Multriwell® - status report 2015

Evaluation of a new landfill gas extraction system

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Multriwell® - status report 2015

Evaluation of a new landfill gas extraction system

Final

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Summary

Multriwell® is a new gas-extraction system that can extract landfill gas (LFG) from landfills and dumpsites. Patent holder of the Multriwell system is Trisoplast International B.V. and Cofra B.V..

Multriwell was first installed on the landfill of Vink, Barneveld in the Netherlands in 2009. Nine Multriwell system are now installed at 8 landfills all around the world.

In this report the Multriwell system is evaluated in comparison to traditional gas collection systems. The evaluation is based on information from the period 2009 till summer 2015 provided by Multriwell B.V. and TerrAdvies B.V..

The following can be concluded about the performance of the Multriwell system:

- Experience over the past six years proof that the Multriwell system is a good alternative for the extraction of LFG from waste bodies;
- Multriwell improves the LFG extraction ratio per volume of waste with a factor of approximately 10. The Multriwell system has an impermeable cap therefore a factor 2 would be expected. Apparently the Multriwell system increases the LFG production with a factor of around 5. If we only use data from the Dutch landfills the factor is approximately 6;
- The LFG extraction flow with Multriwell on Dutch sites is a factor 5.4 higher than the traditional system at its peak in the period 2002-2014. Even if we compensate for the gastight capping the Multriwell still performs much better (a factor 2.7). This result is remarkable because the Multriwell is in older waste and thus theoretically one suspects a lower LFG flow.

There are no examples of the application of water infiltration into the landfill via the Multriwell system. It is recommended to research the possibility of the injection of water into the waste body in order to enhance the LFG production.

Table of contents

Appendix 1: Photos installation Multriwell.

Appendix 2: Characteristics LFG extraction sytems

Appendix 3: Landfill Schinnen, Schinnen (NED)

Appendix 4: Landfill Boeldershoek, Hengelo (NED)

Appendix 5: Landfill Vink, Barneveld (NED)

Appendix 6: Landfill VAM, Wijster (NED)

Appendix 7: Landfill Preobrazhenka, Samara (RUS)

Appendix 8: Landfill Zabrze, Zabrze, (POL)

Appendix 9: Landfill Norte III-B, Buenos Aires (ARG)

1 Introduction

1.1 Introduction

Multriwell® is a gas-extraction system that can extract landfill gas (LFG) from landfills and dumpsites. It was first installed on the landfill of Vink, Barneveld in the Netherlands in 2009. Nine Multriwell systems are now installed at 8 landfills all around the world.

Patent holder of the Multriwell system is Trisoplast International B.V. and Cofra B.V..
Cofra B.V. is a part of the Boskalis Cofra Holding, which is part of the internationally operating dredging company Royal Boskalis Westminster. The Multriwell products are exclusively constructed and installed by Cofra B.V..

The Multriwell system should lead to an optimal water/leachate distribution and therefore optimal biodegradation of organic components together with a maximum extraction of the produced biogas. The result should be a higher extraction of LFG compared to a traditional LFG system and a lower greenhouse gas emission into the atmosphere.

This report describes the status of the Multriwell system in the summer of 2015.

1.2 Objective

The aim of this report is to evaluate the gas extraction with Multriwell systems. The results will be compared with the results from traditional gas collection systems at the same landfill sites.

1.3 Used documents and data

The following documents and data were used in this evaluation:

- General available data, see literature list in this report;
- Information provided by Multriwell and the operators of the landfills.

2 Landfill gas basics

2.1 Landfill gas production

Landfill gas (LFG) is the end product of the biodegradation of organic materials in a landfill. After organic waste is landfilled and compacted, the degradation process in the landfill starts to work. After some months the anaerobic process will start, resulting in the production of LFG. The LFG production rate depends on a large number of factors of which the most important are:

- Composition of waste: type and percentages of organic materials in the waste. The breakdown process can vary from a few days to decades;
- Humidity: Water present in the waste material fulfils an important role in the degradation process. Water is the medium for bacteriological dispersion in the waste;
- Temperature: a constant temperature of approximately 30-35 ºC is optimal for degradation processes within the waste body;
- Acidity: At low pH the methane production rate will decrease. pH in the range of 6-8 is optimal for the degradation processes.

The main components in LFG are 45 to 58% methane (CH_4), 32 to 45% carbon dioxide (CO_2), and nitrogen (N_2) 0-3%.

2.2 Landfill gas modelling

Several models exist to predict LFG production: First order model (TNO), LandGem (US EPA), GasSim (UK), EPER model France, EPER model Germany and Grontmij model.
It is well known that these models have a large uncertainty due to the many variables and the difficulty to accurate measure the production of LFG from a specific landfill [Scharff, 2005][Laner, 2011].

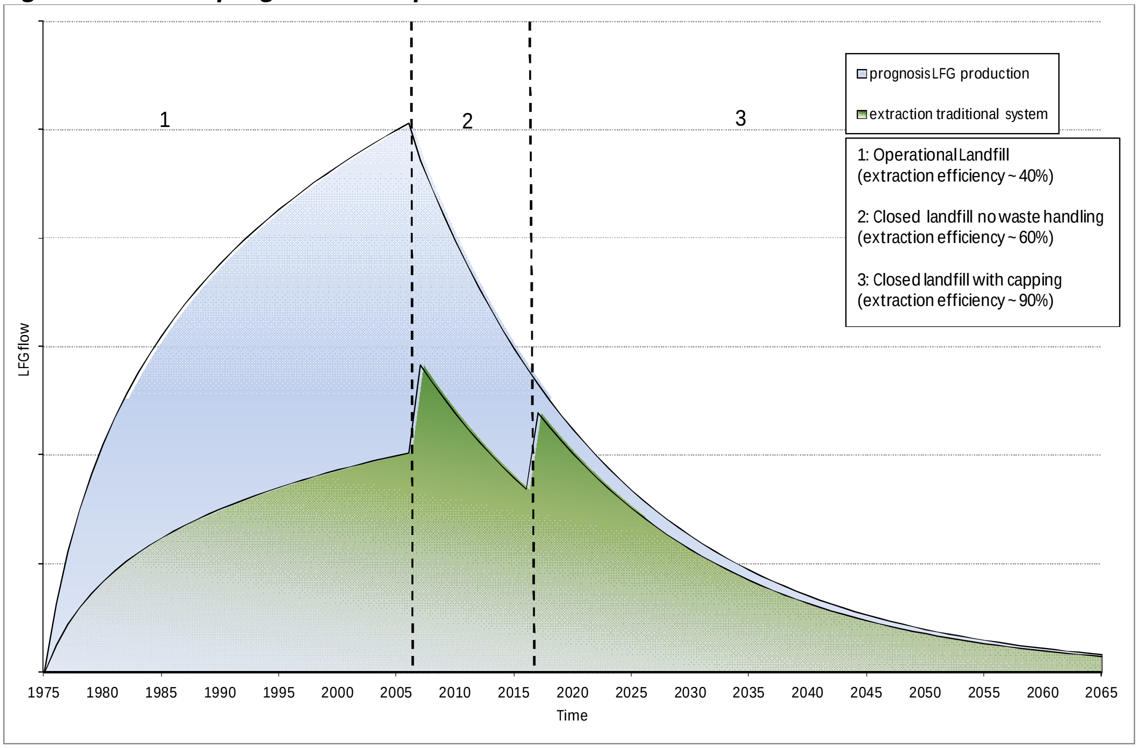
A common outcome of these models is given in figure 1-1. The blue part represents the modelled LFG which is produced over time. During landfilling organic waste is degraded. Some organic waste, like household waste reduces fast, and other organic material like wood degrades slow. Over time, during period 1 (see figure 1-1) the LFG flow increase towards the landfill closure. Due to the absence of new (young) waste after closure of a landfill the modelled LFG flow will drop (period 2).

The extraction efficiency during landfilling and just after closure is between 40 and 60%. This is mainly caused by:

- absence of a cover, resulting in LFG emitting to the atmosphere;
- part of landfill which are to shallow to install an LFG extraction system;
- methane oxidation in cover soils,
- lateral migration of LFG

A temporary top cover installed after closure of the landfill increases the extraction efficiency roughly from 40 to 60%. After installation of the final capping the extraction efficiency increases towards 90%. (See figure 2-1).

Figure: 2-1 basic prognosis LFG production and extraction



2.3 Landfill gas extraction

Traditional extraction consists of a vertical well system with connected horizontal transport pipes. Vertical gas wells are installed during or after the landfill body is built to its maximum height. In general a number of wells per hectare are installed (distance between wells of 50 to 100 m). Depending on the cover at the top of a landfill an additional horizontal system can be present to avoid over pressure problems.
LFG is extracted by a negative pressure. As a consequence of the negative pressure, air ingress can occur resulting in nitrogen (N_2) and oxygen (O_2) in LFG gas.
For an optimal extraction it is important that the extraction system is installed as soon as possible. Efficiency of a traditional extraction system is estimated to be 50 to 80% and 90 to 100% after the a gas tight capping is installed [Scheepers and van Zanten 1994][Laner, 2011].
In a Dutch inventory study an extraction efficiency of 46% was found [Ecofys, 2011].
After capping LFG generation usually decreases due to the lack of water. Infiltration of water has resulted in an increase of the LFG production on a number of landfills [Laner, 2011][Ecofys, 2011].

2.4 Landfill gas emission

Landfill gas emissions are an issue at sites where waste containing degradable organic matter is deposited (i.e. MSW landfills). Landfill gas is environmentally relevant on a global scale due to the methane as a potent greenhouse gas and on a local scale due to potential vegetation damage, odours, and landfill gas migration off site (i.e. explosion hazards) [Laner, 2011]. The global warming potential of methane (CH_4) is more than 20 times higher as for carbon dioxide CO_2 [EPA, 2012]

3 Landfill gas extraction system

3.1 Traditional landfill gas (LFG) extraction system

A traditional LFG extraction system consists of the following items (in order of connection from landfill area to the final gas utilization facilities):

1. Gas extraction wells:
   - vertical gas wells, mostly consisting of PE pipes (diameter 160 mm) and coarse/gravel casings (diameter 500 to 1000 mm, and a common distance between the wells of approximately 50 to 100 m). The depth of the well depends on the depth of waste and will typically terminate at 3 to 5 meters above the base of the waste mass.[EPA 2012] This configuration can change depending on different national requirements or local experiences;
   - horizontal wells. Common spacing of horizontal wells is 30 to 40 m apart. The perforated pipe within the trench is typically 0.10 to 0.20 m in diameter. Although vertical wells are most common design. Horizontal wells are more prone to failure because of blockage.

2. Gas collection system:
   - gas collection and transportation pipes, consisting of connecting pipelines, puts, manifolds boxes, and condensate trap / dewatering well(s). Above ground pipes must be protected against weather effects and movement from thermal expansion or contraction, which may result in more frequent cracks and weld separations. Pipe sizing should also consider the maximum expected LFG flow rates and vacuum loss caused by friction and the avoidance of pipe blockage by allowing LFG flow to continue despite moderate condensate build up;
   - blower/Gas extraction plant. This plant consists of gas pre-treatment equipment, gas pumps and ancillaries. It maintains/creates a lower pressure inside the wells compared to the landfill, thereby initiating/creating a driving force for the landfill gas towards the gas wells. Furthermore it is necessary to treat the LFG by removal of moisture and particulates which is necessary to protect the blower and ensure the LFG will burn effectively in a flare or other combustion device;
   - monitoring equipment: inline methane content analyser, flow meters, flare working hours, data-collection system etc..

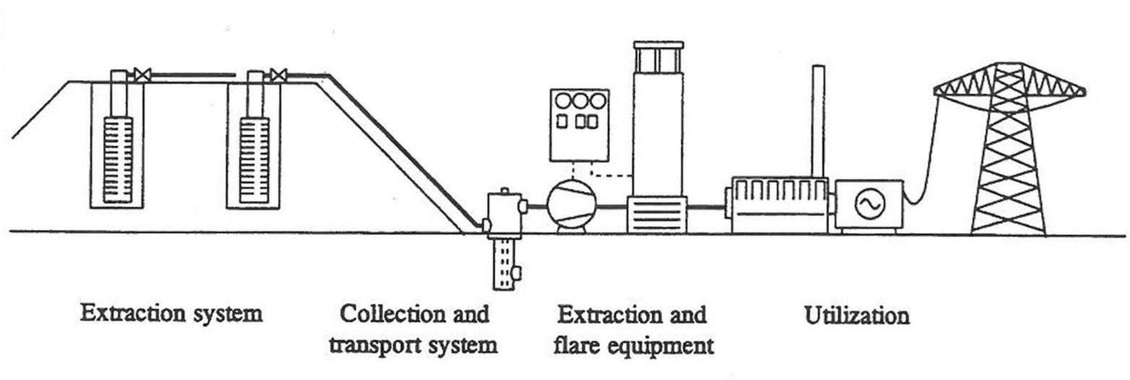
3. Gas conversion systems:
   - power generating units (PGU's), utilizing the landfill gas, generating electrical power to be fed into the nearby available power-grid;
   - flare. At times when there is more land fill gas (LFG) produced than the power generation equipment can utilize, the extracted landfill gas will be combusted in a flare.

The gas collection system is subject to a variety of stresses from the site environment such as system collapse caused by waste settlement, corrosion or aging of materials (including ultraviolet degradation), and damage that might occur as a result of heavy equipment and vehicles coming into contact with the wells and piping. Typical gas collection system maintenance activities include [EPA, 2012]:

- Repair or replacement of damaged wells and valves.
- Removal of leachate and condensate blockages.
- Repair of system components damaged by vehicles.
- Re-grading or replacement of pipe affected by settlement of the waste mass.

- Replacement of components that have failed as a result of aging or fatigue.

Figure 3-1 Schematic representation of a traditional landfill gas extraction system



3.2 Multriwell system

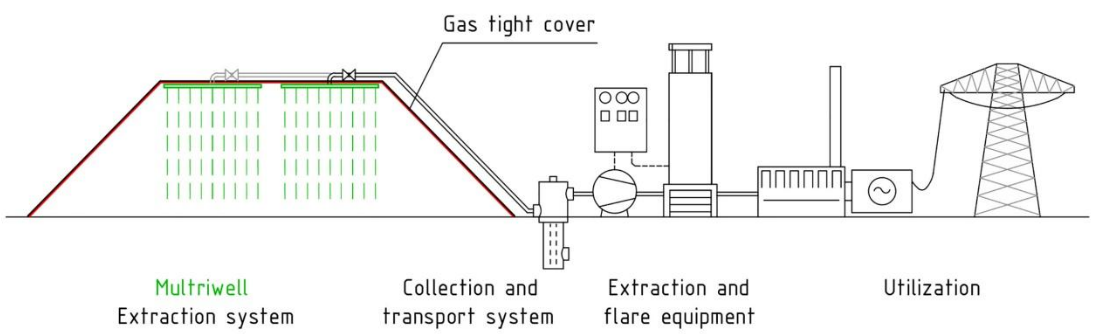
Multriwell is a new technique for LFG extraction. This new technique should enable the extraction of considerably more gas than traditional gas wells. The patented system consists of three components:

- flexible vertical wells conducted of polypropylene (PP), called Multriwell V-type. The V-type has the following dimensions: thickness of 5 mm and width of 100 mm. It's covered with a non-woven Geosynthetic filter material (also PP). See table 1 of an example of the Multriwell V-type.
- horizontal gas collection system that consists of:
  - Multriwell H-type drains. These H-type is a textured polyethylene (PE) sheet and a non-woven Geosynthetic fabric (PP) bonded onto the tops of the truncated cones of the textured PE sheet. See table 3.1 of an example of the Multriwell H-type;
  - Collector drains.
- A gas impermeable capping to prevent air ingress. For instance a Trisoplast® or geomembrane capping construction.

Landfill gas flows into the Multriwell V-type towards the H-type drains. From the H-type drains landfill gas flows into the collector drain(s) and is then transported to the utilization system.

In case of a high leachate table in the landfill, leachate is transported upwards through the V-type drains. This leachate seeps evenly into the waste body again to moisten the waste. This movement of leachate enhances the decomposition of the waste.

