Use of MWC Combined Ash for Highway Embankment Application

Chih-Shin Shieh, Edward H. Kalajian, Paul Cosentino, and Jim Egan
Research Center for Waste Utilization
Florida Institute of Technology, Melbourne, Florida 32901

ABSTRACT

A field study was conducted to demonstrate the suitability of using municipal waste combustor (MWC) combined ash in highway embankment applications. The ash embankment was constructed using conventional techniques and was evaluated for the geotechnical properties and environmental acceptability. Field evaluation of the geotechnical performance of the embankment included specifically California Bearing Ratios (CBR), infiltration, pressuremeter, and cone penetrometer. Environmental analysis determined the ash embankment's leachate and runoff concentrations of As, Ba, Cd, Cr, Pb, Hg, Ag, and Se over time for comparison with drinking water and toxicity standards. Findings of the study indicated that combined ash could be used as highway fill using conventional construction equipment and methods. The percent of the eight elemental metals in the ash lost to leachate or runoff after one year of exposure to natural rainfall was determined to be less than 0.01% and 0.005%, respectively, of their original weight in the ash. This indicates that greater then 99.99% of each of the eight elemental metals were retained in the ash. Concentrations of the eight EPA listed elemental metals in runoff and leachate from the ash embankment were below the EPA TCLP criteria and drinking water criteria. Results of the one-year monitoring study indicated that, based on the elemental metals examined, WMC combined ash is considered to be environmentally acceptable for highway fill material applications.

INTRODUCTION

A two-year study was conducted to determine the feasibility of using municipal waste combustor (MWC) combined ash in highway applications. Research was carried out to evaluate the geotechnical properties and the environmental acceptability of the MWC combined ash used to construct an embankment. The study was conducted by researchers at the Division of Engineering Sciences and the Research Center for Waste Utilization at the Florida Institute of Technology in Melbourne, Florida. Study findings will be used to revise the suggested specifications for using MWC combined ash for road construction developed in Phase 1 of the study for the Florida Department of Transportation (FDOT).

For the embankment construction ash was collected from the Pinellas County Solid Waste Resource Recovery facility located in St. Petersburg, Florida. MWC combined ash utilization as a road construction aggregate has been shown to be a viable material for road construction[1]. Utilization of MWC ashes has been, and is being considered for a variety of applications in the United States. Ash can be utilized as embankment fill material, highway base course material, landfill cover, and as aggregate for concrete mixtures used to make concrete block. The U. S. Environmental Protection Agency (EPA), the U. S. Department of Energy (DOE), and the Federal Highway Administration (FHWA) have partially funded several projects for the use of combined ash in road base or subbase courses[2]. Current practice at WTE facilities in the United States is to dispose of combined ash in monofills or to use it as daily cover in landfills. The engineering and environmental characteristics of ash have been evaluated in the laboratory and results suggest its strong potential for use as a highway construction material[3].

One disadvantage of combustion of municipal solid waste (MSW) is that every year in the United States it produces 4.5 millions tons of ash rich in heavy metals[4]. This volume can be expected to increase, as landfill space becomes more limited. Currently, 85-90 % of the ash produced is disposed of directly in monofills[5]. Most of the remainder is codisposed with raw MSW, often as a cover. Landfill space is becoming ever more limited, producing a growing need to increase the utilization of the ash. A major concern is that the ash contains high concentrations of metals[5]. Kosson et al.,[6] identified metals of environmental concern and total dissolved solids from salts, e.g., chloride, sodium, and potassium, to be the important constituents of ash that could potentially cause environmental harm. A major issue is whether these elements will leach out of the ash into surface and ground water. Laboratory extractions designed to simulate leachate often produce concentrations exceeding drinking water and sometimes toxicity standards[7, 8]. The concentrations predicted by the extractions varied markedly from method to method and often were contradicted by actual leachate concentrations in the few instances where field results were available[8].

The objectives of constructing the combined ash highway embankment as a field demonstration were to (1) evaluate conventional construction methods and quality control procedures, and (2) determine the physical and environmental acceptability of MWC combined ash as a highway fill material. The following tasks were conducted to evaluate the geotechnical properties and environmental acceptability of the MWC ash embankment:

1. Design and construct an embankment using MWC combined ash as the fill material
2. Evaluate the field performance of the embankment specifically California Bearing Ratios (CBR), infiltration, pressuremeter, and cone penetrometer
3. Determine the ash embankment's leachate and runoff concentrations of As, Ba, Cd, Cr, Pb, Hg, Ag, and Se over time for comparison with drinking water and toxicity standards
4. Determine field pH and conductivity of the leachate, runoff, and rainwater over time and compare these trends with elemental metal concentrations
5. Determine the volumes of major inputs and outputs to the embankment, including rainfall, leachate, and runoff quantities, to ensure no extraneous gains or losses of water were occurring to the ash embankment
6. Determine the environmental suitability of MWC combined ash as a highway fill material

