Lund University International Master's Programme in Environmental Science (LUMES)

REQUIREMENTS FOR THE CLOSURE OF OLD LANDFILLS – TOWARDS SUSTAINABLE LANDFILLING IN ESTONIA

MASTER'S THESIS

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SUMMARY

Today many municipal solid waste landfills have reached their filling capacity in Estonia. Two possible methods, leachate recirculation and impermeable cover system can be used for final closure of landfills. There are many factors affecting the closure of landfills, however, the most important in Estonia are if they have proper bottom sealing or not. The evaluation of these two methods for final closure of the landfill shows that the impermeable cover system approach is preferable in most cases in Estonian landfills due to the lack of proper bottom sealing. The impermeable cover system minimises the leachate generation and decreases endanger of groundwater contamination. In addition, uncontrolled escape of landfill gas, as the another environmental impact, will be reduced. The locally available materials are recommended to be used for cover system to reduce costs. Second alternative approach, leachate recirculation technique, is more effective and environmentally friendly and make basic for future sustainable landfill management. By economical reasons, it's likely that Estonia cannot fulfil the EU Directive and Natural Environmental Strategy during the next decade, especially for the closure of all old landfills to optimise the number of MSW landfill sites up to 150. For the future in Estonia the priority number one is a safe waste management strategy that has to be created and prioritise the measures at old landfill sites that have environmental problems. Apart from that the general public environmental education and education programmes for engineers have a great importance, which are considered in this work.

1. INTRODUCTION

The most commonly used method of waste management in the world, as well as in Estonia, has been and still is the deposition of waste in landfills. In the world up to 95% and in Estonia 100% of solid waste generated is currently disposed of in landfills (Bingemer & Crutzen, 1987; El-Fadel et al, 1997; SOE, 2000). From the 40s to 90s, the history of waste generation and landfilling in Estonia clearly reflects that the political system has valued only industrial development and economic growth. During this period the majority of larger industrial enterprises, agricultural farms and municipalities took the liberty to establish their own landfill site on the land, which was not used for agriculture or forestry, without any geological-hydrological investigations (Teder, 1997). Consequences of these policies reverberate in the fact that there are more than 500 landfills in Estonia today (Toomel, 1997a).

One of the main environmental pressures from landfilling of waste is surface and groundwater pollution with toxic substances and nutrient leaching from the waste (EEA, 1999). Any liquids that percolate through the landfilled waste and that is emitted from a landfill is called leachate (EU, 1999). The pollutant load to groundwater is dependent on the quantity and the quality of leachate, which reaches in groundwater aquifer (Bengtsson et al., 1994). The quality of the leachate depends on the waste composition and on the biological, chemical and hydraulically state of the landfill (El-Fadel et al., 1995). In fact, inorganic salts, heavy metals, non-degradable organic matter associated with leachate from municipal solid waste (MSW) landfills has shown to cause serious impacts on the environment (Lee and Jones-Lee, 1993). Moreover, the MSW leachate may also consist of unidentified, unregulated non-conventional pollutants. Therefore a small amount of MSW leachate may pollute very large amounts of groundwater, rendering them unusable for domestic water supply purposes (Lee and Jones-Lee, 1993). Once groundwater is contaminated, it is extremely expensive, difficult, and sometimes impossible to clean it up. Since, the major part of Estonia's inhabitants obtains portable water from groundwater aquifers, all possibilities to avoid or minimise groundwater pollution should be considered in the landfilling process.

Many of today's landfills, which were created in the 70s without protection measures, have reached their filling capacity and now they have to be closed down. Most of the water entries to the landfill body by precipitation (Jesonek et al., 1995; Hogland, 1997). One solution to this problem is the minimisation of water infiltration and the generation of leachate by covering landfills with impermeable cover (Jesonek et al., 1995; Zischak, 1997; EC, 1999; Hoins, 1999; Kämpf et al., 1999). Moreover, this cover will prevent the escape of gas from the disposal site (Kämpf and Montenegro, 1997).

The concept "sustainability" was introduced in Rio de Janeiro Conference in 1992 and after that has been received world-wide acceptance. Generally speaking, Estonian future development has to be more sustainable and economic growth must be carried out without causing damage on environment. For example, the Ministry of Environment, intend to establish similar waste management policy and regulations as the EU and are working towards sustainability. However, many legislation acts are not effective enough due to lack of adequate implementation and enforcement mechanisms.

According to the World Commission on environment and Development, sustainable development is "development that meets the needs of the present without compromising the ability of future generations to

meet their own needs". Applied to waste disposal policy it means that the waste stabilisation should be achieved within one generation (Marques, 1996).

Studies by Toomel (2000b) and Lee and Jones-Lee (1994) show that the building of so-called "Dry tomb" landfill means to postpone the problems to the next generations. Therefore, the leachate should instead be returned back into the landfills. This approach reduces the cost of leachate treatment and accelerates the stabilisation of the landfill and increase landfill gas production. Moreover this technique reduces the potential for long-term landfill gas production and groundwater pollution (Lee and Jones-Lee, 1994a,b; Lee and Jones-Lee, 1996; Lee and Jones-Lee, 1997; Toomel, 1997b; Jones-Lee and Lee, 2000).

1.1 OBJECTIVES

The overall objective of this paper is to find solutions for minimising the environmental impacts of landfilling and especially the groundwater contamination in Estonia. Two alternatives in effectively closing these landfills are analysed in this work. The first approach is to minimise the leachate generation by covering landfills with impermeable cover system, as it suggested by the EU Directives on landfilling of waste (EC, 1999). Secondly, leachate recirculation system in landfills, which is covered with permeable cover system. This approach increases the stabilisation of landfills (Toomel, 1997b, 2000; Lee and Jones-Lee, 1994a). The appropriateness and the implications in applying these alternatives to Estonian conditions are also discussed. Education aspects and common awareness of landfill issues as well economics are penetrated.

1.2 SCOPE OF THE STUDY

The closure of landfill sites is a broad topic and therefore it is impossible to investigate all aspects. However, the chosen landfill closure methods must ensure minimisation of groundwater contamination and limit environmental impacts. In order to use the limited resources and time properly in the closure process, the main factors, which influence landfill site closure and improvement of landfilling quality in general, has to be discussed. This work deals only with municipal solid waste landfilling and not animal carcasses disposal and industrial, hazardous waste landfilling. The technical aspects of installation of landfill closure method are not included in this work.

In order to understand the needs of this research, a brief introduction to the landfilling situation in Estonia and overview of the Estonian legislation regarding landfill management are presented. Economic, social, and educational aspects related to settling a proper final cover system on landfills and recirculation of leachate issue are covered, but without going deep into the details, thus it is not the main issue of this paper. Because landfill gas issue is an important component in this topic, it has also included in some parts of this paper, but more attention has been put on the landfill closure as minimising leachate generation aspect.

1.3 HYPOTHESIS

The hypothesis of this work are as follows

- A recirculation of leachate is a better approach for old landfill closure in Estonia than the "dry tomb" method.
- Locally available materials are suitable for landfill cover system.
- Estonia is not ready to fulfil the EU Directive (EC, 1999) on landfilling of waste.

1.4 MATERIALS AND METHOD

Much of the data on landfilling in Estonia was made and provided by Toomel (1997a,b) in the research projects for the Estonian Landfill Register and Pärnu landfill were used. Also data from Statistical Office of Estonia (SOE) has been utilised. Unfortunately, in many cases, specific data about arranged landfill projects in Estonia were unavailable.

Furthermore, to help understand the system, the causal loop diagram (CLD) has been used as a tool of system thinking, which assists to structure and conceptualise this problem. By drawing mental model the behaviour of problem and feedback in our problem can be predicted.

1.5 OUTLOOK OF THESIS

Apart from introduction and conclusions, the thesis consists of six main chapters, each of them deal with different aspects for further closure of landfills in Estonia. By the help of causal-loop diagram, which is presented in chapter 2, the most important factors that influence landfilling quality system is gathered. Theoretical aspects of landfill management techniques are presented in chapter 3. There are shown the main variables, which cause leachate and gas generation. Two different approaches, impermeable cover system and leachate recirculation method, have been introduced to minimise groundwater contamination. Before the theoretical suggestion can be implemented the current situation of Estonian landfill sites has to be observed. Chapter 4 makes the overview. Chapter 5 analyses and compares the possible closure options under Estonian conditions. Implementation aspects are presented and the most suitable way to minimise groundwater pollution is discussed in chapter 6. Apart from current situation a glance as taken at future and perspectives are presented in chapter 7. Recommendations for future work and research are pointed out in last chapter.

2. CAUSAL-LOOP DIAGRAM ABOUT LANDFILL QUALITY

The landfills in Estonia have been established without environmental protection measures, therefore the quality of landfills is at a very low level today. The proper closure of landfills can be seen as a significant contribution in improving the overall quality of landfills, in order to minimise the environmental impacts. The factors which influence the closure of landfills and landfill quality in Estonia is shown in causal-loop diagram[1] (Fig. 1). The social, education and economic aspects are also included in this system to indicate

[1] Causal-loop diagrams (CLD), a tool of system thinking that can be described as process thinking, understanding cause and effect between different components within a defined system. System behaves in a circular organisation forming feedback loops. Therefore, the effects of the last element influence the input of the first element, which results in a self-regulation of the whole system. Regulation of a system can either result as a self-reinforcing (R) system or a self-

how these aspects are connected with each other. The centre balancing loop indicates that low quality of landfill increases potential danger to groundwater contamination due to leaked leachate and more financial sources has to spend to overcome the problem. Thus increasing the investments for avoiding the groundwater pollution (e.g. by minimising the leachate generation with proper cover system), the quality of landfills is enhanced. Furthermore figure 1 suggests that increases in groundwater pollution may stimulate further research, thus providing more knowledge to operators, which indirectly reduces pollution by increasing the quality of landfills. Additionally, training programmes have an important role to play. From increased research, operators obtain greater knowledge and participate more effectively in environmental projects and contribute to the formulation of better legislation by affecting politicians to improve environmental legislation. Also EU recommendations provides a stimulant to improving legislation for landfills in Estonia.

