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DATA REPORT: IN-SITU PERMEABILITY AND OPEN BOREHOLE ANEMOMETRY MEASUREMENTS IN BOREHOLES 54-1017 AND 54-1018, LOS ALAMOS TA-54

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DATA REPORT: IN-SITU PERMEABILITY AND OPEN BOREHOLE ANEMOMETRY MEASUREMENTS IN BOREHOLES 54-1017 AND 54-1018, LOS ALAMOS TA-54

I. INTRODUCTION

The intent of these measurements is to characterize, on both the large and small scale, the airflow nature of the geologic media. The tests include open borehole anemometry and discrete in-situ straddle packer gas permeability measurements in boreholes 54-1017 and 54-1018. These holes, located in the TA-54 Area G expansion area, were drilled with hollow stem augers in the spring of 1995 in preparation for the Pilot Vapor Extraction Test. Borehole 54-1017, with a total depth of 150 ft., was cased to 75-ft. depth, and served as the vacuum extraction borehole (open interval from 75 to 150 ft.) for the pilot test. Borehole 54-1018, 20 ft. away from 54-1017, served as a monitoring well for the test, and was cased to 10-ft. depth (see Figure 1). The total depth for 54-1018 was 318 ft. After these tests were completed, a SEAMIST™ soil gas sampling membrane was deployed in 54-1018 to monitor the extraction test.

The following sections describe the methods used to field the measurements and reduce the data. Measurement results for boreholes 54-1017 and 54-1018 are provided in Section III.

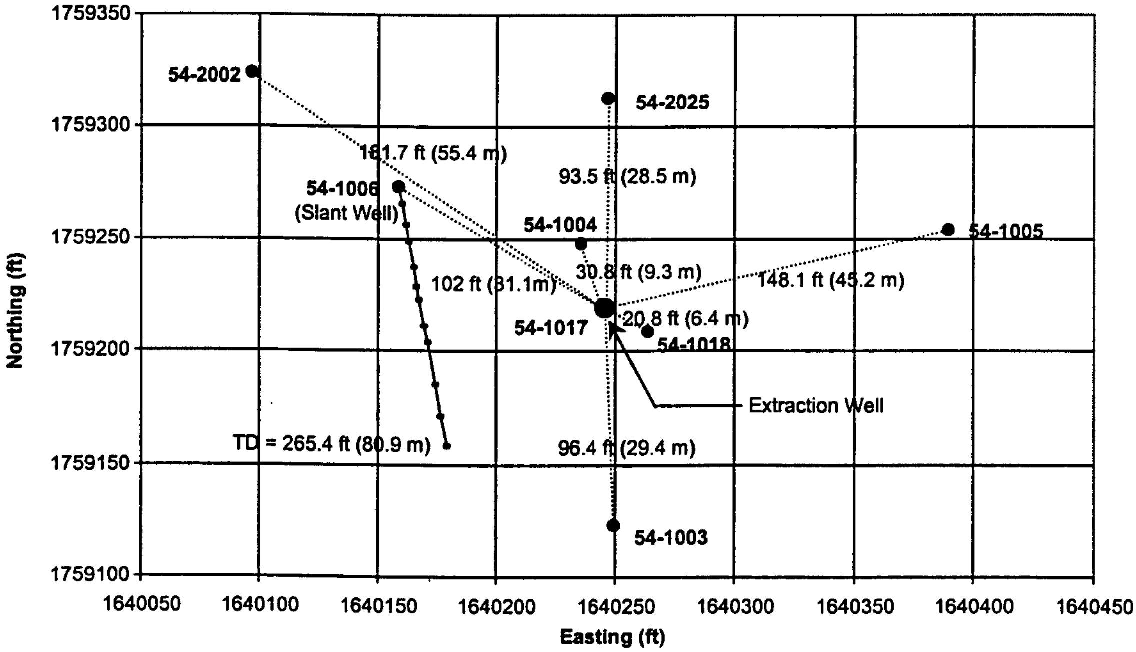

Figure 1. Location of 54-1017 and 54-1018 in relation to other wells in TA-54, Area G.

II. METHODOLOGY

A. Open Borehole Anemometry

Open borehole anemometry measures air production zones in the borehole under either air injection or vacuum extraction conditions. To conduct the anemometry measurements, a blower is configured at the top of the well to apply approximately 6-inch water column (15 mbar) vacuum on the well. The well vacuum is measured with a digital transducer. The blower is allowed to operate for 20 to 30 minutes before logging to allow the borehole flow to stabilize (it initially is high, then drops to a quasi steady condition). During the measurement, a velocity probe is lowered in the well (located within 2 inches of the borehole center) and stopped at discrete locations to collect velocity data. The physical configuration is indicated in Figure 2. The velocity sensor is a TSI hot film anemometry device with a measurement range of 10 ft/min. to 1000 ft/min standard velocity. Its stated accuracy is ±1.5 percent of the reading plus 0.5 percent of its full scale indication. At 10 ft/m this yields an uncertainty of ±5.15 ft/m, and at 100 ft/m the uncertainty is ±6.5 ft/min.

Data is acquired and stored with a Campbell Scientific 21X datalogger located above ground. At each measurement location, the datalogger collects 10 samples (taken once per second), averages them and performs standard deviation calculations. That data is then recorded and stored. The anemometer is moved to the next location and the sequence repeated. Typically, measurements are conducted every 20 feet or more as the anemometer is lowered in the hole; on the way out of the borehole, data is taken every 5 feet. Data at 5-foot spacing (during retrieval) is reported.

