

WATER QUALITY AT A COAL ASH FILLED SURFACE COAL MINE PIT IN INDIANA

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Abstract

Coal Combustion Products (CCPs) such as fly ash, bottom ash, and flue gas desulfurization (FGD) sludge are produced in large quantities as residues from the electric power plants using coal as a fuel. Only a few percent of the CCPs produced nationwide in the United States are placed in surface and underground coal mines. In Indiana, there are a number of active and inactive coal mines where mine filling with CCPs is permitted under Indiana Department of Natural Resources regulations. An inactive open-pit created by a surface mining operation offered a unique opportunity to haul and fill the pit with coal fly ash from a nearby power plant. Cinergy acquired the surface mined land from Peabody Coal in 1988 for the explicit purpose of placing about 1.45 million cubic yards (about 1.6 million tons) of coal fly ash to reclaim the land to its original topography and then to maintain the land as a wildlife habitat. From April of 1989 through the end of October 2001, Cinergy deposited approximately 1.6 million tons of CCPs to completely fill the open-pit created by the Peabody coal mining operations. There is a 5-ft soil cover and ground vegetation being planted to complete final grading and restoration of the site.

Cinergy has for the past 13.5 years carried out quarterly water quality monitoring by measuring a large number of parameters in the groundwater and surface water samples. In year 2001, a research project was initiated to (1) first synthesize and analyze available water quality monitoring data for the Cinergy site, and then (2) conduct additional field and laboratory research to assess aerial and temporal distribution of chemicals that could leach and potentially migrate in the groundwater down gradient of the ash fill.

This paper presents a summary of the monitoring and research project results on groundwater and surface water quality at the Universal Mine site now completely filled and reclaimed by the coal ash. The laboratory and field-scale leachate composition data from the Universal site indicates that sulfate, boron, and arsenic are the three constituents of interest leached at different concentrations and, therefore, would have the potential for migration in groundwater. All other monitored constituents are either not leaching at all or are leached at too low concentrations to be of any concern for impacting water quality.

The surface mining operations prior to the placement of coal ash, and also the presence of auger mined areas, resulted in acid mine drainage (AMD) conditions at the Universal site. The AMD water quality was characterized by high acidity; high concentrations of iron, manganese, and sulfate; and lack of alkalinity. The placement of coal ash, which is alkaline in nature, has resulted in significant improvement in the AMD water quality. Nearly all of the acidity has been neutralized and the water now has excess alkalinity. Iron, manganese, and sulfate all have been significantly reduced to lower concentrations as indicated by the long-term water quality monitoring data. Boron appears to be the only coal ash constituent showing leaching and migration in the down gradient water.

The continuing research is expected to provide a better understanding of the long-term water quality impacts and benefits associated with the CCPs mine filling operation. This research is particularly focusing on the leaching, attenuation, and fate of arsenic and boron in groundwater.

Introduction

More than 1.12 billion tons of coal are extracted annually from surface and deep mines in the United States (2001

data from U.S. Department of Energy). Most of the mined coal is combusted in utility boilers to generate electricity. In the year 2000, the U.S. electric utilities produced approximately 108 million tons of coal combustion products (CCPs). Coal fly ash constituted about 63 million tons or about 58 percent of the total CCPs. About 32 percent of the coal fly ash is used mostly for cement/concrete/grout, structural fill, and roadbase/subbase applications (ACAA, 2001). A very small quantity (less than 3 million tons annually) of coal fly ash is returned to mines; however, there is a large potential to use several million tons of CCPs for mine filling in a beneficial manner. But perceptions and lack of reliable scientific data continue to create obstacles in increasing the utilization of CCPs in active and inactive mines. In a regulatory determination on May 22, 2000, the U.S. EPA decided that the Agency will establish national regulations under Subtitle D of RCRA and/or upgrade SMCRA controls for CCPs used to fill surface and/or underground coal and other mineral mines in order to ensure protection of human health and the environment.

In 1988, Cinergy Corporation acquired and began filling with coal ash a final pit created by surface mining of coal at the Universal site in Indiana. Between April 1989 and the end of October 2001, Cinergy placed approximately 1.6 million tons of coal ash from a nearby power plant to completely fill the open-pit. Cinergy has been conducting quarterly monitoring of groundwater and surface water at the Universal ash fill site since early 1988. In 2001, Ish Inc. obtained funding from the U.S. DOE, Cinergy, EPRI, ACAA, and Ish Inc. to conduct additional field and laboratory research on the environmental processes affecting the water quality related to the placement of coal ash in the surface mine final pit at the Universal site. The laboratory research is being carried out at Purdue University.

This paper provides a tabular and graphical summary of water quality data developed by the compliance monitoring and the research project efforts. The paper also provides information on the composition of bulk ash and leachates generated in the laboratory and in the field. Although 34 parameters were typically measured in the water quality monitoring efforts, only a select few will be addressed in detail in this paper.

Site Description and Ash Placement Operations

The Universal coal mine site is located about 5 miles north-northwest of Terre Haute, Indiana in Vigo County. The site is adjacent to the eastern boundary of the Eastern Region Interior Province coalfields of Illinois and southwestern Indiana. These minefields have typically produced medium-to-high volatility bituminous coals of Pennsylvanian and Permian geologic age. Peabody Mining Company began and completed highwall mining operations at the Universal site along a north-south line in the mid-1980s creating a final pit which was approximately 1920 feet long, 325 feet wide, and 90 feet deep.

The geology of the premined consolidated strata consisted of a thin layer of fine clay overlain by an 18-inch thick coal seam that was overlain by shaley limestone, shale, and a thick deposit of loess. The exposed highwall at the Universal site showed a mantle of about 12 to 16 feet of pre-Wisconsin till and Wisconsin loess over the bedrock. The Universal site area is part of an upland landscape north of Coal Creek and west of the Wabash River. The upland rises about 100 feet above the Coal Creek flood plain and was well dissected before surface mining altered the topography.

PSI Energy, Inc. (now Cinergy Corporation) acquired a portion of the Universal mine site containing the final cut pit for the express purpose of coal ash deposition and surface mine reclamation. Indiana DNR issued a permit to PSI Energy to dispose fly ash/bottom ash from its nearby Wabash River Station to fill and reclaim the mine pit. The permit allowed for approximately 1.448 million cubic yards of CCPs to be disposed with ash deposit thickness ranging from 30 to 75 feet. The coal ash placement began sometime between March 13, 1989 and April 6, 1989 and was completed in October 2001.

The coal ash was hauled by tri-axle road-going trucks and placed dry in the mine pit. The coal ash was deposited in the mine pit until the height of the filled area corresponded to the approximate original topographic contour. A five-foot noncompacted soil cap and vegetation are being established as a final cover. The reclaimed mine pit land is to be maintained as a wildlife refuge.

Table 1 shows the annual tonnage of coal ash and coal gasification slag placed in the mine pit at the Universal site during the 13.5 years of mine filling operation.

Chemical Composition of Coal Ash and Leachates

Between May 1988 and December 2001, 25 samples of coal ash were collected and analyzed for total chemical concentrations and for 18-hours and 30-days leachate concentrations. Table 2 provides a statistical summary given by mean, median, maximum, and minimum values based on the measured concentrations for the bulk ash samples. Table 3 provides a statistical summary for the 18-hours and 30-days leaching tests completed on the same ash samples. Table 4 contains a statistical summary of field leachate composition data based on 17 samples collected and analyzed from leachate monitoring well MW-8.

The coal ash deposited at the Universal site contains aluminum, iron, potassium, calcium, magnesium, sulfate, sodium, and boron at average concentrations of greater than 240 mg/Kg. Manganese, zinc, barium, arsenic, vanadium, nickel, chloride, lead, chromium, copper, and fluoride are present in the average concentration range of 18 to 128 mg/Kg. Molybdenum, selenium, cadmium, silver, and mercury are found to range from non-detect to an average of about 5 mg/Kg. The coal ash is alkaline with an average pH of over 9 s.u., has a net neutralization capacity of about 17.6T/1000T, and contains about 5.8 percent total organic carbon.

The laboratory generated leachates as well as the field leachates all contained sulfate as the most abundant constituent that is released from the coal ash. Aluminum, boron, sodium, and calcium were the next most abundant constituents in the laboratory-generated leachates (tables 2-3). The field leachates, however, showed that calcium, sodium, chloride, boron, and potassium were the next most leached constituents (Table 4). The laboratory-generated leachates contained no silver, mercury, nickel, and lead. The field leachates contained no dissolved cadmium, chromium, copper, iron, lead, mercury, nickel, selenium, silver, and zinc. Field and laboratory leachates also showed arsenic with some variability in concentrations.

Time-series plots for pH, sulfate, boron, and arsenic in leachate monitoring well MS-8 are given in figures 1-4. These plots show that ash leachate has a pH of over 9 throughout the monitoring period of 1997-2001. The sulfate concentration in the ash leachate appears to be holding at about 1700 mg/L and boron is present at a concentration of about 45 mg/L. MW-8 monitoring data shows an initial increase in arsenic concentration in the ash leachate followed by a concentration ranging between 180 and 250 µg/L.

Water Quality Monitoring Program

Both groundwater and surface water are monitored on a quarterly basis for the compliance-monitoring program. The Universal site originally installed four groundwater monitoring wells (i.e., MW-1, MW-2, MW-3, and MW-4) in May 1988, approximately one year before the placement of coal ash began in April 1989. MW-4 is an up gradient well installed in the undisturbed bedrock formation and has been monitored for water level and water quality since May 1988 on a quarterly basis.

Monitoring well MW-1 was installed to the northeast side of the ash fill and had a long screen covering both the bedrock and the overlying spoil material. The MW-1 well has been replaced in December 2000 by two new wells designated as MW-1BR and MW-1UR. Monitoring well MW-2 was installed at the edge of the mine fill to the west presumably in the down gradient direction of the groundwater flow. This monitoring well was replaced by a new well MW-2A in 1997 that was properly screened in the mine spoil material to the west and down gradient of the ash fill. The original well MW-3 was installed to the south of the ash fill area, approximately 30-ft down gradient in the mine spoil material. This well was replaced by MW-3R in December 2000. In 1997, additional compliance wells MW-5, MW-6, and MW-7 were installed in the mine spoil material down gradient of the ash fill. In 1997, MW-8 also was installed in the ash fill to monitor chemical composition of the ash leachate. Therefore, the longest series of groundwater monitoring data is available from monitoring wells MW-1, MW-3, and MW-4, with a shorter time-series of data from monitoring wells MW-2, MW-2A, MW-5, MW-6, MW-7, and MW-8. The replacement wells MW-1BR, MW-1UR, and MW-3R are relatively new and have the shortest set of time-series data.

The Ish Inc. research effort has primarily focused on the south side of the ash fill area that covers the down gradient side for studying the groundwater flow and transport of leachate constituents. There are altogether 16 monitoring wells installed for the research project with the first 12 wells installed in March 2001 and the remaining four wells installed in October 2001. CB-9 is an up gradient well that compares in its location to the old up gradient well MW-

4. CB-1S and CB-1D are two leachate monitoring wells installed in the ash fill and screened at shallow and deep depths within the deposited ash. There are three additional spatial locations outside of the ash fill area, where a pair of monitoring wells have been installed to sample and analyze groundwater from shallow and deep zones. Shallow wells are screened in the mine spoil material. A limited amount of monitoring of these CB wells has been completed to date to generate preliminary results on the groundwater quality on the south side.

