

WATER BUDGETS AS A TOOL FOR LANDFILL OWNERS AND DECISION MAKERS

William Hogland¹

Lars Thörneby¹

Lennart Mathiasson²

Lennart Mårtensson³

¹*University of Kalmar, Sweden*

²*University of Lund, Sweden*

³*University of Kristianstad, Sweden*

ABSTRACT

According to the outcome of a United Nations conference in Johannesburg, 2002, many countries of the world are facing large water management challenges that require groundwater and surface water resources to be protected. Leachate from landfills and city dumps is a significant source of groundwater and surface water contamination. Local Environmental Protection Authorities have, during recent years, increased their requirements on the municipalities, the waste management companies and the industries that are running solid waste landfills. These requirements include having a good knowledge of and control over the water budget and the geohydrological position of the landfill area and its surroundings. In the case of new landfills, the demands are higher. According to the Waste Council Directive 1999/31/EC on landfilling of waste, the Member States should set up a national strategy for pollution reduction, water control and leachate management at landfill areas. A meteorological station should be located on site. In order to ensure a proper and optimized design of the facilities, it is of the highest importance to know the seasonal and short-time variations of the different terms of the water balance, from both a quantitative and a qualitative point of view. Water budgets for an entire area can give a picture of water conservation, water allocation priorities, groundwater and stream flow, pollution tracking and ecosystem requirements in the whole region around the landfill. These budgets can easily be made as hand calculations. In order to ensure adequate designs that are practical and economical, it is essential to have reliable and accurate design tools and models available to estimate the water balance components and to predict liquid movement into, through, and out of landfills of various designs. There are a number of models, such as HELP, PREFLO, MOBYDEC and FILL, available. However, this paper presents water budget calculations on various time bases that can easily be carried out by hand and by the landfill owner.

1 INTRODUCTION

The majority of the landfills in the world are badly located and must be considered to be a threat, from the environmental point of view, to the quality of air, land and waters. Air pollution caused by landfills is dominated by landfill gas emission, of which the methane component (rather than carbon dioxide) is the more serious due to its greater greenhouse effect, but landfill fires and open burning of solid waste are other sources of pollution. Litter can also be spread by the wind if the waste is not covered directly after tipping or it might drop from the garbage trucks during transportation if proper vehicles are not used. Water is affected when dumping is directly at riverbanks, in marshlands, or directly into the sea. Old landfills and dumpsites usually affect ground and surface waters because they have not been located with regard to geohydrological considerations, have not been properly equipped with final coverage, or are not constructed with a bottom liner and leachate collection systems.

In the European Union, a modern landfill should be constructed according to Waste Council Directive 1999/31/EC on landfilling of waste. The Member States should set up a national strategy for pollution reduction, water control and leachate management at the landfill area. A meteorological station should be located on site. In order to create proper and optimized design of the facilities, it is of highest importance to know the seasonal and short-time variations of the different terms of the water balance as well as the geohydrological situation, both from quantitative and qualitative point of view, at the landfill site and the areas where the local treatment systems will be or are constructed. By first order estimations and discussions with local environmental authorities, the seasonal and short-term variations of the different terms of the water balance situation, both quantitative and qualitative, can easily be estimated by hand. Even those landfill owners and waste management companies operating landfills that are following the EU-directive do not always consider the geohydrological situation in the area when designing leachate treatment systems and locate them offsite. In order to design proper and optimized facilities, it is of the highest importance to have detailed knowledge of the water situation in the area at different times. There are a variety of computer-based models such as HELP (Schroeder et al., 1994) PREFLO model (Ugocioni and Zeiss, 1997), MOBYDEC model (Guyonn et al., 1998), FILL that can be used for detailed modelling of the landfill site and its leachate treatments systems.

The General Assembly of the United Nations adopted its resolution 58/217 proclaiming an International Decade for Action, "Water for Life", 2005–2015, to commence on World Water Day, 22 March 2005. The goals will be focused on water-related issues *at all levels* and on implementation of programmes and projects and furtherance of cooperation at all levels. This is in order to emphasize the achievement of the internationally agreed water-related goals in the United Nations Millennium Declaration, in Agenda 21, and in the Johannesburg Plan of Implementation; the World Summit of Sustainable Development of August 2002. The goal is to halve, by the year 2015, the number of people who are unable to reach or to afford safe drinking water as well as the proportion of people without access to basic sanitation. Proper landfilling and leachate treatment can contribute significantly to the protection of surface and ground waters and reduce the degradation of world freshwater sources.

