UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

WASHINGTON, D.C. 20460

EPA-SAB-EEC-90-009

OFFICE OF THE ADMINISTRATOR

March 27, 1990

Honorable William K. Reilly
Administrator
U.S. Environmental Protection Agency
401 M Street, S.W.
Washington, D.C. 20460

Dear Mr. Reilly:

The Science Advisory Board has completed its review of the Office of Solid Waste's (OSW) Combined Analytical-Numerical Saturated Zone (CANSAZ) flow and transport model for use in the EPA Composite Model for Surface Impoundments (EPACMS), and is pleased to submit its final report. This report resulted from a Saturated Zone Model Subcommittee review on May 30-31.

The charge to the Subcommittee identified two major areas for SAB review. The first relates to the appropriateness of the assumptions underlying CANSAZ when used in a nationwide, Monte Carlo assessment, including which parameters should be estimated on a site-specific versus a nationwide basis. The second relates to the adequacy of the code for simulating conditions beneath surface impoundments.

The Subcommittee found that the proposed CANSAZ model represents a significant advance over the current Vertical Horizontal Spread (VHS) model, but that a number of difficulties remain in the model components, inputs and intended mode of application. The following describes the major issues considered by the Subcommittee and the principal findings.

1) Proper mathematical formulation: - The numerical and solution methods are properly formulated and solved. The technique employed is innovative and computationally efficient, and the numerical accuracy of the method is supported by rigorous comparisons with analytical solutions.

2) Adequacy of physical assumptions: - The CANSAZ model includes the basic assumptions and processes incorporated in current management-oriented ground water models, but these models neglect several important processes now known to impact contaminant transport and fate in actual field sites. A number of assumptions restrict the applicability of the model, including:

a) Dimensionality of the model (failure to include transverse flow from mounding),
b) Limitation to steady-state prediction,
c) Assumption of homogeneous aquifer media,
d) The inclusion of limited hydrodynamic, chemical and biological processes.

Particular processes which are not incorporated, but could be important at particular sites, are discussed in our report.

3) Adequacy of Monte Carlo Approach: - The mechanics of the Monte Carlo procedure appear to be properly designed and implemented. However, determining the adequacy of the input distributions is more problematic. These input data are critical to accurate model assessment. The current input data-set is not adequately documented or supported by field data. It is thus recommended that a panel of hydrogeologists, soil scientists, and engineers be convened to review the proposed model input values and documentation.

4) Adequacy of field testing of the model: - The EPA has made a good start at validating the EPACMS model by confirming the numerical accuracy and presenting a preliminary field validation study. The field validation study should be documented, and extended in more detailed studies at other sites. A special effort is needed to validate the EPACMS model if it is used in a nationwide assessment. An extensive nationwide data collection and monitoring program will be needed to accomplish this.

5) Overall modeling approach: - The Subcommittee strongly prefers site-specific determinations. The Agency could consider the use of a provisional delisting, whereby a waste is delisted only if it is disposed at the site which is analyzed. The Subcommittee recognizes that the policy criteria of the Agency may preclude this, indicating instead the use of the generic nationwide evaluation. Should the Agency decide to utilize the nationwide Monte Carlo approach, the assessment would be improved by incorporating regional variations in the assessment and explicitly banning the disposal of delisted wastes in vulnerable hydrogeologic settings so that these sites may be excluded from the model assessment.

These findings and recommendations are made for the use of the CANSAZ and EPACMS models in the limited fashion described in the report. We are pleased to have had the opportunity to be of service to the Agency, and look forward to your response to this report.

Sincerely,

Raymond C. Loehr, Chairman
Executive Committee
Science Advisory Board

Richard A. Conway, Chairman
Environmental Engineering Committee
Science Advisory Board

Mitchell J. Small, Chairman
Saturated Zone Model Subcommittee
Science Advisory Board

EPA | U.S. Environmental Protection Agency | Washington, DC
EPA-SAB-EEC-90-009

Report of the Saturated Zone Model Subcommittee

Review of the CANSAZ Flow and Transport Model for Use in EPACMS

A SCIENCE ADVISORY BOARD REPORT | March 1990

NOTICE

ABSTRACT

The Saturated Zone Model Subcommittee of the Environmental Engineering Committee of the EPA Science Advisory Board (SAB) has prepared a report on the Agency's CANSAZ (Combined Analytical-Numerical Saturated Zone) flow and transport model for use in EPACMS (the EPA Composite Model for Surface Impoundments). The Subcommittee examined the appropriateness of the assumptions underlying CANSAZ for use in a nationwide Monte Carlo assessment, as well as the adequacy of the code for simulating conditions beneath surface impoundments. Specifically, the Subcommittee evaluated five topics which were 1) proper mathematical formulation, 2) adequacy of physical assumptions, 3) adequacy of the Monte Carlo approach, 4) adequacy of field testing of the model, and 5) the overall modeling approach.

While the mathematical equations and the numerical solution methods are properly formulated and solved, the Subcommittee suggests improvements to the physical assumptions, improvements to the current input data-set documentation and validation, and improvements needed to validate the EPACMS model for use in either a site-specific evaluation or a nationwide assessment. The Subcommittee highly prefers site-specific evaluation, but recommendations are made to improve the assessment should the Agency choose to utilize the nationwide Monte Carlo approach. These suggestions are to incorporate regional variations in the assessment, explicitly ban the disposal of delisted wastes in extreme hydrogeologic settings, and provide a mechanism for all constituents in a waste to be evaluated in a listing or delisting decision.

Key Words: modeling, saturated zone modeling, surface impoundment models.

SATURATED ZONE MODEL SUBCOMMITTEE
ENVIRONMENTAL ENGINEERING COMMITTEE
of the
SCIENCE ADVISORY BOARD

Chairman

Dr. Mitchell J. Small
Department of Civil Engineering
Carnegie Mellon University

Dr. Mary P. Anderson
Department of Geology and Geophysics
University of Wisconsin - Madison

Mr. George Carpenter
Environmental Response Division
Michigan Department of Natural Resources

Dr. Keros Cartwright
Illinois State Geological Survey

Dr. Ishwar P. Murarka
Electric Power Research Institute

Dr. Paul V. Roberts
Department of Civil Engineering
Stanford University

Executive Secretary:
Dr. K. Jack Kooyoomjian

Staff Secretary
Mrs. Marie Miller

Director, Science Advisory Board:
Dr. Donald G. Barnes
Science Advisory Board (A101F)
U.S. Environmental Protection Agency
401 M Street, S.W.
Washington, D.C. 20460

Chairman, Executive Committee, Science Advisory Board:
Dr. Raymond C. Loehr
Civil Engineering Department
University of Texas

Chairman, Environmental Engineering Committee:
Mr. Richard A. Conway
Senior Corporate Fellow
Union Carbide Corporation

TABLE OF CONTENTS

1.0 EXECUTIVE SUMMARY

This report presents the EPA Science Advisory Board's (SAB) review of the Office of Solid Waste's (OSW) CANSAZ (Combined Analytical- Numerical Saturated Zone) flow and transport model for use in the EPACMS (EPA Composite Model for Surface Impoundments). This review is based upon two documents, CANSAZ, published in October 1988 (Ref. 5) and EPACMS, published in April 1989 (Ref. 9) and briefings by the OSW to the Saturated Zone Model (SZM) Subcommittee at a meeting on May 30-31, 1989.

The use of CANSAZ and EPACMS distinguishes the OSW model for surface impoundments (EPACMS) from the OSW model for landfills (EPACML), which uses a simpler flow and transport model for the saturated zone which is unable to account for mounding effects. The CANSAZ model is the saturated zone component of the EPACMS, which also includes a module for the saturated zone, FECTUZ (Finite Element Code for Simulating Flow and Transport in the Unsaturated Zone). FECTUZ was reviewed previously by the Environmental Engineering Committee of the Science Advisory Board (Ref. 20).

