

A Study of the Potential for Surface and Ground Water Contamination by Arsenic at the Sunbeam Gold Mine

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ABSTRACT

Sunbeam Mining Corporation has the intention of opening an open pit gold mine with heap leach gold recovery, near Stanley, Idaho. Testing of the spent ore indicated a relatively high arsenic content. Due to the local topographical configuration, the spent ore was planned to be disposed across a small drainage and a lake. During the process of obtaining a permit for spent ore disposal from the federal and state regulatory agencies, concerns about the potential for surface and ground water contamination by the arsenic were expressed. Sunbeam Mining Corporation conducted extensive studies to address the potential for arsenic contamination. These studies consisted of laboratory testing of both geochemical and geotechnical parameters of the spent ore, and the soils underlying the proposed disposal site. Field hydrogeologic and geotechnical investigations were also conducted. Local climatic and hydrologic characteristics were included in the analysis of these data with the use of an IBM PC computer.

Conclusions of studies indicated that although the seepage through the spent ore disposal would contain an elevated dissolved arsenic content, the hydrologic and geochemical characteristics of the site would prevent arsenic migration into the local ground water system. The attenuation of arsenic on soils with high clay content, and dilution after reaching the ground water table would lower the arsenic content to acceptable concentrations.

INTRODUCTION

The Sunbeam Mining Corporation is developing an open pit gold mine using heap leach gold recovery techniques. The mine is located in the central mountain region of Idaho (Figure 1). Testing of the spent ore indicated an elevated arsenic content.

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Arsenic is a common element in the natural environment. Very frequently arsenic is a component of sulfidic ores found in gold deposits. Arsenic is found as arsenides, sulfides and sulfosalts. The most common of these minerals is arsenopyrite. Arsenic is commonly present in igneous and sedimentary rocks with a higher than average content found in sandstones, shales and coals associated with uranium mineralization in Utah, Colorado, Wyoming, and South Dakota. The natural arsenic content in soils varies from 0.1 to 40 mg/k.

A considerable number of studies on arsenic transport in surface and ground water have been performed in connection with mining, waste disposal, industrial pollution and medical research.

SITE CHARACTERISTICS

The Sunbeam mine is located in Central Mountain Division climatic region. The project site is located within the Pinyon Creek Basin at an elevation of 2,000 m above sea level. Pinyon Creek is of perennial character within the area of the proposed spent ore disposal. A total annual volume of water available for infiltration into the waste pile from rainfall and snowmelt was calculated as 58.2 cm/year based on climatological data for the general project area. Most of the water available for infiltration into the spent ore disposal is available in April (5.9 cm) and May (44.2 cm).

Monitoring of water quality at several stations on Pinyon Creek indicated that the water is of calcium bicarbonate type with low concentration of total dissolved solids and with pH ranging from 6.0 to 7.2. The arsenic content in the surface water ranges from <0.005 to 0.031 mg/l for total arsenic and <0.005 to 0.015 mg/l for dissolved arsenic. The project site is located in a small valley named Pinyon Creek Basin and drains into Jordan Creek, Yankey River, and the Salmon River.

The bedrock of Pinyon Basin is composed of Tertiary volcanic rocks of the Challis Volcanic Group. In general, the bedrocks are andesitic and rhyolitic tuffs, with inter-bedded andesite and latite flows. The volcanic bedrocks are covered predominantly with colluvial soils. The thickness of the soils within the area of the proposed spent ore disposal ranges from several meters to over 30 meters. Generally, thicker soil cover is present on the west slope of Pinyon Basin and thinner soil cover is present in the valley bottom. Colluvial soils are composed of a variable mixture of clays with sands, silts and gravels. A high clay content is characteristic for all tested soil samples within the proposed spent ore disposal. A typical geologic composition of the spent ore disposal site is shown on Figure 2.

Ground water is present in the clayey sands and gravels of the colluvium. The depth to the water table from the ground surface ranges from 0.3 to 14 meters. The ground water is closer to the surface at the valley bottom and deeper on the valley slopes. Ground water flow follows the local topography.

A total of fourteen field permeability tests, falling head or slug tests, and seven infiltration tests were performed within the area of

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the proposed spent ore disposal site. Three falling head tests tested horizontal and eleven tested vertical hydraulic conductivity of the colluvial soils and bedrock. The results of testing indicated the following average values of hydraulic conductivity :

Colluvium :	Unsaturated, Vertical, $K = 6.5 \times 10^{-3}$ cm/sec
	Saturated, Horizontal, $K = 1.0 \times 10^{-4}$ cm/sec
Bedrock:	Unsaturated, Vertical, $K = 2.2 \times 10^{-3}$ cm/sec

The average value of infiltration rate in the upper portion of the colluvial soils is 9.2×10^{-3} cm/sec.

