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# CAPABILITIES AND LIMITATIONS OF THE CREAMS MODEL
## (Methodological Aspects)

V.A. Svetlosanov

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INTERNATIONAL INSTITUTE FOR APPLIED SYSTEMS ANALYSIS
A-2361 Laxenburg, Austria

# PREFACE

During the three years between 1978-1980, work on the collection and assessment of the existing models which describe the environmental impacts of agriculture has been carried out at IIASA. The work concentrated on the problems of soil erosion, nitrogen leaching, and phosphorus and pesticide losses. A complex field level model (CREAMS), which can be used for analysis of the above mentioned problems, has been implemented on the IIASA computer and (using this model) research in various countries has been done. A Task Force Meeting (Golubev and Shvytov, 1980) held in June 1980 by IIASA summarized the use of mathematical models for agricultural environmental processes on different field and watershed levels and advanced the understanding of some methodological questions. The main question dealt with the feasibility of transferring the investigation from a field level to a regional one, and the possibility of using a field level model on a regional level. This paper attempts to clarify some aspects of this question.

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## INTRODUCTION

The global population growth and the increasing demands for agricultural products lead on the one hand to the extension of agricultural land and on the other to the intensification of land use. Both methods have detrimental effects on the environment. The problems of agricultural influence on the environment have a global character (for example, see Golubev et al., 1978). Since the beginning of 1978, the analysis of the environmental problems of agriculture is one of the research issues in the Resources and Environment Area at IIASA (Golubev and Shvytov, 1980).

Mathematical models offer one important instrument for investigation of the environmental problems of agriculture. Presently, there are a number of mathematical models dealing with different environmental consequences of agricultural production (Haith, 1980). Of course, there are no perfect and universal models accounting for all environmental consequences of the production yield. Most of the models (Haith, 1980) deal only with a hydrological component, and some of them include the erosion process, but only four (Haith, 1980) consider a combination of factors: a hydrological component, an erosion/sediment component, a pesticide component, and a chemical pollution component from the fields. The scale of application of these models is a field or watershed. At present there are no regional models to evaluate environmental effects of alternative agricultural policy. One possible way to accomplish this, however, is to attempt to use the field level models on a regional level (Golubev and Shvytov, 1980). But before this is done, one must clarify the limits of agricultural field models. This paper makes such an attempt, using the CREAMS model as an example.

## THE BASIS OF THE CREAMS MODEL

The CREAMS model is one of the four models which comprehensively describe the environmental effects of agriculture (Knisel, 1980). This model, developed by the US Department of Agriculture, quantitatively evaluates runoff, the erosion process, and sediment transport, plant nutrient, and pesticide yield from agricultural fields, as a function of rainfall, soil conditions, crops, fertilizers, etc. The CREAMS model program was implemented on the IIASA computer and used to analyze hydrological and erosion processes and nonpoint source chemical pollution from fields. The results of management practices and management alternatives in eight European countries were evaluated.

Let us now consider briefly the mechanism of this model as well as some of its positive and negative aspects. Two papers have been published which use the CREAMS model as an example in discussing the above mentioned problems in England and Czechoslovakia (Morgan, 1980; Holy et al. 1981). Forthcoming papers will round out the analyses of the use of the CREAMS model in various countries.

It was noted that the CREAMS model addresses questions at the field level. In creating this model, the scientists wanted to develop a model which would not require special calibration for different geographical areas. Let us consider this model from the aspect of "homogeneity" of an agricultural field, because the concept of "homogeneity" is the major logical construct for the model. "Homogeneous" means that the field or area considered contains a relatively homogeneous soil composition, experiences uniform distribution of preceiptation, and that the same management practices are applied. If the actual field conditions conform to the definition of homogeneity, the size of the field need not be considered.

The CREAMS model consists of three main parts which generate the output data, characterizing the hydrological, erosion sediment, and chemical pollution processes. The peculiarity of this model is that, relatively, it needs a great deal of initial information--the number of parameters and input data required for the CREAMS model exceeds 70. In fact, the researchers do not usually have complete information for the CREAMS model, but this can be solved in multiple ways. For instance, sometimes additional observations must be made, at other times the values of the coefficients can be taken from the literature, etc.

The first part of the model is the hydrological component, which is extremely important since water is the principal element of the system. The output data from this component defines the erosion process, and sediment and chemical losses from the field. The hydrological component of the CREAMS model includes consideration of many physical processes which deal with water and soil - infiltration, surface runoff, percolation through the root zone of the soil, and evapotranspiration (both soil and plant evaporation losses). The hydrological component uses two options and the choice of one depends on the available data; it can use daily rainfall data (Option 1) or hourly rainfall data (Option 2). The hydrological component of the CREAMS model includes consideration of the geographical position of an agricultural field, topography of the slope, climatic conditions, composition of the soil, and other factors. The number of parameters defining the hydrological component is more than 20. The sensitivity analysis of the CREAMS model (Knisel, 1980) showed three parameters of the hydrological component which influence the final hydrological output very strongly. The first one is the portion of available water storage plant filled at field capacity, the second is the soil evaporation parameter, and the third is a runoff curve number for the antecedent moisture condition. The concrete meaning of the last parameter is taken from the National Engineering Handbook (Knisel, 1980). Note that the quantitative values of these parameters must be measured very carefully since the model is very sensitive to small changes in their values and the deviations in the initial information will be multiplied by the following parts of the CREAMS model.