ASH EMBANKMENT

The MWC combined ash embankment site was located within the slurry wall of the 730-acre Pinellas County Department of Solid Waste Management landfill in St. Petersburg, Florida. The embankment was 25 m (82 ft) long and 9.8 m (32 ft) wide at the base and 1.2 m (4 ft) in height. The top of the embankment was 15.2 m (50 ft) long and 3.1 m (10 ft) wide. Four side slopes were chosen for the embankment. In the longitudinal direction, the side slopes were (5:1) and (3:1); in the transverse direction, the side slopes were (2.5:1) and (3:1). The specifications required that the ash be placed in loose-layer thickness of less than 0.15 m (6 in) and be uniformly compacted to a density of not less than 100% of the maximum density, as determined by FDOT AASHTO T-99[9]. Based on laboratory moisture density testing D698, this required a field dry density of 116 lb/ft^3 (18.2 kN/m^3). A leachate and runoff collection system was designed to capture leachate and runoff from rain across a section of the embankment. The collection system consisted of a sand cushion, geomembrane, perforated polyvinyl chloride (PVC) collection pipes, gravel, geotextile, and ash. Leachate and runoff were captured and collected in separate 55-gallon PVC drums, which could be sampled at specified intervals. The geomembrane isolated the leachate collection system from the ground water at the site and trapped the leachate generated within the leachate collection system. To avoid possible migration of fines, the perforated pipe was wrapped in a geotextile, and the geotextile was spread on top of a gravel layer before placing the combined ash.

The combined ash used for embankment construction was obtained from Pinellas County's Refuse-to-Energy facility. The design capacity for waste processing of the refuse-to-energy plant is 3,000 tons per day, and the plant produces 645 tons of combined ash per day[10]. The combined ash was processed to remove unburned metals from the ash and sieved through the 5/8-inch trammel sieve before stockpiling. A total of 150 cubic meters (200 cubic yards) of combined ash was transported and discharged in piles for aging as recommended by previous studies[11]. The engineering and environmental indicator properties of the Pinellas ash samples taken from the 13-day period were studied. A statistical analysis was performed to evaluate typical day-to-day variations in these MWC ash properties. Based on the uniformity coefficient (C_u) and coefficient of curvature (C_c) ranges, it was concluded that the combined ash would classify as a well graded sand (SW). Both the diameter at 10% passing (D_{10}) and percent passing the number 200 sieve indicate that the combined ash would possess good drainage characteristics.

RESULTS

Environmental Analysis

Leachate and Runoff Concentrations

Figures 1-8 show leachate, runoff and rainfall concentrations of selected metals as a function of time. Time elapsed refers to the number of days after the completion of construction of the ash embankment and leachate collection system. The first set of data points at 20 days represents the first sampling date of the leachate and runoff that had collected for the previous 20 days.

Arsenic concentrations (Figure 1) in the leachate were two orders of magnitude below toxicity standards and below the drinking water standard. The concentration in the leachate showed a general downward trend over time. Runoff concentrations of arsenic were three orders of magnitude below toxicity standards and an order of magnitude below drinking water standards. The runoff concentrations were slightly elevated over rainwater concentrations and show no downward trend with time, eventually matching the concentrations in the leachate after 135 days elapsed.

Barium concentrations (Figure 2) in both the leachate and runoff were well below both toxicity and drinking water standards and showed general downward trends in the concentrations of both over time. Barium concentrations in both the leachate and runoff were clearly elevated over rainwater concentrations. Studies on suspended matters present in the collected filed samples showed that 99% of barium present in the rainwater was in dissolved form (capable of passing through a 45-µm filter. Ninety five percent of barium in the runoff and 97% of the barium in the leachate were also in dissolved form.

The runoff results allow some inferences to be drawn directly from the field data. Runoff concentrations showed barium levels above that of the rainwater. Because very little of the barium was transported as a particulate and because the runoff was not subject to displacement of pore water volumes or leaching, the major mechanism for barium release in the runoff was either washout or rapid dissolution.

Cadmium concentrations (Figure 3) in both leachate and runoff were well below both toxicity and drinking water standards throughout the period of the study. Studies showed that 89% of the cadmium in the rainwater was in dissolved form (passing a 45-μm filter); washout and dry fallout of particulate could contribute the remaining 11%. Forty-one percent of the cadmium in the runoff was in dissolved form. All of the dissolved cadmium in the runoff could be accounted for simply from the dissolved portion of the rainwater concentrations, while the particulate cadmium in the runoff was found to be in excess of the rainwater particulate concentrations. This suggests that the major mechanism of cadmium release in the runoff was particulate transport. Ninety two percent of cadmium in the leachate was in dissolved form; therefore, particulate transport could only play a minor role. This suggests that the most likely mechanisms for cadmium release in the leachate was leaching or displacement of pore water.

Chromium concentrations (Figure 4) in the leachate and the runoff were below the drinking water standard and three orders of magnitude below the toxicity standard. Both leachate and runoff concentrations were elevated above rainwater concentrations. Studies showed that 89% of chromium in the rainwater was found to be in dissolved form (passing a 45-μm filter). Forty-four percent of chromium concentration in the runoff and 80% of the chromium concentration in the leachate was in dissolved form. The 56% of chromium in the runoff transported as particulate accounts for almost all of the chromium in the runoff above the rainwater levels. Twenty percent of the chromium in the leachate was transported as a particulate. Because there was no evidence for washout or rapid dissolution occurring in the runoff, the remaining 80% of chromium were more likely released by leaching or displacement of pore water volume.

