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Project Summary

Assessment of Innovative Techniques to Detect Waste Impoundment Liner Failures

M. J. Waller and J. L. Davis

Recommendations were developed for monitoring systems that will detect leaks in both new and existing landfill liner systems. Both solid and liquid impoundment sites were considered, but liquid waste impoundments were emphasized. The study was conducted in two phases. First a literature review was performed to establish the state-of-the-art in the leak detection field and to identify candidate methods. Second, a multiple-objective ranking matrix was designed and used to rank candidate techniques according to a predefined set of parameters covering pertinent technical, economic, and operational objectives.

Results indicate that no single technique or group of techniques can detect liner failure or leachate leaks with absolute certainty in either existing or planned sites. Several techniques used in combination will improve conventional water quality monitoring techniques at existing sites. In planned lined landfills, several techniques hold promise for future development.

This Project Summary was developed by EPA's Municipal Environmental Research Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

Despite the many lined impoundment and disposal sites in use throughout the country, methods to monitor the performance of liners have not been adequately developed. When liner failures occur at a site, a monitoring system should provide warning before significant environmental damage can occur. Furthermore, such a system must be capable of locating a leak precisely so that repairs can be made. Finally, the monitoring system must be nondestructive to the liner. Efforts to determine the precise locations of liner leaks may be repaid many times in terms of reduced environmental damage, and resulting costly litigation, and by reduced costs for subsequent repairs.

During the course of this program, recommendations were developed for monitoring systems that will permit effective in situ detection of leaks in both new and existing landfill liner systems. Both solid and liquid impoundment sites were considered, but emphasis was placed on liquid waste impoundments.

Because assessing liner performance and detecting leaks varies in approach and complexity between existing and planned sites, each situation was considered separately. At existing sites, any leak detection program is almost totally site-dependent because of considerations such as site area, depth of impoundment, and the presence of waste already in the landfill. Sites still in the planning stage can be tailored to a monitoring program. Thus it may be possible to emplace a leak detection system directly under a planned site before construction, or even to select a configuration for site layout that will readily lend itself to a routine monitoring program.

At the outset of this program, the primary objective for each candidate detection technique was the ability to pinpoint a landfill liner failure within a maximum area of 0.1 m^2 (1 ft^2). But because of restrictions placed on detection systems at existing sites (which in most cases will limit them to surface use), this goal was broadened to encompass any system that could feasibly improve current conventional monitoring techniques. Thus any system with the potential to detect a leachate plume before it contacts the groundwater was reviewed and evaluated. In the case of detection techniques applied to planned disposal sites, the 0.1 m^2 (1 ft^2) goal was retained. Thus plume detection at existing sites is distinguished from actual leak detection at planned sites.

Program objectives were met in two study phases. First, a literature review established a state-of-the-art in the leak detection field and then identified a list of possible candidate methods. Second, a multiple objective ranking matrix was designed and executed. This tool was used to rank candidates according to a predefined set of parameters covering pertinent technical, economic, and operational objectives. The program results in the information needed to set priorities for research and development and to allocate resources for future development of promising leak detection techniques.

Technical Considerations

To help define potential leak detection systems, the study identified certain phenomena that were expected to be associated with liner leaks. Various leak detection techniques for locating or identifying these phenomena were then selected. A review was also made of techniques that had been applied in various environments for a variety of purposes, as well as those that seemed to have conceptual application to the leak detection problem. Phenomena that might yield to leak detection techniques include the following:

- Leachate conductivity,
- Subgrade and landfill materials,
- Groundwater flow fields, and
- Liner and soil distress.

Various geophysical techniques might be applied to detecting these phenomena under favorable site conditions. Some of these techniques were selected for review and evaluation here based on the following criteria:

1. The ability to "sense" beyond their point of application to a depth greater than 30 m (33 yd),
2. The ability to be applied in situ without harming the liner,
3. The ability to improve conventional groundwater monitoring techniques at existing sites, and
4. The ability to detect a leak within 0.1 m^2 (1 ft^2) at planned sites.

Some geophysical techniques apply to both existing and planned sites, whereas others may be used in either one or the other.

The performance of a leak detection system depends on the site environment and the landfill contents. Any particular site may be subject to natural or cultural interferences that can degrade performance of the monitoring system.