The second part of the CREAMS model is the erosion component. This component of the CREAMS model is very closely connected with the hydrological component, which defines the physical process of soil detachment, transport, and deposition. Bird drops detach particles from the soil and cause them to run off. The process is defined by the sediment transport capacity. All detached particles will be removed from the field if the sediment load is less than the sediment transport capacity, otherwise deposition of the soil particles will occur. The model used two options: if using the first one, distribution of the soil particles must be known. If this distribution is not known, the second option is used and it is assumed that there are five particle types. The erosion component includes consideration of the primary particles and their aggregation. The amount of sediment depends on the soil properties, rainfall and runoff, and management policies. The calculation of storm energy depends on the available data: daily or hourly rainfall. The calculation of the erosion/sediment component takes into account configuration of the slope segments. The sensitivity analysis of this component indicates three parameters which are of particular significance from the point of view of the total sediment yield: (1) hydraulic overland flow roughness, (2) channel slope, and (3) friction slope.

The third component is chemistry, which is related to the first and second components. The basic idea defining this component is that nitrogen and phosphorus mix with soil particles in the runoff, whereas soluble nitrogen and phosphorus are removed with the surface runoff. The processes of the removal of nitrogen in the form of nitrate by leaching, by denitrification, and by extraction from the plants, are also considered. Of sixteen chemical elements necessary for the plants, the CREAMS model calculates an average concentration of soluble nitrogen and phosphorus in the runoff, and the average concentration of the nitrate leached from the soil. The chemical component is the most complicated one, because it takes into consideration all elements of the CREAMS model: weather and soil, topography, and crops.

The authors of the CREAMS model considered the sensitivity parameters of the model to different values of nitrogen and phosphorus in runoff and in sediment, leached nitrate and uptake. They concluded that the results depend on certain values of the parameters which are fixed.

## SOME DIFFICULTIES AND RESTRICTIONS IN USING THE CREAMS MODEL

Every model simplifies reality, their purpose being to reflect the most important features of the actual situation. The CREAMS model was developed to describe only certain processes in the agricultural field, such as: runoff, water erosion, pesticide, and plant nutrient losses from the field area. But the question arises: is it possible to use the CREAMS model on a regional level of investigation? (To be discussed later). At present, we want to mention that at the regional level, there are numerous environmental consequences, but the CREAMS model deals with only some of them. The processes of soil condensation, irrigation, salinization and waterlogging, reservoir silting, drainage, wind erosion, etc., are not covered by the CREAMS model. The CREAMS model does have several restrictions partly because it considers only inorganic fertilizers, and not organic fertilizers as well. The agricultural field being studied must be isolated. The runoff, soil particles, and nutrients from other fields cannot enter the field studies. This circumstance must be taken into consideration for comparison of the model output with measured data.

One of the main difficulties in using the CREAMS model is incompleteness of the required initial information although this situation is sometimes provided for in the CREAMS model. In particular, option 1 of the hydrological component is used when there is no hourly rainfall data. But, physically, the erosion process is defined first of all by the intensity of rain and its volume. It may be possible to say that in the case of daily rainfall data (Option 1,which is used more often than Option 2), we have the first order of time aggregation procedures, which may be useful when investigation on a regional level is considered. Concerning aggregation, field level models also present an example of the first order of the solution of space aggregation problem, because in reality there are no completely homogeneous fields. In the field environmental models, one must aggregate from the points of measurement to a field generalization. The first order aggregation over space and time allows the use of physical laws or regularities. In certain cases where there are no physical laws or regularities, statistical relationships on the basis of field observations are used in the field level agricultural model.

The problem of initial numerical information applies to all branches of science when there is no precise experiment to generate the necessary data. Many complex environmental models need data from a long period of time, but usually, not all components of the models contain adequate initial information. Obtaining precise measurements for some components of the models can create considerable economic expense. As a result, a difference between real and model output data is inevitable. This question is especially important in certain case studies using the CREAMS model as an investigative tool. The natural question concerning the comparison of real and model results is: "If the comparison reveals differences, does the model badly reflect reality and vice versa?" The answer to this question can only be arrived at through analysis of coefficients and parameters of the model, and precisely measured information. In many cases the deviation of model data from observed data should not lead to the conclusion that the model inadequately reflects reality, because the deviation can be the result of poor data collection. The analysis of real and model output is especially important for the calculation of erosion and chemical pollution, because these components of the CREAMS model use the calculated results from the hydrological component as input. However, this means that miscalculations of the initial information will be summarized in future. The test of model sensitivity is very important, as the estimation of the sensitivity of every parameter in the CREAMS model is made under the fixed determined values of other parameters (Knisel, 1980). But let us note that under other fixed determined values of these parameters, another set of parameters may become sensitive.

