COMPARISON OF THE RESRAD AND VLEACH CODES TO MODEL LEACHATES FROM THE SEAWAY LANDFILL, TONAWANDA, NEW YORK

This paper presents a comparison of the RESRAD and VLEACH computer codes as it relates to the modeling of material leaching from the Seaway landfill into the groundwater and/or leachate collection system. Once the comparison is completed, then a recommendation on which model to use for Seaway is made. Then the model is reviewed to determine if there are any field data that should be gathered in the upcoming field sampling efforts that would enhance the modeling results.

The following sections include a brief description of the RESRAD and VLEACH models including a list of advantages and disadvantages that were considered. Then the recommended model is identified. Finally, the last section provides a table of appropriate input parameters for the recommended model. This list of input parameters is provided for comparison against available site data.

RESRAD MODEL

The RESRAD model assumes that soil may exist in one of four zones: cover, contaminated zone, unsaturated zone, and saturated zone. Of these, only the contaminated zone may be modeled to contain radioactivity and only the saturated zone contains groundwater. The user can include up to five layers in the unsaturated zone (e.g., clay, loam, etc.), but is limited to one layer in each of the other zones. Zones are stacked like disks that most accurately represent flat sites with horizontally layered soil strata and where groundwater stays below the contaminated zone.

RESRAD models the transport of radionuclides by calculating how much water moves through the contaminated zone. This is accomplished using parameters such a precipitation rate, runoff coefficient, evapotranspiration coefficient, etc. The model also considers for the volume of contaminated zone and the distribution coefficient of each radionuclide, among other variables. If a distribution coefficient is relatively small and is sufficient water moves through to the saturated zone, the model will allow radionuclides to move to the saturated zone. Once below the water table, the contaminants are instantly distributed throughout the saturated zone. That is, the contaminants will enter a well regardless of its location/depth.

Parameters that most significantly impact RESRAD's groundwater model include distribution coefficient, contamination zone volume, and water infiltration rates. RESRAD support documentation may be used to manipulate the code when the site does not contain flat homogenous soil strata or when site-specific data are not available. For example, the runoff coefficients are provided for a range of conditions ranging from flat agricultural to moderately steep and about 70% impervious.

ADVANTAGES AND DISADVANTAGES

A few of the advantages of using the RESRAD code to model the leaching of contaminants into groundwater are listed below:

- RESRAD is designed to handle radionuclides in convenient units (pCi/g for soil);
- RESRAD can provide results with very little site-specific input;
- RESRAD provides a cheap, quick and easy method for modeling leaching to groundwater;
- RESRAD is designed to assess dose and risk in addition to modeling migration from soil to the groundwater;
- RESRAD is designed to take into account the radioactive decay of material and the generation of daughter products;
- RESRAD manuals are available to support modeling efforts that include soil-type-specific defaults; and
- RESRAD is generally accepted by both federal and state regulators (exceptions do exist).

A few of the disadvantages of using the RESRAD code to model the leaching of contaminants into groundwater are listed below:

- RESRAD will not handle non-radionuclides;
- RESRAD can provide results with very little site-specific input;
- RESRAD results may not agree with site data (actual data should always be used);
- RESRAD is not designed to handle inhomogeneous systems;
- RESRAD can not model a contaminated zone that is below the water table;
- RESRAD can not model multiple contaminated zone (pockets); and
- RESRAD is limited to horizontal strata.

It is noted that ANL has participated in comparison studies (see below) and there are several other models available.

Available Literature:

Gnanapragasam, E., C. Yu et al., *Comparison of Multimedia Model Predictions for a Contaminant Plume Migration Scenario*, J. Contaminant Hydrology 46(2):17-38, 2000.

Camus, H. R. et al., *Long-term Contaminant Migration and Impacts from Uranium Mill Tailings*, J. Environmental Radioactivity 42:289-304, 1999.

Whelan, G. et al., *Benchmarking of the Saturated-Zone Module Associated with Three Risk Assessment Models: RESRAD, MMSOILS, and MEPAS*, J. Environmental Engineering Science, 16(1):67-80, 1999.

VLEACH MODEL

VLEACH, version 2.2a (Ravi and Johnson, 1997), is a one-dimensional finite difference vadose zone leaching model developed for the U.S. EPA. VLEACH was developed to evaluate the impact of organic compounds in the vadose zone on the underlying groundwater. As such, it describes the movement of an organic contaminant within and between three phases (aqueous, vapor, and sorbed). Equilibration between the phases occurs according to distribution coefficients defined by the user.