The primary intended use of EPACMS is in the RCRA delisting program, where it will be used to establish the relationship between constitutent concentrations in surface impoundment leachate and concentrations at downgradient well locations (i.e., the dilution attenuation factor). The model will be used in a Monte Carlo mode to perform a nationwide assessment of dilution attenuation factors for the delisting decision. The Subcommittee review focused on the model in this use, but because CANSAZ and EPACMS could also be used for other, possibly site-specific applications, use in this mode was considered as well.

To assess the adequacy of CANSAZ and its use in EPACMS, the Subcommittee considered issues related to the technical validity of the model, and broader issues of model use and implementation in the proposed regulatory approach. The five areas that were examined by the Subcommittee are briefly stated as follows:

1) Proper Mathematical Formulation,
2) Adequacy of Physical Assumtions,
3) Adequacy of Monte Carlo Approach,
4) Adequacy of Field Testing of the Model, and
5) Overall Modeling Approach.

Findings of the Subcommittee on each of the above areas are summarized as follows:

1) Proper Mathematical Formulation:

Given the assumptions of the model, are the numerical formulation and solution methods correct? The CANSAZ model consists of an analytical flow module coupled with a numerical solute transport module which uses a new method known as a the Laplace Transform Galerkin (LTG) method. The equations, boundary conditions and solution methods appear to be properly formulated given the assumptions of the model. The technique employed is innovative and computationally efficient. The accuracy of the method is supported by rigorous comparisons with known analytical solutions and other numerical methods. The Subcommittee thus concludes that the mathematical equations and the numerical solution methods are properly formulated and solved.

2) Adequacy of Physical Assumptions:

Does the model include the important processes (ground water flow, pollutant transport and transformation) which determine contaminant fate? Is it properly formulated in terms of dimensionality, spatial and temporal aggregation? Are there omitted processes and what are their potential implications for this assessment?

The CANSAZ model includes the basic assumptions and processes employed in current management-oriented ground water models. It represents a significant advance over the Vertical Horizontal Spread (VHS) model currently used for delisting. However, management-oriented models of this type are seriously limited in their assumptions and neglect or oversimplify many important processes now known to impact contaminant transport and fate at actual field sites. These assumptions involve the dimensionality of the model (failure to include transverse flow from mounding), the limitation to steady-state prediction, the assumption of homogeneous aquifer media, the inclusion of limited hydrodynamic, chemical and biological processes, and assumptions concerning leachate and source characteristics. Many of these limitations are noted explicitly in the CANSAZ reports and documentation.

Particular processess which are not incorporated in the model include the transport of immiscible organic phases, density-dependent vertical transport of the plume, vertical movement of the water table, nonequilibrium adsorption of contaminants on the soil matrix, biodegradation, multispecies chemical reactions, cosolvent effects, modification of chemical conditions (e.g., pH, Eh, DO) in the receiving aquifer, and the effects of background concentrations. As a result of these limitations, the CANSAZ-EPACMS model is not adequate for rigorous site evaluations which need to consider site-specific processes and phenomena not incorporated in the CANSAZ-EPACMS model. The model can, however, be used for a broad national assessment of regulatory impacts provided adequate input data are obtained. The development of a capability to incorporate the processes discussed above in regulatory models will require extensive, long-term data collection and model development research.

3) Adequacy of Monte Carlo Approach:

Is the probabilistic method technically valid and supported by adequate input data? The purpose of the Monte Carlo approach is to predict the distribution of the dilution attenuation factor (DAF) that would occur between surface impoundment leachate and downgradient well points at surface impoundment sites throughout the United States. To perform this analysis, a distribution of inputs for the EPACMS model is developed and sampled to represent the distribution of meteorological conditions, soil properties, impoundment size and geometry, and well location at existing impoundments.

The mechanics of the Monte Carlo procedure appear to be designed and implemented properly. The Monte Carlo module includes an impressive range of available distributions and is well integrated with the transport code. There are, however, some significant problems in the method presented. In particular, methods are needed to incorporate correlation among parameters currently assumed to be independent, such as the hydraulic conductivity of the soil and the hydraulic gradient at the site, the soil porosity and bulk density, and soil properties and temperature which may covary on a regional basis.

While the mechanics of the Monte Carlo method are generally acceptable, determining the adequacy of the input distributions is more problematic. A properly formulated model can provide accurate and meaningful predictions only if its inputs and parameters are correctly estimated. The current input data set is not adequately documented or supported by field data. To correct this, it is recommended that a panel of hydrogeologists, soil scientists, and engineers be convened to review the proposed model input values and documentation, and consideration be given to subjecting the resulting data set to public review and comment prior to implementing the EPACMS delisting procedure.

4) Adequacy of Field Testing of the Model:

Has the model been tested (calibrated or validated) at particular field sites? What methods are appropriate for validating the nationwide Monte Carlo approach? The EPA has made a good start at validating the EPACMS model by confirming the numerical accuracy and presenting a preliminary field validation study. This field validation study should be documented, and extended in more detailed studies at other sites. A special effort is needed to validate the EPACMS model if it is used in a nationwide assessment. An extensive nationwide data collection and monitoring program will be needed to accomplish this. This will provide information on the proper inputs to the model and indicate the degree of confidence and conservatism in the predicted distribution of the dilution attenuation factors. Improvements in the available data base for site characterization are needed to match the improvements which have occurred in modeling technology.

5) Overall Modeling Approach:

Is the nationwide Monte Carlo approach appropriate for the intended uses (e.g., delisting a waste, or closure of a site)? Which inputs require site-specific data versus national distributions? Are there alternative approaches?

The nationwide assessment using EPACMS applies a generic model to all potential impoundment sites in the United States, with the Monte Carlo evaluation used to capture the site-to-site variability in model parameters. Site-specific hydrogeologic parameters are not used to evaluate the delisting petition of a particular facility.

Site-specific determinations of waste disposal impacts are highly preferred based on scientific criteria. The variations between sites resulting from variations in hydrogeologic conditions are known to be so great that the particular conditions of storage or disposal must be specified to allow for scientifically credible evaluation. The Subcommittee recognizes that the use of a site-specific model to make delisting decisions would require a new administrative approach to the regulation, as a waste could be delisted only for the site that was analyzed. To implement this, a provisional delisting approach could be developed, whereby a waste would revert to its hazardous status if it is disposed of at any site other than that approved. Because the EPA could decide that their administrative and policy objectives dictate that this, or other site-specific approaches, are inappropriate or infeasible, the Agency may choose to utilize the generic, nationwide approach. If this is the case, the Subcommittee believes the nationwide approach could be improved by incorporating the following features:

a) Incorporating regional variations in the assessment;

b) Explicitly banning the disposal of delisted wastes in vulnerable hydrogeologic settings, thereby allowing these to be excluded from the model assessment; and,

c) Providing a mechanism for all significant constituents in a waste to be evaluated in a listing or delisting decision, and ensuring that all significant constituents that must be quantitatively evaluated are analyzed with the EPACMS model.

Furthermore, the Subcommittee would encourage any evolution in the Agency programs which would improve the capability to assess groundwater contamination on a site-specific basis.

