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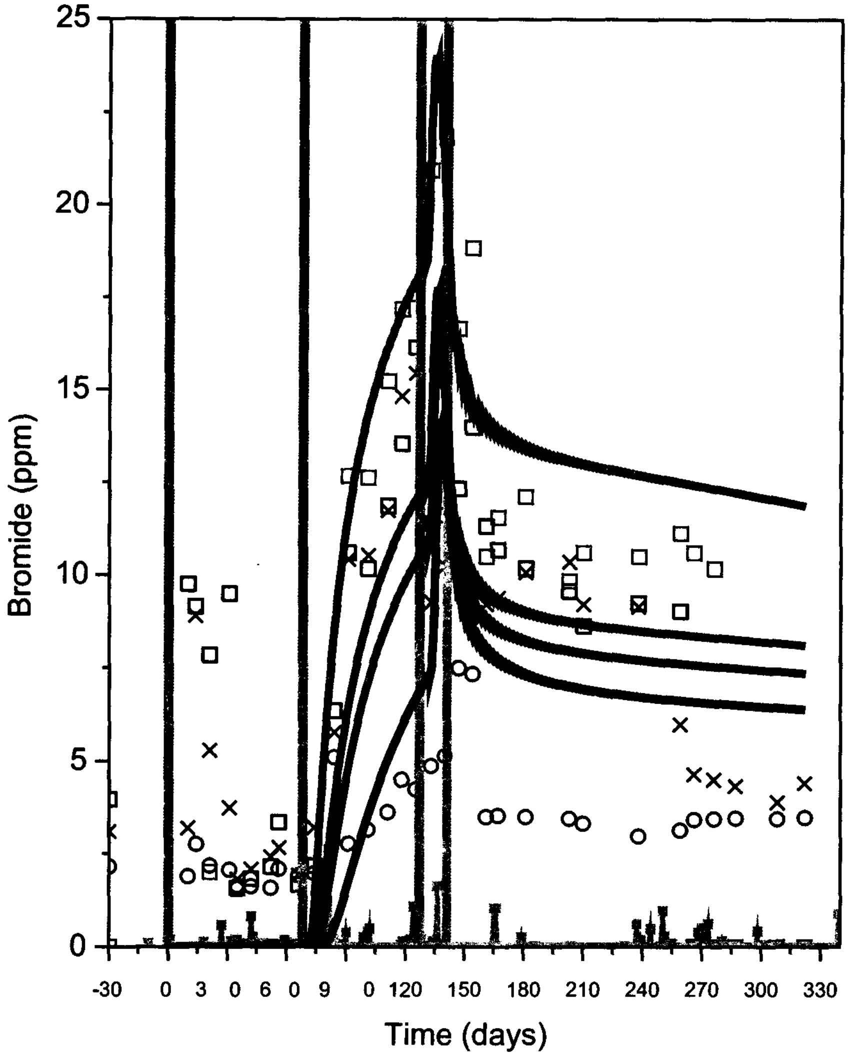
Results of Monitoring at the Los Alamos Canyon Low-Head Weir, 2002–2003



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The cover shows observed (symbols) and modeled (curved lines) concentrations of tracer in groundwater perched at intermediate depth in basalt beneath the weir site. The long vertical lines denote ponding behind the weir that enhanced downward movement of tracer-laced water. The tracer test and monitoring increased our understanding of the connection of surface water and groundwater as well as the hydraulic properties of the basalt underlying the Los Alamos Canyon at the weir site.

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LA-14103-MS
Low-Head Weir Report
Issued: March 2004

Results of Monitoring at the Los Alamos Canyon Low-Head Weir, 2002–2003

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ABBREVIATIONS AND ACRONYMS

bgs	below ground surface
cfs	cubic feet per second
dpm	disintegrations per minute
EES	Earth and Environmental Science (Division)
ER	Environmental Restoration (Project)
FLUTe	Flexible Liner Underground Technology, Inc.
ft/d	feet per day
gpm	gallons per minute
I.D.	inside diameter
KBr	potassium bromide
KI	potassium iodide
LA	Los Alamos
LANL	Los Alamos National Laboratory
LAWS	Los Alamos weir site (well-number prefix)
meq/L	milliequivalents per liter
mg/kg	milligrams per kilogram
NA	not applicable or not available
O.D.	outside diameter
ppm	parts per million
PVC	polyvinyl chloride
Qal	Quaternary alluvium
RRES	Risk Reduction and Environmental Stewardship (Division)
SEA	Science and Engineering Associates, Inc.
ss	suspended sediment (in groundwater sample)
TA	Technical Area
TD	total depth
TDS	total dissolved solids
TIC	total inorganic carbon
TOC	total organic carbon

RESULTS OF MONITORING AT THE LOS ALAMOS CANYON LOW-HEAD WIER, 2002–2003

by

William Stone, Dennis Newell, Daniel Levitt, David Wykoff, Phil Stauffer, Patrick Longmire, Armand Groffman, Catherine Jones, and Robert Roback

ABSTRACT

The U.S. Army Corps of Engineers constructed a low-head weir in Los Alamos (LA) Canyon near the White Rock "Y" in response to concern over the potential for transport of contaminant-laden sediment off Los Alamos National Laboratory (LANL) property in the wake of the Cerro Grande fire in May 2000. However, both the presence of fractured basalt below the channel and the temporary ponding of water behind the weir enhanced the potential for subsurface transport at the site. In 2001, LANL installed and instrumented a vertical well and two angled boreholes to monitor water quantity and quality in the unsaturated and intermediate-depth perched saturated zones at the weir. In addition to monitoring the movement of fire products and LANL-derived contaminants, two tracer tests were conducted (using potassium-bromide and later potassium-iodide) to evaluate the connection of surface water and groundwater.

A June 2002 runoff event caused wetting to 89 ft in the vadose zone within 3 days, suggesting a minimum rate of movement through the fractured basalt of 30 ft/d. Bromide increased in the vertical well within 10 days for a minimum rate of 12–18 feet per day (ft/d). Actual rates are greater than these because the fractures are neither vertical nor straight and thus pathways are longer. Results of subsequent events in 2002 as well as 2003 are consistent with those of this first one. The observed distribution of bromide was simulated quite well using FEHM when the basalt was assumed to be a homogeneous continuum having only fracture porosity in the range of 0.001 – 0.01 and a permeability of 10^{-11} – 10^{-12} m^2.

Elevated values obtained for four constituents (total organic carbon, alkalinity, calcium, and sodium) in the vertical well are attributed to the fire. These were detected after runoff generated by draining the reservoir in upper LA Canyon became ponded behind the weir. Perhaps the most important contribution made by the weir project is that it provides another approach to quantifying hydraulic properties of the basalt, which is a significant element of the conceptual hydrogeologic model for the Pajarito Plateau.

Because monitoring coincided with a period of drought, some issues could not be investigated. Therefore, although Cerro Grande Fire funding ceased at the end of FY 2003, work should continue at this important installation.

INTRODUCTION

A prescribed burn in the Bandelier National Monument in May 2000 went out of control and spread across the Sierra de los Valles and western Pajarito Plateau as the Cerro Grande fire. It was the most devastating wildfire in New Mexico to that date (Joseph 2001, 72662). A common consequence of fire is enhanced runoff in the damaged watersheds. For example, in Water Canyon above NM highway 501, the estimated post-fire peak discharge for one storm event of 840 cubic feet per second (cfs) dwarfs the pre-fire maximum of 0.3 cfs (Gallaher et al. 2001, 72662). In response to concern over the potential for enhanced runoff and transport of contaminant-laden sediment off site in the wake of the Cerro Grande fire, the U.S. Army Corps of Engineers constructed a low-head weir in LA Canyon near the White Rock "Y" (Figure 1). The structure was designed to mitigate surface transport of contaminants adsorbed on sediment.

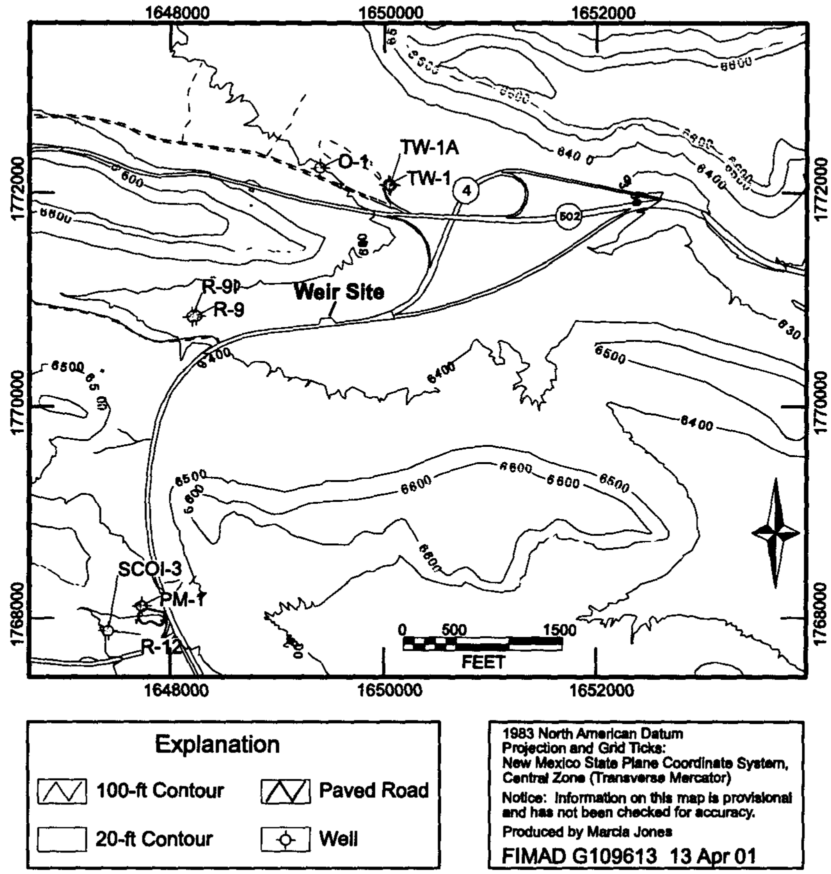

Figure 1. Location of the weir site

However, the project neglected to consider subsurface transport, which is potentially enhanced by both the local geology and temporary ponding of water behind the weir. Thin alluvium along the channel floor is underlain by highly fractured basalt. Grading to make the pond floor flat scraped all of the alluvium away in places, exposing the fractured basalt in the streambed. Even temporary ponding behind the weir provides enough hydraulic head to enhance downward movement of surface water. Therefore, a site was established for monitoring the quality of water perched in the basalt at intermediate depth beneath Los Alamos (LA) Canyon in the vicinity of the weir. A report by Stone and Newell (2002, 73446) documented the installation of the monitoring site. The purpose of this report is to present the results obtained by Los Alamos National Laboratory (LANL) at the weir site.

Hydrogeologic Setting

The study area lies in the eastern part of the Pajarito Plateau, a deeply dissected expanse of volcanic and sedimentary deposits situated between the Jemez Mountains and the Rio Grande. The headwaters of Los Alamos Canyon lie west of the plateau in the Sierra de los Valles. Much of the upper portion of the canyon, west of the Los Alamos townsite, lies in an area where burn severity during the Cerro Grande fire was classified as high.

Streamflow in middle LA Canyon is ephemeral. Most runoff occurs in response to snowmelt in the spring or to convective thunderstorms during the summer monsoon season. These rainstorms can be very localized. That is, there can be runoff at a station even though no precipitation is recorded there. Because the reservoir in upper Los Alamos Canyon was emptied and dredged after the fire to capture intense runoff and related heavy sediment loads, little water from storms in the headwaters escapes to the lower reaches of the canyon and thus the weir. Even runoff from storms centered below the reservoir rarely reaches the weir. Most of the runoff that reached the weir diring the study period, and thus mobilizing tracers, comes through DP Canyon from storms centered over the townsite.

Regional groundwater characterization well R-9i, located approximately 1/4 mi. west of the weir, provides the basis for a good conceptual hydrogeologic model of the portion of Los Alamos Canyon where the weir is located (Broxton et al. 2001, 71250). This well was installed under the Hydrogeologic Workplan (LANL 1998, 59599) to characterize and monitor intermediate-depth perched saturation in the Cerros del Rio basalt near the eastern Laboratory boundary. Two zones of perched groundwater were encountered in R-9i. The upper zone extends from a depth of 142 to 236 ft bgs whereas the lower zone occurred between 264 and 282 ft bgs. Hydrologic testing at R-9i indicated the upper zone was much more productive than the lower zone (Broxton et al. 2001, 71251).

The Weir and Monitoring Site

The weir consists of a rock-and-mesh gabion constructed across the channel in Los Alamos Canyon downstream of a flat-floored area (Figure 2). The structure is classified as "low-head" because water can pass through the gabion and significant long-term ponding behind the weir should not occur. It was designed to cause particles larger than 80 microns in diameter to settle in a flat area graded in the channel behind the weir.

Figure 2. The Los Alamos Canyon low-head weir with ponded runoff

LANL drilled three boreholes, including a vertical well and two angled holes (one at approximately 45° and one at approximately 30° to horizontal), to provide a means of monitoring the impact of the Cerro Grande fire and of the weir itself on water quality beneath the canyon (Figure 3). The boreholes are located upstream of the weir on the south bank of the channel in the northeast corner of the paved parking lot near the White Rock "Y" (Figure 1). The well and angled holes were assigned the prefix LAWS for Los Alamos Weir Site; Table 1 gives their location and elevation. Stone and Newell (2002, 73446) gave complete details of the installation of the monitoring site. However, brief descriptions of the well and boreholes are given below for completeness.

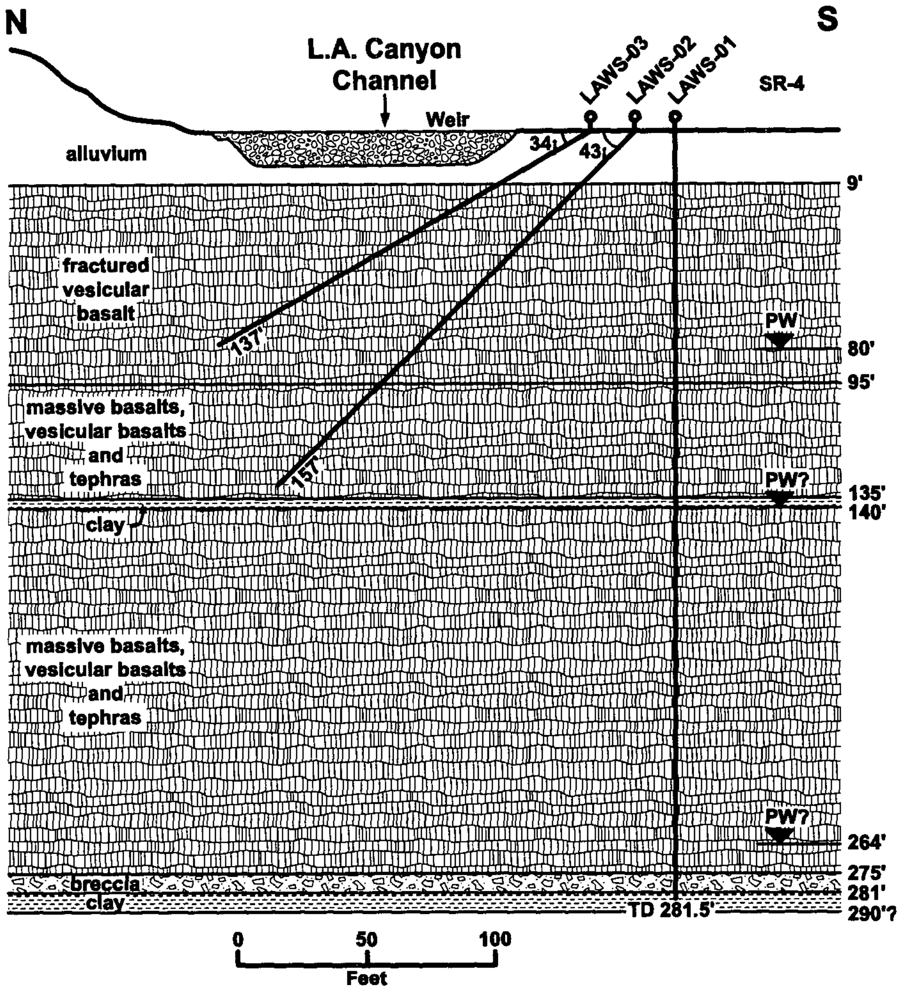

Figure 3. Hydrogeology of the weir site; PW = perched water table

Table 1
Geodetic Data for the Well and Boreholes at the Weir Monitoring Site

Well/Borehole[a]	Bearing/Inclination	Easting (ft)[b]	Northing (ft)[b]	Elevation (ft)[c]
LAWS-01 (LA10135)	NA (vertical)	1649524.5	1770854.0	6363.40
LAWS-02 (LA10136)	N40°E/ ~43°	1649536.913	1770848.298	6363.42
LAWS-03 (LA10137)	N40°E/~34°	1649542.9	1770848.8	6363.42

[a] Number in parentheses is FIMAD ID number for well/borehole.
[b] NAD 83 Survey Coordinates for brass monument in concrete pad.
[c] Above mean sea level.

The vertical hole (LAWS-01), drilled to a total depth of 281.5 ft below ground surface (bgs), was completed as a 278-ft deep polyvinyl chloride (PVC) monitoring well with four screens: one targeting shallow perched water encountered during drilling at 80 ft following an extended period of ponding, two in what may correspond to the upper perched zone at regional groundwater characterization well R-9i (1/4 mi. to the west), and one in what may correspond to the lower perched zone at R-9i (Figure 4). LAWS-01 was outfitted for water-level measurements and sampled with a rubberized fabric sleeve manufactured by Flexible Liner Underground Technology, Inc. (FLUTe™). More specifically, a Water FLUTe™ system deployed in the well isolates the screened intervals while associated transducers and sampling ports permit monitoring both head and water quality in the screened intervals.

The second hole (LAWS-02), drilled at an angle of 43° from horizontal, is 156 ft long and bottoms at a depth of 106 ft bgs (Figure 5). The shallow perched water seen at 80 ft in LAWS-01 was not encountered. The borehole was initially instrumented with a color-reactive liner to locate water-producing fractures. That liner was later replaced by an absorbent liner to collect water from the vadose zone. Electrical-wire pairs associated with the liner provide profiles of relative moisture content, based on resistance. Because of borehole instability, liners were deployed through PVC in which 30-in. long scallops spaced at 6-in. intervals had been cut to permit access to the borehole wall.

The third hole (LAWS-03) was drilled at an angle of 34° from horizontal to a length of 137 ft, as shown in Figure 3. However, because of difficulties in construction, the completed borehole is only 85 ft long and bottoms at a depth of 40 ft bgs. Therefore, LAWS-03 was not used in the monitoring described here.

Three zones of perched saturation were encountered in the Cerros del Rio basalt at the weir site. The shallowest perched water, observed during drilling of the vertical hole at a depth of 80 ft bgs, is apparently ephemeral. Although this zone was not detected during the drilling of LAWS-02, its presence has been subsequently confirmed by periodic saturation in the upper screen (port 1) in LAWS-01. The other two zones of perched water correspond to those encountered at R-9i (Figure 3). The upper zone occupies an interval between approximately 140 and 210 ft bgs. The perching layer is the thick interval of massive basalt below 210 ft bgs. The lower zone extends from a depth of approximately 264 ft to 281 ft. At R-9i, this water is perched upon an 8-ft-thick clay interval overlying the so-called "old alluvium" of Griggs (1964, 65649). The top of this clay interval was encountered in LAWS-01 essentially at the depth predicted from its occurrence in R-9i.

