PALOS VERDES LANDFILL
REMEDIAL INVESTIGATION REPORT

APPENDIX E.13

HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE (HELP MODEL)

E.1.1 Hydrologic Evaluation of Landfill Performance (HELP Model)

The HELP model was developed by the U. S. Environmental Protection Agency as a mathematical tool to estimate landfill cover and/or liner performance. The first version of this model was developed in the early 1980s (Schroeder et. al., 1984). The model was subsequently refined in 1988 based on results from various verification studies performed using bench scale lysimeters or under field conditions (Peyton and Schroeder, 1987). The model has shown good correlation to field results, though, as is the case with many models, HELP is best used for comparative purposes rather than as an absolute predictive model. The model uses landfill design configuration, soil parameters, and weather parameters as input and performs water balance calculations to obtain evapotranspiration, runoff, cover and liner drainage, percolation through the cover, and leachate generation rates.

The HELP model is a quasi-two dimensional hydrologic model of water movement designed to be used to evaluate alternatives in landfill cover and/or liner designs. The model accepts climatologic, soil, and design data and calculates the water movement across, into, through, and out of landfills. Landfill systems including various combinations of vegetation, cover soils, waste cells, and synthetic and soil barrier layers may be modelled. The program can be used for rapid estimations of the amount of runoff and leachate (or infiltration) that may be expected from a wide variety of landfill designs.

In order for the results of the model to be meaningful and credible, it is important to have a good understanding of the equations and assumptions used in the HELP model. The following discussion covers two areas. First, a detailed discussion of the HELP landfill cover model including the applicability of the model equations to the study site is presented. Second, the program limitations and their relation to the interpretation of model results are discussed.

E.1.1.1 Overview of Processes

HELP divides its modelled hydrologic processes into two phases: surface processes and subsurface processes. The surface processes are snowmelt, rainfall interception, surface runoff, and surface evaporation. The subsurface processes are soil evaporation, plant transpiration, vertical unsaturated drainage, lateral saturated drainage, and barrier layer percolation.

HELP uses surface hydrologic processes to indirectly calculate daily infiltration. The daily surface water accounting is calculated as follows. Snowfall is added to surface snow storage, then snowmelt is computed and added to rainfall. HELP uses a rainfall-runoff relationship to calculate runoff volumes. Surface evaporation is then calculated. The snowmelt and runoff that does not run off or evaporate, is considered to infiltrate into the landfill.

The first subsurface processes calculated are soil evaporation and plant transpiration from the evaporative zone. These are computed on a daily basis. HELP calculates vertical or lateral drainage through each subsurface layer using a six hour time step. If the subprofile contains a low permeability barrier layer, the sum of lateral drainage and barrier layer percolation is estimated. HELP then uses a storage-routing procedure to redistribute soil water among the other modelling segments. The routing calculations will yield results for lateral drainage and barrier layer percolation. If the sum of these does not match the original estimate, the procedure is repeated using the new results. HELP repeats the iterations until an acceptable convergence is achieved.

E.1.1.2 Detailed Description of Modelling Processes

E.1.1.2.1 Daily Precipitation and Temperature

The HELP model incorporates a routine for stochastically generating daily values for precipitation, solar radiation, and minimum and maximum temperature. The user has the option of generating stochastic precipitation data rather than using the default precipitation data (data provided with HELP model for years 1974-1978), or using manually entered historical data. The advantages of using synthetically generated precipitation data is that the available historic or default data may not be representative of long term conditions at the site. Synthetically generated precipitation data will model the extremes in precipitation more realistically. No matter what precipitation option is used, the model generates stochastic daily temperature and solar radiation data. The HELP model provides weather generation parameters for many cities throughout the United States. The generation of stochastic weather data can be made quite accurate by entering mean monthly values for precipitation and temperature for the study site.

HELP generates daily synthetic precipitation data using a Markov chain model. In Markov models, the probability of a given event is based on the event immediately preceding it. With respect to a precipitation model, the probability of a day being wet or dry is dependent on the conditions the previous day. The Markov model requires two transitional probabilities. These are the probability of a wet day following a wet day and the probability of a wet day following a dry day. When a wet day occurs a two parameter gamma distribution is used to generate the amount of precipitation. HELP provides the transition probabilities, the parameters of the gamma distribution, and mean monthly precipitation data for 139 locations in the United States. HELP allows the user to input mean monthly precipitation values for the landfill site. This will calibrate the synthetic precipitation generation to the site under study. Should HELP not provide synthetic generation parameters for the city where a landfill is located the user may select generation parameters for a city that has similar rainfall patterns and use mean monthly precipitation values for the landfill to calibrate the synthetic precipitation generation to the modelled site.

