Analysis of Help Model Application in Smi-Arid Areas, Study on Tehran Test Cells

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Received: April 2009 Accepted: February 2010

Abstract: *Hydrologic Evaluation of Landfill Performance (HELP) model is one of the most accepted tools to simulate the hydrological attributes of landfills. Although some major deviations from real values has been reported about the calculated results for leachate generation by HELP model but other researchers and/or engineers in practice have used it in some places to estimate amount of leachate produced in the landfills. On the Other hand this model is elaborated and mainly used in developed countries with the waste having low moisture content and also in climatic conditions with high precipitation. This research investigated the applicability of the model in arid areas, by construction of two 30m× 50m (effective horizontal length) test cells in Kahrizak landfill (longitude=51°, 20', latitude= 35° 27' degrees), and monitoring the real leachate generation from each one. A set of field capacity and saturated water conductivity tests were also performed to determine basic hydrologic properties of municipal waste landfilled. A comparison was made between values calculated by HELP model and recorded values, shows that a prediction of leachate on annual basis can be done by HELP model with acceptable accuracy but when the infiltration of water to waste body increases due to leachate production, the model intents to underestimate water storage capacity of the landfill, which lead to deviation of calculated values from real ones.*

Keywords: *Landfill, Municipal Solid Waste, Hydraulic Conductivity, Field Capacity, Leachate*

1. Introduction

Hydrologic Evaluation of Landfill Performance (HELP) model is one of the most accepted tools to simulate the hydrological attributes of landfills [1]. This model is developed as a layer model, in which, the landfill body is divided to different layers with certain hydrological properties which are constant in each concerned layer. Then the hydrologic balance between these layers is considered in a transient state.

The HELP model is mainly used for designing different cover layers and drainage systems for landfill. It has been applied in some places for determining the leachate production in landfills [1&2] as well. As stated in some of the technical documentation of the model [3], it is recommended to compare liner alternatives performances by HELP rather than prediction of exact leachate amount by this model[4]. Some of the references also report high erroneous values in the output of the model in comparison with real values [5].

HELP model is elaborated in United States and is mainly used in developed countries. In Tehran, there are two main differences concerning the water balance of the landfills:

1. The evaporation rates in Tehran city is higher than typical values in developing countries and hydro-climatological budget is negative (Evaporation exceeds the value of precipitation) which minimizes the precipitation role in leachate production in the landfills.
2. The moisture content of municipal solid waste in Tehran is around 60%-70% [6] and is higher than typical values in Europe and United States. Therefore it is predicted that main part of leachate in Tehran city landfill will be generated by the excessive water content [7].

In the performed research, it was intended to

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survey the suitability of this model for local conditions in Iran, based on large scale field studies and to obtain a solid background on applicability of this model in the Iranian territory and also neighbor countries with similar attributes.

To assess such local attributes, two test cells were constructed near Tehran city in Kahrizak landfill and the collected leachate from these cells were recorded. On the other hand two tests were performed to determine the key hydrological parameters of the waste including field capacity and saturated permeability. These values were used as input model parameters to obtain the amount of produced leachate by HELP. Finally, a comparison between the real and calculated values could lead to proper assessment of model applicability.

2. Material and Methods

2. 1. Test Cells

In order to investigate the field behavior of landfilled waste, two separate cells were considered to be built and operated during the research in Kahrizak landfill area (longitude=51°, 20', latitude= 35° 27' degrees). The main idea behind designation of two different cells were to survey leachate recirculation effect on the hydrologic performance of the landfill while maintaining the minimum dimensions for the cells to be comparable with real landfill size.

Both cells have around 30 meters width and 50 meters length. In one of the cells (Cell-2) leachate recirculation took place while the other one (Cell-1) was operated without any recirculation. Height of each cell was around 5.5 m which was filled in 3 lifts (figure 1 and 2). The side slopes was designed to be 1:3 to avoid any pore water pressure originated instability since leachate accumulation was a possibility during the monitoring phase specially in case of seismic loading[8].

Design of cells was made based on regulations and standards applied to sanitary landfills and mainly based on EPA guidelines [9].

