GW - 31

REPORTS

YEAR(S):

1974 - 1984

Union Geothermal Company of New Mexico

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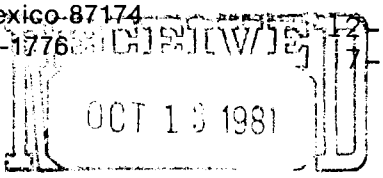
12-600.1
7-740



OIL CONSERVATION DIVISION
SANTA FE

October 9, 1981

Carl Ulvog
State of New Mexico
Oil Conservation Division
P.O. Box 2088
Santa Fe, New Mexico 87501

Dear Mr. Ulvog:

Enclosed please find a copy of the Baca Geothermal Demonstration Project Jemez Watershed Monitoring Program for water year 1979-1980. Chapter 2 contains a description of equipment in the Redondo Creek monitoring station.

Since the publication of the report, one additional ISCO unit has been installed to collect a 100 ml sample from Redondo Creek every eight hours. The ISCO set to collect only during increased flow has been set to collect with an increase of 0.1 cfs. Water year 1980-1981 did not experience the variability of flow related to the spring runoff that 1979-1980 experienced.

Recording pH and conductivity meters are presently being reviewed and a meter to backup the Anlaytical Measurements meter will be purchased to decrease downtime.

I hope the report will be useful to you.

Sincerely,

Lyle Rae Berger
Ecologist

LRB/dp
Enclosure

BACA GEOTHERMAL DEMONSTRATION PROJECT

JEMEZ WATERSHED MONITORING PROGRAM

WATER YEAR 1979-1980

L. R. BERGER

JANUARY, 1981

JEMEZ WATERSHED MONITORING PROGRAM

WATER YEAR 1979-1980

The Jemez River watershed monitoring program was designed to make monthly checks on water from seven sites located either upstream or downstream from Redondo Creek and the Baca Project. Location of the seven sites is designated by number on the map in Figure 1.

Monitoring was begun August 24, 1979 and has been conducted monthly since then.

SAMPLING PROCEDURE:

At each sample site, water temperature and pH are measured using a Beckman Chem-Mate pH Meter with a futura combination field electrode. Temperature is checked with a hand held thermometer. Conductivity is measured using a YSI field conductivity meter. Flow rate is calculated by measuring the time it takes a plastic cup filled with water to pass through a measured volume of stream. A sample of water is collected for transmittal to a local analytical laboratory.

Field data plus pertinent weather and activity information are logged at each site. Figure 2 is a sample log sheet.

Initially, raw water was collected, held at $4^{o}C$ and taken to a laboratory for analysis within six hours. All seven sites were visited in one day.

In February of 1980 a routine check on the laboratory used at the time resulted in the project changing laboratories. The "new" laboratory requested samples be filtered. All water was filtered from May 13 until July 23, 1980 because project policy requires a laboratory receive samples in the condition it requested. Filtering samples increased collection time from one day to two to four days. Since fewer samples were submitted each day, the laboratory was not providing a discount promised for seven samples. The result was a 10% cost increase for analysis and one to three additional days pay for technician services for less useful water quality data.

The problems of increased time elapsed between site collections and increased cost were discussed with the laboratory. It was agreed that raw water from such a source as the Jemez watershed would be acceptable. From August 1980, all water has been collected without filtering. The water has always been held at $4^{o}C$ and transported within six hours of collection.

DATA COLLECTION HISTORY:

Initially, water was collected by supervisory personnel. A field technician was hired to collect watershed samples in conjunction with maintaining Redondo Creek monitoring station in December 1979. Scheduling problems arose from only one person being available which resulted in no water collection for April 1980.

One additional person has been trained to collect samples so that scheduling problems should not occur again. Additionally, backup technical help allows two people to make collections in winter months and during periods of runoff when wading some streams is hazardous.

Two sites, east fork of the Jemez River (7) and Sulfur Creek at Union Gate (2) could not be sampled some winter months because they freeze over.

Flow data could not be collected for any stream some winter months because of ice buildup in the stream course.

Most data collection problems are technician related and involve the Beckman pH meter probe.

COLLECTION PROCEDURE:

A. Collection of a Grab Sample

1. A container, usually of a plastic, is rinsed several times in the water to be sampled and the rinse water is discarded downstream.

2. The rinsed container is then submerged, if possible, into the stream flow and a volume of water is collected.

3. The full container is lifted quickly from the stream and the water is poured carefully into clean bottles supplied by the laboratory.

4. If the sample requires no acidification or other preparation, the cap to the bottle is filled with sample water then carefully sealed to the bottle.

5. If the sample requires acidification, careful measurement of the volume of acid is required. This measurement will be used to calibrate the actual volume of water left in the sample. When the sample has been appropriately treated, the bottle cap is rinsed and sealed to the bottle.

