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Abstract Title: Technologies for Reducing the Risk of Landfill Leakage

Abstract Topic: Please mark all that apply to the subject of your abstract.

☐ Waste minimization, reuse, recycling and management policy, regulation, economics, and planning
☐ Facility operation and design
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☐ Anaerobic Digestion/Fermentation of Solid Waste
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☐ Chemical and biological treatment and processes
☐ Life cycle analysis/Sustainability
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☐ Waste collection, transport, equipment and safety
☐ Environmental characterization of waste
☐ Management and re-use of industrial, oil/gas, coal ash, waste materials
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Preference for Poster or Oral Presentation: Oral Presentation
Technologies for Reducing the Risk of Landfill Leakage

The leakage through an installed landfill lining system is of utmost interest in the preservation of groundwater quality. Once groundwater contamination occurs, it can cost a site millions of dollars to mitigate and potentially even more in litigation fees. Action Leakage Rates (ALRs) are prescribed as a design target for landfill containment facilities in order to avoid impact to groundwater. If site ALRs are not met, a state will typically prevent the receipt of waste into a particular cell unable to meet the ALR until the problem is identified and successfully addressed. Various technologies are available for minimizing landfill leakage and attaining prescribed ALRs, but the materials and methods that must be employed in order to achieve those ALRs have not previously been detailed. This presentation details available technologies for reducing leakage that are economical, effective, and non disruptive to the rigorous construction schedule of landfill construction. The technologies presented include Electrical Leak Location (ELL) surveys (both bare geomembrane and soil-covered geomembrane), conductive-backed geomembrane, and white geomembrane. Providing the probabilities of exceeding a particular ALR after the application of each technology, either alone or in combination, can then inform the materials and methods of modern landfill construction in order to avoid exceeding target leakage rates.

One case study is presented herein, which illustrates the need for the use of the available technologies. The site’s ALR is 5 gpad (46.8 lphd), but typical landfill construction was employed, without the use of ELL or the other available technologies. When leakage was detected through the primary geomembrane well above the state’s ALR, the cell was monitored more closely. Detailed leakage records were kept for over one year while the cell was not allowed to receive waste. A dipole ELL survey was performed, but only two small leaks were found and repaired and there was no difference in the leakage rate. It was suspected that the leakage was due to poor contact conditions such as wrinkles, so the leak detection layer was flooded and a few inches of head maintained over the primary geomembrane, ensuring good electrical contact even in the presence of wrinkles. Six pinhole leaks and one leak measuring approximately 3/16” (4.8 mm) in diameter were subsequently located. The locations and sizes of the leaks were quantified and the leaks were repaired. The site continued to be monitored for leakage through the primary geomembrane after the repairs were made so that the leakage through the repaired leaks could be estimated. The typical equations used to estimate geomembrane leakage including the Giroud equation and the Rowe equation were then applied to the site’s condition when the holes were in place, in order to compare the results of the equations to the measured leakage. The actual hole sizes and corresponding head levels over those holes during the measurement interval were used. The results of this analysis are summarized in Table 1.
Table 1: Leakage from new landfill cell with ALR of 5 gpad (46.8 lphd). The actual measured leakage is shown in column 1. Calculated leakage using different equations are shown in columns 2 through 4. The difference between the Leakage calculated in column 4 and the actual measured leakage is shown in column 5.

<table>
<thead>
<tr>
<th>Actual Leakage Before Repairs (Recorded Daily)</th>
<th>Column 2</th>
<th>Column 3</th>
<th>Calculated Post-Repair Leakage (Column 1 − Column 4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good Contact (Giroud Eq. 2)</td>
<td>0.41</td>
<td>2.26</td>
<td>3.86</td>
</tr>
<tr>
<td>Poor Contact (Giroud Eq. 2)</td>
<td>0.48</td>
<td>2.62</td>
<td>2.08</td>
</tr>
<tr>
<td>Leakage On Wrinkle (Rowe Eq. 3)</td>
<td>0.49</td>
<td>2.70</td>
<td>1.78</td>
</tr>
<tr>
<td>Calculated Post-Repair Leakage (Column 1 − Column 4)</td>
<td>0.37</td>
<td>2.00</td>
<td>4.59</td>
</tr>
</tbody>
</table>