1.1 The water budget

The precipitation falling on the landfill or leachate treatment system as rain, snow or hail either runs off the ground surface, is taken up by the vegetation or, if the landfill is not covered, is absorbed into the waste. If the landfill is not properly covered, part of the precipitation that infiltrates into the landfill percolates further through the waste and generates leachate. The leachate might reach the groundwater table or surface water near by if it is not collected and treated. Evapotranspiration is usually calculated with Thornthwaite's or Penman's equation. Measurements on site with different types of evaporations pans, evapotranspirometers or lysimeters are also possible. Evaporation depends on the ambient temperature, wind speed, differences in vapour pressure between surfaces where evaporation takes place, and the air pressure. These parameters should be measured locally since they vary with the local climatic conditions. Estimations of runoff in the form of stormwater (Marques and Hogland, 2003b) and/or leachate can be made by means of direct measurements in the field or by theoretical calculations. Stormwater at landfill sites is generated at waste sorting areas and roads. A greater amount is produced at modern landfill sites and it must be handled properly. Peak runoff flows can be estimated by the rational method and the degree-day method can be used to estimate snow melt. The daily leachate generation at the landfill site can be estimated either by the mean of the inflow and outflow according to calculations obtained with the water balance method or by using the values observed by field measurements. The delay of the runoff is, of course, always best observed by inflow and outflow control. A test area can be established on the landfill site or offsite at the local leachate treatment site. On the basis of the values for leachate production measured in the test area, or possibly from another landfill site with similar conditions, the volume of leachate from the landfill can be estimated empirically.

The water balance in its simplest form is described as:

$$L_v = P - ET_L - R_o - \Delta S \quad (1)$$

where ΔS is zero when calculated for the hydrological year.

In a more detailed form the water balance can be written as:

$$P + R_{IN} + G_{IN} + W_{IN} = ET_L + L_R + L_G + L_S + R_o + \Delta S + \Delta W + \Delta B + \Delta S_n \quad (2)$$

where P is precipitation, R_{IN} is the inflow of surface water, G_{IN} is the inflow of groundwater, W_i is water contained within the waste, ET_L is water removal by evaporation and transpiration (ET), L_v is leachate generated after installation of a final cover (e.g., $L_R + L_G$), L_R is collected leachate, L_G is leakage of leachate to groundwater, L_S is collected stormwater from roads and sorting areas, R_o is outflow of surface water; ΔS is the change in storage of water in cover soil, ΔW is change in storage of water in the waste, ΔB is change in metabolic water (bacterial production and consumption), and ΔS_n

is snow storage. In Figure 2, a rough water budget calculation is given on an annual basis for the Moskogen landfill, located in the south-eastern part of Sweden.

1.2 The Moskogen landfill

The Moskogen landfill is located in the Ljungby River catchment, which is a typical small river basin system for this part of Sweden. The landfill receives 40,000 tonnes of solid waste annually from three communities, with a total population of 90,000, although the municipality of Kalmar is the predominant source of waste. The annual precipitation in the area varies between 296–782 mm, with a 30-year average of 470 mm (Normal 1931–60, SMHI), there are 93 days per annum with precipitation higher than 1 mm and the average temperature is 6.8 °C. The drained landfill area is in total 29 ha, of which 22 ha is under preliminary cover and 7 ha is in operation. Annually, about 150,000 m³ leachate is produced, of which almost 85,000 m³ is groundwater inflow via the north-western part of the landfill. Before 1998, the production of leachate was 100,000 m³/yr, which was treated in a plant system (SP) in combination with three ponds of size 1.5 ha (volume 30,000 m³), 2.7 ha (volume 45,000 m³) and 2.6 ha (volume 50,000 m³) respectively. Former agricultural land located outside the south-eastern corner of the landfill is planted with willow (*Salix* spp.), 10 ha in total. A part (4 ha) of the old landfill is planted with energy grass (*Phalaris arundinacea*), which is irrigated with leachate. However, about 70,000 m³ of the leachate is still pumped to the wastewater treatment plant in the city of Kalmar.

