Case Study Abstract

Trail Road Landfill
Nepean, Ontario, Canada

Site Name and Location: Trail Road Landfill Nepean, Ontario, Canada	**Geophysical Technologies:** Natural gamma Magnetometry Electrical conductivity Density Temperature	**CERCLIS #** Not applicable
Period of Site Operation: Early 1980's to the present **Operable Unit:** Not applicable		**Current Site Activities:** The Nepean Landfill is capped and closed. Stages 1and 2 of the Trail Road Landfill are capped and closed. Stage 3 is currently being filled and stage 4 is ready to be opened. Stages 3 and four have leachate collection systems. In general, groundwater is monitored 3 - 4 times a year for chemical contamination.
Point of Contact: Keith Watson, 613-838-2799 Darin Abbey, 604-291-5429 C. Jonathan Mwenifumbo, 613-996-2312	**Geological Setting:** A complex mixture of sand, gravels, and silt overlying a lacustrine clay plain. Limestone bedrock underlies a glacial till deposit of sand and gravel which lies under a silty clay layer. There is a shallow aquifer which discharges into a deep aquifer.	**Technology Demonstrator:** Darin Abbey, Carleton University, Ottawa, Canada,

Purpose of Investigation:
The overall goal of this investigation was to show that leachate plume delineation could be accomplished through interpreting data from a full suite of geophysical logs.

Number of Images/Profiles Generated During Investigation:
Eight composite profiles illustrating the results of the logs from each of the above mentioned technologies.

Results:
The use of geophysical measurements from boreholes can provide a continuous vertical profile of the geology and hydrogeology. This information can be used to understand the factors controlling the groundwater composition, and ultimately leachate movement in the subsurface. The geophysical techniques overcome the traditional monitoring limitation of fixed vertical sampling positions for chemical analytes.

EXECUTIVE SUMMARY

The Trail Road and Nepean Landfill sites are located within the Region of Ottawa-Carleton, Canada, with a population of 750,000. The site, approximately 500 acres, is surrounded by light industry, and farmland. The Nepean Landfill began operation in the early 1960s and accepted waste until the early 1980s when it was deemed nearly full and the Trail Road Landfill was opened. The Trail Road Landfill is currently serving as a municipal sanitary landfill accepting non-hazardous waste including residential garbage, construction, commercial, institutional, and light industrial waste.

Leachate, believed to originate from the unlined Nepean Landfill and the stages 1 and 2 of the Trail Road Landfill, has been detected in the groundwater below the site. The leachate consists of a complex mixture of organic and inorganic constituents as well as elevated levels of calcium, magnesium, chloride, sulphate, potassium, ammonia, other nitrogen compounds, other dissolved organic carbons, phenols, and iron.

The landfill site is positioned on a glacial outwash plain which has a complex mixture of sands, gravels, cobbles, clays, and silt. The surface soil consists of a discontinuous dense layer of silt and clay (approximately two meters) beneath which is a layer of sand and gravel which overlies a limestone bedrock forming a deep aquifer, present at a depth of 10 to 30 meters. A clay layer is present beneath part of the Trail Road Landfill site. The clay layer separates the sand and gravel ridge into an upper and lower aquifer.

A geophysical investigation was conducted at the landfill to demonstrate an innovative method for monitoring a landfill leachate plume. The information contained in this report was extracted from the interpretive report of the investigation. Six different geophysical methods were combined in borehole applications to collect the geophysical data for this investigation. The six methods were: natural gamma, gamma-gamma, total magnetic and magnetic susceptibility, electrical conductivity and temperature. Geophysical logs were developed in eight existing monitoring wells.

The geophysical logs correlated well with existing lithologic logs, and identified the presence of a surficial clay layer and a perched aquifer on that layer where leachate may collect. Logs of the deeper aquifer generally showed little evidence of contamination, with the exception of one well, in which a significant anomaly was detected. The conductivity and temperature logs were interpreted to show the presence of leachate contamination in this one well.

Lessons learned at the Trail Road Landfill site were that the major advantage of geophysical logs over traditional sampling techniques is that they provide a continuous representation of the subsurface conditions. The logs can provide a measurement of total dissolved solids as a proxy for ions in water. A major failing of the traditional sampling approach is the fixed vertical screen position. Although actual chemical identification cannot be done by geophysical methods, groundwater with anomalously high conductivities would indicate the need for chemical analyses. These examples show the need for conductivity data to be interpreted in conjunction with other geophysical measurements to illustrate the anomaly in conductivity at a certain depth within a well.