Lead concentrations (Figure 5) in both the leachate and runoff were an order of magnitude below the drinking water standards and three orders of magnitude below the toxicity standards. Both the leachate and runoff concentrations of lead closely approximated the concentrations of lead in the rainwater. Sixty one percent (61%) of the lead concentration in the rainwater was in dissolved form (passing a 45-μm filter); the remaining 39% were in particulate form consistent with washout or dry fallout of particles. Eight percent of lead in the runoff and 100% of the lead in the leachate were in dissolved form. The dissolved portion of the rainwater can account for the entire dissolved portion of the runoff; therefore, transport of particles appears to be the primary mechanism for lead transport in the runoff. No evidence of particulate transport occurred in the leachate. The most likely mechanisms, then, are leaching or pore water displacement.

Mercury concentrations (Figure 6) in both the leachate and runoff were several orders of magnitude lower than toxicity standards, as well as being below the drinking water standard. For the first 100 days the leachate and runoff concentrations were higher then the rainwater level and then both dropped off until they fell below detection limits at 135 days. The mostly neutral pHs found in the leachate inhibit release of mercury that is facilitated in alkaline conditions[5]. Mercury was not detected in either dissolved or particulate form in any of the samples during the sampling periods when the samples were being filtered.

Selenium concentrations (Figure 7) in the leachate were on average two orders of magnitude below toxicity standards. The selenium concentration in the leachate dropped rapidly and after 70 days elapsed remained an order of magnitude below drinking water standards. The selenium concentration of the runoff was an order of magnitude below drinking water standards and three orders of magnitude below toxicity standards. While the selenium concentration in the leachate was elevated above rainwater concentration, the concentration in the runoff roughly approximated rainwater concentrations. Concentrations of selenium in the filtered and unfiltered rainwater and runoff were close to or below detection limits; the percent dissolved must be interpreted very conservatively. One hundred percent of the selenium found in the rainwater was in particulate form. Twenty percent (20%) of the selenium found in the runoff was in particulate form. Concentrations of selenium in the leachate were well within detection limits. Ninety-two percent of the selenium in the leachate was in dissolved form, suggesting that particulate transport was not a major mechanism. Leachate concentrations were greater than an order of magnitude over runoff concentrations; suggesting the major mechanism would likely be leaching or displacements of pore water because they would occur preferentially in the leachate.

Silver concentrations (Figure 8) in the leachate were an order of magnitude below the drinking water standards and three orders of magnitude below the toxicity standards. Initially, the leachate concentration of silver was elevated above the rainwater levels, but after 45 days elapsed, the concentration dropped sharply until it fell below detection limits by 135 days elapsed. The concentrations of silver in the runoff were two orders of magnitude below the drinking water standard and four orders of magnitude below the toxicity standards. The silver concentrations in the rainwater varied over time. The concentration of silver in the runoff mirrored the variations in rainwater and rarely exceeded them. Silver was not detected in particulate or dissolved forms in any of the samples during the sampling periods when samples were being filtered. In laboratory studies, silver was found to a greater extent, and observed to leach more readily, from the fly ash portion then the bottom ash portion of the combined ash[5].

Cumulative Weight of Selected Elements in Leachate and Runoff as a Function of Time

Figure 9 shows the cumulative weight of elements in the leachate as a function of time. The cumulative weight was calculated by multiplying the concentration in weight per volume (w/v) by the volume of leachate (v) collected for that period. The resulting weight was added cumulatively to the weight of the element observed up to that period (see Table 1). The flattening out of the curves as they approach the 70-110 day interval shown in Figure 9 reflected the drop in leached concentration with time contributing less and less to the cumulative weight. Note that the flattening out of the curve of silver occurred early at the 45-day interval, whereas mercury and lead flattened out at 75-day and 110-day, respectively. The curves for cadmium, arsenic, selenium, and chromium appear to begin to flatten out by 110 days. Because the total cumulative weight of these elements was not large, small releases caused a slight increase in the slope of the curves at that time.

Field Engineering Properties

The combined ash embankment held its shape very well and no major signs of degradation were visible during the study period. Double ring infiltration, cone penetrometer, field CBR, and pressuremeter tests were performed after the environmental studies were completed. The results of the cone penetrometer test indicated that the ash exhibited excellent performance in the unbound pavement layers, with respect to strength and deformation. The lower value, which occurred at the surface, resulted from a lack of confining stress and desiccation of the top surface. The value at the base of the embankment was due to the softer sandy soil below the embankment.

The CBR tests results, which were lower than expected in comparison to the Qc cone penetrometer values, were most likely due to the fact that the embankment had not been compacted in 14 months and the surficial ash was unconfined and desiccated. The surface of the embankment was exposed to wetting and drying cycles and the CBR tests should have been performed at least six inches below the surface. However, CPT equipment problems during field-testing prevented testing below the surface.

