Background to the development of LFX
Introduction

In the UK, following European legislation, the majority of engineered landfills are lined typically with 1m of compacted mineral liner overlain by a 2mm thick HDPE geomembrane, a thick geotextile protector and a thickness of drainage stone to collect and convey leachate. Because of concern for the longevity of landfill containment systems, the legislation has taken a conservative approach to landfill design, requiring drainage stone layers up to 500mm thick and forcing waste management contractors to fill hard-won void space with equally hard-won drainage gravel. The environmental need to incorporate safety in design militates against the environmental need to maximise void space and minimise the use of a quarried or dredged stone.

This document describes the use of a carefully-selected Protexia LFX geocomposite to replace a significant part of the drainage stone and provide flow capacity equivalent to the stone it replaces, saving on void space and drainage stone alike. It describes the very successful collaboration between key stakeholders: from conceptual design through to laboratory testing and a full site trial. The indications are that this project has been successful and will pave the way for the wide spread use of basal drainage geocomposites in landfill construction.

The UK Environment Agency has always welcomed innovative development in the engineered landfill lining industry. Engineered liners have evolved from dilute and disperse to a highly sophisticated engineering solution that has European legislation at its heart. Geocomposites have been used as a leachate drainage medium for a number of years in the US, especially as side-wall drainage and as secondary leak detection between double liners at the base, but rarely as a primary leachate drainage layer. In the UK, geocomposites have been used extensively in landfill capping where the environmental risk levels and loadings are fairly low.

This project represents an important step forward in the use of high-performance geocomposites as a leachate drainage medium in landfill containment systems.

A series of laboratory and field trials, leading to a site installation, has been achieved as a result of collaboration between Viridor Waste Management, Wardell Armstrong, GEOfabrics and The Environment Agency.

Pilsworth Landfill Site, near Bury, was identified as suitable for the full-scale trial. The site was considered typical of landfill cells in the UK and had the advantage of having two cells under construction, both with very similar shape and adjacent to each other. This would allow one to be built conventionally using a primary-aggregate, leachate-drainage blanket, and the second with a combined aggregate/geocomposite, leachate-drainage layer. A direct comparison could be made as the rainfall, waste streams and topography would effectively be identical.
Cost Analysis

Apart from the environmental benefits it was important to control costs and optimise the design to achieve proper leachate control at a favourable cost. The proposal was for a 150mm thick stone drainage blanket - the practical minimum that could be placed safely without damaging the underlying composite or liner. The composite was to be manufactured using the most cost-effective materials and be capable of being deployed as quickly as a standard heavy-duty geotextile protector.

A target saving of £10/m², taking into account the saving in void space, installation costs and the LFX cost, made the project an attractive proposition.

Design of the composite

The use of geocomposites in the construction of engineered landfills, although proposed and trialled in recent years, remains limited in the UK. There are, however, real benefits to be gained from their use:

- reduced consumption of primary aggregate
- reduced number of truck movements lessening environmental impact
- reduced carbon footprint
- increased sustainability of landfill as a waste disposal option
- increased ease and speed of construction
- the application of BATNEEC (Best Available Technique Not Employing Excessive Cost)
- factory produced and quality assured

There are, however, other factors to be recognised when proposing the use of these types of materials. Design and operational issues relating to the performance of the material must be addressed and well understood. It is accepted that since their use in the UK remains innovative they are expected to withstand more detailed levels of scrutiny by The Environment Agency than traditional designs. It is with these issues in mind that a large-scale trial was proposed.

Advanced discussions were held with The Environment Agency. Detailed design and analysis, supported by laboratory testing and field trials, was carried out. This was in parallel with research into the use of geosynthetic and geocomposite products as combined protection and drainage media within landfill cell containment systems.

It is beneficial to describe the leachate management system design at the site and provide a summary of the construction layout for Cell 12Ci before discussing the proposed use of the geocomposite.

The design of the leachate management system at Pilsworth Landfill Site is derived from the requirements of the PPC Permit (and the hydrogeological risk assessment undertaken as part of the permit application), regulations issued by government, guidance issued by The Environment Agency and the specific geotechnical design parameters of individual cells.