COLLECTION PROCEDURE (Cont'd)

6. The bottle should have the following information placed on its surface:

    a. sample site
    b. date and time of day
    c. sample temperature (taken in stream)
    d. sample pH (taken in stream or bottle)
        1. If sample was acidified, "natural" pH should be distinguished from acidified and both should be indicated.
    e. flow rate at sample site
    f. conductivity at sample site

7. All samples should be kept cool ($4^{o}C$) and out of the sun.

8. Samples should be collected at same site each sample period.

B. Collection of Field Temperature

1. Place a field thermometer well into the stream for several minutes.

2. Read thermometer directly.

3. Replace thermometer into stream for several more minutes.

4. Read thermometer again.

C. Collection of Field pH

1. Calibrate pH meter.

2. Rinse electrodes with stream water.

3. Insert electrodes well into stream for several seconds.

4. Read pH.

5. Rinse electrodes with stream water.

6. Reinsert into stream several seconds.

7. Read pH.

8. Rinse electrodes well with distilled water.

COLLECTION PROCEDURE (Cont'd)

D. Collection of Field Conductance

1. Same procedure as field pH using conductivity meter.

E. Collection of Flow Rate

1. Select a fairly uniform site.

2. With a tape measure average width of stream.

3. Measure average depth of stream.

4. Measure a given distance on stream bank -- example, 3 feet between point A and B.

5. Drop a floatable object at point A and measure time it takes object to reach point B with a stop watch.

6. Repeat several times.

7. Calculate volume of water measured.

8. Calculate CFS using average time for water to move from A to B and volume of water between points A and B.

F. Collection of Small Flow Rate - Springs

1. If flow is small enough, collect all water flowing in a large container whose volume is known.

2. Measure time to fill the container using a stop watch.

3. Repeat several times.

4. Calculate CFS using volume and average time needed to fill the volume.

BACA SURFACE WATER MONITORING PROGRAM

SAMPLING SITES

JEMEZ WATER SHED

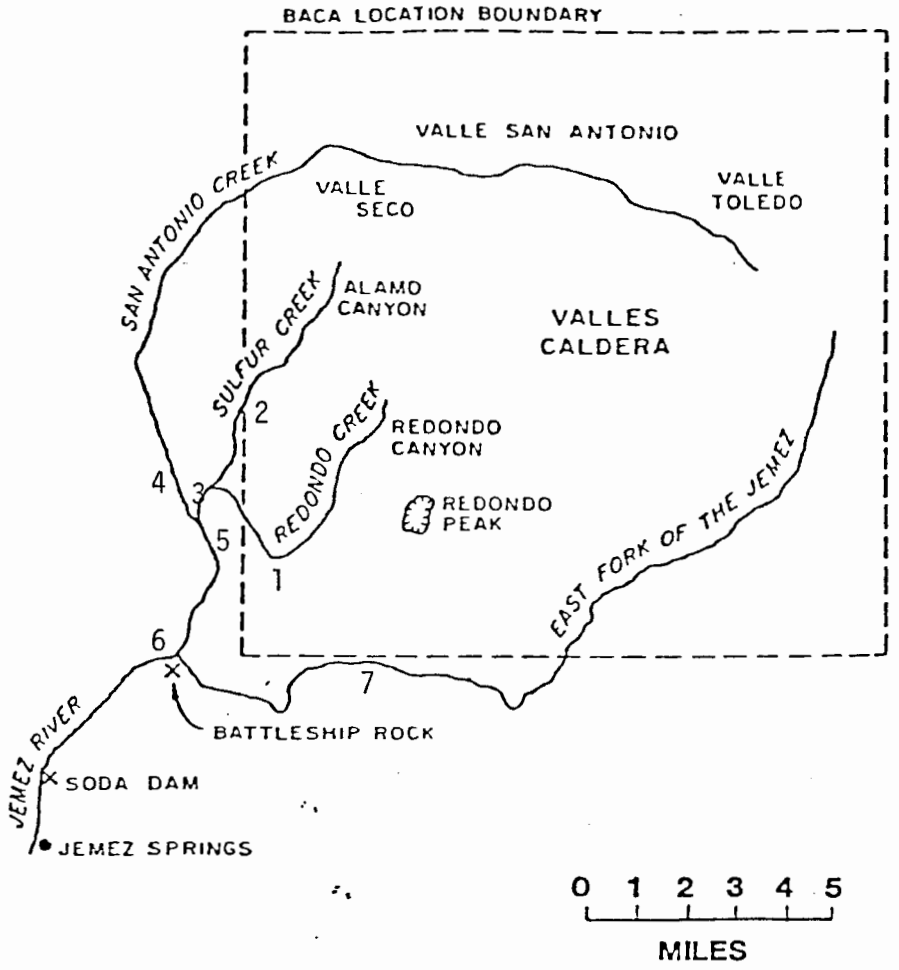


FIGURE 1

FIGURE 2:
IRFACE WATER QUALITY SUMMARY SHEETS
LACA PROJECT, JEMEZ WATERSHED

SITE_____

FIELD DATA		COMMENTS
ate: Time: ater Temp: pH: mos/cm cfs		Weather Conditions: Comments: Comments on Equipment:

ITE_____

IELD DATA		COMMENTS
Date: ime: Water Temp: H: uhmos/cm fs		Weather Conditions: Comments: Comments on Equipment:

ITE_____

IELD DATA		COMMENTS
ate: Time: ater Temp: pH: uhmos/cm fs		Weather Conditions: Comments: Comments on Equipment:

Tables 1-7 outline chemical constituents measured in water samples and values of those constituents for each monitoring site. Monthly water quality data sheets are received from the laboratory by Union and copies are submitted to WESTEC and PNM.

