

# **Evaluation of Water Quality Conditions Associated with the Use of Coal Combustion Products for Highway Embankments**

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## **ABSTRACT**

Potential users, regulators and the public have expressed uncertainty regarding the potential for coal combustion products (CCPs) used as structural fill in highway embankments to degrade ground water quality. The Maryland Department of Natural Resources Power Plant Research Program (PPRP) is conducting field studies at two Maryland sites in which CCPs were used to construct highway embankments to assess ground water quality impacts and promote the beneficial use of CCPs generated in Maryland. One study is being conducted at the Routes 213/301 overpass, and the second study is being conducted at the I-695 overpasses. The purpose of the studies is to determine the potential for leachate to form within the pore water in the CCP embankments, and evaluate whether the leachate is degrading ground water quality.

The study at the I-695 overpasses is in the work plan development phase. The study at the Routes 213/301 overpass was initiated in March 1999 and is substantially completed. Lysimeters, monitoring wells and soil moisture probes were installed in and through the CCP fill on the shoulder of Route 213. A tipping bucket range gauge was installed to monitor precipitation at the study site. Samples were collected to provide information regarding the material's physical and chemical properties, and were used to assess those factors that affect the attenuation of constituents. Pore and ground water samples collected at the site were analyzed for dissolved trace elements, major cations and anions, and alkalinity. Temperature, pH, and specific conductance were measured in the field.

Water quality results indicate elevated concentrations of several trace elements (arsenic and manganese) and major ions (calcium, magnesium, chloride, and sulfate) were found in fly ash pore water, indicating that leachate is forming within the fly ash fill. However, the data also indicate that these constituents are being attenuated in underlying soils and ground water beneath the embankments. The water quality data collected to date indicate that the use of fly ash for highway embankments can adequately protect ground water quality.

## BACKGROUND AND PURPOSE

Use of CCPs as structural fill in highway embankments is a high volume use that has proven to be suitable for implementation in the U.S.. Approximately 3 million tons of CCPs (Class F fly ash) are used annually in the U.S. by the transportation industry for road bases, highway embankments, and structural fill<sup>1</sup>. Two recent projects have been completed in Maryland in which CCPs were used to form highway embankments. In 1993 and 1994, Baltimore Gas & Electric (BGE) and Delmarva Power (now Conectiv) provided approximately 40,000 tons and 20,000 tons of CCPs, respectively, to the Maryland State Highway Administration (SHA) to create the highway embankments for the Route 213 overpass over Route 301 near Centerville on Maryland's eastern shore. Between 1996 and 1998, BGE provided 320,000 tons of CCPs to support the Maryland Transportation Authority (MTA) with the construction of three overpasses during the reconstruction of a portion of I-695 near Sparrows Point, Maryland.

Previous studies at CCP highway embankment and structural fill sites suggest environmental impacts to ground water are localized and naturally attenuate over relatively short distances from the ash fill. Several leachate constituents (barium, calcium, chloride, and sulfate) and pH were found significantly elevated above background levels below the CCP fill for highway construction and structural fill sites<sup>2</sup>. Fruchter et al.<sup>3</sup> found that several leachate constituents (including barium, cadmium, chromium, copper, iron, and sulfate) were controlled by precipitation/dissolution equilibrium reactions. As a result, these constituents tend to re-equilibrate once the leachate migrates beyond the CCP fill.

Despite these previous studies, potential users, regulators and the public in Maryland have expressed uncertainty regarding the potential for CCPs to degrade ground water quality, which in turn impedes widespread acceptance for use in highway construction and other structural fill applications. The Maryland Department of Natural Resources Power Plant Research Program (PPRP) is promoting the beneficial use of CCPs to avoid **development of new landfill sites, which consume valuable land and can affect adversely Maryland's natural resources**<sup>4</sup>. As part of this initiative, PPRP is conducting field studies at the two Maryland highway embankment sites to assess the water quality impacts from CCP fills, which can assuage the uncertainty associated with using CCPs as structural fill. The purpose of the studies is to determine the potential for leachate to form within the pore water in the CCP embankments, and evaluate whether the leachate is degrading ground water quality. This paper discusses the monitoring methods and water quality results for the Routes 213/301 overpass site (Figure 1). The study at the I-695 overpasses is in the work plan development phase, and will be the subject of subsequent technical papers.