Design of current leachate management systems generally follows the guidance issued in the North West Waste Regulation Officers’ Report - 1995. This document details various in-service requirements for leachate-collection systems and prescribes minimum design values to be adopted where appropriate. Best practice for the use of geomembrane protection geotextiles in landfill engineering is provided by The Environment Agency - Interim Guidance on Non-woven Protector Geotextiles for Landfill Engineering, 1999. This document sets out the fundamental design requirements for geotextile protection, prescribes specific performance requirements and details the construction quality-assurance procedures to be adopted during installation.
Minimum recommended design criteria for leachate drainage systems is given in the *Landfill (England and Wales) Regulations 2002*, which transpose into UK law the requirements of the *Landfill Directive*. The regulations specify the installation of a leachate drainage blanket with a minimum thickness of 0.5m. However, this can be reduced on the basis of an acceptable hydrogeological risk assessment. The leachate management system design for landfill cells at Pilsworth was produced with due regard to the above guidance and regulations. The design comprises geotextile protection installed above the flexible geomembrane liner, overlain by a 300mm thick blanket of 10 to 20mm sized drainage stone, which in turn is overlain by a network of piped collection drains and leachate extraction and monitoring chambers.

Design should take account of the long-term performance of the drainage blanket, taking into account any physical and biological clogging, and demonstrate that the leachate management system design is appropriate for the proper management of leachate within the site.

The Protexia LFX geocomposite installed in Cell 12Ci, manufactured by GEOfabrics Limited, comprises four components bonded together:

- an extruded three-layer geonet drainage core forming part of the leachate drainage layer (together with overlying stone drainage and piped drains)
- a woven geotextile filter bonded on both sides of the net core to prevent clogging of the geonet core
- a needlepunched, staple fibre, non-woven geotextile protector on the underside

The geocomposite was installed directly on top of the geomembrane liner - effectively replacing the conventional geotextile protector - allowing the thickness of the overlying stone drainage blanket to be reduced from 300 to 150mm. The key design and in-service requirements that have been identified in this respect are detailed below.
Flow capacity

The flow capacity of the geocomposite is determined principally by the geonet drainage core component. However, the geotextile protection component also has the capacity to accommodate flow. It was intended that the flow capacity of the geocomposite would allow the thickness of the overlying stone drainage blanket to be reduced from 300mm to 150mm. Calculations were carried out to demonstrate the equivalency of the geocomposite’s permeability to that of a 300mm thickness of 10 to 20mm stone (this was conservative with respect to the proposed 150mm thickness of stone to be used). The calculations were based on in-plane-flow-testing results carried out in GEOFabrics’ laboratories. Details of the testing undertaken are given in Laboratory testing and field trials. The design in-plane-flow calculations take into consideration the following factors of safety:

- Intrusion of overlying draining stone into the geocomposite
- Long-term compressive creep of the geonet drainage core element of the geocomposite
- Clogging of the upper geotextile filter layer
- Geocomposite/drainage stone equivalency factor as recommended by the EA

The calculations showed that the drainage properties of the geocomposite exceeded the requirements of Environment Agency guidance for the performance of a 300mm thick drainage blanket.

Physical strength is required to withstand loadings imposed by the overlying waste mass. The essential components of the physical strength are compressive, tensile and puncture.

Compressive Strength

The compressive strength of the geonet component determines the susceptibility of the material to long-term compressive creep. There are generally two types of net available: two- and three-layer nets. From research work carried out in the United States it was decided to use the three-layer net as this was considered as the most stable and had the greatest resistance to compressive creep over time. It is noted by Qian, Koerner and Gray (2002) that the susceptibility of geonets to compressive creep is related to the polymer’s density and a lower reduction factor should be applied for higher density polymers. The three-layer net used in Protexia LFX products is manufactured from high density polyethylene. The in-plane-flow calculations included a conservative factor of safety for reduction of the flow capacity due to compressive creep.

Tensile Strength

Since the leachate drainage blanket covers the floor area of Cell 12Ci and to a height of 3m/4m up the perimeter bunds, tensile strength was not expected to be critical to the performance of the geocomposite. It was felt that the installation process could put some temporary tensile loads into the core.

Puncture resistance and thickness

Puncture resistance and thickness are the principal design parameter for the geotextile protector. This LFX component was specified based on the anticipated waste loadings and anticipated leachate drainage stone size within Cell 12Ci. Two alternative stone sources were considered 10 to 20mm and 20 to 40mm crushed angular quarry stone. The appropriate geotextile was selected by carrying out cylinder tests for each stone type (see Laboratory testing).