2.0 INTRODUCTION AND BACKGROUND

In April 1989, Devereaux Barnes, Director of the Characterization and Assessment Division of the Office of Solid Waste (OSW), requested that the Environmental Engineering Committee (EEC) of the SAB conduct a review of the Combined Analytical-Numerical Saturated Zone (CANSAZ) flow and transport model for use in the EPA Composite Model for Surface Impoundments (EPACMS). The formal request is included as Appendix A of this report. The CANSAZ code was developed to simulate the flow and migration of contaminants beneath surface impoundments, where hydraulic mounding could occur. The CANSAZ module for the saturated zone, together with the unsaturated zone code (FECTUZ), comprise the OSW fate and transport module for surface impoundments (EPACMS). The unsaturated zone code FECTUZ was reviewed previously by the SAB (SAB-EEC-88-030). The use of CANSAZ distinguishes the OSW model for surface impoundments (EPACMS) from the OSW model for landfills (EPACML). EPACML uses a simpler flow and transport model for the saturated zone that does not account for mounding effects.

This review is based upon two documents received by the Saturated Zone Model Subcommittee:

1. CANSAZ: Combined Analytical-Numerical Code for Simulating Flow and Contaminant Transport in the Saturated Zone, Prepared by E.A. Sudicky, University of Waterloo and HydroGeologic, Inc. for U.S. EPA OSW, October 1988 (ANM/123D/FT, ID No. 89-017). (Reference 5).
2. EPACMS: Composite Model for Simulating Leachate Migration from Surface Impoundments and Monte Carlo Uncertainty Analysis, User's Guide, Prepared by Hydro-Geologic Inc. for U.S. EPA OSW, September 1988; Revised April 1989 (ANM/123D/FT, ID No. 89-030). (Reference 9).

In addition, the Subcommittee met and was briefed by the OSW and its consultants on May 30-31, 1989. The Subcommittee review encompasses both the written reports and the oral presentation and discussion which ensued at this meeting.

2.1 Proposed Uses for CANSAZ and EPACMS

An important consideration in the Subcommittee review of CANSAZ and EPACMS is the intended uses of the model. Considerable discussion occurred on this issue at the Subcommittee meeting, and additional documentation was provided by OSW. The following, excerpted from this documentation, describes the intended uses:

OSW is considering using the coupled CANSAZ and FECTUZ modules (EPACMS) in the RCRA Delisting Program. In this use, the Agency intends to specify the model input parameters, to the extent possible, as distributions based on nationwide data. The use of the model in the Delisting Program along with other potential uses are described below:

Delisting Program

Under the RCRA Delisting Program, individual waste generators can petition the Agency to exclude ("delist") their wastes from the lists of hazardous wastes in the Federal Code of Regulations (40 CFR 261.32). An integral part of the delisting evaluation is the use of fate and transport models as predictive tools to estimate dilution/attenuation of chemical constituents leaching from waste sites to nearby drinking water sources.

The model in current use in the Delisting Program (the VHS model) is a simplified one. The Agency has stated that the simplified model will be replaced by comprehensive ones when they become available in a form which is appropriate for use in the Delisting Program.

The CANSAZ is of interest to the Delisting Program because a large number of wastes which are the subject of delisting petitions are managed in surface impoundments. There is no model currently in use for delisting that directly accounts for the specific differences between landfills and surface impoundments, a factor which has raised comments in the review of numerous petitions. The surface impoundment code (if adopted) would provide additional flexibility for the Delisting Program and would help increase the efficiency of the review process. Since delisting decisions are rulemakings and require Federal Register notice and promulgation, any specific uses of the model would be proposed for public comment.

Other Uses

The OSW does not have any other specific uses planned for CANSAZ at this time. However, it is anticipated that any other uses, if identified, would be for the development of regulations under RCRA for the identification of hazardous wastes. The potential uses would be limited to miscible flows (non-oily wastes), and the code would be implemented with most of the input parameters as the Monte Carlo variables.

As indicated, the primary intended use of EPACMS is in the RCRA delisting program, where a nationwide assessment of dilution attenuation factors will be performed to determine maximum allowable contaminant concentrations for delisting impounded wastes. In this application, the EPACMS will replace the current VHS model. The Subcommittee review focused on this use and evaluated the appropriateness of CANSAZ and EPACMS for use in developing a nationwide rule. Because the uses of CANSAZ and EPACMS could include other, possibly site-specific applications, the Subcommittee also considered the adequacy of CANSAZ and EPACMS for use in site-specific evaluations.

3.0 ISSUES ADDRESSED IN REVIEW

The request from OSW identified two major areas for SAB review. The first relates to the appropriateness of the assumptions underlying CANSAZ when used in a nationwide, Monte Carlo assessment, including which parameters should be estimated on a site-specific vs. a nationwide basis. The second relates to the adequacy of the code for simulating conditions beneath surface impoundments. The Subcommittee focused on these issues by evaluating five topics:

1. Proper Mathematical Formulation: Given the assumptions of the model, are the numerical formulation and solution methods correct?
2. Adequacy of Physical Assumptions: Does the model include the important processes (ground water flow, pollutant transport and transformation) which determine contaminant fate? Is it properly formulated in terms of dimensionality, spatial and temporal aggregation? Are there omitted processes and what are their potential implications for the assessment?
3. Adequacy of Monte Carlo Approach: Is the probabilistic method technically valid and supported by adequate input data?
4. Adequacy of Field Testing of the Model: Has the model been tested (calibrated or validated) at particular field sites? What methods are appropriate for validating the nationwide Monte Carlo approach?
5. Overall Modeling Approach: Is the nationwide, Monte Carlo approach appropriate for the intended uses (e.g., delisting a waste, or closure of a site)? Which inputs require site-specific data versus national distributions? Are there alternative approaches? Can the Subcommittee propose a data collection program to support the assessment?

The Subcommittee review thus begins with more narrow questions related to the technical validity of the model, and moves to broader issues of model use and implementation in the regulatory setting. Each of the above areas is now addressed.

3.1 Mathematical Formulation

The CANSAZ model consists of two major components: A flow model and a solute transport model. The flow model is solved analytically. The solute transport model is solved with a new method known as LTG that combines the Laplace Transform (LT) and a finite element Galerkin (G) method. Details of the new solution technique are contained in a paper that has been published in a refereed journal (Reference 17).

The LTG solution approximately simulates dispersion transverse to the cross section, rather than rigorously. Tests suggest that this quasi-3-D solution is relatively accurate when compared with a rigorous 3-D dispersion solution. Extensive comparisons of LTG solutions with analytical solutions and conventional finite element solutions suggest that the numerical errors associated with LTG are of the same magnitude or smaller than other numerical solutions. CANSAZ also provides an analytical solution option for solute transport. The analytical solution has more restrictive assumptions than the numerical solution option, except that the analytical solution treats three-dimensional dispersion rigorously.

The equations and boundary conditions appear to be properly formulated for the assumptions of the model. The model's developers are among the foremost practitioners of hydrogeologic transport model development. The technique employed is innovative, computationally efficient, and highly accurate, judging from the comparisons with analytical solutions presented in the background documentation. The LTG method appears to represent a significant advance over previous computational methods in terms of efficiency and robustness. However, the LTG method incorporated in CANSAZ is intrinsically limited in its ability to deal with heterogeneity and three-dimensional transport. The implications of these and other limiting model assumptions are addressed in the following sections.

3.2 Physical Assumptions

The CANSAZ model includes only a limited set of ground water flow and contaminant transport and fate processes. These include the processes generally incorporated in the current generation of ground water management models. The assumptions are internally consistent and represent a distinct improvement over the VHS model. However, given the rapid evolution of ground water science, it is clear that in many respects the model does not adhere rigorously to currently understood and emerging principles of flow and transport. In most respects, the deviations represent simplifications that are justifiable in terms of computational expediency. However, these simplifications inherently limit the accuracy of the model's predictions, and will particularly limit or preclude its use for detailed site-specific applications and decisions.

