Mine Water and The Environment, Vol 11, No 4, December 1992, pp 23-34

HYDROGEOLOGICAL EVALUATION OF A PROTOTYPE IN-SITU LEACH CELL IN UNSATURATED LEAD-ZINC MINE AND MILL WASTES

Roy E. Williams and Frederick E. Kirschner, Jr.

Department of Geology and Geological Engineering
University of Idaho
Moscow, Idaho, U.S.A.

ABSTRACT

An abandoned waste impoundment located within a portion of the Bunker Hill Superfund Site constitutes a field research area for studying the feasibility of recovering heavy metals in-situ from unsaturated mine and mill wastes. A prototype in-situ leaching cell has been evaluated using liquid-phase tracer tests and other hydrogeologic tests prior to introducing a lixiviant. The results of the tests suggest that: 1) the cell can be operated excursion-free with a low-density lixiviant at an injection/withdrawal rate of approximately 0.32 Vs; and (2) each hydrogeologic unit is highly heterogeneous at the different scales studied.

INTRODUCTION

The Bunker Hill Superfund site occupies approximately 54 square kilometres within the Coeur d'Alene mining district of northern Idaho (Figure 1). The Superfund site is the result of 100 years of controlled and uncontrolled disposal of mining, milling, and smelting wastes. Over 20 lead, zinc, and silver mines have operated within the district. Owing to the steep topography and relatively small amounts of level land found within the district, early mine and mill wastes were disposed predominantly in the South Fork of the Coeur d'Alene River.

Smelterville Flats occupies approximately 13 square kilometres within the Superfund site and is situated within the floodplain of the South Fork of the Coeur d'Alene River (Figure 1). A tailings impoundment constructed in the early 1900's and subsequently decommissioned in the early 1930's occupies a major portion of Smelterville Flats. Wastes within this impoundment are rich in various heavy metals; they also are a source of airborne particulates. Results of work completed by Kunkel

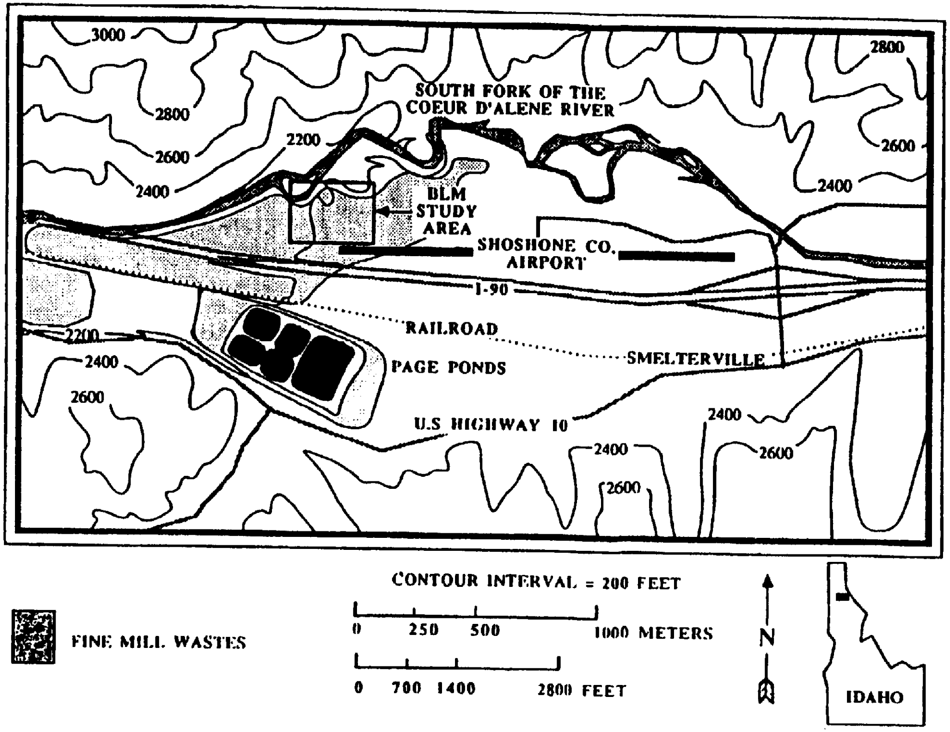

Figure 1. Location of the study area within the Bunker Hill Superfund site and surficial distribution of fine-grained wastes.

