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## The Evaluation of Metals and Other Substances Released into Coal Mine Accrual Waters on the Wasatch Plateau Coal Field, Utah

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# The Evaluation of Metals and Other Substances Released Into Coal Mine Accrual Waters on the Wasatch Plateau Coal Field, Utah

Alberta J. Seierstad, V. Dean Adams, Vincent A. Lamarra, Nancy J. Hoefs, Robert E. Hinchee



Utah Water Research Laboratory  
Utah State University  
Logan, Utah 84322

WATER QUALITY SERIES  
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August 1983

THE EVALUATION OF METALS AND OTHER SUBSTANCES RELEASED  
INTO COAL MINE ACCRUAL WATERS ON THE WASATCH PLATEAU  
COAL FIELD, UTAH

by

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Nancy J. Hoefs  
Robert E. Hinchee

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## ABSTRACT

Six sites on the Wasatch Plateau were chosen representing subsurface coal mines which were discharging or collecting accrual water on this coal field. Water samples were collected monthly at these sites for a period of 1 year (May 1981 to April 1982). Samples were taken before and after each mine's treatment system. Water samples were analyzed for major anions and cations, trace metals, physical properties, nutrients, total organic carbon, oil and grease, trihalomethanes, and algal assay. Predictions were made as to the possible effects these coal mine accrual waters would have when used for drinking water, irrigation water, stock and wildlife watering, and as discharges into freshwater aquatic ecosystems. Compliance of the mine water discharges with NPDES regulations was also noted.

Crushed coal samples were obtained from each of the six mine sites and evaluated with regard to their leaching characteristics in laboratory upflow leaching columns using an aqueous leaching medium characteristic of the area's water supplies. Leachate samples were analyzed for major anions and cations, trace metals, physical properties, and total organic carbon. Laboratory leaching characteristics were compared to the chemical nature of the actual mine water discharges. Mine water discharges were not found to be acidic in nature, the values for most parameters monitored during the field and laboratory portions of the study fell below the toxicity criteria for uses mentioned above, and were generally in compliance with NPDES regulations.

Boron was present in the mine waters, but at levels which would be predicted to cause only minor or no damage to the most sensitive crops. The drinking water limit and the freshwater aquatic life bioaccumulation criterion for mercury were exceeded on several occasions in the coal mine accrual waters sampled. A comprehensive study of fish tissue samples and water samples taken from bodies of water near coal mines is recommended.

Total suspended solids (TSS) and oil and grease were among the most frequently violated parameters with regard to NPDES regulations. Further studies are recommended with regard to the effects of these substances on stream biota, their sources and their fate in aquatic ecosystems.

Coal leaching trends in the laboratory column experiments paralleled many of the trends observed in the field data collected. Trends for pH, aluminum, arsenic, beryllium, cadmium, chromium, cobalt, copper, iron, lead, molybdenum, nickel, silver, zinc, boron, lithium, strontium, alkalinity, chloride, fluoride, potassium, sodium, and silica were generally consistent when

these comparisons were made. Values for water hardness parameters were observed to be specific to the mine site involved and not always comparable to laboratory leachate column data.

Generalizations with respect to leaching trends and origins of chemical substances in coal mine accrual waters must be made with caution due to the great potential variability in coal samples and the complexity of leaching phenomena.

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The principal investigators on this project were Vincent A. Lamarra, Adjunct Research Assistant Professor, Utah Water Research Laboratory; V. Dean Adams, Associate Professor, Department of Civil and Environmental Engineering, Utah State University and the Utah Water Research Laboratory; and Alberta J. Seierstad, Research Scientist-Chemist, Utah Water Research Laboratory. Other investigators were Nancy J. Hoefs, Research Aide II, Utah Water Research Laboratory, and Robert E. Hinchee, Graduate Student, Department of Civil and Environmental Engineering, Utah State University.

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ABBREVIATIONS,  
CONVERSION FACTORS, AND DEFINITIONS

A sampling site - coal mine accrual water sampling site located prior to mine's treatment.

adj. SAR - adjusted sodium absorption ratio.

B sampling site - coal mine accrual water sampling site located after mine's treatment.

°C - temperature in degrees Celsius.

cm - centimeter; 0.01 meter, 0.3937 inch.

coal mine accrual water - underground and surface water that is diverted and collected within a subsurface coal mine and which is sometimes discharged.

col - upflow coal leachate column, followed by mine site number and column replicate number.

DDW - doubly-deionized water.

detection limit - the lowest detectable quantity of the parameter in question.

dissolved constituent - a parameter whose concentration value is determined after the sample is filtered through a 0.45  $\mu$ m membrane filter.

EDTA -  $\text{Na}_2\text{EDTA}\cdot 2\text{H}_2\text{O}$ , [disodium (ethylenedinitrilo) tetraacetate].

EPA - U.S. Environmental Protection Agency.

equivalent weight - the combining weight of a compound depending on the reaction in which it is involved; usually molecular weight divided by oxidation state or number of replaceable hydrogens.

ft - foot; 0.3048 meter.

foot candle - unit of light intensity, 1 lumen incident per square foot, 10.76 lux.

g - gram; 1000 milligrams, 0.002205 pound.

G - gallon; 3.785 liters, 0.13368 cubic foot.

GPM - gallons per minute.

HCl - hydrochloric acid.

HNO<sub>3</sub> - nitric acid.

H<sub>2</sub>SO<sub>4</sub> - sulfuric acid.

in - inch; 2.540 centimeters.

inst. THM - instantaneous trihalomethane; the THM concentration at the time of sample collection.

kg - kilogram; 1000 grams, 2.205 pounds.

km - kilometer; 1000 meters, 0.6214 mile.

km<sup>2</sup> - square kilometer; 0.3861 square mile.

l - liter; 1000 milliliters, 0.2642 gallon.

LC<sub>50</sub> - toxicant concentration producing death of 50 percent of the test organisms at the time of exposure designated.

limiting nutrient - the nutrient most needed for growth in relation to the quantities of other nutrients.

m - meter; 1000 millimeters, 3.281 feet.

m<sup>3</sup>/day - cubic meters per day; 264.2 gallons per day.

maximum standing crop - maximum dry weight of algae attained during an algal assay bottle test.

mean - the summation of the data observations divided by the number of replicates.

mg - milligram; 1000 micrograms, 0.001 gram.

mg/kg - milligrams of substance per kilogram total weight, approximately equal to parts per million.

mg/liter or mg/l - milligrams per liter, approximately equal to parts per million.

MGD - million gallons per day; 0.003785 cubic meters per day.

mi - mile; 1.609 kilometers.

milliequivalent weight - equivalent weight divided by one thousand.



minewater discharge - coal mine accrual water that is discharged usually after treatment, may also include runoff from the site.

ml - milliliter; 0.001 liter.

mm - millimeter; 0.001 meter.

MPN - most probable number with regard to total and fecal coliform bacteria.

MTP THM - maximum total potential trihalomethane, the THM concentration after addition of chlorine to an unchlorinated water source followed by 7 days of incubation.

n - number of replicates.

N - normality; concentration in equivalents per liter.

NH<sub>3</sub>-N - ammonia-nitrogen; ammonia concentration expressed as micrograms nitrogen per liter.

nm - nanometer; 10<sup>-9</sup> meter.

NO<sub>2</sub>-N - nitrite-nitrogen; nitrite concentration expressed as micrograms nitrogen per liter.

NO<sub>3</sub>-N - nitrate-nitrogen; nitrate concentration expressed as milligrams nitrogen per liter.

N:P - nitrogen to phosphorus ratio, total soluble inorganic nitrogen divided by orthophosphate.

NPDES - National Pollution Discharge Elimination System.

Orthophosphate - reactive phosphorus which does not require hydrolysis or oxidative digestion prior to analysis.

percent solutions - solutions prepared volume/volume with DDW to give the percentage indicated.

PO<sub>4</sub>-P - orthophosphate; orthophosphate concentration expressed as micrograms phosphorus per liter.

psi - pounds per square inch.

standard deviation - the square root of the sum of the squares of the deviations from the mean divided by one less than the number of observations.

TDS - total dissolved solids expressed in milligrams per liter.

THM - trihalomethane; a group of organic compounds whose structure contains one carbon atom, one hydrogen atom, and three halogen atoms (chlorine or bromine).

TOC - total organic carbon expressed as milligrams carbon per liter.

total constituent - a parameter whose concentration value is determined using an unfiltered sample; value includes concentration of suspended and particulate materials.

total THM - summation of all trihalomethane compounds detected in a sample.

toxic - producing adverse effects to a test organism, dependent on concentration of the toxicant and time of exposure.

TSIN - total soluble inorganic nitrogen; ammonia-nitrogen plus nitrate-nitrogen plus nitrite-nitrogen.

TSS - total suspended solids expressed in milligrams per liter.

USGS - United States Geological Survey.

UWRL - Utah Water Research Laboratory.

$\mu\text{g}$  - microgram;  $10^{-6}$  gram, 0.001 milligram.

$\mu\text{g}/\text{l}$  - micrograms per liter; approximately equal to parts per billion.

$\mu\text{l}$  - microliter;  $10^{-6}$  liter; 0.001 milliliter.

$\mu\text{mhos}/\text{cm}$  - micromhos per centimeter; unit of specific conductance, equivalent to 0.1 millisiemens.

< - less than.

## INTRODUCTION

Recent shortages of oil and other energy supplies have placed a greater importance on the discovery and development of energy reserves. A good portion of this emphasis has centered on coal reserves, especially those in the western U.S. At the present time there are about 70 coal mines operating in Utah, Idaho, Wyoming, Nevada, Colorado, Arizona, and New Mexico. More than 60 percent of these are subsurface mines (USGS 1979).

Few studies have been involved with the identification and effects of heavy metals, organics and other chemical substances released into the aquatic environment and onto agricultural lands as a direct result of coal mining activities. Most of these studies have concentrated on effects from eastern coal operations where acid drainage can be a severe problem. Western coal sources, especially those on the Wasatch Plateau, are often very low in sulfur content. Here acid drainage is much less of a problem.

Development of coal reserves may have effects on aquatic resources and surface and underground water supplies. Due to the nature of subsur-

face mining, underground and surface water is often accrued within the mine itself. The accrual water can come from the land surface due to subsidence or from underground aquifers which are drained as the coal is removed. (USGS 1979.)

Because these diverted water supplies are often in direct contact with the coal seams and are affected by other aspects of coal mining operations, some alteration in water quality can be expected. The objectives of this study were to determine the nature of coal mine accrual waters collected within and discharged from subsurface coal mines on the Wasatch Plateau coal field. Observations were also made as to the predicted effects of these waters when used for drinking water, irrigation, stock and wildlife watering, as components in freshwater aquatic ecosystems, and with regard to requirements of the National Pollution Discharge Elimination System (NPDES). The second phase of the study evaluated crushed coal samples from each of the mine sites with regard to their leaching characteristics in the laboratory upon contact with an aqueous medium characteristic of the area's water supplies.

## OBJECTIVES

The objectives of this research were to:

1. Determine the chemical nature of coal mine accrual waters discharged from the Wasatch Plateau coal field by sampling waters collected within and discharged from subsurface coal mines on the Plateau for a period of one year.

2. Predict the effects when these waters would be used for drinking water, irrigation water, stock and wildlife watering and as discharges into freshwater aquatic ecosystems.

3. Evaluate compliance of the minewater discharges with NPDES regulations.

4. Evaluate crushed coal samples from each of the mine sites with regard to their leaching characteristics in laboratory upflow leaching columns using an aqueous leaching medium characteristic of the area's water supplies.

5. Compare laboratory leaching characteristics to the chemical nature of the actual minewater discharges.

## LITERATURE REVIEW

Increasing utilization of coal as an energy source has led to the need for more research on the effects brought about by this increased consumption. Potential water quality problems can only be resolved by research which focuses on characterization of the source and transformation and fate of the potential pollutants (The Federal Research Group 1981; Olem 1982). There is also a need to develop analytical techniques which identify the means of occurrence of heavy metals (The Federal Research Group 1981). In reviewing water quality issues, Davis and Boegly (1981b) have seen the need for a standard laboratory leaching test which could identify and predict leachate quality from coal storage piles and other instances which would result in coal-water interactions.

President Carter's 1977 National Energy Plan called for increased usage of the nation's coal reserves and the establishment of a committee to study any possible health and ecological effects. One of the committee's conclusions was that it was safe to proceed if strict compliance was maintained with respect to federal and state air, water and solid waste regulations (The Committee on Health and Environmental Effects of Increased Coal Utilization 1980). The goal of energy sufficiency has resulted in policy conflicts among the energy industry, environmentalists, and government concerning resource scarcity, sense of urgency, lack of experience, administrative complexity, uncertainty about future policies and regulations, technological complexity, and uncertainty about actual impacts (Brown et al. 1979). Coal use can result in large increases of toxic substances in the environment, but since

fate and effects of toxicants are not completely understood, policy considerations are largely dominated by uncertainty (Rogers and Savitz 1980). Specific negative effects of mining on water resources are almost impossible to anticipate before they happen. The coal industry is only one of many concerns competing for groundwater resources. Mining can affect both the quantity and quality of these supplies, sometimes producing degradations which are difficult to reverse. (National Research Council 1981.) Aquatic ecosystems can also be affected by mining in ways other than water quality. Streams can be affected by disruption of natural aquifers, land subsidence can permanently alter spring and stream flows and cause impoundment of groundwater, and increasing local industrialization can result in added demands on municipal and recreational water resources (Ramakka 1979).

The organic structure of coal is very complex, consisting mainly of aromatic rings in a large polymeric configuration with a large number of easily hydrolyzable chemical bonds (Wiser 1973; Kwan and Yen 1979). Embedded within the mineralogical matrix are a number of other substances, such as heavy metals and minerals. All of these parts of the total coal matrix can be leached and removed to some extent under the appropriate conditions. Leaching phenomena are also complex and vary with coal type and source, coal particle size, chemical characteristics of the leaching medium, and the exact manner of hydrological interaction of the coal and leaching medium (Anderson and Youngstrom 1976; Anderson 1978; Seierstad et al. 1979; Israelsen et al. 1980; Peavy 1981).

Much of the initial concern for water pollution resulting from coal mining stemmed from the use of high-sulfur coal reserves which are mainly located in the eastern United States. These coal sources contain large quantities of the mineral pyrite (ferrous sulfide) in conjunction with the organic coal matrix. When pyrite is exposed to the atmosphere or to water, oxidation occurs resulting in the formation of sulfuric acid. When this happens in aquatic systems, pH values fall drastically, resulting in water that is unsuitable for a variety of uses. The drop in pH also increases the leachability of a variety of toxic metals. (Davis and Boegly 1981b.) It has been shown that microbiological processes also contribute to the oxidation process (Ohio State University 1970), resulting in mine drainages that are high in iron and low in pH. When drainage of this nature comes in contact with alkaline river or stream water, an iron floc results which is very harmful to fish and benthic invertebrates in the aquatic ecosystem. (Coutant et al. 1978.) In some cases, rivers seem to recover quickly from the effects of acid and iron (Boyer and Gleason 1977), but many of the long-term effects of other metals present remain largely unknown (Rogers and Savitz 1980). A study of watersheds in Tennessee (Minear and Tschantz 1976) indicated that streams unaffected by mining were very similar in most respects and uniform in characteristics independent of rainfall and temperature. Streams draining watersheds that had been disturbed by mining had distinct individual differences and displayed periodic chemical variations of large magnitudes. The following constituents have been observed in coal mine drainages and coal pile leachates associated with high sulfur coals: total dissolved solids, suspended solids, turbidity, aluminum, arsenic, beryllium, chromium, cobalt, copper, iron, lead, manganese, mercury, nickel, selenium, zinc, acidity, calcium, chloride, magnesium, potassium, silica, sodium, sulfate, chemical oxygen demand,

and phenols (Minear and Tschantz 1976; Boyer and Gleason 1977; Davis and Boegly 1981a,b).

Much less research has been conducted using western coals. In the west, acidic drainage and high concentrations of potentially toxic substances are not as common as in the eastern U.S. Much of the overburden and soils are alkaline in nature (Olem 1982) as are many of the water supplies, thus possessing a high buffering capacity and reducing the availability of trace elements to the aquatic fauna (Ramakka 1979). Drainage from Wyoming's Big Horn Mine strip-mining operation has been studied with regard to effects on the Tongue River (Dettmann et al. 1976). Mining impacts were determined to be relatively small; aquatic biota were responding more to overall water quality trends in the river system. This work was supplemented in 1981 by Woessner et al. (1981) with regard to effects on the nearby Northern Cheyenne Indian Reservation. Large-scale mining was predicted to increase total dissolved solids in the ground and surface water systems producing effects that could last for hundreds of years. Van Voast et al. (1976) have studied the mining areas near Decker in southeastern Montana which are also in the Tongue River drainage. Short-term and short-range hydrologic effects were noted with no indications of serious hydrologic changes; aquifers were expected to develop in the reclaimed land that would be similar to undisturbed sandstone aquifers. This work was updated in 1980 by Knapton and Ferreira (1980) and supplemented with two years of water quality data. Large variations in water quality with time were documented, particularly total dissolved solids and total suspended solids.

Wentz (1974) reported that most of Colorado's metal deposits were made up of sulfide ores with high potential for acid and heavy metal drainage. However, this phenomenon did not occur with respect to coal deposits in the state.

Later work by Wentz and Steele (1976) centered on the monitoring and frequency distribution analysis of surface water quality in Colorado and Wyoming's Yampa River Basin where coal development has been increasing. Deposits of ferric hydroxide were found on some stream bottoms along with anomalously high levels of iron, manganese, cadmium, cobalt and nickel which are known to be associated with pyritic materials in coal seams. Most downstream areas had acceptable metal levels with regard to drinking water quality criteria. The Colorado Department of Health has established dissolved oxygen criteria of 7. mg/liter for cold-water biota and 5. mg/liter for warm-water biota. Oxygen levels at some sites were frequently below these limits. Sampling of macroinvertebrates yielded diversity indices greater than 3 at 45 percent of the sites, indicating clean water areas. About 4 percent of the sites had diversity indices less than 1, indicating heavy pollution (Wilhm and Dorris 1968).

Leachate studies of western coals have shown some leaching trends, but usually those of lesser environmental concern. Davis and Boegly (1981a) studied leachate quality from storage piles of high-sulfur Illinois coal and low-sulfur Montana coal. Leaching of the Illinois samples was greatly influenced by particle size and storage technique, while the Montana samples were influenced to a much smaller degree by these factors. Leachate from the western coal was essentially neutral, with lower concentrations of dissolved metals and dissolution rates which did not increase with time as was observed with Illinois coal samples. However, standards for coal pile runoff (pH between 6. and 9. and total dissolved solids less than 50. mg/liter) were occasionally violated in leachate from the Montana coal.

Israelsen et al. (1980) and Seierstad et al. (1979) studied leaching phenomena from finely ground low-sulfur

coal samples from the Wasatch Plateau and Book Cliffs coal fields in a laboratory-scale coal slurry pipelining study. Milligram per liter quantities of boron, strontium, and organic carbon were leached from the coal samples after 6 days of coal-groundwater medium interactions. Elevated boron and strontium levels have also been observed in relation to water from coal ash settling ponds at a coal-fired power plant in Nevada (Romney et al. 1977). An upflow column laboratory leaching study by Adams et al. (1981b) showed elevated levels of boron and other trace metals leached from calcium and sodium scrubber wastes. Many water supplies affected by coal mining operations are eventually used for crop irrigation (Page 1982). Toxicity effects and damage caused to plants and crops when boron concentrations are high in irrigation water supplies have been reported (Wilcox 1960; McKee and Wolf 1963; EPA 1979; Ayers 1977; Romney et al. 1977; Bingham 1973).

Peavy (1981) evaluated coal from the Rosebud Seam from the Western Energy Mine in Colstrip, Montana, in a laboratory slurry pipelining study. pH of the transport water was seen to drop to 6 although dissolution of metals was not significant; levels remained below limits of detection. Alkalinity, total dissolved solids and sulfate increased. Dissolved organic carbon levels were high (in excess of 10 mg/liter) and were accompanied by the presence of trihalomethane precursors. The author cautioned that problems with carcinogenicity would arise here if the water was chlorinated for reuse.

Anderson (1978) conducted a laboratory slurry experiment using low sulfur, high volatile C bituminous Utah coal. Alkalinity in the transport medium was seen to decrease and was attributed to the neutralization of acidity leached from the coal and/or the coprecipitation of carbonates and hydroxides with metal ions. pH of the medium decreased to slightly less than

7, but acidity problems typical of high sulfur coals were not anticipated by the author. Hardness of the medium increased, but calcium decreased. Sulfate was leached from the coal even when conditions were made anaerobic; this was postulated to be due to some leaching of sulfate salts and to the oxidation of organic sulfur during grinding and storage of the coal sample. The whole coal sample was analyzed for a variety of trace metals and theoretical estimates indicated a potential for leaching of these constituents. However, leachate concentrations of these metals were below the analytical limits of detection. Analysis of a coal-distilled water mixture showed concentrations of aromatic hydrocarbons and hydrocarbon waxes of about 3. mg/liter in the water and concurrent increases in chemical oxygen demand of the same magnitude.

In the final Environmental Impact Statement for the development of coal resources in central Utah (Department of the Interior 1979) statements are made to the effect that water quality should not be significantly altered due to the low sulfur content of the coal (less than 1 percent), the small quantities and rates of water movement associated with coal and overburden (less than 40 acre-feet/year/ mile<sup>2</sup> average) and the highly alkaline nature of the area's water supplies (alkalinity at levels of 100-300 mg CaCO<sub>3</sub>/liter). Evidence was also presented regarding trace metals. Surface waters in the mountainous headwater areas had concentrations of trace elements and heavy metals which were stated to generally be within quality criteria limits for drinking water and freshwater aquatic life. However, in the middle and lower reaches of the Price and San Rafael Rivers and Muddy Creek, concentrations of at least 11 elements were found to be commonly or occasionally in excess of these recommended limits. There was no information on whether coal mines located on these water sources were making a significant contribution to the water quality conditions. Mine dis-

charges on the Wasatch Plateau and Book Cliffs coal fields were analyzed by the U.S. Geological Survey (Waddell et al. 1979). Arsenic, chromium, lead, mercury and selenium drinking water maximum contaminant levels were not exceeded. But, in many cases, total (suspended) metal concentrations were many times higher than their dissolved counterparts. These suspended particulate metals would not be considered a serious problem unless changes in pH and oxidation-reduction potential occurred which would force dissolution, making these metals available to aquatic biota. Waddell et al. stated that although large reductions in pH were not likely, these undissolved substances could migrate to the bottoms of lakes and reservoirs where anaerobic conditions might exist, allowing the metal complexes to dissolve. Analyzed metal concentrations in aquatic systems do not necessarily reflect the degree to which they might affect organisms (Miller et al. 1976). Toxicity must often be evaluated using controlled laboratory conditions.

Care should be taken not to make generalizations regarding water quality, toxic effects, coal-water interactions, etc., because of variations due to experimental conditions and design, methods of data collection, source of coal and other factors. It has been suggested that all published research must completely specify all field and laboratory conditions. Although no standard methodology exists for assessing impacts, some useful statistical methods have lately been applied to the problem. These include pattern recognition assessment and multi-variate statistical methods used by Brown and coworkers (1980) in a study of Trout Creek in Colorado in relation to a coal strip mine. In the stream areas immediately adjacent to the mine, seasonal variations exceeded variations between sites. But the mine did impact Trout Creek strongly mainly due to loading of dissolved solids such as calcium and magnesium, primarily in the form of



sulfates and chlorides. The main impact was below the oldest mine spoils, after which the creek was not affected by further loading, although increases in sodium and alkalinity were seen to continue. The uniform pH and control of dissolved solids loading indicated the creek was well buffered. Statistical analyses showed that trace metal con-

centrations could not be used to distinguish between sites. The negative correlation was thought to be due to the precipitation of metals and the resultant controlling influences played by carbonate equilibria. It was recommended that future evaluation of a system like this should include monitoring of species which are not affected by the carbonate control mechanism.

## MATERIALS AND METHODS

### Coal Mine Accrual Water

#### Coal Mine Accrual Water Sites

To facilitate comparison of discharge waters, all coal mine accrual water sites were located on the Wasatch Plateau. The six sites represent mines either discharging or sumping water in this coal field. Due to preliminary agreements with the mining companies, none of the mines participating in this study are mentioned by name.

The Wasatch Plateau coal field (Figure 1) is located near the geographical center of Utah. It is bounded on the west by the Mt. Pleasant and Salina Canyon coal fields, on the southeast by the Emery coal field and on the northeast by the Book Cliffs coal field. Parts of Carbon, Emery, Sanpete, Sevier, and Utah counties fall within the boundaries of the coal field. It is about 90 miles (140 km) long from north to south and ranges from 7 to 20 miles (11 to 32 km) in width with a land area of about 1100 sq. miles (2800 km<sup>2</sup>). Altitudes range from just under 7000 feet (2100 m) to greater than 10,000 ft (3000 m) above sea level. Most of the coal is found between 7000 and 8000 feet (2100 to 2400 m). Gordon Creek, Huntington Creek, Cottonwood Creek, Rock Canyon Creek, Ferron Creek, Muddy Creek, Quitcupah Creek, Ivie Creek, and Pleasant Valley Creek are the major drainages from the Plateau. All of these, except Pleasant Valley Creek, flow toward the Colorado River in a southeasterly direction. In the northern part of the coal field Pleasant Valley Creek flows northeasterly into the Price River which eventually flows

into the Colorado River (Doelling 1972). Most of these water sources are used for agricultural irrigation. Pleasant Valley Creek (also known as Mud Creek) eventually flows into Scofield Reservoir. Reservoir water is used for industrial and municipal irrigation, recreational fish culture (Page 1982) and as a culinary water source for the Price Water Improvement District.

Sampling of mine accrual water began in April 1981 and continued through May 1982. The mine sites are numbered from 1 through 6 going south to north on the Wasatch Plateau. The numbers also represent the order in which the sites were sampled on each sampling date; sampling began early in the morning and continued through the afternoon.

At the beginning of the year's sampling period mines 1, 2, 5, and 6 were discharging on a continual basis. These sites were scheduled to be sampled monthly. Mines 1 and 2 discharged actively throughout the sampling period. Mine 5 was discharging through the November 1981 sampling date, but began pumping the accrual water to an underground sump area after that date and to the end of the sampling period. The discharge ponds and pipes became frozen at mine 6 by the January 1982 sampling date. Sampling had to be suspended at this site at that time.

Site 3 was a coal mine that had been abandoned in the late 1930s and is now being used to collect drinking water for a small town in the area. Mine 4 was sumping accrual water throughout the sampling period and not discharging. Mines 3 and 4 were sampled approximately every 3 months throughout the sampling period.

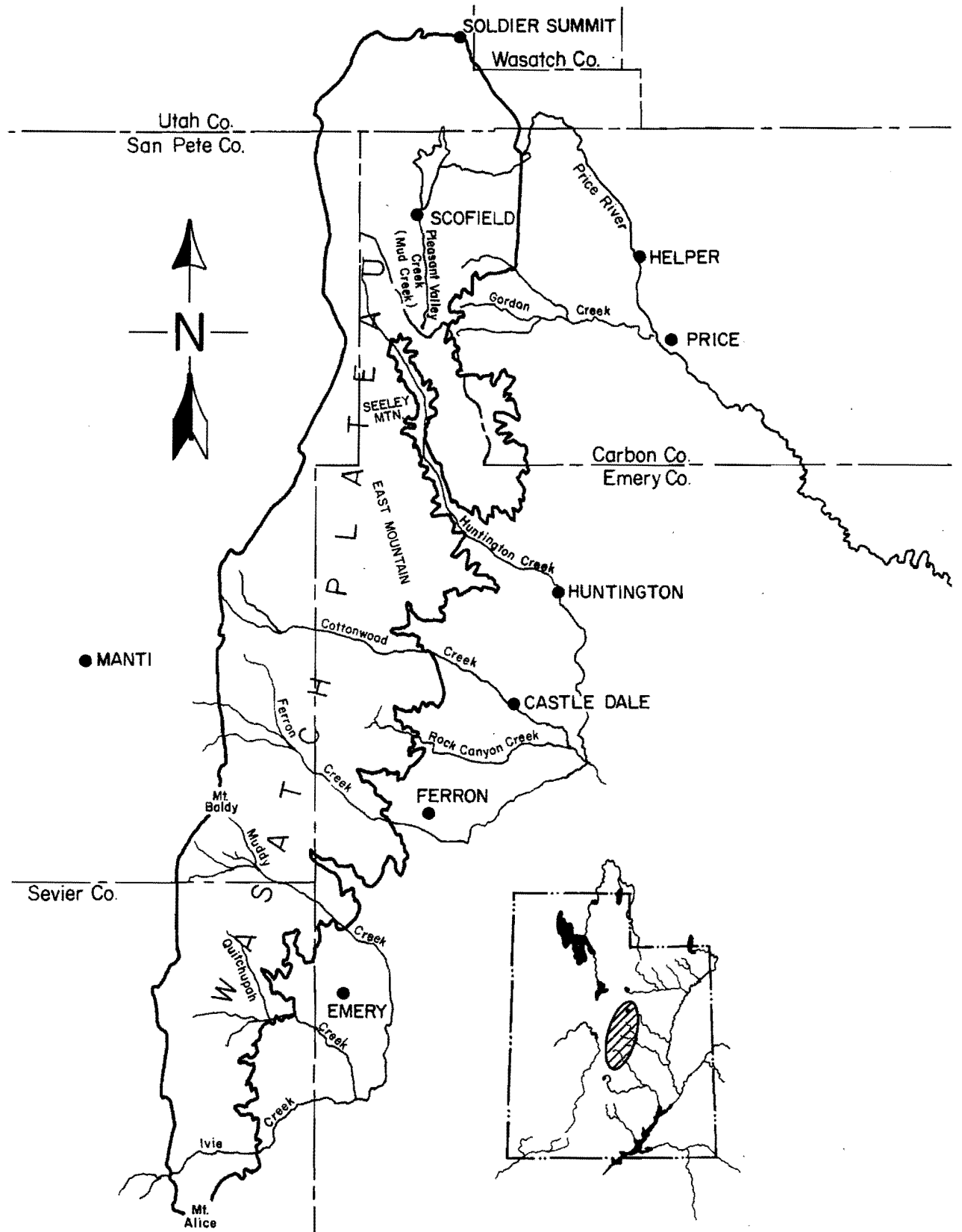


Figure 1. Wasatch Plateau coal field; location and drainages.

A strike by the United Mine Workers Union was in effect through the May 1981 sample date. Mining operations at many of the mines were limited during this time. Beginning with the June 1981 sample date all active mines were again in operation.

#### Coal Mine Accrual Water Field Sampling

At sites where accrual water was discharged (mines 1, 2, 5, and 6), samples were taken before and after treatment to assess treatment effectiveness. These sites were designated A and B.

"A" samples at mines 1, 5, and 6 were taken from flows at discharge pipes before entrance into the treatment system. Treatment at these mines involved the use of two small gravel filtration ponds in series. In addition, grease-skimming devices were used. Mine 6 also had installed a filtration device which was located after the ponds. At mine 2 accrual water was sumped into an abandoned area of the mine. Water for discharge was then drawn by pump from below the surface to minimize oil and grease content. "A" samples at mine 2 were taken by wading out into the sump area to a depth of about 2 feet. Care was taken to gather samples in areas where the bottom sediments were not disturbed. All samples were taken just below the water surface.

"B" samples at mines 2, 5, and 6 were taken at the pipes located after treatment and just before discharge into the existing stream or creek beds. Access to the B site at mine 1 was somewhat difficult. For this reason, samples at mine 1 were taken from the stream about 10 yards below the discharge from the ponds.

Samples at mine 3 were collected from a pipe which discharged excess water from the drinking water sump area into an existing creek bed. Water

samples at mine 4 were taken from a holding basin constructed about 1 mile inside the mine. Samples were taken directly from the basin and just below the water surface. When the water level in the basin was low, samples were taken by lowering a glass bottle on a rope and using this container to fill the sample bottles.

Procedures for selection and preparation of sample bottles and transportation, preservation and filtration of accrual water samples are in accordance with routine procedures at the Utah Water Research Laboratory (Adams et al. 1981a) and procedures accepted by the U.S. Environmental Protection Agency (EPA 1979) and the American Public Health Association, Standard Methods Committee (APHA 1980).

Samples for subsequent analysis of major anions and cations, trace metals and nutrients were collected in 4-liter plastic bottles. These bottles had been washed using the Utah Water Research Laboratory's (UWRL) normal cleaning method (washed with sodium bicarbonate, rinsed with tap water and doubly-deionized water (DDW); detergent was not used) followed by a rinse of 6 normal hydrochloric acid (6N HCl) and several rinses with fresh DDW. Sample bottles were rinsed with accrual water before filling. Since filtration in the field situation was not feasible, further sample handling for these parameters was accomplished at the laboratory.

Samples for analysis of oil and grease were placed in 1-liter glass bottles. These bottles had been cleaned using UWRL standard procedures and then rinsed with 20 percent sulfuric acid (H<sub>2</sub>SO<sub>4</sub>) followed by several rinses with DDW to remove any traces of oil and grease. Teflon or aluminum foil linings inside the bottle lids eliminated contact between the plastic caps and the water sample. Since oil and grease tend to adhere to glass surfaces, these bottles were not prerinsed with accrual water prior to filling.

Forty-milliliter glass bottles with screw caps and teflon-backed rubber septa cap liners were used to collect samples for trihalomethane (THM) determinations. The bottles, caps, and liners were washed in detergent, rinsed with 20 percent  $H_2SO_4$ , and then rinsed with DDW. The caps and cap liners were dried in a  $105^\circ C$  oven for 1 hour and protected from organic contamination while cooling. The openings of the glass bottles were covered with aluminum foil, the bottles dried in a muffle furnace for 30 minutes at  $550^\circ C$  and cooled. For instantaneous THM determinations, 2 to 4 milligrams of L-ascorbic acid was added to each empty vial as a preservative. These vials were labeled to distinguish them from bottles intended for maximum potential THM where a preservative was not required. All bottles were then sealed with caps and teflon liners to prevent contamination. During the collection of samples, the vials were not prerinsed in order to prevent loss of the ascorbic acid preservative. The vials were filled completely with the accrual water sample forming an inverted meniscus at the mouth of the bottle. Precautions were taken so that the sample was not aerated during collection. The vial was sealed with the teflon side of the liner in contact with the sample and in a manner so that no air bubbles remained within the bottle. Duplicate vials were collected for maximum total potential THM. Both vials were dosed with 20 microliters of approximately 5 percent chlorine solution through the rubber septum using a glass syringe.

Samples for analysis of total organic carbon (TOC) were collected in 150-milliliter glass bottles. These bottles were cleaned as previously described, rinsed with 20 percent  $H_2SO_4$  followed by several rinses with DDW, and placed in a muffle furnace for 30 minutes at  $550^\circ C$ . The plastic caps were lined with aluminum foil and the caps placed on the bottles to prevent contamination. The bottles were

rinsed with accrual water sample prior to filling.

Algal assay samples were collected in 4-liter plastic autoclavable bottles. The bottles were washed according to UWRL standard procedures, rinsed with 6N HCl followed by several DDW rinses and sterilized in an autoclave (15 minutes at 15-17 psi and  $121^\circ C$ ). The bottles were kept tightly capped until the samples were collected. The bottles were rinsed with accrual water prior to filling and were filled full, leaving as little air space as possible.

All samples were marked with waterproof labels, packed in ice and transported in coolers to UWRL on the same day they were collected. Upon arrival at the lab, the samples were transferred to a walk-in refrigerator and stored at  $4^\circ C$ .

Filtering and further preservation and analysis of the accrual water samples was begun as soon as possible after arrival at the laboratory. Samples for analysis of dissolved constituents were filtered through a cellulose acetate membrane filter (0.45  $\mu m$  pore size). After filtering, samples for dissolved trace metals were preserved with nitric acid ( $HNO_3$ ) to a pH of less than 2 and analyzed within 6 months. Samples for analysis of major inorganic anions and cations were stored at  $4^\circ C$  after filtering and analyzed within 7 days. Analyses for ammonia-nitrogen and orthophosphate on the filtered samples were completed within 24 hours. Samples for analysis of nitrate- and nitrite-nitrogen were stored in acid-washed vials after filtering, preserved with chloroform and analyzed within 7 days.

Alkalinity, pH, total phosphorus, and oil and grease determinations on unfiltered (total) samples were completed within 24 hours. TOC samples were preserved with phosphoric acid ( $H_3PO_4$ ) to a pH of less than 2, stored at  $4^\circ C$  and analyzed within 7 days.

Samples for subsequent analysis of total trace metals were preserved with HNO<sub>3</sub> to a pH of less than 2 and analyzed within 1 month.

From May 1981 to October 1981, algal assay samples were filter-sterilized using 0.45 µm cellulose acetate membrane filters and sterile glassware (15 minutes at 15-17 psi and 121°C) to remove indigenous biomass. From November 1981 to April 1982, the algal assay samples were autoclaved (60 minutes at 15 - 17 psi and 121°C) to remove indigenous biomass and to solubilize nutrients contained in that biomass. The samples were then filter-sterilized as described above. This second procedure is recommended when it is desired to determine the amount of algal biomass that can be grown from all nutrients in the water, including those contained in filterable organisms and other particulate matter which can be solubilized by autoclaving (Miller et al. 1978).

Samples for instantaneous THM were stored at 4°C and analyzed within 14 days. Maximum total potential THM samples were incubated at 25°C for the required 7 days and then analyzed.

### Crushed Coal

#### Coal Mine Sites

The mine sites for collection of crushed coal were the same as those for the sampling of accrual water. These mines are numbered 1 through 6 in the same manner as described previously.

Coal in the Wasatch Plateau beds has an American Society for Testing and Materials classification as a high-volatile B bituminous, low sulfur and noncoking coal. More than 800 samples from the Wasatch Plateau were analyzed by the Utah Geological and Mineralogical Survey. Only small differences in coal quality were evident from seam to seam and throughout the field (Doelling 1972).

On two occasions during the duration of the project, crushed coal samples were taken at the sites in an effort to study possible mutagenicity and evaluate leaching characteristics. These sampling procedures and results are summarized by Hinchee et al. (1983).

#### Crushed Coal Sampling

Crushed coal samples were collected in specially modified, 55 gallon barrels (Figure 2). Each barrel and lid was lined with a teflon coating to provide an unreactive surface and reduce the possibility of indeterminable reactions between the sample and the container during transportation and storage. Each barrel lid was equipped with a rubber gasket and a clamp to facilitate a tight seal.

If coal is allowed to stand in contact with the atmosphere for extended periods of time, exposed surfaces can be oxidized to varying degrees. This oxidation can alter subsequent leaching characteristics and must be avoided during transportation and storage of crushed coal samples. The barrels were modified (Figure 2) to allow the coal samples to be purged with inert nitrogen gas and stored in a nitrogen atmosphere. A brass off-on needle valve was welded into the lid of each barrel and another on the side of the barrel about 2 cm from the bottom. The lower valve was then connected to a cross-shaped structure of 1/2 inch copper tubing inside and on the bottom of the barrel. This design allowed nitrogen gas to be flushed in through the system (bottom to top). Holes were drilled in the copper tubing to allow appropriate purging of the crushed coal sample by the nitrogen gas. This barrel design was identical to the one used to store coal samples for an earlier UWRL coal slurry pipeline study (Israelsen et al. 1980).

Prior to the collection of samples, the barrels and lids were scrubbed with a nonphosphorus detergent and rinsed several times with tap water. The next

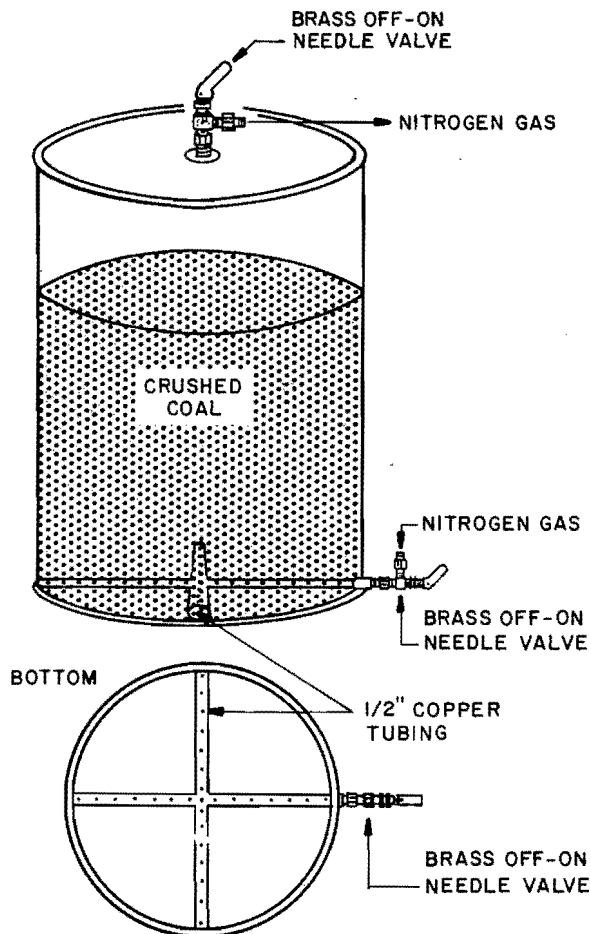


Figure 2. Container for storage of crushed coal samples in an inert atmosphere.

step was a 6N HCl rinse followed by several rinses of DDW. The barrels and lids were then allowed to drain dry.

The barrels were transported to the sample sites with the lids clamped securely in place to prevent contamination. Crushed coal was shoveled into each barrel until it was about two-thirds full. Coal samples were freshly crushed at each mining operation and collected from the tippie or a coal truck. All fresh coal samples were no

more than a few hours old. An exception was the coal sample collected from mine 3 which was abandoned and no longer in operation. A sample here was taken from a coal pile which had been exposed to weathering conditions for about 50 years. After collection of the coal samples, each barrel lid was clamped securely in place with the valves in the off position for transportation to the laboratory.

Mining engineers had suggested the collection of a coal sample composited over 24 hours in time from the crushing operation. This would have provided a sample that was more representative of the mine's total production. However, since the most remote mine site was about 250 miles from the laboratory and the locations of the sites spanned 100 miles, a composite sampling technique was not feasible. Discrete sampling was also justified based on Doelling's work (1972) which demonstrated the relative consistency of coal quality over the Wasatch Plateau.

Purging of the coal samples with nitrogen gas began upon arrival at the laboratory and within 24 hours of sample collection. The needle valve at the bottom of the sealed barrel was connected to a pressurized cylinder of reagent grade nitrogen gas. Both valves were opened and nitrogen was allowed to flow through the sample for a period of 2 hours. The needle valves were closed after the purging process was completed. At all subsequent times, when a portion of the coal was removed, the remaining sample was again purged with nitrogen gas.

In September 1981 samples of crushed coal were collected from five mines (mine 3 was excluded) and composited into one sample for mutagenicity screening (Hinchee et al. 1983). During May 1982 samples were collected from all six sites. These samples were used in leaching column experiments and further mutagenicity assays.

## Coal Leachate Column Experiments

Leachate column studies were used to evaluate the aqueous leaching of coal samples under controlled laboratory conditions for comparison to the actual water discharged by the mines during the field sampling phase of the project. Column methods, in general, appear to represent a more accurate model of environmental conditions than do techniques such as batch elutriation (Adams et al. 1981b).

Upflow columns were used to study the leaching of the coal matrix. Previous work (DiNovo et al. 1975; Maase et al. 1975; Cleave 1979; Maase 1980; Adams 1979; Adams et al. 1981b) has demonstrated several advantages attributable to upflow column design as opposed to gravity flow configuration. Entrapment of air, plugging, and channeling are problems often experienced with gravity drainage columns. Fewer problems of this nature are encountered with upflow columns. Upflow columns have also been shown to permit generation of reproducible leachates.

Since determinations of trace organics (TOC) were to be performed on the coal column leachates, the coal samples and leaching medium were allowed to come into contact with only glass or teflon surfaces. These types of surfaces can be acid-washed and thus made essentially free of organic contamination.

High quality borosilicate glass was used to construct the cylindrical columns depicted in Figure 3. These columns were 61 cm (24 in) long with an inner diameter of 7.6 cm (3 in). A teflon microvalve stopcock at the bottom of each column allowed introduction and flow control of the aqueous leaching medium in an upflow manner through the coal sample. All tubing used to connect parts of the system was made of glass or teflon.

Glass 20-liter reservoirs and 4-liter constant head tanks were

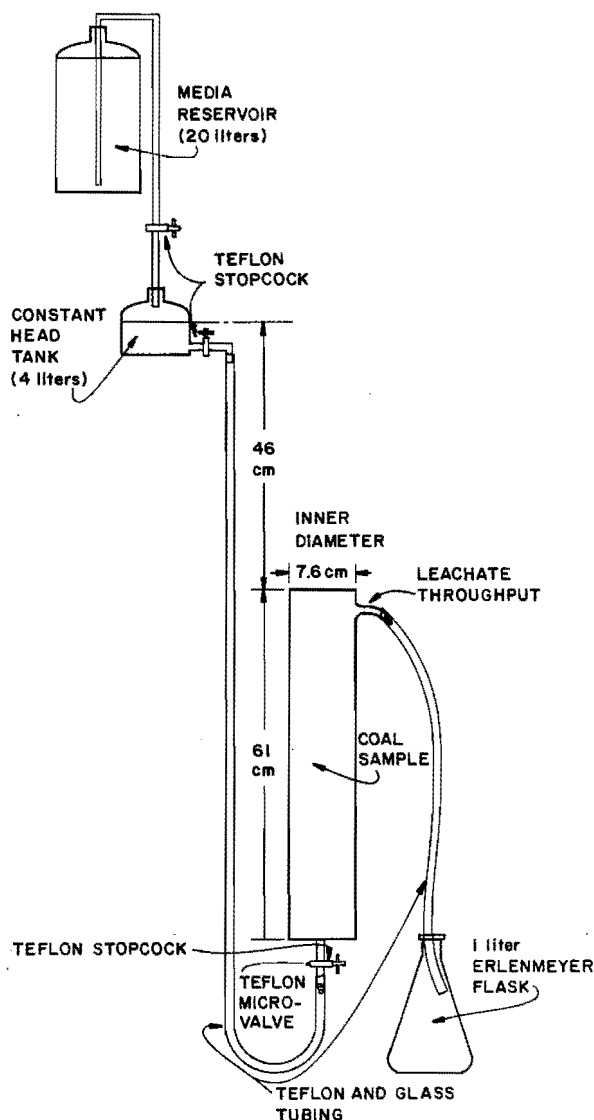


Figure 3. Upflow coal leachate column (adapted from Adams et al. 1981b).

used to introduce the leaching medium into the columns. Each reservoir and constant head tank was set up to flow to four or five upflow columns. Nine columns were used to study six coal samples in triplicate over two analytical runs.

To begin each analytical run, a synthetic leaching medium was prepared.



The medium matched the mean water quality of known water supplies present in the vicinity of the six mine sites. Data for these water sources were obtained from the U.S. Geological Survey (Danielson 1981) and from some limited spring water sampling conducted by UWRL during the project. These data and the mean values used for the synthetic medium are summarized in Table 1. In general, only those sources with complete data for all major anions and cations were used.

As can be seen in Table 1, water that would be potentially diverted into the coal mines is very hard, typically having high levels of calcium, magnesium, and carbonate species. Initial attempts at making up a synthetic medium by adding reagent grade chemicals to DDW were unsuccessful; dissolution of the constituents could not be achieved even with the application of heat and aspiration with carbon dioxide gas for 24 hours. Tap water from the Logan City municipal system was then chosen as the background for the synthetic medium. Each quantity of leaching medium was prepared by adding known amounts of reagent grade chemicals to tap water so that final dissolution would yield a medium that closely matched the values of each constituent shown in Table 1. This procedure worked well since subsequent analyses of the separate batches of media throughout the column experiments showed quite consistent levels of all constituents. Table 2 specifies the identity and amount of each chemical necessary to prepare 20 liters of leaching medium from tap water. Final desired levels of most metal constituents in the leaching medium were very low (microgram/liter quantities). For this reason a concentrated metal stock solution was prepared by dissolving known quantities of chemicals in DDW. The metal stock solution was 20 times as concentrated as the levels of strontium, barium, and aluminum that were required in the final leaching medium. Table 2 describes the procedure for preparation of the metal

stock solution and dilution into the synthetic leaching medium.

Batches of leaching medium were prepared in 20-liter quantities as needed throughout each column run. Quantities of the chemicals for the anion-cation medium listed in Table 2 were weighed on an analytical balance readable to 0.1 mg. The chemicals were transferred to a 20-liter glass container containing about 18 liters of tap water. Heat was applied and reagent grade carbon dioxide gas was bubbled through the solution for several hours or overnight. When dissolution was complete, 1 liter of metal stock medium was added and the solution was allowed to cool to room temperature. More tap water was then added to bring the medium to the calibrated 20-liter mark on the container. The medium was stirred to mix completely and to allow the excess carbon dioxide to escape.

At the beginning of the column analytical runs it became evident that longer periods of time were required to rid the medium of excess carbon dioxide. Batches of media were then prepared ahead of time and allowed to stand overnight. This process assured that excess carbon dioxide escaped into the atmosphere before the medium was transferred to the constant head tank.

To begin each analytical run, all parts of the column set-up shown in Figure 3 were rinsed with 6N HCl, rinsed several times with DDW, and drained. Crushed coal samples were removed from the storage barrels and prepared for column analysis on an as received basis. The coal was passed through a 10 mesh, 2000 micron sieve to achieve a uniform particle size distribution. As soon as possible after sieving, 1750 g of the coal was weighed on a top-loading laboratory pan balance readable to 0.1 g. The coal was packed into each column with small amounts of high quality glass wool on each end to limit flow-through of particle fines. The coal packing

Table 1. Data from selected spring and stream water sites for preparation of synthetic leaching medium.

Site Designation	Sample Date	Alkalinity,	Calcium	Chloride	Fluoride	Magnesium	Potassium	Silica	Sodium	Sulfate	Aluminum	Barium	Boron	Iron	Strontium	Total Dissolved Solids <sup>a</sup>
		mg CaCO <sub>3</sub> /l	mg Ca/l	mg Cl/l	mg F/l	mg Mg/l	mg K/l	mg SiO <sub>2</sub> /l	mg Na/l	mg SO <sub>4</sub> /l	mg Al/l	µg Ba/l	µg B/l	µg Fe/l	µg Sr/l	mg TDS/l
(D-13-6) 14ccd-S1	21 Jul 78	160.	59.	5.0	0.1	7.0	1.2	5.5	3.3	10.	--	--	20.	50.	90.	187.
(D-13-6) 15bda-S1	17 Jul 78	42.	17.	2.8	0.1	2.5	1.0	7.8	2.1	6.9	--	--	60.	60.	40.	66.
(D-13-6) 23cac-S1	21 Jul 78	170.	63.	15.	0.1	8.2	2.3	6.0	3.1	11.	--	--	30.	10.	90.	211.
(D-13-6) 36bba-S1	20 Jul 78	190.	63.	1.9	0.1	7.6	0.5	4.9	2.0	5.1	--	--	20.	<10.	70.	199.
(D-13-6) 36cda-S1	18 Jul 78	94.	34.	1.2	0.1	3.2	1.2	4.6	1.3	2.7	--	--	10.	<10.	40.	105.
(D-16-8) 5bac-S1	15 Aug 78	237.	74.	2.9	0.1	15.	0.5	5.6	1.9	6.0	--	--	10.	<10.	120.	248.
(D-16-8) 18ada-S1	9 Aug 79	250.	70.	3.2	0.2	25.	0.6	7.0	3.4	23.	--	--	10.	10.	260.	283.
(D-16-8) 19abb-S1	9 Aug 79	290.	76.	4.1	0.2	31.	1.0	7.1	4.8	38.	--	--	30.	50.	330.	337.
(D-17-6) 26cba-S1	27 Jun 79	290.	51.	8.4	0.3	38.	1.0	7.0	19.	20.	--	--	50.	0.	480.	320.
(D-17-6) 26ccb-S1	18 Jul 79	390.	60.	14.	0.4	43.	1.3	8.1	49.	39.	--	--	90.	0.	550.	450.
(D-17-6) 27bbd-S1	16 Aug 79	240.	40.	13.	0.2	31.	0.8	5.9	13.	13.	--	--	20.	40.	210.	262.
(D-17-6) 27ccc-S1	16 Aug 79	330.	42.	27.	0.3	44.	1.0	7.5	54.	32.	--	--	50.	0.	490.	406.
(D-17-6) 27daa-S1	12 Jul 79	230.	47.	5.3	0.2	26.	0.8	6.2	13.	14.	--	--	30.	10.	270.	251.
(D-17-6) 35ccb-S1	12 Jul 79	260.	38.	28.	0.2	38.	1.3	6.4	35.	29.	--	--	50.	0.	390.	333.
UWRL-5034-80	9 Dec 80	-- <sup>b</sup>	90.	1.0	0.2	<1.	0.7	6.0	9.	0.7	<0.2	192.	<100.	26.	218.	263.
UWRL-5035-80	9 Dec 80	291.	-- <sup>b</sup>	15.3	0.2	-- <sup>b</sup>	0.9	6.7	12.	9.8	<0.2	181.	<100.	18.	682.	-- <sup>b</sup>
UWRL-4221-81	18 Oct 81	278.	72.	7.0	0.2	25.	<0.6	8.5	10.	6.7	0.3	152.	<100.	<10.	194.	310.
UWRL-4222-81	18 Oct 81	268.	60.	9.0	0.3	31.	<0.6	6.4	12.	7.2	0.2	25.	<100.	<10.	215.	303.
Mean Values		Alk.	Ca	Cl	F	Mg	K	SiO <sub>2</sub>	Na	SO <sub>4</sub>	Al	Ba	B	Fe	Sr	TDS
		236.	56.	9.1	0.2	22.1	1.0	6.5	13.8	15.2	0.2	138.	<100. <sup>c</sup>	18.	263.	267.

