Exploring The Anthropocene : Mapping And Surveying Of Landfills In Flanders

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SUMMARY: The Public Waste Agency of Flanders (OVAM) is the competent authority in charge of waste management, sustainable material management and contaminated soil management in Flanders (northern region of Belgium). This contribution will focus on the aspects of exploring (former) landfills with regard to the feasibility of Landfill Mining as an element within the concept of **Anthropocene mining**. In 2011, an OVAM-vision on **Enhanced Landfill Mining (ELFM)** was approved by the board of directors and resulted in an operational program over the period 2011 – 2015. A tiered approach in three steps was developed in order to investigate the opportunities of ELFM within the framework of sustainable material and soil management. These three steps are **Mapping, Surveying and Mining**. The main goal of this research program is the development of a comprehensive policy that deals with the issue of 2.000 former landfills in a sustainable context, meeting the demands of the current and future generations. A broader concept will be introduced and is described as **Sustainable Landfill Site Management (SLSM)**. SLSM has 4 objectives: **Recycling of waste, Recovery of energy, Reclamation of land and the Preservation of drinking water supplies (R^3P)**. The overall challenge is to turn a threat into an asset at 2.000 landfill sites. Distinction has to be made between the sustainable management of those sites and the effective mining. The latter is rather a long term issue although the optimal conditions of a future mining need to be safeguarded in the short term. In a broader perspective, the protection of the landfill mining potential should also be combined with the protection of the environment. If necessary, remedial actions should be taken within a appropriate timeframe, taken into account the possibilities of ELFM. Due to the amount of landfills and the restricted resources, a general and extensive investigation is not feasible in a short period. A priority ranking was needed and the decision support tool **Flaminco** (Flanders Landfill Mining Challenges and Opportunities) combines several parameters determining the potential of ELFM and the risks of contamination. Based on this ranking, further actions could be planned also including research of innovative technology or a selection of the most appropriate methodology/technology. In collaboration with the Ghent University (LAGH), an evaluation of 5 geophysical prospection techniques was performed at 2 different locations. Based on these experiences a more efficient and effective surveying of landfills can be developed, meeting the R^3P-objectives.

1. INTRODUCTION

OVAM is an environmental agency in Flanders (Belgium) dealing with the issues of Soil Remediation, Waste and Sustainable Material Management. From this perspective, active and former landfills are not a final destination of residual waste which should be monitored eternally but rather an essential part of the policy transition towards sustainable materials usage. The potential reclamation of waste disposal sites should be considered and the concept of **Enhanced Landfill Mining (ELFM)** was introduced, defined as the safe conditioning, excavation and integrated valorization of landfilled waste streams as both materials and energy, using innovative transformation technologies and respecting the most stringent social and ecological criteria (Jones et.al., 2012).

In 2011, a corporate vision on ELFM was approved by the board of directors and resulted in an operational program over the period 2011 – 2015. The introduction of ELFM should also be related with the new concept of Sustainable Material Management and the shift to a Circular economy. From this point of view, landfills are no longer considered as a final and static situation but as a dynamic part of the materials cycle. The potential valorization of the disposed waste is an important aspect in the assessment of the environmental impact of landfills.

The main goal of this concept is the gathering of materials (in its most broad definition) from landfill sites or dump sites and reuse it for some purpose by introducing it again in the material chain. This approach makes it possible to gain important resources such as: materials, energy, drinking water and free space. A secondary benefit is that this concept is also suitable for purposes on soil remediation. In general landfill mining is used as a method to reduce the costs in case of soil and water remediation or induced by infrastructural activities. The approach on material management or resource efficiency as such are rather limited (Umans, 2011).

The OVAM developed a three step approach towards ELFM: **Mapping** (inventory of the landfill sites on the level of the Flemish Region, with indication of specific characteristics of the area), **Surveying** of individual landfill sites (identification of the specific landfill geometry, identification of the composition of the landfilled waste, identification of the geo-physical and -chemical characteristics of specific surroundings of the landfill site), **Mining** of a specific landfill site (extracting the waste, (pre)treatment of the waste to make it suitable for material reuse or valorization).