(in progress), Dames and Moore (1990), and Adams (1989), suggest that such wastes have degraded the quality of ground water within two underlying aquifers also.

The study proposed herein is a subtask that is required in order to evaluate a new reclamation procedure that was first envisioned in 1989 (Kirschner, 1989). The process involves recovering heavy metals from wastes in-situ using a new application of an existing solution mining technology. The proposed technique described herein differs markedly from current applications in that: (1) the technique is applied to surface mine/mill wastes instead of deep ore deposits; (2) the hydrogeological system is unconfined; and (3) the leach cell is situated in and above an aquifer that is connected hydraulically to a major surface water resource.

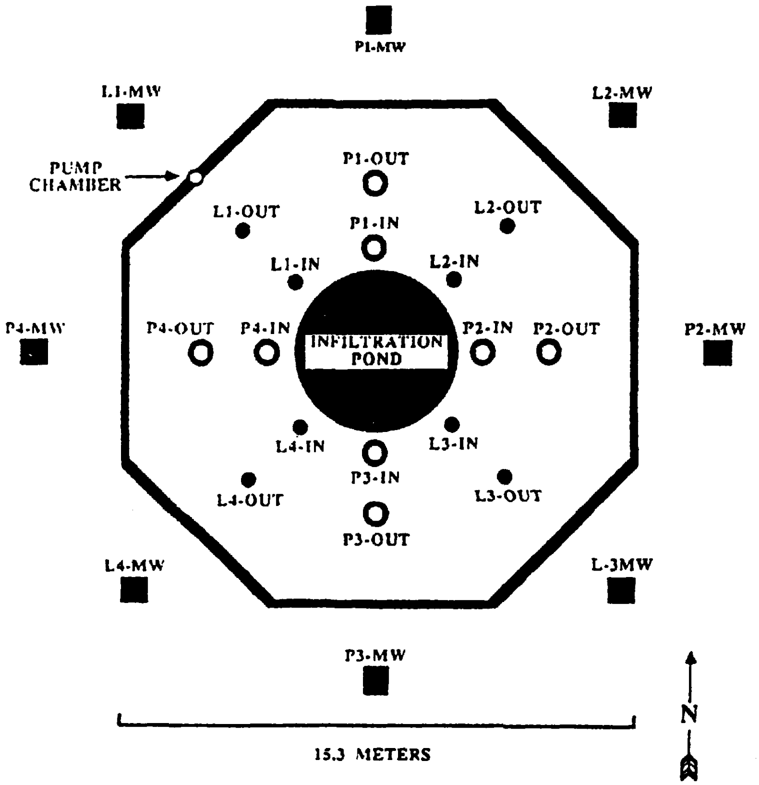

Figure 2. Plan view of the in-situ leach cell showing the location of the drain tile (black octagon), excursion ground water monitoring wells (black squares), lysimeters (black filled circles), and piezometer nests. Nests consist of piezometers completed in the aquifer, grey clayey-silt and sandy-silt units.

The purpose of this investigation is to perform a hydrogeological evaluation of the in-situ leach cell (Figures 2 and 3) via hydraulic stress-testing and liquid-phase tracer testing. The objectives of this investigation are to: (1) develop a conceptual hydrogeological model of the in-situ leach cell when operated at steady-state under nearly saturated conditions; (2) determine whether or not the cell can be operated in an excursion-free manner; and (3) evaluate the current design and associated monitoring system. A variance will be required in order to operate the cell with a lixiviant, in the event that the aforementioned objectives can be achieved.