As part of the compliance monitoring effort, Cinergy also has been sampling and analyzing surface water from an old mine seep location since 1988. Cinergy has since then added five more surface water quality monitoring locations to its compliance monitoring program. These sampling locations are designated as North Pond, Ash Pit-Water Pond, Plug Seep, and two locations in the Coal Creek. In this paper, we will only present and discuss the mine-seep water quality data to depict the benefits and impacts of coal ash placement at the Universal site.

Table 5 provides a list of parameters that have been measured in the water quality samples collected in the groundwater and surface water monitoring programs at the Universal site.

Groundwater Flow

The water level elevation data from the 25 groundwater monitoring wells network suggest that the groundwater from the unmined east side of the ash fill area is flowing to the west into the ash that has resulted in an approximately 30-ft of saturated zone in the reclaimed mine pit. The groundwater then flows in a radial manner to the west, north, and south. This groundwater flow field implies that the old MW-4 and the new CB-9 are up gradient wells and that all other wells are hydraulically down gradient of the placed coal ash.

Groundwater Quality Results

Groundwater quality monitoring data from the wells MW-1, MW-2, MW-2A, MW-3, MW-4, MW-5, MW-6, and MW-7 were evaluated for time trends and changes in concentrations that may be related to the placement of ash. Since MW-3 and MW-4 wells data contain water quality measurements both before and during ash placement from 1988 through the end of 2001, we focused on presenting and discussing those data in this paper. The quarterly monitoring data for pH, acidity, alkalinity, manganese, iron, sulfate, chloride, boron, and arsenic are presented in Figures 5-13 as time-series plots. There are several observations that can be extracted from these time-series plots. The pH time-series plot (Figure 5) indicates that throughout the 13.5 years of monitoring period, pH in groundwater at down gradient well MW-3 is somewhat acidic compared to the near neutral pH in the up gradient well MW-4. Groundwater in well MW-3 contains about 200 mg/L of acidity, whereas MW-4 contains essentially no acidity (Figure 6). Both MW-3 and MW-4 groundwater contains over 350 mg/L alkalinity with MW-3 groundwater being more alkaline than MW-4 from the 1988 through 1998 time period. Both MW-3 and MW-4 have alkalinity of about 450 mg/L between 1998 through 2001 (Figure 7).

Figure 8 shows the time-series plot of manganese concentrations. The up gradient well shows no measurable amounts of manganese for the entire monitoring period, whereas MW-3 has shown manganese present in several mg/L concentration ranges. There appears to be a decrease in manganese concentrations in MW-3 groundwater over the 13-year monitoring period. These monitoring results indicate that dissolved manganese was present at about 5 mg/L level in groundwater down gradient of ash fill area before the ash was placed and, therefore, the observed manganese concentrations in MW-3 are not associated with the placement of ash in the mine pit.

Figure 9 shows the time-series plot of dissolved iron in groundwater at monitoring wells MW-3 and MW-4. Up gradient well MW-4 shows absence of dissolved iron in the groundwater, whereas the down gradient well MW-3 shows an average of about 20 mg/L. Dissolved iron at this elevated concentration was present in well MW-3 before ash placement. The monitoring data leads us to recognize that groundwater in the down gradient well MW-3 contains elevated dissolved iron concentrations that are not associated with the placement of coal ash in the mine pit.

Figure 10 shows the time-series plot of sulfate in groundwater at wells MW-3 and MW-4. The up gradient groundwater measured in MW-4 in an undisturbed geological setting has an average concentration of about 53 mg/L of sulfate, whereas the groundwater in down gradient well MW-3 screened in the mine-spoil material has sulfate concentrations in the range of 1500 mg/L. It is noted that sulfate was present at these elevated concentrations at

MW-3 in water samples collected before the ash placement and that subsequent to ash placement the sulfate level has not increased during 1989 through 2001. This time-series behavior leads us to conclude that even though sulfate is an ash leachate constituent, it has not impacted the down gradient groundwater at MW-3 at the Universal site.

Figure 11 shows the time-series plot of measured chloride concentrations in groundwater at MW-3 and MW-4. The average chloride concentration in the up gradient well MW-4 is about 11 mg/L, and the down gradient well MW-3 contains about 18 mg/L. Chloride in groundwater at these two wells is pretty low and requires no further discussion.

Figure 12 shows the time-series plot for boron concentrations in groundwater at wells MW-3 and MW-4. This plot indicates that the background well MW-4 contains an average concentration of about 0.4 mg/L of boron. The boron concentrations in groundwater at MW-3 do show an increase after early 1990 lasting through 1997 before showing a decrease during 1998 through 2001. The average boron concentration in groundwater at MW-3 is about 2.1 mg/L. Boron is a known leachate constituent associated with coal ash. The field-scale leachate monitoring data show that boron is present in the ash leachate at the site in over 40 mg/L concentrations. Therefore, it is inferred that the elevated boron concentrations in groundwater at MW-3 may be a result of ash leachate migration although there is an approximate 20-fold decrease in concentration between source and the down gradient monitoring well MW-3.

Figure 13 shows the time-series plot for dissolved arsenic in monitoring wells MW-3 and MW-4. The average dissolved arsenic concentration in the up gradient well MW-4 is 5 $\mu\text{g/L}$ with over 95 percent of the data showing below detection limit values. The measured arsenic in MW-3 shows an increase during the monitoring period 1989 through 1996 and then a large variability in concentrations measured during 1997 through 2001. The maximum measured concentration of arsenic in MW-3 was 35 $\mu\text{g/L}$ with about 43 percent of the data showing below detection limit values. The ash leachate data from MW-8 and data from the laboratory leaching tests showed arsenic concentrations to range from about 200 $\mu\text{g/L}$ to 300 $\mu\text{g/L}$. Further research at the Universal site is now evaluating the release and migration of arsenic in groundwater to accurately describe the fate of leached arsenic from coal ash.

The groundwater quality monitoring data also show no significant differences in concentrations of barium, cadmium, chromium, copper, fluoride, lead, mercury, nickel, selenium, silver, and zinc. Sulfate is present at low levels in monitoring wells MW-4 and MW-1, but is found at concentrations between 500 to 2,000 mg/L in wells MW-2, MW-2A, MW-3, MW-5, MW-6, and MW-7. MW-3 contains higher levels of iron, manganese, and boron. Boron concentrations also are higher in groundwater at MW-1, MW-2, MW-2A, MW-5, and MW-6 compared to those found in wells MW-4 and MW-7. The pH in groundwater wells at the site generally falls in the range of 6.8 to 7.2 except for MW-3, which showed a slightly acidic pH of about 6.4.

Table 6 shows a list of wells and distances along an approximate flow path for these wells. CB-9 is the up gradient well, whereas CB3/CB7 wells pair is the furthest down gradient location of the monitoring wells on this flow path. Measured concentrations of sulfate, calcium, and boron as well as pH of groundwater samples collected in December 2001 and February 2002 have been plotted in Figures 10-13 as a function of distance along the groundwater flow path. The concentrations plotted at the 300 feet distance correspond to the ash leachate concentrations in monitoring wells CB-1S and CB-1D. The sulfate plot (Figure 14) shows that in the background well CB-9 (zero feet distance) there is a low level of sulfate, whereas sulfate concentrations in the leachate wells as well as in all other wells extending further down gradient are generally above 400 mg/L with the highest observed value of about 1500 mg/L. Most of these down gradient wells are screened in the mine spoil material.

The calcium concentrations plot in Figure 15 shows that there is a very low level of calcium in the up gradient well CB-9. The leachate wells (CB-1S and CB-1D) have about 650 mg/L calcium with all other down gradient wells showing a range from 100 mg/L to about 400 mg/L. Calcium is typically the ion pair present in sulfate containing water. Generally calcium sulfate and pyrite are involved in defining the geochemistry and the resulting concentrations of calcium and sulfate in groundwater at coal ash and coal mining sites.

Figure 16 shows the boron concentrations plot along the groundwater flow path in the south side of the Universal site. Similar to calcium and sulfate, boron concentrations are quite low in the background monitoring well CB-9. The ash leachate wells CB-1S and CB-1D show some variability between the two depths but contain between 30 to 80 mg/L of dissolved boron. The monitoring well CB-11, located about 15-ft or so outside of the ash fill area, shows boron at 15 to 30 mg/L that decreases to about 5 mg/L in well CB-10 located further down gradient. Boron concentrations in groundwater continue to decrease as one moves further down gradient to well pair CB-7/CB-3.

Figure 17 shows the plot of measured pH in groundwater along the flow path. Both the up gradient well CB-9 and the leachate wells CB-1S and CB-1D show alkaline pH in the range of 9 to 10 s.u. The down gradient wells installed in mine-spoil mostly show a near neutral pH to slightly acidic pH. Therefore, the groundwater pH at the Universal ash site is not affected by the alkaline pH of the ash leachate.

As we collect the longer term monitoring data on the groundwater quality along the flow path, additional evaluations will be completed and findings will be disseminated to interested audiences. The research effort will particularly focus on the leaching, attenuation, and fate of arsenic and boron at the Universal site.

Surface Water Quality

Acid mine drainage (AMD) was present at the Universal site. The AMD was caused by the oxidation of pyrites due to the coal mining operations. An old mine-seep is present to the southeast of the ash fill area. The mine-seep water flows through a surface channel into the Coal Creek located at least 1500 feet further south of the mine-seep area. This old mine-seep water has been quarterly sampled and analyzed for the list of water quality parameters shown in Table 5. We have prepared time-series plots for pH, acidity, alkalinity, manganese, iron, sulfate, chloride, and boron measured in the old mine-seep water since May 1988 through the end of 2001.

Figure 18 is the plot of pH that shows that prior to the coal ash placement, the mine-seep water was highly acidic (i.e., pH < 3.5) and has been completely neutralized to pH 7 by the coal ash deposit in the mine pit. The neutralization of the acidic pH is consistent with the alkaline chemical characteristic of the coal ash.

Figure 19 shows the time-series plot for measured acidity in the mine-seep water. The AMD water contained a large amount of acidity before the coal ash placement in the mine pit. Within one year of the ash deposition, the acidity in the mine-seep water has been nearly eliminated again because of the acid-neutralization capacity of the coal ash placed in the Universal mine pit.

Figure 20 is a time-series plot of measured alkalinity in the mine-seep water. This plot shows the absence of alkalinity during 1988 to 1990 followed by a gradual increase in alkalinity through the end of 2001. Therefore, the coal ash not only has neutralized acidity and increased pH of the groundwater feeding the mine seep, it also has generated additional alkalinity to provide further improvements to the water quality.