B. Straddle Packer Permeability Measurements

Straddle packer permeability measurements have historically been performed to conduct air and water permeability measurements in porous media. For this application, a steady state spherical flow model is used. If the air injection (or extraction) source can be approximated as a sphere, then the steady state air flow into the source, the source equivalent radius, the source pressure, and the ambient soil gas pressure can be used to infer the effective gas permeability k (References 1 and 2):

$$k = \frac{\mu R T \dot{m}}{2\pi M\left(P_0^2 - P^2\right)} \bullet \left(\frac{1}{r_0}\right)$$

where:

μ	=	dynamic gas viscosity
R	=	universal gas constant
T	=	absolute temperature
$\dot{m}$	=	gas mass flow into soil
M	=	gas molecular weight
P_0	=	absolute pressure of source
P	=	ambient absolute soil gas pressure
r_0	=	source radius

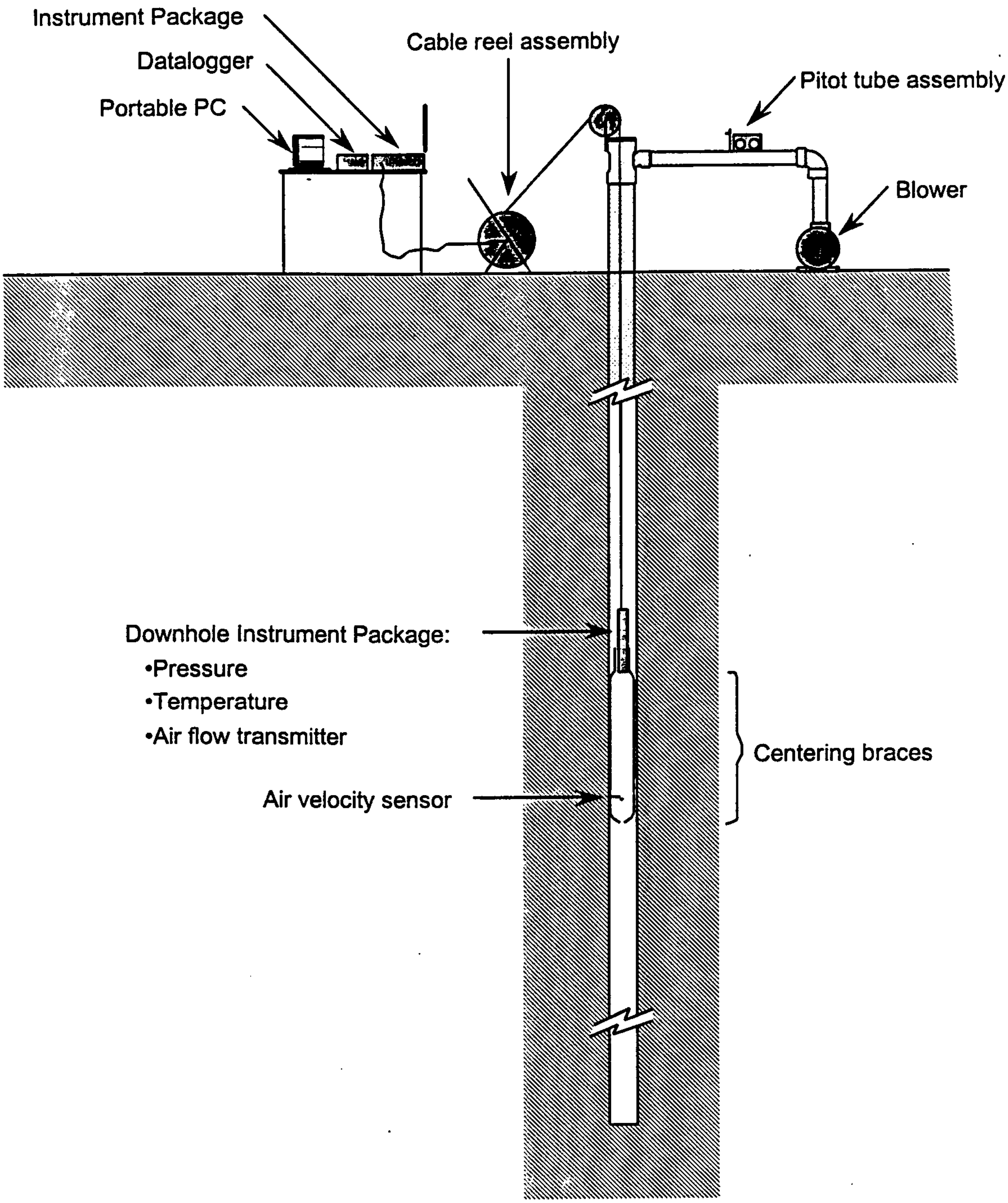

Figure 2. Los Alamos borehole anemometry system.

This model is applied in straddle packer measurements by setting r_o to be the radius of the sphere whose surface area is equal to the area of the exposed borehole wall between the packers (Figure 3).