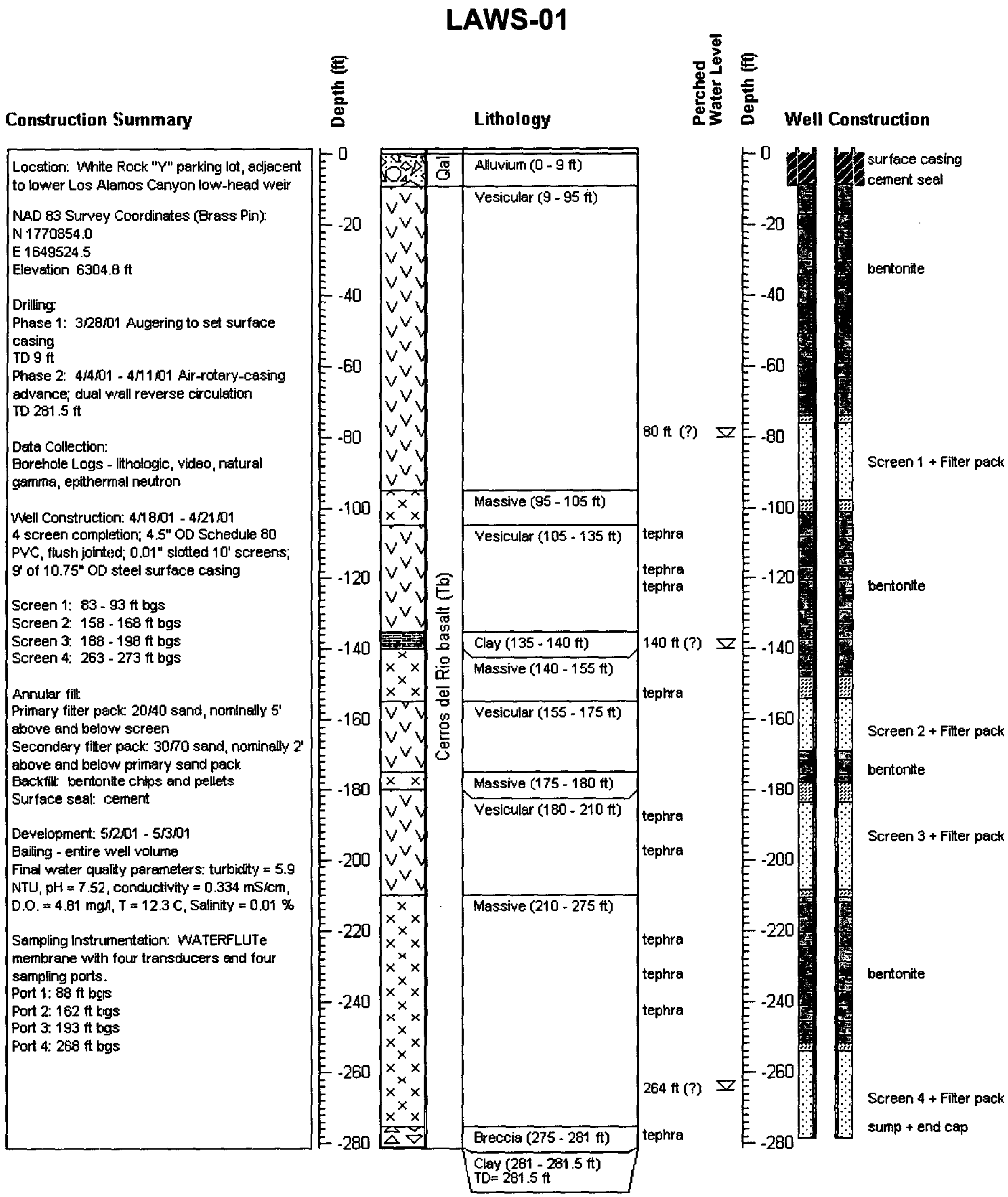

Figure 4. **Hydrogeology and construction of LAWS-01**

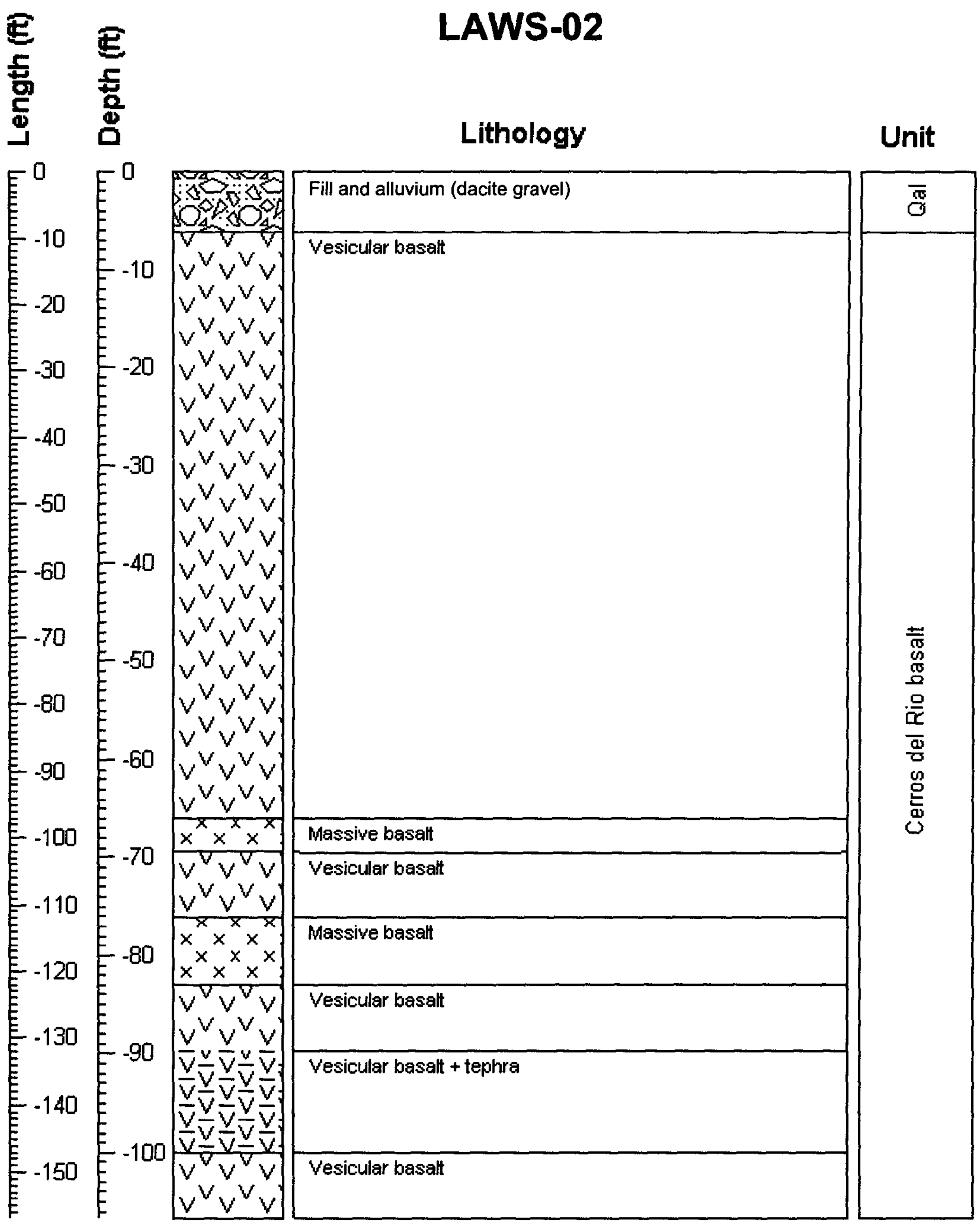

Figure 5. Geology of LAWS-02

TRACER TESTS

Two tracer tests were conducted at the weir site to determine travel times from the surface through the fractured basalt and to the perched water within it. The first test involved potassium-bromide and was initiated in 2002. The second test involved potassium-iodide and was conducted in 2003.

Bromide

In order to properly evaluate tracer-test results, the background concentrations of the tracer constituents at the site were investigated. Analysis of the groundwater sample taken 17 December 2002 from LAWS-01 includes background concentrations for potassium and bromide at the site (Appendix A-1). For all screens, the concentration of potassium was slightly greater than 4 parts per million (ppm) and that of bromide was less than 1 ppm. Presumably, concentrations in samples taken after the tracer was applied that markedly exceed these values represent arrival of tracer.

On 29 April 2002, a 0.2 molar solution of potassium bromide (KBr) was applied to the ground surface behind the weir. That is, a 16,725-ppm solution of KBr was sprayed onto the dry floor of the pond area just upstream of the weir. It was reasoned that the solution would evaporate, leaving KBr salt behind until the next runoff event dissolved and mobilized it. In response to the hydraulic head produced by ponding behind the weir, some tracer would move downward to the perched water body within the highly fractured basalt. It should be noted that because of application by spraying, tracer was introduced not merely to the ground surface but also down into shrinkage cracks in the sediment on the pond floor. This reduced the possibility of all the tracer being washed downstream before it could move downward.

The transport of tracer through the unsaturated basalt was determined in two different ways. We determined movement through the unsaturated zone by analyzing soil water extracted from samples of the absorbent FLUTe™ liners taken at regular intervals after the liners were removed from the 43° borehole (LAWS-02). We monitored the arrival of KBr in the perched zones of saturation by analyzing groundwater samples obtained weekly using the Water FLUTe™ system in the vertical well (LAWS-01). Because of the ease of measurement on samples from the vertical well compared to that involving withdrawal and sampling of a liner from the angled hole, LAWS-01 was the main source of data.

Iodide

A second tracer was deployed in 2003. This was necessary because the initial tracer was already in the unsaturated zone. Thus, if KBr continued to be detected in the vertical well (LAWS-01), its origin in the system would not be clear.

On 6 June 2003, 5 kg of potassium iodide (KI) and 500 gal. of water were mixed in a large trailer-mounted tank. The solution was applied to the dry ground surface behind the weir by means of a fire hose. That is, a 1683-ppm solution of KI was sprayed onto the dry floor of the pond area just upstream of the weir. As in the case of the initial tracer, it was reasoned that the solution would evaporate, leaving KI salt behind until the next runoff event dissolved and mobilized it. In response to hydraulic head produced by ponding behind the weir, some should move downward to the perched water body within the highly fractured basalt.

Again, as it is important to know the background levels of tracer constituents, water samples were collected from ports 3 and 4 in LAWS-01 before the KI was applied and analyzed for iodide content. In both cases, iodide was less than detection (< 0.05 ppm). Although detection is normally 0.01 ppm, these samples had such high anion concentrations that they had to be diluted for analysis. Observed values greater than 0.05 ppm can be assumed to represent the arrival of tracer from the surface.

Our approach to determining movement of iodide through the unsaturated zone was the same as that described above for bromide transport. Results of both tracer tests are presented by storm event below.

DATA COLLECTION

Data related to the quantity and/or quality of precipitation, runoff, soil water, and groundwater were collected as part of the weir project (Table 2). Data associated with specific storms that resulted in ponding at the weir are presented below. A chronological summary of major storms/monitoring activities at the weir site is given in Table 3.

Precipitation

Precipitation data were mainly collected to document storm events. We intended to accomplish this by a tipping-bucket gage installed at the site. However, due to a software problem associated with the datalogger, some results for this gage are unreliable. Thus, data from gages at Technical Area (TA) -74 and White Rock were also consulted to determine whether there was a storm in the area.

Table 2
Overview of Data Collection for the Weir Project

Item	Purpose	Source	Frequency
Precipitation	Document storms	Gages at Weir, TA-74, and White Rock	Continuously
Runoff	Document storms, collect sample	Stations E042 and E050	Continuously
Standing Water	Document ponding	Gage E049	Continuously
Soil Water	Document wetting, detect tracer, and determine transport	Neutron probe, wire pairs, and absorbent liners	As warranted
Groundwater	Monitor water level, detect tracer, and determine transport	Well LAWS-01	Water level continuously; sampled weekly

Runoff

Streamflow is important as it is the means by which both fire products and other potential contaminants are delivered to the weir. The hydraulic head associated with ponded runoff then drives them, as well as the introduced tracers, downward into the basalt. Both quantity (discharge) and quality (chemistry) of runoff were monitored.

Discharge data were collected to further document storm events. Data from two of the 34 gaging stations at LANL (E042 and E050) are pertinent to the weir project (Table 4). Discharge rates associated with runoff events resulting in ponding at the weir are given for specific storms below. Depth of ponding was monitored at 5-min. time steps by a staff gage and bubbler (E049).

Both 2002 and 2003 were dry years. In 2002 there was little snow accumulation and summer monsoons were disappointing. Nonetheless, data were obtained for four runoff/ponding events, one each in June, August, October, and November. Snowfall in 2003 was also below average, and summer monsoons were delayed. However, data were collected for runoff/ponding events in May and August. The main pond-producing runoff in 2003 occurred on 19, 20, and 21 May as a result of draining the Los Alamos Canyon reservoir. Unfortunately this pre-dated the application of the second tracer. However, storms on 11, 22, and 23 August 2003 also produced significant flow to the weir.

Table 3
Chronology of Monitoring at the Weir Site

Date	Activity or Event
2001	
4-6 April 2001	Drilled and completed LAWS-01
5 April 2001	Sampled LAWS-01
6 April 2001	Sampled pond water
22-25 April 2001	Drilled and completed LAWS-02
27-28 April 2001	Drilled and completed LAWS-03
17 December	Sampled LAWS-01
2002	
3 March 2002	Removed scalloped PVC casing from LAWS-03
17 April 2002	Conducted neutron-probe survey in LAWS-03
29 April 2002	Applied 100 lbs KBr tracer to dry pond floor[a]
21 June 2002	Observed water ponded behind weir
10 July 2002	Removed LAWS-02 liner and membrane; sampled for bromide analysis
15July 2002	Conducted neutron-probe survey in LAWS-02 and LAWS-03
28 August 2002	Observed water ponded behind weir
13 September 2002	Conducted neutron-probe survey in LAWS-02
26 October 2002	Observed water ponded behind weir
9 November 2002	Observed water ponded behind weir
2003	
31 March 2003	Conducted neutron-probe survey in LAWS-02
25 May 2003	Observed water ponded behind weir
27 May	Removed liners and membranes from LAWS 02 and LAWS 03
30 May	Installed new liner and membrane in LAWS 02
3 June 2003	Applied 5 lbs KI tracer to dry pond floor[a]
June 2003	Removed liners and membranes from LAWS-and LAWS-03
7 June 2003	Installed new liner and membrane in LAWS-02
11 August 2003	Observed water ponded behind weir
22 August 2003	Significant flow recorded at gages[b]
23 August 2003	Significant flow recorded at gages[b]
3 September 2003	Re-surveyed borehole locations and elevations
9 September 2003	Removed liner and membrane from LAWS02; took and stored samples of liner for iodide analysis
10 September 2003	Installed new liner and membrane in LAWS-02

[a] by spraying in solution

[b] gage for ponding inoperative

Table 4
Source of Runoff Data for the Weir Project[a]

Gage	Location	Maximum Discharge on Record (cfs)	Maximum Discharge Date
E042[b]	LA Canyon, by R-9i	171	22 Aug 1997
E049[c]	LA Canyon, upstream side of Weir	(pond depth only)	
E050[b]	LA Canyon, just below weir	43	23 Aug 2003

[a] From Shaull et al 2003, 76042 and personal communication, August 2003

[b] Measures stage in stream and collects samples

[c] Measures stage in pond only

Chemistry of runoff was monitored in two different ways: by sampling water flowing in the stream channel and by sampling water ponded behind the weir. ISCO™ automatic samplers at gaging stations upstream and downstream of the weir are set to automatically collect stream samples when there is runoff. Unfortunately, the ISCO™ at the upstream gage (E042) collected water only once in 2002 (2 L on 22 June) and only once in 2003 (13 L from the late August storms). The 2002 sample was only analyzed for cyanide and magnesium, apparently because of the small amount of water available. The 2003 analyses have not yet been validated for release. The ISCO™ downstream of the weir (at E050) did not function in either 2002 or 2003. Whenever possible, a grab sample was collected of water in the pond. We analyzed ponded water for both general chemistry and tracer(s). Analytes included possible fire-enhanced constituents as well as contaminants associated with laboratory activities (Appendix A-1).

Soil Water

Information for the unsaturated zone was obtained from the 43° borehole (LAWS-02). Two types of data were collected: moisture profiles and tracer profiles. Moisture profiles were made using resistance data from electrical-wire pairs placed at regular intervals along the absorbent liners deployed in the borehole and using neutron-probe surveys.

Although a liner must be pulled from the borehole to yield tracer data, the wire pairs provide data continuously while the liner is in place. A decline in resistance indicates a wetting event. Wire-pair data provided a good picture of flow in the unsaturated zone at the weir.

Neutron-probe surveys were conducted in July and September 2002 as well as March 2003 to learn the relative soil-moisture distribution in LAWS-02 (Figure 6). Although separated by months, the three logs are remarkably similar. As such similarity would not result in the case of matrix porosity, the neutron-probe data suggest that flow through the basalt at the weir site is predominantly via fracture flow and not matrix flow. The slight deviation of the data at depth is likely a result of instrument drift (logging begins at the bottom of the hole) rather than actual water-content changes since the rest of the neutron-log profiles are nearly parallel for the three measurement dates.

Tracer profiles were made by pulling the absorbent liners when wire-pair data indicated wetting and taking samples of the liner at regular intervals (generally 1 ft). This was facilitated by laying the liner out on the long tables at the nearby FLUTe™ headquarters (Figure 7). Samples of the liner were taken at 1-ft intervals, placed in 1-liter, wide-mouth, polyethylene bottles and stored at 4° C.

Next, water was extracted from the samples and then analyzed for the tracer. A profile of tracer concentration was made by plotting results versus depth.