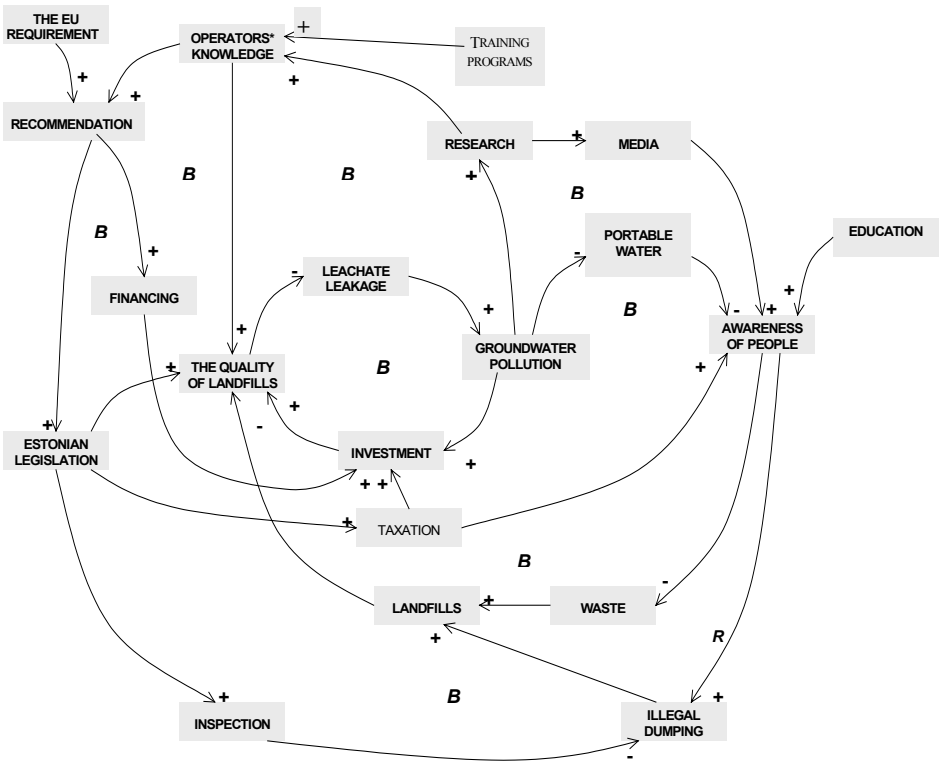

Figure 1. *The causal-loop diagram illustrating the relation of landfill quality with society*

To increase the quality in landfills investments obviously have to be made. The financial resources may come from environmental taxes and financing by foundations, projects etc. If the price charged for the disposal of waste will increase, then this will lead to a decrease in waste generation. This reduces the number

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balancing system (B). The arrows show causes and effects in the system. The signs (+) and (-) in near the arrowhead show how the system responds to changes. For instance, the + sign near the arrowhead indicates that the item at the tail of the arrow and the item at the head of the arrow changes in the same direction. If the tail increases the head decreases, if the tail decreases, the head decreases. The sign (-) indicates that the items changes opposite direction (if the tail increases, the head decreases and vice versa). (Haraldsson, 2000)

and size of landfills, and if there are less landfills to be taken care of, then there are more possibility to concentrate to improvements of landfill quality. A factor that may inhibit the development of more environmentally safe landfills stems from the presence of illegal dumping. If the price charged for the disposal of waste increase then people might prefer illegal dumping instead of decreasing the generation of amount of waste and number of dumpsite will increase. A means to reduce illegal dumping is through the use of legislative control. Another possibility is to increase the people's awareness. Media and education provide a means in increasing this awareness, however local awareness may stem from a decrease in the quality and availability of portable water within local communities. In this causal-loop diagram quantitative and qualitative impacts can be noticed. To ensure increase in landfill quality knowledge and information has to be available but also be credible and of high quality. Likewise, the quality of environmental legislation in Estonia influences quality in inspection and taxation.

3. LANDFILL MANAGEMENT TECHNIQUES

Currently there is an international debate between scientists about the relative benefits of "dry tomb" landfill technique compared to a leachate recirculation technique. A leachate recirculation technique involves controlling the amount of water infiltrating through the landfill in order to accelerate the decomposition of waste (Lee and Jones-Lee, 1994ab; Pacey et al., 1999; Hull, 2000). Alternatively, the "Dry tomb" concept requires a landfill to be completely sealed to prevent the interaction between waste and groundwater and thus reducing water pollution (Lee and Jones-Lee, 1996). In order to analyse the benefits and drawbacks of each approach, an overview of the process involved are discussed in the following chapters.

3.1 HYDROLOGY OF LANDFILLS

In order to design landfills and to manage leachate discharges, it is necessary to have control over the water balance of the landfill. There are several methods and models of leachate production calculation available in literature (see Hogland, 1997; Saarela, 1997; Marques, 2000). Such work provides an estimation of landfill leachate production through the use of simple formulas that take into account only the main factors, e.g. water balance method as it has been represented by Hogland, 1997. Other models, such as the Hydrologic Evaluation of Landfill Performance (HELP; Schroeder et al., 1984) and the Hydrologic Simulation of Solid Waste Disposal Sites (HSSWDS; Perrier and Gibson, 1981) are more detailed, aiming to account for the greater complexity within the system. The general hydrology of the landfills and water balance factors are further discussed below according to Blight (1995), Hogland (1997) and Bengtsson, (1997).

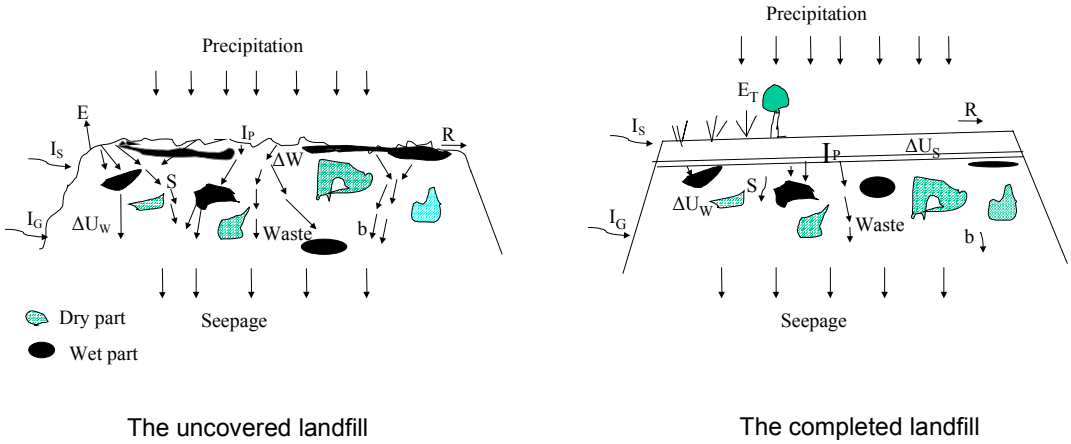
3.1.1 Water balance factors

According to Blight (1995), the water balance for a landfill can be stated as follows:

$$\text{Water input to landfill} = \text{water output} + \text{water retained in refuse body} \qquad (1)$$

The infiltration of precipitation (I_P) is usually the main factor deciding the most part of the water input to the landfill (Fig. 2). However, the moisture content of incoming waste (S) and groundwater (I_G) or surface water

inflow (I_S) into the landfill, water produced during decomposition (b) are the other ways, which also influence the general water content of the landfill. Water output includes evaporation (E) or evapotranspiration (E_T), the water lost in leachate seepage or removed from landfill (L) and overland water runoff (R). The water can retain by waste (ΔU_W) and the upper layer of waste (ΔW) on uncovered landfills and by the cover materials (ΔU_S).



The uncovered landfill

The completed landfill

Figure 2. *The general hydrological balance in uncovered and completed landfills (redrawn according to Bengtsson, 1993; Blight, 1995; Hogland, 1997)*

All these water balance factors are explained in greater detail in following sub-sectors.

3.1.2 Water input into the landfill

Precipitation

The amount of water infiltrating the landfill usually depends on a dominating part on precipitation, which is influenced by climatic conditions, the rainfall intensity and frequency. Additionally, the snowmelt in the spring should be taken into account. The average annual precipitation data can be obtained from the nearest meteorological station. The total surface area of the landfill site is important as well, as the uptake area of the water. This data that is available at statistic databases is necessary for further research of final cover for landfill.

The infiltration of precipitation (I_P) in a landfill site refers to the immediate water penetration into the waste's surface layer for uncovered landfill and for capping materials in terminated landfills. Quality, type and quantity (depth of different layers) of the final cover materials affects infiltration particularly. In addition, the infiltration capacity depends on the composition of waste and how well it has been compacted. There is always water, which has been absorbed and retained by the upper layer of waste (ΔW) on uncovered landfills and by the cover materials (ΔU_S).

The water content of incoming waste

The water content of incoming waste can differ essentially. This depends on the type of waste, the pre-treatment of waste and the seasonal timing of transportation and if the waste containers are covered or not.

As is pointed out by Hogland (1997) household waste arriving at a landfill site can have average moisture content of 5% during dry periods in a warm climate and about 65% during periods with rainfall.

Inflow of surface and groundwater

Additionally, inflow of groundwater (I_G) and run-on of surface water (I_S) occurs from the surrounding land to the landfill sites. Flooding from river overflow or through coastal storm surges can also increase the water content in landfill. These problems could be avoided through the use of dams, embankments or ditches.

Water is also generated during the decomposition process (b), however, compared with other water inflow it is negligible.

3.1.3 Water leaving the landfill

Overland water runoff

Some of the precipitation may be transformed as overland water runoff (R) thus not infiltrating the landfill. R is defined as the remaining amount of water after all other losses are subtracted, such as interception from vegetation, the formation of water pools, wetting of the top surface, evaporation and infiltration. The magnitude of the loss also depends on the final covering of the landfill site: which materials have been used, and how and which kind of the vegetation has been established.

Evapotranspiration

Additional water losses from landfills will occur from evapotranspiration (E_T). Evapotranspiration from landfill includes evaporation directly from the waste (E), from the covering soil, and transpiration from the established vegetation. Evapotranspiration can vary considerably between the landfills, which are completed (covered and closed), and a landfill sites where the waste is exposed. Generally, evapotranspiration depend on climate and season, thickness and material of the cover (moisture content of cover) and if there are vegetation on the landfill or not. Obviously, the less precipitation and the higher evapotranspiration the less potential for generation of leachate.

3.1.4 Storage capacity of waste

There is water absorbed and retained by the waste (ΔU_W). The field capacity is given as a ratio (as a percentage) between the retained volume of water and the weight of the completely dry waste (Hogland, 1997). As decomposition and compaction of refuse occurs in a landfill, the field capacity will progressively decrease from its initial value at the time of deposition. Moreover, the theoretical concept that refuse will continue to absorb moisture until the field capacity is reached, and will thereafter release moisture at the same rate as it received it, is obviously an oversimplification, as it shown by Blight (1995) and Bengtsson et al. (1994). The water is stored in a landfill for shorter or longer periods within waste materials, for example, in package material or in wood, in macropores or woids between densely packed waste or above impermeable layers (e.g. above large plastic bags). Water does not percolate downwards from a part of landfill until this part has reached field capacity. Because the field capacity is different for different parts of a landfill, leachate can be generated from landfill even when the degree of saturation in large parts of the landfill is well below field capacity.

3.1.5 The annual water balance

As summarisation above, according to the annual water balance method the leachate production for uncovered (equation 2) and completed (equation 3) landfills becomes:

$$L = I_P - E_T - \Delta U_W \ (+ S + I_G + I_S + b - R - \Delta W) \qquad (2)$$

$$L = I_P - E_T \ \Delta U_W \ (+ S + I_G + I_S + b - R - \Delta U_S) \qquad (3)$$

Where:

L - volume of leakage (or collected) leachate;
I_P - infiltration of precipitation over landfill site;
E (E_T) - evaporation (evapotranspiration);
S - the moisture content of incoming waste;
I_G - groundwater inflow;
I_S – surface water inflow;
b - decomposition of waste generating small volumes of water;
R - surface water runoff;
ΔU_W - changes in moisture content of the waste;
ΔW - changes in the water storage in the upper layer of waste (on uncovered landfills);
ΔU_S - changes in the water storage in the sealing layer.

As it shown above, numerous inputs and outputs to annual water balance equation may be considered, but most of them are in many cases negligible (presented in brackets in equation 2 and 3). Consequently, in a geo-hydrologically correctly located and/or well-constructed landfill, it can be confirmed that the infiltrated precipitation over the landfill is the dominant factor for the generation of leachate.