Figures 21 and 22 are the time-series plots of measured concentrations of manganese and iron, respectively, in the mine-seep water. Before the coal was placed in the mine pit, the mine-seep, an AMD water, was quite high in dissolved iron (over 100 mg/L) and manganese (over 7 mg/L). But, within a year of ash placement, both iron and manganese concentrations decreased significantly. The long-term monitoring further indicates that dissolved iron has continued to decrease to essentially a non-detect level with manganese also showing a gradual decrease to a concentration of below 2 mg/L in 2001. These decreases are due to the neutralization of acidity and increase in pH achieved by the alkaline ash. An increase in pH and alkalinity has precipitated the dissolved iron and manganese. It is also possible that the lack of oxygen may have stopped the generation of AMD.

Figure 23 is a time-series plot of sulfate concentrations measured in the mine-seep water. This plot shows a clear decrease in sulfate concentrations as a function of time. The sulfate levels of over 2,000 mg/L in 1988 are now reduced to about 1,500 mg/L in 2001. The initially high sulfate concentrations most likely were a result of pyrite oxidation that produced sulfate, iron, and acidic pH waters with low levels of calcium and other base cations in the water. The alkaline coal ash provided large amounts of calcium as well as alkalinity through the leachate. This ash leachate mixed with AMD waters and resulted in the precipitation of iron hydroxide(s) as well as gypsum, thereby creating the modified water quality of the mine-seep that is now low in iron and also sulfate compared to the original AMD waters. Therefore, even though sulfate is a coal ash constituent, in this case there is no distinguishable impact of sulfate on the water quality in the mine-seep.

Figure 24 shows a time-series plot of chloride measured in the mine-seep water. This plot shows a slow increasing trend in chloride concentrations, but the higher chloride levels are still less than about 100 mg/L in 2001.

Figure 25 shows a time-series plot of boron concentrations in the mine-seep water samples monitored since May 1989. For the first two years of monitoring, boron concentrations in the mine-seep water were less than 1 mg/L. Beginning in May 1991, the boron concentrations have been steadily increasing with the highest concentration of about 5 mg/L recorded in 2001. This time-series behavior and the documentation that coal ash leachate at this site contains over 45 mg/L of boron lead to the conclusion that boron contained in the ash leachate has contributed to elevating the boron concentration in the mine-seep water samples.

Summary and Conclusions

This paper provides a limited summary of monitoring results on water quality at a coal ash filled surface coal mine pit in Indiana. The more than 13.5 years of quarterly water quality monitoring data and the more recent extended spatial monitoring data provide insights on coal ash leachates and water quality changes when coal ash has filled and reclaimed a final cut mine pit at the Universal site. The monitoring data to date indicate that the alkaline coal ash leachate has been effective in improving AMD water quality that was present at the site. The coal ash leachate neutralized the acidic pH, increased alkalinity, essentially eliminated acidity, and significantly decreased manganese, iron, and sulfate concentrations. There were no indications of any other trace metals migration via the mine-seep. However, the coal ash leachate did increase significantly boron concentrations in the mine-seep water.

The groundwater quality data similarly show that coal ash leachate has not resulted in the leaching and migration of most of the trace metals contained in ash. Boron, arsenic, and sulfate are leached from the coal ash in different amounts. However, because of the presence of sulfate in groundwater in the spoil material, it is not feasible to discern the migration of sulfate contained in the coal ash leachate from the sulfate contributed by the mine spoil material. The limited data from the research effort does show that boron in the coal ash leachate has migrated out of the mine pit into the groundwater in the mine-spoil material. There is more than an order of magnitude decrease in boron concentration within 150-200 ft down gradient of the ash fill.

The continuing monitoring and the supplemental research at the Universal site will provide better understanding of benefits and impacts from the use of coal ash for mine filling in the next few years.

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Ishwar Murarka has been addressing land and water environmental issues for more than 25 years. Murarka has worked as an environmental professional for Texas Instruments, Argonne National Laboratory, and Electric Power Research Institute (EPRI). After retirement from EPRI in 1998, Ishwar started Ish Inc. as an environmental consulting company specializing in investigating, evaluating, and developing strategies for the remediation of soils, groundwater, and sediments contaminated with metals and organics. He continues to offer consulting services to address environmental issues associated with the disposal and utilization of fossil fuel combustion by-products. He has served on the U.S. EPA's Science Advisory Board (SAB) from 1988 through 2001 in various capacities and continues to be a consultant to the SAB. He is most experienced with the scientific and regulatory deliberations on the management of fossil fuel combustion wastes and the former manufactured gas plant sites. He continues to perform research on leaching, attenuation, and environmental fate of metals and organic constituents. He holds a Ph.D. in Soil Science and Statistics from Oregon State University and an MBA from the University of Chicago. He was an NIH postdoctoral fellow in Biomathematics at North Carolina State University.

Table 1: Annual Tonnage Deposited in the Universal Mine Pit

Year	Coal Ash	Coal Gasification Slag
1989	270,364	0
1990	254,806	0
1991	0	0
1992	320,000	0
1993	0	0
1994	0	0
1995	75,194	0
1996	114,740	0
1997	95,387	0
1998	117,742	23,301
1999	54,368	14,113
2000	152,571	0
2001	151,335	0
TOTAL AMOUNT	\$1,607,507	37,414

Table 2: Statistical Summary of Bulk Composition Data (mg/Kg) of Coal Ash Samples Placed in the Universal Mine Pit

Parameter	# of Samples	Median	Average	Maximum	Minimum
Aluminum	23	7,150	7,373	13,200	42
Iron	25	15,700	15,935	27,500	86
Potassium	23	1,200	1,271	2,700	ND
Magnesium	23	752	714	1,280	ND
Sulfate	25	455	526	2,000	55
Sodium	25	230	276	570	ND
Boron	25	223	241	455	ND
Calcium	4	5,720	5,755	6,680	4,900
Zinc	25	123	129	227	2.1
Barium	25	76	71	220	ND
Manganese	25	80	86	200	1.2
Arsenic	25	57	64	143	ND
Vanadium	23	42	45	71	ND
Nickel	25	40	40	77	ND
Chloride	25	24	41	270	ND
Lead	25	35	36	59	ND
Chromium	25	22	24	42	ND
Copper	25	21	21	41	ND
Fluoride	25	8	18	177	ND
Molybdenum	25	3.7	4.6	12	1.9
Selenium	25	4.1	4.6	9.8	ND
Cadmium	25	1.0	1.1	3.2	ND
Silver	25	ND	0.18	1.6	ND
Mercury	25	0.130	0.113	0.30	ND
Total Organic Carbon	25	52,300	58,357	153,000	5
pH*	22	9.0	9.1	10.6	7.5
Potential Acidity**	25	0.3	2.6	21.6	ND
Neutralization Potential**	25	17.1	19.8	48.6	7.5

*Unit for this parameter is s.u

**Unit for these parameters is T/1000T

.ND = Non-detect

Table 3: Statistical Summary of Concentrations (mg/L) Measured in Coal Ash Leachates

Parameters	18-Hr Leachate			30-Day Leachate	
	# of Samples	Average	Median	Average	Median
Aluminum	23	3.43	2.9	2.73	2.6
Boron	25	2.65	2.3	3.39	3.1
Sulfate	25	135	31	56.8	47
Chloride	25	0.7	ND	1.34	1.1
Iron	25	0.67	ND	0.34	ND
Magnesium	23	0.5	ND	0.44	ND
Potassium	23	0.84	ND	0.78	ND
Sodium	25	1.45	ND	1.59	ND
Arsenic	25	0.285	0.26	0.301	0.31
Fluoride	25	0.225	0.23	0.285	0.29
Vanadium	23	0.18	0.21	0.23	0.27
Molybdenum	25	0.12	0.09	0.13	0.11
pH (standard units)	24	10.05	10.05	9.63	9.66
Barium	25	2	0.04	0.078	ND
Cadmium	25	0.0009	ND	0.0005	ND
Chromium	25	0.01	ND	0.01	0.011
Copper	25	0.008	ND	0.002	ND
Lead	25	0.002	ND	0.006	ND
Manganese	25	0.022	ND	0.004	ND
Nickel	25	0.002	ND	0.003	ND
Selenium	25	0.067	0.058	0.102	0.085
Zinc	25	0.043	0.02	0.018	ND
Silver	25	ND	ND	0.001	ND
Mercury	25	ND	ND	ND	ND
Sulfide	25	0.133	ND	0.077	ND

ND = Non-detect

Table 4: Summary Statistics for Measured Concentrations (mg/L) in MW-8 Leachate Water

Parameter	# of Samples	Mean	Median	Minimum	Maximum
Alkalinity	17	276.2	220	120	530
Boron	17	44.2	46	ND	56
Chloride	17	284.4	91	21	700
Sodium	17	190	120	ND	430
Sulfate	17	1,847	1,700	1,400	3,800
Total Organic Carbon	17	15.4	1.9	ND	110
Magnesium	17	6.6	6.9	ND	8.1
Molybdenum	17	1.7	1.6	0.96	2.3
Aluminum	15	0.38	0.44	ND	0.49
Arsenic	17	0.205	0.208	0.13	0.26
Sulfide	17	0.21	ND	3.4	ND
Barium	17	0.053	0.036	ND	0.35
Fluoride	17	0.007	ND	ND	0.12
Manganese	17	0.012	0.012	ND	0.023
Acidity	17	ND	ND	ND	0.0004
Cadmium	17	ND	ND	ND	ND
Chromium	17	ND	ND	ND	ND
Iron	17	ND	ND	ND	ND
Lead	17	ND	ND	ND	ND
Mercury	17	ND	ND	ND	ND
Selenium	17	ND	ND	ND	0.006
Silver	17	ND	ND	ND	ND
Zinc	17	ND	ND	ND	ND
pH (standard units)	17	8.96	9.2	9.5	6.9

ND = Non-detect

Table 5: List of Water Quality Parameters Monitored at the Universal Site

Acidity	Mercury
Alkalinity	Molybdenum
Aluminum	Nickel
Arsenic	ORP
Boron	Potassium
Cadmium	Selenium
Calcium	Silver
Chromium	Specific Conductivity
Copper	Sulfate
Fluoride	Sulfide
Hardness	Temperature
Iron	TDS
Lead	TSS
Magnesium	TOC
Manganese	Zinc
	pH

Table 6: List of Monitoring Wells and Approximate Linear Distances

Well I.D.	Distance (Feet)
CB-9	0
CB-1S	300
CB-1D	300
CB-11	450
CB-10	480
CB4	580
CB-12S	680
CB-12D	680
CB-13	760
CB-7	830
CB-3	830

Note: These distances are approximate and will be revised once the well locations have been surveyed.

