#1085

CONF-951209

17th ANNUAL U.S. DEPARTMENT OF ENERGY LOW-LEVEL RADIOACTIVE WASTE MANAGEMENT CONFERENCE PROCEEDINGS

Phoenix, Arizona
December 12–14, 1995

Idaho National Engineering Laboratory
National Low-Level Waste Management Program

Work performed under
DOE Contract DE–AC07–94ID13223

A DECISION TOOL FOR SELECTING TRENCH CAP DESIGNS

G.B. Paige, J.J. Stone, T.E. Hakonson*, and L.J. Lane
USDA-ARS, 2000 E. Allen Rd., Tucson AZ. 85719, and
*Center for Ecological Risk Assessment and Management,
Colorado State Univ., Ft. Collins, CO. 80523.

ABSTRACT

A computer based prototype decision support system (PDSS) is being developed to assist the risk manager in selecting an appropriate trench cap design for waste disposal sites. The selection of the "best" design among feasible alternatives requires consideration of multiple and often conflicting objectives. The methodology used in the selection process consists of: selecting and parameterizing decision variables using data, simulation models, or expert opinion; selecting feasible trench cap design alternatives; ordering the decision variables and ranking the design alternatives. The decision model is based on multi-objective decision theory and uses a unique approach to order the decision variables and rank the design alternatives. Trench cap designs are evaluated based on federal regulations, hydrologic performance, cover stability and cost. Four trench cap designs, which were monitored for a four year period at Hill Air Force Base in Utah, are used to demonstrate the application of the PDSS and evaluate the results of the decision model. The results of the PDSS, using both data and simulations, illustrate the relative advantages of each of the cap designs and which cap is the "best" alternative for a given set of criteria and a particular importance order of those decision criteria.

The primary purpose of DOE's Environmental Restoration Program is to manage the health and ecological risks associated with intentional and accidental releases of radioactive and hazardous contaminants to the environment. Containment is viewed as a viable cleanup solution for most DOE sites that have low to intermediate levels of residual contaminants and pose few risks to humans or ecosystems. A trench cap placed over the waste is a central feature of most containment strategies and can range from a very simple soil cap to an extremely complex engineered design that mitigates both the vertical and lateral flow of water and gases. The primary functions of the cap are to isolate the buried waste from the surface environment and to control hydrologic processes, including erosion, that can cause contaminant migration from the site.[1,2]

The process of selecting containment cover technologies for radioactive and hazardous waste landfills requires that trench cap designs be evaluated in a repeatable, objective, and scientifically defensible manner that takes into account all the necessary technical, regulatory, and economic factors. The Environmental Protection Agency (EPA) technical guidance for final covers describes a recommended cap design, often called EPA's RCRA cap, that will meet the final cap performance standard.[3] It is important to note that EPA offers the RCRA cap design as guidance and does not require its use if another design can be shown to meet the technical performance standards. Research in trench cap designs have demonstrated that there may be alternatives to the recommended design which offer certain technical and economic advantages.[2,4,5,6] A basic need is to be able to evaluate and compare these alternative designs with the EPA RCRA design for specific waste sites while taking into account the technical, regulatory, and economic issues. A prototype decision support system (PDSS) to assist the risk manager in evaluating capping alternatives for radioactive and hazardous waste landfills is presented herein. The PDSS incorporates methods for calculating, integrating and valuing technical, regulatory, and economic criteria.

The goal of developing the PDSS is to improve the quality of technical information used by the risk manager to select landfill capping designs that are cost effective and meet regulatory performance standards. The overall objective is to develop and test a prototype decision support system to evaluate landfill cap designs. The use of a DSS to design and evaluate trench cap remediation technology will reduce the likelihood of selecting a trench cap technology that does not meet performance objectives and imposes the attendant costs of fixing mistakes. Candidate remediation technologies can be evaluated beforehand with the DSS to identify technical and regulatory problems inherent in the technologies, and to assess the projected long-term performance and practicality of the designs from a construction and economic viewpoint.