SITE INFORMATION

Identifying Information

Trail Road Landfill
Environment and Transportation Department
Solid Waste Division
Region of Ottawa-Carleton
4475 Trail Road, R.R. #2
Richmond, Ontario, KOA 220
CANADA

Background

Physical Description: The Trail Road Sanitary Landfill site, which includes the Nepean and Trail Road landfills, is located within the Region of Ottawa-Carleton, Canada, with a population of 750,000. The site, approximately 500 acres, is surrounded by light industry and farmland. The terrain consists of grasslands and light forests. Running tangent to the eastern side of Trail Road Landfill is Highway 416. Likewise the southern side is bordered by a lesser road, Trail Road, which also borders the northeastern side of the Nepean Landfill (which is located southwest of the Trail Road Landfill). Moodie Drive runs along the western boundary of the Nepean Landfill. The south end of the entire site is bordered by Barnsdale Road and Cambrian Road runs northeast through the northern boundary of the site, but is not immediately adjacent to the landfills (see Figure 1)[1, 2, 3]. South of the Trail Road Landfill, there is a sand and gravel ridge which serves as a divide for surface water runoff. Surface water flows from this ridge to either the north or the south. For the Trail Road Landfill, the general site surface water flow is in a north to northeasterly direction but is interrupted by site excavations.

The Nepean Landfill began operation in the early 1960s and accepted all landfill waste until the early 1980s when it was deemed nearly full and the Trail Road Landfill was opened. Thereafter, until is was capped in 1993, only construction waste was disposed of in the Nepean Landfill. This landfill is not lined but it is capped with a polyethylene liner and soil [1].

Site Use: The Trail Road Landfill is currently serving as a municipal sanitary landfill accepting solid non-hazardous waste including residential garbage, construction, commercial, institutional, and light industrial waste. The Trail Road Landfill was opened in 1980 and has been continuously operated in stages (see Figure 1). The first two stages are closed and capped with polyethylene and soil but are not lined and do not have leachate collection systems. Stage 3 was constructed with a 60 centimeter (cm)- thick competent clay and a high density polyethylene liner. The third stage, which opened in 1991, is nearly full, and will be capped with a polyethylene liner and soil. Stages 3 and 4 have leachate collection systems. Stage 4 is not yet operational [1, 2].

SITE INFORMATION

Release/Investigation History: Leachate, believed to originate from the unlined Nepean Landfill and the stages 1 and 2 of the Trail Road Landfill, has been detected in the groundwater below the site. The leachate consists of a complex mixture of organic and inorganic constituents as well as elevated levels of calcium, magnesium, chloride, sulphate, potassium, ammonia, other nitrogen compounds, other dissolved organic carbons, phenols, and iron [3].

The groundwater is monitored on a variable basis. All wells are monitored up to 3 times a year for indicators including chloride, boron, bromide, BOD, DOC, and iron [1, 2].