3.2 GAS AND LEACHATE GENERATION

The degradation and settlements of municipal solid waste are these important conditions in landfills that have to be considered in designing interim and final cover. Similarly the same conditions are relevant if vertical barriers have to be built to stop vertical expansion of waste in landfills. As degradation takes place, the solid mass is converted to landfill gas, and void ratio increases, with consequent increase in the compressibility of waste (El-Fadel et al., 1995; Grischek et al., 1999; Jokela et al., 1999; Gabr et al., 2000). Generally speaking, there are many factors, which influence the gas production and leachate generation, which are dependent on in different conditions and age of landfills. Main factors that influence leachate and gas generation are presented in Fig. 3 and discussed in following sub-sections.

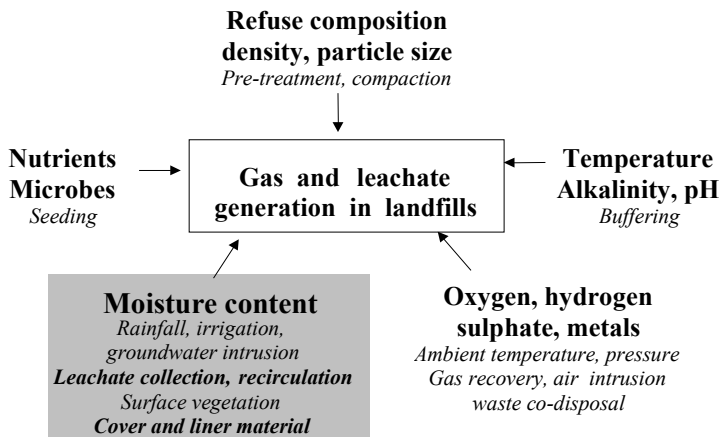


Figure 3. *The main factors influencing gas and leachate generation in landfills (El-Fadel et al., 1995)*

3.2.1 Gas

Biodegradation of waste by microorganisms cause gas generation and intensity of generation depends on biodegradability. Biodegradability rate is a function of waste composition (Gabr et al., 2000). According to Persson (1997), the biological decomposition processes in a landfill site are caused by the capacity of micro-organisms to use organic material as nutrients and water to be able to grow. The moisture content, temperature, hydrogen gas pressure and concentration of oxygen, the presence or absence of buffering agents are of great importance for the growth of microorganisms and generation of methane gas. Oxygen can be toxic to some microorganisms. For instance, methane-producing bacteria will die from exposure to oxygen. If the sulphate reducers will dominate over the methane-producing bacteria than no methane will be produced as long as sulphate is available (Persson, 1997).

Generally, the decomposition processes of the waste are usually divided into five phases. Different decomposition phases as function of time and time scale are shown in Table 1 and Fig. 4

Table 1. *Time scale for different decomposition phases (Pacey and Augestein, 1991)*

	Phase	Time scale
I	Oxygen- and nitrate reduction phase	Hours-1 week
II	Acid phase	1-6 months
III	Unstable methane-generation phase	3 months-3 years
IV	Methane generation phase	8-40 years
V	Humus-generation phase Sulphide-oxidisation phase;	1 at least 40 years

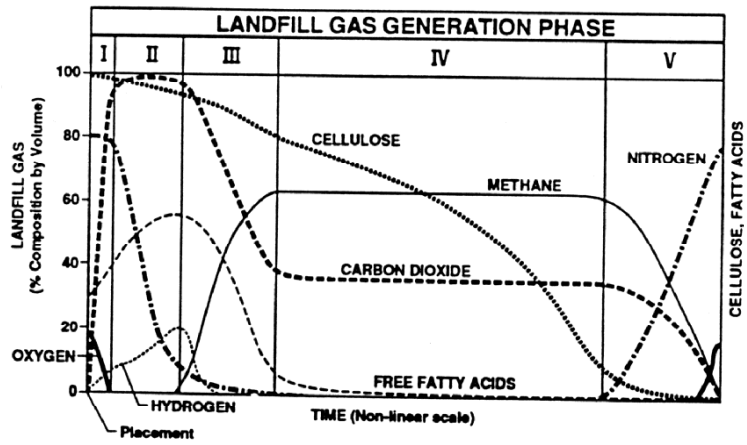


Figure 4. *Landfill gas generation phases (Pacey and Augestein, 1991)*

Infiltration of water into the landfill affects the process of waste decomposition. High moisture content improves the general availability of nutrients and carbon-rich organic matter, and also stimulates bacterial growth directly, while diluting methabolic inhibitors and thus lead to increased methane production (Rees, 1980; Wreford et al, 2000). Methanogenic bacteria are the key factor for complete anaerobic digestion of wastes and are often deficient in fresh refuse due to their oxygen sensitivity. Maximum methane production has been found to occur when the refuse moisture content was in the range of 60-80% wet weight at temperatures under 70˚C. (Wreford et al., 2000). As pointed out by Wreford et al. (2000), increased infiltration increases the concentration of organic matter in leachate.

3.2.2 Leachate

The components in the leachate, which are normally considered as pollutants, are the heavy metals, organic matter, and nitrogen (primarily as ammonium ions). Changes in redoxpotential and pH or microbial production of sulphides, which may entrap the heavy metals in the leachate, can occur during the biological, chemical and physical reactions (Marques et al., 1996). In an anaerobic environment, most heavy metals, in contrast to nutrients like magnesium, potassium, sodium and calcium, form insoluble sulphides. In this case, the heavy metals are usually heavily bonded with solid organic materials (Bramryd, 1997). When oxygen penetrates the landfill in the fifth phase, the heavy metals are oxidised to mobile sulphates and the leaching of the metals starts. (Hogland, 1997). The organic substances included in the leachate are normally analysed in terms of parameters such as BOD and COD (Hogland, 1997). The composition of leachate is widely variable. The composition of the leachate changes as the biological decomposition of the waste undergoes different phases, as well. Generally speaking, the leachate characteristics during these phases are shown in Table 2. The detail characteristics about the quality of leachate during the acid and methane-generating anaerobic phase are presented in Appendix I.

Table 2. *Leachate characteristics during acid and methane generating phase (Hogland, 1997)*

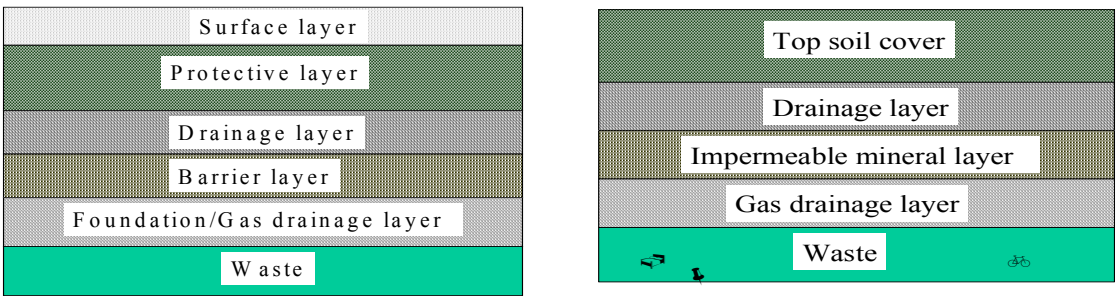
Parameters	Acid-generating phase	Methane-generating phase
Concentration of volatile fatty acids	High	Very low
PH	Acid	Neutral/basic
BOD	High	Low
BOD/COD ratio	High	Low
Contents of NH_4 and organic N	High	High

All the aforementioned factors are relevant to the implementation of final cover of landfill. As it shown on Fig. 3, the generation of leachate is dependent on moisture content of landfill. Keeping landfills open several years is the primary contributor to leachate production in landfills (Hettiaratchi et al., 1999). Therefore, the landfill should be closed immediately after it has reached its capacity. One alternative is to use impermeable cover system to limit the infiltration of precipitation and minimise the generated amount of leachate, as it described in section 3.3. Another alternative possibility is to close landfill with permeable cover system and to use recirculation of leachate, as it is presented in section 3.4.

3.3 FINAL COVERING SYSTEM FOR LANDFILLS

3.3.1 General

Although landfilling activities has continued for long time, the search for cover systems for landfills has become a new research topic during the last decade. Generally, there are several researches (Jesionek et al., 1995; Dutang et al., 1997; Hogland, 1997; Kämpf et al., 1997; Saarela, 1997; Zischak et al., 1997; Gleason et al., 1999; Kämpf et al., 1999;Von der Hude, 1999; etc.), which provide different sub-layers and materials of a final cover system for a closure of solid waste landfills. The potential major components of a final cover systems for the solid waste landfills have been shown on Fig. 5. According to the EU the thickness of topsoil and drainage layers have to be ≥ 1m and ≥ 0.5 m, respectively.



(a) (b)

Figure 5. *Surface sealing systems*

a) redrawn according to Daniel, 1993; Jesonek, 1995

b) according to the EU (EC, 1999).

The capping system varies from simple soil cover to multiple layers of earth and geosynthetic materials. The diversity is acceptable as each a final capping system is tailored to the specific requirements of each particular project.

Final cover systems for MSW landfills serve a variety of functions. The important functions of the final top cover system, according to several researches (Jesionek et al., 1995; Dutang et al., 1997; Kämpf et al., 1997; Hoins, 1999; etc.) are the following:

1. to limit infiltration of precipitation for minimising the generation of leachate;
2. to provide a physical separation between waste and humans, plants and animals;
3. to protect against erosion, frost, desiccation, settling, rooting and burrowing;
4. to control gas migration;
5. oxidising of methane escaping from the landfill;
6. to limit the turnover of oxygen in the landfill;
7. to prevent the output of solute pollutants into surface water;
8. to assure a long term integrity;
9. to allow landscape integration.

3.3.2 The covering system

Every sub-layer of the final covering system has own functions to fulfil as shown in Table 3. All sub-layers together must guarantee the main requirement of the final covering system.

Table 3. *The main functions of the sub-layers of final cover system (Jesionek et al., 1995; Hogland, 1997; Saarela, 1997)*

Type of layer	***Function in the final cover system***
Surface layer	• To promote vegetative growth; • To protect the barrier layer; • To provide possibility for methane oxidation.
Protection layer	• Storage of water that has infiltrated into the cover until the water is later removed by evaporation; • Physical separation of waste from burrowing animals or plant roots; • Minimisation of potential human intrusion into the waste; • Protection of underlying layers in the cover system from excessive wetting-drying and freezing, which could cause cracking of some materials.
Drainage layer	• Drainage overlying protection and surface layers; • Reduction of water on the underlying barrier layer; • Reduction of pore water pressure in cover materials, which improves slope stability.
Barrier layer	• To impede the downward percolation of any water coming into contact with it; • Controls upward movement of landfill gases.
Gas drainage layer	• Intercept gases and direct them out from landfill body via venting mechanisms.
Foundation layer	• To provide a stable working base for laying other layers; • Supporting surface on which the overlying barrier can be constructed.

3.3.3 Materials of sub-layers

As shown below the materials of final capping system can vary widely. There are many properties of the materials, which should be taken into account. For instance, the quality of materials should satisfy requirements, such as tightness and durability. Moreover, the materials used in surface sealing system must be chemically resistant against dump gases as well as rising capillary percolation (Hoins, 1999). However, the using of materials provided in the Table 4, each of them has their advantages and disadvantages, which are detailed described in Appendix IV.

