sediment are also determined. Daily accounting of pesticide fate is modeled to include pesticides transported with surface runoff and sediment, leaving the bottom of the root zone, and lost through degradation. Estimates of soil loss by the Universal Soil Loss Equation (USLE) and sediment yield by the Hydro-geomorphic Universal Soil Loss Equation are also calculated.

Features

● Peak discharges can be determined using the NRCS TR-55 unit peak discharge equation methodology.

● The UTIL data assembly system provides for interactive data entry and editing. UTIL also has a routine that checks data items to ensure they fall within specified ranges. Help screens are provided.

- internal data bases housed within the model include soils, tillage operations, plant growth, and pesticides.

- Organic waste applications can be simulated.

- The crop yield component relates directly to water use and nutrient uptake.

- Management strategies in forested areas can be modeled.

- The capability to build standard data sets that are county specific (identifying the common soils, crops, weather components, etc.) exists. These data sets could be made farm specific by changing 7 to 10 data items.

- Farm level management alternatives can be evaluated on the basis of economics since both cost and yield effects are considered.

- Data input and output can be in English units or metric units.

Limitations

- The internal weather generator is related to the same parent generator as the Water Erosion Prediction Project (WEPP) weather generator. The WEPP weather generator, which is still under development, has a problem reproducing local weather statistics.

- The user manual and user documentation do not completely document the UTIL program, software loading, model execution, and the pesticide processes. The pesticide component is documented in journal articles.

Future Developments

- Revised Universal Soil Loss Equation (RUSLE) will be used to estimate erosion-sediment yield.

- A salinity component will be added.

- The SOILS-5 data base will be added to the model.

- A windows interface with improved graphics is being developed.

- improved waste management options are being developed.

- A GIS interface that uses an UNIX version of EPIC is being developed.

Resource Requirements

EPIC requires a MS-DOS compatible system that has at least 640K of memory and 4 megabytes of disk storage space. A math coprocessor is not required, but is recommended.

Field Crop Decision Aid

May 1995

Developer   Agronomy Department, Kansas State University, Manhattan, Kansas.

Description   Computerized decision aid for evaluating either 1) planting time decisions regarding grain sorghum or 2) replanting decisions regarding grain sorghum. The SORKAM sorghum growth model has been utilized to simulate expected grain yields for a 33 year time period for a combination of planting dates, plant populations, and hybrid maturities for a number of locations in Kansas. The user can obtain expected yield distributions for any combination of these factors within the range of simulations and then is asked to provide economic information. This allows comparisons of both yield and gross returns to allow the producer to evaluate both potential production and potential risks.

**Water
Applications**   Availability Yields are available for each set of management decisions for a number of levels of available soil moisture. These are specific to soil types at each location and represent historical conditions as well as user specified levels of available soil moisture. Thus, if the producer knows what the soil moisture conditions are at the time of making the decision or is willing to estimate them, this additional information can be used is making management decisions.

This may be particularly useful in unusual years in which soil moisture is either exceptionally good or exceptionally poor, or, for example, in looking at double cropping systems where available moisture and planting date could be used to maximize returns or minimize risks.

Features   ● The systems allows for interactive data entry and provides default economic values based on extension agricultural economics worksheets.

● Individual soil types (textures) are available for the locations where a range of soils are likely to be found.

● Pair wise management options can be compared for expected yield ranges and expected gross returns.

● Individual producers economic data can be utilized to more accurately represent a producers situation.

- Alternatives for replanting decisions can be compared for yields and economic returns.

- Printed copies of any of the results can be obtained.

Limitations
- The crop growth model used to obtain the yield distributions assumes no nutrient, weed, insect, or disease problems.
- A limited number of locations are available for evaluation.

- Specific hybrid data are not available.

Support

Distribution diskettes, documentation, and technical support are available through the Extension Office, Department of Agronomy, Throckmorton Hall, Kansas State University, Manhattan, KS 66506. Telephone (913) 532-5776.

Future Developments

The number of locations available in the decision aid will be greatly increased.

Additional crops will be added so that crop comparisons can be made as well as within crop management comparisons.

Resource Requirements

FCDA requires an MS-DOS compatible system with at least 640K of memory and a color monitor.

Fact Sheet -- GLEAMS

**Groundwater Loading Effects of Agricultural Management Systems
NRCS-Version 2.1 0.1**

March 1995

Developer

U.S. Department of Agriculture, Agricultural Research Service (USDA-ARS), Southeast Watershed Research Laboratory, Tifton, Georgia. Presently maintained by USDA-ARS, Grassland, Soil and Water Research Laboratory, Temple, Texas.
Contact Person: David C. Moffitt, environmental engineer, South National Technical Center, P. 0. Box 6567, Fort Worth, TX 76115. Questions about GLEAMS and requests for copies of the model and model documentation should be directed to David at the above address or at (817)334-5242, Ext. 3304; FAX: (817) 334-5584.

Description

GLEAMS is a continuous simulation computer model. It can be used to determine the effect of farm level (field scale) management alternatives on water quality constituents (sediment, pesticides, and nutrients) leaving the bottom of the root zone or edge of the field. GLEAMS assumes the field has homogeneous land use, management, soils, and climate. The model consists of four components: (1) hydrology, (2) erosion/sediment yield, (3) nutrient transformation and transport, and (4) pesticide transport. It estimates surface runoff and sediment yield from the field. GLEAMS is a tool for comparative analysis of complex pesticide and nutrient chemistry, soil properties, and climate.

Uses

The uses of the GLEAMS model are varied, ranging from the simple to the complex. Three uses are listed below:

● Provide estimate of historical pollutant loadings from known or assumed field conditions. Can be used to estimate impacts of present or past agricultural activities on pollutant contributions from agricultural lands.

● Provide estimates of pollutant loadings with application of conservation alternatives (both physical and management. Used to rank the effectiveness of conservation practices or systems of practices in reducing the impact of sediment, nutrient, and pesticide contaminants from agricultural land.

● Track the fate and movement of agricultural chemicals. Can be used to evaluate the type of chemical, application rate, and timing of application as it impacts pollutant loading in surface runoff or leached water. Used in the registration process of agricultural chemicals.

Features	• Data entry is accomplished interactively. Help screens and data tables are provided for typical conditions. National Climate data base included.
	• Separate hydrology, erosion/sediment, nutrient, and pesticide input and output files are maintained and allow the user to concentrate on one component at a time.
	• Up to 110 single parameters or groups of parameters can be selectively chosen and tracked: the data can interact with commercial graphics and statistical packages.
	• Differing amounts of standard output can be user specified.
	• Automatic or manual irrigation, fertigation, and chemigation options are available.
	• Animal manures can be applied as nutrient sources and estimates made on decomposition and disposition.
	• The actual topographic features of a field can be entered in the erosion/sediment component to better track sediment movement.
	• NRCS pesticide data base provided in the pesticide component.
	• Management alternatives in forested areas can be simulated.
	• input and output for hydrology and erosion components can be in either English or metric units; the pesticide component uses metric units.
	• Model is designed to run in either interactive or batch mode.
Limitations	• The user manual does not completely document all the components of the model, but the technology is documented in published literature.
	• Peak discharge relationships are based on a single regression equation, and do not reflect different rainfall patterns (distributions) or initial abstractions.
Future Developments	• Inclusion of weather generator.
	• Accounting for non-uniform agrochemical application (such as banding).

Resource Requirements

GLEAMS is designed to run on the IBM PC-AT or IBM compatible (DOS) systems. The minimum RAM requirement is 512K. The program will run on systems with or without a floating point co-processor, but the use of the co-processor will increase the speed of execution by ten times. Execution of the GLEAMS software can create large output files. Multiple runs in batch mode will require many megabytes of hard disk storage.

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Fact Sheet— *GLYCIM*

The Soybean Crop Simulator

May 1995

Developer   U.S. Department of Agriculture, Agricultural Research Service.

Description   The soybean simulation model GLYCIM is a dynamic simulator of soybean crop growth and yield that is mechanistic at the level of the physical and physiological processes involved in the transfer of materials in the soil, plant, and atmosphere. The model is organized into modules in accordance with a generic modular structure and runs in hourly time steps. Mechanisms involved in the physical and physiological processes in the plant and it's environment are mathematically described in the model. These processes include light interception, carbon and nitrogen fixation, organ initiation, growth and abscission, and flows of water, nutrients, heat, and oxygen in the soil.

The environmental inputs necessary to run GLYCIM are daily total solar radiation, maximum and minimum temperature, rainfall, irrigation amount, method and date, and wind speed. GLYCIM also needs information on the physical and hydraulic properties of the soil, cultivar characteristics, latitude of the field, date of emergence, row spacing, plant population within a row, row orientation, and CO_2 concentration of the atmosphere.

Water Management Applications   The model simulates sprinkler, furrow, and flood irrigation and rainfall effects on soybean growth and development. The model provides simulated leaf water potential and soil water status of the soil profile layer by layer and column by column which can be used as indicators for irrigation management. Since the 1990 growing season GLYCIM has been used by farmers for crop management and input optimization. In addition to water management, the model is being used for selecting cultivar, row spacing, plant density and planting date prior to planting, and for post-planting decisions such as insect control, harvest timing and yield forecasting. The model helps farmers to optimize inputs, maximize profits, and minimize environmental pollution.

Model Structure   The generic modular structure of GLYCIM is as follows: The module SOILIN uses data on the characteristics and initial conditions of soil in the various horizons of the profile to calculate characteristics and initial conditions in each cell of the soil profile. The module WEATHER uses meteorological data and celestial geometry to calculate day length, effective photoperiod, mean day and night temperatures, and hourly values of some environmental variables, including air temperature and vapor pressure deficit.

The module LATENT calculates hourly values of the total photosynthetically active radiation that would be intercepted by the crop canopy. Volumetric water content, water potential, hydraulic conductivity, oxygen concentration, temperature, and concentrations of ammonium and nitrate in each cell in the soil profile are calculated in SOILIN. The vegetative and reproductive developmental rates are calculated in module PHEN. PNET uses single-leaf photosynthetic characteristics to calculate crop canopy characteristics and canopy gross photosynthetic rate. Photorespiration rate and maintenance respiration rate are calculated and subtracted to get net photosynthetic rate, which is corrected for stomatal closure caused by water stress. The net carbon fixation rate and the rate of carbon translocation out of the leaves are also calculated in PNET. The module POTGRO calculates potential rates of growth for all organs on the plant at a given air temperature assuming that carbon, water, and nutrients are plentiful. PARTIT calculates an initial partitioning of carbon to various organs based on priorities that change with stages of growth. WATERS maintains a functional balance between root and shoot by growing roots as necessary to meet transpiration demand. It calculates potential root water uptake for a number of key shoot water potentials and compares these with the potential transpiration rate to estimate shoot water potential. Depending on shoot turgidity, the shoot or root, or both, may grow. Stomatal conductance is a function of shoot turgidity.

Features
- Simulates soybean growth and development at physiological process level.
- Uses interface WINGLY which allows to set up multiple runs and plotting of input/output data.

Limitations
- The model assumes pest, disease and weed free environment.
- Nutrients other than nitrogen are not considered.

Support

Distribution of the program, documentation and technical support are available from the USDA-ARS Systems Research Laboratory, Beltsville, MD.

Future Developments
- A weed model will be incorporated.
- An improved Two-dimensional soil process model 2DSOIL will be added.
- A seed germination module will be incorporated.

Resource Requirements

GLYCIM/WINGLY requires a MS-DOS compatible system with WINDOWS™ that has at least 4MB RAM of memory with a math co-processor and 4MB disk storage space.

Great Plains Framework for Agricultural Resource Management

May 1995

Developer   U.S. Department of Agriculture-Agricultural Research Service, Northern
                     Plains Area, Great Plains System Research Unit and Water Management
                     Research Unit, Fort Collins, CO; USDA-ARS-NPA, Northern Grain Insects
                     Research Lab, Brookings, South Dakota; and Colorado State University, Fort
                     Collins, CO.

Description   The Great Plains Framework for Agricultural Resource Management
                     (GPFARM) decision support system (DSS) is being developed to provide an
                     operational tool for a whole farm/ranch decision support across the Great
                     Plains including site-specific management, socio-economic analysis, and
                     environmental impacts; site database generation; and risk analysis from which
                     alternative agricultural strategies can be developed and tested. The objective
                     of GPFARM is to analyze 1-10 year farm/ranch level management plans,
                     based on the predicted productivity of selected management options and
                     associated environmental and economic risks.

Water Quality
Applications   GPFARM includes soil-crop-animal simulation modules, all appropriate
                     databases, an economic analysis package, and an environmental risk
                     assessment module that evaluates various preselected management options.

                     Land Management Units (LMU's) are defined in each field and include
                     multiple soil series and associated land use (e.g., cropland, grazinglands,
                     wetlands, etc.). Intra-farm transfers of resources will be allowed between
                     LMU's. Based on the selected management options and data from the various
                     databases, the simulation modules predict crop and animal production, water
                     use, nutrient uptake, erosion (water and wind), and quantities of nitrate and
                     pesticides leached. These quantities are used for the economic and
                     environmental risk analyses.

                     The environmental module uses leachate results from the simulation of each
                     LMU to calculate environmental indices (e.g. NLEAP leaching indices) and a
                     composite environmental index reflecting off-site vulnerability and the
                     quantity, toxicity, mobility, persistence to breakdown, etc. of each chemical
                     leached as well as amount of erosion. These indices represent the potential
                     off-farm impact on the environment. Consideration will be given to a
                     composite index calculated from the simulation results for each LMU to
                     reflect changes in the long-term sustainability of the farm. Examples of factors
                     which affect long-term sustainability include lost productivity due to erosion,
                     changes in organic matter content, salinity, aquifer degradation, etc.

Features
- GPFARM is being developed with Microsoft Visual C++ to run on PC compatible 486/Pentium machines using the Microsoft Windows Graphical User Interface (GUI) environment.

- Production economics and environmental impacts are accounted for in order to aid the producer in making advanced planning decisions before management strategies are implemented.

- Multicriteria decision theory is used to determine the "best" management strategies for the set of scenarios being investigated.

- A multimedia on-line help system assists users with interactive data entry and program information.

- Microsoft Access relational databases for soils, land use, climate, management options and model parameters are housed internally within GPFARM.

- Soil-crop-animal simulation modules are used to describe biological, chemical, and physical processes including nutrient cycling, uptake, and leaching; surface and subsurface pesticide transport; evapotranspiration; runoff; deep percolation; infiltration; plant growth; and soil erosion by wind and water.

- Farm enterprise budgeting procedures are used to determine farm profitability in terms of net farm income.

- Total risk analysis combines projected crop yield and animal production data with concurrent environmental impact and economic data.