Data from USGS sites are listed in the first 14 rows (Danielson et al. 1981, Table 10, pp. 78-81; site numbering system explained in text). The remaining data summarize data analyzed at UWRL.

Footnotes:

<sup>a</sup>All TDS data from USGS sources are calculated as the sum of all dissolved constituents in mg/l. UWRL TDS data are determined using the gravimetric analytical method.

<sup>b</sup>Insufficient sample volume to complete all analyses.

<sup>c</sup>The mean value for boron is stated as <100 µg/l since the limit of detection for the colorimetric carmine method used at UWRL is 100 µg/l.

Table 2. Preparation of synthetic medium for upflow leaching experiments.

Parameter	Required Concentration in Medium, mg/l	Approx. Concentration in Logan Tap Water, mg/l	Additional Quantity Required, mg/l	Chemical	Mass (g)/20 ℓ Water	Parameter	Expected Concentration in Medium, mg/l
Alkalinity, Total	236.	163.	73.	For Anion-Cation Medium:		Alkalinity, Total	236.
Calcium, Ca	56.	45.3	10.7	KCl	0.0386	Calcium, Ca	65.
Chloride, Cl	9.1	2.5	6.6	NaCO <sub>3</sub>	0.4871	Chloride, Cl	9.1
Fluoride, F	0.2	0.2	--	Na <sub>2</sub> SiO <sub>3</sub> ·9H <sub>2</sub> O	0.1513	Fluoride, F	0.2
Magnesium, Mg	22.1	16.1	6.0	Mg <sub>2</sub> Cl <sub>2</sub> ·6H <sub>2</sub> O	0.3235	Magnesium, Mg	20.0
Potassium, K	1.0	<1.	1.0	MgSO <sub>4</sub>	0.2012	Potassium, K	1.0
Silica, SiO <sub>2</sub>	6.5	4.9	1.6	CaCO <sub>3</sub>	1.0088	Silica, SiO <sub>2</sub>	6.5
Sodium, Na	13.8	2.0	11.8	For Metal Stock Medium:		Sodium, Na	13.8
Sulfate, SO <sub>4</sub>	15.2	6.1	9.1	SrCO <sub>3</sub>	0.1772	Sulfate, SO <sub>4</sub>	15.2
Aluminum, Al	0.2	-- <sup>a</sup>	0.2	BaCl <sub>2</sub> ·2H <sub>2</sub> O	0.0662	Aluminum, Al	0.2
Barium, Ba	0.138	0.045	0.093	Al <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub> ·14H <sub>2</sub> O	0.8808	Barium, Ba	0.138
Boron, B	<0.100	<0.100	--			Boron, B	<0.100
Iron, Fe	0.02	0.02	--			Iron, Fe	0.02
Strontium, Sr	0.263	-- <sup>a</sup>	0.263			Strontium, Sr	0.263

Procedure:

Chemicals for the metal stock medium were weighed into 18 ℓ of DDW. Heat and aspiration with carbon dioxide gas were used to force dissolution. The solution was cooled to room temperature, diluted to 20 ℓ with DDW and mixed completely. Chemicals for the anion-cation medium were weighed into 18 ℓ of Logan tap water. Heat and aspiration with carbon dioxide gas were used to force dissolution. 1 ℓ of metal stock medium was added and the solution cooled to room temperature. The medium was diluted to 20 ℓ with tap water and mixed completely.

<sup>a</sup>No data were available for aluminum and strontium in Logan tap water.

material extended to within a few centimeters of the upper port of each upflow column.

Flow of the leaching medium through the coal columns was begun immediately. Care was taken to see that each coal sample was thoroughly wetted and that channeling did not occur. The micro-valve on each column was patiently adjusted until the flow rate was close to  $10^{-3}$  mm/sec resulting in a column throughput of 1 liter/day. This slow flow rate was chosen since much of the water diverted through coal mines seeps through seams, cracks, etc., in a slow, percolating manner.

On a daily basis 1 liter of leachate was collected from each column for analysis. The leachates from replicate columns were analyzed on an individual basis and were not composited. The preparation of sample bottles and the preservation and filtration of samples were identical to the methods followed in the field sampling phase of the study. Leachate columns were in operation 10 days.

#### Analytical Methods

The Water Quality section of the Utah Water Research Laboratory maintains an analytical laboratory which is certified by the U.S. Environmental Protection Agency, Region 8, and the State of Utah, Department of Health. Certification requires the acceptable performance on analyses of audit samples received yearly and maintenance of a Quality Assurance program whose guidelines are mandated by the above agencies. Only approved analytical methods are used (EPA 1979 and APHA 1980). Instruments are calibrated with each use and properly maintained. Standard curves are generated on a routine basis and checked prior to each analysis run. The quality and/or standardization of all reagents are verified with each analytical run. A minimum of 10 percent of all sample analyses are performed in

duplicate. Precision and accuracy statements for each method are generated on a yearly basis. Internal quality control samples are analyzed by all technicians on a quarterly basis. All quality assurance records are tabulated and kept on permanent file. Table 3 summarizes the analytical methods used for water samples from the field study and leachate column phases of the project.

Water samples for the Selenastrum capricornutum Printz algal assay bottle test were prepared as previously described. The algal assays were conducted using 500 ml erlenmeyer flasks covered with inverted beakers to prevent contamination but allow free atmospheric exchange of carbon dioxide and oxygen. All glassware was washed with a sodium bicarbonate solution followed by several tap water rinses, a rinse with 50 percent  $\text{HNO}_3$ , and several DDW rinses. Flask openings were wrapped with aluminum foil and the glassware was sterilized in an autoclave (15 minutes at 15-17 psi and  $121^\circ\text{C}$ ).

Accrual water sample plus any macronutrients were added to each flask to make a final volume of 100 ml. Macronutrient stock solutions were made with sterile DDW and stored in sterile containers. Table 4 summarizes the experimental design and quantities of nutrients added. For any given treatment listed in Table 4, each sample was assayed in triplicate for subsequent statistical validation of results.

A portion of Selenastrum capricornutum Printz algal stock culture was then added to each assay flask to give a final concentration of 1000 cells/ml. The initial stock alga was obtained from the Environmental Protection Agency Environmental Research Laboratory in Corvallis, Oregon. It was cultured in sterile synthetic algal nutrient medium for 7 days prior to each sampling date to provide a fresh, healthy culture for the inoculum. The stock and subsequent bottle assays were cultured under

Table 3. Analytical methods for analysis of accrual water and leachate column samples.

Parameter	Method	References
<b>Physical Properties:</b>		
pH	Potentiometric	APHA 1980, pp. 402-409; EPA 1979, Method 150.1
Specific Conductance	Conductivity Meter, Wheatstone Bridge	APHA 1980, pp. 70-73; EPA 1979, Method 120.1
Solids--		
Total Dissolved (Total Filterable)	Gravimetric, Dried at 180°C	APHA 1980, pp. 92-94; EPA 1979, Method 160.1
Suspended (Total Nonfilterable)	Gravimetric, Dried at 103°C	APHA 1980, pp. 94-95; EPA 1979, Method 160.2
Volatile Suspended	Gravimetric, Ignition at 550°C	APHA 1980, pp. 95-96; EPA 1979, Method 160.4
Temperature	Thermometric, Calibrated Thermometer	APHA 1980, pp. 124-125; EPA 1979, Method 170.1
<b>Trace Metals:</b>		
Aluminum, Al	Atomic Absorption, Direct Aspiration	APHA 1980, pp. 157-159; EPA 1979, Method 202.1
Arsenic, As	Atomic Absorption, Sodium Borohydride Reduction, Hydride Generation	APHA 1980, pp. 160-163
Barium, Ba	Atomic Absorption, Carbon Furnace	APHA 1980, pp. 166-168; EPA 1979, Method 208.2
Beryllium, Be	Atomic Absorption, Direct Aspiration	APHA 1980, pp. 157-159; EPA 1979, Method 210.1
Boron, B	Colorimetric, Carmine	APHA 1980, pp. 260-261
Cadmium, Cd	Atomic Absorption, Direct Aspiration	APHA 1980, pp. 152-155; EPA 1979, Method 213.1
Chromium, Cr	Atomic Absorption, Direct Aspiration	APHA 1980, pp. 152-155; EPA 1979, Method 218.1
Cobalt, Co	Atomic Absorption, Direct Aspiration	APHA 1980, pp. 152-155; EPA 1979, Method 219.1
Copper, Cu	Atomic Absorption, Direct Aspiration	APHA 1980, pp. 152-155; EPA 1979, Method 220.1
Iron, Fe	Atomic Absorption, Direct Aspiration	APHA 1980, pp. 152-155; EPA 1979, Method 236.1
Lead, Pb	Atomic Absorption, Carbon Furnace	APHA 1980, pp. 166-168; EPA 1979, Method 239.2
Lithium, Li	Atomic Absorption, Carbon Furnace	APHA 1980, pp. 166-168
Manganese, Mn	Atomic Absorption, Direct Aspiration	APHA 1980, pp. 152-155; EPA 1979, Method 243.1
Mercury, Hg	Atomic Absorption, Cold Vapor	APHA 1980, pp. 164-166; EPA 1979, Method 245.1
Molybdenum, Mo	Atomic Absorption, Carbon Furnace	APHA 1980, pp. 166-168; EPA 1979, Method 246.2
Nickel, Ni	Atomic Absorption, Direct Aspiration	APHA 1980, pp. 152-155; EPA 1979, Method 249.1
Selenium, Se	Atomic Absorption, Sodium Borohydride Reduction, Hydride Generation	APHA 1980, pp. 160-163
Silver, Ag	Atomic Absorption, Direct Aspiration	APHA 1980, pp. 152-155; EPA 1979, Method 272.1
Strontium, Sr	Atomic Absorption, Direct Aspiration	APHA 1980, pp. 152-155
Zinc, Zn	Atomic Absorption, Direct Aspiration	APHA 1980, pp. 152-155; EPA 1979, Method 289.1
Total (Unfiltered) Metals; Fe, Mn, Hg	Preliminary Nitric Acid Digestion	APHA 1980, pp. 143-144; EPA 1979, Section 200.0
<b>Major Anions and Cations:</b>		
Alkalinity, Total	Titrimetric with Potentiometric or Colorimetric Endpoint	APHA 1980, pp. 253-257; EPA 1979, Method 310.1
Chloride, Cl	Titrimetric, Mercuric Nitrate	APHA 1980, pp. 271-273; EPA 1979, Method 325.3
Fluoride, F	SPADNS (Without Preliminary Digestion) or Potentiometric, Ion-selective Electrode (Without Preliminary Digestion)	APHA 1980, pp. 337-339; EPA 1979, Method 340.1 APHA 1980, pp. 335-335; EPA 1979, Method 340.1
Hardness--		
Calcium, Ca	Titrimetric, EDTA	APHA 1980, pp. 185-186; EPA 1979, Method 215.2
Total	Titrimetric, EDTA	APHA 1980, pp. 195-199; EPA 1979, Method 130.2
Magnesium, Mg	Calculation	APHA 1980, p. 213
Potassium, K	Atomic Absorption, Direct Aspiration	APHA 1980, pp. 152-155; EPA 1979, Method 258.1
Silica, SiO <sub>2</sub>	Colorimetric, Molybdosilicate	APHA 1980, pp. 429-432; EPA 1979, Method 370.1
Sodium, Na	Atomic Absorption, Direct Aspiration	APHA 1980, pp. 152-155; EPA 1979, Method 273.1
Sulfate, SO <sub>4</sub>	Turbidimetric	APHA 1980, pp. 439-440; EPA 1979, Method 375.4
<b>Nutrients:</b>		
Nitrogen--		
Ammonia, NH <sub>3</sub> -N	Colorimetric, Indophenol with Nitroprusside, Manual	APHA 1980, pp. 363-366; EPA 1979, Method 350.1; Solorzano 1969
Nitrate, NO <sub>3</sub> -N	Colorimetric, Cadmium Reduction and Diazotization, Automated	APHA 1980, pp. 376-379; EPA 1979, Method 353.2
Nitrite, NO <sub>3</sub> -N	Colorimetric, Cadmium Reduction and Diazotization, Automated	APHA 1980, pp. 376-379; EPA 1979, Method 353.2
Phosphorus--		
Orthophosphate, PO <sub>4</sub> -P	Colorimetric, Ascorbic Acid	APHA 1980, pp. 420-421; EPA 1979, Method 365.2
Total	Colorimetric, Ascorbic Acid with Persulfate Digestion	APHA 1980, pp. 415, 420-421; EPA 1979, Method 365.2
<b>Organics:</b>		
Carbon, Total Organic, TOC	Infrared, with Persulfate and Heat Digestion	APHA 1980, pp. 471-475; OIC 1977
Oil and Grease	Partition-Gravimetric	APHA 1980, pp. 461-462; EPA 1979, Method 413.1
Trihalomethanes, THM	Gas Chromatography, Purge and Trap	Federal Register 1979; Peters 1981, pp. 13-19
<b>Miscellaneous:</b>		
Algal Assay	Printz Bottle Test for Nutrient Limitation	Miller et al. 1978

Table 4. Algal assay experimental design.

Treatments
A Control (sample only)
B Control + 2.10 mg N/1 <sup>a</sup>
C Control + 0.93 mg P/1 <sup>b</sup>
D Control + 0.93 mg P/1 + 2.10 mg N/1
A <sup>+</sup> Control + 1.00 mg EDTA/1 <sup>c</sup>
B <sup>+</sup> Control + 2.10 mg N/1 + 1.00 mg EDTA/1
C <sup>+</sup> Control + 0.93 mg P/1 + 1.00 mg EDTA/1
D <sup>+</sup> Control + 0.93 mg P/1 + 2.10 mg N/1 + 1.00 mg EDTA/1

<sup>a</sup>Added as NaNO<sub>3</sub>.

<sup>b</sup>Added as K<sub>2</sub>HPO<sub>4</sub>.

<sup>c</sup>Added as Na<sub>2</sub>EDTA·2H<sub>2</sub>O [disodium (ethylenedinitrilo) tetraacetate].

cool-white fluorescent light providing 400 + 40 foot candles measured illumination and regulated temperature of 24 + 2°C. The cultured stock was centrifuged, rinsed free of nutrients, and resuspended in sterile sodium bicarbonate solution. Cell counts were determined using a hemacytometer counting chamber.

Assay bottles were then subjected to the light and temperature conditions specified above and the flasks were shaken daily by hand. Algal growth measurements were made at selected

intervals during the test period until maximum algal standing crop was obtained. Growth was monitored for 14 days or until the change in biomass was less than 5 percent per day. Growth measurements were made by determination of relative fluorescence using a Turner Model 111 fluorometer and by optical density at 750 nm using a Bausch and Lomb Spectronic 70 spectrophotometer. After the condition of maximum standing crop was attained, the dry weight of algal biomass in each flask was determined using the gravimetric suspended solids procedure.

## RESULTS AND CONCLUSIONS

### Potential Problems

The values for most parameters monitored during the field and laboratory portions of the study fell below the toxicity criteria for drinking water, irrigation water, freshwater aquatic life, and stock and wildlife watering. Table 5 summarizes the generally accepted water quality criteria for these uses and the appropriate literature references. Water quality criteria define the concentration levels of particular parameters which should not be exceeded in order for the water to be suitable with respect to the intended use.

Criteria levels are determined using a variety of scientific experiments and observations. Many literature sources document acute and chronic effects of various chemical constituents on a wide variety of plant and animal test organisms. Much of the known toxicity data were compiled by McKee and Wolf (1963) and the Environmental Protection Agency (1976). For most parameters, a specific criterion is established or recommended as listed in Table 5. With the exception of drinking water supplies, many of the criteria limits are not viewed as completely rigid standards. New data are continually being collected as a result of ongoing research. In many cases, the specificity of a particular situation must be taken into account when judging the effects of a particular discharge into an established ecosystem.

Specific examples of data from the coal mine accrual water field monitoring and coal leachate column study phases are presented in tabular form in the following discussion.

Field data presented in the following discussions are listed by mine site number (1 through 6 followed by A or B where appropriate) and sampling date encompassing May 1981 to April 1982. Yearly mean concentrations and standard deviations are also calculated for each site. The presence of four asterisks in any column and a footnote stating "no data" indicates that a sample was not collected from that site on the given sampling date due to conditions of no discharge, inaccessibility of site or quarterly monitoring of that parameter.

Data from leachate experiments presented in the following discussions are listed by the abbreviation "Col" and followed by the mine site number (1 through 6). For each day of the experiment, the data from the analysis of three replicate coal column leachates are presented as the mean + standard deviation. Data were collected for 10 days with coal leachate from three sites monitored during each of two analytical runs. Leachate media were prepared and analyzed every other day. Successive batches of medium 1 were used to leach coal from mine sites 1, 2 and 3. Coal from sites 4, 5 and 6 was leached with batches of medium 2. The presence of four asterisks in any column and a footnote stating "no data" indicates that leachates or media samples were not analyzed for that parameter on that day.

Any concentration values for field and leachate column data that were determined to be below the limit of detection for the analysis are represented as less than (<) the detection limit (a value constant for that parameter).

Table 5. Water quality criteria.

Parameter	Drinking Water	Irrigation Water	Freshwater Aquatic Life	Other
Physical Properties				
pH	6.5-8.5 units	Dependent on crop and soil characteristics	6.5-9.0 units	
Solids, total dissolved	1000 mg/l 2000 mg/l if no better source is available	500 mg/l no detrimental effects 500-1000 mg/l can have detrimental effects on sensitive crops 1000-2000 mg/l may have adverse effects on many crops	Criterion not established	
Trace Metals:				
Arsenic	50 µg/l	100 µg/l (1 and 5), 1000 µg/l (2)	1000 µg/l	1000 µg/l stock and wildlife watering
Barium	1000 µg/l	Toxic, but criterion not established	5000 µg/l	
Beryllium	Criterion not established	100 µg/l continuous irrigation on all soils: except 500 µg/l irrigation on neutral to alkaline fine-textured soils	11 µg/l soft water 1100 µg/l hard water	
Boron	Criterion not established 20,000 µg/l recommended	750 µg/l long term irrigation of sensitive crops (see also Table 6)	Criterion not established	
Cadmium	10 µg/l	Criterion not established	0.4 µg/l soft water; cladocerans and salmonids 1.2 µg/l hard water; cladocerans and salmonids 4.0 µg/l soft water; less sensitive aquatic life 12.0 µg/l hard water; less sensitive aquatic life	



Table 5. Continued.

Parameter	Drinking Water	Irrigation Water	Freshwater Aquatic Life	Other
Trace Metals: (continued)				
Chromium	50 µg/l	100 µg/l	100 µg/l freshwater aquatic life (1 and 5) 1000 µg/l fish (2) 50 µg/l aquatic life other than fish	5000 µg/l stock and wildlife watering
Cobalt	Criterion not established	Toxic, but criterion not established	Toxic, but criterion not established	
Copper	1000 µg/l	100 µg/l (2) 200 µg/l (5)	0.1 times a 96-hour LC <sub>50</sub> as determined through nonaerated bioassay using a sensitive aquatic resident species (1) 20 µg/l (2), 10 µg/l (5)	
Iron	300 µg/l permissible 1000 µg/l excessive no MCL established	Criterion not established	1000 µg/l	
Lead	50 µg/l	Toxic, but criterion not established	0.01 times the 96-hour LC <sub>50</sub> value for dissolved Pb using the receiving water or comparable water as diluent, for sensitive resident species (1) 50 µg/l (5)	
Lithium	Criterion not established, 5000 µg/l recommended	Toxic to sensitive crops, but criterion not established	Criterion not established	
Manganese	50 µg/l	500 µg/l	1000 µg/l	10,000 µg/l stock watering
Mercury	2 µg/l	Criterion not established	0.05 µg/l	0.05 µg/l wildlife 1.0 µg/l livestock watering
Nickel	Criterion not established	Toxic, but criterion not established	0.01 times the 96-hour LC <sub>50</sub>	

Table 5. Continued.

Parameter	Drinking Water	Irrigation Water	Freshwater Aquatic Life	Other
Trace Metals: (continued)				
Selenium	10 µg/l	500 µg/l (tentative) (2) 50 µg/l (5)	0.01 times the 96-hour LC <sub>50</sub> using a sensitive resident species (1), 50 µg/l (5)	
Silver	50 µg/l	Criterion not established	0.01 times the 96-hour LC <sub>50</sub> using a sensitive resident species (1), 10 µg/l (5)	
Zinc	5000 µg/l	Toxic, but criterion not established	50 µg/l	
Major Anions and Cations:				
Alkalinity	Criterion not estab- lished	Refer to discussion of adjusted sodium absorp- tion ratio	20 mg/l or more preferred except where natural concentrations are less (1) 100-120 mg/l or more pre- ferred for diversified aquatic life (2)	
Chloride	250 mg/l	100 mg/l	Toxic, but criterion not established; cases should be considered individually	1500 mg/l stock and wildlife
Fluoride	1.6-2.0 mg/l; dependent on air temperature	10.0 mg/l	1.5 mg/l	1.0 mg/l stock watering
Sodium	Criterion not estab- lished	Refer to discussion of adjusted sodium absorption ratio	Toxic, but criterion not established; toxicity varies with species and ionic character of water	
Sulfate	500 mg/l	200 mg/l	Criterion not established	500 mg/l stock watering

Table 5. Continued.

Parameter	Drinking Water	Irrigation Water	Freshwater Aquatic Life	Other
<b>Nutrients:</b>				
Ammonia-nitrogen	Criterion not established; 40-80 µg/l generally accepted as upper limit	Criterion not established; usually desirable for fertilizing value	16 µg/l (as unionized ammonia; dependent on temperature and pH)	
Nitrate-nitrogen	10 mg/l	Criterion not established; usually desirable for fertilizing value	4 mg/l	
Orthophosphate and total phosphorus	Criterion not established	Criterion not established; usually desirable for fertilizing value	Criterion not established; generally accepted upper limit of 50 µg/l (5) or 100 µg/l (2) to control eutrophication	
<b>Organics:</b>				
Oil and Grease	Virtually free from oil and grease, particularly from tastes and odors derived from petroleum products	Criterion not established	<ol style="list-style-type: none"> <li>1. Levels of individual petrochemicals shall not exceed 0.01 times the lowest continuous flow 96-hour LC<sub>50</sub> to several important species each having a high susceptibility to oils and petrochemicals.</li> <li>2. Any levels of oil and grease in the sediments which cause deleterious effects to the biota shall not be allowed.</li> <li>3. Surface waters shall be virtually free of floating petroleum derived oils and floating nonpetroleum oils of vegetable or animal origin.</li> </ol>	
Trihalomethanes	100 µg/l as total THM	Criterion not established	Toxic, but criterion not established	

Table 5. Continued.

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References:

- (1) EPA (Environmental Protection Agency). 1976. Quality criteria for water. 055-001-01049-4. U.S. EPA, Washington, D.C.
- (2) McKee, J. E., and H. W. Wolf. 1963. Water quality criteria. California State Water Resources Control Board. Publication 3-A. 2nd Ed. (reprinted 1976).
- (3) State of Utah Department of Health. 1979. State of Utah public drinking water regulations. Part I - Administrative rules. Part II - Design and construction standards. Bureau of Public Water Supplies, Salt Lake City, Utah.
- (4) Federal Register. 1979. Interim primary drinking water regulations: control of trihalomethanes in drinking water. 44(23), November 29.
- (5) State of Utah, Department of Social Services, Division of Health. 1965. Wastewater disposal regulations, part II, standards of quality for waters of the state. Utah Water Pollution Control Board, Utah State Board of Health. Revised 1967, 1968, and 1978.

Definitions:

1. toxic - producing adverse effects to a test organism, dependent on concentration of the toxicant and time of exposure.
2. LC<sub>50</sub> - toxicant concentration producing death of 50 percent of the test organisms at the time of exposure designated.
3. MCL - maximum contaminant level for drinking water sources.

Data of interest from the leachate column experiments are also presented graphically. The data point plotted for any given day represents the mean concentration value determined for the leachates from the three replicate coal columns representative of a given mine site. Values less than the detection limit were entered as one-half the detection limit when computing the mean. When the mean concentration for a set of triplicate column leachates was less than the detection limit, the point was plotted as one-half the detection limit (Sisson 1983).

Data of interest from field monitoring are also presented graphically. For the purposes of graphing, monthly field data at "A" and "B" sites were averaged and the mean value plotted.

All data collected from the field monitoring and leachate column portions of the study are presented in the Appendix.

### Boron

As evidenced in Table 5, when water supplies are used for drinking, or stock and wildlife watering or for the support of freshwater aquatic life, the levels of boron present in the water are not critical. Boron has not been shown to be necessary for human or animal nutrition, but is essential when considering the nutritional needs of higher plants. Maximum contaminant levels for boron in drinking water have not been established, but 20 mg/liter has been recommended. Levels above 30 mg/liter have been known to interfere with digestion due to boron's preservative action on foods. Some toxicity studies with freshwater fish have been conducted. Lethal concentrations producing death in 50 percent of the test organisms (LC<sub>50</sub>) range from 12,000 mg/liter after 6 hours to 3,600 mg/liter in a 96-hour test (McKee and Wolf 1963). Therefore, it is clear that extremely high levels of boron can be tolerated if the water is intended for use in

drinking, stock watering, or freshwater fish and aquatic life.

Although boron is essential to healthy plant growth, excessive quantities cannot be tolerated in a wide range of crops. Boron can be present in the soil column at levels which cause toxicity problems. However, boron toxicity is more often the result of poor quality irrigation water (Ayers 1977). Boron tolerance is highly dependent on the crop in question as is shown in Table 6. Citrus and stone fruit crops are the most susceptible to boron poisoning. Many truck crops, cotton, and cereal crops are present in the semitolerant category with alfalfa, sugar beets, lettuce, and onions showing a much higher tolerance. The irrigation water used for each type of crop can also be classified and graded from excellent to unsuitable with respect to boron concentration as shown in Table 6.

Boron is absorbed through the roots of a plant from the soil and water column. In aqueous solution the boron is then transported to the leaves where water is lost by transpiration and the visual effects of boron toxicity are observed. Boron accumulates in leaf tips and margins producing yellowing and burning phenomena. Leaves can drop prematurely causing severe reductions in crop production and yield. Discoloration and burning in fruit crops are not as evident as boron accumulates within the plant. Instead, twigs on fruit trees are likely to die back and branches can accumulate gummy substances which restrict growth and yield (Wilcox 1960). Boron injury can sometimes be confused with the symptoms of sulfate toxicity and may not result in visible symptoms for several years (McKee and Wolf 1963).

The type of soil and its drainage characteristics and climatic conditions can also affect boron toxicity. Symptoms of boron injury appear sooner in light as opposed to heavier soils.

Table 6. Water quality criteria for boron in irrigation water.

	Sensitive Crops (300-1000 µg B/l)	Semitolerant Crops (1000-2000 µg B/l)	Tolerant Crops (2000-3000 µg B/l)
	Lemon	Lima Bean	Carrot
	Grapefruit	Sweet Potato	Lettuce
	Avocado	Bell Pepper	Cabbage
	Orange	Tomato	Turnip
	Thornless Blackberry	Pumpkin	Onion
	Apricot	Zinnia	Broad Bean
	Peach	Oat	Gladiolus
	Cherry	Milo	Alfalfa
	Persimmon	Corn	Garden Beet
	Kadota Fig	Wheat	Mangel
	Grape (Sultanina and Malaga)	Barley	Sugar Beet
	Apple	Olive	Palm (Phoenix Canariensis)
	Pear	Ragged Robin Rose	Date Palm (Phoenix Dactylifera)
	Plum	Field Pea	Asparagus
	American Elm	Radish	Athel (Tamarix Aphylla)
	Navy Bean	Sweet Pea	
	Jerusalem Artichoke	Pima Cotton	
	Perisan (English) Walnut	Acala Cotton	
	Black Walnut	Potato	
	Pecan	Sunflower (Native)	
<u>Class of Water</u>			
Excellent	<330 µg/l	<670 µg/l	<1000 µg/l
Good	330-670 µg/l	670-1330 µg/l	1000-2000 µg/l
Permissible	670-1000 µg/l	1330-2000 µg/l	2000-3000 µg/l
Doubtful	1000-1250 µg/l	2000-2500 µg/l	3000-3750 µg/l
Unsuitable	>1250 µg/l	>2500 µg/l	>3750 µg/l

Note: Within each group the crops are listed in order of increasing tolerance to long-term application of boron at the concentration levels indicated.

Table adapted from Wilcox (1960) and Scofield (1935).

Soils with high absorptive capacities can postpone the appearance of deleterious effects (McKee and Wolf 1963). Some researchers have noted that with neutral and alkaline soils having high absorption capacities, irrigation water with 2 mg/liter boron can be applied to sensitive crops for some time without apparent injury (EPA 1976). Increased rates of transpiration and evaporation in arid climates can concentrate the soil solution so that symptoms of boron accumulation are observed at an earlier point in time (McKee and Wolf 1963).

Some authorities recommend the long-term use of irrigation water that is no more than 400-500  $\mu\text{g/liter}$  in boron concentration for protection of the more sensitive crops and caution that boron in the soil solution may be higher than 4000  $\mu\text{g/liter}$  even under these restricting conditions (McKee and Wolf 1963). The U.S. Environmental Protection Agency advocates a 750 g/liter long-term limit for insurance against injury to sensitive crops (EPA 1976). A more explicit classification of irrigation waters is given in Table 6, with ratings ranging from excellent to unsuitable based on type of crop and boron concentration.

Boron can be removed from irrigation water, but the techniques are sophisticated and not economically favorable. Neither is there an economical soil or chemical amendment to detoxify the boron present. Certain changes in fertilization and irrigation practices have been employed with some success (Ayers 1977). It has also been suggested that when boron toxicity is a problem and cannot be reduced by treatment or changes in farming practices, it is often advisable to select a more suitable and boron-resistant crop for production in that area (McKee and Wolf 1963).

The field monitoring of coal mine accrual waters for boron (Table 7) showed the highest values consistently occurring in the southern part of the

Wasatch Plateau at mine 1. Yearly means at the A and B sites here were  $450. \pm 130. \mu\text{g/liter}$  and  $490. \pm 150. \mu\text{g/liter}$ , respectively. Yearly means at all the other sites fell between 100. and 200.  $\mu\text{g/liter}$ . Even though the observed concentrations of boron at mine 1 were high when compared to sites further north, this discharge would only be predicted to cause minor potential problems to the most sensitive crops. Only twice during the sampling year did mine site 1B discharge water with quality below the classification rating of good (330.-670.  $\mu\text{g B/liter}$ ). Monthly discharges at mine sites 2 through 6 were in excess of the most stringent limit for a classification of excellent quality irrigation water ( $< 330. \mu\text{g/liter}$ ) only three times in the course of the year's sampling period. These somewhat higher discharge values all occurred in June 1981 at mine site 5B (330.  $\mu\text{g/liter}$ ) and at sites 6A (370.  $\mu\text{g/liter}$ ) and 6B (410.  $\mu\text{g/liter}$ ).

The regimen of monthly sampling over a year's time seems to show little need for concern with respect to boron toxicity problems in irrigation water usage. However, it must be remembered that all samples collected were of a discrete nature and not composited over a period in time (such as 24 hours). Had this sample collection procedure been possible, there may have been more evidence of anomalies and variations in boron concentration in the discharge. However, it is unlikely that boron concentration in any discharges from the Wasatch Plateau would be dangerously high for any length of time.

Since requirements for quality of irrigation water with respect to boron are the most strict of the water quality criteria (Table 5), it follows that the discharges are acceptable with regard to limits for drinking water, freshwater aquatics, and stock and wildlife watering.

The coal leachate column experiment clearly showed how easily boron is

Table 7. Coal mine accrual water data, boron;  $\mu\text{g B/liter}$ .

	1A	1B	2A	2B	3	4	5A	5B	6A	6B
May '81	300.	280.	140.	110.	****	****	<100.	110.	<100.	<100.
Jun	450.	450.	240.	220.	200.	250.	320.	330.	370.	410.
Jul	330.	350.	120.	<100.	****	****	140.	120.	170.	330.
Aug	390.	420.	100.	170.	****	****	<100.	<100.	<100.	****
Sep	440.	440.	160.	160.	160.	160.	220.	250.	160.	250.
Oct	390.	****	220.	160.	****	****	150.	120.	****	****
Nov	610.	650.	250.	250.	****	****	****	280.	140.	150.
Dec	490.	490.	190.	****.	130.	****	****	****	<100.	<100.
Jan '82	740.	690.	190.	<100.	****	<100.	130.	****	****	****
Feb	530.	550.	290.	220.	****	****	270.	****	****	****
Mar	410.	720.	220.	270.	290.	****	****	****	****	****
Apr	340.	330.	<100.	<100.	****	130.	****	****	****	****
Yearly Mean	450.	490.	180.	140.	200.	140.	150.	170.	120.	190.
Standard Deviation	<u>+130.</u>	<u>+150.</u>	<u>+80.</u>	<u>+100.</u>	<u>+70.</u>	<u>+100.</u>	<u>+120.</u>	<u>+120.</u>	<u>+140.</u>	<u>+170.</u>
n	12	11	12	11	4	4	8	7	7	6

\*\*\*\* no data

A - coal mine accrual water sampling site located prior to mine's treatment.  
 B - coal mine accrual water sampling site located after mine's treatment.

leached from the coal matrix. Table 8 presents the coal leachate column data and shows boron concentrations highest on day 1 in all cases with values following a decreasing trend on succeeding days. Figures 4 and 5 graphically depict the data in Table 8. The samples collected from leaching of the coal from mine 1 exhibited the highest values initially (a mean of 3530.  $\mu\text{g B/liter}$  on day 1) and remained so throughout the entire 10 day experiment. The mean value of 450.  $\mu\text{g/liter}$  on day 10 is comparable to the yearly mean field values of 450. + 130.  $\mu\text{g B/liter}$  at 1A and 490. + 150.  $\mu\text{g B/liter}$  at 1B (Table 7). If discharges to the environment from mine 1 were at the levels observed

initially in the leachate experiment, it is clear that severe irrigation problems could be expected with effects to a wide range of crops likely. However, it seems probable that the actual leaching conditions within mine 1 are different than those simulated in the laboratory. These differences may encompass variances in coal particle size, volume of water with respect to coal surface area, or dilution by some other source within the mine. It must also be noted that coal samples collected from all sites were discrete and not composited. Analysis of leachates from the replicate columns showed homogeneity within the coal sampled. A composite coal sample could have taken into account a greater



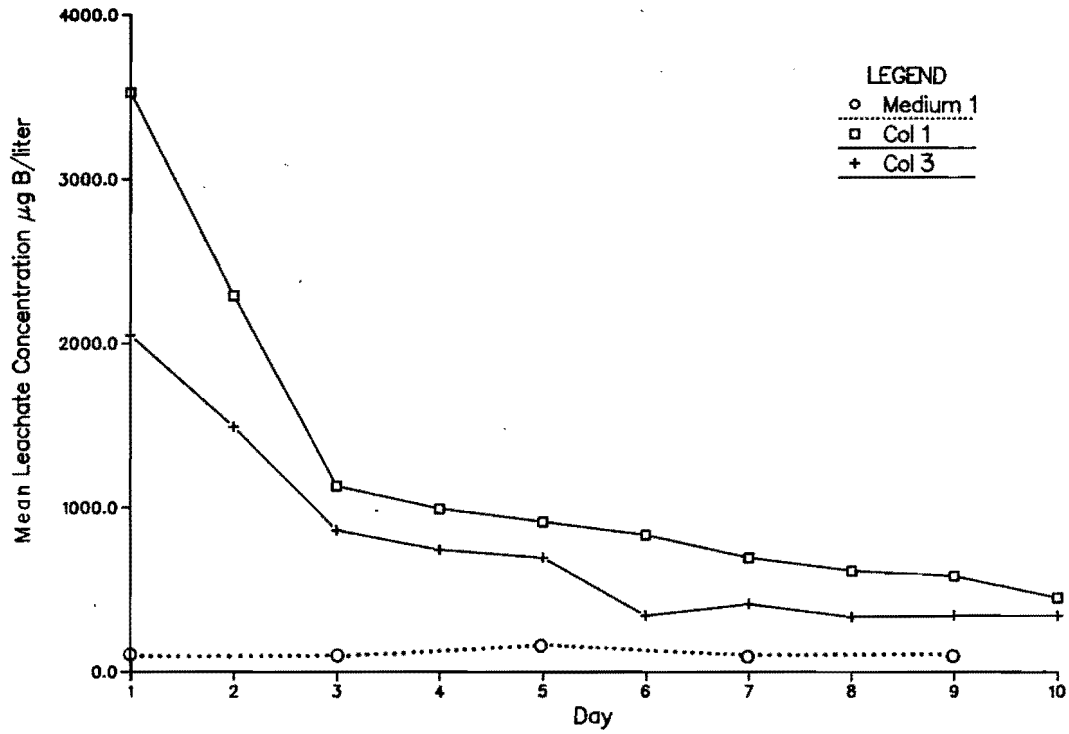


Figure 4. Graphic representation of the leaching of boron from the coal matrices, coal from mines 1 and 3.

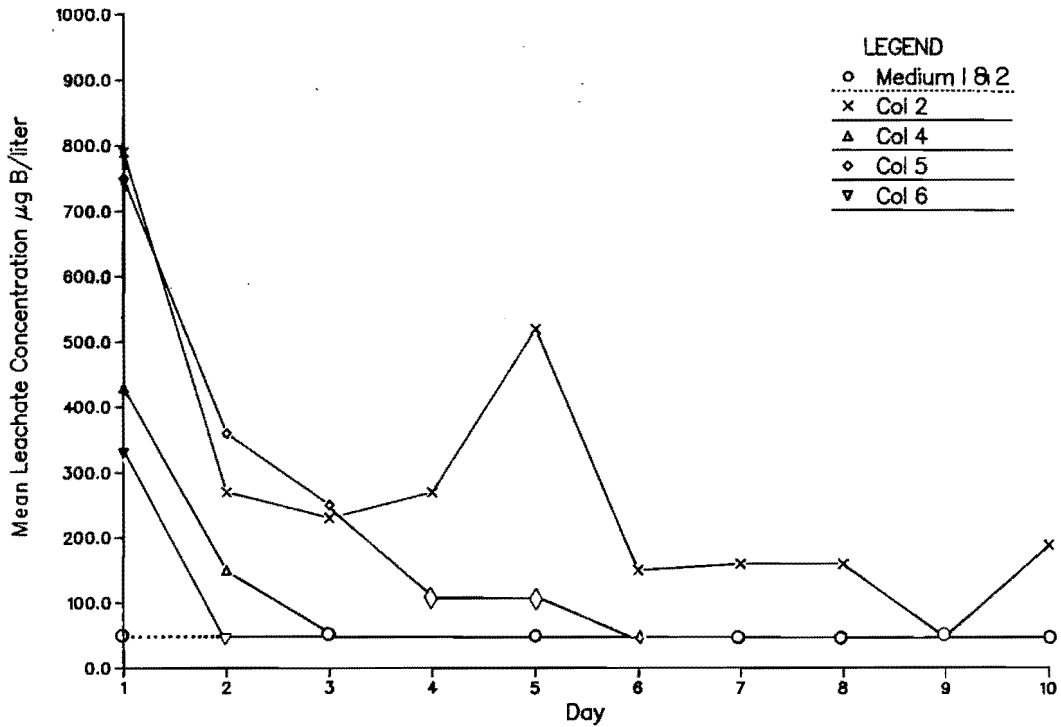


Figure 5. Graphic representation of the leaching of boron from the coal matrices, coal from mines 2, 4, 5, and 6.

degree of variability with respect to time and location within the mine if it existed.

Coal from mine 3 also exhibited extensive leaching of boron from the coal matrix, with high values on day 1

(2050.  $\mu\text{g B/liter}$  mean value), declining to a mean value of 340.  $\mu\text{g B/liter}$  by day 10. Field data at mine 3 are limited due to quarterly monitoring, but boron in the discharge reached a mean value of 200.  $\pm$  70.  $\mu\text{g/liter}$ . This mine has been abandoned for many years and is

Table 8. Coal leachate column data, boron;  $\mu\text{g B/liter}$ .

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10
Medium 1	<100.	****	<100.	****	140.	****	<100.	****	<100.	****
Col 1	3530. +60.	2290. +160.	1130. +30.	990. +130.	910. +0.	830. +200.	690. +20	610. +60.	580. +70.	450. +40.
Col 2	790. +60.	270. +120.	230. +60	280. +280	520. +140.	150. +0.	160. +20.	160. +20	(80.) +60.	190. +0.
Col 3	2050. +30.	1490. +60.	860. +50	740. +130.	690. +200.	340. +40	410. +60.	330. +120.	340. +40.	340. +30.
Col 4	430. +40.	150. +40.	<100. --	<100. --	<100. --	<100. --	<100. --	<100. --	<100. --	<100. --
Col 5	750. +70.	360. +40.	250. +60.	(110.) +60	(110.) +50.	(80.) +50.	<100. --	<100. --	<100. --	<100. --
Col 6	330. +20.	(80.) +50.	<100. --	<100. --	<100. --	<100. --	<100. --	<100. --	<100. --	<100. --
Medium 2	<100.	****	<100.	****	<100.	****	<100.	****	<100.	****

\*\*\*\* no data

Notes:

1. For each day of the experiment, the data from the analysis of three replicate coal column leachates are presented as the mean  $\pm$  standard deviation.

2. Data in parentheses indicate that values less than the detection limit (100.  $\mu\text{g/liter}$ ) were entered when necessary as one-half the detection limit (50.  $\mu\text{g/liter}$ ) to compute the mean and standard deviation (Sisson 1983).

3. Dashes indicate that all values from the three replicate coal columns were less than the detection limit and a standard deviation could not be calculated.

4. See also Appendix Table A-8b.

used to collect drinking water. It could be expected that the boron in the exposed coal surfaces within the mine would have been leached in 50 years time, thus yielding the low concentrations observed during field monitoring. The coal sample collected at this site was obtained from a coal pile approximately 50 years in age. The high quantities of boron in the coal matrix of this sample were surprising, since it was expected that the boron would have previously leached as the coal pile weathered. The leachate column data show that the boron in coal 3 was easily leached due to high concentrations at the onset of the experiment. It is possible that precipitation events were rare enough and of short enough duration in the vicinity of mine 3 to prevent extensive leaching of boron from the coal pile. It is also possible that precipitation leached some boron from exposed coal surfaces, but did not flush it completely from the pile itself. Very intense precipitation at this site in the future could cause an increase in the boron leaching from this coal pile and entering the stream bed. This

increase would likely be sharp but of short duration, so the potential irrigation problems should be minimal.

Coal sampled from mines 2, 4, 5, and 6 contained much less boron than the coals from sites 1 and 3 (Table 8). These coals have a lower long-term potential for contributing to boron toxicity if discharges (or leachates) were used for crop irrigation.

Leaching of boron from the coal matrix has also been documented by Israelsen et al. (1980). In this study coal samples were obtained from four mines on the Wasatch Plateau and the Book Cliffs coal fields in Utah. Sites were numbered from north to south and mine 4 in this 1980 study corresponds to mine site 1 in the current study. The coal samples were ground very finely, as would be indicative of coal slurry pipelining procedures, and slurried for 6 days with three media of increasing salinities on a laboratory bench scale apparatus. As can be seen in Table 9, boron was consistently leached from the coal matrices. Boron concentration in

Table 9. Boron leached from coal (adapted from Israelsen et al. 1980).

Sample	Slurry 1 (2,220. mg/l TDS)		Slurry 2 (4,640. mg/l TDS)		Slurry 3 (13,200. mg/l TDS)	
	B	mg B	B	mg B	B	mg B
	(mg/l)	Leached per kg Coal	(mg/l)	Leached per kg Coal	(mg/l)	Leached per kg Coal
Saline Trans- port Medium	0.1	-	0.5	-	0.7	-
Coal from Mines:						
1	1.4	1.3	1.7	1.2	1.1	0.4
2	2.8	2.7	3.2	2.7	2.0	1.3
3	1.3	1.2	1.9	1.4	2.1	1.4
4	2.4	2.3	2.7	2.2	1.9	1.2

Note: Site 4 in this 1980 study corresponds to site 1 in the current study.

the least saline transport medium (Slurry 1) reached 2.4 mg/liter after slurrying with coal from mine 4 for 6 days. This corresponded to 2.3 mg boron leached per kilogram of coal. Leaching conditions in the current study were somewhat different. The leaching medium was less saline (250. mg/liter average TDS compared to 2,220. mg/liter TDS in the 1980 study) and had a different ionic makeup. The coal was leached with continually flowing portions of medium instead of being batch slurried. And the particle size of the coal was larger in the current study (all particles < 2000 microns compared to the very finely ground coal used in the 1980 study where approximately 20 percent of the particles were smaller than 1.6 microns). After 6 days of leaching in the current upflow column study, a mean value of 9680. µg of boron was leached from 1750. g of coal originating from mine 1. Therefore the coal sample could be said to have contained at least 5.5 mg/kg boron. After 10 days a mean value of 12,010. µg of boron had leached indicating a minimum concentration of 6.9 mg/kg boron in the coal sample from mine 1. Similar calculations for the coal samples from mine 2 through 6 result in minimum boron concentrations of 1.6, 4.3, 0.3, 0.8 and 0.2 mg/kg, respectively. These boron concentrations must be recognized as estimates since leaching was not always complete by day 10 (coal from mines 1, 2 and 3) and any observed leaching must be a function of coal particle size, ionic and physical characteristics of the leaching medium and the hydrologic patterns of the medium's contact with boron present in the coal matrix.

### Mercury

The toxic properties of mercury have long been recognized and the effects may be acute or chronic depending on dosage, chemical form, and means of ingestion by the organism. Mercury is widely distributed in the environment and is not beneficial or

essential to biological systems (EPA 1976).

Mercury can occur in various forms in the environment. Elemental mercury (oxidation state of zero), inorganic salts (oxidation states of +1 and +2) and organic mercury compounds can all be detected. As the oxidation state of mercury increases, so does the solubility of the compounds involved. Therefore these mercuric salts with higher oxidation states are also the most toxic. Many types of organic mercury compounds exist, but methyl- and dimethylmercury are the most dangerous. Recent work has shown that certain microorganisms can produce highly toxic methyl- and dimethylmercury from the less toxic inorganic and organic compounds. These toxic compounds are formed even under what are considered to be normal and naturally-occurring conditions of temperature and pH. Methylation rates vary with water quality, but the methylation process can occur under both aerobic and anaerobic conditions in the pH range of 5 to 9. Since conversion within an aquatic system seems to be relatively simple, it has been recommended that all water quality criteria be based on analysis for the sum of organic and inorganic mercury rather than analysis of inorganic mercury only (EPA 1976).

The most prevalent natural mercuric salt is mercuric sulfide (HgS), also known as the mineral cinnabar (McKee and Wolf 1963). Unpolluted rivers in 31 states where mercury does not occur mineralogically were surveyed and found to have mercury concentrations less than 0.1 µg/liter (Wershaw 1970). Jenne (1972) has also found the majority of U.S. waters to have mercury levels less than 0.1 µg/liter.

Mercury levels in the natural environment are increased by discharges from mining, agricultural, industrial, and waste processes (EPA 1976). Highly soluble mercury salts and organic compounds are widely used in

commerce and industry in medicinal products, disinfectants, herbicides, fungicides, detonators and explosives, preservatives, printing pigments, and in tanning and electroplating processes (McKee and Wolf 1963). A maximum contaminant level (MCL) for mercury in drinking water of 2.0  $\mu\text{g/liter}$  (sum of organic and inorganic) was established by the 1974 Safe Drinking Water Act. Epidemiological studies document mercury toxicity symptoms in humans with prolonged and continuous exposure at about 0.3 mg/70. kg body weight/day. When assuming a safety factor of 10, adults should not ingest more than 30.  $\mu\text{g}$  of mercury per day from all sources (air, water, and food). Children should be exposed to a somewhat lesser quantity. A person drinking 2 liters of water a day which contains 2.0  $\mu\text{g/liter}$  mercury would ingest 4.  $\mu\text{g}$  of mercury and be within a safe limit (EPA 1976).

Livestock and fish tissues consumed by humans should contain mercury levels less than 0.5 mg/kg as established by the U.S. Food and Drug Administration (FDA). It is therefore recommended that livestock water sources contain less than 1.0  $\mu\text{g/liter}$  mercury as the sum of organic and inorganic forms (EPA 1976).

Mercury criteria for freshwater aquatic life are much more stringent due to the fact that mercury is accumulated in body tissues and that many organisms in these systems are located so low in the food chain. Aquatic plants and algae accumulate mercury by adsorption on their surfaces. Higher aquatic organisms accumulate mercury through the water and by food ingestion. A large portion of the mercury present in any aquatic system will eventually be deposited in the bottom sediments where levels of microbial activity are high and conversions to methyl- and dimethyl-mercury are likely. Benthic organisms which are active in this region disturb the sediments and increase the effective area of the water-sediment interface, thus increasing the process of methylation. The benthos also ingest detritus

and accumulate mercury which is then passed along when benthic organisms are preyed upon by fish. Some freshwater fish can bioconcentrate mercury more than 10,000 fold and many fish have a lesser ability to excrete methylmercury compounds than other aquatic organisms. These factors along with the FDA limit of 0.5 mg mercury/kg fish tissue have resulted in a criterion limit of 0.05  $\mu\text{g/l}$  mercury for protection of aquatic systems. Edible fish tissue samples have been known to exceed the 0.5 mg/kg limit in aquatic ecosystems where no toxic effects on the fish itself were observed. However, Daphnia magna (an invertebrate food source for fish) have been shown to develop severely damaged reproductive systems when exposed to 0.04  $\mu\text{g/l}$  mercury as methyl mercuric chloride. It then appears that a freshwater aquatic life criterion of 0.05  $\mu\text{g/l}$  with respect to the sum of organic and inorganic mercury is reasonable (EPA 1976).

The analytical technique for determination of mercury demands the presence of steps which insure rigorous digestion, so that both organic and inorganic forms of mercury are oxidized to the mercuric form before measurement by atomic absorption. Addition of potassium permanganate results in oxidation of a number of organic mercurials. But researchers have found that compounds such as phenyl mercuric acetate and methyl mercuric chloride are only partially oxidized by permanganate (EPA 1979). The addition of a potassium persulfate oxidation step after permanganate oxidation results in 100 percent digestion of the compounds listed above and insures a more accurate estimate of the sum of organic and inorganic mercury forms in any water sample. Application of heat is also employed to aid in the breakdown of methyl mercuric chloride during digestion.

Coal mine accrual water data for total and dissolved mercury are presented in Tables 10 and 11, respec-

tively. All analytical measurements were made after utilizing the most rigorous digestion method by treatment with permanganate, persulfate, and heat. The total mercury designation implies carrying an unfiltered sample through the digestion process and gives a value representing the sum of particulate and dissolved inorganic plus organic mercury. Dissolved samples were filtered and the values indicate the sum of dissolved organic and dissolved inorganic mercury.

The drinking water MCL of 2.0 µg/l for total mercury was exceeded on several occasions as shown in Table 10. Even though samples were collected at site 3 only four times, the data show unacceptably high levels of mercury (2.2 and 3.8 µg total mercury/liter) on two of these sampling dates (December 1981 and March 1982, respectively). Certainly these data are not conclusive, but do merit consideration of the more frequent analysis for total mercury at this water source. Site 3 is the only mine site

Table 10. Coal mine accrual water data, mercury, total; µg Hg/liter.