Table 4. *Materials used in final cover system (Jesionek et al, 1995; Hogland, 1997; Saarela, 1997)*

Type of layer	Typical material
Surface (erosion, vegetative cover, topsoil) layer	Topsoil, geosynthetic erosion control layer; cobbles.
Protection layer	Soil, recycled or reused waste material, cobbles
Drainage layer	Natural gravel, macadam, coarse "inert" waste (e.g. slag, carbon bottom ash); Sand, gravel with the filter; Geonet with geotextile filter; Geocomposite drainage material.
Barrier (infiltration layer) or Impermeable mineral layer & Artificial sealing liner	Compacted clay, clay soils (clay moraine), bentonite mixes; Geosynthetic Clay Liner (GCL); **Geomembrane:** **Plastics:** PVC (polyvinyl chloride); PE (polyethylene); LDPE (low density polyethylene); MDPE (medium density polyethylene); HDPE (high density polyethylene); CPE (chlorinated polyethylene); **Rubber:** Butyl; EPDM (ethylene propylene); Neoprene (polychloroprene); Hypalon (CPSE, chlorosulphuric PE, combination rubber/plastic).
Gas drainage layer	Sand or gravel with soil or geotextile filter, Geotextile drainage fabrics and geonet drains with geotextile filters Glass waste
Foundation layer	Soil; contaminated soil, ash, wastes

The hydraulic conductivity of the materials, which are used in surface covering system, is the most important factor in the prevention of the infiltration of the precipitation into the landfill body. Hydraulic conductivity in different sorted and unsorted soils is presented on Fig. 9. In Table 5, the percentages of the annual precipitation that is infiltrated and related hydraulic conductivity in the hydraulic barrier or the dense soil layer (if no cracks or settlements exists) are presented.

Table 5. *The infiltration of precipitation related to hydraulic conductivity of hydraulic barrier. (Saarela, 1997)*

Hydraulic conductivity (m s^{-1})	***Infiltration of annual precipitation (%)***
10^{-9}	Impervious
10^{-8}	20
$10^{-7} – 10^{-5}$	60-80

Moreover, the thickness of the sub-layers in a final cover system is important to consider. Thickness of sub-layers depends on materials, hydraulic conductivity etc. and therefore the whole system can be different as is depicted by different authors (Gleason, 1997; Kämpf, 1997; Kämpf, 1999; Von der Hude et al., 1999). One recommended thickness of typical final cover system is presented in the Fig. 6.

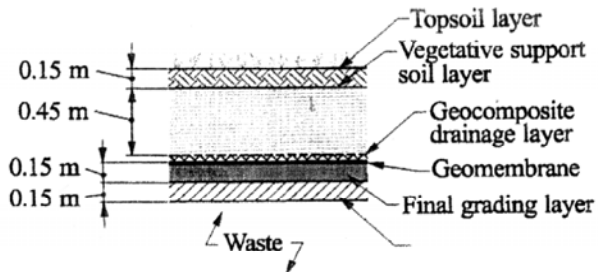


Figure 6. *Typical recommendable final cover system (Gleason et al., 1999)*

3.4 RECIRCULATION OF LEACHATE

The another possibility to close landfills is covering the waste with permeable cover materials. In this case, it is imperative to collect the leachate and thereafter instead of treatment option recirculate it. The bioreactor and leachate recirculating landfills differ from the dry tomb landfills in that they each receive managed liquid additions to augment waste stabilisation (Pacey et al., 1999). The aim of recirculation is to enhance the water flow in the landfill and the leaching of the easily leachable components. This promotes the biodegradation and stabilisation of the landfilled waste through the provision of optimum moisture conditions, a more effective transfer of microbes, substrates, and nutrients throughout the waste body and dilution of high concentrations of inhibiting substances. (Hjelmar et al., 2000). This so-called stabilisation is the conversation of fermentable organics in the waste into carbon dioxide and methane. (Lee and Jones-Lee, 1994a; El-Fadel et al., 1995) Normally, the landfill gas production take 30 to 50 years in a conventional sanitary landfill. If the leachate is introduced back into the landfill, then landfill gas generation is accelerated and takes in 4 to 5 years under field condition, as it pointed out by Lee and Jones-Lee (1994a).

Plastic bags are widely used for home and commercial solid waste disposal nowadays. As appointed by Lee and Jones-Lee (1994a), this hinder the contact between the waste and recirculated leachate and waste inside the plastic bags is insulated and preserved. However, in old landfill these preservation conditions for organic in the bags cannot be affected. In new landfills discarded MSW in plastic bags should be shredded prior

placement in the landfill. After proper shredding the accelerated stabilisation of the fermentable components of MSW is not hindered.

However, in a number of states of the U.S. leachate recirculation has been prohibited due to fact that it increases potentially the groundwater pollution thus hydraulic loading on landfill is increased. This could increase the rate of groundwater pollution by leachate. (Lee and Jones-Lee, 1994a) Therefore, the leachate recycle should not be practiced in an unlined landfill or a single composite lined landfills. The leachate recirculation could be used if landfills with double composite liner, in which the lower composite liner is part of a liner leakage monitoring system.

4. LANDFILLING IN ESTONIA

4.1 WASTE MANAGEMENT IN ESTONIA

The growing amount of waste has become a problem in many countries as well as in Estonia. At present, landfilling is the dominating method of waste treatment in Estonia. The Fig. 6 shows the rate of composting operation and disposal of waste in Estonia. The large-scale recovery/recycling of waste and alternative technology have not developed yet. However, the separate collection system for specific types of waste, such as glass and batteries, are in early stage of development.

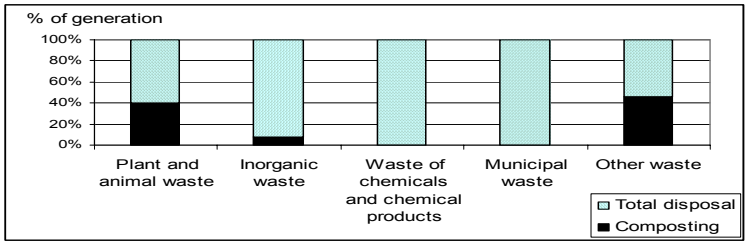


Figure 7. *The composting operation and total disposal of waste in Estonia (SOE, 1999)*

As it shown on Fig. 6, 100% of collected MSW is deposited in landfills in Estonia. According to the definition from Statistic Office of Estonia, municipal solid waste is mixed municipal waste collected from household, institutions and enterprises (SOE, 1999). Mainly the population in towns and settlements (69% of Estonian population) is covered by waste collection systems. It could be said that all the MSW is disposed off at dumpsites without separation, thus the dumping of waste is not properly controlled. Therefore, the composition of the waste dumped at landfills in Estonia is to a larger extent unknown. The available data on the composition of MSW are mostly estimations (Fig. 7). Consequently, there is a quite big possibility that hazardous waste often may be included in the waste dumped at the sites.

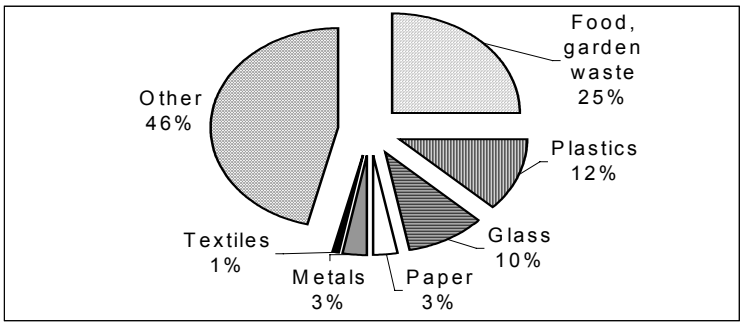


Figure 8. *Composition of municipal solid waste, 1997 (SOE, 1999)*

According to statistics, there was collected 569 000 tonnes of MSW and the amount of generated waste per capita was 393 kg in year 1999 in Estonia. It is somewhat higher than in other Eastern Central European countries (311 kg per capita a year), but lower than the EU member countries (505 kg per capita a year) (SOE, 1999). A goal of the Estonian Environmental Strategy for the year 2010 is to stabilise the generation of municipal waste generation on a level of 250-300 kg per capita (Fig. 8) in order to lower the risk to the environment.

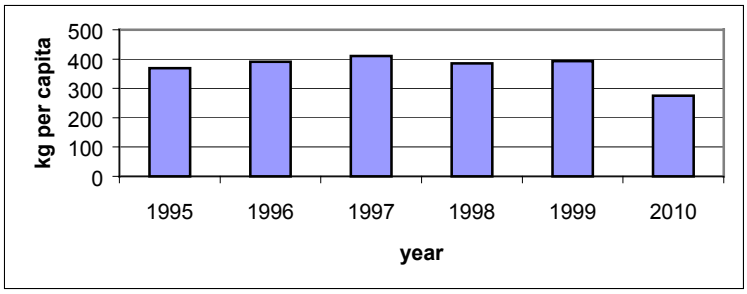


Figure 9. *The generation of municipal waste (kg per capita), 1995-1999 and a goal in 2010 (SOE, 1999).*

4.1.1 The current situation of the landfills in Estonia

According to the Estonian Landfill Register there are totally 523 landfills in Estonia, of which 347 are used for MSW, 78 for industrial waste and 98 for animal carcasses disposal. At present, of the 347 solid domestic waste dumpsites 252 are in use (see Appendix V), 55 are closed down, 32 are finalised (Toomel, 1997a). Generally, these landfills are created without proper methods for environmentally sound disposal. In these cases the landfills should be seen as dumpsites, the use of the term “sanitary landfill” is incorrect. Currently, there are 8 landfills under construction. These landfills are planned considering requirements for sanitary landfills to take into account protection measure of environment.

The risk of groundwater contamination is high, as in the Estonian situation most of the dumpsites are located directly on natural soil layers without environmental protection measures. There is only one landfill in Estonia, Tuula landfill that has artificial bottom sealing, which consist of limestone (flagstone) and 10 mm of

bitumen. As reported by Toomel (1997 a), 18% of the landfills are situated on sandy soils, 31% on natural clay, silt and moraine soil, 1% on the peat. For 49% of the landfills the data about soil layer bellow the landfill is unknown. According to the EU Directive the permeability of natural geological bottom mineral layer of landfill of non-hazardous waste must be $\leq 1 \cdot 10^{-9}$ ms^{-1} and thickness ≥ 1 m to protect groundwater. According to Fig. 9, only these Estonian landfills, which are situated on natural clay and morain clay soils, satisfy the requirements. Thus, most of landfills are not situated on clay soil bottom, the seepage of generated leachate from landfill body cause big threat for groundwater aquifer. This shows that the landfills with permeable cover can not be established without special bottom sealing even though the ground has thick and watertight clay layer. This means all new landfills that are under construction have to have bottom sealing according to the requirements.

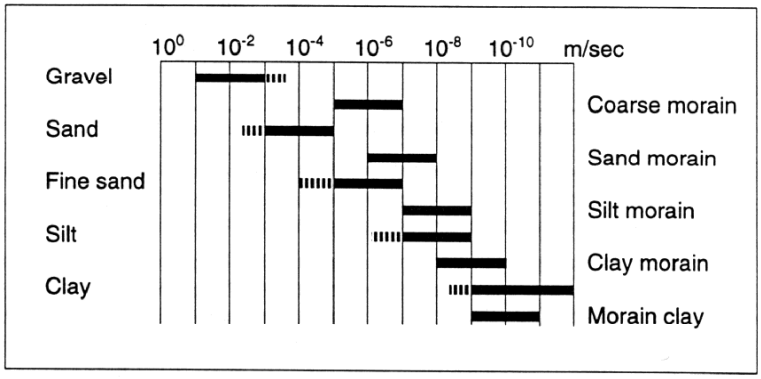


Figure 10. *Hydraulic conductivity in sorted and unsorted soils (Hogland, 1997)*

4.1.2 MSW landfills in operation

The current municipal solid waste (MSW) landfills, which are in operation in Estonia, can be divided in three categories according to landfilling conditions and their threat to the environment (Toomel, 1997a):

1. High waste load and remarkable environmental risk;
2. Moderate waste load and low environmental risk;
3. Low waste load and negligible risk.