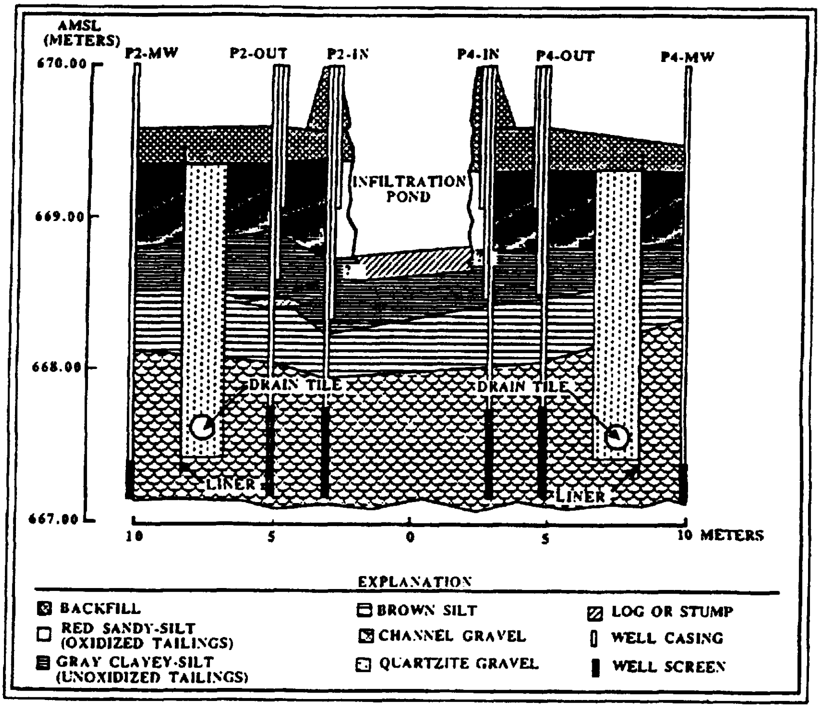

Figure 3. Cross section P2MW-P4MW of the in-situ leach cell depicted in Figure 2.

GENERALIZED HYDROSTRATIGRAPHY OF THE UNITS INVOLVED IN THE LEACHING PROCESS

Four units are involved with the in-situ leach cell (Figure 3). Pleistocene channel gravel constitutes the uppermost aquifer of the region. The aquifer is unconfined during a major portion of the year. A very recent and relatively thin, brown, silty deposit overlies the gravel. The brown silt deposit acts as an upper aquitard for the system during high water-table conditions. The gravel aquifer and the brown silt unit are natural deposits. The two remaining units were deposited in the aforementioned tailings impoundment.

A relatively thin, grey, clayey-silt sized deposit composed predominantly of mill wastes derived from upstream lead, zinc, and silver mining/milling operations lies on top of the aforementioned brown silt deposit. Norton (1980) has shown that this unit is associated with relatively high concentrations of lead and zinc (up to 7.0 and 4.0 percent by weight, respectively).

A relatively thicker, red, sandy-silt sized unit composed of mine/mill wastes overlies the aforementioned grey clayey-silt deposit. This unit also is associated with relatively high concentrations of lead and zinc (up to 5.0 and 3.0 percent by weight, respectively).

The grey clayey-silt and red sandy-silt units are partially saturated throughout most of the year. Recent work by the authors suggests that advectional and diffusional movement of atmospheric oxygen into the wastes oxides pyrite and other metallic sulfide minerals. Acid produced from the oxidation of pyrite enhances the mobility of soluble sulfates (predominantly zinc sulfate) which are subsequently transported downward into the underlying upper aquifer during major infiltration events.

DESIGN CONSIDERATION OF THE PROTOTYPE N-SITU LEACH CELL

The in-situ leach cell depicted in Figures 2 and 3 is designed to recover heavy metals that are present within the unsaturated waste/sediment horizons. The recovery process consists of: (1) enhancing the liquid phase mobility and subsequent transport of such metals by circulating a lixiviant through the sediments that are contained within the Visqueen liner; and (2) using waste-water treatment technologies to reprecipitate metals dissolved in the pregnant lixiviant that is obtained from the cell by pumping the drain tile.

