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Treatment of Landfill Leachate by Spray Irrigation—An Overview of Research Results from Ontario, Canada. I. Site Hydrology

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The Muskoka Lakes municipal solid waste (MSW) landfill site near Port Carling, Ontario is the only known location in the province to have installed a relatively large-scale leachate collection and spray irrigation disposal facility. The system at the present time consists of i) a collection trench which intercepts leachate flow from a contaminated aquifer emanating from the landfill, ii) two settling lagoons where some limited aeration treatment is achieved, and iii) a network of 72 spray irrigation nozzles distributing partially treated leachate over three areas totalling approximately 4.3 ha in a mixed hardwood forest (Figure 1). Chemical constituents and properties of the leachate are presented in Tables 1 and 2.

At current rates, 2.4×10^7 ℓ or more of leachate will be generated and collected annually at this landfill for decades to come. Given the maximum current disposal capacity of about 2.0×10^7 ℓ yr^{-1} between April and October at this site (i.e. assuming that spraying is not abated due to rainfall), even the current scale of operations may prove inadequate over the long-term. Little published research exists on leachate disposal and treatment through irrigation on land which is applicable to Ontario soil and climatic conditions, since most such research has originated in the United States (Menser et al. 1978) and the United Kingdom (Harrington and Maris 1986). This would suggest that unforeseen problems may arise in the future which would preclude leachate application at the present rates and reduce the efficiency and acceptability of this disposal method in both economic and environmental terms.

A study was initiated in 1986 to evaluate leachate spray irrigation as a cost-effective, environmentally-sound, and long-term solution to the Muskoka Lakes sanitary landfill seepage problem. This paper, and the companion paper which follows, report on the results of that study which pertain to site hydrology and soil quality for leachate disposal. Results on stresses imposed on various ecosystem components with leachate exposure are reported elsewhere (Gordon et al. 1988 1989a 1989b).

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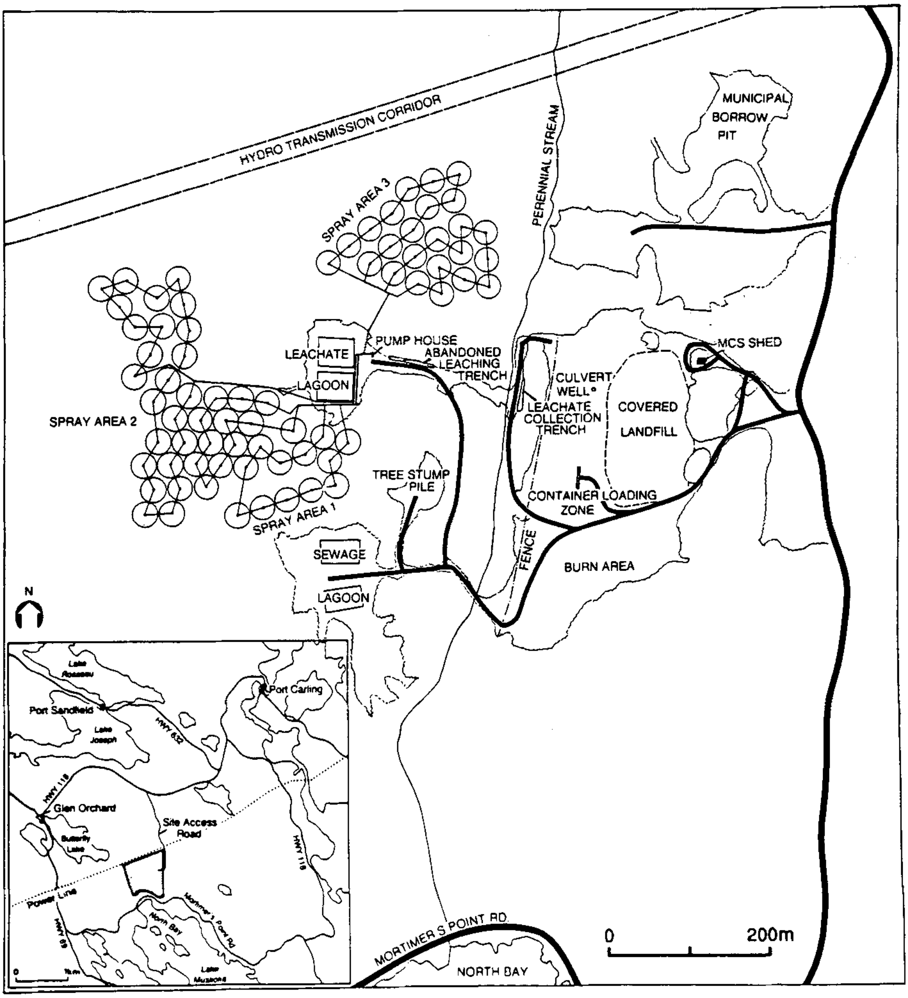

Figure 1. The Muskoka Lakes municipal solid waste landfill site. The landfill site is located near Port Carling on Lots 21, 22 and 23, Concession 1, Medora Ward, Township of Muskoka Lakes, District Municipality of Muskoka, Ont.

Table 1. Muskoka Lakes untreated landfill leachate constituents: Volatile organics (1983-86).

Leachate Constituents	April 1983[1] Collection Trench	April 1983[1] Leaching Trench	July 1986[1] Culvert Well	July 1986[1] Collection Trench	July 1986[1] Lagoon	July 1986[1] Spray Nozzle	July 1986[2] Culvert Well
	$\mu g\ \ell^{-1}$						
toluene	1229	854	1900	2000	106	138	560
dichloromethane	350	270	-	-	-	-	-
methylene chloride	-	-	-	-	-	-	100
total xylene	-	-	100	42	0	6	6
meta-xylene	32	21	-	-	-	-	-
ortho-xylene	17	14	62	25	8	6	-
1,1 - dichloroethane	-	-	23	0	0	0	<1.0
ethylbenzene	17	11	54	23	0	0	15
benzene	9	6	17	8	0	0	4.2
trichloroethylene	6	4	18	0	0	0	13
tetrachloroethylene	-	-	0	0	0	0	2.5
chloroform	2	2	3	0	0	0	2
total organic carbon	-	-	-	-	-	-	1583 $mg\ \ell^{-1}$
total organic halogens	-	-	-	-	-	-	13.9 $\mu g\ \ell^{-1}$
total phenolics	-	-	-	-	-	-	0.136 $mg\ \ell^{-1}$

[1] Testing by Ontario Ministry of the Environment, Toronto, Ontario
[2] Testing by Zenon Environmental Inc., Burlington, Ontario
\- not tested

RESULTS AND DISCUSSION

A major research effort was directed during the 1986 field season toward identifying means of reducing the total volume of leachate being generated and handled at the Muskoka Lakes site due to the recent expansion of the actual spray area in 1985 and the uncertainty regarding the long-term attenuation capacity of the local deltaic sands for land disposal.

Of paramount concern was the ability of the existing silty clay/silty clay loam textured landfill surface liner to adequately reduce surface infiltration of incident precipitation. A grid inventory performed of the surface liner indicated that the clay material was both discontinuous and thin (generally less than 10 cm), where present. The incomplete sealing of the landfill was in

Table 2. Muskoka Lakes untreated landfill leachate constituents: Standard water quality indices (1978-86).

Leachate Constituents	Range over 1978-1980[1]	Sept. 1983[2] Sump	Sept. 1983[2] Lagoon	July 1986[2] Culvert Well	July 1986[2] Collection Trench	July 1986[2] Lagoon	July 1986[2] Discharge to Lake
Plant Macronutrients							
N-total Kjeldahl	3-81	33	33	92	39	33	3
$N\text{-}NH_4$	-	30	31	91	37	33	2
$N\text{-}NO_3$	-	<0.2	0.2	0.75	0.3	<0.2	<0.15
Nitrite	-	-	-	0.55	<0.03	<0.03	<0.03
Phosphate	-	-	-	0.8	0.2	0.2	0.2
Phosphorus	-	0.2	0.2	0.4	<0.5	<0.05	<0.02
Plant Micronutrients							
Cl	9-147	31	31	83	34	33	7
Fe	11-654	49	11	n.a.	n.a.	n.a.	n.a.
Other Indices							
pH	-	6.05	6.28	6.17	5.76	6.02	7.29
Hardness (as $CaCO_3$)	45-583	295	278	18125	327	301.5	73.5
Alkalinity (as $CaCO_3$)	33-988	350	26	1172	354	312	61
Conductivity	-	1071	868	3440	1122	1009	218
BOD	101-2350	900	1150	3920	1090	892	68
COD	159-4033	-	1180	5170	1180	1600	108
TOC (total organic carbon)	-	-	-	1580	-	-	-
DOC (dissolved organic C)	-	370	378	1660	434	365	31
DIC (dissolved inorganic C)	-	31	30	12	3.2	2.4	7.8
TDS (total dissolved solids)	-	858	732	-	-	-	-
DS (dissolved solids)	-	653	670	-	-	-	-

Units ppm (mg ℓ^{-1}) for all but pH and conductivity (μmhos cm^{-1})

[1] Totten, Sims, Hubicki Assoc. Ltd. (1983)
[2] Tested by Ontario Ministry of the Environment, Toronto, Ontario

n.a. not available
\- not tested

part a consequence of the lack of locally available clay soil for liner material. Saturated hydraulic conductivities (K_{sat}) obtained from intact cores using the constant head method (McKeague 1978) confirmed the impermeability of the clay material if properly applied to an adequate depth (minimum $K_{sat} = 5.1 \times 10^{-8}$ cm sec^{-1}) but its unsuitability for this purpose if inadvertently mixed with the local sandy soils in thin lifts (maximum $K_{sat} = 5.5 \times 10^{-4}$ cm sec^{-1}). Low altitude false-colour infra-red photography taken during June and July confirmed these discontinuities in the surface liner through the observation of differential vegetative moisture stress on areas of the grassed landfill with and without the clay material. The liner material possesses a higher plant-available moisture holding capacity than the local sandy soils.

As a result of the above findings, a subsequent experiment looked at possible alternative liner materials. A series of eight 1m x 1m shallow lysimeters were established on the landfill surface to test the ability of various natural and synthetic materials or soil treatments situated under a 5 cm layer of turf to reduce or eliminate downward percolation of precipitation once infiltration had occurred. These treatments included the local sand under both compacted and uncompacted (control) conditions, the existing clay liner material, a bentonite slurry with and without sand incorporated, a bentonite-polyvinyl alcohol (PVA) mixture, an industrial latex polymer-sand mixture, and plastic (Table 3).

Physical barriers imbedded to a depth of about 20 cm were used to segregate the plots on three sides, leaving the downslope side open for collection of surface runoff and interflow above the treated layer. Rainfall events were simulated and the volume of water applied to each plot while at field capacity (i.e. plots pre-saturated and drained) was compared to the volume recovered. A simple moisture balance was used to determine the volume of incident water lost to deep drainage beyond the shallow grass vegetation root zone.

The results of one of several trials are presented in Table 3 and are representative of other trials performed. The results indicate that the industrial latex polymer-sand mixture and the bentonite slurry approach the total exclusion of water that the plastic liner affords while allowing sufficient deep drainage to promote microbial decomposition and stabilization of the landfill refuse. All other treatments fell well short of this optimum degree of water transmissibility which was arbitrarily defined as runoff exceeding deep drainage by a factor of two or more. The existing clay liner was the least effective treatment in reducing deep drainage, even relative to the local sand material. Volumetric shrinkage of the predominantly micaceous clays upon drying is thought to be sufficient to cause cracking through the full depth of the thin clay liner. These structural macropores are capable of increasing the effective hydraulic conductivity of cracked clays by several orders of magnitude to in excess of even coarse-textured materials.

Of importance is that the latex polymer material is available at little or no cost making it a much more attractive option for smaller municipalities like Muskoka Lakes than the expensive synthetic liners now used at some landfill sites in the United States. The latex polymer used in this study is a commercial by-product and was obtained at no cost. Further laboratory analysis revealed little in the chemical composition of the polymer that would be of environmental concern should some weathering occur of a surface liner comprised of this material. In field trials set out in 1986/87, the permeability, trafficability and erodibility of the polymer were not significantly altered after 1 year of exposureto the elements, including a winter season.

Table 3. Results of a soil moisture balance for a single irrigation event on the alternative landfill surface liner lysimeters.

Soil Moisture Balance for Irrigation Event - Sept. 20, 1986

Soil Treatment	Depth of Irrigation	Actual Evapotranspiration	Runoff Collected	Deep Drainage
	mm	mm	mm	mm
Plastic	8.10	2.43	5.67	0
Polymer-sand	8.10	2.43	4.25	1.42
Bentonite slurry	8.10	2.43	4.66	1.01
Bentonite - PVA	8.10	2.43	3.14	2.53
Bentonite - sand	8.10	2.43	2.84	2.83
Existing clay liner	8.10	2.43	1.82	3.85
Sand (control)	8.10	2.43	2.73	2.94
Compacted sand	8.10	2.43	2.94	2.73

A second major investigation of the local site hydrology was aimed at reducing the quantity of groundwater in contact with the landfilled refuse. An extensive piezometer network was installed to determine the major groundwater flow patterns in the vicinity of the landfill (Figure 2). From this it was found that a natural ravine located immediately to the north of the landfill diverts groundwater flow originating from the north toward the perennial stream, thus largely circumventing any direct contact with the landfill. An exposed bedrock ledge situated upgradient and adjacent to the landfill further diverts any groundwater flow in the surficial unconsolidated materials from the east around the landfill. Thus, major groundwater diversion works are not believed to be necessary at this site. Indeed, most of the leachate collected on an annual basis can be accounted for by rainfall amounts directly incident on the landfill area.

In order to test the feasibility of dewatering the area beneath the landfill to eliminate any leachate mounding in the refuse, a 6 m long x 75 cm diameter steel culvert (Figure 1) and a number of piezometers were installed at the base of the landfill (Figure 2). The appropriate location for the well was determined with the use of a Geonics EM31 electromagnetic induction meter which clearly identified an area of apparent concentrated leachate flow. This instrument, by enabling the mapping of solute concentration isolines within the contaminated aquifer, also confirmed the general direction of groundwater flow as being from the landfill toward the existing leachate collection trench. A pump test performed on the culvert well established that the drawdown was significant even after only eight hours of maintaining the well at its minimum level (i.e. 20 cm drop in a piezometer 10 m distant). It is anticipated that continuous pumping from this well would

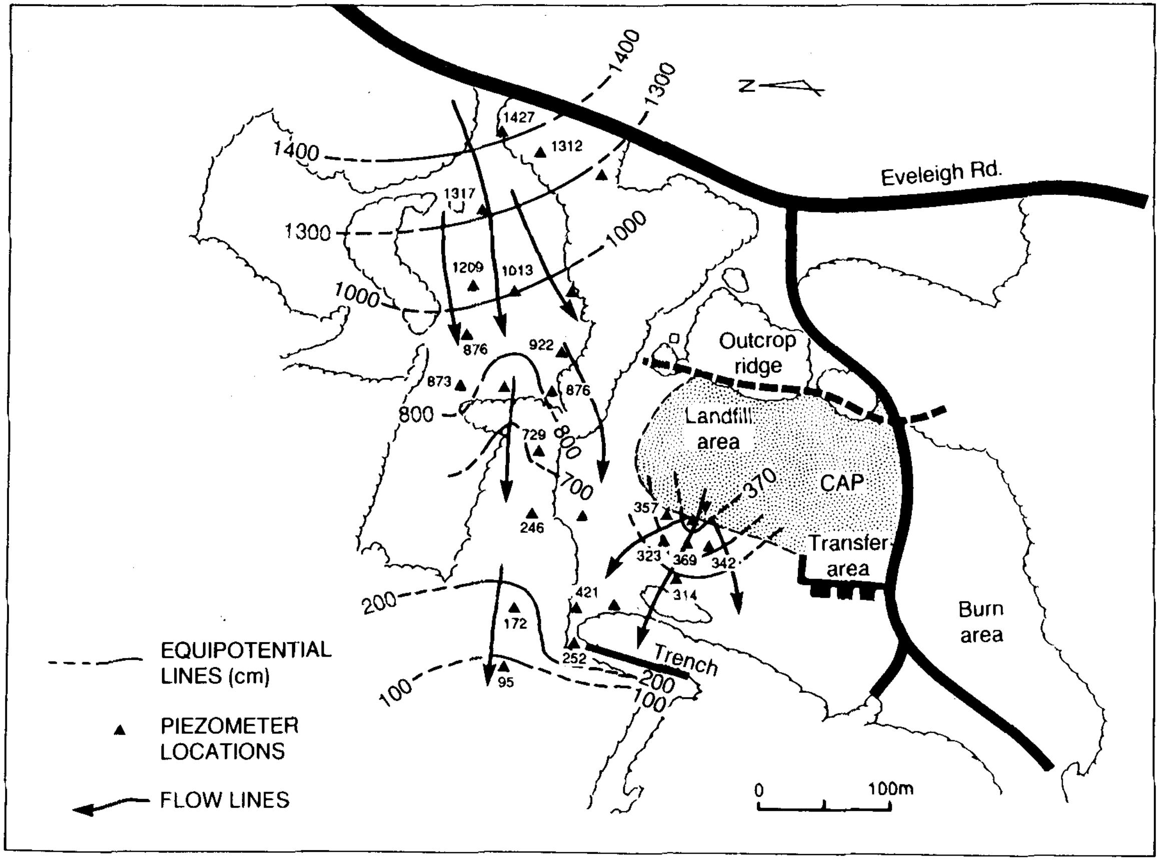

Figure 2. Groundwater flow network (October, 1986).

It is anticipated that continuous pumping from this well would improve the quality of the leachate with time as the groundwater is removed from direct contact with the landfilled refuse.

Investigations made of the hydrologic characteristics of the Muskoka Lakes site suggest that large scale groundwater diversion works are not required around the perimeter of the refuse cell but that a more effective collection system should be installed on the downslope side of the landfill. The long-term resolution of the leachate generation problem, however, rests on the achievement of both a suitable reduction in landfill liner infiltration and removal of groundwater in contact with the landfilled refuse through dewatering operations.

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