METHODS AND MATERIALS

The PDSS presented in this paper follows the approach described by Lane et al. and Paige et al.[7,8] The methodology used in the selection process consists of: 1) selecting and parameterizing decision variables or criteria, 2) selecting feasible trench cap design alternatives, 3) ordering the decision variables, and 4) ranking the design alternatives. The components of the

PDSS include: simulation models, a decision model, and a graphical user interface. Decision variables can be parameterized using the simulation models, data, or expert opinion. The general category of decision variables for the evaluation of trench cap designs is specified by the EPA guidelines.[3] These include such factors as the elements of the water balance, erosion, and subsidence. The specific decision variables will depend on the current state of the science (i.e. unsaturated flow dynamics, contaminant pathway analysis, erosion mechanics), regulations (minimize percolation and erosion), and socio-economics (cost, site location). Further details of the simulation models and the decision model are given below.

Simulation Model

The simulation models embedded in the PDSS are the EPA recommended HELP (Hydrologic Evaluation of Landfill Performance) water balance model[9, 10] and the overland flow erosion component of the CREAMS (Chemicals, Runoff, and Erosion from Agricultural Management Systems) model.[11] The HELP model computes the water balance, soil water movement within the trench cap system, and the necessary input variables for use by the erosion component of the CREAMS model. The erosion component of the CREAMS model is incorporated as an alternative to the EPA recommended USLE (Universal Soil Loss Equation).[12] CREAMS estimates of water-induced erosion of the cap account more explicitly for the temporal and spatial variation of the erosion process than the USLE.

HELP was developed by the U.S. Army Corps of Engineers Waterways Experiment Station (WES) for the EPA Risk Reduction Engineering Laboratory. It is a quasi-two-dimensional model that uses weather, soil and design data and calculates the infiltration, surface runoff, percolation, evapotranspiration (ET), soil water storage, and lateral drainage in a shallow landfill system with up to twelve different layers. The model simulates water flow within three different soil layer types: vertical percolation, lateral drainage, and barrier soil layers with or without a geomembrane. However, the HELP model is unable to simulate flow through a capillary barrier.

The CREAMS overland erosion component has been added to the HELP model to simulate trench cap erosion. The erosion component of CREAMS can be used to predict sediment yield and particle composition of the sediment on an annual or a storm event basis. The erosion component requires the input of hydrologic parameters for each runoff event simulated by the HELP model and an erosion parameter file. The principal outputs from the overland flow component are the soil loss per unit area and the concentration of each particle type for each storm.

Decision Model

The decision model, based on multi-objective decision theory, combines the dimensionless scoring functions of Wymore[13] with the decision tools of Yakowitz et al.[14,15] The conventional and viable alternatives are scored on the same set of decision criteria (i.e., percolation of leachate, runoff, ET, sediment loss, and cost). The scoring functions are used to scale the decision criteria, which have different units and magnitudes, to a common scale ranging from 0 to 1. The individual criterion scores are then aggregated for each alternative with a minimum amount of interaction with the decision maker. In particular, while an additive value function is assumed, the alternatives are not ranked on a single vector of weights associated with the criteria. The method considers all possible weight vectors consistent with an importance order of the decision criteria discerned by the decision model from the simulation results and scoring functions. The trench cap design with the highest aggregated score, for a given importance order of the criteria, is considered to be the "best" design among the conventional and feasible alternatives. The decision model is demonstrated using an example application from the Hill Air Force Base Cover demonstration project.

EXAMPLE: Hill Air Force Base Cover Demonstration

Four shallow landfill cover design test plots were installed at Hill Air Force Base (AFB) in Layton, Utah and their performance monitored for a four year period.[2] There are three basic cover designs: a control soil cover; a modified EPA RCRA cover; and two versions of a Los Alamos Design that contain erosion control measures, an improved vegetation cover to enhance evapotranspiration, and a capillary barrier to divert downward flow of water. The control cap consists of 90 cm of soil. The modified RCRA design consists of 120 cm of soil, 30 cm of sand (lateral drainage layer), 60 cm of compacted clay (hydraulic barrier). The Los Alamos designs consist of a thin gravel mulch over 150 cm of soil, 30 cm of gravel (capillary break). One of the Los Alamos caps was seeded with native perennial grasses and the other (Los Alamos 2) with both native perennial grasses and two species of shrubs to enhance ET. The surface and all of the underlying layers of the trench caps were built with a four percent slope.