## SITE DESCRIPTION

The overpass is located approximately five miles east of the Chester River (Figure 1) on Maryland's eastern shore. The overpass is bordered on all sides by agricultural fields that are primarily used for cultivating corn and wheat, and for grazing. The majority of relief in land surface is in the area of the overpass and along streams. Historical precipitation and temperature

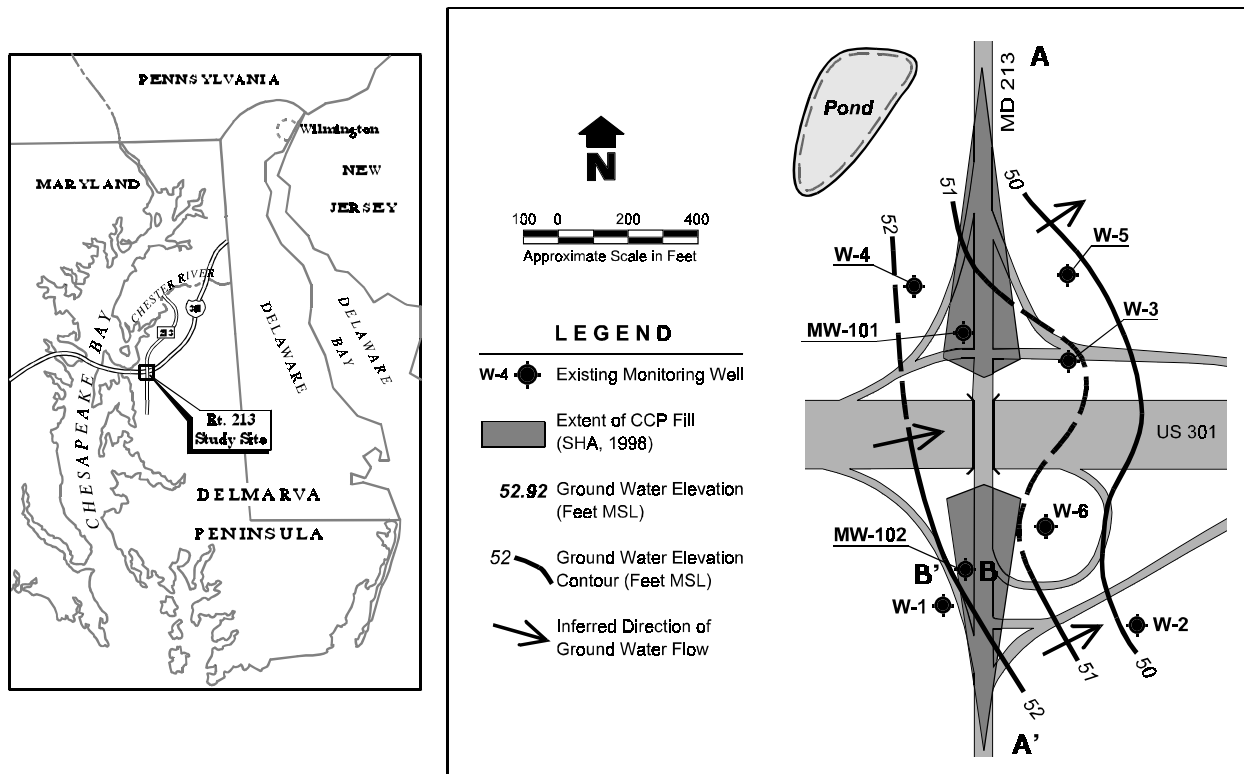


Figure 1. Map of the Rt. 213 study area with well locations. Elevation contours are given for the water table from measurements taken on May 17, 1999. Ground water flow is primarily to the northeast. Also shown is the extent of the CCP fill area.

data for the area indicate that the average annual precipitation is about 42 inches and average temperatures range from 36°F to 86°F<sup>5</sup>.

The overpass is located within the Coastal Plain Physiographic Province, and is underlain with the unconsolidated sediments of the Pensuaken Formation of the Columbia Aquifer. Boring logs for six wells installed by SHA to monitor ground water quality downgradient of the CCPs indicate that the overpass is underlain with inter-layered sand, silt, and clay to at least 39 feet below natural land surface (see Figure 1 for well locations).

The boring log data and the water levels measured in the monitoring wells indicate that ground water beneath the overpass is present under unconfined, water table conditions at an approximate depth of 15 feet below the natural land surface. Based on site topography and the ground water elevations, shallow ground water flow appears to be northeastward towards a stream located 1,500 feet from the overpass. During periods of high water table conditions, ground water likely has a flow component towards a farm pond, located northwest of the site (Figure 1).

