Chapter 1

Effectiveness of Grassland Vegetation on a Temporary Capped Landfill Site

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Additional information is available at the end of the chapter

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Abstract

We studied the effectiveness of grassland vegetation of a temporary capping system consisting of differently compacted boulder marl and its impact on the water balance components. This study presents the modelled water balances for the period between 2008 and 2015, performed with HELP 3.95 D (German edition). The model requires landfill design and weather data as well as soil physical and evapotranspiration parameters including the leaf area indices and evaporative zone depth with regard to the grassland vegetation. The modelled average annual actual evapotranspiration rates ranged between 277 and 390 mm year-1 or rather 33 and 66% of the annual precipitation (10-year average of 728 mm). The actual evapotranspiration rates are strongly influenced by the maximum leaf area indices that increased between 2008 and 2015 from 1.0 to 3.5 as well as the evaporative zone depth that also increased from 20 cm in 2008 to 50 cm in 2015. The empirical-mathematical–based HELP model is a useful option to successfully determine the water balance components of a landfill capping system under the given weather and site conditions including the development of the grassland vegetation.

Keywords: HELP model, water balance, actual evapotranspiration, leachate generation, vegetation growth

1. Introduction

In a global perspective, landfill sites still represent the major option of waste disposal not only in developing countries [1]. In Germany, the qualitative criteria of landfills are legally fixed according to the [2] and define the vegetative and technical standards for engineered barriers [3].

In case of this study, semipermeable, temporary capping systems intend a specific shutdown of the bioreactor, containing heterogeneous wastes and different amounts of biodegradable material, through controlled infiltration of precipitation into the waste body [4] and also allow biogas extraction [5].

Temporary capping systems regularly consist of a recultivated layer, a drainage layer, and a sealing layer consisting of mineral substrates or in combination with polymers [6]. The major aim of the recultivated layer is to restrain landfill gas migration and to minimise leachate generation (precipitation contaminated with heavy metals or polycyclic hydrocarbons) by a high water storage capacity in combination with a distinct evapotranspiration rate from the vegetation and soil surface [3, 7].

Therefore, the choice of a locally adapted vegetation type (grassland, shrubs, forest) is essential to ensure high evapotranspiration rates (grassland: 450–550 mm $year^{-1}$), a quick vegetation establishment (erosion protection, slope stability), and avoid deep shrinkage-induced cracking (capillary rise from deeper horizons) and rooting to protect the sealing layer as last barrier above the waste body depending on the thickness of the recultivated layer [4, 8–10].

The functional requirements of the vegetation in the nutrient and water availability considering a proper air capacity and plant available water capacity [2], whereby the technical challenges in landfill construction, compacted installation versus loose installation of mineral substrates, can significantly influence the growth conditions of the vegetation [3].

The effectiveness of the vegetation can be assessed by the water balance or rather the leachate generation under the specific climate and soil conditions [4, 11, 12]. There are several modelling approaches of landfill capping systems, with and without polymers, combining water balance calculations with the predominant statistical-empirical Hydrologic Evaluation of Landfill Performance (HELP) model [13] or numerical models like Finite Element subsurface FLOW system (FEFLOW) [14]. Such predictive models can be used to support the planning of a landfill and/or to optimise the particular system from an economic point of view [12] and to verify the long-term hydraulic stability of a final capping system.

This study presents modelled water balance data and in particular the annual leachate rate of the Rastorf landfill during an 8-year period in the context of (a) grassland vegetation and (b) local weather conditions.

2. Materials and methods

2.1. Study site and weather conditions

The Rastorf landfill (lat. 54° 16′N, long. 10° 19′E) in Schleswig-Holstein (Northern Germany) was actively operated from February 1977 to May 2005 with a total area of 105,000 m^2 and about 2.0 million tons of municipal domestic wastes were deposited in it (**Figure 1**).

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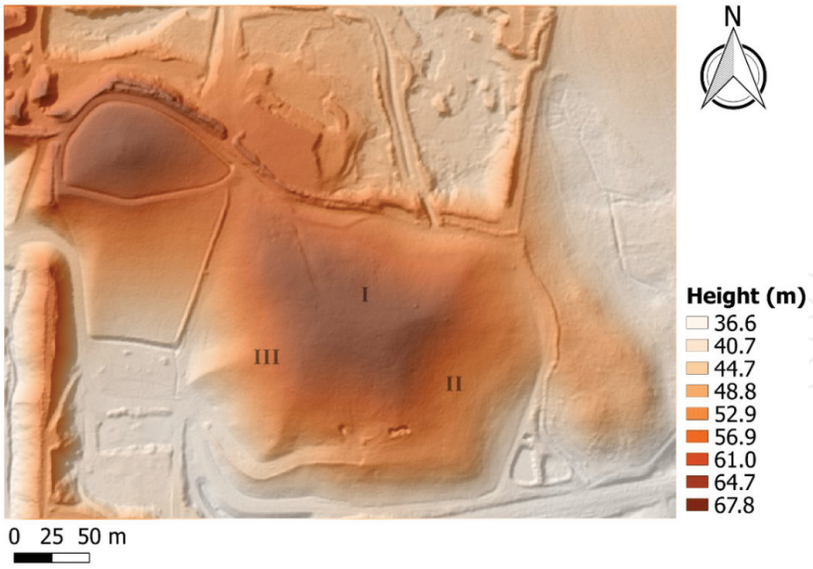

Figure 1. Digital elevation model of the Rastorf landfill with the temporary capped area (section I–III) [15].

