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Project Summary

Areal Predictions of Water and Solute Flux in the Unsaturated Zone

Arthur W Warrick and Azizolah Amoozegar-Fard

This investigation was undertaken to develop procedures for evaluating distribution of water and salt fluxes over land areas. Relevant applications include numerical simulations and sampling in fields of large areal extent. The primary focus is on irrigated lands including effects of salinization and crops on the ground and surface waters. The study was in three parts: 1) observations of distributions for a variety of soil physical parameters and inference on sampling; 2) simulations of water and salt fluxes for nondeterministic systems; and 3) a sensitivity analysis for drainage. The major emphasis was placed on Part 2.

Simulations of water and salt fluxes were made using the "crude" Monte Carlo technique. For infiltration, "Philip's" equation was utilized in a scaled form by solving one time. Individual simulations were made algebraically without repeating the laborious steps of resolving the unsaturated moisture flow equation each time. Similarly, results for the nonlinear drainage case were solved based on only one finite difference determination. The Monte Carlo simulation was carried out by simple interpolation from the one nonlinear solution. Unfortunately, no great short-cut was found for cyclic or *seasonal irrigation regimes,* although some interesting results based on linearized solutions were found for high frequency water applications.

Salt distributions were calculated for cases of equal irrigation amounts over time but with intake rate varying over space. Deterministic calculations based on the mean velocity and apparent diffusion coefficient gave erroneous results compared to the "average" values over the field for both salt profiles or fluxes. The true "average" by depth for a given time is much more dispersed, with more salts reaching very deep depths and also with more salts remaining close to the surface when pulses of salt are added. Similarly, the mass emission of salts averaged over a field for a given depth appear earlier in time and taper off more gradually for a pulse input than deterministic calculations based on mean velocities would indicate.

This Project Summary was developed by EPA's Robert S. Kerr Environmental Research Laboratory, Ada, OK, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

This two-year study dealt with areal predictions of water and solute fluxes within the soil profile The project was designed to develop methods to account quantitatively for the inherent variability of soils over a region — such as an irrigated field or larger. Two very important observations should be made in terms of trends of current research and awareness since the inception of this project: (1) there has been a tremendous increase of interest in variability of soil properties; and (2) there has been an equally impressive increase of interest among hydrologists and soil scientists with regard to geostatistical techniques which were largely ignored until recently.

Soil scientists (and farmers) have always recognized that soils are heterogeneous. The approach to the problem has necessarily been almost universally deterministic in nature. The procedure has generally been to sample, average the samples, and use the results to make calculations. For example, if a mass flux of salts is needed, the land area is multiplied by the "average" profile results to get total emissions. That such an approach may not give the right answer is stated in elementary works on stochastic processes (e.g. Hammersly and Handscomb, 1964, p. 13) and is demonstrated in the case of mean water flux by Warrick et al. (1977b) and in results from this project. In some cases, a choice other than the arithmetic mean may be appropriate; in other cases, no "average" value may be satisfactory to obtain an overall response or integrated estimate. Efforts to adequately assess confidence of results have been generally lacking.

The techniques within this project are somewhat intermediate between the deterministic and the geostatistical methods. Ramifications of spatial variability are pursued in terms of water and salt fluxes, primarily by Monte Carlo simulations. It is hoped that sampling and confidence intervals can be obtained more efficiently in the future, by taking advantage of what is known of the spatial structure and by using geostatistical techniques (Journel and Huijbregts, 1978).

These problems of area distribution and predictions encompass all aspects of earth sciences. An immediate and obvious connection between soil physical properties and soil maps exists and suggests mutual benefits for close cooperation between classifiers and the soil physicists. Not only is this true for soil physical measurement, but also for other soil properties, e.g., fertility level, chemical activity and distributions of biomass and microbes.

Conclusions

Observed variations of soil parameters in the literature were reasonably consistent when more than one source was found. Generally these parameters can be grouped into three classes:

1. Low variability — (Coefficient of variation less than 20%)
   - Bulk density
   - Water content at a zero tension
2. Medium variability — (Coefficient of variation 20-75%)
   - Textures (sand, silt or clay)
   - Field water content
   - Water content at specified tension between 0.1-15 bars
3. High variability — (Coefficient of variation greater than 100%)
   - Saturated hydraulic conductivity
   - Unsaturated hydraulic conductivity
   - Apparent diffusion coefficient
   - Pore water velocity
   - Electrical conductivity of extract
   - Scaling coefficients.