- Results are presented to the user in the form of text, tables, 2-D, and 3-D graphics.

Limitations
- Input is in English units only.

- GPFARM is currently under development.

- The prototype version of GPFARM will be applicable to Colorado only.

- GPFARM is for strategic planning on a field, not watershed or ecosystem, scale.

Support   Technology transfer and maintenance of GPFARM should be a joint interagency effort between ARS, NRCS, and Extension. ARS will maintain technical support for program bugs and extensions that may be become necessary and will also provide training for NRCS and Extension instructors. NRCS and Extension could subsequently provide training on the use and application of GPFARM within their organizations, and training of producer and other groups.

Future Developments   The development of GPFARM is progressing in three distinct phases:

- **Phase 1** - The objective of Phase 1 is to build a prototype of GPFARM for strategic planning and analyzing 1-10 year farm level management plans based on the predicted productivity of selected management options and associated environmental and economic risks. The region of emphasis will include only selected operations of Eastern Colorado.

- **Phase 2** - The objective of Phase 2 is to enhance the prototype of GPFARM to include improved and expanded scientific information, to extend the geographical area of consideration from specific areas of Colorado to the entire Great Plains, to increase the number of crop and animal species represented by the system, and to offer additional management options and government programs.

- **Phase 3** - The objective of Phase 3 is to develop a DSS useful for short-term management of crop and animal production systems by providing management recommendations with sufficient detail to manage individual subareas and soils within fields. A geographic information system (GIS) will be used to manage the detailed information for describing field-level variability within an individual farm. Attribute maps of field aspect, topography, soil and aquifer properties, water stored in the root zone, water sources (including precipitation, aquifers, streams, and impoundments), fertility, land-use, weather, soil erosion, nitrate leaching, pesticide runoff and leaching, economic returns, etc.

System Requirements   GPFARM requires a MS-DOS compatible system running MS Windows 3.11.

**Hydrologic Unit/ Water Quality Tool
NRCS Version 1.4**

March 1995

Developer	U.S. Department of Agriculture, Natural Resources Conservation Service (USDA-NRCS), Information Resources Management Division (IRMD), Fort Collins Colorado.

Developer

U.S. Department of Agriculture, Natural Resources Conservation Service (USDA-NRCS), Information Resources Management Division (IRMD), Fort Collins Colorado.
Contact Person: Phil Smith, HU/WQ Tool project manager, USDA-NRCS. IRMD, 2625 Redwing Road, Suite I I 0, Fort Collins Colorado, 80526-2878. Ph# (303*1)-282-2481, FAX# (303* I)282-141 1, *1 After 4/l/95, the area code will be 970

Description

HU/WQ Tool is a decision support tool for ecosystem planners that integrates GRASS GIS, INFORMIX DBMS and ARS pollutant loading models. Version 1.4 of the tool supports AGNPS version 4.03. Planned future versions will integrate SWRRBWQ, EPIC and GLEAMS. The tool has a robust Graphical User Interface (GUI) that provides a framework for entering data, running pollutant loading models and analyzing simulation results, thus eliminating the need to learn multiple, complex model input and output file formats. The tool provides a consistent means for collecting soil, field, watershed and other base data in the form of GRASS maps keyed to INFORMIX data tables. From the base data, the tool derives the necessary model-specific input files, runs the model, and partitions model-specific output files into GRASS maps and INFORMIX tables for analysis as spreadsheets, graphs and maps.

Uses

The HU/WQ Tool is primarily designed to facilitate ecosystem-based planning efforts in a watershed setting where the effects of landuse practices on water quality are an important concern. The primary users of the tool are located in NRCS State, Project or Area Offices where an inter-disciplinary team approach can best be coordinated. An inter-disciplinary team is needed to install and maintain the system, collect the data, develop alternatives, and understand and evaluate model results. The tool is most useful in four of the nine steps of the NRCS planning process:

- **Inventory Resources** - Provides a consistent direction and methodology for collecting, storing and managing watershed data.

- **Analyze Resource Data** - Provides a tool for analyzing the current effects of landuse practices on water quality in a watershed.

- **Formulate Alternative Solutions** - An understanding of the data elements required by the tool and the physical, chemical and biological processes simulated in the pollutant loading models affords the user a greater understanding of how alternative solutions could be formulated to minimize pollutant loadings.

- **Evaluate Alternatives** - The tool manages input and output data so that alternatives can easily be evaluated by comparing simulation results of baseline conditions to proposed alternative solutions. The selected alternative then provides guidance and direction to field specific planning efforts.

Advantages

- Provides a consistent method to collect, store and manage project data thus reducing the effort required to gather and develop basic model input data.

- Eliminates personal bias by providing a consistent method for deriving model input.

- Facilitates running Multiple pollutant loading models and only collecting data once.

- Facilitates analysis of model results.

- Collected spatial and attribute data can be used for other projects or purposes.

Features

- Provides an intuitive GUI point and click environment to input base data, run models and analyze results.

- Presents database tables as spreadsheets that can be sorted and arranged according to user specifications. In addition, multiple tables can be arranged on the screen simultaneously.

- Preserves original project data when developing an alternative simulation by only allowing the user to edit a copy of the original project data.

- Develops channel hydraulic data and watershed boundaries using terrain analysis techniques.

- Displays any data element(s) in model output as a GRASS map, table value or a time series graph.

- Generates maps and spreadsheets showing the difference between selected simulations.

- Displays multiple output maps, tables and graphs on the screen at the same time.

Limitations
- The user cannot customize how model input parameters are derived.

- Current version (Beta 1.4) only supports AGNPS, to integrate a new model into the system requires considerable effort by professional programmers familiar with GRASS, INFORMIX, C++ and C.

- Considerable resources are required to collect the data.

- Current system is not integrated with FOCS, SSSD, NASIS or other NRCS data.

- Runs only on a Sun Sparc platform.

Planned Development

Version 2.0, planned for release in July of 1995, will contain both AGNPS and SWRRBWQ. Development will continue on the integration with NRCS databases and the incorporation of EPIC and GLEAMS.

System Requirements

Hardware: Sun workstation (IPC, Sparc 11 or better), 16 MB of RAM, I GB disk storage, 3.5 inch floppy disk drive, 1/4 inch or 8 mm tape drive, 17 inch color monitor or larger (preferred), Postscript printer.

Software: HU/WQ version 1.4, SCS-GRASS version 4.12, Informix SE version 4.3 or Informix Online version 5.021 or 5.03, SunOS version 4.I.x (not Solaris), X Windows version XI I Release 5, Motif Windows Manager (mwm) version 1.2.3, Bourne Shell, C Shell.

Fact Sheet -- HYDROSS

Hydrologic River Operation Study System
version 4.4

May 1994

Developer   Bureau of Reclamation, Upper Missouri Region (now the Great Plains
                 Region). Billings, Montana.

Description   HYDROSS is a generalized reservoir-system simulation model used to
                   conduct monthly water supply studies for evaluating existing and proposed
                   water demands within a river system. The river system modeled is
                   characterized by a flow network. The network includes nodes, called stations
                   in HYDROSS, which represent reservoirs, demands, river confluences, and
                   points of known flow. Arcs between nodes represent river reaches and canals.

                   Water allocation in HYDROSS is structured so that flows are spatially and
                   temporally allocated in accordance with water right priorities. Instream flows,
                   reservoir power, storage demand, and diversions can be assigned a water
                   right priority. An instream demand requires flow to be maintained in the river
                   at a given station. A power demand is the flow required at a power plant
                   associated with a reservoir. A storage demand is used to fill reservoirs. A
                   diversion demand depletes water from the river and potentially denies water
                   to other users with junior water rights.

                   Reservoir operations in HYDROSS are performed using five reservoir content
                   levels. A pool maintenance routine is available to balance storage among a
                   system of reservoirs. Power at a reservoir is computed using discharge, head,
                   and efficiency data.

                   The basic input into HYDROSS includes flow data, table data, and network
                   data. Flow data represents pristine monthly flows at each station in the
                   network. Table data includes operational data needed to perform simulations.
                   These data include monthly demand and priority information, reservoir
                   physical characteristics, instream flow requirements, gains, and losses.
                   Network data includes information about the physical relationship between
                   stations and arcs.

Features   **Water Rights** HYDROSS allows the user to assign water rights to
                            diversions, instream flows, reservoir power, and reservoirs.
                            These diversions may occur at any station, and there is no
                            limit to the number of diversions per station. Up to 9,998
                            diversions can be assigned per river system. The user can
                            assign efficiencies to both canals and diversion sites.

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Reservoirs	Five content levels are available to control reservoir operations. The absolute maximum and minimum levels are based on the physical limitations of the dan and outlet works. The maximum and minimum levels are limits which can vary month to month and year tot year. The target level is used to share water among several reservoirs at the end of each month. Stored water can be called for project demands and instream flows. Reservoir seepage can be simulated as a function of either elevation, capacity, or using monthly values which can change year to year.

Return Flows Return flows originate from diversions and may return at any station within the river system. Return flows may be delayed up to 11 months. The user can assign efficiencies to return flows.

Flood Control The user can assign channel capacity at any station. HYDROSS will not release stored water which exceeds channel capacity.

Salinity	HYDROSS has been linked with the Canals, Reservoirs, and River Salinity Accounting model (CRRSAP). CRRSAP is a monthly salinity accounting model. CRRSAP documentation is available.
Output	HYDROSS output consists of fixed format ASCII files and comma separated files for direct inclusion into spreadsheets. Detailed reports are available for station activity, reservoir operations, diversion activity, station flows, shortages, limitation and constraints, and statistics.
GUI	A Graphical User Interface has been developed for HYDROSS. The X windowing system and Motif were used to create the GUI which includes an interactive network builder to define the river system. The GUI runs on a UNIX-based workstation.

Limitations	**Time Step**	HYDROSS only operates on a monthly time step. Weekly, daily, or hourly time steps cannot be used.
	Reservoirs	Currently, HYDROSS assigns a reservoir the lowest possible priority (9999). Subsequently, reservoirs have the most junior water right in the river system.
		Only 15 reservoirs can be assigned within a river system. In addition, computing speed decreases significantly when more than 4 reservoirs appear in series.

Diversions		Multiple ownership of stored water in reservoirs and complicated water right exchanges are not implemented.
Return Flows		Return flows from diversions can only be lagged 11 months.

Resource Requirements

Hardware		HYDROSS version 4.4 has been complied for 1) An IBM-compatible PC with 4 megabytes of available memory; 2) A Sun SPARCstation; 3) A Data General Aviion.
Software		The PC version of HYDROSS 4.4 has been compiled using Lahey Fortran, version 5.20 under DOS 6.0. The UNIX version of HYDROSS 4.4 has been compiled under SunOS version 4.1.3 and DGUX version 4.3.

Fact Sheet -- HYDRUS

A User-Friendly Software Package for the HYDRUS Model

May 1995

Developer

U.S. Salinity Laboratory, USDA-ARS .R. Zhang[1], T. Vogel[2], J. Teed[3], and M. Th. van Genuchten[3]
[1]*Department of Plant, Soil and Insect Sciences, University of Wyoming, Laramie, WY 82071* [2]Department of Applied Mathematics and Computer Science, Charles University, Prague, Czech Republic [3]*U.S. Salinity Laboratory, 4500 Glenwood Dr., Riverside, CA 92501*

Description

A software package was developed for modeling water flow, solute transport, and heat movement in variably saturated soils. The package consists of a preprocessor, a computer model, and a postprocessor. The preprocessor (interface) and postprocessor were developed using C++ under the Windows™ environment (Windows™ is a registered trademark of Microsoft Corporation, Redmond, WA). The interface helps users to prepare appropriate input information, such as parameters in the unsaturated soil hydraulic and root water uptake functions, initial and boundary conditions, and time and spatial discretizations. The postprocessor allows for expanded visual representation of the simulations. The postprocessor interacts seamlessly with the computer model operation. Hence, the simulated processes of water, solute and heat flow in soils can be tracked easily as a function of time and space.

Water Quality Applications

The user-friendly software package was developed to support a computer model, HYDRUS. This model may be used to simulate one-dimensional water, solute, and heat flow in variably saturated soils. HYDRUS can simulate the effects of alternative soil water and chemical management systems (e.q., irrigation, drainage, root water uptake, fertilizer and pesticide application rates and timing) on crop growth and solute loadings to the groundwater table. Meteorological data, such as rainfall and evaporation, are also considered in the modeling process.

Features

- A Microsoft Windows 3.1 graphical user interface (GUI) was developed to facilitate data input and interpretation of model results. The GUI consists of two separate programs: a preprocessor and a postprocessor.

- The interface was written in C++ using the Microsoft Visual C/C++ compiler.

- The preprocessor (PRE_HY.EXE) is a SDI (Single Document Interface) program which prompts users to enter data through a series of linked dialog boxes. The preprocessor checks the data to make sure they are within valid ranges. This procedure helps to ensure that the model's results will be physically meaningful. Finally, the input files are saved for use with the model, or for later manipulations.

- The computer model, HYDRUS, is developed based on the Richards equation for variably-saturated flow and convection-dispersion type equations for both heat and solute transport. Solute transport processes of linear and non-linear adsorption, and decay are also included in the modeling process.

- The postprocessor (POST_HY.EXE) displays the modeling results graphically. Options are provided to choose variables, titles, colors, symbols and thicknesses of curves. The postprocessor is a MDI (Multiple Document Interface) program so that multiple graphs may be shown on the screen at the same time. Support for the traditional windows "cut" operation is built into the program, thus facilitating copying of graphs into the user's favorite word processor or graphics program. The program also support direct printing to a default printer.

Limitations

- The HYDRUS code considers only one-dimensional transport processes.

- The package operates under a Microsoft Windows environment.

Support

Distribution diskettes and documentation are available through the U.S. Salinity Laboratory, 4500 Glenwood Dr., Riverside, CA 92501.

Future Developments

- More elaborate evapotranspiration and crop growth models are under development.

- UNIX versions of the software package may be developed at a later date.

Resource Requirements

The package requires a 386 (or better) compatible running Microsoft 3.1 (or better) system that has at least 640K RAM and 1 megabytes of disk storage space, and a VGA (or better) monitor. The use of a math coprocessor is not required, but is highly recommended.

Fact Sheet -- IEES

Irrigation Economics Evaluation System

May 1995

Developer
Department of Agricultural Economics, Kansas State University, Manhattan, Kansas. Funding for the model was provided by the Cooperative States Research Service and the Kansas Agricultural Experiment Station.