Figure 3-2 Schematic representation of the Multriwell system



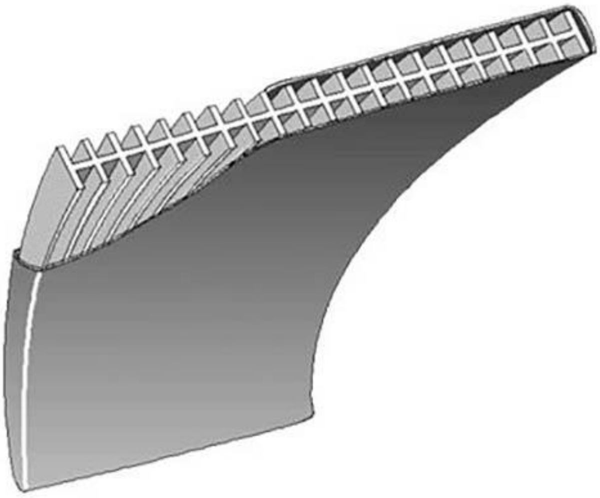
More information on Multriwell can be found on www.multriwell.com

3.3 Components of the Multriwell system

The Multriwell system consists of the following components, from bottom to top:

- Multriwell V-type (vertical flexible wells) in waste
- Porous mineral levelling layer (optional)
- Multriwell H-type (horizontal flexible wells)
- Collector drain/collector puts
- Mineral levelling layer (optional)
  - Trisoplast® or Geomembrane layer
  - Geosynthetic (signal) layer (optional in combination with Trisoplast®)
- Drainage layer (optional)
- Top soil
- Manifold(s) with transportation pipes

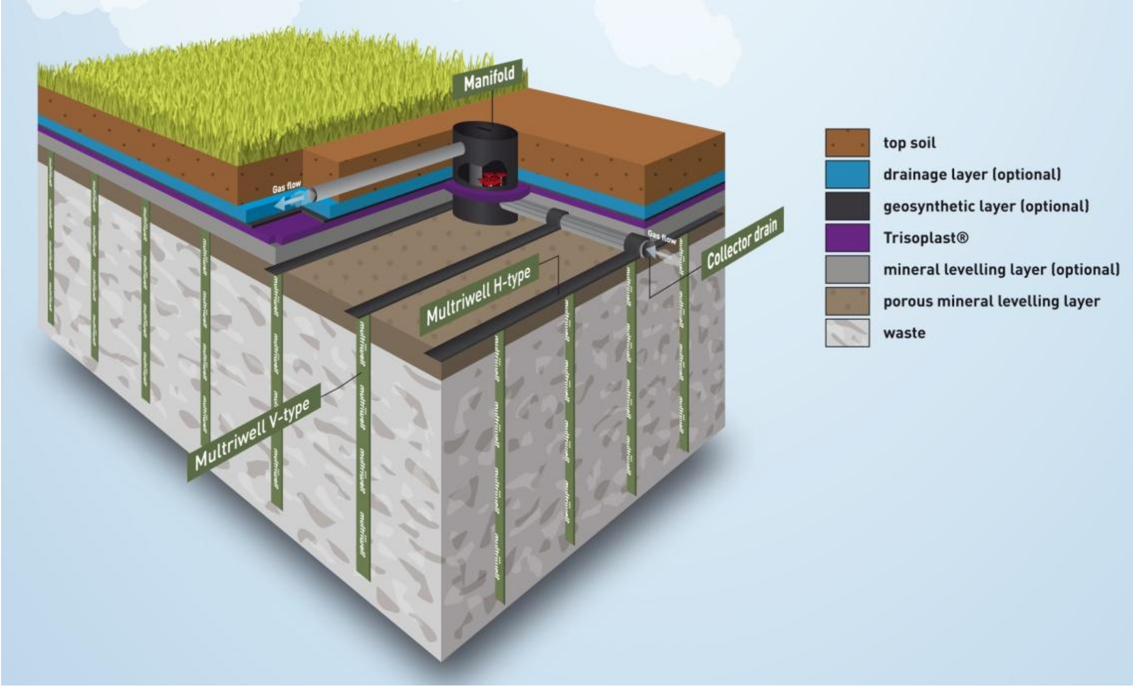
Table 3-1: Components Multriwell system

Multriwell component	photo
Multriwell V-type (grey is filter material, green is core (PP)	
Structure of core Multriwell V-type	

Multriwell component	**photo**
Top view of geosynthetic fabric of Multriwell H-type	
Profile of Multriwell H-type with non-woven and textured sheet	
Top view of textured (truncated cones) sheet of Multriwell H-type	

Figure 3-3 presents a schematic overview of the Multriwell system.

Figure 3-3 Schematic overview of Multriwell system



3.4 Preferred conditions for construction

The following conditions are preferred for the installation of a Multriwell system:

- A minimal thickness of the waste body of around 10 meters.
- A preferred installation depth of 30 meters. The maximum installation depth is 50 meters.
- On average, a percentage organic compounds > 7%.
- The vertical wells are placed with a stitcher attached to an excavator. Safety constraints a minimum clearance height for stitcher and excavator is the installation depth + 5 meters. Due to for instance electric wires.
- Due to safety constrains the installation of the Multriwell V-type can be carried out on a maximum slope 1:8 (vertical : horizontal)

The following constraints should be taken into account:

- A high percentage of big parts of construction and demolition waste (CDW) can hinder the installation.
- In case there are overhead electric cables or other objects an additional safety distance is possibly needed.

Variable aspects:

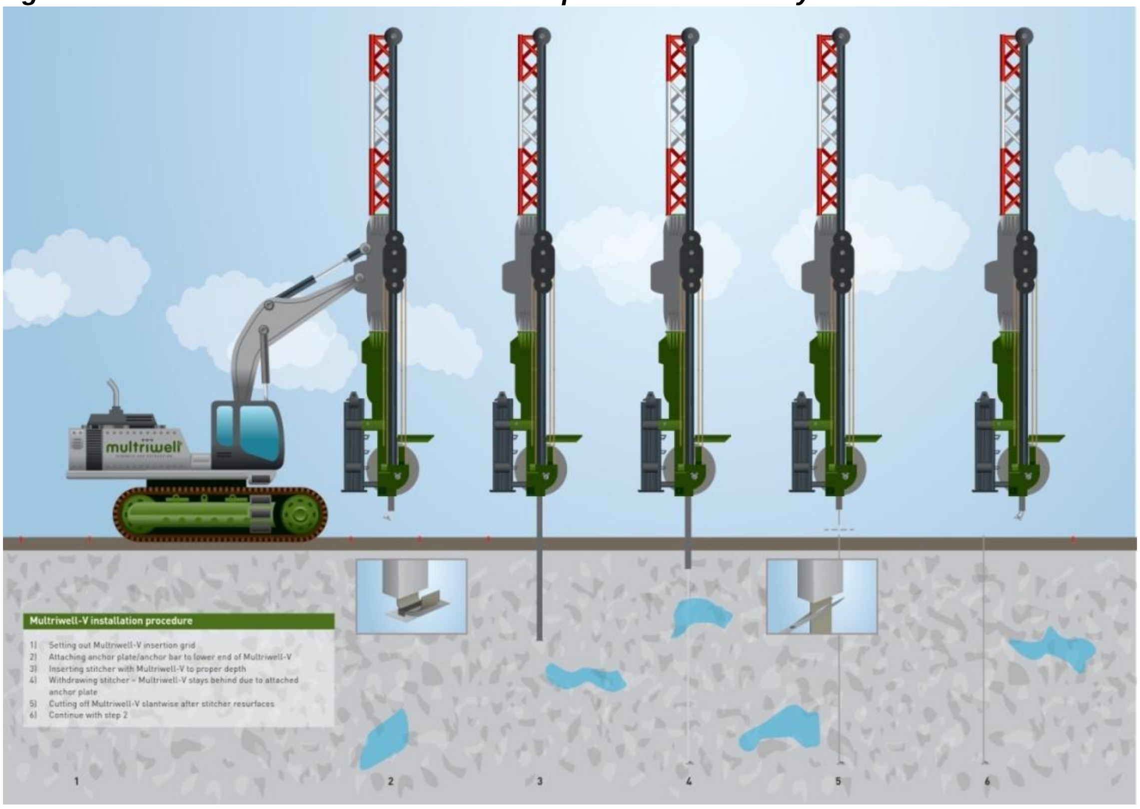
- Depth of the Multriwell V-type (vertical wells).
- Distances between the vertical wells (grid structure, standard is 3 x 3 m)
- Number of manifolds, normally one valve for each 2,500 m^2 to 3,500 m^2

3.5 Installation

For the installation of the Multriwell system the waste surface should be levelled, preferentially by a porous foundation layer. This porous layer spreads the gas that diverges between the V-type wells. Besides collecting and spreading the gas, the layer can also help spreading leachate.

The vertical well (V-type) is installed by inserting a steel mandrel in the landfill with the V-type well inside. This mandrel is moved up and down through a system of cylinders and winches, which in turn are propelled by the excavators' hydraulic system. The V-type extension at the bottom of the mandrel is connected to an anchor plate which closes off the opening so no soil can enter. The mandrel then takes the V-type to the desired depth. When the mandrel is at this depth, it is withdrawn and the resistance created by the anchor plate upon retraction ensures that the V-type remains in place at the right depth. After the mandrel has reached the surface, the V-type is cut and a new anchor plate is connected to the bottom of the next V-type. See figure below.

Figure 3-4 Overview installation vertical part of Multriwell system



The actual maximum depth of each V-type can differ, depending on the friction forces on the mandrel and the resistance of the penetrated waste. Stability during stitching is evident.
The counterweight of the excavator rules the stability and maximum depth. To reach the requested depth, the size and weight of the excavator/stitcher has to be adjusted to local circumstances. For example:

- poor bearing conditions of the support layer demands a heavy excavator for stability purposes;
- long stitcher (depths up to 30 m) demands also a heavy excavator (stability);
- poor-compacted waste can be penetrated with a standard weight excavator;
- high resistance waste layers predicted, the counter weight should be increased.

Minimal weight for excavator is 30 tons.

Inevitable, installation failure can occur due to solids in the waste body such as big concrete blocks. Normal procedure is to put an additional V-type close to this area.
The penetration force and penetration depth are continues observed and registered. In case a bottom-liner is installed, the penetration depth can be automatically maximised (in cm) as perforation precaution.

During installation of the Multriwell system the following safety measures are taken into account:

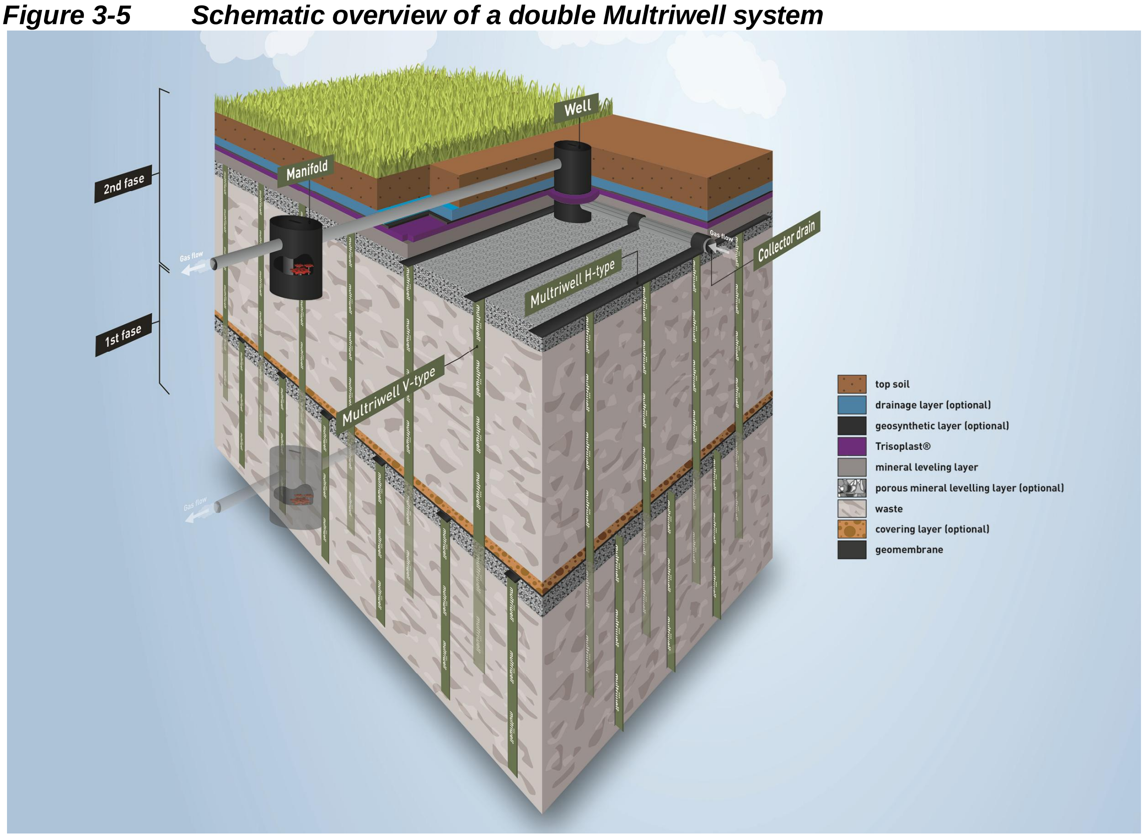
- gas measuring devices;
- gas masks;
- pressurized cabin;
- spark arrester.

The V-type's are connected with the H-type. The H-type are connected to the perforated collector drain. A number of collector drains are connected to a collector put or directly to a manifold depending on the design. Here, the LFG-flow can be regulated with a manifold. From the manifold the LFG is transported by closed pipes to the flare or utilization equipment. See figure 3-3.

The Multriwell system is covered with another levelling layer, topped off with a gas tight capping like Trisoplast® or geomembrane. Depending on the climate conditions and the applicable regulations the sealing layer is covered by other commonly used layers such as a separating geotextile, a drainage layer and the topsoil.

Multriwell can be applied on landfills that are still in operation. In this case the waste is levelled and Multriwell V-type and H-type and the perforated collector drains are applied directly into and on the waste. A porous layer on top of the waste is an option, but not necessary. A thin geo-membrane and ballast is installed on top of the Multriwell H-type and the collector drains. This geo-membrane prevents air ingress.
A new layer of waste can be applied on top of the first Multriwell system before a second Multriwell system will be installed some years later. It is favourable to apply this second system offset from the first Multriwell system. The older waste can be reactivated by this offset and the puncturing of the geomembrane.
Installing Multriwell system on top of each other is a repeatable procedure. See figure below.

Figure 3-5 Schematic overview of a double Multriwell system



KIWA, a Dutch independent certification organization, has assessed the lifetime of the Multriwell system. This assessment focussed on the mechanical durability of the applied materials. Below the results are summarised:

- under aerobic conditions the materials applied in the Multriwell V-type and H-type have an expected lifetime of at least 25 years. Provided that the temperature is not higher than 20 °C,
- when the oxygen concentration is lower than 2%, which is expected for an anaerobic fermentation process, the expected life of the materials applied in Multriwell in the V-type and H-type system at 60 °C is longer than 30 years. [KIWA, 2015]

3.6 Multriwell systems in operation

Today nine Multriwell systems are in operation all over the world. Most of the Multriwell systems are installed in the Netherlands. Outside the Netherlands Multriwell systems are installed in Argentina, Belgium, Poland and Russia. In several other countries among others South Africa, South Korea, China and Ecuador plans are made for the installation of Multriwell system(s).

In this paragraph in three tables an overview of installed Multriwell systems is given. In chapter 4 the Multriwell systems are compared with the traditional extractions systems. The seven landfills taken up in the tables below are selected for the comparison with the traditional extractions systems. This selection of landfills is based on sufficient and available measuring data. The tables below and used data in chapter 4 are summarized in appendix 2.

The Multriwell system in Belgium and the Multriwell test field at landfill Vink, called M26, are not taken up in the comparison due to a lack of information.