Daily values of temperatures and solar radiation are computed from the mean monthly values (and their standard deviations) plus a stochastically generated residual component. Seasonal changes in the means and standard deviations are modelled by a harmonic equation. The residual element preserves important serial and cross correlations. HELP provides temperature and solar radiation parameters for 184 cities in the U.S. As is the case for synthetic precipitation generation, the user may input mean monthly temperatures for the site and the latitude of the site (used for solar radiation generation).

E.1.1.2.2 Soil Characteristics

HELP uses several soil characteristics throughout the program. These are porosity, field capacity, wilting point, soil evaporation coefficient, minimum infiltration rate, hydraulic conductivity, and unsaturated hydraulic conductivity. HELP provides default soil parameters for 18 common soil types. The default values were collected from several sources. Default values for porosity and saturated hydraulic conductivity were taken directly from data compiled by the Agricultural Research Service. Default values for field capacity and wilting point were computed using the Brooks-Corey equation. The Brooks-Corey equation parameters are also taken from the database compiled by the Agricultural Research Service. The default values for evaporation coefficient are taken from experimental results that relate evaporation coefficient to hydraulic conductivity. The unsaturated hydraulic conductivity is computed from the saturated hydraulic conductivity. The default soil characteristics are typical values for uncompacted soils. Should the user specify that the soil is to be compacted, the soil parameters are adjusted accordingly. In addition, HELP adjusts the saturated hydraulic conductivity of the top half of the evaporative zone to allow for the effects of plants. Should the user know only the soil types that are to be used in the landfill design, the model will use the default values for those soil types. However, the user also has the option of using measured values for four of the input soil parameters; porosity, field capacity, wilting point, and hydraulic conductivity. HELP calculates the other soil parameters used by the model as described above.

E.1.1.2.3 Runoff Calculations

HELP models rainfall-runoff relationships using the Soil Conservation Service's (SCS) curve-number method as presented in Section 4 of the National Engineering Handbook (USDA, Soil Conservation Service, 1972). HELP model developers selected the procedure for several reasons. First, the method is computationally efficient. Second, the required input is easily obtained. Third, the method is widely accepted, and fourth, it can handle a wide range of conditions. However, the method has its limitations. First, the method is not designed to handle slopes that are greater than twenty percent. The side slopes of the Palos Verdes Landfill are greater than twenty percent. This problem can be remedied through adjustments in a "curve number" used by the model as discussed below. Second, the curve number method does not consider storm intensity in its runoff calculations. The method does not give accurate runoff representations for short, high intensity storms. This assumption should not affect the modelling of the Palos Verdes Landfill because this type of storm is not characteristic to Southern California.

The SCS procedure was developed from rainfall-runoff data collected from large storms in small watersheds. Runoff was plotted as a function of rainfall. An empirical relationship was developed that expresses total runoff volume as a function of precipitation and a retention parameter. The retention parameter is a function of land management practices and antecedent moisture conditions. Land management practices are expressed through a runoff curve number. The curve number is adjusted to account for antecedent moisture conditions that differ from those used to develop the model. The runoff curve number can be obtained from tables that were developed for use with the model, or can be computed using empirical relationships. HELP will compute the curve number should the user not choose to enter it manually.

As was mentioned above, the curve number method does not directly apply to areas with slopes greater than twenty percent. The curve number may be adjusted to account for greater slopes. Higher curve numbers result in higher runoff volumes. Therefore increasing the curve number will simulate the effect of steeper slopes.

E.1.1.2.4 Interception

Vegetation will stop and store a percentage of precipitation and prevent it from running off. HELP models the maximum interception as a function of the leaf area index of the ground vegetation. The leaf area index is the ratio of total leaf area to the soil surface area.

E.1.1.2.5 Potential Evapotranspiration

HELP uses a modified Penman method to calculate potential evapotranspiration. The potential evapotranspiration (PET) is used in the evapotranspiration model as a limit on daily evapotranspiration. PET is a function of net solar radiation and mean temperature.

E.1.1.2.6 Evapotranspiration

Evapotranspiration from a landfill has three components: evaporation of water retained by foliage on the landfill surface, evaporation from the soil, and plant transpiration. HELP assumes the total subsurface evapotranspiration (soil evaporation plus plant transpiration) is distributed throughout the evaporative zone.