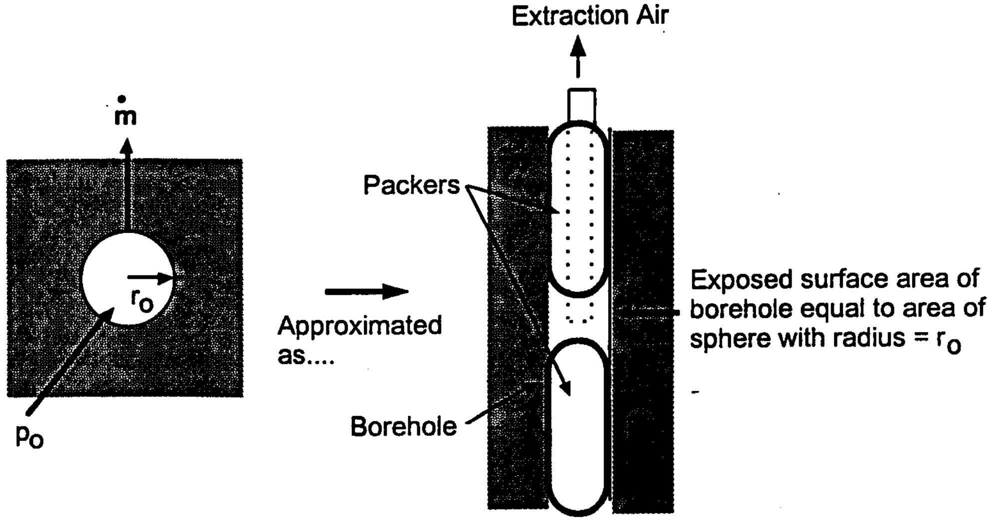

Figure 3. Approximation of a spherical air flow geometry with a conventional straddle packer design for in-situ soil gas permeability measurements.

The packer system is depicted in Figure 4. Packers are located above and below the extraction zone, separated by 27 inches. This separation is selected to increase the possibility of intersecting fractures in the extraction zone. The packers are each 6 feet in length, fabricated of a lightweight packer material and operated at 5 to 6 psi internal pressure during the extraction measurements. The primary instrumentation used in these measurements is the absolute pressure in the extraction zone, the temperature of the air being extracted, and air-flow rate during the extraction. All of the sensors are located in an electronics package situated above the packer system with the data transmitted uphole to a Campbell Scientific 21X datalogger for averaging and recording above ground.

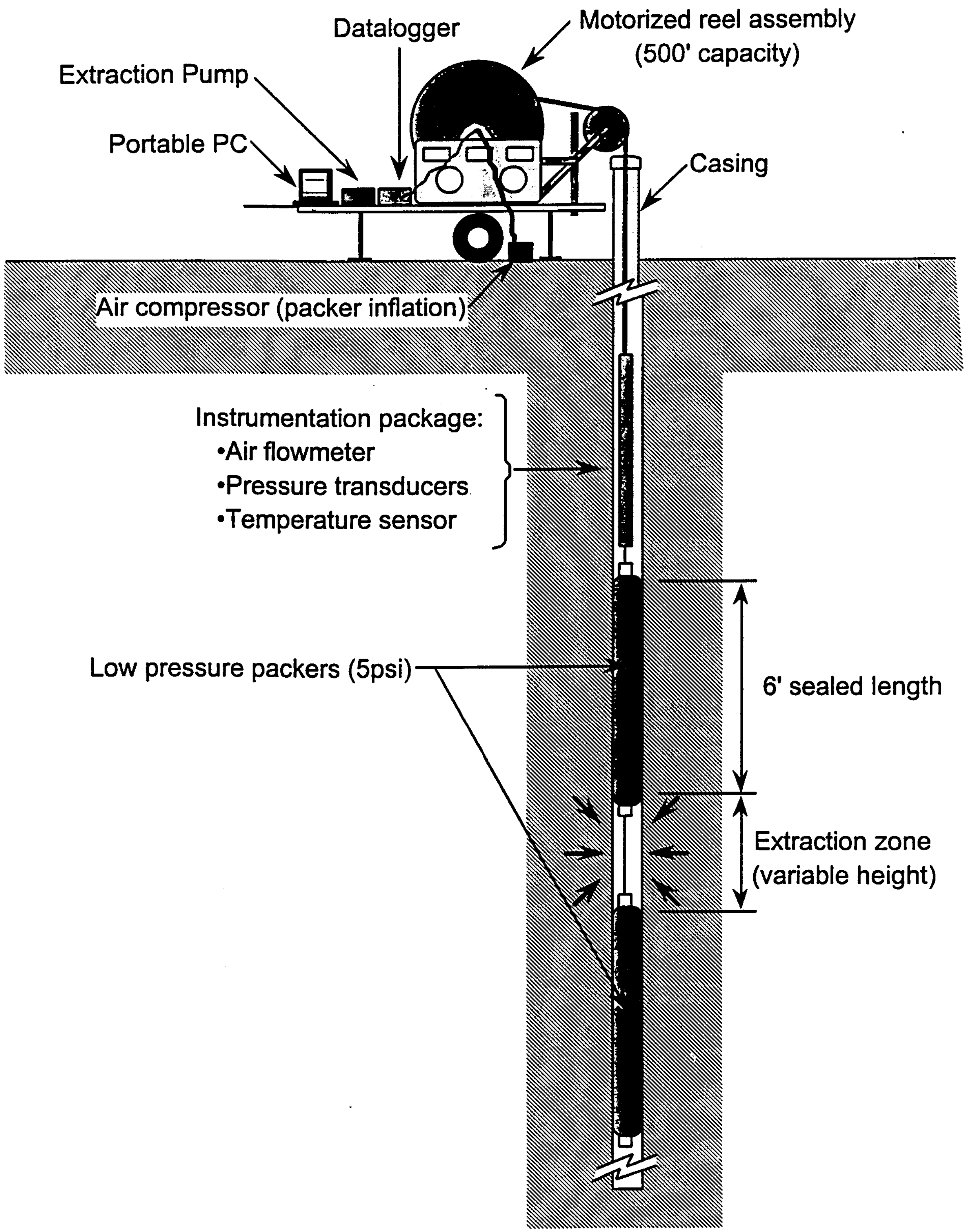

Figure 4. Los Alamos air permeability measurement system.