SEEPAGE THROUGH THE SPENT ORE

During rainfall or snowmelt water will percolate through the waste piles in a vertical direction until it reaches an impermeable strata or water table. Due to the physical properties of the waste material and the total availability of rainfall or snowmelt respectively, the water percolation through the waste material will have the character of unsaturated flow.

Physical properties of the spent ore were verified by a series of grain size and slake durability tests. Grain size analysis of the spent ore indicated that this material is composed of the following particles: 60% sand particles; 24% silt particles; 16% clay particles.

Available grain size analyses of the spent ore were applied to estimate permeability (hydraulic conductivity) of the spent ore using the Hazen method (1). Results of such calculations are approximate since this formula ignores uniformity and density, which are important determinants of permeability. The average hydraulic conductivity from several grain size analyses indicated a value of $K = 0.26$ cm/sec.

Because of the high permeability of the waste material it was assumed that all water available from direct precipitation and snowmelt on top of the disposal, during construction and after cessation of mining, would infiltrate into the waste material. Most of the direct precipitation and snowmelt on the steep slopes of the waste disposal would contribute to the runoff.

An analysis of the unsaturated flow through the spent ore and colluvium was performed using a method published by McWhorter and Nelson (2). Configurations of the spent ore disposal after 5 years of mining were considered in calculating the duration of vertical flow. A seepage rate of $q = 0.26$ cm³/sec per cm² was calculated. At this rate of seepage, the volumetric water content (O_f) behind the wetting front would be approximately $O_f = 0.40$ and the duration of vertical flow (advancement of wetting front through 15 meters of waste) would be approximately $T = 34.2$ min, or 2.28 min/meter.

The seepage conditions would change after completion of mining and final reclamation of the waste disposal. However, due to the lack of top soil in the project area the final reclamation will not substantially alter the rate of infiltration of the available water into the waste disposal.

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After the seepage through the spent ore and unsaturated portion of colluvium would reach the water table in the colluvium the vertical direction of flow would change to horizontal. The horizontal component of flow direction follows the local topography. Using an average value of horizontal permeability in the colluvial strata ($K = 1 \times 10^{-4}$ cm/sec) the hydraulic gradient of the Pinyon Creek stream bed and assuming an average porosity of colluvial strata as 20 percent the velocity of flow would be only, $v = 3.2 \times 10^{-5}$ cm/sec.

ARSENIC TRANSPORT

Equilibrium Soluble Mass (ESM) column leach test on spent ore performed by ACZ, Inc., indicated that water percolating through the spent ore will contain a relatively high arsenic content. The leachate concentration of arsenic reached a peak of 5.2 mg/l at flushing of the sample by 1.05 to 1.58 pore volumes. After this peak, the concentration of arsenic decreased to 1.7 mg/l at 7.35 to 10.5 pore volumes.

Results of this test were used for calculation of leaching potential of the spent ore over the projected mine life and after cessation of mining. Using the quantities of spent ore disposed on the waste pile, its pore volume and available water for infiltration, a seepage scenario was computer generated and a plot was developed (Figure 3).

Results of calculations indicated that at the end of mining only 0.3 of the first pore volume would be flushed and therefore the peak concentration of arsenic in the leachate will not be reached by the end of year 11. The peak concentration of 5.2 mg/l will be reached approximately after 31 years from the beginning of waste disposal. After about 316 years, 10 pore volumes of the disposed waste would be flushed and the arsenic concentration would decrease to 1.28 mg/l. However, these arsenic concentrations would never reach the ground water system. Geochemical reactions between the leachate solution and colluvial soils underneath the waste disposal would substantially decrease the arsenic concentrations. Even without geochemical reactions the arsenic concentration would be diluted in the local ground water system by the recharge potential within the Pinyon Creek Basin.

The presented calculations should be considered as a worst case scenario for the following reasons:

- o leaching of arsenic in the waste disposal will never be as effective as in laboratory column tests, because development of channel permeability will decrease the leachability of the arsenic;
- o clay content in the waste material (16%) and high sodium content will cause sodium ion exchange and in the long term will decrease the permeability of waste and colluvial materials;
- o consolidation of the waste disposal materials with time will decrease the permeability of the waste material.

