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REMOVAL OF METALS FROM LABORATORY SOLUTIONS
AND LANDFILL LEACHATE BY GREENSAND FILTERS

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REMOVAL OF METALS FROM LABORATORY SOLUTIONS
AND LANDFILL LEACHATE BY GREENSAND FILTERS

ABSTRACT

Distilled water spiked with heavy metal cations was passed at a rate of 2-4 ml/min through a filter composed of greensand containing about 80 percent glauconite. The results of chemical analyses of the solutions before and after filtration through the greensand showed:

(1) solutions containing Cd, Co, Cu, Pb, Mn, Ni, Ag, or Zn had an average of 76 percent of the contaminating cation removed from acidic solutions and an average of 73 percent removed from the basic solutions; and,

(2) filtration through greensand tends to neutralize both acidic and basic solutions.

Removal of K, Na, Ca, Mg, Fe, Si, or Al (the principal constituents of glauconite plus Ca from shell material) is not as consistently effective as that of the other cations.

Filtration of landfill leachate through greensand filters showed:

(1) the content of heavy metal cations was considerably reduced,

(2) the unpleasant odor was lessened, and,

(3) the murkiness of the leachate was diminished.

The capability of the greensand to trap metal cations is increased by prolonging the contact time between the leachate and the greensand. Flushing the charged greensand filter with water does not cause significant release of cations back into solution, suggesting that polluted greensand might be disposed in landfills without adding pollutants to either ground or surface water in the vicinity.

INTRODUCTION

Glauconitic greensands are an abundant potential mineral resource of Delaware and other portions of the Mid-Atlantic Coastal Plain. They crop out in many localities and are thus accessible for possible economic extraction. These sediments were originally deposited in marine environments and contain more than 70 percent glauconite at many locations (Jordan, 1962; Pickett, 1970; Pickett and Spoljaric, 1971). They are used as fertilizers and water softeners. However, in recent years their use as fertilizers has been almost completely abandoned due to the availability of artificial products.

The unconsolidated Cretaceous and Tertiary glauconitic greensand deposits of the Atlantic Coastal Plain have potential as an inexpensive and effective primary filter material for removal of contaminants from polluted waters (Spoljaric and Crawford, 1978a). Glauconite ($XY_2[Z_4O_{10}](OH)_2$: where X = K, Ca, Na; Y = Fe^{3+} , Al, Mg, Fe^{2+} , Ti, Mn, Cr; Z = Si, Al) is a hydrous alumino-silicate clay mineral rich in ferric iron with significant amounts of potassium (Table 1). For a review of the literature on glauconites see McRae (1972). Glauconite in the Delaware Coastal Plain (Fig. 1) occurs as dark-, light-, or yellowish-green pellets 0.5 - 1.0 mm long, as casts of fossil shells, as coatings on other grains, and as a clayey sediment matrix.

The Delaware greensands contain up to 80 percent glauconite; the remaining major constituents are quartz grains and calcium carbonate in fragments of fossils. The areal distribution of the Delaware greensands is shown in Figure 1. The bulk of the deposits occur in the subsurface. The principal exceptions are outcrops in the Middletown-Odessa area where the greensands are most accessible.

The purpose of this investigation is to determine:

- (1) the capacity of greensands to purge heavy metal cations from laboratory solutions and landfill leachate,
- (2) the relative effectiveness of greensand, greensand-charcoal, and charcoal-greensand filter systems,
- (3) the significance of leachate flow rate through the filter system, and,
- (4) the tenacity with which a charged greensand filter retains the contaminant cations when flushed with water.

TABLE 1

Chemical Composition of Glauconites
from the Delaware Coastal Plain*

Oxide	1**	2**	3**
	In Weight Percent		
SiO ₂	49.6	47.3	47.3
TiO ₂	0.84	0.28	0.27
Al ₂ O ₃	9.6	7.1	7.2
Fe ₂ O ₃	14.0	17.6	17.5
FeO	2.26	1.89	2.30
MnO	0.04	0.03	0.03
MgO	3.1	3.7	3.6
CaO	trace	2.1	2.2
Na ₂ O	0.11	0.11	0.05
K ₂ O	6.2	8.0	8.0
Cr ₂ O ₃	0.045	0.034	0.056
H ₂ O _{total}	10.13	8.99	8.2
CO ₂	---	1.0	1.1
Total	95.9	98.1	97.8
(Fe _{total} as Fe ₂ O ₃)	(16.5)	(19.9)	(20.1)

* Analyses by atomic absorption spectrophotometry and wet chemical techniques. Glauconite was separated from the raw greensand with a Franz magnetic separator to more than 99% purity.

** Sample 1: outcrop northwest of Odessa, Del. (Fig. 1).

Samples 2 and 3: subsurface, well Je32-4 near Dover, Del.