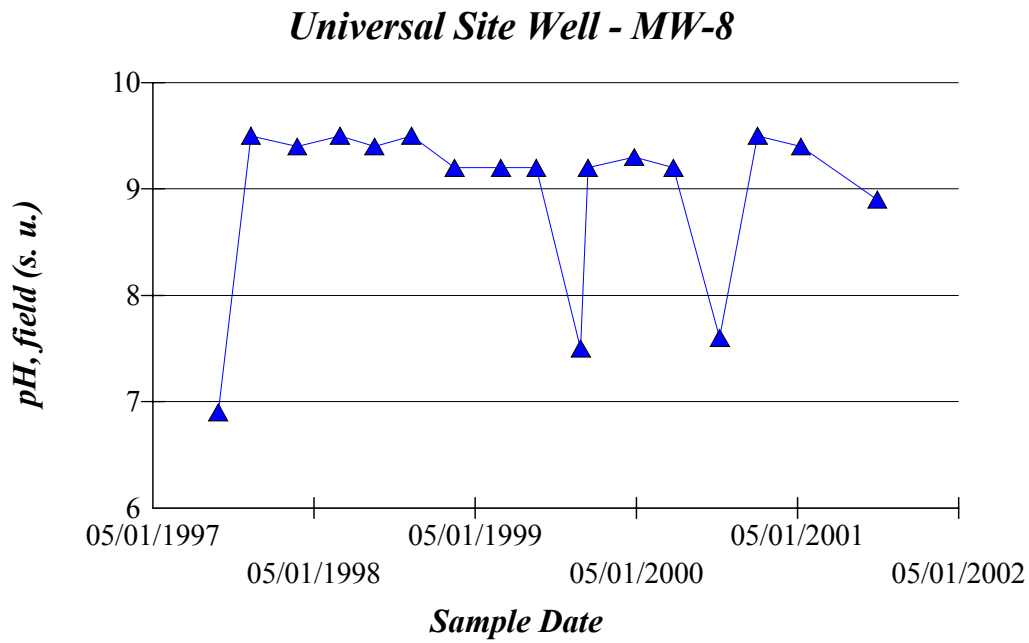


Figure 1. Time Series Plot of Measured pH in Field Leachate Samples

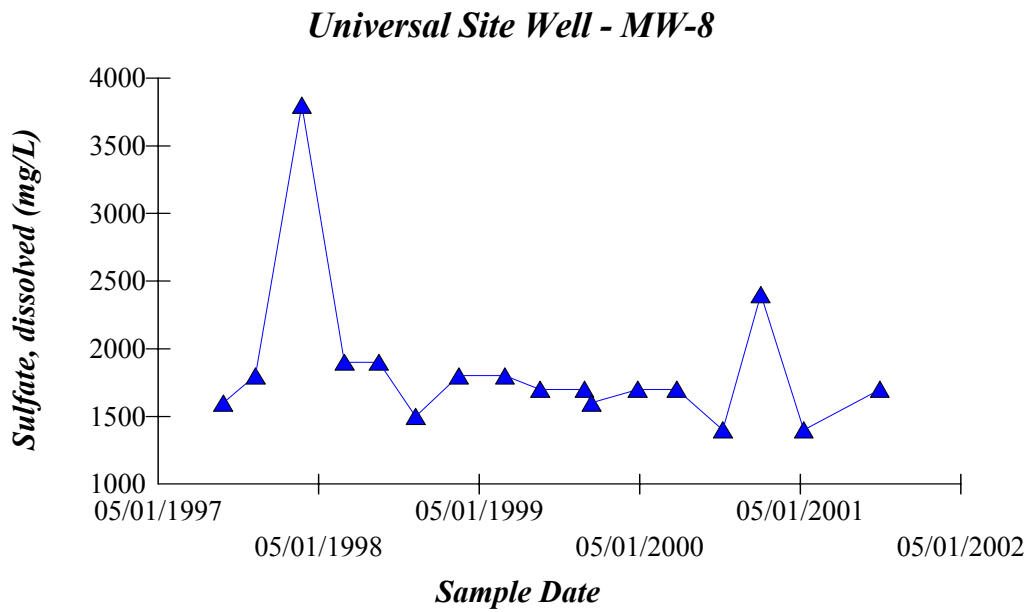


Figure 2. Time-Series Plot of Measured Sulfate Concentrations in Field Leachate Samples

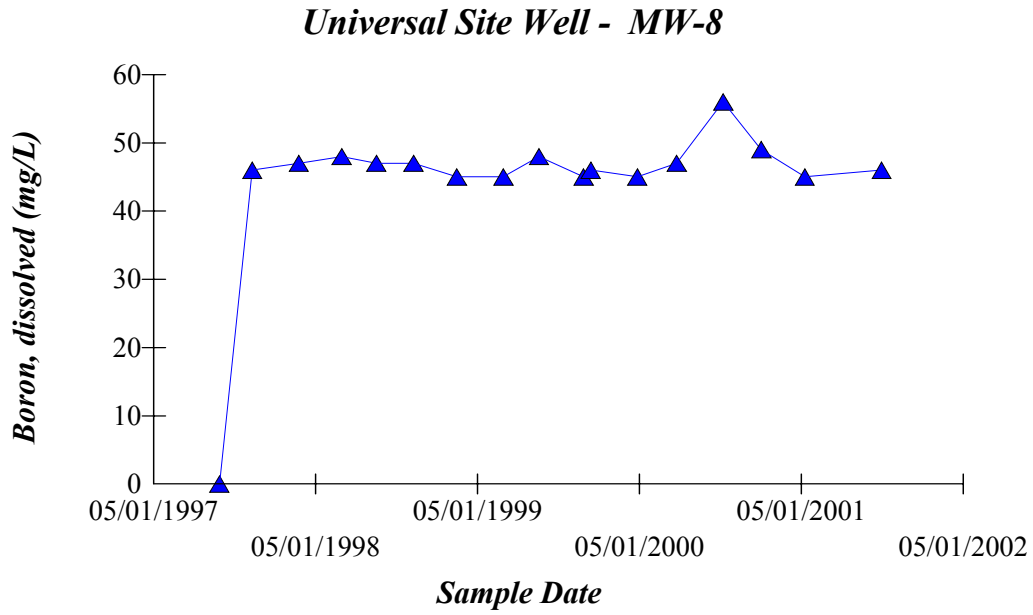


Figure 3. Time-Series Plot of Measured Boron Concentrations in Field Leachate Samples

