

# Landfill closure plan

– a pre-study of Țîntăreni landfill in the  
Republic of Moldova

*Emma Lindberg and Johanna Olsson*

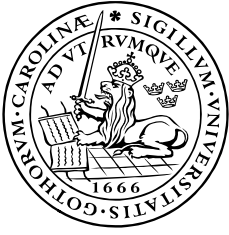
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Environmental and Energy Systems Studies

Department of Technology and Society

Lund Institute of Technology



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Abstract

The Republic of Moldova is aiming towards a membership in the European Union. To achieve this goal the waste management in the country, among other things, needs to be organised. Currently the waste management situation in the country is chaotic.

Țiņțăreni landfill is situated near the capital Chisinau. Approximately 19.5 million m<sup>3</sup> waste is deposited on the landfill, whereof a large part is biodegradable. The deposited waste covers an area of 18 hectare. Țiņțăreni landfill does not meet with the requirements in the European Union landfill directive 1999/31/EC. The landfill is equipped with a landfill gas collecting plant, but it is not used, and the leachate treatment is deficient. The landfill is controversial and conflicts impede the landfill operation.

The aim with this thesis is to present recommendations on how the Moldovans should close Țiņțăreni landfill. Landfilling is an environmental issue and the goal is therefore to present recommendations that will lead to minimal landfill gas and leachate escape. The overall question answered in this thesis is:

*What should the Moldovans do to successfully close the landfill in Chisinau in order to fulfil the EU-directive 1999/31/EC on landfilling?*

To accomplish this aim estimations of produced landfill gas, analysis of leachate composition and chemical parameters in ground water have been carried out. The measured parameters were: BOD, COD, pH, electro-conductivity, alkalinity, temperature, petroleum products, NH<sub>4</sub><sup>+</sup>, Cl, PO<sub>4</sub>, SO<sub>4</sub>, NO<sub>3</sub><sup>-</sup>, NO<sub>2</sub><sup>-</sup>, As, Ca, Mg, Mn, K, Na, Pb, Sr, Cu, fat, detergents, dry particles and suspended particles as well as permeability on clay. An investigation of possible final covering materials was also performed.

The result indicates that Țiņțăreni landfill probably is in between the acid-anaerobic and methanogen phase, and that landfill gas is produced and will be produced for approximately another 100 years at the site. The landfill is built in an area with clay with a permeability of 1.4 \*10<sup>-9</sup> m/s.

Overall the measured ground water in Țiņțăreni does not completely fulfil the requirements for drinking water set up by the Swedish Livsmedelsverket. It is not necessarily Țiņțăreni landfill that is responsible for the poor water quality. A water balance for Țiņțăreni landfill indicates a high evapotranspiration in the area.

Based on the results of the analyses and estimations it is recommended that Țiņțăreni landfill is used until a better waste management alternative is available in the Republic of Moldova, but that sorting is introduced. Clay is a suitable material to use in the hydraulic barrier in the landfill final covering. Other layers needed in the final covering are; a levelling layer, a gas drainage layer, a drainage layer and a protection and vegetation layer. A deep investigation of the leachate treatment is needed. Most important is that the landfill gas equipment is turned on, and all conflicts connected to the landfill are solved.

Keywords

Țiņțăreni landfill, waste management, landfill gas, leachate, final covering, Chisinau, the Republic of Moldova

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Emma Lindberg och Johanna Olsson

LUND May, 2012

## **Letter of contribution**

A natural division of the work assignments has been carried out when working with this report in the Republic of Moldova. Emma Lindberg had the responsibility of translating from Russian to Swedish when needed, and working with the GIS-tool "Geoportal". Johanna Olsson had the administrative responsibility of contacting people and arranging meetings, and had a larger responsibility for designing diagrams. The work with sample gathering, conducting interviews and study visits were completed in complete collaboration of the authors.

Also the report was developed and written in complete collaboration of the authors.

Emma Lindberg och Johanna Olsson

LUND May, 2012

## Summary

The Republic of Moldova is aiming towards a membership in the European Union. To achieve this goal the waste management in the country, among other things, needs to be organised. Currently the waste management situation in the country is chaotic.

Țîntăreni landfill is situated near the capital Chisinau. Approximately 19.5 million m<sup>3</sup> waste is deposited on the landfill, whereof a large part is biodegradable. The deposited waste covers an area of 18 hectare. Țîntăreni landfill does not meet with the requirements in the European Union landfill directive 1999/31/EC. The landfill is equipped with a landfill gas collecting plant, but it is not used, and the leachate treatment is deficient. The landfill is controversial and conflicts impede the landfill operation.

The aim with this thesis is to present recommendations on how the Moldovans should close Țîntăreni landfill. Landfilling is an environmental issue and the goal is therefore to present recommendations that will lead to minimal landfill gas and leachate escape. The overall question answered in this thesis is:

*What should the Moldovans do to successfully close the landfill in Chisinau in order to fulfil the EU-directive 1999/31/EC on landfilling?*

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The result indicates that Țîntăreni landfill probably is in between the acid-anaerobic and methanogen phase, and that landfill gas is produced and will be produced for approximately another 100 years at the site. The landfill is built in an area with clay with a permeability of  $1.4 \cdot 10^{-9}$  m/s.

Overall the measured ground water in Țîntăreni does not completely fulfil the requirements for drinking water set up by the Swedish Livsmedelsverket. It is not necessarily Țîntăreni landfill that is responsible for the poor water quality. A water balance for Țîntăreni landfill indicates a high evapotranspiration in the area.

Based on the results of the analyses and estimations it is recommended that Țîntăreni landfill is used until a better waste management alternative is available in the Republic of Moldova, but that sorting is introduced. Clay is a suitable material to use in the hydraulic barrier in the landfill final covering. Other layers needed in the final covering are; a levelling layer, a gas drainage layer, a drainage layer and a protection and vegetation layer. A deep investigation of the leachate treatment is needed. Most important is that the landfill gas equipment is turned on, and all conflicts connected to the landfill are solved.

**Keywords:** Țîntăreni landfill, waste management, landfill gas, leachate, final covering, Chisinau, the Republic of Moldova

## **Glossary and abbreviations**

<b>S.A. Apa-Canal</b>	water company in Chisinau
<b>BOD</b>	biological oxygen demand
<b>CDM</b>	clean development mechanism
<b>Chisinau</b>	capital of the Republic of Moldova
<b>COD</b>	chemical oxygen demand
<b>Crețoaia</b>	village in Moldova
<b>DOC</b>	degradable organic content
<b>E</b>	evapotranspiration
<b>EC</b>	European Commission
<b>EEC</b>	European Economic Community
<b>EU</b>	European Union
<b>FOD-method</b>	first order decay method
<b>Geoportal</b>	GIS-tool
<b>HMAW</b>	hazardous medical activity waste
<b>IPCC</b>	Intergovernmental Panel on Climate Change
<b>LandGEM</b>	landfill gas modelling tool
<b>MSW</b>	municipal solid waste
<b>NGO</b>	non-governmental organisation
<b>NMOC</b>	non-methane organic compounds
<b>NSR</b>	Nordvästra Skånes Renhållnings AB
<b>P</b>	precipitation
<b>PPP</b>	polluter pays principle
<b>Regia Autosalubritate</b>	waste management company in Chisinau
<b>SYSVA</b>	Sydskaånes avfallsaktiebolag
<b>Țintăreni</b>	village in the Republic of Moldova
<b>TOC</b>	total organic carbon
<b>WEEE</b>	waste of electric and electronic equipment

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# 1 Introduction

Waste of all sorts is produced all over the world. The waste management however does look different in different parts of the world. The most common waste treatment method in the EU and worldwide is depositing of waste in landfills (Avfall Sverige, 2009). This is a bad treatment method from an environmental perspective. Rainwater, groundwater or surface water can infiltrate the waste and thereby produce leachate. This contains many different substances originating from the waste. Leachate can, if not handled properly, contaminate surrounding land and waters. When organic waste is degraded in landfills it is mainly done anaerobically. In this process methane is produced and released into the atmosphere. Methane is 21 times worse than carbon dioxide from a global warming perspective which means that landfills around the world contributes to the climate change (Bernes, 2007).

Waste is generated by consumption. Generally the more money you have the more products you consume and thereby the more waste you produce. In Chisinau the waste production is approximately 400 kg/person and year (Serghienco, 2012C). This figure can be compared to the European Union where the average production of waste per person is 524 kg/year and in Sweden 515 kg/year (Avfall Sverige, 2012A).

There are different treatment methods for waste and alternatives to landfilling. The best method from an economical, spatial and environmental point of view is to make sure that waste is not produced. This is probably impossible, but it is possible to minimize the amount of waste produced. The second best waste treatment alternative is to reuse products before they are being classified as waste. What is waste to a person does not necessarily have to be waste for another. Second hand stores are a good example on how to implement this strategy. After this option material reuse is the best alternative. To implement this method the waste has to be separated. If organic waste is separated from other waste it can be decomposed in decomposition chambers, and the methane produced in this process can be utilized as energy, to produce electricity or even fuel in cars. The next waste treatment method is recycling of waste with energy recovery. Waste contains a lot of energy, and if it is burned in incineration plants the energy can be utilized for example for heating purposes. The worst treatment method is deposition of waste at landfills. With this method the waste is just put in piles. These five treatment steps are the European Union's waste hierarchy and something every member state should follow (2008/98/ EC).

Waste management is not black or white and a combination of the treatment methods is the best way to manage waste. All types of waste cannot be treated with just one treatment method. Waste minimization can nevertheless be used on all types of waste and is something everyone should strive for (Börjesson, 2010).

The landfill for the city of Chisinau, Țițărieni landfill, should be closed according to European Union legislation since the Republic of Moldova wishes to enter the European Union. There are plans to build an incineration plant for waste in the near future, which will decrease the need for landfills in the Republic of Moldova (Arnberg, 2012).

## 1.1 Aim

The aim with this thesis is to present recommendations on how the Moldovans should close Țițărieni landfill. Landfilling is an environmental issue and the goal is therefore to present recommendations that will lead to minimal escape of landfill gas and leachate.



The closing of the landfill will, if implemented, hopefully lead to a better environment for the Moldovan citizens.

To accomplish this aim some sub targets has been set up. The goal is to fully understand the effects of landfilling and how the closure of a landfill is carried out in general. Also to gather all the needed information and data on the studied object, Țiņțăreni landfill.

Since the Republic of Moldova wishes to be a member of the European Union it is important that hazardous waste, energy recovery, producer responsibility, separation of waste at the source and biological treatment is considered in the recommendations.

### **1.1.1 Questions**

The overall question answered in this thesis is:

*What should the Moldovans do to successfully close Țiņțăreni landfill in order to fulfil the EU-directive 1999/31/EC on landfilling?*

To answer this overall question the following sub questions need to be answered:

- What is deposited in the landfill?
  - In which phase of degradation is the landfill?
    - What is the gas producing potential of the landfill?
    - How can the leachate be studied in order to determine the phase of degradation of the landfill and the environmental impact in the landfill surroundings?
  - Considering leachate and landfill gas; what needs to be taken into account when covering the landfill?
- Which materials are possible to use for the final covering?
- When should the landfill be closed in order to minimize the effect on the environment?

### **1.2 Methods**

This thesis starts with a desktop study. In this, different covering methods, as well as different materials used for those methods are looked upon. Problems and difficulties, as well as other factors connected to the landfill, are also considered. The EU legislation on landfilling is studied and used as the legal framework for the thesis.

To answer the questions for the desktop study literature and reports on the subject are studied as well as existing closure plans. Landfills in Sweden belonging to Hăssleholm Miljö AB, NSR and SYSAV are visited in order to gain knowledge on how landfills are closed in Sweden, what type of materials are used, how are they constructed etc. The EU directive 1999/31/EC is studied to cover the legal aspects.

In the Republic of Moldova the landfill is visited to gain knowledge about the area. Suitable measurements are carried out in order to investigate the status of the landfill, and estimate the production of landfill gas and leachate.

To determine the phase of degradation of the landfill leachate samples are analysed. A geological map is used to determine suitable places where clay could be found that fulfil the EU regulations on permeability. This clay is then tested.

In order to answer statistical questions and what has been deposited in the landfill interviews with the owner of the landfill, the Ministry of Environment and experts on the area are carried out. Interviews are also carried out in order to investigate the organic matter in the landfill. A part of the Background chapter and the whole

Description of the landfill area chapter are based on interviews performed in Chisinau, the capital of the Republic of Moldova. These chapters are also partly based on own observations from the authors eight weeks long stay in Chisinau.

### 1.3 Limitations

This thesis focuses on the conditions in the Republic of Moldova, mainly in the capital Chisinau. The studied object is Țîntăreni landfill. The supply of final covering materials may be different for different parts of the world. Therefore the focus is on materials found in the Chisinau region. The legal boundaries are set to EU level and the Moldovan framework is not considered. Regarding time the closed landfill is supposed to last over the next 1000 years, which makes this the time limit on the suggested material for the different covering layers.

More to keep in mind is the economical limitations for the country, which may limit the possibility of using certain materials in the covering process. Also language barriers as well as existing and available information limit the study.

## 2 Background

*This chapter focus on introducing the Republic of Moldova and the legislation around waste and landfilling in the European Union.*

### 2.1 The Republic of Moldova

The Republic of Moldova is a country in Eastern Europe, situated between Romania and Ukraine, with a population of 4.3 millions (Utrikesdepartementet, 2011). The inhabitants are mainly a Romanian-speaking majority and a Russian-speaking minority (Sida, 2012A). The capital is Chisinau and the area of the country is 33 843 km<sup>2</sup> (Utrikesdepartementet, 2011). In Figure 1 is a map over Europe presented, the Republic of Moldova is marked with red, and a map over the Republic of Moldova indicating the location of Țîntăreni landfill.



Figure 1 shows a map over Europe; the Republic of Moldova is the red country, and a map over the Republic of Moldova indicating the location of Țîntăreni landfill (Europa länder, 2012)

The Republic of Moldova is one of the poorest countries in Europe and also one of the youngest, declared independent in 1991 (Sida, 2012A). The financial crisis in 2010 caused the GDP to decrease with 6.5 %. The increase in GDP was before the crisis 4-7 % per year. Approximately 600 000 Moldovans are working abroad and the money sent home by these workers are an important source of income (Utrikesdepartementet, 2011). One of four citizens in the country lives below the poverty limit (Sida, 2012A). Agriculture is the base of the Moldavian economy and almost 90 % of the Republic of Moldova's surface is cultivated (Utrikesdepartementet, 2011). During the Soviet Union the Republic of Moldova was the granary for the entire Soviet Union (Sida, 2012A). Almost all citizens in larger towns have their own allotment outside the cities where they produce fresh food (Istrati, 2012). Russia and Romania are the largest trading partners (Utrikesdepartementet, 2011). Agriculture has since the independence 1991 continued to have a positive development but the need for more modern tools as well as scientific cultivation methods is large (Sida, 2012A).

Transnistria is a breakaway region in the eastern Republic of Moldova, east of the river Dniestr, and the conflict in this area is a prioritised question for the country. An authoritarian regime, with a self-declared president, controls Transnistria. Organized crime, smuggling and trafficking are major problems in the area (Utrikesdepartementet, 2011; Sida, 2012A). The leader of the Russian-speaking population has several times declared the region independent but it has not been accepted by the world (Sida, 2012A).

The Republic of Moldova is dependent on Russia to supply their energy needs. They mainly import oil, natural gas and coal. This import has been used as a weapon in the conflict with Transnistria (Sida, 2012A).

### **2.1.1 Problems in the Moldovan society**

The Republic of Moldova has problems to meet the requirements regarding human rights, and corruption in the country is spread. The Republic of Moldova is classified as 2.9 on a 10 degrees scale over corruption for the year 2011 (Transparency International 2012). A ten corresponds to a total transparency and zero very corrupt. This can be compared to Sweden that has 9.3 on the corruption scale (FN-förbundet, 2012A; Transparency International, 2012). This indicator shows the corruption in the country from an academic, public business operation and from a risk analytic perspective. It includes the corruption in the public sector and the politic system. Instances included are among others the police, the education- and health system as well as government purchases of services from the public business operation sector (FN-förbundet, 2012B).

Violation against human rights can be seen in restrictions in the freedom of expression and freedom of media, and harassments against LGBT-persons and people with different religions other than the Orthodox Church. Many Moldovan girls are victims of trafficking in Europe (Sida, 2012A).

### **2.1.2 The European Union, Sweden, Borlänge Energi and the Republic of Moldova**

The Republic of Moldova aims towards entering the European Union in the future and the cooperation with the EU has increased during the last years. For a long-term solution to the poverty in the Republic of Moldova a membership in the EU is needed (Sida, 2012B). The EU provides the country with financial help. The Republic of Moldova has also collaborations with the World Bank, the International Monetary Fund and the

European Investment Bank as a step towards a membership in the EU. The UNDP, a branch of the UN, fights poverty in the country (Sida, 2012A).

The cooperation between the Republic of Moldova and Sweden focus on democracy, human rights, equality, sustainable city planning and market development (Sida, 2012A). Sweden plays an important role in the Moldovan progress of entering the EU, and help the Moldovan public institutions adapt to the framework, standards and values that are applicable in the EU (Sida, 2012B). Sweden also gives financial support to increase the harvest for farmers. Sweden is the third largest aid state in the Republic of Moldova, and give the country around 110 million SEK each year (Sida, 2012B).

Borlänge Municipality has since 2009 a twin-town agreement with Chisinau Municipality. This has ended up with a ICLD project between AB Borlänge Energi, the energy and waste company of Borlänge Municipality, and Chisinau Municipality with the title "*VA –teknik och hantering*" (Borlänge Municipality, 2012). The project is about exchanging knowledge and technical "know-how" of investments in and work strategies- and planning of water and sewage treatment. This is done by study visits, education, seminars and cooperation with universities in the form of thesis works connected to the topic of the ICLD-project. An ICLD project is a project of supporting democracy (ICLD, 2012).

### **2.1.3 Waste management in the Republic of Moldova**

The Republic of Moldova is a country in the process of changing from a planned economy to a market economy. Therefore the country faces considerable challenges, not least in the environmental field. Waste management is a field in which the country has lagged behind the rest of Europe on many levels. The situation today is chaotic, and large efforts are necessary to help the country catch up with the European Union (MMRM, 2012).

Appropriate waste management and organised collection of waste in general only exists in cities in the Republic of Moldova (MMRM, 2012). In rural areas waste management is not organised at all and waste is dumped randomly (Tugui, 2007). There is also a regional difference in the quality of the waste management in the Republic of Moldova (MMRM, 2012).

The major problems with the waste management in today's Republic of Moldova is "*the presence of illegal and spontaneous dumps, overloaded landfills, sanitarly deficient ramps and deplorable conditions, low efficiency of public services and insufficient treatment of sewage sludge and animal waste*" (Bacal, 2011). All waste produced in the Republic of Moldova today is deposited on landfills, no other waste treatment methods are used to a large extent (Tugui, 2012). Some projects of waste treatment have been made in the southern part of the Republic of Moldova. Hazardous waste is included in the waste deposited on landfills, although some hazardous waste is exported. Hazardous waste generated in medical activities (HMAW) is collected separately, but there is no system in the Republic of Moldova for destruction of HMAW. In Chisinau there is a crematorium that destroys some HMAW but most of the waste produced in hospitals in Chisinau is dumped together with the Municipal Solid Waste (MSW) in the public landfills of Chisinau, including Țiņțăreni landfill (MERM, 2011).

Over 40 % of the dumps in the Republic of Moldova are illegal (Bacal, 2011). The problem is due to a mix of poor administration from the authorities, lack of funds and a careless attitude to waste from the population. The poor administration can be seen in

the licensing procedure, where many ramps are approved even if the applications lack methods for environmental and human protection, and do not meet with current national construction requirements. Inefficient regional policies also lead to misallocated landfills, adding to environmental problems (Bacal, 2011).

The quality of the legal landfills in the Republic of Moldova is insufficient. Many of them lack weighing bridges as well as paved roads (Tugui, 2007). During rainy periods trucks cannot drive on the unpaved roads, resulting in waste being dumped elsewhere than on the landfills (Bacal, 2011).

During recent years a reduction of unauthorized dumps can be seen. This has supported the work with establishing an integrated waste management (Bacal, 2011).

#### **2.1.4 Waste management in Chisinau**

The company "I.M Regia Autosalubritate" is responsible for the waste management in Chisinau. The company is a municipal autonomous company, but is under the control of The General Directorate of housing at Chisinau municipality (Primaria Municipiului Chisinau, 2012). The company's major responsibility is to collect MSW and deposit it at landfills owned by Chisinau municipality, but the company also provides transport, an animal cemetery and is responsible for public clocks.

MSW is not sorted at the source in Chisinau; all types of waste are put in the same containers. There has been a project of introducing separate collection of glass, cardboard and plastics in Chisinau, but due to lack of information people continued to mix the waste and the project failed (Istrati, 2012). Hazardous waste is collected in generating units that are delivered to companies specialized in transportation and capitalization of hazardous materials (MERM, 2011). Hazardous MSW is not collected separately to a larger extent; mostly light bulbs are included in the hazardous MSW-type (Serghienko, 2012A). The average citizen in Chisinau does not sort this waste (Istrati, 2012; Vodă, 2012). Industrial waste produced is in 99.9 % of the cases classified as non-hazardous waste (MERM, 2011). In Chisinau about 3 tonnes of HMAW are collected each day (MERM, 2011).

In Chisinau there are about 10 000 waste containers located all over the city (Primaria Municipiului Chisinau, 2012). 96 trucks belonging to Regia Autosalubritate transport about 4 000- 4 500 m<sup>3</sup> of waste seven days a week. Annually this makes up some 1.5 million m<sup>3</sup> of waste in Chisinau alone (Serghienko, 2012A). Still this only covers 60-90 % of the MSW generated (MERM, 2012). The amount of waste generated in Chisinau grows every day with about 50-60 m<sup>3</sup> (Serghienko, 2012D).

At the moment the waste is transported to a transshipment station in Chisinau, where it is loaded onto bigger trucks. The trucks transport the waste to a "temporary storage" of waste located in the vicinity of the city (Serghienko, 2012A).

In Figure 2 a sorting platform is presented, the waste is very mixed. There is also a private company in Chisinau, ABS Recycle, which collects and recycles plastic bottles, also presented in Figure 2.





Figure 2 shows the sorting alternative in Chisinau today. The left picture shows the collecting system of plastic from the private company (cylinder). The right pictures show the sorting of glass (blue), carton (green), organic household waste (yellow) and also the result from sorting (own pictures).

The waste company Regia Autosalubritate works actively with analysing the possibilities to reintroduce separate collection of waste in the future, but with conditions prevailing in today's Chisinau separate collection is not possible (Serghienko, 2012B)

The 90 000 m<sup>3</sup> of wastewater treatment sludge produced each year at S.A. Apa-Canal in Chisinau is not deposited on landfills (Rusnac, 2012). The sludge initially has a water content of 95-96 %, it is dewatered to 80-82 % and stored in special houses, approximately for five years, until it reaches a water content of less than 70 % (Rusnac, 2012). After this the sludge is put on agricultural land. There is no sanitation step where pathogens in the sludge are killed. The current process of wastewater treatment started in 2009, before this the sludge was stored on plat forms (Rusnac, 2012).

Since this treatment method was started in 2009 the first sludge for agricultural use will not be finished until 2014. The sludge is not an income for the company and they are just trying to find places where to put it (Rusnac, 2012).

#### **2.1.4.1 Benefits of closing the landfill**

Closing a landfill is a multimillion-dollar project; therefore the investments needed to realize such a project cannot be forced upon the already stressed Moldovan economy without a full analysis of the benefits of the project (Arnberg, 2012).