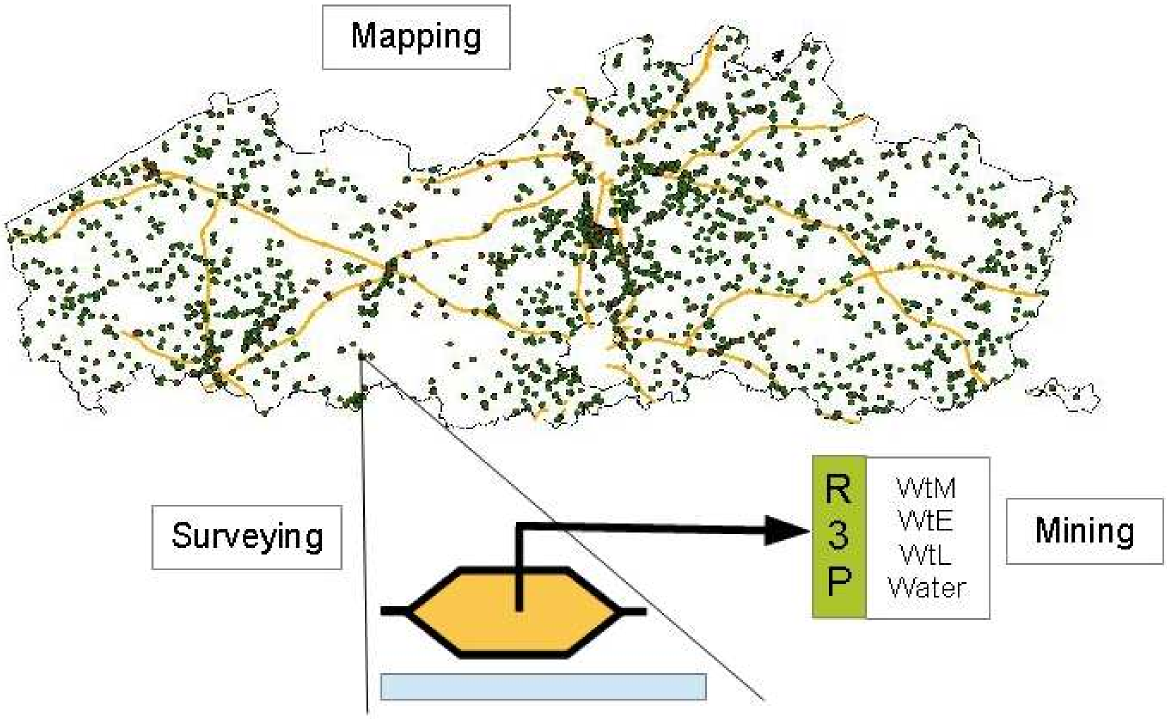

Fig.1 Stages in Anthropocene mining (Landfills in Flanders, OVAM database, 2013)

The mapping revealed moreover 2.000 landfill sites in Flanders. Mining or even investigating all those 2.000 locations in a short period was unrealistic, therefore a methodology for prioritization of potential for Landfill Mining based on a multicriteria-analysis calculation tool was developed. The criteria were based on the content of the landfill site, the period of landfilling of the stored waste, the volume of the landfill body, the actual or future use of the location, the accessibility, the proximity to neighboring landfill sites and the need to remediate the location (Behets et al., 2013).

This decision support tool **Flaminco** (**F**landers **la**ndfill **min**ing **c**hallenges and **o**pportunities) delivered a ranking of landfills and more detailed investigations are and will be executed on a high level (mapping the region of Flanders) and a low level (surveying of individual landfills).

Exploration methods like remote sensing, aerial photographs and geophysical prospecting are tested on several locations. OVAM is evaluating the Strengths, Weaknesses, Opportunities and Threats of these exploration techniques in order to introduce the Best Available Technology to explore landfill sites.
The overall goal is providing reliable data on the composition and magnitude of landfills in Flanders. This information allows a sustainable management of these landfill sites within the context of resource and material management. The R³P-approach includes Recycling of Materials, Recovery of Energy, Reclaiming of Land and the Preservation of Drinking water supplies.