The first group consists of the six largest landfills in Estonian, which receive 60 % of the annual production of the municipal solid waste in the country. These landfills pose the largest potential threat to environment due to large amounts of waste. The general characteristics of these landfills are presented in Table 6.

Table 6. *Characteristics of the six largest landfills in Estonia (Toomel,1997a)*

Landfill	County	Establish-ment decade	Served people	Area (ha)	Received waste annually (t/y)	Amount of disposed waste in 1997 (mil.t)
Pääsküla	Harju	1960s	450 000	28	200 000	4
Pärnu	Pärnu	1970s	50 000	6	42 000	1
Kotinuka	Ida-Viru	1950s	100 000	12	27 000	1.5
Ussimäe	Lääne-Viru	Unknown	20 000	10	25 000	0.3
Räpo	Võru	1970s	17 500	3	24 000	0.5
Aardlapalu	Tartu	1970s	100 000	11	20 000	0.5

The second group consists of 18 landfills, which receive 20% of the annual waste load of MSW. On these landfills the disposal of waste is 5800 t annually in average, and area is approximately 5 hectares, which gives about $1.2 \cdot 10^3$ tonnes/ha. In most of these landfills aerobic conditions are prevalent at present due to no compaction is made. However, the increasing amount of waste disposed on these landfills can lead to the development of anaerobic processes instead. These landfills can pose a potential threat to the environment, therefore the respective measured to avoid pollution should be taken into account.

The landfills from the third group (250) receive in totally 17% of the Estonian MSW load annually. Generally, each dumpsite receives 370 tonnes waste per year in average. Usually most of the dumpsites are situated far from residential areas and cover small areas, the surface area are around 0.7 hectare (Toomel, 1997a).

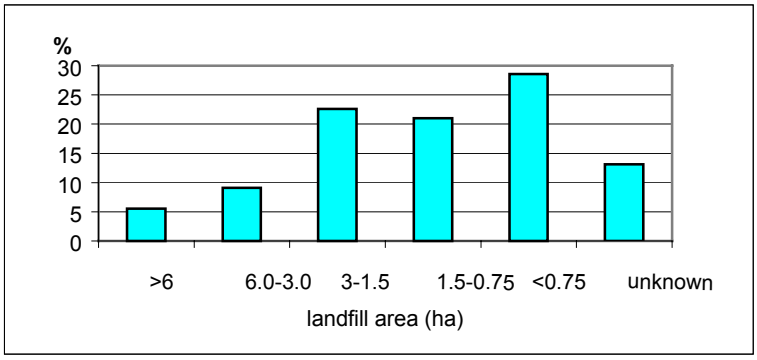


Figure 11. *The size of MSW landfills in Estonia (Teder, 1997; Toomel, 1997a)*

In general, Fig. 10 gives the overview of the size (ha) of landfills, which are in function in Estonia today. Grouping by size, there are 14 larger landfill sites covering an area of over 6 hectares each in Estonia. However, most of landfill sites situate in rural areas and are rather small, with the surface area of 1.5 hectares or less (Toomel, 1997a; Teder, 1997).

4.1.3 Closed MSW landfills

In a number of really small old dumpsites the landfilling activity is finished. Most of these dumpsites are situated far from residential areas and have been low in capacity and small area has been covered. These landfills does not pose a potential threat to the environment any more, because the layer of waste has not been so high and mostly aerobic decomposition process was taking place in waste layer (Lehtla et al., 1997). In many cases, these former dumpsites are just levelled and combined by a bulldozer. Today, the decomposition process is almost finished in these sites and upper layer of decomposed waste has turned to be the base soil for vegetation. These sites are not well noticeable any more. These landfills are included in finalised landfills category (Toomel, 2000). In fact, no noticeable pollution of surface water and groundwater due to these landfills has been discovered (Lehtla et al., 1997). However, this doesn't mean that pollution will not occur in the future due to lack of disposal materials. The packages with hazardous waste can begin leak after several decades. Therefore the control of these landfills cannot be considered superfluous.

Toomel (2000) and Erm (2000), describe a strategy of closing down a landfill. Once filled the landfill is closed off from the public and subsequently undergoes a process of levelling and compacting by bulldozers. If natural soil is locally available waste is covered after levelling. Thus the thickness and quality of soil layer on the landfills varies considerably. According to Toomel (1997a), 63 of all types of landfills are covered with natural soil. Occasionally sawdust has also been used as covering material in Estonia, for example, at 16 landfill sites.
Complains concerning water pollution from large dumpsites located in the vicinity of larger towns have been received (Lehtla et al., 1997). These larger landfills have usually higher height of waste layer and due to that a anaerobic decomposition is prevalent and generation and seepage of leachate cause a potential threat to environment.

4.2 WASTE MANAGEMENT AND LEGISLATION

Environmental concern and legislation have been increasingly attracting more consideration and attention. Since 1995 Estonian government has worked on the national environment strategy and enacted laws according to the EU directives.

4.2.1 Enforcement of environmental legislation

At present, the Chief Inspectors Office (the Environmental and Nature Protection Inspectorate) is responsible for the enforcement of environmental legislation in Estonia. However, many of the day-to-day enforcement tasks are delegated to the County Environmental Department. The County Environmental Department, which is a part of County Government, are responsible for issuing waste permits and supervision and control of their implementation. The towns and municipalities organise the waste collection, transports and disposal of household waste by their own. They have decided on the location of waste disposal facilities in their area until today. Towns and large municipalities may have one technical employee within solid waste management field. The small rural municipalities have only one person dealing with all environmental, waste management and technical issues within the municipality (Lehtla et al., 1997).

4.2.2 Requirements for waste landfilling

The new European Union (EU) Directive 1999/31/EC on the landfilling of waste came in force on 16 July 1999 (EC, 1999). In this directive, the EU has restricted the requirements on the waste and landfills to provide guidance to prevent or reduce as far as possible negative effect from landfilling of waste to the groundwater aquifer, surface water and environment in general terms. Today, every member country of the EU try to act in a more sustainable way in order to protect environment. Therefore, they have made their own legislation according to the EU policy. Estonia belongs to the group of the countries, who are seeking a membership of the EU. Similarly, Estonia needs to establish requirements as in the EU for protect groundwater and environment generally, and this has been the main goal during last years. The National Environmental Strategy has been formulated. One task by the year 2010 that has been set up in the National Environmental Strategy is to minimise the number of MSW landfill sites up to 150 (Lehtla & Viisimaa, 1997). At presence, there are no special legal acts on requirements of closing of landfills in Estonia. However, in 2000, the Estonian Ministry of Environment has established 'Proposal on the Requirements of Foundation, Utilisation and Closing of Landfills' (PPME, 2000), which will come into force on the 16th of July 2001. Generally speaking this Proposal of Provision of the Ministry of environment, to a large extent addresses the same issues on the landfills and landfill capping requirements, etc., as the EU Directive.

According to the EU Directive (EC, 1999) and Proposal on the Requirements of Foundation, Utilisation and Closing of Landfills (PPME, 2000) the cover system of municipal solid waste landfills to be closed after 16 of July 2001, should consist of four sub-layers, as it presented in the Fig. 5.

5. ANALYSES OF THE LANDFILL CLOSURE OPTIONS FOR ESTONIAN CONDITIONS

The number of landfill that are reaching their filling capacity and have not been properly terminated yet must be considered as a significant danger to groundwater and surface water pollution in Estonia. As shown in sections 3.3 and 3.4, two methods, leachate recirculation and impermeable cover system, can be used in the closing of landfills. The opportunities to use these options for reduction of groundwater contamination in Estonian conditions have been discussed in following sections.

5.1 COMPARISON OF TWO LANDFILL CLOSURE METHODS

The leachate recirculation system and capping of landfills with an impermeable cover have both advantages and disadvantages. The following sub-section will analyse the pros and cons of using these methods under Estonian conditions. The first question that becomes important, is what kind or which type of landfill cover must be implemented in Estonia now. This can be analysed by using the CLD (Fig.12). The CLD depicts to the consequences of usage of chosen landfill cover.

Groundwater pollution could be avoided if economical resources will be invested to improve the landfill quality in Estonia. The financial possibilities play important role for choosing a method. There are three different alternatives that could occur. Firstly, if landfill closure will be confined to the placement of permeable cover materials and there is lack of bottom sealing and a leachate collection system, the groundwater pollution will take place. If there are enough resources to cover a landfill with an impermeable cover system, instead of a permeable system, then water input into landfill decreases. The consequences of this are less leachate leakage and less groundwater pollution. Since there is not enough water in a landfill, the degradation processes reduce and landfill stabilisation takes more time. The problem will be postponed to solve for future generations. If the landfill will be rebuilt and bottom sealing and leachate collection system will be established, then there will be less leakage of leachate and less contamination of groundwater. In the case that bottom sealing system has been installed, the leachate recirculation system could be used and impermeable cover system would not be required. A consequence of using of leachate recirculation system is increased degradation processes, leading to accelerated landfill stabilisation. In this case, methane could also be collected and used as an energy resource, helping it to compensate the overall investment.

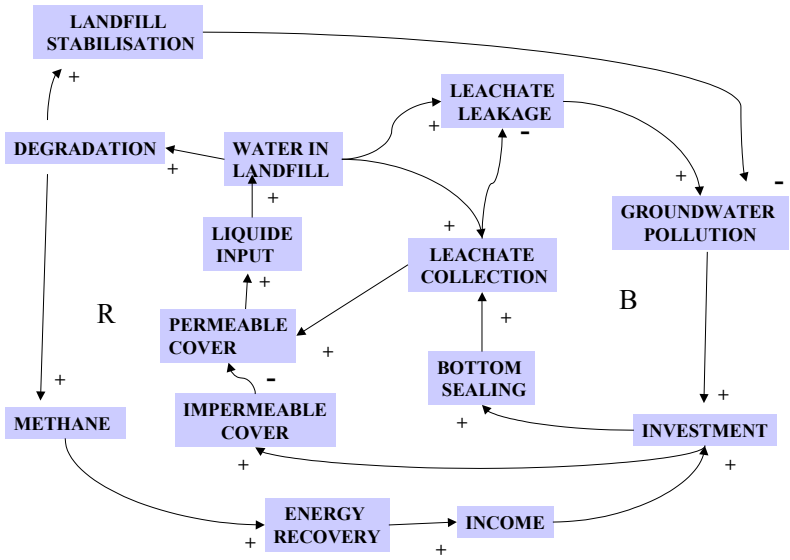


Figure 12. *Consequences of using leachate recirculation and impermeable cover system.*

5.1.1 The leachate recirculation system

Positive aspects:

- The different leachate treatment methods are not well developed yet. Additionally they are relatively expensive in Estonia. Therefore, recirculation of collected leachate back on landfill body seems to be good solution;
- Leachate recirculation system will accelerate decomposition process and Estonian landfills can reach to stabilisation stages earlier, and this reduces the postclosure time of landfills, risk and cost;
- Good method for maximisation of landfill gas capture for environmental recovery projects and at the same time abatement of greenhouse gases (Pacey, 2000);
- Fast settlement of landfill site;

Negative aspects:

- The use of leachate recirculation will increase the hydraulic loading on the landfill and since these landfills do not have bottom sealing, the consequences of this choice is a potential danger for groundwater pollution. Therefore, in current conditions, the recirculation of leachate must be avoided on the Estonian landfills, which do not have bottom sealing.
- Landfills that require this system must be completely reconstructed. Landfills must have appropriate design and double bottom-liner, leachate drainage layer. Because of long reconstruction time, effort and enormous financial investments the system is not easily applicable at current circumstances in Estonia;
- Solid waste pre-treatment (e.g. mechanical shredding to break plastic bags, etc) or segregation should take place at first. It will be higher landfilling cost activity for Estonia;
- Leachates can concentration in some part of landfill body and cause rapid decomposition in some areas (where leachate goes) and slow decomposition in others. It can lead to some drastic differential settlement and leachate breakouts on sideslopes and stability problems with refuse mass and lining

system beneath it (Hull, 2000). This system requires specific mechanics for the leachate reintroduction to avoid it.