	1A	1B	2A	2B	3	4	5A	5B	6A	6B
May '81	0.7	1.0	0.7	0.5	****	****	0.6	0.6	0.5	0.7
Jun	****	****	0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Jul	0.2	0.3	0.4	0.2	****	****	0.6	0.3	0.9	0.4
Aug	4.0	3.0	6.0	4.0	****	****	12.0	3.0	2.0	****
Sep	1.0	0.5	2.0	2.3	0.5	0.8	1.0	0.5	1.1	1.2
Oct	0.2	****	0.2	0.2	****	****	<0.2	1.0	****	****
Nov	0.2	<0.2	<0.2	0.3	****	****	****	0.3	0.3	0.4
Dec	1.6	3.0	<0.2	****	2.2	****	****	****	<0.2	<0.2
Jan '82	3.0	2.0	0.5	4.4	****	1.3	0.3	****	****	****
Feb	1.0	2.0	0.3	0.5	****	****	0.2	****	****	****
Mar	2.1	1.3	4.7	1.0	3.8	****	****	****	****	****
Apr	0.2	<0.2	0.3	0.2	****	****	****	****	****	****
Yearly Mean	1.3	(1.3)	(1.3)	(1.2)	(1.6)	(0.7)	(1.9)	(0.8)	(0.7)	(0.5)
Standard Deviation	<u>+1.3</u>	<u>+1.1</u>	<u>+2.0</u>	<u>+1.6</u>	<u>+1.7</u>	<u>+0.6</u>	<u>+4.1</u>	<u>+1.0</u>	<u>+0.7</u>	<u>+0.4</u>
n	11	10	12	11	4	3	8	7	7	6

Note: Data in parentheses indicate that values less than detection limit (0.2 µg/liter) were entered as one-half the detection limit (0.1 µg/liter) to compute the yearly mean and standard deviation (Sisson 1983).

\*\*\*\* no data

A - coal mine accrual water sampling site located prior to mine's treatment.  
 B - coal mine accrual water sampling site located after mine's treatment.

where the discharge is used specifically for human consumption or where discharges are known to enter a drinking water source.

Most of the discharges from May 1981 to April 1982 could perpetuate excessive bioaccumulation of mercury in fish tissue under certain conditions (see Tables 10 and 11). The limit of detection for the mercury cold vapor technique is 0.2 µg/l (EPA 1979). A more sensitive procedure would be needed to more completely determine which

samples exceed the 0.05 µg/l mercury limit in freshwater ecosystems. Many of the mines' discharges enter streams whose waters may eventually be used to support edible fish life. A comprehensive study of fish tissue samples and water samples taken from bodies of water near coal mines may be advisable. It is not known whether dilution of discharge water may be high enough to prevent excessive bioaccumulation, whether species of fish which have a propensity for efficient bioaccumulation are present, or whether fish being taken

Table 11. Coal mine accrual water data, dissolved; µg Hg/liter.

	1A	1B	2A	2B	3	4	5A	5B	6A	6B
May '81	0.6	0.5	0.4	0.4	****	****	0.4	0.6	0.5	<0.2
Jun	<0.2	0.3	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Jul	0.2	0.2	<0.2	<0.2	****	****	<0.2	0.2	0.5	<0.2
Aug	1.7	0.3	0.5	<0.2	****	****	1.6	0.3	0.6	****
Sep	1.0	0.5	0.3	0.4	0.3	0.3	0.4	0.4	0.3	0.5
Oct	0.2	****	0.2	0.2	****	****	<0.2	1.0	****	****
Nov	0.2	<0.2	<0.2	<0.2	****	****	****	0.3	0.3	<0.2
Dec	<0.2	<0.2	<0.2	****	<0.2	****	****	****	<0.2	<0.2
Jan '82	0.8	0.2	<0.2	0.4	****	0.3	0.2	****	****	****
Feb	1.0	2.0	0.3	0.5	****	****	0.2	****	****	****
Mar	0.2	0.8	0.3	0.2	0.3	****	****	****	****	****
Apr	0.2	<0.2	<0.2	<0.2	****	****	<0.2	****	****	****
Yearly Mean	(0.5)	(0.5)	(0.2)	(0.2)	(0.2)	(0.2)	(0.4)	(0.4)	(0.3)	(0.2)
Standard Deviation	<u>+0.5</u>	<u>+0.6</u>	<u>+0.1</u>	<u>+0.2</u>	<u>+0.1</u>	<u>+0.1</u>	<u>+0.5</u>	<u>+0.3</u>	<u>+0.2</u>	<u>+0.2</u>
n	12	11	12	11	4	3	9	7	7	6

Note: Data in parentheses indicate that values less than the detection limit (0.2 µg/liter) were entered as one-half the detection limit (0.1 µg/liter) to compute the yearly mean and standard deviation (Sisson 1983).

\*\*\*\* no data

A - coal mine accrual water sampling site located prior to mine's treatment.  
 B - coal mine accrual water sampling site located after mine's treatment.

from these water sources could present a hazard for human consumption. A report of this nature is now in the draft stage (Denton et al. 1983) with fish samples collected from the Scofield Reservoir. Mercury concentrations in the five tissue samples ranged from 0.11 mg/kg to

0.24 mg/kg and were below the 0.5 mg/kg FDA limit.

Table 12 presents the data collected upon analysis of the column leachates for inorganic plus organic dissolved mercury. The mercury levels here were

Table 12. Leachate column data, mercury, dissolved;  $\mu\text{g Hg/liter}$ .

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10
Medium 1	0.2	****	2.0	****	<0.2	****	<0.2	****	<0.2	****
Col 1	<0.2 --	****	<0.2 --	****	<0.2 --	****	<0.2 --	****	<0.2 --	****
Col 2	(0.2) <u>+0.1</u>	****	0.4 <u>+0.2</u>	****	<0.2 --	****	<0.2 --	****	<0.2 --	****
Col 3	(0.2) <u>+0.1</u>	****	0.5 <u>+0.2</u>	****	(0.1) <u>+0.1</u>	****	<0.2 --	****	<0.2 --	****
Col 4	0.3 <u>+0.1</u>	0.3 <u>+0.1</u>	(0.1) <u>+0.1</u>	****	(0.2) <u>+0.1</u>	****	<0.2 --	****	<0.2 --	****
Col 5	0.3 <u>+0.1</u>	0.4 <u>+0.2</u>	(0.3) <u>+0.2</u>	****	0.3 <u>+0.0</u>	****	<0.2 --	****	<0.2 --	****
Col 6	0.2 <u>+0.0</u>	(0.2) <u>+0.1</u>	(0.2) <u>+0.1</u>	****	<0.2 --	****	<0.2 --	****	<0.2 --	****
Medium 2	0.2	****	0.5	****	2.0	****	<0.2	****	<0.2	****

\*\*\*\* no data

Notes:

1. For each day of the experiment, the data from the analysis of three replicate coal column leachates are presented as the mean  $\pm$  standard deviation.

2. Data in parentheses indicate that values less than the detection limit (0.2  $\mu\text{g/liter}$ ) were entered as one-half the detection limit (0.1  $\mu\text{g/liter}$ ) to compute the mean and standard deviation (Sisson 1983).

3. Dashes indicate that all values from the three replicate coal columns were less than the detection limit and a standard deviation could not be calculated.

4. See also Appendix Table A-20b.



consistently lower than those in samples taken at the mine discharge sites. These leachates could also cause mercury toxicity and bioaccumulation problems in aquatic ecosystems. However, two factors must be noted. First, the limit of detection here is also 0.2 µg/liter and values presented as < 0.2 µg/liter may also be < 0.05 µg/liter. Second, medium 1 and medium 2 were often determined to have mercury concentrations in excess of 0.2 µg/liter. Therefore, there is no clear leaching phenomenon here, as was seen in the case of boron. However, since the mercury levels during the leachate study were often lower than those in the field and below the limit of detection, it may be reasoned that the mercury in the discharges is probably not resulting from the coal itself. Since mercury is commonly used in a number of industrial products and processes, these sources could be responsible for elevated mercury levels in mine discharges on the Wasatch Plateau.

#### NPDES Discharge Requirements

The National Pollution Discharge Elimination System (NPDES) regulations place specific requirements on what coal mines and other industrial operations may discharge into the environment. Parameters to be monitored are outlined in these regulations along with concentration limits, frequency of monitoring and method of sample collection. Reports are generally filed with the State of Utah Bureau of Water Pollution Control Offices in Salt Lake City on a monthly or quarterly basis. The mining companies involved maintain the responsibility for monitoring and reporting data. The types of parameters monitored and the concentration limits established are designed to help control undesirable effects on the aquatic environments in the vicinity of coal mining operations. Much of the impetus for the promulgation of these regulations stemmed from the very real dangers of acid mine drainage which do occur in certain areas.

Tables 13 through 18 summarize NPDES discharge requirements for the six mines studied on the Wasatch Plateau. The requirements are basically the same for all discharge sites, although some variations do occur. These tables also contain the NPDES discharge data submitted by each mining company for the period of May 1981 to April 1982. Sample site locations in these tables are the same as those used throughout this report, 1 through 6 with A or B designations as appropriate. Data points which indicate violation of NPDES standards are followed by an asterisk. Violations are generally only noted at the B sites or at those points where flow is discharged directly to the environment.

#### Flow

NPDES regulations do not place any restrictions on the volume of discharge. However, the volume must be measured and reported. Usually a metering device is installed on site to record the volume of discharge.

If the flow is intermittent at the point of discharge, the duration of the discharge should also be reported to the NPDES offices. During the field sampling phase of this study, flows were not measured, but the following observations were made. Flows at most A sites were intermittent as was expected since the mine accrual water was often used within the mining operation when needed and discharged when excessive quantities were accrued. Uses of the water were reported to include washing of machinery and in shower facilities for the miners. Flows from pipes at sites 1A, 3, 5A and 6A were intermittent in nature. Sites 2A and 4 were underground sump areas within the mines whose depth and total volume fluctuated throughout the sampling period. The B sites located after treatment operations generally had flows of a more constant nature. The pipe at site 2B was an exception. Flow from this pipe was intermittent and said to be regulated by mining personnel.

Table 13. NPDES discharge requirements and data: mine 1.

Discharge Requirements (effective until 1986):																					
Parameter	Daily Average			Seven-Day Average <sup>1</sup>			Daily Maximum			Monitoring Frequency			Sample Type								
Flow, m <sup>3</sup> /day or MGD <sup>2</sup>	NA <sup>3</sup>			NA			NA			2/Month			Measured								
Solids -																					
Total Dissolved, mg/l	NA			NA			650.			2/Month			Grab								
Total Suspended, mg/l	25.			35.			70.			2/Month			Grab								
Iron, Total, mg/l	NA			NA			2.04			2/Month			Grab								
Oil and Grease, mg/l	Should not exceed 10 mg/l									1/Month			Grab								
pH, standard units	Greater than 6.5 and less than 9.0									2/Month			Grab								
No discharge of floating solids or visible foam other than in trace amounts.																					
No discharge of sanitary wastes.																					
Discharge Data:																					
Sample Site	1A			1A			1A			1A			1A			1A					
Monitoring Period	Apr-Jun 1981			Jul-Sep 1981			Oct-Dec 1981			Jan 1982			Feb 1982			Mar 1982			Apr 1982		
Parameter	Min.	Ave.	Max.	Min.	Ave.	Max.	Min.	Ave.	Max.	Min.	Ave.	Max.	Min.	Ave.	Max.	Min.	Ave.	Max.	Min.	Ave.	Max.
Flow, MGD	****	0.75	****	****	0.76	****	****	0.79	****	****	0.80	****	****	2.8	2.8	****	2.8	2.8	****	0.75	0.75
pH, standard units	7.1	7.5	8.1	7.2	7.6	8.2	7.0	7.68	8.20	7.30	****	8.12	7.5	****	7.7	7.7	****	8.1	7.8	****	7.9
Solids -																					
Total Dissolved, mg/l	325.	374.	410.	****	410.	420.	****	480.	550.	472.	672.	1050.*	420.	425.	430.	389.	399.	412.	290.	304.	318.
Total Suspended, mg/l	1.0	21.	91.* <sup>5</sup>	22.7	22.2	90.* <sup>5</sup>	18.2	18.1	48.0	2.0	18.7	52.0	13.0	19.7	31.0	12.	29.6	60.	21.0	51.*	87.*
Iron, Total, mg/l	0.14	0.26	0.63	****	0.45	0.89	****	1.73	2.66*	0.12	0.17	0.25	0.14	0.14	0.15	0.11	0.26	0.41	0.46	0.48	0.50
Acidity, mg CaCO <sub>3</sub> /l	<0.01	5.3	16.	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****
Alkalinity, mg CaCO <sub>3</sub> /l	186.	203.	216.	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****	****
Oil and Grease, mg/l	0.8	1.3	1.8	****	0.93	2.80	****	0.75	1.20	****	<0.1	<0.1	****	5.0	5.0	****	3.4	3.4	****	2.2	2.2

Note: After the completion of this research project, the monitoring point for NPDES reports was changed to the 1B sampling site for a better evaluation of discharges to the environment.

<sup>1</sup>The seven-day average is determined by calculation of the arithmetic mean of three consecutive samples taken on separate days within a seven-day period.  
<sup>2</sup>If flow is intermittent, the duration of the discharge should be reported.  
<sup>3</sup>Not applicable.  
<sup>4</sup>If total iron exceeds 2 mg/l, then the State of Utah and the permittee shall review the actions necessary to achieve compliance and evaluate the continued appropriateness of the limitation. In no event shall the discharge exceed the daily maximum limitation of 7 mg/l.  
<sup>5</sup>Total suspended solids violation due to pump failure.  
\*Violation of discharge requirements.

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Table 14. NPDES discharge requirements and data: mine 2.

Discharge Requirements (effective until 1986):					
Parameter	Daily Average	Seven-Day Average <sup>1</sup>	Daily Maximum	Monitoring Frequency	Sample Type
Flow, m <sup>3</sup> /day or MGD <sup>2</sup>	NA <sup>3</sup>	NA	NA	2/Month	Measured
Solids -					
Total Dissolved, mg/l	NA	NA	700.	1/Month	Grab
Total Suspended, mg/l	25.	35.	70.	1/Month	Grab
Iron, Total, mg/l	NA	NA	2.0 <sup>4</sup>	1/Month	Grab
Oil and Grease, mg/l	Should not exceed 10 mg/l			1/Month	Grab
pH, standard units	Greater than 6.5 and less than 9.0			1/Month	Grab

No discharge of floating solids or visible foam other than in trace amounts.  
 No discharge of sanitary wastes.

Discharge Data:

Sample Site	2B			2B			2B			2B			2B		
	Apr-Jun 1981			Jul-Sep 1981			Oct-Dec 1981			Jan-Mar 1982			Apr-Jun 1982		
Monitoring Period	Min.	Ave.	Max.	Min.	Ave.	Max.	Min.	Ave.	Max.	Min.	Ave.	Max.	Min.	Ave.	Max.
Flow, MGD	****	0.36	0.43	****	0.17	0.43	****	0.18	0.43	****	0.36	****	****	0.42	****
pH, standard units	****	8.0	8.1	****	8.0	8.1	****	8.0	8.1	7.9	8.03	8.1	7.7	7.83	8.0
Solids -															
Total Dissolved, mg/l	510.	515.	518.	486.	505.	521.	526.	529.	533.	516.	536.	549.	550.	560.	568.
Total Floating, mg/l	0.	0.	0.	0.	0.	0.	0.	0.	0.	****	****	****	****	****	****
Total Suspended, mg/l	>1.0	1.8	3.5	2.0	8.2	16.	0.5	2.33	4.0	3.5	7.33	13.0	0.5	5.17	8.0
Iron, Total, mg/l	0.01	0.07	0.12	0.79	0.9	1.03	0.73	0.90	0.99	0.61	0.65	0.69	0.66	0.71	0.74
Acidity, mg CaCO <sub>3</sub> /l	0.	>0.5	>1.	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	****	****	****	****	****	****
Alkalinity, mg CaCO <sub>3</sub> /l	242.	265.	289.	243.	248.	256.	233.	251.	275.	****	****	****	****	****	****
BOD <sub>5</sub> , mg/l	0.7	0.7	0.7	0.8	0.8	0.8	0.9	0.9	0.9	****	****	****	****	****	****
Oil and Grease, mg/l	>0.5	6.2	17.6*	<0.5	0.8	1.8	<0.5	2.17	3.6	0.5	1.07	2.2	<0.5	<0.5	<0.5
Coliform Bacteria-															
Fecal, N/100 ml	<3.	5.5	9.	<2.	2.	2.	<2.	2.5	3.	****	****	****	****	****	****
Total, N/100 ml	<3.	20.	43.	11.	29.	43.	11.	47.8	150.	****	****	****	****	****	****

<sup>1</sup>The seven-day average is determined by calculation of the arithmetic mean of three consecutive samples taken on separate days within a seven-day period.

<sup>2</sup>If flow is intermittent, the duration of the discharge should be reported.

<sup>3</sup>Not applicable.

<sup>4</sup>If total iron exceeds 2 mg/l, then the State of Utah and the permittee shall review the actions necessary to achieve compliance and evaluate the continued appropriateness of the limitation. In no event shall the discharge exceed the daily maximum limitation of 7 mg/l.

\*Violation of discharge requirements.

Table 15. NPDES discharge requirements and data: mine 3.

Discharge Requirements (effective until 1986):													
Parameter	Daily Average			Seven-Day Average <sup>1</sup>			Daily Maximum			Monitoring Frequency			Sample Type
Flow, m <sup>3</sup> /day or MGD <sup>2</sup>	NA <sup>3</sup>			NA			NA			2/Month			Measured
Solids -													
Total Dissolved, mg/l	720.			NA			NA			1/Month			Grab
Total Suspended, mg/l	25.			35.			70.			1/Month			Grab
Iron, Total, mg/l	NA			NA			2.04			1/Month			Grab
Oil and Grease, mg/l	Should not exceed 10 mg/l									1/Month			Grab
pH, standard units	Greater than 6.5 and less than 9.0									1/Month			Grab
No discharge of floating solids or visible foam other than in trace amounts.													
No discharge of sanitary wastes.													
Discharge Data:													
Sample Site	3			3			3			3			3
	1981												1982
Parameter	Apr-Jun			Jul <sup>5</sup>	Aug	Sep	Oct	Nov	Dec <sup>5</sup>	Jan <sup>6</sup>	Feb <sup>6</sup>	Mar	Apr <sup>5</sup>
	Min.	Ave.	Max.										
Flow, GPM <sup>7</sup>	****	****	****	****	137.	292.	86.	82.	****	****	****	233.	****
pH, standard units	7.4	****	7.8	****	7.8	7.6	7.6	7.2	****	****	****	7.50	****
Solids -													
Total Dissolved, mg/l	****	****	****	****	700.	695.	725.*	600.	****	****	****	628.	****
Total Suspended, mg/l	****	****	****	****	5.0	122.*	3.5	6.0	****	****	****	12.	****
Iron-													
Dissolved, mg/l	****	****	****	****	0.050	0.065	0.075	0.080	****	****	****	0.080	****
Total, mg/l	****	****	****	****	0.079	0.120	0.185	0.177	****	****	****	0.080	****
Manganese, Total, mg/l	****	****	****	****	0.03	0.033	0.030	0.026	****	****	****	0.010	****
Acidity, mg CaCO <sub>3</sub> /l	****	****	****	****	3.8	4.0	28.	22.	****	****	****	36.0	****
Alkalinity, mg CaCO <sub>3</sub> /l	****	****	****	****	356.	352.	348.	293.	****	****	****	324.	****
BOD <sub>5</sub> , mg/l	****	14.5	****	****	****	3.1	****	****	****	****	****	3.4	****
Oil and Grease, mg/l	****	****	****	****	70.*	4.0	<1.0	0.4	****	****	****	<1.0	****
Coliform Bacteria-													
Fecal, MPN <sup>8</sup> /100 ml	****	<2.0	****	****	****	<20.	****	****	****	****	****	<2.0	****
Total, MPN <sup>8</sup> /100 ml	****	<2.0	****	****	****	330.	****	****	****	****	****	110.	****

<sup>1</sup>The seven-day average is determined by calculation of the arithmetic mean of three consecutive samples taken on separate days within a seven-day period.

<sup>2</sup>If flow is intermittent, the duration of the discharge should be reported.

<sup>3</sup>Not applicable.

<sup>4</sup>If total iron exceeds 2 mg/l, then the State of Utah and the permittee shall review the actions necessary to achieve compliance and evaluate the continued appropriateness of the limitation. In no event shall the discharge exceed the daily maximum limitation of 7 mg/l.

<sup>5</sup>No overflow on these sampling dates.

<sup>6</sup>Site inaccessible on these sampling dates.

<sup>7</sup>Gallons per minute.

<sup>8</sup>Most probable number.

\*Violation of discharge requirements.

Table 16. NPDES discharge requirements and data: mine 4.

Discharge Requirements (effective until 1986):					
Parameter	Daily Average	Seven-Day Average <sup>1</sup>	Daily Maximum	Monitoring Frequency	Sample Type
Flow, m <sup>3</sup> /day or MGD <sup>2</sup>	NA <sup>3</sup>	NA	NA	1/Month	Measured
Solids -					
Total Dissolved, mg/l	NA	NA	650.	1/Month	Grab
Total Suspended, mg/l	25.	35.	70.	1/Month	Grab
Iron, Total, mg/l	NA	NA	2.0 <sup>4</sup>	1/Month	Grab
Oil and Grease, mg/l	Should not exceed 10 mg/l			1/Month	Grab
pH, standard units	Greater than 6.5 and less than 9.0			2/Month	Grab
No discharge of floating solids or visible foam other than in trace amounts.					
No discharge of sanitary wastes.					
Discharge Data:					
This mine did not discharge during the period of May 1981 to April 1982.					

<sup>1</sup>The seven-day average is determined by calculation of the arithmetic mean of three consecutive samples taken on separate days within a seven-day period.

<sup>2</sup>If flow is intermittent, the duration of the discharge should be reported.

<sup>3</sup>Not applicable.

<sup>4</sup>If total iron exceeds 2 mg/l, then the State of Utah and the permittee shall review the actions necessary to achieve compliance and evaluate the continued appropriateness of the limitation. In no event shall the discharge exceed the daily maximum limitation of 7 mg/l.

Table 17. NPDES discharge requirements and data: mine 5.

Discharge Requirements (effective until 1987):					
Parameter	Daily Average	Seven-Day Average <sup>1</sup>	Daily Maximum	Monitoring Frequency	Sample Type
Flow, m <sup>3</sup> /day or MGD <sup>2</sup>	NA <sup>3</sup>	NA	NA	1/Month	Measured
Solids -					
Total Dissolved, mg/l	NA	NA	700.	1/Month	Grab
Total Suspended, mg/l	25.	35.	70.	1/Month	Grab
Iron, Total, mg/l	NA	NA	2.0 <sup>4</sup>	1/Month	Grab
Oil and Grease, mg/l	Should not exceed 10 mg/l			1/Month	Grab
pH, standard units	Greater than 6.5 and less than 9.0			1/Month	Grab

No discharge of floating solids or visible foam other than in trace amounts.  
 No discharge of sanitary wastes.

Discharge Data:

Sample Site	5B			5B			5B			5B			5B		
	Apr-Jun 1981			Jul-Sep 1981			Oct-Dec 1981			Jan-Mar 1982 <sup>5</sup>			Apr-Jun 1982		
Monitoring Period	Min.	Ave.	Max.	Min.	Ave.	Max.	Min.	Ave.	Max.	Min.	Ave.	Max.	Min.	Ave.	Max.
Flow, MGD <sup>6</sup>	****	140.	200.	****	90.	100.	****	17.6	50.	****	16.6	50.	No discharge		
pH, standard units	7.70	****	8.00	8.00	****	8.30	8.00	****	8.20	7.90	****	7.90	****	****	****
Solids -															
Total Dissolved, mg/l	4.30	493.	600.	470.	483.	500.	****	345.	550.	****	133.	400.	****	****	****
Total Suspended, mg/l	16.0	46.7*	98.0*	26.5	94.5*	226.*	****	7.6	17.0	****	4.6	14.0	****	****	****
Iron, Total, mg/l	<0.01	<0.01	0.01	0.01	0.10	0.16	****	0.10	0.16	****	0.03	0.08	****	****	****
Acidity, mg CaCO <sub>3</sub> /l	5.00	5.47	5.70	<0.01	3.33	6.00	****	0.67	2.00	****	3.3	10.0	****	****	****
Alkalinity, mg CaCO <sub>3</sub> /l	226.	245.	270.	250.	256.	260.	****	158.	258.	****	103.	310.	****	****	****
Oil and Grease, mg/l	<0.1	2.03	4.00	0.70	3.6	8.60	****	0.40	1.20	****	<0.33	<1.00	****	****	****

<sup>1</sup>The seven-day average is determined by calculation of the arithmetic mean of three consecutive samples taken on separate days within a seven-day period.

<sup>2</sup>If flow is intermittent, the duration of the discharge should be reported.

<sup>3</sup>Not applicable.

<sup>4</sup>If total iron exceeds 2 mg/l, then the State of Utah and the permittee shall review the actions necessary to achieve compliance and evaluate the continued appropriateness of the limitation. In no event shall the discharge exceed the daily maximum limitation of 7 mg/l.

<sup>5</sup>Discharge during a short period in January only.

<sup>6</sup>These field data are probably in units of gallons per minute (GPM) and not million gallons per day (MGD). The actual field data could not be located, but flow data at other mines owned by this company have been recorded in GPM.

\*Violation of discharge requirements.

Table 18. NPDES discharge requirements and data: mine 6.

Discharge Requirements (effective until 1987):					
Parameter	Daily Average	Seven-Day Average <sup>1</sup>	Daily Maximum	Monitoring Frequency	Sample Type
Flow, m <sup>3</sup> /day or MGD <sup>2</sup>	NA <sup>3</sup>	NA	NA	2/Month	Measured
Solids -					
Total Dissolved, mg/l	NA	NA	700.	2/Month	Grab
Total Suspended, mg/l	25.	35.	70.	2/Month	Grab
Iron, Total, mg/l	NA	NA	2.04	2/Month	Grab
Oil and Grease, mg/l	Should not exceed 10 mg/l			2/Month	Grab
pH, standard units	Greater than 6.5 and less than 9.0			2/Month	Grab

No discharge of floating solids or visible foam other than in trace amounts.  
No discharge of sanitary wastes.

Discharge Data:

Sample Site	6B			6B			6B			6B			6B		
	Apr-Jun 1981			Jul-Sep 1981			Oct-Dec 1981			Jan-Mar 1982			Apr-Jun 1982		
Parameter	Min.	Ave.	Max.	Min.	Ave.	Max.	Min.	Ave.	Max.	Min.	Ave.	Max.	Min.	Ave.	Max.
Flow, MGD	****	0.040	0.043	****	0.031	0.078	****	0.007	0.019	****	0.045	0.045	****	0.110	0.213
pH, standard units	8.0	8.1	8.1	7.0	7.9	8.4	7.2	7.7	8.1	7.5	****	7.5	7.1	****	7.7
Solids -															
Total Dissolved, mg/l	280.	334.	430.	345.	386.	480.	325.	353.	385.	500.	500.	500.	340.	464.	610.
Total Suspended, mg/l	3.	45.	154.*	1.0	9.8	35.0	1.0	8.7	23.	2.0	2.0	2.0	1.	66.	217.*
Iron, Total, mg/l	0.04	1.24	4.60*	0.120	0.175	0.250	0.120	0.163	0.210	0.050	0.050	0.050	0.090	0.72	2.55*
Selenium, Total, g/l	<1.	1.	2.	1.	3.	5.	<1.	1.	2.	<1.	<1.	<1.	<1.	<1.	<1.
Acidity, mg CaCO <sub>3</sub> /l	3.8	14.5	32.0	<0.01	0.38	1.90	<0.01	1.7	8.0	4.0	4.0	4.0	4.0	7.0	10.0
Alkalinity, mg CaCO <sub>3</sub> /l	126.	209.	220.	164.	188.	198.	168.	182.	199.	196.	196.	196.	40.5	238.	244.
BOD <sub>5</sub> , mg/l	16.	25.	40.	5.3	5.3	5.3	2.4	2.4	2.4	1.5	1.5	1.5	6.8	6.8	6.8
Oil and Grease, mg/l	<1.0	0.6	1.6	<0.01	0.9	1.80	1.4	26.7*	78.6*	****	<1.0	<1.0	****	<1.0	<1.0
Coliform Bacteria -															
Fecal, MPN <sup>5</sup> /100 ml	<2.	<2.	<2.	2.0	2.0	2.0	5.	5.	5.	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0
Total, MPN <sup>5</sup> /100 ml	23.	51.	79.	4.0	4.0	4.0	700.	700.	700.	2.0	2.0	2.0	7.0	7.0	7.0

<sup>1</sup>The seven-day average is determined by calculation of the arithmetic mean of three consecutive samples taken on separate days within a seven-day period.

<sup>2</sup>If flow is intermittent, the duration of the discharge should be reported.

<sup>3</sup>Not applicable.

<sup>4</sup>If total iron exceeds 2 mg/l, then the State of Utah and the permittee shall review the actions necessary to achieve compliance and evaluate the continued appropriateness of the limitation. In no event shall the discharge exceed the daily maximum limitation of 7 mg/l.

<sup>5</sup>Most probable number.

\*Violation of discharge requirements.

Discharge of water at mine site 5 was decreased in December 1981 and then discontinued in January 1982. Water was needed for use within the mining operations and all samples collected in 1982 were taken from a sump area within the mine and designated 5A. The pipe at site 6B discharged intermittent flows during the winter months when the treatment ponds were frozen.

Total volumes of discharges and average daily flows were calculated using the flow data as reported in Tables 13 to 18. Site 1B discharged about 423. million gallons from April 1981 to April 1982, averaging 1.07 million gallons per day (MGD), ranging from a reported minimum daily average of 0.75 MGD to a maximum daily average of 2.8 MGD. Site 2B discharged about 135. million gallons from April 1981 to June 1982 and averaged 0.30 MGD ranging from 0.17 MGD as the minimum daily average flow reported to 0.42 MGD as the maximum daily average flow. During the period of April 1981 to April 1982, site 3 was reported to have a flow discharge only from August to November 1981 and in March 1982, due to conditions of no overflow or inaccessibility of the site. Using these limited data, flow during this time period was approximately 36.5 million gallons for an average of 0.24 MGD. The lowest flow reported was 82. gallons per minute (GPM) or 0.12 MGD. The maximum reported flow was 292. GPM or 0.42 MGD. Mine site 4 did not discharge during the field sampling period of May 1981 to April 1982, so no flows were reported. Mine 5 reported quite large volume discharges (16.6 to 200. MGD) with discharge ceasing in January 1982. A phone conversation with mine personnel indicated that these data were probably in units of GPM and not MGD. The actual field data could not be located, but flow data at other mines owned by this company have been recorded in GPM. Site 6 discharged 21 million gallons from April 1981 to June 1982 for an average 0.046 MGD. Flows ranged from a reported minimum daily

average of 0.007 MGD to a maximum daily average of 0.110 MGD.

#### pH

NPDES regulations require the discharges to have pH values greater than 6.5 and less than 9.0 at all times. Grab samples were to be collected once or twice each month. This criterion is identical to the limits permitted for the support of freshwater aquatic life and not quite as stringent as the 6.5-8.5 range mandated for Utah drinking water supplies (State of Utah Department of Health 1979). Aquatic ecosystems are very sensitive to pH since the pH affects the solubility or dissociation of a number of toxic compounds. Acid mine wastes can be quite harmful due to the quantities of sulfuric acid present in addition to the toxic heavy metals which are more soluble in the lower, more acidic pH ranges.

pH limits were not exceeded at any of the mine sites during the period of April 1981 to April (or June) 1982 (see Tables 13 to 18). The field data collected concurrently with the mines' NPDES data are presented in Table 19 and also show no violations of the NPDES criterion for pH at all points of discharge to the environment.

#### Solids

NPDES limits for total dissolved solids (TDS) vary with each mine as are evidenced in Tables 13 to 18. The range of upper limits is small, however, varying from 650. to 720. mg/liter.

Violations with respect to total dissolved solids were very infrequent. Mine 1 exceeded the TDS limit for a daily maximum in January 1982 (1050. mg/liter). In October 1981 TDS at site 3 was 725. mg/liter. However, this value only exceeds the NPDES limit by 5. mg/l (less than 1 percent).



Table 19. Coal mine accrual water data, pH; pH units.

	1A	1B	2A	2B	3	4	5A	5B	6A	6B
May '81	8.2	8.2	8.1	8.1	****	****	8.0	8.1	7.8	8.1
Jun	8.3	8.4	8.4	8.3	7.7	8.2	8.2	8.3	8.2	8.3
Jul	8.3	8.2	8.4	8.4	****	****	8.0	8.4	8.4	8.4
Aug	8.1	8.1	8.3	8.2	****	****	8.0	8.1	8.0	****
Sep	8.3	8.2	8.2	8.3	8.0	8.2	8.3	8.3	8.2	8.3
Oct	8.2	****	8.3	8.3	****	****	8.1	8.1	****	****
Nov	8.2	8.2	8.2	8.3	****	****	****	8.2	8.1	8.2
Dec	8.2	8.2	8.1	****	8.0	****	****	****	8.1	8.1
Jan '82	8.3	8.4	8.3	8.4	****	8.3	8.2	****	****	****
Feb	8.3	8.3	8.3	8.4	****	****	8.1	****	****	****
Mar	7.7	8.2	8.2	8.3	8.5	****	****	****	****	****
Apr	8.1	8.2	8.3	8.2	****	8.2	****	****	****	****

\*\*\*\* no data

A - coal mine accrual water sampling site located prior to mine's treatment.  
 B - coal mine accrual water sampling site located after mine's treatment.

Data for TDS from the sampling of coal mine accrual water are presented in Table 20. Again, violations of NPDES limits were rare. The TDS limit was exceeded at site 3 in March 1982 by 1.4 percent. Both this violation and the limit exceeded above still produce water that is suitable for drinking water purposes. All other mines, except site 4, discharged water that was consistently within TDS limits. Asterisks in Table 20 point out TDS levels in excess of permit requirements with regard to mine 4. However, this mine does not discharge to surface water resources, or have plans to do so in the near future. The data collected are limited and this potential problem should be evaluated when this site begins discharging to the environment.

Mine discharges generally contain varying amounts of finely divided coal particles. NPDES limits for total suspended solids (TSS) are explicit; 25. mg/liter for a daily average, 35.

mg/liter for a 7-day average and 70. mg/liter as an acceptable daily maximum.

The U.S. Environmental Protection Agency has recommended that for fresh-water aquatic life settleable and suspended solids should not reduce the depth of the compensation point for photosynthetic activity by more than 10 percent from the seasonally established norm for aquatic life. This criterion is based on the fact that suspended material and plankton reduce the extent of light penetration and the depth of the photic zone, thus reducing primary production and food sources for fish. Suspended particles also absorb heat which causes interference in the natural and seasonal vertical mixing, overturn, and aeration of lake waters. Fish living in water high in suspended solids can also be killed directly or experience lowered growth rates and poor resistance to diseases. Sediments can hamper the development of fish in their larval and egg life stages and damage

Table 20. Coal mine accrual water data, solids, total dissolved; mg/liter.

	1A	1B	2A	2B	3	4	5A	5B	6A	6B
May '81	390	360	550	540	****	****	420	450	540	320
Jun	390	390	490	490	710	780*	470	450	250	330
Jul	360	340	440	540	****	****	530	430	300	370
Aug	370	320	470	500	****	****	440	440	270	****
Sep	390	420	510	440	710	490	460	430	340	310
Oct	380	****	540	510	****	****	460	460	****	****
Nov	400	410	500	520	****	****	****	490	320	380
Dec	460	430	510	****	720	****	****	****	390	390
Jan '82	560	560	540	520	****	670*	520	****	****	****
Feb	420	400	480	510	****	****	460	****	****	****
Mar	400	460	550	560	730*	****	****	****	****	****
Apr	380	380	550	550	****	780*	****	****	****	****

\*\*\*\* no data

\*NPDES violation at point of discharge.

A - coal mine accrual water sampling site located prior to mine's treatment.  
 B - coal mine accrual water sampling site located after mine's treatment.

spawning beds. Food supplies can be reduced due to the damage to benthic invertebrates by settling solids. If the solids increase the organic load of a body of water, dissolved oxygen can be severely depleted giving preference to less desirable aquatic species (EPA 1976).

Excessive levels of TSS were among the most frequently violated parameters with regard to NPDES regulations (Tables 13 to 18). Mine 1 experienced three violations for the daily maximum of 70. mg/liter. These violations occurred in the second and third quarters of 1981 (due to a pump failure) and in April 1982. Mine 2 reported no excessive TSS values. Site 3 experienced high TSS in a sample collected in September 1981. It is not likely that this violation was a result of coal particles since the mine is not active. Criteria were exceeded during the second and third quarters of 1981 at mine site 5 by

concentrations of 98. and 226. mg TSS/liter, respectively, for daily maxima. Quarterly averages of 46.7 and 94.5 mg/liter were also high during this time. TSS values dropped considerably after this point in time until discharge ceased in January 1982. Mine 6 reported excessive TSS values during second quarter 1981 and second quarter 1982. Daily maxima were 154. and 217. mg TSS/liter, respectively, resulting in respective quarterly averages of 45. and 66. mg TSS/liter.

Samples were not analyzed for total suspended solids during the field or leachate column phases of the project.

Since the end of the field sampling phase, some mines have upgraded their treatment facilities in order to improve discharge water quality with respect to suspended solids. Mine 1 has added more sump areas and mine 6 has constructed a new settling basin and filter. Mine 5

has ceased operation and reclamation procedures have begun.

Further studies on the effects of total suspended solids on stream biota are suggested. It is not known what flow characteristics and downstream distances are necessary to significantly reduce suspended matter that is discharged from the coal mines. The exact nature and composition of the particles was not documented. It is not known whether further leaching of the coal particles would occur after settling to the bottom of the stream bed. Little is known about interactions between finely-divided coal particles and benthic invertebrates and subsequent effects on aquatic ecosystems.

### Iron

NPDES requirements for discharge of total iron are uniform throughout the Wasatch Plateau and are set at 2.0 mg/liter as the maximum allowed on a daily basis. If total iron is found to persistently be in excess of this criterion, then provisions are made for officials from the coal mine and the Bureau of Water Pollution Control to confer and review the matter. Means of achieving compliance would be discussed along with the appropriateness of the 2.0 mg/liter limit. The regulations also state that a daily maximum of 7.0 mg/liter must never be exceeded.

The basis of this criterion comes from a history of incidents involving large amounts of iron being present in acid mine wastes. If dissolved oxygen is abundant in the discharge waters, yellow ferric hydroxide ( $\text{Fe}(\text{OH})_3$ ) will form. This compound can remain suspended in the water or precipitate as a flocculant material or gel. Suspended and precipitated  $\text{Fe}(\text{OH})_3$  cause problems similar to those caused by suspended and settled solids in an aquatic ecosystem. Ferric hydroxide floc can coat the gills of many species of fish and cause respiratory failure. Flocculant  $\text{Fe}(\text{OH})_3$  can also form hard conglomerates on

gravel spawning beds for salmonid fishes. The eggs from these types of game fishes specifically require the protection of gravel interstices and highly oxygenated waters passing through the beds (EPA 1976). Iron levels of 1. to 2. mg/liter can be indicative of acid pollution and other water quality limitations to fish. Ninety-five percent of waters in the United States supporting good fish populations have iron concentrations that do not exceed 0.7 mg/liter (McKee and Wolf 1963). Several species of fish are known to die in water with concentrations of 1. to 2. mg/liter iron. A number of species of invertebrates that are utilized by fish as food are known to have 96-hour  $\text{LC}_{50}$  values of 0.32 mg iron/liter. Field observations have led to a 1.0 mg/liter criterion for freshwater aquatic life (EPA 1976).

Violations of NPDES total iron limits were not frequently reported by the mines studied (Tables 13 to 18). Mine 1 reported a high iron sample only once as a daily maximum in the fourth quarter of 1981 (2.66 mg/liter). All other concentrations were considerably lower at this site. Mines 2, 3, and 5 did not exceed iron standards. Mine 6 reported two high iron discharges during second quarter 1981 (4.60 mg/liter daily maximum) and second quarter 1982 (2.55 mg/liter daily maximum). Iron levels in the remainder of the reported discharges were much lower. These high total iron values at site 6 corresponded to concurrent high levels of total suspended solids.

Field data for the monitoring of total iron are represented in Table 21. No violations at the points of discharge were detected. The sample collected from site 5A in August 1981 was found to contain 10.1 mg/liter total iron.

### Oil and Grease

Oil and grease discharges from mines on the Wasatch Plateau are not to

Table 21. Coal mine accrual water data, iron, total; mg Fe/liter.

	1A	1B	2A	2B	3	4	5A	5B	6A	6B
May '81	0.03	0.06	0.18	0.04	****	****	0.19	0.56	0.53	<0.02
Jun	<0.02	<0.02	<0.02	0.03	<0.02	0.10	0.29	0.19	<0.02	<0.02
Jul	****	****	****	****	****	****	****	****	****	****
Aug	0.66	1.22	0.75	0.36	****	****	10.1	1.45	0.72	****
Sep	0.21	0.33	0.15	0.11	0.11	0.23	0.18	0.15	0.34	<0.02
Oct	****	****	****	****	****	****	****	****	****	****
Nov	****	****	****	****	****	****	****	****	****	****
Dec	0.27	0.20	0.15	****	0.75	****	****	****	0.64	1.00
Jan '82	****	****	****	0.59	****	0.80	0.58	****	****	****
Feb	****	****	****	****	****	****	****	****	****	****
Mar	0.81	0.79	0.80	0.47	0.51	****	****	****	****	****
Apr	****	****	****	****	****	0.62	****	****	****	****

\*\*\*\* no data

A - coal mine accrual water sampling site located prior to mine's treatment.  
 B - coal mine accrual water sampling site located after mine's treatment.

exceed 10 mg/liter at anytime according to NPDES regulations.

Oil and grease compounds are very toxic to a wide variety of aquatic organisms. Acute toxicity results in death and sublethal levels of oil and grease (10 to 100 µg/l) can cause chronic damage to feeding and reproductive processes. Bioaccumulation by aquatic species can also occur resulting in potential public health problems. Once oil and grease enter an aquatic ecosystem, these substances may float on the surface, become emulsified, portions may take on a soluble form or settle on the bottom. Floating petrochemicals can cause death or other problems for waterfowl. Soluble and emulsified oil and grease can coat gill surfaces and kill fish, in addition to increasing biochemical oxygen demand. Oil and grease can become part of the sediments where it may be slowly degraded by microbial action, remaining toxic for a long period of time. Since oils are toxic in such a wide variety of specific situations, the criterion for fresh-

water aquatic life is 0.01 times the lowest continuous flow 96-hour LC<sub>50</sub> to several important freshwater species each having a documented high susceptibility to oils and greases. These criteria also recommend the absence of oils and greases in sediments which can cause deleterious effects to the biota there. Surface waters should also be virtually free of oils of all kinds (EPA 1976).

NPDES reports (Tables 13 to 18) indicate that mine discharges at sites 1 and 5 did not exceed the 10. mg/liter limit during the duration of the study. 17.6 mg/liter were detected as a daily maximum for mine 2 during second quarter 1981. Mine 3 showed a very high level of oil and grease in August 1981 (70. mg/liter). This very high value and the fact that the mine is not operating imply that this result may be an anomaly. Site 6 reported violations of oil and grease limits in the fourth quarter 1981 (78.6 mg/liter as a maximum resulting in a quarterly average of 26.7 mg/liter).

Levels for oil and grease in the coal mine accrual waters are reported in Table 22. Data for September 1981 were suspect since values were high at all sites. However, sufficient evidence could not be gathered to justify discarding these data and it is uncertain whether any NPDES violations occurred on this sampling date. Site 1B produced discharges in excess of 10 mg/liter in May 1981 (11.8 mg/liter) and September 1981 (10.4 mg/liter). A sample taken at site 1A in May 1981 was also high (14.9 mg/liter). Samples taken from site 2B were above the NPDES limit in July 1981 (11.2 mg/liter) and September 1981 (35.0 mg/liter); 18.3 mg/liter was detected at site 2A in September 1981. All samples collected at site 3 were less than 10 mg/liter. Site 4 is not discharging; however, oil and grease

were found to be elevated in September 1981 (33.3 mg/liter). Mine site 5B discharged oil and grease above the NPDES limit in May 1981 (14.3 mg/liter), August 1981 (10.8 mg/liter), and September 1981 (60.3 mg/liter). The corresponding samples collected at 5B were also high in August 1981 (11.8 mg/liter) and September 1981 (22.5 mg/liter). When mine 5 was not discharging, one elevated oil and grease sample was analyzed in February 1982 (41.3 mg/liter). One sample discharged at 6B was found to be in excess (September 1981, 38.0 mg/liter). No samples collected at 6A exceeded 10 mg/liter oil and grease.

Many mines employ grease skimmers to treat their water prior to discharge. Others pump water to site B from under the water surface at point A, thus

Table 22. Coal mine accrual water data, oil and grease; mg/liter.

	1A	1B	2A	2B	3	4	5A	5B	6A	6B
May '81	14.9	11.8*	****	8.4	****	****	5.3	14.3*	8.2	3.5
Jun	1.2	1.5	4.5	2.9	<1.0	1.5	2.5	2.7	3.5	2.9
Jul	5.5	1.6	<1.0	11.2*	****	****	<1.0	<1.0	<1.0	1.0
Aug	1.3	5.1	6.6	<1.0	****	****	11.8	10.8*	5.6	****
Sep	7.9	10.4*	18.3	35.0*	8.5	33.3	22.5	60.3*	8.3	38.0*
Oct	****	****	****	****	****	****	****	****	****	****
Nov	3.5	2.7	<1.0	<1.0	****	****	****	<1.0	<1.0	****
Dec	1.3	3.0	<1.0	****	<1.0	****	****	****	<1.0	1.5
Jan '82	1.8	7.4	<1.0	<1.0	****	7.6	2.2	****	****	****
Feb	<1.0	<1.0	<1.0	<1.0	****	****	41.3	****	****	****
Mar	1.1	<1.0	<1.0	<1.0	<1.0	****	****	****	****	****
Apr	1.0	3.7	2.9	<1.0	****	3.9	****	****	****	****

\*\*\*\* no data

A - coal mine accrual water sampling site located prior to mine's treatment.  
 B - coal mine accrual water sampling site located after mine's treatment.

\*NPDES violation at point of discharge.

Note: Data for September 1981 were suspect since values were high at all sites. However, sufficient evidence could not be gathered to justify discarding these data and it is uncertain whether any NPDES violations occurred on this sampling date.

leaving behind quantities of floating oil and grease. Examination of Table 22, however, does not seem to readily indicate any significant and consistent decreases in oil and grease after treatment. At many of the sites, the physical distance between sites A and B was quite large. Settling ponds varied in design and size. Accurate evaluation of the efficacy of treatment processes cannot be accomplished without the use of extensive sequential sampling and determination of the turnover times in each of the ponding systems at the sites. A study of this type might be beneficial to the mining operation.

#### Other Requirements

NPDES discharges are not to contain floating solids or visible foam in excess of trace quantities. Mine 2 completed some monitoring for these parameters in 1981; all results were reported as zero.

Sanitary wastes are not allowed to be discharged in conjunction with mine wastes. Coliform bacteria are the standard indicator organisms whose presence indicates the potential for contamination with human and/or animal wastes. Mine 2 reported values for fecal coliform bacteria from April to December 1981 that ranged from < 2./100 ml to 9./100 ml. Levels of total coliform bacteria were reported for the same dates; results varied from < 3./100 ml to 150./100 ml (Table 14). Utah drinking water regulations state that for community and noncommunity water systems, 1./100 ml is allowable as the monthly arithmetic mean. Counts in excess of 4./100 ml are allowable in only one sample per month when less than 20 samples are analyzed. Mine 3 reported fecal coliforms on three occasions with results ranging from < 2./100 ml to < 20./100 ml. Total coliforms ranged from < 2./100 ml to 330./100 ml in the same samples (see Table 15). This water is chlorinated prior to actual use as a drinking water supply. Microbiological samples were

also collected by the personnel from mine 6 and the results for April 1981 to June 1982 are shown in Table 18. Minimum counts for fecal coliforms were < 2./100 ml and the maximum observed was 5./100 ml. Total coliform analyses ranged from 2./100 ml to a high of 700./100 ml in the fourth quarter 1981.

Some of the mines have analyzed the discharge water for alkalinity and acidity. Amendments to NPDES requirements state that at all times the alkalinity must be greater than the acidity. This criterion was not violated by any of the discharge sites when these parameters were measured. Mine 1 monitored these parameters in the second quarter of 1981 (Table 13); acidity values fell between <0.01 and 16. mg CaCO<sub>3</sub>/liter, while alkalinity ranged from 186. to 216. mg CaCO<sub>3</sub>/liter. During the second, third and fourth quarters of 1981, mine 2 monitored acidity and alkalinity (Table 14) and results ranged from 0. to > 1. mg CaCO<sub>3</sub>/liter for acidity and from 233. to 289. mg CaCO<sub>3</sub>/liter for alkalinity. At mine 3 the lowest acidity detected was 3.8 mg CaCO<sub>3</sub>/liter and rose to 36.0 mg CaCO<sub>3</sub>/liter in March 1982; alkalinity values were between 293. and 356. mg CaCO<sub>3</sub>/liter (Table 15). These parameters were monitored at mine 5 during all times of discharge (Table 17). Acidity ranged from < 0.01 to 10.0 mg CaCO<sub>3</sub>/liter. Alkalinity reached a minimum value of 103. mg CaCO<sub>3</sub>/liter and rose to a maximum of 310. mg CaCO<sub>3</sub>/liter. Acidity at mine 6 ranged from <0.01 to 32.0 mg CaCO<sub>3</sub>/l; the lowest value for alkalinity was 40.5 mg CaCO<sub>3</sub>/liter and the highest was 244. mg CaCO<sub>3</sub>/liter (Table 18).

A few other parameters were reported at various times between April 1981 and June 1982. Mine 2 submitted some data for 5-day biochemical oxygen demand (BOD<sub>5</sub>) (Table 14). This analytical technique measures the amount of oxygen necessary for biological oxidation of wastewaters. All values

reported were very low, ranging from 0.7 to 0.9 mg/liter. Site 3 also reported low BOD<sub>5</sub> values ranging from 3.1 to 14.5 mg/liter (Table 15). BOD<sub>5</sub> values at mine 6 (Table 18) were relatively low with most values close to the minimum reported value of 1.5 mg/liter. A maximum of 40. mg/liter was reported in the second quarter of 1981.

Mine 3 reported values for total manganese (Table 15). All values were in compliance with the drinking water MCL of 50. µg/liter and ranged from 10. to 33. µg/liter.

Mine 6 submitted data for total selenium (Table 18). These values were consistently very low, ranging from < 1. to 5. µg/liter. The drinking water and irrigation water criteria are 10. and 500. µg/liter, respectively. The criterion for freshwater aquatic ecosystems is more stringent and specific (0.01 times the 96-hour LC<sub>50</sub> using a sensitive resident species) and acceptable levels would have to be evaluated on a site-specific basis.

#### Trends and Observations--Comparisons between Coal Mine Accrual Water and Coal Leachate Column Data

The concentration level of some parameters was often observed to be specific to the mine site involved. Some parameters exhibited trends that varied in a north-to-south direction on the Wasatch Plateau. The levels of the majority of parameters monitored in the field appeared to compare very well to the levels of the same parameters generated in the coal upflow column leachate study. When certain water quality constituents were found to be at consistently high levels in the field, these same parameters were also often elevated in the column leachates. Likewise, toxic trace metals which were low during the field sampling also were low in the column leachates, indicating little potential for leaching of toxic metals from the coal matrices.

In the discussion that follows, field data of interest are presented in tabular form. Mine sites are designated by number (1 through 6) with A and B designations as appropriate and data collection from May 1981 to April 1982. Upflow coal column leachate data are also in tabular form with the same mine site designations and further indications as to column replicate; Col 2-3 refers to leachate data from the third column replicate for coal from mine site 2. Coal column leachates were monitored for 10 days. Medium 1 was used to leach coal from mines 1, 2, and 3. Medium 2 was used to leach coal from mines 4, 5, and 6. Data for certain parameters are also presented graphically. Daily data from the three column replicates are averaged for this purpose.

All data collected during field monitoring and the upflow column leachate experiments are presented in the Appendix.