The temporary capped area of nearly 75,000 m^2 with three sections (I: 21,275 m^2, II: 29,961 m^2, III: 22,208 m^2) consists of three mineral layers (boulder marl) with a partially permeable recultivated layer (humus topsoil: 40 cm, humus-poor subsoil: 30 cm) and, below this layer, is a low permeable, 30 cm thick mineral sealing layer, which serves as a water and root barrier to prevent leachate formation and the groundwater contamination. The bottom layer consists of hardly permeable up to 20 m thick clay. A high-density polymer of 2.5 mm thickness and a drainage system above the bottom layer collects the leachate before the treatment by inverse osmosis (**Figure 2**).

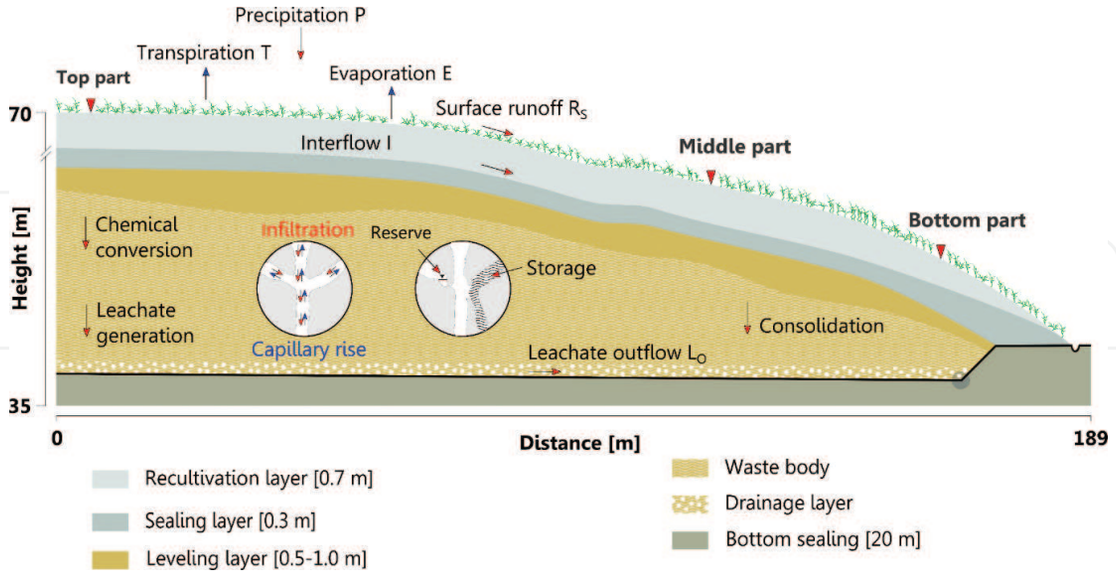

Figure 2. Schematic cross section through the temporary capped area with water balance components, data logger and measuring devices in 20, 50, 80 and 100 cm depth.

Area	I	II	III
Average slope gradient (°)	7 ± 3	14 ± 3	16 ± 4
Average slope length (m)	99 ± 65	48 ± 23	69 ± 4
Exposure	N/NE	SE	SW

The symbol ± corresponds to the standard deviation.

Table 1. Average slope gradient, slope length, and exposure of the sections I–III.

The maritime, semi-humid climate in Rastorf is characterised by an annual precipitation rate which is in the long-term average regularly between 6 and 9 months year-1 higher than the potential evapotranspiration rate [16]. The local weather conditions also affect water balances of the landfill capping system with 10-year average precipitation rates of 728 mm and, between 2012 and 2015, an average annual temperature of 9.0°C. The slope gradient varies between 7 and 16° and the slope length between 48 and 99 m (**Table 1**).

2.2. Laboratory measurements

In 2012, more than 160 undisturbed soil cores (100 cm^3) were sampled in the capping system in vertical (90°) and horizontal (0°) direction in area I (54°28′20″N, 10°32′60″E), II (54°28′11″N, 10°32′71″E) and III (54°28′08″N, 10°32′75″E) in depths of 0.2, 0.5 and 0.8 m. The saturated hydraulic conductivity (Ks) was measured under instationary conditions (n = 10 per depth) according to [17]. The pore size distribution (n = 7 per depth) was determined by a combined pressure plate (saturated, −6, −30) and − 1500 kPa ceramic vacuum outflow method as well as oven-dried at 105°C, respectively [18].

2.3. Hydraulic Evaluation of Landfill Performance (HELP) model

The Hydraulic Evaluation of Landfill Performance (HELP) model is a quasi two-dimensional hydrologic model which combines one dimensional soil physical and hydrological processes in (a) vertical direction and (b) lateral direction according to [13]. Thus, the model requires data of the landfill design, weather conditions, and material properties such as porosity, field capacity, wilting point and saturated hydraulic conductivity as input parameters [19]. In addition, the evaporative zone corresponds to the root depth of the vegetative cover and was calculated to quantify the maximum soil depth from which water can be removed through evapotranspiration [12].