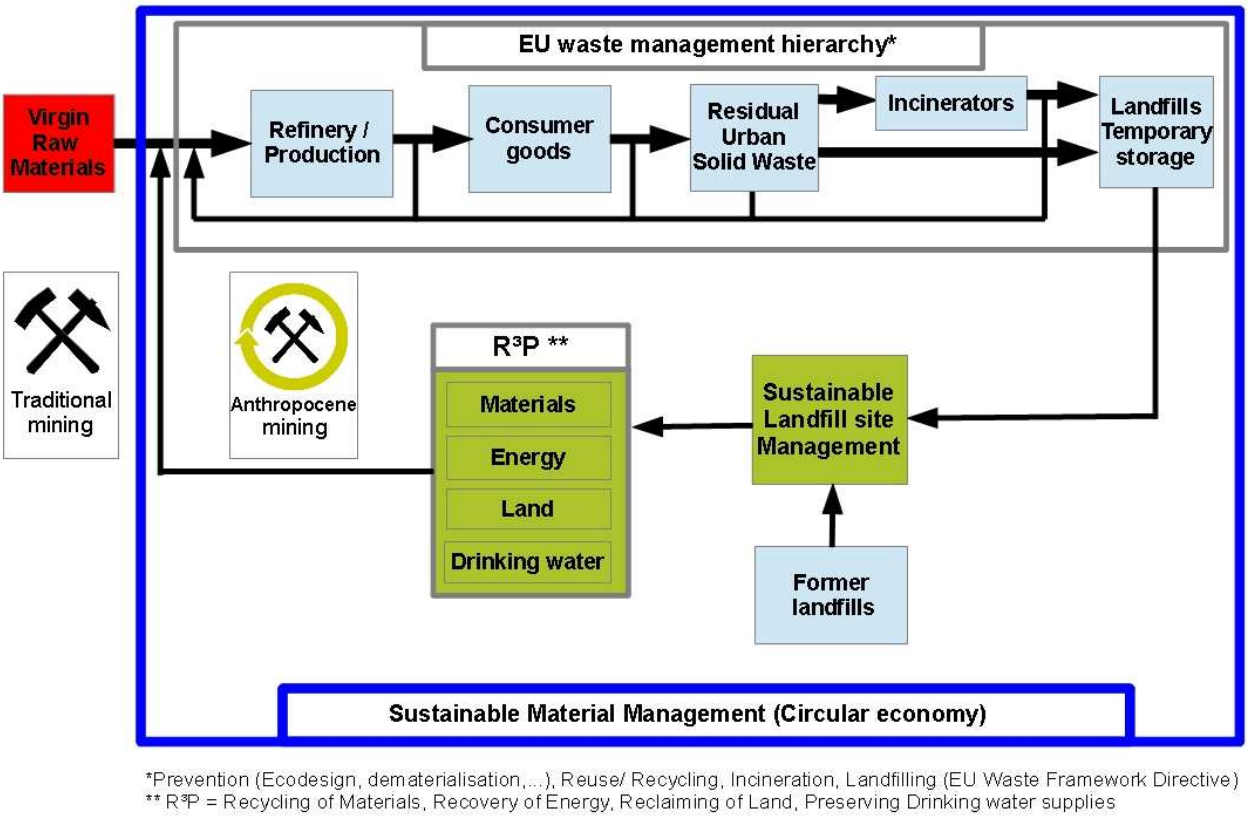

Fig.2 Material loops and R³P

Within this R³P-concept the shift from the Waste Management to Sustainable Material Management is shown. The input of virgin raw materials in this system can be lowered significantly by mining the Anthropocene (Urban Mining and Landfill Mining).

2. WASTE MANAGEMENT AND SOIL REMEDIATION

In Flanders, the awareness of contaminated land as a potential environmental risk has arisen in the late 1980s and was at that time mainly related to hazardous waste treatment and disposal sites. From the early 1990s, systematic data collection on waste was performed and resulted in 3.788 records referring to landfills and waste treatment sites. These inventories reveal the existence of more than 2.000 sites which could be labeled as landfills and dump sites.