A design that confines the wastes in the horizontal dimensions is thought to minimize the likelihood of creating an excursion during operation. Theoretically, a radially symmetrical design (circular) would have been optimal; however, such a design was unachievable owing to the method of excavation. The horizontal radial dimension of the cell was selected based on the cost of excavating and subsequently backfilling the trench. The sloping drain-tile was set when the elevation of the watertable was at its lowest level. Owing to the hydraulic diffusivity of the upper aquifer as described by Kirschner (1991), a small open area of the drain-tile (10 cm^2/m) is required in order to allow the entire circumference to be effective during operation.

The monitoring devices within the central portion of the cell are constructed concentrically from the infiltration pond in order to facilitate comparisons of hydraulic responses and tracer travel times observed at each radius in each direction. Lysimeters are employed because the degree of saturation of the wastes/sediments was unknown prior to testing.

The excursion monitoring wells located outside of the backfilled trench also are equidistant from the centre of the cell. According to Ralston and Kunkel (1989), the vertical component of the natural hydraulic gradient within the uppermost aquifer is not measurable throughout most of the year. Because of this non-detectable natural vertical gradient and because the flow-paths generated while stressing the aquifer will be very shallow, it is hypothesized that if an excursion were to occur, then it will be detected early in the upper portion of the aquifer. Therefore, shallow wells are used as the excursion warning system. In the event that an excursion is detected in the shallow wells, deep wells constructed by Ralston and Kunkel (1989) will be used to monitor the vertical extent of the plume.

Two hydraulic systems are hypothesized to develop while the cell is operating. The first system is perched within the wastes/sediments. The second system resides within the upper portion of the aquifer. The hypothetical procedure for operating the cell with a lixiviant is as follows: (1) a lixiviant is injected into the infiltration pond (an innocuous tracer is used in this study); (2) a mound develops both in and on top of the previously unsaturated wastes/sediments; (3) specific metals are taken into solution as the mound builds both vertically and horizontally; (4) the pregnant or semi-pregnant lixiviant percolates downward from the base of the perched system to the saturated portion of the aquifer via the unsaturated portion of the aquifer and also travels along the top of the silty wastes and down through the drain-gravel; (S) the lixiviant is recovered by pumping the drain tile; (6) the pregnant lixiviant is stripped; and (7) the lixiviant is rejuvenated and then reinjected into the infiltration pond.

During transient-state conditions the unsaturated front of the mound within the perched system builds laterally until the coarse gravel within the backfilled trench is encountered. As the radius of the phrenetic surface increases with time, the gravel no longer acts as a capillary barrier and saturated flow occurs downward through the gravel toward the drain tile. The mound builds vertically by percolating through the wastes and underlying sediments. Operation of the drain tile in the presence of the Visqueen liner depresses the water table causing horizontal flow to occur from the centre of the cell to the drain tile.

RESULTS Hydraulic Stress-Tests

Six hydraulic stress-tests were performed during the investigation. Three tests were performed on the aquifer (AHST-1, AHST-2, and AHST-3), and three tests were performed on the combined wastes/sediments and the aquifer (CHST-1, CHST-2, and CHST-3). Detailed results of each test are discussed by Kirschner (1991). The aquifer portion of the CHSTs differs from AHSTs in that water is added to the aquifer via gravity drainage during the CHSTs. The AHSTs were conducted under different watertable conditions and different pumping rates. All three CHSTs were conducted under similar watertable conditions and similar pumping rates. Transient-state responses observed during the CHSTs are similar for all three tests (Kirschner,1991). The time required to reach steady-state during the CHSTs is approximately 1200 minutes at a pumping/injection rate of 0.32 Vs.

Tracer Test

An induced hydraulic gradient, constant-source, tracer test was conducted concurrently with the third combined wastes/ sediments and aquifer test (CHST-3). The tracer test consists of: (l) injecting a conservative and a non-conservative tracer simultaneously into the steady-stale system at rates that are controlled so as to maintain constant concentrations of the racers in the pond; and (2) sampling each monitoring device depicted in Figure 2. Bromide (Br -) constitutes the conservative tracer. Sulfur hexafluoride (SF_6) constitutes the non-conservative tracer. The concentrations of both tracers were measured on-site in our mobile laboratory. Bromide ion concentration was measured using an ion specific probe and millivolt meter. Sulfur hexafluoride was measured using a gas chromatographic technique. Both tracers were injected concurrently and continuously for the duration of the test. Specific details including quality assurance and quality control procedures are described by Kirschner (1990).