Table 3-2: General characteristics of the landfills with installed Multriwell system

Landfills	***Location***	***Country***	***Landfill size (ha)***
Landfill Schinnen	Schinnen	NLD	22
Landfill Boeldershoek	Hengelo	NLD	55
Landfill Zabrze	Zabrze	POL	10
Landfill Vink Test 5 wells	Barneveld	NLD	38
Landfill Samara	Samara	RUS	>50
Landfill Wijster	Wijster	NLD	90
Landfill Norte III-B	Buenos Aires	ARG	100

Table 3-3: Characteristics of the landfills with installed Multriwell system

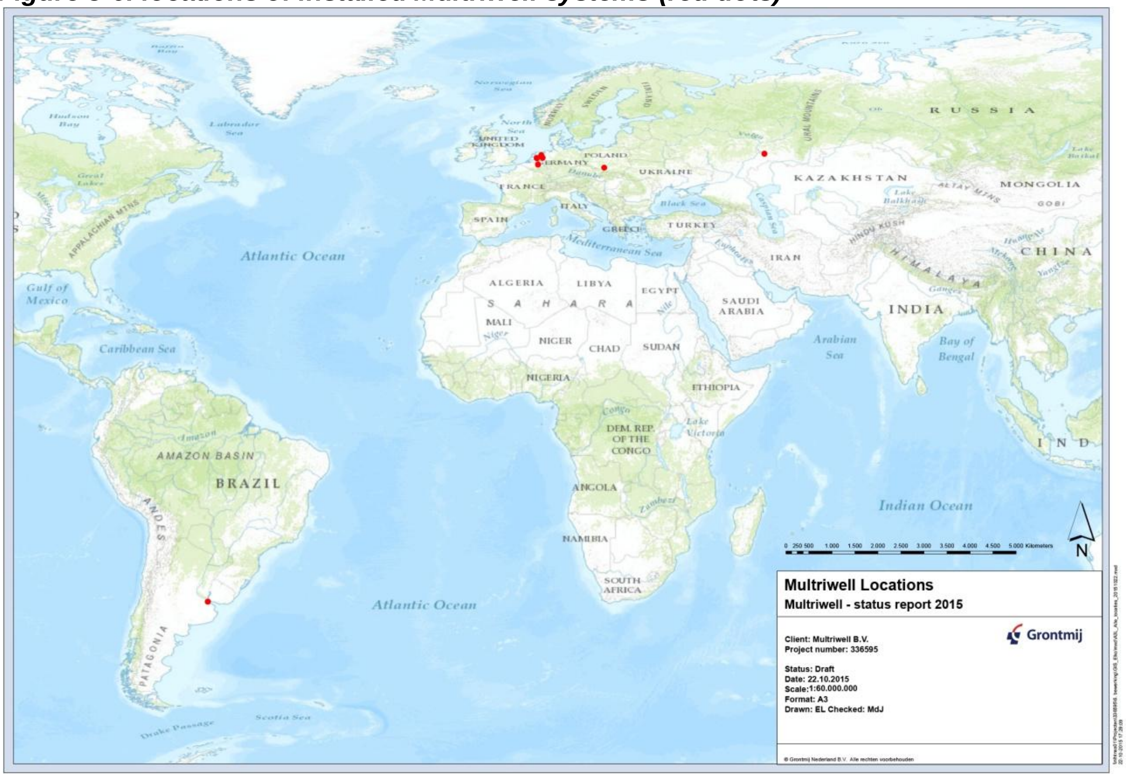
Landfills	***Year of installation Multriwell***	***Volume of waste 2015 (million m^3)***	***traditional LFG area (ha)***	***Multriwell area (ha)***
Landfill Schinnen (phase 3)	2015	2.5	8.49	4.5*
Landfill Boeldershoek (phase 1,2 and 3)	2014	6.8	47.1	0.225
Landfill Zabrze	2013	0.24	1.43	1.395
Landfill Vink Test 5 wells (wells 42-46)	2013	4.8	14	0.14
Landfill Samara	2012	n.a.	n.a.	0.6
Landfill Wijster	2011	14.8	90.2	0.55
Landfill Norte III-B	2010	1.2	100	3.0
Total				10.41

n.a.: data not available
**: data used in this report is from 1 hectare*

Table 3-4: Characteristics of installed Multriwell systems

				Insert depth		***Duration***
Landfills	***Year of installa-tion Mul-triwell***	***Multri-well area (m^2)***	***grid (mx m)***	***Aver-age (m)***	***Max (m)***	***installa-tion (day)***
Landfill Schinnen (phase 3)	2015	45,000	3 x 3	14	22	19
Landfill Boeldershoek (phase 1,2 and 3)	2014	2,250	3 x 3	10	11	2
Landfill Zabrze	2013	13,950	3 x 3	11	21	15
Landfill Vink Test 5 wells (wells 42-46)	2013	1,400	3 x 3	10	17	5
Landfill Samara	2012	6,000	4 x 4	11	20	2
Landfill Wijster	2011	5,500	4 x 5	12	15	5
Landfill Norte III-B	2010	30,000	4 x 4	14	20	9

Figure 3-6: locations of installed Multriwell systems (red dots)



4 Comparison traditional extraction versus Multriwell extraction

4.1 Data used for comparison

As mentioned in paragraph 3.6 a selection of 7 projects is made in order to make a comparison between the traditional extractions system and the Multriwell system. Six of these seven landfills have in common that the installed Multriwell system is operating next to a traditional extraction system on these landfills. At the landfill Samara no traditional system is present anymore. However in the past there was a traditional LFG extraction system. Due to a lack in maintenance this traditional exaction system is out of order.
In order to make a comparison between the two extraction systems measuring data provided is summarised in the following two tables (4-1 and 4-2).

Table 4-1 Characteristics LFG flow traditional system

	Traditional											
	capping	start landfilling	end landfilling	average age waste	area	volume waste	flow measurment start	flow measurment end	flow	CH4	LFG flow/ha	LFG flow/1000m3 waste
Landfills		(year)	(year)	(year)	(ha)	(m3)			(m3/h)	(%)	(m3/h/ha)	(m3/h/1000*m3)
Landfill Schinnen (phase 3) [2015]	partly capping	1992	2000	19	8.49	2,525,775	23-7-2015	5-8-2015	150	n.a.	17.7	0.06
Landfill Samara [2015]	no capping	n.a.	n.a.	15	n.a.	n.a.			n.a.	n.a.		
Landfill Boeldershoek (phase 1, 2 and 3) [2014]	no capping	1985	2005	20	47.1	6,800,000	1-1-2014	31-12-2014	135	n.a.	2.9	0.02
Landfill Vink Test 5 wells (wells 42-46) [2014]	partly capping	1985	2015	15	14	1,250,000	11-9-2014	11-9-2014	571	52	40.8	0.46
Landfill Zabrze [2013]	no capping	n.a.	n.a.	10	1.43	242,590			128	43.5	89.7	0.53
Landfill Wijster [2012]	no capping	1930	2015	43	90.2	14.800.000	1-1-2012	31-12-2012	797	n.a.	8.8	0.05
Landfill Norte III-B [2012]	semi-permeable capping	2006	2010	7	6.62	1,203,600	18-9-2010	3-10-2010	1209	57	182.6	1.00
Average (landfill Samara + Zabrze excluded)										**54.5**	**50.6**	**0.32**
Average (landfill Samara + Zabrze included)										**50.3**	**54.4**	**0.33**

n.a.: not available

Table 4-2 Characteristics LFG flow Multriwell system

	Multriwell												
	capping	start landfilling	end landfilling	average age waste	area	waste volume	flow measurment start	flow measurment end	flow	CH4	LFG flow/ha	LFG flow/1000m3 waste
Landfills		(year)	(year)	(year)	(ha)	(m3)			(m3/h)	(%)	(m3/h/ha)	(m3/h/1000*m3)
Landfill Schinnen (phase 3) [2015]	capping	1992	2000	19	1	140,000	23-7-2015	5-8-2015	93.8	44	94	0.67
Landfill Samara [2015]	capping	n.a.	n.a.	15	0.6	66,000	3-4-2015	3-4-2015	360	47.5	600	5.45
Landfill Boeldershoek (phase 1, 2 and 3) [2014]	capping	1993	1994	22	0.225	22,500	19-12-2014	19-12-2014	12.7	42.5	56	0.56
Landfill Vink Test 5 wells (wells 42-46) [2014]	capping	1985	2015	15	0.14	14,000	11-9-2014	11-9-2014	28		200	2.00
Landfill Zabrze [2013]	capping	n.a.	n.a.	10	1.43	156,970	24-3-2013	18-6-2013	134	55	94	0.85
Landfill Wijster [2012]	capping	1975	1985	35	2	240,000	may 2012	may 2012	40	60	20	0.17
Landfill Norte III-B [2012]	capping	2006	2010	7	3.1	434,000	3-2-2011	3-7-2011	700	44	226	1.61
Average (landfill Samara + Zabrze excluded)										**48.7**	**119.2**	**1.00**
Average (landfill Samara + Zabrze included)										**48.8**	**184.3**	**1.62**

n.a.: not available

No data on start and ending of land filling at the landfills of Samara and Zabrze is available. (see table 4-1) The average age of waste is an estimation by Multriwell.

At the landfill of Schinnen only measuring data for 1hectare of Multriwell is available. After completion in 2015 4.5 hectare Multriwell system will be present at the landfill Schinnen

Data used from table 4-1 and 4-2 for the comparison between the two extraction systems are:

- extraction area (ha)
- measured flow LFG (m^3/h)
- age waste (years)
- volume of waste at extraction area (m^3)
- calculated LFG flow (m^3/h) per hectare
- calculated LFG flow (m^3/h) per volume waste ($1000*m^3$)

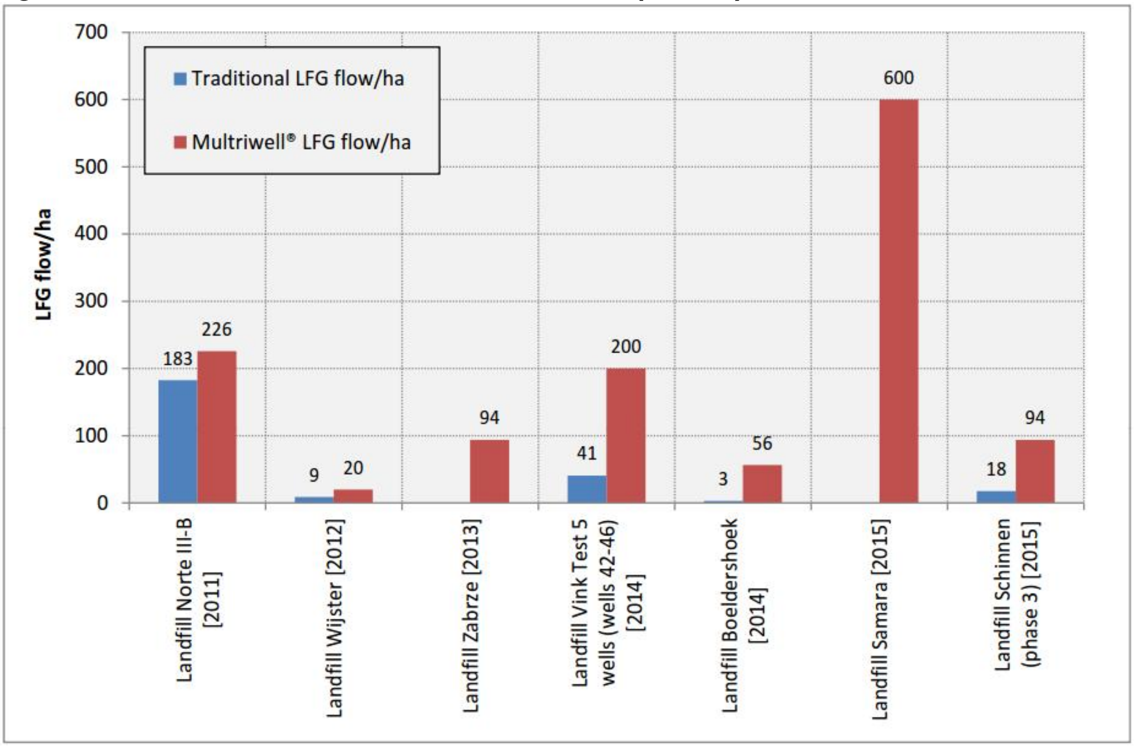
4.2 Results comparison traditional versus Multriwell

4.2.1 Using provided data

Landfill Zabrze does have a working traditional extraction system. However the provided data on LFG flow (128 m^3/h) is not reliable for comparison.

In the graph below the results from five landfills with both a traditional and Multriwell system are shown. At Norte III-B the traditional flow has been estimated. All others data are measured gas flows.
At Vink and Schinnen the Multriwell system is installed within the area of the traditional LFG system.
Landfill Samara is added to this graph for comparison. This landfill has no 'working' traditional system. Landfill Zabrze does have a working traditional extraction system. However the data provided are not reliable.

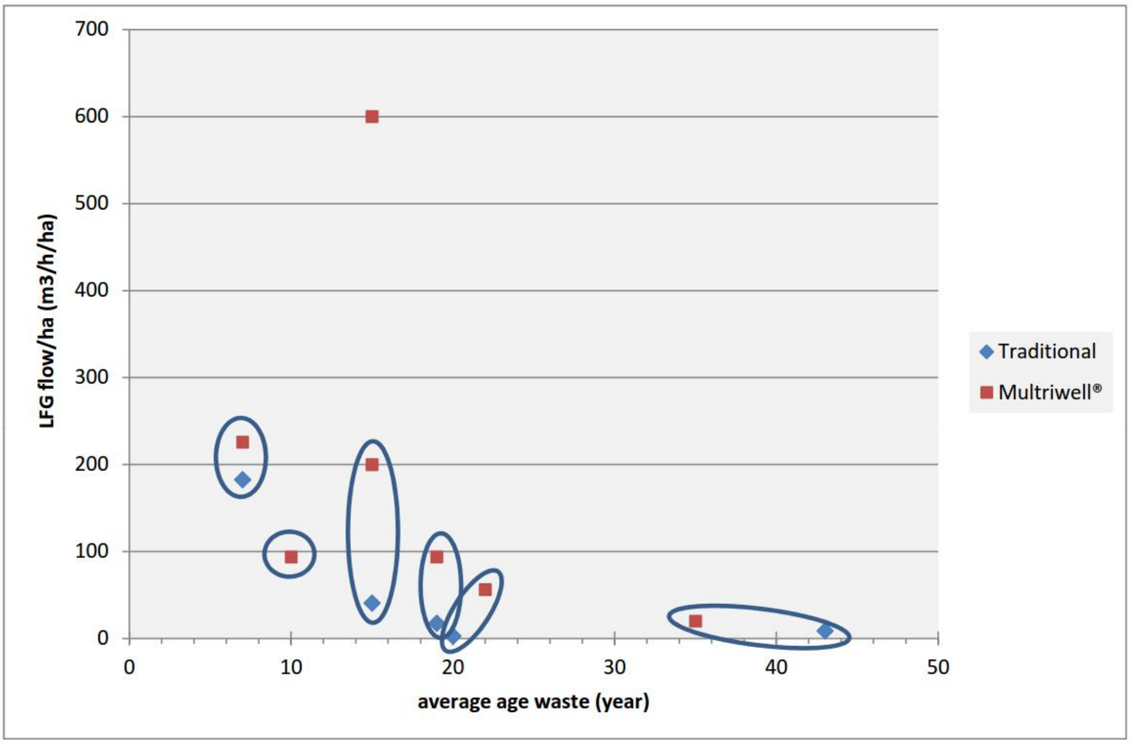
Figure 4-1 Traditional extraction vs. Multriwell (flow/ha)



At all five landfills the LFG extraction flow with the Multriwell system is higher than the traditional system in waste of similar age (see table 4-1 and 4-2). The flow at Samara is very high when compared to the other landfills. This is probably caused by the composition of the waste.

In figure 4-2 the results from seven landfills with both a traditional and Multriwell system are shown. The LFG flow is plotted against the average age of the waste. Plots of the same landfills are indicated with a marker.

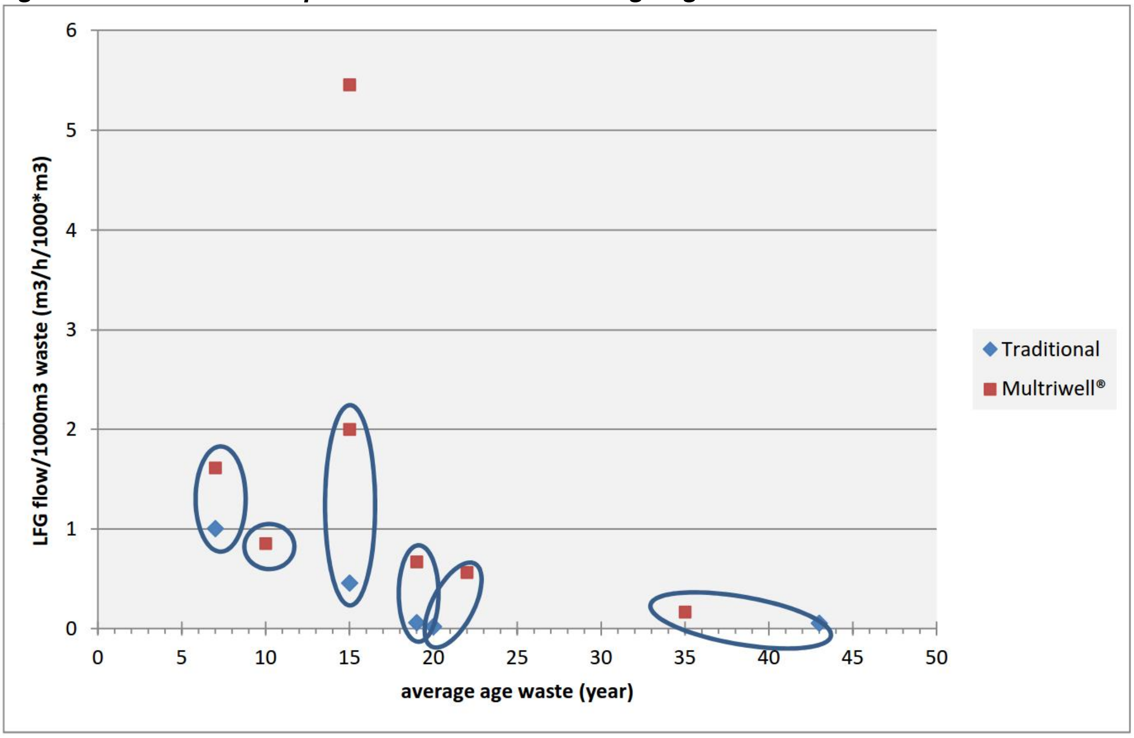
Figure 4-2: LFG flow per hectare versus average age of waste



As expected the flow per hectare decreases with the average age of the waste.
At sites with both traditional and Multriwell the average age of the waste is comparable.
The extraction flow per area with the Multriwell system is at all five locations significantly higher than traditional system.

In the graph below the flow per volume of waste is plotted against the average age of the waste. Plots of the same sites are indicated with an marker.

