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PROJECT SHOAL AREA TRACER TEST EXPERIMENT

prepared by

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Sean Kosinski and Rich Niswonger

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ABSTRACT

On October 26, 1963, a 12-kiloton-yield nuclear detonation occurred at the Project Shoal Area (PSA) about 50 km southeast of Fallon, Nevada. While a three-dimensional groundwater flow and transport model was constructed for the PSA to determine potential migration of radionuclides from the underground test, it was found that further delineation of the subsurface conditions were required to reduce uncertainties associated with model input parameters. To help reduce model uncertainty, a tracer test experiment was conducted. This document presents well descriptions of the upgradient well (HC-6) and downgradient well (HC-7), experimental design, tracer selection, sampling protocol, as well as experimental data collected during the test. Experimental data includes injection and discharge data, water levels, tritium levels and information associated with each tracer (i.e., iodide, carbon-13, deuterium, bromide, lithium, cesium, PFBA and microspheres). Finally, chloride and sulfate chemistry evaluated at well HC-7 are presented.

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ACRONYMS

bgs	below ground surface
CADD	Corrective Action Decision Document
CAIP	Corrective Action Investigation Plan
DOE	U.S. Department of Energy
DRI	Desert Research Institute
FFACO	Federal Facility Agreement and Consent Order
gpm	gallons per minute
ITLV	IT Corporation, Las Vegas
MSL	mean sea level
PFBA	penta-flourobenzoic acid
PSA	Project Shoal Area
TDS	total dissolved solids

INTRODUCTION

Since 1962, all United States nuclear tests conducted at the Nevada Test Site have been conducted underground. The majority of the underground testing occurred on the Nevada Test Site, but a limited number of tests were conducted in other locations. One of these sites is the subject of this report, the Project Shoal Area (PSA), located about 50 km southeast of Fallon, Nevada. The Shoal test consisted of a 12-kiloton-yield nuclear detonation at a depth of 369 m below the ground surface in granitic rock. The test occurred on October 26, 1963, as part of a series of studies to enhance seismic detection of underground nuclear tests, and in particular those nuclear tests conducted in active earthquake areas.

Purpose and Objectives

A three-dimensional groundwater flow and transport model was constructed for the PSA subsurface to determine the potential migration of radionuclides from the underground test (Pohll *et al.*, 1998a). The model was developed to locate an acceptable contaminant boundary within which water-use restrictions would be implemented to prevent exposure to potentially contaminated groundwater. Existing data as well as data collected during the installation and testing of new groundwater investigation wells were used to develop this model. However, it was found that further delineation of the subsurface conditions were required to reduce uncertainties associated with model input parameters.

A data decision analysis (Pohll *et al.*, 1998b) was performed to ascertain the most cost-effective activities that would reduce the current model's uncertainty. The four characterization activities identified include vadose zone modeling, deep well sampling of environmental tracers, collecting additional water-level measurements and conducting a tracer test.

The primary objectives of the tracer test were as follows:

1. Determine the effective porosity of the Shoal granite aquifer.
2. Determine hydraulic properties of the aquifer.
3. Quantify the dispersion coefficient at the 30-m scale, which is nearly equivalent to the size of a single finite difference block used in the groundwater flow and transport model.
4. Quantify the field-scale sorption coefficients for weakly sorbing solutes.
5. Determine the significance of matrix diffusion.
6. Finally, determine the hydraulic properties of the fractures.

The purpose of this document is to present experimental data collected during the tracer test. These data include well descriptions of HC-6 and HC-7, their associated water levels, as well as injection and discharge data obtained during the tracer test experiment.

Participants

Characterization of groundwater contamination at the PSA was conducted by the U.S. Department of Energy (DOE) under the Federal Facility Agreement and Consent Order (FFACO). This order prescribed a Corrective Action Strategy, which, as applied to underground nuclear tests, involves preparing a Corrective Action Investigation Plan (CAIP), Corrective Action Decision Document (CADD), Corrective Action Plan and a Closure Report.

The CAIP for the PSA was approved in September 1996 and revised in 1998. The scope of the CAIP is flow and transport modeling to establish contaminant boundaries that are protective of human health and the environment. Organizations responsible for both characterizing the site and conducting the tracer experiment include the Desert Research Institute (DRI), IT Corporation, Las Vegas (ITLV), the ITLV subcontractors Lang Exploratory Drilling (Elko, NV), Buttar's Mining (Carlin, NV), Colog, Inc. (Boulder, CO), Paragon Analytics Inc. (Fort Collins, CO) and Safety Kleen (Sparks, NV) as well as the DRI subcontractors Powder River Group (Cedar City, UT) and John Lane at the U.S. Geological Survey.

ITLV staff were responsible for the health and safety, environmental compliance/waste management, and drilling oversight. Specific duties included (1) the construction of drilling pads and the lining of fluid storage sumps for drilling, (2) the drilling of new water table wells, Wells HC-6 and HC-7; an intermediate depth well, Well HC-8; and a deep well, Well HC-5, (3) collecting hydrogeologic data during drilling, (4) monitoring drilling effluents for radionuclides and (5) collecting downhole geophysical data. All ITLV subcontractor operations were directly supervised and approved by on-site ITLV personnel. A full description of ITLV's roles and responsibilities at PSA is provided within *Field Instructions for Project Shoal Area Subsurface Investigations, Churchill County, Nevada* (IT, 1999). DRI responsibilities included (1) collecting specific hydrogeologic data, (2) collecting certain downhole geophysical data, (3) providing technical support for and orchestrating the development of the pumping tests to achieve the scientific objectives (Pohll *et al.*, 1999).

Site Description

The PSA consists of a 10.4 km² area in the Sand Springs Range located near Fallon, Nevada, in Churchill County (Figure 1). Ground zero of the underground nuclear test is located at North 1620170 ft, East 557542 ft given Nevada Grid Coordinates and a land elevation of 1,594 m mean sea level (MSL). The nuclear device was emplaced 367 m below the land surface at the end of a 305-m-long drift mined east from a vertical shaft. Figure 2 shows the area near ground zero looking northeast.

The Sand Springs Range is a north-south-trending range with a total relief between the range and the valleys of about 500 m. A major intermittent drainage course in Ground Zero Canyon leads east to Fairview Valley. No permanent water bodies or

streams exist. Sparse, low vegetation covers the area. The ground slopes steeply west to Fourmile Flat and east to Fairview Valley. Ground zero is near the crest of the range on a minor intra-mountain plateau named Gote Flat, which is about 800 m wide. At a depth of 367 m below the land surface, the Shoal working point is nearly at grade with the adjacent valley floors.

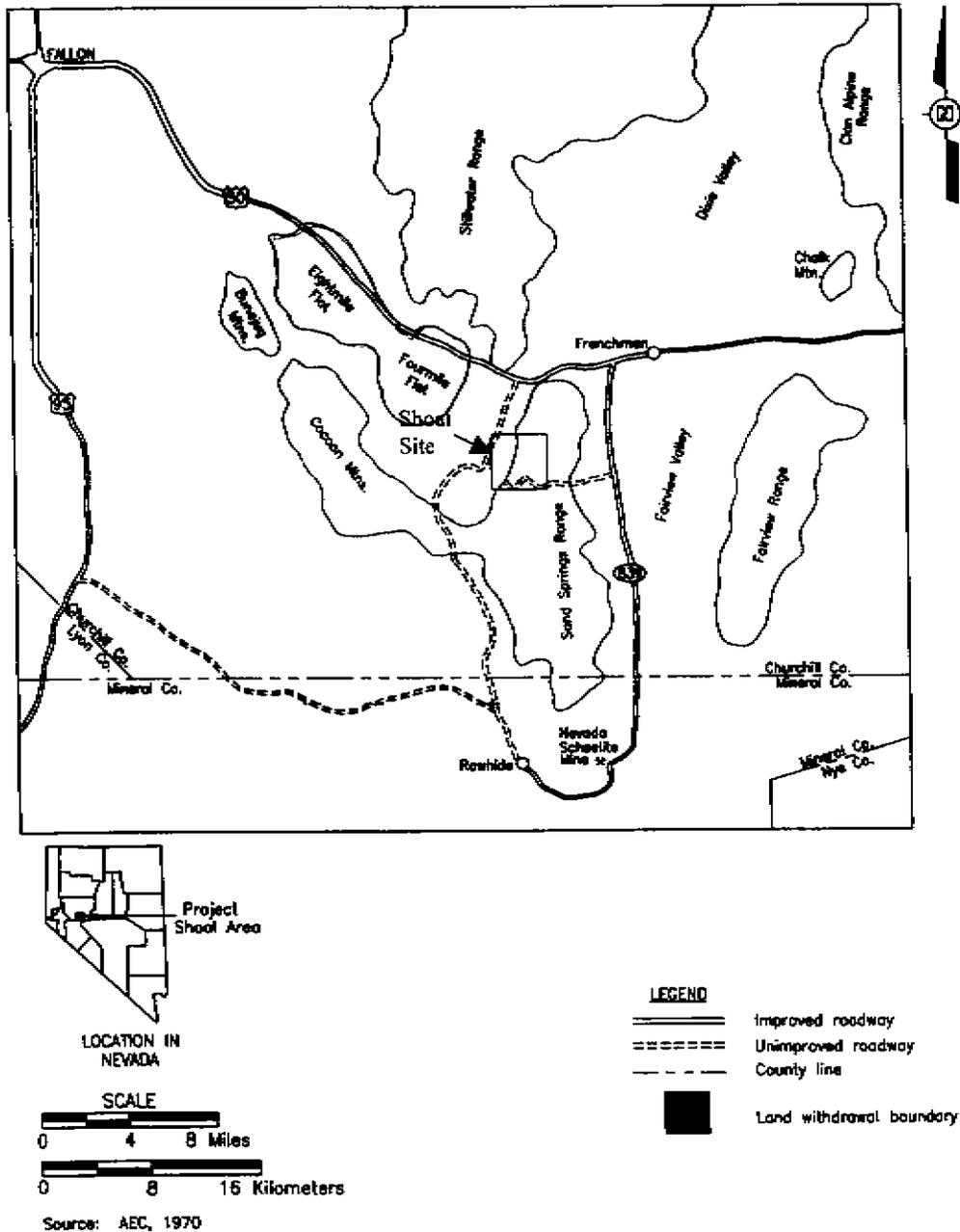


Figure 1. Project Shoal location map.



Figure 2. Shoal site looking northeast (October 1999).

The Shoal site is in a sub-humid to semi-arid region of Nevada's Great Basin. Annual rainfall varies from about 13 cm in the valleys to about 30 cm in the high mountain ranges (Hardman and Mason, 1949). Most precipitation in the mountain ranges occurs as snow. The annual precipitation estimate for the Shoal site varies between 20 cm (Gardner and Nork, 1970) and 30 cm (Hardman and Mason, 1949). Using the relationship between precipitation and recharge described by Maxey and Eakin (1949), an estimated 3 to 7 percent (0.6 to 2.1 cm/yr) of the annual precipitation will infiltrate and become groundwater recharge. A vadose zone model (Pohl *et al.*, 1998a) provides a more rigorous estimate of surface recharge with a predicted median recharge rate of 0.055 cm/yr with a 95 percent confidence interval ranging from 0.0 to 0.159 cm/yr. Daily temperature fluctuations in excess of 10°C can occur. Maximum temperatures exceed 38°C in July and August and minimum temperatures of -18°C occur in December and January.

A two-well, forced-gradient tracer test was developed in which a tracer was injected into the fractured granite at the upgradient well (HC-6) installed in the upper portion of the aquifer. Meanwhile, monitoring and pumping was done at a downgradient well (HC-7) that was also installed in the upper portion of the aquifer. Figure 3 shows the location of the PSA boreholes, ground zero, emplacement shaft and surface fracture expressions. Table 1 provides the geographic and completion data for all newly drilled wells at the PSA. Note that accounting for drilling deviation, wells HC-6 and HC-7 are separated by a horizontal distance of 26.92 m.