A typical record of one of these measurements is shown in Figure 5, for the 305.7-ft. measurement in borehole 54-1018. In that figure are plotted the packer pressure, extraction vacuum, flowrate, and resulting permeability. The instrument uncertainty in this measurement is dominated by the mass flow measurement. This is accomplished with an orifice plate flow meter. Flow calibrations are periodically checked using a Dwyer variable area flowmeter. Given the accuracy of the Dwyer meter (±2 percent) we expect the mass flow determination to be within ±5 percent. This translates to an equivalent instrument uncertainty in the permeability determination of ±5 percent.

Permeability is expressed in Darcies. The following conversions apply:

1 Darcies	=	9.87×10^{-13} m^2
	=	9.87×10^{-9} cm^2

At standard temperature and pressure conditions, 1 Darcy is equivalent to a saturated hydraulic conductivity of 9.5×10^{-4} cm/sec.

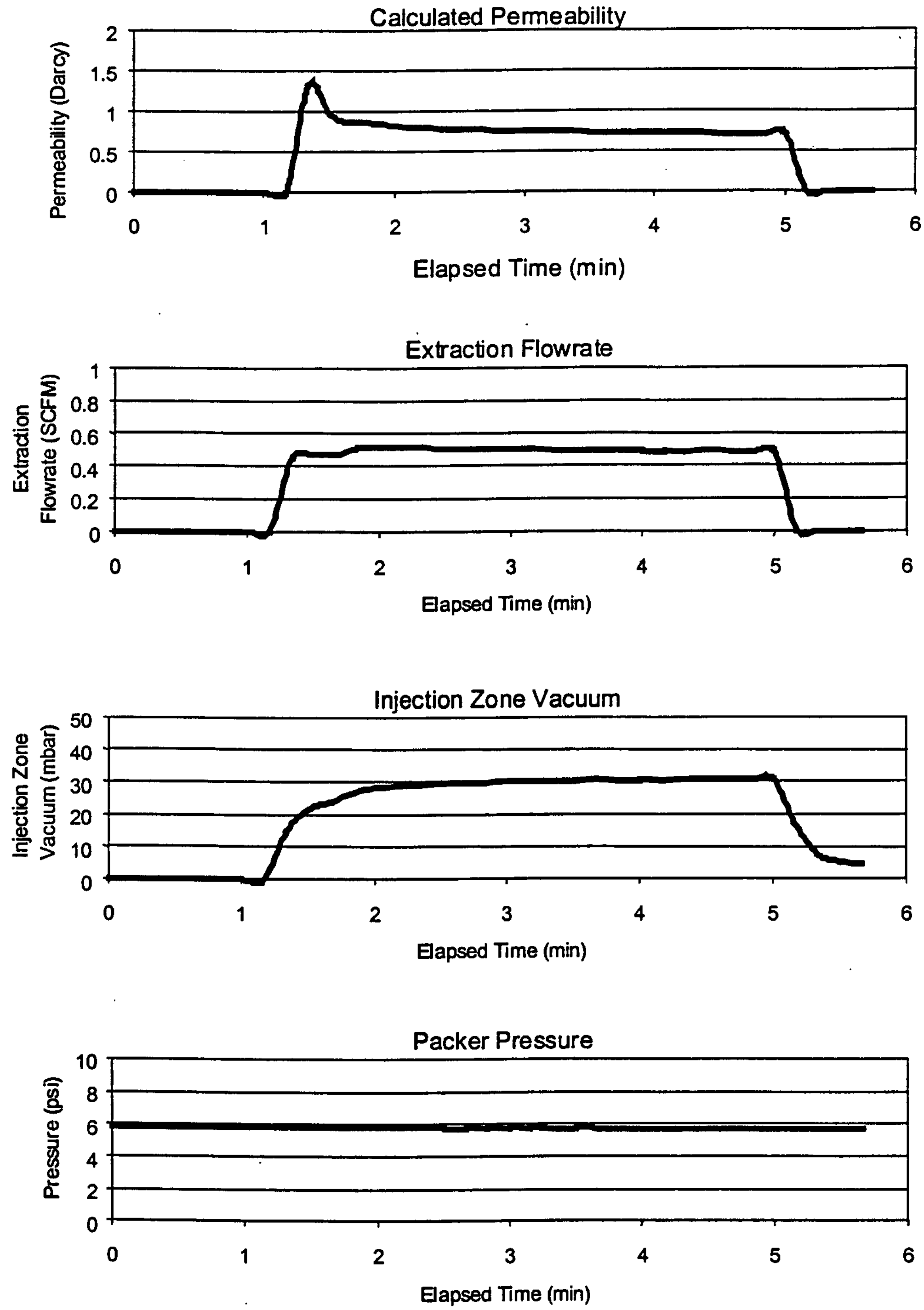

Figure 5. Extraction vacuum, extraction flowrate, calculated permeability, and packer pressure for 54-1018, 305.7-ft. depth.