Figure 4-3: LFG flow per ton of waste vs. average age of waste



This plot shows almost the same result as figure 4-2. The extraction flow per volume of waste with the Multriwell system is at all five locations significantly higher than traditional system.

Table 4-3 LFG extraction ratio Multriwell -traditional per waste volume and area)

Landfills	**LFG extraction ratio Multriwell® vs. Traditional (per waste volume) (Multriwell® : 1)**	**LFG extraction ratio Multriwell® vs. Traditional (per area) (Multriwell® : 1)**
Landfill Schinnen (phase 3) [2015]	11.3	5.3
Landfill Samara [2015]		
Landfill Boeldershoek (phase 1, 2 and 3) [2014]	28.4	19.6
Landfill Vink Test 5 wells (wells 42-46) [2014]	4.4	4.9
Landfill Zabrze [2013]		
Landfill Wijster [2012]	3.1	2.3
Landfill Norte III-B [2012]	1.6	1.2
average	**9.7**	**6.7**

The LFG extraction ratio per volume of waste volume between Multriwell versus traditional is around 9.7 and per area a factor of 6.7 (see table above).This is a remarkable result.
The Multriwell system has an impermeable cap therefore a factor 2 would be expected. Apparently the Multriwell system increases the LFG production (per volume) with an additional factor of 4.9. In other words the Multriwell system increases the anaerobic activity of a landfill body significantly. The data from landfill Norte III-B are less reliable. If we exclude these data, the ratio becomes 11.8 or in other words the LFG production in the Dutch landfills is increased with a factor of 5.9.

Because of a lack of data it is not known how long this increased activity will last. Additional measurements over a longer period is needed. It is expected that the LFG flow in time will decrease significantly. This is because the total amount of organic material to be converted is a given amount. The installation of a system does not influences the total amount of degradable organic material.

4.2.2 Using Dutch survey data

The table below shows the result of a calculation with four Dutch landfills with traditional system. From these landfills extensive LFG flow data are available from the period 2002 until 2014 (annual Dutch waste survey).
The peak flow in this period is compared with the flow which is now found with Multriwell in the same site.
The results indicate that Multriwell performs much better (a factor 5.4) then the traditional system at the peak in the period 2002-2014. Even if we compensate for the gastight capping the Multriwell still performs much better (a factor 2.7).
This result is remarkable because the Multriwell is in older waste and thus theoretically one suspects a lower LFG flow.

Table 4-4 Maximum LFG flow per volume waste traditional vs. measured Multriwell flows per volume waste (m^3/h/1000*m3)

	Traditional		Multriwell			Without capping	With capping
Landfills	**max LFG flow/1000m3 waste (m3/h/1000*m3)**	**estimated max LFG flow after capping/1000m3 waste[@] (m3/h/1000*m3)**	**average age waste (year)**	**LFG flow/1000m3 waste (m3/h/1000*m3)**		**LFG extraction ratio Multriwell® vs. Traditional (per waste volume) (Multriwell : 1)**	**LFG extraction ratio Multriwell® vs. Traditional (per waste volume) (Multriwell : 1)**
Landfill Schinnen (phase 1, 2 and 3)	0.11	0.22	19	0.67		6.0	3.0
Landfill Boeldershoek (phase 1, 2 and 3)	0.11	0.22	22	0.56		5.2	2.6
Landfill Vink	0.21	0.43	15	2.00		9.3	4.7
Landfill Wijster	0.20	0.40	35	0.17		0.8	0.4
Average	**0.2**	**0.3**		**0.8**		**5.4**	**2.7**

[@] ***Capping results in a doubling of LFG flow***

5 Conclusions and recommendations

5.1 Conclusions

The following conclusions can be drawn about the performance of the Multriwell system:

- experience over the past six years proof that the Multriwell system is a good alternative for the extraction of LFG from waste bodies;
- the LFG extraction ratio per volume of waste volume between Multriwell versus traditional is around 9.7. The Multriwell system has an impermeable cap therefore a factor 2 would be expected. Apparently the Multriwell system increases the LFG production with an additional factor of over 4.9. In other words the Multriwell system increases the anaerobic activity of a landfill body significantly. If we only use data from the Dutch landfills the factor is 5.9;
- the LFG extraction flow with Multriwell on Dutch sites is a factor 5.4 higher than the traditional system at its peak in the period 2002-2014. Even if we compensate for the gastight capping the Multriwell still performs much better (a factor 2.7). This result is remarkable because the Multriwell is in older waste and thus theoretically one suspects a lower LFG flow;
- since the Multriwell system delivers a higher landfill LFG gas flow than traditional systems a higher revenue from the LFG gas is expected;
- the Multriwell system prevents the emission of greenhouse gasses into the atmosphere;
- uncontrolled emission of landfill gas resulting in odour problems are negligible with a Multriwell system due to the capping element in the Multriwell system.

5.2 Recommendations

The following recommendations can be given:

- Additional measurements over a longer period (until now 6 years) is needed to monitor whether the higher LFG flows maintain. Because of its size landfill Schinnen is the most preferred site to monitor extensively.
- A possible research topic is to enhance LFG production through the injection of water/treated leachate/air. Up until now, no examples of the application of water into the landfill through the Multriwell system are known. By adding water/treated leachate into the waste body additional LFG production is expected.

6 Literature

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Appendix 1

Photos installation Multriwell

Photo A1-1 Installing Multriwell V-type on test field landfill Barneveld

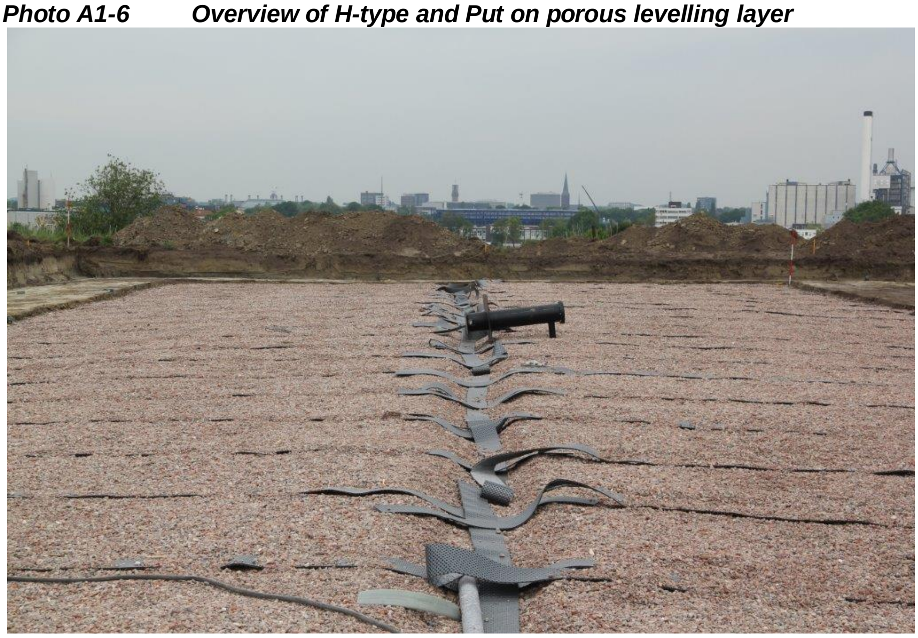
Photo A1-2 Installing Multriwell V-type

Photo A1-3 Installed Multriwell V-type

Photo A1-4 Connecting H-type to V-type

Photo A1-5 Connecting H-type to perforated collector drain

Photo A1-6 Overview of H-type and Put on porous levelling layer



Appendix 2

Characteristics LFG extraction sytems

Landfills	**Landfill Schinnen (phase 3)**	**Landfill Bo-eldershoek (phase 1,2 +3)**	**Landfill Zabrze**	**Landfill Vink 5 test wells (wells 42-46)**	**Landfill Samara**	**Landfill Wijster**	**Landfill Norte III-B**
General characteristics							
Location	Schinnen	Hengelo	Zabrze	Barneveld	Samara	Wijster	Buenos Aires
Country	NLD	NLD	POL	NLD	RUS	NLD	ARG
total landfill size (ha)	22	55	10	38	>50	90	100
Volume of waste 2015 (million m^3)	2.5	6.8	0.24	4.8	n.a.	14.8	1.2
traditional LFG area (ha)	8.49	47.1	1.43	14	n.a.	90.2	100
Multriwell area (ha)	4.5	0.225	1.395	0.14	0.6	0.55	3.0
Year of installation Multriwell	2015	2014	2013	2013	2012	2011	2010
grid (m x m)	3 x 3	3 x 3	3 x 3	3 x 3	4 x 4	4 x 5	4 x 4
insert depth average (m)	14	10	11	10	11	12	14
insert depth max (m)	22	11	21	17	20	15	20
duration installation (day)	19	2	15	5	2	5	9
characteristics LFG flow Traditional system							
capping	partly capping	no capping	no capping	partly capping	no capping	no capping	no capping
start landfilling (year)	1992	1985	n.a.	1985	n.a.	1930	2006
end landfilling (year)	2000	2005	n.a.	2015	n.a.	2015	2010
average age waste (year)	19	20	10	15	15	42,5	7
area (ha)	8.49	47.1	1.43	14	n.a.	90.2	6.62
volume waste (m^3)	2,525,775	6,800,000	242,590	1,250,000	n.a.	14,800,000	1,203,600
flow measurment start	23-7-2015	1-1-2014	n.a.	11-9-2014	n.a.	1-1-2012	18-9-2010
flow measurment end	5-8-2015	31-12-2014	n.a.	11-9-2014	n.a.	31-12-2012	3-10-2010
flow (m^3/h)	150	135	128	571	n.a.	797	1209
CH4 (%)	n.a.	n.a.	43.5	52	n.a.	n.a.	57
LFG flow/ha (m^3/h/ha)	17.7	2.9	89.7	40.8	n.a.	8.8	182.6
LFG flow/1000m^3 waste (m^3/h/1000*m^3)	0.06	0.02	0.53	0.46	n.a.	0.05	1.00
characteristics LFG flow Multriwell system							
capping	capping	capping	capping	capping	capping	capping	capping
start landfilling (year)	1992	1993	n.a.	1985	n.a.	1975	2006
end landfilling (year)	2000	1994	n.a.	2015	n.a.	1985	2010
average age waste (year)	19	21,5	10	15	15	35	7
area (ha)	1	0,225	1,427	0,14	0,6	2	3,1
volume waste (m^3)	140.000	22.500	156.970	14.000	66000	240.000	434.000
flow measurment start	23-7-2015	19-12-2014	41357	11-9-2014	42097	may 2012	3-2-2011
flow measurment end	5-8-2015	19-12-2014	41443	11-9-2014	42097	may 2012	3-7-2011
flow (m^3/h)	93,8	12,7	134	28	360	40	700
CH4 (%)	44	42,5	55		47,5	60	44
LFG flow/ha (m^3/h/ha)	94	56	94	200	600	20	226
LFG flow/1000m^3 waste (m^3/h/1000*m^3)	0,67	0,56	0,85	2,00	5,45	0,17	1,61

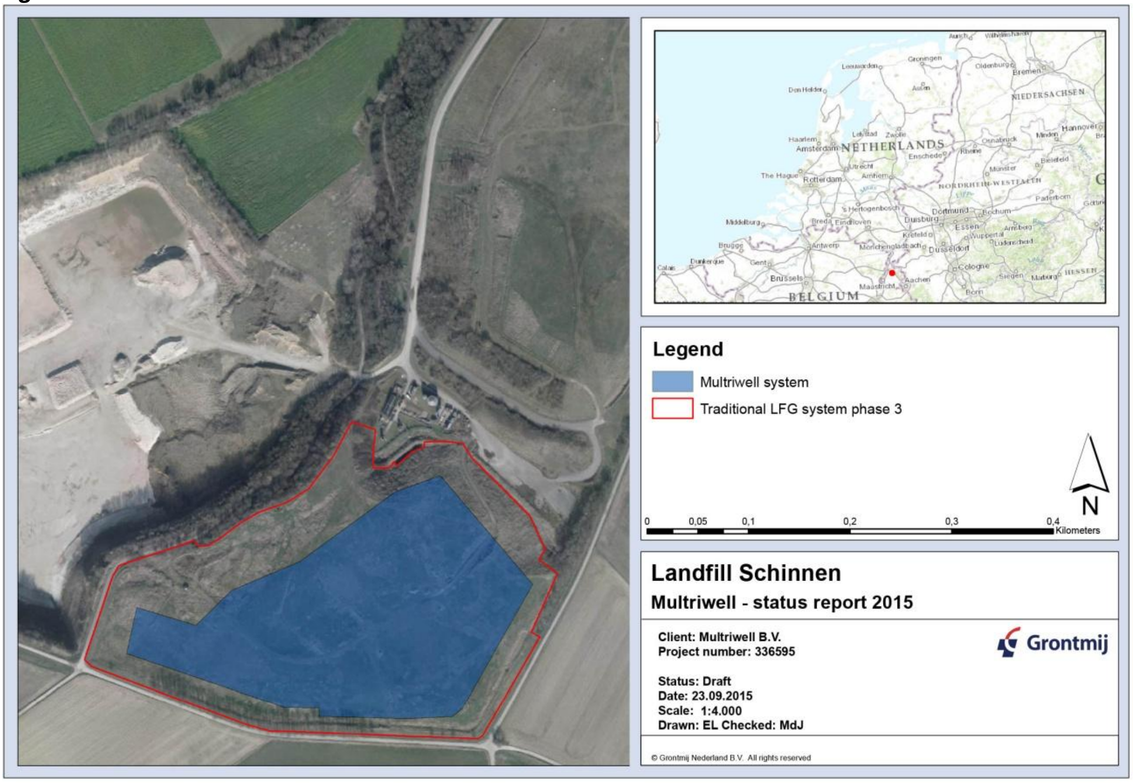
Appendix 3

Landfill Schinnen, Schinnen (NED)

Landfill Schinnen, Schinnen, (NED)

In the figure below the location of landfill Schinnen in the Netherlands is shown. Furthermore the area where the Multriwell system is installed is visualized (blue part).

Figure A2-1 location landfill Schinnen



Description location/ Multriwell system
Landfill Schinnen is a closed municipal waste landfill site (22 hectares) in the south of the Netherlands near the city of Schinnen. The operator of the site is Attero. Attero a waste treatment company is owned by Waterland a private equity investment group.

The landfill is located in an old sand quarry. Besides municipal waste also asbestos, industrial waste, contaminated soil, construction and demolition waste, sewage sludge are landfilled in three landfill phases.

In table A2-1 the characteristics of this landfill are taken up.

Table A2-1: Landfill Schinnen [Grontmij 2014]

	surface (ha)	Start landfilling	End landfilling	Thickness waste min (m)	Thickness waste max (m)	Volume waste (m^3)	Final capping (gas tight)
phase 1/2A	8.26	1973	1983	25	31	2.312.800	1993
phase 2B	4.90	1983	1993	10	29	955.500	2008
phase 3	8.49	1992	2000	26	33.5	2.525.775	2014/2015
Total	**21.65**					**5.794.075**	

Both phase 1 and 2 have no baseliner but do have a final capping of Trisoplast® (gas tight). Phase 3 has a combination baseliner and a final capping of Trisoplast® (gas tight).

In all three phases a traditional landfill gas extraction system is present. In table A2-2 the characteristics of this system is taken up.

Table A2-2: LFG system at Landfill Schinnen [Grontmij 2014]

	Installation from year	Number of wells	Max depth (m)
phase 1/2A	1992	27	16
phase 2B	1992	20	16
phase 3	n.a	26[#]	n.a.
Total		**73**	

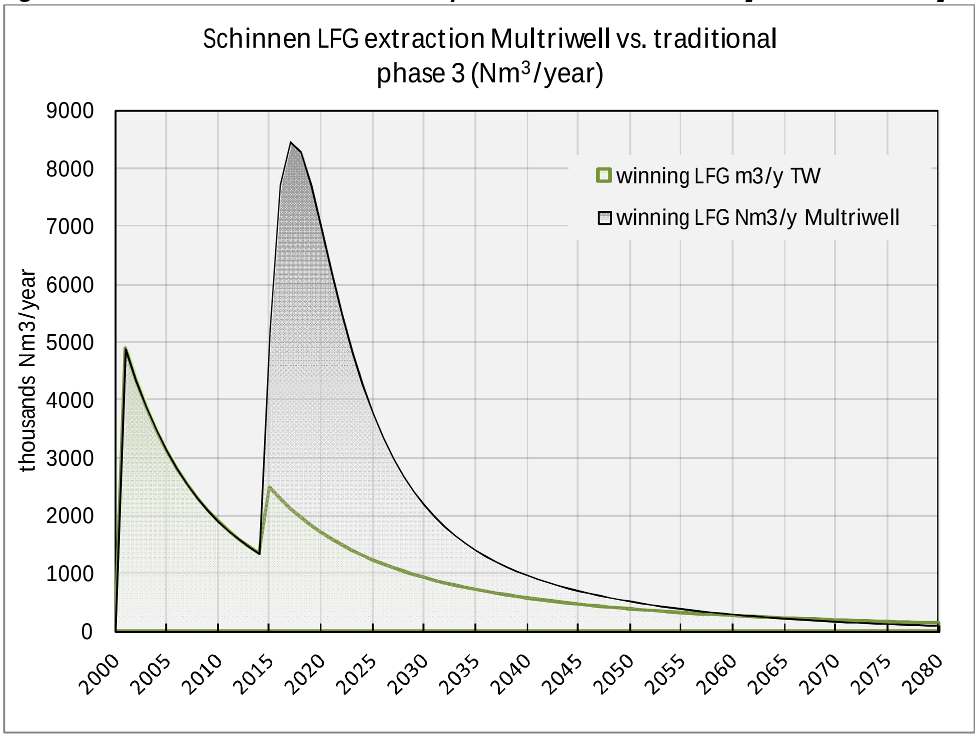
#: planned number of traditional vertical wells
n.a.: not available

The Multriwell system is installed in phase 3 of this landfill. Phase 3 is covered with a capping system with HDPE geomembrane + Trisoplast® (87,500 m^2). At an area of 45,000 m^2 Multriwell was installed. The traditional system is partly also in operation at this landfill (only on phase 1 and 2).