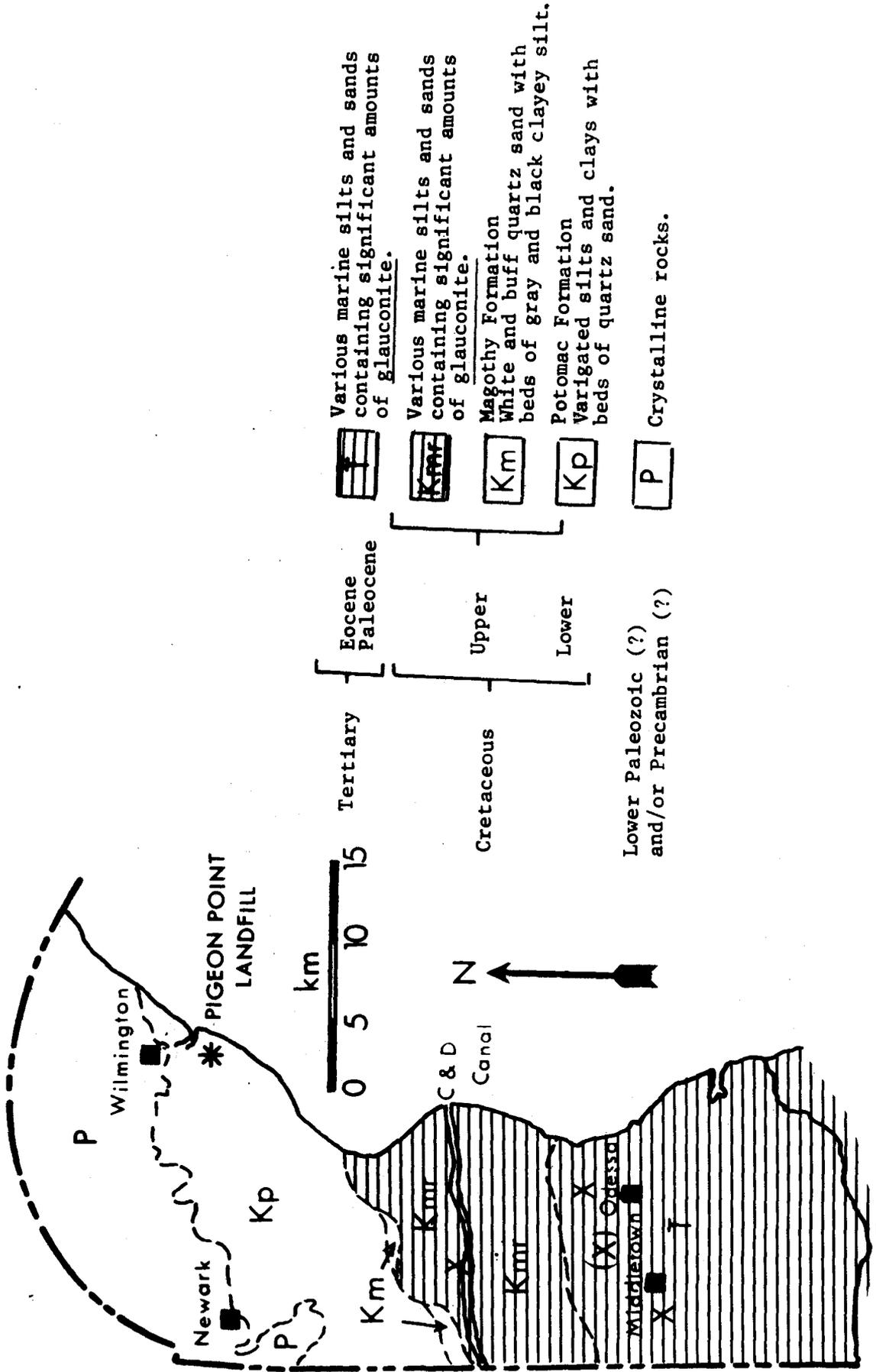


Figure 1. Areal distribution of glauconitic sediments in northern Delaware. X = Greensand outcrop; (X) Odessa outcrop sampled for this study.

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SINGLE CATION FILTRATION EXPERIMENTS

Experimental Procedure

A standard 300 ml Fleaker* was modified by the addition of two pieces of glass tubing to the body of the vessel (Fig. 2); the lower tube serves as the fluid inlet, the upper as the outlet. Glass wool packed around the inlet prevents small particles of greensand from clogging the opening. About 150 cm³ of greensand filled the Fleaker to about 1.5 inches (3.8 cm) below the outlet tube. The manufacturer's cap provided an adequate seal for the top of the vessel.

The greensand used in each filter was not pretreated except for the removal of twigs and root material. Large clots were gently disaggregated to prevent the formation of large voids in the vessel.

The flow direction from the bottom to the top of the vessel almost completely eliminates the transport of clay-size particles out of the container by fluid flow. The flow was controlled by a valve and maintained at about 2-4 ml/minute. Three-hundred milliliters of contaminated water was passed through each filter. Some problems in maintaining such a rate of flow were experienced in running some basic solutions,

* Reg. Trademark, Corning Glass Works

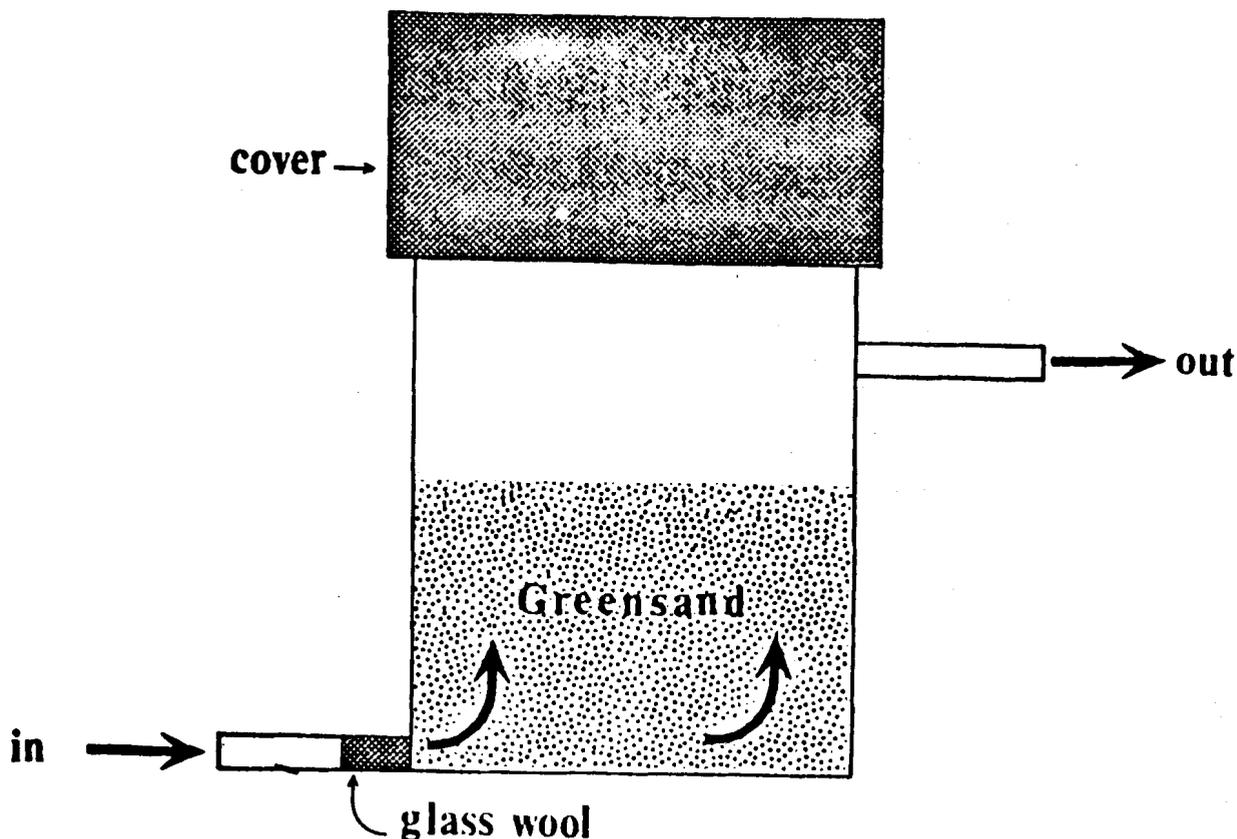


Figure 2. Three-hundred milliliter Fleaker used in the experiments with single element solutions. Flow of solution through the Fleaker is shown by arrows.

especially those containing sodium and potassium, due to deflocculation of clay particles. In such cases it was necessary to decrease the flow rate somewhat.