Base sealing system in test cells was comprised of a 1.5 mm thick geomembrane over a 60cm compacted clay layer. The Clay layer was compacted in 4 separate 15cm layers. To achieve the required impermeability, an optimum moisture content of 13% was used to compact the clay. An alternative for construction of a geomembrane liner would be using fiber included clay to solve the desiccation problem of the

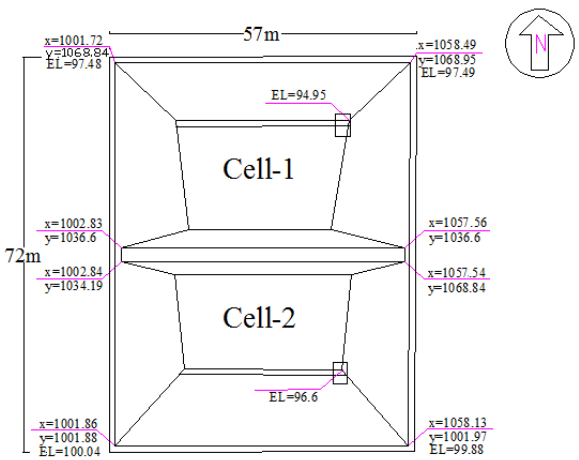

Fig. 1. The schematic presentation of test cells (plan-view)

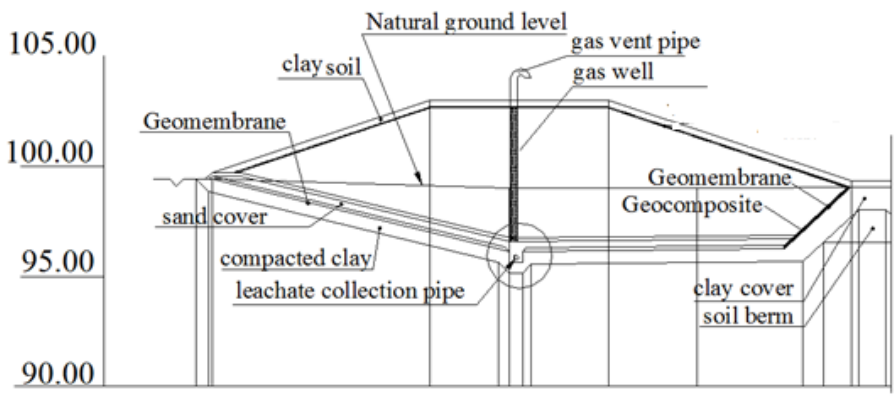

Fig. 2. The schematic presentation of test cells (section).

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compacted clay [10], but it was not considered due to lack of full documentation and literature support for efficiency of such technique.

A geotextile layer is also implemented over the geomembrane layer for protection against geomembrane puncture. Additionally a 10cm thick sand layer was also used to guarantee the soundness of liner in operation period.

Leachate collection system in both cells is comprised of a gravel blanket (16-32mm grain size) with one main pipe (perforated- made of High Density Polyethylene) which conveys the gathered leachate to the monitoring sump where the leachate is pumped out of landfill body. Thickness of gravel blanket was designed to be 45 cm to avoid clogging. A general slope of 2% was also used in the bottom of the landfill for leachate drainage. The drain pipe with diameter of 200 mm was placed in a 60cm wide trench with bottom slope of 1%. A great factor of safety applied for sizing the pipe to avoid any clogging in leachate pipes.

Collected leachate is transferred to a sump with 1m×1m dimension. Access to the sump was provided by a concrete shaft and leachate monitoring and pumping were taken place through this concrete shaft. There were two masonry basins lined with HDPE to store the leachate in the site temporarily and stop infiltration to the groundwater. However there are other sources of pollutants other than test cells and leachate sumps in the area that can be determined by different backward analysis methods [11] but the care was taken not to add a new pollution source to background contamination. Each of these basins has the capacity of 70 m^3.

The method of landfilling in test cells was a combination of trench and area methods. The ground was excavated to 3m depth in the first place. The side slope of 1:4 (1 vertical to 4 horizontal) was used to provide the access for waste handling equipment and trucks. After installation of liner and leachate collection system in the excavated cell, waste filling started and continued to 2.5m height above the earth level.

The waste was deposited in three steps; each of

Table 1. Geometrical characteristics and filling pattern for each test cell.

	Specification	Cell-1	Cell-2
General Description	Area(m^2)	1980	1990
	Total Height(m)	5.3	5.2
	Duration of Disposal and Instrumentation(day)	95	95
First Layer	Area(m^2)	1755	1555
	Total Height(m)	1.6	1.5
	Duration of Disposal and Instrumentation(day)	40	40
Second Layer	Area(m^2)	1505	1460
	Total Height(m)	1.9	2
	Duration of Disposal and Instrumentation(day)	25	25
Third Layer	Area(m^2)	1490	1545
	Total Height(m)	1.8	1.7
	Duration of Disposal and Instrumentation(day)	30	30

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them contained approximately 1600 tons of waste and an intermediate cover with 25cm of coarse soil. Table 1 shows the main geometrical characteristics of each test cell are presented.

In one of the cells (Cell-2) 9 branches of perforated pipes were installed beneath the final cover that could be attached to a pump in the times of leachate recirculation. These pipes have an inside diameter of 4cm with 8mm diameter holes and 50 cm spacing and were put in a trench excavated over the final waste layer and backfilled with gravel. The leachate was re-circulated over expanse of the landfill body through these pipes.