The processes are conceptualized as occurring in one or more polygons that are vertically divided into a series of one or more cells. The polygons may differ in soil properties, recharge rate, and depth to water, but within each polygon homogeneous conditions are assumed, except for contaminant concentration. Therefore, VLEACH can account for lateral variability in site conditions, but is limited when simulating vertical heterogeneity. During each time step, the migration of contaminants between cells is calculated.

Initially, VLEACH calculates the equilibrium distribution of contaminant mass between the liquid, gas, and sorbed phases. For each time step, transport processes (liquid advective based upon infiltration and soil water content; and vapor phase based upon concentration gradients) are then computed. After mass is exchanged between cells, the total mass in each cell is re-equilibrated between the different phases. At the end of the model simulation, the mass flux of contaminants to the groundwater is determined and the results from each polygon are compiled to determine the overall groundwater impact for the entire region.

ADVANTAGES AND DISADVANTAGES

A few of the advantages of using the VLEACH code to model the leaching of contaminants into groundwater are listed below:

- VLEACH is easy to use and well documented, including sample problem input and output to ensure proper code execution;
- VLEACH can account for lateral heterogeneity within the vadose zone parameters;
- VLEACH can account for vertical variations in contaminant concentrations; and
- VLEACH was used to reproduce vadose zone transport of organic constituents at a superfund site (Rosenbloom et. al, 1993).

A few of the disadvantages of using the VLEACH code to model the leaching of contaminants into groundwater are listed below:

- VLEACH is designed for organics only (no metals including radionuclides) and therefore, input parameters must be modified to simulate radionuclide transport;
- VLEACH is not designed to take into account the radioactive decay of material and the generation of daughter products;

- VLEACH assumes homogeneous conditions within each polygon and therefore can not account for vertical heterogeneity;
- VLEACH can not simulate distribution coefficients that exceed 1000 ml/g (similar to some metals and radionuclides) without modification to input parameters;
- VLEACH assumes the moisture profile within the vadose zone is constant; and
- Liquid phase dispersion is neglected resulting in higher dissolved concentrations and lower travel times.

Available Literature:

Ravi, V. and J.A. Johnson. *VLEACH A One-Dimensional Finite Difference Vadose Zone Leaching Model, Version 2.2a*: Dynamac Corporation, prepared for the U.S. Environmental Protection Agency, Office of Research and Development, Robert S. Kerr Environmental Research Laboratory, Center for Subsurface Modeling Support, 1997.

Rosenbloom, J., P. Mock, P. Lawson, J. Brown, and H.J. Turin. *Application of VLEACH to Vadose Zone Transport of VOCs at an Arizona Superfund Site*, Ground Water Monitoring and Remediation, Vol. 13, No.3, pp. 159-169, 1993.

RECOMMENDED MODEL FOR SEAWAY

Based on the above comparison of RESRAD and VLEACH, it is recommended that RESRAD be used to model leachates in the Seaway landfill. This recommendation is made strictly based on the comparison of RESRAD to VLEACH and not on a more comprehensive review of available models. However, it is noted that, while other more complex models are available for use at Seaway, the use of these models may require the collection of a significant amount of additional data, extensive modeling efforts and reviews, and potential significant impacts to overall project cost and schedule. Given these factors, it is conceivable that RESRAD would still be selected based on overall model strengths and weaknesses and impacts to cost and schedule.

EVALUATION OF RESRAD GROUNDWATER MODEL PARAMETERS

The following table lists *some* RESRAD parameters related to the groundwater pathway. In order for RESRAD to produce a reasonable estimate of leachate-related impacts within the Seaway system, each parameter has been scrutinized to determine if the collection of additional data during the upcoming field effort would be beneficial. Additional receptor-specific parameters such as exposure duration, etc., unrelated to physical properties should also be addressed, as appropriate. The table includes RESRAD default values, proposed values specific to the Seaway site (when available) and the relative sensitivity of each parameter. In some cases the site-specific parameter values will vary based on a range of factors and are not listed explicitly. For example, the surface area could vary by location (e.g., Area A, B or C) or could be assigned to evaluate small areas of elevated activity. To rank the relative sensitivity, parameters that would likely have at least a linear impact on results are designated as “High.” Values that could have a significant impact under certain conditions or are not as important as parameters designated as “High” are designated as “Medium.” Under certain conditions the designation of “Medium” for some parameters could be changed to “High.” For example, cover depth could have a significant impact on results if a large thickness is selected and/or other parameters are adjusted appropriately. All parameters not designated as “High” or “Medium” are designated as “Low.”