Notes:
(1) 1 gpad = 9.35 lphd
(2) Assuming actual estimated hole size and geometries and actual estimated hydraulic head at location of leak(s) at time of leakage measurement, GCL thickness of 0.006 m, GCL hydraulic conductivity of $5.0 \times 10^{-11}$ m/s and GCL thickness of 0.006 m.
(3) Assuming wrinkle width of 0.31 m, wrinkle length of 190 m, GCL hydraulic conductivity of $5.0 \times 10^{-11}$ m/s, GCL thickness of 0.006 m and transmissivity of geomembrane/GCL interface of $2.0 \times 10^{-10}$ m²/s (for low compressive stress condition).

The results of this analysis show that the leaks located during the second dipole survey were most likely on wrinkles or other areas of poor contact between the geomembrane and the underlying geosynthetic clay liner (GCL).

As installed geomembranes receive solar radiation they begin to expand, resulting in the formation of wrinkles. Evaluations of wrinkles in exposed geomembranes show that up to 30% of the geomembrane area may be covered by hydraulically connected wrinkles (Chappel, 2012). This means that if there is a hole anywhere within that wrinkled area, the network of wrinkles can provide a hydraulic conduit for liquid that has migrated through the geomembrane. For that portion of the geomembrane, the only remaining barrier is the GCL, and the resulting leakage can be several magnitudes greater than a single hole maintaining intimate contact with the GCL, as the previous case study shows. Forensic evaluation has shown that wrinkles do not disappear when the geomembrane is subsequently covered with soil (Koerner and Koerner, 2013). Rather, the wrinkles are entombed in place.

Many factors can contribute to geomembrane leakage including the number and size of holes, the presence of wrinkles, the depth of waste, the cover system (if in place), the barrier system components, the leachate collection system design, the nature of the barrier system foundation, the nature of the waste and the leachate collection system operation and maintenance (Rowe and Hosney, 2010). Certainly the largest factor contributing to leakage are the holes in the geomembrane; system design and operation can only mitigate or exacerbate the principal problem of leaks. A comparison of leakage resulting from leaks with intimate contact with the underlying GCL, compared with leakage resulting from leaks on a wrinkle shows that the presence of wrinkles can significantly compound the problem of holes (Rowe and Hosney,
This presentation therefore focuses on the technologies for directly avoiding both leaks and wrinkles during the construction phase, since the presence of both leaks and wrinkles work in combination to create the largest risk for exceeding a given ALR throughout the life of a site. The available technologies include ELL surveys, conductive-backed geomembrane, and white geomembrane.

ELL surveys for landfill expansions can be divided into two categories; bare geomembrane surveys and soil-covered dipole surveys. The bare geomembrane survey is performed directly after geomembrane installation and can locate the smallest leaks caused during geomembrane installation. The soil-covered dipole survey is then used to locate any leaks created during placement of the cover soil material. The bare geomembrane methods are generally much more sensitive than the soil-covered dipole method. The soil-covered dipole surveys will not likely find pinholes, knife slices, or other small damage locations created during geomembrane installation. However, most landfills only perform the dipole method for landfill expansions when ELL is required or specified for a site.

The bare geomembrane methods include the water puddle, water lance and arc testing methods. The water puddle and water lance utilize either a puddle or a stream of water to conduct electricity, as the names imply. The electrical current source is grounded to the subgrade underneath the geomembrane. In the presence of a poor contact condition such as a wrinkle, the water may not be able to travel through the hole and down the underside of the wrinkle to complete the electrical connection. The arc tester does not rely on water to conduct electricity; it imposes a high voltage over the geomembrane and is also grounded to the subgrade. However, an electrical arc will not form if the arc tester probe is too far away from the subgrade, as would be the case over a wrinkle. For both methods, effort is made to push down the wrinkles, or the survey is performed at night. However, the risk remains due to the technological limitations of the methods that leaks can be missed on poor contact conditions such as wrinkles.