The waste compaction was done with an 826C Caterpillar waste compactor that makes it possible to achieve waste density near 900 kg/m^3. This was to ensure that the properties of waste would be identical to current engineered landfill in practice. The number of passes to achieve such density was 6 compactor passes for 0.3 meter high waste pile.

During the monitoring period, the leachate infiltrated to the drainage system, was removed from the sump and measured. The application of robust sophisticated bottom liner and effective drainage system made it possible to assume that the monitored volume in the sump was identical to the quantity of leachate produced in the cell.

Based on the recorded values a total amount of 94.9 m^3 leachate is produced in the modeling period in cell-1 while in cell-2 this value reached the sum of 105 m^3 while 164 m^3 of leachate was recirculated over the cell. In the same period the amount of precipitation over the cells amounts to around 334 m^3 based on the precipitation data gathered from nearest station.

The maximum monthly value for leachate discharge in cell-1 was 12.1 m^3 in December while the maximum value for cell-2 took place in November when 12.7 m^3 leachate was recorded in the drainage system outlet.

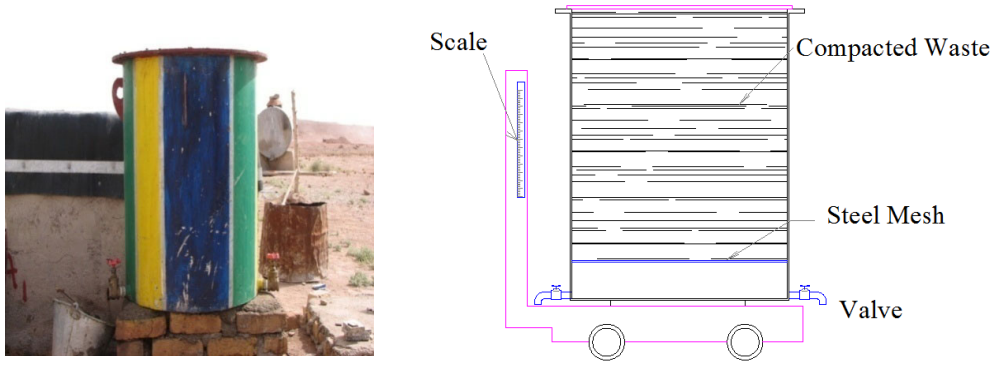

Fig. 3. Field capacity test container picture and schematic drawing.

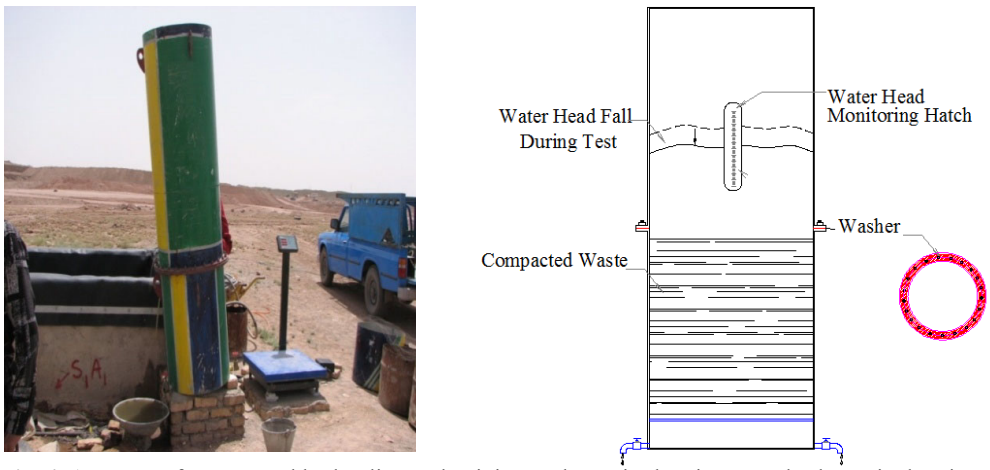

Fig. 4. Apparatus for saturated hydraulic conductivity as shown in the picture and schematic drawing

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2. 2. Field Capacity and Permeability Tests

To determine field capacity and permeability of the soil, standards and well known method are commonly used in practice [12,13,14], but due to non homogenous nature of municipal solid waste, these methods cannot be applied to determine waste characteristics, therefore a modified method was designed to determine field capacity and permeability of the municipal solid waste.

As described by United States Environmental Protection Agency [3] the field capacity is the volumetric water content at a soil water suction of 0.33 bars or remaining after prolonged period of gravity drainage without water supply. Based on this definition using the concept of gravity drainage, a cylinder container with 60cm diameter and 80cm depth was chosen to determine field capacity, this container was filled with compacted municipal waste with density of 900 Kg/m^3 (figure 3).