Regulatory Context: Not Applicable

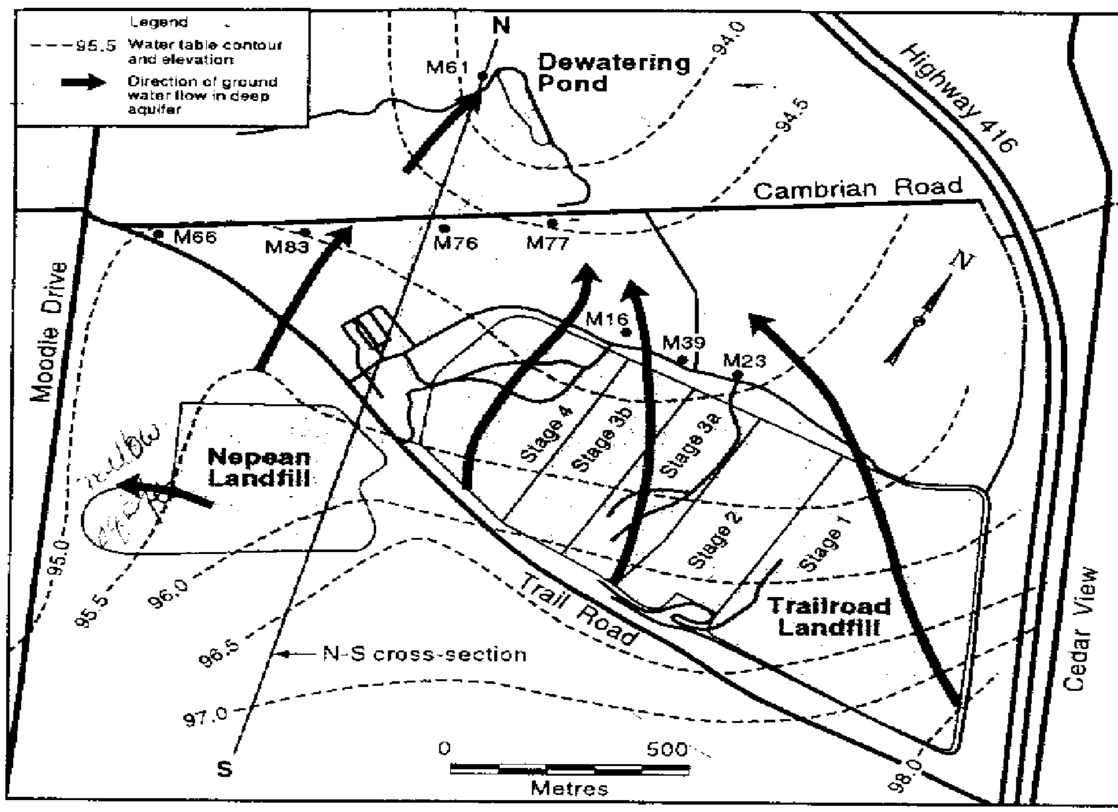

Figure 1: Site Map [3] [Poor Quality Original]

SITE INFORMATION

Site Logistics/Contacts

Site Contact:
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Regional Municipality of Ottawa-Carleton
4475 Trail Road, R.R. #2
Richmond, Ontario, KOA 220
(613) 838-2799

Geophysical Investigator:
Geological Survey of Canada
Mineral Resources Division
601 Booth Street
Ottawa, Ontario, K1A 0E8
CANADA

MEDIA AND CONTAMINANTS

Matrix Identification [3, 5]

Type of Matrix Sampled and Analyzed: Subsurface clays, cobbles, sands, and gravels

Site Geology/Stratigraphy [3, 5]

The landfill site is positioned on a glacial outwash plain which has a complex mixture of sands, gravels, cobbles, clays, and silt (Figure 2). A discontinuous dense layer of silt and clay (approximately two meters in thickness) separates two aquifers. The silt and clay layer is complete under the Nepean Landfill but not under all of the Trail Road Landfill and acts as an aquitard to a perched aquifer.