Parameters that will be measured or refined as a result of the field effort are indicated in the table. The table also includes a description of some parameters. For more detailed descriptions, see the *Data Collection Handbook to Support Modeling the Impacts of Radioactive Material in Soil* (ANL/EAIS-8).

Groundwater Parameters Using RESRAD

RESRAD Parameter	Units	RESRAD Default	Seaway Value [a]	Relative Sensitivity
Area of contaminated zone	m^2	10,000	Varies [b]	Medium
Thickness of contaminated zone	m	2.0	Varies [b]	Medium
Length parallel to aquifer flow	m	100	Default	Low
Cover depth	m	0.0	Varies [b]	Medium
Density of cover material	g/m^3	1.5	Default	Low
Cover depth erosion rate	m/yr	0.001	Default	Medium
Density of contaminated zone	g/m^3	1.5	Default	Low
Contaminated zone erosion rate	m/yr	0.001	0.0	Medium
Contaminated zone total porosity	unitless	0.4	0.45	Low
Contaminated zone effective porosity	unitless	0.2	Default	Low
Contaminated zone hydraulic conductivity	m/yr	10	123	Low
Contaminated zone b parameter	unitless	5.3	Default [c]	Low
Humidity in air	g/m^3	8.0	Default	Low
Evapotranspiration coefficient [d]	unitless	0.5	0.46	Medium
Precipitation	m/yr	1.0	0.96	Low
Runoff coefficient [e]	unitless	0.2	0.25	Medium
Thickness of unsaturated zone [f]	m	4.0	Default [c]	Medium
Density of unsaturated zone	g/m^3	1.5	Default	Low
Unsaturated zone total porosity	unitless	0.4	Default	Low
Unsaturated zone effective porosity	unitless	0.2	Default	Low
Unsaturated zone field capacity	unitless	0.2	Default	Low
Unsaturated zone hydraulic conductivity	m/yr	100	Default	Low
Unsaturated zone b parameter	unitless	5.3	Default [c]	Low
Density of Saturated zone	g/m^3	1.5	Default	Low
Saturated zone total porosity	unitless	0.4	0.46	Low
Saturated zone effective porosity	unitless	0.2	Default	Low
Saturated zone field capacity	unitless	0.2	Default	Low
Saturated zone hydraulic conductivity	m/yr	100	123	Low
Saturated zone hydraulic gradient	unitless	0.02	0.00045	Low
Saturated zone b parameter	unitless	5.3	Default [c]	Low
Water table drop rate	m/yr	0.001	0.0	Low
Well pump intake depth (m below water table)	m	10	1.0 [g]	Medium
Well pumping rate	m^3/yr	250	Default	Medium
Distribution coefficients	cm^3/g	Nuclide-specific	Varies [h]	High

(a) Assumes values consistent with those used in *Technical Memorandum: Modeling of Radiological Risks from Residual Radioactive Materials Following Implementation of Remedial Alternatives for Seaway Landfill Areas A, B, and C, Tonawanda, New York, Rev. 2*.
(b) Area A: use value stated in TM; Areas B and C: refine based on field effort.
(c) Field effort may be used to refine specified values.
(d) The evapotranspiration coefficient represents the fraction of the water leaving the ground as a result of evaporation or transpiration (transferred from the ground to the atmosphere through plants and their foliage) to the total volume of water in the root zone.
(e) The runoff coefficient is the fraction of the total annual precipitation that does not infiltrate into the soil and is not transferred back into the atmosphere through evapotranspiration.
(f) Can model up to five layers.
(g) Assumes water is drawn from near the surface of the water table.
(h) Radionuclide-specific and can be soil-type-specific; see RESRAD manual for potential defaults.

A K_d per RESRAD documentation is defined as follows:

$$\mathit{Distribution\,Coefficient}\ (K_d) = \frac{\mathit{mass\ of\ solute\ on\ the\ solid\ phase\ per\ unit\ mass\ of\ solid\ phase}}{\mathit{mass\ of\ solute\ in\ solution\ per\ unit\ volume\ of\ liquid\ phase}}$$

Field effort will generate soil concentration data and radionuclide concentration in leachate data. Distribution coefficients will be computed using these results and the RESRAD model will be run using the upper 95% confidence limits on the mean value. The model will also be run using uranium values ranging from 10 to 1000 cm^3/g.