A valve is fabricated at the bottom of the container and a galvanized mesh was welded a few centimeters above the valve to prevent clogging of the valve by waste. This valve had been closed during compaction process and then after filling the container and recording the weight, it was opened. The excessive water then flew out the container over time. When the flow stopped (which took 2-3 days) then the weight of the container was measured and the difference between two measurements was deduced as the weight of excessive water to field capacity. By drying the waste sample, the dry weight and the field capacity of the waste was determined.

Before emptying the container, the saturated hydraulic conductivity test was also performed. This test was designed in a way that it could be executed in continuation of field capacity test. Another cylinder, which has a water level indicator, was fabricated over the field capacity container. A plastic washer was used for sealing the joint between containers (Figure.4). After fabrication of apparatus, it was filled with water while the bottom valves were closed. Then two valves were opened simultaneously and the rate of water level drop was recorded. This rate reached a constant value after some seconds that could be considered as the waste permeability. A secondary valve was predicted for this test to let the water discharge from the vessels take place with minimum orifice discharge limitations, and to guarantee that the rate of water discharge is merely dependant on the waste conductivity. The result of both tests is shown in table 2.

The unsaturated Permeability of any media like waste is also important in contaminant transport [15], but as the main focus of the research was on the discharge of the leachate, this was not investigated during the course of investigation.

Table 2. the result of field tests for hydrological properties of municipal waste.

Sample No.	Saturated hydraulic conductivity(cm/s)	Field capacity(Vol/Vol)
1	0.0937	33.6
2	0.0842	29.05
3	0.0833	25.76
4	0.1123	22.76
5	0.0473	27.00

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2. 3. Modeling Leachate Production with HELP

Hydrological Evaluation of Landfill Performance (HELP) model is a layer model developed based on water balance equation for each individual layer. This model was presented by a team of experts supported by United States Environmental Protection Agency Funds [3]. Help Model is one of the most elaborated models developed for predication of landfill hydrological performance. The Model incorporates a large set of assumptions and equations based on approved references. A comprehensive description of technical background and formulation used in HELP model is gathered and available in engineering documentation of the model [3].

After determining the two key hydrological characteristics of the waste (field capacity and permeability) modeling for prediction of leachate generation in both cells were performed to provide a set of data for further comparison with real recorded leachate generation values in the cells.

In cell-1(northern cell), the cell without leachate recirculation, and the following configuration was applied in the model in 9 layers (from top to bottom):

1. First layer: the Final cover layer with low penetration (ML soil type) with 40cm thickness.
2. Second layer: compacted waste with 140cm thickness.
3. Third layer: intermediate cover layer comprised of gravel with 20cm thickness.
4. Fourth layer: compacted municipal layer with 170cm thickness.
5. Fifth layer: intermediate cover layer comprised of gravel with 20cm thickness.
6. Sixth layer: compacted municipal layer with 140cm thickness.
7. Seventh layer: gravel drainage layer with 45cm thickness and 2% slope
8. Eighth layer: sand protection layer for Geomembrane with 10cm thickness
9. Ninth layer: Flexible Membrane Liner(Geomembrane)

The properties of material used in model are mentioned in table 3.

Although a clay layer was constructed under the geomembrane, but as geomembrane layer was considered highly impermeable, and with no holes in it (due to high level of quality control during installation) no leachate penetration through geomembrane was considered, therefore the clay layer was not included in the model.

The leachate that was discharges from layer 7 and 8 was used to determine the amount of leachate generated from the cell. Dimension of the cell was considered 50m×30m. It is important to note that all the model outputs from HELP model are based on mm/m^2. Therefore, to

Table 3. Material properties used in HELP model as Input parameters.

Layer Number	Layer Type	Porosity (Vol/Vol)	Field Capacity (Vol/Vol)	Wilting Point (Vol/Vol)	Effective Saturated Hydraulic Conductivity (Cm/s)
1	Final Cover	0.42	0.31	0.18	0.19×10^{-4}
2	Compacted Waste	0.35	0.27	0.19	0.25×10^{-1}
3	Intermediate Cover	0.32	0.05	0.02	0.2
4	Drainage Material	0.4	0.03	0.01	0.3
5	Protection Sand	0.4	0.24	0.14	0.11×10^{-3}
6	Geomembrane Liner	----	----	----	0.2×10^{-12}

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Table 4. Average monthly precipitation and temperature of input values in HELP.

