



On the current state of the Hydrologic Evaluation of Landfill Performance (HELP) model



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ABSTRACT

The Hydrologic Evaluation of Landfill Performance (HELP) model is the most widely applied model to calculate the water balance of cover and bottom liner systems for landfills. The paper summarizes the 30 year history of the model from HELP version 1 to HELP 3.95 D and includes references to the three current and simultaneously available versions (HELP 3.07, Visual HELP 2.2, and HELP 3.95 D). A sufficient validation is an essential precondition for the use of any model in planning. The paper summarizes validation approaches for HELP 3 focused on cover systems in the literature. Furthermore, measurement results are compared to simulation results of HELP 3.95 D for (1) a test field with a compacted clay liner in the final cover of the landfill Hamburg-Georgswerder from 1988 to 1995 and (2) a test field with a 2.3 m thick so-called water balance layer on the landfill Deetz near Berlin from 2004 to 2011. On the Georgswerder site actual evapotranspiration was well reproduced by HELP on the yearly average as well as in the seasonal course if precipitation data with 10% systematic measurement errors were used. However, the increase of liner leakage due to the deterioration of the clayey soil liner was not considered by the model. On the landfill Deetz HELP overestimated largely the percolation through the water balance layer resulting from an extremely wet summer due to an underestimation of the water storage in the layer and presumably also due to an underestimation of the actual evapotranspiration. Finally based on validation results and requests from the practice, plans for improving the model to a future version HELP 4 D are described.

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1. Introduction

The Hydrologic Evaluation of Landfill Performance (HELP) model is presumably the world's most commonly applied model to calculate the water balance of cover and bottom liner systems for landfills and contaminated sites. The HELP model is a “quasi-two dimensional” layer model which considers many one dimensional hydrologic processes in two directions, vertical (esp. evapotranspiration, infiltration, saturated and unsaturated vertical flow) and lateral (surface runoff, lateral drainage), and combines these processes, but actually does not calculate a two dimensional flow. HELP requires daily weather data for a range of 1–100 calendar years, parameters for calculating evapotranspiration, and soil and design data. Open or closed landfills and bottom liner systems and cover systems may be modeled. The major purpose of the model is the comparison of the hydrologic effectiveness of alternative liner system designs for the climate of the particular site. HELP was developed as a tool for both landfill designers and authorizing agencies (Schroeder et al., 1994a).

The HELP model has a history of 30 years and currently three versions exist (see Section 2). The concept and the modeled pro-

cesses of HELP are described in the model's documentation (see Section 2) and in the literature on landfill technology (e.g. Koerner and Daniel, 1997). A sufficient validation is essential for the use of any model in the planning practice to allow an acceptable confidence in the modeling results. Section 3 provides information on the validation of the HELP 3 for cover systems from the literature as well as comparisons of measured data and simulation results of HELP 3.95 D from test fields in covers of two locations in Northern Germany. Section 4 looks ahead to enhancements of the model planned for a future version HELP 4 D.

2. History of the HELP model

The original version of the HELP model was developed by Paul Schroeder (US Army Waterways Experiment Station, Vicksburg, Mississippi, USA) and several co-developers and was funded by the US Environmental Protection Agency. With its development starting in 1982, HELP version 1 was released in 1984 with an extensive documentation comprising a user's guide and a technical/engineering documentation describing the modeling approach

in detail (Schroeder et al., 1984a,b). Among others HELP 1 was based on two older models, CREAMS (Chemicals, Runoff, and Erosion from Agricultural Management Systems) and HSSWDS (Hydrologic Simulation on Solid Waste Disposal Sites) (see Schroeder et al., 1984a,b for references). The program was written in Fortran and executable on mainframes; a PC version for the DOS operating system was released in 1986.

In 1987 Schroeder and Peyton published two verification studies for HELP 1. Schroeder and Peyton (1987a) was concerned with a comparison of simulation results to measurement results of field-scale test areas. However, these test areas were designed and operated for other purposes, the layer sequences were mostly those of simple covers and the measurement data of input and output values of the HELP model were more or less incomplete. Therefore, the results of the output comparison were only of limited value. Schroeder and Peyton (1987b) was concerned with the lateral drainage sub-model, comparing simulation results to measurement results of physical models in pilot plant scale and to analytical solutions of the underlying Boussinesq-equation.

Taking the verification results of these studies into account, HELP version 2 was released in 1988 by Schroeder and co-authors. HELP 2 included two new sub-models, a weather generator (WGEN, Richardson and Wright, 1984), and a vegetative growth and decay sub-model which was taken from the SWRRB model (Simulator for Water Resources in Rural Basins, Arnold et al., 1990). Furthermore, the modeling of many hydrologic processes was enhanced by improving, for example, the calculation of the unsaturated hydraulic conductivity, and the sub-model concerning lateral drainage which was replaced by an approach of McEnroe and Schroeder (1988). However, a complete documentation of HELP 2 has never been published. The same holds for a verification study of Peyton and Schroeder, based upon the previously mentioned measurement data of field-scale test areas.