The evaporation from the ponds and the irrigation onto the landfill site (energy grass area) has been estimated to about 60,000 m³ per annum. An amount of 50,000 m³–100,000 m³ goes to the area with *Salix* forest (the *Salix* area). The collected drain water from the *Salix* area is about 100,000 m³ of which 70,000 m³ goes to the municipal wastewater treatment plant in Kalmar and the rest, 30,000 m³ is pumped back to pond D2 (see Figure 1). Irrigation of energy forest or land surfaces increases the possibility of natural evaporation. When an area of the landfill is irrigated, the water balance will change. The evapotranspiration will then be close to or above the potential evapotranspiration and thus it is possible to use the difference between precipitation and evapotranspiration for water removal during the period April–September in southern Sweden.

“How clean is clean” is the question that is raised about the water that leaves the drainage pipe underneath the *Salix* plantation. Some assert that, once the water is classified as leachate, it keeps its label even after advanced treatment has produced a quality close to drinking water standards for most parameters. Is it then possible to discharge such water in an environmentally acceptable way outside the landfill? One option at the Moskogen landfill could be to discharge the drainage from the irrigation area into the Tomtebybäcken, a rivulet (grass covered ditch) that, after about 7 km, joins the Ljungby River 1.5 km east of the village Ljungbyholm. In Figure 1, a preliminary water balance for the landfill and the treatment system is given. In the calculation it is assumed that 8,000 m³ of water is absorbed by the incoming waste before reaching field capacity. Water flows in the filling phase of a landfill has been studied by Marques and Hogland (2003a).

KALMAR ECO-TECH '03
 Bioremediation and Leachate Treatment
 KALMAR, SWEDEN, November 25-27, 2003