#### Physical Properties

As discussed with regard to NPDES requirements, pH values of the field samples (Table 19) were always within the limits for NPDES discharges and freshwater aquatic life (6.5-9.0 units) and were also acceptable with regard to drinking water limits (6.5-8.5 units). The pH values of the coal column leachates were similar to those of the field samples (Appendix Table A-1b). Some pH values for coal leachates from mine 1 were in excess of 8.5, but were never higher than 9.0 units. pH values for all column leachates increased above those of the media, but not to dangerous levels. Batches of medium 2 were found to have pH values that were somewhat more acidic (6.6 to 7.8 units) than prepared quantities of medium 1 (7.9 to 8.0 units). This was found to be due to the fact that only part of the carbon dioxide gas used for dissolution of the medium had been dissipated from the solution before introduction into the coal columns. This may explain the

slight, but noticeable, leaching of some trace metals and other constituents in coal from mines 4, 5, and 6, while similar trends were not generally observed in coal from mines 1, 2, and 3.

Specific conductance values (at 25°C) for the mine water samples ranged from 380. to 1200.  $\mu\text{mhos/cm}$  (Appendix Table A-2a). Conductivity values of the column leachates increased above those of the media (350. to 540.  $\mu\text{mhos/cm}$ ) and ranged from 430. to 820.  $\mu\text{mhos/cm}$  (Appendix Table A-2b and

Table 23). Figures 6 and 7 graphically represent the changes in specific conductance with time in the column experiment.

Field data for total dissolved solids (Table 20) were within the range of 250. to 780. mg/liter. TDS values of the coal column leachates were generally observed to increase above the TDS of the media during the first days of leaching, as shown in Table 24 and Figures 8 and 9. As expected, conductivity and total dissolved solids followed quite similar

Table 23. Leachate column data, specific conductance @ 25°C  $\mu\text{mhos/cm}$ .

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10
Medium 1	450.	****	540.	****	510.	****	530.	****	520.	****
Col 1	620. <u>+30.</u>	540. <u>+10.</u>	540. <u>+10.</u>	530. <u>+20.</u>	510. <u>+10.</u>	490. <u>+0.</u>	480. <u>+10.</u>	470. <u>+20.</u>	460. <u>+10.</u>	490. <u>+40.</u>
Col 2	810. <u>+20.</u>	560. <u>+30.</u>	560. <u>+0.</u>	540. <u>+0.</u>	550. <u>+20.</u>	520. <u>+20.</u>	510. <u>+10.</u>	480. <u>+20.</u>	470. <u>+20.</u>	460. <u>+10.</u>
Col 3	730. <u>+30.</u>	540. <u>+10.</u>	610. <u>+30.</u>	580. <u>+20.</u>	560. <u>+30.</u>	530. <u>+20.</u>	520. <u>+10.</u>	510. <u>+10.</u>	500. <u>+10.</u>	510. <u>+20.</u>
Col 4	660. <u>+20.</u>	600. <u>+20.</u>	580. <u>+10.</u>	600. <u>+20.</u>	500. <u>+30.</u>	510. <u>+20.</u>	520. <u>+20.</u>	650. <u>+110.</u>	670. <u>+80.</u>	710. <u>+20.</u>
Col 5	630. <u>+20.</u>	600. <u>+20.</u>	510. <u>+80.</u>	630. <u>+0.</u>	510. <u>+10.</u>	530. <u>+20.</u>	530. <u>+30.</u>	610. <u>+40.</u>	780. <u>+20.</u>	740. <u>+20.</u>
Col 6	660. <u>+20.</u>	550. <u>+50.</u>	530. <u>+20.</u>	570. <u>+20.</u>	530. <u>+20.</u>	510. <u>+20.</u>	550. <u>+20.</u>	620. <u>+20.</u>	760. <u>+70.</u>	710. <u>+10.</u>
Medium 2	350.	****	380.	****	390.	****	470.	****	480.	****

\*\*\*\* no data

Notes:

1. For each day of the experiment, the data from the analysis of three replicate coal column leachates are presented as the mean ± standard deviation.

2. See also Appendix Table A-2b.



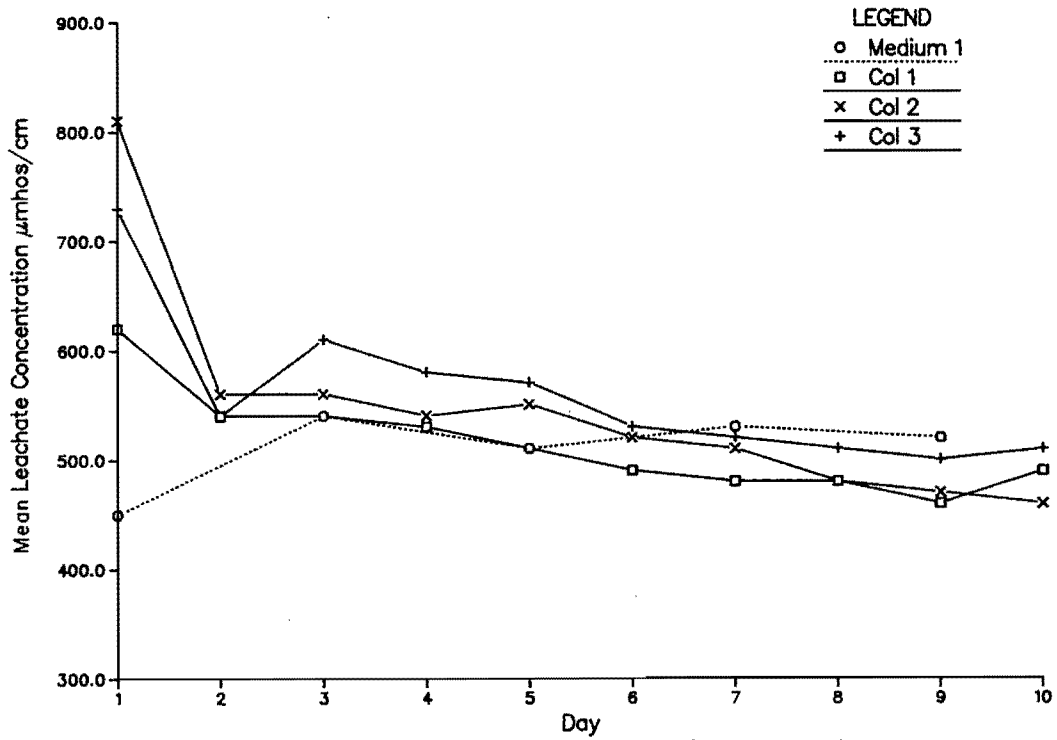


Figure 6. Graphic representation of specific conductance of coal column leachates, coal from mines 1, 2, and 3.

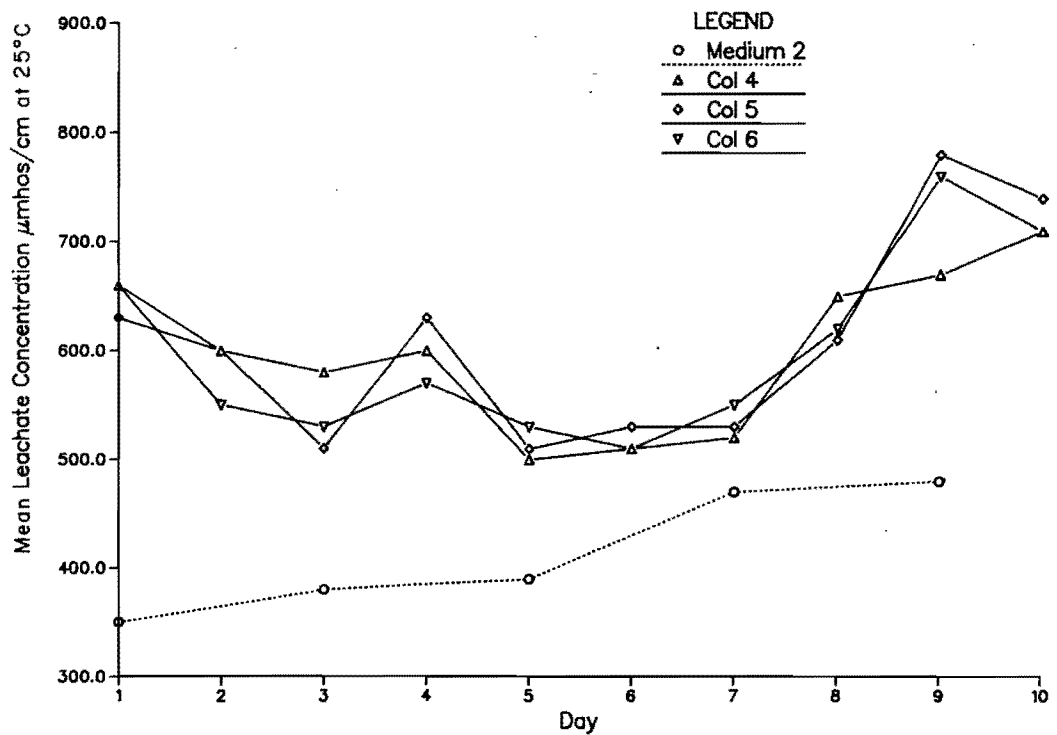


Figure 7. Graphic representation of specific conductance of coal column leachates, coal from mines 4, 5, and 6.

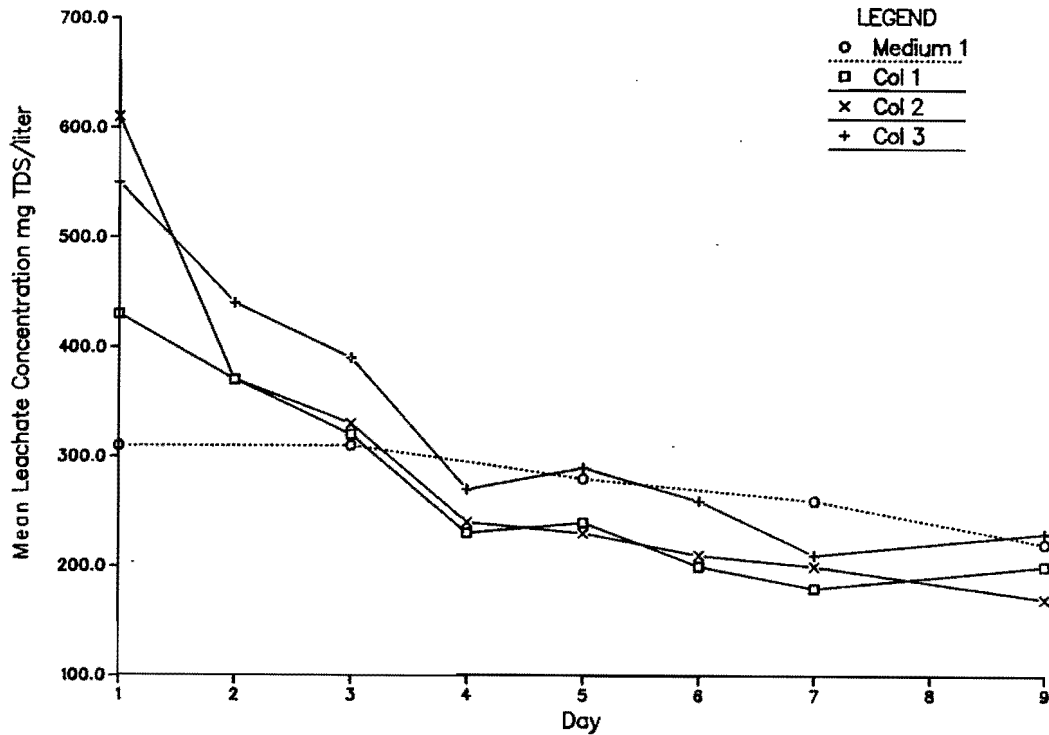


Figure 8. Graphic representation of total dissolved solids in coal column leachates, coal from mines 1, 2, and 3.

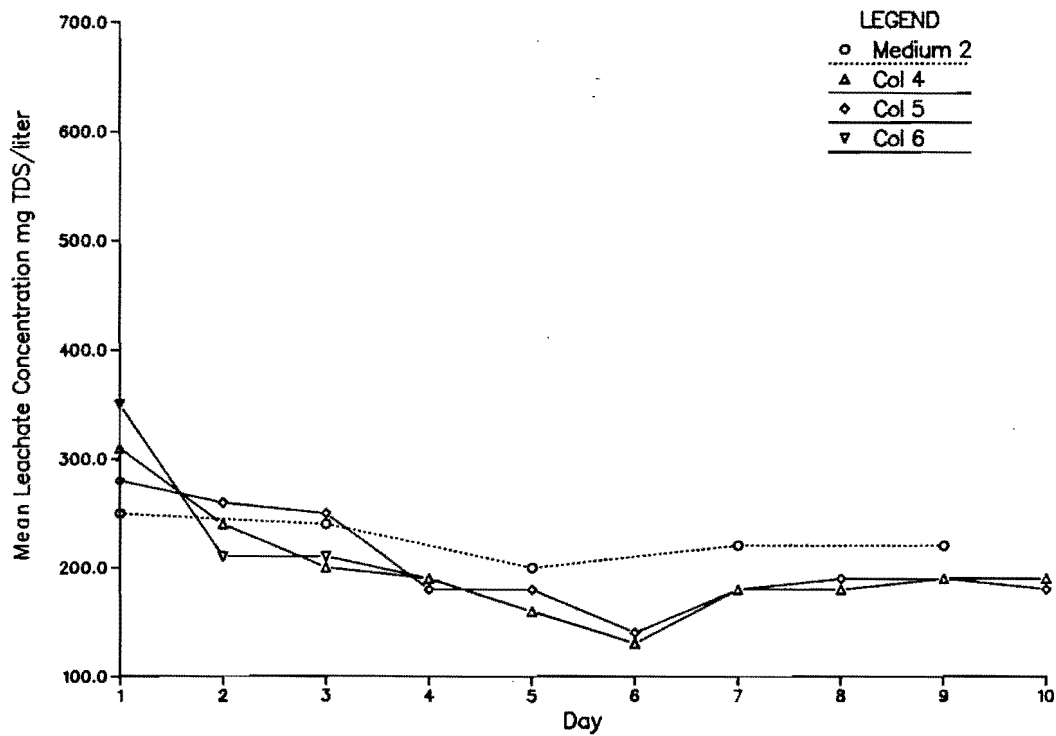


Figure 9. Graphic representation of total dissolved solids in coal column leachates, coal from mines 4, 5, and 6.

Table 24. Leachate column data, solids, total dissolved; mg/liter.

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10
Medium 1	310.	****	310.	****	280.	****	260.	****	220.	****
Col 1	430. <u>+10.</u>	370. <u>+10.</u>	320. <u>+20.</u>	230. <u>+20.</u>	240. <u>+30.</u>	200. <u>+30.</u>	180. <u>+10.</u>	****	200. <u>+20.</u>	****
Col 2	610. <u>+30.</u>	370. <u>+30.</u>	330. <u>+20.</u>	240. <u>+30.</u>	230. <u>+20.</u>	210. <u>+80.</u>	200. <u>+40.</u>	****	170. <u>+10.</u>	****
Col 3	550. <u>+40.</u>	440. <u>+10.</u>	390. <u>+10.</u>	270. <u>+20.</u>	290. <u>+10.</u>	260. <u>+10.</u>	210. <u>+40.</u>	****	230. <u>+20.</u>	****
Col 4	310. <u>+30.</u>	240. <u>+50.</u>	200. <u>+20.</u>	190. <u>+40.</u>	160. <u>+20.</u>	130. <u>+20.</u>	180. <u>+30.</u>	180. <u>+10.</u>	190. <u>+40.</u>	190. <u>+10.</u>
Col 5	280. <u>+30.</u>	260. <u>+20.</u>	250. <u>+40.</u>	180. <u>+30.</u>	180. <u>+30.</u>	140. <u>+10.</u>	180. <u>+30.</u>	190. <u>+10.</u>	190. <u>+20.</u>	180. <u>+10.</u>
Col 6	350. <u>+10.</u>	210. <u>+10.</u>	210. <u>+40.</u>	190. <u>+40.</u>	160. <u>+20.</u>	130. <u>+20.</u>	180. <u>+30.</u>	180. <u>+10.</u>	190. <u>+40.</u>	190. <u>+10.</u>
Medium 2	250.	****	240.	****	200.	****	220.	****	220.	****

\*\*\*\* no data

Notes:

1. For each day of the experiment, the data from the analysis of three replicate coal column leachates are presented as the mean + standard deviation.

2. See also Appendix Table A-3b.

trends in the upflow column experiments. The higher conductivities and TDS values during the first few days of leaching correspond to times when quantities of ionic constituents were also leached from the coal matrices, as is discussed in the following sections. TDS values in the field were comparable to the TDS levels seen during days 1 and 2 of the leachate experiment for sites 1, 2, 5, and 6. Variations between TDS in the leachates and TDS in the mine waters appeared more significant for sites 3, 4, and 5. This may be due to the nature

of the synthetic groundwater leaching medium prepared for the experiment. Its makeup was determined by calculating the mean values of compiled spring and stream water quality data on the Wasatch Plateau (Table 1). The mean value of these data from USGS and UWRL sources produced a TDS of 267. mg/liter, but data used to compute the mean ranged from 66. to 450. mg/liter. The coal from sites 3, 4, and 5 may not have been leached with a medium that was precisely characteristic of the water sources in the vicinity of the mines.

## Trace Metals

A number of trace metal parameters were observed to remain at consistently low levels in the mine waters resulting in relatively little potential for environmental problems. Similar trends were also observed in the upflow column leaching of coal samples from the sites. These data are presented in the Appendix. The following trace metals were generally near or below the analytical limits of detection in both phases of the study: aluminum, arsenic, beryllium, cadmium, chromium, cobalt, copper, dissolved iron, lead, molybdenum, nickel, silver, and zinc.

Beryllium levels in the mine waters at sites 6A and 6B were elevated in June 1981 (105. and 159.  $\mu\text{g/liter}$ , respectively), but remained low ( $< 10. \mu\text{g/liter}$ ) on other occasions (Appendix Table A-7a). These levels of beryllium would likely have no adverse effects on aquatic ecosystems or drinking water sources, but water of this quality could not be used for continuous irrigation of most soils (Table 5). Beryllium is highly toxic to many terrestrial plants causing inhibition of photosynthetic activity (EPA 1976). Inspection of data for the coal leachates from mine site 6 (Appendix Table A-7b) indicates that it is not likely that beryllium would rise to these levels upon leaching of the coal matrix with spring- or groundwater-type media. Beryllium is a rare element in the geological environment and it is not usually present in natural waters (McKee and Wolf 1963).

Cadmium levels in the mine waters sampled in the field were always below the detection limit of  $5. \mu\text{g/liter}$  (Appendix Table A-9a). A cadmium criterion has not been established for irrigation water and the drinking water limit of  $10. \mu\text{g/liter}$  was not exceeded; criteria for cadmium in freshwater ecosystems are more specific, varying with type of organism and water hardness (Table 5). The  $1.2 \mu\text{g Cd/liter}$  criterion for cladocerans and salmonid

fishes in hard water may have been exceeded in the stream waters below the mine discharge sites. However, this situation would have to be verified by use of a more sensitive analytical method for cadmium with a lower limit of detection.

Total iron was usually much higher than dissolved iron in the mine accrual waters (Appendix Tables A-13 and A-14a). Total iron in the field ranged from  $< 19.$  to  $10100. \mu\text{g/liter}$ . Dissolved iron exceeded the  $19. \mu\text{g/liter}$  detection limit only five times during field sampling and, likewise, in the coal column leachates (Appendix Table A-14b).

Detectable quantities of nickel leached from the matrix of the coal from mine 4 (Appendix Table A-22b), but not in quantities that have been reported to be deleterious to humans, aquatic life or plants (EPA 1976).

Some apparent leaching of selenium was observed in the coal from mines 4, 5, and 6 on day 1 of the experiment (Table 25 and Figure 10). This slight leaching phenomenon may have been due to the mildly acidic properties of the medium. Unlike most selenium concentrations in the coal column leachates, selenium values for mine water samples collected in the field were frequently somewhat above the  $1. \mu\text{g/liter}$  detection limit (Appendix Table A-23a). It is unlikely that these quantities of selenium resulted from acidic properties of the accrual water since the pH values of these sources were never observed to drop below 7 (Table 19 and Tables 13 to 18).

Zinc in the coal mine accrual waters was only occasionally in excess of the detection limit of  $5. \mu\text{g/liter}$  (Appendix Table A-26a). This trend was even more consistent in the coal column leachate experiments (Appendix Table A-26b). Fairly substantial quantities of zinc were detected in all batches of media. It appears that coal samples from the Wasatch Plateau might have some

capacity to actually absorb zinc from the leaching medium (Appendix Table A-26b).

The leaching phenomena with respect to boron and mercury and comparisons to field data were discussed in the chapter detailing potential problems.

Lithium has not been demonstrated to be toxic to humans, plants, or aquatic organisms when present in microgram quantities (Table 5). However, trends with respect to lithium were observed upon analysis of the field data (Table 26). Lithium concentrations detected at sites 5A and 5B were con-

Table 25. Leachate column data, selenium;  $\mu\text{g Se/liter}$ .

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10
Medium 1	<1.	****	<1.	****	1.	****	1.	****	1.	****
Col 1	<1. --	****	(1.) +1.	****	(1.) +1.	****	(1.) +1.	****	(2.) +1.	****
Col 2	(1.) +1.	****	(1.) +1.	****	2. +1.	****	1. +0.	****	1. +1.	****
Col 3	<1. --	****	(1.) +1.	****	1. +1.	****	(1.) +1.	****	1. +0.	****
Col 4	6. +2.	3. +0.	2. +1.	3. +1.	4. +1.	****	3. +1.	****	2. +1.	****
Col 5	6. +3.	2. +1.	4. +1.	2. +1.	3. +0.	****	3. +1.	****	3. +1.	****
Col 6	6. +1.	4. +1.	3. +1.	3. +1.	3. +0.	****	3. +1.	****	1. +0.	****
Medium 2	2.	****	3.	****	2.	****	3.	****	3.	****

\*\*\*\* no data

Notes:

1. For each day of the experiment, the data from the analysis of three replicate coal column leachates are presented as the mean + standard deviation.

2. Data in parentheses indicate that values less than the detection limit (1.  $\mu\text{g/liter}$ ) were entered when necessary as one-half the detection limit (0.5  $\mu\text{g/liter}$ ) to compute the mean and standard deviation (Sisson 1983).

3. Dashes indicate that all values from the three replicate coal columns were less than the detection limit and a standard deviation could not be calculated.

4. See also Appendix Table A-23b.

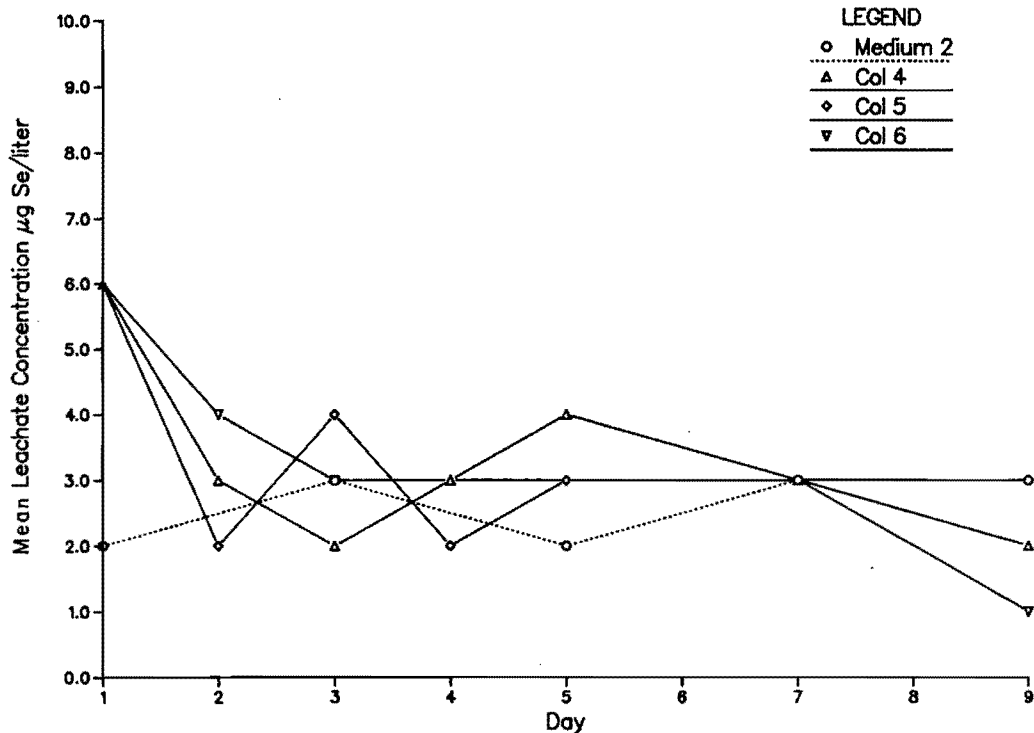


Figure 10. Graphic representation of selenium in coal column leachates, coal from mines 4, 5, and 6.

sistently higher than those at the other mine sites. Lithium in the accrual water at mine 5 ranged from 12. to 37. µg/liter. Lithium was then observed to be leached to a greater extent from the matrix of coal from mine 5 than from coal samples originating from the other sites reaching a peak of 45. µg/liter average on day 2 (Table 27). Some leaching was also observed with respect to coal from mines 4 and 6; these concentrations are comparable to analogous field concentrations. The leaching of lithium in the coal samples from mines 4, 5, and 6 is depicted graphically in Figure 11. Leaching of lithium in coal samples from mines 1, 2, and 3 was much less evident. Field mine water concentrations of lithium at sites 2A and 2B were greater than those observed in the column leachate experiment.

Lithium was also observed to leach from the coal samples studied by Israel-

sen et al. (1980). The concentration levels are comparable to those derived from the upflow coal column leaching experiments. For comparison purposes, the data are summarized in Table 28.

Values for dissolved manganese at the field sites (Appendix Table A-18a) were occasionally in excess of the 50. µg/liter drinking water maximum contaminant level which was established for aesthetic reasons (EPA 1976). Although the drinking water MCL was occasionally violated, the toxicity limits for irrigation water and freshwater aquatics were not (Table 5). Concentrations of total manganese in the mine waters followed the same trends (Appendix Table A-17). The drinking water supply at mine site 3 was not seen to have excess levels of total or dissolved manganese during the field sampling phase or during concurrent NPDES monitoring (Table 15). Some leaching of manganese

Table 26. Coal mine accrual water data, lithium;  $\mu\text{g Li/liter}$ .

	1A	1B	2A	2B	3	4	5A	5B	6A	6B
May '81	3.	3.	12.	9.	****	****	20.	23.	4.	4.
Jun	5.	3.	6.	6.	6.	7.	19.	19.	2.	4.
Jul	4.	3.	13.	14.	****	****	35.	37.	9.	9.
Aug	9.	6.	6.	13.	****	****	14.	32.	37.	****
Sep	5.	5.	14.	15.	12.	11.	34.	33.	5.	7.
Oct	7.	****	7.	6.	****	****	17.	15.	****	****
Nov	3.	2.	3.	3.	****	****	****	12.	2.	1.
Dec	2.	1.	4.	****	1.	****	****	****	1.	1.
Jan '82	1.	1.	2.	8.	****	9.	20.	****	****	****
Feb	2.	1.	8.	8.	****	****	16.	****	****	****
Mar	1.	2.	5.	6.	4.	****	****	****	****	****
Apr	8.	6.	8.	13.	****	10.	****	****	****	****
Yearly Mean	4.	3.	7.	9.	6.	9.	22.	24.	9.	4.
Standard Deviation	<u>+3.</u>	<u>+2.</u>	<u>+4.</u>	<u>+4.</u>	<u>+5.</u>	<u>+2.</u>	<u>+8.</u>	<u>+10.</u>	<u>+13.</u>	<u>+3.</u>
n	12	11	12	11	4	4	8	7	7	6

\*\*\*\* no data

A - coal mine accrual water sampling site located prior to mine's treatment.  
 B - coal mine accrual water sampling site located after mine's treatment.

in the coal samples from mines 4, 5, and 6 was observed (Table 29). Graphic representation of manganese in the coal leachates demonstrates that the daily mean values of three replicate columns never exceeded 50.  $\mu\text{g/liter}$  and that manganese can be somewhat more difficult to leach from the coal matrix than some other constituents (Figure 12).

Analysis of field samples for strontium is summarized in Table 30 and depicted graphically in Figure 13. Strontium was quite consistently higher in the accrual water samples from mine 5 and levels were relatively high at all sites. Yearly means varied from 250. +130. and 260. +80.  $\mu\text{g/liter}$  at sites 6A and 6B, respectively, to 1310.

+590. and 1290. +480.  $\mu\text{g/liter}$  at sites 5A and 5B, respectively. It is difficult to deduce the origin of strontium in mine water samples on the Wasatch Plateau using field data only because background levels of strontium in the area's surface and groundwaters are significant, averaging about 300.  $\mu\text{g/liter}$  and often locally present at higher concentrations (Table 1).

Strontium is found in nature often in the presence of calcium and barium minerals, usually occurring as sulfate or carbonate salts. Soils do not easily absorb strontium, so it has been predicted that the metal would readily be able to reach groundwater supplies (McKee and Wolf 1963).

Strontium is found to be incorporated into the structures of both plants and animals. It is not known to be required for the nutrition of plants and probably would not harm plants if present in high levels in irrigation water (McKee and Wolf 1963). Romney (1977) studied the effects of coal ash leachates on plant growth. Boron was

found to produce toxic effects in the plant species studied, but high levels of strontium were not concentrated appreciably by the plant tissues, nor did the strontium restrict plant growth.

Animal tissues contain strontium in trace amounts while the bony structures of animals have much higher levels of

Table 27. Leachate column data, lithium;  $\mu\text{g Li/liter}$ .

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10
Medium 1	8.	****	2.	****	3.	****	1.	****	1.	****
Col 1	(1.) <u>+1.</u>	****	(1.) <u>+1.</u>	****	1. <u>+1.</u>	****	(1.) <u>+1.</u>	****	(1.) <u>+1.</u>	****
Col 2	6. <u>+0.</u>	****	3. <u>+1.</u>	****	4. <u>+1.</u>	****	2. <u>+1.</u>	****	3. <u>+1.</u>	****
Col 3	2. <u>+2.</u>	****	<1. --	****	1. <u>+1.</u>	****	(1.) <u>+1.</u>	****	(1.) <u>+1.</u>	****
Col 4	16. <u>+1.</u>	18. <u>+1.</u>	18. <u>+1.</u>	15. <u>+2.</u>	13. <u>+1.</u>	****	10. <u>+1.</u>	****	8. <u>+1.</u>	****
Col 5	38. <u>+4.</u>	45. <u>+2.</u>	43. <u>+3.</u>	39. <u>+2.</u>	32. <u>+4.</u>	****	24. <u>+3.</u>	****	17. <u>+2.</u>	****
Col 6	10. <u>+1.</u>	9. <u>+1.</u>	5. <u>+1.</u>	4. <u>+0.</u>	2. <u>+0.</u>	****	<1. --	****	<1. --	****
Medium 2	3.	****	<1.	****	<1.	****	<1.	****	<1.	****

\*\*\*\* no data

Notes:

1. For each day of the experiment, the data from the analysis of three replicate coal column leachates are presented as the mean  $\pm$  standard deviation.

2. Data in parentheses indicate that values less than the detection limit (1.  $\mu\text{g/liter}$ ) were entered when necessary as one-half the detection limit (0.5  $\mu\text{g/liter}$ ) to compute the mean and standard deviation (Sisson 1983).

3. Dashes indicate that all values from the three replicate coal columns were less than the detection limit and a standard deviation could not be calculated.

4. See also Appendix Table A-16b.



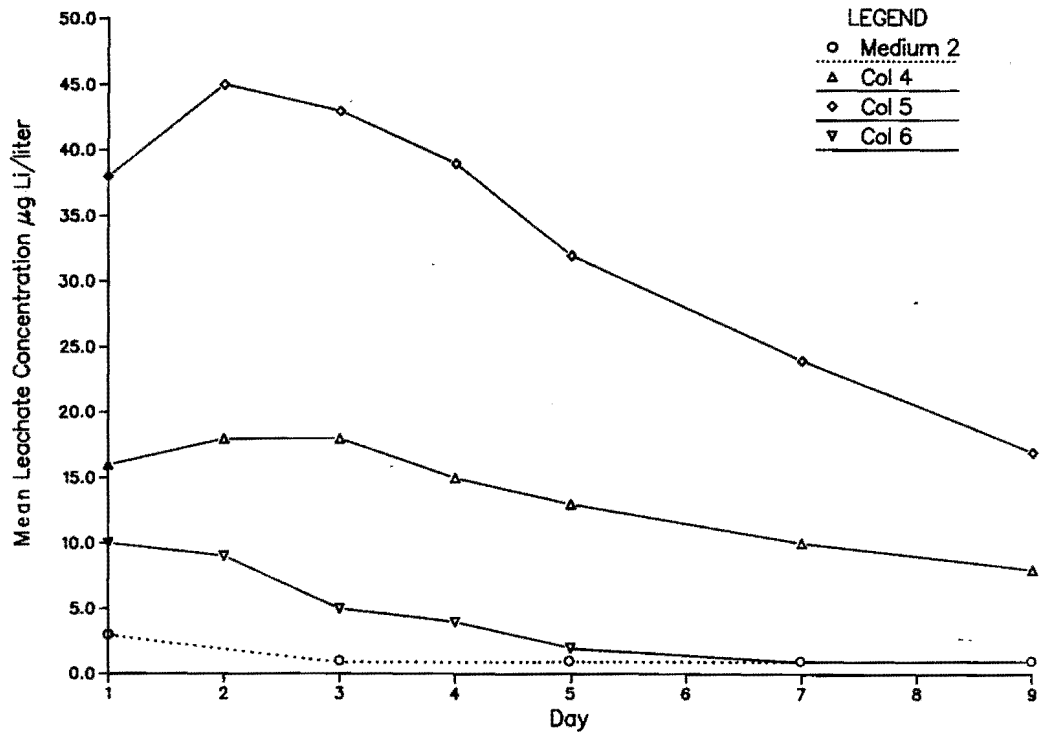


Figure 11. Graphic representation of lithium in coal column leachates, coal from mines 4, 5, and 6.

Table 28. Lithium leached from coal; µg Li/liter (adapted from Israelsen et al. (1980)).

Sample	Slurry 1 (2,220. mg/1 TDS)	Slurry 2 (4,640. mg/1 TDS)	Slurry 3 (13,200. mg/1 TDS)
Saline Trans- port Medium	2.	3.	5.
Coal from Mines:			
1	15.	40.	5.
2	19.	48.	12.
3	16.	36.	14.
4	19.	41.	12.

Note: Site 4 in this 1980 study corresponds to site 1 in the current study.

strontium. Studies have demonstrated that strontium is essential for animal nutrition, being directly involved in the process of calcification of teeth and bones. Strontium levels in human bone structures reach 120. to 234. mg/kg. Nonradioactive strontium has a very low toxicological potential for

humans. Strontium toxicity is probably on the same order as calcium toxicity (McKee and Wolf 1963). Extremely high levels of calcium and strontium (gram-level daily doses) can produce rickets due to overloading of the calcification mechanism, resulting in brittle bones (Wasserman 1961). All strontium levels

Table 29. Leachate column data, manganese, dissolved; µg Mn/liter.

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10
Medium 1	<12.	****	<12.	****	<12.	****	<12.	****	<12.	****
Col 1	<12. --	<12. --	<12. --	****	<12. --	****	<12.	****	<12.	****
Col 2	<12. --	<12. --	<12. --	****	<12. --	****	(9.) +6.	****	<12.	****
Col 3	<12. --	<12.	<12. --	****	<12. --	****	<12. --	****	<12.	****
Col 4	(11.) +4.	<12. --	12. +1.	48. +18.	<12. +2.	****	31. +4.	****	16. +2.	****
Col 5	23. +5.	20. +2.	18. +1.	20. +2.	20. +2.	****	17. +1.	****	21. +3.	****
Col 6	16. +10.	<12. --	(8.) +4.	(9.) +5.	15. +2.	****	35. +17.	****	23. +10.	****
Medium 2	<12.	****	<12.	****	<12.	****	<12.	****	21.	****

\*\*\*\* no data

Notes:

1. For each day of the experiment, the data from the analysis of three replicate coal column leachates are presented as the mean  $\pm$  standard deviation.

2. Data in parentheses indicate that values less than the detection limit (12. µg/liter) were entered when necessary as one-half the detection limit (6. µg/liter) to compute the mean and standard deviation (Sisson 1983).

3. Dashes indicate that all values from the three replicate coal columns were less than the detection limit and a standard deviation could not be calculated.

4. See also Appendix Table A-18b.

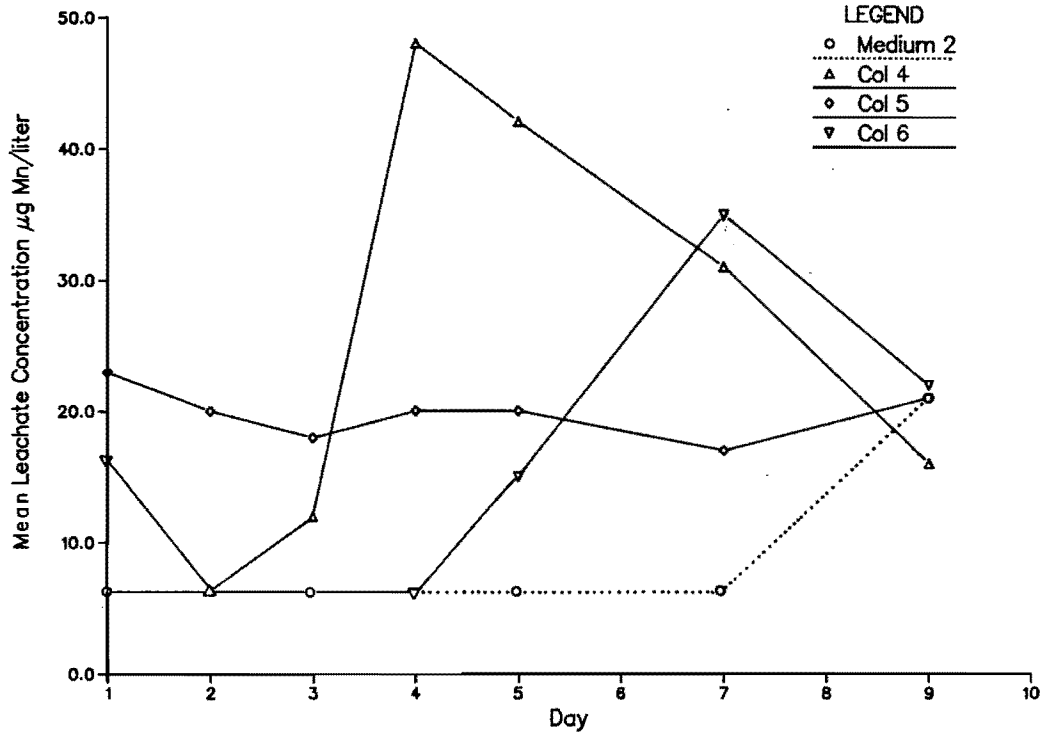


Figure 12. Graphic representation of dissolved manganese in coal column leachates, coal from mines 4, 5, and 6.

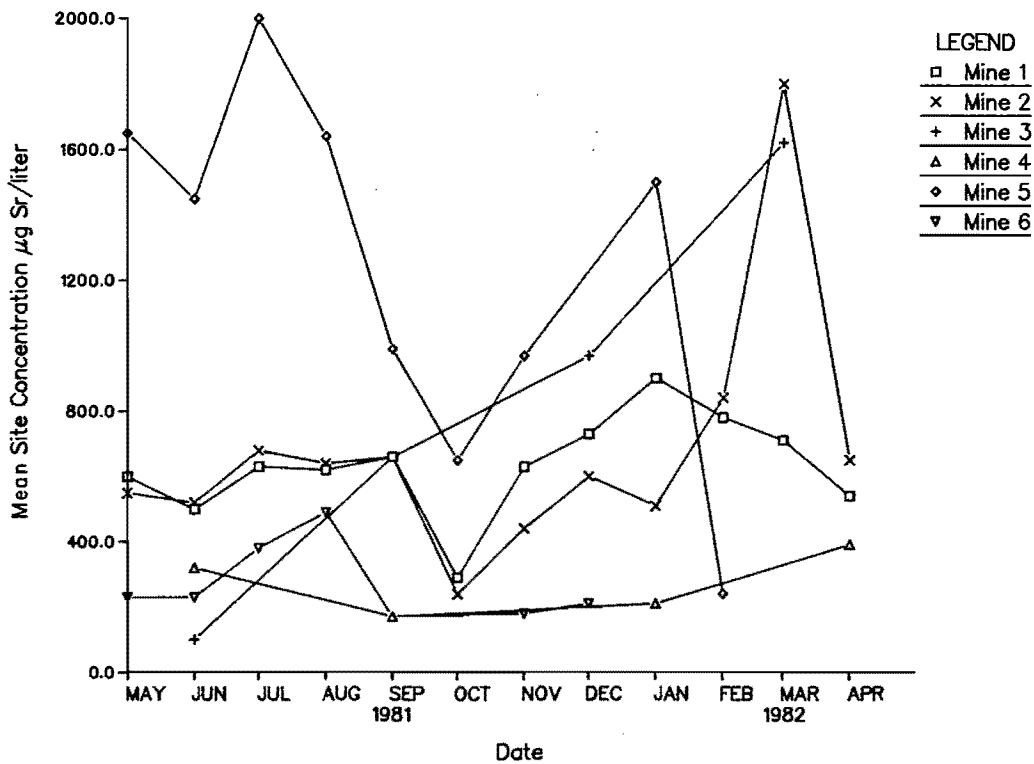


Figure 13. Graphic representation of strontium concentrations in the field, mine sites 1, 2, 3, 4, 5, and 6.

Table 30. Coal mine accrual water data, strontium;  $\mu\text{g Sr/liter}$ .

	1A	1B	2A	2B	3	4	5A	5B	6A	6B
May '81	600.	600.	600.	500.	****	****	1700.	1600.	160.	300.
Jun	500.	500.	500.	530.	100.	320.	1600.	1300.	210.	250.
Jul	660.	600.	660.	700.	****	****	2000.	2000.	370.	380.
Aug	610.	620.	650.	630.	****	****	1680.	1600.	490.	****
Sep	690.	630.	480.	430.	660.	170.	1030.	950.	170.	170.
Oct	290.	****	240.	240.	****	****	710.	590.	****	****
Nov	640.	620.	470.	420.	****	****	****	970.	190.	180.
Dec	760.	700.	600.	****	970.	****	****	****	170.	250.
Jan '82	960.	840.	520.	500.	****	210.	1500.	****	****	****
Feb	800.	750.	830.	840.	****	****	240.	****	****	****
Mar	710.	710.	1940.	1660.	1620.	****	****	****	****	****
Apr	600.	480.	710.	590.	****	390.	****	****	****	****
Yearly Mean	650.	640.	680.	640.	840.	270.	1310.	1290.	250.	260.
Standard Deviation	<u>+160.</u>	<u>+100.</u>	<u>+420.</u>	<u>+370.</u>	<u>+630.</u>	<u>+100.</u>	<u>+590.</u>	<u>+480.</u>	<u>+130.</u>	<u>+80.</u>
n	12	11	12	11	4	4	8	7	7	6

\*\*\*\* no data

A - coal mine accrual water sampling site located prior to mine's treatment.  
 B - coal mine accrual water sampling site located after mine's treatment.

Note: For purposes of graphing (Figure 13), the monthly field data at A and B sites were averaged and the mean value plotted.

observed in the field and column leachates were significant but well below hazardous levels.

Strontium data from the upflow leaching column experiments are presented in Table 31 and in graphic form in Figures 14 and 15. Strontium was observed to leach from the matrix of most of the coal samples. Leaching here appeared to be a slower process than leaching of boron; peak strontium concentrations were generally seen on days 3 to 5. Often the leaching process was apparently not completed by the tenth day.

The greatest quantities of strontium were leached from the coal sample from mine 5. Strontium concentrations at days 1 and 2 (1360. and 1160.  $\mu\text{g/liter}$  mean respectively) were very close to the yearly mean values for the mine site (1310.  $\mu\text{g/liter}$  for 5A and 1290.  $\mu\text{g/liter}$  for 5B). However, as shown in Figure 15, strontium levels peaked on days 3 and 4 (1640. and 1620.  $\mu\text{g/liter}$  mean, respectively); these concentrations are not unlike the mine water concentrations frequently observed at this site (Table 30). Leaching of strontium was not completed by day 10, remaining more than 600.  $\mu\text{g/liter}$  above

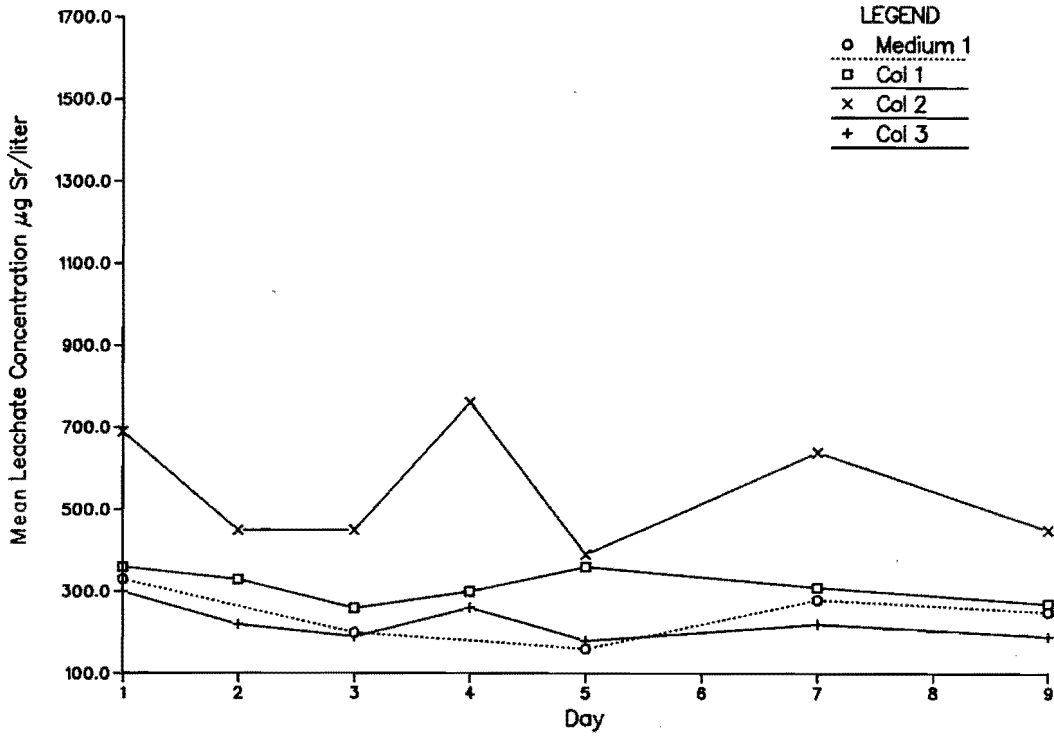


Figure 14. Graphic representation of strontium in coal column leachates, coal from mines 1, 2, and 3.

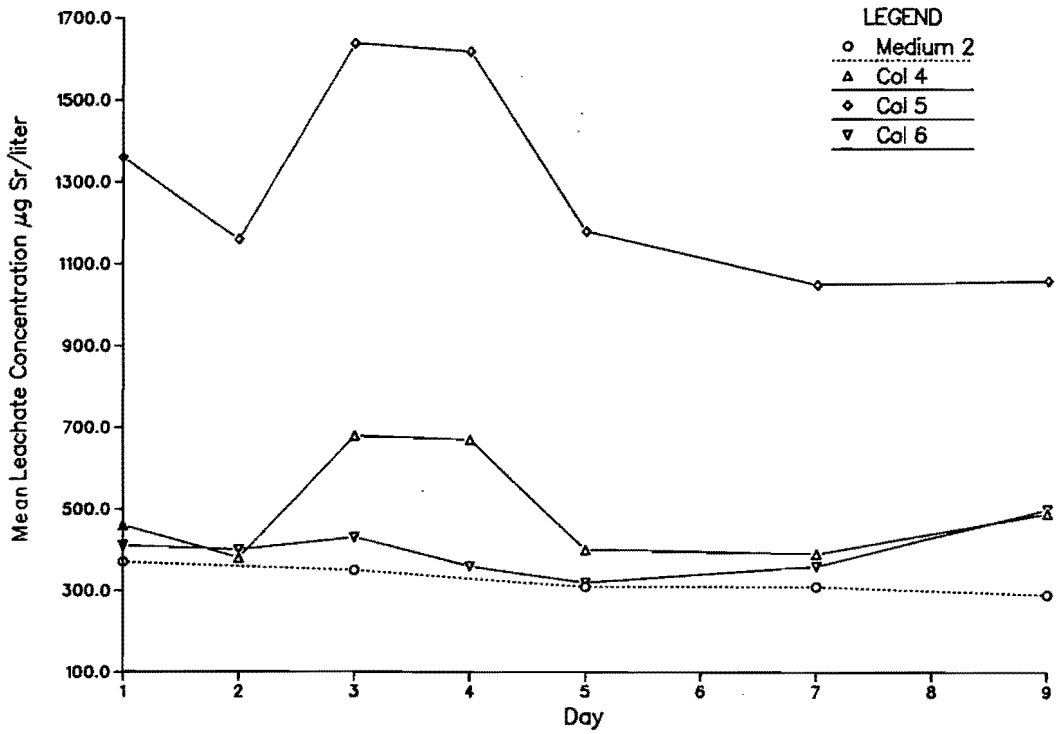


Figure 15. Graphic representation of strontium in coal column leachates, coal from mines 4, 5, and 6.

Table 31. Leachate column data, strontium;  $\mu\text{g Sr/liter}$ .

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10
Medium 1	330.	****	200.	****	160.	****	280.	****	250.	****
Col 1	360. <u>+20.</u>	330. <u>+30.</u>	260. <u>+10.</u>	300. <u>+30.</u>	360. <u>+20.</u>	****	310. <u>+0</u>	****	270. <u>+10.</u>	****
Col 2	690. <u>+70.</u>	450. <u>+40.</u>	450. <u>+20.</u>	760. <u>+50.</u>	390. <u>+20.</u>	****	640. <u>+80.</u>	****	450. <u>+40.</u>	****
Col 3	300. <u>+30.</u>	220. <u>+20.</u>	190. <u>+10.</u>	260. <u>+20.</u>	180. <u>+70.</u>	****	220. <u>+10.</u>	****	190. <u>+0.</u>	****
Col 4	460. <u>+10.</u>	380. <u>+20.</u>	680. <u>+40.</u>	670. <u>+50.</u>	400. <u>+30.</u>	**** ****	390. <u>+20.</u>	****	490. <u>+80.</u>	****
Col 5	1360. <u>+20.</u>	1160. <u>+140.</u>	1640. <u>+110.</u>	1620. <u>+140.</u>	1180. <u>+150.</u>	****	1050. <u>+200.</u>	****	1060. <u>+190.</u>	****
Col 6	410. <u>+10.</u>	400. <u>+90.</u>	430. <u>+10.</u>	360. <u>+40.</u>	320. <u>+50.</u>	****	360. <u>+10.</u>	****	500. <u>+40.</u>	****
Medium 2	370.	****	350.	****	310.	****	310.	****	290.	****

\*\*\*\* no data

Notes:

1. For each day of the experiment, the data from the analysis of three replicate coal column leachates are presented as the mean + standard deviation.

2. See also Appendix Table A-25b.

the concentration of the leaching medium. Manipulating the data for the leachate and media concentrations indicates that the coal sample from mine 5 was in excess of 3.8 mg/kg strontium. The strontium in the water accrued at mine 5 is probably derived mainly from contact with the coal seams.

Some leaching of strontium was also observed with respect to coal samples from mines 2 and 4 (Figures 14 and 15, respectively). Leachate strontium concentration reached a maximum on day 4

(760.  $\mu\text{g/liter}$  mean) for the coal from mine 2, with high values also occurring on days 1 and 7 (690. and 640.  $\mu\text{g/liter}$  mean, respectively). These values are comparable to yearly field mean values of 680. + 420.  $\mu\text{g/liter}$  at 2A and 640. + 370.  $\mu\text{g/liter}$  at 2B (Table 30). Leaching of strontium was apparently not completed by day 10 and the coal sample from mine 2 was calculated to contain at least 1.2 mg/kg strontium. The coal from mine 4 was observed to leach somewhat less strontium during the 10-day experiment than the sample from mine 2 (Figure 15). The maximum stron-

tium concentrations observed were 680.  $\mu\text{g/liter}$  mean on day 3 and 670.  $\mu\text{g/liter}$  mean on day 4. Limited field data from mine site 4 indicate a mean strontium concentration of only  $270. \pm 100. \mu\text{g/liter}$  (Table 30). The field concentrations were also generally less than the mean media concentration (330.  $\mu\text{g/liter}$ ) and the daily mean concentrations of the column leachates (ranging from 380. to 680.  $\mu\text{g/liter}$ ). It is certainly possible that because of the strontium variations in the area's water supplies the water entering mine 4 had a lower strontium concentration than the synthetic medium prepared for the column experiments. The coal sample from mine 4 was calculated to contain at least 0.7 mg/kg strontium.