The major assumptions in the CANSAZ model concern the dimensionality of the model formulation, the aggregation in time (i.e., dynamic vs. steady-state simulation), aggregation in space (the consideration of spatial heterogeneity) and the inclusion of contaminant flow and transformation processes.

Dimensionality: CANSAZ is restricted to two-dimensional flow in the vertical and longitudinal directions, ignoring the horizontal transverse flow resulting from mounding. Formation of a mound at the water table caused by seepage from the impoundment will cause radial flow away from the mound, including a horizontal component of flow transverse to the principal axis. If attention is focused on the centerline of the plume, the effect of neglecting the component of flow transverse to the cross section is conservative in that concentrations will be higher in CANSAZ simulations than in a three-dimensional flow simulation. Indeed, it is generally the case that two-dimensional flow models predict higher concentrations along the longitudinal axis than appropriate for three-dimensional flow fields (Reference 4, 14). (Note: Although CANSAZ neglects flow and advection of contaminants transverse to the cross section, it does simulate dispersion of contaminants transverse to the cross section.) While the two-dimensional flow field assumption is generally conservative, ignoring transverse flow beneath impoundments can seriously misrepresent the shape of the plume, particularly when the regional ground water flow is low compared to the impoundment infiltration rate. The CANSAZ model is not appropriate for use at sites where this is the case. Moreover, if the receptor well location is assumed to vary randomly between 0° and 45° relative to the plume for the Monte Carlo analysis, as described in the EPACMS User's Guide (Ref. 9, pp 101-103), then the two-dimensional model will not be conservative. Rather it will underestimate concentrations at observation points that are far removed from the principal plume axis.

Steady-State Conditions: The flow field is assumed to be steady-state. Also, infiltration from the impoundment is assumed to continue indefinitely. High infiltration rates cause high velocities in the saturated zone. Under the steady-state assumption, the high velocities will persist indefinitely. The model does not allow for the possibility of dilution and attenuation of the plume if seepage from the impoundment should cease. The assumption of steady-state flow (and steady-state input of contaminants) will result in conservative predictions of concentration.

The assumption of steady-state conditions is a major simplification that greatly facilitates computation and communication of the results. However, such a steady-state must be considered hypothetical as well as conservative, as it has yet to be observed in real situations, and, therefore, the corresponding predictions are not amenable to field verification. The steady-state condition is acceptable as a benchmark for Monte Carlo analysis of policy decisions, recognizing that any site-specific analysis, including comparisons with field data for purposes of verification, should be based on transient simulations. Once a verification of this type is performed, a simpler model formulation, limited to only the steady-state condition, could be used for regulatory application. A simpler formulation would be easier to understand and follow by those in the EPA and the regulated community likely to use the model.

Homogeneous Aquifer: The flow component of CANSAZ assumes that the aquifer is relatively homogeneous. Because the solute transport component of the model utilizes output from the flow model, it too is necessarily restricted to homogeneous aquifers. Aquifers, of course, are never homogeneous. While the assumption of homogeneous aquifer material has been frequently used, recent research makes it clear that the assumption is inappropriate for simulating solute transport in ground water. Most disposal sites are highly non-uniform, with high-permeability zones that constitute conduits of rapid transport. Paths of high hydraulic conductivity are important avenues for contaminants in fractured rock and clay, and also exist in continuous porous media (Ref. 2, 16).

There is currently much discussion in the literature over the appropriate way to incorporate heterogeneities into solute transport models. In one approach, the heterogeneities are accounted for in part by adjusting the dispersion coefficient, but this strategy cannot adequately represent the extreme cases of heterogeneity such as fractured media, as these have yet to be studied adequately and deviate significantly from the advection-dispersion model. Many go beyond this viewpoint and suggest that the advection-dispersion equation is simply not valid for application to heterogeneous aquifers of any type. However, at present, no consensus has emerged for a practical alternative to the advection-dispersion equation which is used in CANSAZ.. Nor is there consensus over the appropriate way to incorporate heterogeneities. In view of these doubts about the validity of the assumption of homogeneity, it is critical that EPA remain flexible and be willing to replace CANSAZ with another approach when there is a consensus. Also, it would be prudent at this time to establish strict criteria to delimit the amount of heterogeneity that can be tolerated in applying CANSAZ in site-specific applications. This criterion might be stated in terms of a permissible range of hydraulic conductivity variation at a given site: e.g., four orders of magnitudes or less. The framing of this criterion should be included in the scope of deliberations of an *ad hoc* committee of expert hydrogeologists, recommended later to evaluate the range of inputs used in the model applications.

Hydrodynamic Processes: The CANSAZ model assumes fully dissolved contaminant transport in a steady water flow of uniform density. As such, CANSAZ presumes that contaminants are transported only in aqueous solutions, and that immiscible organic phases do not exist. The Subcommittee believes, on the contrary, that many impoundments and landfills contain significant amounts of immiscible organic phases, and that migrations of such phases can be an important avenue of transport. This issue was also raised in the SAB's review of the unsaturated zone transport model (FECTUZ). Failure to incorporate immiscible transport constitutes a serious limitation, especially in site-specific applications where immiscible contaminant phases are believed to exist. While the OSW indicates that CANSAZ will only be applied for miscible flows (non-oily wastes), multiphase conditions are likely to be present in many situations, even at Subtitle D facilities.

A second hydrodynamic limitation is that CANSAZ presumes contaminants are dilute and that density-dependent transport plays no significant role. Even slight density differences can exert a significant influence on vertical plume movement. For example, two well-documented transport studies (at the Borden and Cape Cod sites) have revealed pronounced vertical dips in plume movement with solute concentrations as low as 1 g/liter. Such amplification of vertical plume movement may not be of great consequence in Monte Carlo simulations conducted with a presumed uniform distribution of monitoring points over the depth. However, in any site-specific application with explicit positions for the monitoring points, it is essential to include this phenomenon.

In terms of the hydraulic conditions represented by EPACMS, the linkage between the saturated model CANSAZ and the unsaturated model FECTUZ does not allow for movement of the water table that would shorten the length of the unsaturated column represented in FECTUZ. This assumption is not likely to affect the proposed regulatory application, but could be an important effect in other applications of the linked model.

Chemical Processes: The CANSAZ model assumes that all chemical transformations can be represented by simulating two processes: adsorption and first-order decay due to hydrolysis. Adsorption is represented using the linear equilibrium model. As such, adsorption has no effect on steady-state predictions, unless the first-order decay is assumed to occur in the adsorbed as well as the liquid phase. Adsorption does affect transient predictions, however, delaying the arrival of the plume.

The assumption of linear equilibrium adsorption appears to be approximately valid for most organic contaminants at low concentration. However, there is a general consensus that linear equilibrium does not apply to metals. CANSAZ should not be applied in its current form to simulate metal transport.

Biodegradation is not currently included in the CANSAZ implementation, although it is recognized as being important in many situations, and can, in principle, be incorporated by adjusting the first-order decay rate in the model. The implications of omitting biodegradation were discussed in detail in the SAB-EEC review of FECTUZ (SAB-EEC-88-030). There it was noted that:

> ...consensus is lacking for generalized prediction of transformation rate constants, as these depend strongly on conditions such as organism adaptations and concentrations, pH, and the presence or absence of electron acceptors (oxygen under aerobic conditions), toxicants, essential nutrients, etc. which are site-specific. Site-specific applications of the FECTUZ (*or, in general, the EPACMS*) model package can lead to over-estimates of solute transport since site-specific biotransformation analyses generally result in biodegradation being a primary process influencing chemical fate. Hence, estimates of chemical transport made without considerations of biotransformation are almost always so overly conservative as to affect regulatory decisions. Generalized chemical transport predictions will necessarily suffer due to lack of generally applicable biotransformation rate constants; however, site-specific analyses should include all of the fate processes for which specific data can be reasonably obtained.
>
> Implementation of the full range of transformation possibilities, including the uncertainties in conditions that influence the rate constants, would magnify enormously the uncertainty spectrum of predicted outcomes in Monte Carlo simulation.