The plots were instrumented to measure the performance of the covers with respect to controlling the hydrology and erosion of the trench cap. Precipitation, surface runoff, lateral flow, and percolation out of the gravel drainage layer were measured on a daily basis. Soil moisture and sediment yield were monitored approximately bi-weekly. Soil moisture content was measured using a neutron probe moisture meter. ET was estimated by solving a simple water balance equation:

$$ET = P - R - L - I - dS$$

where ET is evapotranspiration (m), P is precipitation (m), R is runoff (m), I is lateral drainage (m), and dS is change in soil moisture (m). The annual average values for the four year period are presented in Table 1. The decision criteria considered for evaluating these designs are: runoff (including lateral flow), ET, percolation (leachate production), sediment yield, and cost. Runoff, ET and percolation are important criteria for evaluating the ability of a cover design to control the hydrology of a trench cap. Sediment yield is important criteria for evaluating the long-term integrity of the cap as well as compliance with federal regulations.

For this example the trench cap designs were evaluated using both field data and simulation models. The modified RCRA cap and the control cap were parameterized using the simulation models (HELP3 and CREAMS) and the Los Alamos caps were parameterized using the field data since the HELP model is unable to simulate capillary barriers. The calibrated input files for the two trench cap designs from Hill AFB were used in version 3 of the HELP model and the results compared to those obtained from version 2 of the model.[16] Because the

ET calculation changed from version 2 to version 3, the ET was slightly higher and the percolation was slightly lower for both designs for all four years. However, the overall results of HELP3 for this data set were not significantly different from version 2 in terms of the distribution of the water balance. Scoring functions were selected and set up for each of the decision criteria using the conventional design threshold and baseline values. The two generic score functions used in this example are presented in Figures 1a and 1b. The modified RCRA cap was selected as the "conventional" design because it is currently in widespread use and is considered to be the state-of-the-art by regulators and practicing engineers. For sediment yield a "more is worse" scoring function was selected (Fig. 1c) and parameterized using the results from the simulation models. The generic scoring function included a lower threshold of the sediment yield produced by the conventional design for the four year period. The average annual sediment yield for the conventional cover scored 0.5 by definition. The slope of the scoring function at the baseline value is a function of the threshold values determined by the maximum and minimum annual values of the conventional design. The score for each of the alternative designs was then determined by evaluating the average annual value from the alternative designs for each of the decision criteria (Fig. 1d). The "more is worse" scoring function was also used for cost and percolation. However, for ET and runoff the "more is better" scoring function was selected. The modified RCRA design, as the "conventional" has a score of 0.5 for each of the decision criteria evaluated. The resulting score matrix for this example is presented in Table 2.

The next step is to rank the decision criteria in order of importance. The decision model determines a default importance order using the absolute values of the slopes of the scoring functions of each decision criteria at the baseline values which have been normalized to remove the units. The PDSS will also allow the decision maker to specify the importance or priority order associated with an environmental policy or regulations.

The result of solving the two linear programs in the decision model to determine the best and worst composite scores for each of the alternatives is presented in Figure 2a. The importance order of the decision variables selected for this example (from most to least important) is: cost, percolation, sediment yield, runoff, and ET. The best and the worst composite scores for the modified RCRA design are both 0.5 since this design scores 0.5 for each criterion. The bar graph for each of the alternative designs represents the range of best and worst composite scores considering all possible weight vectors. A large spread in the range of possible composite scores indicates that it is highly sensitive to a particular weight vector. Due to its very low construction cost, the best possible score for the control cap is 1.0 when cost is ranked first in the importance order. However, because it does not score very well in the other decision criteria it can score relatively low depending upon the weight vector.

