UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

December 29, 1993

EPA-SAB-EEC-LTR-94-005

OFFICE OF THE ADMINISTRATOR
SCIENCE ADVISORY BOARD

Administrator Carol M. Browner
U.S. Environmental Protection Agency
401 M Street, S.W.
Washington, D.C. 20460

Re: Ground-Water Monitoring Network Research

Dear Ms. Browner:

The Office of Solid Waste (OSW) requested that the Science Advisory Board's Environmental Engineering Committee (EEC) review the Ground-Water Monitoring Network Design Research Program of the Environmental Monitoring Systems Laboratory is Las Vegas (EMSL-LV). The EEC's Ground-Water Monitoring and Network Design Review Subcommittee (GWMNDRS) conducted its review of a June 1993 draft of the subject research plan at a site visit at EMSL-LV on July 29-30, 1993.

OSW would like to use the results of this research to develop quantitative standards for the design of ground-water monitoring well networks. The Subcommittee found that the goal of developing tools for implementing quantitative data quality objectives (QDQOs) for RCRA ground-water monitoring network system design and performance is achievable and has practical merit for RCRA as well as for the Superfund monitoring programs. Although the scientific quality of the work reviewed is very high, the projects as structured appear to fall short for meeting the stated specific needs for delivering readily useable methods in the near future. Additional planning is needed to improve guidance for new network design and to provide tools for evaluating existing networks and modifying them as needed.

The enclosure with this letter provides elaboration of the following answers to the charge and the Subcommittee's resulting recommendations.

<u>Specific Response to Charge:</u>

1. "(A) Do the quantitative methods employed in the program assist in designing monitoring networks? (B) What advantages do they have over current network design methods, such as best professional judgement? (C) Are the methods too complex for the user community?"

At the program level, there have been several advances in research that could <u>augment</u> professional judgement in designing monitoring networks for detection monitoring (Illinois project) and compliance monitoring (Stanford project), but not remediation monitoring. However, these advances in quantitative methods are not now available in a readily usable form.

2. "(A) Are the underlying assumptions of the models valid? (B) Do the model assumptions make sense considering the physical systems being modeled?"

Each of the models make basic assumptions regarding site characteristics which provide a reasonable starting point for the development of quantitative methods for monitoring network design. However, they may not be appropriate at many facilities. The models have been developed by making assumptions not only regarding the physical system, but also the regulatory and institutional characteristics of the RCRA program. This includes an implicit assumption that an acceptable probability-of-failure can be identified.

No single model can be broadly applicable to all types of sites. Test applications of the methodology should be made in conjunction with hydrogeologists familiar with particular sites (i.e., those who are now exercising their professional judgement in designing monitoring network) and, if possible, using their models (conceptual, or if available, numerical) to represent the site.

3. "(A) Are the data requirements for the models realistic? (B) How does the model address data reliability,variance, and sample sizes? (C) What improvements could be made to address these concerns?"

All of EMSL's proposed methods presumably will add information to the process in terms of correlations among data, physical constraints, or possible answers via the ground-water flow equation. Therefore, better decisions should be possible by using these techniques, especially in combination with existing data bases. However, large amounts of data are required by each technique.

With regard to the second question, none of the projects directly address data reliability as a source of uncertainty in monitoring well network design (although the geostatistical program developed at Stanford does allow the uncertainty of a measured value to be considered).

The Subcommittee's answer to the third part of this question, is to develop means for incorporating expert judgement into the tools that EMSL is developing.

4. "How can the research be used to enhance implementation of the RCRA ground-water monitoring program?"

At the program level, information in the literature and obtained from this research could be incorporated into technical guidance documents, along with active technology transfer and training of EPA staff who are the intended users.

Recommendations

The Subcommittee's chief recommendations are that the Agency: (1) sponsor a comprehensive literature review on the research topic, (2) undertake a "fourth project" that attempts to implement the methods and tools developed in the first three projects at actual RCRA sites, and (3) critically review the problems associated with current approaches to network design.

The Subcommittee thanks you for giving it the opportunity to review this program and looks forward to a written response to its recommendations above.