Month (2007)	January	February	March	April	May	June
Precipitation(mm)	4.5	15.4	16.4	45.8	22.6	46.3
Temperature(°C)	1.8	6.6	8.6	13.8	20.8	28.0
Month (2007)	July	August	September	October	November	December
Precipitation(mm)	1.8	0	0	0	9	43.2
Temperature(°C)	29.8	30	27.4	20.4	15.1	7.2

compare recorded discharges from the cell with model values one should divide the recorded discharge to the area of cell or multiply the values obtained from the HELP by the area of the cell. In all of the presented figures in the article the former method is used.

The simulated time was one year and started 6 months after beginning of the operation(waste dumping) in the cells when the final cover was installed and leachate output from the cells reached a stable regime (It is when the moisture excessive to field capacity during the waste dumping, drained out of the landfill). Therefore the starting simulation period was in January 2007 as set to month-1 for all of the presented charts in the article.

Climatological data and statistics from the nearest weather station (Imam Khomeini Airport station) were used such as precipitation and temperature, etc.. as input values for the model. In table 4 the average monthly temperature and precipitation values used as input parameters in the model is shown.

For Modeling Cell-2 (southern cell with leachate recirculation), as the Help model could not simulate recirculation of leachate, the following methodology was chosen to model the landfill hydrological performance:

1. At first, a model is developed without considering any leachate recirculation and the amount of leachate generation was determined.
2. In the second step, in a different model, the leachate recirculation was represented as precipitation when no other precipitation/evaporation or runoff was introduced to the predefined configuration of the landfill. This will lead to a new leachate generation rates which are caused by leachate recirculation.
3. The leachate generated from step 1 and 2 are then accumulated as the total discharge of the leachate generated from precipitation and also leachate recirculation.

The model outputs from amount of generated leachate then was compared to real values recorded on site. The model results for cell-1 show production of 99.7 m3 in modeling period in cell-1 and 201.9 m3 in cell-2. The detailed discussion over the comparison of model results recorded values will be presented in following section text. The first remarkable result is the negligible difference in two cell discharges in recorded values while the modeling results show a great difference between them.

3. Discussion

The main idea of discussion in this part is to make a comparison between the model outputs and real recorded values to investigate the conformity and also the reasons behind the any observed differences.

In figure 5 a plot of monthly precipitation versus real leachate discharge and modeling results for discharge is presented for Cell-1 (The calculation and monitoring started from January 2006 as the first month in the chart).

As it is understood from figure 5, calculated values have a considerable deviation from measured values in monthly basis and show moderate conformance to precipitation (rain) pattern with 1 month delay.

In figure 6 an accumulative plot of measured

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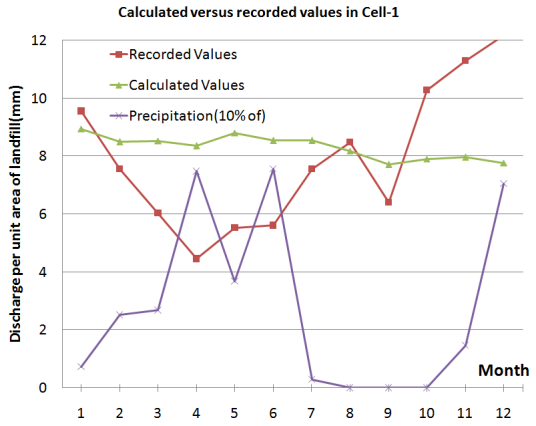

Fig. 5. Calculated discharge by HELP versus recorded values in Cell-1 and precipitation.

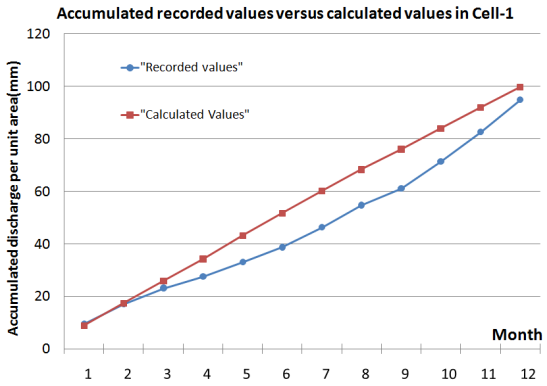

Fig. 6. Accumulated discharge calculated by HELP versus recorded values in cell-1.

and calculated leachate discharge is shown. As it is clear in one annual hydrological cycle, the calculated values conform very well with measured values. So we have not get a good result from the model in monthly basis values, however usable results have been produced in annual calculation.

Other researches show some deviation in monthly discharges even after calibration of the models [16,17], however, the following reasons behind these differences in cell-1 could be figured out as follows:

- The Help model is developed based on water transfer between waste layers and does not have the capability to model drain channels [18]. The drain channels are formed in the waste body because of non-homogeneity of void dispersion in the waste body. The water will flow easier in the parts with more voids in them. These parts will be attached together and form preferential drain channels which transfer the water in waste body [19]. Since HELP model cannot recognize this phenomenon a retention effect will be considered by this program which does not exist in reality, so the leachate will flow out much faster in reality than modeled in the HELP.
- The weather station has 30Km distance to the landfill cells that may cause some deviations in calculated results, especially in monthly and daily basis. That is similar to the situation in practice when one may only use the nearest weather station in Iran or other developing countries when designing leachate treatment facilities.