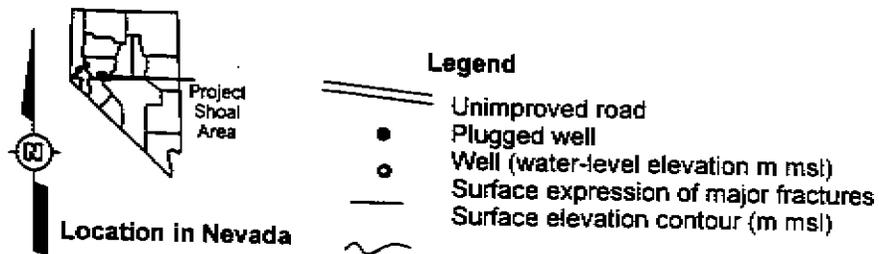
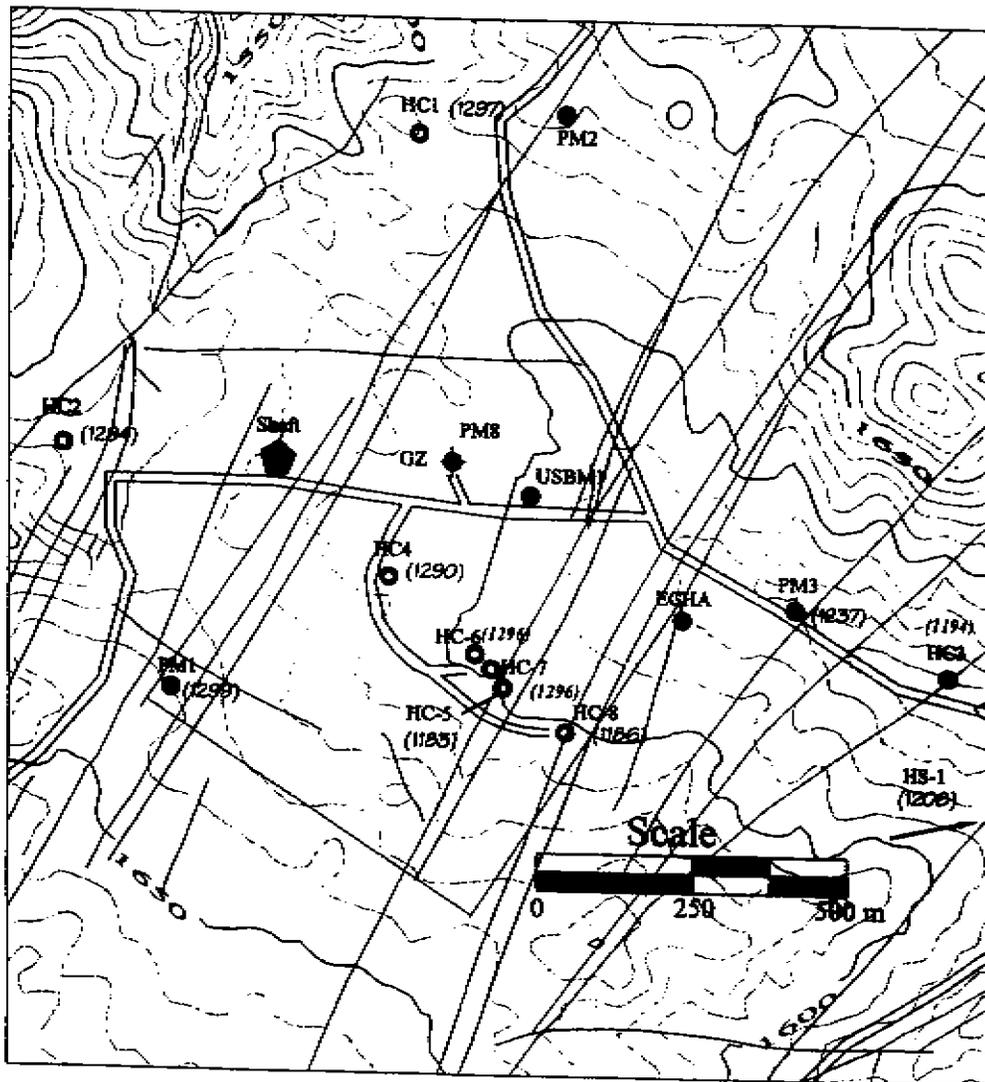


Figure 3. Project Shoal Area wells.

Table 1. Summary information for newly drilled wells at the PSA.

Well	Northing (ft)	Easting (ft)	Elevation Datum	Elevation (m)	Total Depth (m)	Screened Interval Depth		Current Condition	Water Table Elevation (m)
						Top (m)	Bottom (m)		
HC-1	1621927.00	557360.40	Top of 5-in Steel Casing	1618.25	405.38	n/a***	n/a	Operational	1296.68
HC-2	1620208.30	555447.80	Top of 5-in Steel Casing	1629.80	369.42	n/a***	n/a	Operational	1294.02
HC-3	1618822.90	56114.70	Top of 5-in Steel Casing	1548.85	364.21	263.35	n/a	Operational	1193.55
HC-4	1619650.16	557738.95	Top of 5-in Steel Casing	1603.46	375.20*	n/a***	n/a	Operational	1289.51
HC-5	1619056.07	558315.11	Top of PVC Access Tube	1599.32	1086.56	1031.70	1076.07	Operational	1183.04
HC-6	1619312.58	558222.53	Top of 5-in Fiberglass Casing	1593.63	377.93	340.13	375.59	Operational	1295.49**
HC-7	1619237.29	558291.68	Top of PVC Access Tube	1593.94	377.93	337.24	372.94	Operational	1295.78**
HC-8	1618789.06	558642.91	Top of PVC Access Tube	1603.14	771.11	699.30	734.81	Operational	1185.91

*New total depth due to debris at bottom of borehole

** Water level prior to tracer test experiment

***Open borehole in saturated zone

EXPERIMENTAL DESIGN

Preliminary Modeling Results

A preliminary modeling analysis was conducted to design the Shoal tracer test activity. The following recommendations were given (Pohil *et al.*, 1999):

- A short-duration pulse tracer test with a single anion (*e.g.*, iodide) should be considered prior to initiating a test involving injection of multiple tracers. The tracer used in this test should be analyzable in the field to minimize analytical turnaround times, thereby allowing near-real-time tracking of test progress. The response from this "pilot" test would allow the multiple tracer test to be optimized with respect to injection pulse duration and sampling frequency. A 7 to 10-day interval could be reserved for the short-pulse test. Even if there is little or no tracer response in that time, this would indicate that the residence times in the multiple tracer test will be long, and the amount of tracer mass injected should therefore be maximized. Also, flow rates should be increased, if possible, to reduce times. On the other hand, a very fast response might indicate that the tracer injection masses could be reduced significantly, which would reduce the density contrast between the tracer solution and the groundwater.
- A multiple tracer test should involve the simultaneous injection of all tracers, achieved by dissolving the tracers in the same solution. This will ensure that each tracer experiences the same exact flow system and the same flow and pressure transients. Note that adding a sorbing tracer will aid in analyzing diffusional processes that affect tracer transport.
- In the absence of active well bore mixing equipment, every effort should be made to obtain bailed samples from various depths and at various times in at least the injection well bore. This will allow estimates of the well bore residence time distribution so that well bore mixing can be accounted for in the test interpretation. Also, if there is no mixing equipment, the injection pulse should ideally involve a minimum of two injection well bore volumes of tracer solution.
- If the tracer test response is relatively short, one or more flow interruptions should be considered during the tailing portion of the test. Under these conditions, the response(s) to the flow interruption(s) will provide additional information and independent verification of matrix diffusion in the transport system. A jump in concentrations after resumption of flow would be consistent with matrix diffusion because tracers will continue to diffuse out of the matrix and into the fractures during an interruption in the tail of a test.
- It is important to establish background concentrations of tracers prior to testing so that the background can be accounted for when establishing tracer injection masses (as well as subtracted out to correct the responses). Background can play a significant role in tracer analytical precision, as most methods have similar relative analytical errors over wide ranges of concentrations.
- Because tracer responses cannot be established *a priori*, estimates with respect to tracer injection masses for tracer injection should be very conservative. The masses

can always be reduced later if information becomes available to justify doing so (*i.e.*, a short-pulse pilot test).

- Given the impact of fluid density is small, the injection and discharge rates may have relatively large concentrations (*i.e.*, up to 10,000 mg/L TDS).

Well Design

Only wells pertinent to the tracer test experiment (Wells HC-6 and HC-7) are described in this report. Originally, Wells HC-6 and HC-8 were proposed as the upgradient and downgradient well pair for the two-well tracer test. However, hydrogeologic data collected while drilling the HC-8 borehole indicated that the borehole had crossed a significant structural boundary and consequently the proposed wells were located in two distinct structural blocks with different hydrologic characteristics. Water-level data collected while advancing the borehole in HC-8 also showed that the formation was too tight to yield reasonable flows. Therefore well HC-8 was completed as the intermediate depth well, while wells HC-6 and HC-7 were designated as the tracer test well pair. Wells HC-6 and HC-7 are thought to exist in a single hydrologic block free of structural complications (IT, 2000).

Well HC-6 was proposed and completed as the injection well of the tracer test well pair. It was drilled to a total depth of 377.95 m below ground surface (bgs) with the well casing extending to a total depth of 376.03 m bgs and a filtered-packed, slotted interval existing from 340.15 m to 375.60 m bgs (IT, 2000). Both Table 1 and Figure 4 provide details on well construction. A submersible pump was installed to a depth of 368.20 m on October 2, 1999. The pump was used to further develop the well and conduct an aquifer test from October 2 until October 4, 1999.

Well HC-7 was originally proposed as the intermediate depth well (Pohll *et al.*, 1999) but given the hydrogeologic data collected during the drilling of HC-8, HC-7 was completed for use in the tracer test. Well HC-7 was installed 26.92 m south-southeast of HC-6 to be used as the pumping well for the tracer test. It was drilled to a total depth of 377.95 m bgs with the well casing extending to a total depth of 373.41 m bgs and a filter-packed, slotted interval from 337.25 to 372.95 m bgs. Along with Table 1, Figure 5 provides well dimensions. A submersible pump was permanently installed at a depth of 368.20 m on October 19, 1999 (IT, 2000). The pump was used to further develop the well from October 27 until October 28, 1999, and from October 28 until November 29, 1999. DRI continued to pump well HC-7 following well development to facilitate the tracer experiment that was initiated on November 3, 1999, and continued until September 26, 2000. A complete account of HC-6 and HC-7 geology, hydrology, geophysical surveys, radiological monitoring and drilling/construction procedures is contained in IT (2000).