The soil-covered geomembrane dipole method is similar to the bare geomembrane methods in that a positive voltage is introduced above the geomembrane and grounded to the subgrade beneath the geomembrane. The current source is placed in the soil cover material and current will travel through any leaks in the geomembrane, which have good contact with the subgrade below it. A hole located on a wrinkle entombed in the soil cover simply will not be detected because the electricity will not travel through the air gap created by the wrinkle.

Conductive-backed geomembrane is fabricated using the coextrusion process. An electrically insulative HDPE geomembrane is coextruded with an electrically conductive material on the back side as a continuous layer. This results in a conductive layer in intimate contact with the geomembrane. This enables the location of leaks in poor contact conditions such as wrinkles, under the overlap of a fusion weld, or in a location where there is a depression in the subgrade. Special consideration needs to be granted to the installation of a conductive-backed geomembrane in order to ensure that the conductive layers of the discrete panels and patches are electrically connected and that the fusion-welded overlap flaps are electrically isolated. The bare geomembrane method typically used in tandem with conductive-backed geomembrane is the spark testing method, which is similar to the arc testing method described above. However, the other bare geomembrane ELL methods can also be used on conductive-backed geomembrane.
White geomembrane can significantly decrease the surface temperature of an exposed geomembrane (Koerner and Koerner, 1995). The lower geomembrane temperature results in a smaller area of the geomembrane covered by wrinkles (Rowe et. al, 2012). The fewer the wrinkles present, the less likely the resulting lining system will contain a hole on a wrinkle that may not be detected by ELL methods.

In order to calculate the probability of exceeding a particular ALR, one needs only the average estimated leakage rate after application of the technology (Beck, 2012). This can be found by studying landfill leakage statistics directly as reported through the primary geomembrane of a double-lined landfill, or by assuming a leak density and calculating the estimated leakage using available leakage equations. The following assumptions were used to calculate the probabilities presented herein:

**Table 2: Average Estimated Leakage through landfill geomembrane after application of each technology.**

| Technology Applied | Average Leakage (gpad)  
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>13.3^2</td>
</tr>
<tr>
<td>Dipole ELL</td>
<td>7.4^3</td>
</tr>
<tr>
<td>Bare geomembrane ELL and dipole ELL</td>
<td>2.33^4</td>
</tr>
<tr>
<td>Bare geomembrane ELL, dipole ELL and white geomembrane</td>
<td>0.96^5</td>
</tr>
<tr>
<td>Bare geomembrane ELL, dipole ELL and conductive-backed geomembrane</td>
<td>0.00^6</td>
</tr>
</tbody>
</table>

Notes:
(1) 1 gpad = 9.35 lphd
(2) From study of leakage from 122 discrete landfill cells in New York State for reporting year 2010.
(3) From study of leakage from 60 discrete landfill cells in New York State for reporting years 2006-2012.
(4) Calculated from assumptions shown in Table 3; does not consider condensation or diffusion through geomembrane.
(5) Calculated from assumptions shown in Table 3; does not consider condensation or diffusion through geomembrane.
(6) If technology applied correctly; does not consider condensation or diffusion through geomembrane.
Table 3: Assumptions used for leakage calculations.

<table>
<thead>
<tr>
<th>Assumptions for Leakage Calculations</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Equation Applied</td>
<td>Rowe</td>
</tr>
<tr>
<td>Wrinkle Width</td>
<td>12 in. (0.31 m)</td>
</tr>
<tr>
<td>Wrinkle Length</td>
<td>623 ft (190 m)</td>
</tr>
<tr>
<td>GCL hydraulic conductivity</td>
<td>$5.0 \times 10^{-11}$ m/s</td>
</tr>
<tr>
<td>GCL thickness</td>
<td>0.24 in. (0.006 m)</td>
</tr>
<tr>
<td>Transmissivity of geomembrane / GCL interface</td>
<td>$2.0 \times 10^{-10}$ m$^2$/s</td>
</tr>
<tr>
<td>Hydraulic Head</td>
<td>11.8 in. (0.3 m)</td>
</tr>
<tr>
<td>Number of holes per acre</td>
<td>2</td>
</tr>
<tr>
<td>Percent of Area covered by wrinkles (typical geomembrane)</td>
<td>17%$^1$</td>
</tr>
<tr>
<td>Percent of Area covered by wrinkles (white geomembrane)</td>
<td>7%$^1$</td>
</tr>
<tr>
<td>Equal probability of hole occurring anywhere in geomembrane area</td>
<td></td>
</tr>
</tbody>
</table>

Notes:
1. Represents percentage of leaks not detected by ELL methods due to being located on wrinkles.