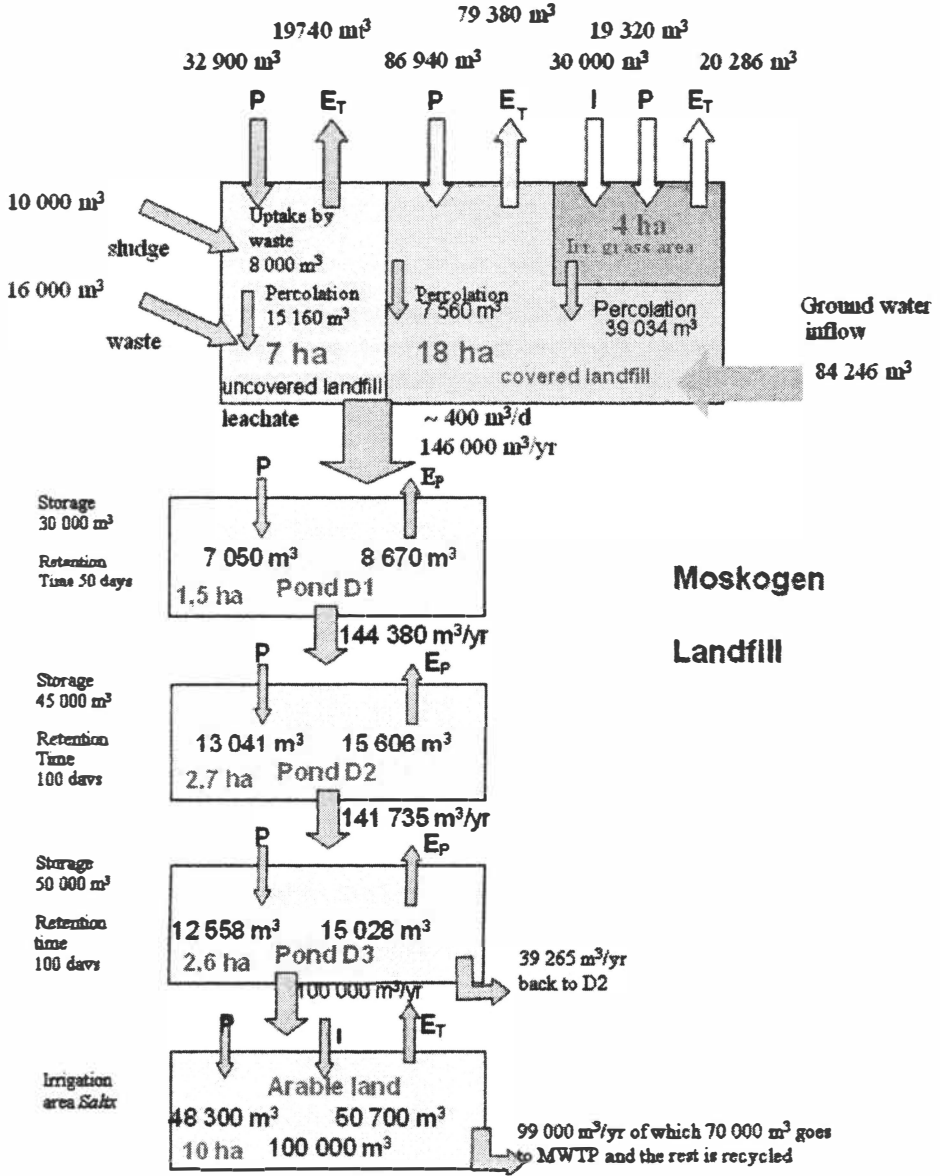


Figure 1. Preliminary water budget for the Moskogen landfill, Sweden (Hogland et al., 2003)

Figure 1. Preliminary water budget for the Moskogen landfill, Sweden (Hogland et al., 2003)

Similar water budgets can be constructed for each month of the year, single weeks and for special rainfall events or snow melts. The water budgets are established for the winter month of December, when no irrigation occurs, evapotranspiration is very low and the groundwater table is close to its maximum level. It has been found that at this time, about 4,800 m³ of precipitation falls over the energy grass and the Salix area together, about 1500 m³ is transpired by vegetation, and the ponds are filling up because of groundwater inflow and leachate production. During the summer month of August, the precipitation over the two irrigation areas is about 8,000 m³, irrigation 22,000 m³ and evapotranspiration 11,000 m³ and the water levels in the ponds are decreasing. It can be seen that the irrigation areas are over-irrigated, indeed, flooded, which results in flushing of the soil underneath the energy grass and the Salix, and this might flush out pollutants. The estimated groundwater inflow during August is considerable and should be controlled by real measurements. A test area constructed similarly to the irrigation areas and equipped with proper bottom liner could give more correct values of the different parts of the water budgets than these rough theoretical calculations and thus better seasonal values of the groundwater inflows.

2 DISCUSSION

Landfill owners must have better control today over their landfill than in earlier days. This stands for the material flow into the landfill, transport of chemical substances at the landfill site and its associated unit operations, as well as a water balance for the landfill and its local treatment system. There must be improved contacts between the landfill owner and the decision-maker. Local environmental protection authorities demand good knowledge/control of the water balance of the landfill from both a quantitative and qualitative point view. This makes it necessary to have detailed knowledge of the geohydrological circumstances of the site and its surroundings. A meteorological station should be located on the landfill site, as recommended in Waste Council Directive 199/31/EC on landfilling of waste, in order to get good control on the water balance. A hydro meteorological gauging system should continuously produce data during the construction, operation and post-operation care phases. Water budgets should be calculated on a weekly basis and summarized to monthly and annual values. The system should also be able to analyse extreme rainfall events of short duration, such as convective rainfall events.

The water budget calculation is considered a simple tool for use in communication with the authorities and the decision-makers. It gives good information about design and redesign, as well as measures to avoid unnecessary groundwater inflow to the landfill and the leachate treatment system. Groundwater and surface water inflows can be reduced by the construction of ditches and trenches or the construction of pumping wells to lower the groundwater table and protect the landfill from runoff. The groundwater inflow is a significant part of the water balance at old landfill sites and this unnecessary pollution of clean ground water (on mixing with landfill leachate) can be avoided by a cut trench or

by pumping. The evaporation from the working face at the landfill and the waste might be hard to estimate because of the difference in water holding capacity between different wastes. It can be assumed that a major part of the precipitation falling over the working faces evaporates from April to the end of September in southern Sweden.