Elastic moduli from pressuremeter testing ranged from 9,000 to 75,000 psi (62-517 MPa), with an average of 32,200 psi (222 MPa). These values also indicate that the ash is an excellent base/subbase/subgrade material. The limit pressures (i.e., similar to ultimate soil strengths) were extremely high. Because they exceeded the limit of the pressure gages, they could not be accurately estimated. A conservative estimate of 300 psi or 22 tsf (2070 kPa) indicates that the ultimate strength of the combined ash is comparable to very high strength base course material.

CONCLUSIONS

The following conclusions on the suitability of MWC combined ash for use as highway fill material were found as a result of this investigation:

- Combined ash can is used as highway fill using conventional construction equipment and methods.
- The percent of the eight elemental metals in the ash lost to leachate or runoff after one year of exposure to natural rainfall was determined to be less than 0.01% and 0.005%, respectively, of their original weight in the ash. This indicates that greater then 99.99% of each of the eight elements were retained in the ash.
- Concentrations of the eight EPA listed elemental metals in runoff and leachate from the ash embankment were below the EPA TCLP criteria and drinking water criteria.
- Results of the one-year monitoring study indicated that, based on the elemental metals examined, WMC combined ash is considered to be environmentally acceptable for highway fill material applications.

REFERENCES

1. Jones, C. M.; Hartman, R. M.; Kort, D.; Rapues, N. “Utilization of Ash from Municipal Solid Waste Combustion”; Final Report, Phase I., National Energy Laboratory, Golden, CO. 1994.

2. Chesner, W. H. “Working Towards Beneficial Use of Waste Combustor Ash”, *Solid Waste & Power*, 1993, September/October, 36-43.

3. Cosentino, P. J.; Kalajian, E. H.; Heck, H. H.; Shieh, C. S. “Developing Specifications for Waste-Glass and Waste-to-Energy Bottom Ash as Highway Fill Materials (Volume 1 of 2 Bottom Ash)”, Final Report, FDOT-WPA 0510650, 1995.

4. Sandell, J. F.; Dewey, G. R.; Sutter, L.L.; Willemin, J. A. “Evaluation of Lead Bearing Phases in Municipal Waste Combustor Fly Ash; *Journal of Environmental Eng*. 1996, Vol. 122, No. 1., 34-40.

5. Buchholz, B. A.; Landsberger, S. "Leaching Dynamics Studies of Municipal Solid Waste Incinerator Ash", Air and Waste Management Assn. 1995, Vol. 45; pp 579-590.

6. Kosson, D. S.; van der Sloot, H. A.; Eighmy, T. T. "An Approach for Estimation of Contaminant Release during Utilization and Disposal of Municipal Waste Combustion Residues", *Journal of Hazardous Materials*, 1996, Vol. 47, 43-75.

7. Andrews, C.; Hoffman, M. "Analysis of Laboratory and Field Leachate Test Data for Ash from Twelve Municipal Solid Waste Combustors"; Municipal Waste Combustion Papers and Abstracts from the Second Annual International Specialty Conference, Air and Waste Management Assn. Pittsburgh, PA., 1991; pp 739-753.

8. Shaub, W.; Sterling, D. *Characterization of Municipal Waste Combustion Ash, Ash Extracts and Leachates*; U.S. Environmental Protection Agency, 1990, EPA 530-SW-90-029A.

9. Florida Department of Transportation, *Standard Specifications for Road and Bridge Construction*. Tallahassee, FL, 1991.

10. Florida Department of Environmental Protection. *Solid Waste Management in Florida*. Tallahassee, FL, 1997.

11. Shieh, C. S.; Kalajian E. "Effect of Aging on the Suitability of Municipal Waste Combustion Ash on Stabilization and Utilization", Project report to the Florida Center for Solid and Hazardous Waste Management, University of Florida, Gainesville, FL., 1995.

Figure 1. Arsenic concentrations in leachate, runoff, and rainwater as a function of time