III. Measurement Results

Both boreholes were drilled in the spring of 1995. Anemometry tests were first conducted in each hole, and that information was combined with the known lithology to specify the locations for discrete straddle packer tests. Caliper logs were not run in these holes, so borehole diameters were assumed.

Anemometry measurements in 54-1018 identified a clear high production zone in the 250-300 ft. depth interval, and moderate production for the balance of the borehole. The anemometry data in Figure 6 is represented as the fraction of total borehole flow (directly proportional to velocity), which is the ratio of the velocity at each discrete location to the velocity of air leaving the surface. It is notable that in the 250 to 300-ft. interval, 75% of the total air flow produced at the wellhead has entered the well, with the balance produced in the remaining distance to the surface. Comparison with the subsequent permeability measurements (see Figure 6) confirmed the presence of a high permeability zone in that region (almost 10 Darcies, compared to the 0.4 to 0.5 Darcies in the upper regions of the borehole).

The anemometry measurements in 54-1017 (Figure 7) showed generally increasing production in the open interval. The production is not so dramatic due to resolution issues with the sensor and the low flow of the well. The total flow out of the well was low resulting in relatively low air velocities (this was due to the overall low permeability of the tuff in the extraction zone). Over the interval of the surface casing (0 to 75 ft.) the air velocity dropped to a low constant value, below the lower measurement range of the velocity sensor. The casing was of a greater diameter than the open borehole below to allow drilling, and the expansion of the flowing air into the larger area of the cased interval resulted in a lower velocity measured in the cased section. Since the flow sensor cannot reliably measure below 10 ft./min, the air velocity need only drop to a third of its value at 85 ft. (15 ft./min at 85 ft.) to fall below the measurement range of the sensor. If the borehole were 8 in. in diameter and the casing 10 inches in diameter, for example, the velocity would drop by 36% due to expansion into the larger pipe. The permeability measurements for 54-1017 are also shown in Figure 7.

The permeability measurements in 54-1017 and 54-1018 are compared in Figure 8, showing extremely good agreement at corresponding depths of the two boreholes. Below the colonade unit (unit lv(c)) at approximately the 125-ft. depth the permeability in both boreholes drops significantly.

Tabular permeability data is listed in the tables following Figure 8.