## POSSIBILITIES OF USING THE CREAMS MODEL ON A REGIONAL LEVEL

What is the feasibility of using the CREAMS model at a regional level? It must be remembered that this model covers only some of the environmental problems of agriculture. Therefore, to answer the question, another question should be posed: What are the principal similarities and differences in the consequences arising from agricultural policy in a field and a region? A partial answer to the first half of this question is that both a field and a region are subject to the same natural input: precipitation, radiation and temperature changes. They also have the same output: evapotranspiration, surface runoff, percolation, and chemical pollution.

The first obvious difference between a field and region is their size. However, the concept of a field is unrelated to its size. A field can be one acre or a few hundred, and both these sizes of field were used in the CREAMS model. The essential characteristic of a field is its homogeneity--homogeneity of the field surface, a relatively homogeneous soil, uniform rainfall, and single management practice.

Therefore, the principal difference between a field and a region is that every region has a very complicated configuration, consists of many fields and does not have homogeneous soil, rainfall, plants, or management practice. But, perhaps one were to divide the region into several parts and, using certain procedures, obtained rather large, but relatively homogeneous model areas; is it possible to use the CREAMS model for these areas? In other words, can one apply the same mathematical relationship used on the field level to large areas? Relevant to this question, is the researcher's statement that the CREAMS model does not require calibration for each specific application. But in fact, many of the mathematical equations of the CREAMS model have limitations. Some examples of this follow. In the hydrological component of the CREAMS model, the equation for peak runoff rate QR is:

$$QR = 200 \bullet (DA)^{0.7} \bullet (CS)^{0.159} \bullet (Q)^{(0.917 \bullet DA^{0.0166})} \bullet (LW)^{-0.187}$$

where DA is the drainage area, CS is the mainstem channel slope, Q is the daily runoff volume, and LW is the length-width ratio of the field. It is easy to see here that there are many coefficients stemming from field study. In order to obtain these coefficients, the data from 304 storms were fed into the CREAMS model. The size of the field areas which were analyzed varied from 0.275 to 24 $mi^2$. There is no statistical information to extrapolate from the size of the areas. Considering the detachment equation, one can determine parameters by observation. For example, the coefficient m, which represents slope length, is constant for a slope less than 150 ft. and there is an experimental equation to calculate the value m for a slope longer than 150 ft. The Yalin sediment transport equation was chosen and modified to describe sediment transport capacity. Some constants in the equation were derived empirically. With the nutrient component, one can find a number of empirical coefficients. Some coefficients are not exactly defined. For example, the amount of soluble phosphorus which contains the phosphorus extraction coefficient was calculated. However, the exact values of the phosphorus and nitrogen extraction coefficients are unknown. These coefficients were chosen from the observed data.

The erosion process is defined by rainfall and runoff. The CREAMS model uses the equation:

$$EI = 8.0 \bullet V_R^{1.51} \quad ,$$

for storm EI when daily rainfall amounts are used; $V_R$ is volume of rainfall. This approximate equation was developed using the regression analysis from 2700 data points.

Using empirical relations is a traditional approach in complex investigations of nature. The use of regression analysis is necessary and extremely helpful in evaluating the numerical coefficients of empirical relations. Nevertheless, the necessary restrictions must be kept in mind. For example, suppose some relatively homogeneous areas were chosen and using its natural characteristics, e.g. soil, climate and morphology of the slopes, the empirical coefficients of some equations were calculated. The numerical values of these coefficients are defined by the average characteristics of the areas. Because the areas are not really homogeneous, the increasing number of areas considered or the territorial expansion of any one area can change the numerical values of the coefficients. With the CREAMS model, the authors rely on a large set of statistical data and as a result, such an approach yields very good empirical relationships. But in principle, the use of these empirical relations is defined by concrete agricultural fields and through them by the size of the areas which were studied. Transference of these relations to larger areas is not acceptable. The following approach is therefore suggested. To include more and/or larger areas in a study, calculation of the average characteristics of these areas by aggregation must first be done. Then, a recalculation must be made of the empirical coefficients of the equations on the basis of the regression analysis, taking into account the average characteristics of the areas and some additional effects which can occur at the regional level. Further calculations may be made following the methodology of the CREAMS model. This approach will represent the second order of the space aggregation.

## CONCLUSIONS

The CREAMS model is a complex model for the field level which relies, when possible, on physical laws and regularities. Like every model, the CREAMS model has some coefficients and parameters which are defined by statistical data from different agricultural fields. The calculation of the numerical values of these coefficients and parameters relies on the large set of statistical data of the specific sizes of agricultural areas. Expanding these areas can lead to a change in numerical values of the coefficients. As a result, using the CREAMS model without making alterations for a regional level can lead to deviations from the real data.

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