Four different concentrations of spiked solutions were made for each ion studied. The compounds used to spike the solutions are listed in Table 2.

Initially 100 ppm and 1,000 ppm (parts per million) stock solutions for experimental filtration were prepared. These were then used to prepare five solutions with different concentrations of each cation. The concentration depended on the cation being investigated, and was determined on the basis of its concentration in some waste waters and criteria for industrial and drinking water standards.

TABLE 2

Compounds Used to Spike Solutions

Element	Compound	Element	Compound
Aluminum	$\text{AlCl}_3 \cdot 6\text{H}_2\text{O}$	Magnesium	$\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$
Arsenic	As_2O_3	Manganese	$\text{MnCl}_3 \cdot 4\text{H}_2\text{O}$
Cadmium	CdCl_2	Mercury	HgCl_2
Calcium	CaCl_2	Nickel	$\text{NiCl}_2 \cdot 6\text{H}_2\text{O}$
Chromium	$\text{CrCl}_3 \cdot 6\text{H}_2\text{O}$	Potassium	KCl
Cobalt	$\text{CoCl}_2 \cdot 6\text{H}_2\text{O}$	Selenium	SeO_2
Copper	$\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$	Silver	AgNO_3
Iron	$\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$	Sodium	NaCl
Lead	PbCl_2	Zinc	ZnCl_2

Standard solutions were made by diluting the commercially prepared 1,000 ppm standards. All chemical analyses were done by flame and flameless atomic absorption spectroscopy and cold vapor generation techniques.

Three hundred milliliters of each concentration was passed through its own filter unit. The pH of the starting solution and the filtrate were measured during the filtration run. The initial and final concentrations of contaminant ions were determined for each of the solutions. The greensand was changed in each filter for each run except that the greensand in the first filter unit was never changed in an effort to determine the maximum capacity of a 150 cm³ filter. One set of five filter units was used for acidic solutions (initial pH about 3), another set for basic solutions (initial pH about 10). Acidic solutions were prepared by adding the appropriate amount of HNO₃ to bring the solution to pH 3. Basic solutions were prepared the same way as the acidic solutions except that an appropriate amount of NH₄OH was added to bring the pH to about 10.

Basic solutions tend to deflocculate clay particles in the greensand thus fogging the filtrate to a certain degree. However, in most cases the upper layer in the solutions was free of clay suspension, and the samples for chemical analyses were collected from this layer. In cases where the fogging was excessive, the filtrates were freed of most of the clay particles by filtering them through a filter paper prior to chemical analysis.

Results

The results of the cation filtration experiments are shown in the following tables. It should be emphasized that the greensand used in the experiments was as it was found in the field. Because of this there may be some differences in the amount of glauconite in the greensands in the filters (Fleakers), although all the greensand was collected from the Tertiary Hornerstown Formation and from the same outcrop. These possible differences should be taken into account when studying the results shown in Table 3 and Table 4.

Acidic Solutions

Attenuation of metal cations by the greensand is quite high for a large number of metals (Table 3). From the results it can be seen that iron and lead were removed most effectively from the spiked solutions: on the average 99% of these two metals was retained by the greensand filter. The least amount removed was of sodium: only 3% was retained by the greensand. The mean amount of all the metals retained by the greensand filter is about 76%. The pH after filtration shows a mean change toward neutrality of about 0.86 pH units. The only exceptions to this trend are the silver and potassium solutions which indicate the opposite trend. The solutions of these two metals show a change from pH of about 5 before filtration to about 4 after filtration.

Basic Solutions

Attenuation of many metal ions by the greensand in the basic solutions is also high (Table 4). The most effective removal from solutions was achieved for silver: 96% of silver was removed from the solution by the greensand. The minimum amount removed was that of aluminum: 2%. The mean amount of all the metals retained by the greensand filter was 73%, only slightly lower than that for the acidic solutions. The pH change toward neutrality is less pronounced and the mean change is only 0.31 pH units.

Release of Cations by the Greensand

The greensand of one filter (samples no. 1 of Table 3 and Table 4) was not changed while 17 successive solutions were passed through it making a total of 5100 ml of fluid filtered by about 150 cm³ of greensand. The mean of all metals removed by this filter from acidic solution is about 54%, and from the basic solutions is about 62%. The results do not clearly indicate any definite trends in the greensand

TABLE 3

Analyses of acidic solutions used in filtration
(ppm)

Cation	Sample No.	Before Filter	After Filter	% Cation Retained (Released) by Filter	pH	
					Before	After
Aluminum	1	20.0	17.6	12	2.47	2.55
	2	21.8	14.2	35	2.46	3.59
	3	17.2	13.8	20	2.60	3.61
	4	13.8	11.4	17	2.71	3.85
	5	10.5	9.5	7	2.95	4.02
Arsenic	1	2.70	3.00	(11)	3.09	3.20
	2	3.13	2.20	30	3.15	3.69
	3	2.68	1.53	43	3.22	4.26
	4	1.88	1.27	32	3.50	4.32
	5	1.33	0.68	49	3.85	4.40
Cadmium	1	3.06	0.02	99	3.00	3.84
	2	3.07	0.16	95	2.92	3.80
	3	2.18	0.19	91	3.05	3.78
	4	1.31	0.03	98	3.21	3.95
	5	0.47	0.02	96	3.55	4.13
Calcium	1	21.5	44.6	(107)	2.54	2.63
	2	21.0	160.3	(663)	2.50	3.84
	3	16.7	126.6	(658)	2.60	3.95
	4	10.7	89.2	(734)	2.73	3.99
	5	4.2	52.0	(1138)	2.95	4.08
Chromium	1	3.93	0.50	87	2.79	2.98
	2	3.96	0.25	94	2.77	3.38
	3	3.10	0.16	95	2.89	3.79
	4	1.86	0.13	93	3.06	3.83
	5	0.91	0.16	82	3.41	3.99
Cobalt	1	3.93	1.01	74	3.00	3.41
	2	3.16	0.09	97	3.10	3.70
	3	2.17	0.02	99	3.13	3.75
	4	1.34	0.04	97	3.25	3.75
	5	0.48	0.03	94	3.60	3.86