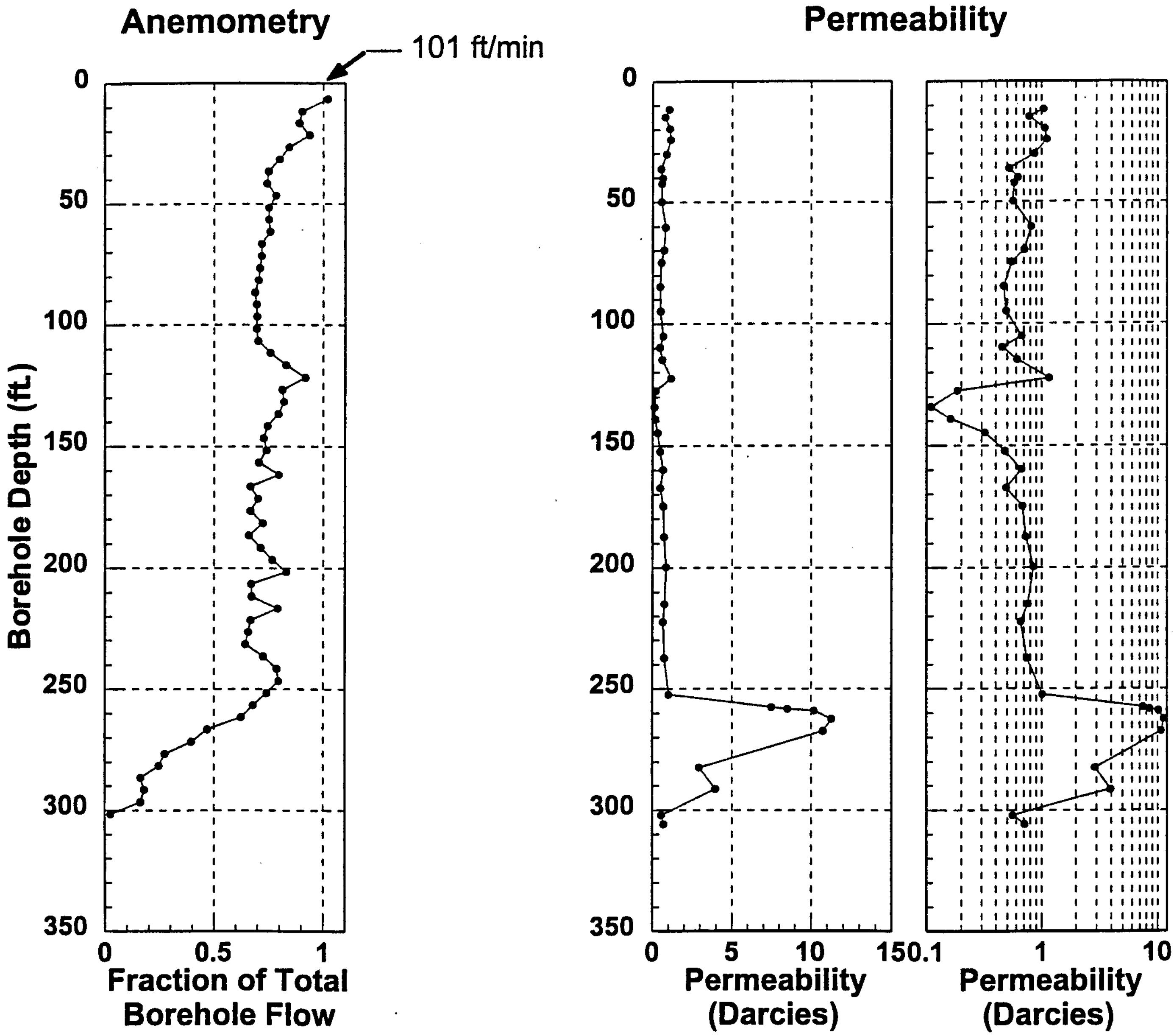

Figure 6. Open borehole anemometry and straddle packers permeability results for borehole 54-1018. Permeability is depicted on both linear and log scales.

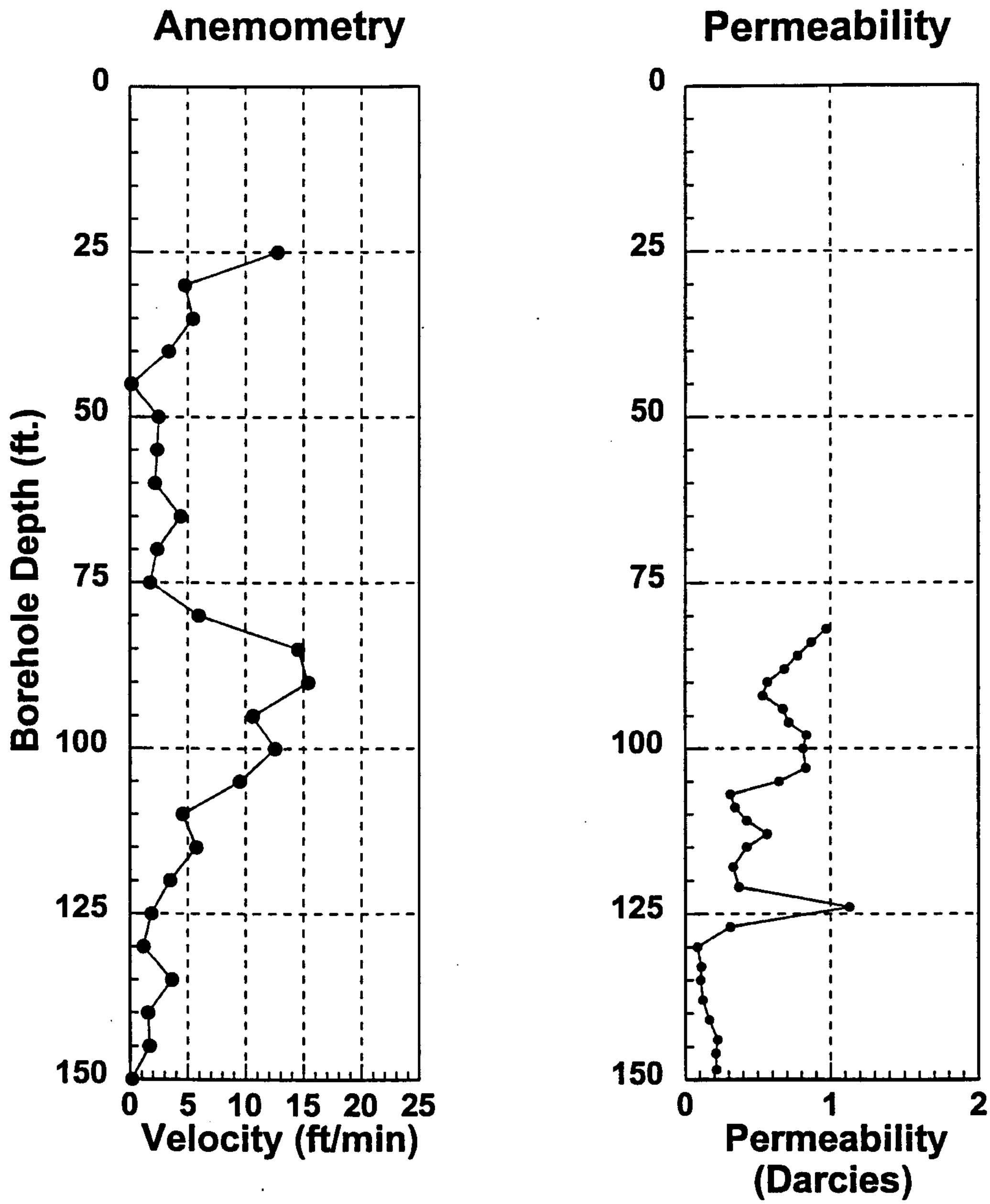

Figure 7. Open borehole anemometry and straddle packer permeability results for borehole 54-1017. The borehole is cased from 0 to 75 ft. depth.