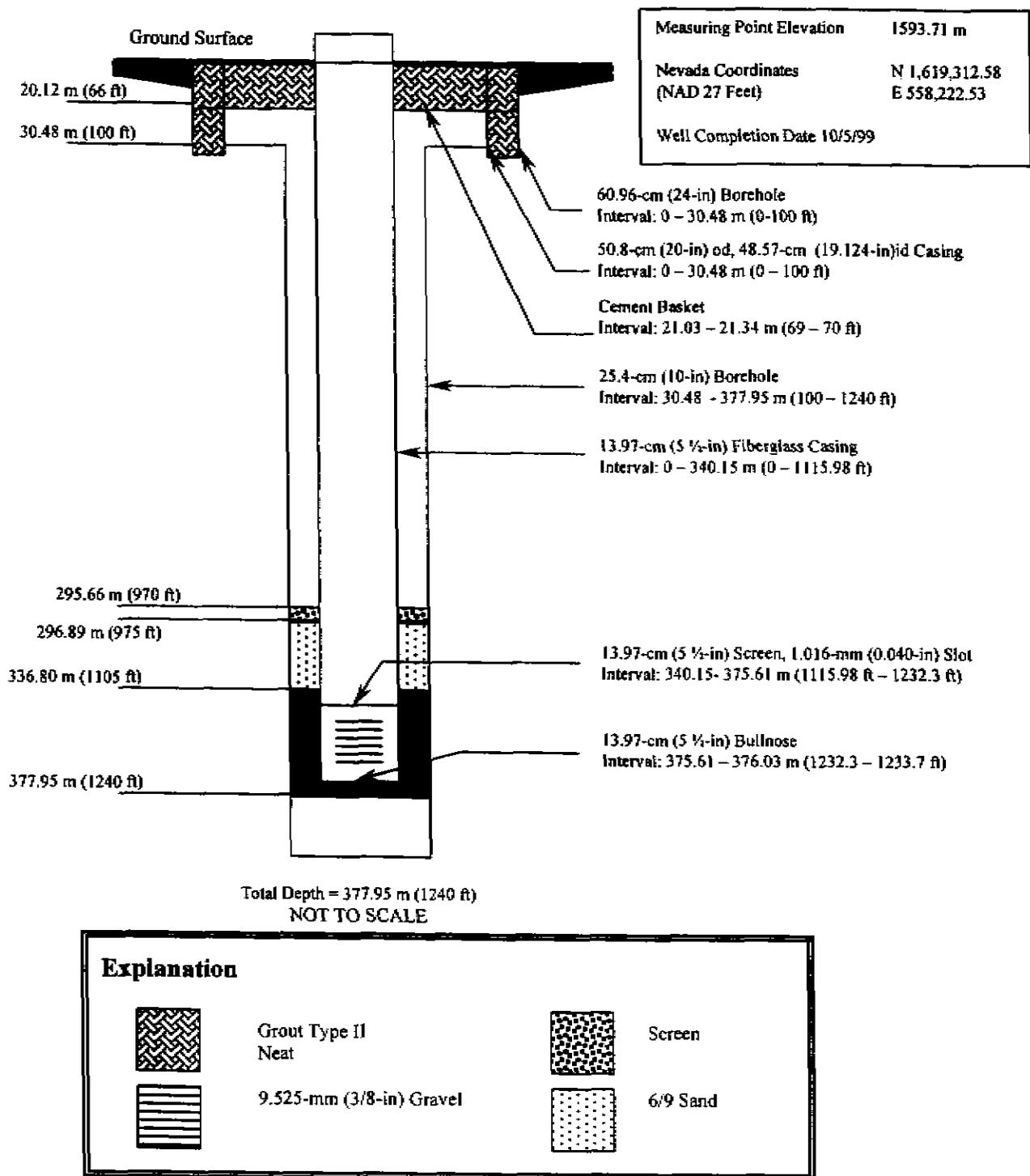
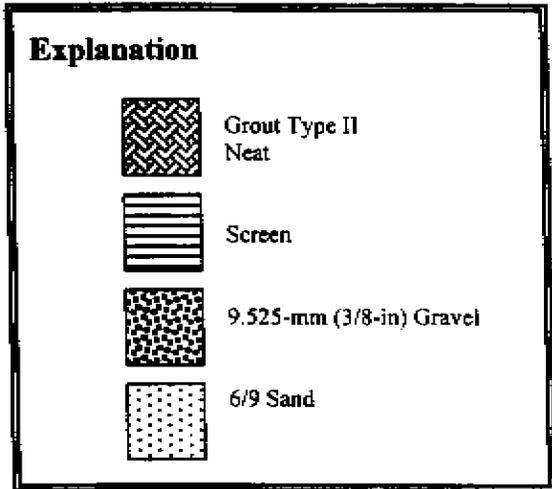
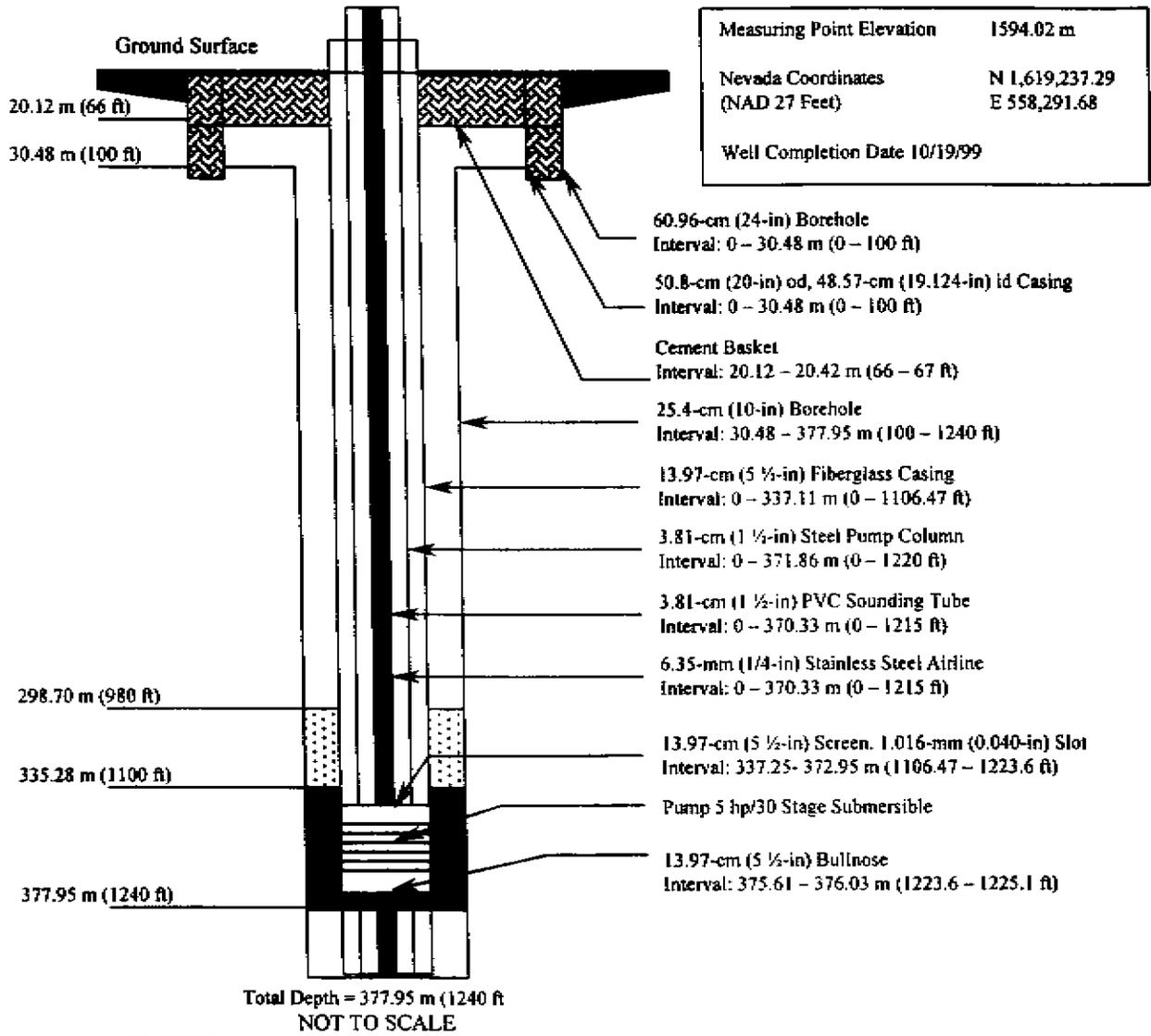


Figure 4. HC-6 well completion diagram (adopted from IT, 2000).



Note:
Top of Filter Pack at 298.70 m (980 ft)
from 4π Gamma Log

Figure 5. HC-7 well completion diagram (adopted from IT, 2000).

The tracer test was initiated immediately after the aquifer test in HC-7. Injection of “clean” water (no tracers) began at HC-6 at a rate of 1.14 L/min (0.3 gpm) with water stabilizing within 24 hours after the initial injection. Pumping occurred at HC-7 with no interruption after the aquifer test to ensure steady-state flow conditions. A schematic of the plumbing used for the tracer tests can be seen in Figure 6. Two sets of tanks were used. The pre-test used one 250-gallon polyethylene tank. Water in the tank was thoroughly mixed to homogenize the solution and to avoid stratification due to density variations. The main tracer tank consisted of one 3,000-gallon polyethylene tank. A pump was installed within this tank to ensure the homogenization of the solution by thorough mixing of the tracers during the test. The tank was equipped with a 5.08-cm (2-inch) clean-out valve, a 7.62-cm (3-inch) fluid fill valve and a 1.905-cm (¾-inch) injection feed line valve. The elevation of the tank bottoms was placed at 0.91 m (3 feet) above the top of the completed wellhead so that gravity could be used to supply solution to a constant head tank. A peristaltic pump withdrew fluid from the constant head tank and injected it into well HC-6.

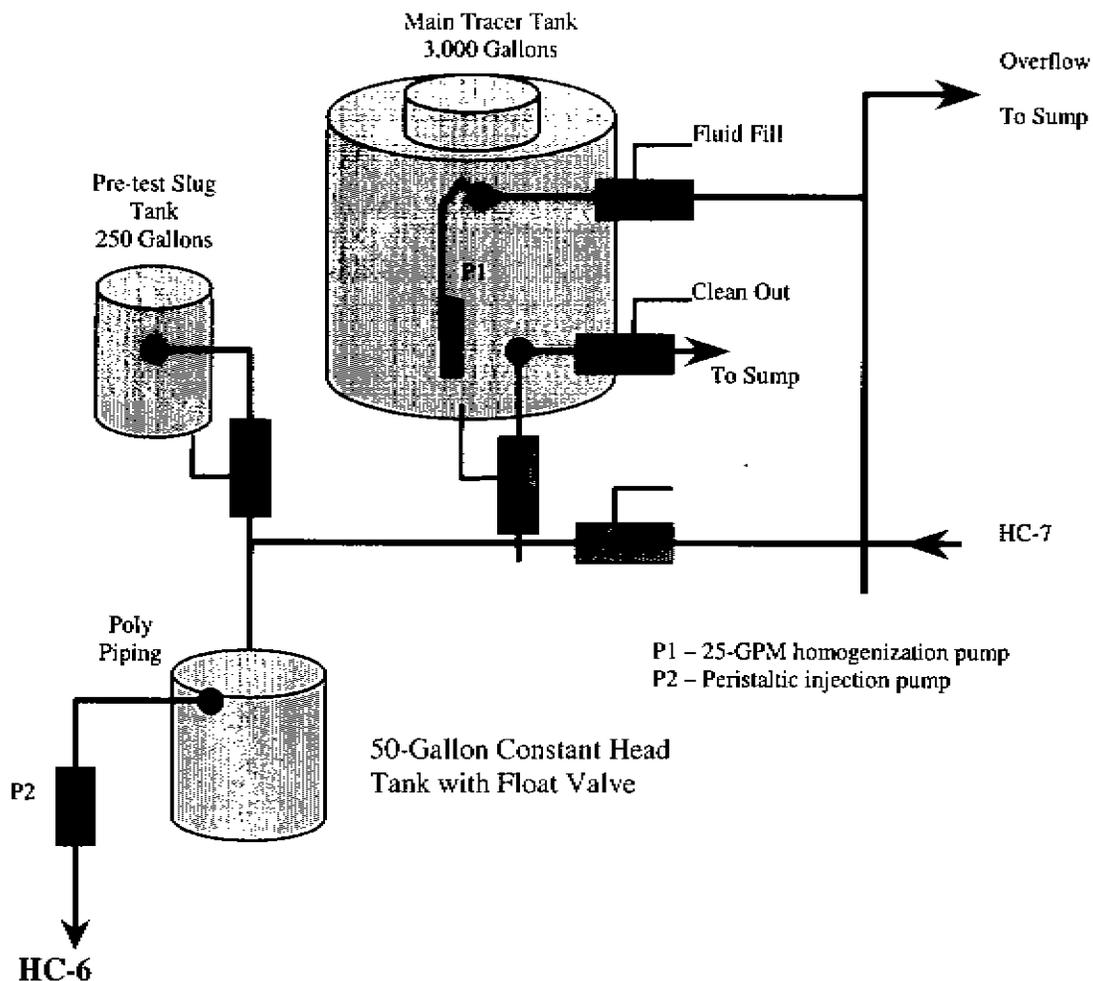


Figure 6. Schematic of the pumping used for the injection of tracers into HC-6 (adopted from Pohll *et al.*, 1999).

Two Bennett pumps were used to homogenize the solution in the injection and to collect samples. Bennett tubing was configured to control two Bennett pumps from the same reel. Air pressure was supplied to each pump via the regular airline and via the current air return line while water samples were conveyed via the water return line. Both pumps exhausted into the well bore. A low-head Bennett pump was used to pump from the bottom of the screen to the water table at a rate of about 5 GPM. A high-head Bennett pump was used to pump water samples from the water table to land surface at a rate of approximately 0.3 GPM. A sample port was installed at the discharge line and the discharge was allowed to cascade back down the injection well. A peristaltic pump was used to accurately inject the tracer at the specified rate. A schematic of the injection well sampling and mixing system is provided in Figure 7.

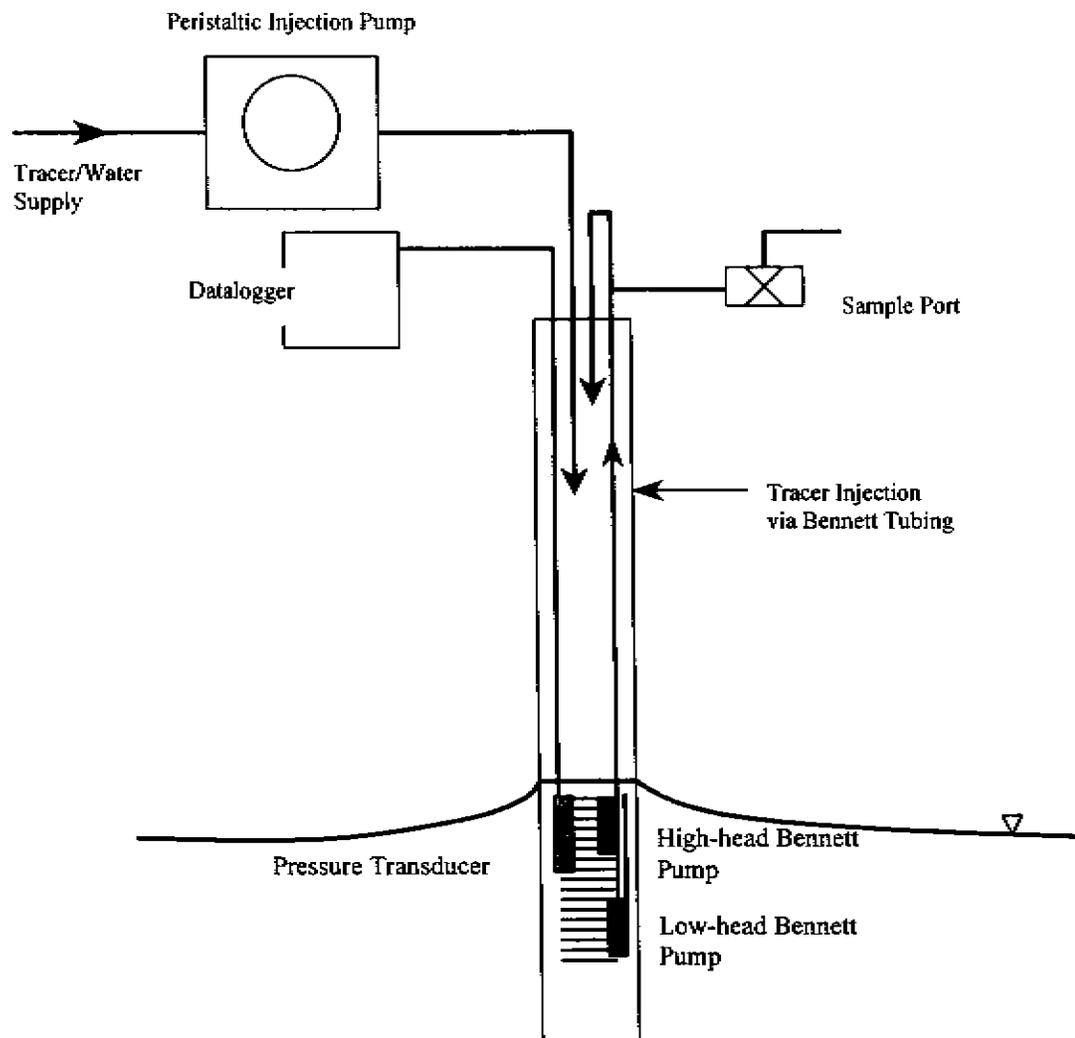


Figure 7. Injection well sampling and mixing system (adopted from Pohll *et al.*, 1999).