First and foremost the health benefits of a closed landfill must be pointed out. Inadequate sanitary conditions at the landfill can cause contagious deceases to be spread (Ruchton, 2003). Vermin and birds are well-known features at landfills, which

contribute to the spreading of diseases (EPA, 2012). The occurrence of disposed pesticides and toxic compounds is yet another risk to keep in mind, which can cause intoxication of humans and animals. Especially scavengers who visit the landfill and lack proper safety equipment and clothes are at risk, but also workers on the landfill (Ruchton, 2003).

The closing of landfills can also contribute to the development of the agriculture in the Republic of Moldova. An orderly closed landfill prevents the spreading of pollutants to soil and waters, which can affect the agriculture negatively (Avfall Sverige, 2012B). Landfills also require large areas. These areas can be used for agriculture instead of landfilling if other waste management methods are used.

Another threat, both to human health and the environment, from landfilling is the production of landfill gas, which contains methane. Landfill gas is not toxic to humans, but it has an unpleasant smell and can cause nausea (Avfall Sverige, 2010A). Methane is toxic to vegetation (Hogland 1997). Due to the high methane content and the presence of hydrogen landfill gas is flammable and very explosive. A concentration of methane around 5-15 % of the volume is enough to cause an explosion (Hogland 1997). Electric wires damaged by settlements can ignite landfill gas (Avfall Sverige, 2010A).

Landfill gas is lighter than air, and can therefore migrate into confined spaces. When methane is produced in a confined space it can displace oxygen. People entering a confined space close to landfills that lack gas drainage therefore risk getting suffocated (Avfall Sverige, 2010A). If no cover prevents the gas it spontaneously migrates towards the surface of the cover, and is released into the atmosphere where it affects the climate. If there is a cover the gas will migrate in a horizontal direction towards the foundation of the construction, or seek its way through cracks or cavities (Hogland 1997). Moreover methane is a more potent greenhouse gas than carbon dioxide, landfills are therefore important contributors to the greenhouse effect (Bernes, 2007).

As mentioned the Republic of Moldova wishes to enter the European Union. Closing of the landfill, which does not fulfil the requirements in the EU directive, is a step towards the Republic of Moldova entering the EU.

## **2.2 Legislation on waste management**

*This part of the report will describe the waste management in the European Union and in the Republic of Moldova.*

### **2.2.1 European Union - Waste directive 2008/98/EC**

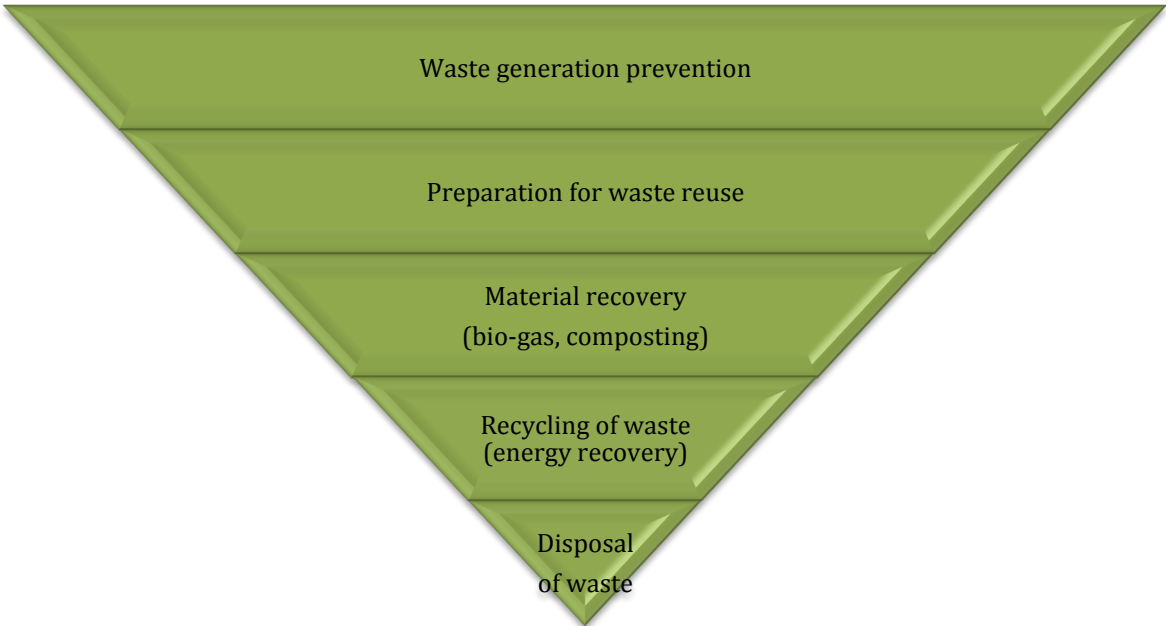
Due to the need of a clarification of the frame directive 2006/12/EC of waste a new European Union waste directive was adopted in 2008 (2008/98/EC). This new directive has more details about the definition of waste and waste management in the EU, the regulations and control measures connected to the waste hierarchy and permissions and requirements of reporting, inspections and overhaul of waste management (Naturvårdsverket, 2012A). Especially the waste definitions and the waste hierarchy have been clarified (2008/98/EC). Moreover the directive 2008/98/EC replaced the directives:

- The frame Directive on waste (2006/12/EC)
- The Directive on hazardous waste (91/689/EEC)
- The Directive (75/439) on waste oil.

MSW in the EU is waste generated by households or waste with similar properties to waste generated by households (1999/31/EC). The characteristics of hazardous waste are described in Appendix III in the waste directive (2008/98/EC). In general waste that is explosive, oxidizing, flammable, irritant, harmful, toxic, toxic for reproduction, mutagenic or eco-toxic is to be classed as hazardous. Also sensitizing substances, which can cause reactions of hypersensitization, waste that releases toxic gas in contact with air, water or acid or waste that can generate leachate that possesses any of the mentioned qualities is to be classified as hazardous (2008/98/EC). This waste is to be sorted out and treated separately from non-hazardous waste according to the waste directive. Hazardous waste generated by households in the EU is foremost batteries, oil, paint and waste generated by medical activities (European Commission, 2000).

**2.2.1.1 The European Union waste hierarchy**

To facilitate the work with waste management in the European Union a waste strategy has been adopted. When waste is to be treated it is important to choose treatment method depending on the properties of the waste. The waste strategy is based on the waste hierarchy and certain principles, and is to be seen as a foundation for legislation and political decisions concerning waste in the EU (2008/98/ EC). The waste hierarchy is illustrated in Figure 3:



**Figure 3 Describes the waste hierarchy (inspired by directive 2008/98/EC).**

An example of waste prevention is not to use unnecessary packaging material. To change how people consume is also an act of waste prevention. A second hand shop is an example of a method for reusing products. Composting is an example of material recovery, while recycling of packaging materials need no explanation. Worth noticing is that for example the incineration of waste with energy recovery also is classified as recycling. The least prioritised step according to the waste hierarchy is to dispose of waste at for example landfills. The members of the EU must take action to ensure that the environmentally best treatment method is used in their countries. The waste must be treated in such a way that neither humans nor the environment suffer great harm from it (2008/98/EC).



The principles on which the waste strategy is based are the polluter pays principle (PPP), the principle of producer responsibility, the subsidiarity principle, the principle of self-sufficiency and the precautionary principle (European commission, 2000). These principles dictate the conditions for how waste is to be treated, and who is responsible for its disposal.

The producer responsibility is the principle that states that the producer of a product is responsible for it from the production until the consumer wishes to dispose it. The producer is obligated to make sure that the product is recycled or disposed of in a less harmful way for the environment. The producer responsibility principle has its foundation in the PPP (Producentansvarsguiden, 2012). In EU there is a producer responsibility on packages, batteries, vehicles and waste of electronic and electric equipment (WEEE). The directives dealing with the products covered by producer responsibility are:

- 94/62/EC for packages and packing material
- 2002/96/EC for WEEE
- 2006/66/EC for batteries
- 2000/53/EC for vehicles

The recycling of products covered by the producer responsibility is to be facilitated for the consumer, by for example the company installing and paying for collection stations or other collection methods, which are easily accessible and free to use for the consumer (2002/96/EC). The consumer at the same time is obligated to bring the product to the recycling station or use the existing collection method. For the introduction of the producer responsibility to be successful it is important that the introduction is supported with information campaigns to the population (94/62/EC).

### **2.2.2 European union - Landfill directive 1999/31/EC**

Landfilling in the eyes of the European Union, directions on how a landfill should be managed and responsibilities connected to landfilling is summarized in Directive 1999/31/EC. The aim of the Landfill Directive is to reduce the harmful environmental effects of waste disposed at landfills (EU, 2011A).

The first thoughts of a common directive on landfilling in the EU derive from the 1980s (Naturvårdsverket, 2003). Voices were then heard that a supplement of the General Directive of Waste 75/442/EEC was needed (1999/31/EC). The landfill directive did not come into force until July 1999.

According to the landfill directive the generation of waste should be prevented (1999/31/EC). This is a key issue in waste management. Still some waste will be generated also in the future, and according to the directive "*the management of this waste should be facilitated and recycling should be preferred*" (1999/31/EC). This means that the waste is to be treated rather than being deposited. Sorting is classified as a treatment. Worth pointing out is that there is no actual ban of depositing waste on landfills in the landfill directive. If landfilling is to take place in the EU however, the directive clearly states that "*the quantity and hazardous nature of waste deposited at landfills should be reduced*" (1999/31/EC). This can be interpreted as that landfilling is not a long-term solution to the waste issue in the EU (EU, 2011B).

There are several requirements associated with owning and operating a landfill, since a landfill is considered to provide a significant environmental impact (1999/31/EC). PPP in the landfill directive 1999/31/EC is to be interpreted as that the owner is responsible

for the landfill, and the environmental consequences of its operation. The landfill owner has to report all environmental effects of the landfill; also after the final closing. Appropriate control procedures and measurements of landfill leachate and gas are therefore to be done. The landfill owner has to control the waste before it is deposited on the landfill. A list of the received waste should be kept to further gain control over the landfill and reduce the risk of harm. In addition, the owner has a responsibility to monitor the landfill, and prevent looting. The employees must have proper training and the owner must have sufficient financial security to operate the landfill (EU, 2011A). All this can be read in the landfill directive.

According to the landfill directive waste must be classified as inert, non-hazardous or hazardous waste before it can be deposited. The different classes of waste should be disposed separately from each other, and must not be mixed (EU, 2011A). The members of EU should make sure that only treated waste is landfilled. A strategy for how the amount of biodegradable waste deposited on landfills is to be diminished and how it can be treated rather than landfilled must be established. In the directive there is a requirement that within 15 years the biodegradable waste going to landfills is to be reduced to 35% of 1995 levels (1999/31/EC). Also routines of how the landfilling of liquid, explosive, inflammable, corrosive, oxidizing or hospital waste or tiers can be avoided should be set up. Dilution of this waste is to be prohibited. To report the progress of the work member states should submit a report on the implementation of the directive containing the strategy every third year (1999/31/EC).

Rules must also be established of how permission for landfilling is requested and the member states must make sure the criteria for permission is respected. Guidelines must be set up for how the management, supervision and remediation of the landfill are to be funded with the landfill fee (1999/31/EC).

Presented in Table 1 are the requirements for the covering of a landfill according to the EU directive 1999/31/EC.

**Table 1 shows the recommended layers for the final cover of a landfill (1999/31/EC).**

<b>Landfill category</b>	<b>Hazardous waste</b>	<b>Non-hazardous waste</b>
Gas drainage layer	Not required	Required
Artificial sealing layer	Required	Not required
Impermeable mineral layer	Required	Required
Drainage layer > 0.5 m	Required	Required
Top soil cover > 1 m	Required	Required

There are no requirements on how thick the layers should be except for the drainage layer and the topsoil cover. The hydraulic barrier should have a permeability of  $10^{-9}$  m/s or less (1999/31/EC). The amount allowed to pass through this barrier is 5 l/m<sup>2</sup> and 50 l/m<sup>2</sup> for landfills with hazardous waste and non-hazardous waste respectively (1999/31/EC).

### **2.2.3 Waste legislation in the Republic of Moldova**

In the Republic of Moldova 35 of 50 existing environmental laws are about waste management (MMRM, 2012). Still the environmental protection from the waste sector is

not sufficient and the legislation on waste in Moldova does not live up to the standard that exists in the European Union (Guvir, 2011).

In the Republic of Moldova MSW today is defined as “waste generated by households, economic- and social units and enterprises, garden and park waste, street waste, sewage sludge, construction and demolition waste” (Guvir, 2011).

A new law on waste has been developed in the Republic of Moldova. The law will enlarge the importance of the PPP and producer responsibility and will correspond to the EU directive on waste (MMRM, 2012). The new law will be approved in the Moldovan parliament later this year (Tugui, 2012).

### **3 Theory**

*In this chapter the theory behind landfilling and covering of a landfill will be studied.*

#### **3.1 Landfilling**

Landfilling is the waste treatment method that is least preferred in the waste hierarchy. The reason for this is the fact that landfilling needs a large area and does not use the capacity of the waste, like energy gain or less material use. Still landfilling has some advantages; it is for example a treatment method, which does not require large investments. All that is needed is a large enough area and no investments in expensive techniques are needed, at least outside the European Union (Börjesson, 2010).

A large amount of different waste is mixed in a landfill and all processes that occur are not known. One of the most important processes is the decomposition of organic material. The decomposition takes place in several steps, first in the presence of oxygen and later on without oxygen (Avfall Sverige, 2012B).

In a landfill many pollutants and chemicals are collected in a small area. The risk of these substances leaking out to the surrounding environment is large. Water that has been in contact with the deposited waste is called leachate. The composition of the leachate depends on what has been deposited at the landfill, the decomposition of the waste and amount of water (Naturvårdsverket, 2012B).

Landfills, in which organic material has been deposited, will produce methane due to the anaerobic decomposition of organic material. Methane is a gas that contributes to the global warming and it is therefore important to not let this gas escape into the atmosphere. The methane has a high energy content and can if collected be used as energy for example for heating or electricity production (Avfall Sverige, 2012B). The landfill gas is flammable and fires in landfills may cause dioxins to be released due to incomplete combustion (Naturvårdsverket, 2012B).

##### **3.1.1 Degradation Phases**

A landfill will go through different degradation phases as time passes. In an active landfill different degradation phases can occur at the same time on different locations (Cerne et al., 2007).

###### **3.1.1.1 Oxygen and nitrogen reducing phase**

The first phase is the oxygen and nitrogen reducing phase and it is dependent on oxygen. Through compaction of the waste the biological activities from bacteria will rapidly consume all oxygen present (Cerne et al., 2007). This phase lasts as long as there is

oxygen left, normally between some days up to some weeks depending on the landfill (Naturvårdsverket, 2008).

#### **3.1.1.2 Acid anaerobic phase**

If the landfill leachate has a pH of about 4-5, and high values of BOD and COD, the landfill is in its fermentation phase (Hogland 1997). This is an acid phase in which fatty acids, mainly acetic acid, carbon dioxide and some hydrogen gas, are produced (Cerne et al., 2007). In this phase the amounts of nitrogen and sulphur are high (Naturvårdsverket, 2008). The quota BOD/COD is in the interval 0.5-0.7 (Naturvårdsverket, 2011). The content of metals in leachate, for example zinc, iron and manganese, is also high. This phase can last for some weeks up to ten years (Naturvårdsverket, 2008).

#### **3.1.1.3 Methanogen phase**

The methanogen phase is completely anaerobic. In this phase the landfill gas, mainly methane and carbon dioxide, is produced (Cerne et al., 2007). The pH changes during this phase to a neutral or basic level. The amounts of BOD are average but the levels of COD, nitrogen, iron and chlorides are high (Naturvårdsverket, 2008). When the pH increases the conductivity will decrease due to less solubility for metals (Jonsson, 1999). The quota BOD/COD is in the interval 0.05-0.3 (Naturvårdsverket, 2011). The leakage of metals will decrease in general but the amounts of lead may increase. This phase will last for a couple of months up to several hundred years (Naturvårdsverket, 2008).

#### **3.1.1.4 Humic forming phase**

It is only the persistent organic substances that are left when the humic forming phase begins. It contains high molecular humic forming compounds with hydroxylic and carboxylic groups bound to phenols. There is a risk that metals are released and if oxygen reaches the landfill this risk increases (Naturvårdsverket, 2008). The quota of BOD/COD is less than 0.05 (Naturvårdsverket, 2011). The humic forming phase can last for over hundred years (Naturvårdsverket, 2008).

### **3.2 Landfill gas and methane production**

Landfill gas is a colourless, mainly odourless gas, which consists of 45-55 % methane (CH<sub>4</sub>) and 25- 40% of carbon dioxide (CO<sub>2</sub>) (Avfall Sverige 2010A). The rest is a mix of oxygen-, hydrogen-, and nitrogen gas, and different pollutants like hydrogen sulphide gas (H<sub>2</sub>S), siloxane and halogenated carbohydrates (Avfall Sverige, 2010B). The composition of the landfill gas depends on where in the landfill the measurements are carried out and also on which phase the landfill is in and the amount of deposited biodegradable material (Avfall Sverige 2010A).

A landfill is usually not constructed to optimize the gas production and the process is therefore slow and time-consuming (Avfall Sverige, 2010B). The temperature and deficiency of nutrients and water mainly limits the microorganisms (Hogland, 1997). The higher temperature the faster decomposition but the microorganisms cannot tolerate too high temperatures (Eldor, 2007). The amount of produced landfill gas depends on factors such as the shape and size of the landfill, the used landfill technique, the composition of the waste, and the chemical and physical properties of the landfill (Avfall Sverige, 2010B).

The anaerobic degradation in a landfill takes place in three steps. The complex organic matter is in the first step hydrolysed by fermentative bacteria into soluble molecules. In the second step acid forming bacteria convert the molecules into simple organic acids,

carbon dioxide and hydrogen (Themelis and Ulloa, 2006). 70 % of the methane in a landfill comes from the conversion of acids (Hogland 1997). It is therefore important that the conditions for the acetogenic bacteria are optimal. Methanogenic bacteria form methane in the third step, either by breaking down the acid to methane and carbon dioxide or by reducing carbon dioxide with hydrogen (Themelis and Ulloa, 2006). Methanogenic bacteria are sensitive to pH changes; a pH of 6-7 is optimal for the bacteria (Hogland 1997). Below are two of the representative reactions presented (Themelis and Ulloa, 2006).

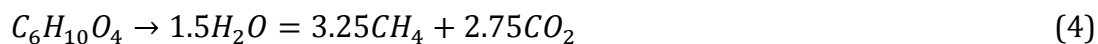
Acetogenesis:



Methanogenesis:



The molecular formulas in 1-3 can determine the maximum amount of natural gas that may be generated during anaerobic decomposition. This is presented below (Themelis and Ulloa, 2006).



If the deposited waste contains sulphate, the sulphate reducing bacteria will dominate over the methanogenic bacteria. No methane will be produced as long as sulphate is available. Demolition waste consist of a great deal of sulphate, hence demolition waste should be avoided in a methane producing landfill for optimal conditions (Hogland 1997).

The transportation of landfill gas depends mainly on diffusion and convection. Diffusion is due to differences in the concentration of materials, and is important in materials having high moisture content and a specific pore structure and porosity. Convection is due to differences in density within materials, and is temperature and concentration dependent. Landfill gas can also be transported by advection, which is caused by pressure differences (Avfall Sverige, 2010A).

### 3.2.1 Collection of landfill gas

A gas collecting system is expensive and in order to find investors it is important that the gas extraction is profitable (Avfall Sverige, 2010B). A gas collection system may contain the following components (BCME, 2010):

- Collection field
- Collection piping
- Land fill gas extraction plant
- Disposal/Destruction system for the gas
- Process control system

The collection field contains the gas wells (BCME, 2010). The gas wells are drilled vertically into the waste or laid out horizontally on the waste in order to collect the gas. The tubes are usually made from plastics or steel. To prevent air from entering the wells the tubes are sealed in the top. The tubes are placed in gravel and the part that reaches

the waste is perforated (Avfall Sverige, 2010B). It is important to plan the location of the tubes and wells in order to reach as much waste as possible (BCME, 2010).

The collection piping consists of a network in order to connect the collection field with the torch or utilization plant (BCME, 2010). Each well has its own outlet pipe and control valve. The pipelines are put into the waste and lead to a common control station (Avfall Sverige, 2010B). The control station is connected to a ventilation/compression station. The gas is then sucked into an extraction plant where the gas is burned in order to utilise the energy content or just flared without energy (Avfall Sverige, 2010B). Even if a plant uses the gas for energy there is always a torch as well. The reason for this is that the gas should be flared if there are operational problems at the facility. The gas is thereby not released into the atmosphere and contributing to the global warming (BCME, 2010).

A problem when construction a gas collecting system is that the landfill gas contains a lot of moist and therefore forms condensate on the inside of the gas pipes. To avoid problems with water, all the pipes should be sloped in order to drain the condensate. The slopes should be towards a collecting area where the condensate can be taken care of (BCME, 2010).

The process control system keeps track of the entire collecting system and ensures proper and safe conditions (BCME, 2010).

### **3.2.2 Estimations on landfill gas production**

A theoretical potential gas volume for a landfill can be calculated based on information of the composition and amount of the waste. Long-term factors important to gas production are water content, pH and temperature of the waste, as well as the structure of the landfill and the landfill technique used. A guideline value for gas production in landfills is 200-300 m<sup>3</sup> gas/ tonne of household waste (Hogland, 1997).

Different substances are decomposed with different rates, which make it necessary to measure the gas production of the landfill. These measurements may give an indication of where in the landfill the gas production is the largest (Avfall Sverige, 2011).

### **3.2.3 Landfill gas production modelling**

When studying the conditions for installing a gas collecting plant it is important to have knowledge of the gas potential of the landfill. The gas potential can be estimated by modelling. There are many models available to model landfill gas formation. Most of the numerous models are based on a first-order decay model or a multi-phase model. Around 10 % of the methane flux from the top-layer is assumed to be oxidized; this has however received less attention in the modelling area (Oonk, 2010). There are many different models to simulate the landfill gas production. Two of the models available are presented in the following chapters.

#### **3.2.3.1 The IPCC model**

The IPCC model is based on the processes that regulate the methane emission. These are according to Samuelsson et al. (2005):

- the methane production that emerge spontaneously in the landfill during anaerobic conditions
- the outtake of methane gas in the pipe lines
- the oxidation of methane that occurs in the boundary layer between aerobic and anaerobic conditions in the surface layer

The methane emission can be described as:

$$CH_4\text{Emission} = CH_4\text{Production} - CH_4\text{Outtake} - CH_4\text{Oxidized} \quad (1)$$

The outtake of methane gas is measured regularly in the landfills that use this technology. The emissions and the oxidized part can be measured by special equipment (Samuelsson et al., 2005).

The IPCC-model is determined by the fact that the production of methane gas is dependent on the amount of waste as well as its gas potential, expressed as a function of the DOC, Degradable Organic Content. There are two models, one standard method where the methane production assumes to take place the same year as the waste is deposited, and the FOD-method, First Order Decay model, that assumes the methane gas to occur according to an exponentially decreasing function which distributes the production over the coming years after the waste was deposited (Samuelsson et al., 2005).

The standard method, which lacks a time factor, gives a good result if the amount of waste is approximately the same each year, steady state. The gas production for a certain year,  $T$ , can then be expressed as (Samuelsson et al., 2005):

$$GasProduction_T = \frac{16}{12} \cdot F \cdot DOCF \cdot MCF \cdot \sum_{X=1}^n MSW_{Xt} \cdot DOC_{Xt} \quad (2)$$

$\frac{16}{12}$  = the recalculation in mole weight from carbon to methane

$F$  = the amount of methane in landfill gas % moles

$DOCF$  = amount of gas potential that is actualized in methane

$MCF$  = an adjustment factor for the receiving praxis at the landfill.  $MCF$  is assumed to be in the interval 0.4-1 and is 1 if there is no compaction, covering or levelling.