Currently, only 1% of the municipal solid waste (MSW) is landfilled and only 12 landfills are still operational in Flanders (OVAM, 2013). Nearly 70 % of the MSW is separately collected and recycled. This process could be described as Urban Mining and is a specific part of the Mining of the Anthropocene. The Anthropocene is an informal geologic chronological term that serves to mark the evidence and extent of human activities that have had a significant global impact on the Earth's ecosystems. According to Crutzen and Stoemer (2000) the Industrial Revolution can be regarded as the start of Anthropocene. The potential of Anthropocene mining is quite larger than the recycling of MSW if former landfills are taken into account. The ELFM-program, set up by the OVAM in 2011, aims at the potential of those 2.000 landfills. The first stages can be defined as the exploring phase and emphasizes on the inventory of the ELFM-potential. Whereas the initial investigation strategies were based on the environmental impact of a landfill, the ELFM-approach must focus on the waste content of a landfill.

The contaminated land and soil remediation policy was developed in the first half of the 1990s and resulted in the Soil Remediation Decree of February 22nd 1995. This legislation was following new tendencies on soil remediation and emphasizes on leaking (underground) storage tanks of (chlorinated) hydrocarbons and its impact on groundwater. A list of risk activities which could adversely impact the soil quality was defined.

Based on the information of delivered operational permits an estimation of 85.000 potentially polluted sites was made; less then 4% were landfills and waste disposal sites.

The remedial process consists of a tiered approach with different stages in the procedure: preliminary soil investigation, descriptive soil investigation, soil remediation project, soil remediation work and monitoring. OVAM enacted generic guidelines on each phase of the remediation process. Accredited Soil Remediation Experts (ASRE) apply these guidelines on a site-specific level (Van Dyck, Wille, 1998).

OVAM elaborated a specific investigation procedure for landfills, emphasizing on the environmental impact. The effort of data collection frames within the context of determining whether a risk is present rather than characterizing the nature and extent of the waste present in a landfill. This phased and risk driven approach was developed within the context of containment remedies. The risk assessment was based on a conceptual site model which is used to identify all exposure pathways associated the landfill source (i.e., direct contact with top soil/waste, exposure to contaminated groundwater, leachate, and/or landfill gas). The containment remedy addresses all pathways associated with the landfill source and avoids exposure and contact to humans and nature. The waste disposal as such is only seldom (partly) removed and remains a potential risk.