Tracer Selection

A variety of tracers were used to analyze transport behavior. An injection mass table as well as injection and discharge data are presented in the Experimental Data section of this report. As recommended by the preliminary model results, the tracer test was conducted in two separate phases. The first phase was a short-duration (6-hour) injection of deuterium, carbon-13 and iodide on November 3, 1999. The purpose of the pre-tracer test was to examine the potential breakthrough period such that the second test could be planned more effectively and to select the reactive tracer. The two choices for the reactive tracer included lithium and cesium. Lithium is assumed to be less reactive and therefore can be transported more quickly than cesium. Despite the fact that iodide migrated out of the injection well (see the Iodide section) and iodide was expected to enter well HC-7 between November 7 and November 28, 1999, no iodide from the pre-tracer experiment was detected at the discharge well. Given that transport times appeared long, lithium was the chosen reactive tracer. The second phase of the tracer test was comprised of three separate injections. The first injection consisted of lithium chloride, lithium bromide penta-fluorobenzoic (PFBA) and sodium hydroxide. Lithium was used as the reactive tracer. Bromide was used to examine the transport behavior of a conservative solute. PFBA is a large molecule, which is less likely to diffuse into the granite matrix and as such would allow one to determine the matrix diffusion properties of the aquifer system by comparing to other solutes. Finally, sodium hydroxide was used to buffer the PFBA solution. Injection began on November 10, 1999, and lasted seven days. The second injection used cesium and occurred on November 28, 1999. Despite potentially long transport times, cesium was used because 1) it was available and 2) batch sorption experiments with cesium have allowed the translation of laboratory sorption parameters to the field scale. Lastly, the third injection used microspheres and occurred on June 12, 2000. Microspheres were used in the tracer experiment for two reasons: 1) they acted as a surrogate for colloidal transport; and 2) they do not participate in matrix diffusion and therefore act as a base case when evaluating the effects of matrix diffusion on transport.

Tracer concentrations were designed to yield TDS concentrations near 10,000 mg/L. Preliminary modeling indicated that the advective velocities in the system may be large and that the associated density increase due to the TDS concentrations would not significantly impact the results and subsequent analysis at TDS concentrations less than 10,000 mg/L. Also, HC-6 contained an additional mixing device to ensure that the dense solutes would not become trapped in the bottom of the borehole.

Sampling Protocol

Tracer Sampling

Well HC-7 was sampled for tracers during the pre-tracer test as well as for the main tracer test. The pilot tracer test used NaI, D₂O and NaH¹³CO₃ to obtain the tracers iodide, deuterium and carbon-13. Injection of the tracers occurred over a 6-hour period and was followed by monitoring and sampling the pumping well (HC-7) for a period of

one week. Injection of the main tracer occurred one week after the pre-tracer test injection. Sampling consisted of collecting discharge samples from the sampling port at HC-7 as well as samples from the homogenization return line at HC-6. Sampling at well HC-7 began just prior to the injection of the tracer and continued every 12 hours until March 1, 2000. From March 1, 2000, until March 14, 2000, samples were collected once a day and then from March 14, 2000 until September 26, 2000, samples were collected every other day. The purpose of sampling the injection well was to monitor the efficiency of the mixing system and monitor the dilution of the tracer over the period of the test. Two 250-ml samples, two 125-ml samples and one one-liter sample were collected from each source, properly labeled and archived. Table 2 provides a breakdown on sample containers, preservatives, holding times and detection limits for each tracer analyzed. This main tracer test had an injection period of seven days and monitoring every six hours until September 26, 2000 (10 months).

Table 2. List of sample containers, preservatives, holding times and detection limits for tracers used in both the pre-tracer and main tracer tests.

Tracer	Container	Preservative	Holding Times	Detection Limit
Iodide	250 ml Poly	no	28 days	0.02 ppm
Lithium	250 ml Poly	HNO ₃ pH<2	6 months	0.005 ppm
Cesium	250 ml Poly	HNO ₃ pH<2	6 months	0.01 ppm
PFBA	60 ml amber glass Teflon lids	no	indefinitely	50 ppb
Microspheres	125 ml glass Teflon lids	no	indefinitely	100 spheres/ml
Deuterium	125 ml glass Polyseal lids	no	indefinitely	$\delta D \pm 1\text{‰}$
Carbon-13	1 L glass Polyseal lids	no	indefinitely	$\delta^{13}C \pm 0.1\text{‰}$

Automated Sampler

Automated samplers were put on-line November 20, 1999, and were used to collect samples from the discharge line at well HC-7.

Water-level Measurement

To verify that the aquifer was in a state of equilibrium during the tracer test, a pressure transducer and datalogger were used to monitor the water level in the pumping well. The datalogger was connected to a cellular telephone so that the operational status could be monitored when the field site was left unattended. The datalogger was programmed to download discharge and water-level data nightly to determine if there was any type of failure. An airline was also attached to the pump column to verify the datalogger readings and to serve as a backup, should the datalogger or transducer fail.

Injection Monitoring

The rate of injection was measured each time a sample was collected. This was accomplished by diverting the injection stream into a graduated cylinder and measuring the volume collected in one minute. The injectate measured was then returned to the injection well.

Fluid Discharge

Water pumped for the tracer test was initially discharged into a lined sump then into an infiltration basin. Provisions were made to transfer the water from the sump to another when the capacity was exceeded. The rate of discharge was measured by a suitable electronic device and recorded by the datalogger. Ten percent of the discharge fluid (1.14 L/min) was used as the injection fluid after the completion of the tracer injection.

Discharge and Sump Sampling

Initially, samples were provided to IT to determine the activities of gross beta, gross alpha, tritium and the concentration of lead. Given that none of these exceeded the Fluid Management Decision Criteria Levels, the water was discharged into an unlined infiltration basin.

After permission for direct discharge of HC-7 water was obtained from the State of Nevada, the discharge stream was sampled on a weekly basis and analyzed for tritium concentrations. These samples were submitted to the DRI Analytical Chemistry Laboratory for unenriched tritium scans (24-hour turn-around time from the time the sample is submitted). If tritium concentrations should have exceeded the 1,000 pCi/L detection limit, then DRI and DOE project managers would have been notified. Such circumstances did not occur (refer to Tritium Data section).

Pre-tracer Test

Using deuterated water, carbon-13 and iodide, a single, short-duration injection pulse was performed. Monitoring was performed to ascertain the potential transport times for the main tracer test and to plan the associated monitoring activities (*i.e.*, exact injection length, injection mass and monitoring period). The following protocol was followed to perform the pre-tracer test:

1. All tanks were filled with HC-7 water.
2. Tracers were mixed and continuously homogenized within the 250-gallon tank.
3. Water samples were collected prior to running the test.
4. A graduated cylinder and stopwatch were used to ensure that the peristaltic pump was adjusted properly.
5. HC-7 water was injected with a peristaltic pump.
6. Once the fluid level equilibrated, the tracers were then injected via the well casing for a total of 6 hours.
7. Samples were taken from the injection well via the Bennett pump to establish the length of time it took to homogenize the tracer in the injection well and to determine the injection concentration.
8. The pumping well (HC-7) was continually monitored and sampled.

9. After the tracer injection was complete, the Bennett pump was kept on until the return water concentration was below the injection water threshold.
10. Finally, HC-7 water was supplied to the injection pump.

Results of the pre-tracer test are presented in the Experimental Data section of this document. Given the three constituents, I, carbon-13 and deuterium, used in the test, both carbon-13 and tritium produced extremely noisy signals, while iodide was never detected at well HC-7. The long travel time interpreted by the lack of iodide at the pumping well suggested the use of lithium, not cesium, for the main tracer experiment.

Main Tracer Test

The main tracer test began one week after the injection of the pre-tracer test and consisted of three separate injections. The first injection consisted of bromide, lithium and PFBA, while cesium and microspheres were each injected at a later date. Below is a list of procedures followed during each phase of the main tracer test.

1. Pump was started to homogenize the water in the 3,000-gallon tank.
2. For the first phase, the tracer was mixed in the 3,000-gallon tank.
The cesium tracer was mixed in the 250-gallon tank, while microspheres were poured directly into the well.
3. Water samples were collected prior to the test.
4. A graduated cylinder and a stopwatch were used to ensure that the peristaltic pump was adjusted properly.
5. The peristaltic pump was installed online.
6. The injection pump was supplied with tracer from the constant-head tank.
Injection of the tracer lasted for one week.
7. Once all of the tracer was injected, a switch was made to injecting HC-7 water.
8. The Bennett pump was used until all injection well tracer levels were below thresholds.

EXPERIMENTAL DATA

Injection and Discharge Data

Discrete injection rates were obtained by computing the time it took to fill a one-liter bottle. The average injection rate during the entire test was calculated to equal 0.28 gpm. All injection data are presented in Table 3, with injection rates shown pictorially in Figure 8. Pumping at discharge well HC-7 began on October 28, 1999, at 20:44 hrs. Cumulative volumes were obtained using a totalizer and rates were calculated by accounting for the time lapsed between the time the sample was taken and the initial time of pumping. The computed average discharge rate is 2.51 gpm. All discharge data are presented in Table 4 and discharge rates are graphed in Figure 9.

Table 3. Discrete injection data collected at well HC-6.

Date	Time	Time to fill 1 liter bottle (sec)	Injection Rate (gpm)
11/10/1999	20:30	53.20	0.30
11/21/1999	14:30	55.00	0.29
11/22/1999	20:00	55.00	0.29
11/23/1999	17:56	54.00	0.29
11/24/1999	8:40	55.00	0.29
11/28/1999	14:00	48.00	0.33
11/29/1999	15:30	49.00	0.32
11/30/1999	12:04	50.00	0.32
12/1/1999	8:05	105.00	0.15
12/17/1999	12:40	59.00	0.27
12/20/1999	14:00	58.00	0.27
12/27/1999	15:23	57.00	0.28
12/30/1999	12:03	58.00	0.27
12/31/1999	9:48	58.00	0.27
1/3/2000	14:32	55.00	0.29
1/6/2000	13:45	56.00	0.28
1/7/2000	10:30	57.00	0.28
1/10/2000	13:25	59.00	0.27
1/15/2000	13:35	61.00	0.26
1/17/2000	13:12	61.00	0.26
1/21/2000	13:01	62.00	0.26
1/24/2000	12:40	66.00	0.24
1/26/2000	14:01	62.56	0.25
4/17/2000	13:15	54.00	0.29
4/24/2000	13:34	54.00	0.29
5/1/2000	14:09	55.00	0.29
5/8/2000	13:06	54.00	0.29
5/15/2000	12:12	57.00	0.28
5/22/2000	13:00	53.00	0.30
5/31/2000	14:45	53.00	0.30
6/5/2000	12:45	57.00	0.28
6/13/2000	10:10	57.00	0.28
6/19/2000	12:20	55.00	0.29
6/26/2000	11:52	57.00	0.28
6/30/2000	11:45	55.00	0.29
7/10/2000	14:00	53.00	0.30
7/17/2000	13:45	57.00	0.28
7/24/2000	10:53	58.00	0.27
7/31/2000	13:15	56.00	0.28
8/7/2000	14:00	55.00	0.29
8/14/2000	12:46	58.00	0.27
8/21/2000	11:05	55.00	0.29
8/30/2000	12:30	51.00	0.31
9/6/2000	15:15	52.00	0.30
9/11/2000	11:32	54.00	0.29
9/18/2000	10:15	55.00	0.29

Table 4. Discrete discharge data collected at well HC-7.