$MSW_{Xt}$  = the deposited amount of waste  $X$  the year  $t$

$DOC_{Xt}$  = the amount of organic carbon for waste  $X$  the year  $t$

### 3.2.3.2 LandGEM

LandGEM is a Microsoft Excel based tool (Davies, 2009). To estimate the annual emissions over a specified period LandGEM uses a first order decomposition rate equation, see Equation (3) (Alexander et al., 2005).

$$Q_{CH_4} = \sum_{t=1}^n \sum_{j=0,1}^1 k \cdot L_0 \cdot \left(\frac{M_t}{10}\right) \cdot e^{-kt_{ij}} \quad (3)$$

$Q_{CH_4}$  = the annual methane generation in the year of calculation ( $m^3$ /year)

$i$  = the year time increment

$n$  = (year of the calculation) – (initial year of waste acceptance)

$j$  = 0.1 year time increase

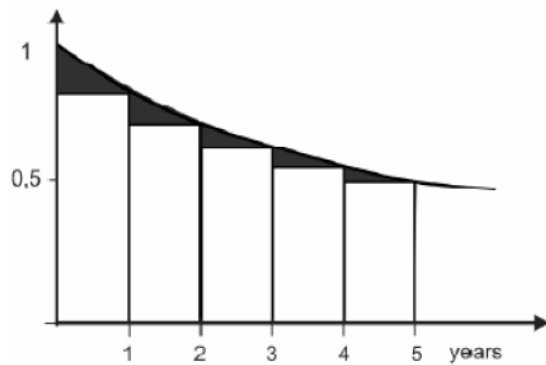
$k$  = methane generation rate ( $year^{-1}$ )

$L_0$  = potential methane generation capacity ( $m^3$ /Mg)

$M_i$  = mass of waste accepted in the  $i^{th}$  year (Mg)

$t_{ij}$  = age of the  $j^{th}$  section of waste mass  $M_i$  accepted in the  $i_{th}$  year (decimal years, e.g. 3.2 years)

A first order decomposition equation is only an approximation. This means that there will be systematic errors when using these types of models (Oonk, 2010). This is illustrated in Figure 4 below.



**Figure 4 error for a conventional first order equation in gas production (Oonk, 2010).**

The LandGEM model is very popular on an international level because of its availability (Davies, 2009).

### 3.3 Leachate

When precipitation infiltrates a landfill and gets in contact with waste leachate is formed. Leachate can also be created when waste is compacted and the water in the waste is squeezed out. Old landfills may also have a problem with ground and surface water infiltration. The amount of leachate is dependent on precipitation, decomposition and temperature (Naturvårdsverket, 2008).

Leachate contains many different substances. Organic substances are usually analysed as BOD, COD or TOC. The concentration of iron and manganese may be high in leachate but the concentration of other heavy metals such as mercury and cadmium are usually lower. This is because the heavy metals are bound to sulphides. Heavy metals can be released if oxygen penetrates the landfill (Hogland, 1997). The amount and type of substances in a landfill depends on the type of waste. It is important not to let out substances in the surroundings in order to decrease the environmental impact from the landfill (Cerne et al., 2007). Common substances in leachate are presented in Table 2:

**Table 2 Presents the most common substances present in leachate (Hogland, 1997).**

BOD	SO <sub>4</sub>	Zn	Cd
COD	Ca	Cl	Ni
NH <sub>4</sub>	Mg	Na	Pb
N	Fe	K	Cr
P	Mn	As	Cu

The infiltration of water can, during the active phase of the landfill, be limited by covering parts of the landfill continuously and thereby only keeping small parts open for infiltration (Naturvårdsverket, 2008).

#### 3.3.1 Water balance on landfills

Surface water will flow off the landfill when it is covered. This water must be collected in a drainage system, and treated before it reaches a recipient. To be able to dimension the



treatment system it is important to know how much water will flow of the landfill. A water balance must therefore be presented (Naturvårdsverket, 2004).

To estimate the surface runoff from the landfill a calculation of the water balance must be carried out. The landfill directive states that the final cover must not have a leakage greater than 5 l/m<sup>2</sup> year for a landfill for hazardous waste (1999/31/EC). An easy variant of estimating the water balance and the assumed surface runoff is defined by Naturvårdsverket (2004) as:

$$P + I_g + I_s + W = E + R + L_c + L_L + M \quad (4)$$

Where

*P*= precipitation

*I<sub>s</sub>*= surface water runoff

*I<sub>g</sub>*= ground water runoff

*W*=water added with the waste

*E*=evaporation

*R*=surface runoff

*L<sub>c</sub>*=collected leachate

*L<sub>L</sub>*=estimated leakage of leachate

*M*=difference in water deposit

According to this equation the water, which is added to the landfill either as rainfall or infiltration, leaves the landfill as runoff, leachate or evaporation, or stays inside the landfill (Naturvårdsverket 2004).

### 3.3.2 Treatment methods of leachate

Different factors such as area needs, composition of the water, water volume, emission standards, and recipients are important to take into consideration when choosing leachate treatment system (Naturvårdsverket, 2008).

The European Union directive on landfilling 1999/31/EC states that water from precipitation that infiltrates the landfill should be controlled. The polluted water and leachate should be collected and treated so it reaches a quality that is acceptable before it is released into the recipient (1999/31/EC).

In Table 3 the limit values for drinking water are presented. The numbers represents the Swedish requirements on drinking water and are the maximum allowed concentration (Livsmedelsverket, 2001).

Table 3 presents the limit values on drinking water in Sweden (Livsmedelsverket, 2001).

Substance	Concentration
Temp. °C	max 20
pH	7.5-9
Arsenic µg/l	10
Calcium mg/l	100
Copper µg/l	2000
Magnesium mg/l	30
Manganese µg/l	50
Sodium mg/l	100
Lead µg/l	10
Chlorine mg/l	100
Sulphate mg/l	100
Turbidity FNU	1.5
Conductivity mS/cm	2.5

### 3.3.2.1 Biological treatment

There are different biological treatment methods for leachate, which are used in order to decompose the organic material and reduce the amount of nitrogen. Bacteria are usually used in order to reduce nitrogen by nitrification and denitrification. The rate of the decomposition is determined by temperature (Naturvårdsverket, 2008).

A way to apply this is to use an aerated dam. In this dam, with dense bottom and sides, the water is collected. There are walls that make it possible to keep the water in one place for long periods of time. The dam has different zones with either aerobic or anaerobic conditions letting both nitrification and denitrification to take place (Naturvårdsverket, 2008).

### 3.3.2.2 Separation technique

An example of a separation technique is chemical treatment, a method that can decrease the amounts of COD, metals, nitrogen and organic compounds. In this cleaning technique a metal salt, usually iron or aluminium salt, is added in order to form solid particles of the substances in the leachate. These substances are then separated from the water through sedimentation. To increase the sedimentation properties flocculants can be added. To achieve the best effect with this treatment method it is important that the leachate is not too diluted (Naturvårdsverket, 2008).

### 3.3.2.3 Recirculation technique

An option for managing leachate is recirculation of leachate. The collected leachate is returned back into the landfill (EPA, 1999). This stimulates the microbial decomposition (Karthikeyan and Joseph, 2006). The benefits of using recirculation of leachate, also known as bioreactor cell landfilling, is increased methane production, reduced time required for leachate treatment and an acceleration of the subsidence of the waste (EPA, 1999).

Leachate treatment plants can be designed differently. A method is to spray the leachate onto the active phase, another is to dig ponds or trenches into the landfill and then filling them with water. Subsurface leachate fields or injection walls are other alternatives (EPA, 1999).

A risk is to contaminate the surface water by for example outbreaks, or leaks, which increases the risk of ground water contamination (EPA, 1999).

### 3.4 Final covering layers and materials

When final-covering a landfill, many different layers are used. The local resources of natural materials and decay product determine the formation of the covering layers (Avfall Sverige, 2007). Figure 5 shows a picture of the different layers.

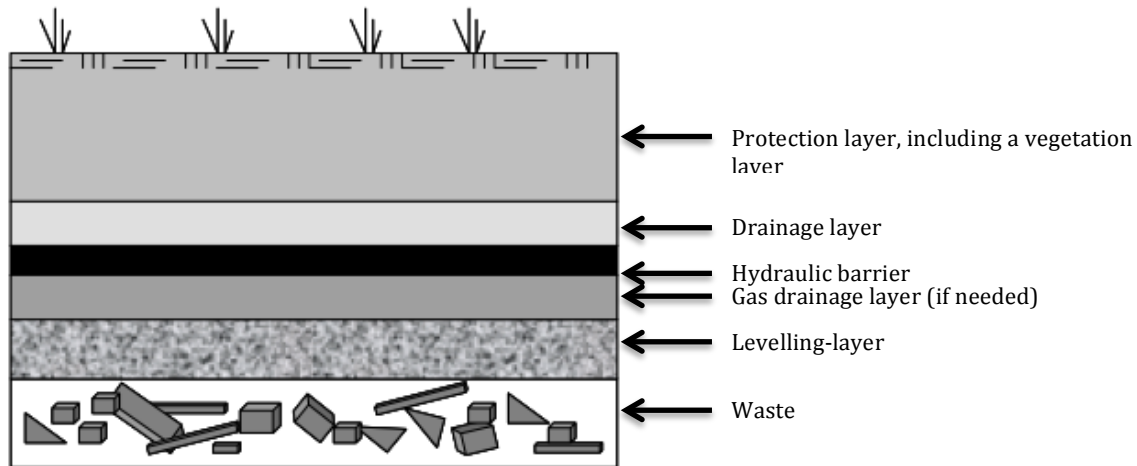


Figure 5 shows a drawing describing the different layers in a final covering of a landfill (Naturvårdsverket, 2004).

Natural materials are preferable to use in a long-term perspective compared to synthetic materials. When choosing these materials it is important to take into account how long the material in the protection layer and drainage layer is supposed to last. It may be necessary to exchange some of the material layers after some years in order to maintain a good coverage (Naturvårdsverket, 2004).

There are several factors that can effect and change the properties of the material:

- Ground frost
- Root penetration
- Erosion
- Differential subsidence
- Physical influences from overloading
- Biological and chemical aging
- Ion exchange
- Gas condense

To keep in mind when final covering a landfill is the stability. Subsidence is collapses in the landfill caused by the compression of the underlying material (NE, 2012). Organic waste being decomposed can cause subsidence. To minimize the risk of subsidence sufficient compacting is required (Naturvårdsverket, 2004). It is important to measure the subsidence in a landfill before it is finally covered and it is not unusual that subsidence measurements needs to be carried out for ten years after the deposition on the landfill has ended (Leander, 2012). If a landfill is finally covered before the subsidence has declined it can ruin the construction. Therefore the process of finally covering a landfill must be allowed to take time (Nilsson, 2012).

Independent of which materials are chosen for the covering process, virgin material or decay products, the material have to have properties like permanency. The leachate and pollutant content of the material should be investigated in full-scale experiments before they are used (Avfall Sverige, 2007).

#### **3.4.1 Levelling layer**

In order to keep the hydraulic barrier in place and to create good conditions for the water run-off it is important to maintain a suitable form of the landfill; this is what the levelling layer is used for. It is also used to ensure that the waste below does not stick out and damages the hydraulic barrier (Avfall Sverige, 2007). The layer is also the foundation of the final cover and should ensure that it has a proper bearing capacity (Beth and Gross, 2012). The recommendation is that the slope gradient is in the range 1:20 to 1:3. In order to maintain stability and to avoid a too thick levelling layer it is important that the waste is compressed and homogenised before it is deposited on the landfill (Avfall Sverige, 2007).

The layer should allow gas to pass through if the landfill contains organic material. The risk of settling, the structure of the waste and desired slope gradient decides how thick the levelling layer should be, it should however not be thinner than 0.5 metres (Avfall Sverige, 2007).

Different constructing processes produces rest products like soil, stone, gravel, concrete etc. These rest products are called excavated masses and can be used in the levelling layer. Bottom ash is another suitable material in levelling layers (Avfall Sverige, 2007). Depending on combustion techniques in different facilities the properties of the ash differs (Carling et al., 2007). Bottom ash is the ash that falls to the bottom of the combustion boiler. It contains unburned or melt together residues of for example ceramics, glass and metals. If the combustion is insufficient the ash is not good for construction due to its high levels of organic compounds.

#### **3.4.2 Gas drainage layer**

If the landfill contains organic material, landfill gas will be produced. The gas can move through the landfill and gather below the hydraulic barrier, which it can penetrate depending on the properties of the layer as well as the pressure and concentration of the gas (Avfall Sverige, 2007). This layer should limit the pressure head against the barrier and minimize the risk of damaging the hydraulic barrier (Beth and Gross, 2012). This is the reason for constructing a gas drainage layer that drains the gas (Avfall Sverige, 2007).

The need for a gas drainage layer is determined by the potential amount of produced gas. This layer may also decrease the risks of damaging the final covering of the landfill as well as the impact on climate change by collecting methane. It can consist of a pipeline that either is active or passive. If the gas should be utilized an active system, where the gas is actively extracted, is preferable (Avfall Sverige, 2007).

This layer can be regarded as a part of the levelling layer. Some extra gravel or sand may be needed in this layer in order to get the wells and pipes in the right position (Avfall Sverige, 2010B).

#### **3.4.3 Hydraulic barrier**

The actual barrier that protects the landfill from water and oxygen penetration is the hydraulic barrier (Carling et al. 2007). Its main objective is to maintain a protection

from spreading of leachate and gas diffusion (Beth and Gross, 2012). A material with a permeability of less than  $10^{-9}$  m/s will make the water run off the surface of the layer and only a small amount will infiltrate the landfill (Carling et al., 2007).

The material used in this layer needs to be permanent for a very long time since the layer should stay intact for hundreds of years (Avfall Sverige, 2007). It should also be able to handle movements in the underlying material (RVF Utveckling, 2002). Due to this requirement natural mineral material, like clays or benthonic mixes, is preferable. Clay-geo-membrane, geo-membranes in combination with mineral materials, or waste with permanent and impermeable properties can also be used. A mineral hydraulic barrier should be at least 0.3 metres thick, but when using clay-geo-membrane the layer only has to be 6-7 millimetres thick (Avfall Sverige, 2007). To protect the hydraulic barrier from cracks, by dehydration or frost, it is important with a solid protection layer with high storage capacity (Avfall Sverige, 2007).

#### **3.4.3.1 Clay based material in the hydraulic barrier**

Clay can have many different forms and consistencies. It is the amount of clay particles that determines if it should be classified as clay. In order to use clay in the hydraulic barrier it has to be compressed in order to form a continuous layer. It is easy to form thin layers of the material due to its cohesive and plastic properties. It is however difficult to keep the right water content in the clay. If there is too little water it is difficult to form the thin layers of the material since it loses its plastic properties. If there is too much water the layer will on the other hand have difficulties to carry the protection layer and machines during the working process since the waste reduces the shearing strength of the clay (Avfall Sverige, 2007).

Important to keep in mind when using clays in the hydraulic barrier is that large amounts will be consumed (EPA, 2000). Since the clay will dry out if it is stored wrongly it is important to make sure that the deliveries is adapted to the need (Avfall Sverige, 2007).

Bentonite, a processed clay with swelling properties, is ideal for using in the hydraulic barrier. This clay can be found in sediment layers formed by weathering of volcanic ashes in marine environments. The bentonite, a dry powder, is mixed with sand silt or other appropriate material. The mix contains 5-13 weight percent of bentonite (Avfall Sverige, 2007). To get a good sealing result it is important that the water content in the mix is right. When the bentonite absorbs water it swells, which is the reason for adding water just before packing it. In order to make sure that the bentonite does not swell too much and spreads to other layers it is important to have a superimposed pressure on the bentonite layer. Bentonite is a material with slow weathering and high permanency properties. If it is exposed to pollutants the swelling and tightening properties may however decrease. Pure bentonite has a hydraulic conductivity of less than  $1 \cdot 10^{-11}$  m/s (Avfall Sverige, 2007). When it is mixed with other materials the permeability increases. The low permeability can however be restored by using a thicker layer (Avfall Sverige, 2007).

#### **3.4.3.2 Other material in the hydraulic barrier**

Geo-membranes are another material that can be used as a barrier towards gas and fluids. It consists of different types of plastic and rubber in cloths in different sizes and it has a high density. Unless the membrane has been damaged or poorly outsourced, transport through the membranes can only occur through diffusion. Polyethylene,

polyvinyl chloride, flexible polypropene and butyl rubber are materials frequently used. The tensile strength can be increased by reinforcements in the geo-membranes. This is usually made by a fabric of polyester, polypropylene, nylon or fiberglass that has been casted into a web. The plasticity of the membrane is however decreased with this and the membrane has difficulties to handle subsidence. The permeability may also increase with the reinforcement. The sustainability of the membrane depends on the amounts UV-light, enzymes and bacteria, organic solvents, heat, cooling and mechanical deformation it is exposed to. These may cause joint fractures or increased permeability. By an immediate cover, with later layers, of the outsourced web the material is protected. Due to uncertainties in life span, it is said to last for hundreds of years, should a geo-membrane not be used as an only hydraulic barrier (Avfall Sverige, 2007).

The starting point when discussing sludge for covering landfills is the permanency of the material (RVF Utveckling, 2002). Sludge is an organic material from wastewater treatment plants (Carling et al. 2007). It contains large amounts of water and pathogens and needs to be dewatered and sanitized before used. If the sludge is dewatered to 70 % it is easier to handle (Avfall Sverige, 2007). Due to the organic content in the material it will be degraded. The rate of degradation is mainly determined by the availability of oxygen, the more oxygen the faster decomposition. The protection layer can be constructed in a way that minimises the oxygen availability in the hydraulic barrier. In general the available oxygen will decrease with increasing depth. It is inevitable that some decomposition of the sludge will take place, since it can occur either with or without oxygen. The degradation of the material can lead to an increased permeability, this can however be avoided by redeposition of the sludge. To do this a heavy overload is needed, in other words a solid protection layer (RVF Utveckling, 2002). The sludge has to be stabilized before usage; this can be done with fly ash from incineration plants. The sealing properties of the mix are supposed to have a permeability of  $1 \cdot 10^{-10}$ - $1 \cdot 10^{-11}$  m/s after compacting (RVF Utveckling, 2004). The permanency of the material is determined by the decomposition rate and it needs to be treated before usage to decrease the decomposition. The leachate of nutrients also affects the decomposition. Depending on the type of treatment different types of nitrogen is consumed (Avfall Sverige, 2007). If the sludge is stabilized with 50-60 % ash and constructed with a 0.5-0.6 metre layer it will meet the European Union requirements (Carling et al., 2007).

Stabilizing the biologically degradable sludge in the protection layer can decrease the risk of leachate formation and pollutant leakage. During the stabilization the organic material will be degraded and the water content in the waste will decrease. Due to this the water holding capacity will increase. The salts and metals will bind harder to the organic material and particles, which decreased the leakage of pollutants. All these factors combined will decrease the risk of substantial gas- and leachate emission as well as the risk of settlements (Naturvårdsverket, 2004).

#### **3.4.4 Drainage layer**

The drainage layer is used to drain the water that penetrates the covering layer in order to stop it from burdening the hydraulic barrier (Beth and Gross, 2012). Suitable materials for this layer are massive gravel or macadam since this layer also should be permanent. Water is stopped from ascending from the landfill and thereby dries out the hydraulic barrier because these materials stop the capillary force. The function as a gas barrier is improved by a high water saturation in the layer. The thickness of the drainage layer is recommended to be at least 0.5 metres (Avfall Sverige, 2007).

Excavated masses can for example be used in the drainage layer. Bottom ash is another suitable material (Avfall Sverige, 2007).

Glass is rather inert waste and can therefore be used as a final cover material for landfills (RVF Utveckling, 2006). It is in the layers above the hydraulic barrier inert material is preferable since rainwater will infiltrate these layers and leach out into the surrounding area. In the drainage layer inert material with quite large particle size is preferable in order to lead away the infiltrating water, in this layer glass can be used (Nilsson, 2012).

#### **3.4.5 Material separating layer**

This layer can maintain the function of the final cover of the landfill longer by ensuring that the different layers are not mixed. In this layer geo-textile or other natural materials like shingle can be used (Avfall Sverige, 2007).

#### **3.4.6 Protection layer**

The protection layer should be at least 1 meter thick (Avfall Sverige, 2007). The risk of erosion, dehydration, frost influence, root penetration and biochemical and mechanical influences may affect the layer negatively (RVF Utveckling, 2002). In order to protect the hydraulic barrier from ground frost is it preferable that the protection layer is not thinner than the maximum ground frost level for the area (Avfall Sverige, 2007).

Clean excavated masses, gravel, sand or fly ash mixed with sludge can be used in the protection layer (Avfall Sverige, 2007). If it is safe, from an environmental and human perspective, clean sludge can be mixed in the top parts of the layer. This can contribute to keep the protection layer moisturised and also facilitate the vegetation establishment (Avfall Sverige, 2007).

#### **3.4.7 Vegetation layer**

The water balance in the final covering of the landfill is dependent on the vegetation layer. Through increased evapotranspiration the vegetation is regulating the water balance, it can also decrease the leachate from the landfill to the surrounding areas. This layer also helps the finally covered landfill to blend into the surrounding landscape (Avfall Sverige, 2007).

Organic materials like black soil or sludge can be mixed into this layer to give the vegetation good conditions to settle. By using compost positive effects like decreased formation of leachate and increased methane oxidation can be achieved (Naturvårdsverket, 2004). In order to protect the hydraulic barrier vegetation with deep roots, like Alder, should be avoided. Another way to avoid deep roots is to make the conditions further down in the final cover unfavourable (Avfall Sverige, 2007). Tree roots have for example difficulties penetrating layers with fine material that are well compacted. Additionally water saturation in the hydraulic barrier makes the situation unfavourable for the roots due to anaerobic conditions (RVF Utveckling, 2002).



## 4 Țîntăreni landfill and its surroundings

*In this chapter Țîntăreni landfill and the area in which it is situated is described.*

### 4.1 Description of the landfill surroundings

The Țîntăreni landfill is situated in the Anenii Noi district, about 5 km from the village Țîntăreni, 3 km from the village Crețoaia, 5.5 km from the city Anenii Noi and 35 km from Chisinau (ALRC, 2012). According to the national census of 2004 Țîntăreni has a population of about 2870 inhabitants, and Crețoaia about 460 inhabitants (Statistica Moldovei, 2012).

The region is characterized by hills, with the highest points of 250 meters above sea level, and the lowest points of the river Dniester of around 30 meter above sea (ALRC, 2012). The area is situated in a markedly agricultural region; around 60 % of the population is occupied with agriculture (MDRC, 2012).

In the entire Republic of Moldova there is a huge problem with illegal dumps and the Anenii Noi district is not an exception of this. In Figure 6 all landfills or dumps with an area larger than one hectare in the Anenii Noi district are presented.



**Figure 6** Legal landfills (green) and illegal dumps (red) with an area greater than 1 ha in the Anenii Noi district (ALRC, 2012).

The green symbols represent legally approved landfills and the red symbols show illegal dumps. There are more dumps over the region with an area less than one hectare increasing the number of illegal dumps. The situation in some places in Țîntăreni and Crețoaia are presented in Figure 7. These dumps are smaller than one hectare and are therefore not presented in Figure 6.



**Figure 7** shows how the waste management is carried out in the village of Țîntăreni (left) and Crețoaia (right) (own pictures).



#### 4.1.1 Climate in the Republic of Moldova

The climate in the Republic of Moldova is moderately continental, with mild winters and hot, relatively dry summers (MENR, 2009). The mean precipitation during 1985-2009 was 645 mm/year in Chisinau (Popescu, 2011), and 564 mm in the total Republic of Moldova during 2006-2011 (SHS, 2012).

The aridity coefficient  $K$  in the Republic of Moldova varies between 0.5-0.65, which indicates a dry or sub-humid climate (MENR, 2009). This gives an evaporation-transpiration,  $E$  used in the water balance, Equation 5, of about 992-1290 mm in Chisinau for the years 1985-2009 and an evaporation of 868-1128 for the Republic of Moldova for the years 2006-2011.