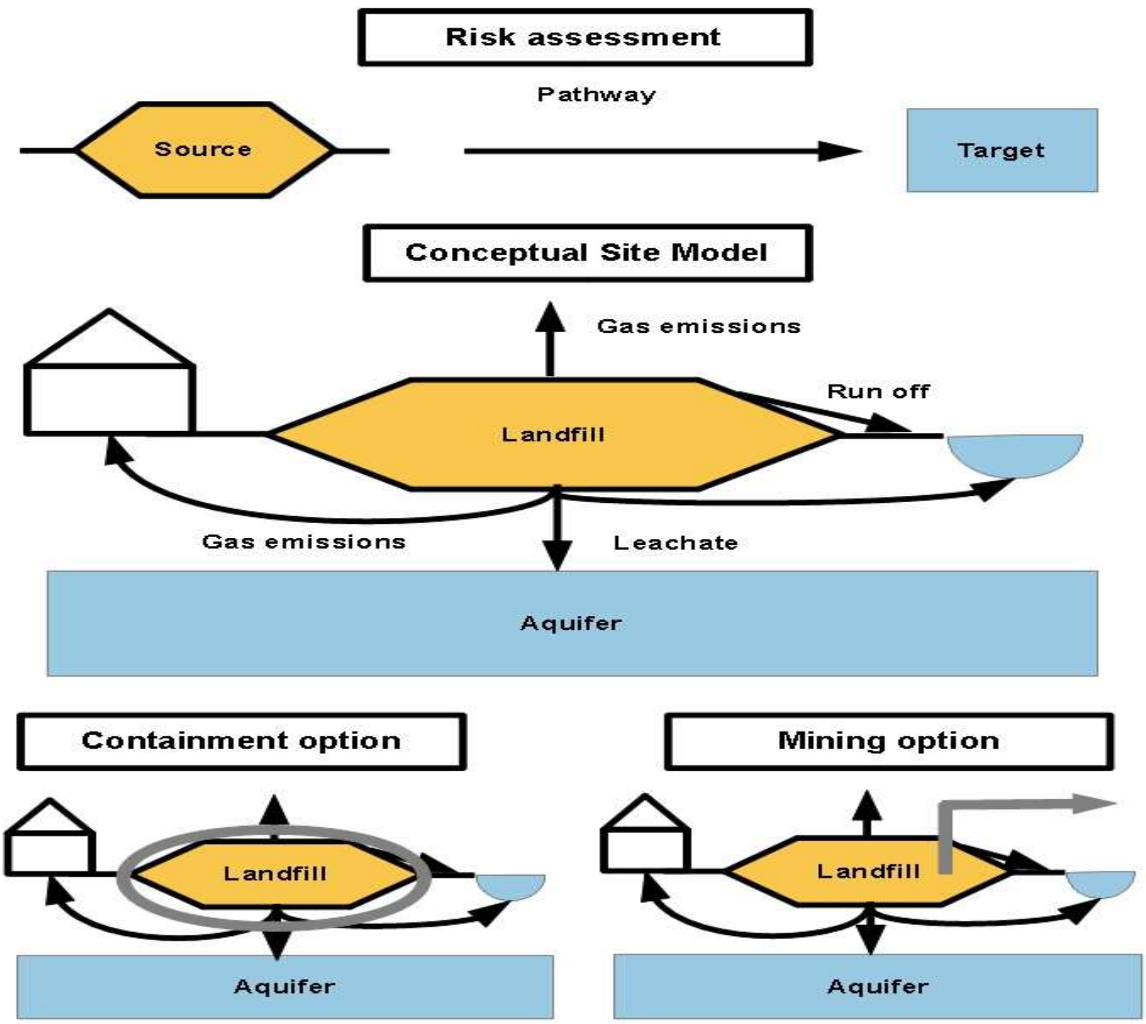

Fig.3 Containment versus mining of landfills

The introduction of the concept of Enhanced Landfill Mining also implies another methodology of site investigation, more focusing on the characterization of the waste content of the disposal site in order to meet the R³P-principle. The valorization of the disposed material is a crucial element and the existing pathways of migrating leachate and/or landfill gas should be rather considered as an important element in determining the mining-potential (Umans et.al., 2013).

3. MAPPING OF LANDFILLS

In preparation of the Flemish Soil Remediation Decree some provincial institutes made an inventory of all the possible sites where there were activities which could potentially cause soil contamination. So most of the historical landfills in Flanders were inventoried. For each site, a file was created containing information about the location (XY-coordinates, topographical map...), type of landfill (MSW, IW, cover, excavation...), period of landfilling, actual use, permits, ownership, subsurface.... In total 1.738 landfills were identified and filed. Due to the fact that nearly 1.500 landfills were closed before 1983 (enactment of new (severe) legislation on operational permits), the existing data on waste content and volume are restricted and unreliable. The ELFM-characterization of landfills aims at filling these gaps and an investigation program is set up by the OVAM. Although not every description was as detailed, this inventory is a good starting point for the database.

As the Flemish Soil Remediation Decree was enacted in 1995, soil investigations were executed at several (former) operational facilities which were considered as potentially soil polluting activities. Such a report had to be made whenever such a plot was transferred or periodically depends on the kind of activity (every 5, 10 or 20 years). In the period between 1995 and 2013, 65% of the known former landfill sites were investigated. All those reports were evaluated by OVAM and the investigated soils were added to a database. This database (Land Information Register) contains certain information on landfill sites, although it was information concerning the situation of pollution of the underground. All the relevant information was added to the ELFM-database.

The last source of information was the database containing operational permits for landfilling. These permits describe the requierements of the landfills such as the kind and volume of the admitted waste. There are also certain obligations concerning applying barriers, covering, landfilling, groundwater monitoring,... Each year, the landfill operator has to submit a report on the landfill activities of the past year and the results of the groundwater monitoring wells.