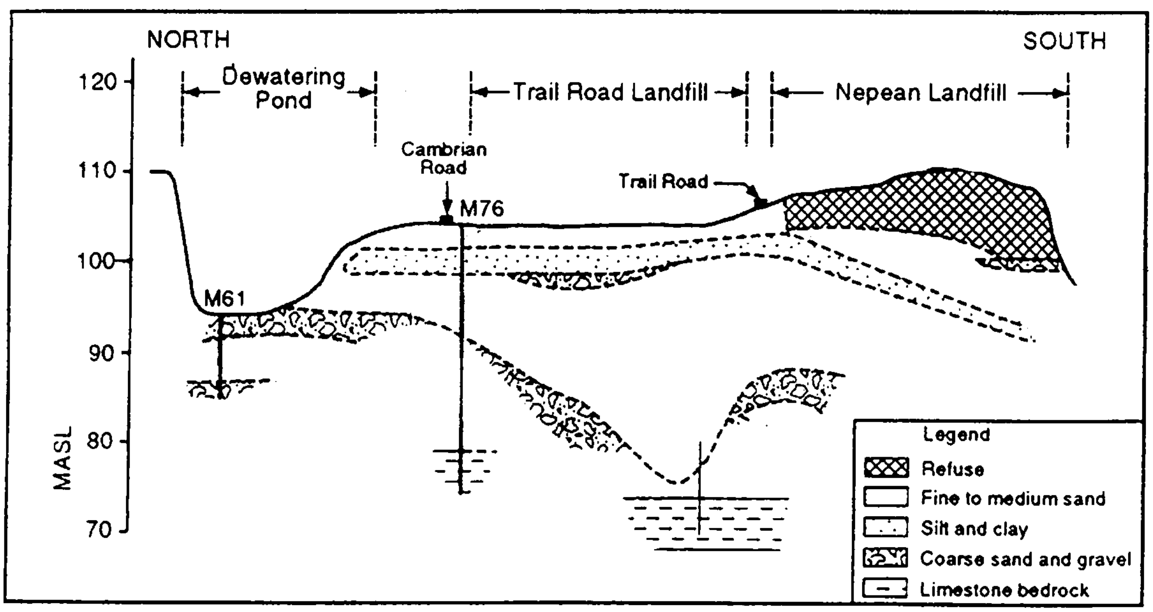

Figure 2: North to South Cross Section of Site [3]

Approximately 500 meters from the northern boundary of Trail Road Landfill on the north side

MEDIA AND CONTAMINANTS

of Cambrian Road is a large de-watering pond used to catch the local groundwater discharge. The pond water eventually discharges into the Jock River which is located approximately 1 km to the north. Southwest of Trail Road is the Nepean Landfill. Surface water runoff flows in a south to southwesterly directly from Trail Road [2, 3].

There are two aquifers, separated by clay, underlying the entire site. A shallow sand aquifer flows in a north to northeasterly direction under the Trail Road Landfill. Surface water penetration creates a shallow groundwater flow in a south to southwesterly direction under the Nepean Landfill. The deep aquifer, located in a layer of bedrock at a depth ranging from 10-30 meters flows in a south to north direction[2].

Contaminant Characterization

Primary Contaminant Groups: The contaminants consists of chemicals within groundwater from landfill leachate. The leachate consists of a complex mixture of organic and inorganic constituents, and is produced by the percolation of water through the waste, which dissolves and suspends some of the chemicals by chemical reaction. The leachate has elevated concentrations of calcium, magnesium, chloride, sulphate, potassium, ammonia, other nitrogen compounds, other dissolved organic carbons, phenols, and iron [3]. The leachate has characteristically high conductivity, hardness, alkalinity, and total dissolved solids (TDS). Exothermic reactions within the landfill can cause elevated groundwater temperatures.

Matrix Characteristics Affecting Characterization Cost or Performance [3, 5]

The density readings taken for sediments above the water table contained a low bias because the density calibration logs assumed a water-filled well. No other characteristics of this site affected the performance of the geophysical technologies.

GEOPHYSICAL INVESTIGATION PROCESS

Investigation Goals [3, 5]

The purpose of this study was to show that by measuring the physical properties of the subsurface, borehole geophysics can refine the hydrogeological interpretation of the landfill site. The interpretation of gamma ray, density, magnetic susceptibility, total magnetic field, electrical conductivity and temperature logs can serve to refine the understanding of the underlying geology and the existence of a leachate plume. Borehole geophysics can also be used to delineate areas of leachate contamination with greater efficiency than sampling and chemical analysis of analytes.

Geophysical Methods [3, 5]

Six different geophysical methods were combined in eight borehole applications to collect the geophysical data for this investigation. The six methods were: natural gamma, gamma-gamma, total magnetic and magnetic susceptibility, electrical conductivity, and temperature.

Gamma Ray and Density

The natural gamma probe detects variation in natural radioactivity of the material surrounding the well. In sediments, ^{40}K is the principal source of natural gamma radiation which is present in clay minerals such as illite and montimorilloninte. The presence of clay layers can be detected by an increase in gamma emissions. Clays, with their low permeability can have the effect of precluding the vertical flow of groundwater and leachate. The technique can be used to determine accurate boundaries between sediment layers, sequences in grain size fining or coarsening which are generally much more accurate than lithologic logs developed by hand.
A gamma-gamma method was used to estimate the density of the geologic units. The density is determined by reading the "scatter back" of a gamma ray emitted from a source crystal containing Cobalt 60 on the probe. The application of density measurements to hydrogeology relies upon the assumption that the lower the density of the formation the greater the porosity and therefore potential for groundwater flow. It can be predicted that the areas within the sands, gravels and cobbles with lower densities will likely have the most water flow, while the limestone bedrock and clays having the least water flow. The gamma data were collected using the IFG Corporation Logging System, utilizing a dual-purpose 512 channel spectral natural gamma and gamma-gamma density probe