The report further notes that any inclusion of biological transformation must explicitly consider the formation of possibly hazardous byproducts.

The CANSAZ and EPACMS models do not allow for chemical reactions between two or more chemical species. As such, CANSAZ is generally restricted to the simulation of groups of contaminants in the dilute range. The documentation, however, does not specify that range. EPA should state specific criteria for the upper limit of concentration. At higher concentrations, a variety of phenomena not considered in CANSAZ may play a role, including the following: facilitated transport, cosolvent effects, and competition for sorption sites. Most of these factors would tend to increase contaminant mobility, and thus to increase the potential health threat.

An additional chemical assumption in CANSAZ is that contaminants exert no effect on ambient chemical conditions. The impact of the waste on the receiving environment can in fact be important. Concentrated leachates often contain sufficient acidity or alkalinity to change the pH in the plume substantially, even where the native ground water possesses moderate buffer capacity. A change in leachate pH, particularly acidification, would enhance the mobilization of many metal species, while concentrated solvent exposure may dry and fracture clays. Many solvents are not contained by clays and could also enhance other contaminant transport. Similar considerations apply to dissolved oxygen concentration and redox state (Eh). It is probably infeasible to take this coupling into account on a generalized, nationwide basis. However, these interactions should be accounted for in any site-specific application in which the important processes (e.g., sorption, transformation or hydraulic stability of confining layer) depend importantly on geochemical conditions (pH, Eh, DO, presence of solvents).

Leachate and Source Characteristics: The discharge rate from an impoundment is determined by the impoundment size (cross-sectional area) and infiltration rate. The infiltration rate can be input directly to the model or computed from the depth of the fluid in the impoundment and the thickness and hydraulic conductivity of the impeding layer at the base of the unit. It is unclear from the reports, however, as to how the impoundment sizes and the amounts of wastes are generated for the nationwide, Monte Carlo assessment. It should be noted that the resulting leachate composition and flux could have a large effect on the dilution attenuation factors and the resulting decisions.

The CANSAZ model evaluates the impact of the impoundment without considering other facilities or background contamination which may be present. Few impoundments are located away from other facilities. Other landfills or lagoons, agricultural leachate, or process or potable water withdrawals may be present and alter site conditions. In the CANSAZ simulations, the saturated zone is assumed to be free from contaminants initially. In areas with industrial or agricultural pollution, or with naturally occurring sources of certain constituents, contaminants may be present in background concentrations. The effects of facilities may also limit applicability of individual replications or runs with fixed flow rates or infiltration. Again, these limitations are most important when considering site-specific evaluations. The CANSAZ model needs to have the ability to be initialized for existing conditions and incorporate other flow-field modifications when used in a site-specific application.

In summary, the CANSAZ model incorporates a number of simplifications concerning the model dimensionality, temporal representation, assumption of homogeneity, omission of hydrodynamic, chemical and microbiological processes, and representation of leachate and source characteristics. These assumptions preclude the use of CANSAZ for rigorous site-specific evaluations. However, the model is formulated at the proper level of detail for nationwide assessments, so long as proper and representative model inputs can be determined.

3.3 Monte Carlo Analysis

The purpose of the Monte Carlo approach is to predict the distribution of the dilution attenuation factor (DAF) that would occur between surface impoundment leachate and downgradient well points at surface impoundment sites throughout the United States. A smaller value of the DAF implies less dilution and attenuation by the aquifer, resulting in a greater impact at the receptor well. To perform the analysis, a distribution of inputs for the EPACMS model is developed to be representative of the distribution of meteorological conditions, soil properties, impoundment size and geometry, and well location at existing impoundments. The joint input distribution is sampled many times in the Monte Carlo analysis, and the model is evaluated with a specified waste quantity for each sample, resulting in a calculated national distribution for the DAF conditioned on the waste quantity. The DAF for which only a small percentage (e.g., 15 percent) of the simulated sites are less than the given value is selected as the design DAF which is assumed to occur for the given waste and waste quantity. Because the DAF is affected by chemical properties, including hydrolysis rates and adsorption coefficients, the analysis must be performed for each chemical.

There are three issues that the Subcommittee addressed to determine the validity of the Monte Carlo approach:

1. Is the nationwide, Monte Carlo approach appropriate for delisting decisions?
2. Are the mechanics of the Monte Carlo method properly formulated?
3. Are the input distributions developed for the Monte Carlo method adequately supported?

The first question is addressed in detail later in this report in Section 3.5, Overall Approach. The general conclusion is that site-specific evaluations are highly preferred to the use of a nationwide assessment, but that if a nationwide assessment is performed because of administrative or other policy constraints, then the second and third issues must be properly addressed. These are now considered.

3.3.1 Monte Carlo Method

The mechanics of the Monte Carlo procedure appear to be designed and implemented properly. The Monte Carlo module includes an impressive range of available distributions and is well integrated with the transport code. There are, however, some particular problems in the method presented.

The major problem is that covariance between model parameters is not incorporated. This is a particular problem for soil properties such as the hydraulic conductivity, hydraulic gradient, porosity and bulk density which are likely to exhibit a high degree of correlation (in the case of the hydraulic conductivity and hydraulic gradient, a negative correlation is expected). Other examples include the aquifer geometry, soil properties, and temperature, which may covary on a regional basis.

The one area where covariance is considered is in the simulation of soil characteristic curve parameters for the unsaturated zone component of the model (FECTUZ). Incorporating a similar procedure for the saturated zone parameters appears to be necessary, but could result in significant computational difficulties. Perhaps the most straightforward way to represent the covariance which occurs at actual field sites is to measure the soil parameters at many sites, and use the input vector for each site as a single, joint input to the model. The Monte Carlo analysis is then equivalent to running the model for each of the sites sampled, assuming they provide a representative sample of the target population. The implementation of a nationwide site sampling and characterization program, discussed later, would thus provide the most direct solution to the problem of identifying and incorporating input variable covariance.

3.3.2 Monte Carlo Inputs

While the mechanics of the Monte Carlo method are generally acceptable, determining the adequacy of the input distributions is more problematic. A properly formulated model can provide accurate and meaningful predictions only if its inputs and parameters are correctly estimated.

The Subcommittee was not able to judge whether the proposed nationwide data base reported in the documentation to EPACMS is appropriate for the intended regulatory use. As such, the model inputs should be carefully reviewed before EPACMS is disseminated for use. The estimation procedures for EPACMS are in many cases undocumented, in other cases incomplete, and in some cases inappropriate. For example, methods proposed for calculating porosity and hydraulic conductivity are wholly inappropriate and do not conform to standard hydrogeologic methods. Estimation of the hydraulic conductivity from mean grain size via the Carman-Kozeny equation (Ref. 9, Eq. 8.2.14.) is invalid for heterogeneous media, and in any case, the relevant grain size is d_{10}, not the mean. The hydraulic conductivity and porosity should be estimated directly from representative field data, rather than indirectly. In other cases (e.g., for dispersivity, the ratio of horizontal to vertical hydraulic conductivity, the aquifer thickness, length of aquifer and distribution coefficient, K_d), the documentation is inadequate to judge whether the proposed distributions are reasonable. Another example is the proposed distribution for ground water recharge. This distribution was generated using data from 100 cities analyzed with the HELP model. The committee was not able to review the input data, nor the HELP model itself. The resulting recharge distribution appears to be biased toward the Great Plains and Midwest. It is unclear how such bias, if present in the recharge distribution, and other parameters, will affect the outcome of the Monte Carlo analysis.