With respect to the landfill design data, the upper part of the recultivation layer (0–0.4 m) was classified as vertical percolation layer, the bottom part (0.4–0.7 m) was conducted as lateral drainage layer to take into account the lateral saturated hydraulic conductivity. The sealing layer was classified as barrier soil liner.

The HELP model was validated with actual landfill data with respect to field and laboratory measurements according to [20].

2.4. Estimation of the water balance components of the Rastorf landfill

The HELP model was validated with actual landfill data with respect to field and laboratory measurements according to [20]. The leachate rate (L) was calculated as follows:

$$L(t_i) = P(t_i) - ET(t_i) - R(t_i) - D(t_i) \pm \Delta S(t_i) \quad (1)$$

where: L = leachate rate, P = precipitation, ET = actual evapotranspiration (including interception), R = runoff, D = lateral drainage (interflow) and ΔS = change in soil moisture content in mm year-1 and m3 and it is the time step, performed from January 1, 2012 until December 31, 2015.

A separate water balance was modelled for each area (I–III) and a weather station located close to the landfill recorded the actual meteorological data such as precipitation (uncorrected), air temperature, wind speed, wind direction, air pressure, air moisture, and relative humidity on daily basis. The global solar radiation was calculated on the basis of [21].

In addition, the wind speed was measured in 10 m height and a logarithmic approximation was used to calculate the wind speed for 2 m height. The leaf area index (LAI) was calculated on the basis of the quarterly measured average vegetation height (h) in 8–10 repetitive transects (1 m^2) per area with a folding ruler according to [21]:

$$LAI = 24 \cdot h \quad (2)$$

The average root intensity was determined annually on the basis of repetitive soil profile images in the three areas with the colour threshold method using ImageJ software [22] and classified according to [23].

2.5. HELP modules

The water balance calculations based on analytical and empirical equations, while a detailed description is shown in [19, 24]. With regard to the atmospheric boundary conditions, the method used in the HELP 3.95 D for calculating evapotranspiration was designed according to [25].

The potential evapotranspiration consists of (a) evaporation of surface water (primarily evaporation of intercepted water, besides this evaporation of snow), (b) soil evaporation, and (c) plant transpiration computed by a simplified approach of [26]:

$$E_{o_i} = \frac{PENR_i + PENA_i}{L_v} \quad (3)$$

$$L_v = \begin{cases} 59.7 - 0.0564T_{c_i} & \text{for water} \\ 67.67 - 0.0564T_s & \text{for snow} \end{cases} \quad (4)$$

where: E_{oi} = potential evapotranspiration on day i (mm), PENRi = radiative component of the Penman equation on day i (langleys), PENAi = aerodynamic component of the Penman

equation on day i (langleys), L_v = latent heat for vaporisation (for evaporating water) or latent heat of fusion (for evaporating snow) in langleys per mm and T_s = snow temperature (°C).

The actual evapotranspiration (ETa) was mainly calculated by an approach of [25] using a model of vegetation growth and decay by [27]. Thus, the vegetative growth and decay sub-model included in HELP was taken from the model SWRRB [27]. The ETa is limited by the water availability at the landfill surface and the maximum depth of the evaporative zone according to [20]. Therefore, the plant available water capacity inside the evaporative zone (field capacity–wilting point) can only be removed by evapotranspiration, while the field capacity (US: −330 hPa) is the lowest soil water content to allow unsaturated vertical flow (drainage) within the evaporative zone [28]. The capacity of the interception storage and the interception height were calculated following Hoyningen-Huene (1983), modified and adapted to German standards by [28].

The area factor v was implemented in the modelling approach and corresponds to the ratio of the monthly sums of the global solar radiation (R_s) on inclined and horizontal reception areas consider the exposure and the inclination angle (°) and a corrected albedo of 0.23 in the summer-half (05/01-10/31) and in the winter-half (11/01-04/30) under climatic conditions in Germany [29].

The vertical percolation (drainage) is estimated using the equation for the unsaturated hydraulic conductivity (Eq. 4) which is based on [30]. The saturated lateral drainage is modelled by a steady-state solution of the Boussinesq equation in combination with the Dupuit-Forchheimer (Forchheimer, 1930) assumptions, which take into account the Ks value of the drainage layer. The unsaturated conductivity for each soil layer was calculated as follows:

$$K_u = K_s \left[\frac{\theta - \theta_r}{\Phi - \theta_r}\right]^{3+\left(\frac{2}{\lambda}\right)} \tag{5}$$

where: K_u = unsaturated hydraulic conductivity (cm s^{-1}), K_s = saturated hydraulic conductivity (cm s^{-1}), θ = actual volumetric water content (m^3 m^{-3}), θ_r = residual volumetric water content (m^3 m^{-3}), Φ = total porosity (m^3 m^{-3}) and λ = pore-size distribution index (−).

Therefore, θ_r is the amount of water remaining in a layer under infinite capillary suction and was estimated as follows [24]:

$$\theta_r = \begin{cases} 0.6\,WP & WP < 0.04 \\ 0.014 + 0.25\,WP & WP \geq 0.04 \end{cases} \tag{6}$$

where: WP = volumetric wilting point (m^3 m^{-3}).