The waste in phase 3 was landfilled from 1992 until around 2000. It predominantly consists of household waste (50%), sludge (30%) and soil (20%).

Landfill gas prognosis
A LFG prognosis is provided by TerrAdvies for phase 3 (4.5 ha). This prognosis is presented in figure A2-2. From this modelling the conclusion can be drawn that an increase with a factor 4.0 can be obtained (243 m^3/h traditional to 968 m^3/h Multriwell) in 2017. This is two years after installation of Multriwell in phase 3.

Figure A2-2 Modelled extraction LFG at phase 3 landfill Schinnen [TerrAdvies 2015].

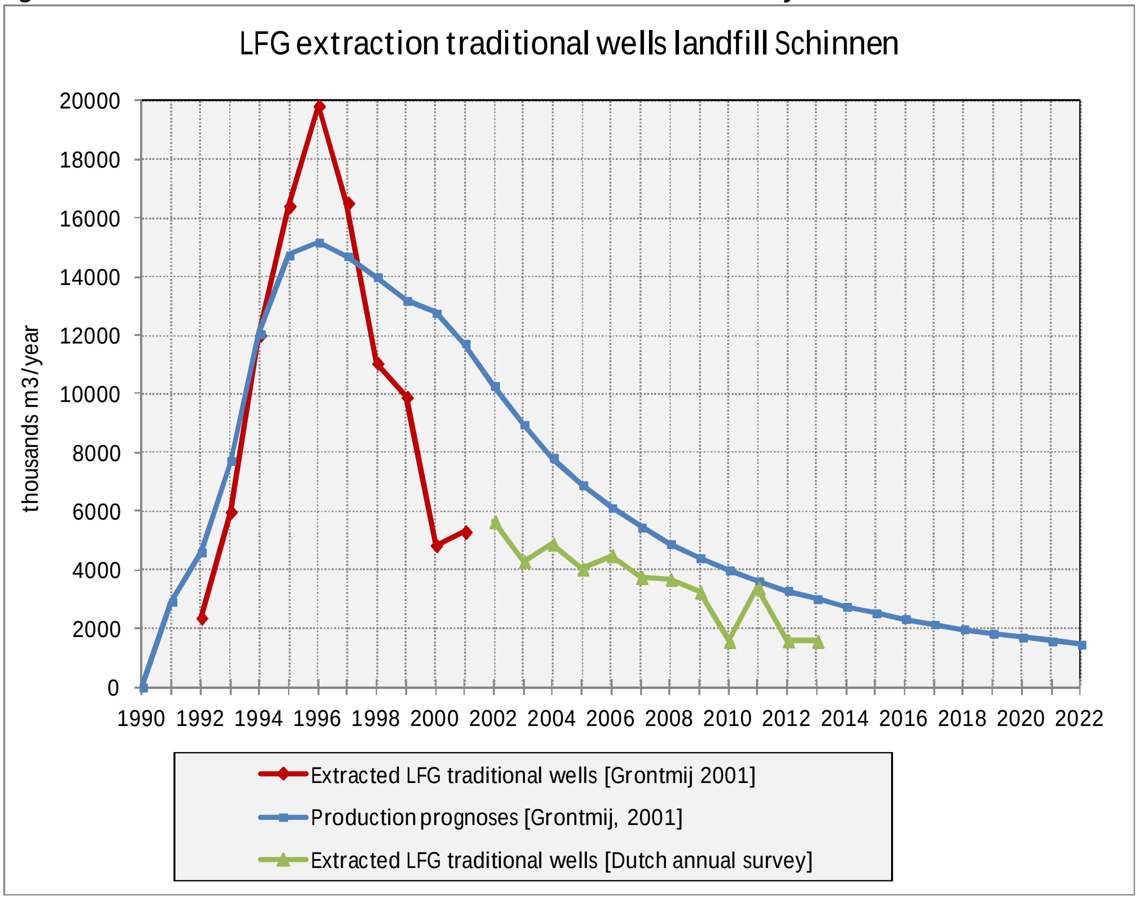


Landfill gas measurements

In figure A2-3 the total extracted LFG (phase 1, 2 and 3) from 1992 up to 2001 at landfill Schinnen with traditional system is given. In this figure also the recorded LFG extraction from 1992 to 2001 is plotted.

A total of 179 m^3/h LFG is extracted in 2013. [Dutch waste Surveys period 2002-2013] This is in line with the measured LFG extraction (September 2015) at landfill Schinnen a total of 184 m^3/h. From this 184 m^3/h, 35 m^3/h is extracted phase 1+2 and the rest (150 m^3/h) from phase 3. [TerrAdvies 2015]

Figure A2-3 Total extracted LFG at landfill Schinnen with traditional system



After the installation of the first hectare, of in total 4.5 hectares, of Multriwell system in phase 3 the Multriwell system extracted between from 23th of July 2015 until 5th of August 2015 29,456 m^3 LFG. See figure A2-5.

This is an average of 94 m^3/hour with an average of around 44 % of CH_4, 24% CO_2 and 3 to 4% of O_2. The presence of oxygen is caused by the fact that phase 3 isn't totally capped. After completion of the capping it is expected that:

- a higher extraction flow of LFG is reached;
- there is no presence of oxygen;
- higher percentages of methane. [TerrAdvies 2015]

Figure A2-4 Extracted LFG between 23-7-2015 and 5-8-2015 at phase 3 landfill Schinnen.

After completion of the total Multriwell® system (45,000 m^2) the prognoses is that Multriwell will produce 4,5 times the measured average. This should by around 420 m^3/h LFG with a CH_4 content of at least 45%.
It is expected that the extraction of LFG will increase up to 600 m^3/h (about 3 years after installation). After that it will drop slowly. The other parts of the area (the traditional wells will produce about 100 m^3/h.[TerrAvies 2015]. The suspected LFG flow (420 m^3/h) extracted with the Multriwell system from phase 3 is far below the modelled LFG flow by TerrAdvies (approximately 970 m^3/h, see figure A2-2).

The modelled total extractable LFG by Grontmij (see figure A2-3) in 2015 is 596 m^3/h. After completion of the capping prognosis is to extract 420 m^3/h LFG with the Multriwell® system at Schinnen. This is a difference of 176 Nm3/h between the modelled and extracted LFG rate.

After installation of Multriwell system Attero found out that the collected leachate from phase 3 was changing of colour. This could be an indication that installing of the Multriwell system enhances the bio reaction in the waste.

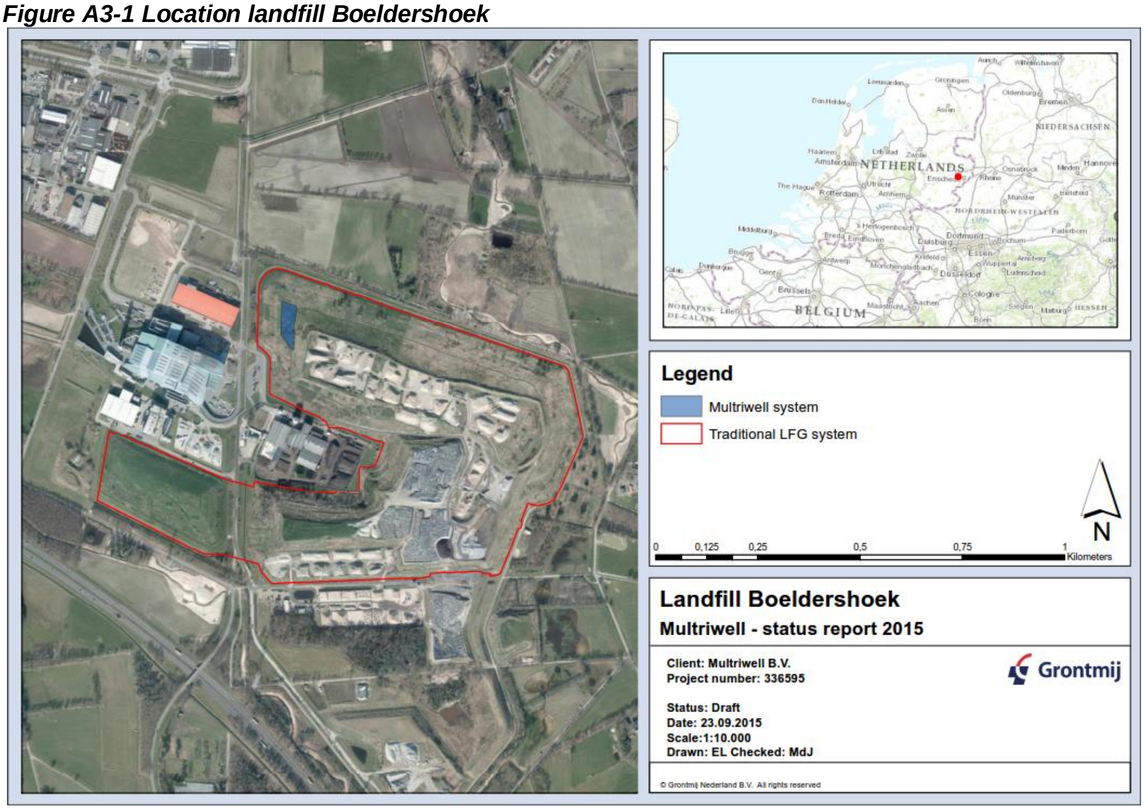
Appendix 4

Landfill Boeldershoek, Hengelo (NED)

Landfill Boeldershoek, Hengelo (NED)

In the figure below the location of landfill Boeldershoek in the Netherlands is shown. Furthermore the area where the Multriwell system is installed is visualized (blue part).

Figure A3-1 Location landfill Boeldershoek



Description location/ Multriwell system

Boeldershoek is a landfill (55 hectares) in the east of the Netherlands near the city of Hengelo. The operator of the site is Twence B.V., a publicly owned waste treatment company.

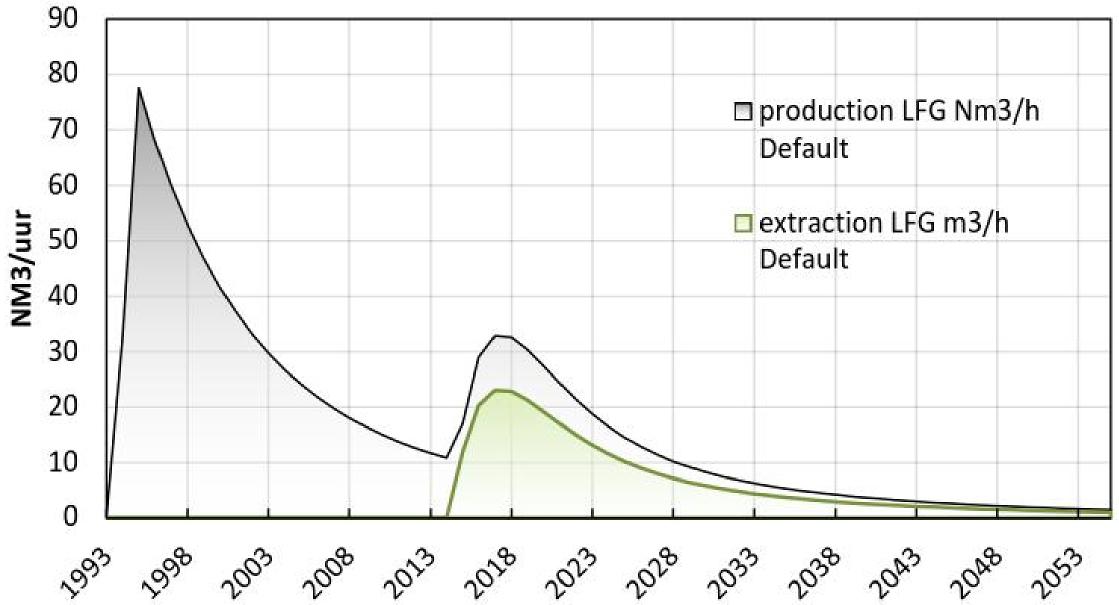
The Multriwell system was installed on a small test field of 2.250 m^2 during the summer of 2014. A traditional system is also in operation at this landfill.

The waste at the Multriwell test field was deposited there in 1993 and 1994. It predominantly consists of household waste (50%), sludge (30%) and soil (20%)
Note: The operator indicated that the aim of the installation of the Multriwell system at this landfill was to remove the perched leachate from the waste body. Collection of extractable gas at landfill Boeldershoek is therefore added value.

Landfill gas prognoses

A LFG modelled prognosis for the Multriwell test site is represented in figure A3-2. The peak of the chart in 2014 coincides with the installation of Multriwell. The potential extractable LFG increases 10 (produced LFG) to 25 (extracted LFG) Nm^3/hour.

Figure A3-2 Modelled LFG prognosis at Multriwell test site landfill Boeldershoek



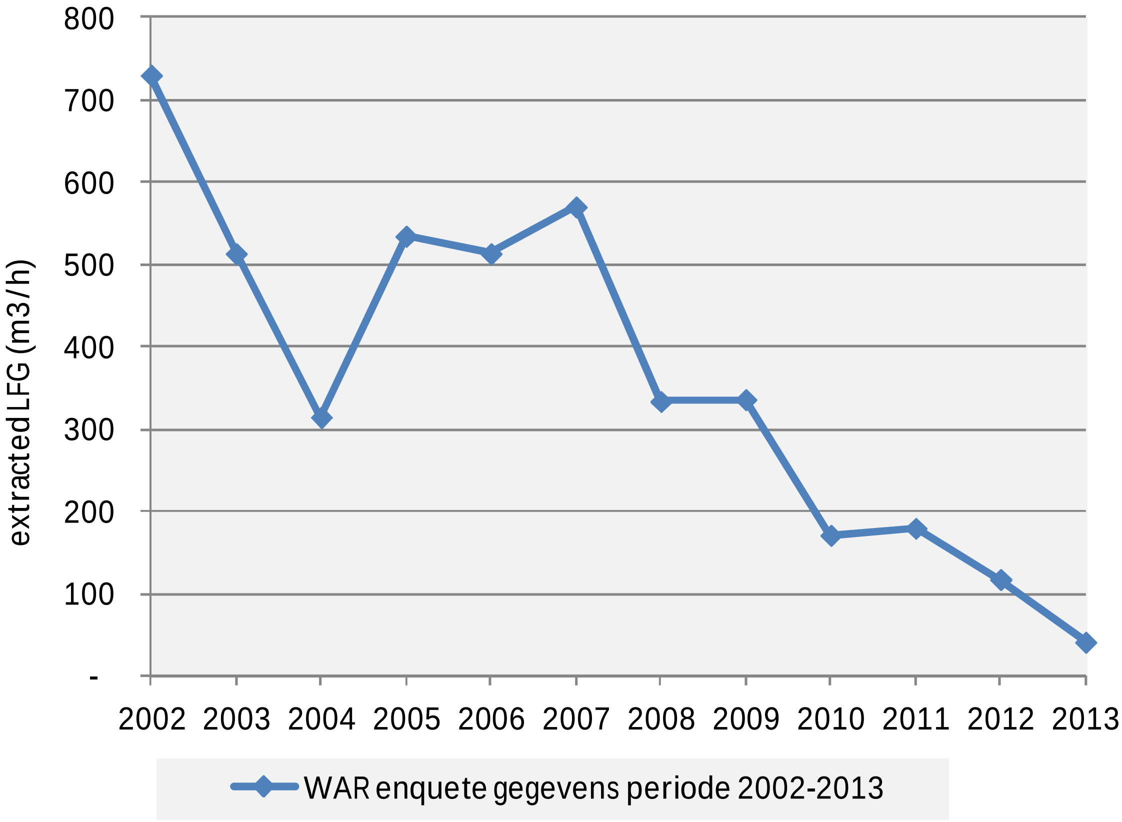
Source: TerrAdvies 2014

Landfill measurements

In figure A3-3 the yearly average extracted LFG by the traditional system at landfill Boeldershoek is shown. Data are from the annual Dutch waste survey. This is the LFG extraction from the entire Boeldershoek site. The Multriwell site is 0,225 ha big. The traditional LFG extraction system is installed in 47 ha.