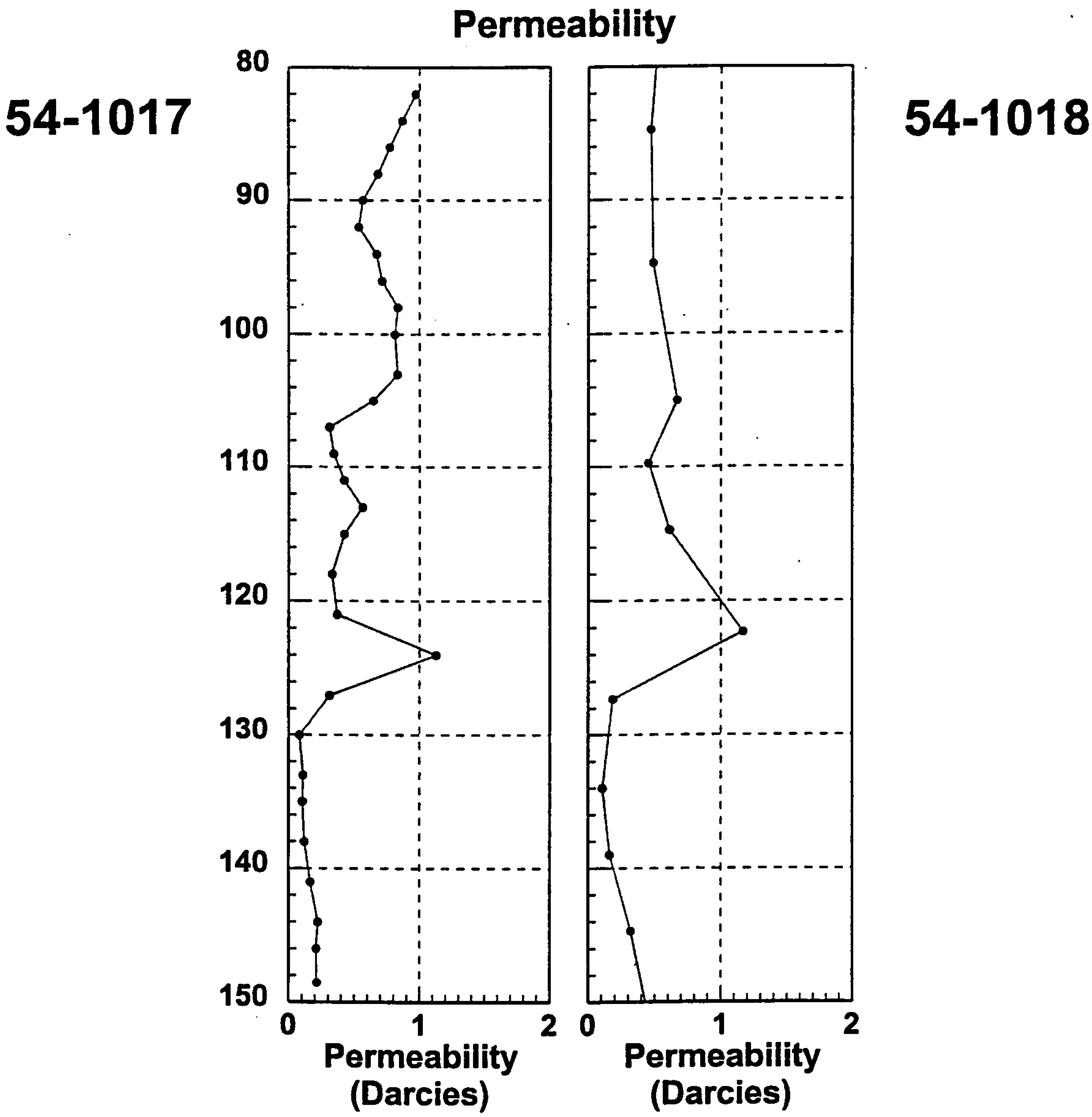

Figure 8. Comparison of straddle packer permeability measurements in 54-1017 and 54-1018.

In-situ Soil Gas Permeability Data

Borehole 54-1017 (assumed diameter 9 in.)