SHA provided information concerning the construction of the Route 213/301 overpass. CCPs in the form of Class F fly ash were delivered to the site from the Delmarva Power's Indian River plant in southern Delaware and from BGE's Brandon Shores facility near Baltimore. Figure 2 is a schematic cross-section (along line A-A' in Figure 1) that shows how the embankments were constructed. The

embankments were constructed with a base layer of silty sand, placement of sandy clay berms to contain the sides of the fly ash, and placement and compaction of fly ash in 8 inch lifts. The fly ash was moistened to about 20 percent prior to compaction. The fly ash was covered with 2 feet of sandy clay, and the portions beneath the road were covered with a stone base and asphalt pavement. The lateral extent of fly ash fill extends approximately 30 feet from the centerline of Route 213. Only about 10 feet of ash is present beyond the edge of the pavement. The fly ash in the south embankment is estimated to be 6 feet thick, and the fly ash on the north side is estimated to be 12 feet thick at the top of the embankment.

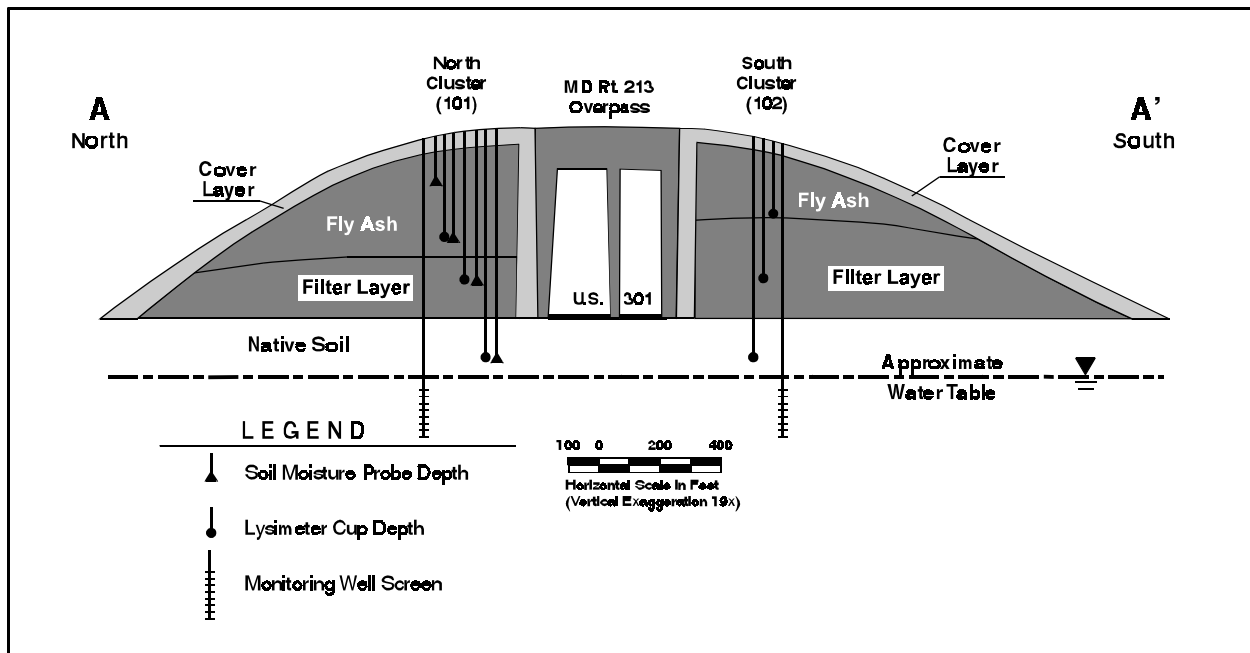


Figure 2. Schematic cross-section of the Rt. 213 Site (along A - A' shown on Figure 1). Also shown are lysimeter, monitoring well and soil moisture probe depths.

## METHODS

Two monitoring instrument clusters consisting of three lysimeters and one monitoring well were installed on the shoulder of the each side of the overpass to characterize the water quality in the unsaturated and saturated zones within the embankments. Sample sites were labeled with the prefix 101 for the north embankment (e.g., L101-12 for the lysimeter installed to a depth of 12 feet on the north embankment) and 102 for the south embankment. Ceramic porous cup-type suction lysimeters were installed at each monitoring location. Table 1 summarizes the well and lysimeters construction details. All instruments were surveyed for horizontal location and vertical elevation.