The primary goals of the test are to determine whether or not the system can be operated in a closed-loop fashion and to evaluate the performance of e excursion monitoring well system. Secondary goals include: (I) verifying the presence of preferentially permeable pathways that were identified during the aforementioned hydraulic testing portion of his study and (2) verifying that the tracer is transported through, and not merely along the top of, the aforementioned grey clayey-silt unit. The results of this test indicate that an excursion probably did not occur. Therefore, the performance of the excursion monitoring well system could not be evaluated during this test.

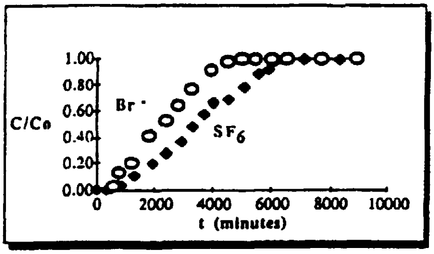

Figure 4. Breakthrough curves of Br- (empty polygons) and SF6 (filled polygons) as observed at the pumped drain tile. Concentrations of each tracer measured (C) are relative to the steady-state concentration in the pond (Co). See Figure 2 for the location of the pumping well.

Differential transport resulting primarily from differences between each of the tracer's abilities to distribute between the aqueous and solid phases is observed (Figure 4). Figure 4 was generated by relating the concentration observed in each monitoring device during a sampling event to the average concentration measured in the pond (6.1 mg/l Br - and 0.9 mg/l SF_6). Elution or break-through curves for each monitoring device are presented in Kirschner (1991); however, for the sake of brevity, only the break-through curve for the drain-tile is shown herein.

Results of the aforementioned hydraulic stress tests during steady-state flow and results of the conservative tracer test (Figure 5) suggest that: (1) the sediments involved in the in-situ leach cell are heterogeneous and anisotropic at the scale of the study and preferential flow-paths are present in all of these units; (2) the majority of flow occurs horizontally in the sandy unit; 3) a small amount of flow occurs vertically in the grey silty unit; and (4) he cell can be operated in an excursion-free manner.

Soil-Gas/Ground-Water Survey Numbers 1 and 2 (SG/GWS-1 and SG/GWS-2)

Soil-gas/ground-water survey No. 1 (SG/GWS-1 was conducted prior to initiating the aforementioned tracer test in order to determine whether or not SF_6 or any halogenated compound was present in background concentrations of soil-gas or ground water that would confound subsequent analyses. The results suggest that no halogenated compounds were present (Figure 6); therefore, SF_6 was determined to be a viable tracer.

The second soil-gas/ground-water survey was conducted during the final stages of the trace test. The tracers were not detected beyond the drain tile. Eight locations on the SG/GWS-1 grid were sampled and 20 locations off of the grid were sampled (Figure 6). All of the aforementioned BLM monitoring wells were sampled also. All of the nodes were not sampled because this survey focused on areas that are located near the cell in order to determine if an excursion occurred that was not identified in the ground-water monitoring network. Water samples were analysed only for SF_6 because: (1) the lower detection limit of SF_6 is much lower than that for bromide; and (2) SF_6 is an anthropogenic tracer that has been demonstrated to be absent prior to initiating the tracer test.

SF_6 was not observed within the excursion ground-water monitoring network, within the BLM wells nor at any of the other locations that were sampled. Owing to the source concentration, the detection limits of the analytical device, and the sampling array, an excursion within the shallow flow system is unlikely.