Redondo Creek water quality data (Table 1) shows a marked difference from other collection periods November 1979 and August 1980. There is a marked rise in field conductivity; boron levels, sodium, calcium, chloride, sulfate and magnesium ions and a decrease in bicarbonate ions and pH in November 1979.

August 1980 data show similar elevation in chloride and sodium concentrations, a potential elevation in sulfate concentrations and conductivity. Less significant ion concentration elevations occur in January 1980.

The November 1979 data, and possibly the January and August 1980 data, probably reflect contribution to Redondo Creek from temporary drain lines in the geothermal well field. Such a potential contribution will be eliminated with installation of permanent pipelines in 1981-82.

Water quality data from Sulfur Creek at Union Gate (Table 2) demonstrates a great deal of variability between monthly collections. The variability probably reflects the percent contribution Sulfur receives from hot springs located one mile upstream from the collection site. The site was selected because it is the first point where Sulfur Creek waters enter public land, and it is above the confluence of Sulfur and Redondo Creeks. The variability of the quality of the waters makes comment difficult.

Table 3 lists water quality data for Sulfur Creek about one mile below the confluence with Redondo Creek. Sulfur and Redondo contribute approximately equal volumes to the sampling site. The water quality excursions discussed for Redondo Creek (Table 1) are not reflected in water quality data for Sulfur at La Cueva. The low SO_4 reading of November 1979 is probably a typographical error from the lab (undocumented by the lab).

February BOD_5 reading on Table 3 is extremely high. Succeeding readings indicate that the source of pollution was probably ephemeral.

Water quality data for San Antonio Creek above La Cueva may be found in Table 4. Dilution effect due to increased flow is the most probable explanation for the major water quality excursion for this site which occurred in May 1980 during spring runoff.

Increased BOD_5 readings for June and July 1980 could indicate contamination from local sewage facilities, possibly from the San Antonio Campground.

Table 5 lists water quality data for San Antonio Creek about 100 yards below its confluence with Sulfur Creek. Sulfur contributes ≈ 10% of San Antonio's volume at this point.

Cloride appears to be the only chemical constituent that changes in the water quality of San Antonio Creek below its confluence with Sulfur. No other clear contribution by Sulfur appears when Tables 3, 4 and 5 are compared.

San Antonio Creek and the East Fork of the Jemez (see Table 7) contribute approximately equal volumes to form the Jemez River at Battleship Rock (see Table 6).

Table 5 shows San Antonio Creek samples to have slightly elevated flourine concentrations when compared to Tables 6 and 7.

Table 7 shows East Fork waters consistently to have lower concentrations of bicarbonate, calcium, sodium and sulfate ions than either San Antonio Creek or Jemez River below Battleship Rock. Conductivity of East Fork samples is also lower than the other two sites. Boron concentration is consistently higher in East Fork samples and Jemez River at Battleship Rock than waters of San Antonio Creek when Tables 5, 6 and 7 are compared.

Slightly elevated BOD_5 concentrations from East Fork samples during June and July may indicate fecal contamination from cattle.

The extremely high BOD_5 concentration recorded in February at the Jemez River site at Battleship Rock could indicate a camper had illegally emptied sanitary tanks recently or that some other temporary pollution source was present near the collection site. Both sites in Tables 6 and 3 are near roads which could be used as illegal dumping points. Such extreme values for BOD_5 should be reflected in other tables if the samples had been improperly handled during the February collection or analysis.