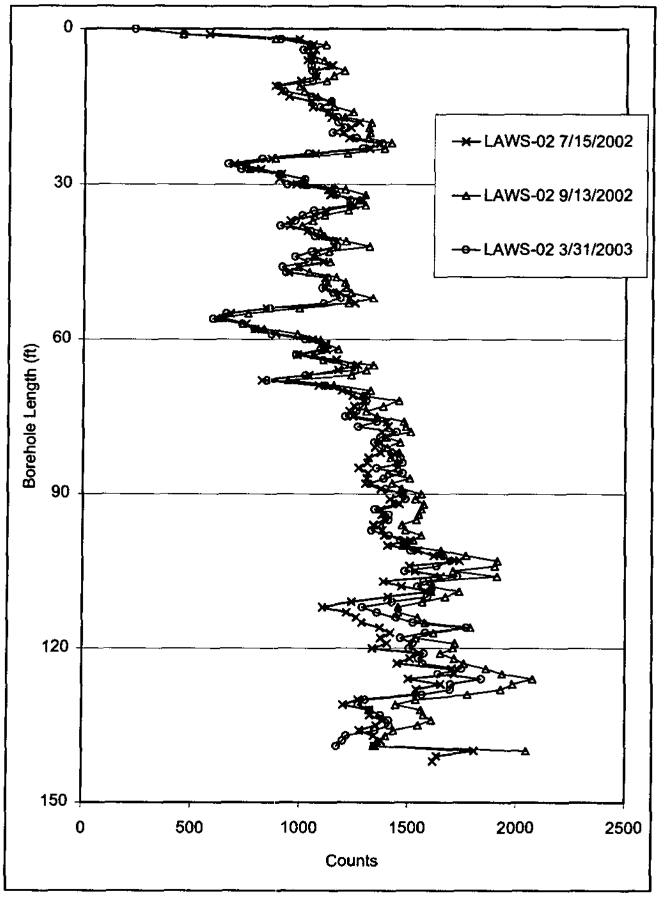

Figure 6. Neutron-Probe Logs for LAWS-02

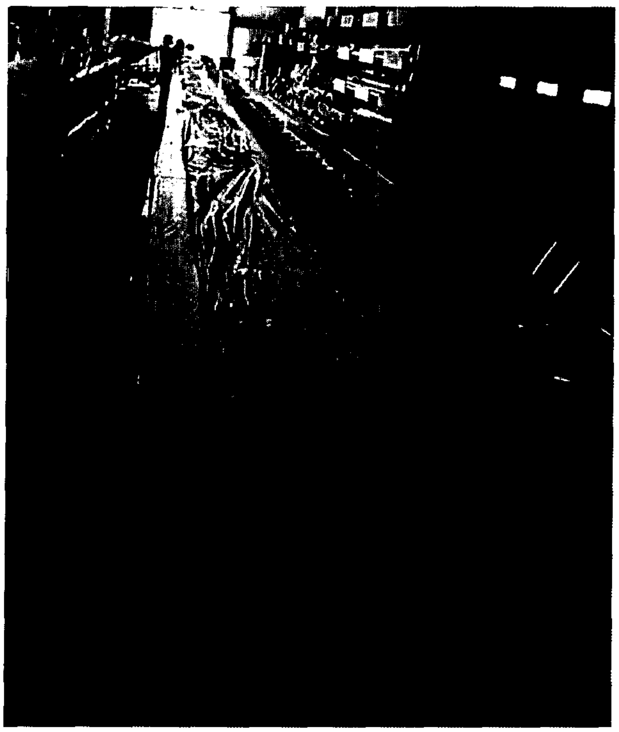

Figure 7. Liner from LAWS-02 laid out for sampling

Groundwater

Information on the saturated zone was obtained from the vertical well (Table 5). Two types of data were collected regularly: water level and tracer concentration. We collected water-level data using the transducers associated with the four screens/ports in the Water FLUTe™ system deployed at each port in the well (Figure 5). We also irregularly collected and analyzed groundwater samples from the vertical well for general chemistry. This sampling and analysis was infrequent because well R-9i, tapping presumably the same perched groundwater 1/4 mi upstream, was being regularly sampled under the Groundwater Protection Program. During and immediately after ponding events at the weir, we collected and analyzed samples of groundwater for tracer on a weekly basis. We measured tracer content by analyzing groundwater samples from LAWS-01 using ion-specific probes in the laboratory.

Table 5
Source of Groundwater Data for the Weir Project

Saturated Zone[a]	Well	Screen (ft bgs)[b]	Port (ft bgs)[b]
Ephemeral	LAWS-01	1 (83-93)	1 (88)
Upper	LAWS-01	2 (158-168)	2 (163)
Lower	LAWS-01	3 (188-198)	3 (193)
Lower	LAWS-01	4 (263-273)	4 (268)

[a] All saturated zones are perched at intermediate depth in Cerros del Rio basalt.

[b] Numbers in parentheses are depths of screens and ports

JUNE 2002 EVENT

Although there was standing water behind the weir in April 2001 while the holes at the site were being drilled, the pond dried up before installation of the monitoring site was completed. A storm on 21 June 2002 generated the first ponding after the site was ready to collect data. The storm was centered on the townsite, rather than LA Canyon. That is, stream flow resulted from urban runoff down DP Canyon, rather than runoff from the fire-impacted headwaters of LA Canyon.

The June 2002 event produced a peak discharge of 160 cubic feet per second (cfs) in LA Canyon at a gage just upstream of the weir (Table 6). This value approaches the maximum peak on record: 171 cfs (Table 4). The difference between the upstream and downstream discharge values in Table 6 is interesting. For the June 2002 event, peak discharge is lower downstream. It is tempting to attribute the difference to seepage loss but retention in the pond as a result of plugging of lower portions of the weir by the vegetal trash that characterizes the front of ephemeral flows is an equally likely explanation.

This runoff resulted in a maximum pond depth of 3 ft, measured at a gage behind the weir (Table 6). This peak was attained early in the flow event (Figure 8). Complete drainage by runoff or seepage of the ponded water was accomplished in approximately 5 hrs.

Chemical analysis of ponded and runoff waters for the June storm was not possible. Ponding occurred over a weekend and was short-lived. Furthermore, the automatic sampler associated with the stream gage below the weir (E-50) failed to function.

Table 6
Summary of Storms that Produced Ponding at the Weir

Precipitation (in.) [a]	21 June 02	28 Aug 02	26 Oct 02	9 Nov 02	25 May 03	11 Aug 03	22 Aug 03	23 Aug 03
White Rock TA-74	0.73 0.12	0.00 0.59	1.37 0.94	0.18 0.19	0.95 0.33	0.00 0.00	0.00 0.00	0.00 0.00
Runoff (cfs) [b]								
E042 E050	160 53	0.32 12	0.32 1.5	0.66 2.1	14[c] 9.8 [c]	6.57 1.57	5.21 15.26	94 4.22
Ponding (ft)[d]								
E049	3.2	1.35	0.81	1.28	1.71[c]	NA[e]	NA	NA

[a] Total rainfall recorded at the gage for date of ponding
[b] Peak discharge recorded
[c] Maximum values for 19-21 May, when reservoir was drained
[d] Maximum depth recorded;
[e] NA = not available (gage inoperative)

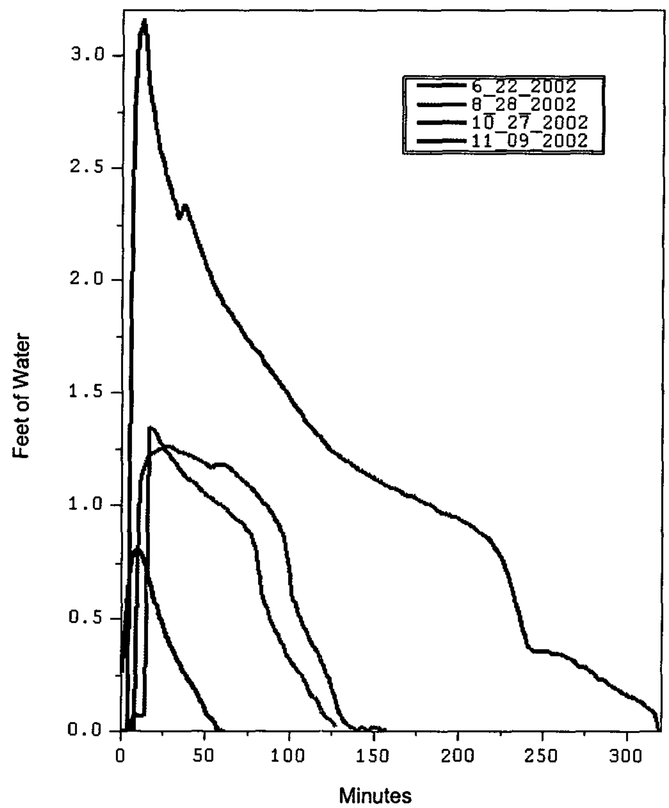

Figure 8. Pond depth recorded behind the weir for 2002 events

June 02 Unsaturated-Zone Data

The 21 June 2002 storm provided the initial information about the unsaturated zone. That is, the rates of movement of moisture and tracer were determined.

Moisture. Following the ponding event on 21 June 2002, resistance measurements from wire-pair sensors in the 43° hole (LAWS-02) were observed to decrease (indicating wetter conditions) at a vertical depth of 88 and 98 ft below the weir floor within 4-7 days, respectively (Figure 9). Curiously, the shallowest wire pair (16 ft bgs) experienced wetting last: 9 days after ponding.

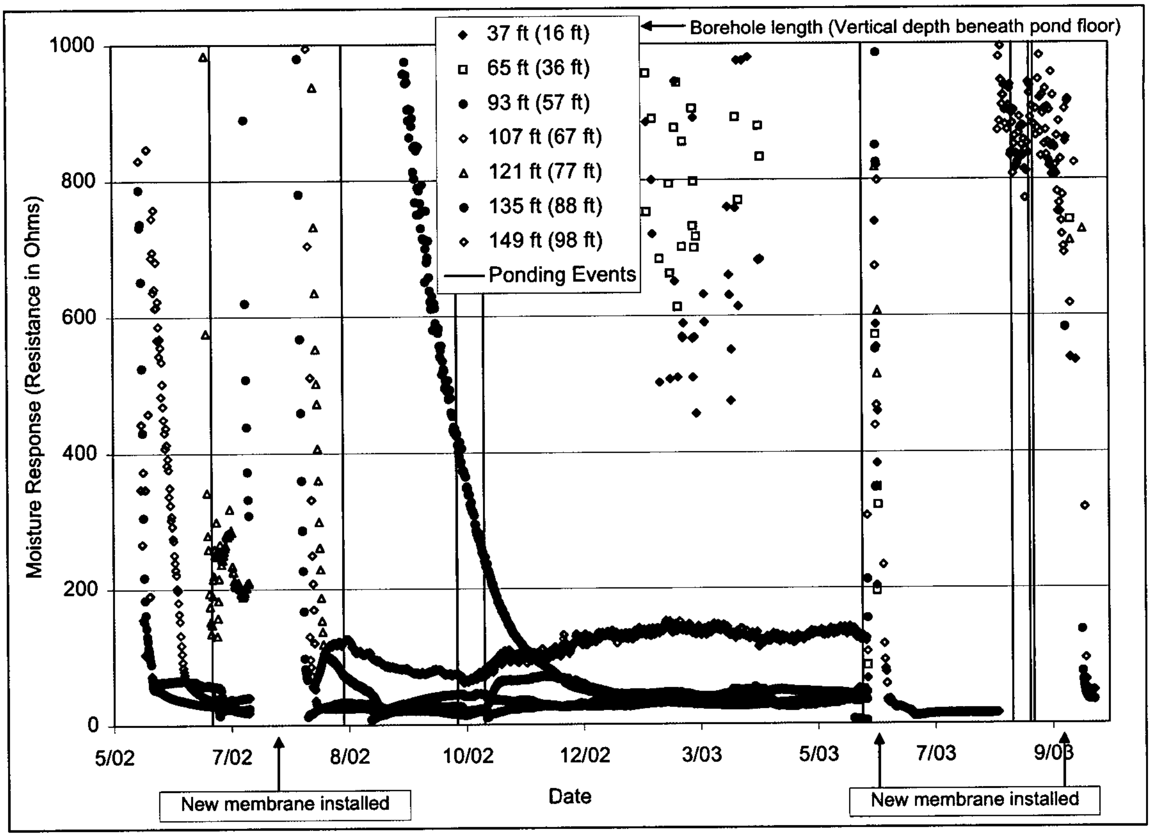

Figure 9. Electrical Wire-Pair Moisture (Resistance) Data for LAWS-02

Bromide. The absorbent liner was removed from LAWS-02 on 10 July 2002. As the short, temporary sleeve placed on the lower end of the liner to facilitate installation constricted the liner, it could not be retrieved by the tether onto a spool in the usual way. Therefore, it had to be extracted from the borehole by hand. The liner was pulled into a clear plastic sleeve to minimize evaporation of soil moisture. It was then stored in a refrigerator until it could be laid out and sampled at the nearby FLUTe™ headquarters, as described under "Soil Water" above. A description of the liner at the time of sampling is given in Appendix B. The plot of bromide vs distance along the borehole resembles a typical soil-water-anion profile (e.g., chloride) until the element of time is considered (Figure 9 and Appendix C). That is, bromide values are associated with water moving through different fractures at different times, as shown by the wire-pair data.

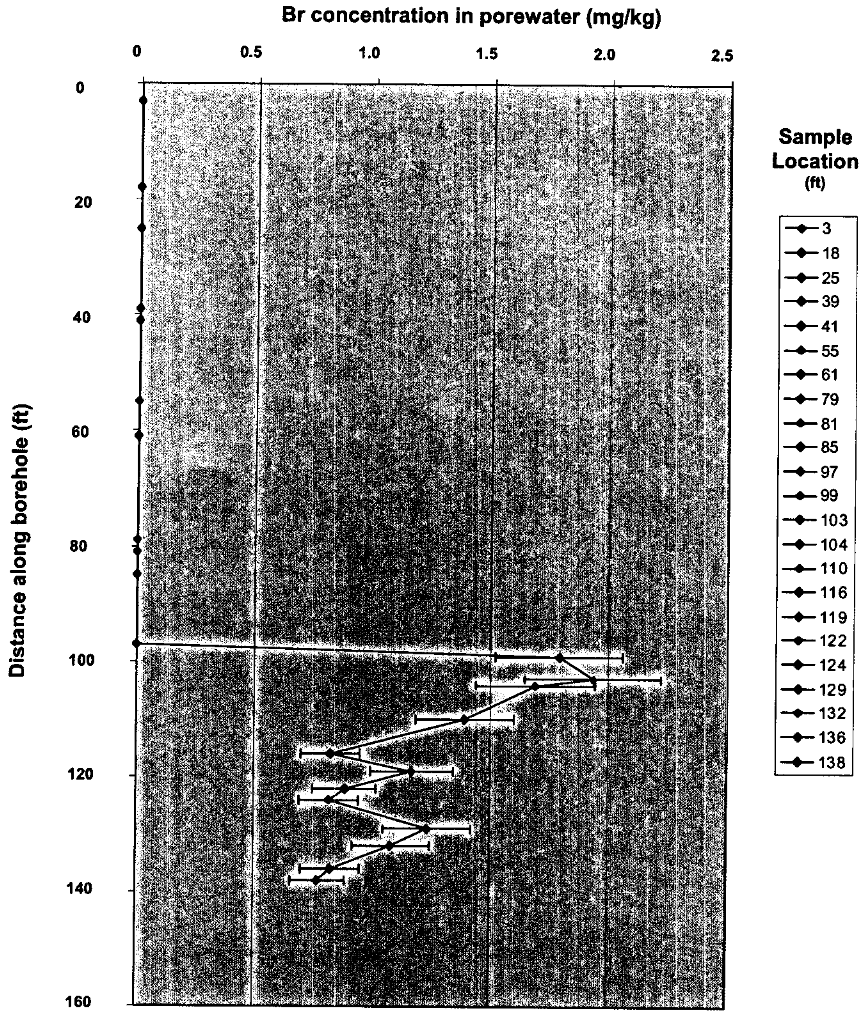

Figure 10. Bromide Concentrations in Soil Water from LAWS-02, 10 July 02

June 02 Saturated–Zone Data

The 21 June storm also provided useful information about the perched zone of saturation. As the vertical well (LAWS-01) was the easiest to interrogate, it gave the first indication of just how fast downward flux can be in the highly fractured basalt at the weir.

Water level. Interestingly, screen 1 was dry (Figure 11; breaks in the data plots indicate no data were available). Apparently it takes a larger event or longer period of ponding to generate saturation at this depth. However, the extent of ponding that occurred in the June event was sufficient to impact deeper water levels. More specifically, water level rose 6 ft in screen 2 (port at 163 ft bgs) and 1 ft in screen 3 (port at 193 ft bgs) just 2 days after the storm.

Bromide. Tracer was also detected in LAWS-01 soon after the 21 June 2002 event. Above-background levels of bromide were detected at screen 2 on 1 July and at screens 3 and 4 on 5 July (Figure 12 and Appendix D).

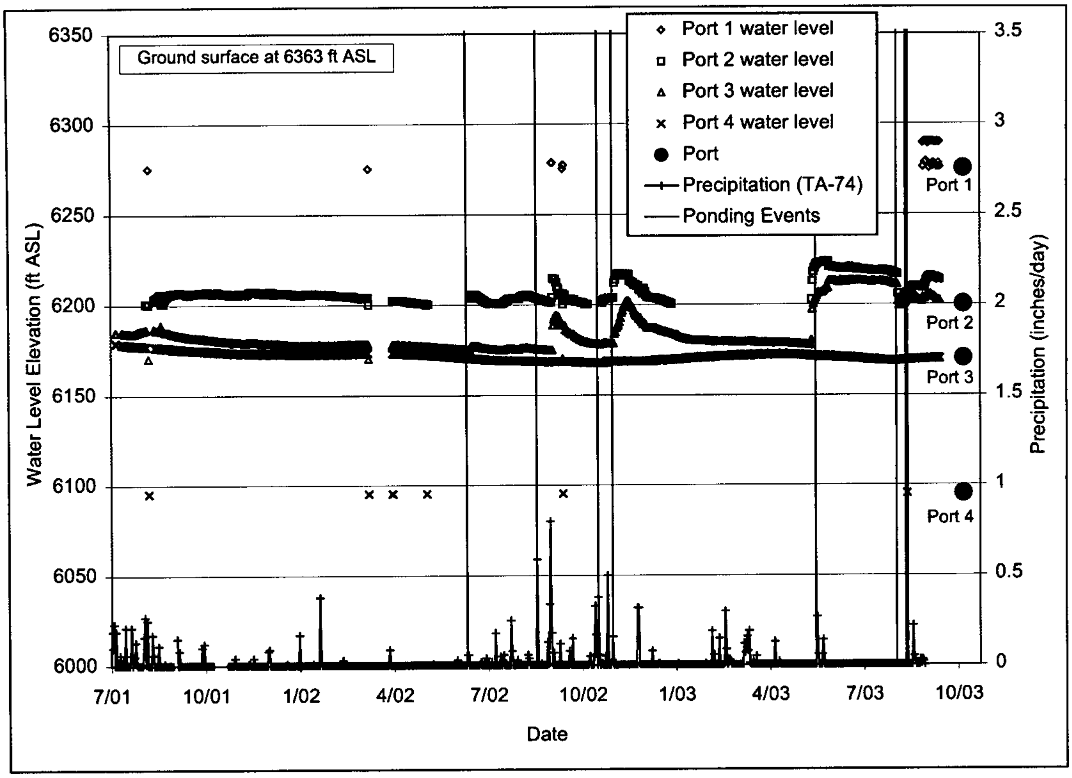

Figure 11. Water levels in LAWS-01

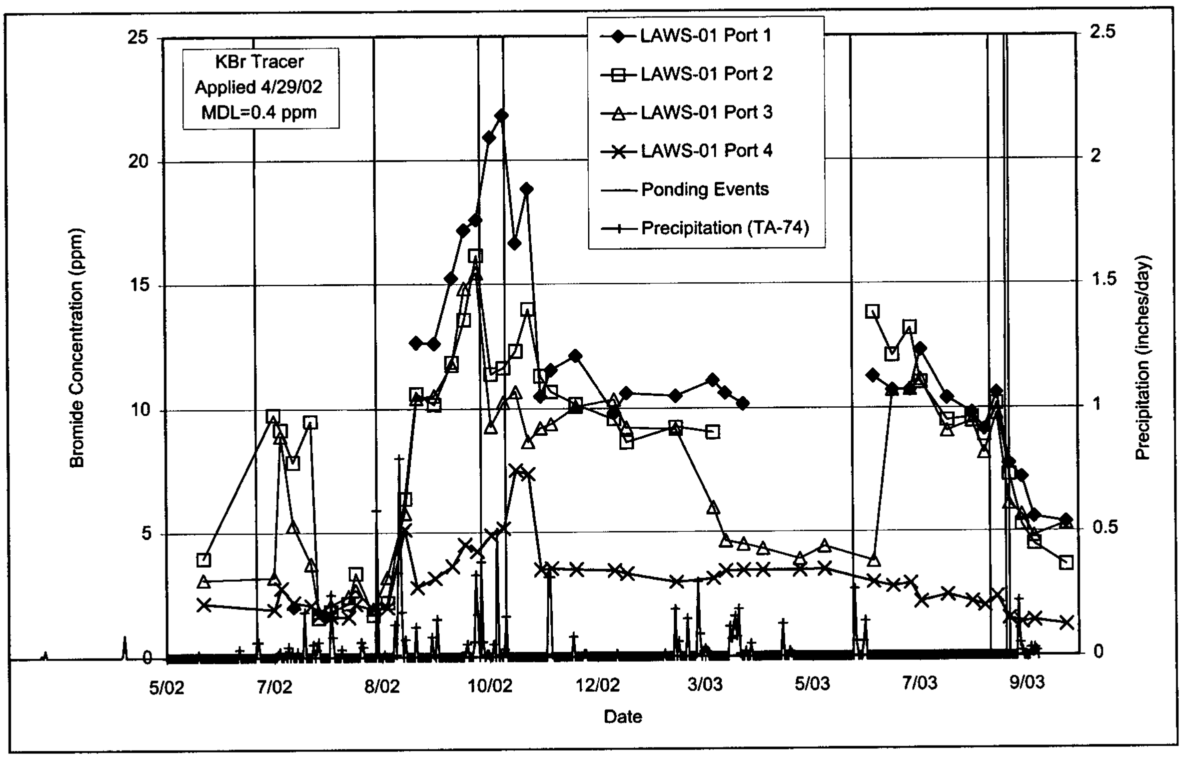

Figure 12. Bromide concentration in LAWS-01 groundwater

Discussion of June Event

The response to the June 2002 event observed in LAWS-01 suggests there is excellent connection between the surface water and the perched zone of saturation in the basalt. This is shown by the rapid change in water level and arrival of tracer. For screen 2, bromide moved at least to a depth of 152 ft in 9 days. Fractures that are perfectly straight and vertical indicate a rate of 17 ft/d. For screen 3, tracer moved at least 182 ft in 12 days for a rate of 15 ft/d. However, actual flux rates must be even greater, because the fractures are neither straight nor vertical, the pathways through the network of fractures are complex, and the distance to the surface is therefore longer.