Some additional concerns were noted with regards to the Monte Carlo analysis. These include:

a. More documentation is needed to support the Gelhar-distribution for longitudinal dispersivity (Ref. 9, pp 98-99).

b. Citation and documentation is needed for the EPIC and REA data on well distances (Ref. 9, p. 102). The report does not indicate what these acronyms represent.

c. The sensitivity analysis which was presented orally to illustrate the effect of different model parameters should be included as part of the written report. Given the assumptions of the model on vertical mixing, and the screening depths generally used for wells, careful consideration should be given to interpreting the effect of well depth.

d. "Monte Carlo" is not a verb and parameters are not "Monte Carloed." They are sampled or generated in a Monte Carlo analysis.

In summary, it appears that ranges and distributions for many of the important inputs for EPACMS have been estimated without the support of adequate field studies and documentation. It is thus recommended that additional work be done in this area, and that a panel of hydrogeologists, soil scientists and engineers be convened to review the proposed or modified model input values and documentation. Consideration should be given to subjecting the resulting data set to public review prior to implementing the EPACMS delisting procedure. The gathering of field data and documentation for the model inputs is an important part of the model validation exercise discussed in the following section.

3.4 Model Validation

There are a number of steps that can be taken to validate models for use in regulatory decisions (e.g., Reference 3, 6). This issue was an important part of the recent SAB-EEC resolution on mathematical models (Reference 21). The resolution states that

> as a preliminary step, the elements of the basic equations and the computational procedures employed to solve them should be tested to ensure that the model generates results consistent with its underlying theory. The confirmed model should then be calibrated with field data and subsequently validated with additional data collected under varying environmental conditions. After the particular regulatory program has been implemented, field surveys and long-term monitoring should be conducted for comparison with model projections. The stepwise procedure of checking the numerical consistency of a model, followed by field calibration, validation and *a posteriori* evaluation should be an established protocol for environmental quality models in all media, recognizing that the particular implementation of this may differ for surface water, air and ground water quality models. It is also recognized that the degree and extent to which the

process of validation is conducted for a model depends on the significance of the environmental issue and the consequence of an erroneous decision concerning the problem.

The OSW and its contractors have taken steps to verify and validate the EPACMS model. The numerical consistency and accuracy of the model have been verified by comparisons with known analytical solutions and other numerical models. An oral presentation was provided to the Subcommittee on the application of EPACMS to model the migration of aldicarb through the unsaturated zone and the underlying aquifer at a field site on Long Island, New York. Site parameters were estimated based on previous modeling studies and entered as input to the EPACMS model. Reasonable, order-of-magnitude agreement between the model and observations was demonstrated, although the model did somewhat underestimate downgradient concentrations. The OSW personnel indicated that a better agreement could be obtained by adjusting model parameters, but that an order-of-magnitude agreement is what they expect to be representative of field test conditions.

The study presented by Dr. Saleem at the Subcommittee meeting represents a good start at model validation, and should be formally documented. It does not, however, constitute a thorough validation. For example, the aldicarb site does not include the flow dynamics of a leaking impoundment. Still, it is representative of the type of field study that the Subcommittee wishes to encourage. Because the EPACMS is proposed for use in a nationwide assessment, the Subcommittee identified a further set of validation studies for the Monte Carlo approach, considering both model inputs and outputs. These are presented in a hierarchical manner, reflecting different levels of effort and resource commitment.

The first approach consists of "limited validation" for one or more actual sites (such as the aldicarb study). In this approach, actual field measurements from a site are utilized to conduct sensitivity and/or site-specific Monte Carlo analysis. The statistical properties are defined by the measurements at the site. Once the model is exercised and the distribution of outputs is obtained, the results are compared with the real-world observations for that site. If the model predictions are consistently higher than those observed, an estimate of the degree of conservatism can be obtained. Use of several sites in this manner will increase the understanding of the expected level of bias and precision in the model results.

In addition to the aldicarb site already analyzed, the EPA program staff has been provided by the Subcommittee with EPRI data (Reference 11) for a 30-year-old site in New York State where the migration of organic compounds in the saturated zone has been measured. The hydrogeological, geochemical, and microbial biodegradation properties have also been investigated. The CANSAZ model should be applied in both a transient and steady-state mode and the results compared to measured concentrations. This comparison should provide an additional validation of the model.

The second approach in the hierarchy requires that a more extensive field validation effort be launched where several sites are rigorously characterized to generate the input data for the model. The model is then exercised to predict steady-state concentrations for each of the validation sites. Field measurements of the plume concentrations at each of the sites are statistically compared to the model generated concentrations. Further information on the consistency, precision and degree of under- or overprediction are obtained from this validation effort.

The use of EPACMS in a nationwide assessment requires a consistent set of input parameters and boundary conditions. The third level of validation requires a critical analysis of the input and output data sets generated by the Monte Carlo scheme. To determine the actual distribution of model input at sites in the U.S., a broad data-gathering program is needed. Following this, the input data generated by the Monte Carlo analysis can be examined to establish which types of the monitored sites are represented and whether the proper geographical weighting is achieved. This type of validation should assure that the distribution of inputs for the model is in close proximity to the distribution of sites in the U.S.

The Subcommittee recognizes that a nationwide monitoring program represents a major effort, and would require a special study and significant funding. If, however, a nationwide evaluation is used for developing regulations, it is necessary to support this effort with adequate nationwide data. The first step in such a study would be a systematic organization and cataloging of the studies thus far conducted and the data collected at present waste disposal sites, including land disposal and impoundment facilities. The information already collected in site investigation studies should provide a good start in the national characterization program, and will help inform the selection of additional sites and monitoring efforts. Considerable care will be needed to ensure that the data base provides an unbiased sample of the national distribution of geologic and hydrologic conditions at sites, as particular locations may currently have more information available due to special characteristics or public or political concerns. A representative national characterization program can provide the data necessary to estimate input parameters for the nationwide model, provide information on downgradient well concentrations for validation of the DAF distribution predicted by the national model, and provide insights on the problems and processes which are most important at real disposal sites.

It is clear that all three approaches will require resources and time to develop the data and conduct the validations. In the near term, we recommend that the Agency, through the ORD, conduct a limited validation along the lines of the first approach outlined above. Plans should then be developed for long-term studies of the type necessary for the second and third levels of validation, particularly if the generic, nationwide approach to the regulation is maintained.

3.5 Overall Approach

The nationwide assessment using EPACMS applies a generic model to all potential impoundment sites in the United States, with the Monte Carlo evaluation used to capture the site to site variability in model parameters. The Subcommittee believes, considering only scientific criteria, that the use of a site-specific assessment for making delisting decisions is clearly preferred to the proposed generic - Monte Carlo approach. This viewpoint is based on the belief that facility-specific decisions on delisting should be based on a site-specific evaluation of the facility where the waste is disposed. Site-specific decisions require site-specific data. The variation among sites resulting from variations in hydrogeologic conditions is known to be so great that the site-specific conditions of storage or disposal must be specified to allow for a scientifically credible evaluation.

The Subcommittee recognizes that this perspective calls into question the entire approach to delisting currently espoused by the Agency. The current delisting procedure applies to the waste, regardless of the facility used for treatment or disposal. In evaluating delisting petitions for wastes, the Agency assumes that the waste could be placed in a Subtitle D land disposal unit anywhere in the United States. The Agency has therefore adopted a national analysis approach in determining whether or not to reclassify a waste from hazardous to nonhazardous. If a waste is reclassified as nonhazardous, its resulting disposal location is unspecified and the waste is no longer subject to Subtitle C regulation.