TABLE 3 (continued)

Cation	Sample No.	Before Filter	After Filter	% Cation Retained (Released) by Filter	pH	
					Before	After
Copper	1	3.56	0.94	74	2.88	3.20
	2	3.45	0.03	99	2.82	3.82
	3	2.53	0.03	99	2.99	3.89
	4	1.50	0.09	94	3.14	3.99
	5	0.55	0.05	91	3.51	4.11
Iron	1	3.55	0.29	92	2.72	2.90
	2	3.53	0.02	99	2.71	3.79
	3	2.61	0.12	95	2.87	3.80
	4	1.57	n.d.*	100	3.02	3.89
	5	0.53	n.d.*	100	3.45	4.01
Lead	1	6.68	2.90	57	2.82	2.91
	2	6.65	(0.03)	99	2.80	3.90
	3	4.73	n.d.*	100	2.91	3.99
	4	2.82	(0.02)	99	3.13	4.15
	5	0.87	(0.02)	98	3.55	4.29
Magnesium	1	9.37	7.53	20	2.79	2.89
	2	9.77	15.79	(62)	2.75	3.79
	3	6.69	10.81	(62)	2.88	3.95
	4	4.93	8.01	(62)	3.00	4.01
	5	2.10	3.63	(73)	3.27	4.19
Manganese	1	3.52	1.00	72	2.82	3.15
	2	3.57	0.18	95	2.80	3.69
	3	1.53	0.06	96	2.92	3.88
	4	1.61	0.05	97	3.09	3.97
	5	0.51	0.04	92	3.51	4.03
Mercury	1	1.57	1.58	(0.6)	2.91	2.93
	2	1.62	1.17	28	2.86	3.93
	3	1.31	0.24	82	2.98	3.98
	4	1.48	0.65	56	3.13	3.96
	5	0.60	0.07	88	3.40	4.02
Nickel	1	3.34	2.87	14	3.07	3.17
	2	3.00	0.11	96	3.05	4.17
	3	2.35	0.09	96	3.18	4.31
	4	1.45	0.08	94	3.38	4.35
	5	0.58	0.16	72	3.72	4.27

TABLE 3 (continued)

Cation	Sample No.	Before Filter	After Filter	% Cation Retained (Released) by Filter	pH	
					Before	After
Potassium	1	54.5	31.0	43	5.50	3.80
	2	61.8	10.0	84	4.41	4.01
	3	41.3	6.0	85	5.48	4.16
	4	28.7	5.2	82	5.63	4.20
	5	19.8	4.2	79	5.60	4.28
Selenium	1	1.95	---	---	3.18	3.26
	2	1.73	0.37	79	3.19	4.09
	3	1.25	0.95	24	3.30	4.10
	4	0.80	0.27	66	3.59	4.20
	5	0.64	0.32	50	3.83	4.27
Silicon	1	39.2	35.5	9	2.72	2.69
	2	37.0	23.4	37	2.67	3.66
	3	29.4	18.9	36	2.76	3.97
	4	20.3	15.9	22	2.97	2.67
	5	14.4	9.9	31	2.95	4.11
Silver	1	2.92	0.61	79	5.26	3.97
	2	2.64	0.03	99	5.22	4.13
	3	1.77	0.01	99	5.20	4.17
	4	1.27	0.73	42	5.22	4.56
	5	0.23	n.d.*	100	5.26	4.16
Sodium	1	17.3	14.7	15	3.18	3.28
	2	17.0	14.0	18	3.16	4.19
	3	12.3	11.6	6	3.24	4.23
	4	8.6	9.3	(8)	3.39	4.29
	5	4.1	5.8	(41)	3.61	4.39
Zinc	1	2.97	0.90	70	2.89	3.14
	2	3.03	0.25	92	2.85	3.73
	3	2.15	0.38	82	2.99	3.64
	4	1.36	0.07	95	3.15	3.98
	5	0.47	0.04	91	3.57	4.10

* not detected

TABLE 4

Analyses of basic solutions used in filtration
(ppm)

Cation	Sample No.	Before Filter	After Filter	% Cation Retained (Released) by Filter	pH	
					Before	After
Aluminum	1	19.5	15.8	19	9.60	9.59
	2	18.2	13.7	25	9.60	9.50
	3	12.0	14.5	(21)	9.70	9.63
	4	8.3	9.2	(11)	9.82	9.72
	5	5.0	8.5	(70)	10.05	9.91
Arsenic	1	6.53	5.00	23	10.41	10.30
	2	6.53	0.50	92	10.36	9.95
	3	5.00	0.09	98	10.40	10.05
	4	3.46	0.27	92	10.49	10.20
	5	2.24	0.05	98	10.58	10.34
Cadmium	1	2.99	0.26	91	10.28	10.21
	2	3.06	0.02	99	10.29	9.86
	3	2.03	0.34	83	10.39	10.11
	4	1.17	0.04	97	10.49	9.88
	5	0.37	0.05	86	10.52	10.18
Calcium	1	19.7	12.2	38	9.69	9.63
	2	19.5	55.0	(182)	9.63	9.34
	3	14.6	31.0	(112)	9.71	9.51
	4	11.8	4.3	63	9.85	9.73
	5	4.9	8.4	(71)	10.01	9.79
Chromium*	1	2.03	0.68	66	10.23	10.22
	2	1.93	0.34	82	10.23	9.87
	3	1.82	0.46	75	10.31	10.13
	4	1.35	0.12	91	10.38	9.74
	5	0.47	0.18	62	10.48	9.87
Cobalt	1	3.05	1.91	37	10.25	10.19
	2	2.96	0.65	78	10.25	9.73
	3	2.18	1.53	30	10.32	10.06
	4	1.26	0.34	73	10.39	9.78
	5	0.40	0.09	77	10.39	9.76