Magnetometry (Total and Susceptibility)

Magnetic susceptibility provides a direct measure of the presence of magnetic sediments. Most unconsolidated sediments have little or no magnetic signature. Thus a higher magnetic susceptibility indicates the presence of iron rich mafic sand, gravel or cobbles. The use of both total field magnetic and magnetic susceptibility logs allow for the detection of ferromagnetic minerals such as pyrite (FeS_2). The measurement of the three orthogonal magnetic field components, which represent the local value of the normal ambient field of the Earth as modified by the remnant magnetization of adjacent sediments. The identification of such magnetic zones indicates layers that may have higher permeabilities, and, therefore, may be potential flow paths for groundwater. Total magnetic field, magnetic susceptibility and temperature were measured using the BMP–04 multi-parameter probe containing a 3 orthogonal fluxgate magnetometer.

Electrical Conductivity

Perhaps the most useful geophysical measurement for detecting groundwater contamination is electrical conductivity. This geophysical method measures the conductivity of subsurface media by generating a current between two electrodes and measuring the potential difference. Electrical conductivity is measured in units of milliSeimens per meter (mS/m). Because soil is a poor

GEOPHYSICAL FINDINGS

conductor, most electric current flow occurs in the soil water when ions such calcium, magnesium, potassium, sodium, dissolved iron, chloride and sulphates are present. Leachate from a landfill typically contains large amounts of these type of ions. Since natural waters can contain many different ions, both ionic and uncharged, electrical conductivity cannot be used to make accurate estimates of specific ion concentrations. A linear relationship between total dissolved solids (TDS) and the electrical conductivity of groundwater exists.

Conductivity measurements were taken using the Geonics EM-39 system consisting of one transmitter coil and one receiver coil operating at 39.2 kHz.

Temperature

Temperature readings can indicate at what depths there is flowing groundwater as well as aid in determining location of exothermic chemical reactions from contamination. This information can be used to characterize the extent of leachate plumes and potential areas of groundwater contamination. The temperature is measured by a thermistor is cable of detecting temperature variations of +/- 0.001 °C. Characteristic water temperature profiles can be amplified using calculated temperature gradient logs to compare with measured temperatures. The temperature-depth profile can be modified by water flow, or exothermic chemical reactions in the leachate.

GEOPHYSICAL FINDINGS

Technology Calibration [3]

Geophysical methods often include calibration of the measurement instrument to a quantitative/ semi-quantitative standard. Natural gamma probes are calibrated to models of known ^{40}K radioactivity. Density is calibrated to models with a known density. Conductivity was calibrated to the ambient conductivity of monitoring wells in which chemical sampling had found no contamination. A background conductivity level of approximately 11 mS/m was established. Temperature was calibrated to the ambient temperature of an upgradient background well. Total magnetic field and magnetic susceptibility readings were zeroed by holding the probe at least 1.5 m above the ground and away from any metal objects.

Investigation Results [3, 5]

Each of eight existing monitoring wells were used in the geophysical investigation. Four of the wells, M66, M83, M76, and M77, are located downgradient from the landfills. The wells are arranged along a line perpendicular to the groundwater flow between the landfills and the quarry (see Figure 1). Three others are located at the downgradient edges of Trail Road Landfill. The two sets of monitoring wells are well placed to monitor contaminant migration from the landfill toward the quarry.

The geophysical logs taken in the four wells located midway between the landfills and the quarry are shown in Figures 3 to 7. These four wells were selected for use in this analysis because of their location across the groundwater migration pathway. If leachate contamination were migrating to the quarry, it would be detected in one or more of these four wells.