#### 4.1.2 Geological conditions close to Țițăreni landfill

The area, in which Țițăreni landfill is situated, is dominated by the sedimentary rock type limestone (Укргеология, 1976). The limestone has elements of gravel, sand, silts and clays. The sedimentary rock type reaches a depth of about 600m, where bedrock of Proterozoic Archean undifferentiated gneisses, granites, gabbros and granulites follows. Only the layers of limestone are of importance for the landfill.

On top of the layers of limestone are layers of Chernozem, black soil with common and carbonate rich humus, which is the dominant soil type in the Republic of Moldova (Круперников 1971). In general Chernozem is fertile, and perfect for agriculture (MENR, 2009). In the area there are also loess- like loams.

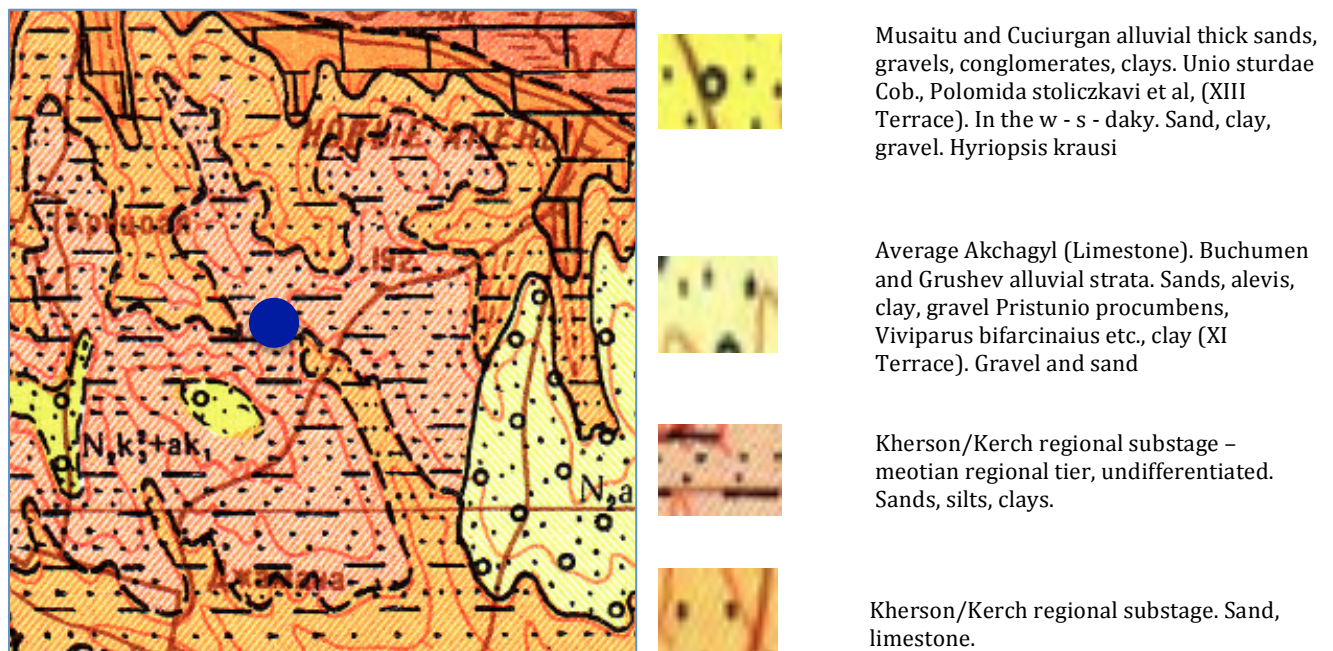


Figure 8 shows the map and the legend over the geological conditions at the landfill site, the blue dot, and its surrounding area (Укргеология, 1976).

As seen in Figure 8 the landfill is constructed on clays, silts and sand.

In the Republic of Moldova mining of minerals is widespread. Most important is the extraction of limestone, granite, slate clay, bentonite clay, sand, diatomite, gypsum and chalk stone (MENR, 2009). In Țițăreni village a quarry is located (ALRC, 2012).

Carbonate rich rocks dating from the Early Sarmatian and Badenian Era are the most extracted material. The extracted materials are used for construction, cement- and

concrete production and used in the food, glass, thermal and electro thermal industry among others (MENR, 2009).

#### 4.1.3 Hydrological basins in the Țîntăreni landfill vicinity

The Țîntăreni landfill is situated in the hydrographical basin of the river Dniester (MENR, 2009). Dniester has an annual water debit of 10.7 km<sup>3</sup>, and occupies around 67 % of the country's territory. The river flows into the Black Sea. The largest water reservoir close to the landfill is the river Bic, which is a tributary river to Dniester and flows through the capital Chisinau before reaching the Țîntăreni area, Anenii Noi district. Bic is heavily polluted with both organic and inorganic chemical toxic substances. Especially high amounts of nitrites, nitrates and ammonia are a big problem for the waters in the Republic of Moldova (MENR, 2007). Nitrates is the most potential substance to pollute drinking wells, and more than 50 % of the water in the Anenii Noi district is polluted by nitrates (MERM, 2011).

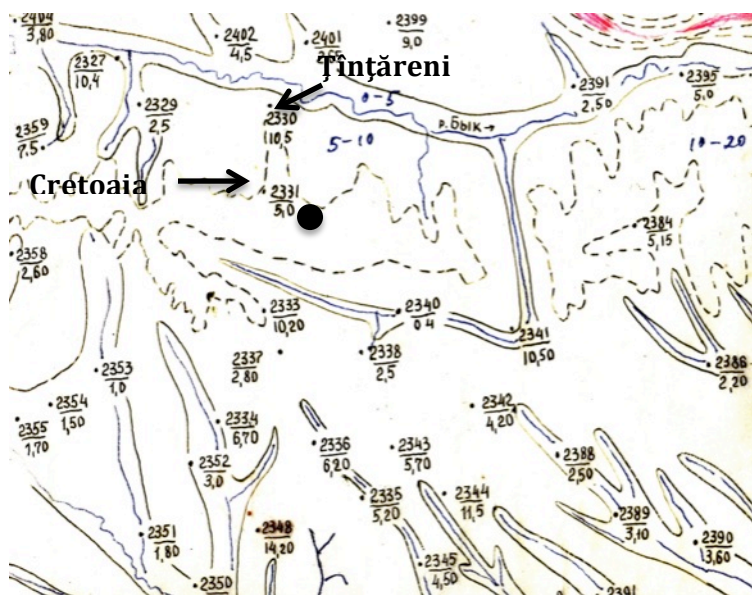


Figure 9 shows a hydrology map over the landfill area. The landfill is marked with a black dot (Bucatcuc et al., 1988).

A groundwater divide separates the villages of Crețoaia and Țîntăreni, see Figure 9. The village of Crețoaia is located on a hill and is therefore not affected by the landfill in the same way as the village of Țîntăreni, which is located in the direction of the water flow from the landfill (Maoraru, 2012; Arnot, 2012).

Ground water is important for maintaining the surface water balance in the Republic of Moldova. Ground waters form a component for the ground water debit, and are important for the hydrological cycle. Subsoil waters are not very important for the feeding of the rivers in the Republic of Moldova, the major source of water is precipitation (MENR, 2009).

The use of pesticides in the Anenii Noi area is low, with a use of less than 25 kg/ ha (MENR, 2007). The frequency of landslides in the area is about 50 per 100 km<sup>2</sup> (MENR, 2007).

#### 4.2 Technical description of the Țîntăreni landfill

The Țîntăreni landfill is located in a natural clay valley and is shaped like a huge slope towards the bottom of the ravine. The landfill was built in 1990 by excavating the valley

from clay, forming a huge hole. The total area of the landfill is 22.5 hectare (Serghienco, 2012B). The excavated clay is stored at the ulterior side of the ravine, seen from the main building, and is used as covering material between layers of waste. When the landfill was built it was one of the most modern in the Soviet Union (Serghienco, 2012B).

When constructing the landfill a 16 metre thick protective dam wall was built at the bottom of the excavated hole. On the inside of the hole a hydraulic barrier of bentonite covered with a 0.8 metre protective layer of soil was placed. For details, see Figure 37 in Appendix 1. A system of drainage pipes was placed on the bottom construction. The construction is 450 m long from the dam wall to the “mountain face”. The landfill is at its widest point 490 metres. The landfill has a capacity of about 44 million m<sup>3</sup> of waste, but today only half of its capacity, 19.5 million m<sup>3</sup> of waste, is deposited on the landfill. The waste covers an area of 18 hectares (Serghienco, 2012B).

The waste in the landfill was planned to be deposited in 2-3 m thick layers and then covered with a 25-30 cm layer of the clay, which was excavated at the landfill construction. In reality this is not the case (Arnberg, 2012). Terraces have been constructed as more waste has been dumped on the site. The slope of the terraces is 1:4, and the total height of the waste today is 35 m. The landfill has been in operation between 1991 and 2010 when the deposition ended (Serghienco, 2012B). Figure 10 shows a simplified drawing of the landfill.

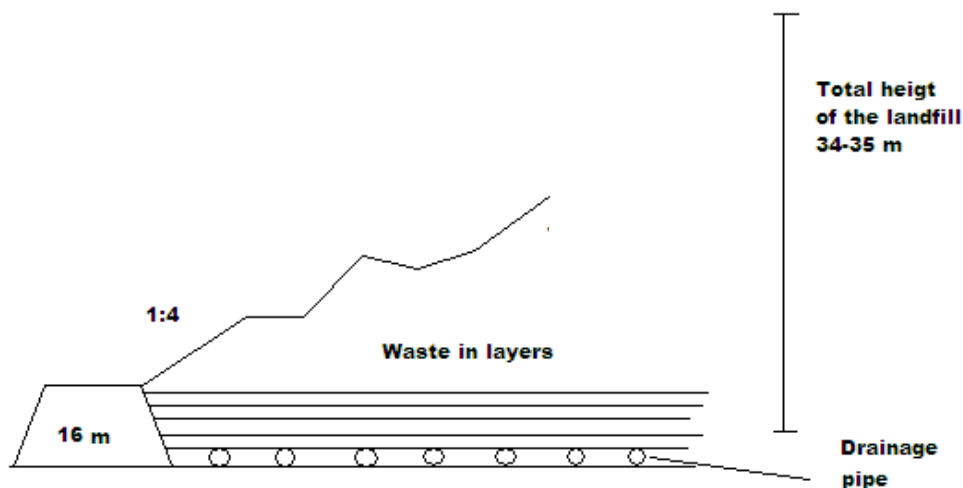


Figure 10 shows a drawing of the landfill construction.

More pictures of the landfill and the surrounding area are presented in Appendix 1.

#### 4.2.1 Landfill gas collection plant

At Țințăreni landfill equipment for gas recovery is installed, consisting of 53 vertical drilled wells connected by pipes to four collection units (Serghienco, 2012B). From the collection units the gas is let into a cleaning station connected to a torch. There is also a generator in which the gas can be used to produce electricity, but it is not connected to the electricity grid (Serghienco, 2012B). A project of installing horizontal gas drainage pipes will be launched if the authorities decide to continue using the landfill.

The equipment is of Italian fabrication and was installed by the Italian company “Biogaz Inter Limited” (Konstantinov, 2012; Primaria Municipiului Chisinau, 2012). The project



was financed by “Unendo Energia S.p.A” as a Clean Development Mechanism (CDM) project (UNFCCC, 2008). Due to a conflict between the Chisinau municipality and Biogaz Inter the gas collection system is turned off and not used (Konstantinov 2012). In Figure 11 is the gas collecting system at the landfill presented.



Figure 11 shows the gas collecting system at the landfill with the flare, wells and tubes (own pictures).

Since the installation of the gas collection system the Ministry of Environment has made measurements of the methane content in the landfill gas. This can be seen in Figure 12.

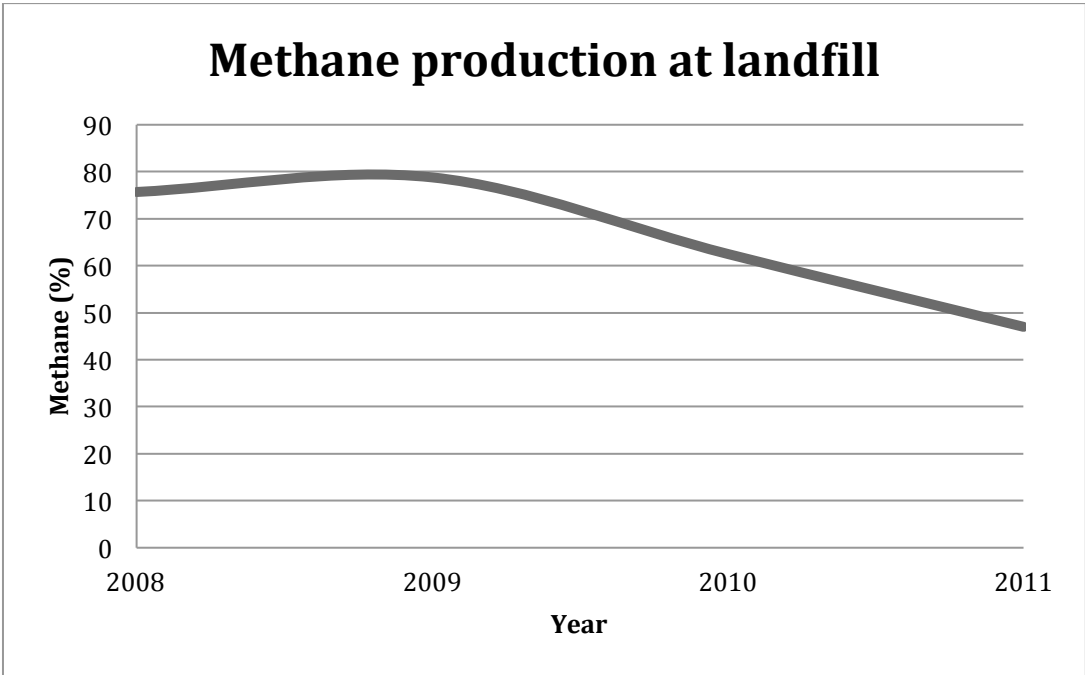


Figure 12 shows the measured methane content in the landfill gas made for the years 2008-2011 (Tapis, 2012).

#### 4.2.2 Leachate treatment

A large problem with the landfill is the leachate. The leachate is treated by a recirculation method and no other treatment method is used. There are no collection ponds for example sedimentation or aeration of the leachate (Serghienco, 2012B).

The recirculation at Țințăreni is achieved by the leachate being pumped into tank-trucks, and manually driven to the top of the landfill where the tanks are emptied over the covered waste, see Figure 13. The leachate is collected by a water drainage system of pipes put on the landfill bottom construction leading to one of two underground catchment tanks at the bottom of the valley. The leachate is collected by the trucks at the collection tanks (Serghienco, 2012 B). As mentioned there are no collection ponds for e.g. sedimentation or aeration of the leachate, but sometimes small ponds are formed on top of the landfill where the tanks are emptied.



Figure 13 Trucks for transporting leachate. The right picture shows a truck emptying leaching water (own picture).

The trip from the bottom of the landfill, where the leachate collection tanks are located, to the top, where the trucks are emptied, and then back to the bottom takes about one hour for each truck. There are two trucks driving 24 hours per day, every day of the year. The trucks carry around 3 m<sup>3</sup> leachate when completely filled. This corresponds to a recirculated amount of leachate of 52 560 m<sup>3</sup> per year. For calculations see Appendix 2. When the weather is unfavourable the tanks empty the leachate from a ramp, but when possible the trucks drive onto the waste and empty the leachate on the middle of the landfill. The reason for using recirculation is primarily to minimize the risk of fires and the amount of dust particles, and not to enhance the methane production (Serghienco, 2012 B).

#### 4.2.3 Deposited waste at the landfill

There are two types of waste deposited on the landfill, industrial waste 30 % and MSW 70 % (Serghienco, 2012C). Regia Autosalubritate have a requirement when accepting industrial waste, it cannot contain more than 40 % moisture (Serghienco, 2012C). There is a permission set up by the Ministry of Environment allowing Regia Autosalubritate to deposit a certain amount of hazardous waste on the landfill. Figure 14 shows a picture over the landfill today. The amount of waste is measured in volume instead of weight (Serghienco, 2012C).



Figure 14 shows picture over the landfill. The waste is hard to detect due to the layer of clay on top of the waste (own picture).

Waste has not been burned deliberately at the landfill in order to decrease the volume of the waste. There have however been two small fires at the landfill, which were stopped within 2-3 hours. These fires were caused by spontaneous ignition (Serghienco, 2012B).

The waste from Chisinau has for the years 1986-2010 been transported to the landfill close to the village Țiņțăreni. The changes in waste composition for these years are presented in Figure 15. The numbers are presented in Table 8 in Appendix 3.

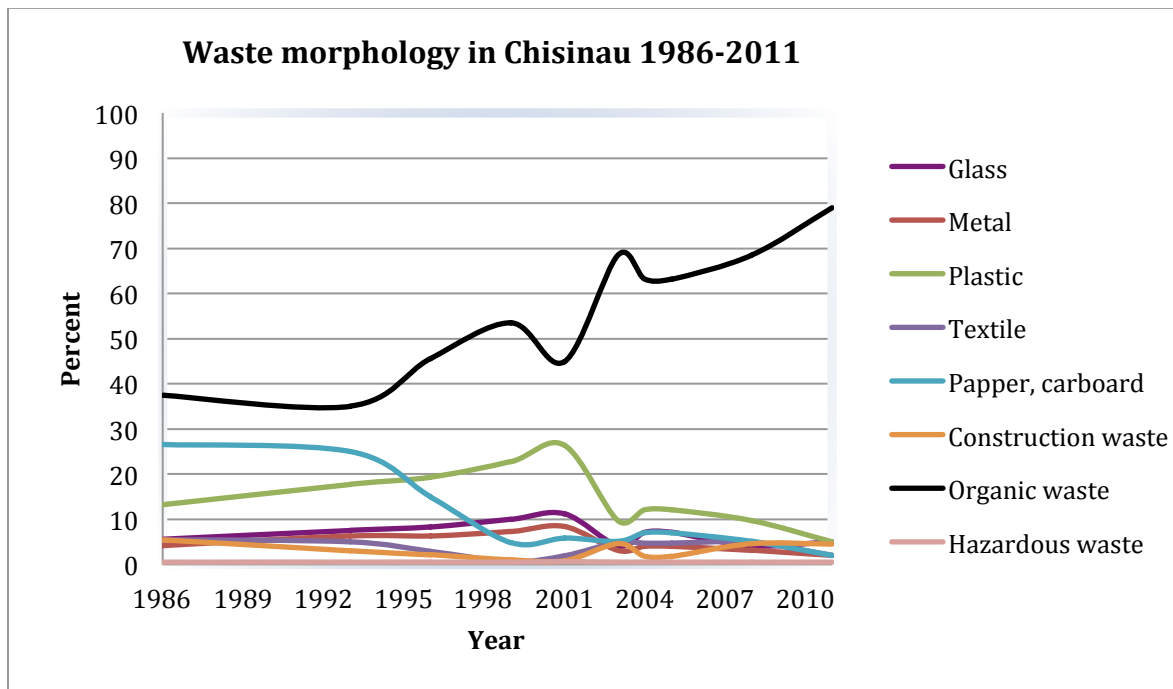


Figure 15 presents the changes in waste for the years 1986-2011( Tugui 2012, Serghienco, 2012C).

The trends from Figure 15 in the waste morphology are that the organic waste has increased, and is increasing, while paper, cardboard and plastic are decreasing. The last years the amount of construction waste has increased.

When presenting household waste there is no category for hazardous waste. The waste type hazardous waste is not defined in the same way as in the European Union. A plastic bottle with chemicals is for example classified as plastics in the Republic of Moldova and as hazardous waste in the EU (Serghienko, 2012D). The number for this type of waste has therefore been estimated by comparing other regions with similar conditions and is the same for all compared years. There is definitely hazardous waste in the household waste since there are no other places to put this waste than together with all the other waste from the households (Arnberg, 2012).

In Figure 16 the total amount of waste for Chisinau for the years 1991-2011 is presented. The figures are presented in Appendix 3, Table 9.

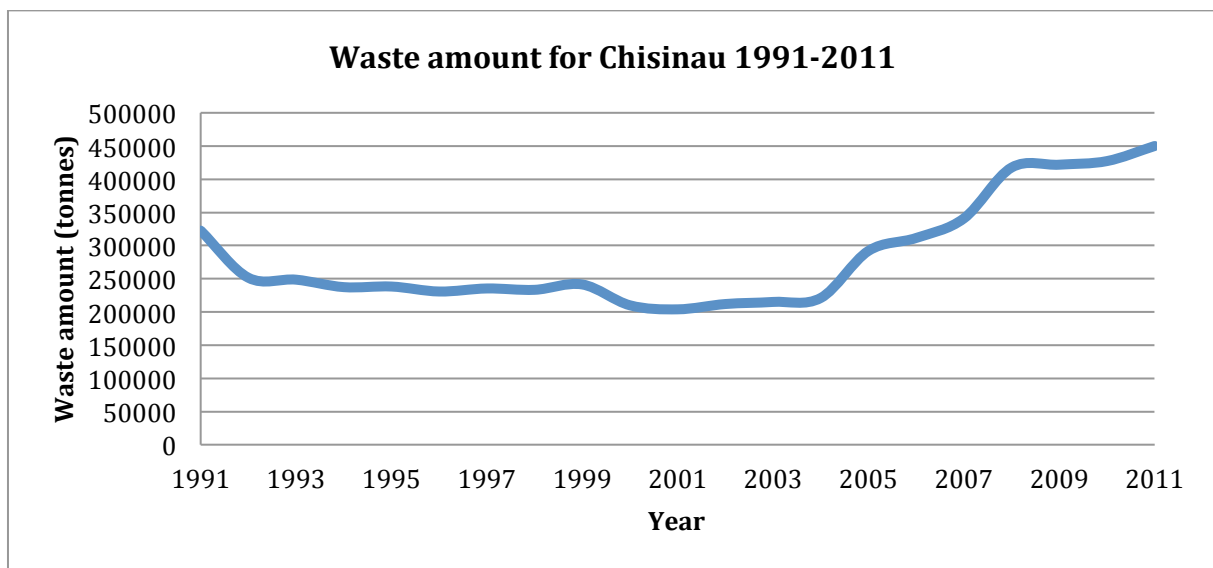


Figure 16 shows the total amount of waste in Chisinau for the years 1991-2011 (Tugui 2012, Serghienko 2012C).

The waste decreases from 1991-2001 and after this the waste amount is increasing. In Chisinau, for the year 2011, the waste amount per person and year is 400 kg (Serghienko, 2012C).

#### 4.2.4 Conflicts related to the Țîntăreni landfill

*Here the conflicts related to the Țîntăreni landfill will be explained.*

##### 4.2.4.1 Conflicts with the villagers in Țîntăreni

The landfilling of the MSW from Chisinau at Țîntăreni landfill is a controversial issue. During the last years a conflict between the locals in the surrounding villages and the Municipality of Chisinau has developed.

The locals complain about smell coming from the landfill and the spreading of diseases (Catana, 2010). The city of Chisinau is transporting their waste to a place far from the city centre, which also is irritating the villagers in Țîntăreni. The fact that the waste can be put where the producer cannot see it is a problem (Dumbrava, 2010). Another



problem is the traffic with many large trucks blocking the roads every day (ProTV, 2011).

On the other hand the Ministry of Environment as well as the waste management company claims that analyses in the area confirms that there is no significant environmental impact from the landfill (ProTV, 2011). The village Țîntăreni also has illegal dumps for waste in the area, which may explain bad smell and pollutants in the area (Serghienco, 2012C).