Volumetric moisture content was monitored using a series of four ML2 Theta Probes<sup>®</sup> installed at the northern monitoring location on the Route 213 embankment (Figure 2). The probes were installed in separate boreholes at depths corresponding to the depths of the three lysimeter cups,

with the fourth probe installed to a depth of 6 feet (Figure 2). A tipping bucket rain gauge was installed adjacent to the north monitoring location and connected to the data logger to measure the amount of precipitation at the site.

Passive vacuum techniques were used to sample the lysimeters. This technique involved applying a vacuum, closing the sample and vacuum lines, and allowing the vacuum to dissipate over a period of hours. The lysimeters were pressurized with air to collect the samples. Air was the preferred method for this study because it could be derived from a hand-operated pump rather than a bottled source and was found to not have a significant affect on leachate chemistry<sup>3</sup>. The samples were collected through the lysimeters Teflon<sup>®</sup> sample lines.

**Table 1. Lysimeter and Monitoring Well Construction Details**

<b>Instrument</b>	<b>Reference Elevation (feet, msl)</b>	<b>Cup/Screen Depth (feet, bgs)</b>	<b>Cup/Screen Elevation (feet, msl)</b>	<b>Unit Monitored</b>	<b>Construction Material</b>	<b>Pore/Slot Size</b>
<b>Lysimeters</b>						
L101-12	89.1	11.5	77.6	Fly Ash	Ceramic	0.45 µm
L101-16	89.2	16.0	73.2	Filter Material	Ceramic	0.45 µm
L101-30	89.5	30.0	59.5	Native Soil	Ceramic	0.45 µm
L102-9	87.0	9.0	78.0	Fly Ash	Ceramic	0.45 µm
L102-13	87.0	13.5	73.5	Filter Material	Ceramic	0.45 µm
L102-27	86.8	27.0	59.8	Native Soil	Ceramic	0.45 µm
<b>Monitoring Wells</b>						
MW-101	88.97	40.0 - 45.0	49.0 - 44.0	Native Soil	2-in. dia Sch 40 PVC	0.01-in
MW-102	88.91	39.0 - 44.0	50.0 - 45.0	Native Soil	2-in. dia Sch 40 PVC	0.01-in
W-1	70.56	14.0 - 34.0	54.0 - 34.0	Native Soil	2-in. dia Sch 40 PVC	0.02-in
W-2	72.87	17.0 - 37.0	53.0 - 33.0	Native Soil	2-in. dia Sch 40 PVC	0.02-in
W-3	70.54	12.5 - 32.5	54.5 - 34.5	Native Soil	2-in. dia Sch 40 PVC	0.02-in
W-4	66.49	12.5 - 32.5	51.5 - 31.5	Native Soil	2-in. dia Sch 40 PVC	0.02-in
W-5	65.64	18.0 - 38.0	45.0 - 25.0	Native Soil	2-in. dia Sch 40 PVC	0.02-in
W-6	69.36	18.0 - 38.0	49.0 - 29.0	Native Soil	2-in. dia Sch 40 PVC	0.02-in

Reference elevations are top of PVC riser pipe.

All elevations are in feet above mean sea level (msl), USGS datum.

Three lysimeters were sampled in May and June 1999, namely L101-12, L102-9, and L102-27. Water samples could not be obtained from lysimeters L101-16, L101-30, and L102-13 because the materials surrounding the porous cups were believed to be to dry.

Samples were collected from the two new wells in May and July 1999. A dedicated polyethylene bailer was used to purge three wetted casing volumes from the wells before collecting the ground water samples. Samples were field filtered to determine dissolved concentrations of inorganic constituents. SHA collected ground water quality data from the six existing wells on an annual basis since 1994, and these water quality data were used as part of this study.

The water samples were analyzed by Lancaster Laboratories, Inc. for the following constituents: trace elements, including arsenic, barium, beryllium, cadmium, chromium, copper, lead, manganese, nickel, selenium; major cation elements, including aluminum, calcium, iron, magnesium, potassium, sodium; major anions, including chloride, fluoride, sulfate, nitrite, nitrate and alkalinity. Water samples were analyzed for pH, temperature and specific conductance using electronic meters.