During the last few decades, the modern landfill sites in Europe have transformed from city dumps via sanitary landfills to industrial waste management parks. Recycling and demolition areas are often located at the modern landfill. This has generated new environmental problems from stormwater and emissions to the air. Stormwater runoff from these areas, as well as from primary and secondary roads might be a significant pollutant source, and the runoff cannot be discharged directly to natural waters. This water must be collected and treated, not led directly to receiving waters or infiltrated directly into the ground outside the landfill area. The amount of leachate and stormwater produced at the landfill is largely related to the local climate and geohydrological conditions, but is also affected by the design and location of the landfill and the degree of compaction and composition of the waste. The design of the landfill must follow the EU-waste directive.

3 ACKNOWLEDGEMENTS

The Waste Management Companies AB ASSY, KRAB, Kalmar Vatten och Renhållning AB and the Knowledge Foundation, the Kalmar Research and Development Foundation – Granging Foundation are acknowledged for their sponsorship of the project.

4 REFERENCES

- [1] Bengtsson, L., Bendz, D., Hogland, W.; Rosquist, H., Åkesson, Å., (1994) Water balances for landfills of different age. *Journal of Hydrology*, No 58. pp 203–214.
DOI: [https://doi.org/10.1016/0022-1694\(94\)90054-X](https://doi.org/10.1016/0022-1694(94)90054-X)
- [2] Blight, G.E., Ball, J.M., Blight, J.J., (1991) Moisture distribution in sanitary landfills. *In Proceedings of Sardinia Third International Landfill Symposium*, Sardinia, Italy.
- [3] Campbell, D.J.V., (1983) Understanding water balances in landfills. *Waste Management (UK)*, November.
- [4] Falk, J., Gottschalk, L., Hellström, T., Hogland, W., Krasovskaia, I., Niemczynowicz, J. (1983) *Hydrologiska undersökningar i Värpinge* (Hydrological studies in Värpinge, Sweden), Report 3076, Department of Water Resources Engineering, University of Lund (In Swedish), p. 120.
- [5] Guyonnet, D., Didier-Guelorget, B., Provost, G., Feuillet, C., (1998). Accounting for water storage effects in landfill leachate modelling. *Waste Management and Research* 16(3):285-295. DOI: <https://doi.org/10.1177/0734242X9801600310>
- [6] Hogland, W., Thörneby, L. Mathiasson, L., 2003 Water Budget for Landfill Leachate Treatment Systems. In: *Proceedings of Sardinia 2003 – the Ninth International Conference on the Waste Management and Landfill Symposium*, S. Margherita di Pula (Cagliari), Sardinia, Italy, 6–10 October, 2003. (CD)

- [7] Holmes, R., (1980) The water balance method for estimating leachate production from landfill site. *Solid Wastes (UK)*.
- [8] Marques, M., Hogland, W., (2003a) Hydrological performance of incineration residues co-disposed with other special waste and MSW co-disposed with sludge in full-scale landfill cells. *Waste Management*, Elsevier Science Ltd. (in Press), p. 13.
- [9] Marques, M., Hogland, W., (2003b) Stormwater runoff and pollutant transport related to the activities carried out in a modern waste management park. *Waste Management & Research* (in press), p. 21.
- [9] Thörneby, L., (2001 a) Water budgets for natural systems. *In proceedings of Kalmar ECO-TECH'01 – Leachate and waste water treatment with high-tech and natural systems*. The 3rd international conference on establishment of cooperation between companies/institutions in the Nordic Countries and the Countries in the Baltic Sea Region, November 26 to 28, Kalmar, Sweden, Hogland, W. and Vysniauskaite, V. (eds), pp. 99–107.
- [10] Thörneby, L., (2001 b) *Treatment of waste waters with emphasis on reverse osmosis and wetlands*. PhD. Thesis, Department of Analytical Chemistry, Lund University, Sweden/Department of Technology, University of Kalmar, Sweden, p. 186.
- [11] Uguccioni, M., Zeis, C., 1997. C. 1997. Comparison of two approaches to modelling moisture movement through municipal solid waste. *Journal of Environmental Systems* 25 (!): 41-63.