Measurements of the water in the area and the lake nearby the landfill show increased levels of suspended particles, ammonium and BOD (Inspectoratul Ecologic de Stat, 2009). There are on the other hand problems with increased levels in many waters in the Republic of Moldova (Leahu, 2012).

Regia Autosalubritate has legal documents confirming that the environmental impact is acceptable from the Ministry of Environment's point of view. Still it seems like the complaints from village people living nearby have been able to stop the landfill. They cannot really explain why the deposition on the landfill has stopped when only half of its capacity has been used (Serghienco, 2012C).

The Ministry of Environment is responsible for the control of the landfill and has documents over measurements made at the landfill. They also make sure that the landfill follows rules and limit values (Serghienco, 2012C).

#### **4.2.4.2 The gas collection conflict at Țîntăreni landfill**

At Țîntăreni landfill equipment for gas recovery is installed. However, the existing gas equipment is not in use and the reasons for this are many.

First there is a conflict between Chisinau Municipality and the gas company "Biogaz Inter". The conflict is about a "Concession contract" which Chisinau municipality has abrogated due to inactivity from the gas company Biogaz Inter (Konstantinov, 2012). The company Biogaz Inter turned off the gas collection system when Unendo Energia S.p.A took all the CDM money that was earned during the first year and then disappeared. At the same time Biogaz Inter had this "concession contract" with Chisinau municipality where the company promised to produce electricity. Since Biogaz Inter has turned off the equipment no gas is collected, and no electricity is produced. The company has not paid rent, which eventually lead to the case being brought to court. The conflict is currently being processed by the Moldovan Court of Justice and a verdict is yet to be decided (Konstantinov, 2012).

Furthermore the maintenance of the landfill has not been carried out satisfactorily at Țîntăreni landfill. To maintain optimal conditions for the production of landfill gas and gas collection sufficient compaction and regular coverage of the waste is needed (Arnberg, 2012). This has not been done sufficiently at Țîntăreni.



## 5 Methods for calculations and field surveys

*In this section the methods for the sample gathering and field surveys are described.*

### 5.1 First sampling of water at Țîntăreni

On March 14 the first samples from Țîntăreni were collected. The bottle, 0.5 dm<sup>3</sup>, was prepared in the morning by first cleaning it and then filling it with boiling tap water for two minutes. The leachate was taken from a well into which the leachate flows from the landfill. This well is located at the ulterior side of the landfill, in the bottom of the valley, from the main office's point of view. The leachate sample was marked nr 1.

Another water sample from a small water reservoir closer to Țîntăreni was also collected. This sample was taken from an illegal dump and is only used for comparison. The sample was marked nr 2.

About three hours after the sampling the water was delivered to the authorized laboratory at S.A. Apa-Canal the wastewater treatment company for Chisinau city. S.A. Apa-Canal performed the chemical analysis of the water.

### 5.2 Field trip with ground water and soil sampling in the Țîntăreni area

On March 28 a ground water sampling of the Țîntăreni area was carried out. The field trip was arranged as a collaboration with the Institute of Geology and Seismology of Moldova under the supervision of Dr Moraru and professor Arnaut. The measurements were taken on the locations presented on the map in Figure 17. Sample number 1C is leachate taken from Țîntăreni landfill. Sample number 2C, 3C and 4C1 are groundwater samples taken from wells in the village Crețoaia and sample number 4C, 5C, 6C, 7C and 8C are ground water taken from wells in the village Țîntăreni. Location 4C corresponds to the location of sample 2 from the first sampling.

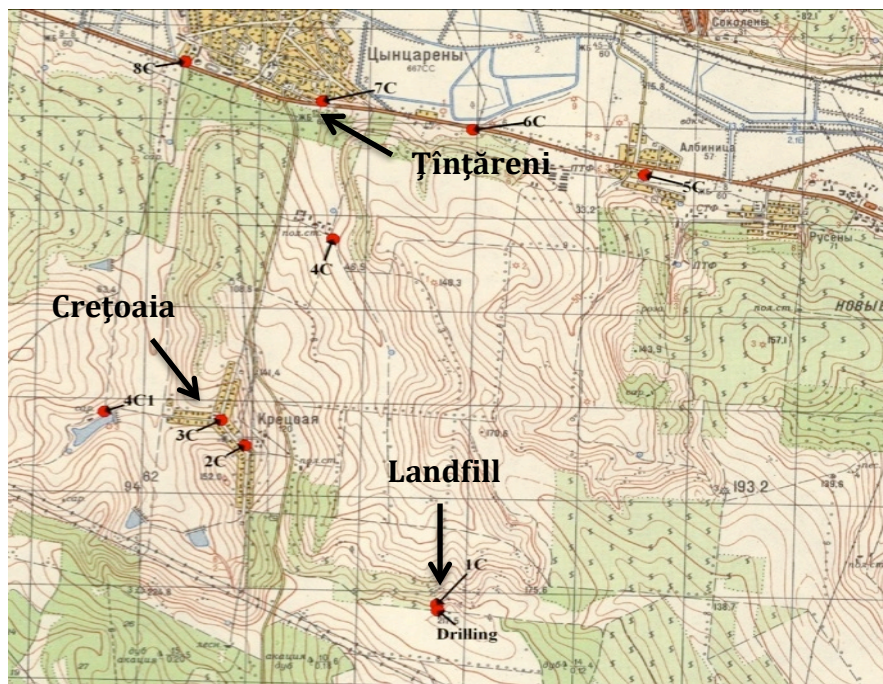


Figure 17 shows the measuring points for the field study. The point 1C is located at the landfill (Arnot, 2012).

These locations were chosen because a ground water divide separates them. By choosing these two different areas the impact from the landfill on ground water can be

studied. In Appendix 4, Table 10 the exact locations for the measuring points are presented.

The day before the field trip eight new 1.5 dm<sup>3</sup> bottles was prepared by the employees at the Institute of Geology and Seismology by cleaning them with distilled water. The bottles were marked in the field from 1C-8C.

At Țîntăreni landfill a sample (1.5 dm<sup>3</sup>) of the leachate was taken from the same location as the first sample two weeks before. This sample was named 1C. The other bottles (sample 2C-8C) were filled with ground water taken from wells in the Țîntăreni area using the bucket attached to each well. A portable GPS was used to determine the exact location of the sampling points, and a measuring tape with a weight was used to measure the depth of the wells, and the depths of the water table. The sampling locations are marked in Figure 17.

A manual Auger-drill (40 mm in diameter) was used for taking a drilling sample of clay at Țîntăreni landfill at the depths from 20- 150 cm (Arnaut 2012). Two clay samples were taken using cylinders with a volume of 0,5 dm<sup>3</sup>. The permeability on this clay was analysed by employees at the Institute of Geology and Seismology.

All samples except the sample of leachate were analysed on sight using a WTW portable mini lab “Multiline F/ SET”, measuring; pH, electro conductivity, temperature, alkalinity (CaCO<sub>3</sub>), sulphate, chlorine, nitrate and nitrite. The leachate was analysed with the “Multiline F/SET” after the return to the Institute of Geology and Seismology.

At 09.00 in the morning of March 29 the water samples were delivered at S.A. Apa-Canal laboratory, where analyses of pH, COD, BOD, ammonium, chlorine, detergents, petroleum, nitrate, nitrite, copper, fat, sulphate, dry substances, suspended particles, arsenic, calcium, magnesium, manganese, potassium, sodium, strontium and lead was made.

In Figure 18 a leachate sample from the Țîntăreni landfill is taken, it also presents the WTW portable mini lab “Multiline F/ SET” used to analyse the samples in field.



Figure 18 sampling pictures from the field studies (own pictures).

### 5.3 Measurements on methane

Since the gas collecting system at the landfill is turned off at the moment all landfill gas produced in the landfill is leaking out. It is therefore not of interest to do any leaking measurements on this since the answer is already known; all is emitted to the atmosphere.

### 5.4 Assumptions used in calculations and models

Many assumptions were made when calculating parameters for the landfill. For the overall calculations it is assumed that the amount of waste at the landfill is 5 577 000 tonnes, the area of the landfill is 18 hectare and that the landfill has been in use 1991-2011. It is also assumed that the density of glass is 2 500 kg/m<sup>3</sup> and the density of construction waste is 2 200 kg/ m<sup>3</sup>. The construction waste is assumed to contain mostly cement, concrete, brick and china. For calculations, see Appendix 6.

For the calculated gas production it is assumed in both models that the landfill gas has a methane content of 50 %. For the years that lack statistics of produced organic waste it is assumed that the amount of organic waste is the same as the previous years. In the simulation with the IPCC model a simplified equation was made which do not take into account the time factor. It is also assumed in the IPCC-model that the methane production starts directly when the waste is deposited. The water content in the waste is assumed to be 40 %. The parameters  $k$ ,  $L_0$  and  $NMOC$  used in LandGEM have been assumed to have values for a conventional MSW landfill. These values correspond to a  $k$  of 0.05 year<sup>-1</sup>, a  $L_0$  of 170 m<sup>3</sup>/ Mg, and a  $NMOC$  value of 4 000 ppmv as hexane.

In the calculation of the water balance for Țițărieni landfill many assumptions are made. The precipitation value,  $P$ , used is based on a mean value for the past 20 years and it is assumed that the precipitation will look the same in the future. The leachate is set to the limits in directive 1999/31/EC that fulfil the requirements for a landfill for hazardous waste. This corresponds to an infiltration of 5 l/ m<sup>2</sup> year. The surface and ground water runoff ( $I_g$  and  $I_s$ ) is assumed to be zero since it is assumed that impermeable clay is used in the construction. The difference in water deposit,  $M$ , is also assumed to be zero considering the landfill being in use for 20 years and is thereby assumed to be fully water saturated (Isacsson, 2007). When calculating the surface runoff it is assumed that the landfill is final covered and the water added by the waste is therefore neglected since it is capsuled by the hydraulic barrier.

## 6 Results

In this chapter the results from the field measurements and calculations will be presented.

### 6.1 Classification of the Țîntăreni landfill

Țîntăreni landfill is classified as a landfill for hazardous waste in this study.

### 6.2 Degradation phase of the Țîntăreni landfill

In order to determine the degradation phase of the landfill pH, conductivity, COD and BOD needs to be studied. The results from the field study of these parameters are presented in Table 4.

Table 4 Presents the results from the measurements made in the field.

Measurments	1	2	Mean value
pH	8.1	8.24	<b>8.17</b>
Conductivity mS/cm		23.7	<b>23.7</b>
BOD mg/l	1550	1350	<b>1450</b>
COD mg/l	3606	4508	<b>4057</b>
BOD/COD	0.43	0.30	<b>0.36</b>

#### 6.2.1 Gas production capacity at Țîntăreni landfill

##### LandGEM

The graphs in Figure 19 show the estimated gas production for the coming years for the landfill based on LandGEM's simulations.

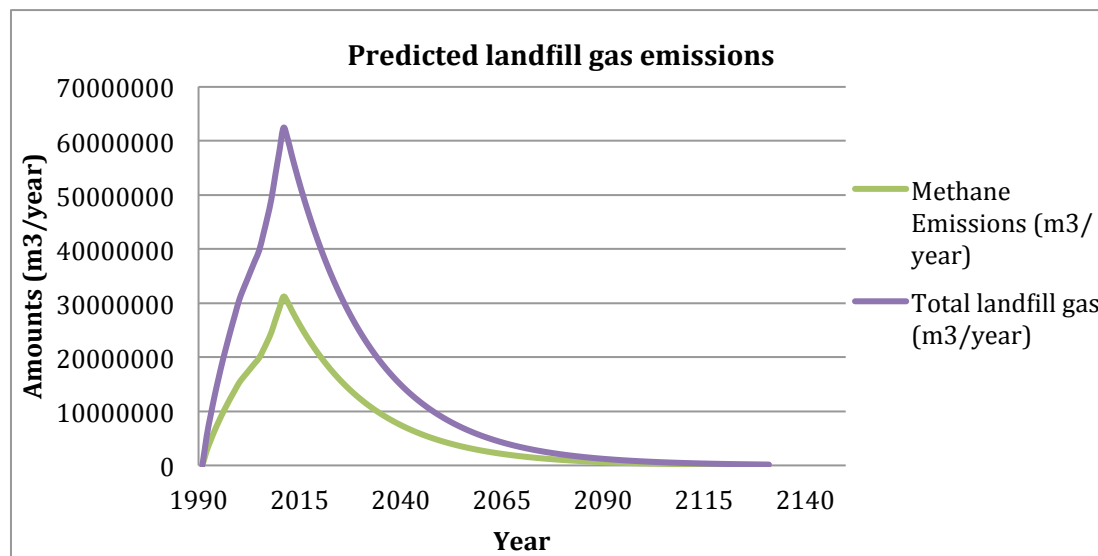


Figure 19 shows the simulation from LandGEM on how much landfill gas and methane that will be produced at the landfill for the coming years.

Figure 19 shows that the methane and landfill gas producing phase has not yet reached its maximum level. It will occur around 2015, approximately four years after the deposition of waste ended. It will continue to produce landfill gas for about one hundred years more. For calculations see Appendix 5.

## IPCC-model

The simulated amount of landfill gas for the years 1990-2011 with the IPCC model is presented in Figure 20.

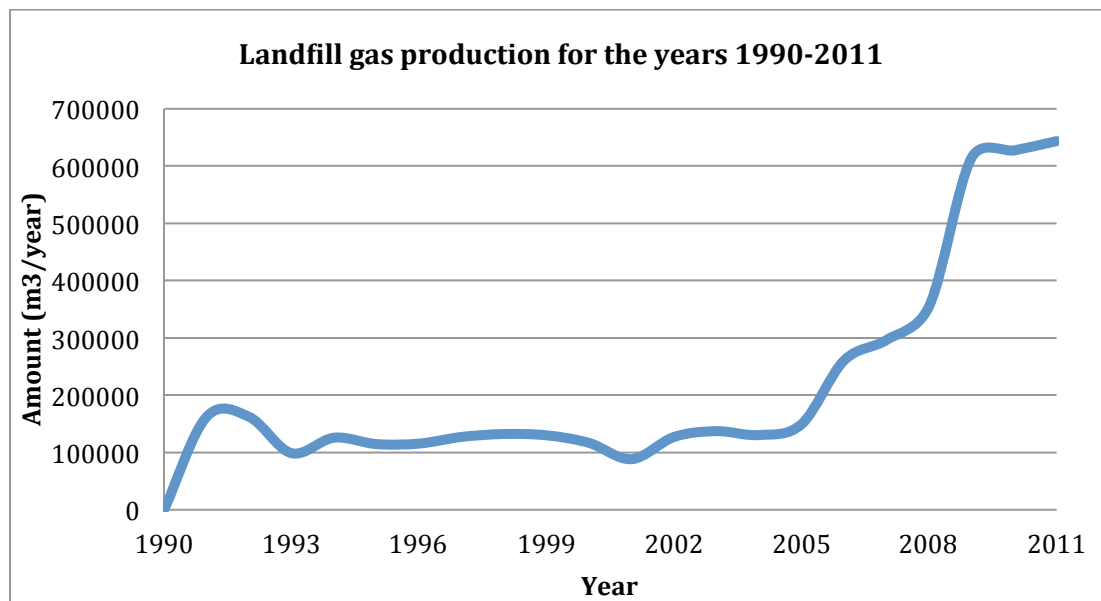


Figure 20 shows the estimated landfill gas production, with the IPCC-model, for the years 1990-2011.

The numbers used for the IPCC simulation are presented in Table 12 in Appendix 5.

### 6.3 Permeability of clay from the Țințăreni area

Permeability tests made on the clay at the landfill site is presented in Table 5.

Table 5 presents the permeability of the clay at the landfill cite.

Depth (m)	Permeability (m/day)	Permeability (m/s)
0.2	0.0012	$1.4 \cdot 10^{-9}$
1.2	0.0039	$4.5 \cdot 10^{-9}$

By using Darcy' s law, Equation 5, the flow through the barrier can be calculated for a specific permeability on the material.

$$\frac{q}{A} = \frac{k \cdot h}{l} = k \cdot i \quad (5)$$

$q$ = flow of water per time unit, m<sup>3</sup>/s

$A$ = cross section area, m<sup>2</sup>

$k$  = permeability, m/s

$h$  = difference in hydraulic pressure, l mvp (one metre water column )

$l$  = length in the flow direction with pressure difference  $h$ , m

$i$  = hydraulic gradient (loss in pressure per length unit in the flow direction  $h/l$ ), no unit

The flow was calculated to 0.021 l/m<sup>2</sup> year for the permeability  $1.4 \cdot 10^{-9}$ . For calculations see Appendix 6.

### 6.4 Water balance at Țințăreni landfill

In Equation 4 the water balance is presented.



$$P + I_g + I_s + W = E + R + L_c + L_L + M \rightarrow R = P + I_g + I_s + W - E - L_c - L_L - M \quad (4)$$

This equation gives a surface runoff, R of -773 mm/m<sup>2</sup> year

The calculations are presented in Appendix 2.

## 6.5 Chemical compounds in the Țințăreni landfill vicinity waters

In this section the results from the groundwater and leachate sampling are presented. Sample number 1C is leachate taken from Țințăreni landfill. Sample number 2C and 3C are groundwater samples taken from wells in the village Crețoaia and sample number 4C, 5C, 6C, 7C and 8C are groundwater taken from wells in the village Țințăreni.

### 6.5.1 Comparison of leachate and groundwater

In Figure 21 the measurements on pH and conductivity are presented and in Figure 22 the measurements on suspended particles and alkalinity are presented.

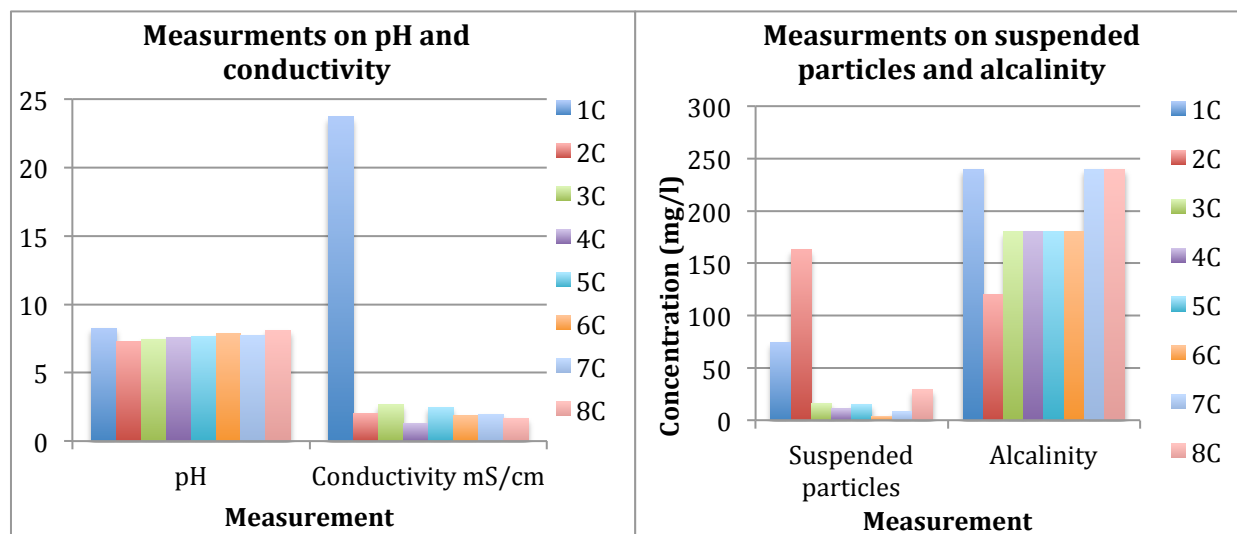


Figure 21 presents the results from the measurements on pH and conductivity at the field study.

Figure 22 presents the measurements made on suspended particles and alkalinity.

Figure 21 shows that the pH is almost constant on all locations. The conductivity on the other hand is higher in the leachate from the landfill than in the measured groundwater. Well 2C has the highest concentration of suspended particles. The concentration in the leachate is the second highest. Something has happened at measure point 2C that has increased the concentration of suspended particles.

The alkalinity, in Figure 22, does not differ much between the leachate and the groundwater. The leachate together with sample 7C and 8C has the highest values.

Figure 23 shows the concentration of dry substances from the measurements.

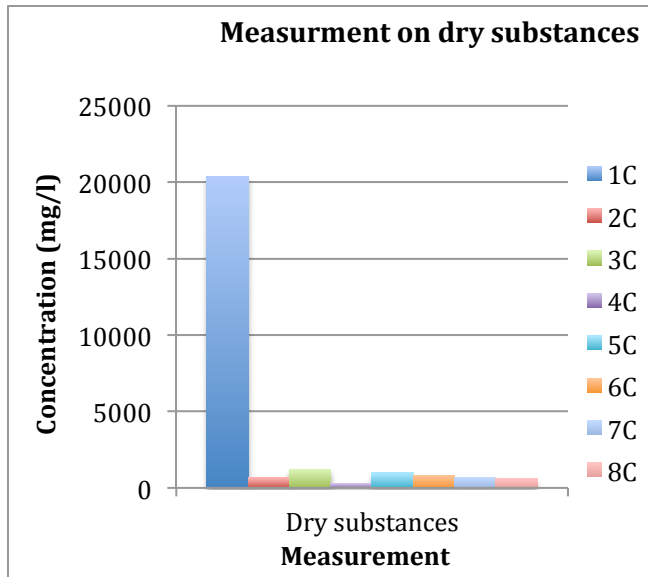


Figure 23 shows the measurements made of dry substances.

The concentration of dry substances is much higher in the leachate than in the groundwater.

### 6.5.2 Comparison of groundwater in Țințăreni and Crețoaia

In Figure 24 and 25 the results from the measurements made on anions (chlorine and sulphate) and cations (calcium, magnesium, potassium and sodium) are presented.

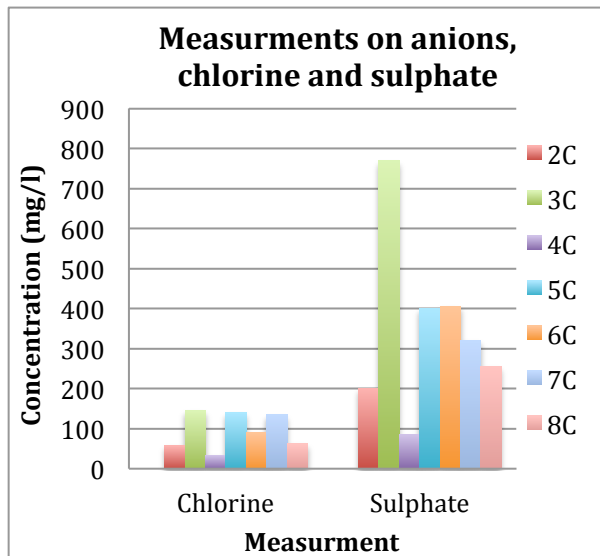


Figure 24 presents the results from measurements of chlorine and sulphate.

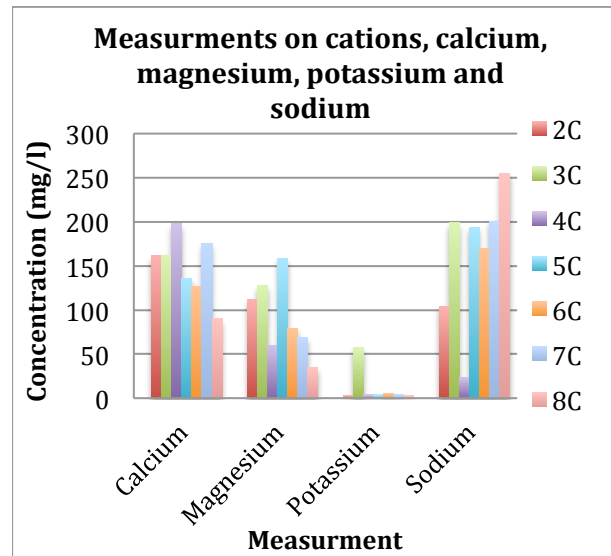


Figure 25 presents the measurements of anions, cations, calcium, magnesium, potassium and sodium.