HELP first exerts the evapotranspirative demand on available water at the surface of the landfill. The available water may be from interception. If the available surface water exceeds the PET for that day, then the surface evaporation is equal to PET, and no plant transpiration occurs.

Any evapotranspirative demand in excess of the available surface water is exerted first through plant transpiration then through soil evaporation. Potential plant transpiration is a function of the leaf area index and the PET. The actual evapotranspiration is a function of soil moisture and the plant transpirative demand. If soil evaporation plus plant transpiration exceeds PET, no soil evaporation occurs.

Potential soil evaporation is a function of PET and the leaf area index. Soil evaporation occurs in two stages. Stage one is controlled by available energy and stage two is controlled by the rate the soil can transmit water to the surface. The total of surface evaporation, plant transpiration, and soil evaporation cannot exceed the PET for that day.

E.1.1.2.7 Vegetative Growth

HELP accounts for seasonal variations in the leaf area index through a general vegetative growth model. The model was developed by the USDA Agricultural Research Service. The model uses values of maximum leaf area index, the beginning and ending dates of the growing season, daily temperature and solar radiation, and mean monthly temperatures. The maximum leaf area index and growing season dates are either input by model user or provided by HELP (for certain cities). Daily temperature and solar radiation are generated by HELP.

E.1.1.2.8 Vertical Drainage

HELP uses Darcy's law to model vertical drainage. This law states that the rate of flow through a porous media is proportional to the hydraulic head gradient. Fracture flow is not considered. The proportionality constant is called the hydraulic conductivity, which is specific to soil conditions. HELP assumes that the head increases uniformly with depth, which is a reasonable assumption for vertical profiles where hydraulic head increases uniformly with depth. The hydraulic head gradient becomes unity and the flow rate is equal to the hydraulic conductivity.

Subsurface water routing proceeds one layer at a time, from top to bottom. The water is routed downwards using a storage routing procedure. Both Darcy's law and a continuity equation are applied to each layer. The continuity equation is evaluated at the midpoint of the time step. The application of both equations results in two equations with two unknowns. HELP solves the equations using a trial and error technique.

Barrier layer percolation is calculated differently. Two further assumptions are used. First, HELP assumes the barrier layer is always saturated. This assumption causes greater flow through the barrier layer because the saturated hydraulic conductivity is greater than the unsaturated hydraulic conductivity. However, if a barrier layer is properly maintained the moisture content of the barrier layer soil is kept close to saturation and the assumption is only slightly conservative. Second, percolation only occurs if there is head in the layer immediately above the barrier layer.

E.1.1.2.9 Lateral Drainage

Lateral drainage is also calculated using Darcy's law. Lateral drainage occurs along the entire length of the drainage layer over the saturated depth of that layer. Any water in the drainage layer in exceedance of field capacity is automatically routed down in the layer to saturate as much depth in the layer as possible.

E.1.1.3 Assumptions and Limitations

The majority of the modelling processes are based on generally accepted simplifying assumptions. Most of these assumptions are outlined in the description of the processes. The assumptions will not provide precise estimates of landfill performance; however, they are consistent with the purpose of the model, i.e. to provide quick evaluations of landfill design alternatives.

E.1.2 HELP Model Setup

The Palos Verdes Landfill site is divided into three areas for modelling purposes. The top deck areas are not irrigated and support fair vegetative growth. This area is approximately 90 acres. The remainder of the site is irrigated. The irrigated side slopes of the landfill are steep and must be considered separately for runoff modelling considerations; therefore, the irrigated portion of the site is divided into two areas for modelling purposes. The steep side slope areas consist of approximately 53 acres and approximately 30 acres of irrigated area is gently sloped.

Table E.1.1 contains the HELP modelling inputs for the six modelling runs which were performed.

E.1.2.1 HELP Model Inputs (Weather)

The HELP model uses daily values of temperature, solar radiation, and precipitation. Solar radiation and temperature are synthetically generated by the model based on weather parameters for the area under study. HELP provides synthetic weather generation parameters for cities throughout the United States. Daily precipitation data may be manually entered into the model or it may be generated synthetically for up to 20 year simulation runs.