TABLE 1: WATER QUALITY DATA - REDONDO CREEK

REDONDO	AUGUST 79	SEPTEMBER 79	OCTOBER 79	NOV. 79	DEC. 79	JAN. 80	FEB. 80	MARCH 80	MAY 80	June 80	July 80	AUG. 80	SEPT. 80
BOD_5 mg/l	----	----	----	----	----	----	6.3	----	3.0	5.0	5.0	2.4	0.25
As "	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	0.01	<0.02	0.05	0.01	0.01	<0.01	<0.01
Ba "	----	----	----	----	----	2.5	2.0	1.5	----		0.01	<0.01	0.02
Hg "	0.00012*	<0.00001*	0.00025*	0.00054*	0.00012*	<0.00001*	<0.001	<0.00001*	<0.001	0.001	0.001	<0.001	<0.001
NO_3 "	0.48	0.05	0.005	0.34	1.5	0.5	0.5	0.7	0.78	0.58	0.10	0.03	<0.01
F "	0.47	0.6	0.28	0.6	0.47	<0.1	0.14	0.22	0.05	0.10	0.42	0.10	0.05
B "	0.2	0.3	0.02	1.1	0.25*	1.75	0.2	0.1	0.03	0.10	0.02	0.50	0.16
HCO_3 "	45.2	29.1	31.9	19.5	30.0	37.5	33.4	48.0	45.0	41.1	37.4	37.3	37.3
Ca "	7.6	4.8	8.8	35.4	7.6	16.7	15.0	18.7	11.0	7.4	7.9	18.0	20.6
Cl "	13.4	12.0	16.0	109.8	18.8	44.0	18.1	23.0	15.9	6.0	17.9	76.4	24.8
Fe (diss)	<0.02	0.05	0.09	<0.02	<0.02	<0.02	.30	<0.02	0.35	0.02	0.09	0.07	0.17
Mg "	0.8	1.1	1.3	6.7	0.8	1.8	1.4	2.3	1.1	0.79	0.78	2.0	1.20
K "	1.6	2.0	1.8	12.4	1.6	4.7	2.8	2.9	3.8	1.2	1.8	4.6	1.90
Na "	6.0	6.9	6.4	50.8	6.0	26.6	13.0	15.7	7.1	11.0	4.0	31.0	8.70
SO_4 "	11.0	7.0	10.0	135.0	12.0	6.0	8.0	10.0	6.6	0.8	0.1	4.0	<0.1
pH	6.4+	6.4+	7.2	5.4	7.7	7.3	6.8	7.5	7.2	7.6	7.1	7.8	7.0
umhos conductance	50	40	70	440	188	130	79	112	70	63	78	245	
Ave. Flow Rt. cfs						1.6	1.6	1.8	2.2				
Temp °C	17°	8°	7°	13°	0°	2°	3.5°	5°	7°	13°	15°	13°	10°0
PO_4 "	.09	0.45	0.23	0.05	0.24	0.1	0.11	<0.1	0.13	0.07	0.08	0.07	0.12

* data questionable - no known technique assures such accuracy
\+ pH electrode questionable
pH, conductance and water temperature are field data

TABLE 2: WATER QUALITY DATA - SULFUR AT UNION GATE

SULFUR AT UNION GATE	AUGUST 79	SEPTEMBER 79	OCTOBER 79	NOV. 79	DEC. 79	JAN. 80	FEB. 80	MARCH 80	MAY 80	JUNE 80	JULY 80	AUG. 80	SEPT. 80
BOD_5 mg/l	--	--	--				14.2	--	<3.0	12.0	9.3	0.6	0.37
As "	<0.02	<0.02	<0.02				<0.02	<0.02	0.01	0.03	<0.01	0.11	0.04
Ba "	--	--	--				<0.02	4.0	--	--	<0.01	<0.01	0.04
Hg "	<0.001	<0.001	<0.001				<0.001	<0.001	0.01	<0.001	<0.001	<0.001	<0.001
NO_3 "	7.02	0.05	0.03				6.8	2.3	0.11	0.08	0.01	0.68	<0.01
f "	0.75	0.74	0.49				0.66	0.45	0.18	1.10	0.31	0.74	0.48
B "	6.3	0.1	<0.02				0.05	0.2	0.13	0.09	0.07	0.07	0.18
HCO_3 "	<0.1	<0.1	<0.1				<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Ca "	22.7	73.4	58.4				152.0	34.6	16.0	58.0	140.0	170.0	254.0
Cl "	<0.2	27.0	6.96				9.6	8.2	3.0	5.0	5.0	5.0	8.9
Fe "	<0.02	2.5	8.6				<0.02	<0.02	2.4	8.6	25.0	56.0	57.3
Mg "	11.2	9.08	20.9				31.6	12.2	1.1	10.0	18.0	20.0	17.9
K "	18.0	18.4	14.9				2.9	11.9	5.2	12.0	19.0	19.0	22.0
Na "	13.8	4.2	17.9				27.4	206.0	3.1	15.0	12.0	25.0	13.8
SO_4 "	1275.0	675.0	975.0				450.0	500.0	68.0	360.0	849.0	887.0	943.0
pH	6.4	6.4	7.2				3.9	2.5	3.5	3.0	2.9	2.8	
mhos conductance	50	40	70				1280	1190	120	780	1400	1310	
Temp °C	17°C	8°C	7°C				0.5°C	3°C	7°C	13°C	15°C	9°C	
PO_4 mg/l	0.23	0.5	0.24				0.42	0.03	0.07	0.05	0.12	0.01	0.10
LOW RATE	≈.35	.12	≈.5	-	-	-	-	-	5 cfs	1.2	≈.03	0.2	

FROZEN IN

* data questionable - no known technique assures such accuracy
\+ pH electrode questionable
pH, conductance and water temperature are field data