- Requires closer attention to system performance, such as control and monitoring processes, to minimise the risk of contamination due to lack of experiences in Estonian conditions.

5.1.2 The impermeable cover system

Disadvantages

- One of the disadvantageous features of an impermeable cover system is that the stabilisation of a landfill takes long time and the after-care period is prolonged. This after-care period includes a control program of the groundwater quality around the closed landfill, which can go on for 30-years or more. Due to a longer exploitation time, the impermeable system must fulfil design criteria to give a safe and long-time protection.
- The materials for different layers and placement on the landfill site require large economic expenditures.

Positive aspects

- An impermeable cover system allows a minimum amount of water to enter to the landfill body and decreases the leachate generation to minimise groundwater pollution. Moreover, it reduces emissions of gases to the air and avoids air inputs into the landfill.
- As indicated above, the EU requirements and in the 'Proposal on the Requirements of Foundation, Utilisation and Closing of Landfills' made by the Ministry of Environment, suggest impermeable cover system for capping of landfills.

5.1.3 The most suitable landfill closure method for Estonia

Consequently, from environmental point of view (as has also been shown on Fig. 12) the impermeable cover system approach is a safer method than leachate recirculation system in Estonian landfills without bottom sealing. In the case, then leachate recirculation system will be used, the rebuilding of landfills should take place at first. This solution is significantly more expensive than landfill covering with impermeable cover. Although the recirculation system is better from long term perspective, but present limited financial resources for many landfills in Estonia, make this option not a possible applicable method in current situation. Landfills that have reached their filling capacity and pose the most of danger for groundwater aquifers should be preferred to start closure process with an impermeable cover system. Therefore, the following chapters are focused on aspects on the implementation of impermeable cover systems.

5.1.4 Benefits of landfill closure with an impermeable cover system

It could be argued that the closure of landfills with impermeable cover system is expensive. There exists a cheaper alternative, such as permeable cover system, that could be used instead. The groundwater is the dominating source of portable water and it must therefore be rigorously protected. If the financial investment does not take place today, it is highly probable that the groundwater contamination will take place in the near future. If a leachate leakage into the groundwater aquifer occurs, then treatment of this kind of leachate polluted water is extremely expensive and specific high technology is needed, which usually gives insufficient results. Toxic compounds (e.g. heavy metals) in the groundwater will cause serious human health

problems and these can be carried forward from mother to child. Contamination will cause unconvertible health effects for this and also next generation. When the groundwater can not be used as portable water resource, then portable water should be provided another way for all consumers. The money that should be paid after pollution will be much more expensive.

6. IMPLEMENTATION OF THE MOST SUITABLE LANDFILL CLOSURE OPTION TODAY

6.1 KEY FACTORS THAT INFLUENCE SETTLING OF LANDFILL COVERAGE SYSTEM

According to the European Union Directive on the landfilling of waste, it is necessary to define when and how a landfill should be closed (EC, 1999). Usually, the final top sealing system are laid or should be laid on the top of landfills when waste accumulation is completed and the landfill has reached its filling capacity. The time it takes for covering landfill affects leachate production from landfill body. This idea of fast landfill covering gets supports by Hettiaratchi et al., (1999) and their investigation. It was shown that keeping landfills open several years is the primary contributor to leachate production. Before closure, the placement of the landfill cover, the landfills actual condition, such as geo-hydrological situation, stability of landfill, waste characteristics, settlement of the waste, hydraulic conductivity of coverage materials and the waste, and gas formation must be taken into consideration in planning and constructing the surface structures of the landfill.

On the contrary to the latter, there are some cases when the placement of the final cover should be forwarded. As pointed out in research made by Jesionek et al. (1995) and by Hoins (1997) this period is when the waste is continuing to settle (e.g. as a result of decomposition) after the landfill has reached its filling capacity. On this occasion, it must be recommended to place a temporary cover on the waste and wait for settlement to take place prior to constructing the final cover system. Secondly, gas generation caused by the biodegradation process of organic matter is another aspect that should be taken into account. Usually, landfill gas migrates upwards into overlying soil and also horizontally into the surrounding ground. Methane gas can migrate into porous soil layers and into trenches with the municipal sewage pipe system and lead the gas into houses in nearby down district. Methane discharging sites cannot be landscaped without methane removing systems due to the limits of explosive danger (6-15%, ratio between methane and oxygen, according to Saarela, 1997). Therefore, gas collection system should be installed inside the waste material or otherwise the restoration should be delayed until gas production declines to an acceptable level, which can be reached within 5-10 years if the decomposition speed can be accelerated.

Nevertheless, the climatic conditions have to be investigated before one can close landfills. In order to decide the necessity of capping with an impermeable cover system it is essential to look at the amount of annual precipitation received at the landfill site and total area of the landfill. As pointed out by Blight (1995), the landfills that receiving more than 750 mm of precipitation per annual will eventually produce leachate and pollution of groundwater can take place dependently of content of leachate. As suggested by the EU

Directive (EC, 1999) and because Estonia receives significant yearly rainfall levels (540 mm), an impermeable cover system is mandatory to avoid groundwater pollution.

The technological aspects, such as the structure the different coverage layers, choice of method of construction and application of cover system are also of importance. Water content, mixing methods, packing methods of natural materials and weather conditions when the work was carried out is of great importance on how impermeable the final cover system will be. As pointed out by Hogland (1997), the installation of natural soil layers requires that the completion and control of the work is of a high standard if the results are to be satisfactory. The institutional and administrative aspects influence the placement time and type of final coverage of the landfill. For instance, as part of the closure activities at the site, a final closure plan, construction drawing specifications and a construction quality assurance plan should be prepared by the designer and be submitted in Estonia. However, the drawback of this is that this method is time-consuming to get papers submitted, and unnecessary pollution can be take place. This can be avoided then efficient planning is undertaken.

As it has been shown above, different conditions which does not have any relationships with each other in the first sight have an importance in closing landfills. Climatic conditions and the current situation at landfill site respect to economical and technological conditions determine the final cover and covering method. Moreover, before selections of design of the final capping of the landfill the further use of the land should be decided, thus it will affect the thickness and characteristics of components of the final cover. Therefore, it is very important that landfill owners/operators, designers and regulatory officials understand that the choosing of components for a final landfill capping system could be not generalised for all sites. For example, often the designers use the phrase "it worked on the last case". This approach can lead to over-designed or under-designed projects. Each site should be evaluated on a case-by-case basis to determine when the cover should be settled and which combination of materials is most beneficial to this particular site.

6.2 COMPOSITION OF IMPERMEABLE COVER SYSTEM IN ESTONIA

6.2.1 Covering materials

The selection of the possible coverage components and materials should be identified, selected. The selection of the natural materials or artificial materials (geo-textiles or plastic liners) is often based on local availability and the cost of materials. The suitability of different cover system materials (presented in Table 4) in Estonian condition is discussed subsequently.

Polyvinyl chloride (PVC) is not suggested for use on Estonian landfill sites as artificial sealing liner. Using PVC could produce more pollution due to possibility to leakage the chloride ion. Moreover, the use of recycled or reused waste materials should be careful (especially different type of ashes), because not all recycled waste materials are suitable for a final cover. Compacted recycled polyethylene (1m^3 bails) could be used very effectively as barrier layer instead of newly produced plastic liners. This alternative increases the possibility to use recycled materials, reduces need to produce new rubber and plastic liners, and moreover it helps to save resources and reduce pollution from production processes. There are recently discovered new

different types of artificial sealing, however, in many cases they are very expensive and therefore not possible to use in Estonia.

The use of natural materials in the surface structure of landfill are more reasonable and realistic in Estonia, as they are relatively inexpensive and in many cases they are found in surrounding areas. Based on international experiences (see for instance, Table 4) natural materials that can be used in the final cover systems in Estonia are suggested in the Table 7.

Table 7. *Suggested materials for the Estonian landfill coverage systems*

Type of layer	**Typical material**
Surface vegetation layer	Local topsoil;
Protection layer	Local soil, recycled and building construction waste, cobbles
Drainage layer	Gravel, sand, coarse "inert" material, bricks and tills
Barrier (infiltration layer) or impermeable mineral layer & Artificial sealing liner	Compacted clay, clayey soils (boulder clay moraine), bentonite mixes, etc. Geosynthetic Clay Liner (GCL); Compacted recycled polyethylene
Gas drainage layer	Sand or gravel, glass waste, crashed bricks and tills
Foundation layer	Local soil; contaminated soil, ash and wastes

In many cases, natural materials, which could be found in the vicinity of landfills do not satisfy landfill liner quality requirements, like the hydraulic conductivity (Fig. 9). In the case of low quality, there are two alternatives to solve this problem. First suggestion is to improve the quality of soil, as presented by Saarela (1997) (shown in Appendix III). Another possibility is to transport the higher quality natural materials from the another places where they are available. However, transporting materials from one place to another, will increase the cost of capping.

There are also some disadvantages of using natural materials. For instance, the difficulties can arise as a result of unsuitable weather conditions. Moreover, the earthen material's properties may change due to erosion, different settlements, freeze-thaw cycles, and desiccation that produce cracks and hydraulic conductivity will increase during the time. Even if natural soils are thoroughly compacted, they cannot be made completely impervious. However, as argued by Saarela (1997), betonite mixes, geomembranes and geosynthetic clay liners are more able to resist these types of damage, therefore the possibility to use these materials should be considered. The using of bentonite mixes as barrier layer will give best results, however it is very expensive and therefore could be not probably afford in Estonian conditions.

The choice of covering material depends also the size of landfills. In the case of smaller Estonian landfills or when clay is not available, plastic liners will be economically reasonable to use as a barrier layer than natural clay materials. In these occasions, the transport of clay materials will be expensive and transportation causes pollution as well. Moreover, the installation process is easier and does not require much machinery and involves fewer workers.

6.2.2 Additional suggestions

Landfills may incorporate both the foundation layer and a gas collection layer (Fig. 5) in the landfill cover systems. As pointed out by Jesionek et al. (1995), these layers can be similarly implemented for Estonian landfills, which a single gas drainage layer could serve as a foundation layer. Nevertheless, the designer should be noticed that neither wet clay nor organic material would serve this purpose.