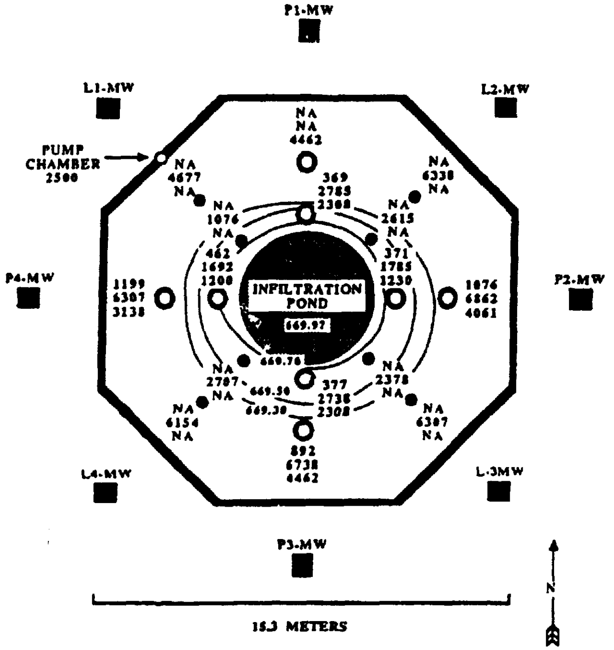

Figure 5. Spatial distribution of break through times (minutes) in the sandy-silt (top value), grey clayey-silt (middle value), and the gravel (bottom value). Steady-state potentiometric surface in the sand unit during CHST-2. Units of the contours are meters AMSL.

Simulated Excursion (SG/GWS-3)

The results of the tracer test and those obtained during SG/GWS-2 indicate that an excursion did not occur. Therefore, the performance of the excursion monitoring well system could not be evaluated with these tests.

The worst case scenario of a total system failure was simulated at the end of the tracer test by turning-off the pump; and allowing the tracers to migrate under a near-natural hydraulic gradient. Ground-water samples were acquired: (1) from all of the excursion monitoring wells, (2) from all of the BLM wells, (3 at all locations on the SG/GWS-1 sampling grid, and (4) at 58 locations off of the SG/GWS- 1 grid. The ground water survey lasted approximately two days and was initiated five days after pumping had ceased.

The plume was delineated in the horizontal dimension (Figure 7) The tracer was observed in six of the excursion monitoring wells and three of the deep BLM wells (BLM-8D, BLM-9D, and BLM-10D). The planimetric boundaries of the plume are bracketed by samples that contain nondetectable (ND) concentrations of SF_6. Sampling density is greater near the cell because more monitoring wells will be completed in this area prior to further testing.

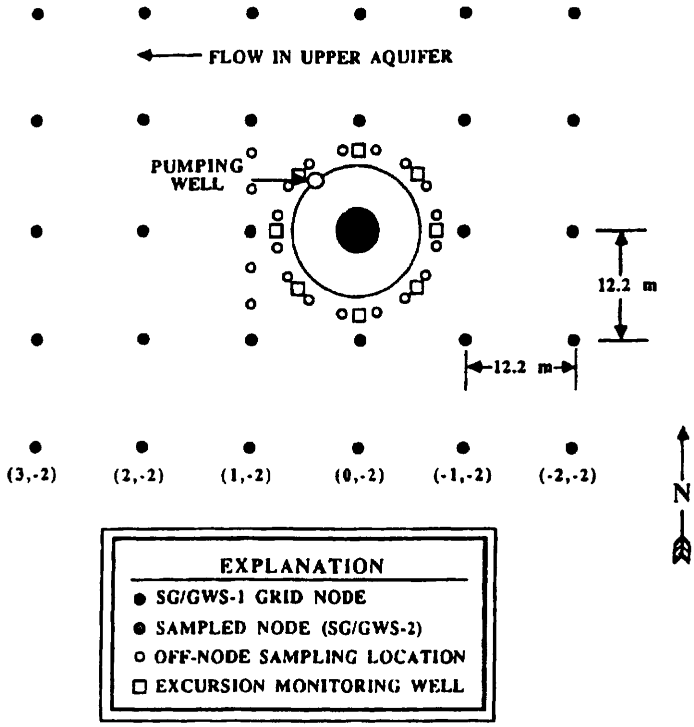

Figure 6. Location of the study area within the Bunker Hill Superfund site and surface distribution of fine-grained wastes.