Geophysical sensing techniques have inherent limitations on their ability to detect leaks, particularly at existing waste sites. Many of the geophysical methods are limited by the waste and background materials, which render surface measurements far from ideal. In many cases, geophysical methods may not be at all useful for detecting leaks under a site and may only be able to detect changed conditions over time in the unsaturated zone before a contaminant reaches the groundwater. Borehole methods improve the probability of detecting leaks because potentially they can reveal conditions under the site and do not have to sense through it. Borehole geophysical techniques are most useful when the distance between boreholes is not greater than about 30 m (33 yd), though this distance varies depending on soil type and conductivity of the host material. Most techniques fail to penetrate at greater distances.

Detecting leaks at sites that might undergo construction at some future date is not simple, but it is much less complex than for existing sites. A variety of sensing systems can be placed near the liner to detect the presence of leachate or its effects, or to evaluate the mechanical integrity of the liner itself. Ultimately, it may be advantageous to design a system combining several geophysical techniques for monitoring conditions such as the presence of leachate and the occurrence of mechanical failures.

At planned sites, the goal of detecting leaks within a 0.1-m^2 (1 ft^2) range becomes a very real possibility. Eventually it may be possible to design an inbuilt system to meet the needs of any site in terms of cost and technical precision. Thus a small site or a municipal landfill with nonhazarous wastes could use a relatively inexpensive system monitored quarterly or twice a year. For vast impoundments of hazardous liquid wastes, where the cost of liner failure would be great, it will eventually be possible to build in a continuous monitoring system with equipment and procedures designed for cell-by-cell monitoring and daily retrieval, processing, interpreting, analyzing, recording, and storing of liner performance data.

State-of-the-Art Review

Based on these technical considerations, a literature search was conducted to identify possible candidate methods being investigated in the laboratory or applied in the field. Five data bases were searched, including GeoRef, EnviroLine, Pollution Abstracts, NTIS, and DOD Documentation Center, followed by a manual search.

The literature review provided little information on actual leak detection techniques in existing or planned lined landfills. Considerably more information was available regarding the problem of leachate plume detection at existing sites. But in no case was successful leachate leak detection reported before it was detected by groundwater quality monitoring, which assumes fairly widespread contamination. This finding does not so much reflect the limitation of current geophysical leak detection techniques as it indicates the state-of-the-practice in groundwater quality monitoring. During the review, no cases were found in which techniques were actually being applied in the field to evaluate liner integrity.

All possible leak detection techniques reviewed in the course of the survey are summarized in Table 1. Techniques that have seen application in the field to detect a leachate plume include HF Pulse Techniques, electromagnetics, resitivity, and seismic techniques. Resistivity techniques appear to have had the greatest field application; these are followed by electromagnetic techniques, which are beginning to see wide application both for

Table 1. *Summary of Candidate Methods*

Technique	*What is Measured in the Ground*	*Used from*	*Range Meters*	*Areal Extent of Anomaly*	*Leachate Properties in Contrast to Host Medium Properties*	*Estimated Cost for Leak Detection*
Electric:						
Resistivity	*Resistance over a length versus horizontal and vertical position*	*Surface borehole*	*≤100's*	*Depth*	*≥2:1*	*Low*
SP	*Voltage generated by electrochemical actions*	*Surface borehole*	*≤1*	*Meters*	*≥10:1*	*Low*
Electromagnetic:						
Low Frequency Electromagnetic	*Conductivity versus horizontal and vertical position*	*Surface*	*≤100*	*Depth*	*≥2:1*	*Low*
High Frequency Electromagnetic	*Dielectric properties versus horizontal and vertical position*	*Surface borehole*	*≤10's*	*≈0.1 Depth*	*≥2:1*	*High*
Acoustic:						
Seismic	*Elastic properties versus horizontal and vertical properties*	*Surface borehole*	*≤1000's*	*≈0.5 Depth*	*≥2:1*	*Moderate*
Acoustic Emission	*Sounds emitted from fluid flow in soils*	*Borehole*	*?*	--	*Rapid flow in large pores*	*Moderate*
For Planned Sites:						
TDR Grid	*Dielectric properties versus position on transmission line*	*Parallel wires in one direction*	*≤100's along line*	*≈Spacing of the line*	*≥2:1*	*High*
DC Grid	*Change of resistance of a wire due to corrosion caused by leak*	*Parallel wires in two directions*	*≤1000's*	*≈Size of grid spacing*	--	*High*

leachate plume identification and areal site surveys. A number of other techniques were identified that are either conceptually applicable or have seen field use in related applications such as petroleum exploration or extensive site evaluations.

Multiple Objective Ranking Matrix

Finally, a multiple objective ranking matrix was structured to compare the candidate methodologies with regard to a defined set of criteria. The criteria defined earlier for geophysical techniques were included. Techniques were eliminated from the matrix if they were not identified in the literature survey as having at least the potential for producing satisfactory results. Also, only techniques that posed no significant risk factors to the operators or to the environment were considered. Thus any technique that could not possibly work without substantial penetration of the dumpsite and the liner was rejected from further consideration. This limitation severely reduces the number of techniques that can be used at existing sites and also the probability of success in detecting leaks under the waste site.