Sincerely,

I. Murarka

Dr. Ishwar P. Murarka, Chair
Ground-Water Monitoring Network
Design Research Subcommittee
Environmental Engineering Committee

Richard A. Conway

Mr. Richard A. Conway, Chair
Environmental Engineering
Committee
Science Advisory Board

Genevieve M. Matanoski

Dr. Genevieve M. Matanoski, Chair
Executive Committee
Science Advisory Board

Enclosure 1

Elaboration of the
Environmental Engineering Committee's Review
of ORD's
draft Monitoring Network Design Research Plan
supplemented by related documents
at a site visit at EMSL-LV on July 29-30, 1993

OSW would like to use the results of the research to develop quantitative standards for the design of ground-water monitoring well networks. The Subcommittee found that the goal of developing tools for implementing quantitative data quality objectives (QDQOs) for RCRA ground-water monitoring network system design and performance is achievable and has practical merit for RCRA as well as for the Superfund monitoring programs. Second, although the scientific quality of the work reviewed is very high, the projects as structured appear to fall short for meeting the stated specific needs for delivering readily useable methods in the near future. Finally, additional planning is needed to improve guidance for new network design and to provide tools for evaluating existing networks and modifying them as needed.

The Ground-Water Monitoring Network Design Research Program funded the following three projects:

1. "OMNe Geostatistical Software for Monitoring" at Stanford University's Civil Engineering Department,
2. "Quantitative Methods for the Design of Groundwater Quality Monitoring Networks" at the University of Illinois at Urbana-Champaign's Department of Civil Engineering, and
3. "Site Characterization for Heterogeneous Porous Media: The Use of Scale Information Via the Wavelet Transform" at the University of Nevada, Reno's Desert Research Institute

The Subcommittee considered both the scientific quality of the individual research projects and their contribution to the EPA's objective of developing tools for implementing QDQOs in RCRA detection monitoring, and related ground-water quality protection activities.

The Subcommittee recommends that the Ground-Water Monitoring Network Design research plan be enhanced to set clearer and more focused goals tied to ORD's ground-water issue research plan. Clear, concise uses for results from the projects should be identified.

Specific Response to Charge:

1. "(A) Do the quantitative methods employed in the program assist in designing monitoring networks? (B) What advantages do they have over current network design methods, such as best professional judgement? (C) Are the methods too complex for the user community?"

At the program level, there have been several advances in research, which could augment professional judgement in designing monitoring networks for detection monitoring (Illinois project) and compliance monitoring (Stanford project), but not remediation monitoring. However, these advances in quantitative methods are not now available in a readily usable form.

The Subcommittee also addressed this question at the project level. The Stanford project on geostatistical methods involves a very productive effort to combine the most advanced suite of spatial statistical tools in a user-friendly computer environment. In the context of the overall effort to develop tools for network design for detection monitoring, these software tools have specific value in characterizing the statistical properties of the spatial field of hydraulic conductivity. However, as currently presented to the Subcommittee, these tools have a more appropriate application to characterizing contaminant concentration distributions, once contamination has occurred.

Although no table was presented that compared the OMNe software from Stanford with other specific current geostatistical tools (such as GEOEAS, a code developed by ORD/EMSL-LV), such a comparison would be useful. The OMNe software package is suited for users with hydrogeological or modeling experience. To enhance statistical confidence, it is anticipated that large amounts of site-specific data will be needed.

The Principal Investigator, Peter Kitandis, describes three-dimensional OMNe code as, "a toolbox or software package that is currently being developed for the geostatistical analysis of hydrogeologic and environmental data used as input in the design of monitoring networks." OMNe, which runs on the UNIX system, can use one-, two, or three-dimensional data.

EMSL-LV developed a two-dimensional code, GEOEAS, for the analysis of soil contamination problems such as mapping the plume of lead in soil around a smelter. GEOEAS, in contrast to the Ada laboratory's GEOPACK does ordinary, rather than disjunctive kriging. The latter is better suited to the sparse data typically available for ground-water environments.

Post-implementation audits at existing sites might also be performed.

The University of Illinois effort on detection monitoring design could strengthen professional judgement. The project on optimization of well placement is, as basic research, well-conceived and implemented. The implementation of advanced optimization techniques and the consideration of performance trade-offs has yielded a number of new and important insights. Although the methods are not conceptually complex, a user friendly product is not yet available. Furthermore, the linkage between the Illinois models and OMNe is not obvious in that OMNe focuses on defining existing plumes and Illinois focuses on detection monitoring.