Date	Time	Discharge Tracer Test Only (gallons)	Discrete Flow Rate (gpm)
11/3/1999	16:07	0	---
11/3/1999	17:37	288	3.20
11/3/1999	22:30	1,221	3.18
11/4/1999	8:45	3,204	3.22
11/4/1999	11:50	3,814	3.30
11/4/1999	14:25	4,228	2.67
11/5/1999	17:12	9,336.4	3.18
11/5/1999	21:03	10,063	3.15
11/6/1999	1:55	10,973	3.12
11/6/1999	18:33	13,935	2.97
11/7/1999	9:00	16,791	3.29
11/7/1999	13:07	17,622	3.31
11/7/1999	16:35	18,252	3.03
11/7/1999	21:05	19,104	3.16
11/8/1999	1:01	19,843	3.13
11/8/1999	4:56	20,523	2.89
11/8/1999	8:38	21,268	3.36
11/8/1999	13:32	22,199	3.17
11/8/1999	20:49	23,546	3.08
11/9/1999	0:02	24,144	3.10
11/9/1999	8:30	25,705	3.07
11/9/1999	9:41	25,926	3.11
11/9/1999	16:17	27,205	3.23
11/10/1999	14:30	30,642	2.58
11/10/1999	20:18	31,666	2.94
11/11/1999	17:50	35,434	2.92
11/18/1999	10:10	63,091	2.87
11/19/1999	12:20	67,504	2.81
11/19/1999	17:10	68,378	3.01
11/20/1999	18:00	72,398	2.70
11/21/1999	15:24	75,882	2.71
11/22/1999	20:00	80,525	2.71
11/23/1999	17:58	84,135	2.74
11/24/1999	9:40	86,665	2.69
11/25/1999	12:08	90,984	2.72
11/26/1999	14:40	95,266	2.69
11/28/1999	15:10	103,098	2.69
11/29/1999	14:20	106,567	2.50
11/30/1999	12:17	109,905	2.53
12/1/1999	9:09	113,165	2.60
12/3/1999	17:15	122,172	2.68
12/6/1999	13:56	132,985	2.62
12/8/1999	13:05	138,935	2.10
12/13/1999	17:10	160,205	2.86
12/17/1999	12:35	174,185	2.55
12/20/1999	14:02	185,334	2.53
12/24/1999	10:10	199,017	2.48

Table 4. Discrete discharge data collected at well HC-7 (continued).

Date	Time	Discharge Tracer Test Only (gallons)	Discrete Flow Rate (gpm)
12/27/1999	15:23	210,224	2.42
12/30/1999	12:05	219,905	2.35
12/31/1999	9:45	223,043	2.41
1/3/2000	14:33	235,033	2.60
1/6/2000	11:35	245,205	2.46
1/7/2000	10:35	248,605	2.46
1/10/2000	13:20	258,665	2.24
1/12/2000	14:20	265,600	2.36
1/15/2000	13:30	272,175	1.54
1/17/2000	13:15	282,231	3.51
1/20/2000	12:58	292,060	2.28
1/21/2000	13:02	295,507.3	2.39
1/24/2000	12:40	305,572	2.34
1/26/2000	13:57	312,751	2.43
4/10/2000	14:00	545,995	2.16
4/17/2000	13:00	564,985	1.90
4/24/2000	13:22	583,597	1.84
5/1/2000	13:50	602,883	1.91
5/8/2000	13:00	622,151	1.92
5/15/2000	12:10	641,273	1.91
5/22/2000	13:00	660,352	1.88
5/31/2000	14:10	682,496.2	1.70
6/5/2000	12:45	698,657	2.27
6/13/2000	10:00	720,089	1.89
6/19/2000	11:55	735,925	1.81
6/26/2000	11:48	754,105	1.80
6/30/2000	11:30	765,425	1.97
7/10/2000	13:45	788,979.3	1.62
7/17/2000	13:50	807,384.5	1.83
7/24/2000	10:50	825,554	1.84
7/31/2000	14:20	844,161	1.81
8/7/2000	14:05	862,385	1.81
8/14/2000	12:48	880,263	1.79
8/21/2000	10:57	897,321	1.71
8/30/2000	12:20	920,246	1.76
9/6/2000	15:17	938,072	1.74
9/11/2000	11:35	950,152	1.73
9/18/2000	10:17	967,368.8	1.72

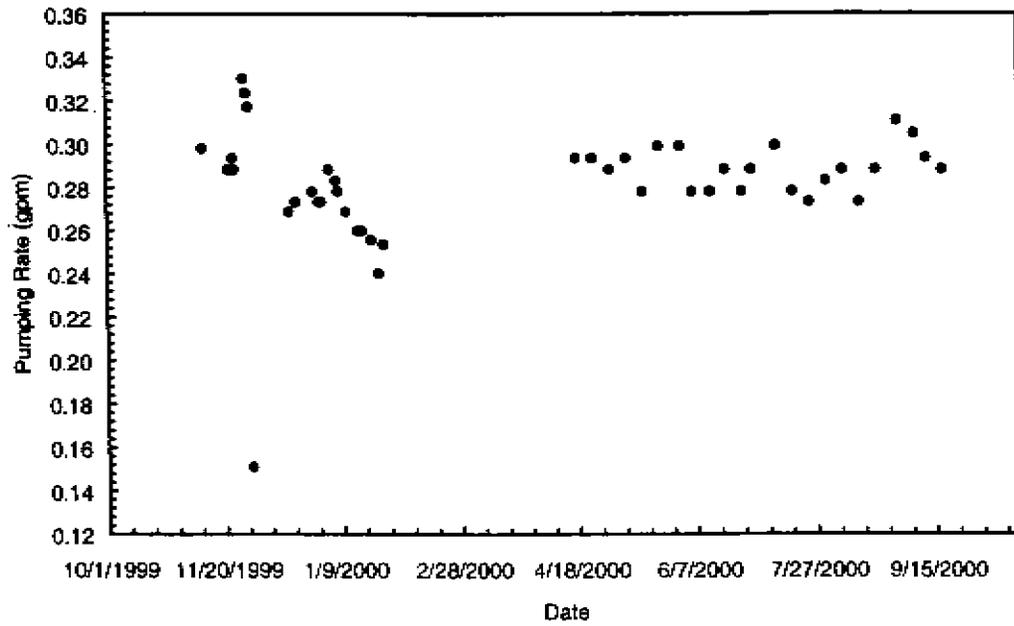


Figure 8. Discrete injection rates (gpm) at well HC-6.

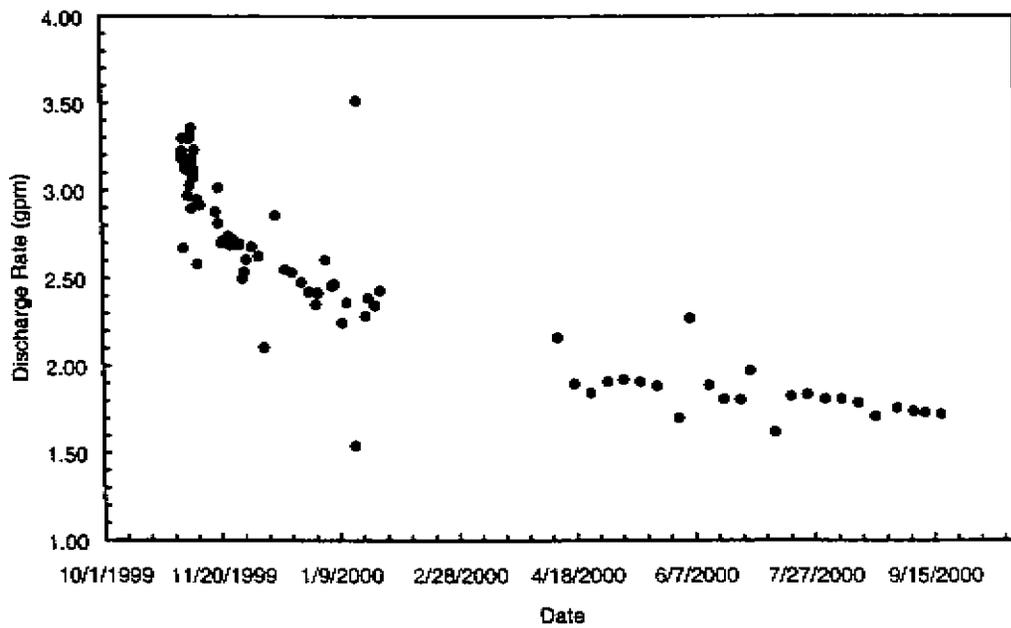


Figure 9. Discrete discharge rates (gpm) at well HC-7.

Water Levels

Water levels were collected within HC-6 at discrete intervals during the tracer test experiment until May 15, 2000, and these water levels are shown in Figure 10. Water levels within HC-7 were measured with SOLINST for the first couple of weeks. On November 20, 1999, an automated sampler was placed online. Samples were then collected from HC-7 every half hour throughout the experiment (except in the case of a pump failure). Figure 11 shows the depth to the water surface within well HC-7. Major pump failures are evident by large spikes in the water surface. These failures are marked within the figure. Smaller spikes seen in the water level at regular intervals are attributed to weekly maintenance on the pump generator, which was turned off for this purpose.

Tritium Data

Table 5 shows tritium concentrations at well HC-7. Samples were collected once a week and all samples were below the 1,000 pCi/L detection limit.

Tracer Data

The first injection (^{13}C , I and D_2O) began on November 3, 1999, and ended six hours later. Analytical data from the injection well indicated that the majority of tracer volume migrated into the formation (*e.g.*, see Iodide section). The second injection began at 17:00 hrs on Wednesday evening on November 10, 1999, and continued for one week. These tracers included lithium chloride, lithium bromide, PFBA and sodium hydroxide (to neutralize the acid). Despite the fact that iodide was not detected in well HC-7, it was

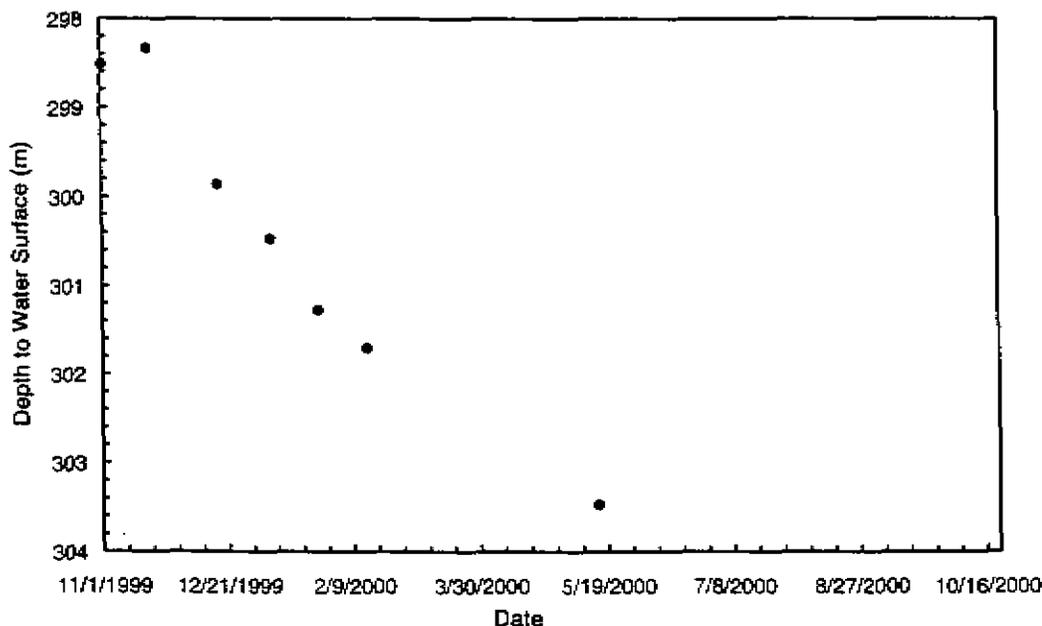


Figure 10. HC-6 water levels.

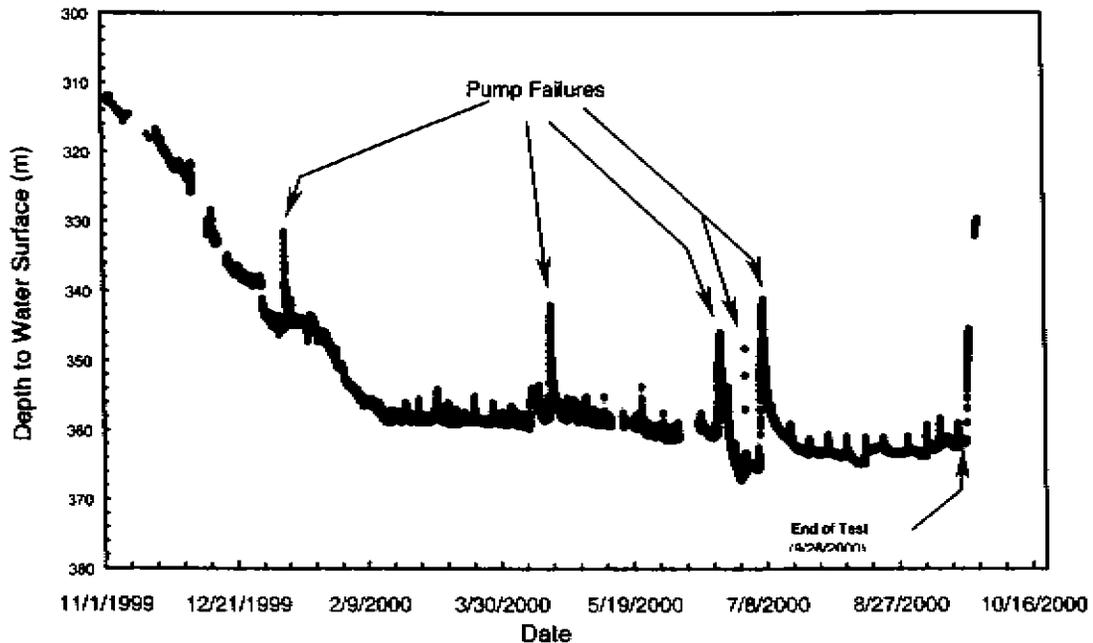


Figure 11. HC-7 water levels.

decided to add cesium to the injection well. This occurred on November 28, 1999. Finally, a small batch of microspheres was injected on June 12, 2000, to ensure that the high ionic strength of the tracer solution did not cause flocculation of the microspheres. Microsphere data were collected for three days following its injection. For a list of tracers, injection masses and the times of injection, refer to Table 6.