To remove these deficiencies, an ongoing research is now being implemented for solving above-mentioned problems by using an on-site weather station and also application a balance method instead of layer model (such as HELP).

These unconformities may also be raised from inaccuracy of input parameters. In table 5 the source of data collection for model inputs are shown. It is understood that all the data used for input values are determined from best sources available, although two main improvements can be made in input data quality:

- Installation of an onsite weather station in the Kahrizak landfill site for higher quality weather data collection (as mentioned before).
- Increasing the number of permeability and field capacity tests and also using bigger size apparatus in the tests to get better results for these two key parameters.

But an important observation in the results of modeling shows that the sources of current errors are not limited to the abovementioned factors. HELP model provides the residual moisture content of each layer in the end of simulation period. The moisture content of each waste should be at minimum equal to field capacity based on field capacity definition, unless a suction force exists on the layer beneath. The calculated values of residual moisture after simulation period were in the range 0.15 to 0.19 (vol/vol) (while the field capacity assigned to the waste was 27 %.) and the value of the residual

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Table 5. Source of data collected as input values for HELP model.

No.	Set Of Data	Source of data collection or production
1	Temperature	From nearest standard weather station on Emam Khomeini airport.
2	Precipitation	From nearest standard weather station on Emam Khomeini airport.
3	Solar Radiation	Calculated by HELP based on Longitude and Latitude of Kahrizak Landfill.
4	Material properties	Based on laboratory tests the classification of different soils was determined and then HELP inventory is used to determine material hydrologic properties.
5	Waste properties	Based on values determined in the field tests described in the article.
6	Run off factors	Based on surveyed geometry of the cell.

moisture content decreased with depth. This will be discussed later in the text when we focus on the cell with leachate recirculation.

In figure 7 a plot of calculated and monitored values in the cell-2, with leachate recirculation is shown. It is revealed that calculated values are mainly higher than the measured values. Accumulated values also show almost 150% deviations from real values on site measurements (see figure 8).

Based on the HELP analysis in cell-2 the landfill does not store any leachate in itself, and simply transfers the water from recirculation or precipitation to leachate drainage system. But in real test cell the leachate is stored in the landfill rather than being transferred to the leachate drainage system; therefore the leachate discharged values observed in the test site are much lower than what is calculated by HELP.

Again we come back to investigate the residual moisture content of the waste at the end of 1 year modeling period. This was surprising to see the moisture contents were much less than field capacity and in the same range of values calculated in the first cell without leachate recirculation that was in contrast to our definition of field capacity.

To identify the problem we should discuss a little bit the concepts of filed capacity and water flow in a landfill. The main parameter that controls the flow in the landfill body is the field capacity. As mentioned before in the text USEPA describes the field capacity as following: “the field capacity is the volumetric water content at a soil water suction of 0.33 bars or remaining after prolonged period of gravity drainage without water supply” [3]. In figure 9, a schematic description of this model is presented.

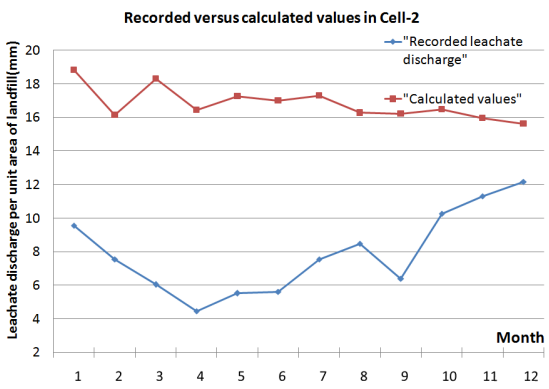

Fig. 7. Calculated discharge by HELP versus recorded values in cell-2.

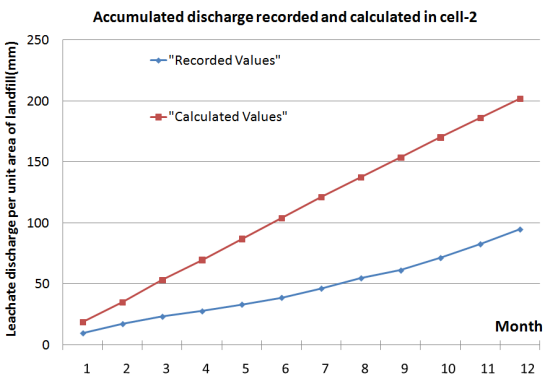

Fig. 8. Accumulated discharge calculated by HELP versus recorded values in cell-2.