TABLE 3: WATER QUALITY DATA - SULFUR AT LA CUEVA

SULFUR AT LA CUEVA	AUGUST 79	SEPTEMBER 79	OCTOBER 79	NOV. 79	DEC. 79	JAN. 80	FEB. 80	MARCH 80	MAY 80	JUNE 80	JULY 80	AUG. 80	SEPT. 80
BOD_5 mg/l	--	--	--	--	--	--	78.7	--	1.8	5.2	4.1	0.6	0.6
As "	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.01	1.5	0.03	0.02	<0.01	0.04	0.04
Ba "	--	--	--	--	--	<0.02	0.5	1.5	--	--	<0.01	<0.01	0.02
Hg "	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	--	<0.001	< 0.001	<0.001	<0.001	<0.001	<0.001
NO_3 "	0.68	0.086	0.003	0.32	1.6	1.3	0.19	0.6	0.10	0.03	0.03	0.01	<0.01
f "	0.36	0.65	0.4	0.43	0.29	0.2	0.24	0.51	0.10	0.27	0.07	0.11	0.09
B "	0.1	0.2	<0.02	0.75	0.2	0.05	0.29	0.1	0.07	0.09	0.04	0.32	0.15
HCO_3 "	22.0	27.6	28.0	32.0	27.0	66.0	78.0	79.8	19.5	29.8	32.1	37.3	37.3
Ca "	10.2	8.6	17.6	7.6	20.8	84.7	45.0	62.3	12.0	13.0	12.0	27.0	29.6
Cl "	18.4	10.8	14.9	45.2	24.8	26.4	29.3	15.2	6.0	6.0	8.0	63.5	24.8
Fe (diss.)	<0.02	0.42	0.43	0.06	<0.02	<0.02	0.03	<0.02	<0.01	0.07	0.16	0.62	0.41
Mg "	1.8	2.2	3.3	1.6	4.1	9.9	6.2	6.9	1.7	1.5	1.5	2.8	2.0
K "	2.4	3.8	1.9	5.2	7.1	2.0	9.8	9.1	2.2	2.1	2.4	4.5	2.4
Na "	8.8	10.9	11.2	22.6	18.8	24.7	30.0	30.1	46.0	11.0	6.1	33.0	10.0
SO_4 "	50.0	34.0	65.0	7.0	90.0	195.0	188.0	135.0	45.0	37.0	21.0	29.0	12.0
pH	--	6.3	6.3	6.2	5.7	--	4.4	4.6	5.2	7.2	6.5	7.1	
mhos conductance	130	130	150	140	160	190	230	255	90	115	130	218	
Temp °C	23°C	12°C	8°C	0°C	6°C	0°C	1°C	5°C	4°C	14°C	17°C	9°C	
PO_4 mg/l	0.1	0.09	0.43	0.28	0.11	0.025	0.03	<0.1	0.09	0.04	0.11	0.02	0.08
LOW RATE	3.6	3.0	1.0	-	-	-	-	-	9 cfs	5.5	2.5	1.6	

* data questionable - no known technique assures such accuracy
\+ pH electrode questionable
pH, conductance and water temperature are field data

TABLE 4: WATER QUALITY DATA - SAN ANTONIO ABOVE LA CUEVA

AN ANTONIO VE LA CUEVA	AUGUST 79	SEPTEMBER 79	OCTOBER 79	NOV. 79	DEC. 79	JAN. 80	FEB. 80	MARCH 80	MAY 80	JUNE 80	JULY 80	AUG. 80	SEPT. 80
BOD_5 mg/l	--	--	--	--	--	--	0.6	--	1.2	10.7	10.2	0.9	0.75
As "	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	0.02	0.01	<0.01	0.06
Ba "	--	--	--	--	--	<0.02	<0.02	2.0	--	0.1	0.03	<0.01	0.13
Hg "	0 .00026*	<0.00001*	0.00013*	0 .00001*	<0.00001*	<0.00001*	<0.00001*	<0.00001*	<0.001	0.05	<0.001	<0.001	<0.001
NO_3 "	0.51	0.068	0.002	0.57	1.7	0.6	0.6	0.8	0.06	0.96	0.03	0.06	<0.01
f "	1.27	1.18	1.26	1.35	1.18	0.86	0.85	0.98	0.24	0.96	0.42	1.10	0.95
B "	0 .02	0.2	0.02	0.2	0.05	0.05	<0.02	<0.02	0.08	0.07	0.07	0.02	0.17
HCO_3 "	67.6	68.5	78.0	68.0	74.0	62.0	58.6	78.0	38.5	102.0	107.0	89.6	120.1
Ca "	4.6	3.7	6.4	5.2	4.2	11.7	13.0	20.4	9.1	17.0	17.0	16.0	22.2
Cl "	12.2	3.6	3.6	3.2	4.8	4.0	7.9	6.0	1.0	2.0	3.0	3.0	4.0
Fe (diss.)	<0.02	0.04	0.16	0.1	0.1	<0.02	<0.02	<0.02	0.10	0.05	0.10	0.59	0.26
Mg "	1.1	1.4	1.8	1.6	1.45	1.6	1.8	2.9	1.60	2.5	2.2	1.90	1.80
K "	2.8	2.6	2.4	2.2	2.4	3.0	2.8	4.7	2.3	2.5	2.8	2.9	2.2
Na "	13.8	16.7	17.9	16.8	18.2	18.2	13.0	32.7	4.2	15.0	16.0	15.0	17.0
SO_4 "	14.0	9.0	10.0	8.0	12.0	15.0	12.0	17.0	10.0	2.0	0.5	5.0	<0.1
pH	6.2	7.3	6.7	7.6	6.7	--	6.4	7.5	7.5	7.2	7.5	7.6	
hos con-ctance	110.0	120.0	100.0	90.0	75.0	82.0	72.0	105.0	68.0	138.0	165.0	155.0	
Temp ^oC	19^oC	17^oC	10^oC	13^oC	2^oC	1.5^oC	2^oC	8^oC	7^oC	14^oC	14^oC	12^oC	
PO_4 mg/l	0.1	0.13	0.70	0.14	--	0.1	0.1	0.3	0.11	0.12	0.05	0.05	0.12
OW RATE	74.0	18.0	12.0	-	-	-	-	-	132.0	18.5	20.0	11.3	

