Model Uncertainty Approaches – Frenchman Flat Corrective Action Unit, Nevada Test Site - 10350

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ABSTRACT

The Underground Test Area (UGTA) Subproject was initiated by the U.S. Department of Energy, National Nuclear Security Administration Nevada Site Office to assess and evaluate the effects of the underground nuclear weapons tests on groundwater on the Nevada Test Site and vicinity. The framework for this evaluation is provided in Appendix VI of the *Federal Facility Agreement and Consent Order*.

Part of this project requires the assessment of potential future radionuclide migration under uncertainty. Two forms of uncertainty are considered: higher-level structural uncertainty in the basic arrangement of the rocks (or hydrogeologic framework model), and parametric or statistical uncertainty for any given framework model. Geologic elicitation was used to develop alternative models permissive with the data to assess the structural uncertainty; flow model calibration constrained null space Monte Carlo analysis was performed to assess flow model parametric uncertainty; and Latin Hypercube sampling was used to evaluate transport model uncertainty.

INTRODUCTION

Underground nuclear testing via deep vertical shafts was conducted at the Nevada Test Site (NTS) from 1951 until 1992. The Frenchman Flat area (Figure 1) of the NTS was used for seven years, with 10 underground nuclear tests conducted in the northern and central parts of the basin. The Underground Test Area (UGTA) Subproject is currently conducting correction action investigations to ensure long-term protection of the public and the environment from contaminated groundwater associated with underground tests. Part of these investigations is the development of a groundwater flow and transport model to forecast the future extent of radionuclide-contaminated groundwater over 1,000 years [1].

Traditionally, the focus of uncertainty analysis in groundwater modeling is on model parameters (statistical or knowledge uncertainty). However, significant sources of additional uncertainty arise from incomplete understanding of the subsurface geologic framework, boundary conditions, recharge, and other conceptual uncertainties (structural uncertainty). There is a growing understanding that the modeling paradigm should be expanded to include more than one plausible conceptual model of the system [2]. For Frenchman Flat, this issue was directly addressed by developing multiple permissive models of structural uncertainties that were then tested for their ability to match observed hydrologic conditions. In addition, null space Monte Carlo analysis of framework flow model parameters and standard Monte Carlo analysis of transport parameters were conducted.