All three of the alternatives have better average scores than the conventional, modified RCRA cap design. The composite scores for Los Alamos designs 1 and 2 are almost the same for this importance order, and show less sensitivity to a particular weight vector than the control cap. For this importance order, ranking the designs in descending order by the average of the best and worst composite scores yields: Los Alamos 2, Los Alamos 1, the control cap, and modified RCRA. It is important to note that the cost decision criterion only represents construction cost, and not long term monitoring, maintenance, or potential remediation costs. Though the control cap costs much less to construct than the alternative designs, it has a much higher percolation rate and therefore the potential for clean-up costs is much greater. These factors should be taken into account when evaluating a particular design with cost as one of the decision criteria.

The risk manager is able to change the importance order of the decision variables in an interactive format and then compare the composite results of the alternatives for different importance orders. For example, the risk manager may consider minimizing percolation into the waste layer or erosion of the trench cap more important than minimizing cost for a given situation, and therefore give them a higher importance level. Changing the importance order of the decision variables so that percolation is the most important, decreases the average score of the of the Los Alamos designs and the control cap and changes the sensitivity of the composite scores (Fig. 2b). This importance order changes the ranking of the alternatives, with the modified RCRA cap scoring highest; followed by the Los Alamos designs and the control cap.

DISCUSSION

Risk managers are interested in assessing the long-term performance of a landfill trench cap design for a particular site. Landfill covers are designed to last hundreds of years. The decision model in the PDSS uses the annual average value of the decision criteria for each of the alternatives. The annual average, maximum, and minimum of the conventional design were used to parameterize the scoring functions. The risk manager is able to change the importance order of the decision variables and then compare the composite results of the alternatives for different importance orders side by side in a graphical presentation.

The PDSS was able to differentiate between the alternatives when using both the data and the simulation models to parameterize the decision variables. Detailed results of the preliminary evaluation of the PDSS using the Hill AFB trench cap demonstration study are presented in Paige et al., 1996.[8,16] For the Hill AFB trench cap designs, changing the importance order of the decision variables has a significant affect on the composite scores of the alternative designs and thus their relative ranking.[8] The specific benefits of each of the trench cap designs were evident in the results of the decision model. The most appropriate design for a particular location also depends on the specific needs and characteristics of the site.

SUMMARY

The PDSS is being developed for the evaluation of landfill trench cap designs. In order to evaluate a complete landfill site design, the risk manager would have to consider multiple external factors including a complete risk analysis. The most appropriate or "best" alternative trench cap design also depends upon the specific needs and characteristics of the site in question, the type of waste and how it is stored, and the potential long-term risks and costs. The ultimate decision would have to be made by the risk manager taking many of these factors, as well as local and federal regulations, into consideration. The goal of the PDSS is to improve the quality of the technical information used by the risk manager to select trench cap designs that are cost effective and meet regulatory performance standards. The HELP model is the only model currently sanctioned by the EPA for design and evaluation of landfill covers. With the addition of the CREAMS erosion component and the decision model, the PDSS becomes a powerful tool for agencies concerned with the design and evaluation of landfill trench caps. The risk manager will be able to evaluate potential landfill trench cap technologies with the PDSS in order to identify technical and regulatory problems inherent in the designs and evaluate long-term projected performance.

ACKNOWLEDGMENTS

We gratefully acknowledge the source of funding to USDA-ARS-SWRC and Los Alamos National Laboratory for the development of the PDSS from the Department of Energy through the Mixed Waste Landfill Integrated Demonstration (MWLID) at Sandia National Laboratories. The Hill AFB landfill capping demonstration was funded by the U.S. Air Force through the Engineering Services Center at Tyndall Air Force Base and the Department of Energy MWLID.

REFERENCES

1. T.E. Hakonson, L.J. Lane, J.G. Steger, G.L. DePoorter, Some interactive factors affecting trench cover integrity on low-level waste sites. *Proc. Nuclear Regulatory Commission on Low-Level Waste Disposal: Site Characterization and Monitoring, Arlington, VA.* pp. 377-399, 1982.

2. T.E. Hakonson, K.V. Bostick, G. Truijilo, K.L. Manies, R.W. Warren, L.J. Lane, J.S. Kent, and W. Wilson, *Hydrologic evaluation of four landfill cover designs at Hill Air Force Base, Utah.* LA-UR- 93-4469 Los Alamos National Laboratory, Los Alamos, NM, 1994.