* Data questionable - no known technique assures such accuracy
+ pH electrode questionable
pH, conductance and water temperature are field data

TABLE 5: WATER QUALITY DATA - SAN ANTONIO BELOW LA CUEVA

AN ANTONIO LOW LA CUEVA	AUGUST 79	SEPTEMBER 79	OCTOBER 79	NOV. 79	DEC. 79	JAN. 80	FEB. 80	MARCH 80	MAY 80	JUNE 80	JULY 80	AUG. 80	SEPT. 80
BOD_5 mg/l	--	--	--	--	--	--	1.2	--	0.9	4.8	5.0	3.0	1.9
As "	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	0.03	0.03	<0.01	<0.01	0.01
Ba "	--	--	--	--	--	<0.02	1.5	1.5	--	<0.1(?)	0.11	<0.01	0.11
Hg "	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	< 0.001	0.001	<0.001	<0.001	<0.001
NO_3 "	0.72	0.023	0.003	0.7	2.0	0.5	1.1	0.6	0.07	0.07	0.01	1.20	<0.01
f "	1.25	1.11	1.21	1.34	1.12	0.84	1.28	0.94	0.22	0.74	0.34	1.10	0.81
B "	<0.02	0.8	<0.02	0.45	0.05	<0.02	<0.02	0.3	0.07	0.09	0.12	0.06	0.13
HCO_3 "	82.2	61.4	65.5	67.0	61.0	51.0	58.6	63.6	42.0	74.6	90.9	84.6	89.6
Ca "	5.0	4.0	6.0	7.9	4.5	10.0	37.6	19.6	8.9	15.0	16.0	19.0	21.3
Cl "	8.8	4.8	4.8	3.6	4.6	6.0	9.2	5.0	9.0	1.0	2.0	28.8(?)	4.8
Fe (diss.)	<0.02	0.09	0.18	<0.02	<0.02	0.12	<0.02	<0.02	0.17	0.05	0.11	0.46	0.25
Mg "	1.1	1.48	1.7	2.0	1.35	1.3	2.7	3.3	1.60	2.20	2.20	2.20	1.6
K "	3.2	3.1	2.3	2.0	2.38	2.7	1.4	2.3	1.9	2.3	2.7	3.2	2.0
Na "	14.6	15.2	14.3	16.6	15.8	13.3	26.4	28.2	3.8(?)	14.0	11.0	22.0	11.2
SO_4 "	11.0	11.0	5.0	13.5	17.0	15.0	19.0	17.0	12.0	12.0	4.1(?)	7.0	<0.1(?)
pH	6.1	7.1	7.0	6.4	6.1	--	8.0*	7.3	7.5	6.9	7.2	7.8	
mhos con-uctance	140	120	100	80	85	80	82	122	75	122	148	148	
Temp °C	20°C	18°C	7°C	5°C	2°C	1°C	4°C	9°C	8°C	13°C	17°C	13°C	
PO_4 mg/l	0.2	0.18	0.55	0.16	0.19	0.1	0.08	0.33	0.10	0.10	0.06	0.05	0.04
LOW RATE	15.0	20.0	15.0	-	-	-	-	-	184.0	23.0	18.0	16.7	

* Data questionable - no known technique assures such accuracy
\+ pH electrode questionable
pH, conductance and water temperature are field data