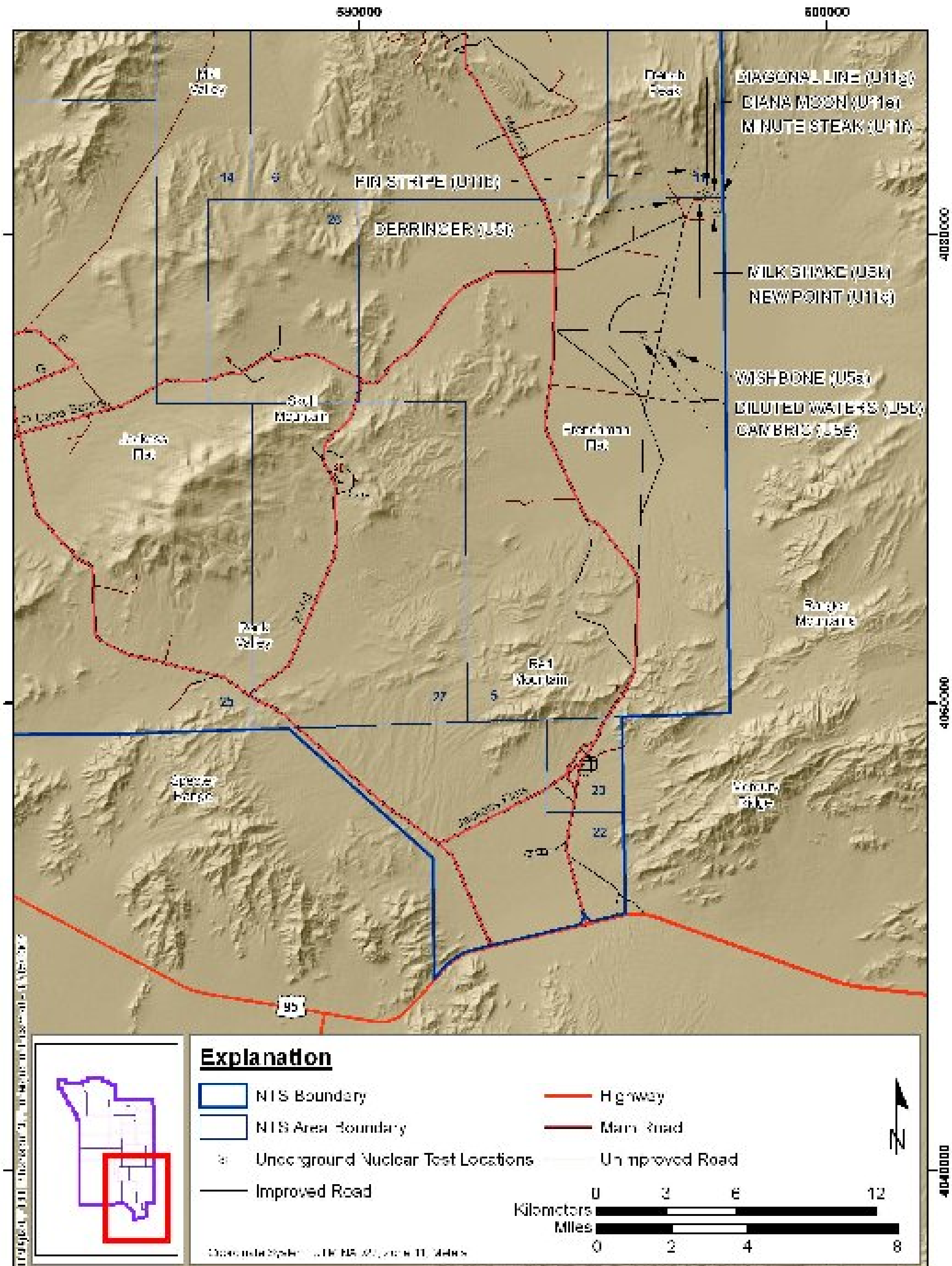

Fig. 1. Site map of Frenchman Flat showing the locations of underground nuclear tests.

The multiple models provide ensembles of forecasts of contaminant transport, which are the fundamental basis for identifying contaminant boundaries and negotiating a compliance boundary for each corrective action unit. Transport modeling simulations are used to compute radionuclide concentrations in time and space within a corrective action unit. These three-dimensional concentration data are integrated into probabilistic forecasts of the likelihood of groundwater exceeding or remaining below the radiological standards of the *Safe Drinking*

Water Act (SDWA) [3] defined as the contaminant boundary. Contaminant boundaries are not discrete predictions of the location or concentration of contaminants but instead are spatial representations of the probability of exceeding the SDWA radiological standards. The forecasts provide planning tools to facilitate regulatory decisions designed to protect the health and safety of the public.

APPROACH

Frenchman Flat is a combined strike-slip/extensional basin typical of the basin and range physiographic province and includes three rock sequences. From oldest to youngest, these are a thick assemblage of Paleozoic marine carbonate and clastic rocks forming basement rocks, distal sections of lava flows and volcaniclastic rocks deposited from volcanic centers to the west and northwest, and basin-fill alluvium. The carbonate assemblage is offset by Mesozoic-age thrust faults, and the volcanic and alluvium are deformed by strike-slip and basin and range normal faults associated with the late Miocene formation of the Frenchman Flat basin. The base framework model for Frenchman Flat has 17 hydrostratigraphic units and 73 faults [4]. The model incorporates features, suggested by a panel of geologists, that represent alternative interpretations of the uncertainty in the available geologic and structural data that may influence groundwater flow or contaminant transport. Addressing the high-level uncertainty present in the arrangement of the rocks in Frenchman Flat requires multiple hydrogeologic framework models (HFMs) that are permissive with the data described in Table I [4]. Figure 2 illustrates the base HFM and one of the HFM alternatives (DETA) developed and evaluated through modeling studies. Each framework model was incorporated into the analysis as an independently calibrated flow model [5]. Transport analysis for each framework model was accomplished by Monte Carlo simulations using Latin Hypercube sampling of transport parameters while leaving the flow field fixed. This approach allows assessment of the discrete uncertainty embodied in the alternative HFMs.

Table I. Frenchman Flat Hydrogeologic Framework Model (HFM) Alternatives.

HFM Alternative	Description
DETA – Detachment fault alternative	This alternative does not include a master detachment fault model associated with basin formation.
DISP – Displacement fault alternative	This alternative allows large displacement of basin-forming faults where the lower carbonate aquifer is juxtaposed against the alluvial and volcanic aquifers.
CPBA – CP Basin alternative	The CP basin alternative extends the upper clastic confining unit of the Paleozoic marine section beneath all of CP basin.
BLFA – Basalt Lava-Flow Aquifer alternative	The BLFA alternative models a buried basin unit at the base of the alluvial section as a single continuous basalt aquifer, rather than three separate basalt lavas.