Iodide

Figure 12 shows the iodide concentrations versus time in the injection well (HC-6) following the injection. The results indicate that the tracer migrated out of the injection well as expected. No iodide was detected within the pumping well.

Carbon-13

All carbon-13 data collected at both the injection and pumping well showed tremendous scatter with results being unreliable. Thus, no carbon-13 data are presented.

Deuterium

Despite the extremely high concentrations of deuterium injected into HC-6, no deuterium was collected. However, deuterium was collected at the pumping well with data presented in Table 7 and Figure 13. Results of the deuterium analysis indicate that the variability of the δD is too large to properly identify a deuterium breakthrough curve. Thus, deuterium sampling was discontinued prior to the end of the tracer experiment.

Table 5. Tritium concentrations and dates/times collected.

Date	Time	Tritium Concentration (pCi/L)
2/28/2000	12:30	<1,000
3/6/2000	14:00	<1,000
4/3/2000	12:00	<1,000
4/10/2000	14:00	<1,000
4/17/2000	13:00	<1,000
4/24/2000	12:50	<1,000
5/1/2000	13:50	<1,000
5/8/2000	13:00	<1,000
5/15/2000	12:10	<1,000
5/22/2000	13:00	<1,000
5/30/2000	14:20	<1,000
6/5/2000	12:45	<1,000
7/10/2000	13:30	<1,000
7/17/2000	13:50	<1,000
7/24/2000	11:00	<1,000
7/31/2000	13:00	<1,000
8/7/2000	13:00	<1,000
8/14/2000	12:00	<1,000
8/21/2000	11:05	<1,000
8/30/2000	11:50	<1,000
9/6/2000	12:30	<1,000
9/11/2000	11:50	<1,000

Table 6. List of tracers, injection masses and time of injection.

Tracer	Injection Mass of Salt (Kg)	Injection Mass of Ion (Kg)	Injection Date	Injection Time
NaI	0.504	0.427	11/3/1999	17:51
NaH ¹³ CO ₃	0.05	0.01	11/3/1999	17:51
D ₂ O	4.00	4.00	11/3/1999	17:51
LiCl	91.11	14.91	11/10/1999	17:00
LiBr	22.62	Li = 1.81 Br = 20.81	11/10/1999	17:00
PFBA	2.30	2.30	11/10/1999	17:00
NaOH	0.43	n/a	11/10/1999	17:00
CsCl	15.00	11.84	11/28/1999	16:00
Microspheres¹	3.0 x 10 ¹⁴	3.0 x 10 ¹⁴	6/12/2000	14:42

¹Injection mass actually indicates the number of spheres injected rather than mass

Note: Ion of interest given in **bold**

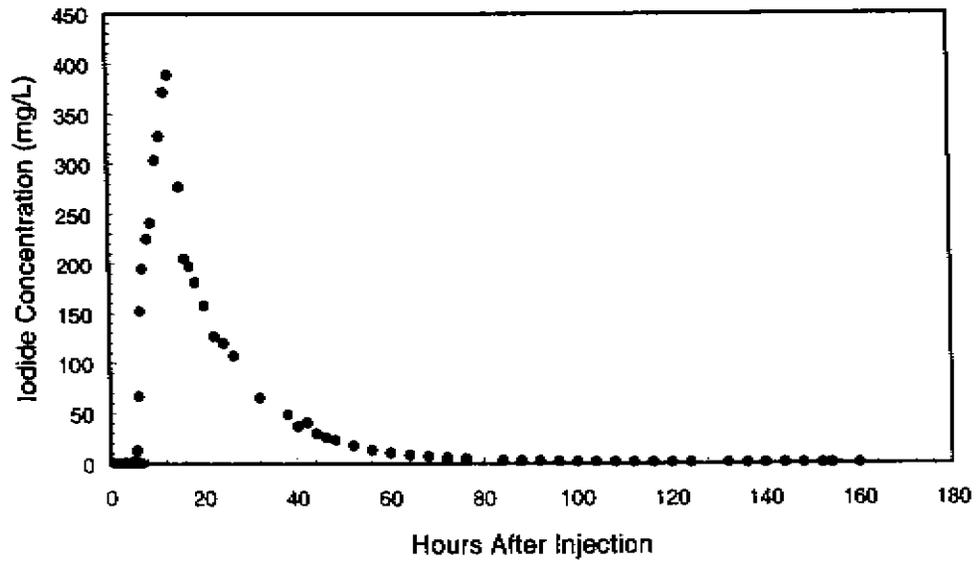


Figure 12. Iodide concentration versus time for the pre-tracer test injection at well HC-6.

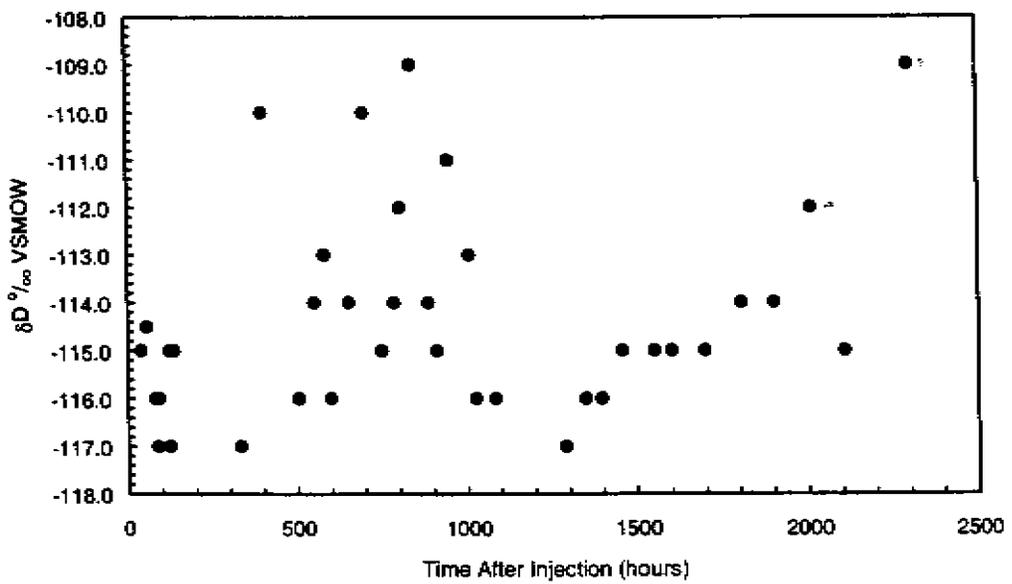


Figure 13. δD concentrations at well HC-7.

Table 7. Deuterium concentrations at well HC-7.

Date	Time	Time After Injection (hrs)	Concentration ($\delta D^{2}/_{\infty} V_{SMOW}$)
11/5/1999	11:08	41.28	-115.0
11/6/1999	5:00	59.15	-114.5
11/7/1999	5:03	83.20	-116.0
11/7/1999	12:00	90.15	-117.0
11/7/1999	15:00	93.15	-116.0
11/8/1999	21:04	123.22	-115.0
11/8/1999	22:02	124.18	-117.0
11/9/1999	11:03	137.20	-115.0
11/17/1999	13:01	331.17	-117.0
11/20/1999	12:03	402.20	-110.0
11/24/1999	18:00	504.15	-116.0
11/26/1999	18:00	552.15	-114.0
11/28/1999	0:00	582.15	-113.0
11/28/1999	18:00	600.15	-116.0
12/1/1999	0:00	654.15	-114.0
12/3/1999	0:00	702.15	-110.0
12/5/1999	0:00	750.15	-115.0
12/6/1999	12:00	786.15	-114.0
12/7/1999	6:00	804.15	-112.0
12/8/1999	18:00	840.15	-109.0
12/10/1999	18:00	888.15	-114.0
12/11/1999	18:00	912.15	-115.0
12/13/1999	6:00	948.15	-111.0
12/15/1999	18:00	1,008.15	-113.0
12/16/1999	12:00	1,026.15	-116.0
12/19/1999	0:00	1,086.15	-116.0
12/27/1999	11:30	1,289.65	-117.0
12/30/1999	0:00	1,350.15	-116.0
1/1/2000	0:00	1,398.15	-116.0
1/3/2000	12:00	1,458.15	-115.0
1/7/2000	10:20	1,552.48	-115.0
1/9/2000	12:00	1,602.15	-115.0
1/13/2000	12:00	1,698.15	-115.0
1/18/2000	0:00	1,806.15	-114.0
1/22/2000	0:00	1,902.15	-114.0
1/26/2000	12:14	2,010.38	-112.0
1/30/2000	12:10	2,106.32	-115.0
2/7/2000	11:40	2,297.82	-109.0

Bromide

Bromide injection data from HC-6 are presented in Table 8 and Figure 14. Bromide data from HC-7 are shown in Table 9 and Figure 15. Normalized discharge concentrations are presented in a composite graph that depicts all tracers analyzed at the pumping well HC-7 (Figure 19). Concentrations in Figure 19 are normalized by the

Table 8. Bromide injection concentrations.

Date	Time	Time After Injection (hrs)	Br Conc. (mg/L)
11/12/1999	17:00	48.00	3,330
11/12/1999	18:59	49.98	3,280
11/12/1999	21:11	52.18	3,370
11/12/1999	23:00	54.00	3,390
11/13/1999	7:00	62.00	3,430
11/13/1999	9:07	64.12	3,450
11/13/1999	11:06	66.10	3,440
11/13/1999	13:05	68.08	3,470
11/13/1999	15:09	70.15	3,460
11/13/1999	17:07	72.12	3,490
11/13/1999	19:07	74.12	3,770
11/13/1999	21:07	76.12	3,520
11/13/1999	23:00	78.00	3,490
11/14/1999	1:00	80.00	3,510
11/14/1999	3:00	82.00	3,530
11/14/1999	5:04	84.07	3,560
11/14/1999	7:00	86.00	3,570
11/14/1999	9:00	88.00	3,550
11/14/1999	11:15	90.25	3,550
11/14/1999	13:05	92.08	3,600
11/14/1999	15:00	94.00	3,620
11/14/1999	17:20	96.33	3,510
11/14/1999	19:05	98.08	3,240
11/14/1999	21:03	100.05	2,260
11/14/1999	23:00	102.00	2,040
11/15/1999	1:00	104.00	2,060
11/15/1999	3:00	106.00	1,840
11/15/1999	5:00	108.00	1,470
11/15/1999	7:00	110.00	1,230
11/15/1999	9:00	112.00	1,090
11/15/1999	13:08	116.13	758
11/15/1999	17:05	120.08	568
11/15/1999	21:00	124.00	425
11/16/1999	1:03	128.05	308
11/16/1999	5:04	132.07	228
11/16/1999	9:05	136.08	166
11/16/1999	13:10	140.17	118
11/16/1999	17:02	144.03	86
11/16/1999	21:06	148.10	62
11/17/1999	1:04	152.07	47
11/17/1999	4:58	155.97	35
11/17/1999	9:05	160.08	26
11/17/1999	13:07	164.12	19
11/17/1999	17:06	168.10	14
11/17/1999	21:05	172.08	11
11/18/1999	0:04	175.07	10
11/18/1999	5:03	180.05	7
11/18/1999	12:05	187.08	5
11/18/1999	18:05	193.08	4
11/19/1999	21:20	220.33	3

Table 9. Bromide concentrations at well HC-7 (Bromide: Co = 3,770 mg/L).