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GEOCHEMICAL CONTROL OF ARSENIC MIGRATION

Laboratory testwork conducted by ACZ, Inc. indicated that a water-soluble form of arsenic is present in the spent ore and that this arsenic would leach from waste material. As discussed previously, the seepage solutions from a waste disposal facility contain excessive concentrations of arsenic. Arsenic concentrations in that range would be of concern to regulatory agencies.

A possible alternative approach to metallurgical treatment or an impermeable liner system was to demonstrate that any seepage of arsenic from the spent ore disposal would not affect surface or ground water quality at the project site. This condition could occur if the site geochemistry is favorable.

Four soil samples representing the typical colluvial soils from the Pinyon Creek Basin study area were chosen for geochemical testwork and characterization. In order to profile the geochemical properties of the Pinyon Creek Basin soils, samples were analyzed for the following parameters: cation-exchange capacity and exchangeable cations, organic carbon content and acid-soluble iron, manganese and pH.

Cation-exchange was measured by using the sodium acetate extraction procedure; exchangeable bases were determined by using a soluble cation extraction procedure and an ammonium acetate extraction procedure in combination.

Although the amount of clay-size material reported in each sample was between 18 and 43 percent, the cation-exchange capacity of the soils and colluvium was relatively low, ranging between 11.1 and 16.75 meq/100 g. The predominant exchangeable cation appears to be calcium. The results suggest that the principal clay-mineral phase is at least partially calcium- or hydrogen-saturated. The reported cation-exchange capacities are reasonable considering that the principal clay-mineral phase is illite (3). Typically, the cation-exchange capacity of illite clay is intermediate between kaolinite and montmorillonite.

Organic carbon was calculated by determining total carbon in the samples as carbon dioxide and subtracting the inorganic fraction. The amount of iron and manganese hydrous-oxides present in each sample was estimated by soaking the sample in dilute hydrochloric acid and measuring the amounts of iron and manganese that were solubilized in the process.

Aside from one carbonaceous sample, the soils in colluvium are somewhat low in organic carbon content. The presence of acid-soluble iron usually indicate the presence of iron hydrous-oxides. The elevated iron results suggest that traces of iron hydrous-oxides may be present as impurities in the subsurface material. Of the four materials tested, only one sample showed the least acid-soluble iron.

GEOCHEMICAL INTERACTIONS

Overall, the Pinyon Creek Basin samples showed favorable geochemical properties which suggests that subsurface material at the site can interact with arsenic-containing seepage. These interactions can lead to removal of soluble arsenic from solution.

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In all likelihood, the bulk of the arsenic in any seepage will be in the +5 oxidation state and in the monovalent arsenate ($\text{H}_2\text{AsO}_4^{1-}$) form. Arsenic (V) undergoes exchange with montmorillonite and kaolinite best in the pH range between about 3 and 7. In this pH range the $\text{H}_2\text{AsO}_4^{1-}$ anion predominates and appears to be the principal species that is adsorbed by clay minerals through a mechanism called anion exchange. The tetrahedral H_2AsO_4^- anion can align itself with the silica tetrahedron of the clay lattice and can form an extension of the crystal lattice. Montmorillonite clay has roughly twice as much edge area as kaolinite and adsorbs about twice as much arsenic as kaolinite clay (4).

In addition to anion exchange with clay minerals, the arsenic in the seepage is likely to undergo adsorption and precipitation reactions with soil impurities. Arsenic will be adsorbed into hydrous oxides of iron and manganese and will be precipitated as insoluble arsenates by metals such as iron, copper, or zinc, and even by calcium and magnesium. Under mildly reducing conditions especially in the presence of soil organic matter, arsenic in the +3 oxidation state may precipitate as a sulfide.

COLUMN TESTWORK

Column tests were conducted by ACZ, Inc. to demonstrate whether Pinyon Creek Basin soils and colluvium would trap arsenic and prevent its movement in the subsurface. Four columns 10 cm in diameter were packed to a height of 30 cm with the Pinyon Creek Basin samples. Actual spent-ore leachate containing at least 1.33 mg/l arsenic was injected through each column at a rate of about 1 ml/min. Effluent from each column was collected, sampled and analyzed for arsenic content.