Clogging

There are two main aspects to be considered when addressing this issue:

- Biological and physical clogging of the geotextile filter
- Physical clogging of the geonet core
There is a balance to be struck between the susceptibility of the upper filter geotextile to clogging versus the ability of the core to transport fine particles on a relatively shallow gradient. In addition, the upper geotextile must be able to withstand the installation process and the selection of the component was also related to its ability to bond to the geonet core. Research has shown that whilst biological clogging can build up to a high level at the base of a landfill there is a marked residual and stable flow capacity that allows adequate flow into the core for leachate drainage requirements. Experiments have shown residual flows to be approximately 50% of original unclogged materials. These experiments are likely to be conservative as they have been carried out with small samples where edge effects have a dominating influence. GEOfabrics have themselves carried out long-term, leachate-immersion tests in anaerobic conditions and found that a 12-year-old sample, when tested, retained 30% of its original flow capacity. The resulting build up was largely crystalline leaving voids for flow between the coated fibres. The leachate used was from typical household landfill wastes similar to those at Pilsworth.

Having researched many of the published papers, it was found that either a theoretical or non-specific route is taken to address biological clogging. The conclusion is that the theoretical ideal material would be an open geotextile (such as an open-weave monofilament geotextile) which has low compressibility and has high in-plane stiffness to minimise biological clogging. This, however, assumes a small filtration area and a high transportation velocity within the core (such as in a highway fin-drain application) which is not the case with leachate drainage systems. Authors have concluded that anaerobic conditions causes the least biological build up, which is likely to be the case at Pilsworth.

The optimum components were used to manufacture the Protexia LFX composite.

A woven filter was selected as the upper filter layer, to provide optimum spanning across the ribs of the geonet core, therefore maximising flow capacity, and also to provide a relatively open weave - 300microns opening size ($O_{90}$) 8% open area - to retain silt material in order to prevent physical clogging of the core. A similar woven was used as the reinforcement layer on the other side of the geonet core to prevent intrusion by the geotextile protector in order to reduce physical clogging of the core and to increase potential flow rate.

GEOfabrics, as a result of the work, developed a number of new techniques for laminating woven fabrics to net core materials.

The in-plane-flow calculations were based on conservative factors of safety to allow for the effects of clogging on the geocomposite and, as previously mentioned, demonstrate that the residual flow capacity of the geocomposite exceeded the minimum criteria for a stone drainage blanket as set out in Environment Agency guidance. By placing a 150mm thickness of drainage stone above the geocomposite, therefore, a reduction factor of 2 was allowed to take account of potential clogging of the geocomposite. This is in line with the residual flow rates suggested by research.
Laboratory testing

The optimum combination of textiles and nets had to be established for the design process. The objective was to find the most economic solution that would allow the onerous requirements of a landfill environment to be met.

Two tests were used to simulate site conditions firstly the cylinder test undertaken in accordance with The Environment Agency document A Methodology for Cylinder Testing of Protectors for Geomembranes, March 1998, to determine the correct geotextile protector for the geonet and stone combination. The second test was to establish long-term, in-plane-flow using a modified version of EN ISO 12958 Geotextiles – Determination of water flow capacity in their plane.

A modified version of the in-plane-flow test was carried out on the LFX composite. This involved using the stone to be used at Pilsworth as the upper platen above the sample and loaded to 254kPa, hydraulic gradient of 0.1 and placed on the lower hard platen. The test duration was 26 days to ensure steady-state conditions to be achieved.

Figure 2: Cylinder test cross section

Figure 3: Photo of loaded cylinder test

Figure 4: Photo of modified in-plane flow
The first prototype composite used three components: a thin, non-woven, heat-bonded geotextile filter, a three-layer net and thick geotextile protector. This combination passed the cylinder test but flow decreased steadily over time as the geotextile was progressively forced into the geonet voids.

A second prototype was manufactured by replacing the upper filter layer with a woven filter and inserting a reinforcing layer between the geonet and the geotextile protector. The two tests were repeated and a high-level flow was sustained.

A second cylinder test was carried out with an alternative stone giving the contractor a choice of stone sources with a load of 65t/m$^2$ for 100 hours using a 2mm thick HDPE membrane. It was found that for the 10 to 20mm stone, a geotextile protector with a puncture resistance of 5kN and a thickness of 5mm was required whilst with the 20 to 40mm stone, a puncture resistance of 14kN and a thickness of 7mm was required. Additional tests proved that the geonet ribs could lead to membrane deformation and that the geotextile protector should have a minimum strength of 5kN and a thickness of 5mm.