Figure 24 shows how the concentration of the anions chlorine and sulphate, respectively, in the groundwater. The measurements on cations in Figure 25 show how the concentration of calcium, magnesium, potassium and sodium differs in the different wells. The concentration of calcium is highest in well 4C, 7C has the second highest value. For magnesium has the well 5C the highest value. The concentration of sodium is highest in the well, 8C. The concentration of potassium is highest at measuring point 3C.

Figure 26 presents the results from the measurements of arsenic, manganese and copper. In Figure 27 the measurements of strontium is presented.

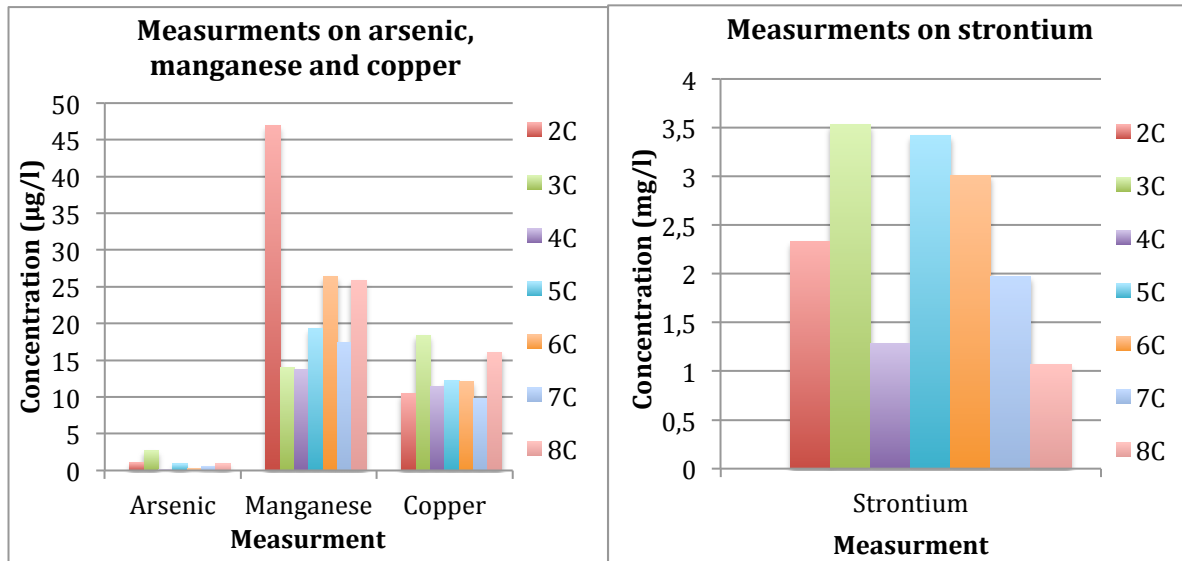


Figure 26 shows the concentration of arsenic, manganese and copper for the groundwater.

Figure 27 shows the concentration of strontium for the groundwater.

The concentration of arsenic is highest at the first two measuring points, 2C and 3C. The concentration of manganese is highest at the first measuring point, 2C. The concentration of copper is almost stable for all the measuring points; location 3C has the highest value. The strontium concentration is highest in well 3C and lowest in well 8C.

Measurements were also made on lead. These concentrations were however so low that the measure instrument could not detect any concentration and the result was therefore presented as <math><0.05 \mu\text{g/l}</math> for all the measuring points.

All the numbers for the measurement on leachate and the groundwater are presented in Appendix 4, Table 11.

## 7 Analysis

From a waste management point of view the Republic of Moldova has somewhat further to go before they can enter the European Union. This is because people have a careless attitude towards waste. The new law on waste to be approved later this year is an initiative to change the current waste management situation according to Tugui (2012). This law is supposed to be in line with the EU directives on waste and landfilling, 2008/98/EC and 1999/31/EC respectively. The first challenge is to get this new law approved in the parliament. After this the Moldovan authorities have to implement it and most importantly get people to follow it.

### 7.1 Classification of the Țiņăreni landfill

Since the Moldovan definition of MSW differs from the definition in the European Union the classification of the landfill may differ depending on which perspective is chosen. The landfill in this study is supposed to be closed in a way that follows the EU directive 1999/31/EC and the classification is therefore to be made considering EU definitions.

The Țiņăreni landfill mainly contains MSW but also some industrial waste. The composition of the landfill is 70 % household waste and 30 % other waste according to



Serghienco (2012C). There has not been dumping of large amount of chemicals or other hazardous waste according to Serghienco (2012A). On the other hand the Ministry of Environment (2011) states that there has been HMAW deposited at the landfill. Also Vodă (2012) and Istrati (2012) have expressed that there are no separation of hazardous waste in the MSW.

As it cannot be assured that there is no hazardous waste deposited on the Țîntăreni landfill the landfill is classified as a landfill for hazardous waste in this report according to the EU directive 1999/31/EC. A gas drainage layer is not required for a landfill for hazardous waste, but the requirements on the hydraulic barrier are higher for a hazardous waste landfill. The classification is based on the interpretation that a landfill cannot be mixed. Since the Țîntăreni landfill is mixed and a large part of the deposited waste is organic degradable a gas drainage layer is justified.

## **7.2 Analysis of the phase of degradation at Țîntăreni landfill**

The waste composition curve in Figure 15 shows a high content of organic material in the waste for all the studied years, 1986-2011. After the country's independence in 1991 the collected amount of paper and cardboard has decreased rapidly. All types of waste decreased during the beginning of 2000 except organic waste. This means that there is a large amount of waste that can be decomposed into methane as described by Themelis and Ulloa (2006).

The pH, presented in Table 4 is somewhat over neutral and it is therefore likely that the landfill has entered a methanogen phase, described by Cerne et al. (2007). The pH is in the interval for the methanogen phase but the landfill is covered with calcareous clay, described by Укреология (1976), which could increase the pH. The pH is however too high for the landfill to completely be in the acid anaerobic phase described by Hogland (1997). Measurement of detergent levels in the leachate, presented in Table 11 in Appendix 4, show that detergents are present in the water, which also increases the pH. The BOD/COD ratio is still too high to have entered the methanogen phase, at least the mean value and the first sample. In the methanogen phase the ratio BOD/COD should be in the interval 0,05-0,3, according to Naturvårdsverket (2011). This indicates that the landfill probably very soon will enter the methanogen phase and now is somewhere in between the acid anaerobic phase and the methanogen phase.

It is unlikely that the landfill is in the oxygen and nitrogen-reducing phase, even though the pH is in the right range, since this phase only last for a few days up to some weeks according to Naturvårdsverket (2008). The landfill has not been used for dumping waste for over a year. This also gives an indicator of which degradation phase it is in. The acid anaerobic phase can last for some weeks up to ten years according to Naturvårdsverket (2008), which makes it possible that the landfill has moved on to the methanogen phase.

To sum up, the measurements made on the leachate indicate that the landfill is in between the acid anaerobic phase and methanogen phase.

### **7.2.1 Țîntăreni landfill gas capacity**

The simulations for the landfill gas production at the Țîntăreni landfill were carried out with two different methods, LandGEM and the IPCC model respectively. The LandGEM simulations show that the landfill will produce maximum amounts of methane around 2015 and then continue to produce methane for at least the coming 100 years, see Figure 19.

The two models gave two completely different results. The LandGEM model simulates a methane production that is ten times higher for each year than the IPCC model simulations. There have been many assumptions made when using these models and it is difficult to tell which one is correct. A conclusion that can be drawn is that both models shows that the landfill produces gas.

In the simulation with the IPCC model a simplified equation was used which does not take into account the time factor according to Samuelsson et al. (2007). Also a lot of assumptions were made when using this model, for example that the landfill gas only contains equal amounts of methane and carbon dioxide. Landfill gas also contains oxygen, hydrogen and nitrogen gas as well as other pollutants according to Avfall Sverige (2010B). Assumptions regarding the water content in the waste were also made. In LandGEM the parameters are assumed to correspond to an average landfill. The conditions differ a lot depending on the composition of the waste among other factors according to Avfall Sverige (2010B).

By not collecting the landfill gas the stability of the landfill is compromised which can cause subsidence and fires described by Avfall Sverige (2010A). By collecting the landfill gas and transforming it into electricity is it possible to reduce the need of import of expensive gas.

The gas collecting problem and conflict has to be solved before the landfill can be closed. If the Republic of Moldova is to enter the European Union they have to take care of the gas considering the requirements in the landfill directive 1999/31/EC.

To summarize, simulations of landfill gas show that the landfill will produce gas in the future and the directive 1999/31/EC states that this gas has to be collected. It is therefore urgent to get the gas collecting system up and running.

### **7.3 Possible final covering materials**

When the decision of closing the landfill for good has been made this process has to be allowed to take time according to Nilsson (2012). The results will not be good if the whole landfill is covered at once and subsidence measurements have to be carried out continuously. According to Leander (2012) it is not unusual that subsidence are measured ten years after the last waste has been deposited on the landfill. Leander (2012) also states that there is no use to cover the landfill while there are still large subsidence, this will only ruin the final cover. A recommendation is to cover the landfill in segments, starting with the oldest parts of the landfill, and perform subsidence measurements continuously in order to avoid damage on the construction. This makes it possible to final cover a part of the landfill, and continuing to deposit waste on another. It also makes it less problematic to store material.

The slopes of the landfill, 1:4, have been constructed while dumping waste on the site. The slopes are in the interval of what is recommended by Avfall Sverige (2007), between 1:3 and 1:20, and there is therefore no need to change them and form a different structure of the landfill with the levelling layer.

In Table 1 the requirements for the covering of a landfill according to the European Union directive 1999/31/EC are presented. There are no thickness requirements of the layers except for the drainage layer and the topsoil cover. This means that the layer can differ depending on the landfill. In order to save material, resources and money the thinnest possible barrier is suggested for each layer.

### Levelling layer

As described by Avfall Sverige (2007) construction waste can be used in the levelling layer. It is difficult to estimate the amount of construction waste for the coming years in Chisinau. An approximation method is to study the past years and see if there are any trends. In Figure 28 below the construction waste amounts for Chisinau for the years 1993-2011 is presented.



Figure 28 shows the amount of construction waste for the years 1993-2011 in Chisinau (Tugui, 2012; Serghienco, 2012C).

Figure 28 shows a small declining trend from 2009-2011 but the amounts of construction waste will probably be somewhere around 20 000 tonnes for the coming years. It is important to start sorting this material and store it separately in order to be able to use this as a layer in the covering process.

The thickness of the levelling layer should be at least 0.5 metres according to Avfall Sverige (2007). In order to cover a landfill of 18 hectares with a layer of 0.5 metres construction waste an amount of 90 000 m<sup>3</sup> is needed. The calculations are presented in Appendix 6.

The amount construction waste in Figure 28 is presented in tonnes, which means that a medium density needs to be assumed in order to compare the figures. The construction waste is assumed to contain mostly cement, concrete, brick and china. This means that the amount needed to cover the landfill is 198 000 tonnes. For calculations, see Appendix 6. This amount corresponds to approximately ten years of construction waste.

### Gas drainage layer

Since the calculations shows that landfill gas is produced a gas drainage layer is needed. This layer can be constructed with horizontal wells connected to a collection system, described by Avfall Sverige (2010B). According to Avfall Sverige (2007) the layer should be constructed in a material that allows the gas to migrate, examples of good materials are gravel or macadam. This layer should be at least 0.2 metres and an amount of 36 000 m<sup>3</sup> is therefore needed. The calculations are presented in Appendix 6.

### Hydraulic barrier

There is a lot of clay in the landfill area, which can be seen in Figure 8. Clay, described by Avfall Sverige (2007), is one of many natural materials that can be used in the hydraulic barrier. The top clay at the Țînțăreni landfill fulfils the European Union legislation

(1999/31/EC) on the hydraulic barrier for a final landfill covering. The permeability on this clay was measured to  $1,4 \cdot 10^{-9}$  m/s. The clay deeper down has a slightly higher permeability and does not meet the requirement on the hydraulic barrier. According to Avfall Sverige (2007) the thickness of the hydraulic barrier should be at least 0.3 meters. By using Darcy's law the flow through the barrier was calculated to 0.021 l/m<sup>2</sup>year for the permeability  $1.4 \cdot 10^{-9}$  m/s. The landfill directive 1999/31/EC states that no more than 5 l/m<sup>2</sup> year is allowed to pass through the barrier. The suggested construction thereby follows the landfill directive.

The amount of clay needed to cover the landfill with a hydraulic barrier of 0.3 metres is 54 000 m<sup>3</sup>, the calculations are presented in Appendix 6.

An alternative to clay as a hydraulic barrier material is wastewater treatment sludge, described by RVF Utveckling (2002), from S.A. Apa-Canal in Chisinau. Studies, by for example RVF Utveckling (2004), have shown that a mix of waste water treatment sludge and fly ash from incineration plants has good properties meeting the requirements on the hydraulic barrier. The Republic of Moldova does not yet have a waste incineration plant, even though there are plans of starting one according to Arnberg (2012). If the plant is to be built ash from this plant can be used as stabilizing material. According to Carling et al. (2007) the hydraulic barrier should have a thickness of 0.5-0.6 metres when using a mix of sludge and ash.

In order to use the sludge stabilized with ash in the hydraulic barrier, with a thickness of 0.5-0.6 metres, the amount of sludge and ash respectively should be; approximately 45 000 m<sup>3</sup> of sludge and 44 000-88 000 m<sup>3</sup> of fly ash. The calculations are presented in Appendix. This means that the sludge needs to be collected for approximately half a year. The calculations for the hydraulic barrier are presented in Appendix 6.

**Drainage layer**

In the drainage layer crushed glass can be used due to its inert properties described by RVF Utveckling (2006). In order to use this waste it needs to be sorted out. The drainage layer should have a thickness of at least 0.5 metres according to the directive 1999/31/EC. In order to cover the landfill with a layer of 0.5 metres an amount 90 000 m<sup>3</sup> is needed.

In Figure 29 the amount of glass waste is presented.

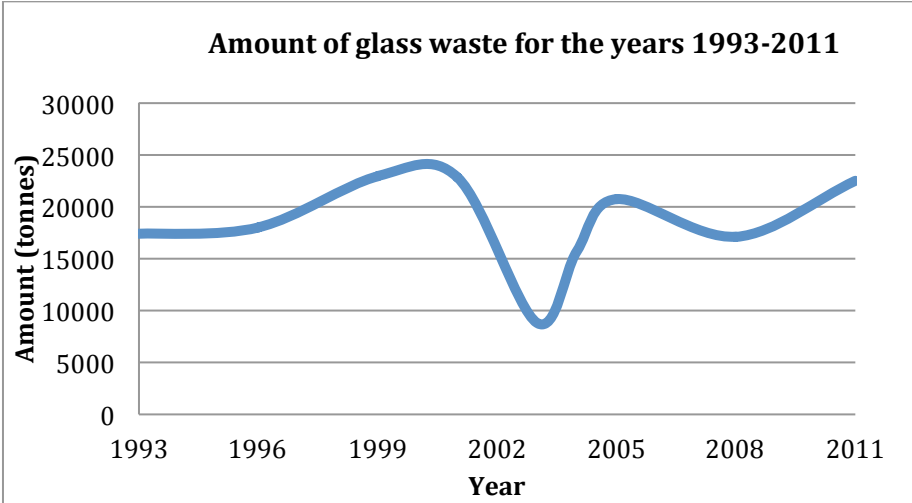


Figure 29 shows the amount of glass waste in Chisinau for the years 1993-2011 (Tugui, 2012; Serghienco, 2012C).

In order to compare the needed amount with the amount in Figure 29 the volume needs to be converted into weight. This gives a needed amount of glass of 225 000 tonnes, the calculations are presented in Appendix 6. This means that glass waste needs to be stored for approximately ten years before covering the landfill.

### **Protection and vegetation layer**

In the protection layer gravel, sand and excavated masses can be used according to Avfall Sverige (2007). In Chisinau's case a mixture of these can be used. According to ALRC (2012) there is a quarry in Țîntăreni, material from this can be used in this layer. The thickness of this layer, together with the vegetation layer should be at least 1 meter according to 1999/31/EC, which means that an amount of 180 000 m<sup>3</sup> is needed to cover the complete landfill. The calculations are presented in Appendix 6.

In the top part of this layer some wastewater treatment sludge can be used according to Avfall Sverige (2007).

According to Naturvårdsverket (2004) black soil can be used in the vegetation layer. On top of this grass and other vegetation can be planted. Avfall Sverige (2007) describes that plants with deep going roots should be avoided since these can destroy the covering construction. If the vegetation layer is 0.2 m thick an amount of 36 000 m<sup>3</sup> of black soil is needed, see Appendix 6.

### **Total material needs for the final covering of Țîntăreni landfill**

If all the material needed to cover Țîntăreni landfill is summed up, from the levelling layer to the vegetation layer, a total volume of 486 000 m<sup>3</sup> material is needed if clay is used in the hydraulic barrier. If ash and sludge is used in the hydraulic barrier 521 000-565 000 m<sup>3</sup> of material is needed. 486 000 m<sup>3</sup> of material corresponds to 48 600 trucks with a capacity of 10 m<sup>3</sup>.

If this material is stored in 10 m high piles a total storage area of 48 600 m<sup>2</sup> is needed when clay is used, and a storage area of 52 100-56 500 m<sup>2</sup> is needed when sludge and ash is used. An area of 48 600 m<sup>2</sup> corresponds to about 7.5 football fields.

The use of waste in the final covering process requires sorting of the waste in order to separate the waste types. The European Union directives that cover the producer responsibility, for example WEEE 2002/96/EC, requires that sorting is introduced and facilitated for the citizens.

## **7.4 Water balance and water treatment at Țîntăreni landfill**

The water balance is according to Naturvårdsverket (2004) used for dimensioning of leachate treatment ponds. The Țîntăreni landfill is assumed to produce -773 mm/year surface runoff water, which corresponds to -773 l/m<sup>2</sup> water per year. This means that a total amount of  $-1.4 \cdot 10^5$  m<sup>3</sup> surface runoff per year has to be redirected; for calculations see Appendix 2. The figure is negative due to the high evapotranspiration in the Republic of Moldova described by the Ministry of Environment and Natural Resources (2009). It is therefore a very little risk that water will be collected in a water column, spring flood is not considered, and there is therefore no need to invest in expensive drainage systems. This money is better spent on treatment plants for the leachate.

Today there is no other leachate treatment than recirculation according to Serghienco (2012B). This is not enough if the landfill should follow the directive 1999/31/EC, which states that there should be cleaning of the leachate.

## 7.5 Water quality in the Țiņțăreni landfill area

The lab performing the analyses failed to present a complete analysis of the leachate and water from the wells. Therefore only some parameters can be compared completely. By comparing the samples taken in Crețoaia with those taken in Țiņțăreni some conclusions can be drawn, since these two areas are separated by a groundwater divide according to Moraru (2012) and Arnot (2012).

The diagrams presented in Figure 21-23 shows that the concentration of chemical substances are much higher in the leachate than in the groundwater. There is however one exception. For suspended particles measure point 2C has a higher value than the leachate. The reason for this is unknown. The fact that the leachate has high concentrations of chemicals in general is an expected result. This also indicates that the barrier around the landfill is rather impermeable.

For the measurements where only groundwater in Crețoaia and Țiņțăreni has been compared, Figure 24-27, the concentrations are rather alike for almost all substances. The results from the groundwater sampling in Țiņțăreni and Crețoaia can be compared with the limit values for drinking water in Sweden according to Livsmedelsverket (2001), presented in Table 3. The wells that fulfil these requirements are marked in Table 6.

Table 6 presents which substances that are in an acceptable range for drinking water according to Livsmedelsverket (2001), marker, for each well.

	Limit	2C	3C	4C	5C	6C	7C	8C
Temp. °C	<20	✓	✓	✓	✓	✓	✓	✓
pH	7.5-9			✓	✓	✓	✓	✓
Arsenic µg/l	10	✓	✓	✓	✓	✓	✓	✓
Calcium mg/l	100							✓
Copper µg/l	2000	✓	✓	✓	✓	✓	✓	✓
Magnesium mg/l	30							
Manganese µg/l	50	✓	✓	✓	✓	✓	✓	✓
Sodium mg/l	100			✓				
Lead µg/l	10	✓	✓	✓	✓	✓	✓	✓
Chlorine mg/l	100	✓		✓		✓		✓
Sulphate mg/l	100			✓				
Conductivity mS/cm	2.5	✓		✓	✓	✓	✓	✓

The requirements on temperature as well as the concentrations of arsenic, copper, manganese and lead are all fulfilled in the measured groundwater. When it comes to the concentration of magnesium none of the analysed wells fulfils the requirements on drinking water from Livsmedelsverket (2001). Table 6 shows that there is no significant difference between the groundwater in Țiņțăreni and Crețoaia. The measured groundwater does not fully meet the requirements on drinking water in Sweden. Whether this depends on the landfill or other circumstances is difficult to tell but Leahu

(2012) states that there are problems with the water in all of the Republic of Moldova. Also Țîntăreni lies next to the river Bic, which according to Ministry of Environment and Natural Resources (2007) is the most polluted river in the Republic of Moldova. Water from this river can infiltrate the wells.

Since a groundwater divide separates Țîntăreni and Crețoaia according to Moraru (2012) and Arnot (2012) only the water in Țîntăreni will be affected by the landfill. The measurements do not indicate that the pollution is higher in Țîntăreni than in Crețoaia. These results do not show that the landfill has a large impact on the groundwater in Țîntăreni. More studies are required to say this for sure.

## **8 Discussion**

There are many factors to consider when final-closing a landfill. It is important to think of the closing technique, material use and construction method, as well as the needed measures for the Țîntăreni landfill. How to implement the considerations is also important.

### **8.1 Landfill final closing techniques**

Many materials can be recommended for the final covering of Țîntăreni, the Republic of Moldova has both waste and natural resources available. The choice is mainly limited by the economic situation in the country.

The Țîntăreni landfill is constructed as a big slope with a dam wall at the bottom of the slope, this is not a construction used in Sweden. In Sweden the waste is put in piles and then covered. It is unclear if the structure is optimal from a stability point of view and if the dam can hold the pressure of more waste. This is not studied in this report and further investigations need to be carried out before continuing using the landfill. Nevertheless the landfill is constructed to hold twice as much waste as today. Therefore it must be assumed that the dam has the right dimensions.

When constructing the Țîntăreni landfill a plan and a vision was set up. When depositing waste at the site some compacting and daily covering has been carried out. Also slope gradients have been considered. It is positive that Regia Autosalubritate has had these things in mind when depositing waste; this will simplify the final covering process.

There is clay near Țîntăreni, which meets the European Union requirements on permeability. An incineration plant, with ash as a by-product that can be used to stabilize wastewater treatment sludge, still has not been built in the Republic of Moldova. Therefore the recommendation in this report is to use clay as a hydraulic barrier in the final covering of the Țîntăreni landfill. It might be possible to import ash from other countries with incineration plants in order to use this as a stabilizer for the sludge. The risk with this is that the Republic of Moldova will become a place where countries dump their ash. Using fly ash also is controversial from an environmental point of view. It is therefore better to recommend clay in the hydraulic barrier and it is probably a cheaper alternative as well. If the incineration plant is built in the near future a mix of ash and sludge can be used in the hydraulic barrier.

A problem with final covering Țîntăreni landfill is the large amounts of material needed to cover it. Although the final covering of a landfill is completed in stages the size of the Țîntăreni landfill is so huge that finding and storing material may still be a problem. In the calculations in this report the thinnest layers recommended has been used in order

to save material. It is unrealistic to store for example construction waste and glass for ten years in order to collect large enough amounts to cover the landfill. Some quarries are located near Chisinau, and material from these can be used in the construction. It may seem like a waste of resources to use natural material in the covering layers but in order to store waste for ten years the Moldovans would have to build a new landfill just for storing material for the final covering. To use some natural material is therefore necessary.