The leakage rate depends upon the depth of the water-saturated soil (head) above the base of the layer, the liner thickness and the Ks value of the barrier soil. So, the leakage occurs whenever the moisture content of the layer above the liner is greater than the field capacity of the layer [19, 24].

In addition, the rainfall-runoff process is modelled using the SCS curve-number method with values above 0 up to 100, as presented in Section 4 of the National Engineering Handbook [31].

The curve numbers for the areas I–III were obtained under the terms of the surface slope, the slope length, and the vegetation cover and also modified according to the previous sensitivity analysis. The SCS-CN method based on the following basic form [32]:

$$R = \begin{cases} \frac{(P - I_a)^2}{P - I_a + S} & P > I_a \\ 0 & P \leq I_a \end{cases} \quad (7)$$

where: R = runoff (m^3), P = precipitation (m^3), S = potential maximum soil moisture retention auf the runoff begins (m^3) and I_a = initial abstractions (sum of interception + evapotranspiration + infiltration + depression storage) in m^3. The retention parameter S is transformed into a curve number (CN) with following relationship [24]:

$$CN = \frac{1000}{S + 10} \quad (8)$$

The lateral drainage layer required information about the maximum drainage length as length of the horizontal projection of a representative flow path and the drain slope for the areas I–III [30]. The lateral drainage equation can be described as follows [19]:

$$y^* = \frac{d^2y^*}{dx^{*2}} + \left(\frac{dy^*}{dx^*}\right)^2 + (\tan\alpha)\frac{dy^*}{dx^*} = \frac{q_D^*}{\cos^2\alpha} \quad (9)$$

where: x* = x/L (nondimensional horizontal distance), y* = y/L (nondimensional depth of saturation above liner), $q_D^* = q_D/K_D$ (nondimensional lateral drainage rate) with K_D = saturated hydraulic conductivity of the drain layer (cm/s) and α = inclination angle of the liner surface.

2.6. Model calibration and sensitivity analysis

The validity of the data used as input and output values for the comparison of observed and modelled data is of major importance [20]. Therefore, the sensitivity analysis, calibration, and validation for the period from 2008 to 2015 were performed in a previous study on the basis of input and output values of the HELP model [28].

Therefore, an increasing evaporative zone depth from 10 to 100 cm can increase the actual evapotranspiration up to 100 mm $year^{-1}$; an increasing LAI from 1 to 5 can increase the ETa values up to 85 mm $year^{-1}$. Additionally, an increasing slope of the drainage layer from 2–30% can reduce the annual leachate rate of about 25%.

The associated calibration study made it necessary to implement a lateral drainage layer instead of a vertical percolation layer in 0.4–0.7 m depth to take into account the basic concept of the landfill capping system due to anisotropic Ks values of the compacted layer (see Section 2.4).

The correlation coefficient (r^2) is an index of goodness of fit between the observed and modelled data according to [33].

3. Results

3.1. Vegetation growth of the Rastorf landfill

The recultivated layer of the temporary capped area is used as pasture with a grass and clover mixture of flat-rooted, densely growing, and perennial grasses. The seed mixture used in 2008/2009 was composed as follows: 20% perennial ryegrass (*Lolium perenne*), 20% cocksfoot (*Dactylis glomerata*), 21% red fescue (*Festuca rubra*), 21% sheep fescue (*Festuca ovina*), 10% meadow grass (*Poa pratensis*), 8% white clover (*Trifolium repens*), and a biannual mowing is carried out. Nowadays, the total coverage of the grass and clover mixture varies between 85 and 100% across the landfill surface (**Figure 3**).

The species composition is significantly different from the initial seed mixture after several years of growth: 70–80% cocksfoot (*Dactylis glomerata*), red and sheep fescue (*Festuca rubra, ovina*), and meadow grass (*Poa pratensis*), respectively (**Figure 3**).

The white clover (*Trifolium repens*) was characterised by an area fraction of about 5% and perennial ryegrass (*Lolium perenne*) with an area fraction of about 10%, predominantly on the areas (1000 m^2) subsequently secured in 2013 because of the reduced vegetation growth with locally available compost made out of tree and shrub cutting (**Figure 4**).

Figure 3. Vegetation growth of the Rastorf landfill between 2008 (left) and 2015 (right).

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Figure 4. Vegetation growth before (left) and after (right) compost application June 2013.

The landscape-ecological inventories and pedological excavations during 2013 and 2015 resulted in fine roots that were able to reach a maximum depth of 25–30 cm (flat rooting) and a weak to medium intensity (< 10 roots dm^{-2}), mainly along smaller hair or shrinkage cracks in the upper part of the recultivated layer (**Figure 4**). The subsequently secured areas showed deeper and pronounced rooting with depths of 35–40 cm (medium rooting) and a medium to strong intensity (11–20 roots dm^{-2}).

3.2. Weather data, vegetative period and leaf are index

The evapotranspiration parameters for the HELP model are summarised in **Table 2**. The average annual wind speed varied between 4.35 m s^{-1} in 2015 and 4.91 m s^{-1} in 2013 and the average relative humidity (%) between 70.6 and 87.3% in the spring and summer months and between 82.5 and 95.2% in the autumn and winter months (**Table 2**). Additionally, the maximum leaf area indices with values between 1.0 and 3.5 were chosen on the basis of average annual LAI measurements in March, May, and July and October, respectively.

