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An easy-to-use tool for the evaluation of leachate production at landfill sites

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ABSTRACT

A simulation program for the evaluation of leachate generation at landfill sites is herein presented. The developed tool is based on a water balance model that accounts for all the key processes influencing leachate generation through analytical and empirical equations. After a short description of the tool, different simulations on four Italian landfill sites are shown. The obtained results revealed that when literature values were assumed for the unknown input parameters, the model provided a rough estimation of the leachate production measured in the field. In this case, indeed, the deviations between observed and predicted data appeared, in some cases, significant. Conversely, by performing a preliminary calibration for some of the unknown input parameters (e.g. initial moisture content of wastes, compression index), in nearly all cases the model performances significantly improved. These results although showed the potential capability of a water balance model to estimate the leachate production at landfill sites also highlighted the intrinsic limitation of a deterministic approach to accurately forecast the leachate production over time. Indeed, parameters such as the initial water content of incoming waste and the compression index, that have a great influence on the leachate production, may exhibit temporal variation due to seasonal changing of weather conditions (e.g. rainfall, air humidity) as well as to seasonal variability in the amount and type of specific waste fractions produced (e.g. yard waste, food, plastics) that make their prediction quite complicated. In this sense, we believe that a tool such as the one proposed in this work that requires a limited number of unknown parameters, can be easier handled to quantify the uncertainties.

1. Introduction

Landfills still remain the dominant municipal solid waste management practice in many parts of the world (El-Fadel et al., 1997a). Despite the evolution of landfill technology from uncontrolled open dumps to highly engineered facilities has progressively reduced the risks associated with landfills, waste landfilling may represent a potential source of adverse effects on the surrounding areas (Pantini et al., 2015a). Namely, the environmental impacts related to landfill sites are mainly due to the emission of strongly polluted leachate and potentially harmful gases, which may cause air, soil and groundwater pollution as well as global warming effects (Aronica et al., 2009; El-Fadel et al., 1997b; Mor et al., 2006a; Pantini et al., 2015b). In order to reduce the environmental loadings and to optimise landfill design and management is essential to assess and predict leachate and biogas production over time based on the site specific conditions (Westlake, 1997; Zacharof and Butler, 2004). Leachate quality and volume may strongly vary with local factors such as waste characteristics, landfill design, disposal method, climatic conditions, as well as several physical and biochemical processes such as liquid and gas movement, biochemical degradation and aging of wastes (Fellner and Brunner, 2010; São Mateus et al., 2012). These factors and processes influence each other and vary in space and time so that the evaluation of leachate production becomes more complex.

In the last decades several mathematical models have been developed. Among these, the Hydrologic Evaluation of Landfill Performance (HELP) model (Schroeder et al., 1994) is one of the most widely used tools for landfill design in the United States, even though in the last years several studies have pointed out a number of limitations and shortcomings (Berger, 2002; De Cortázar et al., 2003; Jang et al., 2002; Pantini et al., 2014; Yang et al., 2015). The HELP model has been designed to conduct water balance analyses of open, partially closed and fully closed landfills (Schroeder et al., 1994) but actually it does not allow to reproduce

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Nomenclature

$\%_{RBOF}$	percentage of RBOF in waste (M/M)
$\%_{SBOF}$	percentage of SBOF in waste (M/M)
ζ	biogas formation factor (-)
η	percentage of cracks in the geosynthetic sheet (L^2/L^2)
ρ_{H2O}	water density (M/L^3)
Cc	compression index (-)
CN	runoff curve number (-)
CS_{max}	waste retention capacity (L^3)
e	void ratio (-)
ET_0	potential evapotranspiration (L)
ET_r	actual evapotranspiration (L^3)
EZD_w	waste evaporative zone depth (L)
FC_w	waste field capacity (L^3/L^3)
FC_{w0}	initial waste field capacity (L^3/L^3)
K_c	hydraulic conductivity of clay (L/T)
K_g	hydraulic conductivity of geomembrane (L/T)
L	produced leachate (L^3)
L_{out}	leakage through the bottom liner (L^3)
MC	moisture content (L^3/L^3)
n	waste porosity (L^3/L^3)
n_{in}	initial waste porosity (L^3/L^3)
P	precipitation (L^3)
PM_{H2O}	molecular weight of water (M/N)
PM_{RBOF}	molecular weight of RBOF (M/N)
PM_{SBOF}	molecular weight of SBOF (M/N)
Q_{inf}	infiltration through cover soil (L^3/T)
Q_{lat}	incoming water in the drainage layer (L^3/T)
Q_{leak}	water flow passing through capping (L^3/T)
Q_{RBOF}	biogas flow by RBOF (L^3/T)
Q_{SBOF}	biogas flow by SBOF (L^3/T)
Q_u	outcoming water in the drainage layer (L^3/T)
R_g	universal gas constant ($L^2M/T^2N\theta$)
RO	runoff (L^3)
S_b	bottom area of the landfill (L^2)
s_c	clay thickness in the bottom liner (L)
T_L	temperature inside the landfill (θ)
$V_{gas,RBOF}$	volume of biogas by RBOF (L^3/M)
$V_{gas,RBOF}$	volume of biogas by SBOF (L^3/M)
V_m	dry waste material volume (L^3)
V_w	waste volume (L^3)
W_{bio}	biotic water consumption (L^3)
WP_w	waste wilting point (L^3/L^3)
W_{rel}	water released by waste (L^3)
W_{ret}	water retained by waste (L^3)
W_{vap}	vapour losses (L^3)
W_w	initial water content (L^3)
α_{RBOF}	stoichiometric water consumption of RBOF (N/N)
α_{SBOF}	stoichiometric water consumption of SBOF (N/N)
ΔC	reduction of the moisture content (L^3)
ΔH	water head on the bottom liner (L)
ΔU	change in moisture content (L^3)
ΔW	change in water volume (L^3)
σ_s	vertical stress on the layer k (F/L^2)