## RESULTS

### *Ground Water Level Measurements and Flow Direction*

Three sets of water level measurements obtained in April through June 1999 from the six existing SHA wells and two newly installed wells indicated that ground water elevations were declining, reflecting the concurrent draught conditions in Maryland. As shown on Figure 1, the inferred direction of ground water flow is northeastward.

### *Material Properties*

Geotechnical and chemical material properties were measured for samples collected during installation of the monitoring instruments. The fly ash is comparable to a silt loam and had a laboratory-measured moisture content of 27 percent. Observations made during the drilling to install the lysimeters indicated that the fly ash was visibly moist. The filter material and native soils are classified as loamy sand and sandy loam and have a laboratory-measured moisture content of about 8 percent. Analysis of the geochemical samples indicates the average pH for the fly ash, filter material and native soil is 8.1, 7.5 and 6.3, respectively.

### *Precipitation and Moisture Content Data*

Precipitation measured in the tipping bucket rain gauge for the period April 12 to July 15, 1999 indicated that the total rainfall at the site was 5.4 inches, which is about half of the normal amount for this period. The rainfall data are consistent with the recent drought conditions in eastern Maryland.

The data collected from the moisture probes indicated that the moisture content in the fly ash, and underlying filter and native material did not change over time. The moisture probes indicated that the moisture content in the fly ash (SP-6 and SP-12) ranged from 33 to 48 percent, which was higher than the laboratory measured moisture content of 27 percent. The 16 and 30 foot probes, completed in the filter and native material, respectively, measured moisture in the 35 to 56 percent range, compared to a laboratory measurement of 8 percent. The moisture probes have provided readings that are elevated compared to the laboratory data, and moisture content does not change over time in several probes as the wetting front advances downward. The absence of rainfall has made it difficult to assess the moisture content data, and the reasons for the anomalous results are continuing to be evaluated.

*Pore Water and Ground Water Quality*

Table 2 contains water quality results from the first round of sampling conducted in May and June 1999. Pore water quality in the fly ash (L101-12 and L102-9) is characterized by calcium concentrations ranging from 347 to 509 mg/L, and sulfate concentrations ranging from 1,050 to 1,440 mg/L. Sodium, magnesium, potassium, fluoride, nitrate and chloride were also detected in the fly ash pore waters. Trace elements detected in the fly ash pore water include arsenic (0.041 to 0.079 mg/L), barium (0.052 to 0.103 mg/L), and manganese (non-detect to 1.04 mg/L).

**Table 2. Embankment Water Quality Data**

Parameter	units	5/17/99	5/17/99	5/17/99	5/17/99	6/9/99
		MW-101	MW-102	L101-12	L102-9	L102-27
<b>Trace Elements</b>						
Arsenic	mg/L	<0.010	<0.010	0.041	0.079	<0.010
Barium	mg/L	0.270	0.114	0.103	0.052	0.052
Beryllium	mg/L	<0.002	<0.002	<0.002	<0.002	<0.002
Cadmium	mg/L	<0.0015	<0.0015	<0.0015	<0.0015	<0.0015
Chromium	mg/L	0.0035	<0.0030	0.0050	<0.0030	<0.0030
Copper	mg/L	<0.004	<0.004	<0.004	<0.004	<0.004
Manganese	mg/L	0.240	0.022	<0.002	1.040	4.240
Nickel	mg/L	<0.005	<0.005	<0.005	<0.005	0.0064
Selenium	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01
<b>Cations</b>						
Aluminum	mg/L	<0.2	<0.2	<0.2	<0.2	<0.2
Calcium	mg/L	35.9	13.7	509.0	347.0	171.0
Iron	mg/L	0.140	<0.100	<0.100	<0.100	0.780
Magnesium	mg/L	22.2	16.3	39.0	74.9	98.7
Potassium	mg/L	2.99	1.96	65.80	12.50	10.10
Sodium	mg/L	16.00	5.47	208.00	82.20	43.40
<b>Anions</b>						
Bicarbonate	mg/L	9.4	3.2	NA <sup>a</sup>	NA <sup>a</sup>	556
Carbonate	mg/L	<1.0	<1.0	NA <sup>a</sup>	NA <sup>a</sup>	<1.0
Chloride	mg/L	104	61	350	190	127
Fluoride	mg/L	<0.10	<0.10	0.72	2.13	1.10
Nitrate	mg/L	5.3	7.7	4.7	<0.1	<0.1
Nitrite	mg/L	<0.050	<0.050	0.069	<0.050	<0.050
Sulfate	mg/L	41.5	<5.0	1440.0	1050.0	212.0
<b>Field Parameters</b>						
Temperature	Celcius	16.10	15.40	18.50	18.30	20.50
Specific Conductance	µS/cm	519	295	3280	2260	1266
pH	--	5.0	5.0	8.0	7.5	6.9

<sup>(a)</sup> NA - Not analyzed due to insufficient sample volume. Key results are shown in boxes.