The use of multiple geophysical methods allows the results of one method to be used to validate the findings of another. For example, in each of the four lithologic logs shown, a clay layer is present at shallow depths, i.e. less than 5 meters. In each case, the results of the gamma and the spectral gamma-gamma logs confirm this finding, as indicated by the sharp peak in counts per second at similar depths. The results of the density logs taken at depths above the water table are not valid, as the instrument calibration assumed a water-filled well. The magnetic logs, both total and susceptibility, are used to detect a coarsening in the subsurface materials, resulting from the presence of gravels and cobbles. Such coarse layers may be potential migration pathways for groundwater. In Figures 3 to 7, the magnetic logs do not indicate such layers at the depth at

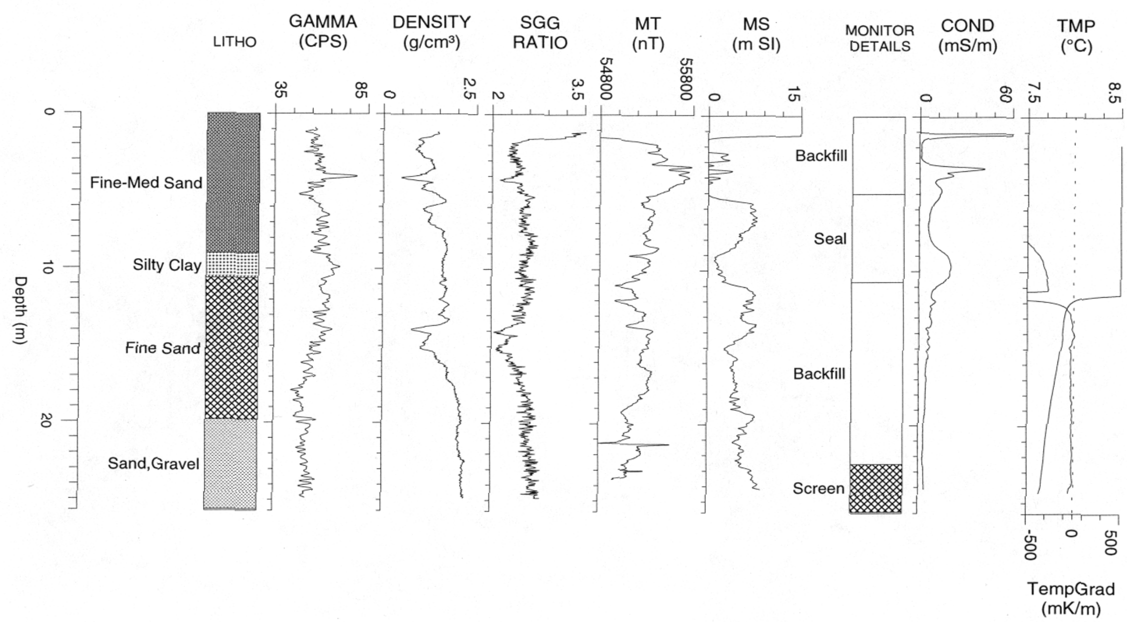

Figure 3: Geophysical Log for Well M66

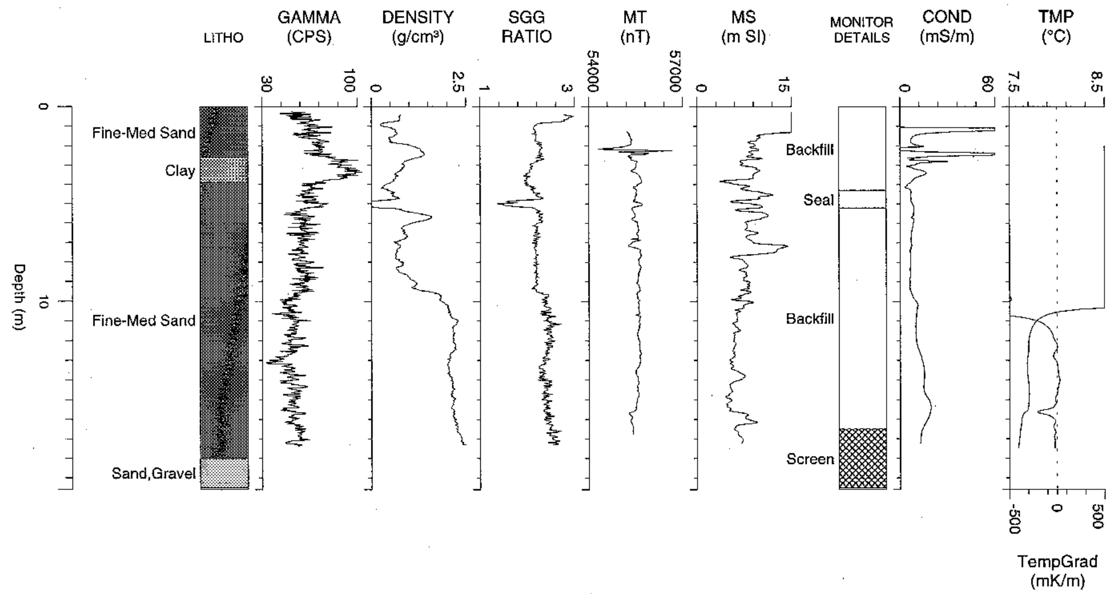

Figure 4: Geophysical Log for Well M83 [5]

