DISCUSSION

Mohsen Mehran, Geosystem Consultants, Inc.
18218 McDurmott East, Suite G, Irvine, California 92714

INTRODUCTION

About two years ago, I posed the following question to Dr. A.S. Hedayat: "How should a sampling strategy reflect system variability so that the data realistically represent the system?"

The systems in which I am particularly interested include environmental media such as soil, ground water, surface water, and air, with respect to the occurrence and distribution of contaminants. After a number of informal discussions, Dr. Hedayat took the initiative in organizing the session on "Statistical Techniques for Waste and Environmental Sampling."

The following papers were selected for presentation:

- o "Spatial Prediction from Networks" by N.A. Cressie, C.A. Gotway, and M.O. Grondona.
- o "Sampling Designs Useful for Solid Waste Sampling" by A.S. Hedayat and John Stufken.
- o "Issues in Environmental Survey Design" by Ronaldo Iachan.

Prior to addressing the specific topics presented in these three papers, I would like to touch on a number of environmental issues which I believe are related to the subject of this session. These issues are as follows:

- o The spatial and temporal variability of contaminants in air, soil, surface water, and ground water.
- o The relationship between sampling strategy and physicochemical characteristics of environmental media.
- o Validity of risk assessment models in relation to the potential impacts of contaminants on human health and/or the environment.
- o Economic and public relation considerations.

A number of these issues have been directly or indirectly addressed by the authors of the papers presented at this session. Therefore, to the extent possible, I will attempt to relate the above issues to the subjects of the papers. The discussion presented herein summarizes my review of the papers and reflects my general views on the subject. A discussion of each paper is presented separately followed by some general considerations.

SPATIAL PREDICTION FROM NETWORKS

In this paper, the application of a random-field model for predicting pollutants is discussed, using data obtained from a spatial network of monitoring sites. The model inherently and justifiably assumes that observations may be dependent on each other and the distance between observation points affects such dependency. Geostatically, this is believed to be a valid assumption.

In a large-scale problem, it is crucial to determine the optimal sampling plan for "best" system representation. Using a known variagram, Kriging techniques have been applied to atmospheric pollutant data for spatial prediction. Spatial sampling techniques such as simple random sampling, stratified random sampling, systematic random sampling, and cluster random sampling are presented in a comprehensive manner. The issue of optimal sampling design has received considerable attention in this paper and other investigations. Kriging is appropriately emphasized as a statistical tool for prediction. However, Kriging should be considered as a linear interpolator. Prediction of data for extrapolation requires special attention and must be treated with caution.

Verification and calibration would increase our confidence in the applicability of statistical models and provide insight and direction in enhancing our physicochemical conceptualization of environmental systems.

SAMPLING DESIGNS USEFUL FOR SOLID WASTE SAMPLING

The application of sampling techniques which avoid contiguous units is discussed in this paper. A number of ideas have been presented which may lead to the development of simple and efficient methods of data collection, particularly as applied to solid waste sampling.

In natural and man-made environmental media, the design of efficient sampling techniques is important. Examples of such media include geologic formations, ground water-bearing zones (aquifers), lakes, reservoirs, and solid wastes. The design of an efficient sampling plan should reflect our knowledge of natural phenomena and man-made processes. Under some circumstances, such as when a system is considered to be homogeneous with respect to a particular variable, it is anticipated that neighboring points may lead to similar observations. Therefore, simple random sampling may not be the most appropriate method. The paper by Hedayat and Stufken addresses the development of sampling plans for a two-dimensional system of units in which neighboring units are anticipated to

provide similar observations. The random stratum boundary method appears to be the easiest method for implementation in this case.

It should be noted that the extension of this idea to address three-dimensional problems is necessary. In most media, such as those mentioned earlier in this section, the height or depth dimension is crucial in sample representation. For instance, as contaminants are generally introduced via the upper surface of an aquifer, and as the areal and vertical propagation of the contaminant plume is a slow process, three-dimensional analysis is valid for thick aquifers.

Hedayat and Stufken also raise the issue of the adequacy of statistical methods in relation to environmental issues. Although it is important to develop new statistical methods to solve environmental problems, it is equally important to utilize existing methods, particularly those which have been tested in other disciplines. Effective communication between statisticians and environmental scientists/engineers is the key for proper usage of statistical tools.

ISSUES IN ENVIRONMENTAL SURVEY DESIGN

This paper presents sample design issues as they relate to several environmental surveys. The diversity and complexity of environmental systems and the associated potential impact on sampling design are well presented in this paper. Examples selected by the author reflect some of the most relevant and large-scale environmental issues existing in the United States today. These examples include National Pesticide Survey, National Radon Survey, National Indoor Air Quality Study, and Total Exposure Assessment Methodology Study. The role of auxiliary information in improving survey accuracy is discussed. Stratification of variables which seem to be correlated with variables of interest is an important element of an efficient design. Two-phase sampling is believed to be useful for a variety of environmental problems.

As indicated by the author, cost plays a significant role in environmental surveys. Two-phase sampling can assist in minimizing cost. For instance, in ground water quality investigations, describing the spatial and temporal variability of contaminants is important. Typically, in the initial stages of an investigation, the ground water flow regime and water quality conditions are not known. As field data become available, our understanding of the system, with respect to the distribution and variability of the contaminants, increases. Application of multi-stage sampling for such circumstances seems reasonable. It is important to note that because of the dynamic nature of environmental systems, flexibility in sampling design is important to reflect system changes with time.

Another important consideration is the selection of indicator parameters. In certain environmental circumstances, the system of interest may contain a large number of contaminants, each with a unique set of physicochemical properties. Selection of indicator parameters is important for such cases in order to reduce the cost of analysis and data interpretation. The selection of parameters should be based on those properties which most likely influence their distribution in the environment and their impact on human health and the environment. Under such circumstances, statistical interpretation of indicator parameters can be applicable to the entire suite of parameters with some degree of conservatism.

GENERAL CONSIDERATIONS

As consultants on soil and ground water contamination/remediation projects, we are confronted with a number of issues which require statistical consideration. These issues are listed below:

- o The relation between randomness and lack of information.
- o Influence of system properties on sampling methods.
- o Statistical analysis of small data sets and censored data.
- o Role of statisticians in developing risk assessment models.
- o Communication between statisticians, users of statistical tools, and environmental regulatory agencies.

I believe that efforts must be made to enhance communication between those who develop the statistical methods and those who are active in environmental disciplines. The cooperation and collaboration of the two groups is essential to meaningful system representation and reasonable solutions to environmental problems.