TABLE 6: WATER QUALITY DATA - JEMEZ RIVER AT BATTLESHIP ROCK

JEMEZ RIVER AT BATTLESHIP ROCK	AUGUST 79	SEPTEMBER 79	OCTOBER 79	NOV. 79	DEC. 79	JAN. 80	FEB. 80	MARCH 80	MAY 80	JUNE 80	JULY 80	AUG. 80	SEPT. 80
BOD_5 mg/l	--	--	--	--	--	--	76.1	--	2.4	2.0	1.8	2.7	1.6
As "	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	0.02	0.01	0.04	<0.01	<0.01	0.03
Ba "	--	--	--	--	--	<0.02	0.5	2.0	--	0.01	0.03	<0.01	0.26
Hg "	<0.00011*	<0.00001*	0.000114*	0.00042*	<0.00001*	<0.00001*	<0.001	0.00001*	<0.001	<0.001	<0.001	<0.001	<0.001
NO_3 "	0.55	0.02	0.003	0.5	0.6	0.9	0.47	0.06	0.07	0.07	0.02	0.02	<0.01
f "	0.72	0.9	1.0	0.51	1.06	0.66	0.86	0.83	0.18	0.60	0.68	0.74	0.63
B "	0.02	0.6	0.02	0.3	0.15	0.02	0.19	0.3	0.12	0.10	0.07	0.04	0.14
HCO_3 "	61.0	61.7	69.0	73.0	62.0	58.0	66.4	60.6	35.7	76.2	77.5	84.6	89.6
Ca "	7.8	3.8	5.0	4.2	3.5	11.2	13.0	21.6	12.0	12.0	14.0	14.0	17.3
Cl "	16.4	4.4	4.4	6.2	5.2	6.0	12.0	6.2	3.0	1.0	2.0	6.0	4.0
Fe (diss.)	<0.02	<0.02	0.09	0.02	<0.02	<0.02	0.23	0.02	0.9	0.06	0.07	0.13	0.14
Mg "	1.0	8.2	2.1	2.2	1.5	2.0	2.2	3.1	1.6	1.2	1.10	2.30	1.8
K "	2.4	2.6	0.2	2.1	2.3	3.1	3.2	2.1	2.8	1.9	2.4	2.4	2.1
Na "	13.6	17.8	15.2	19.1	17.5	17.3	24.0	24.9	8.0	9.5	12.0	15.0	11.3
SO_4 "	11.0	9.5	10.0	8.0	14.0	16.0	15.0	17.0	11.0	7.0	0.8	3.0	<0.1
pH	6.4+	7.0	6.8	7.6	--	--	7.4	7.5	7.5	7.2	6.9	7.9	
umhos conductance	120.0	110.0	85.0	90.0	--	88.0	90.0	120.0	61.0	122.0	148.0	140.0	
Temp °C	17°C	18°C	9°C	3.5°C	--	0°C	4°C	8°C	7°C	18°C	19°C	18°C	
PO_4 mg/l	0.14	0.13	0.45	0.16	0.2	0.08	0.06	0.01	0.09	0.10	0.05	0.04	0.10
FLOW RATE	36.0	30.0	24.0	-	-	-	-	-	305.0	44.0	50.0	27.0	

* Data questionable - no known technique assures such accuracy
\+ pH electrode questionable
pH, conductance and water temperature are field data

TABLE 7: WATER QUALITY DATA - EAST FORK OF JEMEZ

EAST FORK OF JEMEZ	AUGUST 79	SEPTEMBER 79	OCTOBER 79	NOV. 79	DEC. 79	JAN. 80	FEB. 80	MARCH 80	MAY 80	JUNE 80	JULY 80	AUG. 80	SEPT. 80
BOD_5 mg/l	--	--	--		--			--	1.0	4.2	8.0	1.5	1.1
As "	<0.02	<0.02	<0.02		<0.02			<0.02	0.04	0.01	0.01	0.01	0.02
Ba "	--	--	--		--			3.0	--	0.1	0.04	<0.01	0.02
Hg "	0.00018*	0.00001*	0.0026		<0.00001*			<0.00001*	<0.001	<0.001	<0.001	<0.001	<0.001
NO_3 "	0.47	0.032	0.006		2.3			0.5	0.03	0.01	0.02	0.03	<0.01
f "	0.67	0.85	0.79		0.79			0.23	0.18	0.43	0.20	0.52	0.44
B "	0.02	0.9	0.02		0.05			0.7	0.12	0.09	.05	<0.01	0.15
HCO_3 "	44.1	37.8	41.0		47.2			45.9	35.7	47.5	40.1	52.3	52.3
Ca "	4.3	2.5	4.0		2.3			17.6	9.4	7.1	8.0	6.3	8.7
Cl "	17.8	3.0	9.2		4.2			7.6	5.0	1.5	0.4	1.0	1.0
Fe (diss.)	<0.02	<0.02	<0.02		<0.02			3.0	0.75	0.06	0.17	0.29	0.27
Mg "	0.9	1.0	1.0		0.72			2.2	1.3	1.20	1.1	1.1	1.0
K "	1.8	2.4	1.8		2.1			4.6	1.9	1.4	1.7	1.5	1.6
Na "	10.4	9.4	9.3		11.5			21.6	4.5	9.5	6.4	11.0	6.8
SO_4 "	7.0	4.5	55.0		8.0			8.0	2.0	<0.1	<0.1	<0.1	<0.1
pH	5.8+	6.4	7.8		6.0			7.6	7.4	7.3	7.1	7.6	
mhos conductance	90.0	40.0	50.0		65.00			58.0	48.0	70.0	78.0	70.0	
Temp °C	18°C	10°C	8°C		1°C			-1°C	16°C	16°C	18°C	14°C	
PO_4 mg/l	0.3	0.11	0.20		0.17			0.1	0.10	0.10	0.02	0.02	0.02
LOW RATE	23.0	20.0	20.0	-	-	-	-	-	112.0	24.0	18.0	14.0	