Sample numbers may be estimated assuming independence and that the central limit theorem applies, by

$$N = t_\alpha^2 s^2/d^2$$

where N is the number of samples, t_α is the "Student's t" with n-1 degrees of freedom at a probability level of α, s is the standard deviation of the mean, and d is a specified limit. Table 1 shows an analysis of the number of samples required to estimate the mean values of selected soil properties within 10 per cent at the 0.05 significance level.

Scaling techniques offer distinct advantages in terms of economy of calculation and in synthesizing large volumes of data. Figure 1 demonstrates the results of scaling the hydraulic head values for 840 data points. The scaling (based on the assumption that the internal geometry for similar media differs only by the characteristics size) process coalesces the data points into a curvilinear function as shown in Figure 1, A & B. In this particular data set the sum of squares of the scaled data was reduced by 80 percent over the same form of equation for the non-scaled data.

Solute movement is a function of soil water flux and apparent diffusion coefficient. Use of the deterministic value of these parameters can result in erroneous estimates of solute concentration and movement when the pore-water velocity and apparent diffusion are highly variable. Figures 2A and 2B show the solute concentrations with depth after five days using a deterministic approach compared to the mean values for step

Table 1. *Summary of Approximate Number of Samples Required to Estimate Mean Values Within 10% at 0.05 Significant Level (After GUMAA, 1978)*

		Soil Depth, cm				
Parameters	*Field*	*30*	*60*	*90*	*120*	*150*
Low Variation						
Bulk density	*1*	*1*	*1*	*1*	*1*	*1*
	2	*1*	*1*	*1*	*1*	*1*
	3	*1*	*1*	*1*	*1*	*1*
Medium Variation						
In situ field	*1*	*10*	*28*	*24*	*47*	*2*
capacity	*2*	*12*	*23*	*61*	*49*	*75*
	3	*10*	*9*	*15*	*10*	*24*
In situ available	*1*	*21*	*43*	*35*	*55*	*45*
water capacity	*2*	*55*	*36*	*110*	*78*	*116*
	3	*47*	*31*	*33*	*30*	*45*
15 bars	*1*	*20*	*55*	*33*	*57*	*47*
	2	*25*	*78*	*68*	*57*	*125*
	3	*23*	*19*	*31*	*35*	*30*
% clay	*1*	*25*	*49*	*33*	*51*	*47*
	2	*28*	*91*	*104*	*36*	*110*
	3	*20*	*18*	*24*	*36*	*36*
% silt	*1*	*20*	*57*	*66*	*122*	*71*
	2	*16*	*61*	*88*	*83*	*104*
	3	*8*	*20*	*47*	*28*	*40*
% sand	*1*	*15*	*28*	*13*	*27*	*43*
	2	*19*	*16*	*21*	*23*	*47*
	3	*1*	*1*	*3*	*2*	*3*
High Variation						
K_{sat}	*1*	*110*	*150*	*362*	*635*	*155*
	2	*119*	*49*	*155*	*102*	*560*