TABLE 4 (continued)

Cation	Sample No.	Before Filter	After Filter	% Cation Retained (Released) by Filter	pH	
					Before	After
Copper	1	2.73	0.34	87	10.59	10.50
	2	2.65	0.20	92	10.60	10.35
	3	1.66	0.06	96	10.63	10.41
	4	0.98	0.08	92	10.69	10.42
	5	0.44	0.01	98	10.78	10.34
Iron	1	3.9	1.9	51	10.19	10.12
	2	4.1	12.6	(207)	10.20	10.04
	3	2.8	25.6	(814)	10.24	9.99
	4	1.7	36.4	(2041)	10.31	10.01
	5	0.8	33.3	(4062)	10.37	9.90
Lead*	1	3.64	0.21	94	10.10	9.98
	2	2.46	0.02	99	10.08	9.57
	3	3.08	1.30	58	10.18	10.03
	4	2.08	0.10	95	10.27	9.99
	5	0.66	0.22	67	10.47	10.26
Magnesium	1	10.35	0.65	94	9.85	9.78
	2	10.05	2.69	73	9.85	9.47
	3	7.08	1.03	85	9.82	9.76
	4	4.64	0.77	83	10.00	9.90
	5	2.54	2.02	20	10.22	9.30
Manganese	1	3.52	3.12	11	10.29	10.18
	2	3.54	1.22	65	10.29	9.96
	3	2.46	0.98	60	10.32	10.06
	4	1.54	0.64	58	10.47	10.08
	5	0.61	0.36	41	10.56	10.29
Mercury*	1	1.20	0.25	79	10.54	10.50
	2	0.94	0.13	86	10.53	10.39
	3	0.87	0.07	92	10.57	10.40
	4	0.77	0.03	96	10.68	10.50
	5	0.43	0.01	98	10.69	10.45
Nickel	1	3.80	0.06	98	10.11	10.09
	2	4.02	0.07	98	10.10	9.11
	3	3.35	0.06	98	10.15	9.42
	4	1.70	0.06	96	10.31	10.10
	5	0.34	0.08	76	10.41	10.15

TABLE 4 (continued)

Cation	Sample No.	Before Filter	After Filter	% Cation Retained (Released) by Filter	pH	
					Before	After
Potassium	1	76.8	46.6	39	10.58	10.35
	2	75.4	34.6	54	10.50	10.15
	3	59.2	20.0	66	10.52	10.20
	4	35.9	22.5	37	10.50	10.11
	5	18.5	15.3	17	10.53	10.27
Silver	1	3.89	0.42	89	10.30	10.28
	2	4.02	0.02	99	10.31	9.75
	3	2.76	0.10	96	10.36	9.89
	4	1.68	0.08	95	10.40	9.90
	5	0.53	0.04	92	10.40	10.01
Sodium	1	17.6	15.2	14	9.28	9.14
	2	17.8	16.3	8	9.22	9.13
	3	13.7	12.3	10	9.20	9.07
	4	8.0	6.7	16	9.18	8.86
	5	4.7	4.9	(4)	9.19	8.99
Zinc	1	3.00	0.82	73	10.23	10.21
	2	3.13	0.24	92	10.18	10.01
	3	2.13	0.12	94	10.21	9.79
	4	1.35	0.05	96	10.29	9.63
	5	0.48	0.12	75	10.41	10.05

* Partly precipitated. (The prepared concentrations were approximately between 0.5 and 3.5 (ppm) for chromium; 1.0 and 7.0 (ppm) for lead; and 0.5 and 2.0 (ppm) for mercury. The values shown in Table 4 are the actual concentrations at the start of filtration.)

to suggest that it reached a saturation point. It appears that, in general, the attenuation of the metals by this filter is less than in the variable concentration experiments. The only possible exceptions are cadmium and magnesium in the acidic solutions, and magnesium, nickel, and sodium in the basic solutions, which showed larger attenuation than in the variable concentration experiments. Similar to the variable concentration experiments, several metals were in fact released in solution from the greensand rather than being retained by the greensand. In the acidic solutions this was the case with calcium

and mercury; no release was observed in the basic solutions. The pH changes were similar to those observed in the variable concentration experiments, that is the changes were toward neutrality. The exceptions were again silver and potassium in the acidic solutions where pH showed a trend opposite to that for other metals.

FILTRATION OF LANDFILL LEACHATE

Introduction

Samples of landfill leachate were obtained from Pigeon Point Landfill in northern Delaware (Fig. 1). The flow of leachate at this landfill is controlled by a system of drainage channels that lead to a collecting basin from which the samples were collected. The leachate was greenish-black in color, had a very distinct and unpleasant odor, and contained a large amount of black clay- and silt-size particulate matter of unknown composition. In addition, the surface of the leachate in the collecting basin appeared to be covered with some oily substance.

The purpose of the experiments with leachate was to compare the effectiveness of charcoal and greensand filters in removing metal cations from leachate and also to assess the effect of flow-rate, if any, on the retention capacity of the greensand for heavy metals.

Experimental Procedure

The filters used were 6 gallon (23 liter) polypropylene tanks (Fig. 3) composed of two layers of washed gravel separated by a layer of glauconitic greensand (about 15 dm³). The lower gravel layer was supported by a 100 mesh polypropylene net about 1.5 inches (3.8 cm) above the bottom of the filter. The purpose of the hollow bottom chamber was to allow for an undisturbed flow of leachate into the filter.

The leachate entered the filter through six inlets at the bottom (three on each side of the filter), flowed upward through the filter, and out through a larger outlet at the top (Fig. 3). The flow was maintained by a centrifugal polypropylene pump.