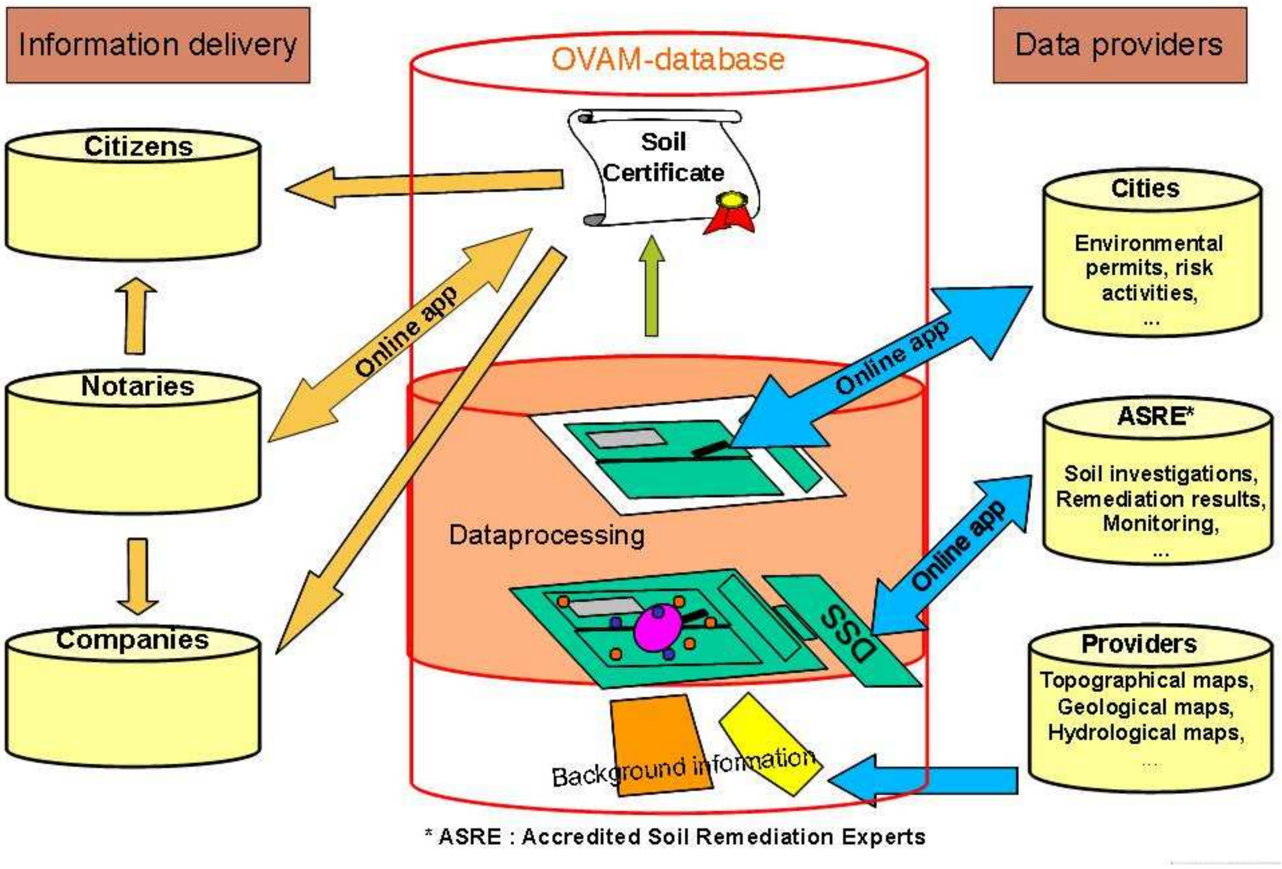

Fig. 4 Data collection, data transfer and data processing on landfills at OVAM

These provided data are stored in a separate OVAM-database and also added to the ELFM-database, resulting in 323 additional landfill sites. Nearly 40% was investigated in compliance with the Soil Remediation Decree. Combining the different databases into one overall ELFM-database provides a pretty good view on the landfill sites in Flanders, the availability of detailed data and the information gaps. The information is also available in a GIS-application and so all the information can be visualized and eventually be transferred to a GPS-device, so it can be carried out on the field.