Description
The microcomputer model, Irrigation Economics Evaluation System (IEES), can be used to estimate costs under a variety of operating conditions and to evaluate irrigation systems for economical water use. IEES is designed to utilize user-supplied data to calculate the operating costs for Medium Pressure Center Pivot, Low Pressure Center Pivot, Low Energy Precision Application Center Pivot, Low Drift Nozzle Center Pivot, Furrow Flood Gaged Pipe, Surge Furrow Flood Gaged Pipe, and Sub-surface Drip irrigation systems that use either natural gas, propane (LP) gas, diesel fuel, or electricity. IEES is designed to calculate operating costs for eleven items associated with operating irrigation systems and the total annual operating costs on a per acre, per hour and per acre-inch basis.

In addition to calculating the annual operating costs, the model has five options that can be used to economically evaluate improvements in the pumping plant or the way the irrigation system is used for crop production. These options are evaluation of pump repair or replacement, evaluation of switching power units from one power source to another, estimates of operating cost changes caused by a falling water table and/or a pump efficiency decline, estimates of operating costs for different levels of water application, and estimates of operating costs under selected fuel inflation rates. The general IEES model components are displayed in Figure 1.

Features
● IEES has a routine that checks data parameters to ensure they fall within a specific range.

● The program will accept data from a file and can save input data entered from the keyboard to a file.

● IEES displays output results on the screen and also allows them to be saved to a file.

● All files of input data or output results can be printed from a file.

● The program will allow the user to step backward through the input data section to correct a value or estimate costs with a different input value.

- Some of the labor use parameters used as default values in the model can be changed by the user to customize the program to their own individual systems.

- Estimates of repair and maintenance costs and other selected costs can be entered directly by the user or can be generated by the computer.

- Input data is in English units.

Limitations
- The user should have a pumping plant performance test conducted to collect the appropriate technical data required for the cost estimates.

- Maintenance and repair costs for the distribution system are based on a percentage of replacement costs and are not a function of hours of use.

- The section of the model that estimates costs under a falling water table scenario requires the user to enter an assumption about the average annual decline in the water table and a corresponding decline in the flow rate. A function which estimates the flow rate as a function of the pumping water depth is not available.

- The component of the model which determines if it is economical to repair or replace the pump assumes the power unit is operating efficiency.

- Output data is in English units.

Support

The program is currently in the testing phase and is not available for public release. Those wishing to examine the program or participate in testing may contact the author for a pre-release version.

Future Developments

Additional components are being constructed that will evaluate switching from a distribution system that is currently in place to a new distribution system, i.e. Furrow Flood Gaged Pipe to Sub-surface Drip. This routine will operate similarly to the engine switch evaluation in the current version.

Resource Requirements

IEES is a compiled executable program which runs in a Windows operating environment. Windows 3.1 is required. The program requires one megabyte of disk storage space. It is suggested the computer also have 4 megabytes of memory available.

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A River System Simulation Model

May 1995

Developer   Colorado State University, Fort Collins, Colorado -- with financial and technical support from the U. S. Bureau of Reclamation

Description   MODSIM is a priority-driven simulation model which provides releases, deliveries, reservoir contents, and other operational parameters of interest for simple or complex river systems. The model uses a system of links (to simulate channel reaches, canals, and other conveyance features) along with a series of nodes (to simulate reservoir, diversions, minimum flow locations, and other key points in the system) as its computational basis. Input data required for MODSIM includes streamflow, gains, losses, evaporation, precipitation, demand, and priority data, along with a variety of physical parameters describing the basin and its reservoirs. In addition to general planning and operation studies, the model can be used for water rights analyses, environmental applications (where minimum flows are critical) and a variety of other purposes.

Features   In addition to the general capabilities described above, sophisticated treatments of multiple storage priorities in reservoirs have recently been developed in order to deal with complex exchanges, rent pools, and other water use arrangements commonly used in the western United States. Subsurface return flow, groundwater withdrawals, and hydroelectric power generation can also be modeled using some simplifying assumptions.

The model is run interactively. It is most commonly run using a monthly time step, but can also be run on a daily or weekly basis. Graphical capabilities are available to view plots of most output parameters including streamflow, reservoir content, and demand delivery. In addition, Graphical User Interface capabilities allow for viewing the hydrologic system on the work station screen. A PC Windows version of the program will soon be available.

Limitations   MODSIM is not presently suitable for supporting very short-term (day-to-day/hourly) operational decisions or for other analyses requiring time steps shorter than daily increments (such as flood control analyses).

Resource Requirements   MODSIM can be run on most IBM compatible PC's as well as on most work stations. Math coprocessor chips are helpful for improved execution time but are not essential.

Documentation   The MODSIM user's manual is updated periodically and is available through: Dr. John Labadie, Civil Engineering Department, Colorado State University, Fort Collins, Colorado 80523.

Montana's Missouri River Water Availability Model

May 1995

Developer	The Montana Department of Natural Resources and Conservation, Helena, Montana; in cooperation with the U.S. Bureau of Reclamation, U.S. Soil Conservation Service, U.S. Geological Survey, U.S. Bureau of Land Management, Montana Department of Fish, Wildlife and Parks, Montana Department of Health and Environmental Sciences, and Montana Power Company.
Description	Computes monthly streamflows, reservoir operations, hydropower production, and irrigation and municipal water uses. In general, the monthly water budget for the basin is simulated by estimating gains and losses to streamflows above or between 40 locations or "nodes" within the Missouri River basin of Montana. Each node defines the outlet of a "node basin". The model is made up of four major components: (1) the irrigation component, (2) the municipal component, (3) the dam and reservoir operation component, and (4) the streamflow component.

Features

- The model can be used to rapidly assess the effects new water developments may have on streamflows, reservoir operations, and hydropower production.

- Accounts for the effects that historic changes in irrigated acres have had on streamflows by adjusting streamflows to reflect a baseline level of irrigation development.

- Reservoirs operations can be modified. The model can then be used to assess the effects of these modifications on water availability, reservoir levels and contents, and hydropower production both at the reservoir and at other nodes downstream.

- Can be used to estimate the effects of water conservation measures on streamflows, reservoir operations, and hydropower production.

- Irrigation depletions are calculated based on system efficiencies. Four types of irrigation systems can be modeled.

- Can easily be updated as more streamflow, climate, and irrigated acreage data become available.

Limitations

- Streamflow, reservoir operations, and hydropower production output is limited to monthly mean values.

- Streamflows are only modeled at 40 locations in the basin. The model can not be used to assess site-specific streamflows on smaller tributaries.

- Only the largest reservoirs in the basin are modeled. Operations at numerous other mid-sized and smaller reservoirs are not accounted for.

- Reservoir operations algorithms are limited to using information such as historic streamflows, target elevations and minimum release criteria. In the real world, reservoir operators have more flexibility and more data available to them. For example, the model can't take advantage of snow survey data and streamflow forecasts.

- The model cannot easily be adapted to other river basins.

- The model was not developed for the casual user. Hence, the operator must spend some time becoming familiar with the code and input files. Documentation on the model is limited.

Support

Diskettes, documentation, and technical support are available through the Montana Department of Natural Resources and Conservation.

Future Developments

- A users guide to the model will be developed.

- UNIX and PC versions of the model will be standardized.

Resource Requirements

The Missouri River water availability model requires a MS-DOS compatible system that has at least 640k of memory and 5 megabytes of disk storage space. A math coprocessor is required. A FORTRAN compiler is necessary if modifications are made to the model code. LOTUS 123 is necessary for the PC version of the model.

A UNIX version of the Missouri River model is also available for use on workstations.

Fact Sheet – NAPRA

National Agricultural Pesticide Risk Analysis

May 1995

Developer   U.S. Department of Agriculture, Natural Resources Conservation Service and Massachusetts Cooperative Extension, Amherst, Massachusetts.

Description   National Agricultural Pesticide Risk Analysis (NAPRA) is an automated pesticide risk screening process that currently utilizes the USDA-ARS environmental fate model GLEAMS (Groundwater Loading Effects of Agricultural Management Systems, Knisel et al., 1994). NAPRA results include climate specific probabilities of off-site pesticide loadings and concentrations. These off-site pesticide concentrations are then compared to individual pesticide toxicities to provide quantitative evaluation of the relative risks associated with different management options. As with GLEAMS, NAPRA evaluation is limited to the bottom of the rootzone and the edge of the field. NAPRA includes pesticide toxicity, because off-site pesticide loading by itself may not tell the whole story. For example, small off-site movement of a highly toxic pesticide, may in fact, pose greater environmental risk than large off-site movement of a marginally toxic chemical. NAPRA software utilizes acute and chronic toxicity values, for both human and aquatic species, allowing users to address multiple water resource concerns.

NAPRA analysis considers soil properties, cropping practices, pesticide properties, regional climate, tillage practices, and field slope and slope length. Simulation of multiple user selected scenarios for a particular application is performed with GLEAMS batch processing. Probabilities of exceeding maximum four-day and average annual pesticide mass loadings and concentrations are developed by running 30 to 50 years of serial climatic data. Pesticide percolation, soluble runoff and sediment-adhered concentrations are then compared with selected toxicity values to develop probabilities of exceeding these levels. Comparing toxicity exceedence probabilities for different scenarios can identify opportunities to reduce hazardous off-site pesticide losses through alternative management.

NAPRA quantifies relative environmental risks associated with pesticides in percolation, solution runoff and erosion. The process allows the user to compare water quality risks resulting from different pesticide, crop and tillage practice management scenarios. NAPRA can also provide field-level pesticide loading and concentration data.

**Water Quality
Applications**

● The NAPRA interface allows the user to populate individual input variables which are combined to form a multitude of scenarios that are batch processed.

● The State Soil Survey Database (SSSD) supplies soils data for NAPRA.

Features

● Soil water holding capacity parameters are mathematically estimated.

● Soil components for a county are mathematically clustered and a representative component is selected for each cluster.

● Runoff Curve Number for each soil is calculated based on water holding capacity.

● The NRCS Climate Data Access Facility supplies serial climatic data.

● The ARS Pesticide Properties Database supplies pesticide physical properties.

● NAPRA toxicity databases are compiled from EPA data and literature review.

● NAPRA evaluates both four-day maximum and average annual losses.

● NAPRA reports the probability of a pesticide loss to exceed a selected toxicity value.

● NAPRA output reports are based on field specific pesticide application rates.

Limitations

● NAPRA requires substantial interdisciplinary interagency technical support.

● Pesticide loss evaluations are limited to the bottom of the rootzone and the edge of the field. Analysis does include direct impacts to ground or surface water.

● Pesticide losses are evaluated individually even though combinations of pesticides may have additive or synergistic toxicity.

● Furrow irrigation cannot be modeled.

● Some crop rotations are difficult to model.

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Support   Diskettes, documentation, and technical support are available from the
                     NAPRA Team, USDA-NRCS, Amherst, MA 01002. NAPRA technology
                     transfer workshops can be arranged for NRCS state office staff and partner
                     agency technical specialists.

**Future
Developments**   ● Better documentation of NAPRA processes and software.

                     ● Develop pesticide toxicity databases for terrestrial animals,
                       macroinvertebrates, birds and plants in addition to maintaining existing
                       human and aquatic databases.

                     ● Simulation of pesticide runoff from the edge of the field into a pond. This
                       will provide a better estimate of potential toxicity than edge of field
                       evaluation.

                     ● Better simulation of crop rotations.

                     ● Ability to simulate furrow irrigation.

                     ● Link the NAPRA process to additional models such as EPIC, PRZM and
                       APEX.

**Resource
Requirements**   MS-DOS compatible system with a minimum of 4 MB RAM, 33 MHz 386
                     with numeric co-processor, and 25 MB free disk storage space per county.
                     Disk storage space requirements will vary with the complexity of the situation
                     being modeled. Once NAPRA Pesticide Loss databases are developed, they
                     can be transferred to systems without numeric co-processors for NAPRA
                     report generation.

Nitrate Leaching and Economic Analysis Package
NRCS-Version 1. 1.3

March 1995

Developer   U.S. Department of Agriculture, Agricultural Research Service, Great Plains Systems Research, Fort Collins, Colorado.
Contact Person: Stefanie Aschmann, conservation agronomist, West National Technical Center, 1 01 S.W. Main Street, Suite 1600, Portland, OR 97204-3225; Telephone: (503) 414-3004; Fax: (503) 414-3102.

Description   Nitrate Leaching and Economic Analysis Package (NLEAP) is a field-scale computer model developed to provide a rapid and efficient method of determining potential nitrate leaching associated with agricultural practices. It uses basic information concerning onfarm management practices, soils, and climate to project N budgets and nitrate leaching indices. NLEAP calculates potential nitrate leaching below the root zone and to ground water supplies. NLEAP has three levels of analysis to determine leaching potential: an annual screening, a monthly screening, and an event-by-event analysis.

Uses   The NLEAP model was designed to answer questions regarding potential leaching of nitrate. The processes modeled include movement of water and nitrate, crop uptake, denitrification, ammonia volatilization, mineralization of soil organic matter, nitrification, and mineralization-immobilization associated with crop residue, manure, and other organic wastes.

The event-by-event analysis provides the best estimate of nitrate leaching. Its water and nitrogen budgets track the impacts of each precipitation, irrigation, fertilization and tillage event on potential nitrate leaching. The event-based procedure is recommended for analysis of potential nitrate leaching to domestic water supplies.

Features
- Extensive validation has shown the model can predict residual soil nitrates and nitrate leaching to within approximately 20 to 50 pounds of nitrogen per acre per year.

- Thorough documentation is available. The publication, *Managing Nitrogen for Groundwater Quality and Farm Profitability,* edited by R.F. Follet, D.R. Kenney, and R.M. Cruse and published by the Soil Science Society of America, contains the documentation for processes modeled in NLEAP.

- The program uses data entry screens with pop-up data selection and on-line help menus.

- Regionalized soils and crop data bases have been developed for the contiguous United States. Climate data bases are currently available for the upper Midwest, Northeast, South, and part of the Western United States. In states where a regional data base is not available, the user must obtain and manually input the required soils and climate information.

- The user can access material from the internal data base files, enter their own farm-specific and field-specific information, or use a mixture of user specified and database information. Users in all regions are encouraged to develop local data bases, as the regional data bases may not accurately describe local conditions.

- User input may be saved to a data file for use in future runs.

- Simulation results help identify shortcomings in water and nitrogen management strategies.

- Simulation results can be presented as monthly tables, graphically, or in a detailed written summary and analysis.

Limitations

- Modeling soil nitrogen processes in organic soils is not currently available. Their inclusion will require additional research and modeling efforts.

- NLEAP does not predict yield reductions caused by pests or nutrient deficiencies. However, the user should consider the effects of these problems when estimating crop yield.

- The model should not be used where rapid water infiltration, leaching, denitrification, and ammonium volatilization require time steps smaller than 1 day. Other situations that should not be modeled include those in which water and solute transport in an aquifer are important considerations, complex layering in the soil profile exists, or a shallow water table supplies crop needs.