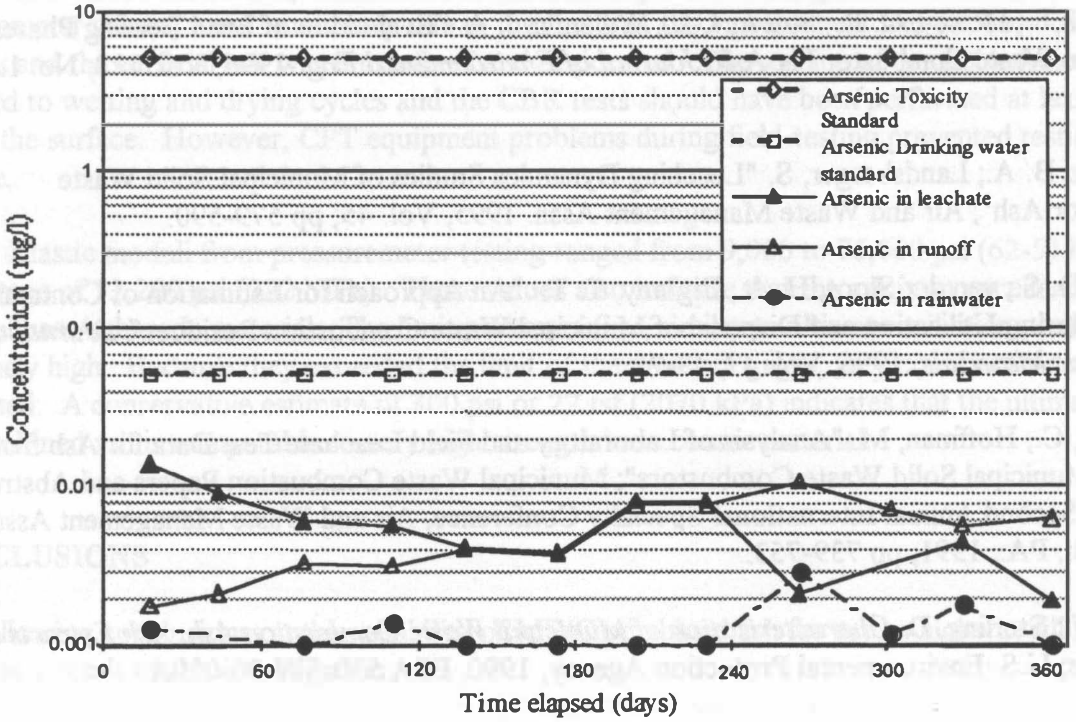

Figure 2. Barium concentrations in leachate, runoff, and rainwater as a function of time

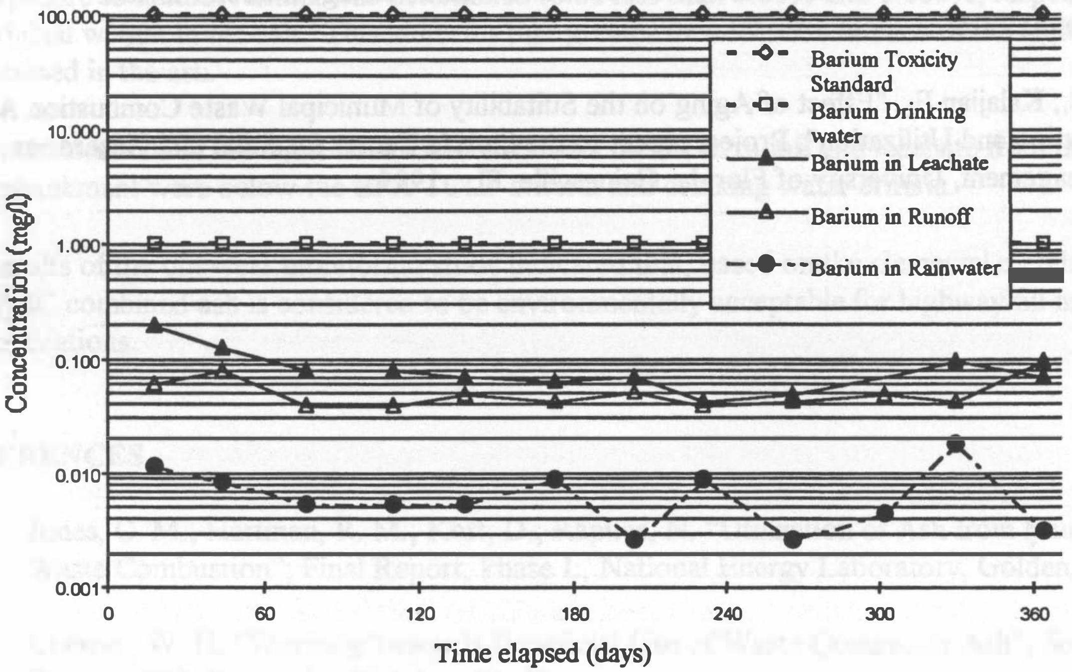

Figure 3. Cadmium concentrations in leachate, runoff, and rainwater as a function of time