Date	Time	Time After Injection (hrs)	Concentration (mg/L)	C/Co
11/17/1999	17:00	168.0	0.607	0.00E+00
11/18/1999	0:01	175.0	0.625	4.77E-06
11/18/1999	18:00	193.0	0.618	2.92E-06
11/19/1999	6:20	205.3	0.613	1.59E-06
11/19/1999	23:45	222.8	0.617	2.65E-06
11/20/1999	12:03	235.0	0.606	1.61E-04
11/21/1999	6:00	253.0	0.603	1.60E-04
11/21/1999	18:45	265.7	0.609	5.31E-07
11/22/1999	0:00	271.0	0.777	2.06E-04
11/22/1999	20:00	291.0	0.816	2.16E-04
11/23/1999	6:00	301.0	0.637	7.96E-06
11/24/1999	0:00	319.0	0.619	3.18E-06
11/24/1999	18:00	337.0	0.634	7.16E-06
11/25/1999	12:00	355.0	0.628	5.57E-06
11/26/1999	6:00	373.0	0.620	3.45E-06
11/27/1999	0:00	391.0	0.624	4.51E-06
11/27/1999	18:00	409.0	0.621	3.71E-06
11/28/1999	12:00	427.0	0.617	2.65E-06
12/1/1999	0:00	487.0	0.650	1.14E-05
12/1/1999	6:00	493.0	0.662	1.46E-05
12/6/1999	6:00	613.0	0.653	1.22E-05
12/6/1999	12:00	619.0	0.656	1.30E-05
12/9/1999	18:00	697.0	0.676	1.83E-05
12/13/1999	12:00	787.0	0.681	1.96E-05
12/14/1999	12:00	811.0	0.684	2.04E-05
12/14/1999	18:00	817.0	0.660	1.41E-05
12/17/1999	11:50	882.8	0.670	1.67E-05
12/20/1999	12:30	955.5	0.690	2.20E-05
12/21/1999	0:00	967.0	0.740	3.53E-05
12/21/1999	12:00	979.0	0.740	3.53E-05
12/22/1999	0:00	991.0	0.730	3.26E-05
12/22/1999	12:00	1003.0	0.740	3.53E-05
12/23/1999	0:00	1015.0	0.740	3.53E-05
12/24/1999	9:24	1048.4	0.760	4.06E-05
12/24/1999	12:00	1051.0	0.750	3.79E-05
12/25/1999	0:00	1063.0	0.750	3.79E-05
12/25/1999	12:00	1075.0	0.760	4.06E-05
12/26/1999	0:00	1087.0	0.780	4.59E-05
12/27/1999	11:30	1122.5	0.800	5.12E-05
12/28/1999	0:00	1135.0	0.820	5.65E-05
12/28/1999	12:00	1147.0	0.820	5.65E-05
12/29/1999	0:00	1159.0	0.810	5.38E-05
12/29/1999	12:00	1171.0	0.840	6.18E-05
12/30/1999	0:00	1183.0	0.830	5.92E-05
12/30/1999	11:37	1194.6	0.830	5.92E-05
12/30/1999	11:37	1194.6	0.820	5.65E-05
12/31/1999	9:45	1216.7	0.900	7.77E-05
1/1/2000	0:00	1231.0	0.900	7.77E-05
1/1/2000	12:00	1243.0	0.900	7.77E-05
1/2/2000	0:00	1255.0	0.900	7.77E-05
1/2/2000	12:00	1267.0	0.900	7.77E-05
1/3/2000	0:00	1279.0	0.910	8.04E-05
1/3/2000	12:00	1291.0	1.000	1.04E-04
1/4/2000	0:00	1303.0	1.100	1.31E-04
1/4/2000	12:00	1315.0	1.090	1.28E-04
1/5/2000	0:00	1327.0	1.090	1.28E-04
1/5/2000	12:00	1339.0	1.060	1.20E-04
1/6/2000	0:00	1351.0	1.050	1.18E-04
1/6/2000	12:00	1363.0	1.000	1.04E-04

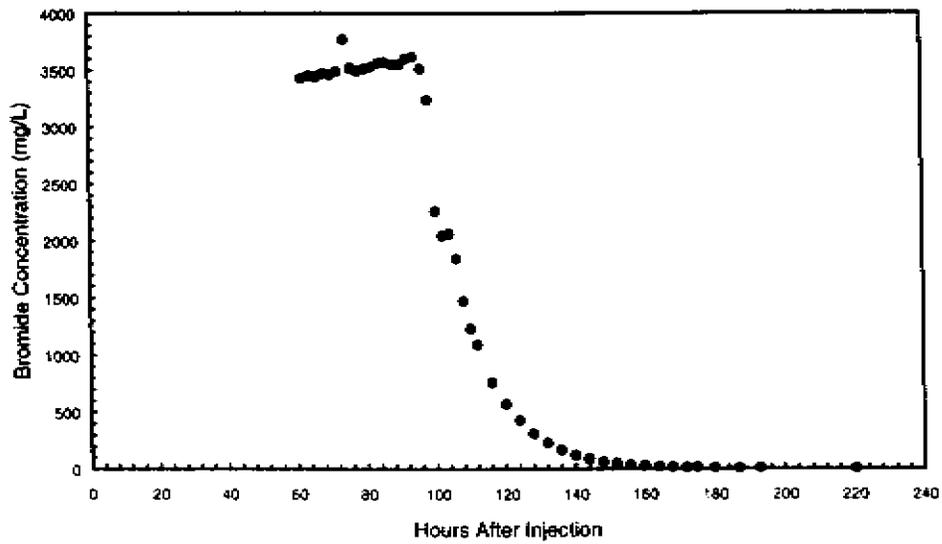


Figure 14. Bromide concentration decay at injection well HC-6.

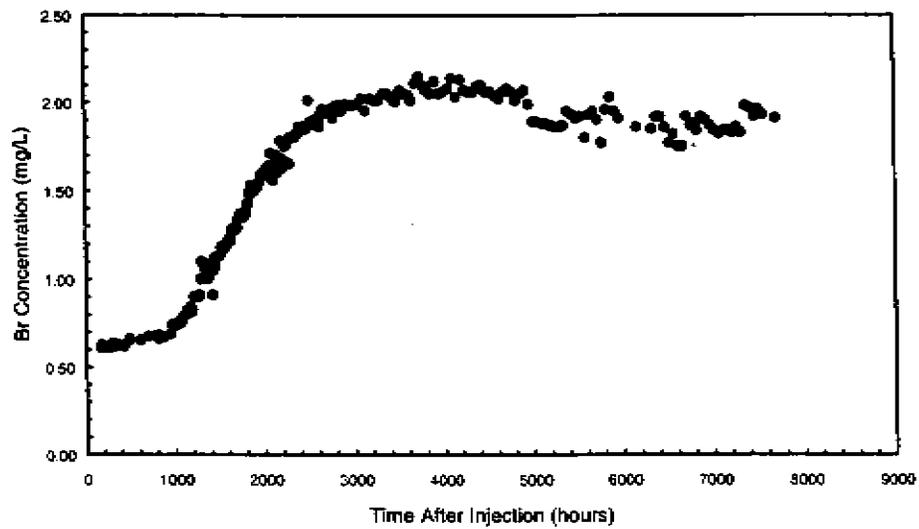


Figure 15. Br concentrations at discharge well HC-7.

injection concentration. Note that any noise in the breakthrough curve is attributed to pump variations in HC-7 during maintenance periods but these variations do not impact the overall shape of the curve.

Lithium

While no lithium data are available at the injection well, data collected at the pumping well are presented in Table 10, with concentrations shown in Figure 16 and normalized concentration shown within the composite graph given in Figure 19. Lithium data show a lag from bromide due to sorption of lithium to the granite matrix. The tendency for lithium to bind with granite retards its migration.

Cesium

For time of injection and mass injected, refer to Table 6; otherwise, no breakthrough data are available for cesium.

PFBA

PFBA injection data and its expected concentration decay are presented in Table 11 and Figure 17. Discharge data are shown in Table 12 with concentrations presented in Figure 18 and normalized concentrations given in the composite graph (Figure 19). PFBA has an earlier arrival time than lithium due to its large molecules not diffusing into the granite matrix. Its breakthrough curve shows a similar trend to bromide but with slightly larger relative concentrations observed due to reduced matrix diffusion.

Microspheres

For time of injection and mass injected, refer to Table 6; otherwise, no breakthrough data are available for microspheres.

General Chemistry

Chloride and sulfate chemistry were evaluated at the discharge well HC-7 at discrete times during the tracer test experiment to determine if well HC-7 was receiving water similar to that seen in well HC-5. It was found that both chloride and sulfate concentrations are lower in well HC-5. Given no trend in the general chemistry was detected between wells HC-5 and HC-7, it appears that well HC-7 does not bring water from the deep aquifer tapped by well HC-5. Data for well HC-7 are presented within Table 13 as well as on the composite graph given in Figure 19.

Table 10. Lithium concentrations at discharge well HC-7 (Lithium: Co = 2,948 mg/L).

Date	Time	Time After Injection (hrs)	Concentration (mg/L)	C/Co
01/10/2000	12:00	1,459.0	0.083	0.00E+00
01/12/2000	12:09	1,507.1	0.085	5.77E-07
01/20/2000	12:37	1,699.6	0.090	2.31E-06
01/26/2000	12:14	1,843.2	0.095	4.04E-06
02/04/2000	14:22	2,061.4	0.102	6.34E-06
02/09/2000	11:20	2,178.3	0.106	7.50E-06
02/14/2000	12:04	2,299.1	0.100	5.63E-06
02/17/2000	12:15	2,371.2	0.114	1.04E-05
02/23/2000	13:21	2,516.3	0.123	1.33E-05
02/24/2000	0:10	2,527.2	0.119	1.21E-05
03/07/2000	12:05	2,827.1	0.124	1.38E-05
03/08/2000	12:05	2,851.1	0.124	1.38E-05
03/09/2000	12:05	2,875.1	0.126	1.45E-05
03/10/2000	12:05	2,899.1	0.126	1.45E-05
03/11/2000	12:05	2,923.1	0.128	1.51E-05
03/12/2000	12:05	2,947.1	0.128	1.51E-05
03/13/2000	12:05	2,971.1	0.126	1.45E-05
03/14/2000	12:00	2,995.0	0.129	1.55E-05
03/16/2000	12:00	3,043.0	0.129	1.55E-05
03/18/2000	12:00	3,091.0	0.133	1.68E-05
03/20/2000	12:00	3,139.0	0.133	1.68E-05
03/22/2000	12:00	3,187.0	0.143	2.02E-05
03/24/2000	12:00	3,235.0	0.143	2.02E-05
03/26/2000	12:00	3,283.0	0.144	2.06E-05
03/28/2000	12:00	3,331.0	0.144	2.06E-05
03/30/2000	12:00	3,379.0	0.146	2.12E-05
04/01/2000	12:00	3,427.0	0.146	2.12E-05
04/03/2000	12:00	3,475.0	0.148	2.19E-05
04/05/2000	12:00	3,523.0	0.150	2.26E-05
04/07/2000	12:00	3,571.0	0.148	2.19E-05
04/09/2000	12:00	3,619.0	0.150	2.26E-05
04/10/2000	14:00	3,645.0	0.148	2.19E-05
04/12/2000	12:00	3,691.0	0.150	2.26E-05
04/14/2000	5:30	3,732.5	0.156	2.46E-05
04/16/2000	12:50	3,787.8	0.153	2.36E-05
04/17/2000	12:50	3,811.8	0.150	2.26E-05
04/19/2000	12:00	3,859.0	0.164	2.73E-05
04/21/2000	12:00	3,907.0	0.173	3.04E-05
04/23/2000	12:00	3,955.0	0.167	2.84E-05
04/25/2000	12:00	4,003.0	0.165	2.77E-05
04/27/2000	12:00	4,051.0	0.167	2.84E-05
04/29/2000	12:00	4,099.0	0.170	2.94E-05
05/01/2000	12:00	4,147.0	0.167	2.84E-05
05/03/2000	12:00	4,195.0	0.173	3.04E-05
05/05/2000	12:00	4,243.0	0.171	2.97E-05
05/07/2000	12:00	4,291.0	0.170	2.94E-05
05/09/2000	12:00	4,339.0	0.180	3.28E-05
05/11/2000	12:00	4,387.0	0.180	3.28E-05
05/13/2000	12:00	4,435.0	0.178	3.21E-05
05/15/2000	12:00	4,483.0	0.180	3.28E-05
05/17/2000	12:00	4,531.0	0.181	3.31E-05
05/19/2000	12:00	4,579.0	0.180	3.28E-05
05/21/2000	12:00	4,627.0	0.181	3.31E-05
05/23/2000	12:00	4,675.0	0.187	3.51E-05
05/25/2000	12:00	4,723.0	0.185	3.45E-05
05/27/2000	12:00	4,771.0	0.189	3.58E-05
05/29/2000	12:00	4,819.0	0.185	3.45E-05
05/31/2000	12:00	4,867.0	0.180	3.28E-05

Table 11. PFBA concentration data at injection well HC-6.