The viewpoint that only site-specific evaluations are acceptable leads to administrative difficulties, as it would require that the disposal site for the delisted waste be specified. However, the entire purpose of the delisting procedure is to remove the burden of hazardous waste regulations from the waste in question; requiring a specification of the waste disposal location and requiring an analysis of potential impacts at that site would dictate a level of effort similar to that for facility permitting. Solution of this dilemma of an apparent conflict between the administrative and scientific objectives of the Agency would require a new approach to the regulation. One possible suggestion is to conduct a site-specific analysis to implement a provisional delisting. That is, if a given waste is disposed of at a given approved site, then it is delisted. Any disposition at other than the given site makes the waste hazardous. The burden of gathering the site and waste data and conducting the model analysis (e.g., using a model such as CANSAZ with appropriate modifications for the particular site), would be placed fully upon the waste generator. The generator must demonstrate that the waste can be safely disposed of at the subject surface impoundment for the delisting petition to be acceptable.

The Subcommittee recognizes that, based on administrative or other policy considerations (e.g., the desire to facilitate rapid delisting without undue administrative requirements and delay), the Agency may elect to maintain the proposed nationwide framework. The question then arises as to how this type of assessment can best be performed, in particular, whether regionalization is appropriate, and whether a very extreme or conservative decision threshold is necessary to be protective of the environment.

The proposal for regionalization of the ground water impact assessment has been made in a previous SAB-EEC report on the RCRA land-ban proposals (Reference 19). Without regionalization, the same Monte Carlo data set is used to represent all sites across the country. Yet there are vast differences in the hydrogeology and environmental sensitivity across the country. Sites in the arid west with hundreds of feet to the water table and little rain, sites in the southeast karst regions, sites in the Gulf Coastal Plain, and sites in the High Plains of the Dakotas are all represented by the same range of national data. This places severe restrictions on facilities located in environmentally sound sites, and may allow poorly located facilities to be delisted. The Subcommittee thus suggests that some sort of regional approach be considered by the Agency. Regional ranges of data inputs for the hydrologic parameters could reduce the uncertainty and reduce both false positives and false negatives. The regional approach could use either geographic regions or hydrogeologic regions. The EPA has developed a ground water flow assessment model, DRASTIC, based on hydrogeologic regions (Ref. 22). A similar approach could be considered for the current application, however, further analysis would be required to determine the suitability of DRASTIC, or any other framework, for this purpose. (The Subcommittee did not review the DRASTIC model.) Once a basis for regionalization is determined, model input parameters such as recharge, hydraulic conductivity, porosity, hydraulic gradient distributions and ground water temperature can be selected to be more representative of the possible range of aquifer conditions within regions. However, as conditions still vary greatly even within regions, the use of site-specific analysis is still preferable to the regionalization approach proposed.

Another issue related to the consideration of different hydrogeologic regions is whether highly conservative delisting thresholds should be required in the use of a nationwide model. While this is in many respects an issue of Agency policy, it includes some scientific issues as well. If all possible disposal sites are permitted for delisted wastes, then a nationwide demonstration must consider worst case conditions, or at least the minimal requirements of Subtitle D facilities (because the waste must be demonstrated safe for that lower level of waste management). A Monte Carlo analysis of the entire range of environmental conditions would not be appropriate because disposal in high transmissivity conditions, like fractured rock or karst, will certainly lead to problems and should be prohibited. If Monte Carlo analysis is used with all sites considered, a very high level of facility protection is required to account for disposal in these extreme settings. Certainly, an 85% threshold is unacceptable because this would allow a 15% failure rate and result in a substantial number of contamination sites requiring remediation. A way to address this dilemma would be to ban the disposal of delisted wastes at sites with known high transmissivity conditions, such as fractured rock or karst. This would impose some degree of regulation on delisted wastes, but much less than that required for a Subtitle C waste, and the simple restriction should be straightforward to implement. Once such vulnerable hydrogeologic settings are excluded from the set of potential disposal sites for delisted wastes, a decision based on Monte Carlo analysis of the remaining sites is more likely to provide adequate protection.

One final problem identified by the Subcommittee is that only a limited number of contaminants will be simulated by the model. In the current application, unless a waste stream contains only those simulated compounds, the waste could not be delisted. Few wastes are so simply limited to a few compounds. The full range of compounds in a waste must be considered in a listing or delisting decision. Once all are identified, toxicological and other evidence could be presented to demonstrate that certain compounds are not hazardous, perhaps at some predetermined threshold level, and these would not be subject to further evaluation. Then, only compounds which are hazardous would be subjected to migration potential review before delisting. Thus, all significant constituents of the waste would be evaluated in some manner before a delisting decision is made. It is clear, however, that the CANSAZ model and data base will not be ready for use until they can handle all significant constituents that must be quantitatively addressed in a delisting petition.

APPENDIX A - THE CHARGE TO THE SUBCOMMITTEE

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

APR 4 1989

OFFICE OF
SOLID WASTE AND EMERGENCY RESPONSE

MEMORANDUM

SUBJECT: Science Advisory Board Review of the Surface Impoundment Groundwater Code (CANSAZ)

FROM: Devereaux Barnes, Director
Characterization and Assessment Division (OS-330)

TO: Dr. Donald Barnes, Director
Science Advisory Board (A-101)

The purpose of this memorandum is to request your review of the Combined-Numerical SAturated Zone (CANSAZ) flow and transport module for the simulation of flow and transport of contaminants in the saturated zone. The code was developed to better simulate the migration of contaminants beneath those surface impoundments where hydraulic mounding occurs. The incorporation of CANSAZ represents the major difference between the OSW fate and transport models for landfills (EPACML) and for surface impoundments (EPACMS). Both EPACMS and EPACML are applicable to aqueous wastes and are generally implemented on a nation-wide basis using the Monte Carlo techniques.

SPECIFIC AREAS OF REVIEW

The two major areas listed below are identified for SAB review. However, there may be other concerns about the CANSAZ module. Some of these concerns may be generic to groundwater models in general; they include the biodegradation of contaminants, heterogeneities and fractures in the subsurface materials, multiphase transport, and the quality and quantity of the data. The OSW is aware of these concerns and welcomes the SAB's views on them. However, at this time we are particularly interested in comments specific to the CANSAZ module.

1) Assumptions Underlying the CANSAZ

CANSAZ was developed for possible use in the development of regulations in the hazardous waste identification program. The code possibly could be used in the Delisting Program because a large portion of petitioned wastes are managed in surface impoundments. In this program, the code would be implemented on a nation-wide basis using the Monte Carlo techniques, although certain parameters related to the dimensions of the surface impoundment and the volume of the waste may be fixed based on site-specific conditions.

Two important questions concerning assumptions are: 1) Are the assumptions made in the development of the code appropriate, considering the intended use and the limitations of the available data? and 2) Which parameters should be used only as part of a Monte Carlo Analysis and which ones could be set to site-specific conditions?

2) Adequacy of CANSAZ

The code was developed to account for the effects of mounding beneath surface impoundments on the transport of contaminants. The mounding creates a variable velocity field which requires that both the horizontal and the vertical components of the velocity be considered in simulating transport of contaminants. A critical review question is whether the code is adequate for simulating the transport of contaminants beneath surface impoundments containing aqueous wastes, keeping in mind the intended regulatory uses of the code.

Thank you for your help. Please contact me, Alec McBride (382-4761) or Dr. Zubair Saleem (382-4767), if we can be of any assistance on this project.