Depending on which kind of materials have been used, the filter may be needed to separate the different layers if they consist of grains of different size (e.g. gas collection layer materials from an overlying barrier layer). In order to guarantee a high permeability to gas the granular material needs to be maintained in a relatively dry state.

Establishment of the right vegetation on the top of the Estonian landfill site reduces infiltration by evapotranspiration and water interception. Since the rate of evapotranspiration depends on type of vegetation, more attentions should be taken on selection of plants. Investigation made by Saarela (1997) in Finland showed that the plantation of willow can reduce by about 20-30% and certain grasses by about 15-20%, and poorer growing grass about 5-10% of the annual precipitation. Therefore, as Estonian climatic conditions are quite similar to Finland, willow, such as salix, or grass is suggested to be planted. The thickness of the top layer is selected so root penetration of layers underneath is avoided. As pointed out by Saarela (1997), the minimum thickness of the vegetation layers for trees should be 150 cm, 50 cm for bushes and 30 cm for grass.

Normally there is significant snowfall during the winter months in Estonia. To reduce the amount water generated by snowmelt available for infiltration into the landfill body and generation of leachate, the snow should be removed from landfill site, like has been done in Finland (Saarela, 1997). On the other hand, a negative consequence of snow removal is decreased protection against frost. Thus, the snow removal is suggested in the beginning of spring before snowmelt has started and the soil start to be unstable and there will be the risk that machinery used caused damage on the top soil.

These two above mentioned suggestions, snow removing and the establishment of vegetation on the landfill, for reduction of rainwater infiltration might also be used on Estonian landfill sites, without impermeable cover systems that have been closed down for years.

6.3 CONDITIONS THAT AFFECT IMPLEMENTATION OF LANDFILL CLOSURE METHODS

The way of reducing groundwater contamination can be achieved by using either a final proper impermeable cover or a leachate recirculation system with perfect bottom sealing. The main conditions that will affect the suitability of these two options for Estonian landfills are:

- economical possibilities,
- political decision,
- awareness of decision makers, engineers and personnel involved,
- environmental aspects.

6.3.1 Political aspects

Legislation is a key factor, which influence the choice and implementation of landfill closure in Estonia. The choice of the landfill cover system should be done according to regulations, which indicate minimum standards and permissible configurations for the landfill cover systems. Since Estonia is seeking membership in the EU, the steps to establish similar requirements on landfilling activities have been considered in a legislation framework. As indicated above, the EU requirements and in the 'Proposal on the Requirements of Foundation, Utilisation and Closing of Landfills' made by the Ministry of Environment impermeable cover system for capping of landfills is suggested. However, decision-makers have to consider if Estonia is actually ready to implement this legislation today or if the country may have difficulties at implementation stage.

6.3.2 Economical possibilities

There are different economical conditions that play an important role when discussing landfilling in Estonia. There is an critical question in this area. The question is who should pay these environmental protection actions? Is it the government, the municipality or the landowner? There are no adequate fees and available funds from Estonian central budget, or they are simply insufficient to finance adequate levels for all landfill projects. In order to get fast action, it is suggested that the government make a reservation in the budget, create funds, or offer favourable loans to landfill operations.

There are many landfills (or part of the big landfills), which have reached their filling capacity and need to be closed down. At the same time, eight new landfills are under construction. On both occasions financial support is needed. New sanitary landfills will be built according to the EU requirements – having already had financial assistance in place. Therefore, the landfill closure should be accomplished with relatively low price that Estonia could afford both actions at the same period. Nevertheless, the lower expense on the chosen method should not affect the quality of landfill closure. Obviously, the closing of all old landfills simultaneously is not realistic proposition in Estonia. Consequently, the best results will be achieved if the action is effectively planned. Due to limited sources of financial support, the decision must be made in which order the landfill should be closed. Moreover, the strategy of landfill closure must show, which landfill should receive impermeable cover, which could be covered with permeable cover system or which landfills really need rebuilding, and on which landfill the leachate recirculation system could be used. The chosen methods have to be reliable to decrease environmental impacts from landfilling in Estonia.

6.3.3 Environmental aspects

Specific site characteristics have to be collected and analysed for risk assessment. This analyses helps to determine which landfills pose the most danger to groundwater aquifers. These landfills that have reached their filling capacity and pose the most of danger for groundwater aquifers should be preferred to start closure process with an impermeable cover system in order to minimise leachate generation and percolation into the groundwater. This is particularly important for landfills located on the groundwater aquifer used as a resource of portable water.

6.3.4 Awareness by decision makers, engineers and personnel involved

Chosen technologies can be effective for protecting groundwater aquifer, in theory. Practically, the foreseeable dangers lie not only with the proper and expensive material (systems), but also with untrained designers, careless contractors and imprudent operators. Effective capping system depends on worker

awareness and how responsible they are to fulfil exactly the requirements described by experts. If workers do the laying process without accuracy and care, it does not matter how expensive materials will be used or how good the quality of materials is, the final cover system will fail due to improper laying technique. In this case, the human's failures and neglects will negatively affect all Estonian society.

As is shown chapter 4.1.3. some landfills has been closed down. Nevertheless, it does not mean that all landfills are closed down on up-to date level. Some of municipal solid waste landfills are ordered to be closed by local government, but closure have not taken place in reality (Teder, 1997). Due to a lack of information, waste management in an environmentally sound manner has not yet attained adequate attention. Generally speaking, there is lack of educated workers today on the landfill management sector in Estonia. Therefore, it is important to take into account the numbers of people who are needed to implement the chosen system and how knowledgeable they should be in this field.

6.4 EVALUATION OF EXISTING LANDFILL SITES AND SUGGESTION OF MEASURES

As seen in section 4.1.2, Estonian landfills are divided in three categories according to the threat to the environment. Each landfill or groups of landfills need an individual approach for their closure.

6.4.1 High risk landfills

The first group, which has the highest environment risk, needs the most attention and the best covering method. Due to high environmental risk in this group, an impermeable capping system has to be designed for these landfills in order to minimise leachate generation and percolation into the groundwater. This is particularly important for landfills located on the groundwater aquifer used as a resource of portable water. Furthermore, the cover enables to collect the gas for further application. Three landfills from first group (as it presented in Table 5) planned be closed down in the near future. Therefore, these landfills have been taken as example for analysing possible closure option. The largest (28 ha) landfill in Estonia, Pääsküla landfill, has to be closed down within 10 years, when it will reach its filling capacity. The Kotinuka and Pärnu landfills have already reached their filling capacity and have to be closed.

<u>Closure of Pääsküla, Pärnu and Kotinuka landfills</u>

The characterisation of leachate in Estonian landfills has been shown in Appendix II. If these values are compared with general data presented by Spinosa et al. (1991, shown in Appendix I). It can be found that the Estonian landfills are in the methane phase today (see Fig. 4) and anaerobic decomposition processes are prevalent. This could be expected, because normally a landfill goes in to the methane phase already after some years after the waste is landfilled (see Table 1). Landfill gas and heavy metal contaminated leachate is a result of high intensity of these processes. Especially Cu and Cr have high concentrations in leachate. Moreover, the content of Cl is high in Pärnu and Pääsküla landfills' leachate. This could be caused by deposited fatty or wood sludge. As shown in Table 6, that the landfilling activity started already in 50s and the total deposited waste load in Kotinuka landfill is large. Consequences of that the anaerobic processes may be prevalent also in this landfill. It could be expected that characteristics about Kotinuka landfill leachate contain heavy metals to.

It is important that the landfill capping has settled before air begin to diffuse into the landfill and landfill enters so-called humus-generation (sulphide-oxidisation) phase. Since exact composition of landfilled waste is estimated (Fig.7), Estonian landfills contain quite likely hazardous compounds (waste). Therefore, it is important that a cover system is set on the landfill to avoid oxygen penetration into the landfill body. If the oxidisation process of insoluble sulphides compounds to mobile sulphates starts, than the leaching of the metals take place and this causes higher pollution of groundwater and more serious environment problems.

Since these landfills pose the big threat to groundwater, the establishment of impermeable cover system for the minimisation of negative environmental impact is highly recommended. In addition, trenches around landfills should be created to hinder leachate flow into surface water. However, due to the lack of relevant information about the stage of landfill settlements, the technique of landfilling, the precise suggestions about exact covering method cannot be given.

6.4.2 Landfills with lower environmental impact

The second and the third group, namely landfills, which have medium or low waste loads and are not considered as environmental risks, do not need urgent actions at the first stage. At these landfill sites the leachate is not considered to cause harmful effects to surface or groundwater. Even though these landfills do not cause direct pollution of groundwater now, it is recommended that they will be monitored.

Paide landfill and Tori landfill leachate characteristics has been presented in Appendix II. The composition of heavy metals is not high and due to low waste load and low waste compaction rate, the probabilities of anaerobic processes are low. Therefore the local cover materials with a lower permeability could be use instead of expensive impermeable cover system. In addition, trenches around landfills should be created to hinder leachate flow into surface and ground water. If the probability of the toxic component in the leachate is higher than plastic sealing could be used under the soil cover layer to reduce water infiltration. The using of plastic sealing instead of clay layer like as barrier layer is more economic on small landfills, due to easier transportation and installation. And if necessary the landfills, which cause the risk for groundwater aquifer, should be covered with proper cover according to the EU requirements.

<u>Tuula landfill</u>

As described in chapter 4.1.1, this landfill is the only one in Estonia, which has artificial bottom sealing. The fact that leachate soaks over brink of landfill shows that bottom sealing operates. In this case, the irrigation with leachate system may be utilised as pilot project, with monitoring system for minimising risk of groundwater. The recirculation of leachate in this landfill site is chosen, the leachate pumping system is required. Due to the climatic conditions ponds for collection and storage of leacahte should be created beside the landfill. The top cover cannot be impervious, no impervious immediate layers should exist in landfill. The interim cover, for example, consists of soil, crushed wood chips, compost should be settled on landfills. The using of compost as interim cover helps to minimise smell problems on the landfill site. In this case, the impermeable daily cover is not needed, because of it could hinder water and air inflow into the landfills.

7. EDUCATION AND FUTURE PERSPECTIVES

7.1.1 Education

More training and education programmes should be arranged for workers who are constructing the capping systems at landfill sites. Only the education and training of employees can guarantee an environmentally and occupationally safe handling of waste in landfills. Moreover, the employees themselves should be interested in participation of education and training programs to seek for qualifications and skills. One argument against education is willingness to invest money by company due to the fact that is too expensive. In general, there is strong tendency to underestimate the costs of education. This could be leaded to more expenses for cleaning up and restoring the environment after unprofessional and careless handling of waste and bad performance of construction.

There are also another alternative education people, who could work on waste and landfilling issues. This can be achieved by the involvement of students from environmental departments at Estonian universities. After learning the basic concepts in the field, students should be able to connect theory to applied work. Therefore, the lectures would have more practical work as a compliment to their theoretical content. Training activities, such as study visits, meetings, lectures and development of action plans could also be included. The students should be involved as collaborators in environmental projects conducted by the official agencies, the municipalities and with the people from County Environmental Department.