There is a lot of variety between the listed sites and also the level of accuracy and detail of the available data is versatile. In order to improve the quality of the data and elaborate a comprehensive ELFM-policy, an investigation program was set up. Investigating moreover 2.000 sites in a short period was unrealistic, therefore a methodology for prioritization of potential for Landfill Mining based on a multicriteria-analysis calculation tool was developed. The decision support tool **Flaminco** delivered a ranking of landfills and more detailed investigations are and will be executed on a high level (mapping the region of Flanders) and a low level (surveying of individual landfills). Both results are based on the currently existing database.

In the future, exploration of the most promising landfills will be performed, eliminating gaps and uncertainties in the database. Aerial photographs allow a determination of the volume and also provide useful data on the history of the operations. Notwithstanding the good results on geometry, limited information on the waste composition and internal structure of the landfill was obtained. Remote sensing remains promising and needs further investigation. OVAM applied successfully Infrared-remote sensing to locate hotspots and consequently the production rate of landfill gas. New projects are planned to facilitate this method of large scale landfill mapping.

4. SURVEYING

4.1 Background information

Drilling boreholes and monitoring wells are the currently used investigation methods. However, seldom samples were taken from the waste material itself and it is not always an option to obtain such samples. This approach implies a lack of significant data of the geometry of a landfill and its waste content. Again, the risk driven approach prevails on the exploration of the deposits. The composition of a landfill is an important criterion in the Flaminco-tool and reliable files or documents describing the former activities are often missing. The information about geometry and waste content has been explored by means of geophysical prospecting. The lateral extent of the landfill and changes in electrical conductivity can be explored by electromagnetic profiling. More information is gathered by ground penetrating radar (GPR) and geo-electrical tomography. The results of GPR are promising because it provides information about the vertical extent and composition of the landfill. At selected zones of interest, the vertical distribution of resistivity is collected by geo-electrical tomography. In combination with the results of the flux gate magnetometer, the high resistivity values can be assigned to magnetic metals.

Besides the limiting factor of the accessibility of the landfill, each application has his own restraints. Therefore, at a test site, a combination of different geophysical methods are applied. OVAM is evaluating the strengths, weaknesses, opportunities and threats of these exploration techniques in order to introduce the Best Available Technology to explore landfill sites.

The first study area is located in the eastern part of Flanders, close to Hasselt. During a decade, from mid 1960s till mid 1970s, the study area was used as a domestic waste disposal with a total surface of 25480 m². In 1980, limited actions were taken to cover the dumping site. Through this rudimental cover, demolition waste, car and truck tires, flasks,… are visible at the surface. A second landfill site was selected to carry out the same techniques. These results will be communicated at the 2nd ELFM conference at Houthalen (14-16 October 2013).

4.2 Evaluation of the methods applied at the pilot test site

At the pilot test site, the best results were obtained by electromagnetic profiling and with the fluxgate magnetometer. Zones where probably a significant amount of metals are dumped can be deduced. They correspond with the descriptions made during the drillings. Also zones where it is more likely to find plastic, glass or rubber can be distinguished. These methods do not allow to determine at what depth the materials are buried. Indication of depth can be deduced by ERT. Also the base of the landfill is recognized by this method. In this case, it was at a depth of ca. 1.3 m. On the other hand, the condition of the landfill (dense vegetation, obstacles of bricks, tires, wood,…) limited the accessibility of the field, and the survey by means of GPR therefore didn't give the expected results.

The use of the **fluxgate magnetometer** is very easy. One person walks along the profile and measures every 0.5 to 1 m. The obstacles can easily avoided by walking around them. Plotting the results on a map, zones with the same magnetic flux can be distinguished. The higher the values, the more likely iron can be found in the subsoil. Non-magnetic metals will not be discovered. This method gives no information about the depth of the buried materials, nor the base of the landfill nor the depth of the water table can be deduced. Although it is a time consuming method to cover a study area, it can be applied in zones where detailed information is needed. This method is very suitable in combination with ERT or electromagnetical profiling.