Leaching of strontium with respect to the coal samples from mines 1, 3, and 6 was much less evident (Figures 14 and 15) and could not be easily quantified. It is probable that the coal obtained from these locations did not contain appreciable amounts of strontium. Strontium levels in the field could be indicative of background strontium in the area's water supplies, or coal strontium levels could vary dramatically with grab samples collected.

Leaching of strontium from coal samples was also observed by Israelsen et al. (1980). The apparent strontium leachability and strontium content of the coal samples were fairly consistent but showed some variation with the chemical characteristics of the leaching medium. Strontium leached from the coal samples varied from less than 1 mg/kg to more than 9 mg/kg. The coal from mine 4 (which corresponds to mine 1 in this report) leached  $2.22 \pm 0.42$  mg/kg strontium during three slurry studies with media ranging from 2,220 to 13,200 mg/liter total dissolved solids. The observed strontium leaching phenomena were considerably different in this coal slurry study than in the current research where only slight to negligible leaching was observed (Figure 14). Since leaching is a complicated process,

these differences may be due to a number of factors such as chemical characteristics of the leaching medium, coal particle size, percolation rate of the medium, etc. It is also possible that collection of a grab sample of coal may not provide homogeneous quantities of leachable constituents like strontium.

#### Major Anions and Cations

Most alkalinity values for the field mine water samples ranged between 150. and 300. mg  $\text{CaCO}_3/\text{liter}$  (Appendix Table A-27a) as did concentrations in the coal column leachates (Table 32). Some leaching of carbonate species was observed as is shown graphically in Figures 16 and 17. Medium 1 and medium 2 differed slightly with respect to alkalinity; medium 2 was slightly lower in pH with more predominance of bicarbonate species and carbon dioxide gas. The leaching characteristics and the shapes of the curves in Figures 16 and 17 seem to be dependent on the medium characteristics. For the coal samples from mines 1, 2, and 3, the highest alkalinities were generally observed on day 1, with leachate concentrations being somewhat below that of the medium by days 8 and 9. The leachate alkalinities of the coal sample from mine 2 showed less variation from medium 1 than did the samples from mines 1 and 3. Coal samples from mines 4, 5 and 6 exhibited peak alkalinity leachate concentrations on days 9 and 10 with a secondary peak from days 3 to 5. These increases in leachate carbonate concentrations late in the experiment parallel concurrent increases in specific conductance (Figure 7).

Mine water chloride concentrations in the field were low with most being less than 30. mg/liter (Appendix Table A-28a). On two occasions chloride did exceed the 100. mg/liter limit for continuous irrigation of crops, but chloride levels were never excessive with regard to drinking water, freshwater aquatics, and stock and wildlife watering (Table 5). Chloride concentra-

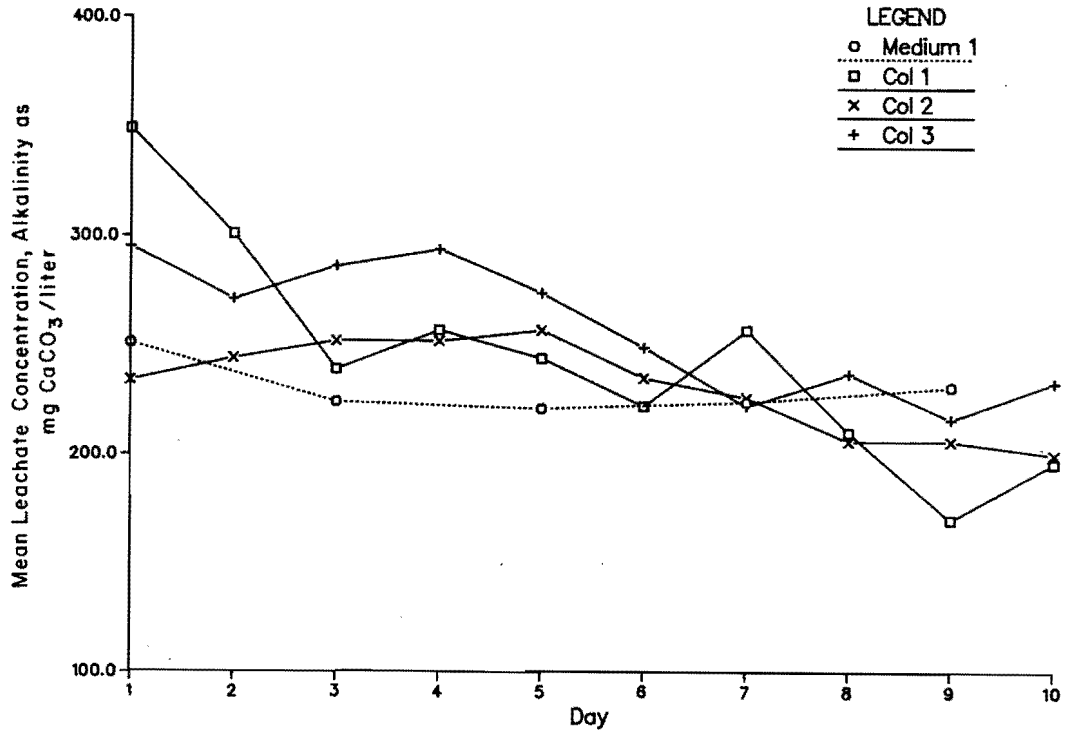


Figure 16. Graphic representation of alkalinity in coal column leachates, coal from mines 1, 2, and 3.

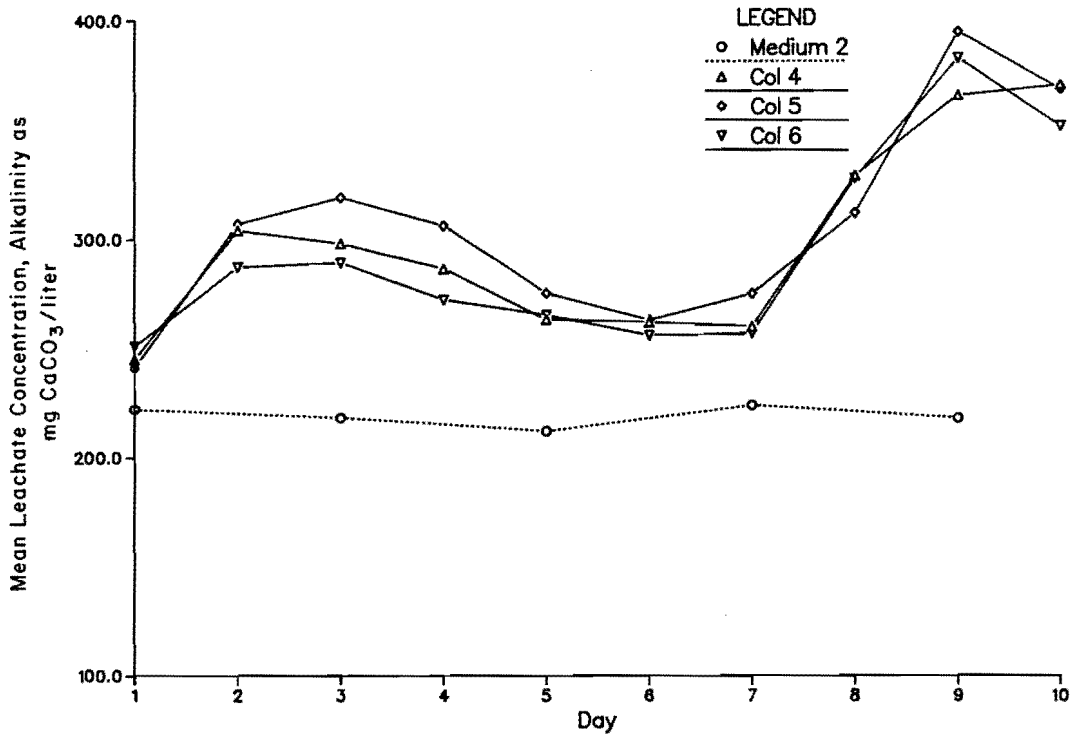


Figure 17. Graphic representation of alkalinity in coal column leachates, coal from mines 4, 5, and 6.



Table 32. Leachate column data, alkalinity, total; mg CaCO<sub>3</sub>/liter.

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10
Medium 1	251.	****	224.	****	221.	****	224.	****	231.	****
Col 1	349. <u>+22.</u>	301. <u>+4.</u>	239. <u>+8.</u>	257. <u>+8.</u>	244. <u>+20.</u>	222. <u>+5.</u>	257. <u>+59.</u>	210. <u>+11.</u>	170. <u>+14.</u>	196. <u>+8.</u>
Col 2	234. <u>+11.</u>	244. <u>+17.</u>	252. <u>+7.</u>	252. <u>+12.</u>	257. <u>+10.</u>	235. <u>+13.</u>	226. <u>+3.</u>	206. <u>+4.</u>	206. <u>+9.</u>	200. <u>+8.</u>
Col 3	295. <u>+4.</u>	271. <u>+49.</u>	286. <u>+22.</u>	294. <u>+30.</u>	274. <u>+17.</u>	249. <u>+7.</u>	222. <u>+7.</u>	237. <u>+14.</u>	216. <u>+8.</u>	233. <u>+3.</u>
Col 4	245. <u>+13.</u>	304. <u>+10.</u>	298. <u>+5.</u>	286. <u>+15.</u>	263. <u>+7.</u>	262. <u>+13.</u>	260. <u>+10.</u>	329. <u>+17.</u>	366. <u>+28.</u>	371. <u>+32.</u>
Col 5	241. <u>+17.</u>	307. <u>+15.</u>	319. <u>+12.</u>	306. <u>+14.</u>	275. <u>+13.</u>	263. <u>+9.</u>	275. <u>+9.</u>	312. <u>+12.</u>	395. <u>+15.</u>	369. <u>+9.</u>
Col 6	251. <u>+21.</u>	287. <u>+13.</u>	289. <u>+10.</u>	272. <u>+10.</u>	265. <u>+12.</u>	256. <u>+12.</u>	257. <u>+21.</u>	328. <u>+1.</u>	383. <u>+44.</u>	352. <u>+17.</u>
Medium 2	222.	****	218.	****	212.	****	224.	****	218.	****

\*\*\*\* no data

Notes:

1. For each day of the experiment, the data from the analysis of three replicate coal column leachates are presented as the mean + standard deviation.

2. See also Appendix Table A-27b.

tions in the coal column leachates paralleled those observed in the field, with apparent slight leaching early in the experiment (Appendix Table A-28b).

Fluoride has been preported to be a potential problem with respect to many coal sources. However, fluoride concentrations during the field sampling phase were always less than or equal to 0.7 mg/liter (Appendix Table A-29a). These levels are well below the drinking water MCL and criteria for all other uses as summarized in Table 5. Fluoride levels during the leachate column experiments

were comparable to those obtained in the field (Appendix Table A-29b). Some slight leaching of fluoride was observed with respect to the coal sample from mine 1.

Field data for the water hardness indicators (calcium, total hardness, and magnesium) are summarized in Tables 33 and 34 and Appendix Table A-32a, respectively, with calcium and total hardness depicted graphically in Figures 18 and 21. The water hardness parameters remained fairly consistent with time at each mine site. Although the data are

Table 33. Coal mine accrual water data, hardness - calcium; mg Ca/liter.

	1A	1B	2A	2B	3	4	5A	5B	6A	6B
May '81	58.	59.	79.	77.	****	****	56.	64.	110.	71.
Jun	60.	63.	81.	81.	142.	143.	77.	76.	64.	64.
Jul	69.	65.	75.	82.	****	****	77.	78.	71.	68.
Aug	60.	59.	80.	85.	****	****	85.	76.	65.	****
Sep	73.	49.	98.	81.	159.	92.	78.	70.	83.	60.
Oct	64.	****	92.	78.	****	****	85.	73.	****	****
Nov	74.	86.	86.	85.	****	****	****	80.	79.	80.
Dec	78.	76.	96.	****	166.	****	****	****	90.	80.
Jan '82	83.	67.	70.	70.	****	93.	74.	****	****	****
Feb	75.	73.	77.	71.	****	****	84.	****	****	****
Mar	80.	80.	82.	82.	158.	****	****	****	****	****
Apr	69.	61.	82.	75.	****	105.	****	****	****	****
Yearly Mean	70.	67.	83.	79.	156.	108.	77.	74.	80.	70.
Standard Deviation	+8.	+11.	+8.	+5.	+10.	+24.	+9.	+5.	+16.	+8.
n	12	11	12	11	4	4	8	7	7	6

\*\*\*\* no data

A - coal mine accrual water sampling site located prior to mine's treatment.  
 B - coal mine accrual water sampling site located after mine's treatment.

Note: For purposes of graphing (Figure 18), the monthly field data at A and B sites were averaged and the mean value plotted.

limited, the water appears to be considerably harder at sites 3 and 4 which are located about midway up the Wasatch Plateau. Most of the hardness at site 3 is due to calcium while calcium and magnesium contribute about equally to the hardness at mine site 4.

Calcium in the coal column leachates is listed in Table 35 and presented graphically in Figures 19 and 20; total hardness in the leachates is listed in Table 36 and depicted in Figures 22 and 23.

The coal from mine 1 consistently produced leachates with lower concentrations of calcium and total hardness than

medium 1. Some slight leaching of magnesium was observed also (Appendix Table A-32b). It can be said that this coal sample possessed some ability to absorb calcium and act as a cation exchanger. Therefore, some of the calcium could have been exchanged with magnesium during the process of interaction with the coal matrix, resulting in absorption of calcium and leaching of magnesium. However, conversion of the chemical constituents involved to equivalent weights does not account for all of the calcium that was lost from the medium (about 1-2 milliequivalents per day). The remainder of the calcium can generally be accounted for by looking at the quantities of sodium

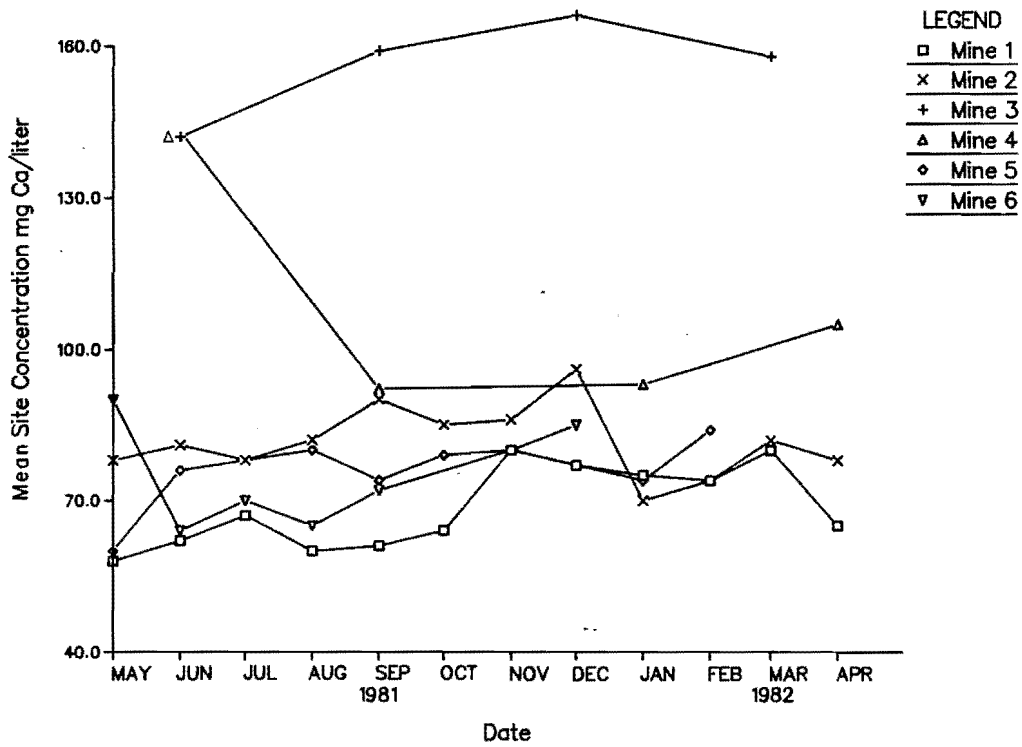


Figure 18. Graphic representation of calcium in the field, mine sites 1, 2, 3, 4, 5, and 6.

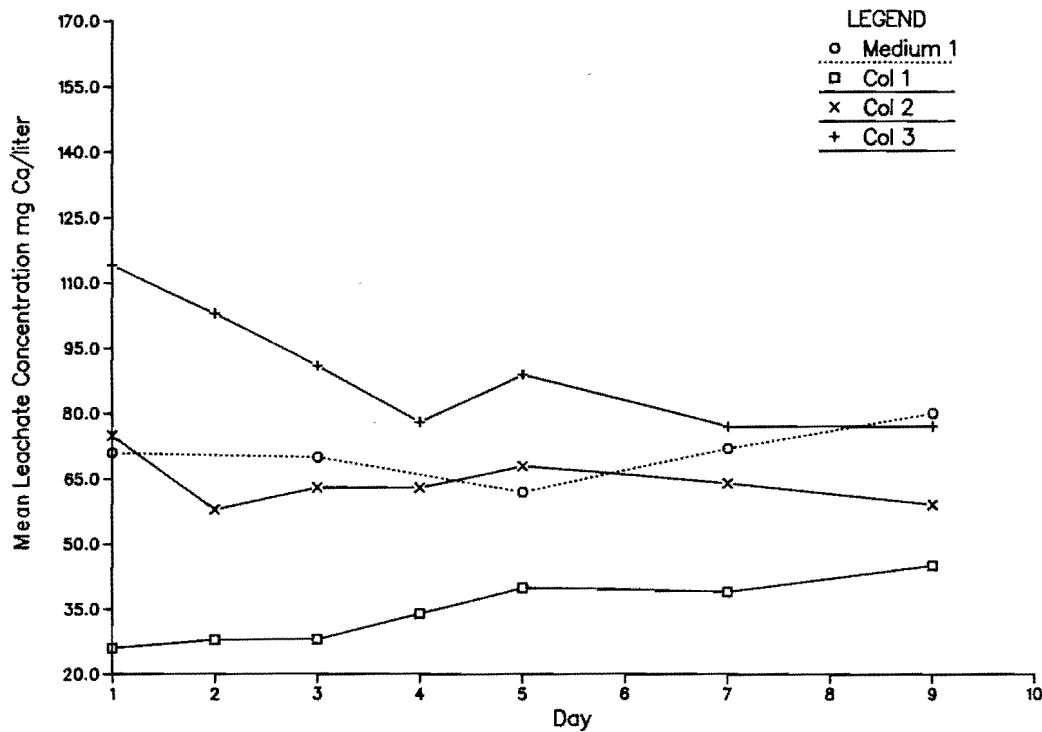


Figure 19. Graphic representation of calcium in coal column leachates, coal from mines 1, 2, and 3.

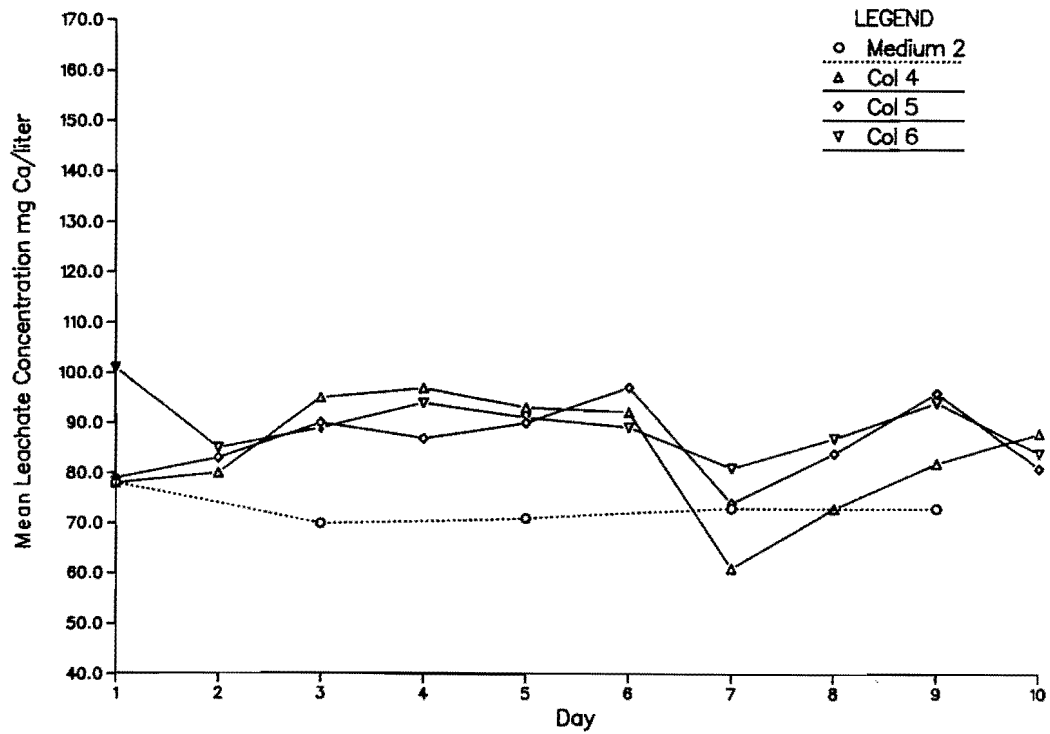


Figure 20. Graphic representation of calcium in coal column leachates, coal from mines 4, 5, and 6.

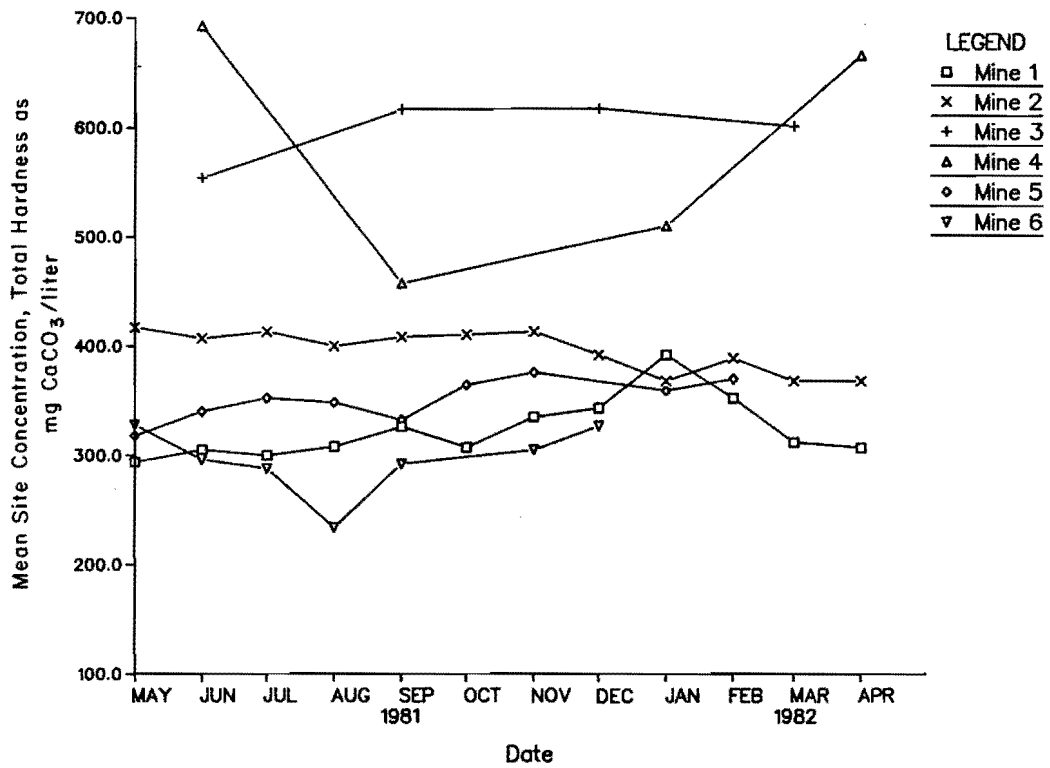


Figure 21. Graphic representation of total hardness in the field, mine sites 1, 2, 3, 4, 5, and 6.

Table 34. Coal mine accrual water data, hardness - total; mg CaCO<sub>3</sub>/liter.

	1A	1B	2A	2B	3	4	5A	5B	6A	6B
May '81	296.	291.	417.	417.	****	****	320.	315.	378.	277.
Jun	305.	305.	408.	406.	554	693.	344.	335.	277.	315.
Jul	299.	302.	405.	421.	****	****	358.	346.	286.	289.
Aug	288.	329.	421.	380.	****	****	370.	327.	234.	****
Sep	328.	325.	415.	400.	616.	457.	330.	335.	294.	290.
Oct	307.	****	410.	410.	****	****	410.	317.	****	****
Nov	341.	329.	408.	418.	****	****	****	376.	281.	329.
Dec	353.	333.	392.	****	617.	****	****	****	326.	328.
Jan '82	399.	384.	366.	370.	****	510.	359.	****	****	****
Feb	355.	350.	388.	390.	****	****	370.	****	****	****
Mar	310.	315.	373.	364.	601.	****	****	****	****	****
Apr	309.	305.	368.	368.	****	666.	****	****	****	****
Yearly										
Mean	324.	324.	398.	395.	597.	582.	358.	336.	297.	305.
Standard										
Deviation	+32.	+26.	+20.	+22.	+30	+116.	+28	+21.	+45.	+22.
n	12	11	12	11	4	4	8	7	7	6

\*\*\*\* no data

A - coal mine accrual water sampling site located prior to mine's treatment.

B - coal mine accrual water sampling site located after mine's treatment.

Note: For purposes of graphing (Figure 21), the monthly field data at A and B sites were averaged and the mean value plotted.

leached from the coal sample from mine 1 (Table 39 and Figure 28). Large quantities of sodium were leached in the first days of the experiment, resulting in more sodium leached from the coal matrix than analogous milliequivalent quantities of calcium absorbed. Values for all water hardness parameters in the coal column leachates were lower than those observed in the field for mine site 1.

Some increases in the hardness parameters were observed during the first few days of the experiment when leaching coal samples from mines 2 and 3 (Figures 19 and 22). Increases in total hardness with respect to the coal from mine 2 were due to leaching of magnesium; calcium was not observed to leach from the coal sample. Field data

for hardness parameters at site 2 were usually higher than those observed in the leachate column experiment. Increases in total hardness with respect to the coal from mine 3 were due to leaching both of calcium and magnesium. Field data for hardness parameters at mine 3 were almost always higher than those observed in the laboratory leachates.

Some general increases in water hardness were observed when leaching coal samples from mines 4, 5 and 6 (Figures 20 and 23). Values for the hardness parameters in these leachates remained above those of medium 2 for most of the 10-day experiment. Field data for calcium, total hardness and magnesium at mine 4 were usually much higher than those observed in

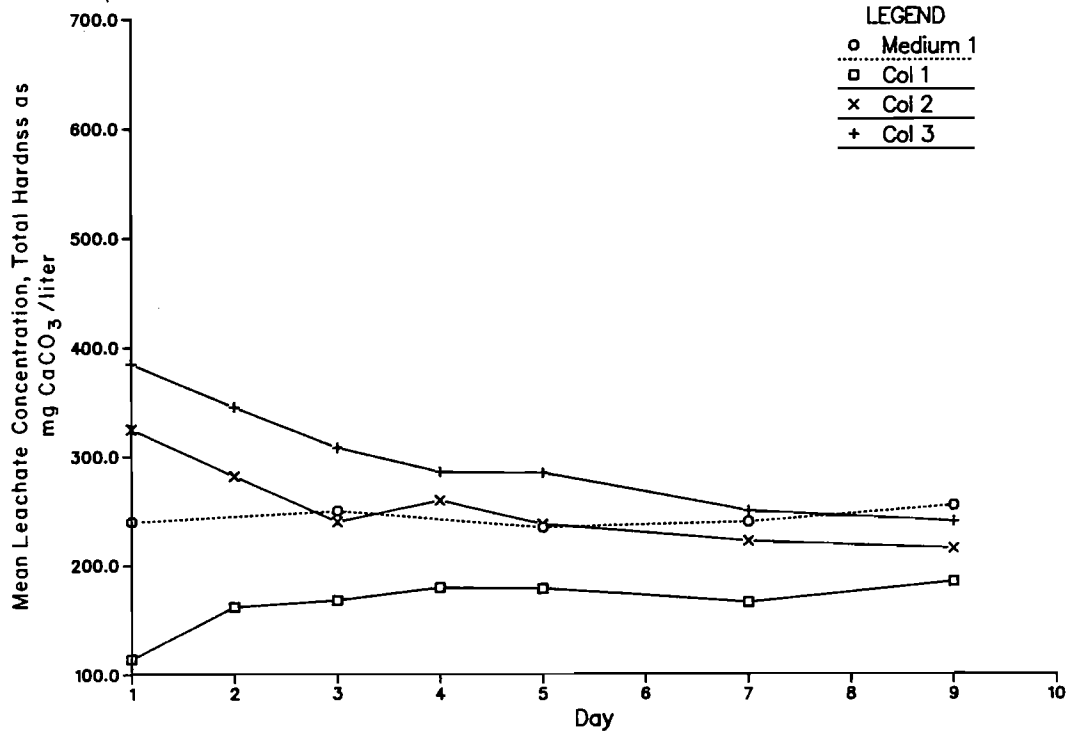


Figure 22. Graphic representation of total hardness in coal column leachates, coal from mines 1, 2, and 3.

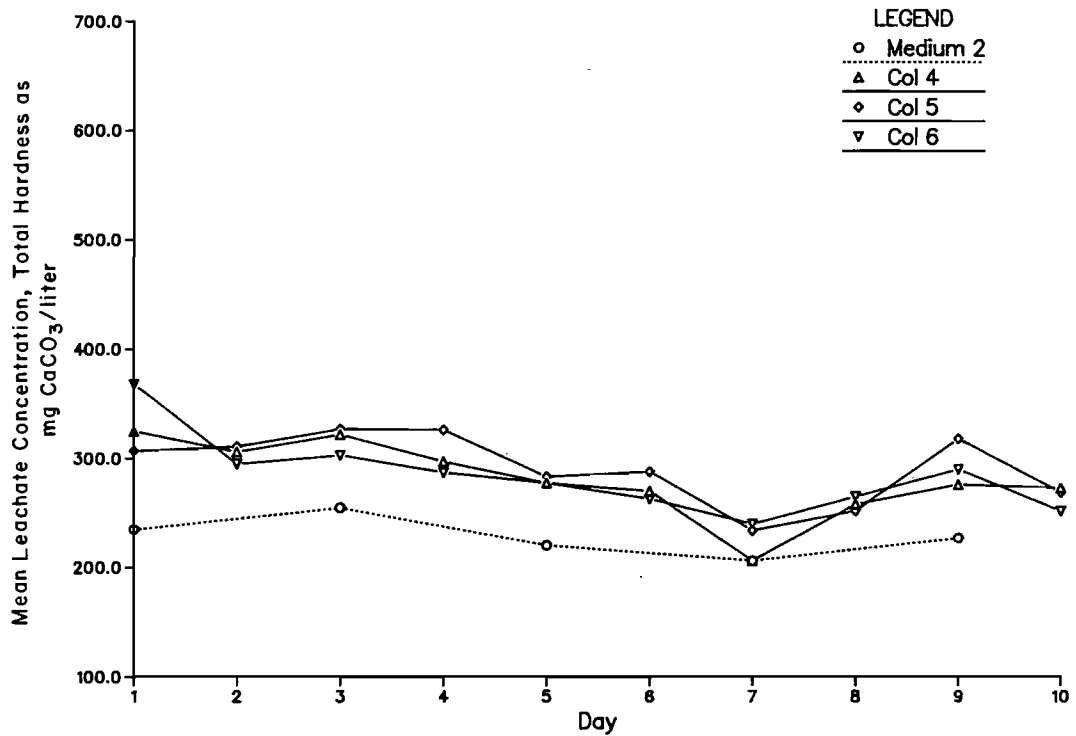


Figure 23. Graphic representation of total hardness in coal column leachates, coal from mines 4, 5, and 6.

Table 35. Leachate column data, hardness - calcium; mg Ca/liter.

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10
Medium 1	71.	****	70.	****	62.	****	72.	****	80.	****
Col 1	26. <u>+5.</u>	28. <u>+2.</u>	28. <u>+3.</u>	34. <u>+2.</u>	40. <u>+3.</u>	****	39. <u>+4.</u>	****	45. <u>+3.</u>	****
Col 2	75. <u>+3.</u>	58. <u>+2.</u>	63. <u>+1.</u>	63. <u>+4.</u>	68. <u>+14.</u>	****	64. <u>+7.</u>	****	59. <u>+3.</u>	****
Col 3	114. <u>+5.</u>	103. <u>+13.</u>	91. <u>+8.</u>	79. <u>+5.</u>	89. <u>+5.</u>	****	77. <u>+2.</u>	****	77. <u>+11.</u>	****
Col 4	78. <u>+8.</u>	80. <u>+6.</u>	95. <u>+3.</u>	97. <u>+5.</u>	93. <u>+3.</u>	92. <u>+3.</u>	61. <u>+2.</u>	73. <u>+9.</u>	82. <u>+8.</u>	88. <u>+7.</u>
Col 5	79. <u>+2.</u>	83. <u>+6.</u>	90. <u>+8.</u>	87. <u>+6.</u>	90. <u>+2.</u>	97. <u>+5.</u>	74. <u>+6.</u>	84. <u>+8.</u>	96. <u>+4.</u>	81. <u>+4.</u>
Col 6	101. <u>+11.</u>	85. <u>+1.</u>	89. <u>+4.</u>	94. <u>+2.</u>	91. <u>+4.</u>	89. <u>+3.</u>	81. <u>+2.</u>	87. <u>+11.</u>	94. <u>+8.</u>	84. <u>+8.</u>
Medium 2	78.	****	70.	****	71.	****	73.	****	73.	****

\*\*\*\* no data

Notes:

1. For each day of the experiment, the data from the analysis of three replicate coal column leachates are presented as the mean + standard deviation.

2. See also Appendix Table A-30b.

the column leachates. Total hardness and magnesium concentrations for the mine waters sampled at site 5 were generally somewhat higher than those values observed in the laboratory; calcium concentrations in the field were somewhat lower than in the coal column leachates. Calcium field and column data for mine site 6 were in the same concentration ranges; magnesium concentrations in the coal column leachates were always higher than those observed in the field situation.

It appears that water hardness levels and chemical composition with

respect to calcium and magnesium can change as water comes into contact with the coal matrix. The levels of water hardness parameters in accrued mine waters appear to be functions of both the chemical constituency of the water before it comes into contact with the coal and the nature of interactions with the coal matrices.

Potassium concentrations in the accrued mine waters were always less than or equal to 11. mg/liter with the highest levels observed quite consistently at mine 5 (Appendix Table A-33a). Some leaching of potassium was

Table 36. Leachate column data, hardness - total; mg CaCO<sub>3</sub>/liter.

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10
Medium 1	240.	****	250.	****	235.	****	240.	****	255.	****
Col 1	114. +4.	162. +4.	168. +3.	180. +5.	179. +5.	****	166. +5.	****	185. +11.	****
Col 2	325. +13.	282. +15.	240. +9.	257. +15.	238. +15.	****	222. +15.	****	215. +5.	****
Col 3	385. +40.	345. +10.	308. +20.	286. +30.	285. +15.	****	250. +30.	****	240. +18.	****
Col 4	325. +5.	306. +6.	322. +10.	297. +16.	277. +3.	270. +5.	206. +9.	258. +31.	276. +31.	273. +13.
Col 5	307. +12.	311. +7.	327. +6.	326. +7.	283. +12.	288. +6.	234. +22.	252. +28.	318. +5.	269. +17.
Col 6	368. +28.	295. +10.	303. +12.	287. +15.	277. +15.	263. +12.	240. +8.	265. +29.	290. +28.	252. +14.
Medium 2	235.	****	255.	****	220.	****	206.	****	227.	****

\*\*\*\* no data

Notes:

1. For each day of the experiment, the data from the analysis of three replicate coal column leachates are presented as the mean + standard deviation.

2. See also Appendix Table A-31b.

observed with respect to coal samples from mines 2, 4, and 5; the highest leachate concentrations occurred on day 1 (Appendix Table A-33b) and leachate data in general paralleled the field data.

Silica concentrations in the samples collected during field monitoring are listed in Table 37 and represented graphically in Figure 24. It can be seen that there is a quite definite directional trend; silica in the water sources increases with movement in a north to south direction along the Wasatch Plateau coal field.

Some leaching of silica from the coal samples was observed, (Table 38) and is shown in Figures 25 and 26. (The silica value for the sample of medium 1 taken on day 1 was higher than expected; it was probably due to a contamination of the sample container, but could not be proven. The presence of this possible outlier lends ambiguity to the coal and leaching medium interactions during days 1 and 2, Table 38 and Figure 25.) Silica present in the coal matrix is easily removed with highest concentrations generally observed after one or two days of leaching. The coal samples from mines



Table 37. Coal mine accrual water data, silica; mg SiO<sub>2</sub>/liter.

	1A	1B	2A	2B	3	4	5A	5B	6A	6B
May '81	10.6	10.4	9.3	9.8	****	****	9.3	9.3	6.1	6.5
Jun	10.1	10.4	9.1	9.1	9.1	8.7	7.5	8.5	6.7	6.4
Jul	11.7	11.8	10.1	10.1	****	****	9.6	9.5	8.0	8.2
Aug	12.3	11.6	10.7	10.3	****	****	9.9	9.6	7.4	****
Sep	11.6	10.9	9.8	9.7	9.2	8.6	8.2	8.5	6.3	7.8
Oct	11.1	****	11.3	9.5	****	****	8.4	8.1	****	****
Nov	11.7	11.6	8.5	9.2	****	****	****	7.7	6.1	9.1
Dec	11.2	11.9	8.8	****	9.4	****	****	****	6.6	6.9
Jan '82	10.4	10.7	8.2	8.9	****	9.5	7.8	****	****	****
Feb	10.1	10.2	8.5	9.3	****	****	8.3	****	****	****
Mar	10.1	10.1	7.9	7.9	9.2	****	****	****	****	****
Apr	9.4	9.4	7.1	7.8	****	11.6	****	****	****	****
Yearly Mean	10.9	10.9	9.1	9.2	9.2	9.6	8.6	8.7	6.7	7.5
Standard Deviation	<u>+0.9</u>	<u>+0.8</u>	<u>+1.2</u>	<u>+0.8</u>	<u>+0.1</u>	<u>+1.4</u>	<u>+0.9</u>	<u>+0.7</u>	<u>+0.7</u>	<u>+1.1</u>
n	12	11	12	11	4	4	8	7	7	6

\*\*\*\* no data

A - coal mine accrual water sampling site located prior to mine's treatment.  
 B - coal mine accrual water sampling site located after mine's treatment.

Note: For purposes of graphing (Figure 24), the monthly field data at A and B sites were averaged and the mean value plotted.

2, 3, 4, and 5 were observed to leach silica; the coal from mines 1 and 6 exhibited little or no tendency to leach silica. The concentrations of silica in the column leachates throughout the experiment are comparable to levels of silica observed in the field mine water samples, with the exception of mine 1. Silica field concentrations at mine site 1 were somewhat higher than those observed in the laboratory.

When coal from mine 1 was evaluated for coal slurry pipelining (Israelsen et al. 1980), that sample was observed to leach small but significant quantities of silica after contact with the least saline transport medium. The most

saline medium used in the third slurry experiment had a chemical composition differing from the first two; it contained less calcium and magnesium and much greater quantities of sodium and chloride. Under the conditions of the third laboratory slurry, the coal from mine 1 (designated mine 4 in the 1980 report) was actually observed to absorb and remove almost 70 percent of the silica present in the transport medium.

Sodium concentrations of the mine water samples collected in the field are listed in Table 39 and graphically presented in Figure 27. Sodium levels were generally lower at mine sites 3, 4, and 6 (usually less than 10. mg/liter).

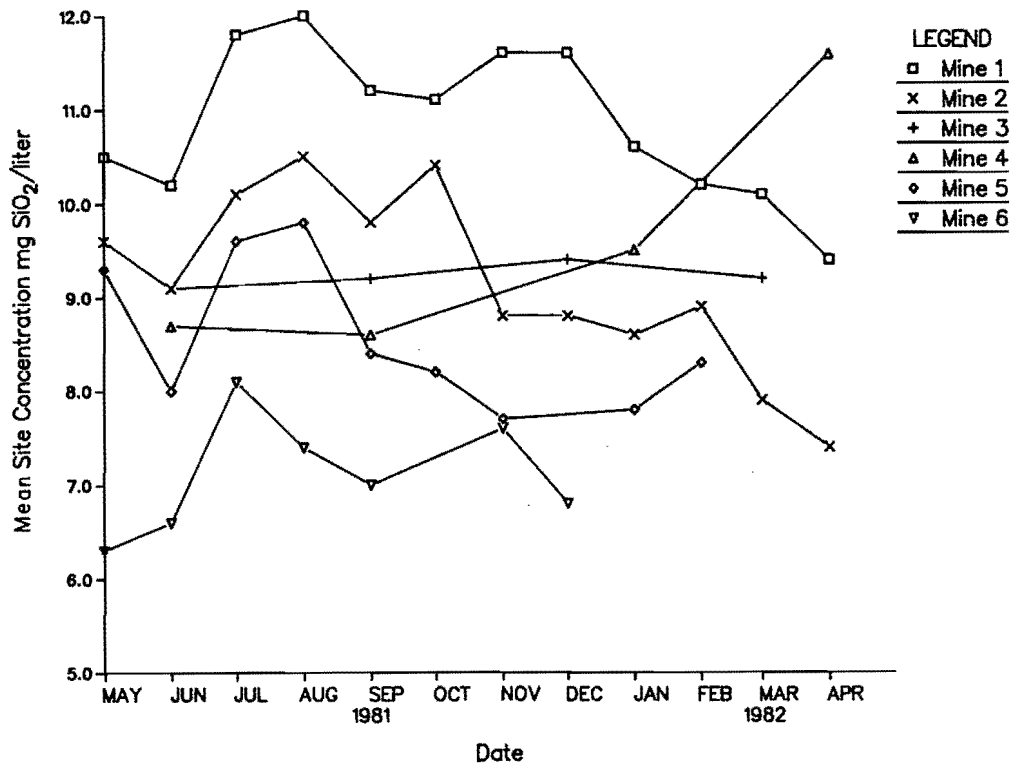


Figure 24. Graphic representation of silica in the field, mine sites 1, 2, 3, 4, 5, and 6.

Higher values were consistently observed at sites 1, 2 and 5, ranging from 20. to 58. mg/liter.

A criterion for sodium in drinking water has not been established (Table 5), but a limit of 100. mg/liter for the majority of the population and 20. mg/liter for those on sodium restricted diets has been recommended (Safe Drinking Water Committee 1977). Even with limited data available at site 3, this drinking water source is likely to continually meet the strictest of these criteria.

Sodium can be a harmful constituent in irrigation water since it can cause toxicity responses in plants and can degrade soil conditions when present in high concentrations (McKee and Wolf 1963). When sodium in irrigation water is present at concentrations less than

3. milliequivalents/liter or 69. mg/liter, water quality guidelines indicate no potential hazards to crop production with long-term use of the water source. Further estimates of potential hazards can be made by use of the sodium absorption ratio (SAR) which takes into account the presence of excess sodium or limited calcium. Recent work (Ayers 1977) has developed the concept of adjusted SAR (adj. SAR) which also includes effects of carbonate and bicarbonate. For the purposes of long-term irrigation, adj. SAR values should fall below 3. Levels from 3.0-9.0 adj. SAR can cause increasing problems with most soils and crops; adj. SAR values in excess of 9.0 will cause severe problems (Ayers 1977). Table 40 summarizes the adj. SAR values calculated for the mine water discharges to the environment, along with observed levels of calcium, magnesium, sodium,

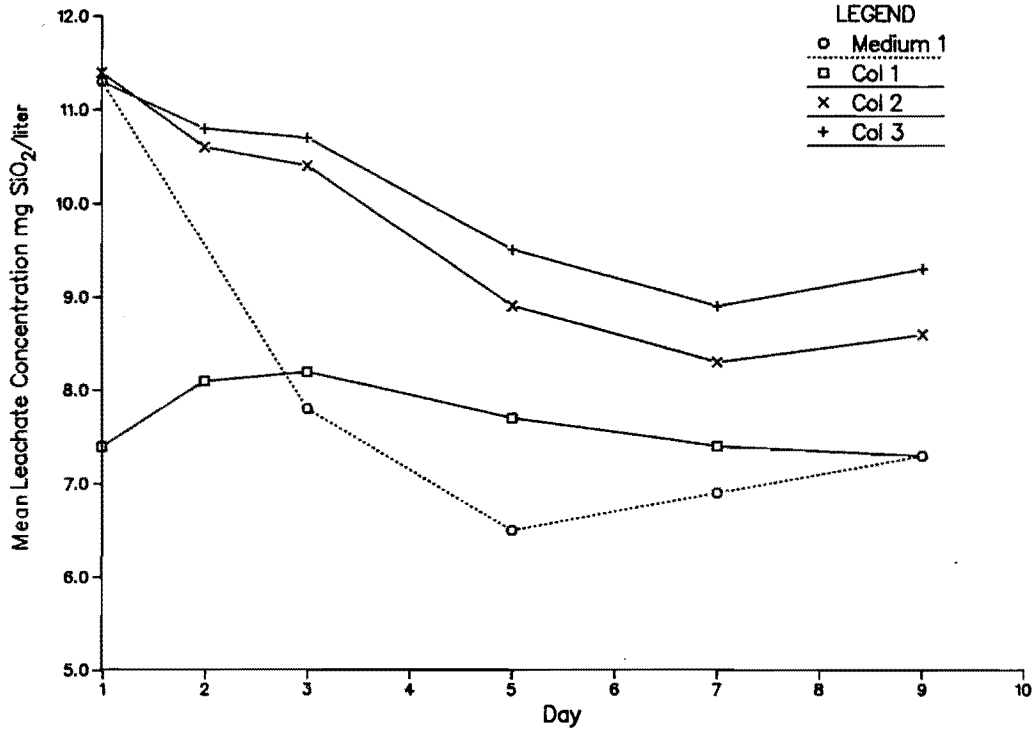


Figure 25. Graphic representation of silica in coal column leachates, coal from mines 1, 2, and 3.

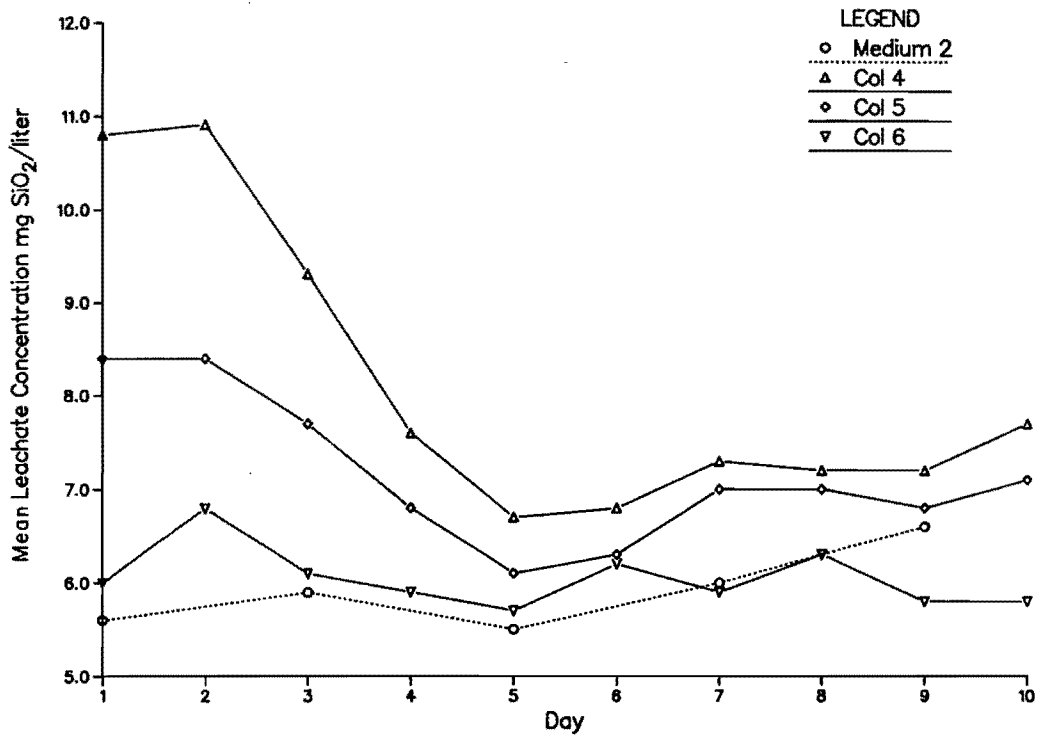


Figure 26. Graphic representation of silica in coal column leachates, coal from mines 4, 5, and 6.

Table 38. Leachate column data, silica; mg SiO<sub>2</sub>/liter.

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10
Medium 1	11.3	****	7.8	****	6.5	****	6.9	****	7.3	****
Col 1	7.4 <u>+0.0</u>	8.1 <u>+0.4</u>	8.2 <u>+0.1</u>	****	7.7 <u>+0.2</u>	****	7.4 <u>+0.1</u>	****	7.3 <u>+0.1</u>	****
Col 2	11.4 <u>+0.4</u>	10.6 <u>+0.2</u>	10.4 <u>+0.6</u>	****	8.9 <u>+0.4</u>	****	8.3 <u>+0.1</u>	****	8.6 <u>+0.2</u>	****
Col 3	11.3 <u>+0.0</u>	10.8 <u>+0.2</u>	10.7 <u>+0.2</u>	****	9.4 <u>+0.3</u>	****	8.9 <u>+0.2</u>	****	9.3 <u>+0.3</u>	****
Col 4	10.8 <u>+0.6</u>	10.9 <u>+0.3</u>	9.3 <u>+0.2</u>	7.6 <u>+0.3</u>	6.7 <u>+0.4</u>	6.8 <u>+0.3</u>	7.3 <u>+0.1</u>	7.2 <u>+0.2</u>	7.2 <u>+0.1</u>	7.7 <u>+0.1</u>
Col 5	8.4 <u>+1.0</u>	8.4 <u>+0.1</u>	7.7 <u>+0.4</u>	6.8 <u>+0.2</u>	6.1 <u>+0.1</u>	6.3 <u>+0.3</u>	7.0 <u>+0.2</u>	7.0 <u>+0.3</u>	6.8 <u>+0.2</u>	7.1 <u>+0.2</u>
Col 6	6.0 <u>+0.3</u>	6.8 <u>+0.3</u>	6.1 <u>+0.2</u>	5.9 <u>+0.3</u>	5.7 <u>+0.1</u>	6.2 <u>+0.9</u>	5.9 <u>+0.1</u>	6.3 <u>+0.0</u>	5.8 <u>+0.0</u>	5.8 <u>+0.0</u>
Medium 2	5.6	****	5.9	****	5.5	****	6.0	****	6.6	****

\*\*\*\* no data

Notes:

1. For each day of the experiment, the data from the analysis of three replicate coal column leachates are presented as the mean ± standard deviation.

2. See also Appendix Table A-34b.

and alkalinity in these waters. It is evident that all adj. SAR values were below the most restrictive limits.

Sodium toxicity in the freshwater aquatic environment is known to vary with the species involved and the chemical composition of the water (Table 5). A survey of waters across the U.S. which support good fish populations reported that 95 percent of these waters contained sodium plus potassium concentrations less than 85. mg/liter (McKee and Wolf 1963). Minewater concentrations of sodium plus potassium never

exceeded 85. mg/liter from May 1981 to April 1982.