If constructed materials like geo-membranes are used in the hydraulic barrier the material use decreases. The republic of Moldova however is the poorest country in Europe and it would cost a lot more money to use these types of materials in the final covering of the Țîntăreni landfill. The risk of subsidence in the landfill is also a reason for not using constructed hydraulic barriers since these are more sensitive of movements in the landfill.

Considering the resources and land needed to build a new landfill it is not a bad idea to continue to use the Țîntăreni landfill. During the time they continue using this landfill Regia Autosalubritate can gather material for the final covering. The resources, that they would otherwise have used for building a new landfill, can be used for developing their waste management with sorting of waste etc.

## **8.2 Measures to consider at Țîntăreni landfill**

Today there is no other leachate treatment than recirculation in the Țîntăreni landfill. This is not enough if the landfill should follow the directive 1999/31/EC, which states that there should be cleaning of the leachate. To avoid future pollution it is important to develop the leachate treatment system. Sedimentation ponds, flood plains and ponds for aeration should be constructed downhill the landfill where the leachate must be redirected. This could be founded by a revision of the waste tariff, but it needs to be investigated. It is inevitable that investments have to be made in order to develop the leachate system. How large and what type of investments needs to be studied more in detail.

The water balance for the Țîntăreni landfill is based on the past years precipitation and it is therefore assumed that the precipitation will be similar in the future. Many assumptions have been made in the water balance, which makes it uncertain. The water balance can however say something about the surface water runoff in the future. Even though there are many assumptions made on the parameters the calculated surface runoff can still be of use when the dimensions of the water collection basins are determine.

Since there have been a lot of complaints on the landfill from the villagers in Țîntăreni the measurements on leachate and groundwater in Țîntăreni and Crețoaia are interesting to compare. Unfortunately the same substances were not analysed by the laboratory for the wells and the leachate, and therefore a conclusion cannot be made. However, all measured wells in Țîntăreni do meet with Livsmedelsverktes requirements on safe drinking water for heavy metals. This indicates that the landfills impact on its surroundings is limited. In the cases when the water in the wells in Țîntăreni do not meet with Livsmedelsverkets requirements the conclusion cannot be made that it is the landfill that has polluted it. When visiting the Țîntăreni village many examples could be seen on how the villagers just threw their garbage outside the village border and not caring if there was water nearby, see Figure 7. For suspended particles measure point 2C has a higher value than the leachate. The reason for this is unknown but it may be



that the well is constructed in a way that allows particles to enter the water, for example degradation of the well walls. When this sample was taken one could see sedimented particles in the bottom of the sample bottle.

As the authors understand it the reason why the landfill is not in use today is because of the complaints from the Țîntăreni village. The complaints are about polluted water but both own measurements and earlier measurements show that the water quality is acceptable. Still the villager's complaints are enough for Chisinau not to use the landfill. Thus it is suspected that the whole picture of this conflict is not clear. Unfortunately the villagers in Țîntăreni did not want to be interviewed to tell their side of the story. Therefore it is unclear where to stand in this conflict. All to say is that own measurements show that the landfill probably does not have a large impact on its surroundings.

The amount of organic waste has since the 1990's been high. This together with the degradation phase of the landfill at the moment indicates that the landfill produces and will produce methane for many years to come. When all these factors are taken into account it is urgent to make the gas collecting system work. The gas has to be collected and if it is not possible to transform the gas into electricity the gas can be flared. The important thing is to collect the gas. Methane is a 21 times worse greenhouse gas than carbon dioxide and at the moment the landfill has a large impact on the climate. The collection system is in place, it just needs to start operating.

By turning on the gas collecting system and making sure that it is connected to the electricity generator electricity for the landfill operation can be produced. For example could pumps be installed and used to pump the leachate, with help from the produced electricity, instead of driving trucks up and down the landfill. The transportation of leachate in trucks is absurd from an economical and environmental point of view, it is also very inefficient. This is an improvement that is rather easy to implement, and which can be funded by selling of the trucks. This would probably also save money since the fuel for the trucks are expensive, especially considering the large amounts needed in order to drive the trucks every day. Also if the gas collecting system is turned on the energy can be used as a "bribe" to the villagers in Țîntăreni. If the landfill is continually used the Țîntăreni village can get free electricity. This require investment in power lines to Țîntăreni village though, and the cost of this needs to be investigated.

### **8.3 Achieving the closure of Țîntăreni landfill**

A good initiative to develop the waste management in the Republic of Moldova is the new law on waste, which is to emphasise the producer responsibility. This law can help introducing sorting of waste in Chisinau. The country does not lack experts in waste management, but the tools and resources needed for the authorities to assure that the existing law is followed are missing. There is however a risk that the Moldovan people are not ready to apply sorting supported by this new law into their everyday life. Trips around the city as well as in the villages show that it is a big step for people just to throw their waste into a trash bin instead of in their back yard. The map in Figure 6 is just one example of how many illegal dumps there are in the vicinity of Chisinau. The risk of polluting the surrounding environment is huge from these dumps as well as the risk of spreading diseases in the villages. The behaviour of dumping waste randomly has roots many generations back in time and the problems with illegal dumping of waste can only be solved if the overall attitude towards waste is changed. The authorities also have to improve the waste management outside the cities, installing waste bins is a start. This

will take time and it is therefore unlikely that the country will be able to follow the waste hierarchy set up by the European Union and implement sorting of waste in the near future.

Sorting needs to be introduced as soon as possible in Chisinau in order to collect material for the final covering but also for saving resources. By not sorting the waste the Republic of Moldova are wasting resources and thereby money. This is something that a country like the Republic of Moldova cannot afford. It is therefore important to invest in sorting campaigns as well as sorting platforms. NGO:s could be used as a tool for launching sorting campaigns. From an environmental point of view sorting of hazardous waste and WEEE are important to focus on. This however is waste that individual people do not produce in large quantities. Packages are waste people produce daily. This makes packages suitable to use as an introduction waste to sorting in large extent, especially glass that can be used as a construction material in the final covering of Țîntăreni landfill. It is also important that organic waste is sorted and not deposited on the landfill. Composting should be investigated further as an alternative for landfilling of organic waste. Composed organic waste can be used as fertilizers and thereby improving the soil quality. The landfill construction does not allow any storage of covering material. Therefore a storage area needs to be constructed for the covering material, and a location for this needs to be found.

In Chisinau's case it is probably wise to install collection stations, just like the already existing units for plastic bottles. These are easy to install and maintain. Important to think of if installing stations is that they are placed easily accessible. The funding of the stations can be solved by the producer responsibility introduced by the new law on waste. For sorting to be introduced successfully it is important that the authorities make sure that this law is respected. The waste tariff needs to be evaluated, to see if people pay for the service of waste management. Sorting campaigns needs to be run and financed by the authorities, but the actual work of the campaigns can be conducted by NGO:s and media. Information is important in order to get people to sort their waste. Corruption could be problematic for sorting to be introduced successfully, and this is an area for the authorities to focus on.

Hazardous waste probably has to be deposited on landfills even when other waste management methods than landfilling are used in the Republic of Moldova, and it is important that new landfills for hazardous waste are constructed with proper bottom constructions and leachate treatment. Even though Țîntăreni landfill in this report is classified as a landfill for hazardous waste it is not recommended that new hazardous waste is placed on the landfill.

Looking into the future, when the landfill is finally closed and covered the landfill area can be used as a recreation area. This area will not be suitable for construction of new buildings or as agriculture land.

#### **8.4 Criticism of method and sources**

Before going to the Republic of Moldova our conception of the landfill was very different from what it turned out to be. We thought that the conditions on the landfill were horrible, there was no bottom construction and that waste was dumped randomly. Moreover we expected that the landfill gas collecting system was in use and that the gas was torched. We only thought that it was the electricity generator that was not in use. Furthermore we believed that it would be difficult to get in touch with waste experts, it

was not the case. On the other hand we expected more visits to the actual landfill, at least a visit per week.

A thing is certain, the working conditions and traditions in the Republic of Moldova and Sweden are very different. A procedure, which in Sweden would have taken not more than a minute, such as getting statistics on waste, takes hours or days in the Republic of Moldova. This is because few reports are published on the Internet. Usually public information is accessible, but the information is kept printed, in a binder, in someone's office. To get information and statistics a visit to the person who possesses the information is thus required. Also the Republic of Moldova is a young country, and the tradition of collecting statistics is not yet as developed as in Sweden. Since the country has had a civil war and financial problems during its short existence the authorities focus perhaps has been elsewhere than on gathering statistics. Therefore statistics sometimes simply does not exist at all, and if it does exist it does not go back long in time.

There are restrictions in the freedom of media and expression in the Republic of Moldova and corruption is spread. This is to keep in mind when searching for information in the Republic of Moldova. If statistics is to be found it has to be critically examined, since all information in the Republic of Moldova can be bought, also information from the governmental institutions. Someone always pays for the results from chemical analyses. If a company needs it they can pay a laboratory to give them the results they want on for example environmental parameters. The authors did not pay for the analyses made in this report, and someone else must have paid for them. Since it is unknown who it is there is reason to be critical of the results from the chemical analyses.

None of the chemical or physical analyses used in this report were carried out under the supervision of the authors, since only authorized personnel are allowed in the laboratories in the Republic of Moldova. Thus the methods and materials used for the analyses are not known. This is the prevalent working culture in the Republic of Moldova, and nothing can be said about it. However this suggests that the credibility of the analyses can be discussed. It might be that none of the analyses actually were made in reality, and that all the figures are made up by the laboratory. It is impossible to say if this is the case, but only accredited laboratories were used so the analyses ought to be trustworthy.

The fact that there have been difficulties finding information, and the fact that the information found may not be true, makes the result in this report very uncertain. On the other hand to have exact numbers in calculations is not crucial. Even though many things are uncertain in this report there are still a lot of conclusions that can be drawn from it.

Furthermore there is a culture in the Republic of Moldova of not bringing up the past. The landfill gas collection conflict described in chapter 4 is a good example of this. The procurement of the gas collection system was done when the communist party were ruling in the Republic of Moldova. Today another party is ruling the country, and according to the current ruling party many "peculiar" decisions were made during the communist regime. Therefore decisions made during the communist regime cannot be spoken off. If this is because people are afraid of reprisals if they reveal too much because of the restrictions in the freedom of expression, or something else, is difficult to say.

More that can have an impact on the results in this report is the language barrier. The report was made using many Russian and Romanian references and sources. Therefore both translators and “Google Translate” were used. In situ the Republic of Moldova a translator familiar with the technical language of an engineer usually was used, but not always. At these times another translator had to be used who not always fully understood the questions asked. Therefore it is likely that information was lost in translation when this translator was used. Also Google translate is famous for not always return a correct translated text, and when this tool was used information can have been translated wrongly.

## 9 Conclusion

The landfill in this report is classified as a landfill for hazardous waste. Therefore the hydraulic barrier in the final covering must be thick enough, and the materials chosen must have a low permeability, to make sure that the construction does not allow infiltration of more than 5 l/ m<sup>2</sup> year. Materials recommended in the construction, based on the local availability in the Republic of Moldova, are presented in Figure 30.

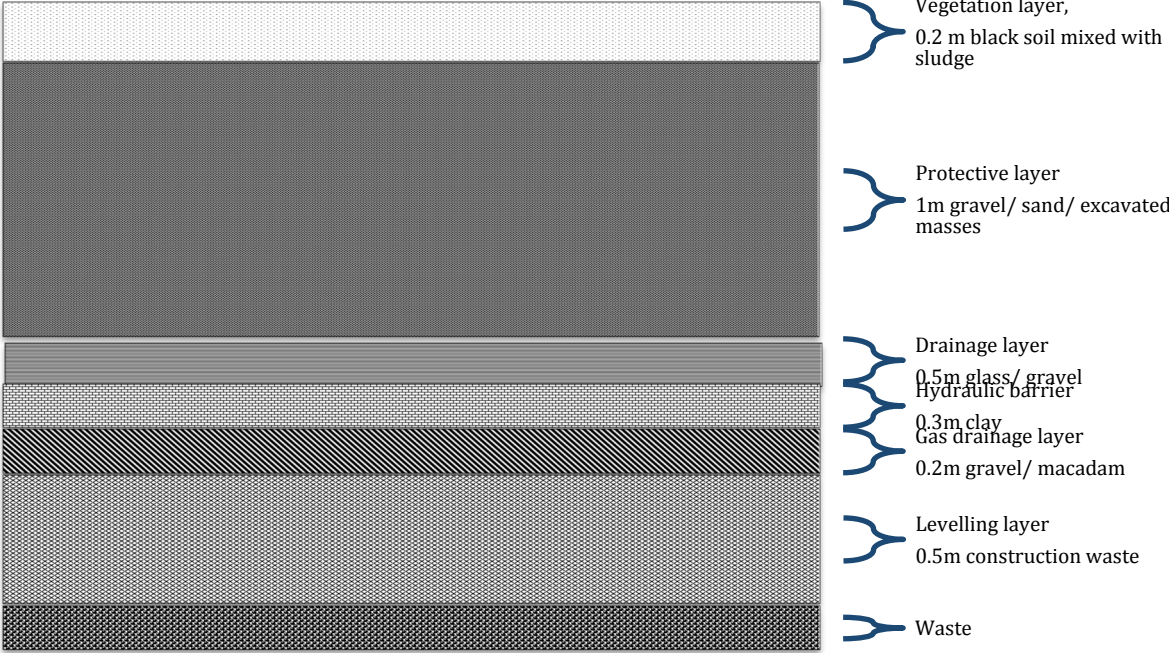


Figure 30 shows the recommended structure of the final covering for the Țiņăreni landfill.

It is important both from an economic, environmental and security perspective that the gas collecting system is turned on and used. There has been organic waste deposited on the landfill. At the moment the landfill is about to enter the methanogen phase meaning that the most methane will be produced during this period. It is careless to let all the methane out into the atmosphere. The gas can be used as an energy source and the technology for this is already installed. It is also important to develop the leachate system in order to avoid large impacts on the surrounding environment.

In order to collect all these materials sorting needs to be introduced. It is necessary to use both rest products like waste and also natural material like gravel. Covering a landfill takes time, which will simplify the job with collecting material. Subsidence measurements are also needed before the work can start.

The absence of sorting platforms is one of the reasons why the Țîntăreni landfill should continue to be used until a better waste management method, like a waste incineration plant, has been built. Using Țîntăreni landfill, and not building a new landfill for MSW will save money, which instead can be spent on introducing sorting, building sorting platforms and developing the waste management. Measurements on water wells in the landfill area indicate that the Țîntăreni landfill is built on clay with low permeability thus not letting too many substances escape from the landfill. This is also a factor for the recommendation of continuing using the Țîntăreni landfill.

It will take time to change the Moldovans' attitude towards waste and in order to develop the waste management investments in sorting platforms, organized waste management outside the cities and public sorting campaigns are necessary.

### **9.1 Recommendations**

In this section all the recommendations, measures and needed investments are presented.

- Solve the gas conflict and get the gas collecting system working
- Close the Țîntăreni landfill when a better waste management alternative than landfilling is available
- Measure subsidence on the landfill
- Use clay as a first choice for the hydraulic barrier, the material for the other layers are presented in Figure 30
- Introduce sorting and implement the new waste law
- Replace leachate trucks with pumps and a sprinkler system
- Invest in leachate treatment facilities
- Invest in an electric cable in order to utilise electricity from landfill gas

Much can be done to proceed with the closing of Țîntăreni landfill. This is just a pre-study and a more profound analysis of all the topics discussed in this report is necessary. For example a further case study of the leachate treatment is needed. Also a deep economic analysis of the investments is necessary.

## 10 List of references

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## Appendix 1 – Landfill properties

### Landfill aerophotos

In this chapter the landfill and its properties are presented in detail with aero photos with explanations.



Figure 31 Landfill overview (ALRC, 2012).



Figure 32 Landfill surroundings (ALRC, 2012).

### Landfill properties

In this document the properties of the landfill is presented. All estimations are made with the measurement program “Geoportal” (ALRC 2012). The area of the waste is



presented in 33, the width and length are presented in Figure 34 and the diagonal length in Figure 35.



Figure 33 The landfill area occupied by waste, clay storage is not included (ALRC, 2012).

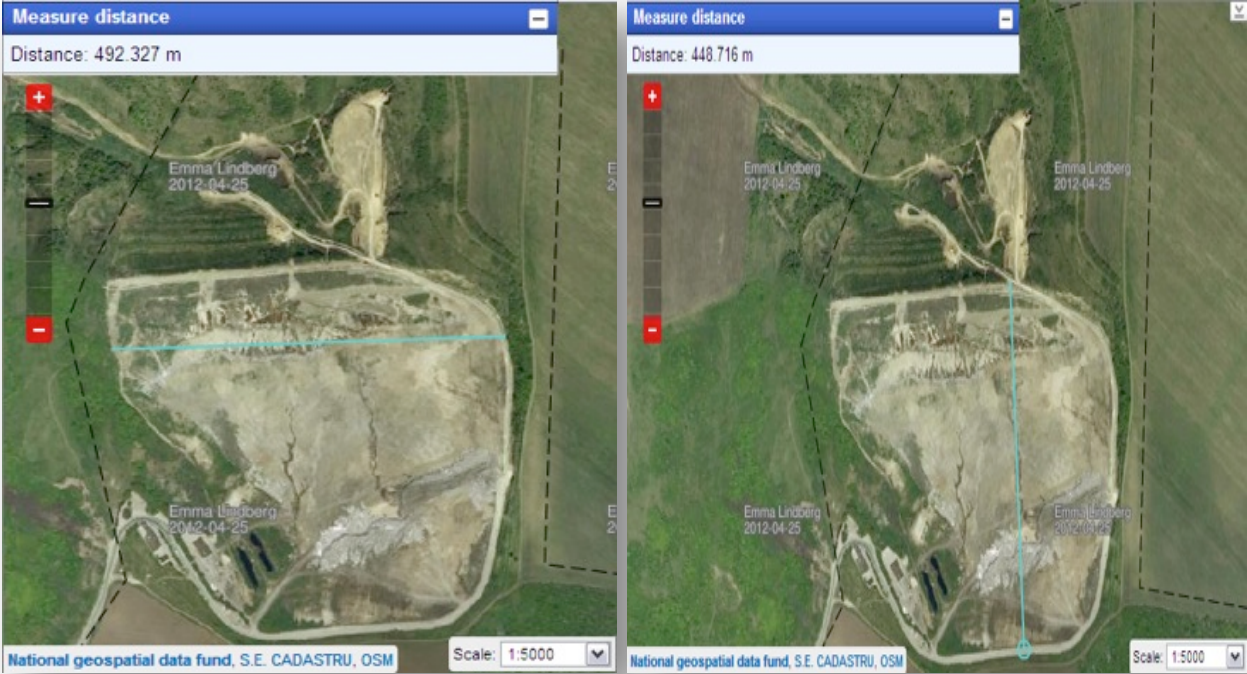


Figure 34 Landfill length and landfill width (ALRC, 2012).

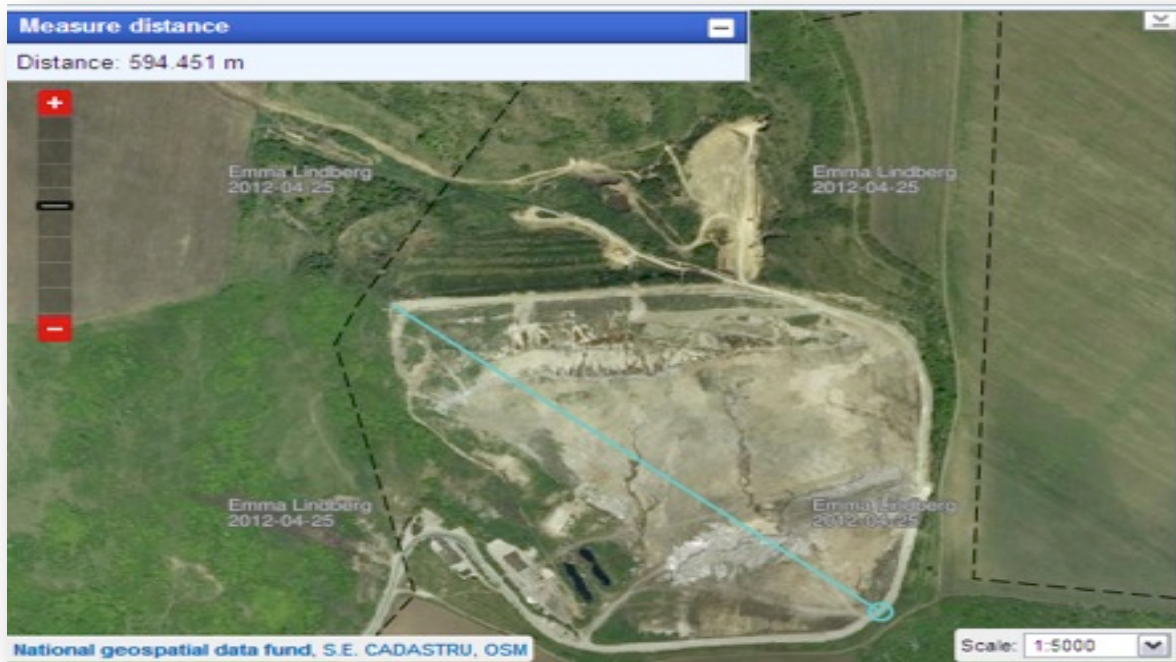


Figure 35 Landfill diagonal length (ALRC, 2012).

## Topography

The topography of the landfill and its surroundings are presented in Figure 36.

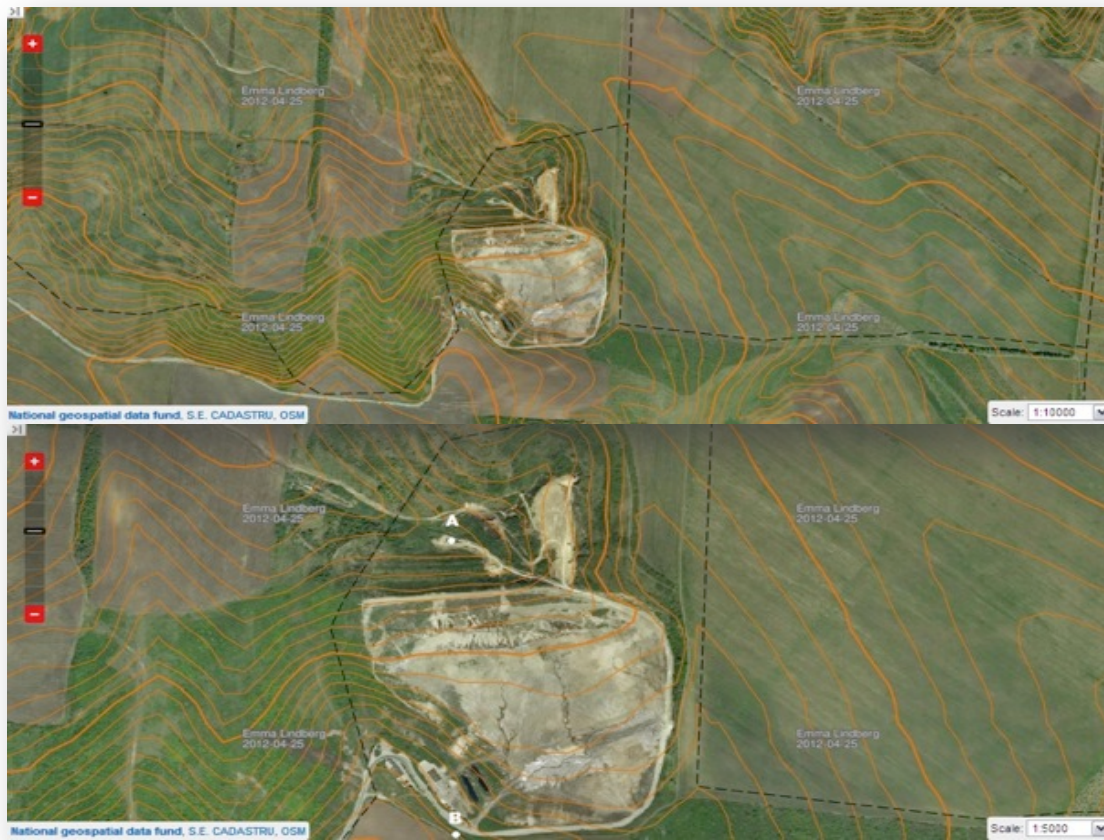


Figure 36 Landfill topography and topography of the surroundings (ALRC, 2012)



Point A in Figure 37 is located 118 meter above sea level, and point B is located 190 meter above sea level. This gives a difference in altitude of 72 meter.