The changes in arsenic concentration with each pore volume of solution throughput are shown in Figure 4 as a function of the pore fraction of leachate passed through each soil column. Over 8.5 pore volumes, better than 90 percent of the arsenic which came in contact with sample 86-T2 was removed from solution. About 75 percent of the arsenic in contact with the sample 86-T4 and 86-T3 was being removed from solution after 9.5 and 8 pore volumes of throughput, respectively. Sample 83-T1 was least effective at trapping arsenic. However, after 10 pore volumes of throughput about 50 percent of the arsenic was being removed from solution. Not surprisingly, sample 83-T1 reported the lowest organic carbon and acid-soluble iron analyses of the 4 samples.

The amount of arsenic that was removed from solution was related to the pH of the soil or colluvium. Sample 86-T2 was the most acidic of the 4 soils tested and was the most effective at neutralizing the alkalinity (pH 8.3) of the column feed solution. The effluent which was produced from this sample ranged between pH 4.8 and 6.4. In this slightly-acid range, arsenate adsorption by clay minerals is maximized (4).

CONCLUSIONS

The conclusion of our studies was that in a worst case scenario the maximum arsenic content in the ground water of the Pinyon Creek Basin could reach approximately 0.18 mg/l. This arsenic content would be further diluted after reaching the ground water system of Jordan Creek. With additional dilution in the Jordan Creek alluvium the maximum

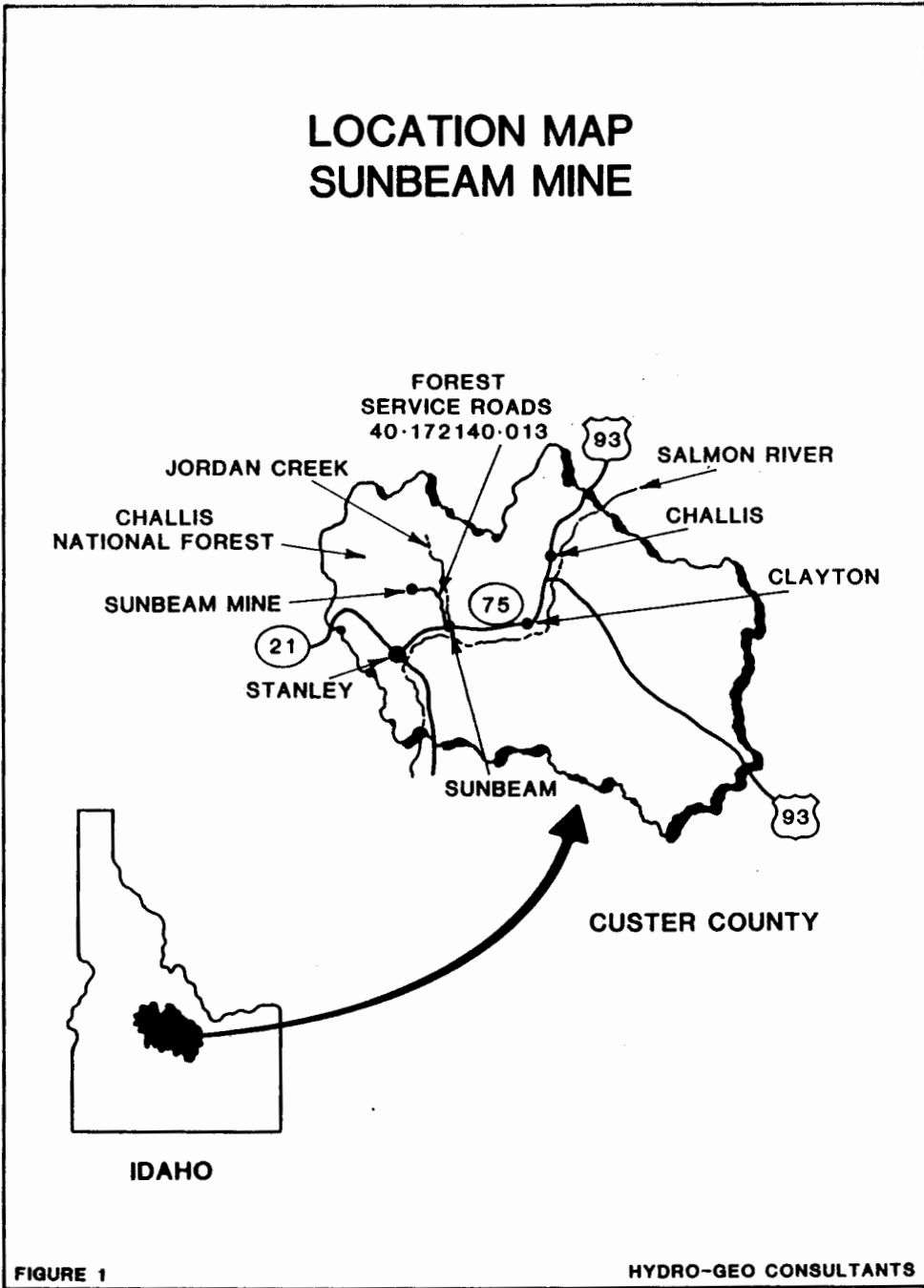
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arsenic concentration in the ground water system would decrease to approximately 0.002 mg/l (Figure 3). This concentration is well below the EPA Primary Drinking Water Standard of 0.05 mg/l of arsenic.