HELP provides temperature and solar radiation generation parameters for Los Angeles. These parameters are used to generate temperature and radiation data for use in the model. HELP does not provide precipitation generation parameters for Los Angeles, but does provide generation parameters for San Diego. The Sanitation Districts believes that the generation parameters for San Diego will adequately model Los Angeles precipitation patterns.

The Sanitation Districts used the synthetic precipitation generation option in order to more realistically model the potential precipitation patterns. Synthetic precipitation values will model both extreme and average precipitation patterns. Monthly precipitation data at the landfill was measured by Los Angeles County Flood Control District from 1939 - 1990. This data base provided comprehensive monthly precipitation averages for input into the HELP model's synthetic precipitation generator (see Table E.1.2). These values are used by HELP to better calibrate the synthetic precipitation generation routine to the landfill site. The synthetic precipitation generator was used to generate 20 years of daily precipitation data. The yearly precipitation totals ranged from 6.99 to 27.36. Since the average precipitation rate for the Los Angeles area is about 15 inches based on data collected from the last 100 years, the HELP modelling has covered extreme weather conditions.

E.1.2.2 HELP Model Inputs (Soil Characteristics)

The existing final cover was modelled as one 60 inch layer. This is the design thickness of the final cover material as reported in "Report of Site Closure, Palos Verdes Landfill" submitted to the Regional Board in 1983.

The side slope soils were modelled using the model's default soil characteristics for each of the two soil types that were identified in the final cover in a 1981 Woodward-Clyde investigation. Woodward-Clyde drilled twelve exploratory borings into the in place final cover material. In addition, three well permeameter test were conducted to estimate the hydraulic conductivity of the cover soil. The borings revealed that the final cover materials were, on average, five feet thick and that the soil types were either sandy clay or silty clay. In 1986 the Sanitation Districts performed landfill cover hydraulic conductivity testing as part of an in-house investigation. This available landfill cover data was used to evaluate the default soil characteristics for their applicability.

Both sandy clay and silty clay have default soil characteristics in the HELP model. The default hydraulic conductivities of sandy clay and silty clay are similar to the hydraulic conductivities found in the Woodward-Clyde study and in a cover permeability study performed by the Sanitation Districts in 1986 (unpublished). Table E.1.3 compares the default soil characteristics to those found in the aforementioned cover soil studies. Because the default soil hydraulic conductivities compare to measured hydraulic conductivities and because of the lack of other measured data for the landfill cover soils, the model's default soil characteristics for sandy clay and silty clay were used in the model.

The HELP model calculates the runoff curve number based on soil types and land management practices. This calculated curve is used for the top deck and non-side slope irrigated areas. In order to more accurately represent the runoff conditions on the side slopes, the irrigated area curve numbers were increased by ten when modelling the side slope areas.

E.1.2.3 Vegetative Parameters

HELP models vegetative growth using a maximum leaf area index. The maximum leaf area index corresponding to excellent grass was used owing to the heavy vegetation (supported by an extensive irrigation system) on the irrigated areas of the landfill. The model recommends an evaporative zone depth of 48 inches for excellent grass in the Los Angeles area. Final cover studies at the Puente Hills Landfill indicated a root zone depth of 40 inches on the irrigated side slopes. The evaporative zone depth extends deeper than the root zone depth due to capillary forces.

The vegetation for the top deck was set to fair grass. This is the model's recommendation for non-irrigated areas in the Los Angeles area. Fair grass has a evaporative zone depth of 32 inches.

E.1.2.4 Irrigation

HELP does not specifically allow for modelling irrigation. Irrigation is best modelled as if it were precipitation. Therefore, the daily precipitation data file is adjusted to account for irrigation when modelling the irrigated areas of the landfill. The Sanitation Districts calculated average monthly water use over the previous eleven years. The average monthly irrigation rates were evenly distributed over the days of the month. Table E.1.4 contains the average daily irrigation rates for each month. The Sanitation Districts adjusted the daily precipitation data file to include daily irrigation.

E.1.3 HELP Results

Table E.1.5 contains the modelling results for the three modelled areas. The total average yearly percolation for the three areas is less than the average amount of water extracted from the landfill through the condensate system and Sump 7. Because the model includes many simplifying assumptions, the modelling results should not be considered as an accurate indicator of percolation amounts. However, the predicted values from the model do accurately indicate that only a very small percentage of the rainfall and irrigation that falls on the landfill will percolate the cover due to both evapotranspiration and runoff.