OTHER NOTABLE EVENTS

Four other events produced runoff that reached the weir. However, ponding was minor or short-lived. Nonetheless, some data were collected for these events as well. This includes discharge upstream and downstream of the weir, depth of ponding behind the structure, electrical wire-pair data at LAWS-02, bromide concentrations in groundwater from LAWS-01, and water levels at LAWS-01. These observations are shown in Table 6 as well as Figures 8, 9, 10, and 11.

August 2002

A storm on 28 August produced the second ponding at the weir since the monitoring site was established. The August 2002 event produced a peak discharge of 0.32 cfs at gage E042 upstream of the weir (Table 6). Maximum pond depth, measured at gage E049 on the upstream side of the weir, was 1.35 ft. Peak discharge below the structure for this event, measured at gage E050, was 12 cfs. There are two explanations for a larger discharge value being observed at the downstream gage than the upstream gage. Because a basalt mound underlies the pond area behind the weir, the alluvium is thinner or missing there and groundwater is forced to the surface, thus enhancing streamflow. Furthermore, because the channel is much wider at the weir and the structure backs up water, larger volumes are released from the pond to the channel than are recorded upstream. However, the difference may simply result from varying data quality at the two gages. The value for the upper gage is too low to be accurate.

Unsaturated-Zone Data. Resistance measurements from wire-pair sensors in LAWS-02 were observed to decrease (indicating wetter conditions) 13 to 17 days after the ponding event on 28 August 2002, at vertical depths of 77, 88, and 98 ft below the weir floor (Figure 8). The liner in LAWS-02 was not pulled following this event, so bromide movement cannot be evaluated.

Saturated-Zone Data. Fourteen days after the flooding on 28 August 2002, water levels in LAWS-01 were observed to rise (Figure 11). In both ports 2 and 3, water levels rose 14 ft within a 30-hr period between 11 and 12 September 2002. Water levels in ports 2 and 3 then declined to previously-observed levels within about one month.

Bromide concentrations in LAWS-01 groundwater increased sharply following this flood event (Figure 12). Bromide values for the three lower ports increased from their background levels of 2-3 ppm to values of 15-17 ppm within a period of about 2 months. Due to a lack of water, no samples could be collected from port 1 until 20 September 2002 (3 weeks after the flood). Water could be sampled from port 1 every week thereafter until 24 March 2003 when water level dropped below port 1 again.

October 2002

A storm on 26 October produced a small amount of discharge and minor ponding. Runoff was recorded at E042 between 21:30 and 23:15. The peak discharge of 0.32 cfs was measured at 21:35, 21:45, 21:50, and 21:55 (Table 6). Maximum pond depth for this storm was 0.81 ft, recorded by E049 at 00:45 on

27 October. Peak discharge below the weir, as measured at gage E050 was 1.5 cfs. Both discharge values are too low to be accurate and should be regarded as merely qualitative.

Unsaturated-Zone Data. Resistance measurements from wire-pair sensors in LAWS-02 were observed to decrease (indicating wetter conditions) between 3 and 12 November 2002 (1-2 weeks after the flood event) at vertical depths of 67, 77, and 88 ft below the pond floor (Figure 8). Apparently the shallow depth of ponding associated with this event was not sufficient to impact fractures other than those intersected at these depths. The liner in LAWS-02 was not pulled following this event, so bromide movement cannot be evaluated.

Saturated-Zone Data. Groundwater elevations were not observed to rise following this flood event (Figure 11). However, bromide concentrations continued to rise at port 1 in LAWS-01 to values of about 22 ppm, and increased slightly in port 4, while concentrations decreased in ports 2 and 3 to values of about 9-12 ppm (Figure 12).

November 2002

A storm on 9 November produced runoff at E042 between 06:20 and 11:40. Peak discharge was 0.66 cfs at 07:20 (Table 6). Peak discharge at gage E050 downstream from the weir was 2.1 cfs. Again, these low peak flows may only have qualitative value. This event produced a maximum pond depth of 1.26 ft, recorded by E049 at both 09:15 and 09:30.

Unsaturated-Zone Data. There was no discernable drop in resistance measurements, which would indicate wetter conditions, following the flood event on 9 November 2002 (Figure 8). The liner in LAWS-02 was not pulled following this event, so bromide movement cannot be evaluated.

Saturated-Zone Data. Groundwater elevations were observed to rise following this flood event. Water levels were observed to rise at port 2 in LAWS-01 by 13 ft in 24 hours, immediately following the ponding event (Figure 11). A rise in port 3 of 23 ft occurred over a 2-week period following the 9 November 2002 ponding event. This may represent a lagged effect from the 26 October 2002 event. Groundwater elevations in port 4 did not change following this ponding event.

In port 1, bromide concentrations decreased slightly and then increased within 13 days of the ponding event (Figure 12). These data from port 1 indicate a travel time of 88 ft between 7 and 13 days (or 7-13 ft/day). Bromide concentrations increased slightly in ports 2, 3, and 4 following this event.

May 2003

Release of water from the LA Canyon reservoir produced runoff at the weir on 19, 20, and 21 May 2003. Peak discharges recorded over this 3-day period range from 2.7 to 14 cfs at E042 and from 7.8 to 9.8 cfs at E050. These discharge values are probably high enough to be quantitative. Maximum pond depth at E049 associated with these runoff events ranged from 1.68 to 1.71 ft. Table 6 shows values for 21 May, which were the greatest.

Unsaturated-Zone Data. There was no discernable drop in resistance measurements, which would indicate wetter conditions, immediately following the May 2003 flooding events (Figure 8). As the liner and membrane were removed from LAWS-02 on 6 June 2003, any delayed change in moisture conditions in the unsaturated zone could not be measured. The liner was not analyzed for bromide because it had been in place for a period of nearly 11 months, and tracer concentrations would be the result of multiple ponding events. A new membrane was installed on 7 June 2003.

Saturated-Zone Data. Groundwater elevations were stable from approximately January through May 2003 (Figure 11). Ports 1 and 2 in LAWS-01 were dry during this period. Curiously, groundwater elevations in ports 2 and 3 increased dramatically several days before the May 2003 ponding events. These observed increases may have resulted from underflow in the alluvium prior to runoff in response to the upstream release of water from the LA Canyon reservoir. Groundwater elevations in ports 2 and 3 rose 23 and 20 ft, respectively, between 21 and 25 May 2003.

Bromide concentrations were not measured until 6 June 2003, 16 days after the first observed increase in groundwater elevation on 21 May 2003 (Figure 12). Bromide concentrations increased slightly in ports 1 and 2 over this period, while an increase of 4 to 11 ppm was observed in port 3 by 11 June 2003. No increase in bromide concentration was observed in port 4.

11 August 2003

This August storm produced runoff at E042 between 19:25 on 11 August and 00:05 on 12 August. Peak discharge was 6.57 cfs at 19:30, 11 August (Table 6). Runoff was also recorded at gage E050 downstream from the weir between 21:15 on 11 August and 08:25 12 August. The peak discharge at this lower gage was 1.57 cfs at 21:35 through 22:05 on 11 August (Table 6). This value may be too low to be accurate. E049 was not functioning, so no pond depth is available for this storm.

Unsaturated- Zone Data. Wire-pair data indicate very dry conditions throughout the borehole associated with this event (Figure 8). The wire-pair data from a vertical depth of 98 ft beneath the weir floor indicate wet conditions prevailed until 3 August, 2003. Thereafter, it too was dry.

The membrane installed in June 2003 was removed in September 2003. However, as project funding ended with the fiscal year, the liner was sampled and archived for later analysis.

Saturated-Zone Data. Groundwater levels at the time of this event were similar to those measured after the May 2003 event (Figure 11). Within 6 days after the ponding event, water levels in ports 2 and 3 dropped 14 and 11 ft, respectively. There was a slight increase in bromide concentrations in all four ports following this event (Figure 12).

A KI tracer was applied to the pond floor on 6 June 2003. Groundwater samples collected between 6 June and 15 August 2003 suggest essentially background levels of KI in all four ports until 22 August (Figure 13 and Appendix E). The multiple discharge/ponding events around that time (Table 3) are no doubt responsible for the marked increase.

18–20 August 2003

Precipitation over the period 18 through 20 August resulted in runoff at one or both of the two stream gages. Both gages detected runoff on 18 and 19 August whereas only the lower gage detected runoff on 20 August. Neither gage detected runoff on 21 August. Peak discharge was generally less than 1 cfs, except on 19 August when a flow of 1.27 cfs was recorded at E050. At these low discharge rates there was probably no ponding and these dates are excluded from Table 6.

Unsaturated-Zone Data. Wire-pair data indicate dry conditions prevailed during this event as well (Figure 8). There was apparently not enough ponding to cause rapid downward water movement.

Saturated-Zone Data. Water levels at the time of these storms have not been downloaded and possible groundwater response to this event has not been evaluated. No groundwater samples were collected in association with these storms, so tracer concentrations are not available.

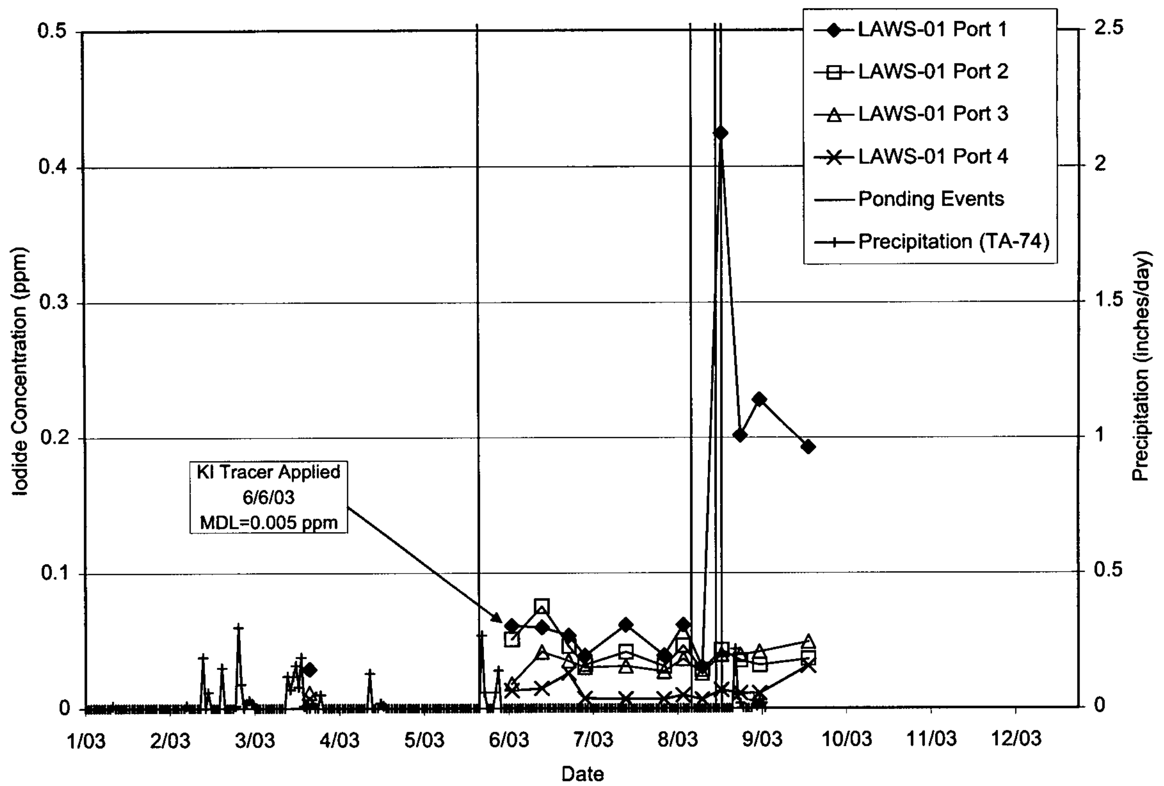

Figure 13. Iodide concentration in LAWS-01 groundwater

22 August 2003

A storm on 22 August produced runoff at E042 between 12:50 and 17:05. Peak discharge was 5.21 cfs at both 13:05 and 13:15 (Table 6). Runoff was also recorded at gage E050 downstream from the weir between 12:30 and 23:30. The peak discharge at this lower gage was 15.26 cfs at 13:05 (Table 6). These discharge rates are probably high enough to be quantitative. E049 was not functioning so no pond depth is available for this storm.

Unsaturated-Zone Data. Although this was a wetter event, wire-pair data did not register moisture movement as of 1 September 2003 (Figure 9).

Saturated-Zone Data. As for the 18–20 August storm, water levels at the time of this storm have not been downloaded and possible groundwater response to this event has not been evaluated. No increase in bromide concentrations were observed for the 22 August event (Figure 12). In fact, a declining trend spans the August and September 2003 data. The continued decline in bromide concentrations may indicate that the tracer is being flushed out of the system.

Groundwater sampled after the 20 August flood event indicate an increase in iodide concentration at port 1 (Figure 13). Iodide concentrations increased from a value of about 0.05 ppm to 0.42 ppm and then rapidly dropped to a value of about 0.2 ppm. However, iodide concentrations in the other three ports remained at background levels.

23–24 August 2003

Precipitation on 23 and 24 August produced the largest runoff at the weir of any storm in 2003. Runoff at E042 began at 15:05 23 August and ended at 08:45 on 24 August. A peak discharge of 94 cfs was recorded at 16:00 on 23 August (Table 6). Runoff at E050 began at 15:20 on 23 August and ended at 05:30 24 August. The peak discharge of 42.2 cfs was recorded at 176:15 on 23 August. At least the flow rate for the upper gage is large enough to be accurate. Because E049 was not functioning, no pond depth is available for this storm.

Unsaturated-Zone Data. Wire-pair data indicate dry conditions until early September (Figure 9).

The membrane installed in June 2003 was removed in September 2003. However, as project funding ended with the fiscal year, the liner was sampled and archived for later analysis. Therefore, no tracer data are available yet.

Saturated-Zone Data. Water levels at the time of these storms have not been down loaded and possible groundwater response to this event has not been evaluated. No groundwater samples were collected in association with these storms, so tracer concentrations are not available.

Discussion of the Other Notable Events

Although the June 2002 event was the most significant, the smaller subsequent events improved our understanding of the hydrogeologic system at the weir site.

The drought that prevailed during the weir project limited the kinds of data that could be collected. Until the liner was pulled from LAWS-02 in 2003, we continued to monitor wire-pair moisture data from that hole as well as water levels and bromide concentrations in LAWS-01. Data that were collected during these other minor events basically confirm those for the June event.

MODELING BROMIDE TRANSPORT

Although there has been considerable previous work on modeling flow in the Cerros del Rio basalt at LANL, its transport behavior remains poorly understood. Better constraints on hydraulic properties of this unit are vital not only to understanding movement of water beneath the weir site but beneath large areas of the Pajarito Plateau as well. The bromide tracer test at the LA Canyon low-head weir provided an excellent opportunity to model the transport properties of the basalt. The following is a brief summary of the preliminary modeling effort (Stauffer 2003, 81725). Complete details of the modeling are to be presented in the Los Alamos issue of the *Vadose Zone Journal.*

Approach

To numerically represent the bromide tracer test, the complex physical system at the field site was simplified:

- The system was modeled as a 2-D cross section perpendicular to LA Canyon (Figure 14). Since the hydrologic system is essentially symmetrical about the centerline of LA Canyon and the data sources are all on one side, only that half of the cross section was modeled.
- The top boundary is handled two different ways. The left-most 14 m on the top of the grid are assigned infiltration corresponding to the stream channel for the initial background and the ponding events. The remaining portion of the top boundary is assumed to be characterized by no flow.

- The lateral boundaries of the domain are both no-flow and placed such that water from ponding events would not propogate to it.
- The bottom boundary is situated below the deepest port in LAWS-01 and conceptualized as a drain in this study.
- A reasonable average value for infiltration in the stream channel was used, while the rest of the top boundary was conceptualized as being quite dry with effectively zero net long-term infiltration.
- The maximum amount of tracer available for downward transport is calculated as the total mass of bromide (45 kg KBr) divided by the total area of the pond floor (19,600 ft^2) or 16.8 g Br/m^2.
- Some portion of the applied bromide was no doubt removed from the modeled area by wind before the first ponding event or by flow downstream through the weir after dissolution in surface water.
- Because a crystalline igneous rock such as basalt has no matrix porosity, we envision that the bulk of flow and transport occurs through a network of fractures, as are observed in borehole video logs.
- The initial conditions for the simulations of bromide transport are generated by running a background streambed infiltration of 10 cm/yr for 10^8 days.
- To maintain a consistent approach for the movement of tracer from the pond floor to the subsurface, bromide concentrations are fixed in the initial pulse of pond infiltration such that the entire simulated bromide input is applied in the first 0.01 days for all simulations. Subsequent pulses are input with zero concentration.

The simulations were run with FEHM, version 2.21 (Zyvoloski et al. 1997, 70147), a multidimensional finite-volume heat- and mass-transfer computer code. The model domain consists of a 100-m-square area that corresponds directly with the conceptual model described above (Figure 14). The finite-volume grid is rectangular with horizontal spacing of 1.0 m and vertical spacing of 0.5 m. This arrangement leads to a grid consisting of 20,000 elements and 20,301 nodes.