The pore water collected from the underlying native soil (L102-27) indicates that the same constituents were present, but for the most part, at lower concentrations. Calcium decreases almost two-to three-fold, and sulfate decreases five-fold between the 102-9 and L102-27 lysimeters. Arsenic was not detected in the native soil pore water and barium remained at the same concentration. On the other hand, there was a four-fold increase in manganese and iron. Iron was not detected in the fly ash pore water, but was detected in the native soil pore water at a concentration of 0.78 mg/L.

Ground water quality data from wells MW-101 and 102, which are located beneath the lysimeters, indicate that the same major cation and anion constituents are present, but at much lower concentrations. Two exceptions are barium and nitrate. Barium in the underlying ground water is two-fold higher than the pore water, and nitrate is equal to the pore water concentration.

## DISCUSSION

Pore water quality collected from lysimeters L101-12 and L102-9 indicate that leachate is formed when precipitation infiltrates through the fly ash. Precipitation appears to infiltrate into the fly ash through the cover material on the shoulder of the Route 213. The leachate is characterized by elevated concentrations of calcium and sulfate, sodium and chloride, arsenic, magnesium, potassium, barium and fluoride. The presence of calcium and sulfate in the pore water indicate that gypsum (calcium sulfate and water) present in Class F fly ash is dissolving.

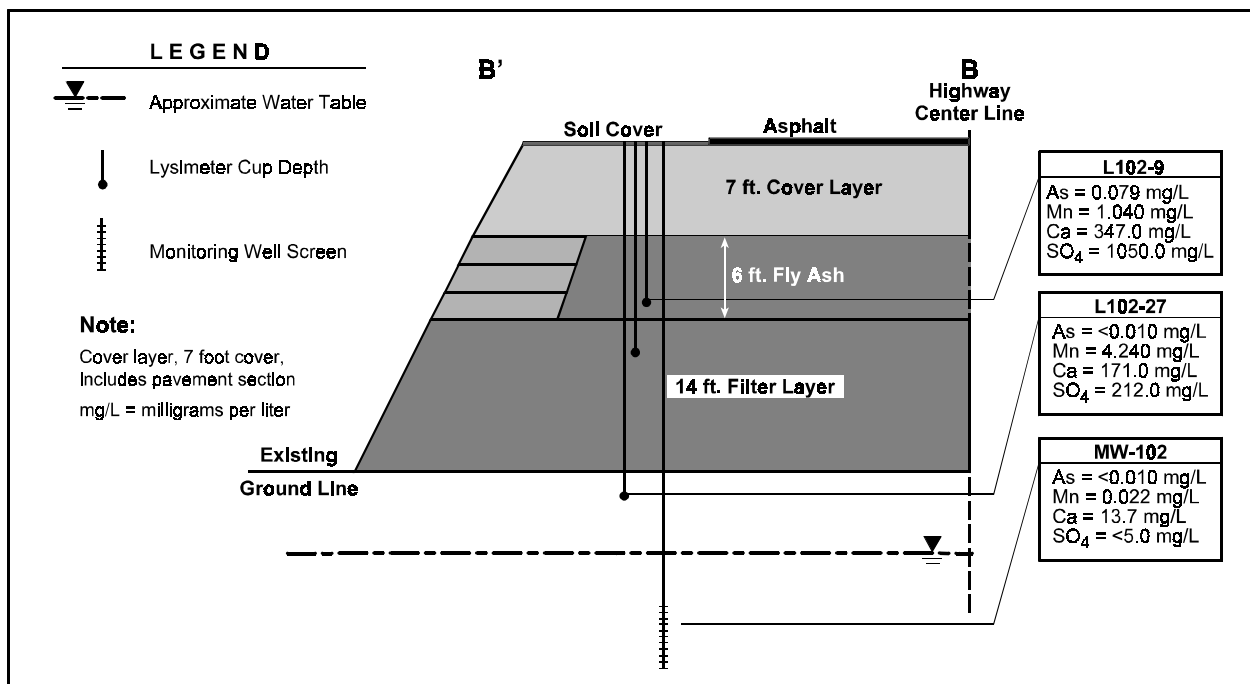


Figure 3. Schematic half-section of Rt. 213 overpass (along line B - B' on south side of Figure 1). Shown are select water quality results for the South (102) Cluster. L102-13 was dry at the time of sampling.