TABLE E.1.1

HELP MODELLING INPUTS

PALOS VERDES LANDFILL - DPRIR ADDENDUM

	TOP DECK[1]	TOP DECK[2]	SIDE SLOPE[1]	SIDE SLOPE[2]	IRRIGATED AREA[1]	IRRIGATED AREA[2]
COVER DESIGN						
Thickness (in)	60	60	60	60	60	60
Soil Porosity (%)	37.7	42.2	37.7	42.2	37.7	42.2
Soil Field Capacity (%)	29.6	34.1	29.6	34.1	29.6	34.1
Wilting Point (%)	22.1	25.1	22.1	25.1	22.1	25.1
Initial Soil Water Content (%)	25.8	29.6	29.6	34.1	29.6	34.1
Saturated Hydraulic Conductivity (cm/sec)	4.95×10^{-6}	3.75×10^{-6}	4.95×10^{-6}	3.75×10^{-6}	4.95×10^{-6}	3.75×10^{-6}
GENERAL						
SCS Curve Number	88.1	89.55	91	93	81.4	83.2
Area (acres)	90	90	53	53	30	30
Evaporative Zone Depth (in)	32	32	48	48	48	48
CLIMATOLOGICAL						
Maximum Leaf Area Index	2	2	5	5	5	5
Irrigation (Y/N)	N	N	Y	Y	Y	Y

[1] Sandy Clay Soil
[2] Silty Clay Soil

TABLE E.1.2

AVERAGE MONTHLY PRECIPITATION (1939 - 1990)

PALOS VERDES LANDFILL - DPRIR ADDENDUM

MONTH	AVERAGE PRECIPITATION (IN)
JANUARY	3.30
FEBRUARY	2.94
MARCH	2.24
APRIL	1.12
MAY	0.16
JUNE	0.03
JULY	0.00
AUGUST	0.08
SEPTEMBER	0.22
OCTOBER	0.40
NOVEMBER	1.91
DECEMBER	2.28

TABLE E.1.3

COMPARISON OF HELP DEFAULT SOIL PARAMETERS WITH MEASURED VALUES

PALOS VERDES LANDFILL - DPRIR ADDENDUM

	HELP DEFAULT	**WOODWARD-CLYDE 1981**	**SANITATION DISTRICTS 1986**
SANDY CLAY HYDRAULIC CONDUCTIVITY (CM/SEC)	$4.95\text{x}10^{-6}$	$3.38\text{x}10^{-5}$	$1.97\text{x}10^{-6}$
SILTY CLAY HYDRAULIC CONDUCTIVITY (CM/SEC)	$3.75\text{x}10^{-6}$	$9.67\text{x}10^{-6}$	$2.10\text{x}10^{-6}$

TABLE E.1.4

AVERAGE DAILY IRRIGATION RATES

PALOS VERDES LANDFILL - DPRIR ADDENDUM

MONTH	AVERAGE DAILY IRRIGATION (IN)
JANUARY	0.01
FEBRUARY	0.02
MARCH	0.03
APRIL	0.05
MAY	0.08
JUNE	0.09
JULY	0.10
AUGUST	0.10
SEPTEMBER	0.09
OCTOBER	0.06
NOVEMBER	0.04
DECEMBER	0.02

TABLE E.1.5

HELP MODELLING RESULTS

PALOS VERDES LANDFILL - DPRIR ADDENDUM

	TOP DECK[1]	TOP DECK[2]	SIDE SLOPE[1]	SIDE SLOPE[2]	IRRIGATED AREA[1]	IRRIGATED AREA[2]
Precipitation (in) (including irrigation)	14.91	14.91	35.64	35.64	35.64	35.64
Runoff (in) / Percent of precipitation	8.162 / 54.75	8.705 / 58.40	7.109 / 19.95	8.156 / 22.88	6.957 / 19.52	8.020 / 22.5
Evapotranspiration (in) / Percent of precipitation	6.795 / 45.59	6.265 / 42.03	28.341 / 79.52	27.369 / 76.79	28.463 / 79.86	27.846 / 77.11
Change is Soil Water Storage (in) / Percent of Precipitation	-0.051 / -0.34	-0.065 / -0.44	0.075 / 0.21	0.08 / .022	0.075 / 0.21	0.01 / 0.23
Percolation (in) / Percent of precipitation	0.0004 / 0.00	0.001 / 0.01	0.0068 / 0.33	0.0362 / 0.10	0.1461 / 0.41	0.0554 / 0.16

[1] Sandy Clay Soil
[2] Silty Clay Soil