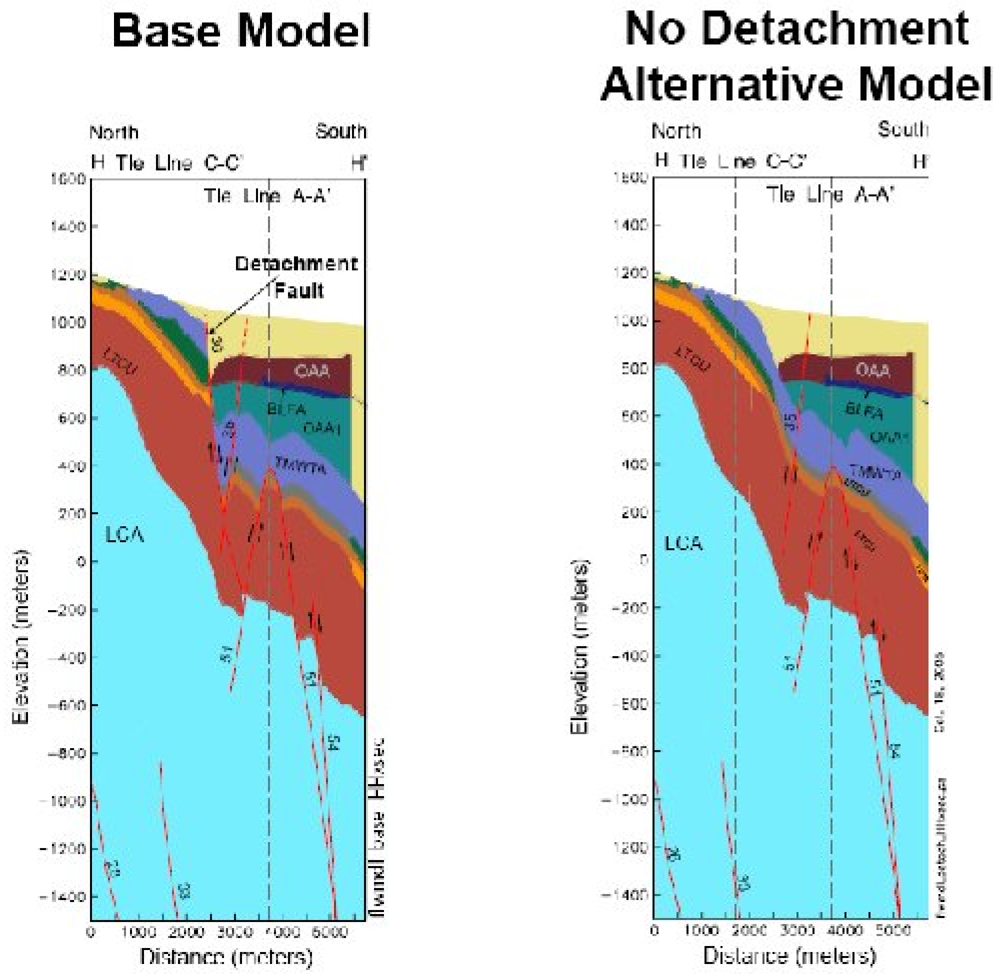

Fig. 2. Example of alternative HFM (right) used in the flow and transport models.

Parameterizing the alternative HFMs for flow model analysis created an additional layer of uncertainty in assigning hydraulic properties. This uncertainty arises from limited knowledge of rock properties over the scale of the basin, and additionally because of uncertainty in the conceptual models of spatial variability in the permeability of rocks units across the basin. This element of uncertainty is addressed during flow model calibration using constrained null space Monte Carlo analysis as described by Tonkin and Doherty [6] and is combined with transport parameter uncertainty.