Overall, the water quality data indicate that the inorganic constituents in the fly ash leachate are naturally attenuated as they migrate vertically. Figure 3 illustrates the evolution of the pore water quality as it migrates through the fly ash and native soil, and into the underlying ground water. Three trends regarding the fate and transport of inorganic constituents derived from the fly ash are evident. First, the concentrations of calcium and sulfate and other cations and anions decrease as the leachate migrates vertically. The decreasing concentrations with depth suggest that the calcium sulfate, as well as sodium, magnesium and potassium chloride, are precipitating or adsorbing in the filter material. Second, arsenic was not detected in the L102-27 native soil pore water sample, nor in the underlying ground water sample. Arsenic will adsorb on to ferric hydroxides in oxidizing and high pH environments, thus limiting its mobility. Third, manganese concentrations increase with depth, suggesting that the leachate formed in the fly ash is mobilizing manganese (and possibly iron) in the filter layer or native soil.

Figure 3 shows that concentrations of arsenic, manganese, calcium and sulfate decrease in the underlying ground water, indicating that the leachate is diluted with clean ground water. Barium shows a reverse trend in that the barium concentrations in ground water are two-fold higher than in the fly ash and native soil pore water samples. Concentrations of barium in ground water possibly reflect barite (barium sulfate) naturally present in Coastal Plain soils.

**Table 3. Ground Water Quality Data from July 1994 through June 1999**

Location: Sample ID:	Source		Background			Downgradient		
	MW-101	MW-102	W-1	W-2	W-4	W-3	W-5	W-6
<b>CCP Quality</b>								
Barium, mg/L	0.270	0.114	0.090	0.360	0.260	0.460	0.170	0.120
Calcium, mg/L	35.9	13.7	18.0	14.0	51.0	27.0	54.0	34.0
Magnesium, mg/L	22.2	16.3	10.0	17.0	37.0	34.0	8.9	7.3
Manganese, mg/L	0.24	0.02	0.30	0.05	0.13	2.10	0.02	0.01
Sulfate, mg/L	41.5	<5.0	15.0	2.9	61.0	30.0	15.0	19.3
<b>Roadsalt</b>								
Chloride, mg/L	104	61	34	70	130	240	97	30
Sodium, mg/L	16.0	5.5	10.0	23.0	33.0	120.0	28.0	5.8
<b>Agricultural</b>								
Nitrate, mg/L	5.3	7.7	12.0	17.6	18.2	5.6	9.3	10.0

Results for samples W-1 through W-6 are the maximum reported concentration during the period from July 1994 to June 1998.

Table 3 presents a summary of the ground water quality data collected from the site monitoring wells. The concentrations of calcium and sulfate at MW-101 are not significantly different from background wells, which indicates that the leachate from the fly ash has no discernable impact on water quality. The data also indicate that there could be other anthropogenic effects on water quality, including land application of fertilizer and de-icing salt. The sodium and chloride concentrations in wells W-3 and W-4 are believed to be due to the application of road salt. Elevated nitrate in almost all of the monitoring wells reflects fertilizer applications on the surrounding fields.

## CONCLUSIONS

The key findings of the water quality monitoring at the 213 overpass to date are:

1. The water quality data indicate that the potential for leachate to form in the fly ash is being realized, despite the fact that the majority of the fly ash used in the embankment is covered with impermeable pavement.
2. The leachate constituents, including calcium, sulfate, arsenic, sodium and chloride, are being attenuated in the underlying native soils, possibly due to adsorption and precipitation reactions.
3. Concentrations of arsenic, manganese, calcium and sulfate decrease in the underlying ground water, indicating that the leachate is diluted with clean ground water.
4. The ground water data indicate that the leachate from the fly ash has no discernable impact on ground water quality.

The water quality data collected to date indicate that the use of Class F fly ash for highway embankments can adequately protect ground water quality. Continued monitoring will further evaluate the relationship between precipitation events and leachate formation, seasonal climatic influences, and leachate travel time from the fly ash to ground water.

## ACKNOWLEDGEMENTS

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