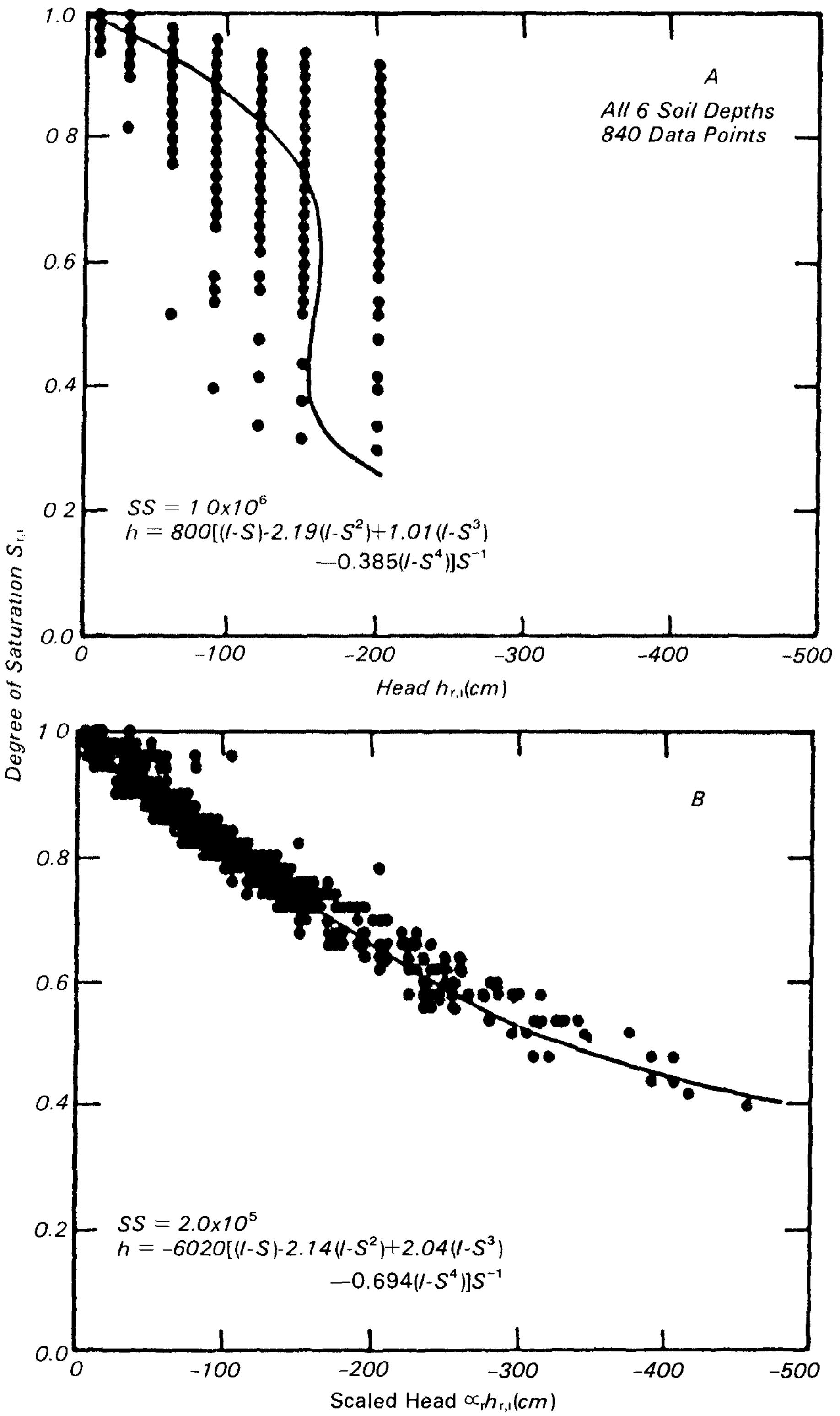

Figure 1. *Soil water characteristics data for six depths of Panoche soil: (A) unscaled and (B) scaled.*

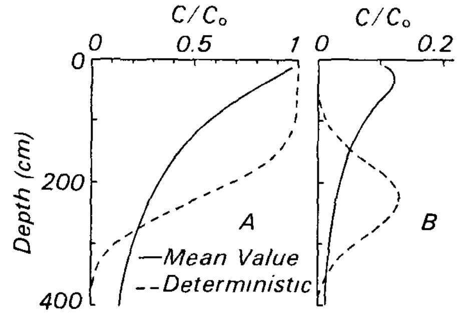

Figure 2. *Salt concentration with depth for a "step input" (A) and a "pulse input" (B) after 5 days*

and pulse inputs. The true means were evaluated using the Monte Carlo simulations in which an average of 2000 salt profiles is calculated for each case. For both step and pulse inputs, the solute concentration at larger depth is greater for the mean values than the deterministic solution. The depth at which $c/c_o = 0.5$ is about 220 cm for the deterministic and 110 cm for the mean value for step input, a consequence of averaging in some of the high velocity sites. For the pulse input, the maximum concentration for the mean value is closer to the soil surface although it is less than the deterministic value. In fact, there is no single value of pore-water velocity that could give the shape of the true mean for this example.

Recommendations

The variability in data of soil parameters should always be included in addition to mean values when reporting environmental data. Information regarding the frequency distribution and/or the spatial distributions of the data should be included.

Sensitivity analysis should be conducted to evaluate the behavior of dependent variables in relation to changes in the independent variable. Relative sensitivity is more meaningful when the range of variability is masked by the numerical magnitude of the parameter.

Techniques such as geostatistics should be examined in soil science to provide basic descriptions of soil physical properties and for integrating over large land areas.

References

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Arthur W. Warrick and Azizolah Amoozegar-Fard are with the Department of Soils, Water, and Engineering, University of Arizona, Tucson, AZ.
***Arthur Hornsby** is the EPA Project Officer (see below).*
The complete report, entitled "Areal Predictions of Water and Solute Flux in the Unsaturated Zone," (Order No. PB 81-191 124; Cost: $9.50, subject to change) will be available only from:
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650
The EPA Project Officer can be contacted at:
Robert S. Kerr Environmental Research Laboratory
U.S. Environmental Protection Agency
P. O. Box 1198
Ada, OK 74820

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