In 2013 approximately 1 m^3/h/ha is extracted with the traditional system.

Figure A3-3 Extracted LFG at Boeldershoek by the traditional system



The extraction rate of the Multriwell system during the spring of 2015 was around 1 m^3/hour (verbal information provided by Twence). This is the same flow as with the traditional system in 2013 however extracted from a much smaller area.

Measurements from December 2014 show that with an suction pressure between 0.25 and 0.5 mbar a LFG extraction flow between 5 and 10 m^3/h with a methane concentrations between 40 and 50% can be obtained [TerrAdvies, 2014A]. This is far below the modelled extractable LFG (see figure A3-2).

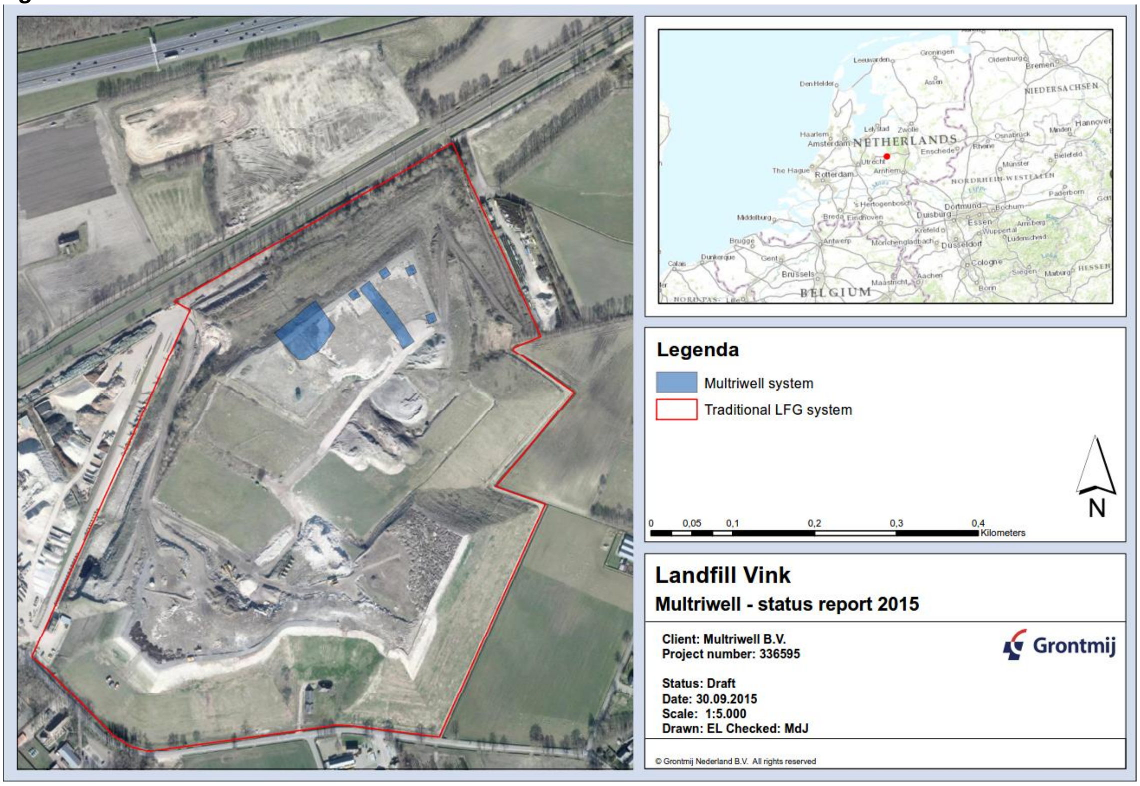
Appendix 5

Landfill Vink, Barneveld (NED)

Landfill Vink, Barneveld (NED)

In the figure below the location of landfill Vink in the Netherlands is shown. Furthermore the areas where the Multriwell system is installed is visualized (blue parts).

Figure A4-1 location landfill Vink



Description location/ Multriwell system

Vink is a landfill in the middle of the Netherlands near the city of Barneveld. The operator on site is Afvalverwerking Vink B.V., a private company. The landfill is approximately 38 ha. There is a traditional system and also a Multriwell system in operation for landfill gas extraction.

The Multriwell system was installed in august 2009. It is therefore the oldest installed system in the world. This Multriwell system called “Well 26M” is installed around the traditional well 26. Well 26 is a part of the traditional LFG collection system at this landfill. Multriwell is installed in a grid of 2x2m and a depth of 10 m below surface on a site of 1.600m^2 [Terradvies, 2010A]. Well 26 is the most left blue field shown in figure A4-1. The test results of this Multriwell system aren’t discussed in this report. Because this is the first Multriwell field installed and performs as test field. Therefore some data are not reliable for the comparison with the traditional LFG extraction system.

In February 2013 another Multriwell field was installed at Vink. At manifold 43, a rectangular shaped Multriwell field (1,377 m^2, average depth 14 m and grid 3x3 m). Besides this rectangular field four wells (numbered 42, 44, 45 and 46) are installed. From these wells 16 to 32 Multriwell V-type are installed into the waste at an angle. These four wells are connected at one wellhead. This report describes the status of the installed Multriwell fields 42 to 46.

Table A4-1: Characterisation installed Multriwell system 2013 [TerrAdvies 2014]

Name	Characterisation	Average depth Multriwell V-type (m)
42	single well, V-type installed at an angle	14
43	field (1,377 m^2). V-types installed vertically	14
44	single well, V-type installed at an angle	11
45	single well, V-type installed at an angle	13
46	single well, V-type installed at an angle	14

Figure A4-2 gives an view on the bundled V-type drains as installed in wells 42, 44, 45 and 46. Figure A4-3 gives an overview of the installed Multriwell system in 2013 at landfill Vink.

Figure A4-2 Multriwell V-type placed under angel and connected in 1 collector put at landfill Vink

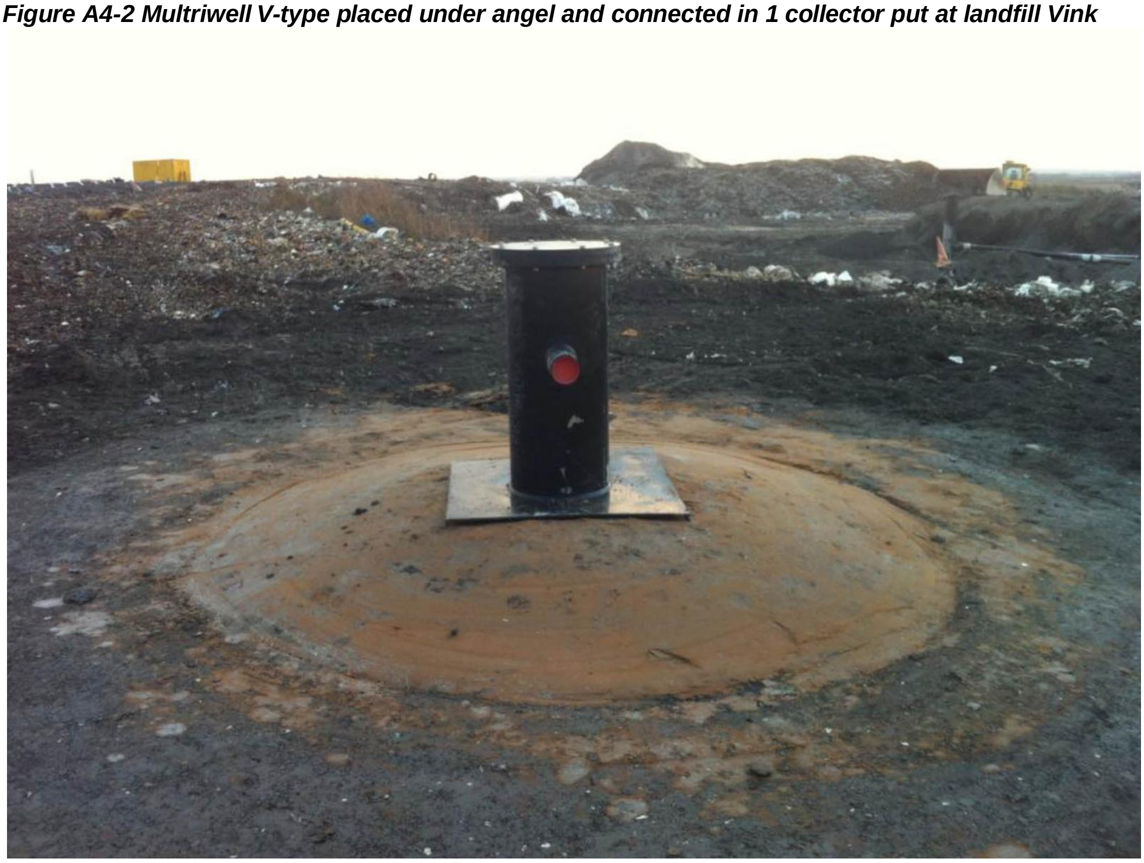
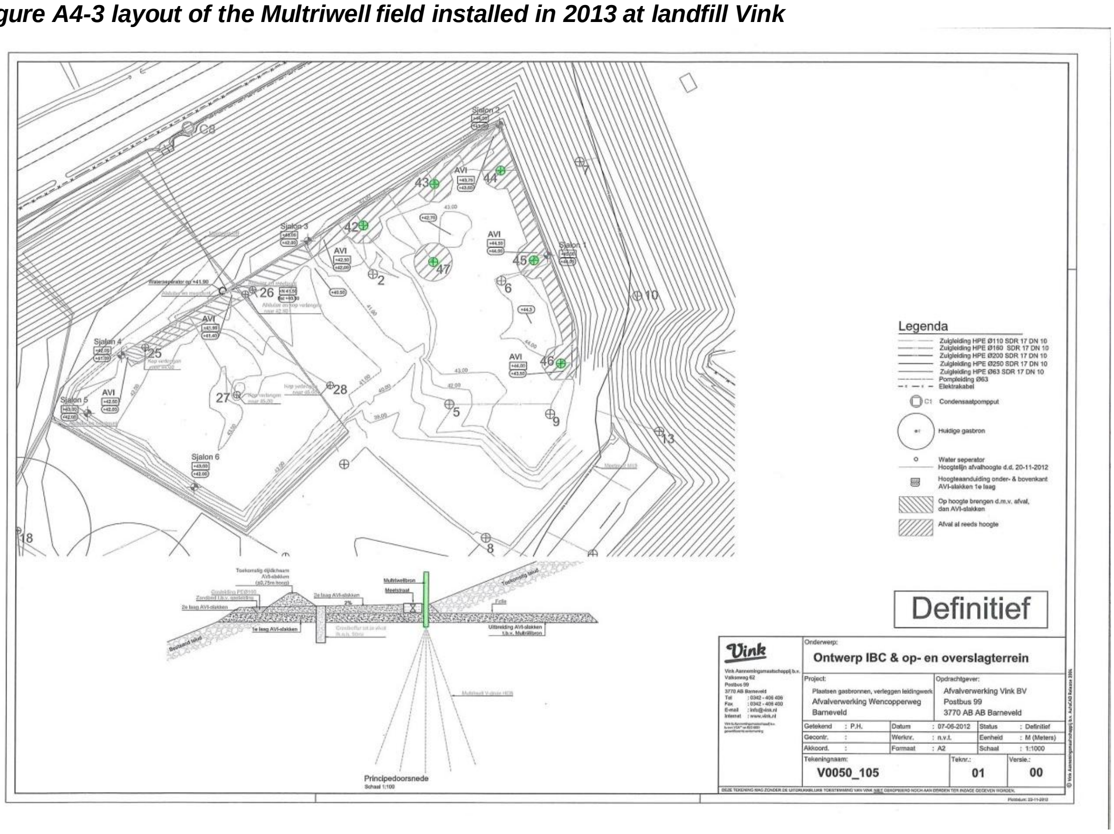


Figure A4-3 layout of the Multriwell field installed in 2013 at landfill Vink



Landfill gas prognoses
The following table gives the calculated LFG flows of the Multriwell system (42 to 46) based on measurements on the 11th of September [TerrAdvies 2014]

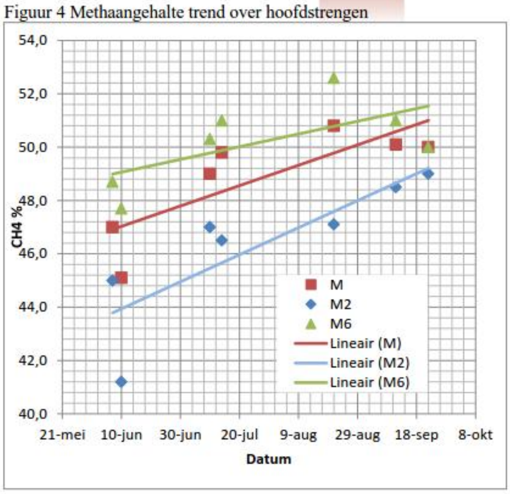
Table A4-1: calculated LFG flow installed Multriwell system 2013 [TerrAdvies 2014]

Name	LFG flow (m3/h) 11 September 2014
42	1.6
43	24
44	0.8
45	0.8
46	0.8
Total LFG flow	609

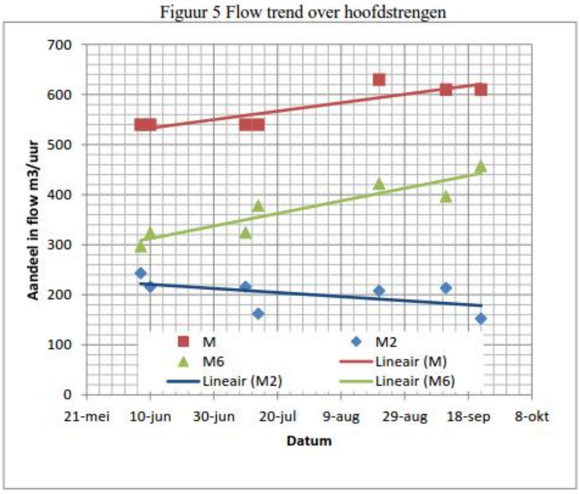
Landfill measurements
Test results from 19th of April until the 18th of May 2013 showed that the Multriwell field 43 has on average an LFG flow 31 m^3/h with an average methane concentration of approximately 47%, CO_2 concentration of 23%, no oxygen and a pressure of -0.4 mbar. This Multriwell field is 0.138 ha large. This gives a LFG flow of approximately 225 $m^3/h/ha$.

In the graphs below the methane concentration and LFG flow from 21st May until 8th October 2014 are plotted for the headers M2 and M6. The Multriwell field 43 and wells 42, 44, 45 and 46 are part of header M2. Since the installation of the Multriwell system in February 2013 the methane concentration in M2 went up. However the LFG flow dropped from approximately 220 m^3/h to 160 m^3/h. This is a quit remarkable result. The Multriwell system is known to improve the LFG flow.

Figuur 4 Methaangehalte trend over hoofdstrengen



Figuur 5 Flow trend over hoofdstrengen



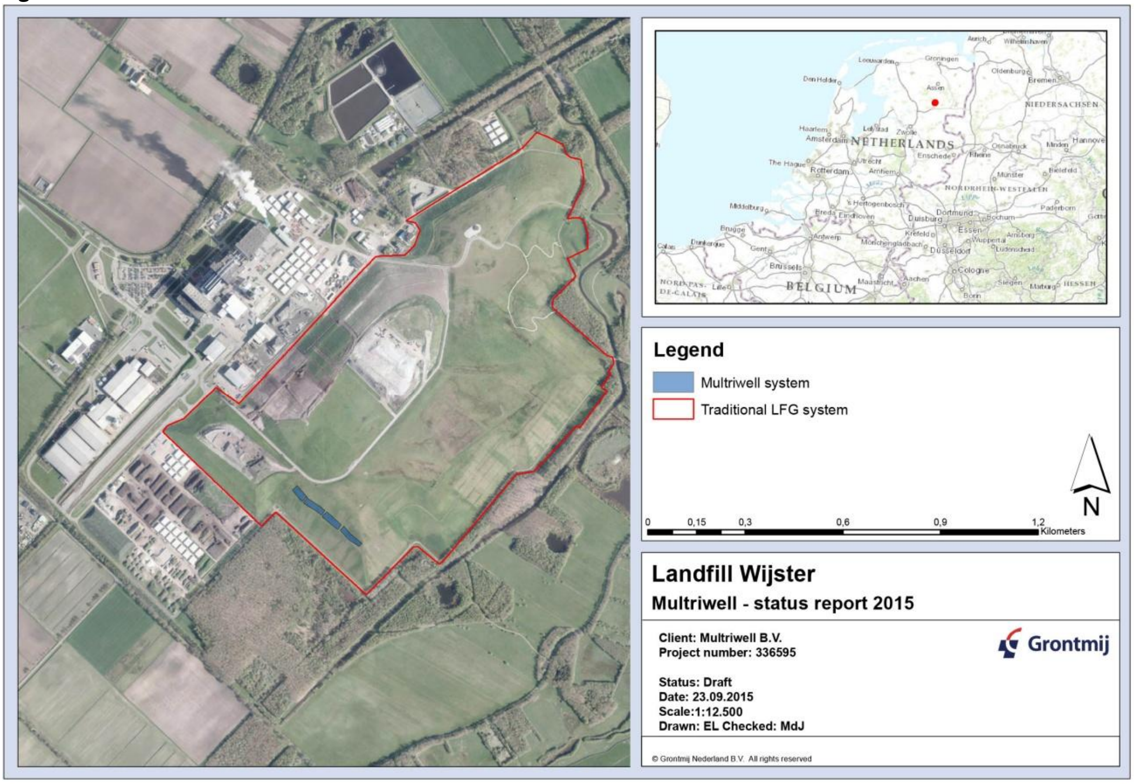
Appendix 6

Landfill VAM, Wijster (NED)

Landfill VAM, Wijster (NED)

In the figure below the location of landfill VAM in the Netherlands is shown. Furthermore the area where the Multriwell system is installed is visualized (blue part).