7.1.2 Public awareness

Landfilling has been a relatively inexpensive method of waste management until today in Estonia. The price, which was charged for collection of waste, did not appear to reflect the actual cost of waste management. Following the EU directive, the price for waste delivery and the tipping fee will increase and it may lead to two outcomes in Estonia. First, a consequence of this is that the generation of waste will decrease. Also, there is quite a big possibility that the illegal dumping activities will increase due to low income and low willingness to pay by people. Awareness and income levels of people are the main factors, which influence frequency of illegal dumping activities. As shown in statistics, the number of delinquencies against waste managing activities has caused 82.5 thousand Estonian Crowns in damage in 1999 (SOE, 1999a). Therefore, the probability of increasing of illegal behaviour is high in Estonia. As it could be seen from chapter 4.2, there are limited number of people who are working in the environmental field in the town governments and rural municipalities. Therefore, the control system is not effective. To increase awareness of people, the more relevant information should be presented in TV, radio and press. In general, the environmental courses are recommended all level in school, even in preliminary school. The environmental thinking and awareness should find a way to human mind already in the young ages. Besides, the avoidance of the illegal dumping activity could be achieved by the establishment of stricter legislation and by the improved control system.

One of the goals according the Estonian Environmental strategy (see Fig. 8) is to decrease waste production to 250-300 kg per capita. This is possible if people are aware of this sustainable waste management. Therefore, policy will prefer sustainability ideas to high consumption and uncontrolled landfilling.

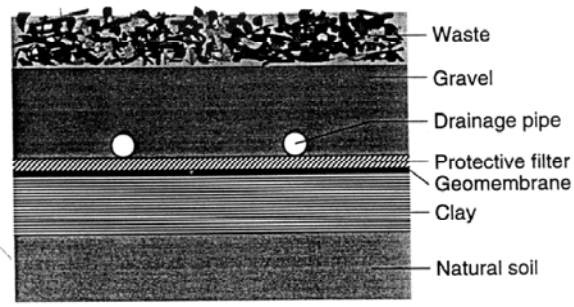
7.1.3 Sustainability

In Estonia the current landfill techniques have to be revised in an effort to provide more sustainability. There are two routes towards achievement of sustainable development. Primarly, by changing already developed operation and measures more sustainable. Secondly, by introducing alternative waste management techniques. Until today, landfills that have reached their filling capacity, are only covered with heterogeneous soil materials. This performance does not minimise water infiltration in to the landfills and potential groundwater pollution is high. Using the impermeable cover systems instead of permeable capping is one step to improve the landfill technology and avoid environmental pollution. However, this option postpones the after care period of landfill site, leaving problems to the next generations. Therefore, the covering of landfills with impermeable cover systems is a short-term solution. To solve the problems beyond one generation, after the principle each generation take care of their waste, it will be necessary to encourage degradation of waste in the landfills to take place rapidly. As it shown in chapter 3.4, the recirculation of leachate is an approach to achieve it. Therefore, the recirculation of leachate is long-term solution. On the other hand, this solution could not be used today, thus it will lead to greater groundwater pollution already during this generation due to lack of bottom sealings under landfill sites. When landfill has proper bottom sealing to avoid the groundwater contamination the using of leachate recirculation approach it is highly recommended. Thus this could be sustainable solution in the case then sanitary landfills are completed in Estonia.

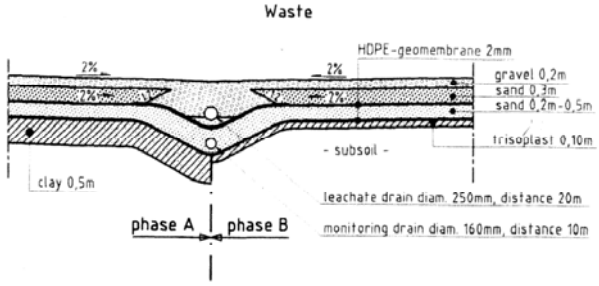
Disposal of waste is least desirable element in a hierarchy of waste management policy (Marques, 1996). There are plans to improve quality of waste management by building new sanitary landfills in Estonia. Since organic waste will be probably landfilled at least into the next decade, then for implementation of leachate recirculation or bioreactor technology in future sanitary landfills, will be good option to stabilise and detoxify landfills. Moreover, this kind of biological treatment could be used to recover nutrients through the leachate and/or to extract energy through the collection of biogas, as it shown by Bramryd (1997). If landfills are operated as bioreactors, waste decomposition and gas production are accelerated, thus fulfiling the recovery possibility, as preferred in second stage of waste hierarchy. This second stage of waste hierarchy is recovery, which includes recycling, composting and conversion of waste to energy, either by digestion or thermally. Advantage of recycling is that it saves on recourses, but may not necessarily provide energy savings.

7.1.4 Prospects for Sanitary landfills in Estonia in the future

Since leachate recirculation is a good method to accelerate the stabilisation of landfill, the idea of using this kind of technique should be considered already in construction of the sanitary landfills in Estonia. Similarly with the U.S. (Lee and Jones-Lee (1994a,b; 1996; 1997)), the newly built landfills in Estonia should have a double composite lined bottom, in which the lower composite liner is part of the liner leakage monitoring system. This type of construction has especially large importance in order to avoid the expensive impermeable capping system when landfill will reach its filling capacity and for making it possible to use leachate recirculation systems. Fig. 13 shows a recommended structure of bottom sealings, (a) only the type of layers and (b) the layers with determined thickness, respectively to Hogland (1997) and Ouden (1999).



(a)



(b)

Figure 13. *Structure of bottom drainage system a) according to Hogland, 1997; b) according to Ouden, 1999.*

In a long term perspective, the use of the leachate circulation technique in sanitary landfills seems to be safer landfilling technology. The after-care period will be shorter, which gives lower overall costs of landfills. In the future, the landfill mining concept could be used as a possibility to remove waste from some landfills being potential groundwater pollution risks (Hogland et al., 1995).

8. CONCLUSIONS

The hypothesis drown up that recirculation of leachate is a better approach for old landfill closure in Estonia than the "dry tomb" method is not valid. The evaluation of the two methods for final closure of the landfill shows that dry tomb approach is preferable in most cases in Estonia. The main reason for this is that there is lack of proper bottom sealing at most Estonian landfills and soil types underneath the landfills has high hydraulic conductivity do not fulfilling the EU Directive. The use of a leachate recirculation system will endanger to groundwater aquifers and, therefore, is not suggested. However, this statement is not valid as a recommendation as a final closure procedure for all old landfills in Estonia. Each site should be evaluated on a case-by-case basis to reach the right decision of which combination of sub-layers and materials that is most beneficial on the site in question. The top cover vegetation on the landfill must be selected properly so its roots will not penetrate and destroy the protecting soil layers and no risk for erosion occur and it should be fit into surrounding landscape. Efforts to use local natural materials of proper quality as coverage should be done in order to reduce costs. Any leachate produced can preferably be collected, stored and safely handled in natural vegetative system or artificial made wetlands in away surface and ground water is not contaminated. It is of importance that implementation of these new methods are combined with educational program for engineers and workers involved so all works are made with a high quality.

Due to economical reasons, it's likely that Estonia cannot fulfil the EU Directive and National Environmental Strategy during the next decade, especially for the closure of all old landfills to minimise the number of MSW landfill sites up to 150. Therefore, the plan of landfill closure has to be prepared in order to work effectively and avoid groundwater pollution. In addition, the leachate recirculation option should be implemented in legislation framework to achieve right landfill manage in future.

9. RECOMMENDATIONS FOR FUTURE WORK AND RESEARCH

- Introduce modelling tools, such as the HELP model to carry out calculations of leachate production from Estonian landfills;
- Work out of a methodology for establishing environmental plans for old landfills;
- Carry out the risk assessment of environmental effects from the landfills and classify each landfill due to its size and its hazardousness;
- Create a strategy for remediation and final closure of old landfills that should be implemented and economic support for the program reserved;
- Each landfill shall have a minimum clean up program;
- Create a handbook in Estonian should be written to support educational programs for engineers and workers;
- The general awareness of people should be improved in order to avoid illegal dumping activity as might be consequence of increased fees for delivery of waste;
- A pilot closure landfill should be established as demonstration and research object and the following research activities is suggested;
    - Test leachate recirculation and evaluation of risk for contamination of groundwater;
    - Tests for improvement of the quality of the local soil for use as cover material and protection layers;
    - Test of leachate treatment in natural vegetation system and artificial wetlands;
    - Landfill mining research project should be carried out as a pilot land remediation investigation;

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APPENDICES

Appendix I. Characterisation of leachate. Mean values are given in parentheses. (Spinosa et al., 1991)

Parameter	Acid-generating phase (mg/l)	(mg/l)	Methane-generating phase (mg/l)
pH	(6.1)		(8.0)
BOD5	4 000-40 000 (13 000)		(180)
COD	6 000-60 000 (22 000)		500-4 500 (3 000)
BOD5/COD	(0.58)		(0.06)
NH4-N		30 3 000 (750)	
N-tot		50-50 000 (1 250)	
P-tot		0.1-30 (6)	
SO4	70- 1 750 (500)		(80)
Ca	10- 2 500 (1 200)		(60)
Mg	50-1 150 (470)		(180)
Fe	20-2 100 (780)		(15)
Mn	(25)		(0.7)
Zn	(5)		0.03-4 (0.6)
Cl			
Na			
K		100-5 000 (2 100)	
		50-4 000 (1 350)	
		10-2 500 (1 100)	
		(µg/l)	
As		5-1 600 (160)	
Cd		0.5 140 (6)	
Ni		20-2 050 (200)	
Pb		8 1 020 (90)	
Cr		30-1 600 (300)	
Cu		4 1 400 (80)	
Hg		0.2-50 (10)	

Appendix II. Characterisation of leachate in Estonian landfills (Toomel, 1997b).

Parameters	Pääsküla	Aardlapalu	Pärnu	Paide	Tori
Area of landfill (ha)	26	11	20	2.3	0.43
Precipitation (mm/y)	540	580	540	600	560
Waste (t/y)	200 000	20 000	42 000	5 000	300
Leachate (m^3/a)	50 100	17 450	30 150	3 860	624
Leachate (m3/ha/day)	5.4	4.4	4.2	4.7	4.0
	(g/m^3)	(g/m^3)	(g/m^3)	(g/m^3)	(g/m^3)
BOD7	290	90	125	168	168
NH_4	154	429	1 453	679	56
NO_3	49	0.7	2.8	17.5	123
Tot-P	8.8	4.4	12	8.4	8.4
Cl	8 725	499	2 219	381.4	447
SO_4	465	10.4	37	170.8	528
Pb	184	181	70	25	15
Zn	436	905	500	75	75
Cr	666	113	281	50	25
Ni	335	905	211	15	14
Cu	981	136	105	15	62

Appendix III. Soil improvement possibilities (Saarela, 1997).

Samples of natural material	Shortage that should be improve	Possibility to improvement
Mixture of mineral soil and park waste	Too light	Add silt moraine type of soil
Rather coarse-grained soil	To improve water and nutrient retaining capacity	Add peat
Rather grained soil (especially for lawn)	-	Add peat or coarser mineral soil
Soil	Poor humus content	Requires extra peat
Soil	The specific electrical conductivity is high	To use only in soil mixtures, where the other soil's specific electrical conductivity is low. Liming and fertilisation depends on the nutrient of other soil mixtures.
Sandy clay with humus	-	As a green material it is required extra soil improvements agents, peat and sand.
Mud (e.g. very decomposed park waste)	-	Add extra sand moraine type of mineral soil
Sandy clay type of soil	Clay becomes airtight	Add extra peat and sand
Silty clay type of soil	Poor composition	Add extra peat and sand