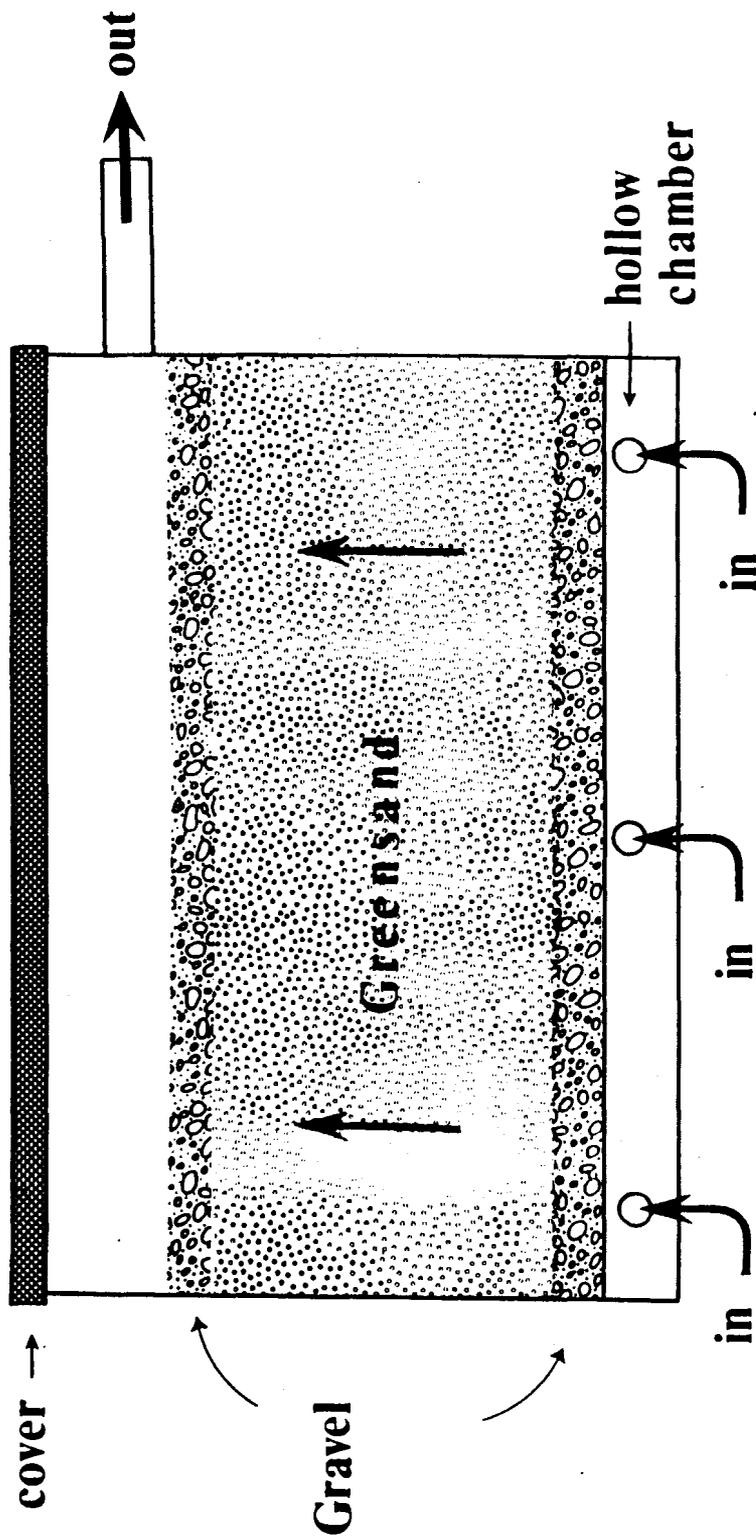


Figure 3. Schematic cross-section of glauconitic greensand filter unit showing leachate flow direction.

The filtration of leachates through the filter system started about one hour after the samples were collected in the field. First, 20 gallons (76 liters) of leachate were passed through the greensand filter, followed by the charcoal filter (System A). An additional 20 gallons (76 liters) of leachate were then passed through the charcoal filter first, followed by the greensand filter (System B). The first 20 gallon (76 liter) sample was collected on March 9, 1977 and the second sample on March 10, 1977. Both samples were filtered at about 1,000 ml/minute.

On March 17, 1977 an additional 10 gallon (38 liter) sample of leachate was collected and passed through a filter system containing only greensand (System C) at a reduced flow rate, about 80-100 ml/min (Fig. 4).

Results

The samples for chemical analyses and pH determinations were taken before the filtration and after the leachate passed through each individual filter. Thus the experiment assessed the effects of glauconite, charcoal, glauconite plus charcoal, and charcoal plus glauconite filters. The results of the analyses are shown in Tables 5, 6, and 7.

Effect of Flow Rate

Table 8 shows the effect of flow rate on the capacity of the greensand to remove heavy metals from leachate. The capacity seems to be inversely related to the rate of flow through the greensand. It is possible that by reducing the flow rate even further, or by increasing the thickness of the greensand filter bed, or both, the attenuation of heavy metals from the leachate by the greensand can be increased even more.

CONCLUSIONS

Single Cation Solutions

Glauconite-bearing greensands appear to be useful filtration material for the removal of arsenic, cadmium, chromium, cobalt, copper, lead, manganese, mercury, nickel, selenium, silver, and zinc from contaminated water regardless of the pH of solutions. In addition, in acidic solutions, some aluminum, magnesium, potassium, and sodium will be retained by the greensand, but calcium will be released in the

GUIDE TO FILTRATION SYSTEMS
USED IN EXPERIMENTS

SYSTEM A



SYSTEM B



SYSTEM C



Figure 4. Flow of leachate through filters shown by arrows. X, Y, and Z designate sampling points for chemical analyses.

TABLE 5

Analyses of Pigeon Point Landfill leachate
used in filtration through System AFlow Rate: 1000 ml/min
(ppm)

Cation	Before Filtra- tion	After Green- sand	% Retained (Released) by Filter	Followed by Charcoal	% Retained (Released) by Filter
Aluminum	0.16	0.52	(225)	0.34	35
Arsenic	0.039	0.023	41	0.025	(91)
Cadmium	0.082	0.003	96	0.004	(33)
Calcium	181	141	22	143	(1)
Chromium	0.13	0.17	(31)	0.07	50
Cobalt	0.024	0.015	37	0.008	47
Copper	0.28	0.24	14	0.44	(83)
Iron	13.7	8.4	39	9.4	(12)
Lead	0.18	0.12	33	0.22	(83)
Magnesium	164	122	26	138	(13)
Manganese	6.13	3.20	48	3.19	0
Mercury (ppb)*	1.2	0.6	50	0.9	(50)
Nickel	0.21	0.18	14	0.18	0
Potassium	364	139	62	299	(115)
Silver	0.056	0.046	18	0.047	(2)
Sodium	585	582	0	575	1
Zinc	0.78	0.62	20	0.85	(37)
pH	7.50	6.62		6.68	

*ppb - parts per billion (micrograms/liter).

filtrate. If the solution is basic, one may expect to remove minor amounts of magnesium, potassium, and sodium, but calcium, aluminum, and iron will be released into the filtrate. Solutions containing a mixture of contaminant ions will probably not behave precisely as these individually spiked solutions.