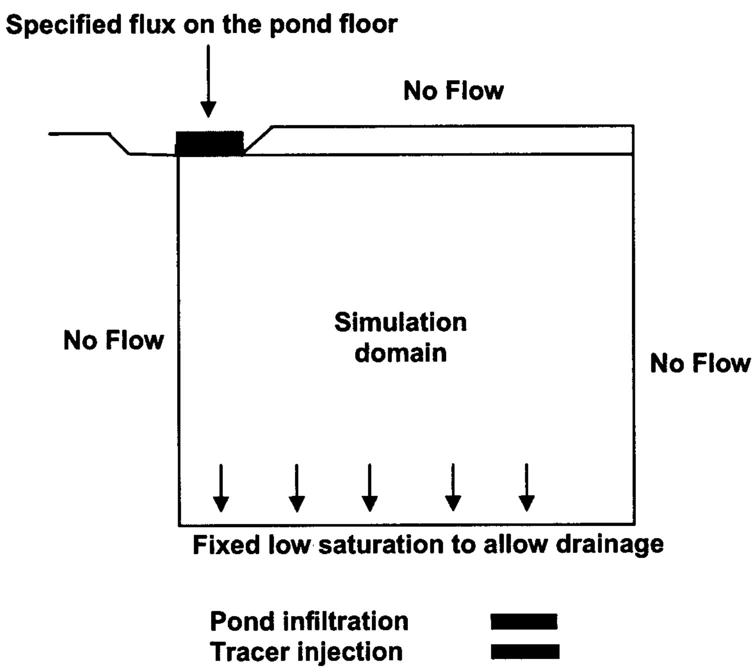

Figure 14. Conceptualization of the weir site for modeling

Modeling addressed four ponding events within the time period of interest: 330 days starting on 22 June 2002, but because the last two events (in October and November 2002) are closely spaced in time, they are lumped together to simplify modeling. Values assumed for independent variables are given in Table 7. During the first two events, pond infiltration is applied evenly over a 3-day period. The last event is varied from 3 days for low infiltration simulations (< 0.25 m) to 14 days for simulations with high infiltration (> 1.0 m). Fluid flow and tracer time-step size during infiltration are kept small (0.2 and 0.02 days respectively) to accurately capture the transient pulses. For the intervals between the ponding events, time-step size is increased to 2.0 days for fluid flow and 1.0 days for transport. In each of the four simulations, adjustable variables from the conceptual model were varied until the simulated bromide concentrations at ports 1-4 were brought within the range of the observed data (0-25 ppm). The specific input values used for these simulations (S-1, S-2, S-3, and S-4) are listed in Table 8.

Results

The four simulations show the range of basalt properties that resulted in a reasonable fit of the bromide data. The porosity range explored in these simulations spans an appropriate range of possible in situ conditions at the weir: 0.001 to 0.01. Figure 15 shows the simulated time/breakthrough results for bromide at ports 1-4 in LAWS-01. These images show how various porosities and consequently moisture contents impact the transport of bromide through the basalt. S-1, with a porosity of 0.1%, requires that 80% of the applied bromide be swept downstream and out of the system. Simulations of lower porosity would inevitably lead to a smaller fraction of the applied bromide entering the subsurface. At the high end of the porosity explored, 1% in S-4, the simulations are unable to generate the sharp spike seen at approximately 120 days. This is due to the larger volume of soil water available for transport at higher porosity. The increased volume acts as storage and limits the magnitude of spikes caused by increased flow.

Table 7
Values Assigned in all Simulations of Bromide Transport at the Weir Site

Independent Variable	Assigned Value
van Genuchten α (m^{-1}) (unperched section)	3.84
van Genuchten n (unperched section)	1.474
Residual water content (unperched section)	0.01
Bromide Diffusion Coefficient (m^2/s)	3.0×10^{-10}
Longitudinal and transverse Dispersivity in the unperched section (m)	0.5
Longitudinal and transverse Dispersivity in the perched section (m)	2.0
Background infiltration in the stream bed (m)	0.1
Background bromide concentration (mol/kg)	0.0

Table 8
Input Parameters for each Simulation of Bromide Transport at the Weir Site

Simulation	Porosity	Permeability (m^2)	Pond1 Volume Flux(m)	Pond 2 Volume Flux (m)	Pond3 Volume Flux (m)	Pond 3 Duration (days)	Br Mass Loading (g/m^2)
S-1	0.001	1.e-12	0.0025	0.025	0.25	6.	3.2
S-2	0.005	1.e-11	0.025	0.125	1.0	12.	9.0
S-3	0.0075	1.e-11	0.025	0.25	1.25	15.	16.8
S-4	0.01	1.e-11	0.125	0.25	0.75	9.	16.8

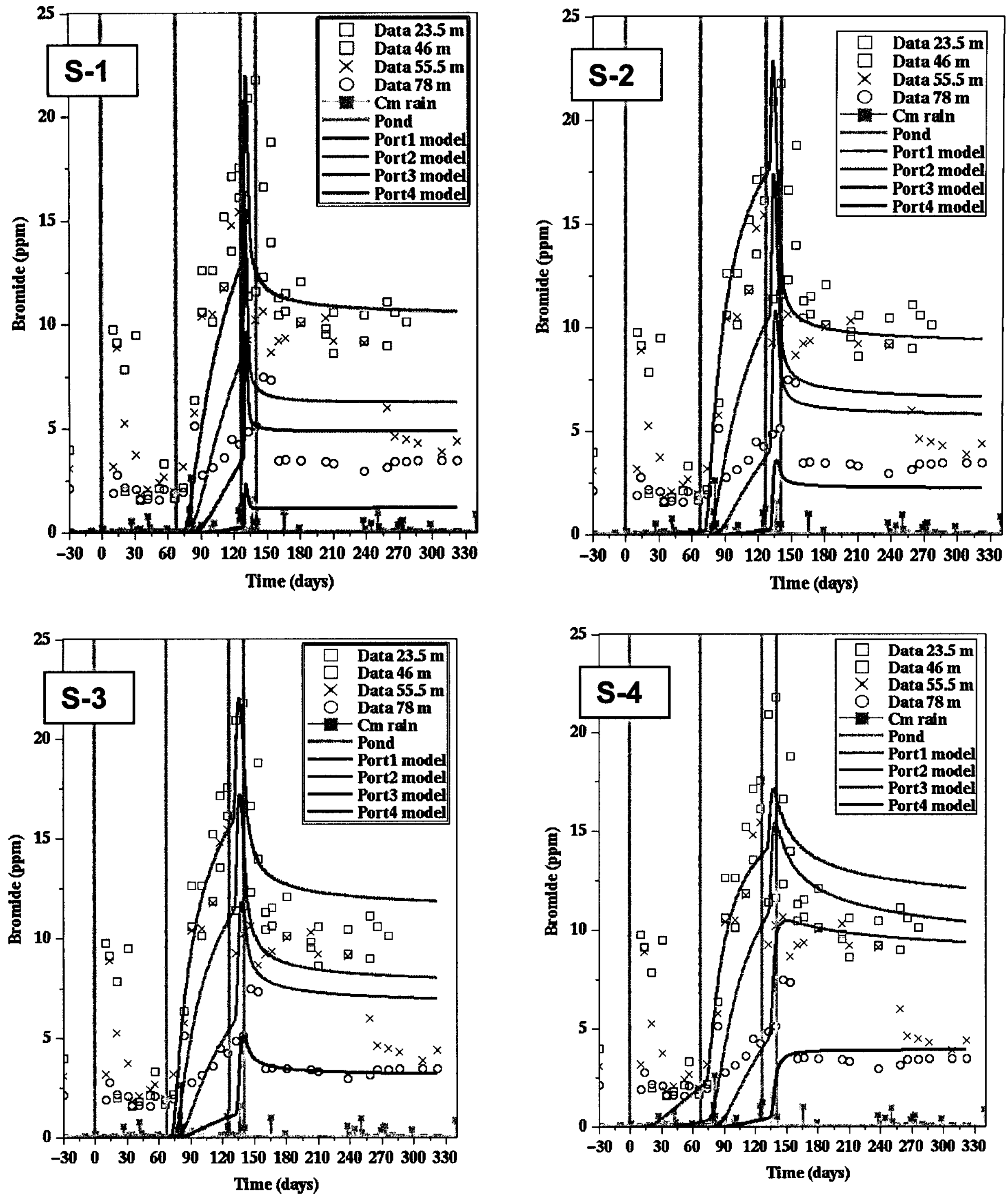

Figure 15. Modeled vs observed distribution of bromide for different input parameters

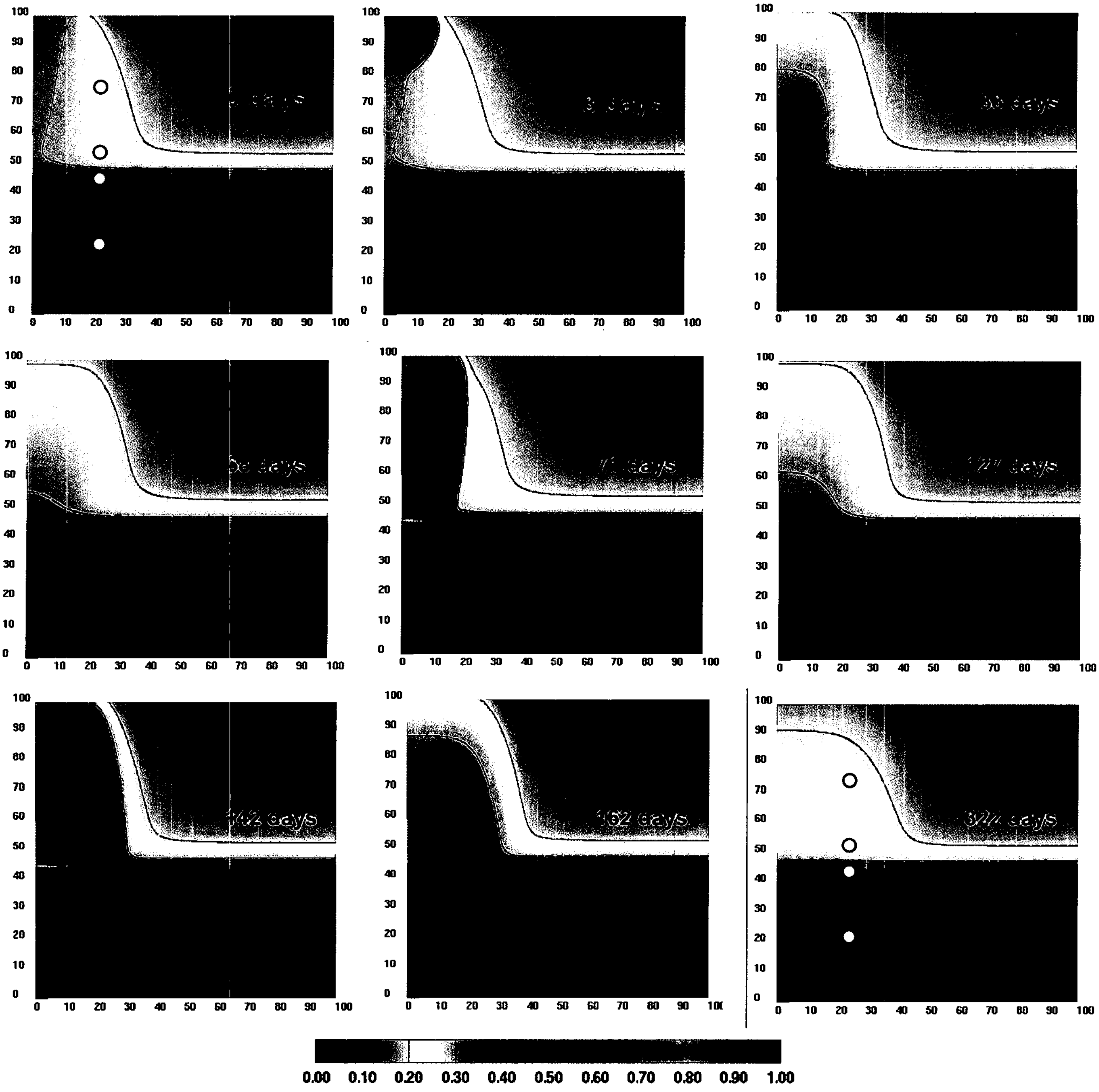

Figure 16. Modeled distribution of saturation through time for simulation. S-3. (LAWS-01 lies at x=25 m, while ports 1-4 are located at elevations of z=76.5m, 54. m, 44.5 m, and 22 m, respectively. The approximate locations of the ports are marked on the 0.6 and 322 day images as white circles.)

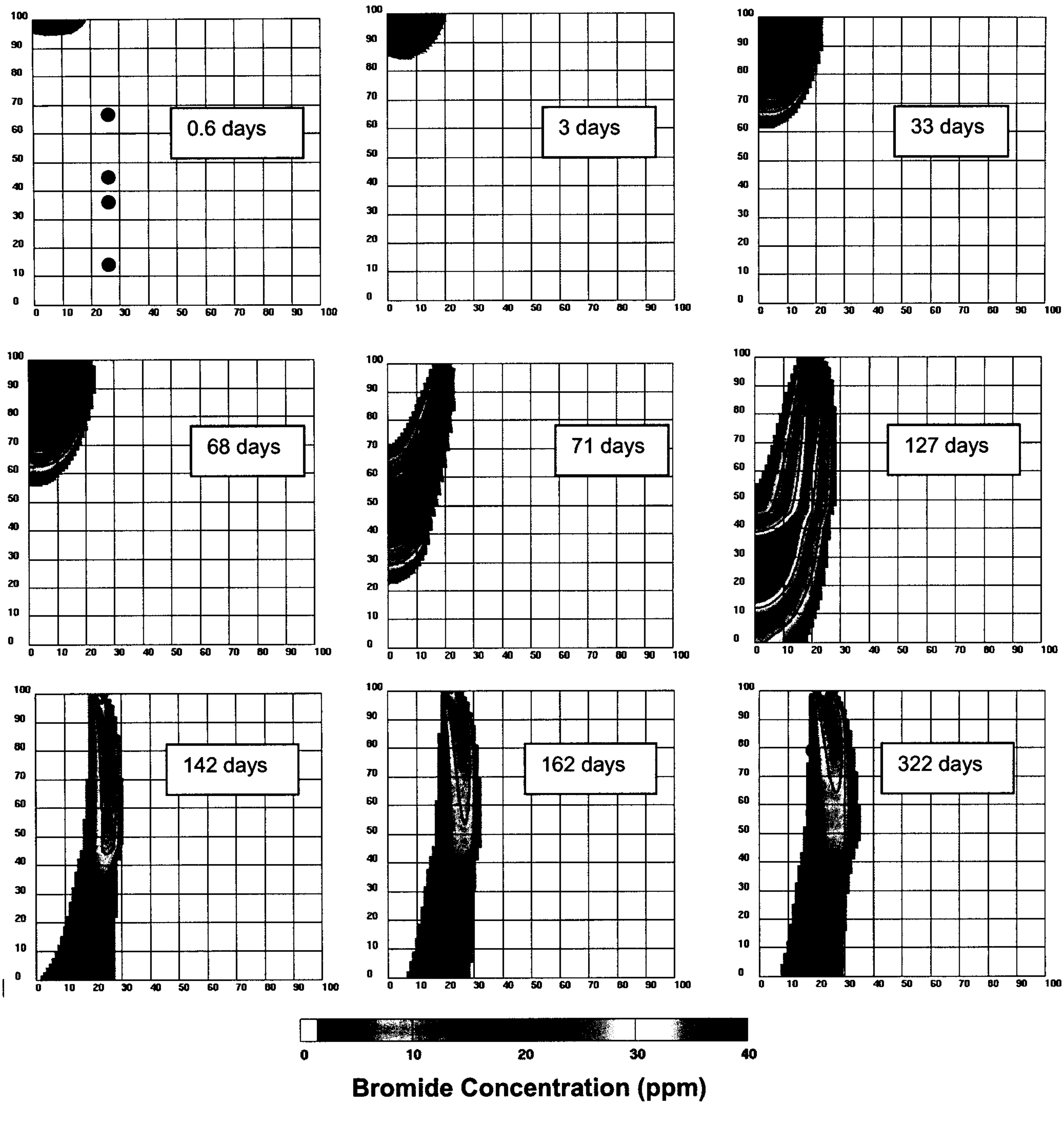

Figure 17. Modeled migration of bromide plume for simulation S-3. (Initial concentration is well over 10,000 ppm, however the colorbar has been truncated at 40 ppm to more clearly show the growth of the plume. LAWS-01 lies at x=25 m, while ports 1-4 are located at elevations of z=76.5m, 54. m, 44.5 m, and 22 m respectively. The approximate locations of the ports are marked on the 0.6 and 322 day images as black circles.)

Simulations of the tracer-test results suggest that the Cerros del Rio basalt has an effective fracture porosity in the range of 0.001 to 0.01 (Figure 18) and permeabilities in the range of 10^{-11} to 10^{-12} m^2.

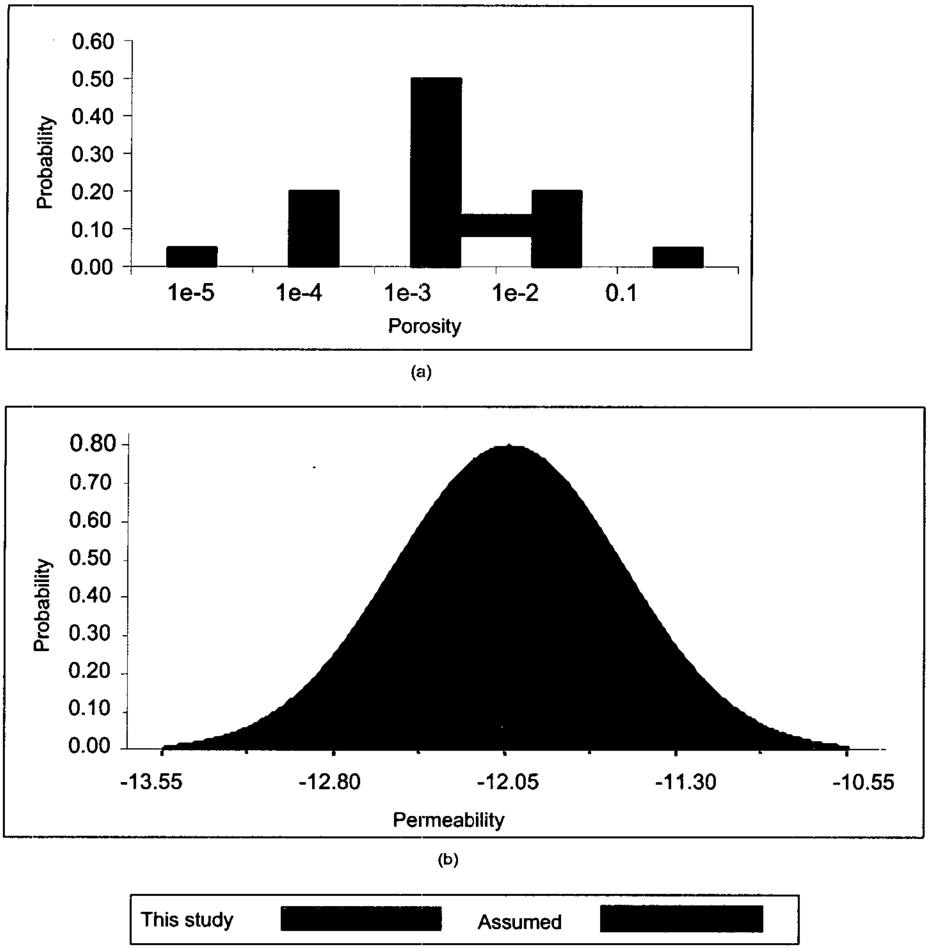

Figure 18. Comparison of hydraulic-property distribution previously assumed for the Cerros del Rio basalt at LANL and that determined in the weir study; (a) = porosity, (b) = permeability

Discussion of Modeling

The most interesting conclusion drawn from Figure 17 is that the location of LAWS-01 was ideal for monitoring breakthrough over a 1-yr+ period. The plume moves away from the center of the pond (and toward LAWS-01) because it is displaced by infiltration/percolation of water containing bromide. Placed laterally 11 m from the edge of the ponding area, ports in LAWS-01 are in the region where bromide is driven by the percolation, and left behind at measurable concentrations. This bromide fringe, especially apparent from 127 days onward, is much less suceptible to flushing by later ponding events and for this reason is quite useful in learning about transport in the basalt. The simulations suggest that a borehole drilled directly in the axis of the weir pond (x = 0.0) would have needed a much higher frequency of sampling to capture the bromide breakthrough and would have been flushed rapidy, thereby providing less information about the overall system than did LAWS-01.