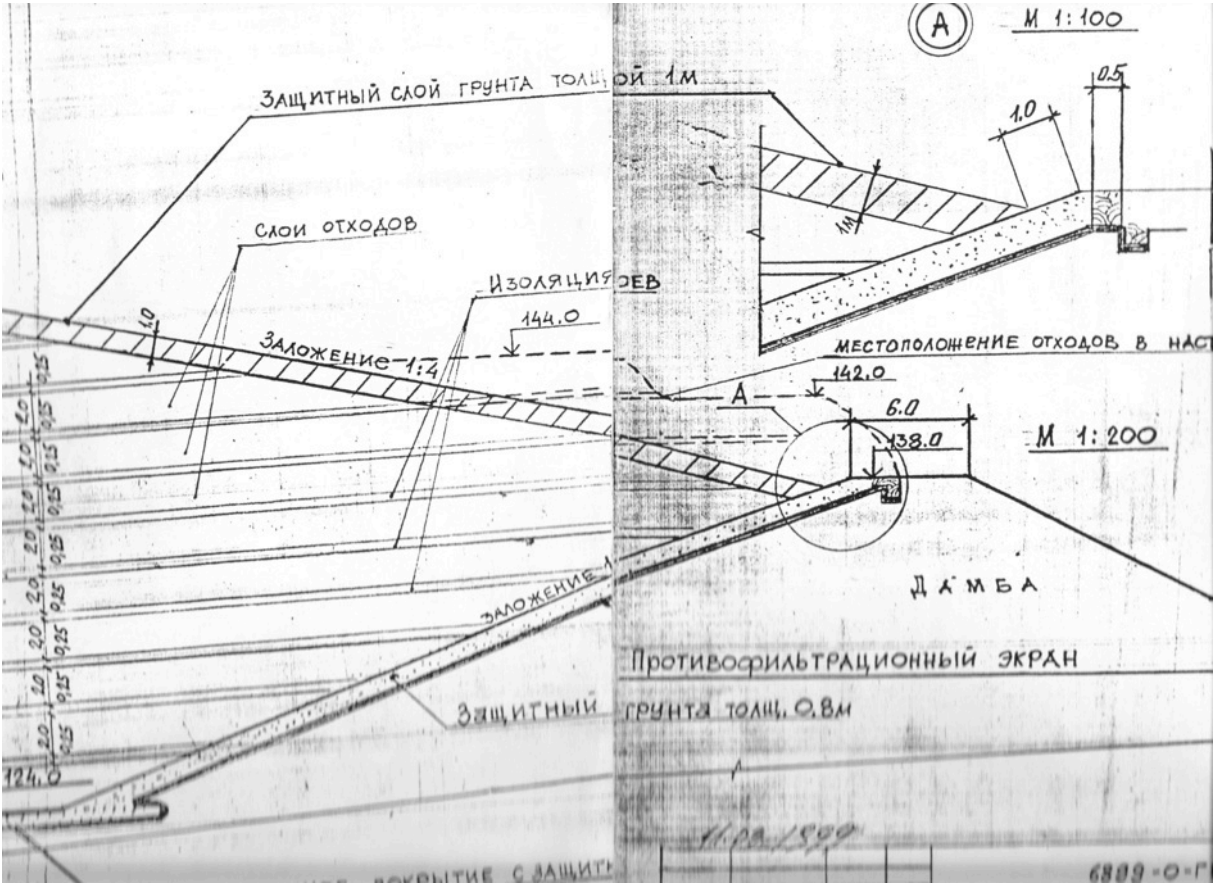


Figure 37 drawing of the landfill construction (Serghienco, 2012C).

## Appendix 2 - Water

The amount of leachate generated at the landfill is:  $2 \text{ (trucks/day)} \cdot 3 \text{ (m}^3\text{/day)} \cdot 24 \text{ (hours/day)} \cdot 365 \text{ (days/year)} = 52560 \text{ m}^3\text{/year}$

The evapotranspiration factor was calculated by the following expression:  $E = \frac{P}{0.575}$ .

This expression was taken from the Ministry of Environment and Natural Recourses (2009). A mean value for all the years has been calculated.

The amount of leachate has been transformed from  $\text{m}^3\text{/year}$  into  $\text{mm/year}$ . This calculation was made as follows: The total amount of leachate per year is  $52560 \text{ m}^3$ . The landfill area is  $180000 \text{ m}^2$ .

$$\frac{52560}{180000} = 0.292 \text{ m/year} = 292 \text{ mm/year}$$

$$P + I_g + I_s + W = E + R + L_c + L_L + M \rightarrow R = P + I_g + I_s + W - E - L_c - L_L - M \quad (4)$$

$P = \text{precipitation} = 644.1 \text{ mm/year}$

$$I_g = 0$$

$$I_s = 0$$

$$W = 0$$

$$E = 1120.2 \text{ mm/year}$$

$$R = ?$$

$$L_c = 292 \text{ mm/year}$$

$$L_L = 5 \text{ mm/year (from the directive 99/31/EC)}$$

$$M = 0$$

The total amount of runoff is:  $R \cdot \text{Landfill area} = -773 * 180000 = -1.4 \cdot 10^5 \text{ m}^3\text{/year}$

Table 7 presents the figures used in the water balance equation.

Year	Precipitation mm/year	Amount leachate mm/year <sup>^^^</sup>
1990	471	292
1991	655 <sup>^</sup>	292
1992	518 <sup>^</sup>	292
1993	557 <sup>^</sup>	292
1994	456 <sup>^</sup>	292
1995	609 <sup>^</sup>	292
1996	835 <sup>^</sup>	292
1997	587 <sup>^</sup>	292
1998	891 <sup>^</sup>	292

1999	564 <sup>^</sup>	292
2000	451 <sup>^</sup>	292
2001	711 <sup>^</sup>	292
2002	578 <sup>^</sup>	292
2003	618 <sup>^</sup>	292
2004	515 <sup>^</sup>	292
2005	800 <sup>^</sup>	292
2006	683 <sup>^</sup>	292
2007	618 <sup>^</sup>	292
2008	773 <sup>^</sup>	292
2009	445 <sup>^</sup>	292
2010	703 <sup>^^</sup>	292
2011	488 <sup>^^</sup>	292
<b>Mean value</b>	<b>644.1</b>	<b>292</b>
<b>Year</b>	<b>Evapotranspiration mm/year</b>	<b>LL mm/year</b>
1990	819.1	5
1991	1139.1	5
1992	900.9	5
1993	968.7	5
1994	793.0	5
1995	1059.1	5
1996	1452.2	5
1997	1020.9	5
1998	1549.6	5
1999	980.9	5
2000	784.3	5
2001	1236.5	5
2002	1005.2	5
2003	1074.8	5
2004	895.7	5
2005	1391.3	5
2006	1187.8	5

2007	1074.8	5
2008	1344.3	5
2009	773.9	5
2010	1222.6	5
2011	848.7	5
<b>Mean value</b>	<b>1120.2</b>	<b>5</b>

^ Popescu, 2011

^^SHS, 2012

^^^Serghienco, 2012C

### Appendix 3 – Waste composition and amounts

The waste type hazardous waste is not presented as a separate waste type in the statistics. This number is according to Arnberg (2012) around 0.5. For each waste type has  $0.5/7=0.07$  been subtracted and added to the column for hazardous waste.

The waste morphology from Tugui (2012) has presented glass, metal and plastics as a common category called other waste. In order to compare the figures has this category been transformed using the same fraction as glass, metal and plastics have regarding each other for the year 2010. This is 42 % is glass, 16 % is metal and 42 % is plastics.

Table 8 Presenting the figures from the waste morphology (Tugui 2012; Serghienko, 2012C; Arnberg 2012; Gavrilita, 2008).

YEAR	1986*	1993*	1996*	1999*	2001*
Glass	9.59	12.11	12.91	16.35	19.25
Metal	3.61	4.57	5.11	6.19	7.29
Plastics	9.59	12.11	12.91	16.35	29.25
Textile	7.43	7.93	4.83	1.53	2.43
Paper. Cardboard	26.43	24.93	14.93	4.73	5.73
Construction material (stone, wood)	5.43	2.93	2.03	0.93	0.73
Organic waste (food, garden)	37.43	34.93	54.53	53.43	44.83
Hazardous waste**	0.5	0.5	0.5	0.5	0.5
YEAR	2003*	2004***	2005*	2008****	2011****
Glass	14.08	4.03	11.52	4.03	4.93
Metal	5.32	3.03	4.35	3.03	1.93
Plastics	14.08	9.63	11.52	9.63	4.93
Textile	1.93	4.83	5.73	4.83	1.93
Paper, Cardboard	6.13	5.03	6.93	5.03	1.93
Construction material (stone, wood)	1.03	4.53	3.43	4.53	4.93
Organic waste (food, garden)	56.43	68.43	56.03	68.43	78.93
Hazardous waste**	0.5	0.5	0.5	0.5	0.5

\*Tugui 2012

\*\*Arnberg, 2012

\*\*\*Gavrilita, 2008

\*\*\*\*Serghienko, 2012C

Table 9 Presenting the total amount of waste in Chisinau (Tugui 2012; Serghienko, 2012C).

YEAR	Total amount of waste	Total amount of waste
	Tonnes/year	m <sup>3</sup> /year
1991*	322436	1126
1992*	251508	1127.4
1993*	248620	879.4
1994*	237380	869.3
1995*	238267	830
1996*	230773	833.1
1997*	235349	806.9
1998*	233319	822.9
1999*	241384	815.8
2000*	209981	844
2001*	203918	734.2
2002*	211926	713
2003*	215072	741
2004*	221078	752
2005*	292006	773
2006*	311454	1021
2007*	340912	1089
2008****	417560	1192
2009*	421850	1460
2010*	427284	1475
2011****	450000	1494

The figures were originally presented in m<sup>3</sup>/year. A conversion factor, in order to transform the figures into tonnes/year, was calculated from the following relation presented by Mr Serghienko at Regia Autosalubritate:

$$4200 \text{ m}^3 = 1200 \text{ tonnes.}$$

This gives the following relation:  $1 \text{ m}^3 = \frac{1200}{4200} = 0.286 \text{ tonnes.}$

## Appendix 4 – Field surveys

Measurements from the field surveys are presented in this Appendix.

**Table 10** Presents the geographical and hydrologic information on the different locations.

Nr.samp.	GPS_coord	GPS_coord	X geog	Y geog	X, m	Y, m	Elevation, m	Water table,m	Well depth, m	Abs.water table,m
1C	46-46-19,7	29-10-38,5	29-09-37,0	46-50-56,0	5664740	5192860	200			
Drilling	46-51-15,3	29-10-10,4	29-09-38,0	46-50-54,0	5664750	5192795	210			
2C	46-51-51,3	29-08-07,8	29-08-14,0	46-51-54,0	5662938	5194525	100	1,0	9,0	99,0
3C	46-52-01,5	29-07-57,6	29-08-05,0	46-52-02,0	5662715	5194790	70	5,0	8,0	65,0
4C	46-53-09,2	29-08-41,2	29-08-50,0	46-53-03,0	5663700	5196750	45,5	1,3	5,8	38,8
4C1	46-52-02,2	29-07-02,9	29-07-01,0	46-52-01,0	5661640	5194860	76	8,5	10,8	69,5
5C	46-53-29,9	29-10-59,8	29-11-07,0	46-53-25,0	5666550	5197500	19	1,5	6,5	17,5
6C	46-53-46,0	29-09-31,7	29-09-05,0	46-53-42,0	5664960	5197950	20	1,9	5,1	18,1
7C	46-53-51,3	29-08-35,2	29-08-47,0	46-53-50,0	5663575	5198225	30	2,0	14,0	28,0
8C	46-53-58,1	29-08-04,9	29-07-49,0	46-54-05,0	5662300	5198620	25	1,5	11,5	23,5

**Table 11** shows the results from the measurements made during the field surveys.

Nr.samp.	pH 120314	pH field 120328	pH lab 120328	EC,mS/cm	Alcalinity (CaCO <sub>3</sub> ), mg/l
1C	8,24	8,24	8,28	23,7	240
Drilling					
2C		7,25	7,08	2,04	120
3C		7,44	7,48	2,66	180
4C	7,72	7,54	7,43	1,314	180
4C1					
5C		7,66	7,78	2,46	180
6C		7,85	7,43	1,839	180
7C		7,73	7,2	1,959	240
8C		8,08	8,13	1,682	240
Nr.samp.	COD 120314	BOD 120314	COD 120328	BOD 120328	t° C, water
1C	3606 mg/l	1550 mg/l	4508 mg/l	1350 mg/l	14,7
Drilling					
2C					9,7
3C					7,7
4C	105 mg/l	27 mg/l			10,2
4C1					
5C					9,8
6C					8,1
7C					10,6
8C					10
Nr.samp.	As µg/l	Ca mg/l	Cu µg/l	Mg mg/l	Mn µg/l



1C					
Drilling					
2C	1,1	161,3	10,5	111,9	47
3C	2,67	162,3	18,4	127,6	14
4C	0,12	197,7	11,4	60,2	13,7
4C1					
5C	0,91	135,6	12,2	158,3	19,3
6C	0,23	127	12,1	79,1	26,4
7C	0,59	175,4	9,8	68,8	17,4
8C	0,92	89,8	16	34,4	25,9
<b>Nr.samp.</b>	<b>K mg/l</b>	<b>Na mg/l</b>	<b>Sr mg/l</b>	<b>Pb µg/l</b>	<b>Petroleum productsmg/l</b>
1C					1,2
Drilling					
2C	3,19	103,7	2,33	<0,05	
3C	57,35	198,8	3,53	<0,05	
4C	3,77	23,8	1,28	<0,05	
4C1					
5C	3,61	194	3,42	<0,05	
6C	5,8	169,4	3,01	<0,05	
7C	4,3	200,6	1,97	<0,05	
8C	2,67	254,6	1,07	<0,05	
<b>Nr.samp.</b>	<b>NH4+ 120314</b>	<b>NH4+ 120328</b>	<b>Cl, mg/l</b>	<b>Cl (lab) mg/l</b>	<b>PO4mg/l</b>
1C	1225 mg/l	1766 mg/l	3000 or higher	3602	10,6
Drilling					
2C			0	58	
3C			500	145	
4C	2,2 mg/l		0	34	4,6
4C1					
5C			0	140	
6C			bellow 500	90	
7C			500	135	
8C			0	62	
<b>Nr.samp.</b>	<b>SO4, mg/l</b>	<b>SO4 lab mg/dm3</b>	<b>Detergents (anionic) mg/l</b>	<b>Cu mg/l</b>	<b>Fat mg/l</b>
1C	over 1600	1648	3,5		
Drilling					
2C	bellow 200	200		0	8,8
3C	bellow 200	770		0	11,2
4C	bellow 200	85		0	6,5
4C1					
5C	bellow 200	400		0	5,7
6C	bellow 200	405		0	5,4

7C	bellow 200	320		0	17,1
8C	bellow 200	256		0	7,2
<b>Nr.samp.</b>	<b>NO2-</b>	<b>NO2- (lab) mg/l</b>	<b>NO3-, mg/l</b>	<b>NO3- (lab) mg/l</b>	
1C	++	14,56	1< NO3 >500	2,09	
Drilling					
2C	+		0		
3C	+		0		
4C	++		0		
4C1					
5C	+		0		
6C	0		0		
7C	+		0		
8C	++		0		
<b>Nr.samp.</b>	<b>Dry particles mg/l</b>	<b>Suspended particles mg/l</b>			
1C	20400	73,9			
Drilling					
2C	670	163			
3C	1230	16			
4C	302	11			
4C1					
5C	980	15			
6C	840	4			
7C	710	8			
8C	610	29			

## Appendix 5 – Landfill gas

### Calculations on landfill gas

#### LandGEM

In order to estimate the potential landfill gas production LandGEM, a calculation tool for landfills, was used. In this program the following parameters are inserted:

- Name of the landfill
- Start year for the landfill
- Stop year for the landfill
- Waste design capacity or amount of waste when closed
- Yearly deposited amounts of waste from start to stop (tonnes)

Most data regarding waste amount is presented in  $m^3$ , in order to use these values in the LandGEM model these have to be converted into weigh.

The amount of waste at the landfill is at the moment  $19.5 \cdot 10^6 m^3 = 5\,577\,000 \text{ tonnes}$ .

The landfill has been in use 1991-2011.

Besides this start information different values on parameters can be used. These parameters are:

- Methane generation rate,  $k$
- Potential methane generation capacity,  $L_0$
- NMOC (NonMethane Organic Compound) concentration
- Methane content

For these parameters LandGEM have values for a conventional MSW landfill, which has been used in this study.

These values are:

$$k = 0.05 \text{ year}^{-1}$$

$$L_0 = 170 \text{ m}^3 / \text{Mg}$$

$$\text{NMOC} = 4\,000 \text{ ppmv as hexane}$$

$$\text{Methane content} = 50 \% \text{ by volume}$$

#### IPCC-model

$$\text{GasProduction}_T = \frac{16}{12} \cdot F \cdot \text{DOCF} \cdot \text{MCF} \cdot \sum_{x=1}^n \text{MSW}_{xt} \cdot \text{DOC}_{xt}$$

In order to calculate the F-fraction the assumption of 50 % methane and 50 % carbon dioxide was made. The total mole mass for these two compounds are:  $M_{tot} = M_{CH_4} + M_{CO_2} = 16 \text{ g/mole} + 44 \text{ g/mole} = 60 \text{ g/mole}$ . Assume a total amount of 100g and thereby 50g methane and 50g carbon dioxide. This gives 3.125 moles of methane and 1.136 moles of carbon dioxide,  $\frac{m}{M} = n$ . The total amount of moles are 4.261 and the F-parameter thereby becomes  $\frac{3.125}{4.261} = 0.73$ .

The organic content amount was calculated from the amount of organic waste in the waste statistics. For those years that lac statistics the previous year's amount of organic waste was assumed.

**Table 12 Presenting the figures used in the IPCC-model in order to calculate the gas production at the landfill.**

<b>Year</b>	<b>F % methane moles</b>	<b>DOCF % methane</b>	<b>MCF 0.4-1 correction factor</b>
1990	0.73	0.5	1
1991	0.73	0.5	1
1992	0.73	0.5	1
1993	0.73	0.5	1
1994	0.73	0.5	1
1995	0.73	0.5	1
1996	0.73	0.5	1
1997	0.73	0.5	1
1998	0.73	0.5	1
1999	0.73	0.5	1
2000	0.73	0.5	1
2001	0.73	0.5	1
2002	0.73	0.5	1
2003	0.73	0.5	1
2004	0.73	0.5	1
2005	0.73	0.5	1
2006	0.73	0.5	1
2007	0.73	0.5	1
2008	0.73	0.5	1
2009	0.73	0.5	1
2010	0.73	0.5	1
2011	0.73	0.5	1
<b>Year</b>	<b>MSW (m3) amount waste</b>	<b>DOC (m3) organic content</b>	<b>Gas production m3</b>
1990	0	0	0
1991	1126*	394.1	161971
1992	1127.4*	394.59	162374

1993	879.4*	307.79	98795
1994	869.3*	396.4008	125776
1995	830*	378.48	114661
1996	833.1*	379.8936	115519
1997	806.9*	431.6915	127141
1998	822.9*	440.2515	132233
1999	815.8*	436.453	129961
2000	844*	378.956	116741
2001	734.2*	329.6558	88342
2002	713*	488.405	127105
2003	741*	507.585	137284
2004	752*	475.264	130450
2005	773*	529.505	149397
2006	1021*	699.385	260636
2007	1089*	745.965	296510
2008	1192****	816.52	355252
2009	1460*	1153.4	614647
2010	1475*	1165.25	627341
2011	1494****	1180.26	643608

\*Tugui, 2012

\*\*\*\*Serghienko, 2012

## Appendix 6 – Covering materials

In this appendix the calculations for the estimated amount of materials needed to cover the landfill, displayed in chapter 7, are presented:

Area of the landfill: 180000 m<sup>2</sup>

### Construction waste

Amount needed for a 0.5 m thick layer:  $180000\text{m}^2 \cdot 0.5\text{m} = 90000\text{ m}^3$

Calculation from volume to mass:

Mean density construction waste:

$$\delta_{\text{cement}} = 2500\text{ kg/m}^3$$

$$\delta_{\text{concrete}} = 2400\text{ kg/m}^3$$

$$\delta_{\text{brick}} = 1500\text{ kg/m}^3$$

$$\delta_{\text{china}} = 2400\text{ kg/m}^3$$

$$\delta_{\text{construction waste}} = \frac{(2500+2400+1500+2400)}{4} = 2200\text{ kg/m}^3$$

The amount needed in weight to cover the landfill is:  $90000\text{m}^3 \cdot \frac{2200\text{kg}}{\text{m}^3} = 198000\text{tonnes}$ .

### Clay

The flow is calculated for 1 m<sup>2</sup> of the landfill.

Darcy's law: 
$$\frac{q}{A} = \frac{k \cdot h}{l} = k \cdot i$$

q= flow of water per time unit, m<sup>3</sup>/s

A= cross section area, m<sup>2</sup>

k = permeability, m/s

h = deferens in hydraulic pressure, l mvp (one metre water column )

l = length in the flow direction with pressure difference h, m

i = hydraulic gradient (loss in pressure per length unit in the flow direction h/l), nu unit

The permeability of the clay is 10<sup>-9</sup> m/s

The area is 1 m<sup>2</sup>

The length of the landfill is 450 metres

The height of the clay layer is 0.3 metres

This gives a flow of:  $\frac{1.4 \cdot 10^{-9} \cdot 1 \cdot 0.3}{450} = 0.021\text{ l/m}^2\text{ year}$  which meets the requirements of maximum 5 l/m<sup>2</sup> year.

The amount of clay needed to cover the landfill with a layer of 0.3 metres is:

$180000 \text{ m}^2 \cdot 0.3 \text{ m} = 54000 \text{ m}^3$  of clay.

### **Sludge and bottom ash**

The amount of sludge for one year is:  $90\,000 \text{ m}^3$

$\frac{9 \cdot 10^4}{18 \cdot 10^4} = 0.41 \text{ m}$  is the powerfulness that one-year production of sludge can produce.

Of the 0.5-0.6 metres of tightening material should 40-50 % be sludge, this results in a  $0.5 \cdot 0.4 = \mathbf{0.2} - 0.6 \cdot 0.5 = \mathbf{0.3}$  metres of sludge.

The height of ash needed is 0.2-0.4 metres which approximately results in an amount  $18 \cdot 10^4 \cdot 0.2 = \mathbf{44\,000 \text{ m}^3} - 18 \cdot 10^4 \cdot 0.4 = \mathbf{88\,000 \text{ m}^3}$ .

### **Drainage layer**

Amount needed  $180\,000 \text{ m}^2 \cdot 0.5 \text{ m} = 90000 \text{ m}^3$

The density of glass is  $2500 \text{ kg/m}^3$ .

$90000 \text{ m}^3 \cdot \frac{2500 \text{ kg}}{\text{m}^3} = 225000 \text{ tonnes}$