Sodium was observed to leach from the coal matrices of samples from mines 1 and 2 only (Table 41 and Figure 28); the sodium concentrations in all other leachates did not seem to differ appreciably from those of the media. Sodium leached easily from the samples from sites 1 and 2 reaching a peak on day 1 and dropping sharply thereafter. The coal from mine 2 had completed the leaching process by day 5 while the coal from mine 1 was still releasing some

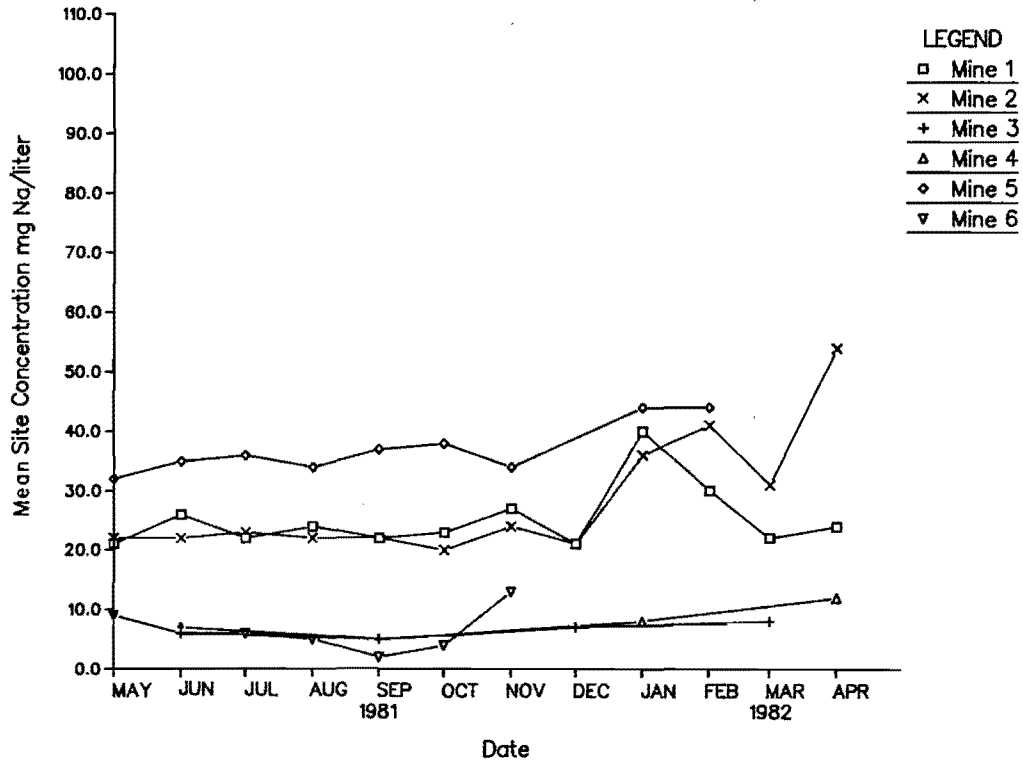


Figure 27. Graphic representation of sodium in the field, mine sites 1, 2, 3, 4, 5, and 6.

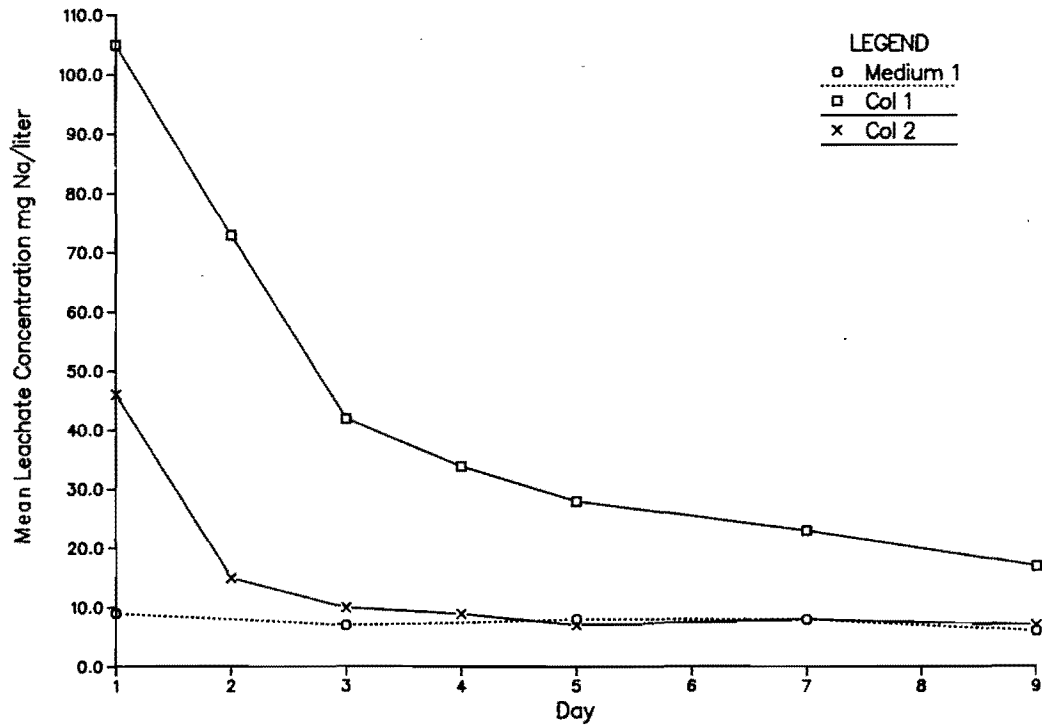


Figure 28. Graphic representation of sodium in coal column leachates, coal from mines 1, 2, and 3.

Table 39. Coal mine accrual water data, sodium; mg Na/liter.

	1A	1B	2A	2B	3	4	5A	5B	6A	6B
May '81	21.	21.	21.	23.	****	****	32.	31.	13.	5.
Jun	26.	26.	22.	22.	6.	7.	35.	35.	5.	6.
Jul	21.	23.	24.	23.	****	****	36.	36.	6.	5.
Aug	24.	23.	22.	22.	****	****	34.	35.	5.	****
Sep	23.	20.	22.	22.	5.	5.	39.	35.	2.	4.
Oct	23.	****	20.	21.	****	****	36.	39.	****	****
Nov	27.	27.	25.	24.	****	****	****	34.	3.	5.
Dec	21.	21.	21.	****	7.	****	****	****	20.	6.
Jan '82	42.	38.	38.	35.	****	8.	44.	****	****	****
Feb	32.	29.	44.	38.	****	****	44.	****	****	****
Mar	20.	24.	38.	24.	8.	****	****	****	****	****
Apr	21.	27.	49.	58.	****	12.	****	****	****	****
Yearly Mean	25.	25.	29.	28.	6.	8.	37.	35.	8.	5.
Standard Deviation	<u>+6.</u>	<u>+5.</u>	<u>+10.</u>	<u>+11.</u>	<u>+1.</u>	<u>+3.</u>	<u>+4.</u>	<u>+2.</u>	<u>+6.</u>	<u>+1.</u>
n	12	11	12	11	4	4	8	7	7	6

\*\*\*\* no data

A - coal mine accrual water sampling site located prior to mine's treatment.  
 B - coal mine accrual water sampling site located after mine's treatment.

Note: For purposes of graphing (Figure 27), the monthly field data at A and B sites were averaged and the mean value plotted.

Table 40. Adjusted sodium absorption ratios.

Site	Calcium mg/liter	Magnesium mg/liter	Sodium mg/liter	Alkalinity mg CaCO <sub>3</sub> /l	Adj. SAR
1B	67.	38.	25.	230.	1.24
2B	79.	48.	28.	255.	1.35
3	156.	50.	6.	301.	0.30
4	108.	76.	8.	242.	0.33
5B	74.	37.	35.	275.	1.69
6B	70.	31.	5.	201.	0.24

Notes:

1. All calculations of adj. SAR are made in accordance with Ayers (1977).
2. Yearly mean values of calcium, magnesium, sodium, and alkalinity were converted to millequivalent weights and used to calculate adj. SAR.

Table 41. Leachate column data, sodium; mg Na/liter.

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10
Medium 1	9.	****	7.	****	8.	****	8.	****	6.	****
Col 1	105. <u>+1.</u>	73. <u>+1.</u>	42. <u>+3.</u>	34. <u>+1.</u>	28. <u>+1.</u>	****	23. <u>+1.</u>	****	17. <u>+2.</u>	****
Col 2	46. <u>+2.</u>	15. <u>+3.</u>	10. <u>+1.</u>	9. <u>+1.</u>	7. <u>+0.</u>	****	8. <u>+1.</u>	****	7. <u>+0.</u>	****
Col 3	4. <u>+1.</u>	4. <u>+1.</u>	4. <u>+1.</u>	5. <u>+1.</u>	5. <u>+0.</u>	****	6. <u>+0.</u>	****	5. <u>+1.</u>	****
Col 4	17. <u>+1.</u>	13. <u>+1.</u>	13. <u>+1.</u>	12. <u>+0.</u>	12. <u>+1.</u>	****	12. <u>+0.</u>	****	12. <u>+1.</u>	****
Col 5	15. <u>+1.</u>	13. <u>+0.</u>	12. <u>+1.</u>	12. <u>+0.</u>	12. <u>+1.</u>	****	12. <u>+0.</u>	****	12. <u>+1.</u>	****
Col 6	13. <u>+0.</u>	12. <u>+1.</u>	12. <u>+1.</u>	12. <u>+0.</u>	12. <u>+1.</u>	****	12. <u>+0.</u>	****	12. <u>+1.</u>	****
Medium 2	11.	****	11.	****	11.	****	12.	****	12.	****

\*\*\*\* no data

Notes:

1. For each day of the experiment, the data from the analysis of three replicate coal column leachates are presented as the mean + standard deviation.

2. See also Appendix Table A-35b.

sodium from the matrix on day 10. As was discussed previously, the coal from mine 1 exhibited some cation exchange ability and a portion of the sodium leached could be attributed to this phenomenon. Sodium levels in the coal leachates from mine 1 during the last half of the experiment were comparable to field concentrations. Field levels and laboratory leachate concentrations were comparable for mine sites 2, 3, 4, and 6. Little or no leaching of sodium from the coal from mine 5 was observed, and levels were much less than those observed in the field. Since sodium is easily leached,

it is possible that minewater sodium concentrations at this site were largely due to background levels in the area's water supplies. However, it is also possible that the coal sample collected from mine 5 was not indicative of the average composited coal being mined at this site.

Minewater sulfate concentrations in the field were fairly consistent at each site and are presented in Appendix Table A-36a. As summarized in Table 5, the drinking water MCL is 500. mg/liter and was not exceeded at any of the sites. The irrigation water criterion

of 200. mg/liter was exceeded on occasion at several sites; however, it is indicated that sulfate concentrations up to 500. mg/liter are permissible. Sulfate is relatively less toxic than chloride when present in irrigation water, but can also cause precipitation of beneficial calcium (McKee and Wolf 1963). The criterion for stock watering (500. mg/liter) was also not exceeded.

Some sulfate was leached from the coal samples in the first three days of the column experiment (Table 42 and Figures 29 and 30). The leaching trends

are not as evident with the use of medium 2 which was consistently lower in pH than medium 1. Sulfate concentrations in most leachates were much less than the levels observed during field monitoring. Compiled USGS and UWRL spring and stream water quality data for the area indicated average sulfate concentrations to be less than 20. mg/liter (Table 1). The origin of sulfate in the minewater accrual samples then is unclear. The USGS and UWRL data were limited and it may be that water actually entering the mine was higher in sulfate than these data

Table 42. Leachate column data, sulfate; mg SO<sub>4</sub>/liter.

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10
Medium 1	16.	****	15.	****	16.	****	16.	****	16.	****
Col 1	39. <u>+1.</u>	19. <u>+0.</u>	17. <u>+0.</u>	17. <u>+0.</u>	17. <u>+1.</u>	17. <u>+1</u>	16. <u>+0.</u>	****	17. <u>+1.</u>	****
Col 2	171. <u>+17.</u>	44. <u>+9.</u>	22. <u>+1.</u>	18. <u>+0.</u>	18. <u>+1.</u>	18. <u>+1.</u>	18. <u>+1.</u>	****	17. <u>+1.</u>	****
Col 3	92. <u>+12.</u>	37. <u>+6.</u>	22. <u>+2.</u>	17. <u>+1.</u>	17. <u>+1.</u>	17. <u>+1.</u>	16. <u>+0.</u>	****	18. <u>+2.</u>	****
Col 4	62. <u>+4.</u>	16. <u>+1.</u>	10. <u>+1.</u>	10. <u>+1.</u>	10. <u>+2.</u>	10. <u>+1</u>	10. <u>+0.</u>	****	8. <u>+0.</u>	****
Col 5	50. <u>+10.</u>	16. <u>+1.</u>	11. <u>+1.</u>	11. <u>+0.</u>	9. <u>+1.</u>	10. <u>+0</u>	10. <u>+0.</u>	****	9. <u>+0.</u>	****
Col 6	78. <u>+8.</u>	16. <u>+2.</u>	10. <u>+1.</u>	10. <u>+1.</u>	10. <u>+1.</u>	10. <u>+1</u>	10. <u>+0.</u>	****	8. <u>+0.</u>	****
Medium 2	9.	****	8.	****	8.	****	9.	****	9.	****

\*\*\*\* no data

Notes:

1. For each day of the experiment, the data from the analysis of three replicate coal column leachates are presented as the mean + standard deviation.

2. See also Appendix Table A-36b.



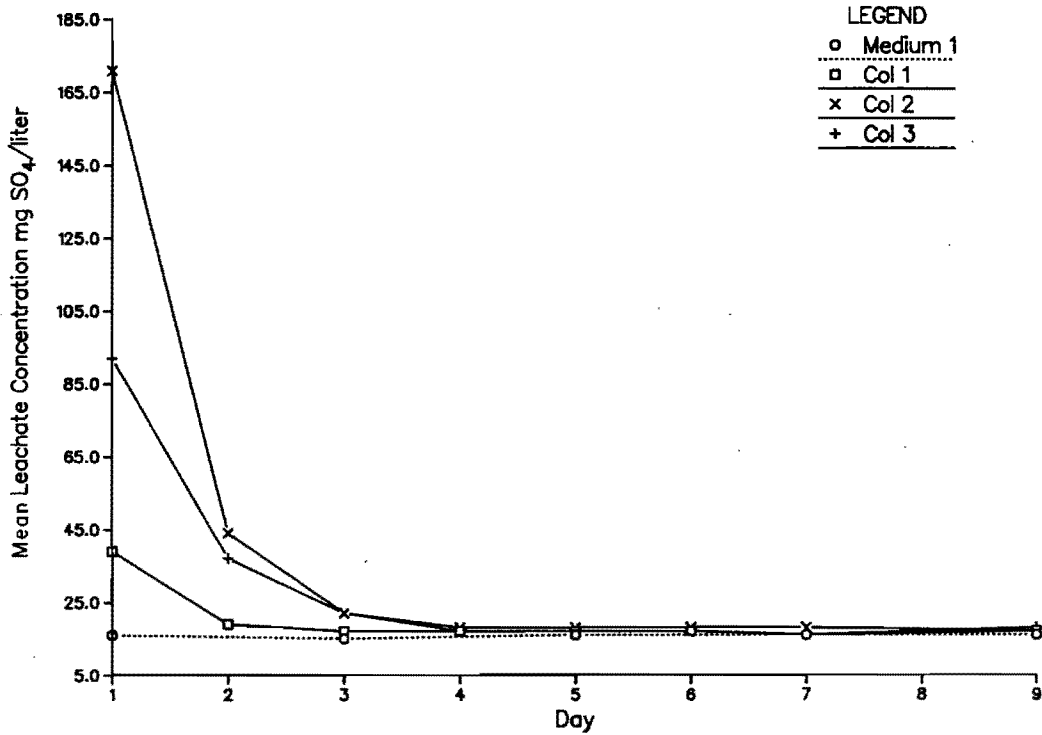


Figure 29. Graphic representation of sulfate in coal column leachates, coal from mines 1, 2, and 3.

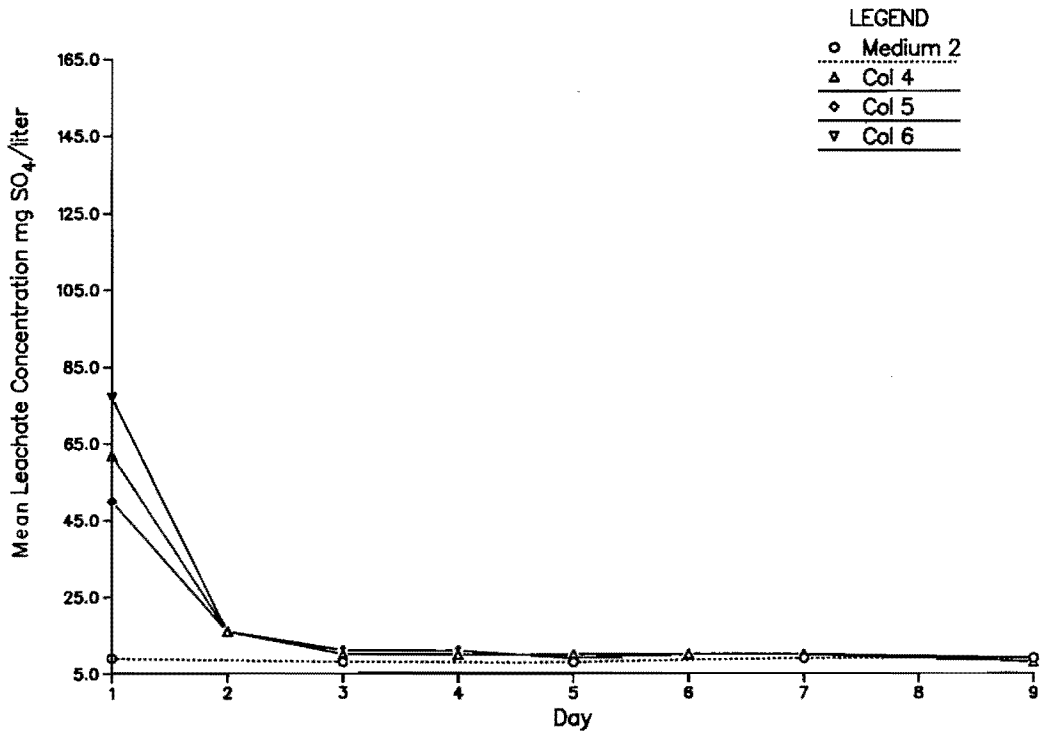


Figure 30. Graphic representation of sulfate in coal column leachates, coal from mines 4, 5, and 6.

imply. Although some sulfate did leach from the coal matrices in the laboratory, leaching conditions within the mine may be more favorable to the leaching process. It is also possible that sulfate may be originating from some other source or process within the mining operation.

### Nutrients

Ammonia-nitrogen ( $\text{NH}_3\text{-N}$ ) was usually less than 10.  $\mu\text{g/liter}$  during the field monitoring (Appendix Table A-37). The notable exception was at site 5 where  $\text{NH}_3\text{-N}$  averaged more than 100.  $\mu\text{g/liter}$ ; limited data collected after the mine stopped discharging showed levels less than 10.  $\mu\text{g/liter}$ . A drinking water MCL with respect to  $\text{NH}_3\text{-N}$  has not been established, but 40. to 80.  $\mu\text{g NH}_3\text{-N/liter}$  has generally been recommended (Table 5, and McKee and Wolf 1963). When ammonia-nitrogen is present in the unionized form ( $\text{NH}_3$  as opposed to  $\text{NH}_4^+$ ) it is very toxic to freshwater aquatic life. The criterion for freshwater aquatic ecosystems is 20.  $\mu\text{g NH}_3/\text{liter}$  or 16.  $\mu\text{g NH}_3\text{-N/liter}$  (Table 5, and EPA 1976). Unionized ammonia in aqueous solution is in equilibrium with ammonium ions ( $\text{NH}_4^+$ ) and hydroxide ions ( $\text{OH}^-$ ). Therefore, the levels of toxic, unionized

ammonia are dependent on ammonia-nitrogen concentrations, pH, and water temperature. Table 43 demonstrates how levels of unionized ammonia can be predicted based on pH and temperature variations. The temperatures of the mine waters were within the range of 5. to 15.  $^\circ\text{C}$ ; pH values ranged from 7.7 to 8.5 standard units during the sampling period. It can be seen that 0.39 to 8.0 percent of the ammonia-nitrogen detected in a sample could be present as toxic, unionized ammonia. Using Table 43 and the relatively high ammonia-nitrogen levels observed at site 5, unionized ammonia concentrations were calculated to always be less than 10.  $\mu\text{g/liter}$  and, thus, nontoxic to freshwater aquatic life.

The drinking water limit for nitrate-nitrogen ( $\text{NO}_3\text{-N}$ ) is 10.  $\text{mg/liter}$  and criteria have not been established for the other uses summarized in Table 5.  $\text{NO}_3\text{-N}$  levels exceeded 10.  $\text{mg/liter}$  on a few occasions, but not at the drinking water source at mine 3 (Appendix Table A-38).

Other nutrients remained at relatively low levels during field sampling and the results are summarized in the Appendix.

Table 43. Percent unionized ammonia ( $\text{NH}_3$ ) in aqueous ammonia nitrogen solutions (adapted from EPA 1976).

Temperature ( $^\circ\text{C}$ )	pH, Standard Units								
	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0
5	0.013	0.040	0.12	0.39	1.2	3.8	11.	28.	56.
10	0.019	0.059	0.19	0.59	1.8	5.6	16.	37.	65.
15	0.027	0.087	0.27	0.86	2.7	8.0	21.	46.	73.
20	0.040	0.13	0.40	1.2	3.8	11.	28.	56.	80.
25	0.057	0.18	0.57	1.8	5.4	15.	36.	64.	85.
30	0.080	0.25	0.80	2.5	7.5	20.	45.	72.	89.

## Organics

The field data for total organic carbon (TOC) are presented in Appendix Table A-42a. No distinct trends in the accrued minewaters were observed. Most of the samples contained widely varying quantities of coal particles. It is likely that a significant and indeterminate portion of the coal particles were oxidized during the persulfate digestion process. Therefore, analysis of the total, unfiltered samples produced data that were difficult to interpret. TOC data for the coal column leachates are presented in Appendix Table A-42b. Although it was evident that organic carbon leached from the coal matrix at some points during the experiment, the trends are indistinct here also due to presence of coal particles. Attempts were made to filter some of the samples before analysis, but this technique did not appear to significantly improve the results, indicating the presence of coal particles smaller than 0.45 microns or the presence of varying quantities of dissolved organic carbon. Organic carbon was observed to leach from the coal samples evaluated for the purpose of coal slurry pipelining (Israelsen et al. 1980). The quantities of organic carbon leached were characteristic of the coal sample studied and did not vary appreciably with increasing salinity of the transport medium.

Oil and grease levels in the mine accrual waters are discussed in the section on NPDES requirements.

Field minewater samples were analyzed for instantaneous (inst.) and maximum total potential (MTP) trihalomethanes (THM) (Appendix Tables A-44 - A-48). Trihalomethanes are a class of toxic and carcinogenic, low molecular weight organic compounds which include chloroform, dichlorobromomethane, dibromochloromethane and bromoform. THMs were discovered in some drinking water supplies in 1974, which resulted in the promulgation of regula-

tions and an MCL of 100. µg/liter total THM by the EPA in 1979 (Federal Register 1979). THMs are usually introduced in the course of water treatment as the by-products of the chlorination disinfection process (Cotruvo 1981). Inst. THM represents the THM concentration at the time of sample collection. MTP THM is the THM concentration after addition of chlorine to an unchlorinated water source followed by 7 days of incubation. The sample treatment for MTP THM is designed to give an indication of the quantities of trihalomethane precursors present in the water sample. Instantaneous THM concentrations for all THM compounds were always less than the 1. µg/liter limit of detection, indicating little potential for toxicity to the aquatic systems into which the mine waters discharge. Addition of chlorine produced widely varying MTP THM levels with the more chlorinated species predominating. MTP THM levels were frequently in excess of 100. µg/liter total THM. However, limited data from the drinking water source collected at mine 3 show a lesser potential for the formation of trihalomethanes; levels did not exceed 50. µg/liter here. Since the coal structure is largely organic in nature, dissolved organic compounds and suspended coal particles in the mine-water samples were the likely sources of THM precursors.

## Algal Assay

Chemical analyses are useful for the identification of specific constituents, but these analyses cannot distinguish between substances that are available for algal growth and those that are not. The presence of certain metals in various forms can be toxic to biological systems. By itself, chemical analysis for toxicants cannot completely evaluate the situation with regard to biological availability and the responses of living organisms to the toxicants.

Algae inhabit all natural waters and serve many functions. Most impor-

tantly, they fix carbon from atmospheric carbon dioxide through photosynthesis and provide a major carbon and energy source to the aquatic ecosystem. In addition, oxygen is supplied to the rest of the aquatic ecosystem as a result of their photosynthetic activity. Heavy nutrient loading and abundant light can lead to algal blooms causing disagreeable tastes and odors in drinking water supplies and toxic effects from algal metabolic by-products.

The Printz algal assay bottle test is designed to measure the algal growth potential of a water source by identifying the limiting nutrient(s) and inferring the presence of toxicants which limit growth when nutrients are in adequate supply. The test alga adopted for use by the U.S. EPA is Selenastrum capricornutum. It is a green alga with wide tolerances toward a variety of environmental conditions. Indigenous algae and other organisms are removed from the water sample prior to the assay to insure reliable interpretation of test results with use of a single, widely-accepted test organism grown under standard laboratory conditions. Indigenous algae can be isolated and identified, but their use is not recommended when evaluating the algal growth potential of a system. In a natural system, dominant species can change throughout the growth season and laboratory culturing of an indigenous species has not been shown to be more indicative of natural conditions than culturing of a laboratory test organism (Miller et al. 1978).

Algal assay experimental design with respective nutrient and chelator additions is summarized in Table 4. The algal growth potential of the control (sample only) was monitored along with flasks containing singular and combined additions of nitrogen and phosphorus nutrients at levels of 2.1 mg N/liter and 0.093 mg P/liter. The above treatments were also duplicated on selected sample dates with the addition of 1.00 mg/liter [disodium (ethylenedinitrilo)

tetraacetate] or EDTA. EDTA is a metal chelator and can aid in the evaluation of metal toxicity phenomena. The 1.00 mg/liter EDTA spike was chosen to ensure the availability of trace micronutrients and to complex any heavy metals present without causing complexation of macronutrients such as calcium and magnesium.

Background chemical data were collected for pH, ammonia-nitrogen, nitrate-nitrogen, nitrite-nitrogen, orthophosphate, and total phosphorus and are presented in Appendix Tables A-1a and A-37 through A-41, respectively. Total soluble inorganic nitrogen to orthophosphate (N:P) ratios can be calculated and used as a preliminary guideline to predict limiting nutrients in most natural waters. When N:P ratios are greater than 11:1, phosphorus may be considered limiting. When N:P ratios are less than 11:1, it is likely that nitrogen is the limiting nutrient. N:P ratios for the mine accrual waters are presented in Table 44. There were only three instances when N:P ratios were less than 11; site 1A February 1982, site 2B May 1981 and site 2B July 1981.

Monitoring of the algal assays conducted from May 1981 to April 1982 resulted in approximately 200 experimentally derived data sets of growth measurements (maximum optical density at 750 nm) and dry weights after achievement of maximum standing crop. Linear regression analysis of these data resulted in the following equation for use in converting all maximum optical density measurements to equivalent biomass:

Dry weight (mg/liter) =

$$7.26 + 232.(\text{optical density}) \quad . \quad . \quad (1)$$

This equation was used to calculate all of the values for average maximum standing crop as mg/liter equivalent dry weight of S. capricornutum which are listed in Table 45.

Table 44. Nitrogen-phosphorus ratios.

Mine Site	Sample Date	TSIN <sup>a</sup> μg/l	PO <sub>4</sub> -P <sup>b</sup> μg/l	N:P <sup>c</sup>
1A	May '81	50.	3.	17.
	Jun	90.	<2.	>45.
	Jul	60.	3.	20.
	Aug	****	2.	****
	Sep	80.	3.	30.
	Oct	610.	<2.	>305.
	Nov	60.	<2.	>30.
	Feb '82	40.	4.	10.
	Mar	80.	<2.	>40.
	Apr	70.	2.	35.
1B	May '81	50.	<2.	>25.
	Jun	100.	<2.	>50.
	Jul	1160.	<2.	>580.
	Aug	****	3.	****
	Sep	930.	3.	310.
	Nov	60.	4.	15.
	Dec	90.	<2.	>45.
	Feb '82	40.	3.	13.
	Mar	240.	<2.	>120.
	Apr	60.	3.	20.
2A	May '81	60.	3.	20.
	Jun	90.	<2.	>45.
	Jul	110.	<2.	>55.
	Aug	****	3.	****
	Sep	980.	4.	245.
	Oct	540.	<2.	>270.
	Nov	110.	4.	28.
	Dec	340.	<2.	170.
	Feb '82	530.	4.	133.
	Mar	1210.	9.	134.
Apr	1250.	2.	625.	
2B	May '81	60.	7.	9.
	Jun	80.	<2.	>40.
	Jul	80.	7.	11.
	Aug	****	2.	****
	Sep	680.	3.	227.
	Oct	90.	<2.	>45.
	Nov	130.	5.	26.
	Feb '82	510.	6.	85.
	Mar	1100.	<2.	>550.
	Apr	1270.	3.	423.

Table 44. Continued.

Mine Site	Sample Date	TSIN <sup>a</sup> μg/l	PO <sub>4</sub> -P <sup>b</sup> μg/l	N:P <sup>c</sup>
3	Sep '81	620.	8.	78.
	Dec	80.	<2.	>40.
	Mar '82	50.	<2.	>25.
4	Sep '81	300.	4.	75.
	Apr '82	720.	8.	90.
5A	May '81	550.	<2.	>275.
	Jun	580.	<2.	>290.
	Jul	510.	3.	170.
	Aug	****	4.	****
	Sep	1040.	3.	347.
	Oct	1080.	<2.	>540.
	Feb '82	630.	3.	210.
5B	May '81	540.	<2.	>270.
	Jun	600.	<2.	>300.
	Jul	480.	24.	20.
	Aug	****	<2.	****
	Sep	450.	3.	150.
	Oct	820.	<2.	>410.
	Feb '82	460.	4.	115.
6A	May '81	780.	<2.	>390.
	Jun	270.	<2.	>135.
	Jul	3680.	27.	136.
	Aug	****	27.	****
	Sep	1130.	6.	188.
	Nov	980.	<2.	>490.
	Dec	850.	6.	142.
6B	May '81	210.	8.	26.
	Jun	150.	<2.	>75.
	Jul	180.	12.	15.
	Sep	450.	16.	28.
	Nov	290.	9.	32.
	Dec	510.	10.	51.

\*\*\*\* missing data

<sup>a</sup>Total Soluble Inorganic Nitrogen; the sum of NH<sub>3</sub>-N + NO<sub>3</sub>-N + NO<sub>2</sub>-N.

<sup>b</sup>Orthophosphate.

<sup>c</sup>Nitrogen-phosphorus ratio; TSIN ÷ PO<sub>4</sub>-P.

Table 45. Algal assay; average maximum standing crop as mg/liter equivalent dry weight of Selenastrum capricornutum.

Site/Date	Treatment								Statistical Evaluation <sup>1</sup>
	Control	Control	Control	Control	Control	Control	Control	Control	
	A	+N B	+P C	+N+P D	+EDTA A+	+N+EDTA B+	+P+EDTA C+	+N+P+EDTA D+	
Mine Site 1A									
May '81	9.2	8.6	13.4	31.6	8.0	8.1	11.8	30.4	c.
Jun	8.8	7.9	9.7	32.8	8.0	7.8	9.2	66.0	c.
Jul	7.7	7.7	9.9	33.9	7.7	8.1	10.4	41.3	c.
Aug	11.4	9.7	11.6	40.0	9.7	10.0	10.2	36.9	c.
Sep	8.8	8.7	11.6	23.7	8.7	8.7	12.0	45.6	c.
Oct	8.7	8.7	10.0	27.2	9.2	8.6	10.0	45.2	c.
Nov	7.3	7.3	10.1						p.
Feb '82	7.9	8.0	21.4	25.3					p.
Mar	7.7	7.7	13.3	15.0					p.
Apr	8.7	9.0	33.3	33.9					p.
Mine Site 1B									
May '81	7.6	7.6	13.4	25.8	7.5	12.1	10.7	29.5	c.
Jun	8.0	8.0	10.0	36.2	8.4	8.1	11.4	20.4	c.
Jul	7.6	7.6	7.7	7.5	7.5	7.7	7.7	7.7	c.
Aug	9.6	10.0	11.4	34.0	9.6	9.8	10.0	32.4	c.
Sep	8.0	9.0	10.3	14.8	9.0	9.0	10.6	29.5	c.
Nov	7.3	7.3	9.3	11.8					p.
Dec	8.0	8.0	10.0	59.4					p.
Feb '82	7.7	8.2	9.0	21.2					p.
Mar	7.7	7.7	16.0	22.8					p.
Apr	8.9	9.0	10.4	40.5					c.

<sup>1</sup>Legend for statistical evaluation (Duncan's Multiple Range):

- c. indicates that maximum standing crops for treatments A, B, and C were not found to be statistically different from each other, thus inferring possible colimitation with regard to nitrogen and phosphorus.
- p. indicates that maximum standing crops for treatments A and B were found to be statistically different from maximum standing crops for treatment C, thus inferring phosphorus limitation.

Table 45. Continued.

Site/Date	Treatment								Statistical Evaluation <sup>1</sup>
	Control A	Control +N B	Control +P C	Control +N+P D	Control +EDTA A+	Control +N+EDTA B+	Control +P+EDTA C+	Control +N+P+EDTA D+	
Mine Site 2A									
May '81	7.6	7.8	9.8	23.5	7.7	10.7	10.5	30.2	c.
Jun	7.7	8.0	10.1	22.0	8.0	8.0	9.7	29.3	c.
Jul	8.0	8.0	10.7	40.9	7.8	9.7	11.7	46.7	c.
Aug	10.2	10.0	12.3	53.3	9.7	10.1	11.4	39.4	c.
Sep	8.2	8.7	12.2	51.9	9.0	8.6	12.6	52.0	c.
Oct	9.0	9.2	10.5	59.2	9.3	8.4	10.3	61.2	c.
Nov	7.3	7.4	12.1	12.8					p.
Dec	8.0	8.1	21.6	64.9					p.
Feb '82	7.7	7.7	20.3	28.3					p.
Mar	8.2	8.5	17.8	17.5					p.
Apr	8.4	8.2	19.9	33.0					p.
Mine Site 2B									
May '81	9.2	8.6	13.4	31.6	8.0	8.1	11.8	30.4	c.
Jun	8.8	7.8	9.7	32.8	8.0	7.8	9.2	46.0	c.
Jul	7.7	7.7	9.9	33.9	7.7	8.1	10.4	41.3	c.
Aug	11.4	9.7	11.6	40.0	9.7	10.0	10.2	36.9	c.
Sep	8.8	8.7	11.6	23.7	8.7	8.7	12.0	45.6	c.
Oct	8.7	8.7	10.0	27.8	9.2	8.6	10.0	45.2	c.
Nov	7.3	7.3	10.1	26.0					p.
Feb '82	8.0	8.0	21.4	25.4					p.
Mar	7.7	7.7	13.4	15.0					p.
Apr	8.7	9.0	33.3	33.9					p.

<sup>1</sup>Legend for statistical evaluation (Duncan's Multiple Range):

- c. indicates that maximum standing crops for treatments A, B, and C were not found to be statistically different from each other, thus inferring possible colimitation with regard to nitrogen and phosphorus.
- p. indicates that maximum standing crops for treatments A and B were found to be statistically different from maximum standing crops for treatment C, thus inferring phosphorus limitation.



Table 45. Continued.

Site/Date	Treatment								Statistical Evaluation <sup>1</sup>
	Control A	Control +N B	Control +P C	Control +N+P D	Control +EDTA A+	Control +N+EDTA B+	Control +P+EDTA C+	Control +N+P+EDTA D+	
Mine Site 3									
Sep '81	7.9	7.5	7.8	12.8	7.6	7.6	8.4	14.5	c.
Dec	7.7	7.7	8.0	14.3					c.
Mar '82	8.0	7.6	9.5	48.3					c.
Mine Site 4									
Sep '81	7.9	7.8	13.1	30.2	7.6	7.4	14.2	28.0	c.
Apr '82	9.1	8.8	30.9	62.0					c.
Mine Site 5A									
May '81	7.6	7.9	21.3	22.3	7.7	8.0	25.0	31.9	p.
Jun	7.8	8.0	17.8	21.0	7.9	8.5	17.7	20.6	p.
Jul	8.3	7.7	23.5	28.0	7.6	8.0	24.1	34.9	p.
Aug	9.7	9.6	15.5	50.2	9.6	10.9	13.6	49.4	p.
Sep	9.0	8.5	19.5	20.3	8.2	8.4	20.2	38.8	p.
Oct	9.2	8.8	21.5	40.3	8.9	9.6	21.3	42.0	p.
Feb '82	7.8	7.7	28.1	29.9					p.
Mine Site 5B									
May '81	8.0	7.7	23.2	30.5	9.0	8.0	25.5	36.0	p.
Jun	7.9	9.5	14.5	20.0	7.8	9.1	17.4	20.9	p.
Jul	8.3	7.8	24.7	44.9	7.9	7.7	26.6	25.6	p.
Aug	9.6	9.6	14.5	35.5	9.7	10.7	13.2	30.2	p.
Sep	8.1	8.0	22.1	37.5	8.4	8.4	20.9	48.7	p.
Oct	8.5	9.3	27.4	44.1	9.1	8.9	28.9	48.4	p.
Feb '82	7.5	7.3	20.6	16.0					p.

<sup>1</sup>Legend for statistical evaluation (Duncan's Multiple Range):

- c. indicates that maximum standing crops for treatments A, B, and C were not found to be statistically different from each other, thus inferring possible colimitation with regard to nitrogen and phosphorus.
- p. indicates that maximum standing crops for treatments A and B were found to be statistically different from maximum standing crops for treatment C, thus inferring phosphorus limitation.

Table 45. Continued.

Site/Date	Treatment								Statistical Evaluation <sup>1</sup>
	Control A	Control +N B	Control +P C	Control +N+P D	Control +EDTA A+	Control +N+EDTA B+	Control +P+EDTA C+	Control +N+P+EDTA D+	
Mine Site 6A									
May '81	8.0	8.0	27.7	31.7	9.0	8.4	32.1	35.6	p.
Jun	9.4	8.0	13.6	34.2	10.4	9.0	14.1	51.2	c.
Jul	17.6	18.0	17.9	29.9	14.5	19.0	18.0	37.0	c.
Aug	9.4	9.3	17.8	44.8	10.0	10.7	20.7	36.6	p.
Sep	8.9	8.9	27.2	33.9	8.7	8.6	27.8	39.4	p.
Nov	7.5	7.4	12.3	15.0					p.
Dec	8.0	8.0	23.8	25.9					p.
Mine Site 6B									
May '81	9.0	9.5	17.8	38.8	11.3	16.3	16.0	49.0	p.
Jun	8.3	9.3	10.0	31.9	8.7	9.3	9.8	43.8	c.
Jul	11.2	10.5	13.4	28.2	10.0	13.8	13.3	31.3	c.
Sep	9.0	8.7	10.6	22.0	8.6	8.5	10.5	41.2	p.
Nov	7.5	7.3	15.9	16.9					p.
Dec	8.3	8.2	25.0	67.7					p.

<sup>1</sup>Legend for statistical evaluation (Duncan's Multiple Range):

- c. indicates that maximum standing crops for treatments A, B, and C were not found to be statistically different from each other, thus inferring possible colimitation with regard to nitrogen and phosphorus.
- p. indicates that maximum standing crops for treatments A and B were found to be statistically different from maximum standing crops for treatment C, thus inferring phosphorus limitation.

The variations of maximum standing crop with treatment were then evaluated statistically using the Duncan's multiple range method (Duncan 1955). These statistical results are also summarized in Table 45 and explained in the following discussion. Complete results from the statistical evaluations using Duncan's multiple range method are available at the Utah Water Research Laboratory Library (Hoefs and Seierstad 1982).

N:P ratios from chemical data (Table 44) predict phosphorus nutrient limitation in the vast majority of the water samples assayed. With regard to algal assays, phosphorus is limiting when growth response in the control (treatment A) and in the nitrogen and EDTA treatments taken singly and in combination (treatments B, A<sup>+</sup> and B<sup>+</sup>) are statistically identical, but different from the maximum standing crops in the phosphorus treatments (C and C<sup>+</sup>). Most of the accrual waters assayed were found to have phosphorus as the limiting nutrient; especially those samples collected from late fall 1981 to spring 1982 and those originating from the northern end of the Wasatch Plateau.

Nitrogen can be termed the primary growth limiting nutrient if the maximum standing crops of the control (treatment A) and of the phosphorus and EDTA treatments evaluated singly and in combination (treatments C, A<sup>+</sup> and C<sup>+</sup>) are statistically identical, but different from the growth responses in the nitrogen treatments (B and B<sup>+</sup>). Statistical evaluation did not indicate nitrogen nutrient limitation in any of the water sources (Table 45).

Nitrogen and phosphorus colimitation can be inferred when the maximum standing crops of the control (A and A<sup>+</sup>), nitrogen (B and B<sup>+</sup>) and phosphorus (C and C<sup>+</sup>) treatments are not found to be statistically different from each other and when a significant growth response can be observed only in the

combined nitrogen and phosphorus treatments (D and D<sup>+</sup>). Using these criteria, statistical evaluation indicates the possibility of colimitation in a number of water samples, as can be seen in Table 45. However, guidelines established by the EPA (Miller et al. 1978) state that the phenomenon of colimitation is most commonly observed in highly productive, eutrophic waters with N:P ratios between 10. and 12. Chemical analyses of the accrual water samples in question did not produce the high nutrient concentration levels which are commonly associated with eutrophication. Analysis of two accrual water samples did produce N:P ratios between 10. and 12. (site 1A February 1982 and site 2B July 1981). The water sample from site 1A in February 1982 produced growth responses and statistical evaluation indicative of phosphorus limitation; the sample from 2B in July 1981 produced standing crops and statistical comparisons consistent with nitrogen and phosphorus colimitation. However, it is unlikely that colimitation processes did actually occur in any of these water systems; phosphorus limitation is a more creditable explanation.

The presence of fine coal particles in many of the field samples may have contributed significantly to ambiguous algal assay interpretations such as colimitation. As was discussed previously, filtration (0.45 micron) did not remedy problems with interpretation of total organic carbon results, indicating the possible presence of coal particles in the sample after filtration. Replicate analyses for TOC and algal assay produced results that were less precise than those that could be expected from samples of a different nature. It is possible that very fine coal particles could also act as a nutrient source for *S. capricornutum* and possibly as a substrate for algal growth.

Inhibited growth responses in the control treatments are often indicative of heavy metal toxicity. Addition of appropriate quantities of EDTA to the

sample will chelate the heavy metals and produce growth which correlates with the predicted theoretical yield (Miller et al. 1976). Metal toxicity is indicated when control plus EDTA treatments (A<sup>+</sup>) produce statistically much more biomass than the control (A). As can be seen in Table 45, evidence of metal toxicity was not detected for any of the coal mine water accrual samples. These conclusions are also supported by the wide variety of trace

metal analyses that were performed throughout all phases of this study. Most trace metals were found to remain at consistently low concentration levels which would not be expected to produce toxic effects in aquatic ecosystems.

Since A and A<sup>+</sup> treatments were found to be statistically similar, it can also be concluded that stimulatory effects due to trace metals did not occur.

## SUMMARY AND RECOMMENDATIONS

1. The values for most parameters monitored during the field and laboratory portions of the study fell below the toxicity criteria for drinking water, irrigation water, freshwater aquatic life, and stock and wildlife watering and were in compliance with NPDES regulations.

2. Coal leaching trends in the laboratory column experiments paralleled many of the trends observed in the field data collected. It appears that leaching columns with an upflow design and slow flow rates of the leaching medium can produce similar trends when compared to environmental situations such as coal mine accrual water discharges. Trends for the following parameters were generally consistent when comparisons were made between field and leachate column data: pH, aluminum, arsenic, beryllium, cadmium, chromium, cobalt, copper, dissolved iron, lead, molybdenum, nickel, silver, zinc, boron, lithium, strontium, alkalinity, chloride, fluoride, potassium, sodium, and silica.

3. The field monitoring for boron showed the highest values consistently occurring in the southern part of the Wasatch Plateau at mine 1 (450. + 130.  $\mu\text{g/liter}$  at 1A and 490. + 150.  $\mu\text{g/liter}$  at 1B). These discharges would be predicted to cause only minor damage to the most sensitive crops. Yearly averages at all other sites fell between 100 and 200  $\mu\text{g/liter}$ . It is unlikely that boron concentrations in any discharges from the Wasatch Plateau would be dangerously high for any length of time. Leaching of the coal from mine 1 also produced the highest boron concentrations and levels were comparable to those observed in the field

discharges. Leaching of the 50-year old coal sample from mine 3 showed high levels of boron, indicating that less weathering or flushing of boron had actually occurred than anticipated. Boron was leached easily from the coal surfaces; the highest concentrations were always observed on day 1. However, leaching was often not complete by day 10. Whole coal samples were estimated to contain at least 0.2 mg/kg (coal from mine 6) to 6.9 mg/kg (coal from mine 1).

4. The drinking water MCL (2.0  $\mu\text{g/liter}$ ) and the freshwater aquatic life bioaccumulation criterion (0.05  $\mu\text{g/liter}$ ) for mercury were exceeded on several occasions during the field sampling of coal mine accrual waters. More frequent analysis for total mercury at the drinking water source (site 3) might be warranted. A comprehensive study of fish tissue samples and water samples taken from bodies of water near coal mines is recommended. It is not known whether dilution of discharge water might be high enough to prevent excessive bioaccumulation, whether species of fish which have a propensity for efficient bioaccumulation are present, or whether fish being taken from these water sources could present a hazard for human consumption.

5. Mercury was observed to leach from coal samples in the laboratory to yield concentrations lower than those observed in the field. Mercury in the discharges is probably not resulting from the coal itself, but from some other source or process within the mining operations.

6. The mine accrual water discharges were not found to be acidic in

nature and were always within the NPDES and freshwater aquatic life limits for pH of 6.5 to 9.0. Limited data for acidity also indicate that alkalinity values were greater than acidity values.

7. NPDES limits for total dissolved solids were not commonly violated but were slightly in excess of the limits on three occasions. Limited data at mine 4 showed violations of TDS limits in three of the four samples collected. However, this mine was not discharging.

8. Total suspended solids (TSS) was among the most frequently violated parameters with regard to NPDES regulations; violations were reported on 11 occasions. Further studies on the effects of TSS on stream biota would be useful. It is not known what flow characteristics and downstream distances are necessary to significantly reduce suspended matter that is discharged from coal mines. It is not known whether further leaching of the coal particles would occur after they settle to the bottom of the streambed. Little is known about interactions between finely-divided coal particles and benthic invertebrates and subsequent effects on aquatic ecosystems.

9. Violations of NPDES total iron limits were not observed frequently at the mine sites studied. This would be expected given the low sulfur nature of coal on the Wasatch Plateau and the low incidence of pyritic mineral deposits. Violations in excess of 2.0 mg/liter were observed on three occasions; at no time did monitored discharges to the environment exceed 7.0 mg/liter.

10. Violations of NPDES oil and grease limits were fairly common throughout the duration of the study; the 10 mg/liter limit was exceeded on 12 occasions at the points of discharge to the environment. Further study is recommended here to determine sources, fates, and effects to aquatic ecosystems. Characterization of the organic

compounds present in the oil and grease deposits would be necessary along with toxicity assays to document effects to organisms.

11. Sampling at designated A and B sites did not readily indicate any significant and consistent decreases in oil and grease or other parameters after the mines' treatment processes. Further study would be useful to determine holding and turnover times in the settling ponds accompanied by sequential sampling to more accurately evaluate the mines' treatment systems.

12. Strontium was observed to leach from the coal samples from mines 2, 4, and 5. Coal from mine 5 leached the greatest quantities of strontium and accrual water discharges from mine 5 had the highest levels of strontium also. Estimated strontium concentrations in the coal samples ranged from undetectable quantities to more than 3.8 mg/kg in the coal from mine 5. Strontium is leached less readily from the coal matrices than boron; peak concentrations were typically observed on days 3 to 5. Leaching was often not completed by day 10. Where leaching of strontium was evident (coal from mines 2, 4, and 5), it can be postulated that significant portions of strontium in the accrual waters are originating from contact with the coal. Leaching of strontium with respect to coal samples from mines 1, 3, and 6 was much less evident. Strontium levels at these field sites could be indicative of background strontium in the area's water supplies, or coal strontium levels could vary dramatically with grab samples collected.

13. The concentration levels of boron, lithium, strontium, potassium, silica, and sodium were observed to be specific to certain mine sites and were often consistent with observed leaching phenomena in the laboratory.

14. Values for water hardness parameters were observed to be specific

to the mine site involved and not always comparable to laboratory leachate column data. Compiled USGS data showed much variation in water hardness across the Wasatch Plateau. It appears that water hardness levels and chemical composition with respect to calcium and magnesium can change as water and coal interact. But the levels of water hardness parameters in accrued mine waters appear to be functions of both the chemical constituency of ground and surface waters in the area and the nature of interactions with the coal matrices.

15. Silica concentrations in the coal mine accrual waters increased

in a north to south direction along the Wasatch Plateau coal field.

16. Generalizations with respect to leaching trends and origins of chemical substances in coal mine accrual waters must be made with caution. This is due to the great potential variability in coal samples, and the extreme complexity of leaching phenomena, and coal-water interactions.

17. Table 46 summarizes the potential for problems and violations of water quality criteria at each of the six sites.

Table 46. Summary of potential for problems or violations of water quality criteria.

	Mine 1		Mine 2		Mine 3		Mine 4		Mine 5		Mine 6	
	Field	Lab	Field	Lab	Field	Lab	Field	Lab	Field	Lab	Field	Lab
NPDES Discharge Requirements:												
Flow		****		****		****	none	****	discharge ceased Jan 82	****		
pH												
Solids -												
Total dissolved	1 violation				2 violations		(3 violations)					
Total suspended	4 violations	****		****	1 violation	****		****	4 violations	****	2 violations	****
Iron, total	1 violation	****		****		****		****		****	2 violations	****
Oil and Grease	2 violations	****	3 violations	****	1 violation	****	(1 violation)	****	3 violations	****	3 violations	****
Trends and Observations:												
Physical Properties												
Trace Metals	boron-IW mercury-FAL	boron-IW	mercury-FAL		mercury-FAL mercury-DW	boron-IW	(mercury-FAL)		mercury-FAL			
Major Anions and Cations												
Nutrients		****		****		****		****		****		****
Organics												

Notes:

1. Violations or potential problems are indicated when they occur; no entry in the table implies no NPDES violations or no concentration levels consistently high enough to warrant concern at this mine site. The number of violations with regard to NPDES regulations are noted and were determined from data reported to NPDES, and from field and laboratory data generated during this project. Violations at mine 4 are in parentheses since this mine was not discharging. Other potential problems are listed with regard to intended use.

2. Field data columns summarize potential problems observed during field sampling of coal mine accrual water and from NPDES reports filed. Lab data columns summarize potential problems observed during leaching of coal samples in upflow columns. Other field and lab trends which would not be expected to cause problems are discussed in the text.

3. \*\*\*\* no data.

4. Abbreviations of intended uses--DW = drinking water, IW = irrigation water, FAL = freshwater aquatic life.



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## APPENDIX

### COAL MINE ACCRUAL WATER AND UPFLOW COAL COLUMN LEACHATE DATA

Field data for coal mine accrual water samples and upflow coal column leachates are summarized here in their entirety for mine sites numbered 1 through 6.

#### Notes:

1. \*\*\*\* - no data; due to quarterly monitoring of the field parameter, periodic analysis of coal column leachates and batches of media, broken sample bottles, or shortage of sample.
2. Numerical values for all parameters are derived from analysis for dissolved constituents unless designated as total.
3. Field data are listed by mine site number (1 through 6 followed by A or B site designations where appropriate) and sampling dates encompassing May 1981 to April 1982. "A" sampling sites were located prior to the mine's treatment. "B" sampling sites were located after the mine's treatment.
4. Data from upflow coal leachate columns are listed by the same mine site number (1 through 6) with additional designations indicating column replicates; Col 4-2 indicates column leachate data for coal from mine 4 from the second leaching column of three replicates. Data were collected for 10 days. Medium 1 was used to leach coal samples from mines 1, 2, and 3; medium 2 was used to leach coal samples from mines 4, 5, and 6.
5. Coal mine accrual water field data and leachate column data for any given parameter are presented on the same page.
6. Appendix data are presented in the same order as the parameters listed in Table 3 (Analytical Methods) in the text and appear alphabetically within the following categories: Physical Properties, Trace Metals, Major Anions and Cations, Nutrients, Organics.

PHYSICAL PROPERTIES:

Table A-1a. Field data, pH; pH units.