Although the four simulations lead to similar breakthrough curves, the specific combinations of material properties and magnitude of ponding are quite different (Table 8). In the case of the low-porosity simulation (S-1), the total amount of water allowed to seep from the pond during the first event is 50 times less than that allowed in the high-porosity case (S-4). Similarly, the second event for S-1 is best fit with 10 times less infiltration than for S-4. Interestingly, the bromide mass loading in S-1 is only a factor of 5 times less than for S-4. Our results show that the simulated porosity and permeability are highly sensitive to the surface flux of both water and bromide.

We propose that a bimodal distribution of fractures could lead to a small percentage of the bromide quickly reaching depth while the bulk of the transport occurs through a slower fracture network with higher effective porosity. The ranges of both porosity and permeability explored in the modeling falls well within but considerably narrows those currently used by the Los Alamos Risk Reduction and Environmental Stewardship (RRES) Project for transport calculations, based on both experiments and modeling (Figure 17). Because this is the first controlled study to address tracer movement in the Cerros del Rio basalt, our results should help confirm the current distribution of hydraulic properties for this important hydrostratigraphic unit.

IMPLICATIONS OF PROJECT

The weir project addressed four questions. Two pertain strictly to the impact of the Cerro Grande fire and efforts to mitigate it while the other two concern more global hydrologic issues at LANL:

- What is the post-fire quality of intermediate-depth perched groundwater in this part of LA Canyon?
- What is the impact of the low-head weir on the groundwater quality?
- How connected are surface water and intermediate-depth perched groundwater, especially in this part of LA Canyon?
- What are the hydraulic properties of the Cerros del Rio basalt?

The results of the monitoring, tracer test, and modeling have implications for each of these issues.

Post-Fire Groundwater Quality

Groundwater samples, taken in April and December 2001 from all screens in the vertical well (LAWS-01) where there was water (screens 2, 3, and 4), were analyzed for a comprehensive suite of inorganic analytes (Appendix A-1). The impact of the Cerro Grande fire on intermediate-depth perched groundwater in the vicinity of the weir is evidenced by elevated concentrations of several constituents:

alkalinity (Alk),
calcium (Ca),
sodium (Na), and
total organic carbon (TOC).

While alkalinity, calcium, and sodium are somewhat elevated relative to typical values observed at LANL, the TOC content was extremely elevated, especially in one sample (Table 9). Whereas, a typical value for TOC at LANL is on the order of 3 ppm, the December 2001 sample from screen 2 contained more than 300 ppm TOC. However, the impact of the fire on water quality is mitigated by the fact that the Los Alamos reservoir, farther upstream, has been dredged so as to collect most direct runoff from the fire-impacted portion of the watershed and thus fire-enhanced contaminants rarely reach the weir.

Table 9
Fire-Related Constituents in LAWS-01 Groundwater (ppm)

Depth of Port (ft bgs)[a]	Date	Alk[b] (55-80)[d]	Ca (14-17)[d]	Na[c] (15-18)[d]	TOC (3-3.5)[d]
163 (2)	5 Apr 01	80.7	33.4	32.6	5.2
	17 Dec 01	125.4	30.3	24.5	375
193 (3)	5 Apr 01				
	17 Dec 01	107.4	26.2	21.8	18.8
268 (4)	5 Apr 01		42.1	32.7	4.5
	17 Dec 01	108.2	32.5	20.0	30.4

[a] Associated screen number given in parentheses.
[b] Alk = alkalinity as ppm $CaCO_3$; -- = not sampled or not analyzed.
[c] The source of the elevated level of Na could be road salt instead of the fire.
[d] Typical non-fire-impacted values in parentheses for comparison

Concentrations of fire-related constituents in samples of intermediate-depth perched water at nearby well R-9i are also elevated, but less so than at the weir (Figure 19). The reason for the lower concentrations at R-9i is probably that there is no weir or temporary ponding to enhance downward movement of surface water.

Impact of the Weir on Groundwater Quality

While the weir does address a surface-water problem (it caused the deposition of contaminant-bearing sediment west of the eastern LANL boundary), it creates a groundwater problem. Although the structure was designed to be permeable and thus not result in long-term ponding of water, the weir causes at least temporary ponding. A comparison of pre- and post-weir monitoring data would be necessary to determine the extent to which such ponding promotes the downward flux of contaminated surface water. While we only have post-weir monitoring data, one would expect (from Darcy's law) that the increased head associated with ponding enhances the downward movement of the surface water. The highly fractured basalt at the surface further facilitates seepage.

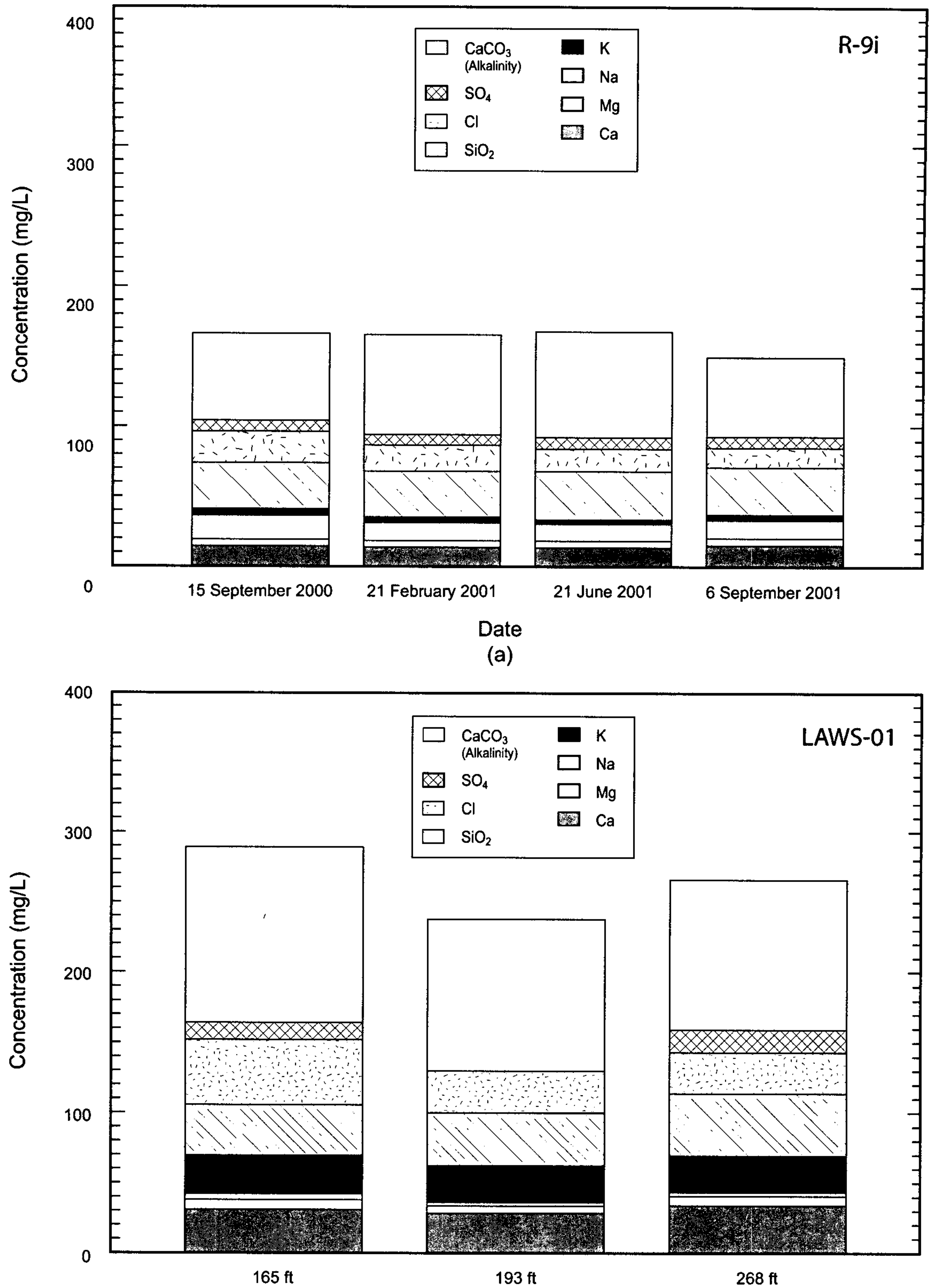

Figure 19. Major-ion chemistry of groundwaters in Los Alamos Canyon; a) at R-9i, b) at LAWS-01

Surface Water/Groundwater Connection

Observations at the weir support the conclusion that surface water and groundwater perched in the basalt are very well connected (Stone et al. 2002, 80928). Based on both the wire-pair data and tracer-test results, water moves rapidly between the surface and subsurface monitoring points. Admittedly, alluvium was stripped away from the pond area so the basalt lies at the surface. However, in view of such rates of movement, connection must also be good even where the basalt is overlain by some thickness of alluvium. Although not measured, the thickness of the alluvium at the weir prior to grading for a flat pond floor is estimated to have been less than 5 ft.

A comparison of major-ion chemistry of surface water and groundwater at the weir confirms that they are well connected. Stiff-like diagrams for a sample of surface water and two samples of groundwater from LAWS-01are very similar, suggesting the waters are in communication (Figure 20). The main difference between the analyses is an increase in total dissolved solids content with depth, as is to be expected.

Hydraulic Properties of the Basalt

Perhaps the most significant contribution made by the weir project is that it provided another approach to quantifying hydraulic properties of the basalt, which is an important element of the conceptual hydrogeologic model for the Pajarito Plateau. The modeled distribution of bromide tracer matched the observed distribution for the June 2002 event when it was assumed that porosity is limited to fractures. In other words, the model was designed to assume the unsaturated zone has no matrix porosity, which is realistic for basalt. The understanding gained through this analysis will help to reduce uncertainty in models used to predict future risk associated with transport of contaminants at various sites within the Los Alamos National Laboratory.

Further Work Needed

The weir site is an important facility that provides a unique opportunity to investigate various hydrologic issues. Some of these issues were identified in the initial project but not addressed because of the drought or instrument problems (i.e. water and tracer mass balance). Other issues were not necessarily targeted for this study but are nonetheless important (i.e. modeling the specific control of hydraulic properties by fractures).

Additional data collection would be beneficial. For example, because of the drought conditions that prevailed since the application of iodide to the pond floor, this tracer was not mobilized until just before Cerro Grande fire funding ran out (end of FY 03). The liner from LAWS-02 was pulled and sampled but samples could not be analyzed in time for inclusion in this report, which had to be completed in FY03. Nonetheless, these liner samples were archived (stored under refrigeration) for analysis in the future.

Similarly, additional modeling would be productive. With better experimental constraints on both water and tracer mass balance, we envision that modeling could further reduce the uncertainty in the estimates of hydraulic properties for the basalt. The level of complexity required to set up a system for a bimodal distribution of fractures numerically was beyond the scope of the current effort but may prove to be a worthwhile topic for future work.

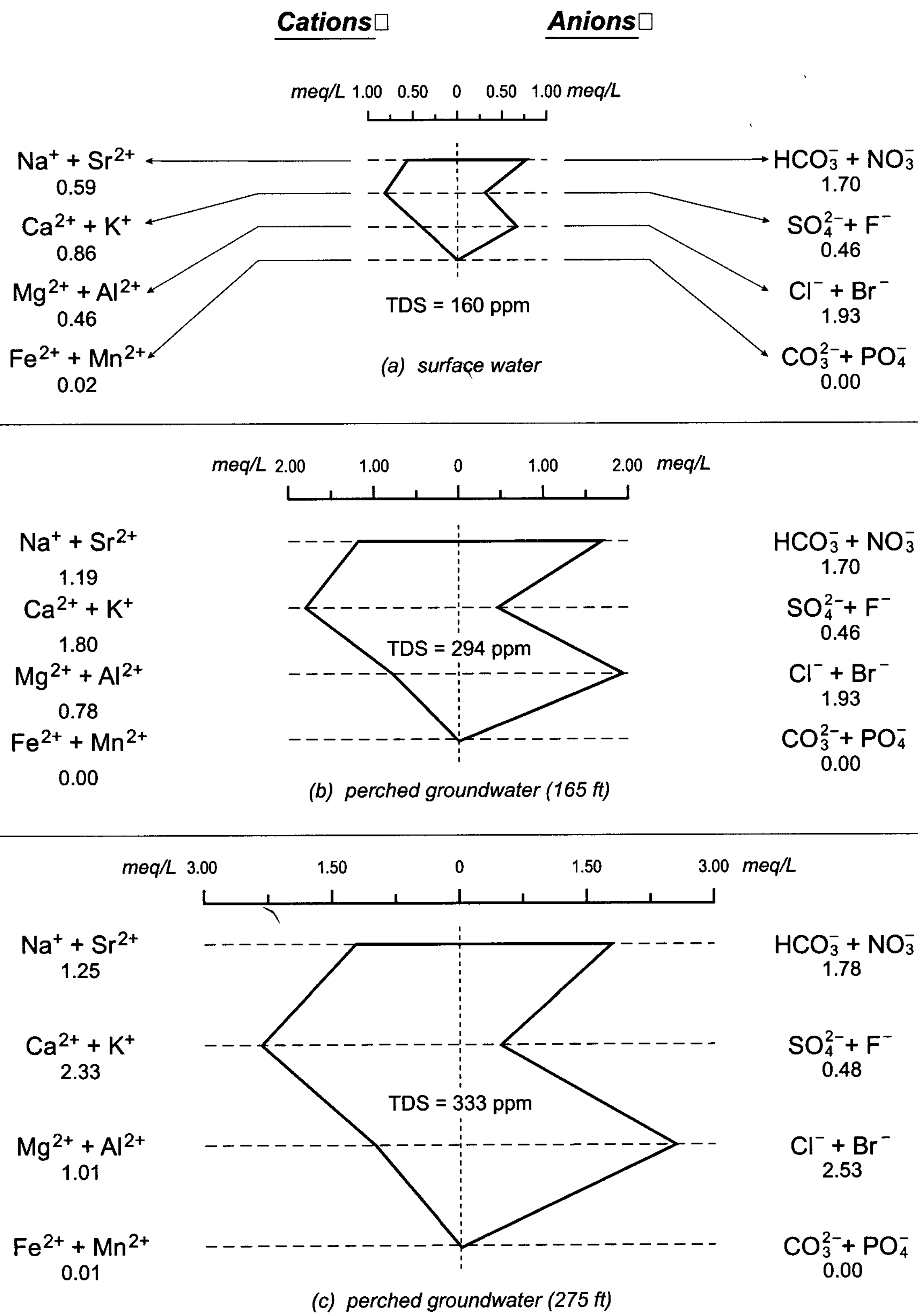

Figure 20. Stiff-like diagrams for surface water and groundwater at the weir

SUMMARY AND CONCLUSIONS

The key findings and resulting conclusions are summarized below.

1. The low-head weir addressed a surface-water problem, but created a groundwater problem.
2. Elevated levels of total organic carbon, alkalinity, calcium, and sodium were detected in perched groundwater in the basalt beneath the weir site following runoff from the fire-impacted part of LA Canyon.
3. A chemical comparison of groundwaters from R-9i and LAWS-01 shows higher levels of fire-constituents in the weir well than at R-9i, because runoff and ponding at the weir enhances movement of water to the subsurface.
4. The installation of scalloped casing permitted the successful use of flexible liners in LAWS-02 and should be a useful approach in other unstable, angled boreholes.
5. Based on a tracer test, surface and groundwaters are well connected in this reach of LA Canyon; movement of tracer to perched groundwater in basalt underlying the weir site on the order of as much as 182 ft in 12 days was documented.
6. The basalt is dominated by fracture porosity and permeability; transport occurs at different rates in different fractures.
7. Modeling reproduced the observed distribution of tracer quite well when the basalt was assigned no matrix porosity, an effective fracture porosity in the range of 0.001 to 0.01 and permeability in the range of 10^{-11} to 10^{-12} m^2.

It is hoped that the significant findings of this project will inspire further work at this important installation.

ACKNOWLEDGEMENTS

This project was made possible through emergency funds provided to the DOE and LANL for remediating damage and addressing demonstrated vulnerabilities associated with the Cerro Grande fire. The work was conducted by LANL through the Wellhead Protection Task (Task 0043) of the Cerro Grande Rehabilitation Project that addressed near- and long-term activities required for the Laboratory to fully recover from the fire. Steve Rae and Charlie Nylander (both RRES) managed the fire monies during the project.

Alan Shumaker (SEA) assisted with pulling and installing liners. Candace Christiansen (SEA) helped analyze the soil-water samples for tracer(s). Candace Christiansen (SEA) and Neva Mason (formerly with SEA) prepared and maintained the initial database for the weir project. Dave Shaull (RRES) installed and maintained surface-water gages at and below the weir and provided surface-water data for those gages as well as one above the weir in LA Canyon. Anthony Garcia (EES-6) prepared Figures 1 and 3. Alan Shumaker prepared Figures 4 and 5. Marvin Wetovsky (IM-1) edited this document, and Randi Moore (IM-1) was the compositor.