Figure A5-1 location landfill VAM

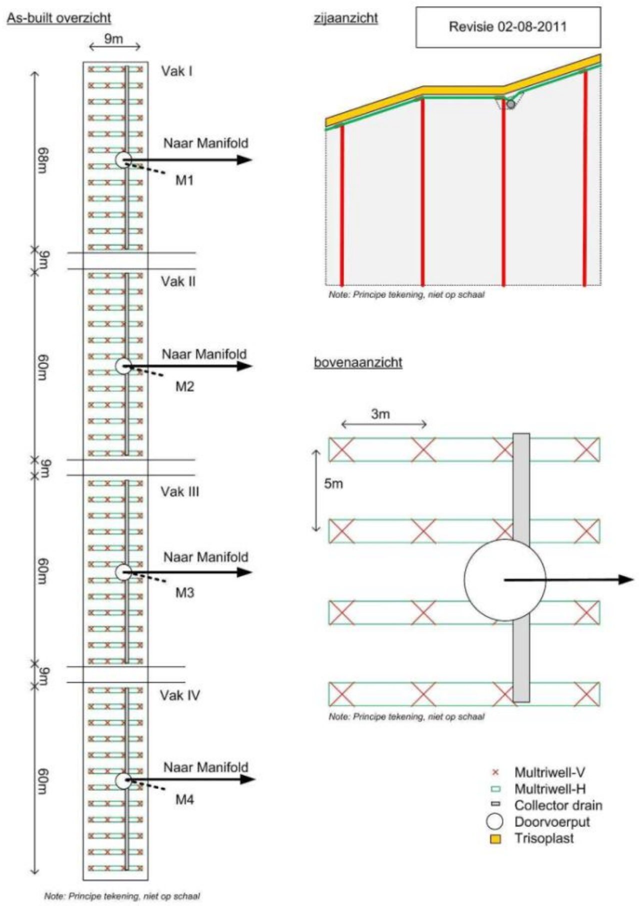


Description location / Multriwell system

The landfill VAM at Wijster is located near the city of Hoogeveen in the north of the Netherlands. The operator of the landfill is Attero B.V.. This landfill of 90 ha is the largest in the Netherlands. A traditional gas extraction system is installed on the landfill. The installed wells in this traditional system have an influence area of approximately 50 to 70 m per well. [Attero, 2011]

Area 3.1 is approximately 6ha big and is covered with a single liner for 20 years. Installing a final capping (combination of HDPE and a Trisoplast® mineral layer) is the moment for the installation of Multriwell. In the early days LFG is extracted from area 3.1 However this traditional system is out of order for a long period.
Multriwell was installed at a part of area 3.1 (approximately 20.000m^2) in 2011. [Attero, 2011]
See blue area in figure A5-1.
A total of 192 V-type with an average depth of 11,5m were installed. These wells are connected to 4 manifolds (M1 to M4). [Attero 2011].

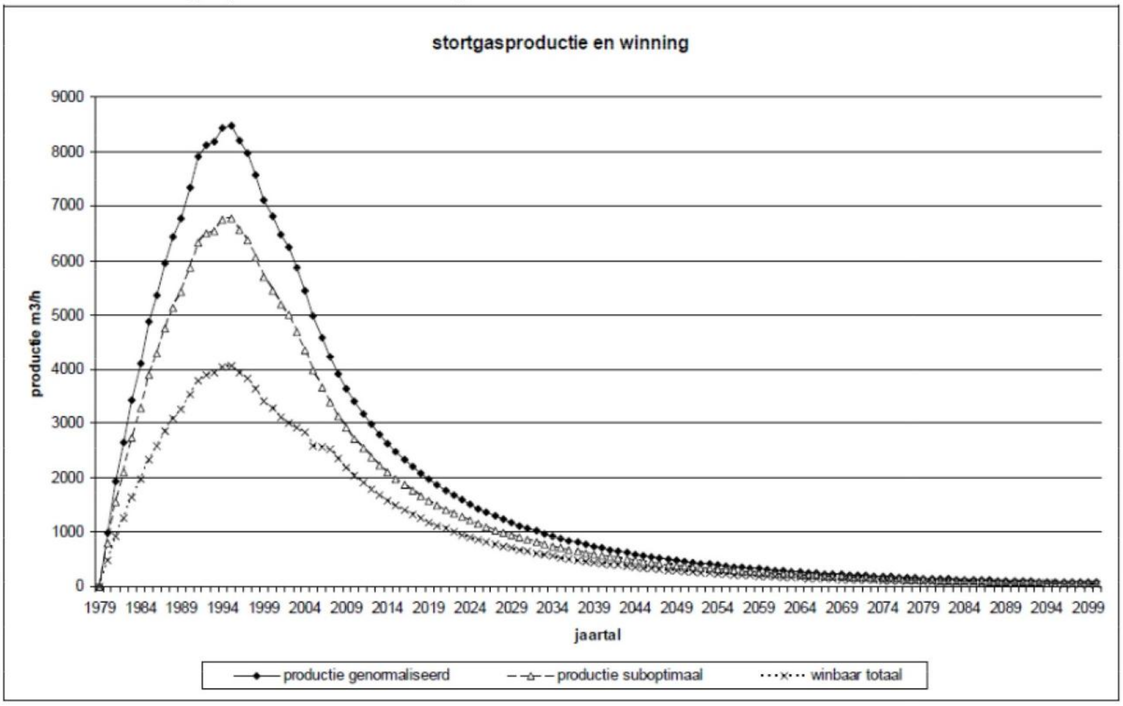
Figure A5-2 As build overview Multriwell system landfill VAM



Landfill gas prognoses
Attero has prepared a business case for internal use only. The proposal is described in "Amendment (AWA) Multriwell.doc", dated May 3, 2011.
No public LFG prognosis with respect to the installation of the Multriwell system is performed.

For the traditional system a prognosis is carried out by Grontmij. The modelled production and extraction of LFG with the traditional extraction system at the VAM landfill is shown in figure A5-3 [Grontmij 2012]. The prognosis is that with the traditional system approximately 2.000m^3/h LFG at the landfill VAM in 2012 will be extracted.

Figure A5-3 modelled LFG production and extraction at landfill VAM with the traditional system [Grontmij 2012]



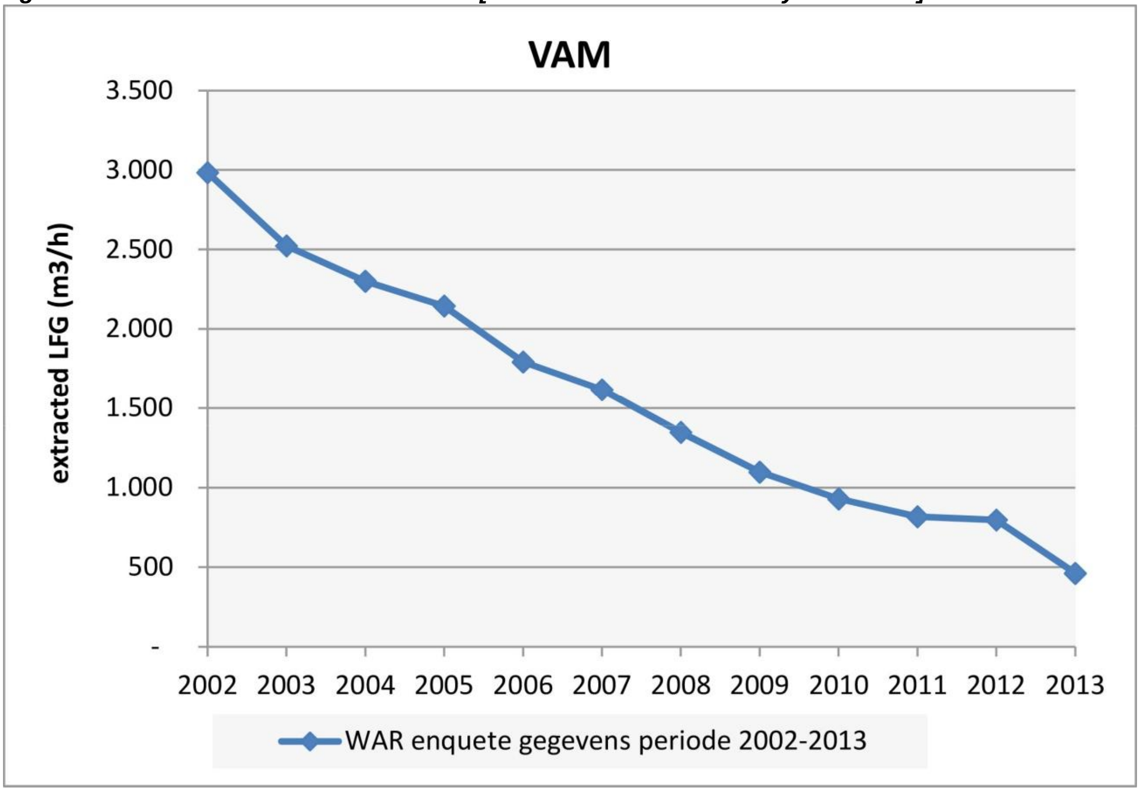
Landfill gas measurements

At the area where the Multriwell system is installed, there is no traditional system in operation. Therefore, no comparison between the two extraction systems can be made. Furthermore no prognosis for the Multriwell field is made.

A year after installation, three out of four wells (M1, M3 en M4) produced a flow and quality of LFG higher as expected. The flow of the Multriwell field is approximately 40 m^3/h. The LFG contains 60% CH_4, 20% CO_2 and 0,5 % O_2. [Attero 2012] [Overzet, D., Woelders H., 2013]
NB. One well (M2) was shut down due to the poor quality and flow of LFG, possibly caused by the composition of the waste.

The extracted 40m^3/h with the Multriwell system is just over 5% of the total extracted LFG with the traditional system. In 2012 according to the annual Dutch waste survey 797 m^3/h LFG was extracted from the VAM landfill (see figure A5-4). However this 797m^3/h was extracted from the whole landfill. The Multriwell area is just over 2% of the total landfill area.

Figure A5-4 Extracted LFG at landfill VAM [annual Dutch waste survey 2002-2013]



At the Multriwell site at landfill VAM the odour levels dropped near leachate well 6. Leachate from area 3.1 (the Multriwell site) flows to leachate collection well 6. Also the leachate composition changed after the installation. Measurements with a Flame Ionization Detector (FID) showed no emissions of elevated volatile components. The absence of odour and the change in the leachate composition is attributed to the presence of the Multriwell system. [Attero, 2012]

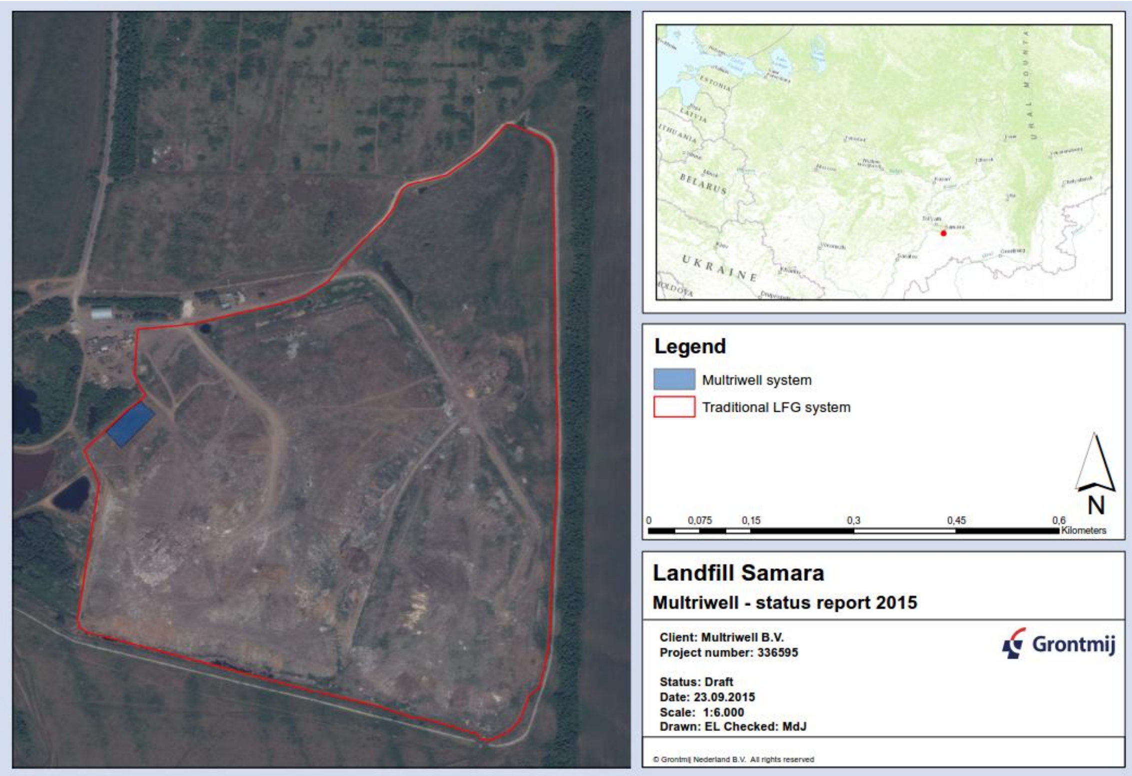
Appendix 7

Landfill Preobrazhenka, Samara (RUS)

Landfill Preobrazhenka, Samara (RUS)

In the figure below the location of landfill Preobrazhenka in Russia is shown. Furthermore the area where the Multriwell system is installed is visualized (blue part).

Figure A6-1 location landfill Samara



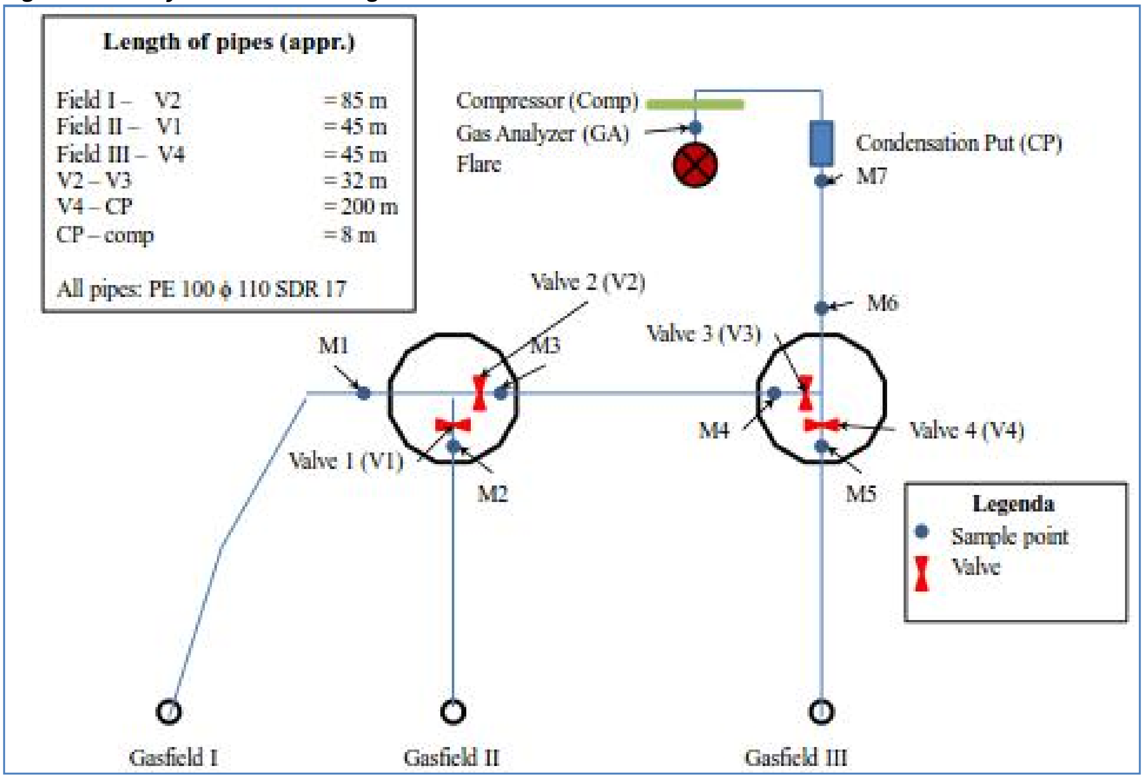
Description location/ Multriwell system
The landfill of Preobrazhenka is located near the city of Samara in Russia, approximately 1050 kilometres southeast of Moscow. The operator of the landfill is Ecologija.