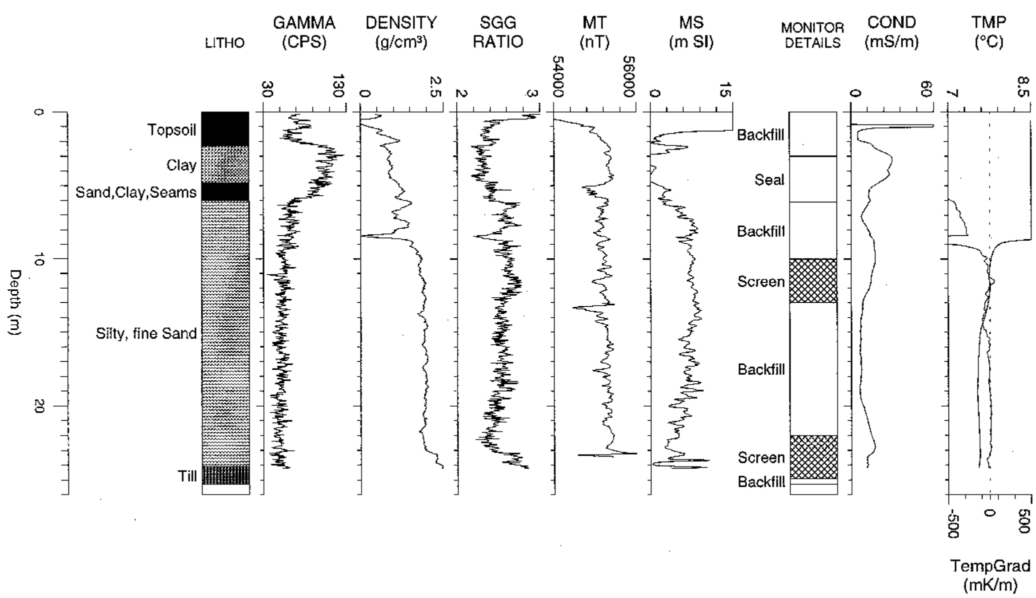

Figure 5: Geophysical Log for Well M76 [5]