The completed matrix evaluates each technique on the following parameters:

- Technical factors (such as range, resolution, lateral extent, flow direction, etc.)
- Sensitivity (soil type, waste type, and cultural noise)
- Data reduction (data acquisition time, interpretation time, etc.)
- Impacts (safety, site disruption, and site safety and liability)
- Economic factors (capital cost, installation cost, etc.)
- System capabilities (operator skill, portability, survivability, and availability)

Since some of the parameters are more vital for success than others, a weighted scale was devised. The weighted curve applied to the matrix parameters appears in Figure 1. All the values are given on a relative scale of 1 to 10.

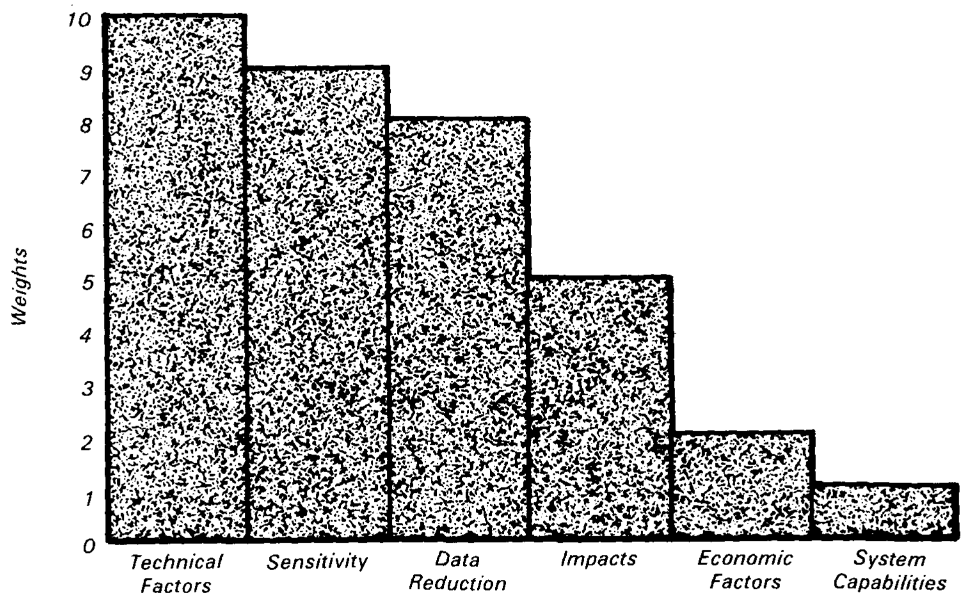

Figure 1. *Weighting curve applied to matrix parameters.*

Matrix Results

Matrix results are summarized and displayed in Tables 2 and 3. The average values for all parameters tend to group around 6.7, except for the two grid techniques, which are about 7.8. Clearly, no significant variation exists among the techniques. Considering the conditions under which methodologies were included in the matrix, this consistency is neither surprising nor unreasonable.

All of the techniques are very sensitive to the soil and waste type, with an average sensitivity value of about 4. This value indicates that probably none of the techniques will work in certain situations found in a typical waste dumpsite. The two grid techniques are less sensitive to the site conditions because they are only feasible for planned sites where optimum conditions can be selected.

All the values in the impacts group have very high ratings because the only techniques that were considered were those that had no significant risk factors for the operators or the waste dumpsite. Lower values were given if the technique required the use of holes for short rods on the site or if boreholes near it were necessary. Obviously, if any risk exists for the operator or the site, the technique is impractical. This limitation severely reduces the number of techniques that can be used, and with it the probability of success for detecting leaks under the waste site.

All of the values in the technical factors group for existing sites tend to be about 6.7. This result appears to be discouraging at first, and it certainly indicates the difficulty of using any of the geophysical or other techniques for monitoring or detecting leaks from an existing waste dumpsite. Clearly no single technique stands out as superior for detecting leaks in existing sites. This matrix makes it abundantly clear that a composite of techniques must be used to solve this complex problem, particularly in existing sites. Nearly all the techniques are sensitive to the various electrical properties of a leachate in the host medium. The exceptions are the seismic and acoustic mission techniques, which are sensitive to the elastic properties and density changes caused by a leak or the acoustic emission from the fluid flow from a leak. A composite geophysical survey can be designed to monitor a complex of material properties, thus enhancing confidence in the survey results.