Two major portions of the plume exist that can be attributed either to a single point source or to multiple point sources. The presence of two portions of the plume that are associated with different rates of transport suggests that either: (1) two plumes originating from two point sources are present, both of which are probably associated with preferential flow-paths within the aquifer or (2) the aquifer cannot be considered as being homogeneously heterogeneous at the scale of the cell.

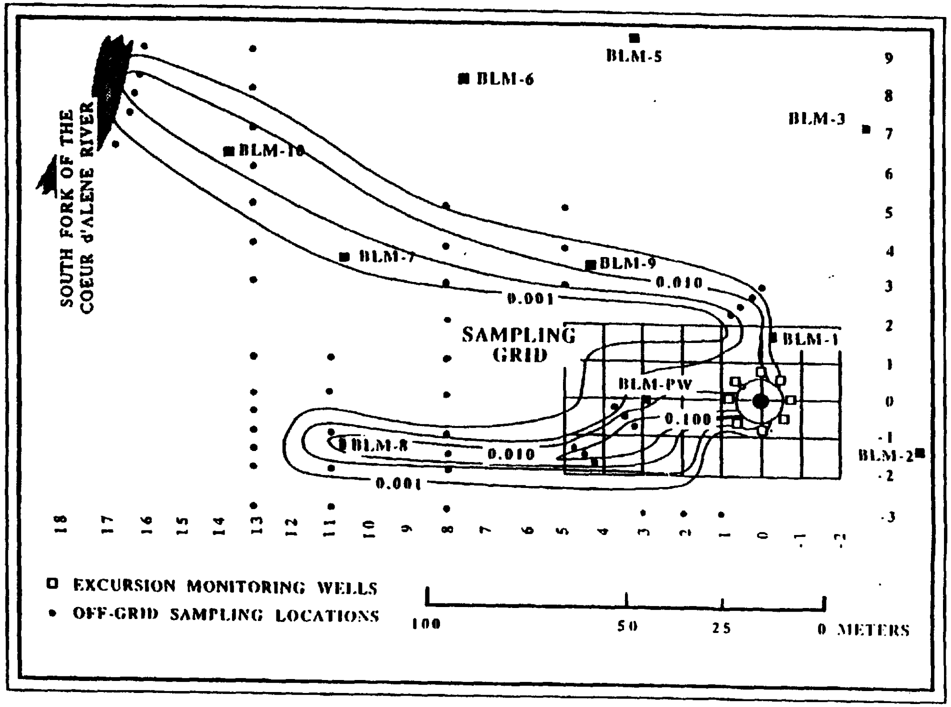

Figure 7. Results of soil-gas/ground-water survey number 3 (SG/GWS-3). Concentrations reported are mg/l SF_6. Shallow and deep BLM wells (black squares), SG/GWS-1 sampling grid (nodes), and off-grid locations (black disks) also are shown. Grid numbering system is Cartesian with axes centered on the pond.