3.3. Landfill design and soil physical parameters

The porosities of the boulder marl differ between 0.292 and 0.307 m^3 m^{-3} in the barrier soil layer and 0.317 and 0.356 m^3 m^{-3} in the drainage layer as well as the percolation layer. The FC values range between 0.175 and 0.213 m^3 m^{-3}, while the WP values varied between 0.117 and 0.167 m^3 m^{-3} (**Table 3**). The highest Ks values were identified in the drainage layer between

Year	2008	2009	2010	2011	2012	2013	2014	2015
Average annual wind speed (m s^{-1})	4.76	4.56	4.73	4.75	4.78	4.91	4.58	4.35
Evaporative zone depth (cm)	20	20	30	50	50	50	50	50
Maximum leaf area index (−)	1.0	2.0	2.0	3.5	3.5	3.5	3.5	3.5
Vegetative period (days)	262	345	219	231	230	220	266	255
Average relative humidity (%)								
1. Quarter	82.5	88.2	87.6	87.7	88.5	89.7	89.2	90.8
2. Quarter	70.6	71.2	77.5	73.8	78.1	79.7	80.8	79.0
3. Quarter	81.0	76.3	80.5	87.3	82.3	81.6	82.0	82.6
4. Quarter	91.1	89.4	93.1	93.9	94.6	92.8	95.2	93.5

Table 2. Input data for the HELP model: Evapotranspiration parameters (latitude 54.2°).

Study area and layer		Porosity	FC*	WP**	Ks	WC***	Slope length and gradient
		(m^3 m^{-3})	(m^3 m^{-3})	(m^3 m^{-3})	(m s^{-1})	(m^3 m^{-3})	(m)/(%)
I	Percolation layer	0.356	0.184	0.127	4.5E-06	0.212	62/12
	Drainage layer	0.317	0.206	0.136	5.6E-04	0.244	
	Barrier soil layer	0.292	0.175	0.121	3.7E-09	0.292	
II	Percolation layer	0.352	0.191	0.117	5.8E-06	0.259	44/28
	Drainage layer	0.327	0.213	0.147	6.3E-04	0.226	
	Barrier soil layer	0.302	0.196	0.143	6.1E-09	0.302	
III	Percolation layer	0.332	0.207	0.167	5.9E-06	0.215	52/30
	Drainage layer	0.325	0.196	0.139	5.8E-04	0.217	
	Barrier soil layer	0.307	0.213	0.149	3.6E-09	0.307	

Data of the three subcatchment areas (I–III), n = 7–10 undisturbed soil cores per layer for the average values of porosity, field capacity (FC), wilting point (WP) and saturated hydraulic conductivity (Ks), including initial water content (WC) and slope length and gradient.
*Field capacity (−33 kPa), **Wilting point, ***Water content at the beginning of the year 2012.

Table 3. Input data for the HELP model: landfill design and soil physical parameters.

5.6e-04 and 6.3e-04 m s^{-1}, lower values were determined in the percolation layer between 4.5e-06 and 5.9e-06 m s^{-1} and the barrier soil layer had values ≤6.1e-09 m s^{-1}.

3.4. Modelled water balance components of the Rastorf landfill between 2008 and 2015

In the study period between 2008 and 2015, the climatic water balance was positive (precipitation > evapotranspiration) and with regard to the German weather conditions, the outflow (2008–2010) and the actual evapotranspiration (2011–2015) were the greatest output values of the water balance (**Table 4**). The years 2012 and 2013 showed lower annual

Water balance [mm year^{-1}]	2008	2009	2010	2011	2012	2013	2014	2015
Precipitation	757	726	852	760	655	669	753	767
Potential evapotranspiration*	602	619	555	557	526	556	571	534
Actual evapotranspiration*	277	284	280	383	390	332	362	364
Outflow**	351	297	457	262	179	270	285	300
Δ soil moisture content	0	0.5	−0.5	1.5	0.2	−0.2	−0.3	−0.3
Leachate	149	137	116	103	84	70	109	105

*Including interception.
**Surface runoff and lateral drainage.

Table 4. Average annual water balance components for the period between 2008 and 2015.

precipitation rates with 655 and 669 mm, respectively, compared to the average annual precipitation rate of 728 mm. The winters of 2008–2015 were mostly mild and only had some snow.

The modelled average annual ETa values ranged between 33% in 2010 and 60% in 2012, and the outflow rates between 39% in 2009 and 54% in 2010 of the annual precipitation. The changes in soil moisture content with −0.3 and 1.5 mm year^{-1} were moderate and the modelled leachate rates ranged between 14 and 18% in 2008–2010, and between 11 and 15% in 2011–2015 of the annual precipitation (**Table 4**).

These drier phases are characterised by higher discrepancies between ETp and ETa up to 4.9 mm d^{-1}, especially in the warmer months between June and September (**Figure 5**). On the other side, the early warming phase during March to May showed moderate discrepancies of 0.6–2.7 mm d^{-1}, and the period October to February of the following year indicated mostly no discrepancies between the potential and actual evapotranspiration.