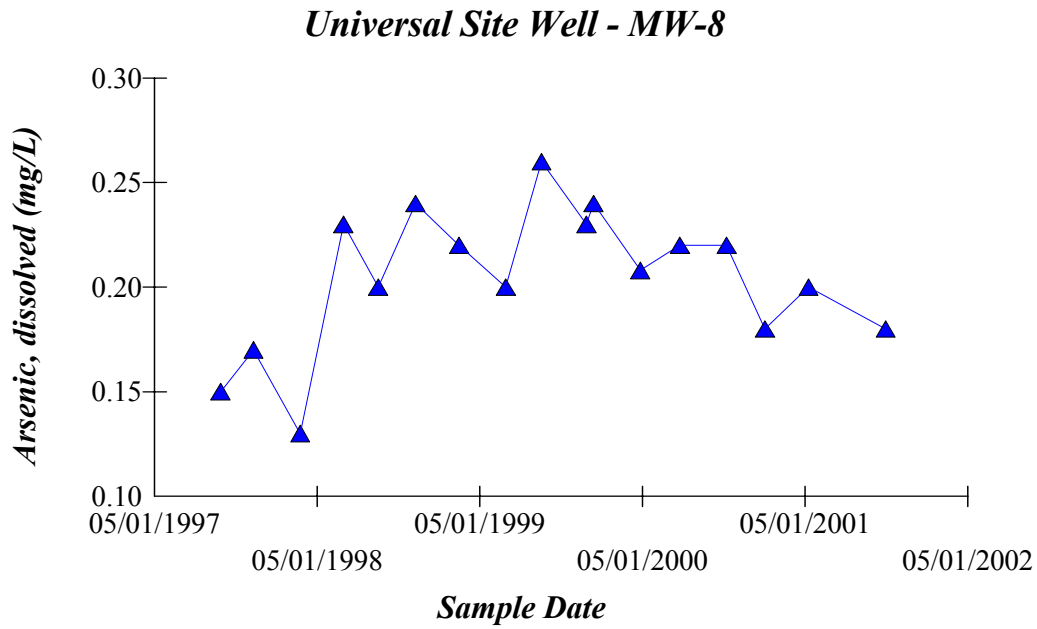


Figure 4. Time-Series Plot of Arsenic Concentrations in Field Leachate Samples

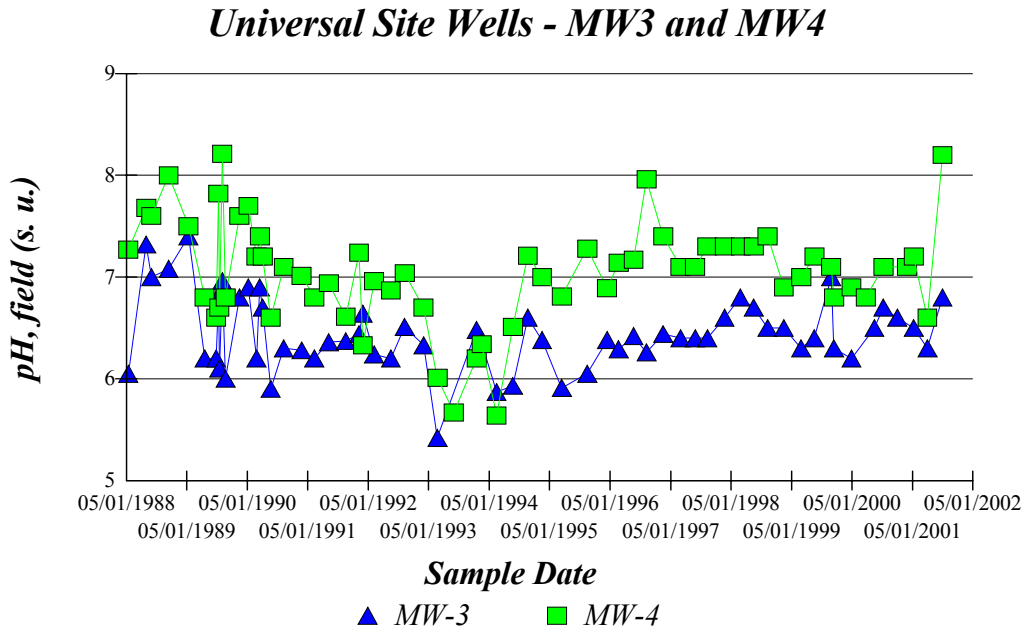


Figure 5. Time-Series Plot Showing pH Measured in Groundwater Samples

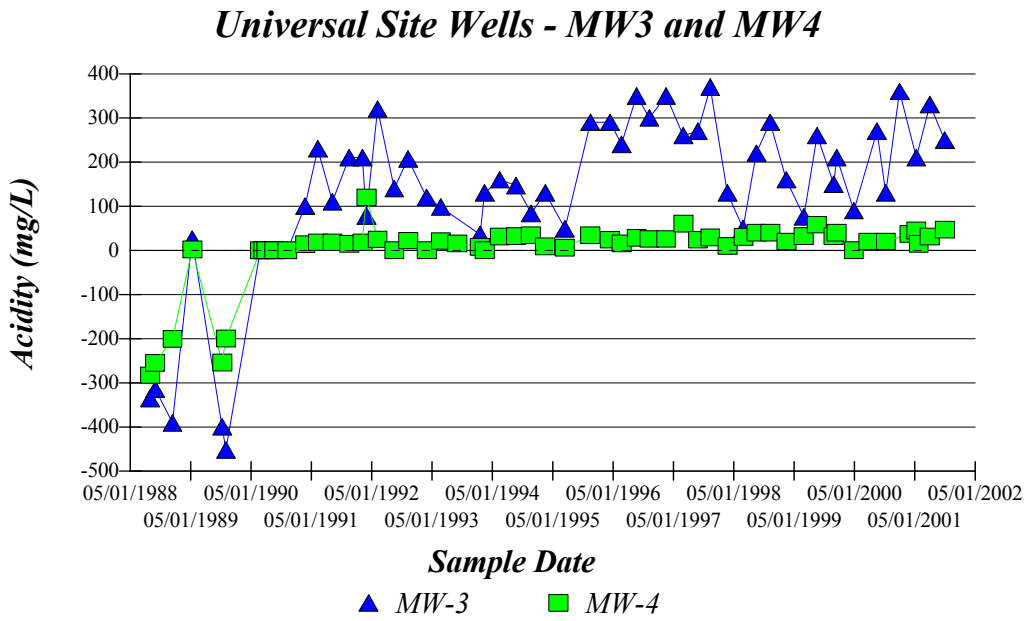


Figure 6. Time-Series Plot of Acidity Measured in Groundwater Samples

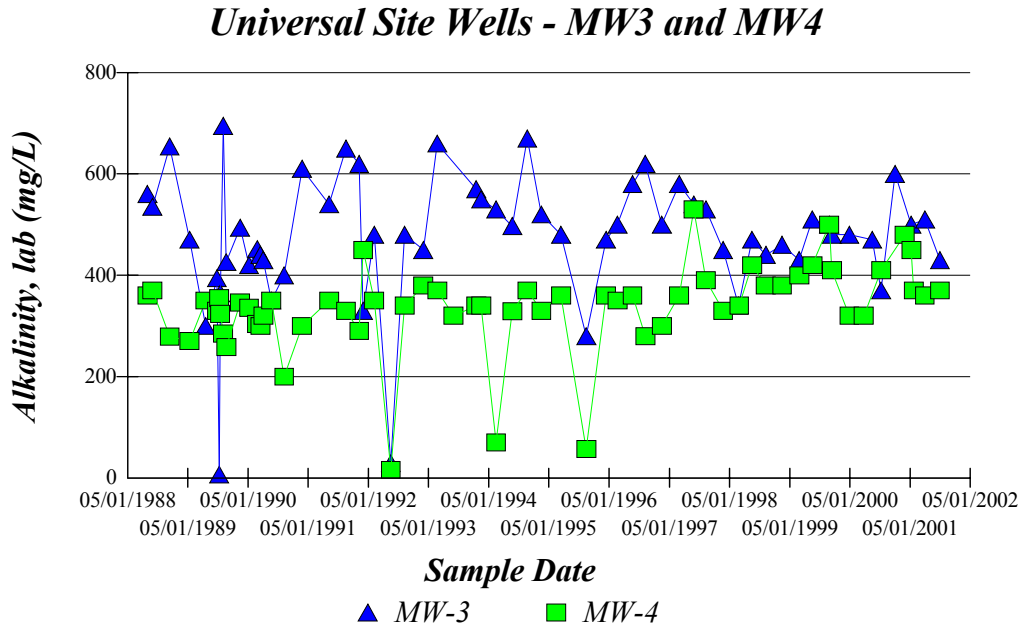


Figure 7. Time-Series Plot of Alkalinity Measured in Groundwater Samples

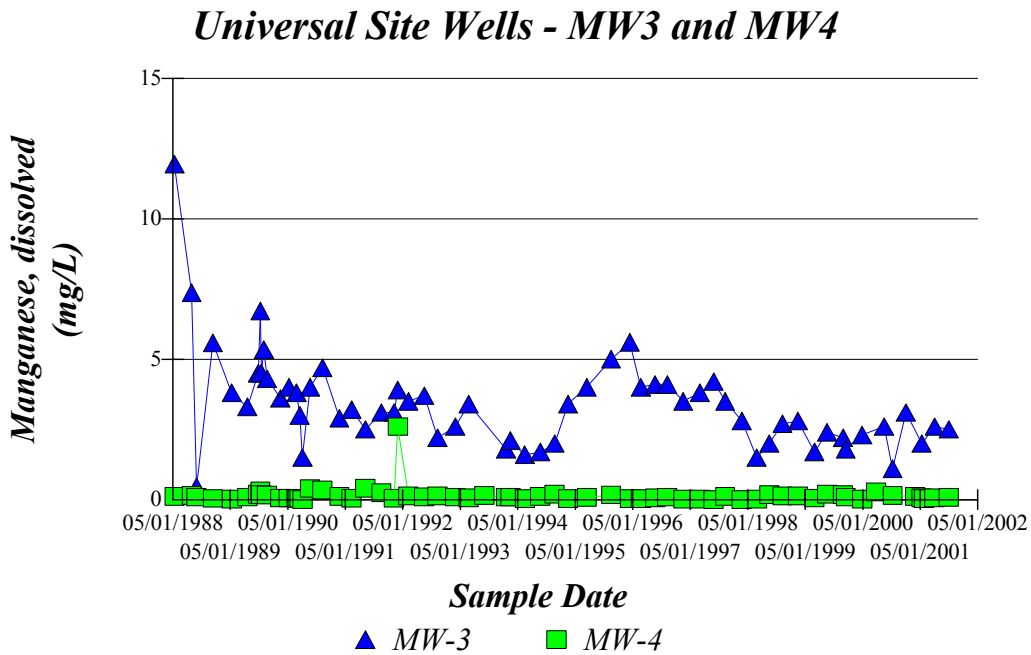


Figure 8. Time-Series Plot of Manganese Measured in Groundwater Samples

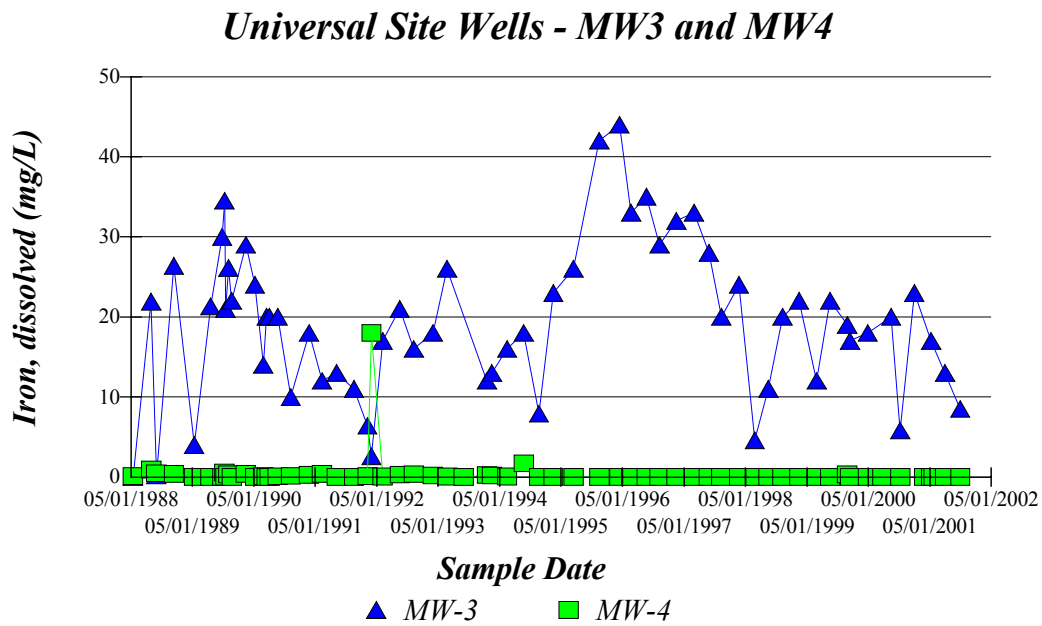


Figure 9. Time-Series Plot of Iron Measured in Groundwater Samples

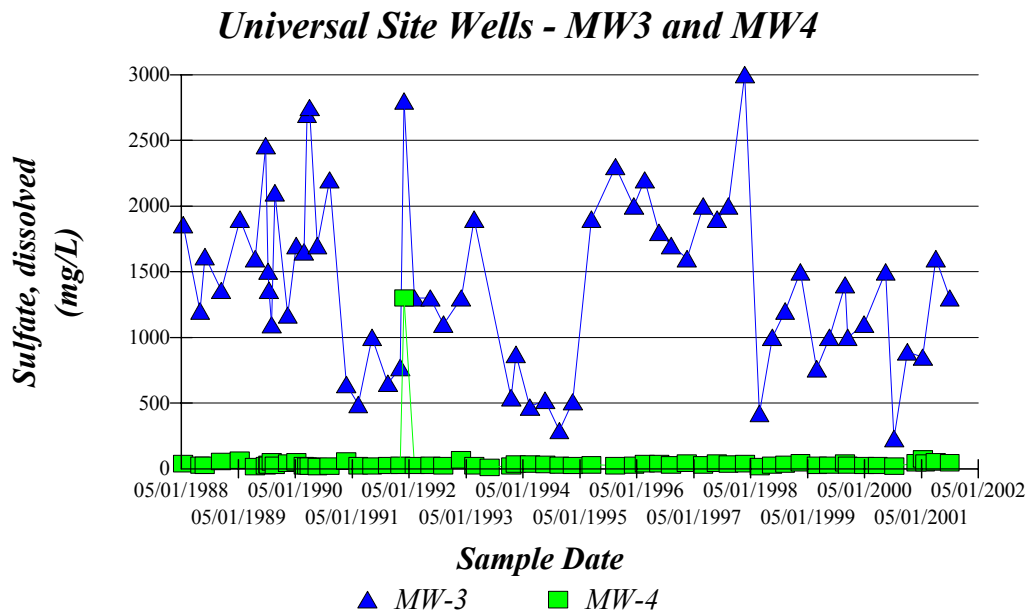


Figure 10. Time-Series Plot of Sulfate Measured in Groundwater Samples.