Date	Time	Time After Injection (hrs)	PFBA Conc. (ppb)
11/10/1999	20:31	3.52	3,033.9
11/10/1999	20:33	3.55	544,420.0
11/10/1999	21:32	4.53	7,906.8
11/10/1999	22:34	5.57	33,719.0
11/10/1999	23:31	6.52	65,487.0
11/11/1999	0:31	7.52	89,071.0
11/11/1999	1:30	8.50	106,400.0
11/11/1999	2:30	9.50	121,330.0
11/11/1999	3:30	10.50	125,620.0
11/11/1999	4:35	11.58	151,490.0
11/11/1999	9:15	16.25	192,780.0
11/11/1999	13:05	20.08	241,360.0
11/11/1999	19:02	26.03	291,410.0
11/11/1999	23:02	30.03	304,010.0
11/12/1999	3:01	34.02	334,060.0
11/12/1999	7:00	38.00	335,770.0
11/12/1999	11:01	42.02	335,480.0
11/12/1999	15:03	46.05	332,890.0
11/12/1999	18:59	49.98	369,840.0
11/13/1999	5:03	60.05	359,490.0
11/13/1999	11:06	66.10	379,550.0
11/13/1999	17:07	72.12	391,830.0
11/13/1999	23:00	78.00	397,670.0
11/14/1999	5:04	84.07	383,370.0
11/14/1999	9:00	88.00	359,980.0
11/14/1999	13:05	92.08	395,250.0
11/14/1999	15:00	94.00	396,370.0
11/14/1999	17:20	96.33	391,460.0
11/14/1999	19:05	98.08	370,200.0
11/14/1999	21:03	100.05	266,130.0
11/14/1999	23:00	102.00	254,430.0
11/15/1999	1:00	104.00	229,640.0
11/15/1999	3:00	106.00	206,210.0
11/15/1999	5:00	108.00	171,460.0
11/15/1999	7:00	110.00	140,180.0
11/15/1999	9:00	112.00	124,340.0
11/15/1999	17:05	120.08	667,91.0
11/16/1999	1:03	128.05	345,91.0
11/16/1999	9:05	136.08	188,87.0
11/16/1999	17:02	144.03	105,65.0
11/17/1999	1:04	152.07	5,705.0
11/17/1999	9:05	160.08	509.0
11/17/1999	21:05	172.08	0.0
11/18/1999	12:05	187.08	0.0
11/19/1999	21:20	220.33	0.0

Table 12. PFBA concentrations at discharge well HC-7 (PFBA: Co = 397,000 ppb).

Date	Time	Time After Injection	Concentration	C/Co
12/18/1999	0:00	895.0	8.80	2.22E-05
12/19/1999	0:00	919.0	10.70	2.70E-05
12/20/1999	0:00	943.0	11.30	2.85E-05
12/21/1999	0:00	967.0	13.90	3.50E-05
12/22/1999	0:00	991.0	16.47	4.15E-05
12/22/1999	12:00	1003.0	16.90	4.26E-05
12/27/1999	11:30	1122.5	30.40	7.66E-05
12/31/1999	0:00	1207.0	40.77	1.03E-04
1/3/2000	12:00	1291.0	49.47	1.25E-04
1/8/2000	0:00	1399.0	73.83	1.86E-04
1/12/2000	12:09	1507.1	82.42	2.08E-04
1/16/2000	12:00	1603.0	90.82	2.29E-04
1/19/2000	0:00	1663.0	100.71	2.54E-04
1/21/2000	0:00	1711.0	101.31	2.55E-04
1/25/2000	0:00	1807.0	109.82	2.77E-04
1/27/2000	0:10	1855.2	125.94	3.17E-04
1/31/2000	0:10	1951.2	132.54	3.34E-04
2/2/2000	0:01	1999.0	137.33	3.46E-04
2/4/2000	14:22	2061.4	138.25	3.48E-04
2/7/2000	11:40	2130.7	153.56	3.87E-04
2/9/2000	0:01	2167.0	148.54	3.74E-04
2/10/2000	12:01	2203.0	150.97	3.80E-04
2/12/2000	12:11	2251.2	155.42	3.91E-04
2/17/2000	0:10	2359.2	150.40	3.79E-04
2/19/2000	0:01	2407.0	162.73	4.10E-04
2/21/2000	0:01	2455.0	163.50	4.12E-04
2/23/2000	0:01	2503.0	158.04	3.98E-04
2/25/2000	0:10	2551.2	155.57	3.92E-04
2/27/2000	0:10	2599.2	173.16	4.36E-04
2/29/2000	12:05	2659.1	171.50	4.32E-04
3/2/2000	12:05	2707.1	164.15	4.13E-04
3/4/2000	12:05	2755.1	172.19	4.34E-04
3/6/2000	11:20	2802.3	167.92	4.23E-04
3/7/2000	12:05	2827.1	199.72	5.03E-04
3/8/2000	12:05	2851.1	173.96	4.38E-04
3/10/2000	12:05	2899.1	171.74	4.33E-04
3/12/2000	12:05	2947.1	179.34	4.52E-04
3/13/2000	12:05	2971.1	199.72	5.03E-04
3/14/2000	12:00	2995.0	171.16	4.31E-04
3/16/2000	12:00	3043.0	172.30	4.34E-04
3/18/2000	12:00	3091.0	161.12	4.06E-04
3/20/2000	12:00	3139.0	180.39	4.54E-04
3/22/2000	12:00	3187.0	187.71	4.73E-04
3/24/2000	12:00	3235.0	177.62	4.47E-04
3/30/2000	12:00	3379.0	179.00	4.51E-04
4/5/2000	12:00	3523.0	208.55	5.25E-04
4/10/2000	14:00	3645.0	185.50	4.67E-04
4/19/2000	12:00	3859.0	188.80	4.76E-04
4/23/2000	12:00	3955.0	191.40	4.82E-04
4/27/2000	12:00	4051.0	179.40	4.52E-04
5/5/2000	12:00	4243.0	181.10	4.56E-04
5/9/2000	12:00	4339.0	175.30	4.42E-04
5/13/2000	12:00	4435.0	179.00	4.51E-04
5/17/2000	12:00	4531.0	175.95	4.43E-04
5/21/2000	12:00	4627.0	178.50	4.50E-04
5/25/2000	12:00	4723.0	178.54	4.50E-04
5/29/2000	12:00	4819.0	177.97	4.48E-04
6/2/2000	12:00	4915.0	174.91	4.41E-04

Table 13. Cl and SO₄ concentrations at discharge well HC-7.

Date	Time	Time After Injection (hrs)	Cl Conc. (mg/L)	SO ₄ Conc. (mg/L)
11/10/1999	17:00	0	189	329
12/14/1999	1:00	817	198	339
1/25/2000	7:00	1,831	210	345
3/13/2000	19:00	2,995	211	337
4/28/2000	19:00	4,099	206	329
6/3/2000	19:00	4,963	199	322

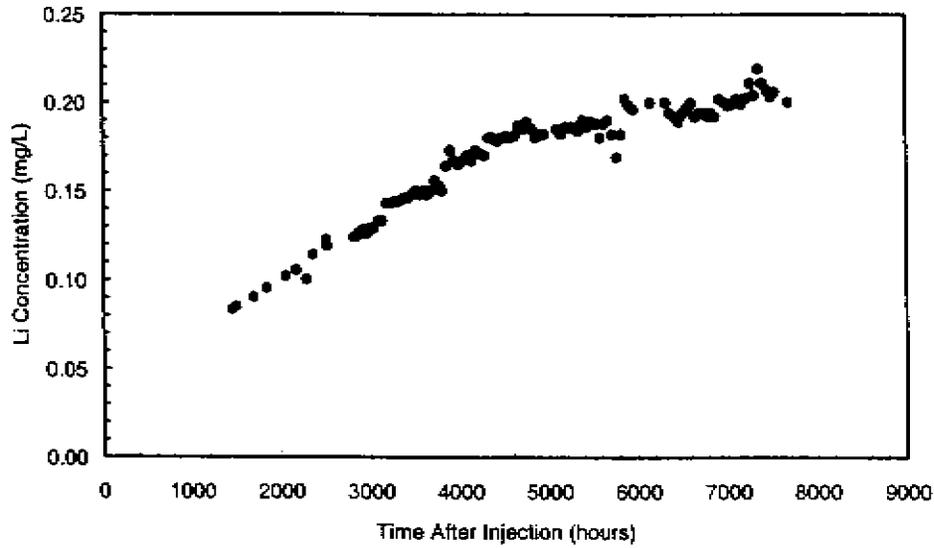


Figure 16. Lithium concentrations at discharge well HC-7.

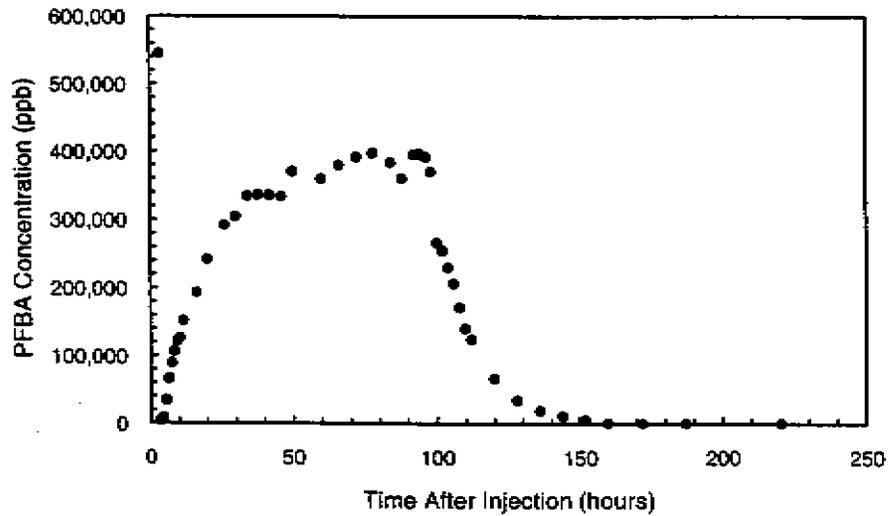


Figure 17. PFBA concentrations at injection well HC-6.

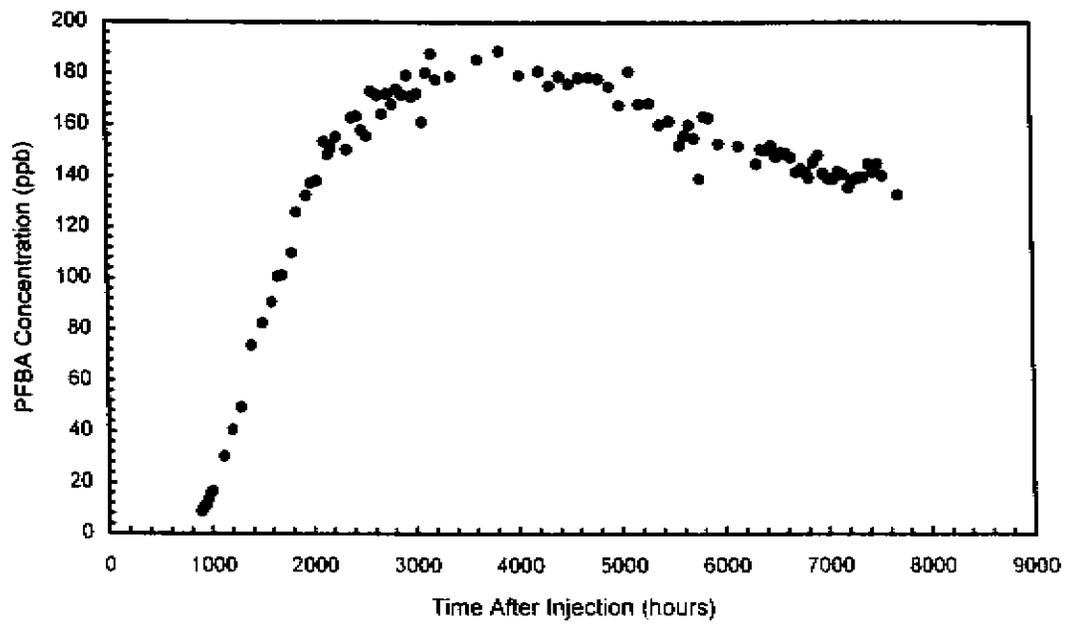


Figure 18. PFBA concentrations at discharge well HC-7.

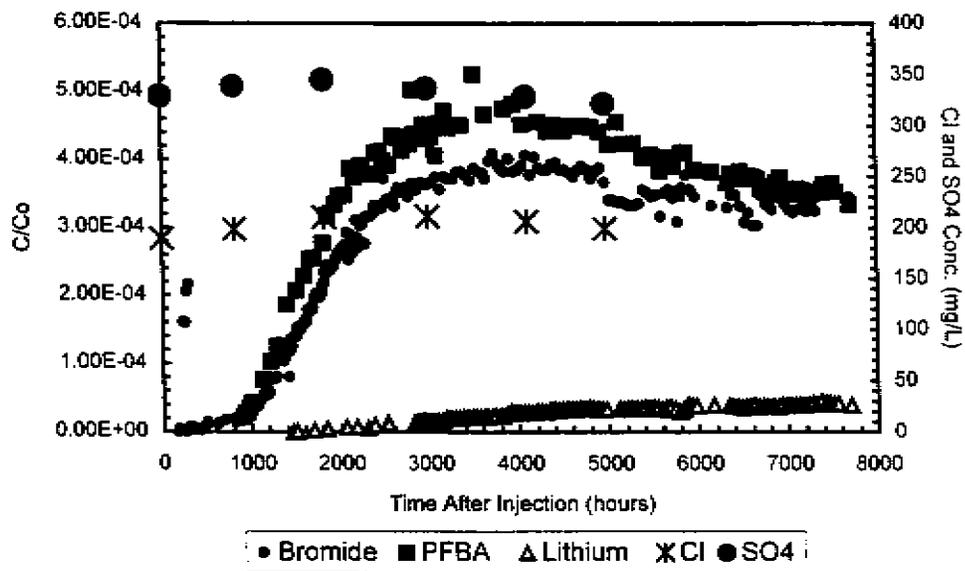


Figure 19. Normalized concentrations of Br, PBFA and Li as well as actual concentrations of Cl and SO₄.

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