Landfill Leachate

The results of this study show that greensands do indeed have the capacity to remove many heavy metals from landfill leachate. It seems that one of the most important parameters

TABLE 6

Analyses of Pigeon Point Landfill leachate
used in filtration through System BFlow Rate: 1000 ml/min
(ppm)

Cation	Before Filtra- tion	After Char- coal	% Retained (Released) by Filter	Followed by Greensand	% Retained (Released) by Filter
Aluminum	0.18	0.17	6	0.13	24
Arsenic	0.04	0.03	24	0.02	33
Cadmium	0.026	0.019	27	0.004	79
Calcium	152	153	(1)	127	17
Chromium	0.071	0.079	(11)	0.060	24
Cobalt	0.008	0.008	0	0.007	12
Copper	0.24	0.24	0	0.35	(46)
Iron	22.0	19.8	10	17.8	10
Lead	0.23	0.18	22	0.18	0
Magnesium	132	134	(15)	120	10
Manganese	7.16	5.62	21	4.23	25
Mercury (ppb)*	0.9	3.6	(300)	1.5	58
Nickel	0.13	0.17	(31)	0.15	12
Potassium	280	287	(3)	262	9
Silver	0.039	0.053	(36)	0.050	6
Sodium	374	438	(17)	390	11
Zinc	0.69	0.69	0	0.68	1
pH	7.10	7.08		6.94	

*ppb - parts per billion (micrograms/liter)

that determines the effectiveness of the greensands to retain heavy metals is the flow rate of leachate through the greensand. At high flow rate (1,000 ml/min) on the average less than 20 percent of metal cations is retained by the greensand. At a reduced flow rate (100 ml/min) the attenuation of metals by greensand increases more than four fold; nearly 80 percent of metal cations is retained by the greensand. In addition, at the slower flow rate the unpleasant odor and foginess were also reduced.

TABLE 7

Analyses of Pigeon Point Landfill leachate
used in filtration through System CFlow Rate: 80-100 ml/min
(ppm)

Cation	Before Filtration	After Greensand	% Retained by Greensand
Aluminum	0.68	0.17	75
Arsenic (ppb)*	2.2	0.2	91
Cadmium (ppb)*	6	1	83
Calcium	129	48	63
Chromium	0.03	0.01	66
Cobalt	0.015	0.003	80
Copper	0.38	n.d.**	100
Iron	8.06	1.14	86
Lead	0.13	n.d.**	100
Magnesium	62	20.4	67
Manganese	4.06	0.48	88
Mercury (ppb)*	8.7	n.d.**	100
Nickel	0.074	0.003	96
Potassium	122	74	39
Silver (ppb)*	1.4	0.7	50
Sodium	275	175	36
Zinc	0.49	0.16	67
pH	7.65	6.29	

* ppb - parts per billion (micrograms/liter).

** n.d. not detected

By comparing the results shown in Table 5 with those in Table 6, it can be seen that the greensand is a more effective filter of heavy metals from leachate than is charcoal. It appears that in some instances, for example in the cases of iron, zinc, and manganese, the charcoal filter, when placed before greensand filter in the system, reduces the capacity of the greensand to retain these metals.

TABLE 8

Pigeon Point Landfill leachate

Effect of flow-rate on the retention of metals

Cation	Percent Retained (Released) by Greensand Filters of	
	System A	System C
Aluminum	(225)	75
Arsenic	41	91
Cadmium	96	83
Calcium	22	63
Chromium	(38)	66
Cobalt	37	80
Copper	12	100
Iron	39	86
Lead	33	100
Magnesium	26	67
Manganese	48	88
Mercury	50	100
Nickel	14	96
Potassium	62	39
Silver	18	50
Sodium	1	36
Zinc	20	67

FLUSHING CHARGED GREENSAND FILTERS WITH WATER

Systems A and B

After filtration of leachates at a flow rate of 1,000 ml/min., the filtering system was flushed with tap and distilled water. The flushing experiment was conducted in the following manner: ten gallons (37 liters) of tap water were passed through system A (greensand-charcoal); following this, 10 gallons (37 liters) of distilled water were passed through system B (charcoal-greensand). Samples for chemical analyses were taken before flushing and after the tap and distilled waters were passed through each individual filter. The results of the chemical analyses are shown in Tables 9, 10, 11, and 12.

TABLE 9

Analyses of tap water used
in flushing System A

(ppm)

Cation	Before Flushing	After Flushing Charcoal	After Flushing Charcoal and Greensand
Aluminum	0.05	0.11	0.23
Arsenic *	0.8	n.d.**	0.4
Cadmium *	n.d.**	6	6
Calcium	8	15	23
Chromium	0.002	0.027	0.11
Cobalt	3	4	6
Copper	1.20	0.28	0.12
Iron	0.73 1	3.69	3.95
Lead	0.06	0.06	0.02
Magnesium	1.5	6.6	11.8
Manganese	0.01	0.04	0.89
Mercury *	0.2	not determined	0.4
Nickel	0.057	0.11	0.069
Potassium	1.3	30	46
Silver *	1	6	5
Sodium	11	120	144
Zinc	0.13	0.05	0.04
pH	6.58	6.52	6.30

* parts per billion (micrograms/liter)
** n.d. - not detected

System C

The greensand filter charged with landfill leachates at the flow rate of 100 ml/min was flushed in the following manner: first, 6 gallons (25 liters) of tap water were passed through the charged greensand (System C) at the flow rate of 100 ml/min; following this 6 gallons (25 liters) of distilled water were passed through the same greensand filter at the same flow rate. Samples of tap water and

TABLE 10

Analyses of distilled water
used in flushing System B

(ppm)

Cation	Before Flushing	After Flushing Greensand	After Flushing Greensand and Charcoal
Aluminum	0.02	0.15	0.19
Arsenic *	0.5	0.5	0.6
Cadmium *	4	1	1
Calcium	1.2	not determined	3.7
Chromium	0.001	0.031	0.073
Cobalt *	4	4	3
Copper	0.16	0.08	0.21
Iron	0.4	not determined	5.7
Lead *	20	20	40
Magnesium	0.2	0.5	0.9
Manganese	n.d.**	0.05	0.13
Mercury *	0.5	0.7	0.5
Nickel	0.043	0.081	0.097
Potassium	0.02	n.d.**	13
Silver *	2	n.d.**	11
Sodium	0.09	not determined	29
Zinc *	30	30	30
pH	6.35	6.84	6.45
* parts per billion (micrograms/liter)			
** n.d. - not detected			

distilled water for chemical analyses were collected before and after passing through the greensand. The results of the analyses are shown in Table 13 and Table 14.