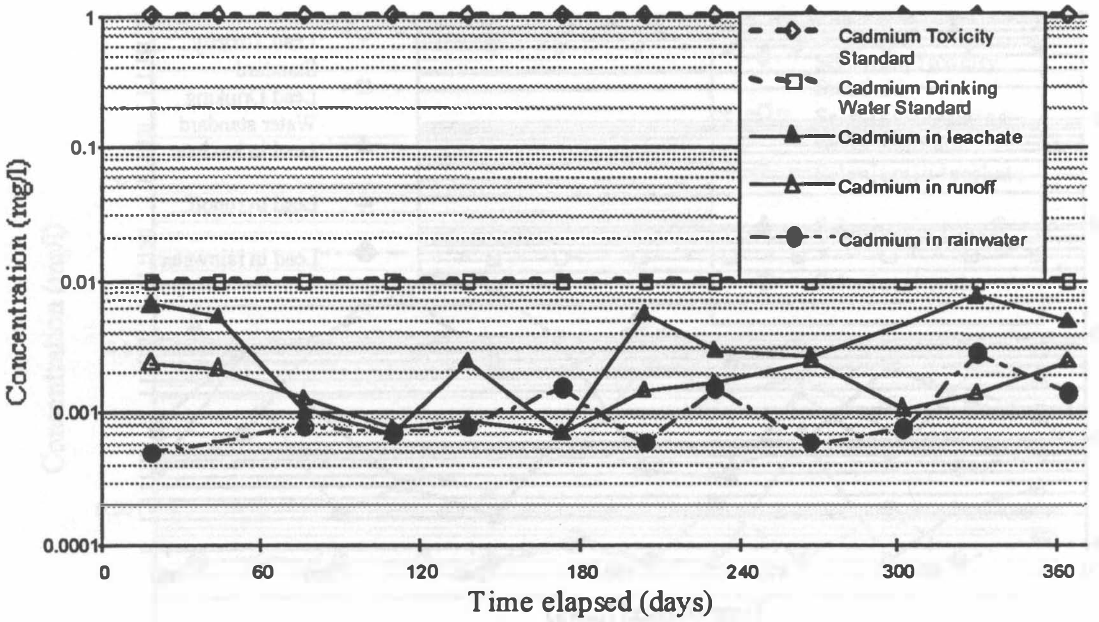

Figure 4. Chromium concentrations in leachate, runoff, and rainwater as a function of time.

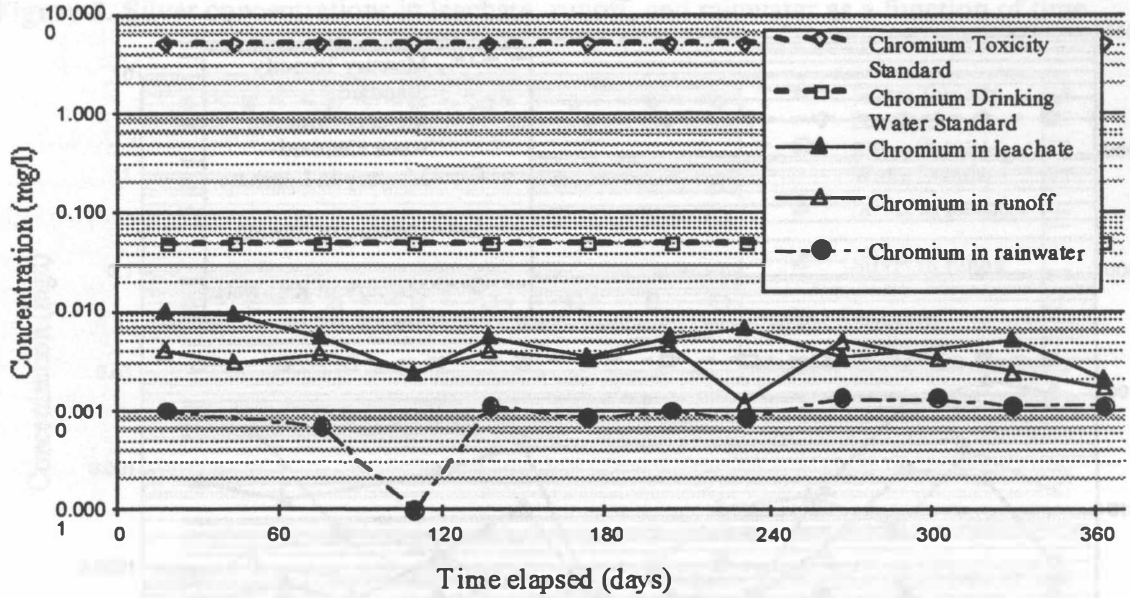

Figure 5. Lead concentrations in leachate, runoff, and rainwater as a function of time

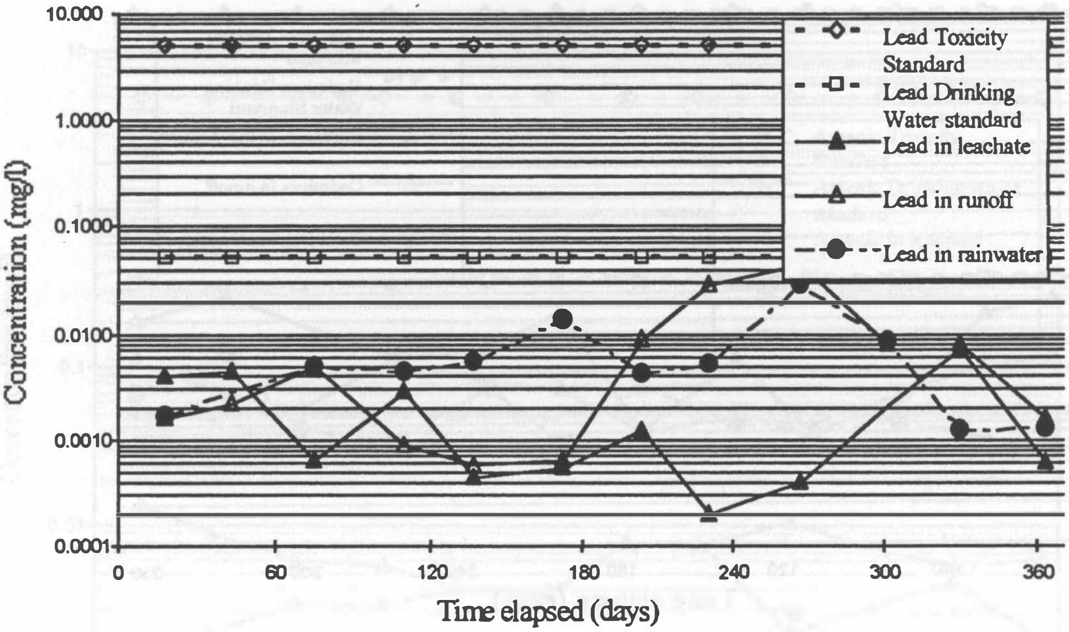

Figure 6. Mercury concentrations in leachate, runoff, and rainwater as a function of time