The ETa values ranged between 46 and 50%, and since 2011 between 60 and 69% of the ETp with the increasing depth of the evaporative zone (20, 30–50 cm) and the maximum leaf area

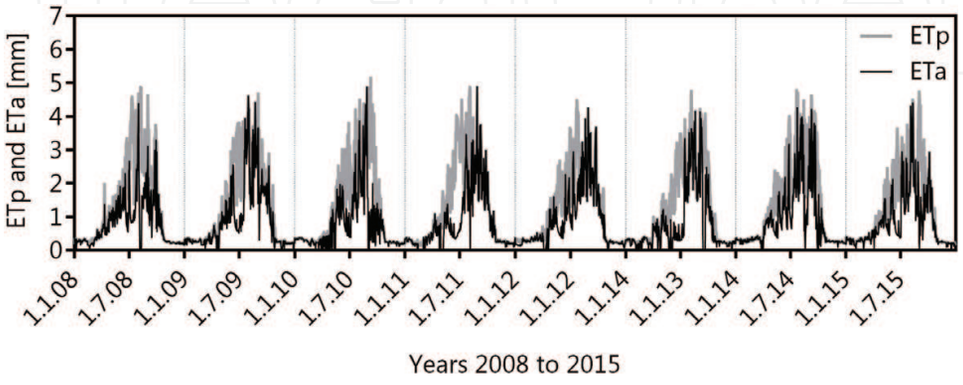

Figure 5. Average modelled potential and actual evapotranspiration rates (ETp, ETa) between 2008 and 2015 for the areas I–III.

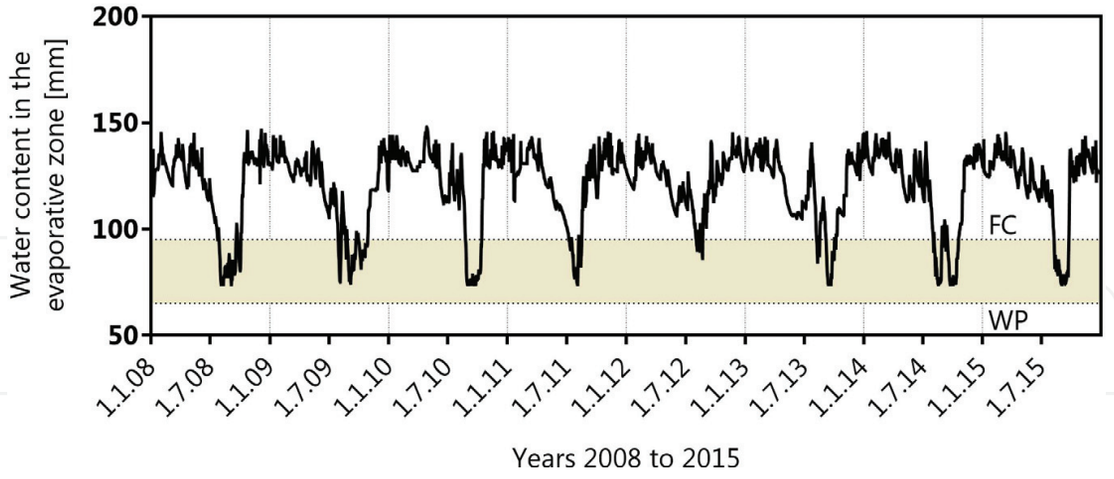

Figure 6. Average water content in the evaporative zone between 2008 and 2015 for the areas I–III. The dashed lines indicate the area between the HELP correlated field capacity (FC) and wilting point (WP).

indices (1, 2–3.5), respectively (**Figure 5**). The maximum depth complied with the part of the recultivation layer, in which the water content fluctuated intensely during the study period. The modelled water content in this evaporative zone appeared mostly above the field capacity of 95 mm, while longer phases during the vegetative period (July–September) nearly reached the wilting point of 65 mm, resulting in a decreased ETa capacity (**Figure 6**).

4. Discussion

The validity of the modelling results depends on the quality of the input data and related measurement methods that exhibit random errors depending on the site and weather conditions.

In this study, a weather station located close to the landfill recorded precipitation with a German Hellmann type gauge including wind-induced precipitation losses with an average underestimation of the actual annual precipitation of 10% [19]. Additionally, snow or rather snowmelt were no water balance factors during the study period between 2008 and 2015 under the weather conditions in Northern Germany.

The average annual actual evapotranspiration in Central Europe with an uncorrected precipitation rate of 700–800 mm (i.e., Rastorf landfill) is valued of approx. 450–550 mm for grassland vegetation with a good stand [34]. Therefore, the modelled annual ETa values, ranging between 277 and 390 mm are significantly lower than the mentioned ETa values for grassland vegetation. The modelled average annual ETa values ranged between 33 and 60% of the annual precipitation, but smaller than the ETa values of approx. Two-third of the annual precipitation in Hamburg (landfill Georgswerder) under approx. Comparable weather conditions as mentioned in [13]. The differences can be explained by the maximum leaf area index which strongly influences the evapotranspiration rate [3], while the HELP model assumed a constant LAI of 1, 2 or 3.5 for the whole year, respectively. On the other side, the daily average values of the wind speed do not reflect the actual wind conditions

of an entire day [21] and the evaporative capacity of the wind-exposed Rastorf landfill must also be regarded as underestimated.