The probabilities of exceeding typical landfill ALRs of 5 gpad (46.8 lphd) and 20 gpad (187.1 lphd) were calculated for each of the technologies discussed in the previous sections, both alone and in tandem. The probability of exceeding an ALR of 5 gpad (46.8 lphd) without applying any of the technologies discussed in this paper was calculated to be 68.7%. The probability of exceeding an ALR of 20 gpad (187.1 lphd) without applying any of the technologies discussed in this paper is calculated to be 22.2%. The probability of exceeding an ALR of 5 gpad (46.8 lphd) after applying a dipole ELL survey only was calculated to be 50.7%. The probability of exceeding an ALR of 20 gpad (187.1 lphd) after applying a dipole ELL survey only was calculated to be 6.6%. If white geomembrane is used, the probabilities are decreased to 47.0% and 4.9% for an ALR of 5 gpad (46.8 lphd) and 20 gpad (187.1 lphd), respectively. For enhanced quality control, a bare geomembrane survey should be performed after geomembrane installation, followed by a dipole survey after placement of the cover material. The probability of exceeding an ALR of 5 gpad (46.8 lphd) after applying a bare geomembrane survey and a dipole method ELL survey after placement of the cover soil was calculated to be 11.7%. The probability of exceeding an ALR of 20 gpad (187.1 lphd) after applying a bare geomembrane survey and a dipole method ELL survey after placement of the cover soil was calculated to be 0.0187%. The probability of exceeding an ALR of 5 gpad (46.8 lphd) by using white geomembrane and applying a bare geomembrane survey and a dipole method ELL survey after placement of the cover soil was calculated to be 0.546%. The probability of exceeding an ALR of 20 gpad (187.1 lphd) by using white geomembrane and applying a bare geomembrane survey and a dipole method ELL survey after placement of the cover soil was calculated to be 8.88 x 10^{-8}. The probability of exceeding either ALR is virtually zero if conductive geomembrane is used in tandem with an exposed bare geomembrane survey followed by a dipole survey after cover soil placement (if applicable). This follows from the assumption that the ELL survey is
performed per ASTM standard practices and is thus effective and that the conductive-backed geomembrane is properly installed. It has been reported for sites constructed using these specifications that leakage through the geomembrane is always attributed to faulty pipe penetrations and can be mitigated by a prefabricated pipe penetration design, which allows for spark testing the weld attaching the prefabricated pipe penetration to the geomembrane sheet. In a region of California where the regional water board prescribes double-lined ponds with essentially zero leakage through the primary geomembrane, this is the approach taken, and has been successful.

In summary, the following guidelines are provided. If a site is required to comply with an ALR of 5 gpad, it is advisable to specify either white or conductive geomembrane, in tandem with performing both a bare geomembrane survey and a dipole survey after placement of the cover soil. With the application of these technologies, there is less than a 1.0% probability of exceeding the ALR. If a site is required to comply with an ALR of 20 gpad, it is advisable to specify both a bare geomembrane survey and a dipole survey after placement of the cover soil. With these measures, there is less than a 0.1% probability of exceeding the ALR. If only a dipole survey is specified, it is more likely than not that a landfill cell will exceed an ALR of 5 gpad, while the probability of exceeding an ALR of 20 gpad can be as high as 6.6%. The belt and suspenders approach to minimizing leakage would certainly be the application of conductive-backed geomembrane and both a bare geomembrane survey during construction and a dipole survey after the cover soil placement. This approach is recommended for any sites requiring a leakage rate of less than 5 gpad. Any lesser approach to landfill construction results in higher risk that groundwater could be impacted.

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References:


