

Groundwater Contamination: Movement of Organic Pollutants in the Granby Landfill

By Brij L. Sawhney and John A. Raabe

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Municipal landfills have been the depositories not only of household wastes, brush, and building debris, but, in many cases, of industrial wastes, too. Organic chemicals in household solvents, detergents, cleansers, as well as a wide variety of chemicals in industrial wastes have thus entered the landfill sites. These chemicals, some potentially hazardous to human health, can leach through the soil and reach groundwater, the source of drinking water for about half the population of the United States. Soils also receive organic compounds in the form of agricultural chemicals, such as pesticides. These too can leach to groundwater. Other potential sources of groundwater contamination with organic chemicals include industrial holding ponds and lagoons and waste disposal sites. Once contaminants enter groundwater, they move slowly and may be altered little (Pye et al., 1983). There are also no economical methods for decontamination of groundwater aquifers. These concerns lend importance, even urgency, to learning how organic chemicals react with and move through soils, and how groundwater contamination by them can be abated. In this report, we examine the movement of organic pollutants in relation to the geohydrology of the municipal landfill in Granby, CT, and the abatement of groundwater contamination by "capping" the landfill.

Analysis of leachates from landfills in several towns in Connecticut showed a wide range of concentrations of a number of organic chemicals (Sawhney and Kozloski, 1984). Groundwater samples collected from monitoring wells are called leachates in this report. Most of the common organic chemicals detected in landfill leachates are industrial solvents (Table 1). Analysis of well water from several dwellings near the municipal landfill in

Granby revealed that the groundwater was contaminated with the same compounds found in the landfill leachates. The polluted wells contained toluene, methane, methyl ethyl ketone (MEK) and methyl isobutyl ketone (MIBK) (Sweeney and Raabe, 1982). To investigate the transport of organic pollutants to groundwater, samples containing landfill leachates were collected monthly for almost one year and were analyzed for pH, redox potential, temperature and organic compounds. Groundwater elevations were monitored in test wells to determine groundwater recharge throughout the year. To evaluate the effect of capping the landfill on groundwater pollution, concentration and distribution of the pollutants were examined both before and after capping.

LANDFILL

The Granby landfill occupies about 8 acres near the end of Old Stagecoach Road, approximately 1500 feet south of the Notch Road intersection (Fig. 1). The landfill is located on a sand and gravel aquifer underlain by

Table 1. Common organic pollutants detected in landfill leachates.

- Acetone
- Benzene
- Toluene
- Phenols
- Methyl ethyl ketone (MEK)
- Methyl isobutyl ketone (MIBK)
- Xylenes
- Several aliphatic and aromatic acids.
- (Most chemicals are industrial solvents)

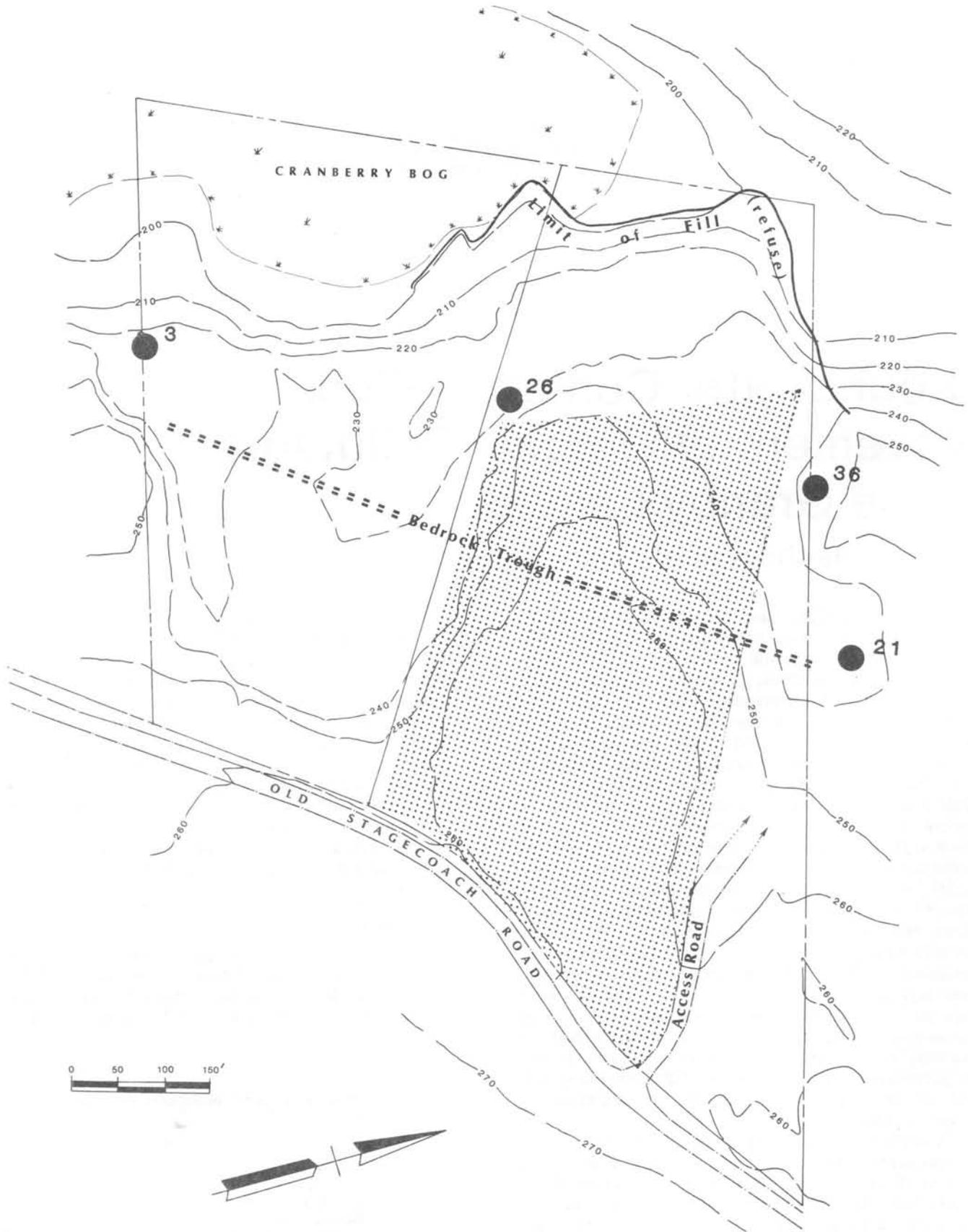


Figure 1. Topographic map of Granby landfill indicating the limit of refuse and the locations of monitoring wells. The trend of the bedrock trough is indicated south of Well #21.

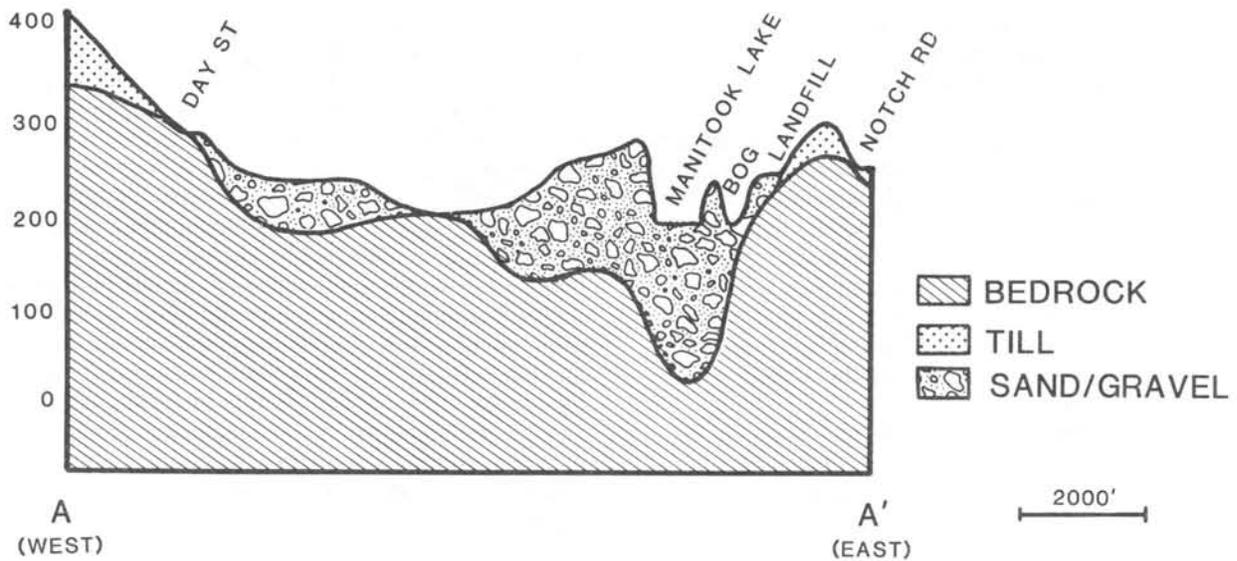


Figure 2. Generalized cross section showing relationships of regional geohydrologic units in the Granby landfill area.

sandstone bedrock. The sand and gravel aquifer becomes thicker west of the landfill and becomes a major regional aquifer. The landfill has been in operation since the mid-1950's, first as a dump site and later as a sanitary landfill. It has received both residential and commercial refuse from the town of Granby (1981 population about 8,400). The northerly half of the landfill area has received the final cover and has been capped (shaded area in Fig. 1), while the southerly half of the landfill is now in use. Capping a landfill involves covering the surface with a 6-8" layer of low permeability clay material and redirecting the precipitation falling on the surface so as to prevent its percolation through the landfill. Grass seed or fast growing plants are then planted to prevent surface erosion.

GEOHYDROLOGY

Regional Geohydrology. The relative positions of the various geohydrologic units in the aquifer are shown on the regional scale by a cross section (AA') in Fig. 2. An important feature of the area is a prominent impermeable till-bedrock ridge east of the site which sheds surface water westerly, where the water either infiltrates through the landfill or flows around it. It then enters a bog where the water level is controlled by the level of Manitoook Lake, a man-made lake, located on the sand and gravel aquifer, west of the bog. The nature and extent of these stratigraphic features were determined by examination of "spin samples" obtained from borings by power auger, and the lithologic units thus observed were mapped to outline their distribution (Sweeney and Raabe, 1982).

To determine the regional groundwater flow, static water levels in a large number of area wells were obtained and mapped as shown in Fig. 3. The piezometric contours in the figure show that the regional groundwater flow is southerly in the major valley aquifer but westerly in the landfill area.

Local Geohydrology. Although sandstone bedrock

dips to the east, glacial erosion has produced a west-facing bedrock beneath the landfill area. Because the permeability of the bedrock is much less than that of the

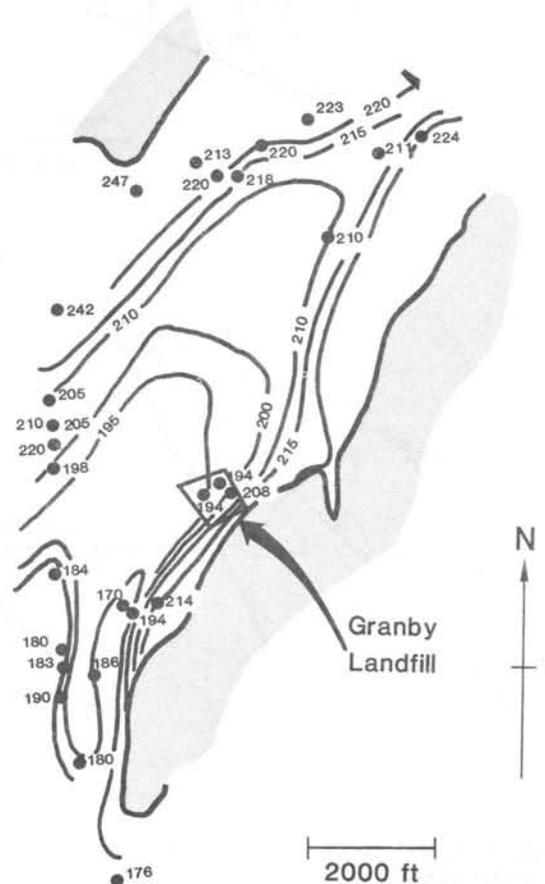


Figure 3. Regional piezometric surface based on water elevations in area wells, contoured in the aquifer area.

unconsolidated material above it, the groundwater gradient in the landfill is westerly along the bedrock surface. When a large amount of water is present, it clearly flows east to west. However, a number of borings within the landfill site revealed (Sweeney and Raabe, 1982) that the bedrock surface is corrugated, forming a north-south trough passing through the landfill site as shown in Fig. 1. The width of the trough varies from 40 to 50 feet in the north to half this width near the southerly limit of the landfill. The depth is about 8 to 10 feet. During high flow, leachate reaching the trough can flow over the corrugated ridge and the movement of the pollutants continues in the westerly direction. During low flow, on the other hand, leachate is caught in the trough and redirected into a southerly flow.

The four wells numbered 3, 21, 26, and 36 (Fig. 1) were selected to determine the groundwater flow and various characteristics of the landfill leachates.

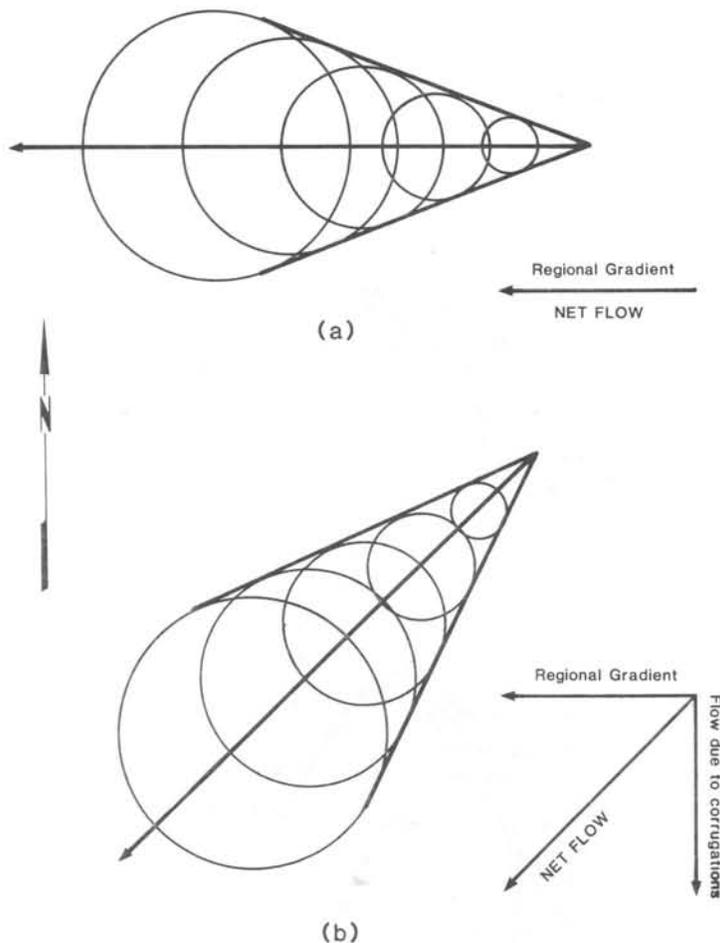


Figure 4. Comparison of generalized plumes formed under constant rate of dispersion showing development under uniform flow conditions (a) where the net flow follows the regional gradient and under non-uniform conditions (b) where a local component of flow diverts the net flow from the regional gradient.

Plume Geometry. The geometry of the leachate plume determines the path and the extent of the flow of pollutants in the groundwater and thus where the pollutants can affect water quality. The shape of the plume is determined primarily by the direction of groundwater flow and rate of dispersion of the pollutants in water. In a uniform medium, where the groundwater flow follows the maximum piezometric gradient, the geometry of the plume is bilaterally symmetrical along the direction of the flow. Its elongation is determined by the velocity of groundwater flow and its width is a function of the rate of dispersion of the contaminants in groundwater (Fig. 4a). Where the direction of flow is altered from the direction of maximum piezometric gradient, the plume is skewed. The deviation can result from several factors including differences in aquifer permeability, interference from impeding strata, or corrugation in the underlying bedrock. In the Granby landfill, local corrugation causes the plume to be directed in the southerly direction, as illustrated in Fig. 4b.

METHODS

Piezometric Measurements. Water elevations in the monitoring wells were measured by lowering a weighted tape into the wells. Depths to the water surface were recorded when the weight touched the water surface, and elevations of wells were determined from a common reference datum.

Sampling and Analytical Procedures. Leachate samples from the wells were collected by lowering a 30" PVC tube (1.25" i.d.), fitted with a floating valve, into the groundwater and withdrawing it when filled. We used a separate sampling tube for each well. A portion of the sample was transferred to a glass bottle, and its temperature, pH and redox potential measured immediately using a portable digital pH/temperature meter. The remaining portion or a second sample similarly collected was transferred to two 40 ml glass vials with Teflon-lined screw caps, leaving no air space. These samples were termed "initial". Two well-volumes of groundwater were then withdrawn. After the wells recovered for about an hour, a second set of samples was then collected and marked "final". The samples were refrigerated in the field, and at 4°C in the laboratory until analyzed.

Purgeable organic compounds were analyzed in the laboratory with a HP-5840A gas chromatograph (GC) equipped with a HP-7675A purge and trap unit and a FID detector (Sawhney and Kozloski, 1984). Briefly, a 10 ml leachate sample was transferred into a purge tube and purged for 5 minutes with nitrogen gas at a flow rate of 20 ml/min. The purged organics were collected on the GC column and analyzed. The organic compounds were identified by their characteristic GC peaks and their amounts by the heights of the peaks.

DOMESTIC AND MONITORING WELLS

Analyses for organic compounds, including those used by the CT Dept. of Environmental Protection (DEP) for reporting hydrocarbons in water, during 1981 and 1982 showed contamination in some wells used for domestic water south of the landfill (Sweeney and Raabe, 1982). These were generally bedrock wells with low to moderate

Table 2. Organic pollutants (ppb) in bedrock domestic wells nearby Granby landfill.

Organic Pollutant	Well No.										
	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11
Methane*	10,000							240		HIGH	
Butane										TR	
Acetone						4200	TR				
Benzene								15			
Carbon tetrachloride						40					
Cyclohexane						TR					
Methyl isobutyl ketone*				25	53	150		TR			
Methyl ethyl ketone*			1700		2000	5200					
Pentane	20							60			
Toluene*	40			1300	650	2800		70			80
Trichlorotrifluoroethane					1700						
Xylene (ortho)						TR					
Xylene (para)						TR					
Ethanol			TR								
Metaxylene						60					
Ethyl benzene						30					
Propanol						15					

* Characteristic pollutant

yields and contained contaminants similar to those observed in the monitoring wells within the landfill. Therefore, the landfill is the likely source of contamination of the wells. As discussed under "Local Geohydrology", the landfill leachate is caught in the bedrock trough and directed into the southerly direction during low flow. Thus, bedrock wells in the path of the southerly flow could receive the pollutants in the landfill leachate. The organic pollutants reported by Sweeney and Raabe (1982) in domestic wells near the Granby landfill are given in Table 2. Compounds that occur in high concentration and/or frequency were termed characteristic pollutants (Table 2) and were included in subsequent monitoring.

The data show a wide range of concentrations of several organic compounds in these wells. Methane was

considered to occur naturally and not a characteristic pollutant.

RESULTS AND DISCUSSION

Groundwater Elevation. Elevations of groundwater in the four monitoring wells when sampled are shown in Table 3. Although changes in groundwater elevations tended to follow precipitation patterns, the differences in elevations were small. A westerly groundwater gradient was observed throughout the study period. For example, groundwater elevations were the highest in well No. 21, which is in the eastern-most section of the landfill, followed by well No. 36, which is to the west of well No. 21. Elevations in wells No. 26 and 3, which are further

Table 3. Groundwater elevations (ft.) in wells at Granby landfill.

Well	May 1984	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan. 1985	Feb.
#3	—	195.3	—	194.0	194.5	—	194.2	194.5	194.2	194.3
#21	—	210.1	—	208.4	208.6	208.3	208.0	208.3	208.6	208.5
#26	—	197.9	—	193.2	193.4	193.3	193.4	194.5	193.4	193.5
#36	—	—	—	194.5	—	—	—	—	—	194.6

Table 4. pH, redox potential (redox, mV) and temperature (temp. °C) of water samples in monitoring wells.

		May 1984	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan. 1985	Feb.
Well #3											
pH	initial	6.42	6.70	5.92	6.43	6.01	5.83	5.55	5.49	5.55	5.83
	final	6.04	6.51	5.80	6.06	5.82	6.48	5.66	5.60	5.68	5.81
redox	initial	50	-26	-29	-44	2	17	57	—	69	66
	final	11	-38	-64	-69	-4	0	51	—	82	69
temp.	initial	19.4	15.1	15.5	16.5	15.5	13.1	12.9	11.8	9.8	14.1
	final	14.0	16.0	15.7	16.5	14.5	12.8	12.1	10.4	8.1	12.9
Well #21											
pH	initial	5.96	5.85	5.78	6.27	6.35	—	—	—	6.18	6.35
	final	5.78	6.19	5.79	6.29	6.01	—	—	—	5.89	7.15
redox	initial	69	-4	-49	-82	-81	—	—	—	90	89
	final	31	-21	-80	-93	-99	—	—	—	75	51
temp.	initial	14.1	15.2	14.4	18.3	14.4	—	—	—	8.6	13.4
	final	14.7	15.6	16.5	18.5	15.9	—	—	—	9.0	12.9
Well #26											
pH	initial	6.42	6.45	5.85	6.06	5.95	5.94	5.75	6.03	5.83	6.29
	final	6.37	6.38	6.15	6.13	6.19	5.90	5.80	5.85	5.71	6.26
redox	initial	-107	-58	-89	-82	-70	-76	-83	—	-5	-39
	final	-84	-72	-88	-80	-68	-76	-61	—	13	-30
temp.	initial	17.8	19.7	18.4	20.5	18.0	16.6	16.3	14.7	9.8	17.0
	final	19.1	19.0	20.1	20.7	18.4	16.3	14.7	12.4	11.8	16.6
Well #36											
pH	initial	6.16	6.05	5.57	5.95	6.06	5.52	5.14	5.09	5.60	5.81
	final	5.88	6.32	5.59	5.94	5.80	5.51	5.49	5.38	5.30	5.89
redox	initial	-48	-28	-31	-43	-13	-40	-16	—	5	-25
	final	-25	-47	-72	-59	-60	-46	-25	—	4	9
temp.	initial	18.6	21.0	18.9	20.6	18.8	16.9	17.6	15.7	12.1	18.0
	final	18.1	19.7	20.7	22.4	20.7	16.9	16.9	12.7	12.3	15.7

west, are still lower. The elevation was the lowest during the high flow period in June, 1984 in well No. 3, which is located at the western boundary of the landfill.

pH, Redox Potential and Temperature. The pH, redox potential and temperature of both initial and final water samples obtained from the wells during May, 1984 through February, 1985, are listed in Table 4. During this period, the pH of samples varied between 5.09 and 7.15, and initial and final values were essentially the same.

The temperature of the samples varied seasonally from 8.1°C to 22.4°C. Again, differences between initial and final values were small. Mean temperatures of leachates from wells No. 3, 21, 26, and 36 were 13.3°C, 14.7°C, 16.9°C, and 17.6°C, respectively. Leachates from well No. 26 were expected to be warmer than those from wells No. 3 and 21 because well No. 26 is at the base of the landfill and the other two wells are at the edge of the landfill. The cause of the higher temperature of the leachates from well No. 36 is unclear, but it may be due to a recent underground fire nearby.

Redox potentials of the water samples from wells No. 26 and 36 are not only more negative than the samples from wells No. 3 and 21, but remained negative during most of the year. Thus, the former two are more anaerobic than the latter two. While the greater anaerobicity of well No. 26 is possibly caused by its location at the base of the landfill, the cause of the anaerobicity of well No. 36 is not clear.

Organic Pollutants. Figures 5a, 6a, and 7a show the concentrations of diethyl ether, benzene and toluene in the initial leachate samples and Fig. 5b, 6b, and 7b show the concentrations of the same compounds in the final leachates.

Several relationships are shown. First, variations in concentrations in the initial and final leachates show similar trends. For example, concentrations of diethyl ether in leachate samples increased from May to June, 1984 and then decreased through August, followed by an increase in November and then a steady decrease through February, 1985 (Fig. 5). Well No. 21 was an exception where the concentration of diethyl ether was high in January. These variations in the concentrations are likely caused by variations in precipitation and, hence, by the dilution of flow. Similar general relationships occur for benzene (Fig. 6) and toluene (Fig. 7).

Second, concentrations of the pollutants in the final leachate are higher than in the initial leachate. The initial leachate samples represent stagnant water where portions of the volatile organic pollutants are likely lost to the air. Consequently, their concentrations in the initial samples are lower than in the final samples that were obtained after stagnant water was withdrawn and the wells were allowed to recharge. A comparison of the concentrations of diethyl ether in initial and final leachates from the four wells is shown in Table 5. In all wells, mean concentrations in initial leachate samples are lower than in final samples,

and the standard deviations of the initial and final samples are similar. Also, the concentrations of diethyl ether in the initial and final samples are correlated. These observations suggest that whereas initial samples are adequate for evaluating groundwater pollution in an area, analyses of samples obtained after removal of stagnant water provide a more accurate estimate of the relative concentrations of different pollutants.

Third, as expected, the movement of organic pollutants at the Granby landfill site follows the relations predicted from the regional geohydrology of the area. Superimposed on these, however, is the local geohydrology of the site, which strongly influences the movement of the pollutants.

Effect of Regional Geohydrology. The plume geometry, inferred from the regional geohydrology of the site, indicates that well No. 26, located in the westerly portion of the landfill, and well No. 3, located at the south-westerly corner, characterize the chemistry of the east-west flow. The concentrations of pollutants in well No. 3 should be smaller than the concentrations in well No. 26 because well No. 3 is farther from the landfill, thus

Table 5. Statistical comparison of the concentration of diethyl ether in initial and final leachate samples from the four monitoring wells.

Well No.	Leachate Sample	Mean	Std Dev.	Correl Coeff.
3	Initial	12.2	8.7	0.79
	Final	18.8	9.7	
21	Initial	25.6	19.5	0.76
	Final	23.9	18.6	
26	Initial	20.4	14.3	0.87
	Final	25.1	17.7	
36	Initial	5.4	3.0	0.53
	Final	6.1	2.7	

allowing the pollutants to be diluted during transport. In well No. 26, minimum dilution of the leachate occurs because this well is located underneath the base of the

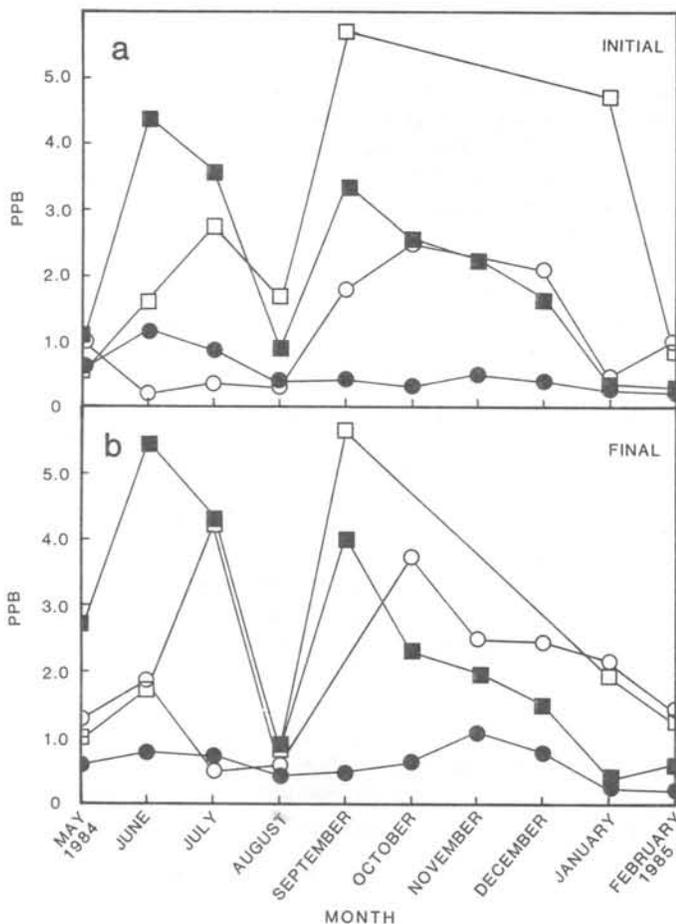


Figure 5. Concentrations of diethyl ether in initial and final groundwater leachates obtained from four monitoring wells at the Granby landfill [3 (○), 21 (□), 26 (■) and 36 (●)].

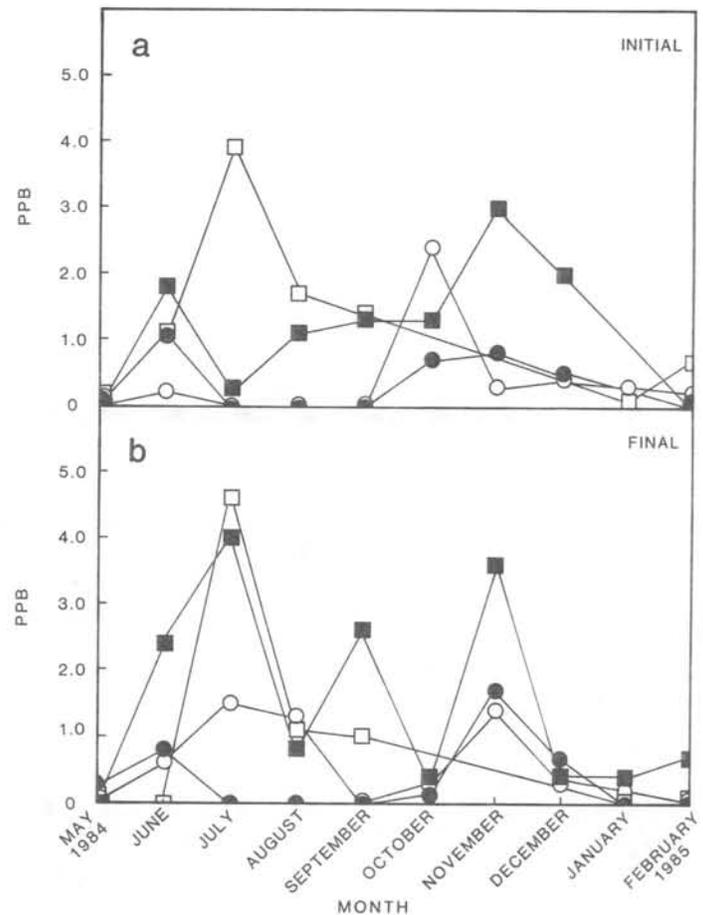


Figure 6. Concentrations of benzene in initial and final groundwater leachates obtained from four monitoring wells at the Granby landfill [3 (○), 21 (□), 26 (■) and 36 (●)].

landfill. Well No. 36 lies at the northern boundary of the leachate plume, and therefore should contain only small concentrations of the pollutants. The data in Table 6 confirm these inferences; the average concentrations during the period were the highest in well No. 26 and lowest in well No. 36. The concentrations of the pollutants observed in samples taken monthly (Fig. 5, 6, and 7) also show similar trends. Clearly, the general geohydrology of the site governs the movement of the organic pollutants in these wells.

Effect of Local Geohydrology. While regional geohydrology governs the movement of pollutants to the

Table 6. Average concentration of organic pollutants (ppb) in four monitoring wells at the Granby landfill.

Organic Pollutant	Well No.			
	3	21	26	36
Diethyl ether	18.8	23.9	25.0	6.1
Benzene	0.57	0.96	1.52	0.36
Toluene	0.18	0.24	0.51	0.10

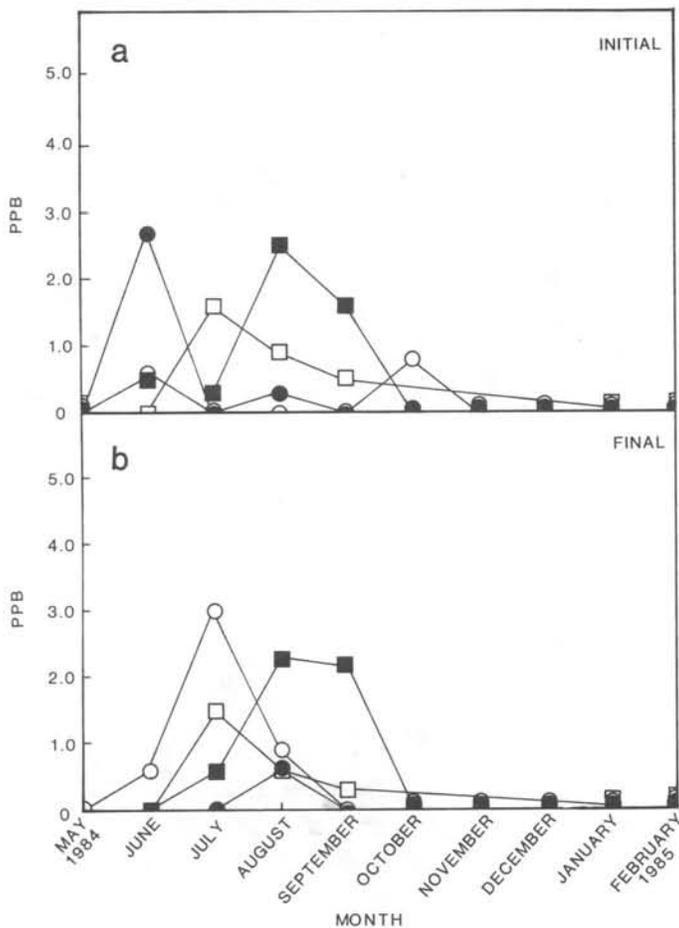


Figure 7. Concentrations of toluene in initial and final groundwater leachates obtained from four monitoring wells at the Granby landfill [3 (O), 21 (□), 26 (■) and 36 (●)].

monitoring wells in the landfill, local geohydrology appears to control the movement of pollutants to the wells south of the landfill. Large concentrations of the organic pollutants in the domestic wells (Table 2) south of the landfill and out of the influence of the westerly leachate plume caused by the regional geohydrology, are obviously caused by the leachate collected in the north-south trough and directed in the southerly direction. The influence of the local geohydrology on leachate movement is further confirmed by comparing the effect of capping the landfill on the concentrations of organic pollutants in the monitoring wells in the landfill and domestic wells south of the landfill as discussed below.

Effect of Capping the Landfill. Capping and storm water diversion at the landfill rapidly lowered the concentration of the pollutants in the monitoring wells. The characteristic pollutants decreased markedly after capping the landfill (Table 7). For example, in well No. 21 toluene concentrations, which ranged from 653 to 2800 ppb in 1981-82 before capping, decreased after capping to less than 10 ppb in 1983-84 and remained at this level during 1985 (data not shown). Similarly, MIBK and MEK decreased from 53-150 and 2,000-5,000 ppb, respectively, in 1982 to undetectable levels in 1984. Similar decreases in pollutants were observed in other wells at the landfill. Concentrations of inorganic constituents, such as Ca, Cr, Fe, SO₄, Cl, NH₃, as well as total dissolved solids also decreased in the monitoring wells after capping (Sweeney and Raabe, 1982).

In contrast to the marked decreases in the concentrations of pollutants in the monitoring wells, occasional monitoring of the domestic bedrock wells south of the landfill (Raabe, 1985) showed that the concentrations of the organic pollutants in these wells were not diminished by capping the landfill. Although the leachate generation was diminished by capping, the seepage of leachate from the bedrock trough into the bedrock aquifer feeding the domestic wells may have remained unchanged. This is because only a portion of the leachate entering the trough likely seeps into the bedrock aquifer because permeability of the bedrock is two to three times less than the permeability of the soil or the sand and gravel aquifer that feeds the trough. Another factor that may prevent decrease or may even increase the concentrations of organic pollutants in the wells that draw partially or wholly on the trench is the reduced dilution of the leachate from decreased percolation and flow caused by capping and storm water diversion.

Table 7. Concentration of the characteristic pollutants (ppb) in leachates from monitoring well No. 21, before and after capping and storm water diversion at the Granby landfill.

Pollutant	Before Capping			After Capping	
	12/81	1/82	3/82	8/83	4/84
Toluene	1300	2800	653	1	7
MIBK	25	150	53	100	ND ^a
MEK	1700	5200	2000	—	ND

^a None Detected

DILUTION OF POLLUTANTS ENTERING GROUNDWATER AND THEIR REMOVAL

Pollutants entering groundwater from landfill leachates and other sources are diluted considerably by mixing with water from surrounding areas. The type of aquifer and the hydraulic gradient are the main factors affecting these processes. In a coarse-textured sand and gravel aquifer with a large hydraulic gradient, the dilution will be much greater than in a tight bedrock aquifer with little or no gradient. Calculations of the dilution factor at the Granby site are given below:

Use of Darcy's law permits estimation of groundwater flux, Q , through the site as:

$$Q = KA \, dh/dl$$

where K is the proportionality coefficient depending on soil permeability; A is the area of the saturated flow; and dh/dl is the groundwater gradient. For the Granby site, these parameters are: $K = 400 \text{ ft}^3/\text{ft}^2/\text{day}$, $A = 5000 \text{ ft}^2$ and $dh/dl = 0.001$ and, therefore, $Q = 2000 \text{ ft}^3/\text{day}$.

Daily flow in the regional aquifer to which flow from the landfill is tributary is calculated to be about 500,000 ft^3/day . Thus, the dilution for the landfill leachate, assuming that it is uniformly mixed in the groundwater aquifer, is 250 (500,000 $\text{ft}^3/2,000 \text{ ft}^3$).

Infiltrometer measurements showed that after capping the landfill, only 12 percent of the precipitation infiltrated through, resulting in an 8-fold decrease in the leachate volume. Consequently, the landfill leachate, and pollutants therein, entering the regional groundwater aquifer would be diluted 2000-fold (250 X 8).

Calculations with Darcy's law illustrate that in bedrock aquifers or in aquifers with a small hydraulic gradient and permeability, a large reduction in the concentration of a pollutant takes a long time. For example, calculations show that in an aquifer with values of K , A and dh/dl given above, it would take about 3 weeks to reduce the concentration of a pollutant from 1 ppm (part per million) to 1 ppb (part per billion) in a 100 foot deep well with 1 foot diameter. In a similar well in a bedrock aquifer with only one-tenth the permeability or $K = 40 \text{ ft}^3/\text{ft}^2/\text{day}$ and $dh/dl = 0.0001$, it would take 4 to 5 years to attain the same reduction in concentration. Complete removal of a body of contaminated water in a bedrock aquifer may require decades or even centuries, depending upon the bedrock characteristics.

SUMMARY AND CONCLUSIONS

Movement of organic contaminants to groundwater in the municipal landfill site in Granby was related to both

the regional and the local geohydrology. Leachate taken monthly from a number of monitoring wells within the landfill and water samples from domestic bedrock wells south of the landfill site were analyzed for organic pollutants. Movement of the pollutants in groundwater underneath the landfill occurred as predicted from the regional geohydrology of the area. However, superimposed on the regional geohydrology is a local geohydrologic feature of the site which strongly influenced the movement of the pollutants to the domestic bedrock wells. The findings suggest that understanding the movement of pollutants to groundwater requires knowledge of both the general geohydrology and local geohydrological features. Local geohydrology can, in some cases, control the plume geometry and pollutant movement, as in the Granby landfill.

Capping and storm water diversion markedly reduced the concentrations of the characteristic pollutants in the monitoring wells within the landfill. The concentrations of characteristic organic pollutants in domestic wells south of the site, however, are altered only slightly. This was attributed to a bedrock trough, which collects some leachate seeping through the refuse despite landfill capping. Clearly, capping the landfill and storm water diversion are effective and economical practices for abating the groundwater contamination.

ACKNOWLEDGEMENT

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