- Sequential year runs involving complex crop rotations are difficult to simulate.

Future Developments

- The capability to operate NLEAP in conjunction with GRASS and other GIS systems has been developed and is currently being validated.

- A metric version of NLEAP is being developed for international use.

- The model is being modified to simplify simulation of sequential year runs and expand file handling capabilities.

- A routine is being added that will separate gaseous denitrification losses into N_2 and N_2O components.

- Fertilizer and irrigation input routines are being improved.

- Future enhancements will permit the user to directly access NRCS soil and climate data bases for NLEAP input and allow access to NLEAP through FOCS.

- A users manual and NRCS workbook are under development.

Resource Requirements

NLEAP requires an IBM AT 286, 386, 486, or pentium compatible system that has at least 640K of memory, DOS version 2.1 or newer, and 4.5 megabytes of disk storage space. The use of a math coprocessor is recommended. NLEAP may be run with either a monochrome or color monitor. Program execution is unpredictable if any memory resident programs are loaded.

Fact Sheet --NWQDB

National Water Quality Database

May 1995

Developer   U.S. Department of Agricultural, Cooperative States Research, Education and
                    Extension Service and Purdue Cooperative Extension Service.
                    Contact Person: Eldon Fredericks Internet: freder@ecn.purdue.edu; phone:
                    317-494-8679 fax: 317-496-1117

Description   The National Water Quality Database is an information management tool for
                    locating water quality and waste management educational resources created
                    by the 50 State Cooperative Extension Services.

                    This computer-based information is available by computer search using
                    several different network tools. The database includes more than 2,400
                    citations and nearly 800 full-text documents. While the majority of listings are
                    publications, approximately one-fourth of the citations describe 35mm slides,
                    videotapes, and computer application software.

                    Anyone with a networked computer may access this database and use the
                    search and retrieval capabilities. Internet, interactive access is provided by
                    Telnet, Gopher, or World Wide Web; or the database may be searched via
                    E-mail from most any network service capable of supporting the transmission
                    and receipt of electronic mail across the Internet.

Water Quality
Applications   The National Water Quality Database is a resource to help insure a safe water
                    supply. It provides those who teach in K-12, colleges and universities, and
                    adult classes with access to educational materials developed throughout the
                    country.

                    Teachers may use the materials to prepare their own curriculum enrichment in
                    environmental science classes. Or, they may assign research projects to
                    students who may expand their knowledge with a search and retrieval of
                    information directly from the database with their networked computers.

                    The database is a valuable resource for elected and appointed county, state or
                    national government staff. Public policy as well as specific environmental
                    methods are included in the various materials.

Features   The educational materials are grouped into eight categories: Conservation,
                    Drinking Water Quality, Nutrient Management, Pest Management, Testing,
                    Waste Management, Wells, and Other. Each of these categories is further

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divided into smaller sub-categories. The bibliography is arranged by category, sub-category, and state. In addition, each item is referenced by intended audience. These include: agriculture, general, residential, youth, and other.

These divisions give the user an opportunity to search for materials by area of interest. References include slides, videotapes, films, and computer software as well as publications. The audiovisual references are placed at the end of each category and are listed by category-audiovisual. Each entry lists all the information provided by the state, including:

- Title of the product
- Publication number (assigned by the state)
- A description of the item
- Category
- Sub-category
- Audience (agriculture, general, residential, youth, other)
- Date of publication
- Cost (if applicable)

An address for each State Cooperative Extension Service is listed at the end of the bibliography. Specific information about listings may be obtained from those addresses. When available, phone numbers and electronic mall addresses are included.

**Computer
Access**

- **Telnet:**
  The address is: *HERMES.ECN.PURDUE.EDU*
  login: cerf
  password: purdue

- **Gopher:**
  point your gopher client at: *HERMES.ECN.PURDUE.EDU*
  Choose: The Purdue Cooperative Extension Information Server
                   Environment
                   Water Quality

- **World Wide Web**:
  The Uniform Resource Locator (URL) is:
  http://hermes.ecn.purdue.edu:8001/server/water/water.html

Support
This database and related activities are supported by a team of specialists at Purdue University working in close coordination with the Water Initiative Team of the CSREES, USDA. Addresses are provided below.

Future Developments

The National Water Quality Database has evolved from a bibliographical listing published in printed form in 1989. By 1990 the bibliography and a few full-text documents for demonstration purposes were available via telnet or dial-up modem through the CERF program. And, the E-mail search and retrieval through the Almanac server was operational. In 1992 Gopher access was added and experimentation with the WAIS search index began. In 1993 all citations and documents were made available through the World Wide Web (WWW) server.

Throughout this evolution, the development team has maintained the original approach to make materials available to those with the lowest network connections (e-mail and text-only terminals) while developing enhanced capabilities for those with graphic display capabilities and direct Internet connections. That philosophy continues.

In 1994 the WWW display was improved with the addition of a "filter" placed in the system which automatically adds the necessary coding into the plain text files used by all search and retrieval programs used by the database. This feature allows the display of formatted text when viewed by Mosaic or Netscape graphic WWW viewers. And, it allows Mosaic, Netscape or Lynx viewers to use their hyperlink capability to "jump" from one location inside the database to another location where a similar thought or keyword appears.

Further development is underway to include graphics with documents. Again, the automatic "filter" program will sense the presence of a graphic, and provide that display to those computer screens using the Mosaic or Netscape viewers.

Other developments with the WWW interface will allow access to some of the computer application programs included in the bibliography. It will also be possible to include color images such as the 35mm slides to be selected and retrieved.

Resource Requirements

Computer requirements to gain access to the National Water Quality Database range from the most basic:

1. Must be able to emulate a VT100 or other relatively standard.
2. A computer or terminal with modem and telephone line.
3. A computer or terminal with direct connection to host computer.
4. A computer with adequate connection to send and receive E-Mail to another computer located on the Internet.
5. A text-only Gopher or Lynx client.
   For more sophisticated access to the interactive and graphic resources:
6. A computer and network connections that support the WWW graphic intensive readers such as Mosaic or Netscape.

Fact Sheet -- PHABSIM

Physical Habitat Simulation System
Version II

May 1995

Developer   National Ecology Research Center, U.S. Fish and Wildlife Service. (now Midcontinent Ecological Research Center, National Biological Service). Fort Collins, Colorado.

Purpose   The Physical Habitat Simulation System (PHABSIM) simulates the relationships between streamflow and physical habitat for various life stages of an aquatic species (i.e. fish, etc) or a recreational activity. The basic objective of physical habitat simulation is to obtain a biological representation of the physical attributes of a stream so that the stream may be linked to the social, political, and economic world.

Knowledge of the relations between benefits from water instream and the streamflow is useful in water allocation decisions. In general, the benefit of an out-of-stream use can be quantified in terms of some type of production function that relates the quantity of water used to the benefits produced. The functions produced by PHABSIM are production functions between the physical habitat and streamflow. They are used to examine the tradeoff between the value of water used instream with the water used out-of-stream. Therefore, tradeoffs can be made between alternative uses and mutually acceptable management criteria developed. The decision as to the "best" allocation of the available water is a matter of negotiation among various interest groups.

Logic   The physical habitat of streams and rivers is a function of three attributes: the velocity, the water depth, and the nature of the stream bed. Physical attributes for a specific stream discharge are combined with the needs of the aquatic animal (or recreational use) to give to estimate the quality (worth) of a small area of the stream as physical habitat for the animal. The worth times the area gives the weighted usable area for the small area. The sum of the small areas over a reach of the stream gives the weighted usable area for the reach at the specified discharge. Repeating the simulation for a series of discharges gives the weighted usable area function for the aquatic species.

The two basic components of PHABSIM are the hydraulic simulation programs that give the physical attributes, and habitat simulations programs that combine the physical attributes with the biological attributes (called habitat suitability criteria). Hydraulic simulation is used to describe the area of a stream having various combinations of depth, velocity, and channel characteristics as a function of flow. The result is called the Weighted Usable Area of the stream segment for the life stage of the aquatic animal.

Applications   There are four steps. The first is to simulate water surface elevations (depths are calculated from the water surface elevations), the second is to simulate velocities, the third is to simulate the physical habitat versus streamflow relationship, and the fourth is to simulate the physical habitat when combinations of flows or species are involved.

The user must collect data to calibrate the hydraulic models and must define the habitat suitability criteria. The user must select between hydraulic simulation programs and alternatives, select an approach to using the channel index, and select among the habitat simulation models.

Features
- The velocity simulation may be either mean or point velocities (usually near the bottom of the stream).

- The velocity distribution across the channel and the simulation of point velocities .

- The water surface elevation simulations may be made using the variation of the Manning's roughness coefficient with discharge in a stream. The variation of roughness in a sand bed river is related to the changes in the dunes and riffles resulting from changes in streamflow; in a gravel bed river, the variation results from changes in the depth relative to the size of the bed material (relative depth).

- The cross- channel distribution of velocities may be related to the distribution of depths, the relative depths, and the morphological characteristics of the river only, or these factors plus a calibration set of velocities.

Limitations
- The hydraulic simulation models assume a rigid channel.

- Physical habitat is required in order for an aquatic animal to exist in the stream but is not sufficient to guarantee the existence of the animal in the stream. Other factors not included in the model may limit populations of the animal.

Support   Distribution diskettes and documentation are available from a contractor to the Midcontinent Ecological Research Center (MESC). Technical Support is given by MESC staff. A one week course on the use of PHABSIM is given through a cooperative agreement between MESC and the Fish and Wildlife Department at Colorado State University.

**Resource
Requirements**   An IBM compatible microcomputer with DOS 3.0 or higher. Random Access Memory (RAM) requirements are 512K with 10 megabytes of hard disk space for a full installation. A numeric coprocessor is not required but is recommended. A Color Graphics Adapter (CGA) card (or higher) is required to use the screen graphics options in the programs.

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Fact Sheet -- PRSYM

Power and Reservoir System Model

March 1995

Developer

University of Colorado's Center for Advanced Decision Support (CADSWES) with financial and technical support from U.S. Bureau of Reclamation, Western Area Power Administration, the Tennessee Valley Authority, and the Electric Power Research Institute.

Description

PRSYM uses an object-oriented software approach which is datacentered in that a specific river/reservoir system and its operating policies are defined by the data supplied when the river network is constructed. This allows a basin model to be easily modified to reflect new features or new operating policies, and allows complete transportability to other river basins. The software is constructed to provide full extensibility as well, so that additional methods for computing physical processes, additional objects for modeling new features, and even additional controllers for solving the network can easily be added.

Features

The user constructs a model by selecting reservoir, reach, confluence, and other objects from a palette, naming the objects, and linking them together to from the basin network topology. Particular methods for modeling the physical processes associated with each object (i.e., river reach routing, hydropower calculation, etc.) are then selected from a menu for each object type. This methodology allows users from each sponsoring agency to add new methods as needed to customize behavior of particular objects without sacrificing portability. All computations are done in standard metric units, but users can specify particular units for importing, exporting, and displaying purposes, as well as dynamically define new unit types. Operational policy is either added through a constraint editor or through the rulebase editor, depending on which controller the user wishes to use.

As of March, 1995, controllers supported include basic simulation, linear programming/goal programming, rulebased simulation, and simulation plus water quality (temperature and salinity). Computational time steps supported are hourly, 6-hourly, daily, weekly, and monthly.

Data associated with an object can be entered through the Graphical User Interface (GUI), imported and exported from ASCII files, or automatically imported and exported through Data Management Interfaces (DMI's). Users can write customized DMI's in any standard

programming language to access data from a variety of sources including relational databases.

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PRSYM also provides a utility whereby the user can set up and automatically execute many PRSYM runs using one of the controllers (multiple run management). Results of single or multiple runs can be viewed graphically or by setting up a control table which provides a spreadsheet format view of user-selected variables. Any number of views can be configured, saved and used by the user.

Limitations   As of March 1995, PRSYM does not support water rights allocation and accounting. Development plans for 1995, however, include this functionality.

Support   As of March 1995, technical documentation is being developed and is not available. Licensing information is available from the Electric Power Research Institute.

Licensing: Dr. David McIntosh
Electric Power Research Institute 415-855-7918

Technical Information:
Terry Fulp
US Bureau of Reclamation
303-492-8572
email: tfulp@cadswes.colorado.edu

Edie Zagona
University of Colorado - CADSWES
303-492-2189 or 492-3972

Dick Shane
Tennessee Valley Authority 615-632-1884

Resource Requirements   PRSYM currently is supported on Sun workstation running the Solaris operating system (Unix). Plans for 1995 include support for HP and Silicon Graphics workstation.

Fact Sheet -- RHESSys

Regional HydroEcological Simulation System

February 1995

Developer   Lawrence Band[1], Ramakrishna Nemani[2], Steven Running[2], Richard Lammers[1], Christina Tague[1]. [1]Department of Geography, University of Toronto, Toronto, Ontario, Canada. [2]School of Forestry, University of Montana, Missoula, MT.

Description   A data and simulation system designed to compute and map carbon, water, and nutrient fluxes at various spatial scales. Three models in the system, in combination, perform the computation of ecosystem flux rates across the landscape: FOREST-BGC (Running and Coughlan, 1988), an ecosystem simulation processor; TOPMODEL (Beven and Kirkby, 1979), a simulation model for computing hillslope-level hydrologic processes; and MT-CLIM (Running et al., 1987), a topoclimatological model for extrapolating meteorological data across the landscape. The system uses a complement of digital terrain analytical methods and geographic information system processing for preparation of the landscape and estimation of model parameters.

FOREST-BGC is a process level ecosystem simulation model that calculates cycling of carbon and nitrogen through forest ecosystems. The model calculates canopy interception and evaporation, transpiration, photosynthesis, growth, and maintenance respiration, leaf water potential, litterfall, decomposition of carbon; and deposition, uptake, litterfall, and mineralization of nitrogen. Potential evapotranspiration is calculated using a Penman-Monteith equation, modified slightly by LAI to define surface roughness because wind-speed data are rarely available.

TOPMODEL simulates baseflow and overland flow generation in moderate to steep topography. The model is based on principles of hillslope hydrology, and handles variations in soil water content and soil water flux as functions of surface topography and distribution of soils. TOPMODEL is considered to be "quasi-distributed" as it uses a topography-soils similarity index to stratify zones of differing soil water dynamics. Any tow points with the same similarity index are considered hydrologically identical so that the simulation is only necessary over the index distribution, and not explicitly over the whole terrain. TOPMODEL is based primarily on three assumptions. The first is that surface runoff is generated when precipitation falls on a saturated portion of the watershed. The second is that the rate of subsurface flow at a given location in the watershed depends upon the saturated hydraulic conductivity, surface slope, and saturation deficit at that point. The third assumption is that saturated hydraulic conductivity decreases with depth in the upper soil layers according to an exponential decay due to greater abundance of macropores in the upper soil horizons and greater soil compaction with depth.

