## Sensitivity and Uncertainty Analyses for RCRA/CERCLA Groundwater Modeling PROTOCOL

The following protocol has been developed to support the Savannah River Site (SRS) Soil and Groundwater Closure Projects (SGCP) program. A detailed technical discussion on the actual background of this summary can be found in the ER Engineering Technical Memo entitled "Guidance: Sensitivity and Uncertainty Analyses for RCRA/CERCLA Groundwater Modeling"(ERTEC-2003-00006). This protocol has been reviewed by the Groundwater Modeling Design Team, made up of technical experts representing SCDHEC, USEPA, and WSRC and summarizes the basic steps for analyses.

A sensitivity analysis is performed on a calibrated model by varying one parameter at a time and evaluating model calibration and other pertinent model results. An uncertainty analysis is performed by simultaneously varying multiple uncertain parameters, and evaluating results within a certain calibration range.

### *Sensitivity Analysis*

The basic steps for a sensitivity analysis are:

#### Step 1. Identify the parameters

The parameters used in the sensitivity analysis should be recommended by the technical project staff, and agreed to by the core team. At a minimum, the following parameters should be considered in the sensitivity analysis: hydraulic conductivity (horizontal for aquifers, vertical for aquitards), recharge, sorption, dispersivity, and porosity.

#### Step 2. Identify the output results to observe

Model outputs as agreed by the technical staff and core team can include: water balance, calibration statistics, model fluxes, and transport predictions (transport times, concentrations, total plume masses/activities, mass/activity fluxes, etc.).

#### Step 3. Execute the simulations

Simulation runs of a single change from the calibrated value for a single parameter will be performed and the outputs identified in Step 2 are saved, as appropriate. Non-convergence cases may need additional runs with appropriate documentation.

Depending on specific project requirements, the impact of significant dependencies or correlations between model parameters may be investigated.

**Step 4. Document the results**

The documentation of a sensitivity analysis should include: discussion of the parameters and parameter ranges/values selected for evaluation, the methodology used, and the results of the analyses with appropriate Tables and Figures. Significant results should be presented in graphical forms.

*Uncertainty Analysis*

The basic steps for an uncertainty analysis are as follows:

**Step 1. Identify the output results to study**

Necessary outputs must be identified in consultation with the project and core teams prior to initiation of the analysis. These may include: contaminant flux to streams, location of maximum contaminant concentration discharge to streams, reduction in stream flux due to remedial alternative implementation, concentrations at designated locations, plume volume/mass/activity, and vertical extent of contamination, etc. Outputs should be recommended by the technical project staff, and agreed to by the core team.

**Step 2. Identify and define the uncertain parameters to evaluate**

Uncertain parameters for the analysis should be selected from the set of parameters that the model was most sensitive to, as identified in the sensitivity analysis. Appropriate individual parameter functions (PDFs – normal, lognormal, uniform, etc.) should be defined based on qualitative and quantitative information available for each parameter. Parameters and PDFs should be recommended by the technical project staff, and agreed to by the core team.

**Step 3. Define the calibration criteria**

The calibration criteria for the uncertainty analysis should be similar to the criteria used in the original model calibration and only realizations meeting calibration criteria should be included in the uncertainty analysis results.

**Step 4. Execute the analysis**

A Monte Carlo analysis, using custom or commercial software, will be implemented and consists of creating a combined set of results from different realizations. A plan for computation configuration (single computer, distributed processing, etc.) should be made to allow completion in a reasonable time frame.

### Step 5. Evaluate adequacy of the results

In order to determine if there have been enough realizations to adequately represent the results, the result statistics (mean, variance) should be evaluated along with appropriate repeatability checks, as applicable, to the specific project.

### Step 6. Calculate confidence intervals

Confidence intervals will be calculated by determining the confidence limits from the set of Monte Carlo realizations of output results. The values at the limits are determined by creating a cumulative distribution function and using the appropriate percentiles.

### Step 7. Document the results

A thorough discussion of the methods, inputs, and results of the uncertainty analysis should be presented with detailed information on the input distributions, input parameter correlations (dependencies), adequacy of the results (with plots of cumulative statistics -- mean and variance), along with confidence intervals for each output defined in Step 1.