GROUND WATER

Editorial

Is a Probabilistic Performance Assessment Enough?

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Recent advances in hydrogeology have led many of us to reexamine the classical debates in physics, chemistry, and geosciences between those who believe in a deterministic world and those who believe it is stochastic. In hydrogeology, deterministic models have been the tools of choice for many years, but their predictive accuracy is often low. The recognition of our inability to accurately and precisely define the properties and boundary conditions for a subsurface system led to much research in recent years on the nature of uncertainty in hydrologic systems and how to deal with it. Geostatistical methods represent one broad class of approaches that have proved to be of great value. These methods, however, do not, and will not, eliminate the need to understand, as well as possible, the ground water flow and transport processes and the properties of the hydrogeologic framework in which they occur.

One example of an area in which deterministic and stochastic approaches have been linked is assessment of potential sites for geological disposal of radioactive wastes. Federal regulations recognize the existence of hydrogeologic uncertainty and require that repository site assessments be conducted within a probabilistic framework. This is commonly accomplished through an approach generally called "performance assessment" (PA). A PA has been completed for the WIPP site in New Mexico, which was recently approved by the U.S. Environmental Protection Agency for opening and operation as a transuranic waste repository. The U.S. Department of Energy has just released the congressionally mandated "total systems performance assessment" as part of the viability assessment of the proposed nuclear waste repository at Yucca Mountain.

PA methodology was originally developed for engineered systems, such as nuclear power plants. As useful as the probabilistic approach has been, it is not yet clear to a few skeptics (such as us) that reliable and meaningful assessments can indeed be generated by applying a probabilistic performance assessment approach to complex natural hydrogeologic and geochemical systems. Much of our concern is with the magnitude of the uncertainty in characterizing natural systems for a repository in which performance is evaluated for periods of tens of thousands of years.

A basic premise of the probabilistic PA process appears to be that the uncertainty in parameters and boundary conditions can be adequately characterized, so that the statistical distribution of the outcomes (for example, travel times) of a large enough number of realizations will yield meaningful values. This is a major and critical underpinning that is virtually unprovable; if accepted, it must be done so on faith. One could argue that if the parameter distributions to be sampled are wide enough, then all probable outcomes will be encompassed. But this begs the question of whether the generated probabilistic estimates are meaningful. Hydrogeologists with extensive field experience may remain skeptical because they believe that the degree and nature of the uncertainties are themselves highly uncertain and difficult to characterize, and this does not appear to be accounted for in the PA analysis. Probabilistic estimates based on erroneous statistical distributions of parameters could not be expected to be reliable. To the extent that the uncertainty in a probabilistic analysis obscures the usefulness of the final result, one must be concerned about the usefulness of risk-based regulations.

In Las Vegas, you can play roulette and many other games of chance. While you do not know if you will win or lose at a particular time, you can at least accurately characterize the probability of the outcome—you know (or should know) the odds, if you know the game. In hydrogeologic and geochemical systems, not only can we not accurately characterize the properties of a system, but there may also be significant uncertainty in the estimates of uncertainty. Therefore, we do not know the odds. In fact, we probably do not even know all of the rules of the game (or perhaps even which game we are playing); that is, for these natural systems there will be uncertainty in the conceptual models and in the complex nonlinear coupling between models.

In a probabilistic performance assessment of geologic repositories, as the methodology is generally implemented, probability

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distributions for many parameters are assumed (on the basis of limited available data and/or mathematical convenience). Realizations are generated on the basis of sampling from these assumed distributions. The sensitivity of calculated results to errors in the assumed distributions themselves is difficult to assess. Also, there are many variables, and generally each is sampled independently. Yet many parameters are correlated. Ignoring these correlations can certainly bias the calculated risk statistics by generating realizations that incorporate infeasible combinations of parameter values. Furthermore, the deterministic models that lie at the core of the statistical performance assessment method are often designed for computational efficiency because many individual simulations must be made. This creates a need to oversimplify, lump, and linearize. To some extent, this is necessary, desirable, and appropriate. But the simplifications must be carefully evaluated and tested, and often this is difficult to do.

Sensitivity analyses are typically performed with the PA models, but these analyses can examine the sensitivities of parameters only within the framework of the chosen models. The PA models themselves cannot evaluate their sensitivity to other concepts or processes not incorporated into the model. PA proponents might argue that it does not matter, because the analysts sample over a large range in values of the coefficients of the governing equations. But it is never demonstrated (and probably cannot be) that solving the equations many times, using a wide range of parameter values, will yield a scientifically meaningful probabilistic distribution of outcomes, if the equations are wrong!

The linking of multiple, complex, deterministic models in the PA approach makes it difficult to find and analyze weaknesses in the underlying conceptual models or even errors generated by faulty linkages and inconsistent assumptions among various submodels. We urge extreme caution before accepting the probabilistic outcomes generated by the PA process. On the other hand, we need not be frozen into inaction by an endless loop of analyses. Complex PA models should be complemented by more transparent simplified analyses. Decisions should rely on sound technical judgment, an assessment of risks relative to other choices (including no action), and site approval should require confirmatory long-term monitoring.

In summary, we offer a quote from Ansel Adams (as cited by T.N. Narasimhan in his 1998 editorial): "There is nothing more disturbing than a sharp image of a fuzzy concept." ♦