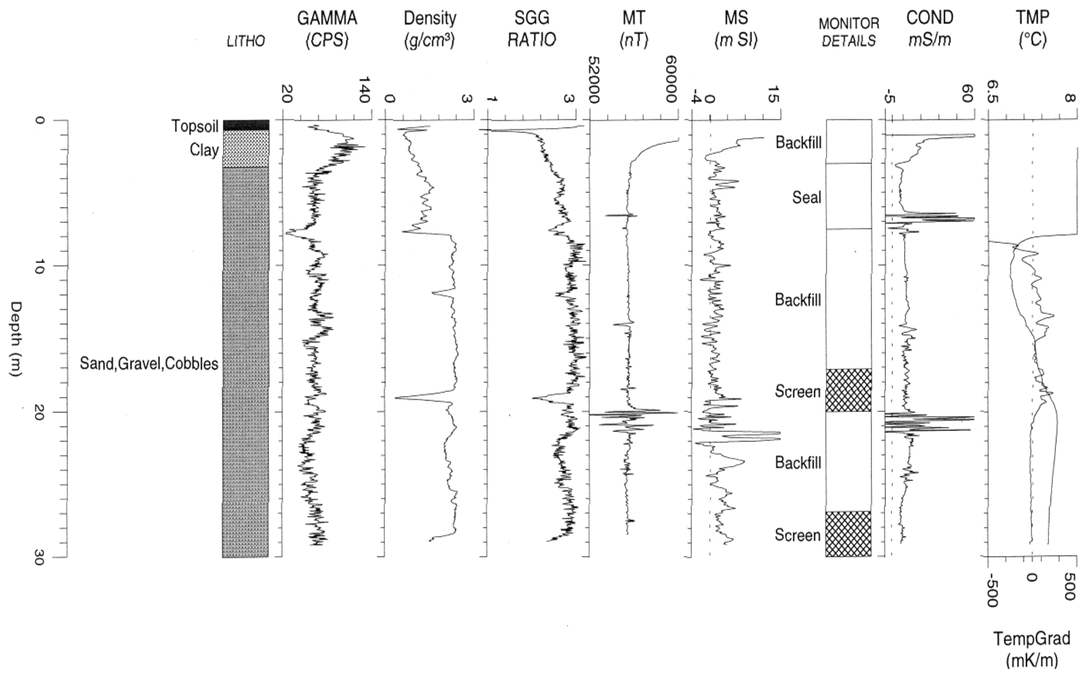

Figure 6: Geophysical Log for Well M77

which the clay layer is encountered. By inference, this result can be taken as a validation of the lithologic findings. Electrical conductivity logs also confirm the presence of the clay layer at the depths shown in the lithologic logs. The peak in conductivity measurements shows a distinct peak at depths at which clay is present in the lithologic log and lower values where sandy soils predominate. Conductivity and temperature logs were taken to identify the presence of leachate contamination. An examination of these logs in the four wells does suggest that in only one well, M77, may such contamination be present. The conductivity log for M77 clearly shows two anomalous spikes at depths of approximately eight and 20 meters. The first peak occurs at the water table. While some conductivity increase can be expected as the probe comes into contact with water, the reading in this well may also indicate the presence of contaminated groundwater. The second peak in conductivity occurs at approximately 20 meters. At this depth, there is no indication in the gamma or lithologic logs of clay lenses that might cause such a peak in conductivity measurements. Density and magnetic logs, indicators of porosity, both show the presence of a porous layer which may be controlling groundwater flow at this depth. The temperature log at this depth shows a marked increase in temperature, rising to a maximum of 7.7 °C, that may be due to the presence of exothermic reactions occurring in the groundwater. These findings, taken together, suggest the presence of leachate contamination at this depth.

GEOPHYSICAL FINDINGS

Results Validation [3, 5]

Chemical sampling at the landfill, as part of the on-going monitoring effort, confirmed the findings of the geophysical investigation.

LESSONS LEARNED

Lessons learned at the Trail Road Landfill site were the following:

- Geophysical logs provided a continuous representation of the subsurface conditions which was a major advantage over the fixed depth readings obtained with traditional monitoring methods. The information obtained using fixed-depth sampling was relevant only at the depth the readings were taken. Geophysical logs provided continuous readings for the full depth of the borehole.

- The geophysical logs successfully delineated the leachate plume migrating from the landfill as regions of groundwater with anomalously high electrical conductivity. Chemical analyses conducted as part of the on-going monitoring program at the landfill confirmed the presence of leachate contamination moving from the landfill.

- The use of several, complementary, geophysical methods provided a cross-validation between the results of various methods. This cross-validation increases the confidence with which the geophysical data are interpreted.

REFERENCES

1. Personal Communication with Dave Ryan, Trail Road Landfill Engineer, Region of Ottawa-Carleton, Ontario, Canada. December 1, 1998.

2. Personal Communication with Keith Watson, Site Manager, Region of Ottawa-Carleton, Ontario, Canada. November 25, 1998.

3. Abbey, Daron G., et al. *The Application of Borehole Geophysics to the Delineation of Leachate Contamination at the Trail Road Landfill site: Nepean, Ontario.* Proceedings of the Symposium on the Application of Geophysics to Engineering and Environmental Problems (SAGEEP) 1998.

4. Personal Communication with Barbara Elliot, Borehole Geophysical Scientist, Geological Survey of Canada, Mineral Resources Division, Borehole Geophysics Section, Ottawa, Ontario, Canada. December 14, 1998.

5. Abbey, Daron G. *The Application of Borehole Geophysics to the Delineation of Leachate Contamination at the Trail Road Landfill site: Nepean, Ontario.* Carleton University, Ottawa, Ontario. December 1995.

6. Personal Communication with John Stowell of Mt. Sopris Instruments. Golden, CO. December 1, 1998.

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