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This model has also been used in other researches for describing the storage capacity of the waste [20] however the presentation is original. As it shown in figure 9, the flow out of waste body when only the gravity is acting upon the waste will continue until the moisture content reaches the field capacity. Further discharge from a waste layer is possible only if the suction would be present up to the wilting point. Further desiccation of waste will then be only possible by heating up the waste [3]. In the landfill the main suction inductive mechanism is evaporation, while the drainage of the leachate from the landfill bottom is caused by gravity [20].

Therefore if there is no suction in the landfill (which is applicable in our case) then the minimum moisture content in the waste should be equal to the field capacity introduced to the model. In both cells, as mentioned before, the residual moisture content calculated(15%-19%) is less than the designated field capacity (27%-or if we choose the option to let the model initialize the moisture content based on steady state condition a lower value than the field capacity is designated by it). This shows a great underestimation of waste storage capacity. An effort was performed to see if the residual moisture content can be changed by increasing the field capacity in the model, but this had a minor effect on the output values.

As the residual moisture content were less than field capacity, therefore a source of suction should have been considered somewhere in the model.

After some try and errors it was guessed that the source of suction is in drainage layer. This could be explained by a review on the engineering documentation of the HELP that revealed the fact that a source of suction can be formed in the bottom of landfill [21]:

"Drainage downward by soil suction exerted by dry soils lower in landfill profile is modeled as Darcian flow for any soil having relative moisture content greater than lower soils. The drainage rate is equal to unsaturated hydraulic conductivity computed as function of soil moisture content. As such the rate is assumed to be independent of pressure gradient."

This shows that if a suction force is developing in the landfill bottom, the magnitude of suction force and its ability to attract water from upper layers is proportional to the permeability of drainage layer.

To investigate this theory a number of model runs was implemented with different permeability of drainage layer. The abstract result of these runs is shown in figure 10.

In figure 10, two main phenomena in both ends of the curve are shown. When we decrease the permeability of drainage layer, the residual moisture content will grow near the expected value of field capacity (27%) which confirms the fact that by decreasing the permeability, the amount of water discharge and suction to drainage layer decreases. While permeability increases the suction will be stronger and the residual moisture content will be reduced that shows the suction is proportional to permeability. Therefore the theory of bottom suction can explain the current function of the model is underestimating the storage capacity of the waste.

Another way to check the applicability of the theory is to set the wilting point equal to field capacity in the model. If the bottom suction is the reason behind reduction in water content of the waste, then by setting wilting point equal to field capacity, the residual water content should not be

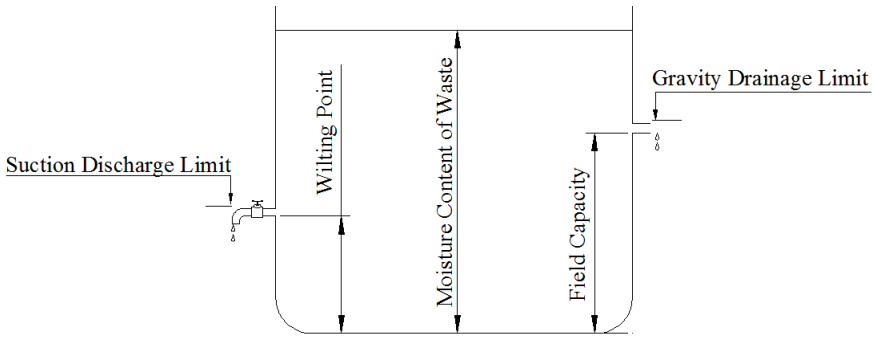

Fig. 9. Simplified hydrological model designated by HELP for municipal waste.

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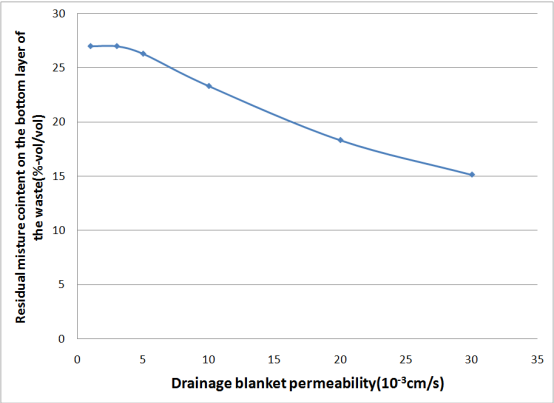

Fig. 10. The variation of residual moisture content when the bottom drainage blanket permeability changes.

decreased. The recalculation using this assumption shows that the water content of the waste will remain equal to 27% which in turn proves the applicability of bottom suction theory.