The Desert Research Institute (DRI) project took a basic research approach to the same problem as the Stanford project.

The DRI project on wavelets is at the leading edge of research and considers many of the newest and most advanced methods for stochastic characterization of the subsurface. Advances in this area could be important to the long-term evolution of ground-water science, and the eventual benefits may be realized in a broad range of ground-water programs. The research team demonstrates a solid capability and performance in this area. However, as a very advanced tool, the methodology will not likely be used by regions or facility operators for characterization of their RCRA sites for many years as yet. Another aspect of the DRI project is that it is not clear how this approach will incorporate field data and subjective estimates of uncertainty and variability.

2. "(A) Are the underlying assumptions of the models valid? (B) Do the model assumptions make sense considering the physical system being modeled?"

(A) Each of the models make basic assumptions regarding site characteristics. These assumptions include homogenous and isotropic porous media, steady flow, and miscible transport. Such assumptions provide a reasonable starting point for the development of quantitative methods for monitoring network design. However, they may not be appropriate at many facilities. The presence of fractured media and non-aqueous phase liquids (NAPLs) are two examples of real-world conditions that are not included in the current models.

The models focus on uncertainty and variability in transport parameters, such as hydraulic conductivity. Uncertainties in subsurface geometry such as buried channels and discontinuous confining units are not addressed in the current work. Effects of uncertainties in boundary conditions may also be important but are not included in the current work. The models have been developed by making assumptions not only regarding the physical system, but also the regulatory and institutional characteristics of the RCRA program. This includes an implicit assumption that an acceptable probability-of-failure can be identified.

(B) No single model can be broadly applicable to all types of sites. Test applications of the methodology should be made in conjunction with hydrogeologists familiar with particular sites (i.e., those who are now exercising their professional judgement in designing monitoring network) and, if possible, using their models (conceptual, or if available, numerical) to represent the site.

The current research projects define monitoring in terms of ground-water wells. Other technologies such as surface geophysics and soil gas analysis should also be considered.

The Subcommittee also addressed these questions at the project level.

For the Stanford work, the validity of assumptions will depend on site-specific application and the tools developed are not suitable for sites with geologic discontinuities (such as clay lenses, buried channels). The DRI's work did not seem to show that natural media exhibit the characteristics assumed in its model.

For the work performed at Illinois, the validity of assumptions likewise depends on site-specific conditions. Unfortunately, the fate and transport part of the model is too simple to be realistic for all but a few field situations.

Although the Illinois work is a good starting point, many sources of uncertainty were not considered (e.g. boundary conditions, chemical transformations) and there is a need to consider other types of monitoring methods (e.g. soil vapor, geophysical). The idealized aquifer representation used by the model may not be sufficiently representative of individual sites to allow direct application for network design.

The ground-water model used to demonstrate the methodology was fairly simple in order to illustrate the optimization approach. Future use of this approach should incorporate a more realistic and complex ground-water flow and transport model. Some of the limitations of this model are addressed in the DRI's proposal for future research. Proposed recommendations for improvement include:

i. The use of variable or uncertain boundary conditions and recharge. This would allow the model to address the common issue of proper placement of background wells when the ground-water flow direction is radial, seasonally variable, or uncertain.
ii. Addition of adsorption and degradation processes.
iii. Use of conditioning when there are measured values of hydraulic conductivity.
iv. The need to develop methodologies and approaches for incorporating subjective information into the network design process.

Work currently being conducted at DRI is theoretical and field complexities have not been incorporated into the model to date. Therefore an evaluation at this time is premature.

3. "(A) Are the data requirements for the models realistic? (B) How does the model address data reliability, variance, and sample sizes? (C) What improvements could be made to address these concerns?"

All of EMSL's proposed methods presumably will add information to the process in terms of correlations among data (Stanford and DRI), physical constraints, or possible answers via the ground-water flow equation (U of Illinois). Therefore, better decisions should be possible by using these techniques, especially in combination with existing data bases. However, when the question is asked, "how much data are required in terms of computer code input?", it appears that large amounts of data are required by each technique. To fulfill such data needs in practice, the field people who currently design networks use a large amount of subjective judgement. Therefore, the answer to the third part of this question, and the resolution of this problem, is not to choose one technique over another on the basis of large or small data requirements, but to combine the two techniques into one approach by developing means for incorporating expert judgement into the tools that EMSL is developing.