MT-CLIM receives from RHESSys the hillslope topography (elevation, slope, aspect, and a comparison between base station and mean site isohyets). This spatial information is then used to extrapolate daily base station minimum/maximum air temperature and precipitation to yield a distribution of climate variables across the landscape. Each hillslope (or elevation band within a hillslope) will have a unique daily climate. Precipitation is varied linearly with the difference between base station and hillslope elevations. Radiation is calculated as a complex function of hillslope elevation, slope, aspect, LAI, and site latitude. Temperature is adjusted from base station temperature by hillslope elevation, temperature lapse rate, radiation, and LAI. Humidity and vapor pressure deficit are determined from temperature.

Remote sensing and soils data are registered to topography. LAI are derived from vegetation maps. Soil and topographic information are combined to produce a Topography-Soils Index (TSI), defined as $\ln(\alpha T_e / T_i \tan\beta)$, where α (drainage area upslope of each pixel) and β (slope of a given pixel) are derived from terrain analysis, and T_e (mean transmissivity of soil for landscape unit) and T_i (transmissivty of a given pixel) are derived from soil maps. If transmissivities cannot be calculated, one can set transmissity to be uniform across the basin, thus T_e and T_i would be equal, leaving $\ln(\alpha/\tan\beta)$ as the TSI. The products of these steps are two landscape parameterization files: the cartridge file holds mean parameter values for each hillslope for slope, aspect, elevation, LAI, and soil water holding capacity; the frequency file holds the frequency distribution of vegetation and soil parameters within each elevation band, where one or more elevation bands are contained in a hillslope. These frequency distributions are generated based on the TSI. Once the cartridge/frequency files are generated for a landscape, they can be "pulled out" and another set of cartridge/frequency files can be inserted for another landscape.

Water Quality Applications

RHESSys is a stand level forest ecosystem model used to calculate ecosystem flux rates at different spatial scales from a single hillslope to basins as large as 63,000 km².

The system outputs snowpack depth, outflow, runoff, leaf water potential, photosynthesis, respiration, depth to water table, soil water content, litter water content, transpiration, evaporation, and precipitation at the basin, hillslope, or frequency interval resolution. Outputs can be mapped back to the topography.

Features
- Integrates GIS data layers in the parameterization so that soil, vegetation, and topographic information can be spatially represented.

- Generates daily temperature and precipitation over complex topography with data from a single weather station.

- Redistributes snow according to TSI intervals.

- Hillslopes of high relief can be subdivided into elevational bands.

- Ecosystem processes can be represented at various resolutions.

Limitations
- No mechanism for modeling rain on snow events.

- Little user documentation or comments in the code to describe parameters, and no formal instructions on how to perform digital terrain analysis to create cartridge and frequency files.

- Has been applied mostly to areas with forests on high relief topography.

Future Developments
- Define vegetation and snowpack parameters by elevational terraces or by hillslope.

- Parameterization for grasslands.

- Documentation.

Resource Requirements

Currently RHESSys runs under UNIX environments on SUN and other workstations. The simulation models and digital terrain analysis is written in C. Graphic output and visualization of spatial patterns are accomplished with the a raster-based GIS.

Reservoir and River Modeling System

March 1995

Developer	United States Bureau of Reclamation, Great Plains Region, Billings, Montana
Description	ROMS is an user interactive computer model that simulates the operation of reservoirs and stream flow in a given river basin. The Rapid Creek Basin in South Dakota, is used to demonstrate the capability of this model. The model simulates the operation of the reservoir, reservoir releases for irrigation, river fishery, flood control and power generation. The model utilizes all of the user friendly features of Microsoft Windows.
Surface Water Applications	ROMS is an user interactive computer model that simulates the operation of reservoirs and stream flow in a given river basin. The Rapid Creek Basin in South Dakota, is used to demonstrate the capability of this model. The model simulates the operation of the reservoir, reservoir releases for irrigation, river fishery, flood control and power generation. The model utilizes all of the user friendly features of Microsoft Windows.
Features	The model is designed around the Windows environment and utilizes most of the user friendly features of Windows including:

- The model is designed to be interactive with various window versions of Spreadsheet programs providing a great deal of flexibility and the ability to take advantage of the many features of the spreadsheet programs including graphics, sorting, statistical evaluations, etc.

- Input data to the model can be easily edited through the use of a mouse and pull down menus.

- The model is designed around a basic framework which can be adapted to develop site specific reservoir system models.

- The model can operate over virtually any time frame ranging from one month to several years. The model can be easily set up to start its evaluation in any month of the year without modifying the runoff data in the data file.

- Although the model is designed primarily as a management tool to assist in operating existing reservoir and river systems it can also be used for planning purposes to evaluate proposed changed in the physical conditions on a river system or proposed changes in reservoir and river operating criteria or rules.

- Forecasted runoff data used as input to the model can be developed in an accompanying spreadsheet program and imported directly into the model.

- Help files are available providing documentation to the model as well as river basin and reservoir system schematics.

Resource Requirements

The model will run on most IBM compatible 386 or 486 PC's installed with Windows. A window version of a spreadsheet program is desirably to provide graphical display of the output or input data.

Fact Sheet -- RZWQM

Root Zone Water Quality Model
Version 3.0

May 1995

Developer

U.S. Department of Agriculture - Agricultural Research Service, Great Plains Systems Research Unit, Fort Collins, Colorado.
Contact Person: Ken Rojas, P.O. Box E, 301 S. Howes St., Fort Collins, CO, 80522, (303) 490-8326, (FAX) (303) 490-8310

Description

Root Zone Water Quality Model (RZWQM) simulates major physical, chemical, and biological processes in an agricultural crop production system. RZWQM is a one-dimensional (vertical in the soil profile) process-based model that simulates the growth of the plant and the movement of water, nutrients and agro-chemicals over, within and below the crop root zone of a unit area of an agricultural cropping system under a range of common management practices.

Water Quality Applications

The primary use of RZWQM will be as a tool for assessing the environmental impact of alternative agricultural management strategies on the subsurface environment. These alternatives may include: conservation plans on field-by-filed basis; tillage and residue practices; crop rotations; planting date and density; and irrigation- , fertilizer- , and pesticide-scheduling (method of application, amounts and timing).

The model predicts the effects of these management practices on the movement of nitrate and pesticides to runoff and deep percolation below the root zone. That is, the model predicts the potential for pollutant loadings to the groundwater thus allowing an assessment of nonpoint-source pollutant impacts on surface and ground water quality.

Features

RZWQM consists of six major scientific submodules or processes that define the simulation program, a Numerical Grid Generator, and an Output Report Generator. Interaction between these programs is achieved through the use of seven input datafiles and three generated output files. The user can create and modify input files using a commercial editor. The model generators three general output files with twenty-five optional debugging output files that provide detailed results generated by the model. The Output Report Generator uses model results to create summary tables and publication quality graphical output in 2- and 3-dimensional formats.

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- **Physical processes** include a large number of hydrologic processes; infiltration; chemical transport during infiltration; chemical transport to runoff during rainfall, water and chemical flow through soil matrix and macropores (i.e., root and worm channels), soil heat flow; fluctuating water table; tile drain, bare and residue-covered soil evaporation; crop transpiration; and soil water and chemical redistribution between rainfall and irrigation events. Snow accumulation and melt are also considered

- **Plant growth processes** predict the relative response of plants (corn, soybean, wheat) to changes in environment. Environmental changes can be manifest either as normal variations in climatic variables or by differences in management practices. The model simulates carbon dioxide assimilation, carbon allocation, dark respiration, periodic tissue loss, plat mortality, root growth, water and nutrient (currently only N) uptake.

- **Soil chemical processes** consist of the soil inorganic environment in support of nutrient processes, chemical transport, and pesticide processes. The chemical state of the soil is characterized by soil pH, solution concentrations of the major ions, and adsorbed cations on the exchange complex. The model is capable of handling soil solution chemistry across a wide range of soil pH.

- **Nutrient processes** define carbon and nitrogen transformation within the soil profile. Given initial levels of soil humus, crop residues, other organics, and nitrate and ammonium concentrations, the model simulates mineralization, nitrification, immobilization, denitrification, and volatilization of appropriate nitrogen.

- **Pesticide processes** include the transformations and degradation of pesticides on plant surfaces, plant residue, the soil surface, and in soil profile. Given the plant, crop residue, soil and pesticide characteristics, coupled with environmental conditions, the model simulates the fate of pesticides above and within the soil. Adsorption coefficients are updated daily to account for variations in organic matter decomposition and bulk density changes. Degradation algorithms allow for 1st order, 2 compartment/ 1st order, specific pathway, and daughter product dissipation.

- **Management processes** consist of description of management activities influencing the state of the root zone. It includes tillage practices and the impacts on surface roughness, soil bulk density, and macroporosity; fertilizer, pesticide, and manure applications; crop planting; irrigation scheduling for flood furrow, sprinkler, and drip systems; and BMP algorithms for dynamic nitrogen-rate determination. Soil surface reconsolidation as a function of time, rainfall, and tillage. Decomposition and bioincorporation of surface residues as affected by water content and temperature, to describe ridge-tilled and no-tilled systems.

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Limitations	● The crops parameterized are limited to corn, soybean and wheat.

● Both input and output are in metric units.

● The complexity of the processes and the need to interpret model results favor the technical staff of most agencies as model users.

● Frozen soil dynamics are not considered.

● Rainfall is entered as break point increments

● A fairly detailed description of the soil profile and initial state has to be known to give good simulation response for the system.

Support ● Although the model has not been released for general public consumption, information on the model is available upon request from the Technical Documentation, which may be obtained through a mutual collaborative agreement with USDA-ARS Great Plains System Research Unit, Fort Collins, CO.

● Once a collaborative agreement is established, the full support of the RZWQM development staff is available for all questions.

**Future
Developments** ● A special research version will be available soon which will have a complete balanced solution for the heat and water balance equations which included frozen soil conditions

● Expand the current management system to allow for regional evaluation of Best Management Practices (BMP's) in the midwest cornbelt over longterm simulations (> 10 years).

● Incorporation of the CROPGRO families of crop simulation models.

● Overland flow and erosion with chemical transport processes.

● Link to GIS system to study spatially distributed systems such as those on the farm scale.

● MS Windows™ interface.

**Resource
Requirements** RZWQM requires an 80386 or better CPU based computer with math coprocessor, one hard disk with at least 10 megabytes free space, one floppy disk drive capable of reading high density formatted disks (5-1/4" or 3-1/2"), IBM PC-DOS or MS-DOS operating system (Ver. 5.0 or later), at least 4 megabytes of RAM with 640 kilobytes of conventional memory, a graphic display card (VGA, EGA, or better).

Soil Water Budget Model for Irrigation Management

May 1995

Developer   U.S. Department of Agriculture, Agricultural Research Service, Water Management Unit, Fort Collins, CO 80523

Description   SCHED is a soil water budget model designed to aid producers improve their irrigation management, primarily under center pivots. Daily climatic data are used to calculate reference evapotranspiration (ET_{ref}) for a well-watered reference crop of alfalfa. Estimates of the average ET_{ref} beyond the current date are calculated using a exponential function that can be calibrated with local data. Actual crop water use is calculated by multiplying ET_{ref} by a computed crop coefficient based on either time since planting or time since effective cover as well as water stress coefficient based on depletion level in the root zone. Evaporation from a wet soil surface is also calculated using ET_{ref} and a coefficient based on soil type and time since wetting. Since infiltration is not modeled explicitly, irrigation and rainfall amounts are entered on a net basis and must reflect all runoff losses if the application rate exceeds the soil intake rate. Any part of the infiltrated depth in excess of field capacity for the root zone is considered to move through the root zone over several days depending on soil type. During this drainage period, this excess water can be used to satisfy crop water requirements. Upward movement of water from a shallow water table is not modeled.

Applications   SCHED can be run at an interval of 1 to 31 days. It can calculate general crop water use by various crops without regard to soil moisture or precipitation, or it can use predicted soil moisture depletions at two points in a field to recommend a range of dates for the next irrigation. The *earliest date* prevents irrigating too soon and causing deep percolation while the *latest date* assures irrigation before yield reducing stress occurs. If the timing of the next irrigation is desired, the user selects the amount of detail to be printed. The most detailed output produces daily values for crop water use, water applied, and depletion levels for two points in the field as well as a range of irrigation dates for each of 3 possible amounts of rainfall.

Features   ● User selection for:
        Units for input data
        Method of determining reference ET - modified Penman, Jensen-Haise or direct entry
        Units for output
        Detail of output presented

- Ability to calibrate reference ET equation based on local measurements

- Ability to add crops and modify the polynomial coefficients for describing crop coefficients

- Checking of input data within specified ranges

Limitations

- Does not partition applied water between infiltrated depth and runoff.

- Upward movement of soil water and effects of salinity are not modeled.

- Root zone modeled as a single layer.

- Only time based method for calculating crop coefficients is supported.

- Maximum update interval between schedules is 31 days.

- Output intended primarily for center pivots.

Support

Distribution disks, documentation, and technical support are available through the Water Management Research Unit, USDA -Agricultural Research Service, AERC CSU Foothills Campus, Fort Collins, CO 80523. Phone # (970) 491-8511.

Future Developments

- Simplified nitrogen budgeting with nitrogen management recommendations.

- Additional methods for computing crop coefficients will be supported.

- Optional graphical output of user selected variables.

- MS Windows environment

Resources Requirements

Requires IBM compatible microcomputer (preferably 80386 or better) with MS-DOS 2.0 or higher and 640K of RAM. A hard disk drive is recommended to minimize disk access time but a floppy disk system can be used.

Fact Sheet — SCS Scheduler

SCS Microcomputer Irrigation Scheduling Package
Version 3.0

May 1995

Developer
Department of Agricultural Engineering, Michigan State University, East Lansing, Michigan, and the U.S. Department of Agriculture, Natural Resource Conservation Service (formerly the Soil Conservation Service).

Description
SCS Microcomputer Irrigation Scheduling Package (ver. 3.00) (SCS-Scheduler) computes the water balance of crops and determines irrigation needs. SCS-Scheduler can handle an unlimited number of fields. Measured soil water data can be used to update soil water levels during the growing season.

SCS-Scheduler uses soil (soil water holding capacity by depth), crop (rooting development and crop coefficients), and weather (daily air temperature maximum and minimum, daily relative humidity maximum and minimum, six hour mean wind speeds, daily solar radiation, daily net radiation), and farm data (rainfall and irrigation) data. Historical information on air temperatures and rainfall is used to establish past records for determining rainfall probabilities and long-term evapotranspiration (ET) trends. Weather data are entered manually or automatically logged from an automated weather station. The water balance is computed based on the estimated ET and deep percolation and input rainfall and irrigation data. The crop coefficient data can be input based on a seasonal time scale or based on growing degree days.