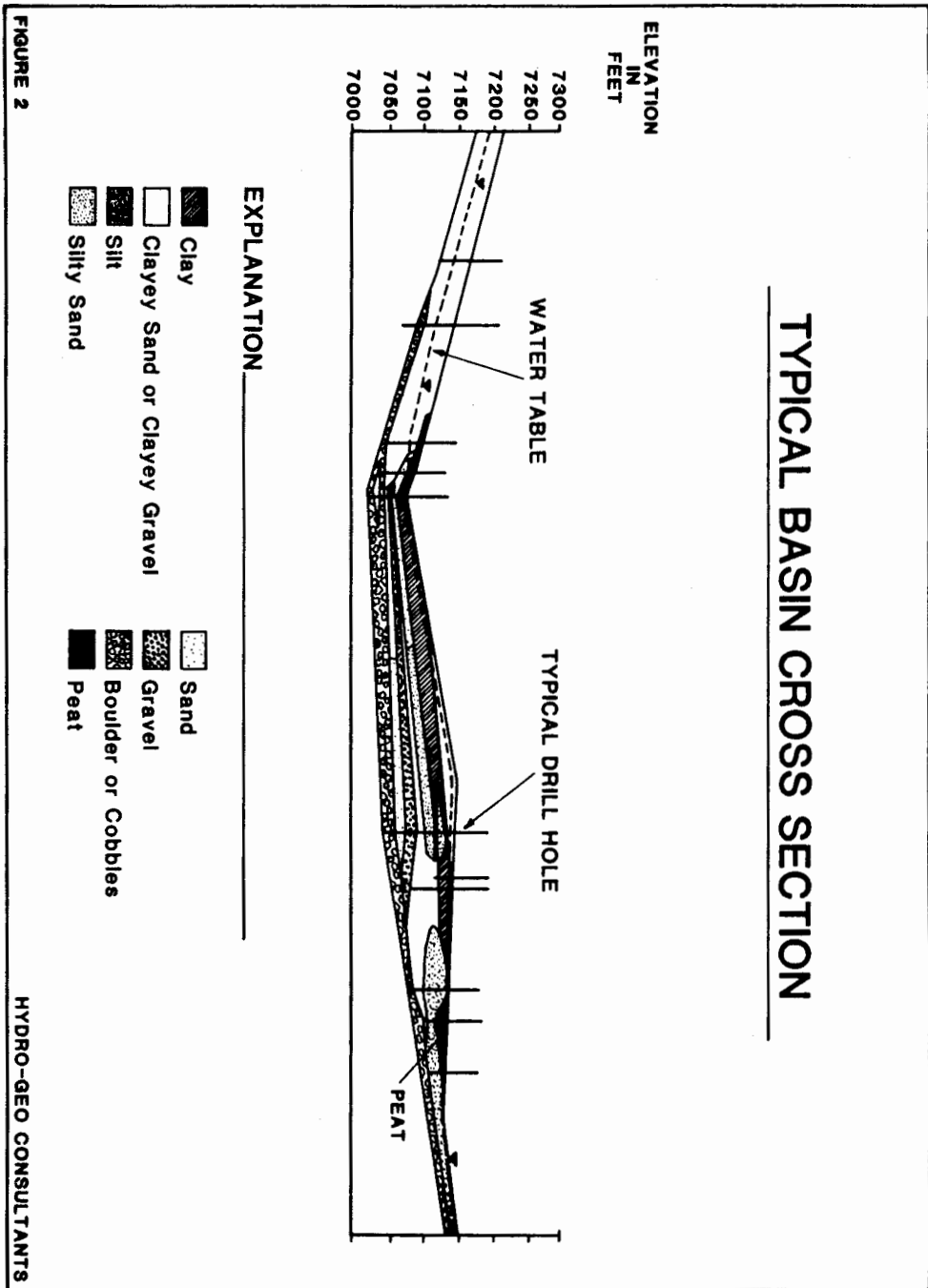
Our worst case scenario was founded in the results of spent-ore leaching tests and arsenic attenuation tests which in themselves are very conservative. This conservatism introduces one additional environmental safeguard against arsenic contamination of the Jordan Creek ground water system.