Attachment

cc: Matt Straus
Alec McBride
Dr. Jack Kooyoomjian
Dr. Zubair Saleem

APPENDIX B - ACRONYMS

ASTM -	AMERICAN SOCIETY OF TESTING MATERIALS
CANSAZ -	COMBINED ANALYTICAL-NUMERICAL SATURATED ZONE FLOW AND TRANSPORT MODEL
DAF -	DILUTION ATTENUATION FACTOR
DO -	DISSOLVED OXYGEN
DRASTIC -	DEPTH TO GROUNDWATER, NET RECHARGE, AQUIFER MEDIA, SOIL MEDIA, TOPOGRAPHY, IMPACT OF VADOSE ZONE, HYDRAULIC CONDUCTIVITY OF AQUIFER
EEC -	ENVIRONMENTAL ENGINEERING COMMITTEE OF THE SCIENCE ADVISORY BOARD
Eh -	REDOX STATE
EPA -	U.S. ENVIRONMENTAL PROTECTION AGENCY (ALSO USEPA)
EPACML -	EPA COMPOSITE MODEL FOR LANDFILLS
EPACMS -	EPA COMPOSITE MODEL FOR SURFACE IMPOUNDMENTS
EPRI -	ELECTRIC POWER RESEARCH INSTITUTE
FECTUZ -	FINITE ELEMENT CODE FOR SIMULATING FLOW AND TRANSPORT IN THE UNSATURATED ZONE
G -	GALERKIN FINITE ELEMENT METHOD
HELP -	HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE
IAHS -	INTERNATIONAL ASSOCIATION OF HYDROLOGICAL SCIENCES
K_d -	DISTRIBUTION COEFFICIENT
LT -	LAPLACE TRANFORM
LTG -	COMBINED LAPLACE TRANSFORM (LT) AND FINITE ELEMENT GALERKIN (G) METHOD
NWWA -	NATIONAL WATER-WELL ASSOCIATION
OSW -	OFFICE OF SOLID WASTE OF THE U.S. ENVIRONMENTAL PROTECTION AGENCY
pH -	NEGATIVE LOG OF HYDROGEN ION CONCENTRATION
RCRA -	RESOURCE CONSERVATION AND RECOVERY ACT
SAB -	SCIENCE ADVISORY BOARD OF THE U.S. ENVIRONMENTAL PROTECTION AGENCY
Subtitle D Facilities -	NON-HAZARDOUS WASTE LAND TREATMENT, DISPOSAL OR STORAGE FACILITIES AS SPECIFIED BY THE RCRA LEGISLATION AND IMPLEMENTING REGULATIONS
SZM -	SATURATED ZONE MODEL
SZMS -	SATURATED ZONE MODEL SUBCOMMITTEE
VHS -	VERTICAL, HORIZONTAL SATURATED ZONE MODEL

APPENDIX C - RESOURCE MATERIAL AND REFERENCES CITED

1) Ambrose, Robert B., Jr. and Thomas O. Barnwell, Jr., "Environmental Software at U.S. Environmental Protection Agency's Center for Exposure Assessment Modelin (undated reprint), 18 pages.

2) Anderson, M.P., "Hydrogeologic Facies Modes to Delineate Large-Scale Spa Trends in Glacial and Glaciofluvial Sediments," Geological Society of Amer Bulletin, 101(4), 1989, pp. 501-511.

3) ASTM, "Standard Practice for Evaluating Environmental Fate Models of Chemica American Society for Testing and Materials (ASTM), Committee E-47 on Biologi Effects and Environmental Fate, Designation E978-84, Philadelphia, PA, 1984.

4) Burnett, R.D. and E.O. Frind, "Simulation of Contaminant Transport in Th Dimensions, 2. Dimensionality effects," Water Resources Research, 23(4), 1987, 695-705.

5) CANSAZ: Combined Analytical-Numerical Code for Simulating Flow a Contaminant Transport in the Saturated Zone, Prepared by E.A. Sudicky, J.B. K and P.S. Huyakorn, University of Waterloo and HydroGeologic, Inc. for the U.S. E Office of Solid Waste,(ANM/123D/FT, ID No. 89-017), October 1988.

6) Chapra, S.L. and K.H. Reckhow, 1983, Engineering Approaches for La Management, Volume 2: Mechanistic Modeling, Ann Arbor Science, Butterwo Boston, 1983.

7) Corson, Alan S., U.S. EPA Office of Solid Waste Memo to Harry Torno, Liaison to Science Advisory Board, entitled "Response to the Science Advisory Boar Comments on OSW's Development of the RCRA Hazardous Waste Identification a Land Disposal Restrictions Groundwater Screening Procedure," February 19, 1985

8) EPACML: Background Document for EPA's Composite Landfill Model, Woodwa Clyde Consultants, 1988.

9) EPACMS: Composite Model for Simulating Leachate Migration from Surfa Impoundments and Monte Carlo Uncertainty Analysis, User's Guide, Prepared HydroGeologic Inc. for U.S. EPA Office of Solid Waste, (ANM/123D/FT, ID N 89-030) September 1988; Revised April 1989.

10) EPRI, A Review of Field Scale Physical Solute Transport Processes in Saturated a Unsaturated Porous Media, Electric Power Research Institute (EPRI), Palo Alto, C 1985.

11) EPRI, Personal Communication, I.P. Murarka.

12) FECTUZ: Finite Element and Semi-Analytical Code for Simulating One-Dimensional Flow and Solute Transport in the Unsaturated Zone, U.S. EPA Office of Solid Waste, Washington, D.C., 1988.

13) Freeze, R.A. and J. Cherry, Groundwater, Prentice Hall, Englewood Cliffs, N.J., 19

14) Frind, E.O., E.A. Sudicky and J.W. Molson, "Three-Dimensional Simulation Organic Transport with Aerobic Biodegradation," In: Groundwater Contaminati IAHS Publication No. 185, 1989, pp. 89-96.

15) Looney, Brian B. et al, "Analysis of the Validity of Analytical Models Used Assessment of Forty-Five Waste Site Areas: Subsurface Flow and Chemi Transport," Proceedings of the NWWA Conference and Exposition on Solv Ground Water Problems with Models, Vol. 2, Denver, Colorado, February 10- 1987, pp. 954-982.

16) Silliman, S.E. and A.L. Wright, "Stochastic Analysis of Paths of High Hydra Conductivity in Porous Media," Water Resources Research, 24(11), 1988, 1901-1910.

17) Sudicky, E.A., "The Laplace Transform Galerkin Technique: A Continuous Time-Continuous Finite Element Theory and Application to Mass Transport in Groundwater," Water Resources Research, 25(8), 1989, pp. 1833-1846.

18) U.S. EPA, Hazardous Waste Management System: Land Disposal Restrictions, Proposed Rule, Federal Register, Vol. 51, No. 9, January 14, 1986, pp. 1602-1766.

19) U.S. EPA/SAB, Report of the Environmental Engineering Committee of the Science Advisory Board, "On the Review of the RCRA Hazardous Waste Identification and Land Disposal Restrictions Ground Water Screen Procedure," April 1985.

20) U.S. EPA/SAB, Report of the Unsaturated Zone Code Subcommittee of the Environmental Engineering Committee of the Science Advisory Board, "Review of the Office of Solid Waste's Unsaturated Zone Code (FECTUZ) for the OSW Fate and Transport Model" SAB-EEC-88-030, July 12, 1988.

21) U.S. EPA/SAB, Report of the Environmental Engineering Committee of the Science Advisory Board, "Resolution on the Use of Mathematical Models by EPA for Regulatory Assessment and Decision-Making," EPA-SAB-EEC-89-012, January 1989.

22) U.S. EPA, "DRASTIC: A Standardized System for Evaluating Ground Water Pollution Potential Using Hydrogeologic Settings," EPA/600/2-85/018, 1985.