With regard to the second question, none of the projects directly address data reliability as a source of uncertainty in monitoring well network design (although the geostatistical program developed at Stanford does allow the uncertainty of a measured value to be considered).

4. "How can the research be used to enhance implementation of the RCRA ground-water monitoring program?"

At the program level, information in the literature and obtained from research could be incorporated into technical guidance documents, along with active technology transfer and training of EPA staff who are the intended users.

If consistency can be developed between the modeled and the true environments (both physical and regulatory), then the research can provide an additional tool to aid in network design. The quantitative methods might be used to demonstrate alternatives to some default-level monitoring requirement.

Monitoring network design should be linked with site characterization activities and with liner and facility design activities. Trade-offs exist among these three activities in that more monitoring may be warranted at sites with less site characterization data or at sites with less conservative engineering designs.

5. "What other technical expertise or resources within EPA, other federal agencies, national laboratories, and academic institutions could be utilized to better serve the clients' needs?"

This is an issue at the program level. Increased interaction within the EMSL-LV and with other relevant projects outside of the lab should be encouraged. For example, performance assessment associated with the high-level radioactive waste isolation program has focused on stochastic methods that EMSL-LV should consider.

EPA should, at a minimum, conduct a workshop to further such interaction. Such a workshop should include ground- water scientists and engineers conducting research on site and monitoring network design, as well as groups responsible for establishing existing and planned monitoring networks at particular facilities. This would encourage a better match between new conceptual approaches and the realities of actual site problems.

Specific Recommendations

1. The Subcommittee recommends that a more comprehensive literature review be conducted and documented to define the state of the practice for monitoring network design. Such a review should determine the current state-of-the-art and technology needs for the RCRA ground-water monitoring research program, and also serve as the basis for a RCRA program guidance document that could be periodically updated to include future research findings. Such a basic literature review should include case studies for which these methods have been used, and will, thus, provide helpful guidance for project managers at hazardous waste sites. A good beginning for such a review can be found in the thesis of Philip D. Meyer, "The Optimal Design of Ground-Water Quality Monitoring Networks Under Conditions of Uncertainty (section 1.1 A Brief Review of Some Previous Work)," University of Illinois Urbana-Champagne (1992). Statistical methods can be summarized using documents such as Methods for Evaluating the Attainment of Cleanup Standards-Volume 2: Ground Water (EPA, 1992).

2. In view of the above findings presented in the Summary above, the Subcommittee recommends that the projects within the EMSL-LV program be better coordinated to achieve the specified goals.

Further, the Subcommittee recommends that any model or tool developed under the plan utilize similar assumptions so modeling components or subsets are easily combined together. Such improved coordination between projects should result in the generation of products which are timely, readily usable and easily combined while filling current technology gaps. Coordination will require additional support, perhaps in the form of a fourth project specifically designed to develop tools to facilitate the implementation of QDQOs for RCRA ground-water detection monitoring.

Such a "fourth project" should use the methods and tools developed in the three existing projects and attempt to implement them at actual RCRA sites, in cooperation with site hydrogeologists and in conjunction with existing ground-water models for those sites.

This project might begin by considering only the simpler sources of variability and uncertainty at a site, such as the location of a release.

The professional judgement of the site hydrogeologist can be used to identify a small number of alternative conceptual models for the aquifer (e.g., with vs. without possible high permeability zones) that could be assigned initial probabilities for their occurrence. Best estimate hydraulic conductivity fields could then be assigned to, or simulated for, each conceptual model. The probability simulation would then consider only the use of the selected alternative conceptual models and the random location of the release. Such an approach would facilitate the dissemination of probabilistic modeling experience. It could even provide a basis for an interim methodology for implementing probabilistic QDQOs, until methods and experience with stochastic simulation of hydraulic conductivity fields become more readily accessible.

3. The Subcommittee recommends that EPA undertake a review of the problems associated with current approaches to network design.

This should provide the program with a clearer specific direction for the development of new techniques. The Subcommittee remained unclear as to whether the program research was initiated because: (1) current monitoring-well networks are failing, (2) there is no way to quantitatively assess the performance of existing networks, or (3) to provide a more efficient (in terms of cost and time) approach to network design.