TABLE 11

Analyses of metals in total Pigeon Point Landfill leachate and tap water used in System A

Cation	Amount of Metals in 76 liters (mg/76 L)	Total Metals Retained by Filtration of 76 Liters of Pigeon Point Landfill Leachate		Total Metals Released by Flushing with 37 Liters of Tap Water	
		Retained by Charcoal (mg/76 L)	Retained by Charcoal + Greensand (mg/76 L)	Released from Charcoal (mg/37 L)	Released from Charcoal + Greensand (mg/37 L)
Aluminum	13.725	0.975	3.975	2.22	6.66
Arsenic	3.04	0.75	1.52	0	0
Cadmium	1.95	0.525	1.65	0.222	0.222
Calcium	11,400	0	1,875	259	259
Chromium	5.325	0	0.825	0.925	3.996
Cobalt	0.6	0	0.075	0.037	0.111
Copper	18.225	0	0	0	0
Iron	1,650	165	315	109.52	119.14
Lead	17.25	3.75	3.75	0	0
Magnesium	9,900	0	900	188.7	381.11
Manganese	537	0	0	14.43	32.55
Mercury	0.0675	0	0	not determined	0.0074
Nickel	9.45	0	0	1.961	0.444
Potassium	21,000	0	1,350	1,061.9	1,653.9
Silver	2.925	0	0	0.185	0.148
Sodium	28,050	0	0	4,033	4,921
Zinc	51.75	0	0.75	0	0

TABLE 12

Analyses of metals in total Pigeon Point Landfill leachate and distilled water used in System B

Cation	Amount of Metals in 76 Liters (mg/76 L)	Total Metals Retained by Filtration of 76 Liters of Pigeon Point Landfill Leachate		Total Metals Released by Flushing with 37 Liters of Distilled Water	
		Retained by Greensand (mg/76 L)	Retained by Greensand + Charcoal (mg/76 L)	Released from Greensand (mg/37 L)	Released from Greensand + Charcoal (mg/37 L)
Aluminum	12	0	0	4.81	6.29
Arsenic	2.964	1.216	1.064	0	0.0037
Cadmium	6.15	5.925	5.85	0	0
Calcium	13,575	3,000	2,850	not determined	92.5
Chromium	9.375	0	4.125	1.11	2.664
Cobalt	1.8	0.675	1.2	0	0
Copper	20.85	2.55	0	0	1.85
Iron	1,027.5	397.5	322.5	not determined	196.1
Lead	13.5	4.5	0	0	0.74
Magnesium	12,300	3,150	1,950	11.1	25.9
Manganese	459.75	219.75	221.25	1.85	4.81
Mercury	0.09	0.045	0.0225	0.0074	0
Nickel	15.825	2.175	2.025	1.406	1.998
Potassium	27,300	16,875	4,875	0	480.26
Silver	4.2	0.75	0.675	0	0.333
Sodium	43,875	225	750	not determined	1,069.67
Zinc	58.5	12	0	0	0

TABLE 13

Analyses of tap water and distilled water
used in flushing System C

Cation	Tap Water		Distilled Water	
	Before Flushing	After Flushing	Before Flushing	After Flushing
Aluminum	0.02	0.056	0.074	0.61
Arsenic (ppb) *	1.3	0.5	n.d.**	5.7
Cadmium	n.d.**	n.d.**	n.d.**	n.d.**
Calcium	8.5	3.3	1.5	4.7
Chromium	trace	0.009	n.d.**	0.035
Cobalt	0.045	0.011	0.035	0.0005
Copper	0.37	0.26	0.40	0.31
Iron	0.40	2.81	0.14	5.07
Lead	0.02	n.d.**	n.d.**	n.d.**
Magnesium	4.1	1.5	0.2	2.2
Manganese	0.05	0.16	0.03	0.16
Mercury (ppb) *	0.2	0.4	0.2	0.3
Nickel	0.036	0.047	0.014	0.026
Potassium	2.0	34	0.4	13
Silver (ppb) *	0.1	0.1	0.2	0.1
Sodium	17.0	58	2	40
Zinc	0.14	0.084	0.14	0.046
pH	5.97	6.42	5.74	6.49

* ppb - parts per billion (micrograms/liter)

** n.d. - not detected

TABLE 14

Analyses of metals in total Pigeon Point Landfill leachate, tap water, and distilled water used in System C

Cation	Total Metals Retained by Filtration of 37 Liters of Pigeon Point Landfill Leachate		Total Metals Released by Flushing with 25 Liters of Tap Water } followed by } 25 Liters of Distilled water	
	Amount of Metals in 37 Liters (mg/37 L)	Retained by Greensand (mg/37 L)	Released from Filter by Tap Water (mg/25 L)	Released by Distilled Water (mg/25 L)
Aluminum	17	12.75	1.4	13.3
Arsenic	0.055	0.050	0.0125	0.1425
Cadmium	0.15	0.125	0	0
Calcium	3,225	2,025	82.5	80
Chromium	0.75	0.50	0.225	0.875
Cobalt	0.375	0.3	0.2625	0
Copper	9.5	9.5	0	0
Iron	201.5	173	70.25	123.25
Lead	3.25	3.25	0	0
Magnesium	1,550	1,040	37.5	50
Manganese	101.5	89.5	4.0	3.25
Mercury	0.2175	0.2175	0.005	0.0025
Nickel	1.85	1.775	1.175	0.3
Potassium	3,050	1,200	800	315
Silver	0.035	0.0175	0	0
Sodium	6,875	2,500	1,450	950
Zinc	12.175	8.25	0	0

Conclusion

Only small amounts of some metals were released from charged filters after flushing them with tap or distilled water. This suggests that it might be possible to dispose charged greensands in existing landfills without endangering the surface and ground water in the vicinity.

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