A traditional gas extraction system was installed on the landfill. Due to lack of maintenance this traditional extraction system is not in operation anymore. No information on LFG extraction rates (m^3/h) with traditional system is available.

Figure A6-2 Old non-functioning vertical LFG extraction wells

In 2012 the Multriwell system was installed on a site of approximately 4.250 m^2 at the landfill. A total of 615 V-type were installed in a grid 4x4m (two fields) and 2x2 (1 field). The stitching was carried out with a 30 ton (CAT 330) excavator. It was possible to use a smaller excavator because the waste at this site wasn't tightly compacted.
The maximum stitching depth was 18 m, the average depth 15 m. A schematic overview of the installed LFG system is shown in figure A6-3. A large part of the test site was covered with only a geo-membrane. A small part of the test field, mainly around the outlet pipes, was covered with a mineral liner (Trisoplast®).

Figure A6-3 Layout of field configuration landfill Samara



Landfill gas prognoses

No information on landfill gas prognoses available

Landfill measurements

The performance of the installed Multriwell system was tested from September 17 to December 29, 2012.
The LFG contains 56% CH_4, 42% CO_2 and 0,2 % O_2 at the compressor at a given under pressure of -18mbar at the sampling point ('condensation put'). This quality was confirmed in a second measurement 22 days later. The flow was 240 Nm^3/h. [TerrAdvies 2012].

On the 3rd of April 2015 a LFG flow of 360 Nm^3/h was extracted containing 47,5% CH_4, 0,5 % O_2 and 28 ppm H_2S (see figure A6-3).

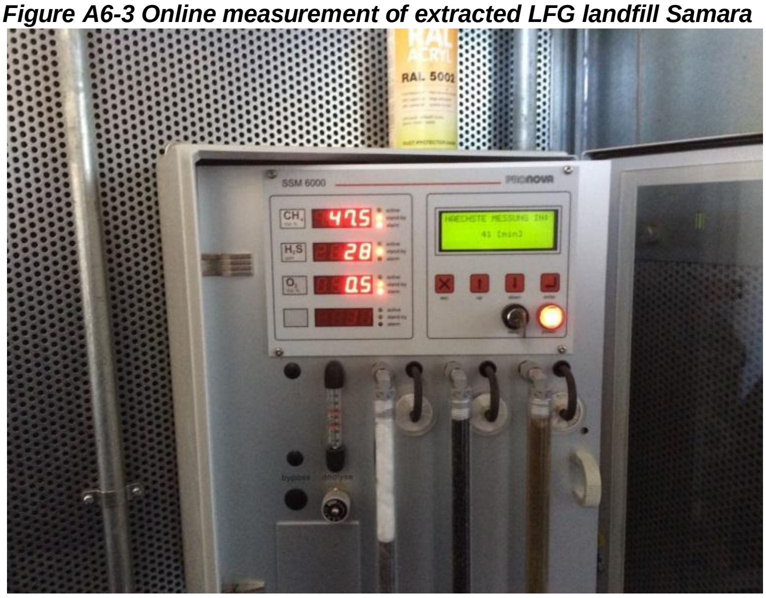
Table A6-1 Energetic value extracted LFG at Samara Landfill

year	flow (m^3/h)	methane content (%)	Density# (kg/m^3)	Energetic value (kg/h)
2012	240	56%	0.671	90.2
2015	360	47,5%	0.671	114.7

#: at 1 bar and 15 degrees Celsius

From the table above it can be concluded that although the methane content decreased the past three years the energetic value of the extracted LFG in 2015 is higher than in 2012.

Figure A6-3 Online measurement of extracted LFG landfill Samara



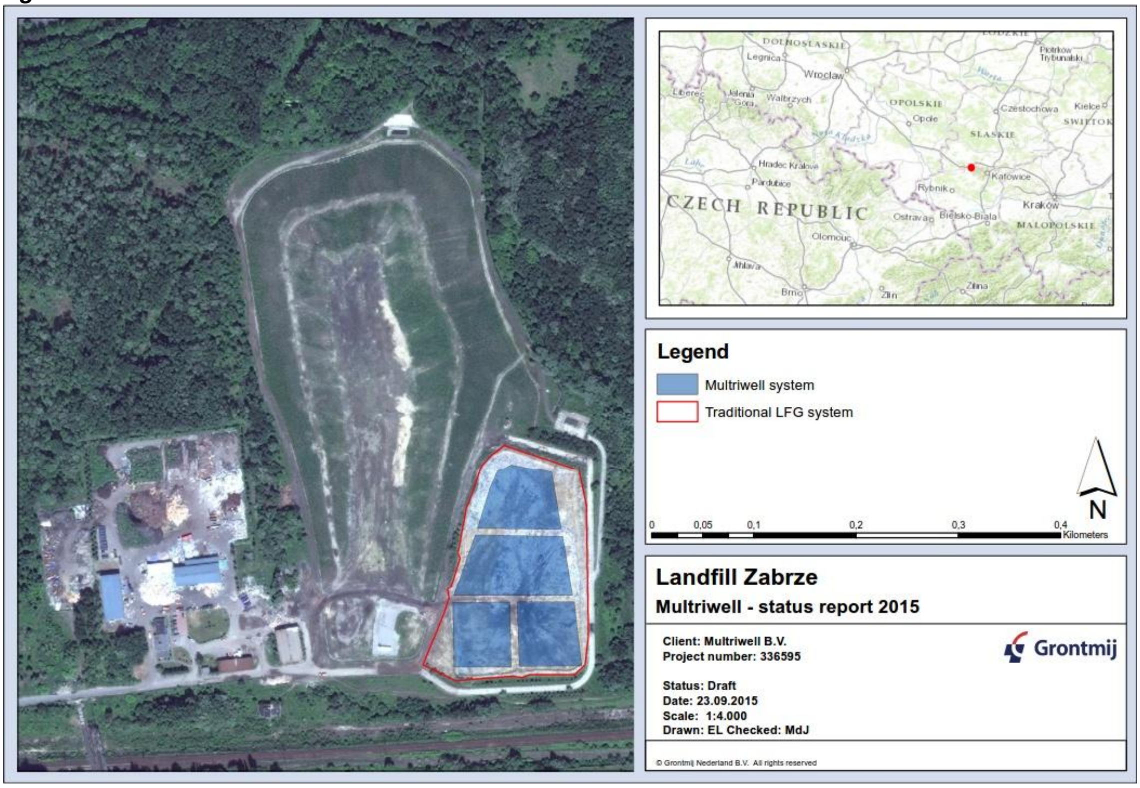
Appendix 8

Landfill Zabrze, Zabrze, (POL)

Landfill Zabrze, Zabrze (POL)

In the figure below the location of landfill Zabrze in Poland is shown. Furthermore the area where the Multriwell system is installed is visualized (blue part).

Figure A7-1 location landfill Zabrze



Description location/ Multriwell system

The landfill of Zabrze is located near the city of Katowice in the south of Poland. It is operated by Vireo Energy Polsk sp. Z.o.o.. The landfill is 10 ha. At the south-eastern part of the landfill a traditional landfill gas system of 1,395 ha and 25 extraction wells is installed.
Multriwell was installed next to this LFG extraction system in 2013. At total of 1,549 V-type (grid 3x3 m) with an average depth of 15 meters are placed in 4 fields (field 1 west, field 1 east, field 2 and field 3) that predominately contain household waste. The 4 fields are covered with a geomembrane (0,5 mm) and on top of the geomembrane 20 cm soil.

Multriwell field 1 west and field 1 east at the landfill Zabrze were installed during the winter. On top of the waste a support layer of sand and soil was applied just before a snow and frost period. After the period of snow and frost the melted snow wasn’t able to permeate trough the waste creating mud pools. The ‘mud/sludge’ penetrated into the Multriwell system (in H-type and V-type) in field 1 east and field 1 west causing a lower extraction of LFG than predicted.

Landfill gas prognoses

No information on landfill gas prognoses available

Landfill measurements

The characteristics of the four fields are taken up in the table A7-1.

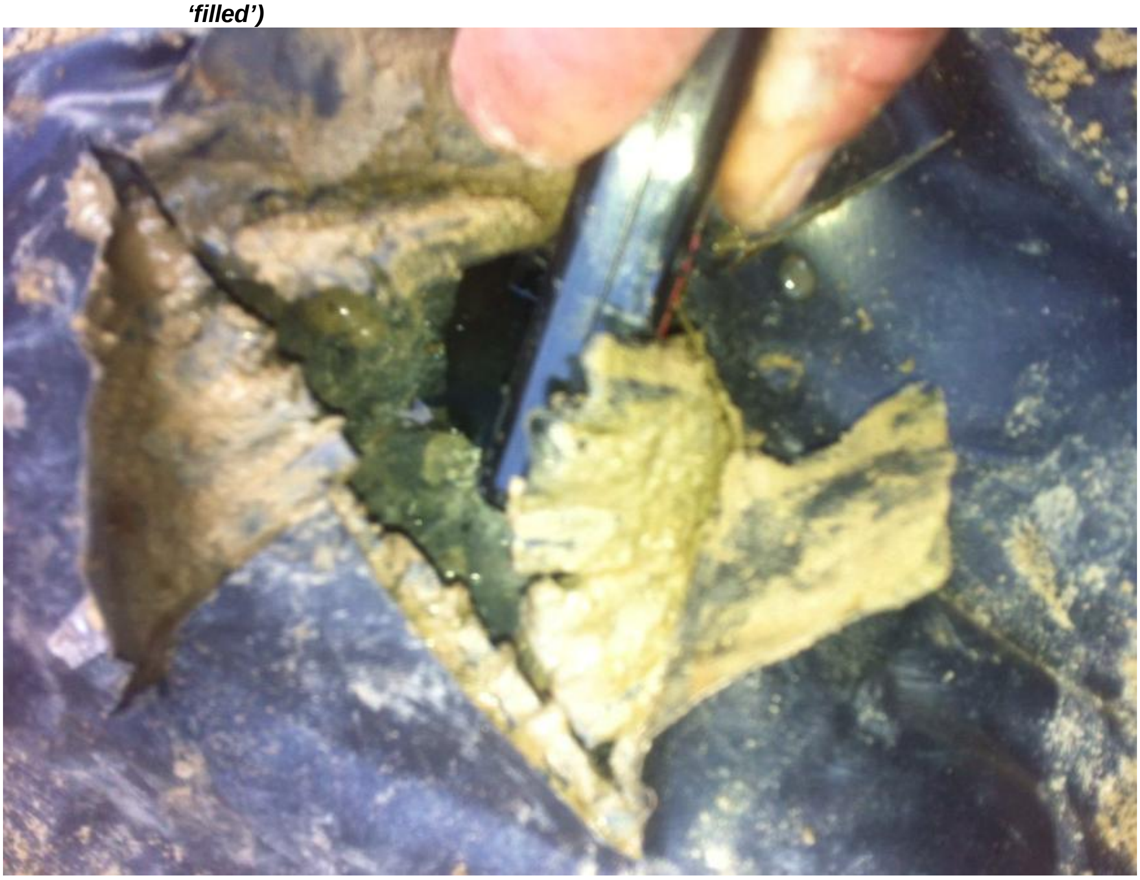
Table A7-1 Characteristics of the four Multriwell fields at landfill Zabrze

area	Area covered with geomembrame (m^2)	Extracted LFG flow June 2013 (m3/h)	Extracted LFG flow (m3/ha)	CH_4 (%)
field 1 west	2.500	± 15	± 60	38,7
field 1 east*	3.490			
field 2	4.560	± 15	± 33	61,5
field 3	3.720	± 20	± 54	50,0
total	**14.270**	**± 50**	**± 35**	

Source: [Terradvies, 2013A]

The low flow at the Zabrze landfill was mainly caused by a blocked collector drain and the absence of a good (gas) permeable support layer. The support layer consists of wet clayey soil and waste with a significant amount of plastic. This layer is has a low gas permeability. [Terradvies 2013A, 2013B]

Figure A7-2 Drain collector put at Zabrze landfill Visible wet clayey soil around drain (ribs are 'filled')



Source: Terradvies 2013B.

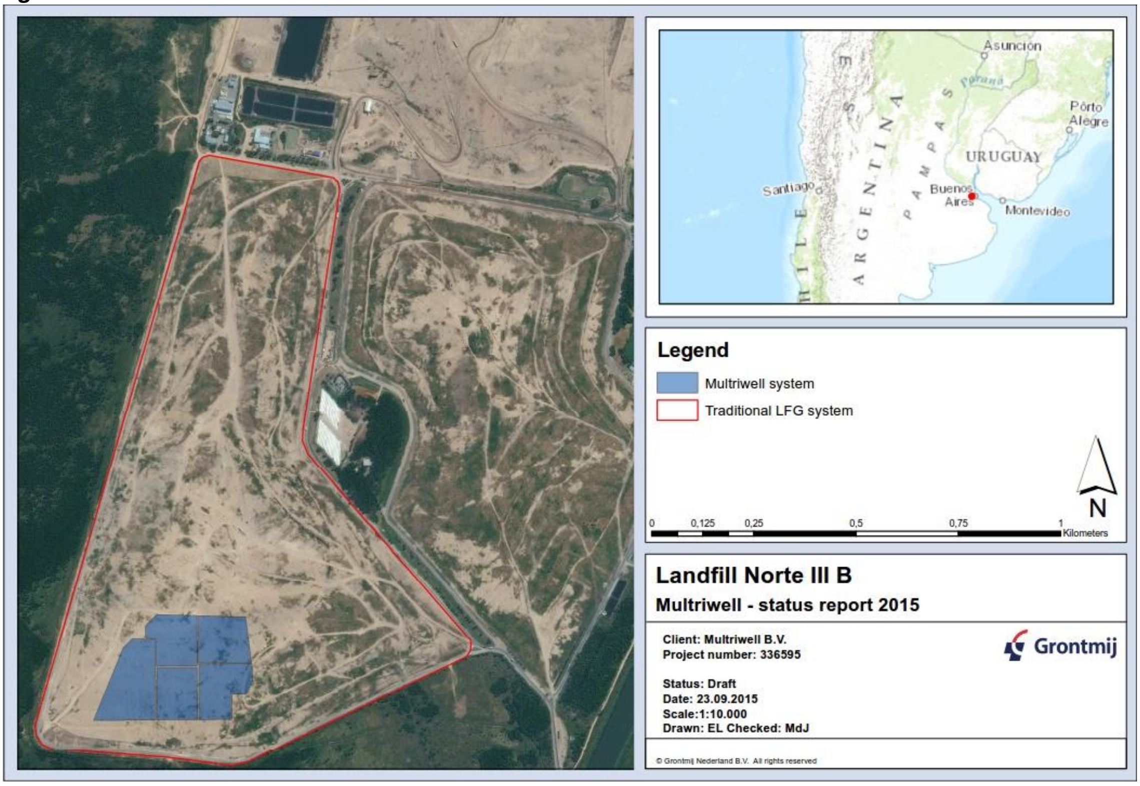
Appendix 9

Landfill Norte III-B, Buenos Aires (ARG)

Landfill Norte III-B, Buenos Aires (ARG)

In the figure below the location of landfill Norte III-B in Argentina is shown. Furthermore the area where the Multriwell system is installed is visualized (blue part).

Figure A8-1 location landfill Norte III-B



Description location

The Norte III-B landfill covers a total area of 100 hectares and has been operated by CEAMSE since 2008. It receives waste from the Buenos Aires Metropolitan Area (the City of Buenos Aires and some municipalities located in the suburbs of Buenos Aires). 266 traditional LFG wells are situated on a part of the Norte III-B landfill. [Catepillar, 2014; Ganfer, 2011]
The Multriwell system was installed on 3,1 hectare next to the traditional LFG extraction system in 2010. The Multriwell system consists of four extraction fields.

Landfill gas prognoses

Preliminary calculations predicted a LFG production of approximately 2.200 m^3/h at a site of 6,62 ha. These calculations do not take seasonal influences into account. [TerrAdvies 2011B]

A traditional system with no cap should be able to extract 1.325 m^3/h LFG with an extraction efficiency of 60%.
Based on the points listed below, a calculation was made of what the flow of LFG in the Multriwell area could be:

- data on performance of individual traditional wells
- the total flow from the influence area of the involved former lineas corrected for the installed influence area of the Multriwell system . [TerrAdvies 2011B].

Landfill measurements

The LFG extraction rate from the Multriwell system should be about 650 m^3/h (the average of 720 and 574 m^3/h) when the influence area and seasonal influence are taken into account.

The actual average LFG extraction flow in the Multriwell system measured between February 3 -17, 2011 was 700 m^3/h with an CH_4 content of approximately 44%. The flow of 700 m^3/h was an 8% increase compared to the calculated average based on data from the traditional wells.

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