REFERENCES

Broxton, D., D. Vaniman, W. Stone, S. McLin, M. Everett, and A. Crowder, 2000. "Characterization Well R-9i Completion Report," Los Alamos National Laboratory Report LA-13821-MS, Los Alamos, New Mexico. (Broxton et al. 2000, 71251)

Gallaher, B., K. I. Mullen, and M. Alexander, 2001. "Runoff Following the Cerro Grande Fire," *in* New Mexico Bureau of Mines and Mineral Resources, New Mexico Decision-Makers Field Guide No. 1, pp. 48–49. (Gallaher et al. 2001, 72662)

Griggs, R.L., 1964. Geology and Ground-Water Resources of the Los Alamos Area, New Mexico: U.S. Geological Survey, Water-Supply Paper 1753, Washington, D.C. (Griggs 1964, 65649)

Joseph, K., 2001. "The Cerro Grande Fire, Santa Fe National Forest, May 2000," *in* New Mexico Bureau of Mines and Mineral Resources, New Mexico Decision-Makers Field Guide No. 1, pp. 34–36. (Joseph 2001, 72662)

LANL (Los Alamos National Laboratory), 1998. "Hydrogeologic Workplan," rev. 01, Los Alamos National Laboratory Report, Los Alamos, New Mexico. (LANL 1998, 59599)

Shaull, D.A., D. Ortiz, M.R. Alexander, R.P. Romero, 2003. "Surface Water Data at Los Alamos National Laboratory -- 2002 Water Year," Los Alamos National Laboratory Report LA –14019-PR, Los Alamos, New Mexico. (Shaull et al. 2002, 76042)

Stauffer, P., 2003. "Modeling the Los Alamos Canyon Weir Bromide Tracer Experiment," Los Alamos National Laboratory Report LA-UR-03-82448, Los Alamos, New Mexico (Stauffer 2003, 81725)

Stone, W.J., 2002. "Use of Flexible Liners in Unstable Angled Boreholes at LANL" (poster abstract), Proceedings of the New Mexico Geological Society Annual Spring Meeting, Socorro, New Mexico, p. 50. (Stone 2002, 72663)

Stone, W.J., and D.L. Newell, 2002. "Installation of the Monitoring Site at the Los Alamos Canyon Low-Head Weir," Los Alamos National Laboratory Report LA-13970, Los Alamos, New Mexico. (Stone and Newell 2002, 73446)

Stone, W., Longmire, P., Newell, D., Levitt, D., Jones, C, and Groffman, A., 2002. "Impact of the Cerro Grande Fire on Intermediate-Depth Perched Water Quality -- Preliminary Results from the Low-Head Weir Site, Los Alamos National Laboratory (abstract)," Proceedings, New Mexico Water Resources Research Institute, New Mexico Water Research Symposium, Socorro, New Mexico, p. D43. (Stone et al. 2002, 80928)

Zyvoloski, G.A., B.A. Robinson, Z.V. Dash, and L.L. Trease, July 1997. "Summary of the Models and Methods for the FEHM Application - A Finite-Element Heat- and Mass-Transfer Code, "Los Alamos National Laboratory report LA-13307-MS, Los Alamos, NM. (Zyvoloski et al. 1997, 70147)

Appendix A

Full-Suite Inorganic Analyses of Waters at the Weir Site

A-1. Results for 05 April 2001

A-2. Results of 17 December 2001

A-1. Results for 05 April 2001

		Date	Ag	Al	Std. Dev.	Alk(Lab)
Sample ID	Description	MM/DD/YY	ppm	ppm	±	ppm $CaCO_3$
LAWS surface	Surface water into pond area	04/06/01	<0.001	1.29	0.02	37.6
LAWS-01 165 ft	LAWS-01 165 ft bgs	04/05/01	<0.001	0.025	0.001	80.7
LAWS-01 275 ft	LAWS-01 275 ft	04/05/01	<0.001	0.023	0.001	84.4
LAWS-01 165 ft ss	LAWS-01 165 ft bgs adsorbed	04/05/01	<0.02	5108	40	—
LAWS-01 275 ft ss	LAWS-01 275 ft adsorbed	04/05/01	<0.02	4632	80	—

		Date	As	Std. Dev.	B	Std. Dev.
Sample ID	Description	MM/DD/YY	ppm	±	ppm	±
LAWS surface	Surface water into pond area	04/06/01	0.0007	0.0001	0.013	0.001
LAWS-01 165 ft	LAWS-01 165 ft bgs	04/05/01	0.0004	0.0001	0.021	0.001
LAWS-01 275 ft	LAWS-01 275 ft	04/05/01	0.0005	0.0001	0.023	0.001
LAWS-01 165 ft ss	LAWS-01 165 ft bgs adsorbed	04/05/01	0.20	0.01	9.99	0.19
LAWS-01 275 ft ss	LAWS-01 275 ft adsorbed	04/05/01	0.20	0.01	11.1	0.2

		Date	Ba	Std. Dev.	Be	Std. Dev.	Br
Sample ID	Description	MM/DD/YY	ppm	±	ppm	±	ppm
LAWS surface	Surface water into pond area	04/06/01	0.043	0.001	<0.001		0.03
LAWS-01 165 ft	LAWS-01 165 ft bgs	04/05/01	0.060	0.001	<0.001		0.07
LAWS-01 275 ft	LAWS-01 275 ft	04/05/01	0.065	0.001	<0.001		0.09
LAWS-01 165 ft ss	LAWS-01 165 ft bgs adsorbed	04/05/01	111	2	0.61	0.01	—*
LAWS-01 275 ft ss	LAWS-01 275 ft adsorbed	04/05/01	98.5	1.9	0.79	0.02	—

		Date	C TIC	C TOC	Ca	Std. Dev.
Sample ID	Description	MM/DD/YY	ppm	ppm	ppm	±
LAWS surface	Surface water into pond area	04/06/01	9.4	7	16.1	0.1
LAWS-01 165 ft	LAWS-01 165 ft bgs	04/05/01	20.3	5.2	33.4	0.1
LAWS-01 275 ft	LAWS-01 275 ft	04/05/01	21.4	4.5	42.1	0.1
LAWS-01 165 ft ss	LAWS-01 165 ft bgs adsorbed	04/05/01	—	—	8366	20
LAWS-01 275 ft ss	LAWS-01 275 ft adsorbed	04/05/01	—	—	8687	40

* — = Not analyzed

A-1. Results for 05 April 2001 (continued)

		Date	Cd	Std. Dev.	Cl	ClO_3	ClO_4
Sample ID	Description	MM/DD/YY	ppm	±	ppm	ppm	ppm
LAWS surface	Surface water into pond area	04/06/01	<0.001		24.6	<0.02	<0.002
LAWS-01 165 ft	LAWS-01 165 ft bgs	04/05/01	<0.001		68.3	<0.02	<0.002
LAWS-01 275 ft	LAWS-01 275 ft	04/05/01	<0.001		89.5	<0.02	<0.002
LAWS-01 165 ft ss	LAWS-01 165 ft bgs adsorbed	04/05/01	0.065	0.001	—	—	—
LAWS-01 275 ft ss	LAWS-01 275 ft adsorbed	04/05/01	0.043	0.001	—	—	—

		Date	Co	Std. Dev.	CO_3	Cr	Std. Dev.
Sample ID	Description	MM/DD/YY	ppm	±	ppm	ppm	±
LAWS surface	Surface water into pond area	04/06/01	<0.001		0	0.002	0.001
LAWS-01 165 ft	LAWS-01 165 ft bgs	04/05/01	<0.001		0	0.004	0.001
LAWS-01 275 ft	LAWS-01 275 ft	04/05/01	<0.001		0	0.005	0.001
LAWS-01 165 ft ss	LAWS-01 165 ft bgs adsorbed	04/05/01	17.6	0.2	—	4.03	0.01
LAWS-01 275 ft ss	LAWS-01 275 ft adsorbed	04/05/01	7.75	0.09	—	3.27	0.03

		Date	Cs	Std. Dev.	Cu	Std. Dev.	F
Sample ID	Description	MM/DD/YY	ppm	±	ppm	±	ppm
LAWS surface	Surface water into pond area	04/06/01	<0.001		0.0015	0.0001	0.09
LAWS-01 165 ft	LAWS-01 165 ft bgs	04/05/01	<0.001		0.008	0.001	0.43
LAWS-01 275 ft	LAWS-01 275 ft	04/05/01	<0.001		0.0021	0.0001	0.40
LAWS-01 165 ft ss	LAWS-01 165 ft bgs adsorbed	04/05/01	0.043	0.001	44.8	1.7	—
LAWS-01 275 ft ss	LAWS-01 275 ft adsorbed	04/05/01	0.048	0.001	14.4	0.1	—

		Date	Fe	Std. Dev.	Hardness	HCO_3
Sample ID	Description	MM/DD/YY	ppm	±	$CaCO_3$ ppm	ppm
LAWS surface	Surface water into pond area	04/06/01	0.41	0.01	58.9	45.9
LAWS-01 165 ft	LAWS-01 165 ft bgs	04/05/01	<0.01		129.9	98.5
LAWS-01 275 ft	LAWS-01 275 ft	04/05/01	<0.01		165.2	103
LAWS-01 165 ft ss	LAWS-01 165 ft bgs adsorbed	04/05/01	13214	80	—	—
LAWS-01 275 ft ss	LAWS-01 275 ft adsorbed	04/05/01	9975	20	—	—

A-1. Results for 05 April 2001 (continued)

		Date	Hg	Std. Dev.	K	Std. Dev.
Sample ID	Description	MM/DD/YY	ppm	±	ppm	±
LAWS surface	Surface water into pond area	04/06/01	0.00006	0.00001	3.52	0.07
LAWS-01 165 ft	LAWS-01 165 ft bgs	04/05/01	<0.00005		6.68	0.14
LAWS-01 275 ft	LAWS-01 275 ft	04/05/01	<0.00005		6.87	0.03
LAWS-01 165 ft ss	LAWS-01 165 ft bgs adsorbed	04/05/01	0.0041	0.0003	753	2
LAWS-01 275 ft ss	LAWS-01 275 ft adsorbed	04/05/01	0.0052	0.0002	946	4

		Date	Li	Std. Dev.	Mg	Std. Dev.
Sample ID	Description	MM/DD/YY	ppm	±	ppm	±
LAWS surface	Surface water into pond area	04/06/01	0.006	0.001	4.53	0.01
LAWS-01 165 ft	LAWS-01 165 ft bgs	04/05/01	0.013	0.002	11.3	0.1
LAWS-01 275 ft	LAWS-01 275 ft	04/05/01	0.021	0.003	14.6	0.1
LAWS-01 165 ft ss	LAWS-01 165 ft bgs adsorbed	04/05/01	4.44	0.07	9532	40
LAWS-01 275 ft ss	LAWS-01 275 ft adsorbed	04/05/01	4.42	0.09	7611	20

		Date	Mn	Std. Dev.	Mo	Std. Dev.
Sample ID	Description	MM/DD/YY	ppm	±	ppm	±
LAWS surface	Surface water into pond area	04/06/01	0.019	0.001	0.012	0.001
LAWS-01 165 ft	LAWS-01 165 ft bgs	04/05/01	0.011	0.001	0.015	0.001
LAWS-01 275 ft	LAWS-01 275 ft	04/05/01	0.14	0.01	0.014	0.001
LAWS-01 165 ft ss	LAWS-01 165 ft bgs adsorbed	04/05/01	501	2	0.13	0.01
LAWS-01 275 ft ss	LAWS-01 275 ft adsorbed	04/05/01	463	2	0.20	0.01

		Date	Na	Std. Dev.	NH_4	Ni	Std. Dev.
Sample ID	Description	MM/DD/YY	ppm	±	ppm	ppm	±
LAWS surface	Surface water into pond area	04/06/01	15.9	0.1	<0.02	0.0015	0.0001
LAWS-01 165 ft	LAWS-01 165 ft bgs	04/05/01	32.6	0.2	<0.02	0.003	0.001
LAWS-01 275 ft	LAWS-01 275 ft	04/05/01	32.7	0.1	<0.02	0.003	0.001
LAWS-01 165 ft ss	LAWS-01 165 ft bgs adsorbed	04/05/01	844	4	—	22.0	0.5
LAWS-01 275 ft ss	LAWS-01 275 ft adsorbed	04/05/01	1172	2	—	17.8	0.2

A-1. Results for 05 April 2001 (continued)

		Date	NO_2	NO_3	Oxalate	Pb	Std. Dev.
Sample ID	Description	MM/DD/YY	ppm	ppm	ppm	ppm	±
LAWS surface	Surface water into pond area	04/06/01	<0.02	4.37	<0.02	0.0013	0.0001
LAWS-01 165 ft	LAWS-01 165 ft bgs	04/05/01	<0.02	5.54	<0.02	<0.001	
LAWS-01 275 ft	LAWS-01 275 ft	04/05/01	<0.02	5.73	<0.02	<0.001	
LAWS-01 165 ft ss	LAWS-01 165 ft bgs adsorbed	04/05/01	—	—	—	13.0	0.1
LAWS-01 275 ft ss	LAWS-01 275 ft adsorbed	04/05/01	—	—	—	8.28	0.02

		Date	pH	PO_4	Rb	Std. Dev.
Sample ID	Description	MM/DD/YY	Lab	ppm	ppm	±
LAWS surface	Surface water into pond area	04/06/01	7.61	0.25	0.006	0.001
LAWS-01 165 ft	LAWS-01 165 ft bgs	04/05/01	7.48	<0.05	0.010	0.001
LAWS-01 275 ft	LAWS-01 275 ft	04/05/01	7.70	<0.05	0.010	0.001
LAWS-01 165 ft ss	LAWS-01 165 ft bgs adsorbed	04/05/01	—	—	2.50	0.01
LAWS-01 275 ft ss	LAWS-01 275 ft adsorbed	04/05/01	—	—	3.09	0.08

		Date	Sb	Std. Dev.	Se	Std. Dev.
Sample ID	Description	MM/DD/YY	ppm	±	ppm	±
LAWS surface	Surface water into pond area	04/06/01	0.0002	0.0001	<0.001	
LAWS-01 165 ft	LAWS-01 165 ft bgs	04/05/01	0.0005	0.0001	0.001	0.001
LAWS-01 275 ft	LAWS-01 275 ft	04/05/01	0.0004	0.0001	0.001	0.001
LAWS-01 165 ft ss	LAWS-01 165 ft bgs adsorbed	04/05/01	0.020	0.001	0.20	0.04
LAWS-01 275 ft ss	LAWS-01 275 ft adsorbed	04/05/01	0.033	0.001	0.15	0.02

		Date	Si	Std. Dev.	SiO_2	SO_4
Sample ID	Description	MM/DD/YY	ppm	±	ppm calc	ppm
LAWS surface	Surface water into pond area	04/06/01	15.3	0.1	32.7	15.3
LAWS-01 165 ft	LAWS-01 165 ft bgs	04/05/01	12.5	0.1	26.8	20.8
LAWS-01 275 ft	LAWS-01 275 ft	04/05/01	10.6	0.1	22.7	22.1
LAWS-01 165 ft ss	LAWS-01 165 ft bgs adsorbed	04/05/01	2813	20	6020	—
LAWS-01 275 ft ss	LAWS-01 275 ft adsorbed	04/05/01	3114	20	6664	—

A-1. Results for 05 April 2001 (continued)

		Date	Sn	Std. Dev.	Sr	Std.D.
Sample ID	Description	MM/DD/YY	ppm	±	ppm	±
LAWS surface	Surface water into pond area	04/06/01	<0.001		0.11	0.01
LAWS-01 165 ft	LAWS-01 165 ft bgs	04/05/01	<0.001		0.16	0.01
LAWS-01 275 ft	LAWS-01 275 ft	04/05/01	<0.001		0.20	0.01
LAWS-01 165 ft ss	LAWS-01 165 ft bgs adsorbed	04/05/01	0.12	0.01	55.0	0.2
LAWS-01 275 ft ss	LAWS-01 275 ft adsorbed	04/05/01	0.056	0.002	62.1	0.2

		Date	Th	Std. Dev.	Ti	Std. Dev.
Sample ID	Description	MM/DD/YY	ppm	±	ppm	±
LAWS surface	Surface water into pond area	04/06/01	<0.001		0.034	0.001
LAWS-01 165 ft	LAWS-01 165 ft bgs	04/05/01	<0.001		<0.001	
LAWS-01 275 ft	LAWS-01 275 ft	04/05/01	<0.001		<0.001	
LAWS-01 165 ft ss	LAWS-01 165 ft bgs adsorbed	04/05/01	3.65	0.02	50.2	0.5
LAWS-01 275 ft ss	LAWS-01 275 ft adsorbed	04/05/01	4.31	0.03	23.8	0.3

		Date	Tl	Std. Dev.	U	Std. Dev.
Sample ID	Description	MM/DD/YY	ppm	±	ppm	±
LAWS surface	Surface water into pond area	04/06/01	<0.001		<0.001	
LAWS-01 165 ft	LAWS-01 165 ft bgs	04/05/01	<0.001		0.0022	0.0001
LAWS-01 275 ft	LAWS-01 275 ft	04/05/01	<0.001		0.0030	0.0001
LAWS-01 165 ft ss	LAWS-01 165 ft bgs adsorbed	04/05/01	0.037	0.001	0.88	0.01
LAWS-01 275 ft ss	LAWS-01 275 ft adsorbed	04/05/01	0.037	0.001	0.99	0.02

		Date	V	Std. Dev.	Zn	Std. Dev.	TDS
Sample ID	Description	MM/DD/YY	ppm	±	ppm	±	ppm
LAWS surface	Surface water into pond area	04/06/01	0.002	0.001	0.005	0.001	165.3
LAWS-01 165 ft	LAWS-01 165 ft bgs	04/05/01	0.002	0.001	0.004	0.001	304.7
LAWS-01 275 ft	LAWS-01 275 ft	04/05/01	0.002	0.001	0.003	0.001	340.3
LAWS-01 165 ft ss	LAWS-01 165 ft bgs adsorbed	04/05/01	4.92	0.07	56.6	0.2	—
LAWS-01 275 ft ss	LAWS-01 275 ft adsorbed	04/05/01	6.73	0.08	27.5	0.2	—

A-1. Results for 05 April 2001 (concluded)

		Date	Cation	Anion	Balance	B/Cl	Li/Cl
Sample ID	Description	MM/DD/YY	Sum	Sum	Difference	by wt	by wt
LAWS surface	Surface water into pond area	04/06/01	2.128	1.845	0.1424	0.0005	0.0002
LAWS-01 165 ft	LAWS-01 165 ft bgs	04/05/01	4.194	4.087	0.0260	0.0003	0.0002
LAWS-01 275 ft	LAWS-01 275 ft	04/05/01	4.915	4.787	0.0265	0.0003	0.0002
LAWS-01 165 ft ss	LAWS-01 165 ft bgs adsorbed	04/05/01	—	—	—	—	—
LAWS-01 275 ft ss	LAWS-01 275 ft adsorbed	04/05/01	—	—	—	—	—

		Date	F/Cl	Na/Cl	K/Cl	SO_4/CL	HCO_3/Cl
Sample ID	Description	MM/DD/YY	by wt	by wt	by wt	by wt	by wt
LAWS surface	Surface water into pond area	04/06/01	0.0037	0.6463	0.1431	0.6220	1.8659
LAWS-01 165 ft	LAWS-01 165 ft bgs	04/05/01	0.0063	0.4773	0.0978	0.3045	1.4422
LAWS-01 275 ft	LAWS-01 275 ft	04/05/01	0.0045	0.3654	0.0768	0.2469	1.1508
LAWS-01 165 ft ss	LAWS-01 165 ft bgs adsorbed	04/05/01	—	—	—	—	—
LAWS-01 275 ft ss	LAWS-01 275 ft adsorbed	04/05/01	—	—	—	—	—

		Date	Cs/Cl	Br/Cl
Sample ID	Description	MM/DD/YY	by wt	by wt
LAWS surface	Surface water into pond area	04/06/01	0.0000	0.0012
LAWS-01 165 ft	LAWS-01 165 ft bgs	04/05/01	0.0000	0.0010
LAWS-01 275 ft	LAWS-01 275 ft	04/05/01	0.0000	0.0010
LAWS-01 165 ft ss	LAWS-01 165 ft bgs adsorbed	04/05/01	—	—
LAWS-01 275 ft ss	LAWS-01 275 ft adsorbed	04/05/01	—	—

A-2. Results for 17 December 2001

		Date	ER	Ag	Al	Std. Dev.
Sample ID	Description	MM/DD/YY	Req#	ppm	ppm	±
GW72-01-0022	Los Alamos Weir Site, scr#4, 263-273 ft	12/17/01	384S	<0.001	<0.002	
GW72-01-0024	Los Alamos Weir Site, scr#3, 188-198 ft	12/17/01	384S	<0.001	0.0024	0.0001
GW72-01-0026	Los Alamos Weir Site, scr#2, 158-168 ft	12/17/01	384S	<0.001	<0.002	

		Date	Alk (Lab)	As	Std. Dev.
Sample ID	Description	MM/DD/YY	ppm $CaCO_3$	ppm	±
GW72-01-0028	Los Alamos Weir Site, scr#4, 263-273 ft	12/17/01	108.2	0.0018	0.0001
GW72-01-0030	Los Alamos Weir Site, scr#3, 188-198 ft	12/17/01	107.4	0.0019	0.0001
GW72-01-0032	Los Alamos Weir Site, scr#2, 158-168 ft	12/17/01	125.4	0.0019	0.0001

		Date	Std. Dev.	Ba	Std. Dev.	Be
Sample ID	Description	MM/DD/YY	±	ppm	±	ppm
GW72-01-0034	Los Alamos Weir Site, scr#4, 263-273 ft	12/17/01	0.001	0.048	0.001	<0.001
GW72-01-0036	Los Alamos Weir Site, scr#3, 188-198 ft	12/17/01	0.001	0.082	0.001	<0.001
GW72-01-0038	Los Alamos Weir Site, scr#2, 158-168 ft	12/17/01	0.001	0.129	0.002	<0.001