Features
- SCS-Scheduler uses the modified FAO equation for reference or "potential" ET (ET_o).

- Local weather data from a Campbell 011 weather station can be transferred automatically via a telephone modem.

- Weekly rainfall probabilities can be directly entered or computed using historical data.

- Crop coefficients can be entered based on percent of growing season length based either on days or accumulated growing degree days (GDD).

- GDDs can be computed as the simple mean temperature less the specified base temperature.

- Rootzone depths are input and the soil water in each layer can be input.

- Measured soil water data can be used to update or adjust the water budget.

- Graphical outputs can display seasonal trends in soil water with irrigations and rainfall events.

- Graphs of excess water (either from rainfall or irrigations) and crop ET and ET_o as daily rates or accumulated values and graphs of daily weather data can be displayed and printed.

- Graphs of historical ET_o, GDD (accumulated or daily), and rainfall probabilities can be displayed and printed.

- English or metric units can be used for weather data inputs.

- Conversion programs are provided to convert previous SCS-Scheduler files to the current version.

- An irrigation schedule can be determined based on a predetermined net irrigation amount to determine the earliest date to avoid overfilling the rootzone.

- Irrigation schedule report shows the latest date for an irrigation before the soil water is depleted to the management level.

Limitations

- Runoff is not predicted directly, but any water received above the soil saturation is considered excess (runoff or percolation).

- Alternative ET_o equations indicated as options are not currently operational.

- Several data files are random access and not ASCII formats.

- Crop data files cannot be changed from seasonal days to growing degree days.

- Irrigation capacity is not considered as a constraint.

- Irrigation application losses are not directly considered.

- Growing degree day base temperature cannot be less than 35°F (1.7°C).

- SCS-Scheduler uses mean crop coefficients that do not directly account for irrigations or rainfall effects on ET (compared with the basal crop coefficients).

Support   Distribution diskettes and documentation are available through the Irrigation
                           Engineers at the NRCS National Technical Centers (NTCs).

**Future
Developments**
- Other ET_o equations can be included besides the modified FAO equation.

- Provide ASCII data input options for weather data from other files and
  from other weather station formats.

- Adjust GDD computations for minimum air temperatures below the lower
  base temperature and for maximum air temperatures above the upper
  temperature threshold.

**Resource
Requirements**   SCS-Scheduler requires a MS-DOS (ver. 3.0 or higher) compatible system
                           that has at least 512 kb (kilobytes) of random access memory (RAM) with a
                           hard disk with at least 3 Mb of available space with either a 3-1/2 in. or a 5-
                           1/4 in. diskette drive. A graphics adapter is needed for screen graphic
                           displays but is not required for program operation. A Hayes Smartmodem (or
                           Hayes compatible modem) with a 1200 baud speed is required for
                           communication to an automated weather station. SCS-Scheduler supports the
                           use of any IBM compatible dot matric or HP Laserjet printer. A Microsoft
                           mouse is desirable but not required.

Fact Sheet -- SNTEMP

Stream Network Temperature Model

May 1995

Developer   National Biological Service, Midcontinent Ecological Science Center, Fort Collins, Colorado. (Formerly U.S. Fish and Wildlife Service, National Ecology Research Center.)

Description   SNMP is a mechanistic, one-dimensional heat transport model that predicts the daily mean and maximum water temperatures as a function of stream distance and environmental heat flux. Net heat flux is calculated as the sum of heat to or from long-wave atmospheric radiation, direct shortwave solar radiation, convection, conduction, evaporation, streamside vegetation (shading), streambed fluid friction, and the water's back radiation (Figure 1). The heat flux model includes the incorporation of groundwater influx. The heat transport model is based on the dynamic temperature-steady flow equation and assumes that all input data, including meteorological and hydrological variables, can be represented by 24-hour averages.

**Water Quality
Applications**   SNTEMP was developed to help aquatic biologists and engineers predict the consequences of stream manipulation on water temperatures. Water temperatures may affect aquatic systems in many ways, ranging from acute lethal effects, to modification of behavioral cues, to chronic stresses, to reductions in overall water quality. Manipulations may include reservoir discharge and release temperatures, irrigation diversion, riparian shading, channel alteration, or thermal loading. The model has been used to help formulate instream flow recommendations, assess the effects of altered stream flow regimes, assess the effects of habitat improvement projects, and assist in negotiating releases from existing storage projects

Features   ● Applies to a stream network of any size or order.

● Predicts the solar radiation penetrating unshaded water as a function of latitude and time of year.

● Predicts the riparian and topographic shading of that radiation.

● Corrects air temperature, relative humidity, and atmospheric pressure as functions of elevations within the watershed.

● Fills and optionally smooths missing observed water temperature measurements.

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- Provides statistical goodness-of-fit tables to help judge the model's power of estimation.

- Uses time steps ranging from 1 month to 1 day.

- Uses readily available data.

Limitations

- Inability to deal with rapidly fluctuating flows. Uses an empirical approach to predicting maximum daily water temperatures.

- Turbulence is assumed to thoroughly mix the stream vertically and transversely (i.e., no microthermal distributions).

Support

- Technical Support is available from:
  National Biological Service
  4512 McMurry Avenue
  Fort Collins, CO 80525-3400
  303-226-9319

- Software is available from:
  Johnson Controls World Services
  P.O. Box 270308
  Fort Collins, CO 80527
  303-226-9413

- Training is available from:
  Conference Services
  Colorado State University
  Fort Collins, CO 80523
  303-491-7767

Future Developments

- The maximum daily water temperature calculations can be improved.

- Additional pre- and post-processor utilities will continue to be added as necessary.

Resource Requirements

SNTEMP requires an MS-DOS-compatible system that has at least 640k of memory and 3 megabytes of disk storage space. A math coprocessor or equivalent is required.

Seasonal Transport of Snow by Wind

May 1995

Developer	U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Laramie, Wyoming
Description	This spreadsheet computes the amount of water available from drifting snow in regions where most of the winter precipitation is snow, and much of this snowfall is relocated by wind. The user enters an estimate of winter snowfall, and the fraction of this precipitation that is relocated. The model computes the amount of drifting snow that is lost to evaporation, and the drifting volume that passes a point of interest during the design winter.
Applications	The model is the basis for designing snowdrift control structures such as snow fences. It is also useful in evaluating moisture conservation practices, such as snow storage by crop residue, in regions where winter snowfall is windblown. The computations provide estimates of deposition volumes in avalanche catchments.

Features

- Scientific basis, well-tested, metric and English units.

- Format compatible with most spreadsheet programs.

- Accounts for snow storage on the upwind fetch.

Limitations

- Assumes average winter conditions during the drifting.

- Assumes snow retention on the fetch is uniform.

Support	Available through R. L. Jairell, USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, 222 S. 22nd St., Laramie, Wyoming 82070 (307) 742-6621 Fax: (307) 742-0397.
Future Developments	This is part of a library of programs for designing snow drift control that is under continuing development.
Resource Requirements	Any computer system with a spreadsheet program that accepts a Lotus 1.2.3® file (*.WK1) in MS-DOS® format, or imports ASCII files (20K bytes).

Pit-Reservoir Design for Storage of Drifting Snow

May 1995

Developer	U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Laramie, Wyoming
Description	This spreadsheet aids design of small ponds in regions of the Great Plains where most of the winter precipitation is snow, and most of this snowfall is relocated by wind. The user gives values for winter snowfall, and the distance upwind to the nearest barrier to drifting snow. The program computes the total amount of water available from wind-transported snow, the pit size required to hold that water, the height of a snow fence that will maximize the volume of drift snow trapped, and the cost of the system.
Applications	The model computes the size and cost of snow fence/pit reservoir systems to provide or augment stock water on early-season pastures in the Great Plains. It is also useful in developing small riparian areas such as farm ponds, and in designing water supplies for wildlife, where snowdrifts offer the only water source.
Features	● Well-tested scientific basis. Metric and English units. ● Format compatible with most spreadsheet programs.
Limitations	● Does not account for snow storage on upwind fetch. ● Assumes snow deposition is 50% water. ● For use only where drifting snow is a significant part of the winter water balance.
Support	Available through R. L. Jairell, USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, 222 S. 22nd St., Laramie, Wyoming 82070 (307) 742-6621 Fax: (307) 742-0397.
Future Developments	We will add the option of tree rows in place of the snow fence. This program is part of a library of programs for designing snow drift control that is under continuing development.
Resource Requirements	Any computer system with a spreadsheet program that accepts a Lotus 1.2.3® file (*.WK1) in MS-DOS® format, or imports ASCII files (20K bytes).

Fact Sheet — SWMS-2D

An Interactive Graphics-Based User Interface for the SWMS-2D Code

May 1995

Developer

J. Simůnek[1], M. Sejna[2], and M. Th. van Genuchten[1]
[1] U.S. Salinity Laboratory, U.S. Department of Agriculture, Agriculture Research Service, Riverside, CA.
[2] PC Progress, Prague, Czech Republic.U.S. Salinity Laboratory

Description

An interactive graphics-based user interface was developed in support of the computer model SWMS_2D. SWMS_2D may be used to simulate two-dimensional water flow and solute transport in variably-saturated soils. The code also considers three-dimensional exhibiting radial symmetry about a vertical axis. SWMS_2D uses the Richards' equation for simulating variably-saturated flow and the Fickian-based convection-dispersion equation for solute transport. The user interface includes data pre-processing and graphical presentation of the output results in a Microsoft Windows 3.1 environment. Data pre-processing involves specification of the flow region having an arbitrary continuous shape bounded by poly-lines, arcs and splines, discretization of domain boundaries, and subsequent automatic generation of an unstructured finite element mesh. We also incorporated an alternative structured mesh generator for a simple quadrilateral domains. An unstructured triangular mesh is generated based on a Delaunay criterion. A small catalog of soil hydraulic properties was made part of the user-friendly interface. Graphical presentation of the output results consists of simple two-dimensional x-y plots, as well as contour and spectral maps, velocity vectors, and animation of both contour and spectral maps. Graphs along any cross-section can be readily obtained.

Water Quality Application

The model may be used to predict water and/or solute transfer processes between the soil surface and the groundwater table. The model may be an especially useful tool for (1) predicting water and solute movement in the vadose zone, (2) analyzing specific laboratory or field experiments involving unsaturated water flow and/or solute transport, and (3) extrapolating information from a limited number of field experiments to different soil, crop and climatic conditions, as well as to different tillage and water management schemes etc.

Features

A Microsoft Windows 3.1 interactive graphics-based user interface (GUI) was developed to facilitate data input and interpretation of model results. The interface was written in C++ using the Microsoft Visual C/C++ compiler. The GUI consists of five modules, and a dynamic linked library as follows:

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SWMS_2D

Main program unit and overall computational environment of the system. This module controls execution of the program and determines which other optional modules are necessary for a particular application.

POSITION

Dynamically linked library to manage data of existing projects, and to help locate, open, copy, delete and/or rename the desired projects, or their input or output data.

GEOMETRY

Windows application to design boundary curves of virtually any two-dimensional computational domain. Boundary curves can consist of any number of poly-lines, arcs, circles or cubical splines. The module allows one to specify internal boundaries (drains, wells, impermeable objects), as well as internal curves.

MESHGEN

Discretizes the two-dimensional flow region into an unstructured triangular mesh. The method used for generating the unstructured triangular mesh is based on a Delaunay criterion

BOUNDARY

Specifies the boundary and initial conditions, as well as spatial distribution of parameters describing the properties of the flow domain (materials, scaling factors, root water uptake, anisotropy tensor), and/or observation nodes.

GRAPHICS

Presents results of the simulation by means of contour maps, isolines, spectral maps, velocity vectors, and animation of both contour and spectral maps.

SWMS_WIN

The actual FORTRAN model simulating water and solute movement in two-dimensional variably saturated media. Relevant features of SWMS_WIN are:

● Numerically solves the Richards' equation for saturated-unsaturated water flow and the convection-dispersion equation for solute transport.

● The flow equation incorporates a sink term to account for water uptake by plant roots.

● The solute transport equation includes provisions for linear equilibrium adsorption, zero-order production, and first-order degradation.

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- The program may be used to analyze water and solute movement in unsaturated, partially saturated, or fully saturated porous media.

- The program can handle flow domains delineated by irregular boundaries.

- The flow region itself may be composed of nonuniform soils having an arbitrary degree of local anisotropy.

- Flow and transport can occur in the vertical plane, the horizontal plane, or in a three-dimensional region exhibiting radial symmetry about a vertical axis.

- The water flow part of the model considers prescribed head and flux boundaries, as well as boundaries controlled by atmospheric conditions.

- The program implements a simplified representation of nodal drains using results of electric analog experiments.

- The code implements a scaling procedure designed to simplify the Description of the spatial variability in the unsaturated soil hydraulic properties in the flow domain.

- Three stabilizing options are used to avoid oscillations in the numerical solution of the solute transport equation: upstream weighting, artificial dispersion, and performance indexing.

- The governing flow and transport equations are solved numerically using Galerkin-type linear finite element schemes.

- The matrix equations resulting from discretization of the governing equations are solved using: (1) Gaussian elimination for banded matrices, (2) the conjugate gradient method for symmetric matrices, or (3) the ORTHOMIN method for asymmetric matrices.

Limitations   The interface operates only under a Microsoft Windows environment. SWMS_2D does not handle preferential flow. SWMS_2D may fail for extremely nonlinear problems. Numerical instabilities may develop for convection-dominated transport problems when no stabilizing options are used. The effect of air phase on water flow is neglected. The spatial distribution of the root water uptake is constant with time.

Support   Distribution diskettes are available through the U.S. Salinity Laboratory, 450 Box Springs, Riverside, CA, 92 507

Resource Requirements   The SWMS-2D package requires a MS-DOS compatible system (386 with a mathematical co-processor, or better) running Microsoft Windows 3.1 (or later), 4 Mb of RAM memory, VGA (SVGA is recommended), and at least 10 Mb of available disk space.

Simulator for Water Resources in Rural Basins-Water Quality
NRCS-Version 321 OSCS94a

March 1995

Developer
U.S. Department of Agriculture, Agricultural Research Service, and Texas Agricultural Experiment Station, Temple, Texas.
Contact Person: Salvador Palalay, planning/hydraulic engineer, Northeast National Technical Center, 160 East, 7th Street, Chester, PA 19013-6092. Questions about SWRRBWQ and requests for copies of the model and model documentation should be directed to Sal at the aforementioned address or at (610)490-6063; Fax: (610) 490-6009.

