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THE SCALING ISSUE IN WATER RESOURCES MANAGEMENT

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INTRODUCTION

The issue of scaling represents not only a scientific challenge but also a practical problem in water resources management and hydrological modeling. Models are scale specific because different processes are important at different scales. Hydrological modeling is being carried out at spatial scales ranging from point scale to global scale.

Since the early 1980's, a large number of models have been developed to describe the complex interactive physical, chemical and biological processes. Most of them were developed for research purposes but some have now entered into the management arena and are used as tools in the decision–making process by public authorities, industry, consultants and agriculture advisers.

Models are cost effective management tools since they are both cheaper and powerful. At best, they enable valuable insight into the workings of the complex natural soil system and allow the user to evaluate the likely impacts of alternative mitigation strategies while minimizing the need for extensive and expensive field experiments.

On contrast to physically based models, the conceptual models use empirical process descriptions. They have been developed to describe runoff generation and overall water balance but failed to provide details of water solute and energy flows and soil moisture dynamics. These models are applied at larger scales than the physically based models.

Processes description in hydrology is often studied at point scale. Modeling water and solute transport at catchment scale is complicated by the natural variability of the governing parameters.

Models are scale specific because:

1- different processes are important at different scales
2- The input data availability is reduced at larger scales.

One of the weaknesses of the first generation of simulation models of water and solute transport is that the soil was treated as macroscopically homogeneous. One frustrating issue facing hydrologists in dealing with the unsaturated zone both in terms of modeling & experiment is the overwhelming heterogeneity of the subsurface. One manifestation of the heterogeneity at local scale involves the preferential flows of water and chemicals through soil macropores and rock fractures.

On contrast to rocks, soil near surface processes such as shrinking-swelling, freeze-thaw, biological activity leading to earthworms and root channels and physical manipulation such as cultivation, can dynamically alter pathways leading to temporal variations in preferential flow processes. Such temporal variation tends to decrease with depth where fractured rocks also dominate.

Preferential flow is the accelerated movement of water, surface applied fertilizers, pesticides and pollutants into and through the unsaturated zone. Process based description of preferential flow invokes dual porosity models. Such models assume that the medium consists of two interacting pore regions. Accounting for heterogeneity and preferential flow is crucial in studies of agrochemical transport and in leaching saline soils.

Emerging issues: how to handle spatial heterogeneity, the existence or otherwise of natural or preferred time and space scales, and the linkages between scales of state variables, parameters and conceptualizations.

THE SCALE ISSUE

The natural focus of many hydrologists was to investigate specific processes such as unsaturated flow, overland flow, evaporation, etc. The outcome was verified against small scale experiments. Hydrological modeling has been carried out at spatial scales ranging from point scale to global scale. The importance of scale effects has been recognized by hydrologists, water resources managers, and other water practitioners. The unanswered questions are:

1- Do the mathematical descriptions often developed in laboratories or plot scale applied to catchment scale?

2- How can physical properties such as hydraulic conductivity measured at isolated points be used to accurately represent catchment scale water fluxes such as groundwater recharge or contaminant fluxes such as nitrate flows?

3- How can this spatial variability be incorporated in a model grid square and how is this affected by the size of the grid?

Hydrologists have made impressive gains in research leading to understanding and quantifying individual hydrological processes and in a variety of environments. However, theories of many processes such as infiltration, evaporation, overland flow, water, solute and sediment transport have been and continue to be developed at small scale. The record in implementing these theories towards the development of predictive models at much larger space and time scales has not been equally impressive. The extrapolation of theories of non-linear hydrological processes to larger scale natural systems such as basins, flood plains, wetlands continues to pose serious problems. New analytical formulations for atmosphere-soil-vegetation interactions and methods for their experimental verifications are urgently needed in regional water resources planning, water quality in large river basins, in validation of Global circulation model;s (GCM's) and in prediction and or interpretation of the hydrological impacts of global climate change.

At catchment scale, the hydrological processes combine and interact in a complex manner. The development of physically based catchment scale models provides a framework to represent the interaction of these processes at catchment scale. Applying scaling where several processes govern catchment flows and interact with each other, still represent a formidable challenge.

There is a need to discover hydrologic laws at catchment scales that represent more than a single process. However, it is recognized that different hydrological processes are dominant at different scales.

Although a clear picture is emerging about the nature and extent of the "scale problem", there is, as yet, no consensus on the solution to the problem. The need for continued and sustained research on scale issues is therefore self-evident.

The problem of scale may be differentiated as scale and scaling problems.

The scale problem: Different processes may dominate hydrological processes at different scales so that different theories and models may be appropriate at different scales.

The scaling problem: Denotes that processes description at one scale to be formally transferred to represent the hydrological response at a different scale. In other words, it is about development of a theory that would allow predictions at larger scale on the basis of small scale process information.

Due to the uniqueness of place, different points in the landscapes are characterized by different parameters such as slope, aspect, vegetation characteristics, soil physical, biological and chemical properties. These parameters are measurable but in practice this is a very difficult task to do, given the spatial and temporal variability. In reality, these parameters are measured at different and often incompatible scales and it is inconceivable that they will be measured everywhere in the landscape.

UPSCALING

Aggregation : Denotes that , small scale equations are applied at the small scale where they were derived and the outputs are aggregated to larger scale units. This allows the smaller scale parameters to be assigned directly from field data.

UpScaling : Process equations and associated parameters are modified or substituted when moving from the small scale to the larger scale. It can be conducted in three ways:

1- The small scale equations are assumed valid at larger scale without change. In this case the effective parameters are corresponding to the larger scale computational unit and produce bulk behaviour of heterogeneous medium. The estimation of parameters values in such case need to be done by calibration of key parameters.

2- The small scale equations are extended in a theoretical framework to account for spatial variability of small scale parameter over a larger scale. This is often carried out in a stochastic framework. Here it is possible to assess the large scale parameters directly from field data. However, effective parameters need to be assessed through calibration.

3- New equations are developed particularly for larger scale.

One of the major goals of the hydrological research is to extend our understanding of impact of changing scale on hydrological processes. Obviously there is a need to develop tools to properly treat these scale problems.

This paper will show some examples of scaling/downscaling or aggregation/ desegregation and how to deal with spatial variability at different scales. The examples are focused on water resources management: in urban areas, in rural areas using remote sensing and in coastal areas to quantify surface water, groundwater and sea water intrusion (see figure below) using a newly developed Integrated Hydrological Modelling System (IHMS) successfully tested on two catchments in Cyprus.