Longer phases during the vegetative period (July–September) nearly reached the wilting point of 65 mm, so, the evaporative zone (0.5 m) dried out more strongly and the transpiration capacity and thereby the ETa values of the grassland were restricted by (a) the inadequate water availability in the evaporative zone and (b) the limited water storage capacity, and (c) the limited capillary rise from deeper soil layers due to the compacted construction of the temporary capping system [5, 6]. Thus, phases with water contents below the critical field capacity of 95 mm should be as short as possible to prevent desiccation in the deeper layer, thus, the modelled water content is a first indicator to describe the hydraulic stability of the capping system.

Tree species or shrub vegetation (i.e., *Salix caprea* and *Ligustrum vulgare*) have a higher transpiration potential with ETa values of 600–700 mm year^{-1} and are more effective than grassland to minimise the leachate generation of landfill capping systems [13]. However, more deep-rooted plants require thicker recultivation layers (2.0–3.0 m) to prevent shrinkage-induced crack formation in soil barriers due to desiccation and plant root penetration [9, 10]. Thus, the conflict of interest with regard to the choice of vegetation mainly depends on the local weather conditions, where robust grassland species should be preferred for locations with low precipitation [34], while more transpiring plant species are useful in more humid locations.

The modelled leachate rates were at a consistent level of 11–18% of the annual precipitation rate without significant deviations but exceeded the requirements of [2] at most 60 mm year^{-1} 5 years after construction at the latest.

Otherwise, the modelled leachate rates indicate a sufficient percolation of water into the waste body to support the microbial processes [4]; between 2008 and 2017, the settlements of the waste body decreased from >20 to <4 cm year^{-1}, so, the temporary system fulfils its purpose.

The slightly varying annual leachate rates indicate the functionality of the temporary capping system; continuously rising leachate rates would be an indicator for shrinkage crack formation or root penetration in the sealing layer [10], thus, the capping system would be ineffective. So, the hydraulic stability of the temporary capping system and especially the barrier soil layer can be assumed as ensured.

In summary, the water balance model is not suitable to estimate more specific soil physical problems (i.e., preferential flow through cracks or root holes) of recultivation or sealing layers [5]. For an approved process description due to the model limitations, the numerical-based FEFLOW could be a more precise two-dimensional process description of the water fluxes of the Rastorf landfill in the saturated and unsaturated soil [14].

5. Conclusion

The HELP model is one of the most commonly used statistical-empirical approaches and is an useful option to successfully determine the leachate quantity of landfill capping systems and to

proof which final capping system could be installed under the given weather and site conditions due to the statutory requirements.

The grassland vegetation of the Rastorf landfill changed in its plant-specific composition but is still effective to ensure moderate to high evapotranspiration rates and slope stability, while avoiding shrinkage-induced cracking and deeper rooting to protect the barrier soil or rather sealing layer. The future development depends on the intensity of wetting/drying cycles and further studies are required to improve the understanding of the long-term hydraulic stability of a mineral temporary capping system under climate change.

In order to finally proof the detailed water fluxes in structured landfill capping systems the more physically-based models will give more detailed insights into the variations in the soil water characteristics and the risk of crack formation in soil barriers due to desiccation and plant root penetration that may influence the functionality of it.

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Conflict of interest

The authors do not declare conflict of interest.

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References

[1] Hoornweg D, Bhada-Tata P. What a waste: A global review of solid waste management. In: Urban Development Series, Knowledge Papers (15). World Bank, Washington, DC; 2012

[2] DepV – Decree on landfills (Landfill Ordinance): Decree on landfill sites and long-term storage facilities in the form of the resolution of the Federal Cabinet dated April 27th 2009

[3] Hauser VL. Evapotranspiration Covers for Landfills and Waste Sites. Boca Raton, FL: CRC Press: Taylor & Francis; 2008

[4] Rowe RK. Systems engineering: The design and operation of municipal solid waste landfills to minimize contamination of groundwater. Geosynthetics International. 2011;**18**(6):391-404

[5] Widomski MK, Beck-Broichsitter S, Zink A, Fleige H, Horn R. Numerical modelling of water balance for temporary landfill cover in North Germany. Journal of Plant Nutrition and Soil Science. 2015;**178**(3):401-412

[6] Beck-Broichsitter S, Fleige H, Horn R. Compost quality and its function as a soil conditioner of recultivation layers – A critical review. International Agrophysics. 2018;**32**(1):11-18

[7] Arnold S, Schneider A, Doley D, Baumgartl T. The limited impact of vegetation on the water balance of mine waste cover systems in semiarid Australia. Ecohydrology. 2014;**8**(3): 355-367

[8] Horn R, Baumgartl T. Dynamic properties of soils. In: Warrick AW, editor. Hrsg Soil Physics Companion. Boca Raton, Florida: CRC Press LLC; 2002. pp. 17-48

[9] Horn R, Stępniewski W. Modification of mineral liner to improve its long-term stability. International Agrophysics. 2004;**18**:317-323