Description
Simulator for Water Resources in Rural Basins-Water Quality (SWRRBWQ) simulates hydrologic and related processes in rural basins. SWRRBWQ is a comprehensive, continuous simulation model covering aspects of the hydrologic cycle, pond and reservoir storage, sedimentation, crop growth, nutrient yield, and pesticide fate. The objective of the model is to predict the effect of management decisions on water, sediment, nutrient, and pesticide yields at the subbasin or basin outlet.

A basin can be divided into a maximum of 10 subbasins to account for differences in soils, land use, crops, topography, vegetation, or weather. SWRRBWQ allows for simultaneous computation on each subbasin and routes the water, sediment, and chemicals from the subbasin outlets to the basin outlet. it also has a lake water quality component that tracks the fate of pesticides and phosphorus from their initial application on the land to their final deposition in a lake.

Uses
SWRRBWQ can model the effects of farm level management systems, such as crop rotations, tillage, planting date, irrigation scheduling, and fertilizer and pesticide application rates and timing. The effect these management systems have on the movement of contaminants can be tracked to the watershed outlet.

The model partitions nitrate loss between runoff, lateral subsurface flow, percolation, and crop uptake. Soluble and sediment attached phosphorus is calculated. The amount of pesticide lost with runoff and leached through the root zone is computed. Sediment yield is calculated using several procedures including the N RCS recommended Hydro-geomorphic Universal Soil Loss Equation (RUSLE). Nutrient, pesticide, and sediment yields at the basin outlet are determined after accounting for channel transmission losses and deposition.

Features

- The UTIL data assembly system provides for interactive data entry and editing. Help screens are provided. UTIL also has a routine that checks data parameters to ensure they fall within a specified range.

- Parameters from the SOILS-5 data base and a pesticide data base are housed internally in the model.

- Peak discharges are determined using the NRCS TR-55 unit peak discharge equation methodology.

- Sediment yield originating from cropland is determined independently from streambed and bank sources.

- The curve number can be adjusted at planting and at harvest.

- Automatic or manual irrigation and furrow irrigation are options.

- Measured monthly water and sediment yields can be input by the user. The model will make a statistical comparison on the measured and predicted values.

- The usefulness of ponds or reservoirs to trap sediment at the subbasin or the watershed outlet can be determined.

- Run-time graphics allow the operator to see selected processes being graphed as the model is executing. Any of the output variables can be plotted with respect to time (years). Eight graphs can be displayed on the screen simultaneously.

- Input is in English or metric units.

Limitations

- The internal weather generator is related to the same parent generator as the Water Erosion Prediction Project (WEPP) weather generator. The WEPP weather generator, which is still under development, has a problem reproducing local weather statistics.

- Measured daily precipitation and daily temperature can be entered as weather input to the model; however, the solar radiation is always generated.

- A maximum of 10 subareas per analysis is allowed.

- Organic waste applications are not modeled.

- As nutrients and pesticides flow from each subbasin to the basin outlet, no gradation occurs.

● Hydraulic residence time is not considered by the lake water quality module.

● Output is in metric units.

**Future
Developments**   SWRRBWQ is no longer under active development, however, the technology is now incorporated in the Soil and Water Assessment Tool (SWAT) under development in Temple, Texas.

**System
Requirements**   SWRRBWQ requires a MS-DOS compatible system that has at least 640K of memory and 10 megabytes of disk storage space. The use of a math coprocessor is not required, but is recommended.

Fact Sheet--TETrans

Trace Element Transport Transient-State SoluteTransport Model

May 1995

Developer

U.S. Department of Agriculture, Agricultural Research Service, U.S. Salinity Laboratory, 450 Big Springs Road, Riverside, California 92507 (Dennis L. Corwin, Ph.D.).

Description

TETrans (acronym for Trace Element Transport) is a functional, layer-equilibrium model of one-dimensional solute transport through the vadose zone under transient-state conditions. This type of model is often referred to as a "tipping-bucket model". TETrans is a capacity model that defines changes in amounts of solute and water content rather than rates of change. As such, it is driven by the amounts of rainfall, irrigation or evapotranspiration and only considers time indirectly by using the time from one irrigation or precipitation event to another. TETrans predicts the average concentration of a solute within each defined soil layer or depth increment. Transport through the soil profile is modeled as a series of events or processes for a finite collection of discrete depth intervals. These sequential events or processes include: (i) infiltration and drainage to field capacity, (ii) instantaneous chemical equilibration for reactive solutes, (iii) water uptake by the plant root resulting from transpiration and evaporative losses from the soil surface, and (iv) instantaneous chemical reequilibration. Each process is assumed to occur in sequence within a given depth interval as opposed to reality where transport is a collection of simultaneous processes. TETrans accounts for the hydraulic and physicochemical processes of water flow including preferential flow, evapotranspiration with a root growth and water uptake distribution function, adsorption-desorption, and drainage. The model determines the vertical profile distributions of total, soluble and adsorbed concentrations of a solute within and beyond the root zone; soil water content profile distribution; total drainage; total solute loading beyond the root zone; plant water uptake distribution; and leaching efficiency.

Applications

TETrans was developed around the design philosophy of user-friendliness both in operation and in the parameter input requirements necessary for its operation. For this reason, TETrans is best suited as a preliminary assessment tool for use in situations where minimal input data is available to the user.

TETrans was designed specifically for the application of simulating non-point source pollutants at a regional scale to determine areal distributions of solute loading to the groundwater. The model has been coupled to a geographic information system, ARC/INFO, to achieve this purpose.

Features   An IBM-compatible (TETrans 1.5) and Macintosh version (TETrans 1.6) of TETrans are available with accompanying user's manuals for either version.

- Default settings based on soil texture are available for some input parameters.

- The Macintosh version possesses a sophisticated graphics user interface (GUI) to simplify operation and data entry. The GUI is based on the menu-driven interface found on all commercial Apple Macintosh applications software.

- The Macintosh version possesses an internal run-time graphics package permitting the 2-D and 3-D graphing of output data. Any output variable can be plotted against time, depth or pore volumes of applied water.

- Internal data entry checks are made to warn the user of erroneous data entry.

- Internal diagnostic error messages are provided tto warn the user of attempts to simulate impossible solute transport scenarios.

- Input is in metric units.

Limitations   • TETrans assumes the soil to be a finite series of discrete layers differing in their physical and chemical properties. A maximum of 25 soil layers or horizons can be specified.

- Chemical equilibrium is assumed; consequently, kinetic reactions are not considered.

- Salt chemistry reactions including precipitation, dissolution and exchange reactions are not considered.

- Vapor phase flow, degradation and upward water flow are not considered.

- A fundamental description of dispersion-diffusion is not made within the model, rather a single hydraulic parameter the mobility coefficient accounts for bypass, dispersion and diffusion. The mobility coefficient can be estimated from chloride profile data.

- A knowledge of the amount of evapotranspiration between irrigation or precipitation events is needed as input.

- The time step for the model is from one irrigation or precipitation event to the next.

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- Calculated concentration distributions are average concentrations for each depth increment.

Support   Distribution of diskettes, documentation, source code, and technical support are available through Dr. Dennis L. Corwin, USDA-ARS, U.S. Salinity Laboratory, 450 Big Springs Road, Riverside, CA 92507 (phone: 909-369-4819 or fax: 909-369-4818).

Future Developments   Currently the constant capacitance chemical model has been incorporated into a research version of TETrans. Once validated and p tested, the additional chemical model will be incorporated into the user version for distribution.

- Account for upward water flow and solute movement.

- Account for the degradation of organic contaminants.

- Account for the transformations of nitrogen, ammonia volatilization, and plant nitrogen uptake.

- Account for the diffusion of a solute between mobile-immobile water phases.

- Account for vapor phase flow.

- Account for salt chemistry reactions.

- Account for the effect of salinity upon root water uptake distributions.

Resource Requirements   IBM-compatible version of TETrans (TETrans 1.5) minimum hardware requirements: 286 with I MB of RAM

Apple Macintosh version of TETrans (TETrans 1.6) minimum hardware requirements:
- MacPlus with 1 MB of RAM
- Preferable: Mac 11, SE/30 or higher with 4-5 MB of RAM . Macintosh System 6.0 or higher.

Fact Sheet -- UNSATCHEM

An Interactive Graphics-Based User Interface
for the UNSATCHEM Model

May 1995

Developer   J. Simůnek, D. L. Suarez, and M. Sejna; U.S. Salinity Laboratory, U.S.
                     Department of Agriculture, Agriculture Research Service

Description   An interactive graphics-based user interface was developed in support of the
                     computer model UNSATCHEM. UNSATCHEM may be used to simulate
                     one-dimensional water flow, carbon dioxide transport, heat transport, and
                     multicomponent solute transport with major ion equilibrium and kinetic
                     chemistry in variably-saturated soils. UNSATCHEM uses the Richards'
                     equation for simulating variably-saturated flow and the Fickian-based
                     convection-dispersion equation for heat, carbon dioxide, and solute transport.
                     The multicomponent chemistry is represented by the chemical speciation
                     model considering major ions (calcium, magnesium, sodium, potassium,
                     sulfate, nitrate, chloride, and alkalinity) and their interaction with the solid
                     phase. The user interface includes data pre-processing and graphical
                     presentation of the output results in a Microsoft Windows 3.1 environment.
                     Data pre-processing involves specification of all necessary parameters to
                     successfully run the UNSATCHEM Fortran code, the discretization of the soil
                     profile into finite elements, as well as definition of the vertical distribution of
                     the parameters characterizing the soil profile.

Water Quality
Application   The model may be used to predict water and/or solute transfer processes
                     between the soil surface and the groundwater table. The model may be an
                     especially useful tool for (1) predicting water and solute movement in the
                     vadose zone, (2) analyzing specific laboratory or field experiments involving
                     water flow and/or solute transport, and (3) extrapolating information from a
                     limited number of field experiments to different soil, crop and climatic
                     conditions, as well as to different tillage and water management schemes etc.
                     Knowledge of the salt content and distribution in the soil profile is a
                     requirement for efficient water management under arid and semiarid
                     conditions.

Features   A Microsoft Windows 3.1 interactive graphics-based user interface (GUI) was
                     developed to facilitate data input and interpretation of model results. The
                     interface was written in C++ using the Microsoft Visual C/C++ compiler. The
                     GUI consists of two modules, and a dynamic linked library as follows:

UNSATCHEM

Main program unit and overall computational environment of the system. This module controls execution of the program and determines which other optional modules are necessary for a particular application. The module contains both the pre-processing and post-processing units. The pre-processing unit includes specification of all necessary parameters to successfully run the UNSATCHEM Fortran code. At first the processes (water flow, chemical transport, heat transport, CO2 transport, root growth, and/or root water uptake) to be simulated are selected, the time and space scales are specified, boundary conditions are entered and so on. A small catalog of soil hydraulic parameters based on the soil texture is part of the pre-processing unit. The post-processing unit consists of simple x-y graphics for graphical presentation of soil hydraulic properties, time changes of a particular variable at selected observation points in the profile, and actual or cumulative water, CO2, and solute fluxes across upper and lower boundaries. The water content, pressure head, CO2, temperature, concentration (solution, adsorbed, precipitated) and chemical (SAR, EC, pH, pIAP, ...) profiles can be readily obtained.

POSITION

Dynamically linked library to manage data of existing projects, and to help locate, open, copy, delete and/or rename the desired projects, or their input or output data.

PROFILE

External module which may be used to discretize a one-dimensional soil profile into finite elements. The module also helps a user in the specification of initial conditions, as well as with the definition of the spatial distribution of other parameters characterizing the soil profile (e.g., spatial distribution of soil materials, root water uptake parameter), and/or observation nodes. All parameters in this module are specified in a graphical environment with the help of a mouse.

UNSATCH

The actual FORTRAN model simulating water, heat, carbon dioxide, and multicomponent solute movement with major ion equilibrium and kinetic chemistry in one-dimensional variably saturated media. Relevant features of UNSATCH are:

- Numerically solves the Richards' equation for saturated-unsaturated water flow and the convection-dispersion equation for heat, carbon dioxide, and multicomponent solute transport.
- The flow equation incorporates a sink term to account for water uptake by plant roots.
- The water flow part of the model considers prescribed head and flux boundaries, as well as boundaries controlled by atmospheric conditions, and free and deep drainage.

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- The root growth is simulated based on the degree day concept combined with a logistic growth function.
- The diffusion in both liquid and gas phases and convention in the liquid phase are considered as CO_2 transport mechanisms.
- CO_2 production is assumed to be the sum of the production rate by soil microorganisms and the production rate by plant roots.
- The reduction of the CO_2 production due to water and osmotic stress, as well as temperature and CO_2 concentration is considered.
- The program may be used to analyze water and solute movement in unsaturated, partially saturated, or fully saturated porous media.
- Solid phases considered: calcite, dolomite, gypsum, nesquohonite, hydromagnesite, sepiolite.
- Kinetic expressions for precipitation/dissolution of calcite and dissolution of dolomite are considered.
- The activity coefficients are calculated either with an extended Debye-Huckel or with Pitzer equations.
- Three stabilizing options are used to avoid oscillations in the numerical solution of the solute transport equation: upstream weighting, artificial dispersion, and performance indexing.
- The governing flow and transport equations are solved numerically using Galerkin-type linear finite element schemes.

Limitations

- The interface operates only under a Microsoft Windows environment.

- UNSATCHEM does not handle preferential flow.

- UNSATCHEM may fail for extremely nonlinear problems.

- Numerical instabilities may develop for convection-dominated transport problems when no stabilizing options are used.

- The effect of air phase on water flow is neglected.

Support

Distribution diskettes are available through the U.S. Salinity Laboratory, 450 Box Springs, Riverside, CA, 92507

Resource Requirements

The UNSATCHEM package requires a MS-DOS compatible system (minimum of 386 with a mathematical co-processor) running Microsoft Windows 3.1 (or later), 4 Mb of RAM memory, VGA (SVGA is recommended), and at least 10 Mb of available disk space.

Fact Sheet -- WASHOUT

Water-Alluvium-Solute Hydrographic OUTflow

May 1995

Developer U.S. Department of Agriculture, Agriculture Research Service, Northwest Irrigation and Soils Research Laboratory, Kimberly, Idaho.

Description The Water-Alluvium-Solute Hydrographic OUTflow (WASHOUT) program automatically analyzes furrow flow and runoff component data. The objective of the program is to compute and plot irrigation inflow, runoff, and infiltration values, and ongoing pollution-component-losses in furrow tailwater. Subsequently, WASHOUT computes net values for the above variables.

WASHOUT can optionally compute net application of a liquid additive (from a stock solution) that is injected into the furrow stream at the furrow head.