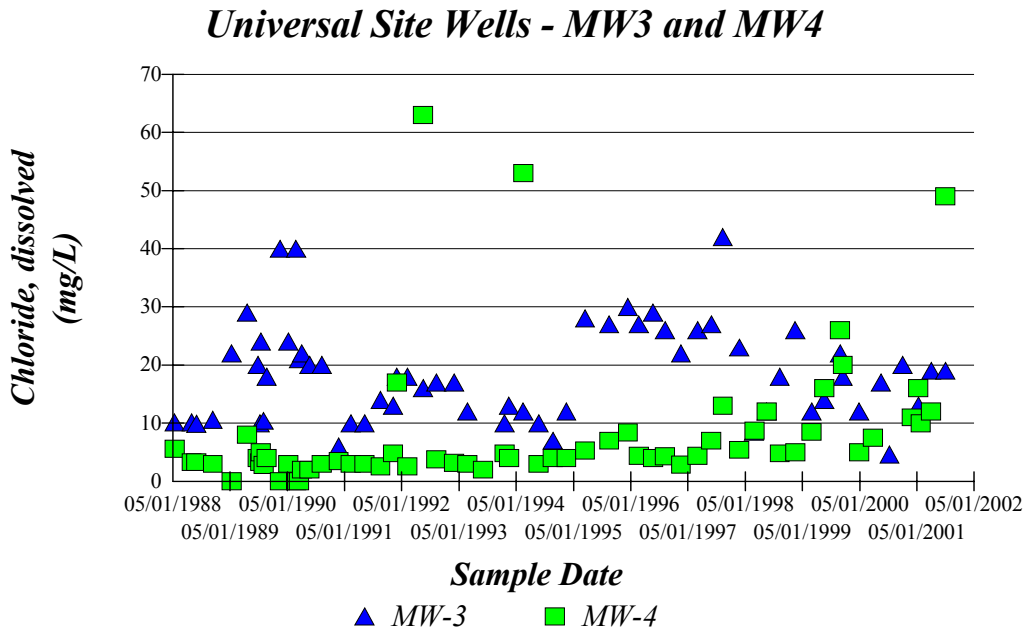


Figure 11. Time-Series Plot of Chloride Measured in Groundwater Samples

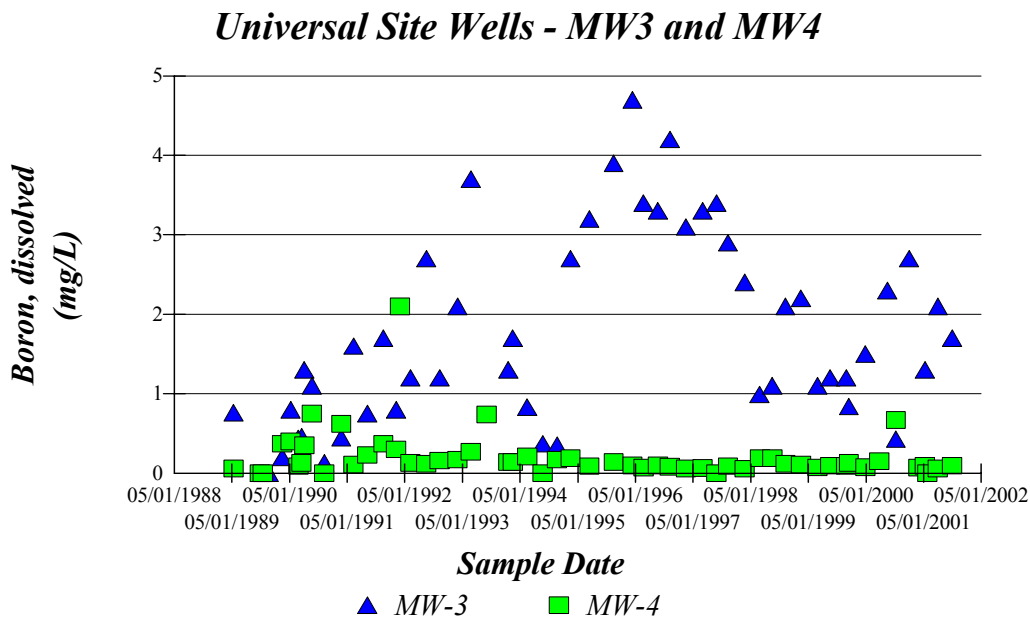


Figure 12. Time-Series Plot of Boron Measured in Groundwater Samples

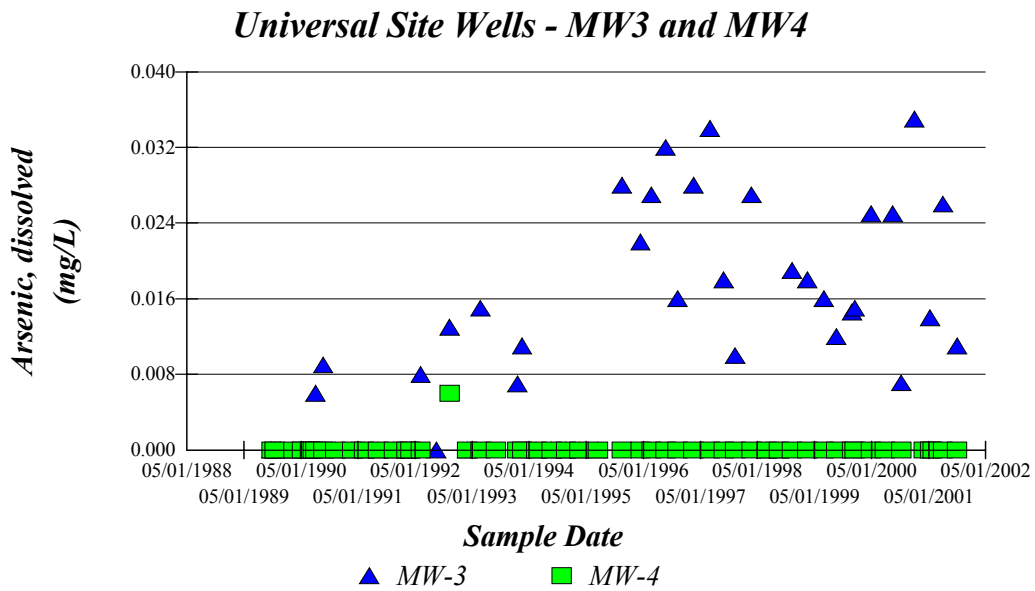


Figure 13. Time-Series Plot of Arsenic Measured in Groundwater Samples

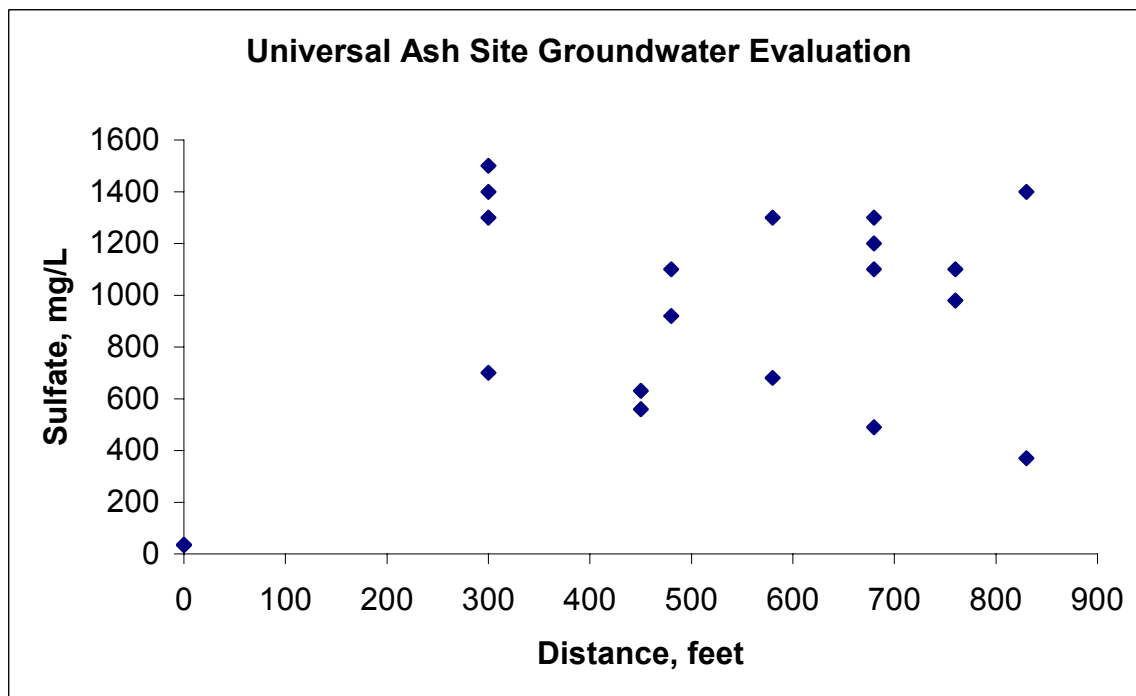


Figure 14. Plot of Sulfate Concentrations as a Function of Distance Along a Groundwater Flow Path

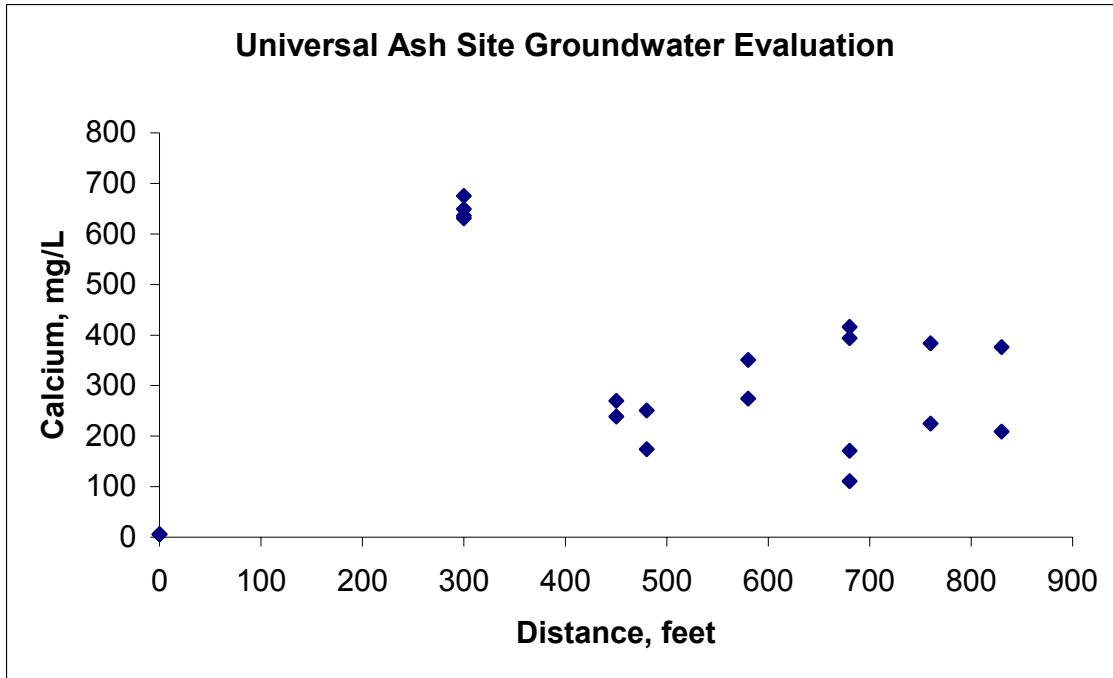


Figure 15. Plot of Calcium Concentrations as a Function of Distance Along a Groundwater Flow Path