the progressive disposition of waste, the aging of materials and other important processes that affect leachate generation (e.g. water consumption due to waste biodegradation, waste compression and consolidation, change in waste physical-mechanical properties). Indeed, the HELP model assumes constant parameters and simulates the leachate transport and generation after all solid wastes are placed and stability conditions of refuse are reached. To overcome these limitations, in the last years, more detailed integrated models and simulation tools have been developed. Namely, these models account for several phenomena that have been tackled separately by previous models, such as water consumption due to biodegradation and biogas production, waste filling method and settlements effects (Oni and Okunade, 2009; Papadopoulou et al., 2007; São Mateus et al., 2012). For instance, the first attempts to evaluate the generation and transport of leachate using simplified water balance approaches have been developed by El-Fadel et al. (1997a), Korfiatis et al. (1984) and Straub and Lynch (1982). Later, Demirekler et al. (1999) introduced a three dimensional mathematical model to estimate the moisture and leachate distribution through the landfill profile, accounting for the variability of waste hydraulic conductivity with overburden pressure and time, depending on the landfill configuration. De Velásquez et al. (2003) proposed a model based on the Water Balance method, in order to evaluate the total leachate likely to be produced, introducing the interaction effects between wastes layers. Zacharof and Butler (2004) presented a mathematical model that simulates hydrological and biochemical processes, performing a parameter perturbation model sensitivity analysis; they found a high sensitivity to key parameters and a high uncertainty associated to input data. De Cortázar et al. (2002a,b) and De Cortázar and Monzón (2007) developed a landfill simulation program called MODUELO, one of the most complete tools for water balance modelling, which estimates the leachate flow and organic pollutants transport as a consequence of the water flowing through the waste and the degradation of organic matter in the landfill. Fellner and Brunner (2010) presented a mathematical model that pointed out the importance of the heterogeneity of the water flow within a landfill volume, due to the highly non-uniformity of waste mass and to the presence of preferential pathways. São Mateus et al. (2012) presented an attempt to model the water balance in a Brazilian MSW landfill, focusing on aspects such as the effects of the waste compression and the distinction of the stored water between free water and water retained by the waste. Very recently, Yang et al. (2015) proposed a leachate quantification method for MSW landfills in China highlighting the key role to leachate production resulting from the water squeezed out of the waste.

The above mentioned models differ in the underlying assumptions, the conditions at which they may be applied and the amount of data input requirements. Specifically, the more sophisticated models (e.g. Fellner and Brunner, 2010; De Cortázar and Monzón, 2007) account in details for the physical and biochemical complexity of a landfill system but they require significant amounts of data, most of them not easily available at landfill sites. This may lead to a winding calibration process without a clear improvement in simulation results when compared to field data (Zacharof and Butler, 2004). On the contrary, simplified approaches may fail to represent the key processes leading to less reliable leachate predictions (Zacharof and Butler, 2004). Therefore, it is necessary to find a good compromise between the need to limit data requirements and the need to represent all the fundamental processes occurring in landfills.

In this view, an improved version of the *Landfill Water Balance model* (Pantini et al., 2014) is introduced in this study. The model accounts for all the key processes influencing leachate generation, while keeping a simple analytical approach that requires a relatively limited amount of input data. With respect to the original model (Pantini et al., 2014), the improved version includes new and more detailed approaches for landfill volume discretization, different waste disposal methods, a new surface water balance for actual evapotranspiration and runoff and a weather generator.