



Geostatistical Modeling of Spatially Heterogeneous Material Properties

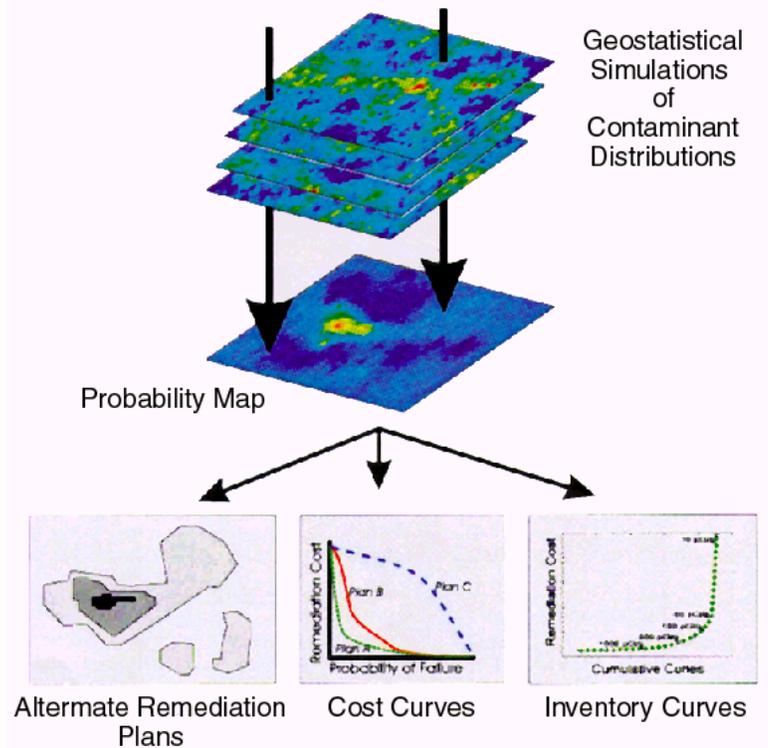
Need

The spatial distribution of physical and hydrological properties in natural materials is difficult to predict deterministically. Limited sampling programs, especially in subsurface drilling situations, further complicate prediction of the occurrence of such properties. Prediction of the spatial occurrence of material properties in either an optimal “best-guess” sense or within a probabilistic framework is necessary for effective numerical modeling of physical and hydrological processes that act on those heterogeneous properties.

Solution

Recent work at Sandia National Laboratories has applied geostatistical estimation (kriging) and simulation techniques to the problem of modeling spatial variability from limited sample sets. Contrary to traditional statistics where independence between samples is generally assumed, geostatistics takes advantage of the fact that samples located in proximity to one another are often more similar than those obtained at large separation distances. Geostatistics provides a means of quantifying this spatial correlation in material properties and then exploiting that information for use in both interpolation and stochastic simulation techniques.

Geostatistical simulation is a spatial Monte Carlo process where a random draw from a local cumulative distribution function simulates a value of a property at a given location. The simulation process is run multiple times to produce a series of realizations (maps) all of which honor, the observed data at the sample locations, the univariate distribution of (histogram) and the spatial correlation of the observed data. In essence, each realization is a plausible representation of the underlying reality given the available data. These multiple realizations can be used as input to a transfer



Processing of multiple geostatistical simulations into a probability of exceedence map that can be used to design remediation plans, analyze cost-benefit alternatives and assess total contaminant inventory



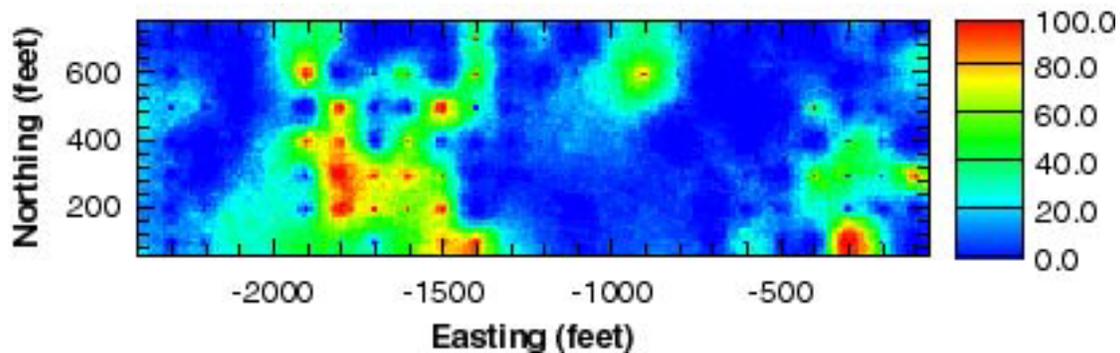
function (e.g., multiple realizations of permeability as input to a groundwater flow and transport model), or processed to provide a map of the probability of a given statement being true (e.g., a map of the probability that a contamination level exceeds a regulatory threshold). The results of the transfer function can often be evaluated in terms of economic loss and/or risk.

Example Applications

Applications of geostatistical techniques by SNL to various problems include:

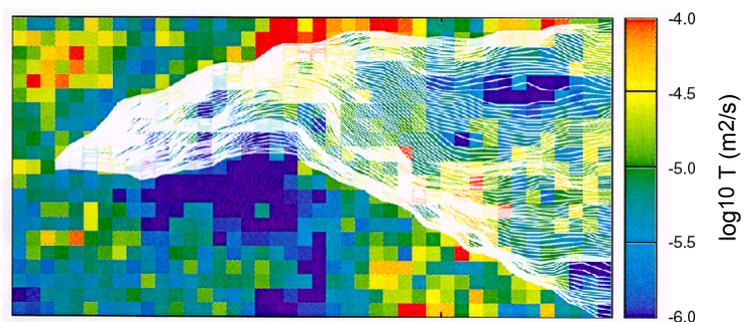
- Three-dimensional modeling of rock properties and corresponding spatial uncertainty in support of site-characterization activities at Yucca Mountain, Nevada.
- Development of the Smart Sampling program to assist DOE cold-war legacy sites in optimizing site characterization and remediation decisions. In order to accomplish this optimization, spatial uncertainty in contaminant levels is combined with sampling, remediation, and failure costs in an economic objective function.

Uncertainty in the spatial prediction of porosity in the subsurface at Yucca Mountain, Nevada. Cut away view shows boreholes as vertical lines.



Probability, shown as percent, of exceeding 25 pCi/g total Pu in the soil at PRS-379, Mound Plant, Miamisburg, Ohio. Probability map is derived from 100 geostatistical simulations.

- Two and Three-dimensional modeling of fracture permeability in support of groundwater flow and transport modeling for the WIPP and Yucca Mountain projects. These efforts have been applied to interpretation of tracer test data and in performance assessments of nuclear waste repositories.



Groundwater flow lines moving through a heterogeneous transmissivity field from a line source (right side) to a pumping well.

Ongoing Research and Development at SNL

Integration of multiple sources of data into coherent maps of a variable of interest. These multiple sources of data may be at different scales and levels of precision (e.g., combining data from handheld environmental sensors with satellite imagery).

Bayesian and non-bayesian techniques for determining the optimal location(s) for future samples. Optimal is defined by those samples that provide the greatest “worth” and/or reduction in uncertainty.

Outreach programs for education and technical assistance to DOE and other customers.

Further development of casting environmental decision making into economic terms.

Selected References

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