At the end of 1994 HELP version 3 was released (Schroeder et al., 1994a,b). HELP 3 represents a major enhancement beyond HELP 2 in two respects. Firstly HELP 3 included a menu-driven, though proprietary, user interface for DOS. Weather data from the USA and Canada can be imported from external databases. Weather data can also be imported from ASCII files. Model input and output is not only possible in English (in HELP so called “customary”) units but also in metric units. Secondly major enhancements in the modeling approaches were implemented. Flow through geomembranes was added as independent hydrologic process, the sub-model of potential evapotranspiration was replaced by a simplified Penman approach, and the snow melt sub-model was replaced by procedures based upon the SNOW-17 routine of the National Weather Service River Forecast System. Additionally, in the surface runoff sub-model slope and slope length were considered and some new processes were added, although some in a very rudimentary manner (e.g. freezing and thawing of the soil, subsurface inflow, recirculation of lateral drainage). The current original HELP version is HELP 3.07 from November 1997, executable in DOS.

The Canadian company Waterloo Hydrogeologic, Inc. (which was purchased by Schlumberger in January 2005) developed a Windows user interface for the HELP 3.07 model which was technically adapted to this user interface. Since about 1997 both are commercially available as Visual HELP stand-alone or as part of the UnSat Suite Plus; the current version is dated November 2004 (Schlumberger Water Services). Major features of Visual HELP are a database for the weather generator containing parameters of more than 2400 locations worldwide, the graphic design of the studied landfill profile, and a report generator for simulation results including graphics of daily, monthly and yearly results. However, the input files of Visual HELP and HELP 3.07 are incompatible because they differ in format.

In the 1990s the German Federal Environmental Protection Agency (“Umweltbundesamt”) had an interest in the availability of a water balance model for practical applications resulting from the regulations of that period. Therefore a validation study for HELP 3.07 was implemented for German climate conditions, funded by the Federal Ministry of Education and Research (BMBF) (Berger, 1998, see also Berger, 2000, 2002). The objectives of the study were to determine the limits of application of the model in Germany and to adapt HELP 3 for use in Germany. The adapted version HELP 3.07 D was released in early 1999 and contained databases with German soil textures and locations for the weather generator as well as a German-language User's Guide. The model itself was not modified. Based upon the results of the validation study and further investigation in the following years the author released the enhanced versions HELP 3.50 D (2001), 3.55 D (2002) and 3.80 D (2004). All versions were executable in DOS.

In these versions some of the sub-models were enhanced or replaced, including representations of actual evapotranspiration, vegetative growth and decay, frozen soil, and unsaturated/saturated vertical flow in vertical percolation layers. The enhancements are described in more detail in Berger (2002, 2003) and in the supplement to the Engineering Documentation of HELP 3.95 D (Berger and Schroeder, 2013). Two aspects shall be pointed out here:

- The sub-models of evapotranspiration and vegetative growth and decay were enhanced in several ways. The interception sub-model was replaced by an adapted empirical model of von Hoyningen-Huene. This model was developed for several crops, includes interception storage from one day to the next and allows calculating the interception of vegetation with larger values of the maximum leaf area index than for grasses. The evapotranspiration sub-model was modified to allow a more realistic relation between soil evaporation and transpiration and a more realistic influence of the vegetation on evapotranspiration. The implementation of the vegetative growth and decay model was completed and the decrease of plant growth due to short air (aeration stress) was added from the model EPIC.
- The frozen soil sub-model was pragmatically enhanced. The periods with frozen soil were shortened for German climate conditions and the process representations of soil freezing and thawing were modified to allow a smooth instead of an abrupt freezing and thawing of the soil within the evaporative zone. Consequently the estimation of surface runoff and of the time distribution of lateral drainage in the drainage layer below the topsoil during and after thawing becomes more realistic.

Furthermore, since HELP 3.80 D HELP-D allows the user to change vegetation and soil properties within a simulation run to simulate the aging of a landfill profile. For example, it may now account for vegetation succession or the deterioration of lateral drainage layers due to clogging. The usability was enhanced by separate output files for daily, monthly and yearly simulation results which can be imported into a spreadsheet for further processing.

To upgrade from the outdated DOS user interfaces, unable to run under the 64-Bit versions of Windows 7 and 8, in 2011 the author released HELP 3.90 D with a basic Windows user interface. It is compatible to the DOS interface of HELP 3. Some import options for weather data of HELP 3.07 were dropped, and an import option for Visual HELP weather files was added. In the current version HELP 3.95 D (Berger and Schroeder, 2013), released in August 2013, the user interface was enhanced by some new features like on-line help texts and the option to simulate with the model versions HELP 3.95 D or HELP 3.07 which was recompiled with technical adaptations to the current Windows versions.

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