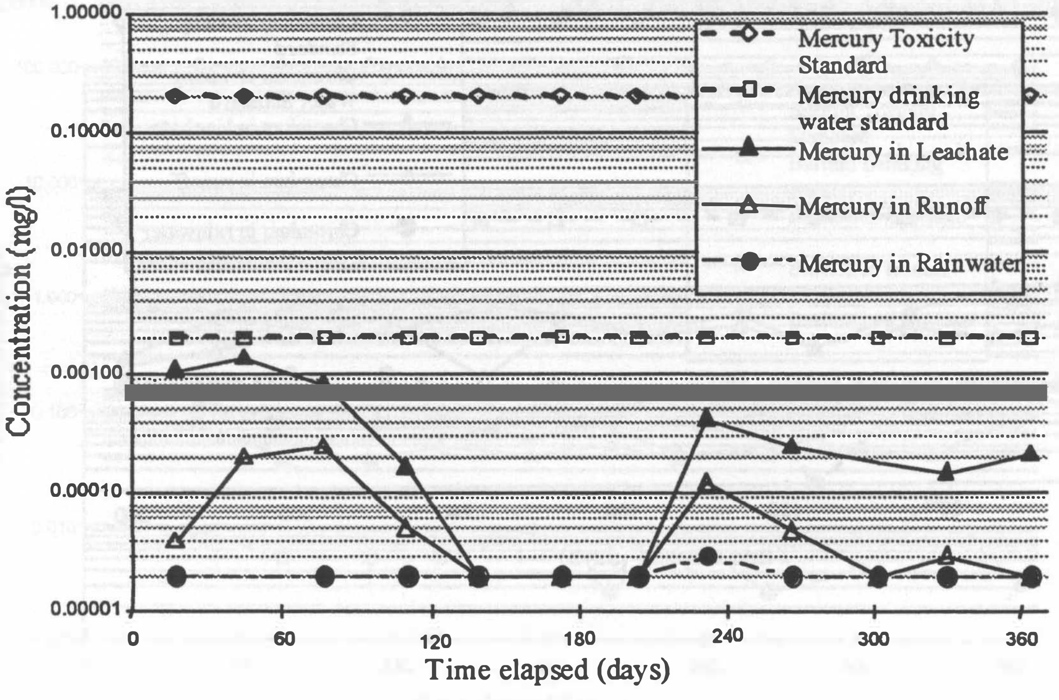

Figure 7. Selenium concentrations in leachate, runoff, and rainwater as a function of time

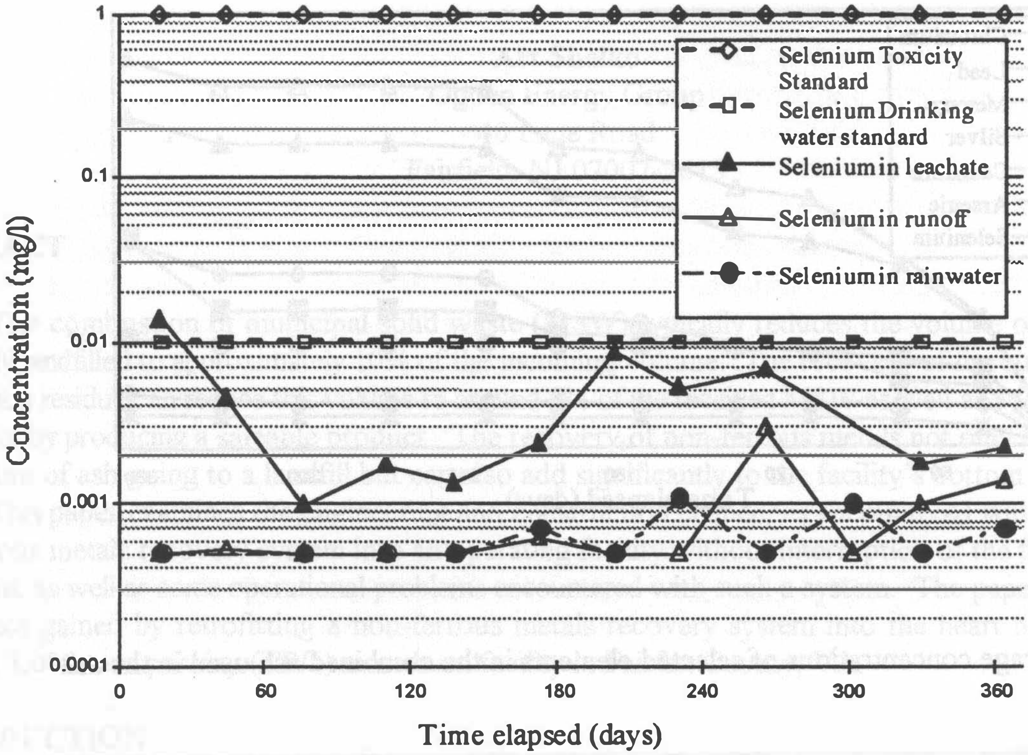

Figure 8. Silver concentrations in leachate, runoff, and rainwater as a function of time