The results of the **electromagnetical profiling** method give indication of zones with higher/lower conductivities. It should be considered that the conductivity can be influenced by leachate of the landfill or by metals. Lower conductivities might indicate buried plastic, rubber, glass,… . The depth of the buried materials can be deduced from different spacings of the coils. It is straight forward that increasing the distance between the coils results in increasing investigation depth, but it will be more difficult to detect small objects. Object with a high contrasting conductivity compared to the surrounding conductivity will be more easily detected. A combination of the distance between the coils can give some information about the depth of the target. Using electromagnetical profiling gives no information about the composition of the target. Therefore, it is advised to combine different geophysical methods, for example with the fluxgate magnetometer at the zone of interest. The importance of the accessibility of the field depends on the instrument and the desired investigation depth. Some instruments are operated by one person, others by 2 persons. In the last case, it is important that there are no obstacles between the 2 persons because the cable that connects the 2 persons can get stuck at the obstacles.

Electromagnetical profiling is very useful at landfills that are covered by a seal. The measurements can go through the seal without losing information.

Seismic refraction is the least applicable investigation method for this purpose. The vertical and lateral heterogeneity of the landfill influences the seismic velocity. Beneath the geophone, the composition of the landfill differs, so conclusions about the seismic velocity are difficult. In exceptional conditions, the base of the landfill might be deduced.

The application of **GPR** is very promising, provided that conditions at the site are favorable. The surface of the site must be flat to roll or slide the equipment over it. Branches, stones, tires,… prevent the practical execution and the interpretation of the measurements. Under ideal circumstances, the depth and size of the target can be deduced but the exact composition of the target remains unknown. Indications of group of material (metal, porous object,…) are possible by using different antennae. The results of GPR can be presented by 3D images. In case a detailed composition of the landfill is desired, the distance between the profiles should be kept small (0.5 to max. 1m). The heterogeneity of the landfill can be deduced together with the landfill depth and the depth of the water table.

ERT is a powerful investigation method. The vertical as well as the lateral distribution of the resistivity along a profile is given. Zones with higher/lower resistivities can be deduced. High resistivity gives indication of unsaturated conditions. Within the unsaturated zone, low resistivities can occur in very restricted zones that can be due to more humid soil or, in case of a landfill, no metals. Most of the time, the base of the landfill can be deduced. In many cases, a landfill contains biodegradable products that influence the resistivity of the groundwater. This should be considered during the interpretation of the data. In this case, it will be more difficult to define the basis of the landfill. The application of ERT is rather time consuming, because of the time needed to place the electrodes and connecting the cables with the electrodes. Accessibility of the investigation site by car will help a lot, because the equipment is heavy to carry (cables, electrodes,…). It speaks for itself that the subsoil should be soft, because the electrodes need to be placed in the surface. It is not possible when the surface consists of rocks or other hard material. This method is not applicable in case the landfill is sealed. The electrodes might damage the sealing.

5. CONCLUSION

The investigation of landfills is currently often based on a risk assessment approach. However, the characterization of the waste content (quality and quantity) is an important issue in the determination of the mining potential. Evolving from waste management to sustainable material management implies a reliable inventory of the stock (landfills). Due to restrictions on trial pits and boreholes, geophysical methods contribute to this exploration need.

The results of the applied methods at the pilot test site mainly depend on the site's accessibility. In case there are no restraints on accessibility, and provided the surface is flat, the application of GPR is expected to be very appropriate to deduce the structure and composition of a landfill. Also ERT provides good results in 3D. However, the application is very time consuming for a detailed investigation of an entire study area. Therefore, it is advised to use this method to restricted zones where extra information is desired. The fastest method to explore a study area is by means of the electromagnetical induction method. Zones with aberrant conductivity can be deduced, but information about the composition of the waste and/or thickness of the landfill will not be provided. Magnetical profiling is very time consuming, but it gives very accurate and unambiguous information about the location of iron on the condition that the measured are closely spaced. This method can be applied to zones that need detailed information. The implementation of refraction seismic is unsuitable for this kind of research. In many cases the composition of the landfill is very heterogeneous with materials with different seismical velocities.

It can be concluded that a combination of geophysical methods gives promising results. Further research is planned at another landfill site with different characteristics in order to evaluate the above-mentioned results.

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