The final geocomposite was therefore comprised four components with each component tested to EN Standards (European Norm) (see *Installation and quality assurance*):

- woven separator/filter
- geonet drainage core
- woven separator/filter
- non-woven protector

**Field testing**

Whilst laboratory trials had proved successful, the performance of the product during installation had still to be confirmed. A site installation trial was undertaken at the Pilsworth site using all the relevant material and plant which were to be used in construction of the cell. Three field trials were carried out to confirm that the installation of the geocomposite and drainage stone was practical and that the specified geotextile protector would perform adequately under dynamic loading with the specified drainage stone. The test pad comprised:

- a nominal thickness of clay (approximately 0.5m thick) placed and compacted using a bulldozer and a vibratory roller
- a 2mm thick high density polyethylene geomembrane liner
- the LFX geocomposite
- 150mm thick stone drainage blanket

The field trials were undertaken under the supervision of a Wardell Armstrong, GEOfabrics and The Environment Agency. Each trial pad was approximately 5m by 10m.
The first trial involved the use of an LFX composite based on a GEOfabrics HPS5 geotextile protector and 10 to 20mm stone as it was anticipated that this configuration would be used for the construction of Cell 12Ci. The second used an LFX composite based on HPS14 geotextile and 20 to 40mm stone. As an extreme worst case, a third used an LFX composite based on HPSS and a brick hardcore drainage layer.

The objective was to establish that the proposed overlap detail was adequate and that the lengths would not separate during stone placement or allow stone to pass through the joints and come into direct contact with the geomembrane.

Once the tracking had been completed, the geocomposite was exposed, removed and inspected to check for damage and integrity and to check the condition of the underlying geomembrane.

The results for the tests were very encouraging as the only obvious damage was in the worst case scenario - using the brick hardcore. Here scuffing of the top filter layer resulted in a 10mm hole and a few other smaller holes. Checks were made at the joints. Joints in the composite were opened to inspect for damage to the composite and the geomembrane. None were observed.

**Installation & quality assurance**

A report describing the Manufacturing Quality Assurance (MQA) and the Construction Quality Assurance (CQA) plans was submitted to, and accepted by, The Environment Agency.

An independent, suitably-qualified CQA Engineer, provided by Wardell Armstrong, supervised the installation. This Engineer provided independent confirmation that the works were carried out in accordance with the approved installation method statement document that was approved by The Environment Agency (and any amendments approved by The Environment Agency) and any documents listed therein.
The CQA Engineer supervised the works to ensure that the testing of the geocomposites to be used in the works was undertaken in accordance with the details given in the installation method statement. The CQA Engineer checked all sample test results to ensure compliance with the relevant criteria. Rolls of the geocomposite were delivered to site in packaging, which protects the rolls from degradation, by ultra violet light.

GEOfabrics were required to provide production test certificates for each of the LFX rolls delivered to site:

<table>
<thead>
<tr>
<th>Test/CQA procedure</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>In-plane flow capacity (soft/hard platens)</td>
<td>EN ISO 12958</td>
</tr>
<tr>
<td>Puncture resistance</td>
<td>BS EN ISO 12236</td>
</tr>
</tbody>
</table>

*Table 1. Frequency of laboratory testing to be carried out on the geocomposite*

Samples of geocomposite were taken by the CQA Engineer upon delivery and tested by an independent laboratory in accordance with Table 1.

In addition, GEOfabrics was required to provide MQA test certificates for the geocomposite components and, as a minimum, test data was included as per table 2.

The CQA Engineer was required to reject any rolls of geocomposite in total, or in part, for any of the following reasons:

- the geocomposite had been holed, torn or ripped or was otherwise damaged
- the production test certificates provided by the GEOfabrics failed to demonstrate conformance with necessary maximum/minimum test values quoted by Geofabrics for the product
- the samples tested in the laboratory failed to demonstrate conformance with necessary maximum/minimum values quoted by GEOfabrics for the product

The underlying geomembrane was inspected and any stones, debris, etc, which had the potential to damage the geomembrane was removed. The CQA Engineer supervised the geocomposite installation on a full-time basis and ensured that all lengths had a minimum 200mm overlap. The geocomposite was permanently secured around the perimeter of the cell by running out and ballasting with drainage stone.

Full details of the installation of the geocomposite were presented within the validation report for the construction of Cells 12Ci and 12Cii produced by the CQA Engineer for submission to The Environment Agency. Information relating to the LFX geocomposite included:

- All CQA test certificates provided by GEOfabrics
- The results of all material testing undertaken including any failures and subsequent re-testing
- As-built plans of the works
<table>
<thead>
<tr>
<th>TEST</th>
<th>METHOD</th>
<th>UNITS</th>
<th>MEASURED VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geotextile filter</td>
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<td></td>
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<tr>
<td>Pore size</td>
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<td>µm</td>
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<tr>
<td>Water flow</td>
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<tr>
<td>Tensile strength (md/cmd)</td>
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<td>kN/m</td>
<td>30/30</td>
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<tr>
<td>Tensile elongation (md/cmd)</td>
<td>BS EN ISO 10319</td>
<td>%</td>
<td>18/28</td>
</tr>
<tr>
<td>Geonet drain</td>
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</tr>
<tr>
<td>Thickness @200kPa</td>
<td>BS EN 964-1</td>
<td>mm</td>
<td>5.8</td>
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<tr>
<td>Tensile strength</td>
<td>BS EN ISO 10319</td>
<td>kN/m</td>
<td>30</td>
</tr>
<tr>
<td>In-plane flow capacity i = 1 @ 200kPa (md) (hard platens)</td>
<td>BS EN ISO 12958</td>
<td>m²/s</td>
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<tr>
<td>Geotextile protector</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>CBR puncture resistance</td>
<td>BE EN ISO 12236</td>
<td>kN</td>
<td>5</td>
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<tr>
<td>Tensile Strength (md)</td>
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<td>Geocomposite</td>
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<tr>
<td>In-plane flow capacity i = 1 @ 200kPa (md) (soft/hard platens) *</td>
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<td>m²/s</td>
<td>1.7 x 10⁻⁴</td>
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<tr>
<td>CBR puncture resistance</td>
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<td>kN</td>
<td>8</td>
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</tbody>
</table>

Values are Typical, with the exception of Thickness, which is Nominal. Typical indicates the mean value derived from the samples taken for any one test as defined in the BS EN ISO standard – usually the mean of five samples. Nominal is a guide value.

Table 2: GEOfabrics specification for the components and composite used in the Pilsworth Trial

* Platens to simulate actual site conditions within the standard test. The upper platen was soft to present a surface similar to actual site conditions. The lower platen was hard, simulating the well-supported HDPE geomembrane surface.
Monitoring

The two cells have been monitored over time to assess and compare the performance of the LFX composite against the standard stone drainage blanket. In addition, long-term laboratory-based simulation tests have been undertaken to study potential clogging of the core and geotextile filter.

As part of the design, alternative methods of removing leachate were incorporated as an insurance against failure of the LFX composite to work as predicted. They were ultimately found not to be required.

The two cells, 12Ci with the conventional 300mm stone drainage blanket and the trial cell 12Cii with 150mm stone drainage blanket and geocomposite were compared for performance once the cells were filled to capacity and the leachate systems were operational.

The monitoring methods were:

- Monitoring of leachate levels in both cells during the operational phase.
- Draw-off rates compared when pumping leachate down through wells. Readings from intermediate wells and from piezometers across the cells were taken. This gave a profile of the leachate head across the site whilst pumping took place.

Laboratory Monitoring

A number of LFX samples and the individual separate components were immersed in the leachate in the laboratory.

Conclusions

This project was undertaken cautiously and steadily involving all the relevant stakeholders in the project. The result has been a well-developed trial which could potentially have a large impact on the design of engineered landfills in the UK and beyond.

It has been shown that all of the benefits identified earlier *(Design of the composite)* can be realised with consequent cost savings, additional revenue and reduced environmental impact.

- reduced consumption of primary aggregate
- reduced number of truck movements lessening environmental impact
- reduced costs for site operators
- reduced carbon footprint
- increased sustainability of landfill as a waste disposal option
- increased landfill void space
- increased ease and speed of construction
- the application of BATNEEC (Best Available Technique Not Employing Excessive Cost)
- factory-produced and quality-assured geocomposite

Wardell Armstrong’s final report concluded that the composite system is effective for leachate drainage and membrane protection.

Use of the LFX will permit the reduction of the granular drainage layer thickness by up to 50% with the consequent reduction in both direct and indirect costs as well as a significant reduction of the environmental impact of delivery trucks.
Bibliography

2. Biological Clogging of geotextile filters a five-year study, Mackey R E, Koerner G R, Geosynthetics 99.
10. Determination of the allowable flow rate of a drainage geocomposite, Geosynthetic Research Institute GRI Standard – GC8 4/2001 – Equivalent methodology of assessment as used in the United States of America

Case Studies using three layer net

1. New River Regional Landfill, Union County, Florida USA - three-layer composite used to replace traditional gravel and pipe. Geocomposite covers the base of the landfill and is used as the leachate collection layer above the liner and as a leak detection layer below.
2. Atlantic Waste Disposal, Waverly, VA, USA - Used as a leak detection system under high compression loads (100m deep) Tests showed that the residual flow under these very high compression loads were still 50% of original.
3. Three-layer net case history reference list from 1995 onwards. Approximately 120 projects completed with 50 of these acting as primary leachate drainage in the base of landfills in the USA. Normal construction from base upwards is HDPE liner/geocomposite/200mm sand/waste. It is interesting to note that designs are being modified following damage tests to change the sand drainage layer to gravel.