3. U.S. Environmental Protection Agency, *Technical Guidance Document: Final covers on hazardous waste landfills and surface impoundments.* EPA/530-SW-89-047. Office of Solid Waste and Emergency Response, Washington D.C., 1989.

4. Lane, L.J. and J.W. Nyhan, *Water and contaminant movement: migration barriers.* Los Alamos National Laboratory Report LA-10242-MS, 1984.

5. Nyhan, J.W., T.E. Hakonson, and B.J. Drenon, A water balance study of two landfill cover designs for semiarid regions. *Journal of Environmental Quality.* 19:281-288, 1990a.

6. Nyhan, J.W., T.E. Hakonson, and S. Wolnlich, Field experiments to evaluate subsurface water management for landfills in snowmelt-dominated semiarid regions of the USA. F. Arendt, M. Hinsenveld, and W.J. van der Brink (eds) In: *Contaminated Soil '90.* pp. 1205-1206, 1990b.

7. Lane, L.J., J.C. Ascough, and T.E. Hakonson, Multi-objective decision theory -decision support systems with embedded simulation models. *Proceedings ASCE National Conference on Irrigation and Drainage Engineering. July. Honolulu, HI,* 1991.

8. G.B. Paige, J.J. Stone, L.J. Lane, D.S. Yakowitz, and T.E. Hakonson, Evaluation of Prototype Decision Support System for Selecting Trench Cap Designs *Journal of Environmental Quality* 25(1) (accepted for publication), 1996.

9. Schroeder, P.R., J.M. Morgan, T.M. Walski, and A.C. Gibson, *The hydrologic evaluation of landfill performance (HELP) model.* Vol. I and II. EPA/530-SW-84-010, U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, Washington, DC, 1984

10. P.R. Schroeder, T.S. Dozier, P.A. Zappi, B.M. McEnroe, J.W. Sjostrom, and R.L. Peyton, *The Hydrologic Evaluation of Landfill Performance (HELP) model: Engineering documentation for version 3,* EPA/600/9-94/168a(b), U.S. Environmental Protection Agency Risk Reduction Engineering Laboratory, Cincinnati, OH, 1994.

11. W.G. Knisel, *CREAMS: A Field-Scale Model for Chemicals, Runoff, and Erosion from Agricultural Management Systems.* USDA, Conservation Res. Rep. No. 26, 640 pp., 1980.

12. W.H. Wischmeier and D.D. Smith, Predicting rainfall erosion losses- a guide to conservation planning. *USDA Agricultural Handbook 537.* 58 pp., 1978

13. W.A. Wymore, Structuring system design decisions. *Proceedings of International Conference on systems Science and Engineering 88.* International Academic Publishers. Pergamon Press. p 704-709, 1988.

14. D.S. Yakowitz, L.J. Lane, J.J. Stone, P. Heilman, R.K. Reddy, and B. Imam, Evaluating land management effects on water quality using multi-objective analysis within a decision support system, *First International Conference on Ground Water Ecology,* Tampa, FL USEPA, AWRA, 1992.

15. D.S. Yakowitz, L.J. Lane, and F. Szidarovszky, Multi-attribute decision making: dominance with respect to an importance order of the attributes. *Applied Mathematics and Computation.* 54:167-181, 1993

16. G.B. Paige, J.J. Stone, L.J. Lane, and T.E. Hakonson, Calibration and Testing of Simulation Models for Evaluation of Trench Cap Designs. *Journal of Environmental Quality* 25(1) (accepted for publication), 1996.

Table 1. Observed Results: Average Annual Value for Each Decision Criterion.

Cap Designs	Decision Criteria				
	Runoff	Percolation†	Lateral Flow	ET	Sediment Yield
	cm				Kg/ha
Control Cover	1.40	14.74	N/A‡	27.37	118.70
RCRA Cover	1.30	0.13	10.74	28.80	76.70
Los Alamos 1	0.35	6.82	4.83	24.25	4.50
Los Alamos 2	0.56	7.28	2.95	33.99	4.80

†percolation out of trench cap and into waste storage layer.
‡ not applicable.