[10] Witt KJ, Zeh RM. Crack due desiccation in cover lining systems. Phenomena and design strategy. International Workshop Hydro-Physico-Mechanics of Landfills, Grenoble 21–22.03. 2005; 2005

[11] Beck-Broichsitter S, Fleige H, Horn R. Waste capping systems processes and consequences for the longterm impermeability. In: Levin M, Kim HJ, Morel JL, Burghardt W, Charzynski P, Shaw RK, editors. Soils within Cities-Catena Soil Sciences. Stuttgart, Germany; 2017. pp. 148-152

[12] Pantini S, James Law H, Verginelli I, Lombardi F. Predicting and Comparing Infiltration Rates through Various Landfill Cap Systems using Water-balance Models – A Case Study. In: Proceedings ISWA World Congress 2013. Dettagli; 2013

[13] Berger K. On the current state of the hydrologic evaluation of landfill performance (HELP) model. Waste Management. 2015;**38**:201-209

[14] Diersch HJG. FEFLOW, Finite Element Subsurface Flow and Transport Simulation System – User's Manual/Reference Manual/White Papers. Berlin, Germany: WASY Ltd, Release 5.0; 2002

[15] QGIS Development Team. QGIS Geographic Information System. Open Source Geospatial Foundation; 2009

[16] Peel MC, Finlayson BL, McMahon TA. Updated world map of the Köppen-Geiger climate classification. Hydrology and Earth System Sciences. 2007;**11**:1633-1644

[17] Hartge KH. Ein Haubenpermeameter zum schnellen Durchmessen zahlreicher Stechzylinderproben. Zeitschrift für Kulturtechnik und Flurbereinigung. 1966;**7**:155-163

[18] Hartge/Horn. In: Horton R, Horn R, Bachmann J, Peth S, editors. Essential Soil Physics, an Introduction to Soil Processes, Structure, and Mechanics. Stuttgart, Germany: Schweizerbart Science Publishers; 2016

[19] Berger K, Schroeder PR. The hydraulic evaluation of landfill performance model. Version HELP 3.95 D. Software and Electronic Documents as PDF: User's Guide. Supplement to the Engineering Documentation of HELP 3.07. Germany: Institute of Soil Science, University of Hamburg; 2013

[20] Berger K. Validation of the hydrological evaluation of landfill performance (HELP) model for simulating the water balance of cover systems. Environmental Geology. 2000;**39**(11): 1261-1274

[21] Allen GA, Pereira LS, Raes D, Smith M. Crop evapotranspiration-guidelines for computing crop water requirements. In: FAO Irrigation and Drainage Paper 56. Rome, Italy; 1998. pp. 78-86

[22] Schneider CA, Rasband WS, Eliceiri KW. NIH image to image J: 25 years of image analysis. Nature Methods. 2012;**9**(7):671-675

[23] Boden Ad-Hoc-AG. Bodenkundliche Kartieranleitung. 5. Auflage. Hannover, Germany: Bundesanstalt für Geowissenschaften und Rohstoffe in Zusammenarbeit mit den Staatlichen Geologischen Diensten; 2005

[24] Schroeder PR, Dozier TS, Zappi PA, McEnroe BM, Sjostrom JW, Peyton RL. The hydrologic evaluation of landfill performance (HELP) model: Engineering Documentation for Version 3. EPA/600/R-94/168a. Risk Reduction Engineering Laboratory. Cincinnati, Ohio, USA: US Environmental Protection Agency; 1994

[25] Ritchie JT. A model for predicting evaporation from a row crop with incomplete cover. Water Resources Research. 1972;**8**(5):1204-1213

[26] Penman HL. Vegetation and Hydrology, Technical Comment No. 53, Commonwealth Bureau of Soils. Harpenden, England; 1963

[27] Arnold JG, Williams JR, Nicks AD, Sammons NB. SWRRB, a Basin Scale Simulation Model for Soil and Water Resources Management. College Station: Texas A&M University Press; 1990

[28] Berger K. Potential and limitations of applying HELP model for surface covers. Practice Periodical of Hazardous, Toxic, and Radioactive Waste Management. ASCE. July 2002;**6**(3): 192-203

[29] Unger H, Skiba M. Solare Strahlung auf geneigte Flächen. Sonnenenergie. 1998;**1**(98):48-50. (in German)

[30] Brooks RH, Corey AT. Hydraulic properties of porous media. In: Hydrol. Paper 3. Fort Collins, CO, USA: Colorado State Univ.; 1964

[31] USDA, Soil Conservation Service. National Engineering Handbook, Section 4, 115 Hydrology. Washington, D.C.: US Government Printing Office; 1985

[32] Soulis KX, Valiantzas JD. SCS-CN parameter determination using rainfall-runoff data in heterogeneous watersheds - the two-CN system approach. Hydrology and Earth System Sciences. 2012;**16**:1001-1015

[33] R Development Core Team. R: A Language and Environment for Statistical Computing. Vienna, Austria: R Foundation for Statistical Computing; 2008

[34] GDA-Empfehlung E2–32. Gestaltung des Bewuchses auf Deponien. Published in January 2010. http://www.gdaonline.de [Accessed: February 22, 2018]. (in German)

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