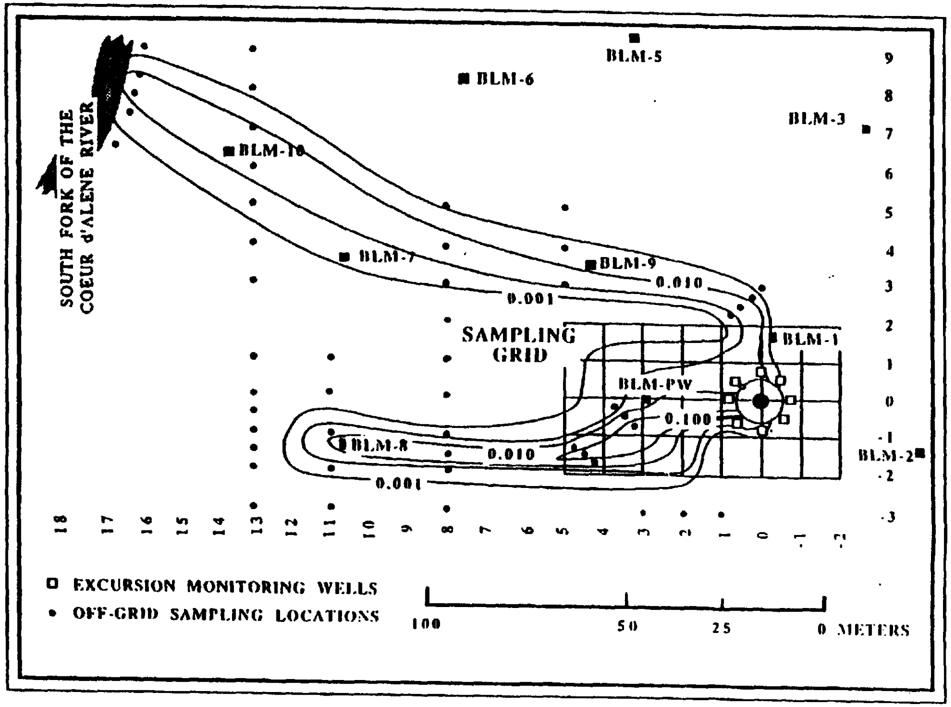

Figure 7. Results of soil-gas/ground-water survey number 3 (SG/GWS-3). Concentrations reported are mg/l SF_6. Shallow and deep BLM wells (black squares), SG/GWS-1 sampling grid (nodes), and off-grid locations (black disks) also are shown. Grid numbering system is Cartesian with axes centered on the pond.

CONCLUSIONS

Results of the tests described herein suggest that each hydrogeologic unit involved with the cell is heterogeneous at each scale of study; therefore, only a qualitative conceptual model can be developed using the existing data. The current design of the in-situ leach cell permits excursion-free operation at an injection/withdrawal rate of 0.32 Us. However, short-circuiting caused by preferential low-paths that connect the pond directly to the aquifer reduces the sweep efficiency of the cell. The current design of the excursion monitoring well system is adequate.

ACKNOWLEDGMENTS

The authors wish to acknowledge the financial support of the United States Department of the Interior, Bureau of Mines. The Project was funded under a Cooperative agreement between the Bureau of Mines and the University of Idaho (Agreement Number C0278001).

REFERENCES CITED

Adams, J. A., 1989, "Evaluation of the Hydraulic Connection of Two Aquifers Underlying the Smelterville Flats Area", M. S. Thesis, University of Idaho. 173 p.

Dames and Moore, 199(), "Bunker Hill Site RI/FS Task 3.0: Final Hydrogeologic Assessment, U. S. EPA Pre-Issuance Copy, 263 p.

Kirschner, F. E., Jr., 1991, "Hydrogeo-logical Evaluation of an In-situ Leach Cell in Abandoned Mine and Mill Wastes at the Kellogg, Idaho Superfund Site Using Tracers", Ph. D.Dissertation, University of Idaho, 262 p.

Kirschner, F. E., Jr., I 5g4, "Testing the Feasibility of In-Situ Leaching Heavy Metals from the Smeiterville Flats Portion of the Kellogg Superfund Site", pp 3 - 44, In: "Evaluation of Waste and Water Contamination for Closure of a Hard Rock Mine Complex", October 30, U.S. Bureau of Mines Cooperative Agreement No.C027801, 287P.

Kunkel, D. in progress. M. S. Thesis, University of Idaho.

Norton, M. A., 1980, "Hydrogeology and Potential Reclamation Procedures for an Uncontrolled Mine Waste Deposition Site, Kellogg, Idaho", M.S. Thesis, University of Idaho, 230 p.

Ralston, D. R. and Kunkel, D., 1989, "Characterisation of the Hydrostratigraphy of the Valley Alluvium and Tailings Near Smelterville Flats", pp. 45 - 77, In: "Evaluation of Waste and Water Contamination for Closure of a Hard Rock Mine Complex", June 30, U.S. Bureau of Mines Cooperative Agreement No. C027801, 310 p.