Table 2. Score Matrix used in the decision model.

Cap Designs	Decision Criteria				
	Runoff & Lateral flow	Percolation	ET	Cost	Sediment Yield
Control Cover	0.0	0.0	0.632	1.0	0.16
RCRA Cover	0.5	0.5	0.5	0.5	0.5
Los Alamos 1	0.03	0.0	0.23	0.89	1.0
Los Alamos 2	0.01	0.0	0.23	0.89	1.0

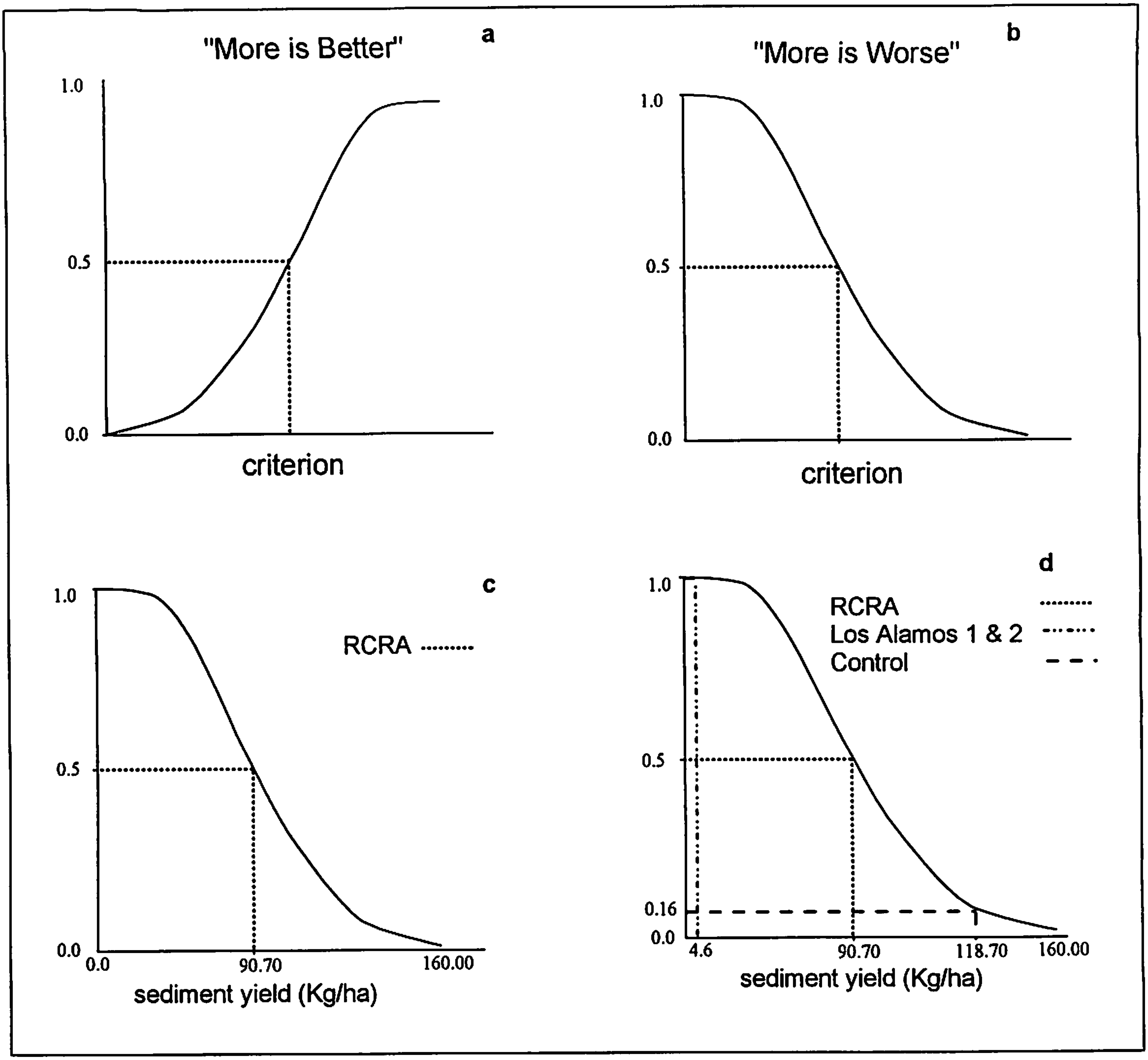

Figure 1. Scoring functions. a) generic more is better; b) generic more is worse; c) sediment yield scoring function parameterized using the modified RCRA cap; and d) scoring of the alternative designs for sediment yield.