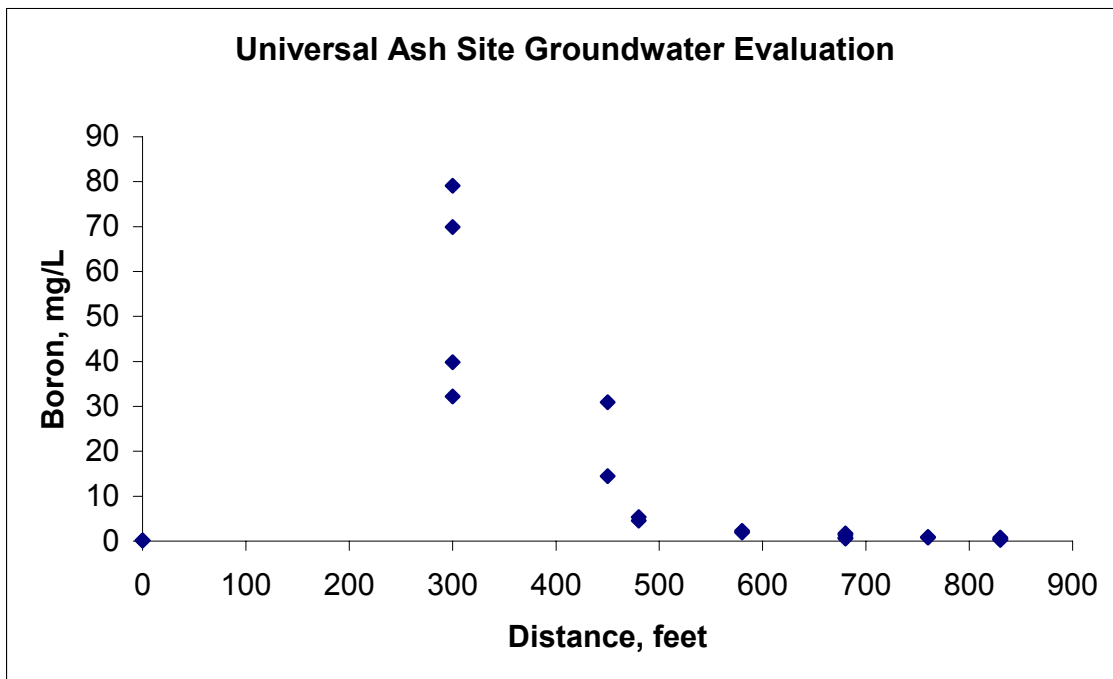


Figure 16. Plot of Boron Concentrations Along a Groundwater Flow Path

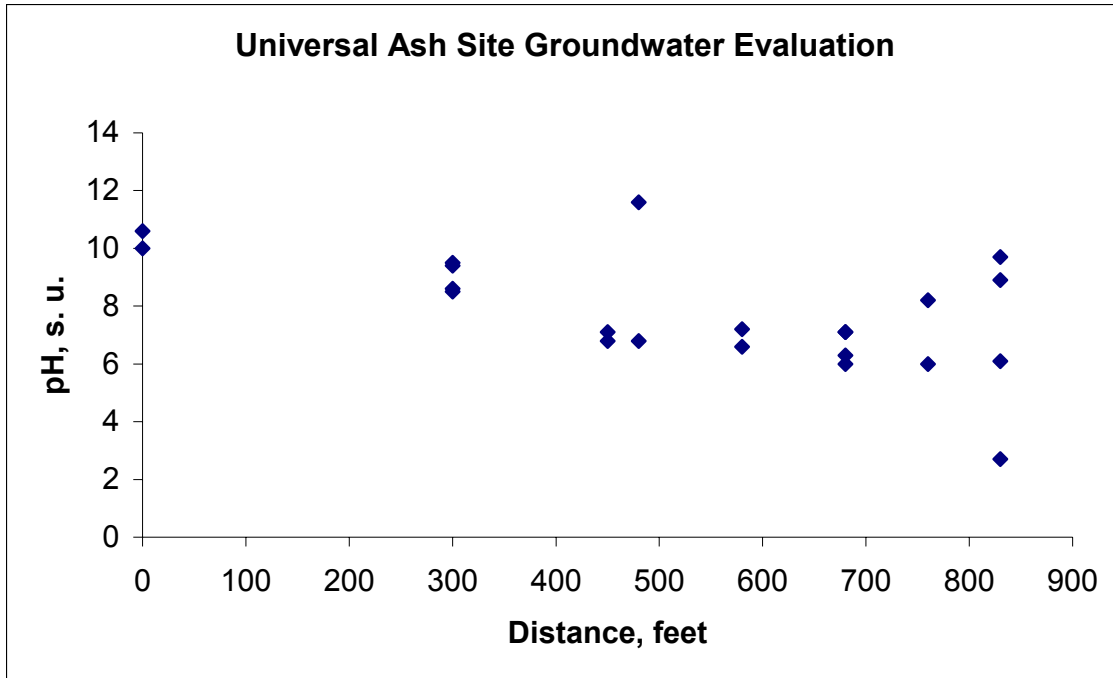


Figure 17. Plot of pH as a Function of Distance Along a Groundwater Flow Path

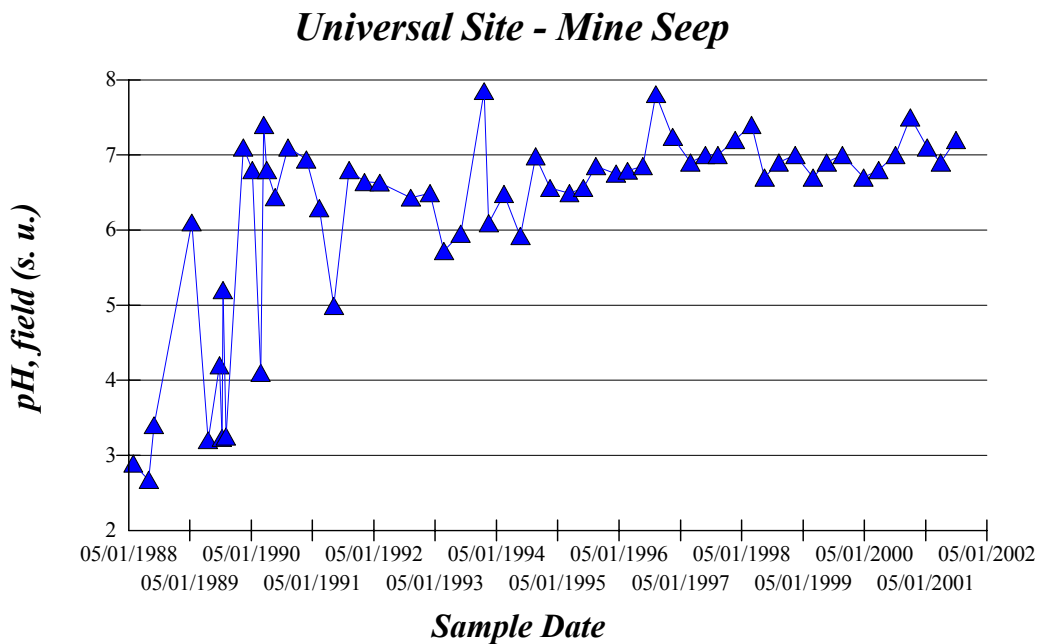


Figure 18. Time-Series Plot of pH Measured in Mine-Seep Water Samples

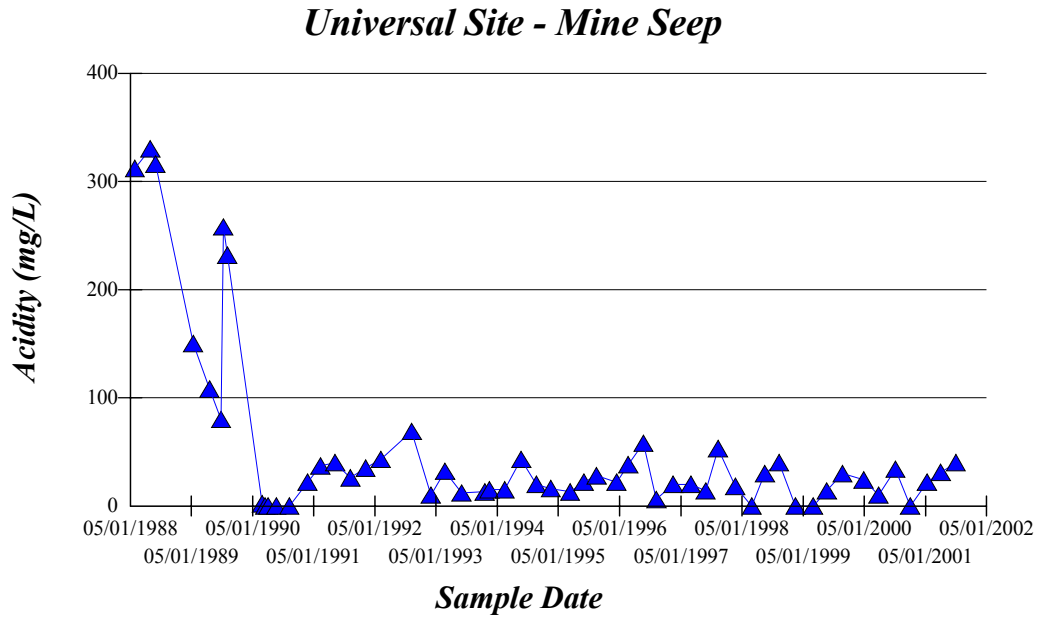


Figure 19. Time-Series Plot of Acidity Measured in Mine-Seep Water Samples

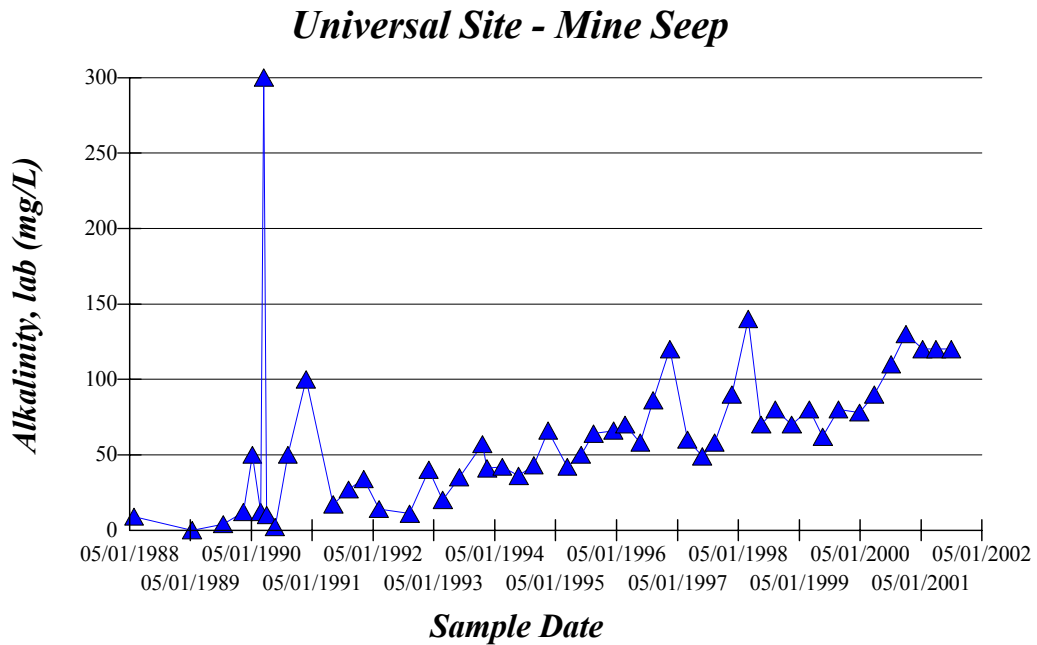


Figure 20. Time-Series Plot of Alkalinity Measured in Mine-Seep Water Samples