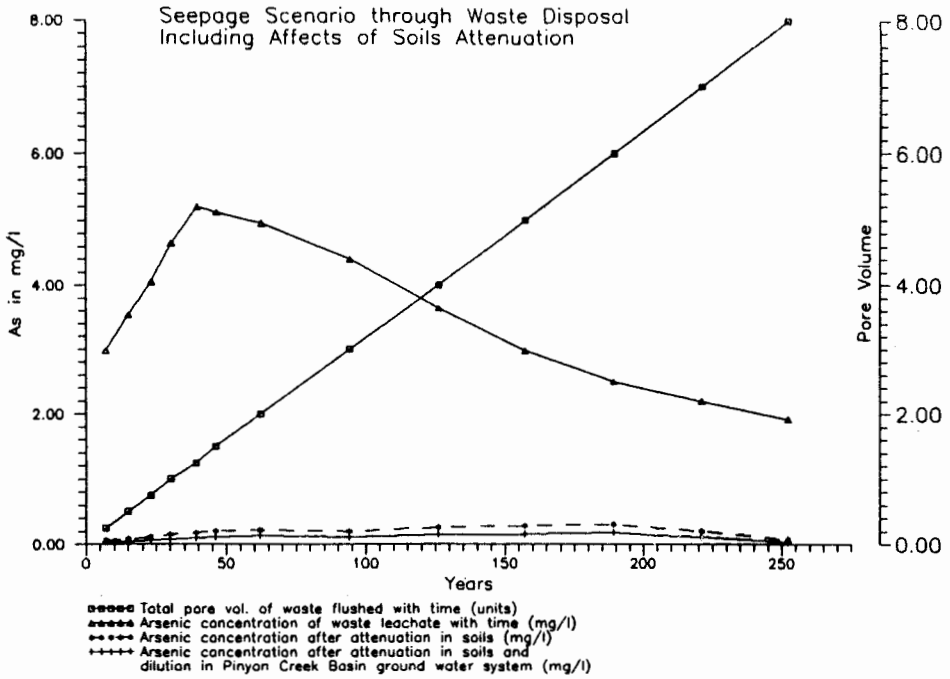
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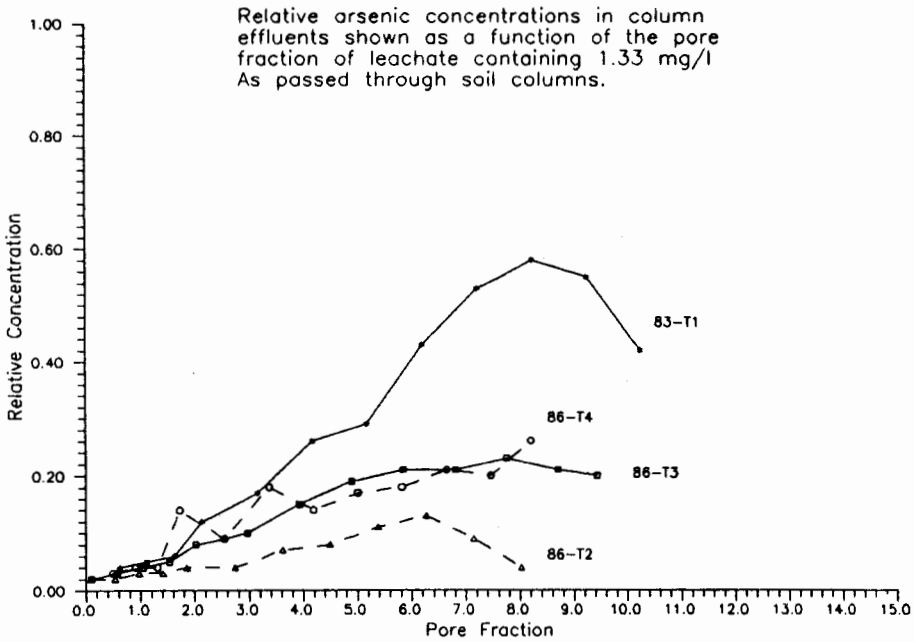


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HYDRO-GEO CONSULTANTS FIGURE 3



HYDRO-GEO CONSULTANTS FIGURE 4