Note that techniques evaluated for planned sites received overall higher scores, This result reflects the reality of the problem described in both the literature survey and the matrix results. Landfill liner integrity and performance monitoring programs will be easier to design when they are included and planned for at the conception of a total waste disposal program. Note that despite the problems associated with geophysical techniques, they still hold greater promise of success under optimum site conditions than do the conventional monitoring methods. Leak detection at existing lined sites is and will continue to be more problematic. But skillful use of the techniques described here should often lead to leak detection before extensive groundwater contamination occurs.

Table 2. *Applied Methods Summary of Ranking Matrix*

Technique	*Technical Factors*	*Sensitivity*	*Data Reduction*	*Impacts*	*Economic Factors*	*System Capabilities*	*Average of All Parameters*
Significance of Values	±1	±1.7	±1.7	±1.7	±1.7	±1.7	±1.5
Mutual Inductance	6.2	4.3	8.4	10.0	10.0	10.0	7.1
VHF Wave Tilt	6.1	3.7	7.4	10.0	10.0	10.0	6.7
HF Pulse Surface	7.2	4.7	7.5	10.0	7.6	6.8	7.1
Resistivity Schlumberger/Wenner	6.9	4.0	6.3	9.4	8.5	8.6	6.6
Resistivity Pole-dipole	7.1	4.0	6.3	9.4	8.2	7.9	6.5
SP Surface	5.3	3.5	8.4	10.0	10.0	9.2	6.6
Seismic Surface	7.5	4.0	6.7	10.0	8.6	9.9	6.9

Table 3. *R&D Methods Summary of Ranking Matrix*

Technique	Technical Factors	Sensitivity	Data Reduction	Impacts	Economic Factors	System Capabilities	Average of All Parameters
Significance of Values	±1	±1.7	±1.7	±1.7	±1.7	±1.7	±1.5
Seismic Surface to Borehole	7.4	4.0	6.7	9.2	7.7	9.9	6.7
Seismic Borehole to Borehole	7.3	4.7	6.7	9.2	7.7	9.9	6.8
HF Pulse Borehole to Borehole	7.2	4.7	7.5	10.0	7.2	7.7	7.1
Resistivity Borehole to Borehole	6.5	4.4	6.8	10.0	8.7	8.0	6.8
Resistivity Borehole	5.6	4.3	8.1	9.8	8.8	8.6	6.7
Induced Polarization	6.6	4.0	6.7	9.4	7.4	8.3	6.4
CW/HF Borehole to Borehole	6.8	4.0	5.0	10.0	6.1	5.9	6.1
CW/HF Surface	6.2	4.0	5.1	10.0	6.6	7.2	6.0
SP Borehole	4.8	3.8	8.4	9.5	9.5	9.2	6.4
Planned Sites							
TDR Grid	8.5	6.7	6.8	10.0	7.9	8.0	7.8
DC Grid	7.2	6.7	8.1	10.0	8.6	8.3	7.8
Acoustic Emission	6.1	4.5	9.8	6.8	9.7	8.7	6.8

Conclusions and Recommendations

Results of the survey and the ranking matrix indicate that no single technique currently exists that is applicable in all or even many situations, particularly in existing sites. Each geophysical technique has both theoretical and site-specific limitations. Further research is needed to demonstrate the advantages and limitations of a number of the candidate methods in various dumpsite configurations. Such investigations should include both solid and liquid sites in various soil types, and they should include an array of techniques used in a composite mode. The optimum configuration for planned sites that are to be monitored may be long trenches up to 30 m (33 yd) wide. This shape should reduce the range limitations that exist with geophysical monitoring techniques.

Though no single technique or group of techniques has been identified as a solution to the leak detection problem, the group of techniques reviewed and evaluated here can be applied systematically and synergistically to existing lined sites with the eventual hope of detecting leachate contamination before damage occurs to the groundwater. Cetainly such techniques should be applied routinely in conjunction with water quality sampling at any site identified as a potential problem. In the case of planned sites, several solutions hold promise for future development.

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M. J. Waller and J. L. Davis are with EarthTech Research Corporation, Baltimore, MD 21227.
***Carlton C. Wiles** is the EPA Project Officer (see below).*
The complete report, entitled "Assessment of Innovative Techniques to Detect Waste Impoundment Liner Failures," (Order No. PB 84-157 858; Cost: $14.50, subject to change) will be available only from:
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650
The EPA Project Officer can be contacted at:
Municipal Environmental Research Laboratory
U.S. Environmental Protection Agency
Cincinnati, OH 45268