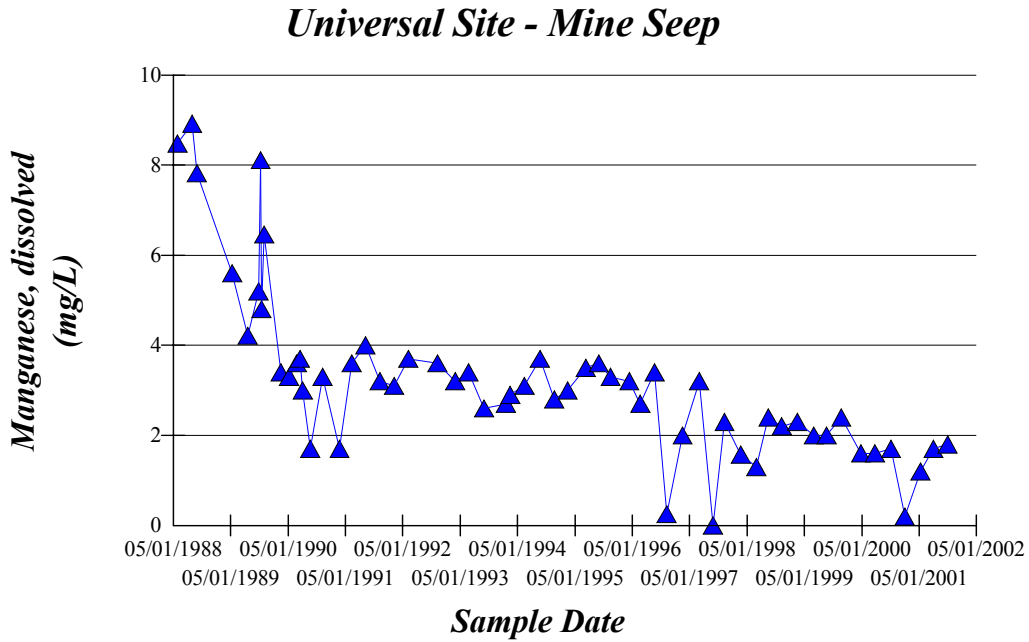


Figure 21. Time-Series Plot of Manganese Measured in Mine-Seep Water Samples

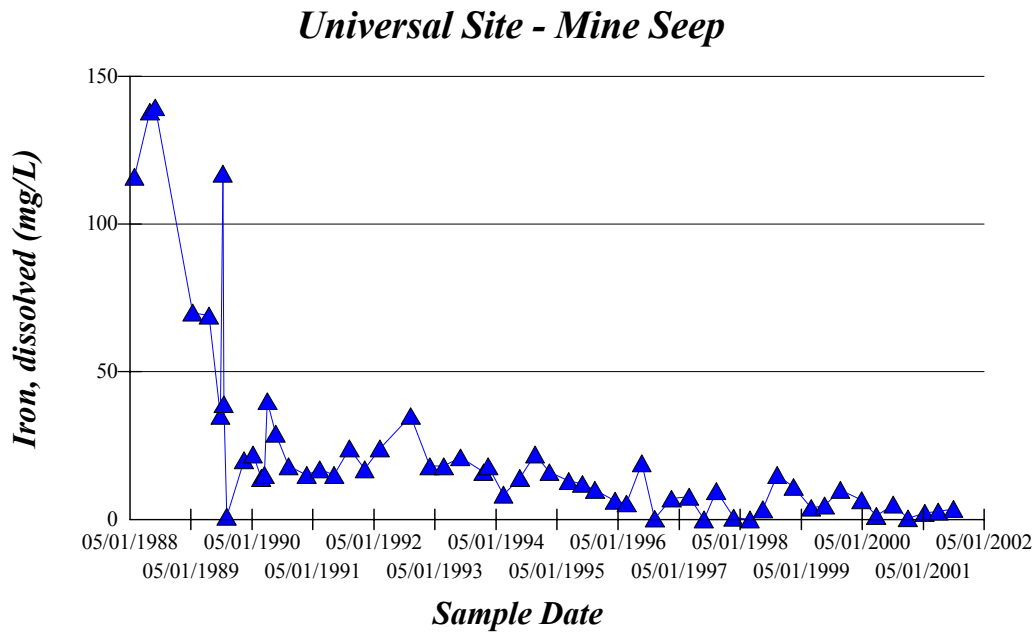


Figure 22. Time-Series Plot of Iron Measured in Mine-Seep Water Samples

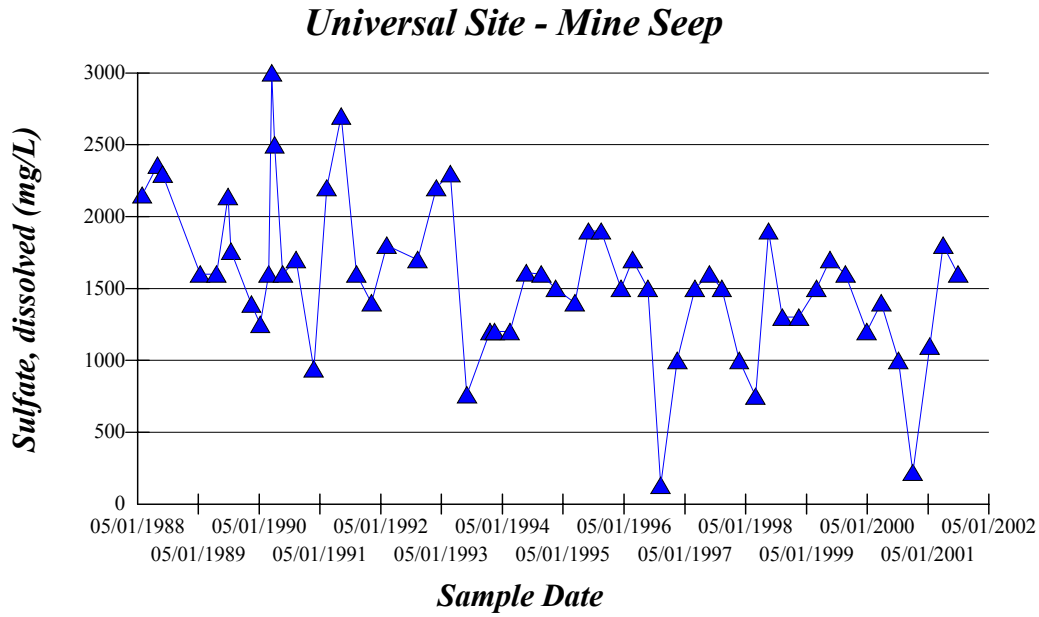


Figure 23. Time-Series Plot of Sulfate Measured in Mine-Seep Water Samples

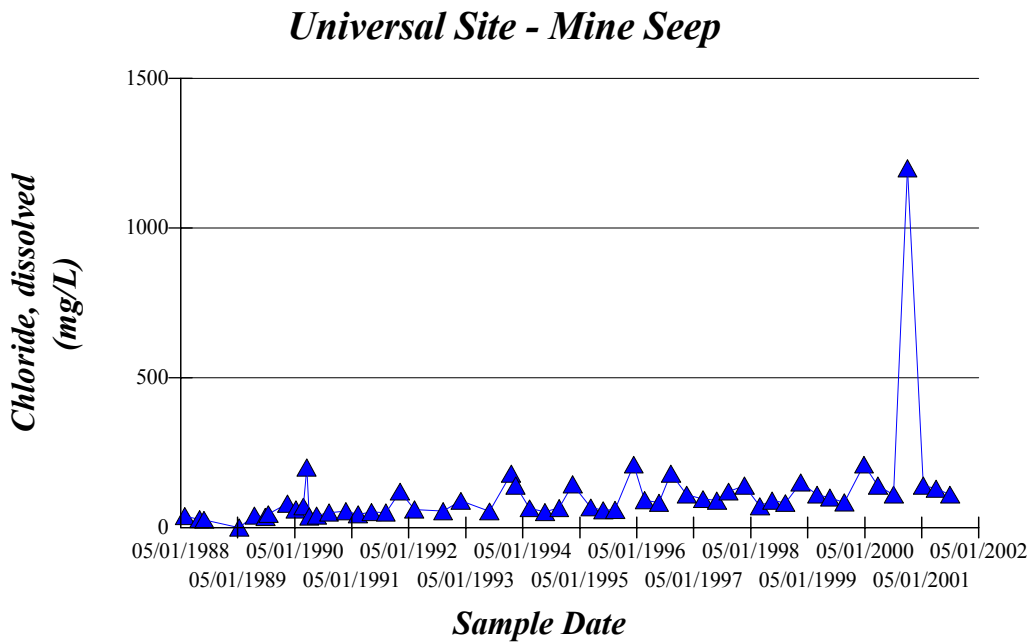


Figure 24. Time-Series Plot of Chloride Measured in Mine-Seep Water Samples

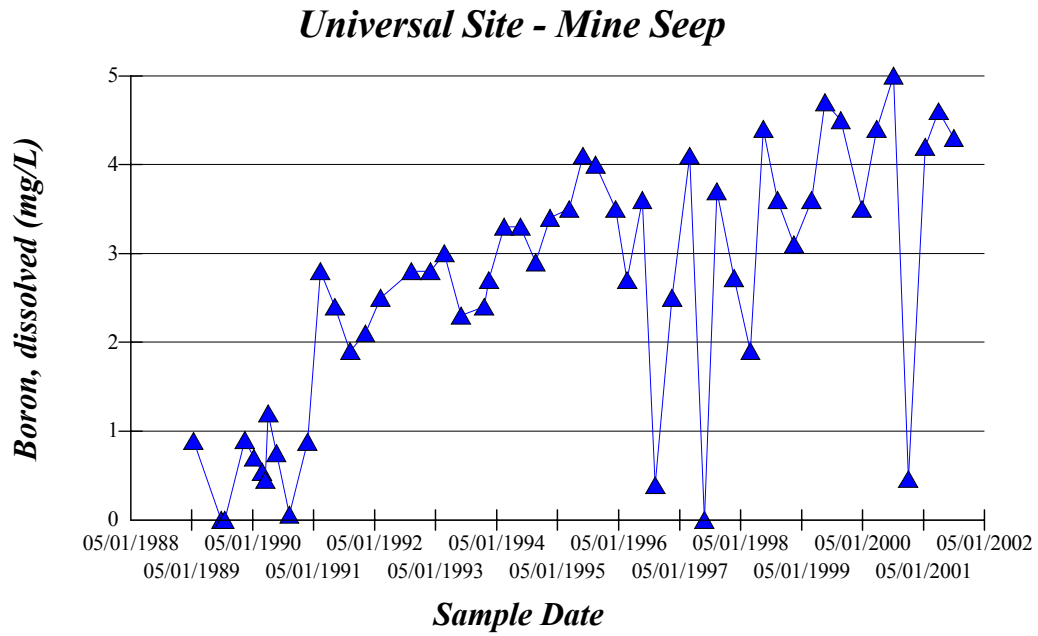


Figure 25. Time Series Plot of Boron Measured in Mine-Seep Water Samples