	1A	1B	2A	2B	3	4	5A	5B	6A	6B
May '81	8.2	8.2	8.1	8.1	****	****	8.0	8.1	7.8	8.1
Jun	8.3	8.4	8.4	8.3	7.7	8.2	8.2	8.3	8.2	8.3
Jul	8.3	8.2	8.4	8.4	****	****	8.0	8.4	8.4	8.4
Aug	8.1	8.1	8.3	8.2	****	****	8.0	8.1	8.0	****
Sep	8.3	8.2	8.2	8.3	8.0	8.2	8.3	8.3	8.2	8.3
Oct	8.2	****	8.3	8.3	****	****	8.1	8.1	****	****
Nov	8.2	8.2	8.2	8.3	****	****	****	8.2	8.1	8.2
Dec	8.2	8.2	8.1	****	8.0	****	****	****	8.1	8.1
Jan '82	8.3	8.4	8.3	8.4	****	8.3	8.2	****	****	****
Feb	8.3	8.3	8.3	8.4	****	****	8.1	****	****	****
Mar	7.7	8.2	8.2	8.3	8.5	****	****	****	****	****
Apr	8.1	8.2	8.3	8.2	****	8.2	****	****	****	****

Table A-1b. Leachate column data, pH; pH units.

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10
Medium 1	8.0	****	7.2	****	7.5	****	7.9	****	7.3	****
Col 1-1	8.6	8.2	8.7	8.6	8.5	8.5	8.5	8.4	8.0	8.2
Col 1-2	8.6	8.0	8.7	8.5	8.5	8.5	8.5	8.4	8.0	8.2
Col 1-3	8.6	8.0	8.7	7.4	8.5	8.5	8.5	8.3	8.0	8.2
Col 2-1	8.3	8.0	8.2	8.1	8.0	8.0	8.2	8.2	8.4	8.2
Col 2-2	8.3	7.4	8.4	8.0	8.1	8.2	8.2	8.2	8.3	8.2
Col 2-3	8.3	7.2	8.3	7.9	8.2	8.2	8.3	8.3	8.3	8.2
Col 3-1	8.2	7.7	8.4	8.3	8.4	8.4	8.5	8.3	8.3	8.3
Col 3-2	8.2	7.7	8.4	8.4	8.4	8.4	8.4	8.2	8.4	8.3
Col 3-3	8.3	7.0	8.5	8.4	8.4	8.4	8.4	8.3	8.3	8.4
Col 4-1	8.3	8.2	8.1	7.9	8.2	8.1	8.4	8.3	8.1	8.3
Col 4-2	8.4	8.3	8.2	8.2	8.4	8.1	8.3	8.2	8.0	8.3
Col 4-3	8.3	8.3	8.2	8.2	8.4	8.1	8.3	8.1	8.0	8.2
Col 5-1	8.1	8.3	8.0	8.2	8.1	8.0	8.3	8.1	8.0	8.3
Col 5-2	8.2	8.2	8.2	8.3	8.1	8.1	8.4	8.2	8.0	8.2
Col 5-3	8.1	8.3	8.3	8.2	8.0	8.1	8.3	8.0	7.8	8.2
Col 6-1	8.2	8.2	8.2	8.0	8.1	8.1	8.3	8.1	7.7	8.3
Col 6-2	7.9	8.2	8.3	8.3	8.4	8.3	8.3	8.1	7.9	8.3
Col 6-3	8.1	8.2	8.1	8.2	8.4	8.2	8.2	8.0	8.0	8.2
Medium 2	6.9	****	6.7	****	7.8	****	6.6	****	7.3	****

Table A-2a. Field data, specific conductance;  $\mu\text{mhos/cm}$ .

	1A	1B	2A	2B	3	4	5A	5B	6A	6B
May '81	590	580	820	520	****	****	660	730	****	****
Jun	620	620	880	440	1140	****	770	760	500	610
Jul	500	490	940	520	****	****	810	760	640	590
Aug	410	380	660	450	****	****	630	430	****	****
Sep	660	650	760	570	940	550	720	650	480	****
Oct	450	****	790	820	****	****	830	700	****	****
Nov	670	640	800	780	****	****	****	820	500	600
Dec	730	670	800	****	1050	****	****	****	620	600
Jan '82	533	860	540	650	****	930	730	****	****	****
Feb	700	690	730	840	****	****	830	****	****	****
Mar	590	700	840	620	540	****	****	****	****	****
Apr	640	640	920	930	****	1200	****	****	****	****

Table A-2b. Leachate column data, specific conductance;  $\mu\text{mhos/cm}$ .

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10
Medium 1	450	****	540	****	510	****	530	****	520	****
Col 1-1	640	540	540	520	510	490	480	460	470	540
Col 1-2	620	540	530	520	520	490	480	470	450	470
Col 1-3	590	550	540	550	510	490	470	490	470	470
Col 2-1	820	530	560	540	530	500	520	460	460	450
Col 2-2	810	560	560	540	570	530	500	490	490	470
Col 2-3	790	580	560	540	550	530	500	490	460	460
Col 3-1	730	540	640	590	600	520	530	510	510	510
Col 3-2	760	540	610	580	550	530	520	510	500	500
Col 3-3	700	550	580	560	550	550	520	520	500	530
Col 4-1	670	610	570	610	470	490	500	570	750	690
Col 4-2	640	580	590	600	510	530	520	600	660	700
Col 4-3	660	600	590	580	530	520	530	770	600	730
Col 5-1	650	620	430	630	520	520	560	560	790	750
Col 5-2	610	590	510	630	500	510	540	630	750	720
Col 5-3	620	580	600	630	510	550	500	630	790	760
Col 6-1	680	510	530	590	540	530	570	640	840	700
Col 6-2	660	540	540	550	500	490	550	620	730	720
Col 6-3	640	610	510	580	540	510	540	610	700	700
Medium 2	350	****	380	****	390	****	470	****	480	****



Table A-3a. Field data, solids, total dissolved; mg/liter.

	1A	1B	2A	2B	3	4	5A	5B	6A	6B
May '81	390	360	550	540	****	****	420	450	540	320
Jun	390	390	490	490	710	780	470	450	250	330
Jul	360	340	440	540	****	****	530	430	300	370
Aug	370	320	470	500	****	****	440	440	270	****
Sep	390	420	510	440	710	490	460	430	340	310
Oct	380	****	540	510	****	****	460	460	****	****
Nov	400	410	500	520	****	****	****	490	320	380
Dec	460	430	510	****	720	****	****	****	390	390
Jan '82	560	560	540	520	****	670	520	****	****	****
Feb	420	400	480	510	****	****	460	****	****	****
Mar	400	460	550	560	730	****	****	****	****	****
Apr	380	380	550	550	****	780	****	****	****	****

Table A-3b. Leachate column data, solids, total dissolved; mg/liter.

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10
Medium 1	310	****	310	****	280	****	260	****	220	****
Col 1-1	420	370	340	250	280	190	170	****	200	****
Col 1-2	430	370	300	220	220	180	190	****	180	****
Col 1-3	430	380	310	220	230	240	170	****	220	****
Col 2-1	640	340	310	210	250	280	240	****	170	****
Col 2-2	610	390	340	270	230	230	200	****	180	****
Col 2-3	590	390	340	250	220	120	170	****	170	****
Col 3-1	570	430	400	260	280	260	240	****	220	****
Col 3-2	570	430	380	290	290	270	220	****	250	****
Col 3-3	500	450	380	270	290	260	170	****	210	****
Col 4-1	290	200	190	200	150	110	160	190	230	200
Col 4-2	290	290	220	150	160	150	160	180	160	180
Col 4-3	340	220	190	230	180	140	210	170	190	190
Col 5-1	250	250	250	180	160	150	210	190	170	180
Col 5-2	290	280	210	160	210	130	190	180	200	200
Col 5-3	300	250	280	210	180	130	150	200	190	160
Col 6-1	340	210	250	200	150	110	180	190	230	200
Col 6-2	350	220	180	150	160	150	160	180	160	180
Col 6-3	350	210	190	230	180	140	210	170	190	190
Medium 2	250	****	240	****	200	****	220	****	220	****

## TRACE METALS:

Table A-4a. Field data, aluminum;  $\mu\text{g Al/liter}$ .

	1A	1B	2A	2B	3	4	5A	5B	6A	6B
May '81	<200	<200	<200	<200	****	****	<200	<200	<200	<200
Jun	<200	<200	<200	<200	<200	<200	<200	<200	<200	<200
Jul	****	****	****	****	****	****	****	****	****	****
Aug	****	****	****	****	****	****	****	****	****	****
Sep	<200	<200	<200	<200	<200	<200	<200	<200	<200	<200
Oct	****	****	****	****	****	****	****	****	****	****
Nov	****	****	****	****	****	****	****	****	****	****
Dec	<200	<200	<200	****	<200	****	****	****	<200	<200
Jan '82	****	****	****	<200	****	<200	<200	****	****	****
Feb	****	****	****	****	****	****	****	****	****	****
Mar	<200	<200	<200	<200	<200	****	****	****	****	****
Apr	****	****	****	****	****	****	<200	****	****	****

Table A-4b. Leachate column data, aluminum;  $\mu\text{g Al/liter}$ .

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10
Medium 1	200	****	<200	****	<200	****	<200	****	<200	****
Col 1-1	<200	****	<200	****	<200	****	<200	****	<200	****
Col 1-2	<200	****	<200	****	<200	****	<200	****	<200	****
Col 1-3	<200	****	<200	****	<200	****	<200	****	<200	****
Col 2-1	<200	****	<200	****	<200	****	<200	****	<200	****
Col 2-2	<200	****	<200	****	<200	****	<200	****	<200	****
Col 2-3	<200	****	<200	****	<200	****	<200	****	<200	****
Col 3-1	<200	****	<200	****	<200	****	<200	****	<200	****
Col 3-2	<200	****	<200	****	<200	****	<200	****	<200	****
Col 3-3	<200	****	<200	****	<200	****	<200	****	<200	****
Col 4-1	<200	300	<200	200	<200	****	200	****	<200	****
Col 4-2	<200	200	200	200	200	****	200	****	<200	****
Col 4-3	<200	<200	300	200	200	****	200	****	<200	****
Col 5-1	<200	300	200	<200	<200	****	<200	****	<200	****
Col 5-2	<200	<200	<200	200	<200	****	<200	****	<200	****
Col 5-3	<200	<200	<200	<200	400	****	200	****	200	****
Col 6-1	<200	<200	<200	<200	200	****	200	****	200	****
Col 6-2	<200	<200	200	<200	200	****	200	****	200	****
Col 6-3	200	200	<200	300	<200	****	<200	****	200	****
Medium 2	500	****	200	****	<200	****	200	****	<200	****

Table A-5a. Field data, arsenic; µg As/liter.

	1A	1B	2A	2B	3	4	5A	5B	6A	6B
May '81	<1	<1	<1	<1	****	****	<1	<1	<1	<1
Jun	<1	2	4	5	<1	2	<1	<1	<1	2
Jul	****	****	****	****	****	****	****	****	****	****
Aug	****	****	****	****	****	****	****	****	****	****
Sep	<1	<1	<1	9	<1	<1	7	<1	<1	<1
Oct	****	****	****	****	****	****	****	****	****	****
Nov	****	****	****	****	****	****	****	****	****	****
Dec	<1	<1	<1	****	<1	****	****	****	3	4
Jan '82	<1	<1	<1	<1	****	<1	<1	****	****	****
Feb	<1	<1	<1	<1	****	****	2	****	****	****
Mar	<1	<1	<1	<1	<1	****	****	****	****	****
Apr	****	****	****	****	****	1	****	****	****	****

Table A-5b. Leachate column data, arsenic; µg As/liter.

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10
Medium 1	7	****	2	****	2	****	<1	****	<1	****
Col 1-1	1	****	<1	****	<1	****	<1	****	<1	****
Col 1-2	<1	****	1	****	1	****	<1	****	1	****
Col 1-3	2	****	1	****	<1	****	<1	****	<1	****
Col 2-1	3	****	2	****	<1	****	<1	****	<1	****
Col 2-2	4	****	1	****	2	****	1	****	1	****
Col 2-3	2	****	2	****	<1	****	<1	****	<1	****
Col 3-1	3	****	<1	****	1	****	<1	****	<1	****
Col 3-2	<1	****	1	****	<1	****	<1	****	<1	****
Col 3-3	1	****	<1	****	<1	****	<1	****	<1	****
Col 4-1	4	3	4	3	3	****	3	****	****	****
Col 4-2	2	4	3	3	4	****	3	****	****	****
Col 4-3	2	4	3	3	3	****	4	****	****	****
Col 5-1	1	2	2	4	3	****	1	****	3	****
Col 5-2	1	2	2	3	4	****	3	****	3	****
Col 5-3	2	4	4	3	4	****	4	****	3	****
Col 6-1	2	3	4	3	3	****	4	****	****	****
Col 6-2	2	4	3	2	2	****	5	****	****	****
Col 6-3	4	4	4	4	2	****	4	****	****	****
Medium 2	4	****	3	****	2	****	4	****	3	****

Table A-6a. Field data, barium; µg Ba/liter.

	1A	1B	2A	2B	3	4	5A	5B	6A	6B
May '81	44	35	3	<2	****	****	4	4	<2	<2
Jun	169	160	127	107	46	21	45	39	43	41
Jul	109	103	41	55	****	****	56	46	60	33
Aug	****	****	****	****	****	****	****	****	****	****
Sep	40	35	19	16	11	9	15	31	9	27
Oct	67	****	33	26	****	****	30	92	****	****
Nov	57	54	46	46	****	****	****	40	27	52
Dec	84	90	77	****	42	****	****	****	45	60
Jan '82	59	45	67	46	****	15	44	****	****	****
Feb	53	33	20	37	****	****	15	****	****	****
Mar	32	43	22	21	15	****	****	****	****	****
Apr	81	173	74	65	****	6	****	****	****	****

Table A-6b. Leachate column data, barium; µg Ba/liter.

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10
Medium 1	20	****	501	****	19	****	125	****	65	****
Col 1-1	49	****	282	****	35	****	445	****	223	****
Col 1-2	44	****	189	****	40	****	473	****	215	****
Col 1-3	33	****	127	****	41	****	422	****	249	****
Col 2-1	18	****	309	****	59	****	384	****	215	****
Col 2-2	12	****	360	****	44	****	362	****	218	****
Col 2-3	18	****	342	****	22	****	390	****	195	****
Col 3-1	<3	****	68	****	5	****	76	****	38	****
Col 3-2	4	****	55	****	<3	****	59	****	39	****
Col 3-3	5	****	48	****	<3	****	64	****	21	****
Col 4-1	37	****	52	****	17	****	16	****	145	****
Col 4-2	36	****	53	****	19	****	12	****	151	****
Col 4-3	32	****	50	****	24	****	12	****	155	****
Col 5-1	60	****	103	****	38	****	16	****	314	****
Col 5-2	73	****	94	****	32	****	26	****	262	****
Col 5-3	57	****	90	****	33	****	19	****	236	****
Col 6-1	51	****	34	****	15	****	10	****	128	****
Col 6-2	50	****	32	****	11	****	9	****	113	****
Col 6-3	45	****	25	****	15	****	8	****	112	****
Medium 2	85	****	20	****	9	****	<2	****	78	****

Table A-7a. Field data, beryllium;  $\mu\text{g Be/liter}$ .

	1A	1B	2A	2B	3	4	5A	5B	6A	6B
May '81	<10	<10	<10	<10	****	****	<10	<10	<10	<10
Jun	<10	<10	28	<10	<10	22	<10	<10	105	159
Jul	****	****	****	****	****	****	****	****	****	****
Aug	****	****	****	****	****	****	****	****	****	****
Sep	32	<10	<10	<10	<10	<10	<10	<10	<10	<10
Oct	****	****	****	****	****	****	****	****	****	****
Nov	****	****	****	****	****	****	****	****	****	****
Dec	<10	<10	<10	****	<10	****	****	****	<10	<10
Jan '82	****	****	****	<10	****	<10	<10	****	****	****
Feb	****	****	****	****	****	****	****	****	****	****
Mar	<10	<10	<10	<10	<10	****	****	****	****	****
Apr	****	****	****	****	****	<10	****	****	****	****

Table A-7b. Leachate column data, beryllium;  $\mu\text{g Be/liter}$ .

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10
Medium 1	<10	****	<10	****	<10	****	<10	****	<10	****
Col 1-1	<10	****	<10	****	<10	****	<10	****	<10	****
Col 1-2	<10	****	<10	****	<10	****	<10	****	<10	****
Col 1-3	<10	****	<10	****	<10	****	<10	****	<10	****
Col 2-1	<10	****	<10	****	<10	****	<10	****	<10	****
Col 2-2	<10	****	<10	****	<10	****	<10	****	<10	****
Col 2-3	<10	****	<10	****	<10	****	<10	****	<10	****
Col 3-1	<10	****	<10	****	<10	****	<10	****	<10	****
Col 3-2	<10	****	<10	****	<10	****	<10	****	<10	****
Col 3-3	<10	****	<10	****	<10	****	<10	****	<10	****
Col 4-1	<10	<10	<10	<10	<10	****	<10	****	<10	****
Col 4-2	<10	<10	<10	<10	<10	****	<10	****	<10	****
Col 4-3	<10	<10	<10	<10	<10	****	<10	****	<10	****
Col 5-1	<10	<10	<10	<10	<10	****	<10	****	<10	****
Col 5-2	<10	<10	<10	<10	<10	****	<10	****	<10	****
Col 5-3	<10	<10	<10	<10	<10	****	<10	****	<10	****
Col 6-1	<10	<10	<10	<10	<10	****	<10	****	<10	****
Col 6-2	<10	<10	<10	<10	<10	****	<10	****	<10	****
Col 6-3	<10	<10	<10	<10	<10	****	<10	****	<10	****
Medium 2	<10	****	<10	****	<10	****	<10	****	<10	****

Table A-8a. Field data, boron;  $\mu\text{g B/liter}$ .

	1A	1B	2A	2B	3	4	5A	5B	6A	6B
May '81	300	280	140	110	****	****	<100	110	<100	<100
Jun	450	450	240	220	200	250	320	330	370	410
Jul	330	350	120	<100	****	****	140	120	170	330
Aug	390	420	100	170	****	****	<100	<100	<100	****
Sep	440	440	160	160	160	160	220	250	160	250
Oct	390	****	220	160	****	****	150	120	****	****
Nov	610	650	250	250	****	****	****	280	140	150
Dec	490	490	190	****	130	****	****	****	<100	<100
Jan '82	740	690	190	<100	****	<100	130	****	****	****
Feb	530	550	290	220	****	****	270	****	****	****
Mar	410	720	220	270	290	****	****	****	****	****
Apr	340	330	<100	<100	****	130	****	****	****	****

Table A-8b. Leachate column data, boron;  $\mu\text{g B/liter}$ .

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10
Medium 1	<100	****	<100	****	140	****	<100	****	<100	****
Col 1-1	3560	2440	1110	860	910	1060	710	640	640	430
Col 1-2	3560	2290	1170	1110	910	710	680	640	610	430
Col 1-3	3460	2130	1110	1010	910	710	680	540	500	500
Col 2-1	860	200	200	<100	600	150	190	150	<100	190
Col 2-2	760	200	300	200	350	150	150	190	<100	190
Col 2-3	760	400	200	600	600	150	150	150	150	190
Col 3-1	2080	1420	910	600	600	290	400	190	360	360
Col 3-2	2030	1520	860	750	550	360	360	360	360	360
Col 3-3	2030	1520	810	860	910	360	470	430	290	300
Col 4-1	410	100	<100	<100	<100	<100	<100	<100	<100	<100
Col 4-2	410	170	<100	<100	<100	<100	<100	<100	<100	<100
Col 4-3	480	170	<100	<100	<100	<100	<100	<100	<100	<100
Col 5-1	730	340	200	100	140	140	<100	<100	<100	<100
Col 5-2	690	340	240	<100	<100	<100	<100	<100	<100	<100
Col 5-3	830	410	310	170	140	<100	<100	<100	<100	<100
Col 6-1	340	<100	<100	<100	<100	<100	<100	<100	<100	<100
Col 6-2	310	<100	<100	<100	<100	<100	<100	<100	<100	<100
Col 6-3	340	140	<100	<100	<100	<100	<100	<100	<100	<100
Medium 2	<100	****	<100	****	<100	****	<100	****	<100	****

Table A-9a. Field data, cadmium;  $\mu\text{g Cd/liter}$ .

	1A	1B	2A	2B	3	4	5A	5B	6A	6B
May '81	<5	<5	<5	<5	****	****	<5	<5	<5	<5
Jun	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Jul	****	****	****	****	****	****	****	****	****	****
Aug	****	****	****	****	****	****	****	****	****	****
Sep	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Oct	****	****	****	****	****	****	****	****	****	****
Nov	****	****	****	****	****	****	****	****	****	****
Dec	<5	<5	<5	****	<5	****	****	****	<5	<5
Jan '82	****	****	****	<5	****	<5	<5	****	****	****
Feb	****	****	****	****	****	****	****	****	****	****
Mar	<5	<5	<5	<5	<5	****	****	****	****	****
Apr	****	****	****	****	****	<5	****	****	****	****

Table A-9b. Leachate column data, cadmium;  $\mu\text{g Cd/liter}$ .

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10
Medium 1	<5	****	31	****	11	****	9	****	8	****
Col 1-1	<5	****	<5	****	<5	****	<5	****	<5	****
Col 1-2	<5	****	<5	****	<5	****	<5	****	<5	****
Col 1-3	<5	****	<5	****	<5	****	<5	****	<5	****
Col 2-1	<5	****	<5	****	<5	****	<5	****	<5	****
Col 2-2	<5	****	<5	****	<5	****	<5	****	<5	****
Col 2-3	<5	****	<5	****	<5	****	<5	****	<5	****
Col 3-1	<5	****	<5	****	<5	****	<5	****	<5	****
Col 3-2	<5	****	<5	****	<5	****	<5	****	<5	****
Col 3-3	<5	****	<5	****	<5	****	<5	****	<5	****
Col 4-1	<5	<5	<5	<5	<5	****	<5	****	<5	****
Col 4-2	<5	<5	<5	<5	<5	****	<5	****	<5	****
Col 4-3	<5	<5	<5	<5	<5	****	<5	****	<5	****
Col 5-1	5	<5	<5	<5	<5	****	<5	****	<5	****
Col 5-2	6	<5	<5	<5	<5	****	<5	****	<5	****
Col 5-3	<5	<5	<5	<5	<5	****	<5	****	<5	****
Col 6-1	<5	<5	<5	<5	<5	****	<5	****	<5	****
Col 6-2	<5	<5	<5	<5	<5	****	<5	****	<5	****
Col 6-3	<5	<5	<5	<5	<5	****	<5	****	<5	****
Medium 2	5	****	<5	****	<5	****	<5	****	<5	****

Table A-10a. Field data, chromium;  $\mu\text{g Cr/liter}$ .

	1A	1B	2A	2B	3	4	5A	5B	6A	6B
May '81	<11	<11	<11	<11	****	****	<11	<11	<11	<11
Jun	14	<11	14	<11	<11	<11	<11	<11	<11	<11
Jul	****	****	****	****	****	****	****	****	****	****
Aug	****	****	****	****	****	****	****	****	****	****
Sep	<11	<11	<11	<11	<11	<11	<11	<11	<11	<11
Oct	****	****	****	****	****	****	****	****	****	****
Nov	****	****	****	****	****	****	****	****	****	****
Dec	<11	<11	<11	****	<11	****	****	****	<11	<11
Jan '82	****	****	****	<11	****	<11	<11	****	****	****
Feb	****	****	****	****	****	****	****	****	****	****
Mar	<11	<11	<11	<11	<11	****	****	****	****	****
Apr	****	****	****	****	****	<11	****	****	****	****

Table A-10b. Leachate column data, chromium;  $\mu\text{g Cr/liter}$ .

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10
Medium 1	<11	****	<11	****	<11	****	<11	****	<11	****
Col 1-1	<11	****	<11	****	<11	****	<11	****	<11	****
Col 1-2	<11	****	<11	****	<11	****	<11	****	<11	****
Col 1-3	<11	****	<11	****	<11	****	<11	****	<11	****
Col 2-1	<11	****	<11	****	<11	****	<11	****	<11	****
Col 2-2	<11	****	<11	****	<11	****	<11	****	<11	****
Col 2-3	<11	****	<11	****	<11	****	<11	****	<11	****
Col 3-1	<11	****	<11	****	<11	****	<11	****	<11	****
Col 3-2	<11	****	<11	****	<11	****	<11	****	<11	****
Col 3-3	<11	****	<11	****	<11	****	<11	****	<11	****
Col 4-1	<11	<11	<11	<11	<11	****	<11	****	<11	****
Col 4-2	<11	<11	<11	<11	<11	****	<11	****	<11	****
Col 4-3	<11	<11	<11	<11	<11	****	<11	****	<11	****
Col 5-1	<11	<11	<11	<11	<11	****	<11	****	<11	****
Col 5-2	<11	<11	<11	<11	<11	****	<11	****	<11	****
Col 5-3	<11	<11	<11	<11	<11	****	<11	****	<11	****
Col 6-1	<11	<11	<11	<11	<11	****	<11	****	<11	****
Col 6-2	<11	<11	<11	<11	<11	****	<11	****	<11	****
Col 6-3	<11	<11	<11	<11	<11	****	<11	****	<11	****
Medium 2	<11	****	<11	****	<11	****	<11	****	<11	****



Table A-11a. Field data, cobalt;  $\mu\text{g Co/liter}$ .

	1A	1B	2A	2B	3	4	5A	5B	6A	6B
May '81	<10	<10	<10	<10	****	****	<10	<10	<10	<10
Jun	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Jul	****	****	****	****	****	****	****	****	****	****
Aug	****	****	****	****	****	****	****	****	****	****
Sep	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Oct	****	****	****	****	****	****	****	****	****	****
Nov	****	****	****	****	****	****	****	****	****	****
Dec	<10	<10	<10	****	<10	****	****	****	<10	<10
Jan '82	<10	<10	<10	39	****	<10	<10	****	****	****
Feb	****	****	****	****	****	****	<10	****	****	****
Mar	<10	<10	<10	<10	<10	****	****	****	****	****
Apr	****	****	****	****	****	<10	****	****	****	****

Table A-11b. Leachate column data, cobalt;  $\mu\text{g Co/liter}$ .

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10
Medium 1	11	****	<10	****	<10	****	<10	****	<10	****
Col 1-1	<10	****	<10	****	<10	****	<10	****	<10	****
Col 1-2	<10	****	<10	****	<10	****	<10	****	<10	****
Col 1-3	<10	****	<10	****	<10	****	<10	****	<10	****
Col 2-1	14	****	<10	****	<10	****	<10	****	<10	****
Col 2-2	13	****	<10	****	<10	****	<10	****	<10	****
Col 2-3	<10	****	<10	****	<10	****	<10	****	<10	****
Col 3-1	13	****	<10	****	<10	****	<10	****	<10	****
Col 3-2	<10	****	<10	****	<10	****	<10	****	<10	****
Col 3-3	<10	****	<10	****	<10	****	<10	****	<10	****
Col 4-1	<10	<10	<10	<10	<10	****	<10	****	<10	****
Col 4-2	<10	<10	<10	<10	<10	****	<10	****	<10	****
Col 4-3	<10	<10	<10	<10	<10	****	<10	****	<10	****
Col 5-1	<10	<10	<10	<10	<10	****	<10	****	<10	****
Col 5-2	<10	<10	<10	<10	<10	****	<10	****	<10	****
Col 5-3	<10	<10	<10	<10	<10	****	<10	****	<10	****
Col 6-1	<10	<10	<10	<10	<10	****	<10	****	<10	****
Col 6-2	<10	<10	<10	<10	<10	****	<10	****	<10	****
Col 6-3	<10	<10	<10	<10	<10	****	<10	****	<10	****
Medium 2	<10	****	<10	****	<10	****	<10	****	<10	****

Table A-12a. Field data, copper;  $\mu\text{g Cu/liter}$ .

	1A	1B	2A	2B	3	4	5A	5B	6A	6B
May '81	<9	<9	<9	<9	****	****	<9	<9	<9	<9
Jun	<9	<9	<9	<9	<9	<9	<9	<9	<9	<9
Jul	****	****	****	****	****	****	****	****	****	****
Aug	****	****	****	****	****	****	****	****	****	****
Sep	<9	<9	22	16	19	17	15	18	<9	21
Oct	****	****	****	****	****	****	****	****	****	****
Nov	****	****	****	****	****	****	****	****	****	****
Dec	<9	<9	<9	****	<9	****	****	****	<9	<9
Jan '82	****	****	****	<9	****	<9	<9	****	****	****
Feb	****	****	****	****	****	****	****	****	****	****
Mar	<9	<9	<9	<9	<9	****	****	****	****	****
Apr	****	****	****	****	****	<9	****	****	****	****

Table A-12b. Leachate column data, copper;  $\mu\text{g Cu/liter}$ .

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10
Medium 1	11	****	11	****	22	****	19	****	22	****
Col 1-1	<9	****	<9	****	<9	****	<9	****	<9	****
Col 1-2	<9	****	<9	****	<9	****	<9	****	<9	****
Col 1-3	<9	****	<9	****	9	****	<9	****	<9	****
Col 2-1	<9	****	<9	****	<9	****	<9	****	<9	****
Col 2-2	<9	****	<9	****	<9	****	<9	****	<9	****
Col 2-3	<9	****	<9	****	<9	****	<9	****	<9	****
Col 3-1	<9	****	9	****	<9	****	11	****	<9	****
Col 3-2	<9	****	<9	****	<9	****	<9	****	<9	****
Col 3-3	<9	****	<9	****	<9	****	<9	****	<9	****
Col 4-1	<9	<9	<9	<9	<9	****	<9	****	<9	****
Col 4-2	<9	<9	<9	<9	<9	****	<9	****	<9	****
Col 4-3	<9	<9	<9	<9	<9	****	<9	****	<9	****
Col 5-1	48	<9	<9	<9	<9	****	<9	****	<9	****
Col 5-2	<9	<9	<9	<9	<9	****	<9	****	<9	****
Col 5-3	<9	<9	<9	<9	<9	****	<9	****	<9	****
Col 6-1	<9	<9	<9	<9	<9	****	<9	****	<9	****
Col 6-2	<9	<9	<9	<9	<9	****	<9	****	<9	****
Col 6-3	<9	<9	<9	<9	<9	****	<9	****	<9	****
Medium 2	<9	****	<9	****	<9	****	<9	****	<9	****

Table A-13. Field data, iron, total;  $\mu\text{g Fe/liter}$ .

	1A	1B	2A	2B	3	4	5A	5B	6A	6B
May'81	26	60	178	38	****	****	194	560	533	<19
Jun	<19	<19	<19	34	<19	95	290	188	<19	<19
Jul	****	****	****	****	****	****	****	****	****	****
Aug	658	1220	749	364	****	****	10100	1450	721	****
Sep	214	330	153	111	105	234	181	146	339	<19
Oct	****	****	****	****	****	****	****	****	****	****
Nov	****	****	****	****	****	****	****	****	****	****
Dec	273	199	151	****	750	****	****	****	643	995
Jan'82	****	****	****	586	****	802	580	****	****	****
Feb	****	****	****	****	****	****	****	****	****	****
Mar	807	790	801	472	508	****	****	****	****	****
Apr	****	****	****	****	****	623	****	****	****	****

Note: Coal column leachates were not analyzed for total iron.

Table A-14a. Field data, iron, dissolved; µg Fe/liter.

	1A	1B	2A	2B	3	4	5A	5B	6A	6B
May '81	<19	<19	21	<19	****	****	<19	<19	<19	<19
Jun	<19	<19	<19	<19	<19	<19	<19	<19	<19	<19
Jul	****	****	****	****	****	****	****	****	****	****
Aug	<19	<19	<19	20	****	****	21	<19	<19	****
Sep	<19	<19	<19	<19	58	<19	<19	<19	<19	<19
Oct	****	****	****	****	****	****	****	****	****	****
Nov	****	****	****	****	****	****	****	****	****	****
Dec	<19	<19	73	****	<19	****	****	****	<19	<19
Jan '82	****	****	****	<19	****	<19	<19	****	****	****
Feb	****	****	****	****	****	****	****	****	****	****
Mar	<19	<19	<19	<19	<19	****	****	****	****	****
Apr	****	****	****	****	****	<19	****	****	****	****

Table A-14b. Leachate column data, iron, dissolved; µg Fe/liter.

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10
Medium 1	<19	****	<19	****	<19	****	<19	****	<19	****
Col 1-1	<19	****	<19	****	<19	****	<19	****	<19	****
Col 1-2	<19	****	<19	****	<19	****	<19	****	<19	****
Col 1-3	<19	****	<19	****	<19	****	<19	****	<19	****
Col 2-1	<19	****	<19	****	<19	****	<19	****	<19	****
Col 2-2	<19	****	<19	****	<19	****	<19	****	<19	****
Col 2-3	<19	****	<19	****	<19	****	<19	****	<19	****
Col 3-1	<19	****	<19	****	<19	****	<19	****	<19	****
Col 3-2	<19	****	<19	****	<19	****	<19	****	<19	****
Col 3-3	<19	****	<19	****	<19	****	<19	****	<19	****
Col 4-1	<19	<19	<19	23	<19	****	<19	****	<19	****
Col 4-2	<19	<19	<19	<19	<19	****	57	****	<19	****
Col 4-3	<19	<19	<19	<19	<19	****	31	****	<19	****
Col 5-1	<19	<19	<19	<19	<19	****	<19	****	<19	****
Col 5-2	<19	<19	<19	<19	<19	****	<19	****	<19	****
Col 5-3	<19	<19	<19	<19	<19	****	<19	****	<19	****
Col 6-1	<19	<19	<19	27	<19	****	<19	****	<19	****
Col 6-2	<19	<19	<19	20	<19	****	<19	****	<19	****
Col 6-3	<19	<19	<19	<19	<19	****	<19	****	<19	****
Medium 2	<19	****	<19	****	<19	****	<19	****	<19	****

Table A-15a. Field data, lead; µg Pb/liter.

	1A	1B	2A	2B	3	4	5A	5B	6A	6B
May '81	<2	<2	<2	<2	****	****	<2	<2	<2	<2
Jun	<2	<2	<2	<2	<2	<2	2	<2	<2	****
Jul	****	****	****	****	****	****	****	****	****	****
Aug	****	****	****	****	****	****	****	****	****	****
Sep	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Oct	****	****	****	****	****	****	****	****	****	****
Nov	****	****	****	****	****	****	****	****	****	****
Dec	<2	<2	<2	****	6	****	****	****	5	<2
Jan '82	****	****	****	<2	****	<2	<2	****	****	****
Feb	****	****	****	****	****	****	****	****	****	****
Mar	<2	2	<2	<2	<2	****	****	****	****	****
Apr	****	****	****	****	****	****	<2	****	****	****

Table A-15b. Leachate column data, lead; µg Pb/liter.

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10
Medium 1	2	****	2	****	2	****	<2	****	<2	****
Col 1-1	<2	****	<2	****	<2	****	<2	****	<2	****
Col 1-2	<2	****	<2	****	<2	****	<2	****	<2	****
Col 1-3	<2	****	<2	****	<2	****	<2	****	<2	****
Col 2-1	<2	****	<2	****	<2	****	<2	****	<2	****
Col 2-2	<2	****	<2	****	<2	****	<2	****	<2	****
Col 2-3	<2	****	<2	****	<2	****	<2	****	<2	****
Col 3-1	<2	****	<2	****	<2	****	<2	****	<2	****
Col 3-2	<2	****	<2	****	<2	****	<2	****	<2	****
Col 3-3	<2	****	<2	****	<2	****	<2	****	<2	****
Col 4-1	<2	****	<2	****	<2	****	<2	****	<2	****
Col 4-2	<2	****	<2	****	<2	****	<2	****	<2	****
Col 4-3	<2	****	<2	****	<2	****	<2	****	<2	****
Col 5-1	<2	****	<2	****	<2	****	<2	****	<2	****
Col 5-2	<2	****	<2	****	<2	****	<2	****	<2	****
Col 5-3	<2	****	<2	****	<2	****	<2	****	<2	****
Col 6-1	<2	****	<2	****	<2	****	<2	****	<2	****
Col 6-2	<2	****	<2	****	<2	****	<2	****	<2	****
Col 6-3	<2	****	<2	****	<2	****	<2	****	<2	****
Medium 2	2	****	<2	****	<2	****	<2	****	<2	****

Table A-16a. Field data, lithium;  $\mu\text{g Li/liter}$ .

	1A	1B	2A	2B	3	4	5A	5B	6A	6B
May '81	3	3	12	9	****	****	20	23	4	4
Jun	5	3	6	6	6	7	19	19	2	4
Jul	4	3	13	14	****	****	35	37	9	9
Aug	9	6	6	13	****	****	14	32	37	****
Sep	5	5	14	15	12	11	34	33	5	7
Oct	7	****	7	6	****	****	17	15	****	****
Nov	3	2	3	3	****	****	****	12	2	1
Dec	2	1	4	****	1	****	****	****	1	1
Jan '82	1	1	2	8	****	9	20	****	****	****
Feb	2	1	8	8	****	****	16	****	****	****
Mar	1	2	5	6	4	****	****	****	****	****
Apr	8	6	8	13	****	10	****	****	****	****

Table A-16b. Leachate column data, lithium;  $\mu\text{g Li/liter}$ .

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10
Medium 1	8	****	2	****	3	****	1	****	1	****
Col 1-1	1	****	<1	****	2	****	1	****	1	****
Col 1-2	1	****	<1	****	1	****	2	****	1	****
Col 1-3	<1	****	1	****	1	****	<1	****	<1	****
Col 2-1	6	****	3	****	3	****	2	****	4	****
Col 2-2	6	****	3	****	4	****	1	****	2	****
Col 2-3	6	****	4	****	4	****	2	****	2	****
Col 3-1	4	****	<1	****	1	****	2	****	2	****
Col 3-2	2	****	<1	****	1	****	<1	****	1	****
Col 3-3	1	****	<1	****	2	****	<1	****	<1	****
Col 4-1	17	19	18	16	13	****	11	****	7	****
Col 4-2	16	17	18	13	14	****	10	****	8	****
Col 4-3	15	18	17	15	13	****	10	****	8	****
Col 5-1	43	44	46	40	33	****	26	****	18	****
Col 5-2	37	43	40	37	28	****	20	****	14	****
Col 5-3	35	47	44	39	35	****	25	****	18	****
Col 6-1	10	10	6	4	2	****	<1	****	<1	****
Col 6-2	9	8	5	4	2	****	<1	****	<1	****
Col 6-3	10	9	5	4	2	****	<1	****	<1	****
Medium 2	3	****	<1	****	<1	****	<1	****	<1	****

Table A-17. Field data, manganese, total;  $\mu\text{g Mn/liter}$ .

	1A	1B	2A	2B	3	4	5A	5B	6A	6B
May '81	<12	14	<12	17	****	****	20	20	58	<12
Jun	<12	<12	<12	<12	21	39	<12	21	13	<12
Jul	****	****	****	****	****	****	****	****	****	****
Aug	****	****	****	****	****	****	****	****	****	****
Sep	53	24	17	14	30	28	16	21	47	12
Oct	****	****	****	****	****	****	****	****	****	****
Nov	****	****	****	****	****	****	****	****	****	****
Dec	14	<12	<12	****	32	****	****	****	14	<12
Jan '82	****	****	****	16	****	28	35	****	****	****
Feb	****	****	****	****	****	****	****	****	****	****
Mar	20	22	25	14	32	****	****	****	****	****
Apr	****	****	****	****	****	73	****	****	****	****

Note: Coal column leachates were not analyzed for total manganese.

Table A-18a. Field data, manganese, dissolved;  $\mu\text{g Mn/liter}$ .

	1A	1B	2A	2B	3	4	5A	5B	6A	6B
May '81	<12	<12	<12	<12	****	****	15	<12	58	<12
Jun	<12	<12	<12	<12	<12	37	<12	<12	<12	<12
Jul	****	****	****	****	****	****	****	****	****	****
Aug	27	<12	28	<12	****	****	26	25	37	****
Sep	53	24	<12	<12	24	19	16	<12	42	<12
Oct	****	****	****	****	****	****	****	****	****	****
Nov	****	****	****	****	****	****	****	****	****	****
Dec	<12	<12	<12	****	<12	****	****	****	<12	<12
Jan '82	****	****	****	<12	****	19	35	****	****	****
Feb	****	****	****	****	****	****	****	****	****	****
Mar	12	12	<12	<12	31	****	****	****	****	****
Apr	****	****	****	****	****	53	****	****	****	****

Table A-18b. Leachate column data, manganese, dissolved;  $\mu\text{g Mn/liter}$ .

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10
Medium 1	<12	****	<12	****	<12	****	<12	****	<12	****
Col 1-1	<12	<12	<12	****	<12	****	<12	****	<12	****
Col 1-2	<12	<12	<12	****	<12	****	<12	****	<12	****
Col 1-3	<12	<12	<12	****	<12	****	<12	****	<12	****
Col 2-1	<12	<12	<12	****	<12	****	16	****	<12	****
Col 2-2	<12	<12	<12	****	<12	****	<12	****	<12	****
Col 2-3	<12	<12	<12	****	<12	****	<12	****	<12	****
Col 3-1	<12	<12	<12	****	<12	****	<12	****	<12	****
Col 3-2	<12	<12	<12	****	<12	****	<12	****	<12	****
Col 3-3	<12	<12	<12	****	<12	****	<12	****	<12	****
Col 4-1	14	<12	13	64	45	****	28	****	14	****
Col 4-2	13	<12	12	28	41	****	30	****	17	****
Col 4-3	<12	<12	12	53	41	****	36	****	18	****
Col 5-1	18	19	17	18	20	****	16	****	18	****
Col 5-2	28	22	19	20	22	****	17	****	21	****
Col 5-3	23	20	18	21	18	****	18	****	23	****
Col 6-1	15	<12	13	<12	17	****	15	****	34	****
Col 6-2	<12	<12	<12	14	14	****	43	****	20	****
Col 6-3	26	<12	<12	<12	13	****	46	****	14	****
Medium 2	<12	****	<12	****	<12	****	<12	****	21	****



Table A-19. Field data, mercury, total;  $\mu\text{g Hg/liter}$ .

	1A	1B	2A	2B	3	4	5A	5B	6A	6B
May '81	0.7	1.0	0.7	0.5	****	****	0.6	0.6	0.5	0.7
Jun	****	****	0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Jul	0.2	0.3	0.4	0.2	****	****	0.6	0.3	0.9	0.4
Aug	4.0	3.0	6.0	4.0	****	****	12.0	3.0	2.0	****
Sep	1.0	0.5	2.0	2.3	0.5	0.8	1.0	0.5	1.1	1.2
Oct	0.2	****	0.2	0.2	****	****	<0.2	1.0	****	****
Nov	0.2	<0.2	<0.2	0.3	****	****	****	0.3	0.3	0.4
Dec	1.6	3.0	<0.2	****	2.2	****	****	****	<0.2	<0.2
Jan '82	3.0	2.0	0.5	4.4	****	1.3	0.3	****	****	****
Feb	1.0	2.0	0.3	0.5	****	****	0.2	****	****	****
Mar	2.1	1.3	4.7	1.0	3.8	****	****	****	****	****
Apr	0.2	<0.2	0.3	0.2	****	****	****	****	****	****

Note: Coal column leachates were not analyzed for total mercury.

Table A-20a. Field data, mercury, dissolved; µg Hg/liter.

	1A	1B	2A	2B	3	4	5A	5B	6A	6B
May '81	0.6	0.5	0.4	0.4	****	****	0.4	0.6	0.5	<0.2
Jun	<0.2	0.3	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Jul	0.2	0.2	<0.2	<0.2	****	****	0.2	0.2	0.5	<0.2
Aug	1.7	0.3	0.5	<0.2	****	****	1.6	0.3	0.6	****
Sep	1.0	0.5	0.3	0.4	0.3	0.3	0.4	0.4	0.3	0.5
Oct	0.2	****	0.2	0.2	****	****	<0.2	1.0	****	****
Nov	0.2	<0.2	<0.2	<0.2	****	****	****	0.3	0.3	<0.2
Dec	<0.2	<0.2	<0.2	****	<0.2	****	****	****	<0.2	<0.2
Jan '82	0.8	0.2	<0.2	0.4	****	0.3	0.2	****	****	****
Feb	1.0	2.0	0.3	0.5	****	****	0.2	****	****	****
Mar	0.2	0.8	0.3	0.2	0.3	****	****	****	****	****
Apr	0.2	<0.2	<0.2	<0.2		****	<0.2	****	****	****

Table A-20b. Leachate column data, mercury, dissolved; µg Hg/liter.

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10
Medium 1	0.2	****	2.0	****	<0.2	****	<0.2	****	<0.2	****
Col 1-1	<0.2	****	<0.2	****	<0.2	****	<0.2	****	<0.2	****
Col 1-2	<0.2	****	<0.2	****	<0.2	****	<0.2	****	<0.2	****
Col 1-3	<0.2	****	<0.2	****	<0.2	****	<0.2	****	<0.2	****
Col 2-1	0.2	****	0.5	****	<0.2	****	<0.2	****	<0.2	****
Col 2-2	<0.2	****	0.4	****	<0.2	****	<0.2	****	<0.2	****
Col 2-3	0.3	****	0.2	****	<0.2	****	<0.2	****	<0.2	****
Col 3-1	0.2	****	0.6	****	<0.2	****	<0.2	****	<0.2	****
Col 3-2	<0.2	****	0.6	****	<0.2	****	<0.2	****	<0.2	****
Col 3-3	0.2	****	0.2	****	0.2	****	<0.2	****	<0.2	****
Col 4-1	0.2	0.3	0.2	****	0.3	****	<0.2	****	<0.2	****
Col 4-2	0.4	0.4	<0.2	****	<0.2	****	<0.2	****	<0.2	****
Col 4-3	0.2	0.3	<0.2	****	<0.2	****	<0.2	****	<0.2	****
Col 5-1	0.4	0.6	0.4	****	0.3	****	<0.2	****	<0.2	****
Col 5-2	0.3	0.3	0.3	****	0.3	****	<0.2	****	<0.2	****
Col 5-3	0.3	0.4	<0.2	****	0.3	****	<0.2	****	<0.2	****
Col 6-1	0.2	<0.2	0.3	****	<0.2	****	<0.2	****	<0.2	****
Col 6-2	0.2	0.2	<0.2	****	<0.2	****	<0.2	****	<0.2	****
Col 6-3	0.2	0.2	<0.2	****	<0.2	****	<0.2	****	<0.2	****
Medium 2	0.2	****	0.5	****	2.0	****	<0.2	****	<0.2	****

Table A-21a. Field data, molybdenum;  $\mu\text{g Mo/liter}$ .

	1A	1B	2A	2B	3	4	5A	5B	6A	6B
May '81	<2	11	<2	<2	****	****	5	7	5	<2
Jun	<2	<2	6	6	<2	<2	4	<2	<2	<2
Jul	****	****	****	****	****	****	****	****	****	****
Aug	****	****	****	****	****	****	****	****	****	****
Sep	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Oct	****	****	****	****	****	****	****	****	****	****
Nov	****	****	****	****	****	****	****	****	****	****
Dec	<2	<2	6	****	****	****	****	****	<2	<2
Jan '82	****	****	****	5	****	<2	<2	****	****	****
Feb	****	****	****	****	****	****	****	****	****	****
Mar	<2	<2	<2	<2	<2	****	****	****	****	****
Apr	****	****	****	****	****	6	****	****	****	****

Table A-21b. Leachate column data, molybdenum;  $\mu\text{g Mo/liter}$ .

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10
Medium 1	3	****	2	****	<2	****	<2	****	2	****
Col 1-1	3	****	<2	****	2	****	<2	****	3	****
Col 1-2	4	****	<2	****	<2	****	10	****	2	****
Col 1-3	5	****	4	****	<2	****	3	****	2	****
Col 2-1	12	****	<2	****	3	****	3	****	<2	****
Col 2-2	12	****	<2	****	2	****	<2	****	<2	****
Col 2-3	11	****	<2	****	4	****	<2	****	<2	****
Col 3-1	2	****	<2	****	2	****	3	****	<2	****
Col 3-2	<2	****	3	****	<2	****	3	****	3	****
Col 3-3	4	****	<2	****	<2	****	2	****	3	****
Col 4-1	<2	****	<2	****	<2	****	4	****	2	****
Col 4-2	<2	****	<2	****	<2	****	<2	****	<2	****
Col 4-3	<2	****	<2	****	<2	****	<2	****	<2	****
Col 5-1	<2	****	<2	****	<2	****	2	****	<2	****
Col 5-2	<2	****	<2	****	<2	****	<2	****	<2	****
Col 5-3	<2	****	<2	****	<2	****	4	****	<2	****
Col 6-1	<2	****	<2	****	<2	****	<2	****	<2	****
Col 6-2	<2	****	<2	****	<2	****	55	****	<2	****
Col 6-3	<2	****	<2	****	<2	****	<2	****	<2	****
Medium 2	7	****	<2	****	<2	****	<2	****	<2	****

Table A-22a. Field data, nickel;  $\mu\text{g Ni/liter}$ .

	1A	1B	2A	2B	3	4	5A	5B	6A	6B
May '81	<10	<10	<10	<10	****	****	<10	<10	<10	<10
Jun	<10	<10	<10	<10	<10	17	<10	<10	<10	<10
Jul	****	****	****	****	****	****	****	****	****	****
Aug	****	****	****	****	****	****	****	****	****	****
Sep	15	22	<10	<10	<10	<10	<10	<10	<10	13
Oct	****	****	****	****	****	****	****	****	****	****
Nov	****	****	****	****	****	****	****	****	****	****
Dec	<10	<10	<10	****	<10	****	****	****	<10	<10
Jan '82	****	****	****	<10	****	14	<10	****	****	****
Feb	****	****	****	****	****	****	****	****	****	****
Mar	<10	<10	<10	<10	<10	****	****	****	****	****
Apr	****	****	****	****	****	<10	****	****	****	****

Table A-22b. Leachate column data, nickel;  $\mu\text{g Ni/liter}$ .

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10
Medium 1	<10	****	<10	****	<10	****	<10	****	<10	****
Col 1-1	<10	****	<10	****	<10	****	<10	****	<10	****
Col 1-2	<10	****	<10	****	<10	****	<10	****	<10	****
Col 1-3	<10	****	<10	****	<10	****	<10	****	<10	****
Col 2-1	<10	****	<10	****	<10	****	<10	****	<10	****
Col 2-2	<10	****	<10	****	<10	****	<10	****	<10	****
Col 2-3	<10	****	<10	****	<10	****	<10	****	<10	****
Col 3-1	<10	****	<10	****	<10	****	<10	****	<10	****
Col 3-2	<10	****	<10	****	<10	****	<10	****	<10	****
Col 3-3	<10	****	<10	****	<10	****	<10	****	<10	****
Col 4-1	10	<10	<10	<10	28	****	20	****	10	****
Col 4-2	19	<10	<10	<10	18	****	23	****	<10	****
Col 4-3	25	10	23	13	13	****	33	****	13	****
Col 5-1	<10	<10	<10	<10	<10	****	<10	****	<10	****
Col 5-2	<10	<10	<10	<10	<10	****	<10	****	<10	****
Col 5-3	<10	<10	<10	<10	<10	****	<10	****	<10	****
Col 6-1	<10	<10	<10	<10	<10	****	<10	****	<10	****
Col 6-2	<10	<10	<10	<10	<10	****	<10	****	<10	****
Col 6-3	<10	<10	<10	<10	<10	****	<10	****	<10	****
Medium 2	<10	<10	<10	<10	<10	****	<10	****	<10	****

Table A-23a. Field data, selenium; µg Se/liter.

	1A	1B	2A	2B	3	4	5A	5B	6A	6B
May '81	2	5	3	3	****	****	8	10	7	8
Jun	<1	<1	1	2	<1	<1	3	3	3	3
Jul	****	****	****	****	****	****	****	****	****	****
Aug	****	****	****	****	****	****	****	****	****	****
Sep	<1	<1	<1	<1	<1	1	<1	<1	<1	<1
Oct	<1	****	3	<1	****	****	4	1	****	****
Nov	2	2	3	3	****	****	****	2	2	3
Dec	3	3	3	****	2	****	****	****	1	2
Jan '82	2	4	2	3	****	2	2	****	****	****
Feb	3	3	4	2	****	****	3	****	****	****
Mar	2	4	3	2	3	****	****	****	****	****
Apr	<1	2	2	4	****	3	****	****	****	****

Table A-23b. Leachate column data, selenium; µg Se/liter.