This theory can explain what is happening in the bottom drainage layer when there is a considerable storage capacity in the landfill. In figure 11 two mechanisms of conventional field capacity theory and HELP performance is shown. The HELP model calculates water balance parameters on a daily basis. In a day when there is no water in waste layer excessive to field capacity; the drainage layer goes dry and immediately develops suction because it is dryer than the waste layer above. That will cause the water going out of the waste layer although neither considerable inflow exists, nor storage capacity overran. This does not happen in reality when a layer of gravel is dryer than the waste layer above; the moisture will not come down until field capacity is reached. That is a reason why the residual moisture calculated are not correct and consequently the amount of leachate discharge is not accurate.

The theory also shows why the residual moisture content decreases in model calculation when we come near to bottom of the landfill as the suction force is stronger. This also shows why in our test cells this suction makes such errors which have not been reported in the literature about real size landfills. The depth of the test cell was not as high as real landfills. Therefore the suction of the leachate drainage layer could affect main waste body of the landfill while in the real landfills deeper waste dumping takes place and therefore this suction induces less erroneous results.

In cell-2 where the leachate was recirculated, the large amount of leachate recirculation mobilized the storage capacity of the test cell, thus the suction which nullifies the effect of field capacity demonstrates a greater influence and higher errors are noticed.

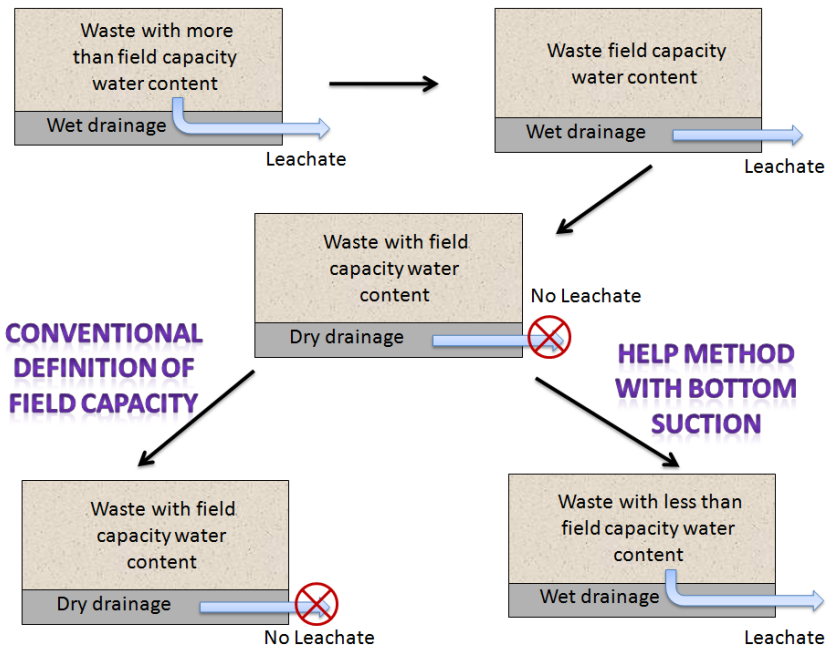

Fig. 11. The mechanism of bottom suction and its contradiction with accepted field capacity concept.

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4. Conclusion

Although some major deviations from real values have been reported about the calculated results by HELP model but other researchers and/or people in field practice have used it in some places. This research confirms these deviations in the model output and also delineates some causes for them.

The results gained by study in cell-1, without any recalculation, shows that the leachate prediction in arid areas can be predicted with a good accuracy in annual basis but for the monthly values a factor of 1.7 should be applied as a safety factor. This factor of safety can be resulted from figure 5 where the maximum difference between calculated values and observed values is around 70% of the real value.

But when the infiltration to the landfill increases due to leachate recirculation, HELP model tends to underestimate the storage capacity of landfills and long deviations will happen from real values. The main reason for this deviation is the development of the suction in leachate drainage layer in the bottom of landfill in the calculation that causes a drastic decrease in water storage capacity in the landfill.

Other sources of errors in the results were also confirmed as the distance of the cells to the nearest weather station and inability of layer models like HELP to simulate channeling phenomena but they were not considered to have substantial effect.

The authors believe by removing such malfunction, the deviation in the values calculated by HELP model, will be reduced significantly although other limitations like neglecting channeling phenomena will also cause some error in leachate prediction.

The conclusion of this research came from limited number of field test which cannot be representative for heterogeneous nature of municipal solid waste and further investigation in this regard is advised to get better understanding of landfill hydrologic performance.

5. Acknowledgement

This research was financially supported by President Deputy for Strategic Planning and Control, (former Iranian Management and Planning Organization) and Organization of Waste Recycling and Composting (OWRC) of Tehran municipality.

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