4. The Subcommittee recommends that appropriate resources be allocated to implement the research plan once it is well defined and focused and, for limited resources, the research plan should be implemented in phases. That is, funding should match expectations.

5. The Subcommittee recommends that EPA develop a consistent approach to evaluating improvements to the methods for describing the spatial variability of hydraulic conductivity--both relative to other methods and relative to "reality." For example, if the program continues to use "synthetic" realities to check the accuracy of the new techniques, then the Subcommittee suggests that all methods be tested on the same artificial hydraulic conductivity fields data. In addition, the Subcommittee suggests that the program develop a means of comparing the fields generated by these techniques with data from real sites. Such standardization of comparison methods should provide potential users not only a clearer distinction among the techniques but also assurance that they are potentially applicable to their sites.

6. The Subcommittee recommends that the role of temporal variations in monitoring data be considered for inclusion in the current work.

7. The Subcommittee recommends that continued support from EPA's Office of Research and Development (ORD) shift focus to meet the needs for Superfund and RCRA compliance or enforcement monitoring.

8. The Subcommittee recommends that the specific technical comments made in the response to the charge be considered in any program revisions.

Enclosure 2

U.S. ENVIRONMENTAL PROTECTION AGENCY
Science Advisory Board
Environmental Engineering Committee
Ground-Water Monitoring Design Review Subcommittee
Members and Consultants

Chair

Dr. Ishwar P. Murarka, Manager, Waste, Land and Water Programs
Electric Power Research Institute, Palo Alto, California

Members

Dr. Linda M. Abriola, Associate Professor
University of Michigan, Dept. of Civil & Environmental Engineering
Ann Arbor, Michigan

Dr. George F. Carpenter, Michigan Dept. of Natural Resources
Environmental Response Division, Lansing, Michigan

Mr. Paul A. Davis, Department Manager, SANDIA National Laboratory
Albuquerque, New Mexico

Dr. James Johnson Jr.,Professor and Chairman
Department of Civil Engineering, Howard University
Washington, District of Columbia

Dr. Joel W. Massmann, Professor, Department of Civil Engineering
University of Washington, Seattle, Washington

Dr. James W. Mercer, President
GeoTrans, Inc., Sterling, Virginia

Dr. Mitchell J. Small, Professor
Department of Civil Engineering, Carnegie-Mellon University
Pittsburgh, Pennsylvania

Enclosure 3

U.S. ENVIRONMENTAL PROTECTION AGENCY
Science Advisory Board
FY93 Environmental Engineering Committee

Chairman

Mr. Richard A. Conway, Senior Corporate Fellow
Union Carbide Corporation, So. Charleston, West Virginia

Members

Dr. Linda M. Abriola, Associate Professor
University of Michigan, Dept. of Civil and Environmental Engineering
Ann Arbor, Michigan

Dr. George F. Carpenter, Michigan Dept. of Natural Resources
Environmental Response Division, Lansing, Michigan

Dr. James H. Johnson, Jr., Professor and Chairman
Department of Civil Engineering, Howard University
Washington, District of Columbia

Dr. Wayne M. Kachel, Martin Marietta Corporation
Oak Ridge, Tennessee

Dr. Ishwar P. Murarka, Manager--Waste, Land and Water Programs
Environmental Division, Electric Power Research Institute
Palo Alto, California

Dr. Frederick G. Pohland, Weidlein Chair of Environmental Engineering
Department of Civil Engineering, University of Pittsburgh
Pittsburgh, Pennsylvania

Dr. Robert B. Pojasek, Corporate Vice President--Environmental Programs
GEI Consultants, Inc., Winchester, Massachusetts

Dr. Wm. Randall Seeker, Senior Vice President
Energy & Environmental Research Corp., Irvine, California

Dr. Walter M. Shaub, President, CORRE, Inc., Reston, Virginia 22090

Dr. C. Herbert Ward, Director & Professor, Energy and Environmental
Systems Institute, Rice University, Houston, Texas

Distribution List

Administrator
Deputy Administrator
Assistant Administrators
EPA Regional Administrators
EPA Laboratory Directors
Director, Office of Modeling,
  Monitoring Systems and Quality Assurance
Director, Office of Solid Waste
EPA Headquarters Library
EPA Regional Libraries
EPA Laboratory Libraries