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10
Medium 1	<1	****	<1	****	1	****	1	****	1	****
Col 1-1	<1	****	<1	****	<1	****	<1	****	3	****
Col 1-2	<1	****	2	****	1	****	1	****	1	****
Col 1-3	<1	****	2	****	<1	****	1	****	<1	****
Col 2-1	<1	****	<1	****	1	****	1	****	2	****
Col 2-2	<1	****	<1	****	2	****	1	****	1	****
Col 2-3	2	****	1	****	3	****	1	****	1	****
Col 3-1	<1	****	<1	****	2	****	<1	****	1	****
Col 3-2	<1	****	1	****	1	****	1	****	1	****
Col 3-3	<1	****	<1	****	1	****	1	****	1	****
Col 4-1	6	3	3	3	4	****	4	****	2	****
Col 4-2	7	3	1	3	3	****	3	****	2	****
Col 4-3	4	3	2	2	4	****	3	****	1	****
Col 5-1	7	3	3	1	3	****	2	****	2	****
Col 5-2	3	2	4	2	3	****	2	****	3	****
Col 5-3	8	2	4	2	3	****	4	****	3	****
Col 6-1	5	4	4	3	3	****	3	****	1	****
Col 6-2	6	3	3	2	3	****	3	****	1	****
Col 6-3	6	4	3	3	3	****	2	****	1	****
Medium 2	2	****	3	****	2	****	3	****	3	****

Table A-24a. Field data, silver;  $\mu\text{g Ag/liter}$ .

	1A	1B	2A	2B	3	4	5A	5B	6A	6B
May '81	<9	<9	<9	<9	****	****	<9	<9	<9	<9
Jun	<9	10	<9	<9	<9	9	<9	11	<9	<9
Jul	****	****	****	****	****	****	****	****	****	****
Aug	****	****	****	****	****	****	****	****	****	****
Sep	<9	<9	<9	<9	<9	10	<9	<9	<9	<9
Oct	****	****	****	****	****	****	****	****	****	****
Nov	****	****	****	****	****	****	****	****	****	****
Dec	<9	<9	<9	****	<9	****	****	****	<9	<9
Jan '82	****	****	****	<9	****	<9	<9	****	****	****
Feb	****	****	****	****	****	****	****	****	****	****
Mar	<9	<9	<9	<9	<9	****	****	****	****	****
Apr	****	****	****	****	****	<9	****	****	****	****

Table A-24b. Leachate column data, silver;  $\mu\text{g Ag/liter}$ .

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10
Medium 1	<9	****	<9	****	<9	****	<9	****	<9	****
Col 1-1	<9	****	<9	****	<9	****	<9	****	<9	****
Col 1-2	<9	****	<9	****	<9	****	<9	****	<9	****
Col 1-3	<9	****	<9	****	<9	****	<9	****	<9	****
Col 2-1	<9	****	<9	****	<9	****	<9	****	<9	****
Col 2-2	<9	****	<9	****	<9	****	<9	****	<9	****
Col 2-3	<9	****	<9	****	<9	****	<9	****	<9	****
Col 3-1	<9	****	<9	****	<9	****	<9	****	<9	****
Col 3-2	<9	****	<9	****	<9	****	<9	****	<9	****
Col 3-3	<9	****	<9	****	<9	****	<9	****	<9	****
Col 4-1	<9	<9	<9	<9	<9	****	<9	****	<9	****
Col 4-2	<9	<9	<9	<9	<9	****	<9	****	<9	****
Col 4-3	<9	<9	<9	<9	<9	****	<9	****	<9	****
Col 5-1	<9	<9	<9	<9	<9	****	<9	****	<9	****
Col 5-2	<9	<9	<9	<9	<9	****	<9	****	<9	****
Col 5-3	<9	<9	<9	<9	<9	****	<9	****	<9	****
Col 6-1	<9	<9	<9	<9	<9	****	<9	****	<9	****
Col 6-2	<9	<9	<9	<9	<9	****	<9	****	<9	****
Col 6-3	<9	<9	<9	<9	<9	****	<9	****	<9	****
Medium 2	<9	****	<9	****	<9	****	<9	****	<9	****

Table A-25a. Field data, strontium;  $\mu\text{g Sr/liter}$ .

	1A	1B	2A	2B	3	4	5A	5B	6A	6B
May '81	600	600	600	500	****	****	1700	1600	160	300
Jun	500	500	500	530	100	320	1600	1300	210	250
Jul	660	600	660	700	****	****	2000	2000	370	380
Aug	610	620	650	630	****	****	1680	1600	490	****
Sep	690	630	480	430	660	170	1030	950	170	170
Oct	290	****	240	240	****	****	710	590	****	****
Nov	640	620	470	420	****	****	****	970	190	180
Dec	760	700	600	****	970	****	****	****	170	250
Jan '82	960	840	520	500	****	210	1500	****	****	****
Feb	800	750	830	840	****	****	240	****	****	****
Mar	710	710	1940	1660	1620	****	****	****	****	****
Apr	600	480	710	590	****	390	****	****	****	****

Table A-25b. Leachate column data, strontium;  $\mu\text{g Sr/liter}$ .

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10
Medium 1	330	****	200	****	160	****	280	****	250	****
Col 1-1	350	330	250	320	370	****	310	****	280	****
Col 1-2	390	300	260	270	330	****	310	****	260	****
Col 1-3	350	350	260	300	370	****	310	****	260	****
Col 2-1	660	450	440	720	370	****	550	****	410	****
Col 2-2	630	420	450	810	390	****	670	****	480	****
Col 2-3	770	490	470	750	410	****	690	****	460	****
Col 3-1	310	210	190	280	160	****	220	****	190	****
Col 3-2	320	240	180	260	130	****	230	****	190	****
Col 3-3	270	220	190	250	260	****	220	****	190	****
Col 4-1	470	400	640	630	380	****	400	****	530	****
Col 4-2	450	370	720	720	430	****	370	****	400	****
Col 4-3	470	360	670	650	390	****	400	****	550	****
Col 5-1	1360	1320	1770	1700	1290	****	1040	****	970	****
Col 5-2	1350	1100	1570	1460	1010	****	850	****	940	****
Col 5-3	1380	1050	1590	1700	1230	****	1250	****	1280	****
Col 6-1	420	300	440	410	310	****	370	****	540	****
Col 6-2	410	450	420	350	270	****	360	****	480	****
Col 6-3	400	450	440	330	370	****	360	****	480	****
Medium 2	370	****	350	****	310	****	310	****	290	****

Table A-26a. Field data, zinc;  $\mu\text{g Zn/liter}$ .

	1A	1B	2A	2B	3	4	5A	5B	6A	6B
May '81	<5	<5	<5	<5	****	****	<5	<5	<5	<5
Jun	9	12	<5	15	<5	<5	65	<5	<5	<5
Jul	****	****	****	****	****	****	****	****	****	****
Aug	****	****	****	****	****	****	****	****	****	****
Sep	<5	<5	<5	<5	<5	<5	<5	<5	63	11
Oct	****	****	****	****	****	****	****	****	****	****
Nov	****	****	****	****	****	****	****	****	****	****
Dec	11	<5	<5	****	<5	****	****	****	69	8
Jan '82	****	****	****	<5	****	<5	8	****	****	****
Feb	****	****	****	****	****	****	****	****	****	****
Mar	<5	<5	<5	<5	<5	****	****	****	****	****
Apr	****	****	****	****	****	<5	****	****	****	****

Table A-26b. Leachate column data, zinc;  $\mu\text{g Zn/liter}$ .

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10
Medium 1	230	****	225	****	230	****	225	****	210	****
Col 1-1	<5	****	<5	****	<5	****	<5	****	<5	****
Col 1-2	<5	****	<5	****	<5	****	<5	****	<5	****
Col 1-3	<5	****	<5	****	<5	****	<5	****	<5	****
Col 2-1	5	****	<5	****	8	****	<5	****	<5	****
Col 2-2	<5	****	<5	****	6	****	<5	****	<5	****
Col 2-3	<5	****	<5	****	<5	****	<5	****	<5	****
Col 3-1	<5	****	<5	****	<5	****	<5	****	<5	****
Col 3-2	<5	****	<5	****	<5	****	<5	****	<5	****
Col 3-3	<5	****	<5	****	<5	****	<5	****	<5	****
Col 4-1	<5	<5	<5	<5	<5	****	<5	****	<5	****
Col 4-2	<5	<5	<5	<5	<5	****	<5	****	<5	****
Col 4-3	<5	<5	<5	<5	<5	****	<5	****	<5	****
Col 5-1	<5	<5	<5	<5	<5	****	<5	****	<5	****
Col 5-2	<5	<5	<5	11	<5	****	<5	****	8	****
Col 5-3	<5	<5	5	<5	<5	****	<5	****	<5	****
Col 6-1	<5	<5	<5	<5	<5	****	<5	****	<5	****
Col 6-2	<5	<5	<5	<5	<5	****	<5	****	9	****
Col 6-3	5	<5	<5	<5	<5	****	<5	****	<5	****
Medium 2	116	****	79	****	102	****	270	****	82	****



MAJOR ANIONS AND CATIONS:

Table A-27a. Field data, alkalinity, total; mg CaCO<sub>3</sub>/liter.

	1A	1B	2A	2B	3	4	5A	5B	6A	6B
May '81	228	217	259	259	****	****	284	256	129	217
Jun	231	271	231	256	274	270	292	286	227	205
Jul	232	236	259	263	****	****	192	303	223	222
Aug	229	226	253	236	****	****	288	274	172	****
Sep	229	223	236	236	352	257	265	262	163	189
Oct	219	****	233	233	****	****	258	251	****	****
Nov	238	227	258	260	****	****	****	292	140	190
Dec	219	206	235	****	317	****	****	****	165	165
Jan '82	249	242	257	260	****	236	299	****	****	****
Feb	240	242	275	270	****	****	301	****	****	****
Mar	234	227	266	260	262	****	****	****	****	****
Apr	226	218	270	276	****	204	****	****	****	****

Table A-27b. Leachate column data, alkalinity, total; mg CaCO<sub>3</sub>/liter.

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10
Medium 1	251	****	224	****	221	****	224	****	231	****
Col 1-1	324	298	248	256	231	227	325	199	181	203
Col 1-2	362	306	235	250	235	219	227	210	176	187
Col 1-3	362	300	235	265	267	219	218	221	154	198
Col 2-1	224	258	245	242	248	221	224	202	215	198
Col 2-2	245	250	253	265	267	245	229	210	204	209
Col 2-3	234	225	259	250	256	240	224	205	198	193
Col 3-1	294	285	312	327	292	250	230	235	225	231
Col 3-2	299	312	275	288	270	256	218	224	214	237
Col 3-3	291	217	272	268	259	242	218	251	209	231
Col 4-1	258	310	292	303	258	250	249	313	381	404
Col 4-2	232	292	300	282	260	276	262	347	334	341
Col 4-3	245	309	302	274	271	260	268	327	383	367
Col 5-1	255	307	323	315	260	266	281	300	391	375
Col 5-2	245	292	305	290	286	271	265	313	383	359
Col 5-3	222	321	328	313	278	253	280	324	412	372
Col 6-1	242	285	300	272	278	266	278	327	433	356
Col 6-2	237	275	282	262	255	243	236	327	368	333
Col 6-3	275	300	285	282	263	258	257	329	349	367
Medium 2	222	****	218	****	212	****	224	****	218	****

Table A-28a. Field data, chloride; mg Cl/liter.

	1A	1B	2A	2B	3	4	5A	5B	6A	6B
May '81	7	10	10	10	****	****	4	5	22	21
Jun	10	9	14	15	2	10	7	9	18	28
Jul	22	16	15	20	****	****	110	12	18	17
Aug	17	16	15	13	****	****	12	16	16	****
Sep	14	13	13	15	8	9	8	10	9	15
Oct	24	****	21	16	****	****	15	19	****	****
Nov	17	17	15	13	****	****	****	11	17	20
Dec	15	17	14	****	4	****	****	****	17	14
Jan '82	13	14	12	12	****	12	13	****	****	****
Feb	11	13	10	11	****	****	11	****	****	****
Mar	14	42	11	13	3	****	****	****	****	****
Apr	16	16	11	11	****	112	****	****	****	****

Table A-28b. Leachate column data, chloride; mg Cl/liter.

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10
Medium 1	16	****	16	****	20	****	16	****	14	****
Col 1-1	18	20	14	12	15	****	12	****	21	****
Col 1-2	20	23	13	15	15	****	15	****	19	****
Col 1-3	17	26	15	68	15	****	15	****	17	****
Col 2-1	26	24	15	23	14	****	16	****	17	****
Col 2-2	27	41	14	19	16	****	13	****	15	****
Col 2-3	28	52	14	23	13	****	15	****	15	****
Col 3-1	14	24	14	13	13	****	15	****	17	****
Col 3-2	13	21	12	14	13	****	16	****	16	****
Col 3-3	14	60	15	14	13	****	13	****	****	****
Col 4-1	22	15	11	****	12	****	11	****	****	****
Col 4-2	23	15	12	****	12	****	11	****	****	****
Col 4-3	26	16	11	****	9	****	10	****	****	****
Col 5-1	22	14	10	****	14	****	12	****	****	****
Col 5-2	19	14	11	****	16	****	11	****	****	****
Col 5-3	22	13	10	****	17	****	11	****	****	****
Col 6-1	21	13	10	****	18	****	13	****	****	****
Col 6-2	30	16	12	****	11	****	16	****	****	****
Col 6-3	26	16	14	****	17	****	10	****	****	****
Medium 2	17	****	11	****	13	****	12	****	****	****

Table A-29a. Field data, fluoride; mg F/liter.

	1A	1B	2A	2B	3	4	5A	5B	6A	6B
May '81	0.2	0.2	0.3	0.4	****	****	0.1	0.3	0.2	0.1
Jun	0.4	0.4	0.3	0.2	0.4	0.5	0.5	0.2	0.2	0.3
Jul	0.4	0.4	0.3	0.4	****	****	0.3	0.3	0.3	0.3
Aug	0.4	0.4	0.4	0.4	****	****	0.4	0.4	0.4	****
Sep	0.6	0.6	0.5	0.6	0.5	0.5	0.5	0.5	0.6	0.4
Oct	0.5	****	0.4	0.5	****	****	0.5	0.4	****	****
Nov	0.6	0.6	0.6	0.6	****	****	****	0.6	0.7	0.7
Dec	0.5	0.5	0.4	****	0.4	****	****	****	0.3	0.3
Jan '82	0.4	0.4	0.3	0.3	****	0.5	0.3	****	****	****
Feb	0.3	0.4	0.4	0.4	****	****	0.7	****	****	****
Mar	0.5	0.6	0.5	0.6	0.5	****	****	****	****	****
Apr	0.3	0.3	0.3	0.3	****	0.5	****	****	****	****

Table A-29b. Leachate column data, fluoride; mg F/liter.

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10
Medium 1	0.4	****	0.4	****	0.4	****	0.4	****	0.4	****
Col 1-1	0.9	0.5	0.4	0.4	0.4	****	0.4	****	0.4	****
Col 1-2	0.9	0.5	0.4	0.4	0.4	****	0.4	****	0.4	****
Col 1-3	0.9	0.5	0.4	0.4	0.4	****	0.4	****	0.4	****
Col 2-1	0.6	0.5	0.4	0.4	0.4	****	0.4	****	0.4	****
Col 2-2	0.6	0.5	0.4	0.4	0.3	****	0.3	****	0.4	****
Col 2-3	0.6	0.5	0.4	0.4	0.3	****	0.3	****	0.4	****
Col 3-1	0.5	0.5	0.5	0.4	0.4	****	0.4	****	0.4	****
Col 3-2	0.6	0.6	0.5	0.5	0.4	****	0.4	****	0.4	****
Col 3-3	0.6	0.5	0.5	0.5	0.4	****	0.4	****	0.4	****
Col 4-1	0.5	0.3	0.2	0.1	0.1	0.1	0.1	****	0.2	****
Col 4-2	0.5	0.3	0.2	0.1	0.1	0.1	0.2	****	0.2	****
Col 4-3	0.5	0.3	0.2	0.1	0.1	0.1	0.2	****	0.2	****
Col 5-1	0.3	0.2	0.2	0.1	0.1	0.1	0.1	****	0.1	****
Col 5-2	0.3	0.2	0.2	0.1	0.1	0.1	0.1	****	0.1	****
Col 5-3	0.3	0.2	0.2	0.1	0.1	0.1	0.1	****	0.1	****
Col 6-1	0.4	0.2	0.2	0.1	0.1	0.1	0.2	****	0.2	****
Col 6-2	0.4	0.2	0.2	0.1	0.1	0.1	0.1	****	0.2	****
Col 6-3	0.4	0.2	0.2	0.1	0.1	0.1	0.1	****	0.2	****
Medium 2	0.3	****	0.2	****	0.1	****	0.1	****	0.2	****

Table A-30a. Field data, hardness - calcium; mg Ca/liter.

	1A	1B	2A	2B	3	4	5A	5B	6A	6B
May '81	58	59	79	77	****	****	56	64	110	71
Jun	60	63	81	81	142	143	77	76	64	64
Jul	69	65	75	82	****	****	77	78	71	68
Aug	60	59	80	85	****	****	85	76	65	****
Sep	73	49	98	81	159	92	78	70	83	60
Oct	64	****	92	78	****	****	85	73	****	****
Nov	74	86	86	85	****	****	****	80	79	80
Dec	78	76	96	****	166	****	****	****	90	80
Jan '82	83	67	70	70	****	93	74	****	****	****
Feb	75	73	77	71	****	****	84	****	****	****
Mar	80	80	82	82	158	****	****	****	****	****
Apr	69	61	82	75	****	105	****	****	****	****

Table A-30b. Leachate column data, hardness - calcium; mg Ca/liter.

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10
Medium 1	71	****	70	****	62	****	72	****	80	****
Col 1-1	31	26	29	32	43	****	43	****	45	****
Col 1-2	21	29	24	33	37	****	36	****	42	****
Col 1-3	25	30	30	36	40	****	39	****	48	****
Col 2-1	77	56	64	60	76	****	72	****	60	****
Col 2-2	72	60	62	68	76	****	58	****	62	****
Col 2-3	76	58	62	62	52	****	62	****	56	****
Col 3-1	118	104	100	84	84	****	76	****	88	****
Col 3-2	114	116	86	76	92	****	80	****	76	****
Col 3-3	109	90	88	76	92	****	76	****	66	****
Col 4-1	86	86	96	102	90	90	63	67	91	81
Col 4-2	70	75	98	98	96	96	61	69	75	87
Col 4-3	78	79	92	92	92	90	60	83	80	95
Col 5-1	78	79	90	92	92	92	81	89	101	77
Col 5-2	82	80	98	88	88	100	71	75	95	81
Col 5-3	78	90	82	80	90	100	69	89	93	85
Col 6-1	96	84	92	96	92	90	80	76	91	83
Col 6-2	94	86	90	92	86	86	79	89	103	77
Col 6-3	114	85	84	94	94	92	83	97	87	93
Medium 2	78	****	70	****	71	****	73	****	73	****

Table A-31a. Field data, hardness - total; mg CaCO<sub>3</sub>/liter.

	1A	1B	2A	2B	3	4	5A	5B	6A	6B
May '81	296	291	417	417	****	****	320	315	378	277
Jun	305	305	408	406	554	693	344	335	277	315
Jul	299	302	405	421	****	****	358	346	286	289
Aug	288	329	421	380	****	****	370	327	234	****
Sep	328	325	415	400	616	457	330	335	294	290
Oct	307	****	410	410	****	****	410	317	****	****
Nov	341	329	408	418	****	****	****	376	281	329
Dec	353	333	392	****	617	****	****	****	326	328
Jan '82	399	384	366	370	****	510	359	****	****	****
Feb	355	350	388	390	****	****	370	****	****	****
Mar	310	315	373	364	601	****	****	****	****	****
Apr	309	305	368	368	****	666	****	****	****	****

Table A-31b. Leachate column data, hardness - total; mg CaCO<sub>3</sub>/liter.

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10
Medium 1	240	****	250	****	235	****	240	****	255	****
Col 1-1	118	163	165	180	183	****	160	****	190	****
Col 1-2	110	158	170	175	173	****	170	****	173	****
Col 1-3	113	165	168	185	180	****	168	****	193	****
Col 2-1	330	265	235	240	235	****	225	****	210	****
Col 2-2	335	295	235	270	255	****	235	****	220	****
Col 2-3	310	285	250	260	225	****	205	****	215	****
Col 3-1	415	345	330	320	300	****	215	****	245	****
Col 3-2	400	355	290	263	285	****	265	****	255	****
Col 3-3	340	335	305	275	270	****	270	****	220	****
Col 4-1	325	312	310	315	275	265	201	222	308	283
Col 4-2	320	300	325	290	275	270	201	273	247	278
Col 4-3	330	307	330	285	280	275	216	278	272	258
Col 5-1	300	317	330	320	290	295	258	247	318	253
Col 5-2	320	303	320	325	270	285	216	227	313	287
Col 5-3	300	312	330	333	290	285	227	283	323	268
Col 6-1	350	287	310	290	280	270	232	232	288	247
Col 6-2	355	292	290	270	260	250	247	282	318	242
Col 6-3	400	307	310	300	290	270	242	282	263	268
Medium 2	235	****	255	****	220	****	206	****	227	****

Table A-32a. Field data, hardness - magnesium; mg Mg/liter.

	1A	1B	2A	2B	3	4	5A	5B	6A	6B
May '81	37	35	54	55	****	****	44	39	25	24
Jun	38	36	50	50	48	81	37	36	28	38
Jul	29	34	53	53	****	****	40	38	27	29
Aug	34	44	46	41	****	****	39	33	18	****
Sep	35	50	41	48	54	56	33	39	21	34
Oct	36	****	44	52	****	****	48	33	****	****
Nov	38	28	47	50	****	****	****	44	20	31
Dec	38	35	37	****	49	****	****	****	25	31
Jan '82	46	53	47	48	****	67	42	****	****	****
Feb	41	41	47	52	****	****	40	****	****	****
Mar	27	28	41	39	50	****	****	****	****	****
Apr	36	37	40	44	****	99	****	****	****	****

Table A-32b. Leachate column data, hardness - magnesium; mg Mg/liter.

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10
Medium 1	15	****	18	****	20	****	15	****	13	****
Col 1-1	10	24	23	24	18	****	13	****	19	****
Col 1-2	14	21	27	22	20	****	20	****	17	****
Col 1-3	12	22	23	23	20	****	17	****	18	****
Col 2-1	34	31	18	22	11	****	11	****	15	****
Col 2-2	38	35	20	24	16	****	22	****	16	****
Col 2-3	29	34	23	26	31	****	12	****	18	****
Col 3-1	29	21	20	27	22	****	6	****	6	****
Col 3-2	28	27	18	18	38	****	16	****	15	****
Col 3-3	16	16	21	21	10	****	20	****	13	****
Col 4-1	24	21	15	12	10	12	10	13	20	20
Col 4-2	33	25	17	9	7	7	12	16	15	15
Col 4-3	30	24	22	11	10	10	21	17	17	6
Col 5-1	23	27	23	20	12	13	14	6	16	11
Col 5-2	26	23	16	23	10	7	10	10	18	15
Col 5-3	23	19	28	30	13	7	13	15	22	14
Col 6-1	24	16	17	10	10	9	16	10	15	10
Col 6-2	27	16	13	8	9	7	12	15	15	12
Col 6-3	26	21	22	13	11	7	9	10	11	9
Medium 2	10	****	18	****	8	****	6	****	11	****

Table A-33a. Field data, potassium; mg K/liter.

	1A	1B	2A	2B	3	4	5A	5B	6A	6B
May '81	2	2	4	4	****	****	8	8	2	3
Jun	2	2	4	4	5	4	8	8	4	4
Jul	2	2	4	4	****	****	8	8	5	4
Aug	2	2	4	4	****	****	8	7	2	****
Sep	2	2	4	4	4	4	8	8	1	4
Oct	2	****	4	4	****	****	9	9	****	****
Nov	2	2	4	4	****	****	****	9	1	2
Dec	2	2	5	****	4	****	****	****	11	2
Jan '82	2	2	5	5	****	4	10	****	****	****
Feb	2	2	5	6	****	****	10	****	****	****
Mar	2	2	6	6	4	****	****	****	****	****
Apr	2	2	6	6	****	6	****	****	****	****

Table A-33b. Leachate column data, potassium; mg K/liter.

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10
Medium 1	2	****	1	****	1	****	1	****	1	****
Col 1-1	2	2	1	1	1	****	1	****	1	****
Col 1-2	2	2	1	1	1	****	1	****	1	****
Col 1-3	2	2	1	1	1	****	1	****	1	****
Col 2-1	9	5	4	4	3	****	2	****	2	****
Col 2-2	9	6	5	5	4	****	3	****	2	****
Col 2-3	9	6	5	5	4	****	3	****	2	****
Col 3-1	1	1	1	1	1	****	1	****	1	****
Col 3-2	1	1	1	1	1	****	1	****	1	****
Col 3-3	1	1	1	1	1	****	1	****	1	****
Col 4-1	6	7	6	5	3	****	2	****	2	****
Col 4-2	6	7	7	6	4	****	3	****	2	****
Col 4-3	6	7	7	6	4	****	3	****	2	****
Col 5-1	9	8	7	5	4	****	3	****	3	****
Col 5-2	8	8	6	4	3	****	3	****	3	****
Col 5-3	8	8	8	6	4	****	3	****	3	****
Col 6-1	3	3	2	2	2	****	2	****	2	****
Col 6-2	3	3	2	2	2	****	2	****	2	****
Col 6-3	3	3	3	2	1	****	2	****	2	****
Medium 2	1	****	1	****	1	****	1	****	2	****

Table A-34a. Field data, silica; mg SiO<sub>2</sub>/liter.

	1A	1B	2A	2B	3	4	5A	5B	6A	6B
May '81	10.6	10.4	9.3	9.8	****	****	9.3	9.3	6.1	6.5
Jun	10.1	10.4	9.1	9.1	9.1	8.7	7.5	8.5	6.7	6.4
Jul	11.7	11.8	10.1	10.1	****	****	9.6	9.5	8.0	8.2
Aug	12.3	11.6	10.7	10.3	****	****	9.9	9.6	7.4	****
Sep	11.6	10.9	9.8	9.7	9.2	8.6	8.2	8.5	6.3	7.8
Oct	11.1	****	11.3	9.5	****	****	8.4	8.1	****	****
Nov	11.7	11.6	8.5	9.2	****	****	****	7.7	6.1	9.1
Dec	11.2	11.9	8.8	****	9.4	****	****	****	6.6	6.9
Jan '82	10.4	10.7	8.2	8.9	****	9.5	7.8	****	****	****
Feb	10.1	10.2	8.5	9.3	****	****	8.3	****	****	****
Mar	10.1	10.1	7.9	7.9	9.2	****	****	****	****	****
Apr	9.4	9.4	7.1	7.8	****	11.6	****	****	****	****

Table A-34b. Leachate column data, silica; mg SiO<sub>2</sub>/liter.

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10
Medium 1	11.3	****	7.8	****	6.5	****	6.9	****	7.3	****
Col 1-1	7.4	8.5	8.3	****	7.8	****	7.5	****	7.3	****
Col 1-2	7.4	7.8	8.2	****	7.8	****	7.4	****	7.4	****
Col 1-3	7.4	7.9	8.2	****	7.5	****	7.4	****	7.3	****
Col 2-1	11.1	10.4	9.8	****	8.4	****	8.4	****	8.3	****
Col 2-2	11.3	10.8	10.5	****	9.0	****	8.2	****	8.7	****
Col 2-3	11.9	10.7	10.9	****	9.2	****	8.4	****	8.7	****
Col 3-1	11.3	10.9	10.7	****	9.5	****	8.7	****	9.2	****
Col 3-2	11.3	10.9	10.9	****	9.6	****	9.1	****	9.6	****
Col 3-3	11.3	10.5	10.6	****	9.1	****	9.0	****	9.1	****
Col 4-1	10.1	10.5	9.1	7.3	6.8	6.9	7.4	7.2	7.1	7.7
Col 4-2	11.1	11.1	9.4	7.8	6.3	7.0	7.3	7.4	7.3	7.7
Col 4-3	11.1	11.0	9.5	7.8	7.1	6.5	7.2	7.1	7.2	7.6
Col 5-1	9.1	8.4	8.0	6.7	6.2	6.5	6.8	7.3	7.0	7.2
Col 5-2	7.3	8.4	7.3	6.7	6.0	5.9	7.0	6.9	6.7	7.2
Col 5-3	8.8	8.5	7.7	7.1	6.2	6.4	7.1	6.8	6.7	6.8
Col 6-1	6.4	7.1	6.2	6.2	5.8	7.2	6.0	6.3	5.8	5.8
Col 6-2	5.8	6.7	6.3	5.7	5.6	5.6	5.8	6.3	5.8	5.8
Col 6-3	5.9	6.5	5.9	5.9	5.8	5.8	5.9	6.3	5.8	5.8
Medium 2	5.6	****	5.9	****	5.5	****	6.0	****	6.6	****



Table A-35a. Field data, sodium; mg Na/liter.

	1A	1B	2A	2B	3	4	5A	5B	6A	6B
May '81	21	21	21	23	****	****	32	31	13	5
Jun	26	26	22	22	6	7	35	35	5	6
Jul	21	23	24	23	****	****	36	36	6	5
Aug	24	23	22	22	****	****	34	35	5	****
Sep	23	20	22	22	5	5	39	35	2	4
Oct	23	****	20	21	****	****	36	39	****	****
Nov	27	27	25	24	****	****	****	34	3	5
Dec	21	21	21	****	7	****	****	****	20	6
Jan '82	42	38	38	35	****	8	44	****	****	****
Feb	32	29	44	38	****	****	44	****	****	****
Mar	20	24	38	24	8	****	****	****	****	****
Apr	21	27	49	58	****	12	****	****	****	****

Table A-35b. Leachate column data, sodium; mg Na/liter.

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10
Medium 1	9	****	7	****	8	****	8	****	6	****
Col 1-1	105	72	45	34	28	****	23	****	19	****
Col 1-2	105	74	40	34	29	****	23	****	17	****
Col 1-3	104	72	41	33	27	****	24	****	15	****
Col 2-1	47	12	9	8	7	****	8	****	7	****
Col 2-2	46	16	10	9	7	****	8	****	7	****
Col 2-3	44	18	10	9	7	****	9	****	7	****
Col 3-1	3	3	5	6	5	****	6	****	4	****
Col 3-2	3	3	4	5	5	****	6	****	5	****
Col 3-3	5	5	3	4	5	****	6	****	5	****
Col 4-1	16	13	13	12	12	****	12	****	13	****
Col 4-2	17	13	13	12	12	****	12	****	12	****
Col 4-3	17	14	12	12	11	****	12	****	12	****
Col 5-1	15	13	12	12	11	****	12	****	12	****
Col 5-2	14	13	12	12	12	****	12	****	13	****
Col 5-3	15	13	13	12	12	****	12	****	12	****
Col 6-1	13	12	13	12	11	****	12	****	12	****
Col 6-2	13	12	12	12	12	****	12	****	12	****
Col 6-3	13	13	12	12	12	****	12	****	13	****
Medium 2	11	****	11	****	11	****	12	****	12	****

Table A-36a. Field data, sulfate; mg SO<sub>4</sub>/liter.

	1A	1B	2A	2B	3	4	5A	5B	6A	6B
May '81	90	90	170	190	****	****	120	230	****	60
Jun	120	120	200	200	270	330	140	140	40	80
Jul	90	90	200	200	****	****	120	110	70	60
Aug	90	90	210	210	****	****	130	140	40	****
Sep	120	120	190	190	250	180	130	110	80	40
Oct	90	****	190	200	****	****	150	120	****	****
Nov	100	100	140	120	****	****	****	150	70	100
Dec	140	140	190	****	290	****	****	****	130	110
Jan '82	210	210	170	160	****	300	140	****	****	****
Feb	140	140	190	190	****	****	130	****	****	****
Mar	110	110	180	190	240	****	****	****	****	****
Apr	100	100	170	190	****	350	****	****	****	****

Table A-36b. Leachate column data, sulfate; mg SO<sub>4</sub>/liter.

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10
Medium 1	16	****	15	****	16	****	16	****	16	****
Col 1-1	39	19	17	17	17	17	16	****	18	****
Col 1-2	40	19	17	17	18	17	16	****	16	****
Col 1-3	38	19	17	17	17	16	16	****	16	****
Col 2-1	189	35	21	18	18	17	17	****	17	****
Col 2-2	155	45	22	19	19	19	18	****	16	****
Col 2-3	168	52	22	18	18	19	18	****	18	****
Col 3-1	99	32	20	17	18	17	16	****	17	****
Col 3-2	99	35	21	17	17	17	16	****	21	****
Col 3-3	79	43	24	18	17	16	16	****	17	****
Col 4-1	57	17	10	11	8	9	10	****	8	****
Col 4-2	64	16	11	10	11	10	10	****	8	****
Col 4-3	64	16	10	10	10	10	10	****	8	****
Col 5-1	50	16	11	11	9	10	10	****	9	****
Col 5-2	41	16	11	11	9	10	10	****	9	****
Col 5-3	60	15	10	11	10	10	10	****	9	****
Col 6-1	86	14	10	9	10	11	10	****	8	****
Col 6-2	71	16	11	10	9	9	10	****	8	****
Col 6-3	76	17	10	10	10	9	10	****	8	****
Medium 2	9	****	8	****	8	****	9	****	9	****

NUTRIENTS:

Table A-37. Field data, nitrogen - ammonia;  $\mu\text{g NH}_3\text{-N/liter}$ .

	1A	1B	2A	2B	3	4	5A	5B	6A	6B
May '81	<10	<10	<10	10	****	****	312	201	17	<10
Jun	<10	<10	<10	10	20	31	290	196	10	<10
Jul	<10	<10	<10	10	****	****	244	<10	11	19
Aug	<10	<10	<10	10	****	****	233	162	<10	****
Sep	16	21	33	15	17	14	84	69	33	<10
Oct										
Nov	<10	<10	32	20	****	****	****	<10	<10	<10
Dec	<10	<10	26	****	<10	****	****	****	<10	<10
Jan '82	<10	<10	<10	<10	****	<10	<10	****	****	****
Feb	<10	<10	30	34	****	****	<10	****	****	****
Mar	<10	29	<10	<10	<10	****	****	****	****	****
Apr	<10	<10	<10	<10	****	<10	****	****	****	****

Note: Coal column leachates were not analyzed for ammonia-nitrogen.

Table A-38. Field data, nitrogen - nitrate;  $\text{mg NO}_3\text{-N/liter}$ .

	1A	1B	2A	2B	3	4	5A	5B	6A	6B
May '81	0.05	0.05	0.06	0.06	****	****	0.22	0.32	0.72	0.21
Jun	0.09	0.09	0.08	0.08	0.06	0.48	0.27	0.38	0.25	0.15
Jul	0.06	1.16	0.10	0.07	****	****	0.26	0.30	3.70	0.16
Aug	26.5	19.	0.05	25.	****	****	26.8	19.	15.	****
Sep	0.06	0.06	0.95	0.66	0.61	0.26	0.93	0.36	1.10	0.45
Oct	0.61	****	0.54	0.09	****	****	0.92	0.56	****	****
Nov	0.07	0.06	0.07	0.08	****	****	****	0.46	0.98	0.28
Dec	0.05	0.08	0.28	****	0.08	****	****	****	0.85	0.51
Jan '82	0.04	0.06	0.40	0.39	****	0.55	0.90	****	****	****
Feb	0.04	<0.04	0.50	0.47	****	****	0.63	****	****	****
Mar	0.06	0.15	1.20	1.19	0.04	****	****	****	****	****
Apr	0.05	0.04	1.25	1.27	****	0.64	****	****	****	****

Note: Coal column leachates were not analyzed for nitrate-nitrogen.

Table A-39. Field data, nitrogen - nitrite;  $\mu\text{g NO}_2\text{-N/liter}$ .

	1A	1B	2A	2B	3	4	5A	5B	6A	6B
May '81	2	2	<2	<2	****	****	25	15	2	<2
Jun	3	2	<2	<2	<2	6	24	15	13	<2
Jul	5	5	<2	<2	****	****	27	27	2	<2
Aug	10	9	2	1	****	****	30	25	6	****
Sep	3	2	2	3	<2	13	34	16	3	<2
Oct	4	****	2	2	****	****	21	15	****	****
Nov	3	3	9	8	****	****	****	<2	4	<2
Dec	6	5	18	****	<2	****	****	****	6	<2
Jan '82	<2	<2	<2	<2	****	11	34	****	****	****
Feb	<2	<2	7	6	****	****	2	****	****	****
Mar	21	57	7	7	7	****	****	****	****	****
Apr	18	16	2	<2	****	80	****	****	****	****

Note: Coal column leachates were not analyzed for nitrite-nitrogen.

Table A-40. Field data, phosphorus - orthophosphate;  $\mu\text{g PO}_4\text{-P/liter}$ .

	1A	1B	2A	2B	3	4	5A	5B	6A	6B
May '81	<10	<10	<10	<10	****	****	<10	<10	<10	<10
Jun	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Jul	<10	<10	<10	<10	****	****	<10	24	27	12
Aug	<10	<10	<10	<10	****	****	<10	<10	<10	****
Sep	<10	<10	<10	<10	<10	<10	<10	<10	<10	16
Oct	<10	****	<10	<10	****	****	<10	<10	****	****
Nov	<10	<10	<10	<10	****	****	****	37	<10	<10
Dec	<10	<10	<10	****	<10	****	****	****	<10	10
Jan '82	<10	<10	<10	<10	****	<10	<10	****	****	****
Feb	<10	<10	<10	<10	****	****	<10	****	****	****
Mar	<10	<10	<10	<10	<10	****	****	****	****	****
Apr	<10	<10	<10	<10	****	<10	****	****	****	****

Note: Coal column leachates were not analyzed for orthophosphate.

Table A-41. Field data, phosphorus - total;  $\mu\text{g P/liter}$ .

	1A	1B	2A	2B	3	4	5A	5B	6A	6B
May '81	8	15	17	<10	****	****	67	42	<10	<10
Jun	<10	<10	15	<10	<10	<10	<10	<10	<10	<10
Jul	<10	29	<10	35	****	****	<10	89	82	23
Aug	23	27	30	17	****	****	15	29	126	****
Sep	122	110	32	24	<10	32	10	19	57	<10
Oct	186	****	38	27	****	****	55	54	****	****
Nov	120	151	100	34	****	****	****	37	74	39
Dec	81	62	24	****	<10	****	****	****	40	121
Jan '82	30	30	64	31	****	26	25	****	****	****
Feb	****	****	****	****	****	****	****	****	****	****
Mar	35	42	40	21	<10	****	****	****	****	****
Apr	49	52	36	22	****	86	****	****	****	****

Note: Coal column leachates were not analyzed for total phosphorus.

ORGANICS:

Table A-42a. Field data, carbon, total organic; mg C/liter.

	1A	1B	2A	2B	3	4	5A	5B	6A	6B
May '81	2.0	0.7	4.7	1.2	****	****	9.1	2.9	1.9	<0.5
Jun	35.5	****	****	****	12.4	27.4	****	****	****	****
Jul	8.3	7.2	4.6	1.6	****	****	2.4	22.2	9.0	1.5
Aug	9.0	7.8	2.4	****	****	****	7.2	3.8	3.4	****
Sep	23.0	7.6	7.6	15.7	19.1	6.2	2.4	<0.5	9.2	9.5
Oct	13.9	****	7.9	2.4	****	****	2.4	4.8	****	****
Nov	7.6	10.1	4.4	10.6	****	****	****	****	3.7	6.9
Dec	6.9	5.7	1.4	****	3.4	****	****	****	5.3	3.9
Jan '82	15.4	29.0	7.3	52.3	****	2.0	1.0	****	****	****
Feb	1.8	33.4	7.4	1.6	****	****	9.9	****	****	****
Mar	10.0	7.2	10.3	6.2	2.7	****	****	****	****	****
Apr	5.1	6.2	8.0	3.1	****	15.5	****	****	****	****

Table A-42b. Leachate column data, carbon, total organic; mg C/liter.

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10
Medium 1	<0.5	****	4.2	****	0.6	****	0.6	****	0.9	****
Col 1-1	4.1	1.7	6.6	2.2	1.2	2.4	<0.5	2.5	<0.5	2.1
Col 1-2	3.4	12.2	3.4	6.2	1.1	4.3	****	3.1	0.9	0.9
Col 1-3	6.0	6.8	1.3	7.7	0.8	5.7	0.9	1.4	10.0	0.7
Col 2-1	4.0	1.1	5.4	3.9	2.8	13.9	2.9	2.5	1.1	2.0
Col 2-2	3.0	2.5	6.5	6.9	3.0	4.4	<0.5	2.8	0.8	<0.5
Col 2-3	5.2	2.1	1.9	6.6	6.9	10.4	2.4	2.8	1.3	1.1
Col 3-1	10.0	8.2	7.5	4.2	7.7	3.7	3.0	4.3	2.9	<0.5
Col 3-2	9.6	7.2	5.6	6.2	4.5	9.0	3.2	4.8	2.9	2.3
Col 3-3	10.2	9.4	10.5	4.9	5.2	6.5	3.6	4.6	4.2	2.3
Col 4-1	2.6	<0.5	<0.5	<0.5	<0.5	0.8	0.8	7.9	1.7	2.9
Col 4-2	1.5	<0.5	10.4	<0.5	<0.5	<0.5	<0.5	****	2.3	1.4
Col 4-3	2.7	<0.5	0.8	<0.5	<0.5	<0.5	0.6	1.1	1.9	1.9
Col 5-1	10.8	1.5	1.4	0.8	0.6	1.0	1.2	2.4	2.3	1.5
Col 5-2	11.4	1.2	1.6	0.8	0.7	1.4	1.1	1.2	1.7	1.8
Col 5-3	11.8	1.7	1.8	7.0	1.2	1.2	1.3	1.3	2.2	2.3
Col 6-1	3.0	<0.5	<0.5	<0.5	<0.5	0.7	0.6	4.1	1.7	2.3
Col 6-2	7.3	<0.5	1.2	1.9	<0.5	2.1	2.1	1.5	2.5	1.6
Col 6-3	9.7	0.7	1.0	1.2	<0.5	0.6	0.8	0.9	1.7	2.4
Medium 2	1.0	****	<0.5	****	0.6	****	3.0	****	3.4	****

Table A-43. Field data, oil and grease; mg/liter.

	1A	1B	2A	2B	3	4	5A	5B	6A	6B
May '81	14.9	11.8	****	8.4	****	****	5.3	14.3	8.2	3.5
Jun	1.2	1.5	4.5	2.9	<1.0	1.5	2.5	2.7	3.5	2.9
Jul	5.5	1.6	<1.0	11.2	****	****	<1.0	<1.0	<1.0	1.0
Aug	1.3	5.1	6.6	<1.0	****	****	11.8	10.8	5.6	****
Sep	7.9	10.4	18.3	35.0	8.5	33.3	22.5	60.3	8.3	38.0
Oct	****	****	****	****	****	****	****	****	****	****
Nov	3.5	2.7	<1.0	<1.0	****	****	****	<1.0	<1.0	****
Dec	1.3	3.0	<1.0	****	<1.0	****	****	****	<1.0	1.5
Jan '82	1.8	7.4	<1.0	<1.0	****	7.6	2.2	****	****	****
Feb	<1.0	<1.0	<1.0	<1.0	****	****	41.3	****	****	****
Mar	1.1	<1.0	<1.0	<1.0	<1.0	****	****	****	****	****
Apr	1.0	3.7	2.9	<1.0	****	3.9	****	****	****	****

Note: Coal column leachates were not analyzed for oil and grease.

For trihalomethane (THM) data, Tables 44-48:

1. Legend - inst. THM/MTP THM - where: inst. THM = instantaneous THM

MTP THM = maximum total potential THM

2. Where one asterisk (\*) appears for MTP THM, this indicates that there was no chlorine residual remaining in the sample when it was analyzed. If chlorine residual had been present, the analyzed values could well have been higher.

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Table A-44. Field data, trihalomethanes - chloroform, instantaneous and maximum total potential;  $\mu\text{g CHCl}_3/\text{liter}$ .

	1A	1B	2A	2B	3	4	5A	5B	6A	6B
May '81	<1/151	<1/<1	<1/****	<1/96	****/****	****/****	<1/340	<1/199	<1/99	<1/28
Jun	<1/97*	<1/168	****/49	<1/80	<1/21	<1/65	<1/****	<1/37	****/93*	<1/14
Jul	****/****	****/****	****/****	****/****	****/****	****/****	****/****	****/****	****/****	****/****
Aug	****/****	****/****	****/****	****/****	****/****	****/****	****/****	****/****	****/****	****/****
Sep	<1/90*	<1/135*	<1/62	<1/40*	<1/<1*	<1/59	<1/20	<1/34	<1/94	<1/42
Oct	****/****	****/****	****/****	****/****	****/****	****/****	****/****	****/****	****/****	****/****
Nov	****/****	****/****	****/****	****/****	****/****	****/****	****/****	****/****	****/****	****/****
Dec	<1/545	<1/700	<1/95	****/****	<1/37	****/****	****/****	****/****	<1/340	<1/165
Jan '82	****/****	****/****	****/****	****/****	****/****	<1/175	<1/350	****/****	****/****	****/****
Feb	****/****	****/****	****/****	****/****	****/****	****/****	****/****	****/****	****/****	****/****
Mar	<1/254*	<1/260	<1/218	<1/130	<1/31	****/****	****/****	****/****	****/****	****/****
Apr	****/****	****/****	****/****	****/****	****/****	****/****	****/****	****/****	****/****	****/****

Note: Coal column leachates were not analyzed for chloroform.

Table A-45. Field data, trihalomethanes - dichlorobromomethane, instantaneous and maximum total potential;  $\mu\text{g CHBrCl}_2/\text{liter}$ .

	1A	1B	2A	2B	3	4	5A	5B	6A	6B
May '81	<1/17	<1/<1	<1/*****	<1/16	*****/*****	*****/*****	<1/7	<1/2	<1/7	<1/7
Jun	<1/15*	<1/17	*****/18	<1/25	<1/4	<1/16	<1/*****	<1/12	*****/13*	<1/7
Jul	*****/*****	*****/*****	*****/*****	*****/*****	*****/*****	*****/*****	*****/*****	*****/*****	*****/*****	*****/*****
Aug	*****/*****	*****/*****	*****/*****	*****/*****	*****/*****	*****/*****	*****/*****	*****/*****	*****/*****	*****/*****
Sep	<1/20*	<1/20*	<1/14	<1/10*	<1/<1*	<1/10	<1/8	<1/7	<1/8	<1/12
Oct	*****/*****	*****/*****	*****/*****	*****/*****	*****/*****	*****/*****	*****/*****	*****/*****	*****/*****	*****/*****
Nov	*****/*****	*****/*****	*****/*****	*****/*****	*****/*****	*****/*****	*****/*****	*****/*****	*****/*****	*****/*****
Dec	<1/22	<1/26	<1/15	*****/*****	<1/8	*****/*****	*****/*****	*****/*****	<1/10	<1/10
Jan '82	*****/*****	*****/*****	*****/*****	*****/*****	*****/*****	<1/15	<1/15	*****/*****	*****/*****	*****/*****
Feb	*****/*****	*****/*****	*****/*****	*****/*****	*****/*****	*****/*****	*****/*****	*****/*****	*****/*****	*****/*****
Mar	<1/19*	<1/23	<1/20	<1/24	<1/9	*****/*****	*****/*****	*****/*****	*****/*****	*****/*****
Apr	*****/*****	*****/*****	*****/*****	*****/*****	*****/*****	*****/*****	*****/*****	*****/*****	*****/*****	*****/*****

Note: Coal column leachates were not analyzed for dichlorobromomethane.

Table A-46. Field data, trihalomethanes - dibromochloromethane, instantaneous and maximum total potential;  $\mu\text{g CHBr}_2\text{Cl}/\text{liter}$ .

	1A	1B	2A	2B	3	4	5A	5B	6A	6B
May '81	<1/5	<1/<1	<1/*****	<1/6	*****/*****	*****/*****	<1/<1	<1/<1	<1/1.4	<1/3
Jun	<1/4*	<1/4	*****/8	<1/10	<1/<1	<1/4	<1/*****	<1/5	*****/<1*	<1/4
Jul	*****/*****	*****/*****	*****/*****	*****/*****	*****/*****	*****/*****	*****/*****	*****/*****	*****/*****	*****/*****
Aug	*****/*****	*****/*****	*****/*****	*****/*****	*****/*****	*****/*****	*****/*****	*****/*****	*****/*****	*****/*****
Sep	<1/10*	<1/5*	<1/6	<1/10*	<1/<1*	<1/3	<1/4	<1/3	<1/<1	<1/4
Oct	*****/*****	*****/*****	*****/*****	*****/*****	*****/*****	*****/*****	*****/*****	*****/*****	*****/*****	*****/*****
Nov	*****/*****	*****/*****	*****/*****	*****/*****	*****/*****	*****/*****	*****/*****	*****/*****	*****/*****	*****/*****
Dec	<1/10	<1/6	<1/5	*****/*****	<1/2	*****/*****	*****/*****	*****/*****	<1/<1	<1/4
Jan '82	*****/*****	*****/*****	*****/*****	*****/*****	*****/*****	<1/3	<1/5	*****/*****	*****/*****	*****/*****
Feb	*****/*****	*****/*****	*****/*****	*****/*****	*****/*****	*****/*****	*****/*****	*****/*****	*****/*****	*****/*****
Mar	<1/5*	<1/7	<1/9	<1/8	<1/3	*****/*****	*****/*****	*****/*****	*****/*****	*****/*****
Apr	*****/*****	*****/*****	*****/*****	*****/*****	*****/*****	*****/*****	*****/*****	*****/*****	*****/*****	*****/*****

Note: Coal column leachates were not analyzed for dibromochloromethane.



Table A-47. Field data, trihalomethanes - bromoform, instantaneous and maximum total potential;  $\mu\text{g CHBr}_3/\text{liter}$ .

	1A	1B	2A	2B	3	4	5A	5B	6A	6B
May '81	<1/<1	<1/<1	<1/****	<1/<1	****/****	****/****	<1/<1	<1/<1	<1/<1	<1/<1
Jun	<1/<1*	<1/<1	****/<1	<1/<1	<1/<1	<1/<1	<1/****	<1/<1	****/<1*	<1/<1
Jul	****/****	****/****	****/****	****/****	****/****	****/****	****/****	****/****	****/****	****/****
Aug	****/****	****/****	****/****	****/****	****/****	****/****	****/****	****/****	****/****	****/****
Sep	<1/<1*	<1/<1*	<1/<1	<1/<1*	<1/<1*	<1/<1	<1/<1	<1/<1	<1/<1	<1/<1
Oct	****/****	****/****	****/****	****/****	****/****	****/****	****/****	****/****	****/****	****/****
Nov	****/****	****/****	****/****	****/****	****/****	****/****	****/****	****/****	****/****	****/****
Dec	<1/<1	<1/<1	<1/<1	****/****	<1/<1	****/****	****/****	****/****	<1/<1	<1/<1
Jan '82	****/****	****/****	****/****	****/****	****/****	<1/<1	<1/<1	****/****	****/****	****/****
Feb	****/****	****/****	****/****	****/****	****/****	****/****	****/****	****/****	****/****	****/****
Mar	<1/<1*	<1/<1	<1/<1	<1/<1	<1/<1	****/****	****/****	****/****	****/****	****/****
Apr	****/****	****/****	****/****	****/****	****/****	****/****	****/****	****/****	****/****	****/****

Note: Coal column leachates were not analyzed for bromoform.

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Table A-48. Field data, trihalomethanes - total, instantaneous and maximum total potential;  $\mu\text{g T-THM/liter}$ .

	1A	1B	2A	2B	3	4	5A	5B	6A	6B
May '81	<1/173	<1/<1	<1/****	<1/118	****/****	****/****	<1/347	<1/201	<1/107.4	<1/38
Jun	<1/116*	<1/189	****/75	<1/115	<1/25	<1/85	<1/****	<1/54	****/106*	<1/25
Jul	****/****	****/****	****/****	****/****	****/****	****/****	****/****	****/****	****/****	****/****
Aug	****/****	****/****	****/****	****/****	****/****	****/****	****/****	****/****	****/****	****/****
Sep	<1/90*	<1/135*	<1/62	<1/40*	<1/<1*	<1/59	<1/32	<1/44	<1/102	<1/58
Oct	****/****	****/****	****/****	****/****	****/****	****/****	****/****	****/****	****/****	****/****
Nov	****/****	****/****	****/****	****/****	****/****	****/****	****/****	****/****	****/****	****/****
Dec	<1/577	<1/732	<1/115	****/****	<1/47	****/****	****/****	****/****	<1/350	<1/179
Jan '82	****/****	****/****	****/****	****/****	****/****	<1/193	<1/370	****/****	****/****	****/****
Feb	****/****	****/****	****/****	****/****	****/****	****/****	****/****	****/****	****/****	****/****
Mar	<1/278*	<1/290	<1/247	<1/162	<1/43	****/****	****/****	****/****	****/****	****/****
Apr	****/****	****/****	****/****	****/****	****/****	****/****	****/****	****/****	****/****	****/****

Note: Coal column leachates were not analyzed for total trihalomethanes.