Monte Carlo transport simulation results are used to develop future radionuclide plumes from transport of radionuclides downgradient of underground testing sites; these contaminant plumes are evaluated against the radiological standards of the SDWA to assemble sets of contaminant boundary forecasts. The contaminant boundary is defined as the set of all nodes at which a maximum contaminant level (MCL) is exceeded for alpha particles, beta- and photon-emitters, or uranium over 1,000 years. A metric representing a continuous variable that is amenable to quantitative analysis, the cumulative exceedance volume (CEV), was developed. The CEV is the total volume of all nodes at which the MCL is exceeded for any radiological standard of the SDWA, at any time within a 1,000-year interval from the time of source release, per Monte Carlo run. Combining the CEV over all model realizations forms a probability distribution function or cumulative distribution function of exceeding the SDWA. The CEV distribution enables quantitative comparisons of transport simulation output between the alternative flow models for assessment of their influence on transport. Figure 3 shows the CEV distributions for a range of discrete HFMs and flow model null space Monte Carlo analyses – there is clearly variation in the probabilistic forecasts themselves associated with parameter and model structure changes.

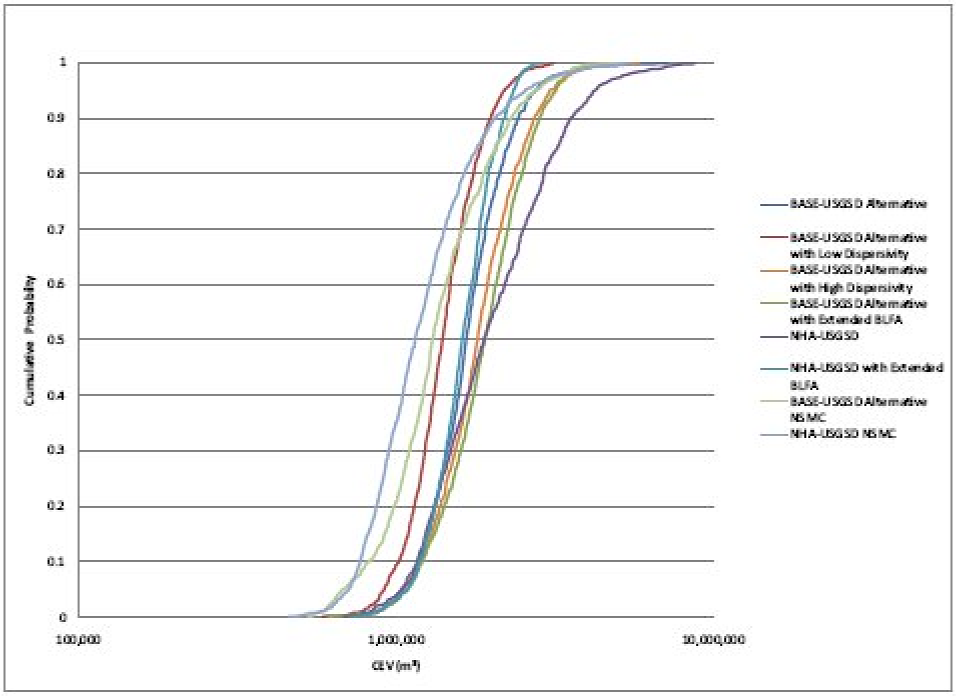

Fig. 3. Cumulative distribution functions of the cumulative exceedance volume for alternative models of contaminant transport.

CONCLUSIONS

Alternative HFMs were developed as part of uncertainty analysis, and the associated flow models were calibrated. Parameter uncertainty for a base case HFM was considered via null space Monte Carlo analysis, which was successful in developing calibration-constrained flow fields. The greatest difference in prediction uncertainties was not from high-level geologic uncertainty (conceptual or structural uncertainty) but from alternative parameterizations of individual HFMs. This result may be unique to Frenchman Flat, which has geologic complexity coupled with a modest amount of data (26 observation wells and 1 pumping test for calibration). One of the alternative HFMs that could have, at least conceptually, more impact on the prediction of radionuclide migration was uninformed by flow model calibration − a very important type of uncertainty. However, this result would not have been known without conducting analyses to quantify statistical and structural uncertainty.

Traditionally, the focus of uncertainty analysis in groundwater modeling has been the uncertainty in model parameters. There is a growing understanding that the modeling paradigm should be expanded to include more than one plausible model of the system. Beven [7] argued for considering multiple alternative models and model structures due to the problem of "equifinality," the concept that a unique model with an "optimal" set of parameters is inherently unknowable. Instead, he argued for a set of acceptable and realistic model representations that are consistent with the data. Developing alternative geologic models permissive with the data, while useful, should be an iterative process combining all aspects of uncertainty for the assessed environmental problem. A proper assessment of uncertainty in flow and transport of radioactive contaminants cannot be completed without careful identification and evaluation of multiple uncertainty components.

REFERENCES

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