Program inputs are irrigation interval measurements of inflow and runoff rates, and outflow pollutant concentration. Input measurements and output data are processed for individual furrows.

Water Quality Applications WASHOUT can calculate the loss of sediment, fertilizer nutrients, pesticides, and other components in tailwater leaving irrigated furrows.

Features
- The Datachk3 utility examines data input files, ensuring that file format is correct and parameter values fall within an appropriate range. When errors are discovered, Datachk3 automatically loads the offending data segment into a text editor for correction, and replaces the original data with the modified text.

- Calibration functions relating measured component indexes to runoff component concentration (e.g. functions relating volume of settled sediment in Imhoff cones to mass of sediment per unit volume runoff) are automatically computed.

- Optionally, the user may request a piece-wise linear regression, entering the component index value at which slope transition occurs.

- Calibration functions can be computed separately for different furrow conditions and statistically compared to determine whether the individual functions are required to compute furrow component losses.

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- Inflow, runoff, infiltration and component loss rates are computed for each measurement interval during the irrigation. Irrigation duration may be given in hour units, or as a percent of the total irrigation set.

- Cumulative component loss (kg) and component concentration (g/L) in tailwater are computed for each measurement interval during the irrigation.

- Net component loss is computed by integrating the interval component loss-rate over the irrigation period.

- Net outflow is calculated by integrating outflow rate over the entire irrigation

- Graphical output may be displayed on-screen or printed to a variety of printers. Furrow output is plotted as a function of irrigation duration. Seven graphs and a data summary are displayed on-screen simultaneously.

- Furrow groups in the input data file can be identified and their output characteristics computed using data-base searching and averaging programs.

Limitations

- Component concentration in inflowing water is not directly addressed in the program.

- A maximum of 30 irrigation measurement intervals is allowed.

- A maximum of 20 irrigation inflow rate changes allowed per irrigation set.

- A maximum of 1000 monitored furrows allowed per input data file.

- Output is in metric units

Support

Program diskettes, documentation, and limited technical support are available through the USDA Agricultural Research Service, Northwest Irrigation and Soils Research Laboratory, Kimberly, Idaho.

Future Developments

- Directly include inflow component concentrations in calculations.

- Improve the program interface.

- Develop a Windows version of the program.

Resource Requirements

WASHOUT requires a MS-DOS compatible system with 640K of memory and 1 megabyte of disk storage space. A math coprocessor is not required.

Fact Sheet-- WATBAL

Subalpine Water Balance Model

May 1995

Developer   Rocky Mountain Forest and Range Experiment Station 240 West Prospect
Road, Fort Collins, CO 80524 Attn. C.A.Troendle

Description   WATBAL is a deterministic, process oriented water balance model that, once
calibrated, is useful in evaluating the effect of forest management or
vegetation manipulation/disturbance on water yield. Based on available data,
the watershed is divided into as many as 25 discrete hydrologic units. For
each unit, the model simulates canopy interception, net snowpack
accumulation and subsequent melt, surface interception and evaporation, flow
path (over vs through soil), transpiration, and streamflow. These are then
aggregated to watershed level. A nomographic version (WRENSS) has also
been developed. WRENSS does not address transport and timing processes
but it does simulate the water balance and changes in the water balance
resulting from manipulation.

Application   WATBAL is best suited for application in snow dominated hydrologic
regimes. However with the recent incorporation of PROSPER , to simulate
summer evapotranspiration, and VSAS, to simulate flowpath; the model
functions well in any hydrologic regime. WRENSS is a nomographic model,
developed from simulations using WATBAL,that works in the same
environments but is more generic and less data demanding.

Features   WATBAL has a menu that allows selection of simulation components. The
strength of the simulation is in the estimation of the change in the water
balance.

Limitations   WATBAL is very data demanding and requires knowledge of hydrology to
execute. WRENSS, on the other hand, still requires knowledge of hydrology
but it is far less data demanding and is usually operable on any watershed.

Support   WATBAL is currently supported by, and available from, the Rocky Mountain
Station in Fort Collins. Since it is primarily a research tool at this time, field
support, beyond consultations, is minimal. It has been used successfully by
numerous consultants and is part of their software packages.

**Future
Developments** Refinements in WATBAL will continue as research on the water balance
continues. Short term development will include better linking with growth and
yield models.

**Resource
Requirements** WATBAL requires an MS-DOS environment on a 386DX or larger system
with 8MB RAM and 200MB hard drive.

Fact Sheet -- WAVE03

Simulator of TDR pulse propagation

May 1995

Developer   U.S. Department of Agriculture, and Duke University Phytotron, Durham, North Carolina

Description   WAVE03 will simulate a TDR trace and choose the dielectric parameters of the TDR probe handle and waveguides that give the best match to the measured trace. The dielectric constant is the parameter that is directly related to the water content of soil surrounding the TDR wave guides. A calibration relationship between the dielectric constant and water content must be available. The model can also be used to obtain dielectric parameters from traces taken in association with measured water contents to construct a calibration function.

The simulator can find dielectric constants in soil with variable water content along the waveguides, and therefore the profile distribution of water contents can be determined with a set of waveguides of different lengths. In this case the dielectric parameters are found sequentially for each range of depth covered by waveguides starting from the soil surface.

The simulator is based on a multiple voltage reflection model that accounts for the effects of waveguide geometry and dielectric properties of soil on the propagation of high frequency electromagnetic waves and on their transmission and reflection at boundaries between homogeneous sections of the propagation pathways.

Water Quality Applications   The simulator can reliably analyze TDR data and therefore help to monitor the soil water regime at small spatial and temporal scales. Therefore small-scale spatial differences in water transport as well as small scale breakthrough of water below the root zone caused by storm events can be registered and quantified. This will provide reliable boundary condition information for water and solute transport models in the vades zone and in groundwater, which operate on larger temporal and spatial scales.

Features
- The WAVE03 simulator accounts for the rise-time of the TDR instruments.

- Short waveguides can be used.

- Subjective aspects of the common manual method to determine the dielectric constant are eliminated.

- Low soil water content can be determined reliably.

- Measurements of water contents with long vertical waveguides are possible.

Limitations
- Calculations are time consuming

- Rough initial estimate of water content is required.

- A separate calibration is needed for different handle-waveguide geometries of the TDR sensors.

Support   A distribution diskette and documentation are available from USDA-ARS, Systems Research Laboratory, Beltsville, MD.

Future Developments
- An automated method to obtain initial estimates will be added.

- More efficient solution method will be implemented to speed up calculations.

Resource Requirements   The WAVE03 simulator requires a MS-DOS compatible systems that has 640K of memory and at least 4 MB RAM, 3Mb of the disk storage space, and a math coprocessor.

Water Erosion Prediction Project

May 1995

Developers	U.S. Department of Agriculture - Agricultural Research Service (lead agency), Natural Resources Conservation Service, Forest Service; U.S. Department of the Interior - Bureau of Land Management, and United States Geological Survey.
Description	The Water Erosion Prediction Project (WEPP) computer program is a process-based, distributed parameter, continuous simulation, erosion prediction model which allows estimation of runoff, soil loss, sediment deposition, and sediment delivery from small upland watersheds or for individual hillslope profiles. WEPP incorporates modern hydrologic and erosion science, and was developed as a replacement for USLE technology. Individual hillslope profiles in WEPP can be divided into a maximum of 10 different land management units which allow for simulation of nonuniform soils, crops and management down a hill. In watershed applications, users can describe up to 75 hillslopes, 75 channels, and 25 impoundments for a total of 175 watershed elements.
Applications	WEPP will be applied in conservation planning, and inventory and risk assessments by the action agencies (NRCS, FS, BLM) and others. WEPP allows easy comparison of the effects of alternative management systems on cropland, rangeland, and forests. In addition to providing estimates of on-site erosion amounts and specific locations of soil detachment, WEPP also provides information on off-site sediment delivery and sediment characteristics. The extensive WEPP databases allow its application in every county in the United States.
Features	● A user-friendly interface provides easy access to databases, existing WEPP input and output files, input file building programs, and output viewing programs. Extensive on-line help is available. ● A soils database containing WEPP parameter information for almost every soil in the United States allows widespread use within the U.S. ● The CLIGEN model and database allow creation of simulated climate sequences for over 1000 weather stations within the United States. WEPP can run in both a single storm and a continuous simulation mode. ● Storm events are approximated with a double exponential curve storm shape when generated climate is used. Users also have the option of creating and inputting to the model break-point precipitation files which may contain observed storm data.

- A modified Green and Ampt equation is used to estimate infiltration and predict rainfall excess.

- Solutions to the kinematic wave equations or approximations to these solutions are used to predict peak runoff discharge rate on hillslopes. In watershed applications, a modified Rational formula (modified EPIC) or the CREAMS method (empirical equations) are used to predict peak runoff rates in channels.

- Erosion estimates are based on a steady-state sediment continuity equation, with contributions to sediment load coming from both rill and interrill areas. Interrill erosion is driven by rainfall intensity and runoff rate. Rill and channel detachment are functions of excess flow shear stress. Sediment transport capacity is computed using a modified Yalin equation. Sediment deposition is predicted when sediment load exceeds transport capacity.

- Plant growth is based upon heat unit accumulation, with a harvest index to partition yield. Biomass production is a function of Photosynthetic Active Radiation. Growth is limited by water and temperature stresses.

- Residue decomposition is based upon decomposition day theory, with decomposition rate affected by moisture and temperature conditions.

- The Plant/Management input file builder contains 35 cropland plant parameter sets, 10 rangeland plant community parameter sets, and 78 tillage implement parameter sets. A separate program called CPIDS (Crop Parameter Intelligent Database System) assists users in developing crop parameters for plants not in the WEPP database.

- Depletion-level and fixed-date scheduling options are available for both stationary sprinkler irrigation systems and furrow irrigation systems.

- Winter components of the WEPP model are based upon simple heat flow theory, which estimates frost and thaw development in the soil, as well as snow accumulation and snow melt water generation.

- The effects of impoundments such as farm ponds, terraces, culverts, filter fences, and check dams, on sediment discharge and sediment characteristics can be estimated.

Limitations   WEPP is designed to estimate sheet, rill, and channel erosion due to runoff from overland flow. It is not designed for estimation of erosion in perennial streams and channels. WEPP is not designed for estimation of other types of erosion processes, such as mass failure which is typical in classical gully erosion and landslides.

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- Current limitations as imposed by model developers are 10 flow elements per hillslope, 75 hillslopes per watershed, 75 channels per watershed, and 25 impoundments per watershed.

- Compaction effects due to machinery or livestock traffic are not currently modeled. Manure applications are not currently modeled.

Support

Developmental versions of WEPP and supporting programs and documentation are currently available through anonymous FTP on the Internet to the USDA-ARS National Soil Erosion Research Laboratory (NSERL) file server (*soils.ecn.purdue.edu*).

- This information is also available through a World Wide Web home page link at the NSERL (*http://purgatory.ecn.purdue.edu/NSERL/nserl.html*).

- For users without Internet access, diskettes and documentation can also be provided by the NSERL.

- Model maintenance and support following final delivery will continue at the NSERL, though hard copy distribution duties may be handled by others.

Future Developments

Placement of all final WEPP programs, databases, documents, and training materials in a publicly-accessible location on the Internet. This will likely be the major means of delivery, as well as the means of routinely scheduled updates.

- Additional functionality, particularly for forests and disturbed land sites will be added to future updates of the model.

- Expanded plant and field implement data sets will become available through the user agencies.

- Continued recoding of the model code will improve its maintainability and execution efficiency.

- Use of new compilers will allow increased flexibility in model use due to dynamic memory allocation.

- The Grid application version of WEPP is still under development and will allow linkage with a GIS.

Resource Requirements

WEPP requires a 386 class or better IBM-compatible personal computer (PC) with a math coprocessor, running DOS 5.0 or greater. A minimum of 15 Mbytes of disk space is required on the hard drive for installation of the program, interfaces, and databases. Extended memory, a fast disk drive, and a color monitor are helpful.

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Fact Sheet -- 2DSOIL

Two-dimensional Modular Soil Simulator for Crop Modeling

May 1995

Developer   U.S.Department of Agriculture, Duke University Phytotron, Durham, North
                       Carolina, and Department of Agronomy, University of Idaho, Moscow, Idaho.

Description   The two-dimensional Modular Soil Simulator for Crop Modeling (2DSOIL)
                       simulates transport of water, solutes, heat and gases, root growth and uptake,
                       transformation of nitrogen-containing compounds, and chemistry of
                       macroelements in soil. 2DSOIL is a modular simulator constituted of highly
                       independent modules modeling separate processes. Modules are easily
                       replaceable and the simulator is easily expandable and interfaceable with plant
                       and micrometeorologic models. The purpose of the simulator is to predict the
                       effect of management practices on water and nutrient transport in soils for
                       row crops and intercrops.

                       A soil profile between rows of crops is divided into cells. For each cell,
                       2DSOIL provides for computations of water, solute, heat, and gas transport
                       driven by and affected by root uptake, surface evaporation, precipitation and
                       irrigation, application of chemicals, tillage, residue placement, and engineered
                       drainage.

Water Quality
Applications   The model can trace the amount and chemical composition of solutions
                       leaving the soil profile to percolate into the vadose zone. It can simulate the
                       effect of management practices on the quality of the soil solutions below the
                       root zone. Seasonal variations in soil leachate compositions and effect of
                       storm events can be traced.

Features   ● The 2DSOIL simulator can be interfaced with comprehensive plant
                         models to improve their assessment of effects of plant growth and
                         development on the soil leachate quality.

                       ● The expendability of the 2DSOIL simulator makes it easy to add detailed
                         submodels of management practices.

                       ● Uneven soil surfaces, ridges, local placement of chemicals and residues
                         can be modeled

                       ● The graphic user's interface facilitates subdivision of the soil profile into
                         cells

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	● Flood, furrow, sprinkler, and drip irrigation can be modeled
Limitations	● The 2DSOIL simulator requires soil water retention and soil hydraulic conductivity data.
	● Surface sealing and crusting are not modeled.
	● A programmer is required to interface 2DSOIL simulator with plant and atmosphere components of a crop model.
	● A separate graphic software is required to visualize distributions of water, chemicals, heat, and gases within the soil profile.
Support	Distribution diskettes, documentation, and technical support are available from USDA-ARS, Systems Research Laboratory, Beltsville, MD.
Future Developments	● The library of modules will be expanded to simulate existing and new management practices.
	● A pesticide property data base will be included in the simulator.
	● A set of standard subdivisions of the soil profile into cells will be included.
	● Graphic capabilities to visualize results will be developed
Resource Requirements	The 2DSOIL simulator requires a MS-DOS compatible systems that has 640K of memory and at least 4 Mb RAM, 3Mb of the disk storage space, and a math coprocessor.