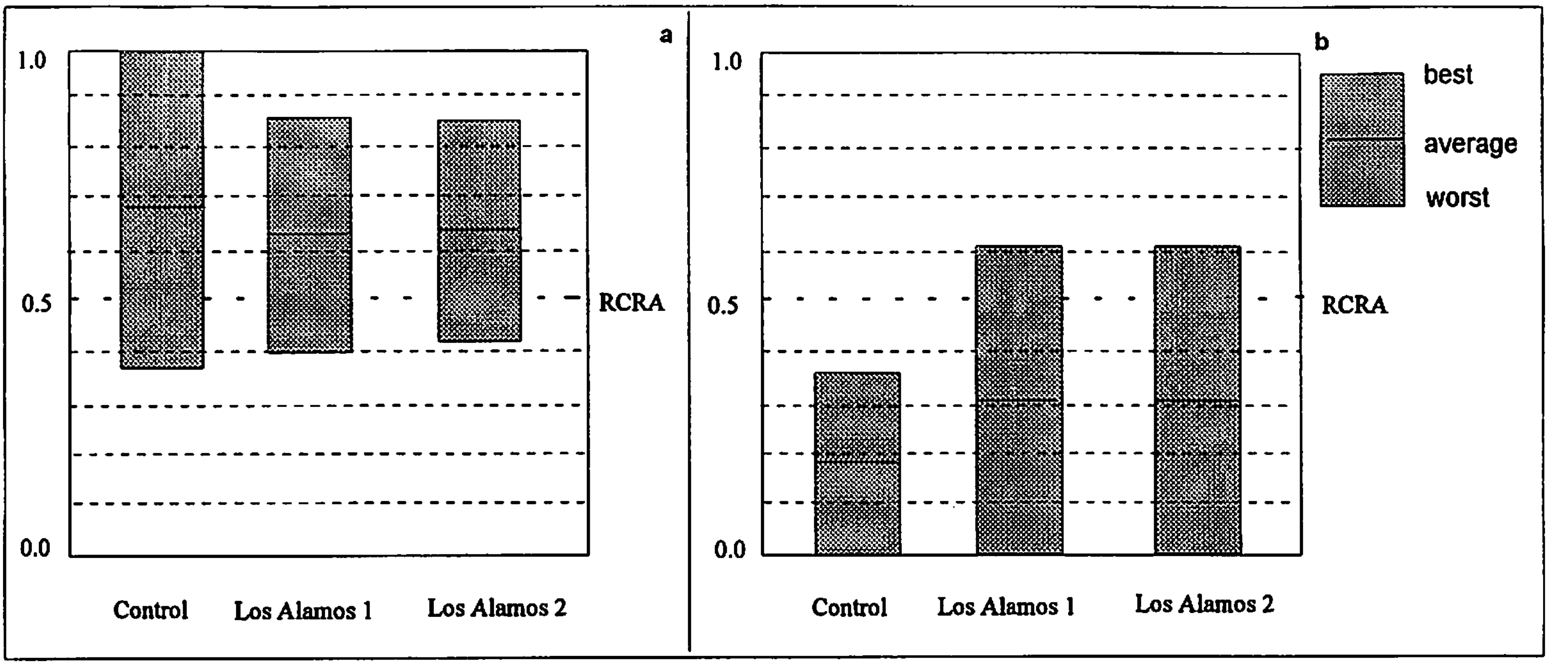

Figure 2. a) Results of the decision model for importance order 1: cost, percolation, sediment yield, runoff, and ET, and b) results of the decision model for importance order 2: percolation, sediment yield, runoff, and ET. Each bar represents the range of best and worst possible scores for the alternative based on that particular importance order.