Date	Time	Depth (ft.)	Hole Dia. (in.)	Extraction Zone Ht. (in.)	Packer Press. (psig)	Ambient DH Press. (mbar)	Extraction DP (mbar)	Extr. Air Temp. (C)	Air Flow (scfm)	Permeability (Darcies)
6/7/95	857	148.5	9	27	5.84	797.62	94.43	11.8	0.440	0.216
6/7/95	909	146	9	27	5.73	796.95	94.35	12.1	0.429	0.211
6/7/95	921	144	9	27	5.64	796.88	99.83	12.5	0.479	0.224
6/7/95	932	141	9	27	5.51	797.57	115.93	12.7	0.411	0.167
6/7/95	944	138	9	27	5.64	798.52	149.32	13.1	0.377	0.122
6/7/95	955	135	9	27	5.73	797.12	142.64	13.3	0.321	0.108
6/7/95	1007	133	9	27	5.74	796.34	146.90	13.6	0.340	0.112
6/7/95	1032	130	9	27	5.80	796.46	169.01	14.0	0.294	0.086
6/7/95	1043	127	9	27	5.45	792.90	104.94	13.8	0.692	0.312
6/7/95	1054	124	9	27	5.60	792.61	30.83	13.7	0.774	1.132
6/7/95	1105	121	9	27	5.71	792.77	82.64	13.8	0.660	0.372
6/7/95	1116	118	9	27	5.51	792.58	95.97	13.8	0.676	0.332
6/7/95	1128	115	9	27	5.71	792.45	78.27	13.9	0.717	0.426
6/7/95	1139	113	9	27	5.86	792.47	59.23	13.8	0.734	0.569
6/7/95	1150	111	9	27	5.57	792.45	63.40	14.0	0.583	0.424
6/7/95	1235	109	9	27	5.44	792.71	69.31	13.6	0.518	0.345
6/7/95	1300	107	9	27	5.46	792.69	78.55	13.7	0.529	0.313
6/7/95	1311	105	9	27	5.43	773.34	45.35	13.8	0.629	0.647
6/7/95	1322	103	9	27	5.50	791.79	30.37	13.8	0.560	0.832
6/7/95	1335	100	9	27	5.56	792.14	39.89	13.8	0.714	0.812
6/7/95	1347	98	9	27	5.33	791.89	32.04	13.9	0.592	0.835
6/7/95	1359	96	9	27	5.88	791.65	45.17	13.9	0.708	0.715
6/7/95	1415	94	9	27	5.74	791.74	45.41	14.0	0.671	0.673
6/7/95	1436	92	9	27	5.62	791.59	58.17	13.9	0.679	0.537
6/7/95	1447	90	9	27	5.92	791.15	50.45	13.9	0.625	0.567
6/7/95	1459	88	9	27	6.06	790.95	44.25	13.9	0.663	0.683
6/7/95	1509	86	9	27	5.91	790.82	40.31	13.8	0.686	0.774
6/7/95	1521	84	9	27	5.89	790.99	37.44	13.9	0.718	0.870
6/7/95	1532	82	9	27	5.58	790.92	35.60	13.8	0.763	0.972

In-situ Soil Gas Permeability Data

Borehole 54-1018 (assumed diameter 9 in.)

Date	Time	Depth (ft.)	Hole Dia. (in.)	Extraction Zone Ht. (in.)	Packer Press. (psig)	Ambient DH Press. (mbar)	Extraction DP (mbar)	Extr. Air Temp. (C)	Air Flow (scfm)	Permeability (Darcies)
5/30/95	1034	305.7	9	27	5.73	805.44	30.44	13.8	0.486	0.709
5/30/95	1046	302.0	9	27	5.66	804.60	42.44	13.8	0.531	0.560.
5/30/95	1058	291.3	9	27	5.66	803.04	6.22	14.3	0.562	3.964
5/30/95	1111	282.3	9	27	5.45	802.79	10.24	14.7	0.681	2.930
5/30/95	1123	267.3	9	27	5.47	802.26	2.95	14.8	0.718	10.671
5/30/95	1134	262.3	9	27	5.45	802.09	2.36	14.9	0.606	11.270
5/30/95	1145	259.0	9	27	5.51	801.84	2.72	15.1	0.630	10.197
5/30/95	1157	258.3	9	27	5.49	801.74	2.87	15.2	0.557	8.544
5/30/95	1208	257.5	9	27	5.57	801.69	3.46	15.2	0.591	7.517
5/30/95	1310	252.3	9	27	5.23	802.89	24.64	15.1	0.565	1.021
5/30/95	1321	237.3	9	27	5.15	803.00	31.55	14.9	0.586	0.660
5/30/95	1332	222.3	9	27	5.44	803.61	38.60	15.0	0.567	0.659
5/30/95	1343	214.7	9	27	5.37	803.09	39.48	14.9	0.671	0.764
5/30/95	1354	199.7	9	27	5.31	802.94	28.75	15.2	0.546	0.847
5/30/95	1408	187.3	9	27	5.17	803.61	31.47	15.1	0.512	0.727
5/30/95	1419	174.7	9	27	5.30	802.99	37.12	14.8	0.562	0.679
5/30/95	1430	167.3	9	27	5.21	803.71	45.54	14.8	0.492	0.487
6/1/95	1021	159.7	9	27	5.38	801.38	43.82	28.3	0.618	0.666
6/1/95	1033	152.3	9	27	5.49	800.93	48.21	25.5	0.493	0.480
6/1/95	1044	144.7	9	27	5.51	800.81	70.54	23.2	0.480	0.322
6/1/95	1056	139.0	9	27	5.42	803.98	115.92	21.4	0.392	0.163
6/1/95	1108	134.0	9	27	5.55	804.33	151.83	20.0	0.338	0.109
6/1/95	1119	127.3	9	27	5.49	800.15	145.80	18.7	0.550	0.185
6/1/95	1130	122.3	9	27	5.58	799.24	22.52	17.7	0.584	1.169
6/1/95	1141	114.7	9	27	5.56	799.31	51.81	17.0	0.693	0.613
6/1/95	1154	109.7	9	27	5.67	800.59	60.43	16.3	0.598	0.454
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6/1/95	1504	14.7	9	27	5.73	795.95	32.75	12.9	0.572	0.782
6/1/95	1517	11.5	9	27	5.66	795.65	30.20	13.1	0.706	1.047

IV. REFERENCES

1. Keller, C.; D. D. Engstrom; and F. West. "In-Situ Permeability Measurements for the Event in U1-C." Los Alamos Report LANL-5425-MS. Science and Engineering Associates, 1973.

2. Lowry, B., and S. Narbutovskih "High Resolution Gas Permeability Measurements with the SEAMIST™ System" In Proceedings of the 5th National Outdoor Action Conference in Aquifer Restoration, Ground Water Monitoring, and Geophysical Methods. Las Vegas, NV, May 1991.