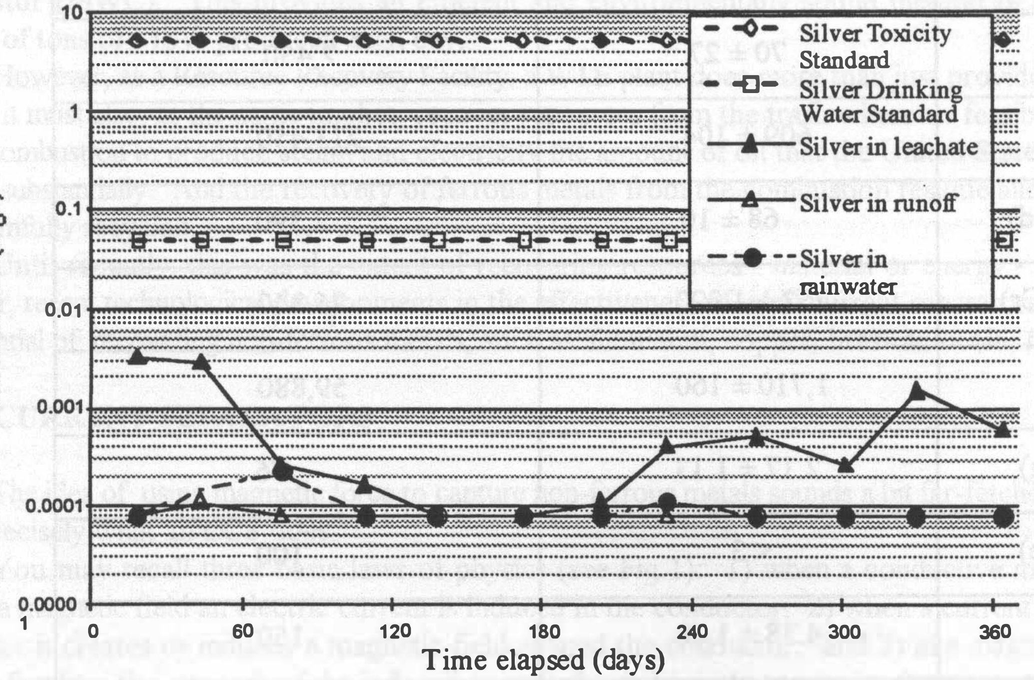

Figure 9. Cumulative weights of selected elements in the leachate as a function of time.

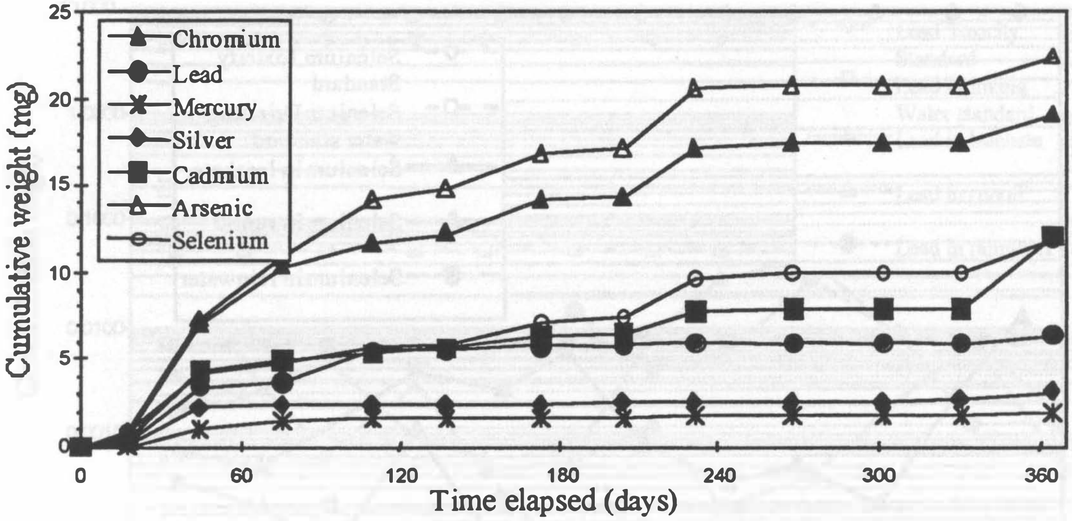

Table 1. Average concentrations of selected elements in the combined ash used in the ash embankment.

Elemental Metal	Average Ash Concentration (mg/kg)	Total Weight in Leachate Area (g)
Arsenic (As)	70 ± 27	2,450
Barium (Ba)	609 ± 104	213,450
Cadmium (Cd)	68 ± 10	2,390
Chromium (Cr)	752 ± 1,990	26,340
Lead (Pb)	1,710 ± 160	59,880
Mercury (Hg)	2.17 ± 1.13	76
Selenium (Se)	< 3	100
Silver (Ag)	4.38 ± 1.68	150

± represents Standard deviation, N=13