		Date	Br	C TIC	C TOC
Sample ID	Description	MM/DD/YY	ppm	ppm	ppm
GW72-01-0040	Los Alamos Weir Site, scr#4, 263-273 ft	12/17/01	0.13	27.0	30.4
GW72-01-0042	Los Alamos Weir Site, scr#3, 188-198 ft	12/17/01	0.10	23.7	18.8
GW72-01-0044	Los Alamos Weir Site, scr#2, 158-168 ft	12/17/01	<0.02	27.2	375

A-2. Results for 17 December 2001 (continued)

		Date	Ca	Std. Dev.	Cd	Cl
Sample ID	**Description**	**MM/DD/YY**	**ppm**	**±**	**ppm**	**ppm**
GW72-01-0046	Los Alamos Weir Site, scr#4, 263-273 ft	12/17/01	33.5	0.4	<0.001	29.4
GW72-01-0048	Los Alamos Weir Site, scr#3, 188-198 ft	12/17/01	26.2	0.0	<0.001	29.5
GW72-01-0050	Los Alamos Weir Site, scr#2, 158-168 ft	12/17/01	30.3	0.0	<0.001	47.1

		Date	ClO_3	ClO_4	Co	CO_3
Sample ID	**Description**	**MM/DD/YY**	**ppm**	**ppm**	**ppm**	**ppm**
GW72-01-0052	Los Alamos Weir Site, scr#4, 263-273 ft	12/17/01	<0.02	<0.002	<0.001	0
GW72-01-0054	Los Alamos Weir Site, scr#3, 188-198 ft	12/17/01	<0.02	<0.002	<0.001	0
GW72-01-0056	Los Alamos Weir Site, scr#2, 158-168 ft	12/17/01	<0.02	<0.005	<0.001	0

		Date	Cr	Std. Dev.	Cs
Sample ID	**Description**	**MM/DD/YY**	**ppm**	**±**	**ppm**
GW72-01-0058	Los Alamos Weir Site, scr#4, 263-273 ft	12/17/01	0.0032	0.0001	<0.001
GW72-01-0060	Los Alamos Weir Site, scr#3, 188-198 ft	12/17/01	0.0027	0.0001	<0.001
GW72-01-0062	Los Alamos Weir Site, scr#2, 158-168 ft	12/17/01	0.0028	0.0001	<0.001

		Date	Cu	Std. Dev.	F
Sample ID	**Description**	**MM/DD/YY**	**ppm**	**±**	**ppm**
GW72-01-0064	Los Alamos Weir Site, scr#4, 263-273 ft	12/17/01	0.0010	0.0001	0.48
GW72-01-0066	Los Alamos Weir Site, scr#3, 188-198 ft	12/17/01	<0.001		0.22
GW72-01-0068	Los Alamos Weir Site, scr#2, 158-168 ft	12/17/01	<0.001		0.25

A-2. Results for 17 December 2001 (continued)

		Date	Fe	Std. Dev.	Hardness	HCO_3
Sample ID	Description	MM/DD/YY	ppm	±	$CaCO_3$ ppm	ppm
GW72-01-0070	Los Alamos Weir Site, scr#4, 263-273 ft	12/17/01	<0.002		121	132
GW72-01-0072	Los Alamos Weir Site, scr#3, 188-198 ft	12/17/01	0.84	0.01	95.1	131
GW72-01-0074	Los Alamos Weir Site, scr#2, 158-168 ft	12/17/01	1.60	0.01	113	153

		Date	Hg	K	Std. Dev.
Sample ID	Description	MM/DD/YY	ppm	ppm	±
GW72-01-0076	Los Alamos Weir Site, scr#4, 263-273 ft	12/17/01	<0.00005	4.44	0.01
GW72-01-0078	Los Alamos Weir Site, scr#3, 188-198 ft	12/17/01	<0.00005	4.11	0.03
GW72-01-0080	Los Alamos Weir Site, scr#2, 158-168 ft	12/17/01	<0.00005	4.47	0.05

		Date	Li	Std. Dev.	Mg	Std. Dev.
Sample ID	Description	MM/DD/YY	ppm	±	ppm	±
GW72-01-0082	Los Alamos Weir Site, scr#4, 263-273 ft	12/17/01	0.014	0.001	9.08	0.04
GW72-01-0084	Los Alamos Weir Site, scr#3, 188-198 ft	12/17/01	0.006	0.001	7.20	0.06
GW72-01-0086	Los Alamos Weir Site, scr#2, 158-168 ft	12/17/01	0.006	0.001	9.11	0.12

		Date	Mn	Std. Dev.	Mo	Std. Dev.
Sample ID	Description	MM/DD/YY	ppm	±	ppm	±
GW72-01-0088	Los Alamos Weir Site, scr#4, 263-273 ft	12/17/01	0.0025	0.0001	0.0021	0.0001
GW72-01-0090	Los Alamos Weir Site, scr#3, 188-198 ft	12/17/01	0.50	0.00	0.0017	0.0001
GW72-01-0092	Los Alamos Weir Site, scr#2, 158-168 ft	12/17/01	0.90	0.00	0.0052	0.0001

A-2. Results for 17 December 2001 (continued)

Sample ID	Description	Date MM/DD/YY	Na ppm	Std. Dev. ±	Ni ppm	Std. Dev. ±
GW72-01-0094	Los Alamos Weir Site, scr#4, 263-273 ft	12/17/01	20.0	0.1	0.0032	0.0001
GW72-01-0096	Los Alamos Weir Site, scr#3, 188-198 ft	12/17/01	21.8	0.1	<0.001	
GW72-01-0098	Los Alamos Weir Site, scr#2, 158-168 ft	12/17/01	24.5	0.3	<0.001	

Sample ID	Description	Date MM/DD/YY	NO_2 ppm	NO_3 ppm	Oxalate ppm	Pb ppm
GW72-01-0100	Los Alamos Weir Site, scr#4, 263-273 ft	12/17/01	<0.02	7.62	<0.02	<0.001
GW72-01-0102	Los Alamos Weir Site, scr#3, 188-198 ft	12/17/01	<0.02	<0.02	<0.02	<0.001
GW72-01-0104	Los Alamos Weir Site, scr#2, 158-168 ft	12/17/01	2.55	<0.02	<0.02	<0.001

Sample ID	Description	Date MM/DD/YY	pH Lab	PO_4 ppm	Rb ppm	Std. Dev. ±
GW72-01-0106	Los Alamos Weir Site, scr#4, 263-273 ft	12/17/01	6.98	0.68	0.009	0.001
GW72-01-0108	Los Alamos Weir Site, scr#3, 188-198 ft	12/17/01	7.59	<0.05	0.005	0.001
GW72-01-0110	Los Alamos Weir Site, scr#2, 158-168 ft	12/17/01	7.49	1.05	0.005	0.001

Sample ID	Description	Date MM/DD/YY	Sb ppm	Std. Dev. ±	Se ppm
GW72-01-0112	Los Alamos Weir Site, scr#4, 263-273 ft	12/17/01	0.0005	0.0001	<0.001
GW72-01-0114	Los Alamos Weir Site, scr#3, 188-198 ft	12/17/01	<0.0002		<0.001
GW72-01-0116	Los Alamos Weir Site, scr#2, 158-168 ft	12/17/01	0.0004	0.0001	<0.001

A-2. Results for 17 December 2001 (continued)

		Date	Si	Std. Dev.	SiO_2	SO_4
Sample ID	**Description**	**MM/DD/YY**	**ppm**	**±**	**ppm calc**	**ppm**
GW72-01-0118	Los Alamos Weir Site, scr#4, 263-273 ft	12/17/01	20.9	0.3	44.7	15.9
GW72-01-0120	Los Alamos Weir Site, scr#3, 188-198 ft	12/17/01	17.4	0.0	37.3	0.85
GW72-01-0122	Los Alamos Weir Site, scr#2, 158-168 ft	12/17/01	16.4	0.0	35.1	11.6

		Date	Sn	Sr	Std. Dev.	Th
Sample ID	**Description**	**MM/DD/YY**	**ppm**	**ppm**	**±**	**ppm**
GW72-01-0124	Los Alamos Weir Site, scr#4, 263-273 ft	12/17/01	<0.001	0.196	0.003	<0.001
GW72-01-0126	Los Alamos Weir Site, scr#3, 188-198 ft	12/17/01	<0.001	0.243	0.001	<0.001
GW72-01-0128	Los Alamos Weir Site, scr#2, 158-168 ft	12/17/01	<0.001	0.250	0.001	<0.001

		Date	Ti	Tl	U	Std. Dev.
Sample ID	**Description**	**MM/DD/YY**	**ppm**	**ppm**	**ppm**	**±**
GW72-01-0130	Los Alamos Weir Site, scr#4, 263-273 ft	12/17/01	<0.001	<0.001	0.0016	0.0001
GW72-01-0132	Los Alamos Weir Site, scr#3, 188-198 ft	12/17/01	<0.001	<0.001	<0.0001	—
GW72-01-0134	Los Alamos Weir Site, scr#2, 158-168 ft	12/17/01	<0.001	<0.001	0.0005	0.0001

		Date	V	Std. Dev.	Zn	Std. Dev.
Sample ID	**Description**	**MM/DD/YY**	**ppm**	**±**	**ppm**	**±**
GW72-01-0136	Los Alamos Weir Site, scr#4, 263-273 ft	12/17/01	0.005	0.001	0.009	0.001
GW72-01-0138	Los Alamos Weir Site, scr#3, 188-198 ft	12/17/01	0.001	0.001	<0.001	
GW72-01-0140	Los Alamos Weir Site, scr#2, 158-168 ft	12/17/01	0.001	0.001	0.002	0.001

A-2. Results for 17 December 2001 (continued)

Sample ID	Description	Date MM/DD/YY	TDS ppm	Cation Sum	Anion Sum	Balance Difference
GW72-01-0142	Los Alamos Weir Site, scr#4, 263-273 ft	12/17/01	329.3	3.411	3.486	-0.0219
GW72-01-0144	Los Alamos Weir Site, scr#3, 188-198 ft	12/17/01	279.1	3.025	3.011	0.0048
GW72-01-0146	Los Alamos Weir Site, scr#2, 158-168 ft	12/17/01	697.5	3.565	4.163	-0.1549

Sample ID	Description	Date MM/DD/YY	B/Cl by wt	Li/Cl by wt	F/Cl by wt	Na/Cl by wt
GW72-01-0148	Los Alamos Weir Site, scr#4, 263-273 ft	12/17/01	0.0025	0.0005	0.0163	0.6815
GW72-01-0150	Los Alamos Weir Site, scr#3, 188-198 ft	12/17/01	0.0005	0.0002	0.0075	0.7396
GW72-01-0152	Los Alamos Weir Site, scr#2, 158-168 ft	12/17/01	0.0002	0.0001	0.0053	0.5202

Sample ID	Description	Date MM/DD/YY	K/Cl by wt	SO_4/Cl by wt	HCO_3/Cl by wt	Cs/Cl by wt
GW72-01-0154	Los Alamos Weir Site, scr#4, 263-273 ft	12/17/01	0.1511	0.5408	4.4898	0.0000
GW72-01-0156	Los Alamos Weir Site, scr#3, 188-198 ft	12/17/01	0.1394	0.0288	4.4407	0.0000
GW72-01-0158	Los Alamos Weir Site, scr#2, 158-168 ft	12/17/01	0.0949	0.2463	3.2484	0.0000

Sample ID	Description	Date MM/DD/YY	Br/Cl by wt	Acetate ppm	Formate ppm
GW72-01-0160	Los Alamos Weir Site, scr#4, 263-273 ft	12/17/01	0.0044	-[a]	-
GW72-01-0162	Los Alamos Weir Site, scr#3, 188-198 ft	12/17/01	0.0034	+[b]	+
GW72-01-0164	Los Alamos Weir Site, scr#2, 158-168 ft	12/17/01	0.0000	+	+

[a] - = not detected;

[b] + = detected qualitatively at high concentration

Appendix B

Description of Membrane Pulled from LAWS-02, July 2002

Description of Membrane Pulled from LAWS-02, July 2002

The flexible liner installed in LAWS-02 consisted of a urethane-coated nylon fabric carrier sleeve covered by an absorbent cloth membrane. Because of borehole stability problems, the liner had to be installed through 6-in., schedule-80 PVC casing. The liner made contact with the unsaturated basalt in the borehole walls outside the casing through 30-in. long scallops cut at 6-in. intervals along one side of each 10-ft joint of PVC. The liner could not be extracted in the normal way, so was pulled from this angled hole by hand and threaded into a clear plastic sleeve to protect it against moisture loss. This caused some fine rock debris to be smeared along the membrane. After removal from LAWS-02, the absorbent membrane was laid out on a 200-ft table at the nearby FLUTe™ headquarters for sampling (Figure 7).

Following is a brief description of features observed through the plastic moisture-protect sleeve in each 10-ft interval of membrane at the time it was sampled and placed in jars.

0–10 ft (top of borehole) – no visible moisture or smudging with rock debris

10–20 ft no visible moisture; slight smudging 11.5–13.5 ft and 17–20 ft.

20–30 ft no visible moisture; entire interval smudged and streaked with dust, apparently as a result of being pulled out of hole. Small tears in membrane noted in four places.

30–40 ft some moisture; slight streaking of dust 30.5–35.5 ft and brown dirt (fracture-filling or drilling spoil?). Portion at 37.5–40 ft (may correspond to a scallop).

40–50 ft moisture not apparent through plastic; smudges from 40 to 48 ft, especially strong 41–42 ft.

50–60 ft moisture not apparent; smudging at 55–59.5 ft (55–57 may represent scallop position)

60–70 ft plastic sleeve torn 66–68; possible moisture loss. Slight smudging 61–63 ft, darker 61–62 ft.

70–80 ft moisture increasing; dark smudges with red staining related to color-reactive liner installed previously 76.5–80 ft (probable scallop location).

80–90 ft moisture apparent, especially in areas of red staining; red staining and fine rock debris 81-83.5 ft and 84.5–86.5 ft (scallops). Membrane relatively clean 88–90 ft.

90–100 ft fairly wet; red staining 94.5–96, yellow staining 95.5–97.5, up to 1-mm, circular biological growths 95.5–97.5 and much dirt 97.5–100 (staining and dirt associated with scallops)

100–110 ft variable moisture throughout; wetter 102–104 ft. Smudged 100–104 ft and 108–110 ft; red and yellow staining 106.5–107.5 and 108.5–110 ft.

110–120 ft slight moisture at bottom; dirt smudged throughout, trace of red and yellow staining and biological growths as above. Possible scallop position 117.5–120 ft.

120–130 ft more moisture, especially 121–122 ft and damp 129–130 ft.; biological growths as above 120-125 ft. Trace of red and yellow staining 125–128 ft.

130–138 ft (end of membrane) – damp 130–131 (scallop outline apparent), slight moisture 136–138 ft, plastic sleeve torn in 132–133 ft interval (possible moisture loss); smudged along most of length with yellow staining.

Appendix C

Bromide Data for the Unsaturated Zone in LAWS-02, July 02

Bromide Data for the Unsaturated Zone in LAWS-02, July 02

Distance along borehole (ft)	Porewater Br concentration (mg/kg)	Sample moisture content (g)
3.00	0.00	2.90
18.00	0.00	6.00
25.00	0.00	8.70
39.00	0.00	7.90
41.00	0.00	10.10
55.00	0.00	7.60
61.00	0.00	10.80
79.00	0.00	25.30
81.00	0.00	25.20
85.00	0.00	32.50
97.00	0.00	64.00
99.00	1.79	100.10
103.00	1.93	87.30
104.00	1.69	85.60
110.00	1.39	180.60
116.00	0.82	100.40
119.00	1.17	133.20
122.00	0.88	114.50
124.00	0.82	119.10
129.00	1.24	126.50
132.00	1.08	124.00
136.00	0.82	93.70
138.00	0.77	173.00

Appendix D

*Bromide Data for the Saturated Zone in LAWS-01**

*Bromide Data for the Saturated Zone in LAWS-01**

Date	Port 1 88 ft deep	Port 2 163 ft deep	Port 3 193 ft deep	Port 4 268 ft deep
5/22/2002		3.97	3.10	2.15
7/1/2002		9.76	3.20	1.90
7/5/2002		9.15	8.90	2.76
7/12/2002	2.00	7.84	5.29	2.18
7/22/2002		9.50	3.75	2.07
7/26/2002		1.57	1.82	1.64
8/2/2002		1.82	2.08	1.62
8/12/2002		2.15	2.42	1.59
8/16/2002		3.36	2.68	2.10
8/26/2002		1.68	1.94	1.92
9/3/2002		2.18	3.21	1.98
9/13/2002		6.37	5.78	5.11
9/20/2002	12.66	10.60	10.42	2.78
9/30/2002	12.62	10.17	10.52	3.16
10/10/2002	15.23	11.86	11.74	3.63
10/17/2002	17.16	13.55	14.82	4.51
10/24/2002	17.58	16.14	15.44	4.24
11/1/2002	20.93	11.39	9.27	4.87
11/8/2002	21.81	11.62	10.24	5.15
11/15/2002	16.64	12.32	10.67	7.50
11/22/2002	18.82	13.98	8.66	7.35
11/29/2002	10.49	11.31	9.21	3.50
12/5/2002	11.54	10.67	9.37	3.53
12/19/2002	12.11	10.17	10.07	3.50
1/10/2003	9.83	9.56	10.35	3.45
1/17/2003	10.60	8.63	9.21	3.32
2/14/2003	10.49	9.24	9.15	2.98
3/7/2003	11.12	9.02	5.99	3.14
3/14/2003	10.60		4.65	3.43
3/24/2003	10.17		4.51	3.45
4/4/2003			4.32	3.46
4/25/2003			3.90	3.46
5/9/2003			4.41	3.49
6/6/2003	11.27	13.82	3.81	2.98
6/17/2003	10.72	12.11	10.72	2.79
6/27/2003	10.72	13.19	10.76	2.92
7/3/2003	12.33	11.03	11.15	2.18
7/18/2003	10.38	9.50	9.07	2.44
8/1/2003	9.81	9.63	9.46	2.18
8/8/2003	9.13	8.91	8.17	2.02
8/15/2003	10.61	10.16	9.77	2.38
8/22/2003	7.74	7.30	6.12	1.49
8/29/2003	7.19	5.26	5.69	1.33
9/5/2003	5.58	4.49	4.82	1.41
9/23/2003	5.38	3.65	5.32	1.23

* Concentrations of bromide tracer are in ppm; blank spaces indicate no bromide detected in water sample.

Appendix E

*Iodide Data for the Saturated Zone in LAWS-01**

*Iodide Data for the Saturated Zone in LAWS-01**

Date	Port 1 88 ft deep	Port 2 163 ft deep	Port 3 193 ft deep	Port 4 268 ft deep
1/10/2003				
1/17/2003				
2/14/2003				
3/7/2003				
3/14/2003				
3/24/2003	0.02907		0.01165	0.00728
4/4/2003				
4/25/2003	—			
5/9/2003	—			
6/6/2003	0.06095	0.05103	0.01830	0.01321
6/17/2003	0.05983	0.07526	0.04194	0.01487
6/27/2003	0.05394	0.04600	0.03524	0.02621
7/3/2003	0.03894	0.03236	0.03028	0.00733
7/18/2003	0.06140	0.04178	0.03119	0.00699
8/1/2003	0.03909	0.03130	0.02750	0.00689
8/8/2003	0.06163	0.04634	0.03670	0.00990
8/15/2003	0.03073	0.02864	0.02611	0.00671
8/22/2003	0.42430	0.04315	0.03995	0.01366
8/29/2003	0.20179	0.03571	0.03967	0.01135
9/5/2003	0.22813	0.03214	0.04181	0.01119
9/23/2003	0.19280	0.03672	0.04913	0.03158

* Concentrations of iodide tracer are in ppm; blank spaces indicate no iodide detected in water sample.

Los Alamos
NATIONAL LABORATORY

Los Alamos NM 87545

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