FROZEN IN

* Data questionable - no known technique assures such accuracy
\+ pH electrode questionable
pH, conductance and water temperature are field data

SURFACE WATER MONITORING DATA

REDONDO CREEK

WATER YEAR 1979-1980

SURFACE WATER MONITORING DATA, REDONDO CREEK

WATER YEAR 1979-1980

The Redondo Creek water quality monitoring station is located about 1.5 miles downstream from the Baca project. The station consists of a steel Parshall measuring flume with a 30" throat, 24" depth and a listed 23.94 cfs capacity maximum set into the creek bed. A shelter covers the flume and its attached stilling well to protect monitoring equipment from temperature extremes and weather. The station cannot be held at constant temperature or humidity. A butane heater and a backup electric heater prevent the recorders from freezing. Flow rate, pH and water temperature are recorded continuously at the station from the stilling well. Flow increase triggers collection of up to 28 aliquots directly from Redondo Creek. A field technician is required to ensure that all equipment is functioning and that collected samples are processed in a timely manner. The instruments are checked at least once each week, charts are collected and transported to Union's Rio Rancho office each Friday.

Flow is recorded on a Stevens type F meter with an 8 day hand wind clock, 5" float, 1.2" per day time scale and a 1:1 English gauge scale. The Stevens recorder was selected because of its long history of durability and dependability under field operating conditions.

Selection of a field operable pH/temperature recorder required extensive research. Temperature and pH are recorded by an Analytical Model 30 AC pH/temperature recording meter with ranges of 2-12 pH, 0^{o}-50^{o}C. The instrument carries an automatic temperature compensation, gear train set for 1/4" per hour and is run by electric hook-up. Although Analytical Instruments are a relatively new firm, this instrument appeared to have the sturdiness necessary for field conditions that other instrumentation lacked without exorbitant cost.

A Barton temperature meter with a 7 day hand wind clock and a range of 0-100^{o}F serves as a backup for the Analytical instrument. There is no backup pH recording unit.

Samples of water from Redondo Creek are collected automatically by an ISCO Model 2100 Sampler. Samples are collected by a peristaltic pump with a self purging mode between sample collections and a precollection wash mode. ISCO is run by direct electric hook-up but may be battery operated. ISCO is set to collect samples during increased flow only and to shut off after flow has decreased. It is capable of collecting up to 28 sequential samples of predetermined volume at predetermined frequency. Considerable variation in trigger levels and collection frequency have occurred over the year; to be discussed later.

DISCUSSION

The Parshall flume was installed into Redondo Creek August 14, 1979. The instrument stand was installed over the stilling basin and the shelter built by August 24, 1980. On August 24th the Stevens flow meter and ISCO were installed. ISCO was run by battery. The Analytical temperature meter had not yet been purchased. pH and temperature were collected at the site as frequently as a technician was present. A flow rate was measured regularly to calibrate the readings from the flume. The Analytical meter was installed November 30, 1979 when electricity was available to the water shelter. From that time ISCO was also run by electricity. The instruments are calibrated with field measurements regularly. The station has been fully operational since December 1, 1979.

Data is collected on continuous graph charts that must be tabulated. Table 1 has hourly averages of water temperature and pH from December 1, 1979 through September 30, 1980. Blank spaces following a value for pH or temperature indicate that no change occurred. Sections of the table that reflect periods where no data were collected are marked "no data". Loss of data usually occurred because of improper placement of the paper roll in the instrument. Additional admonishment of field technicians resulted in a decrease in the frequency of this type of loss. Data loss for the period from May 29 to July 30, 1980 resulted from periods when a local electric company was working on wires in the area, which resulted in power surges or cutoffs to the water station. ISCO was set to battery operate during the problem period but the Analytical meter had to be shut off. Contiguously, a short in the Analytical pH probe cable was discovered and the cable had to be replaced. Data was lost from August 1 to August 8, 1980. Additional probes have been purchased to eliminate future problems.

The Barton temperature meter collected temperature data for part of the time the Analytical meter was down. Barton data from June 26 through July 31, 1980 and from August 1 through August 8, 1980 may be found in Table 2. (^{o}F have been converted to ^{o}C.)

Flow data may be found in Tables 3 and 4. Table 3 lists daily average flows after the style of USGS Water Resources data for New Mexico. Possible explanation for certain flow changes have been listed. Those days for which data are not available are marked by a blank space. Data was usually lost because a technician was not available to change charts as frequently as necessary. Additional technicians have been trained in monitoring the water station to prevent such losses in the future.

Figures 1 thru 14 graph hourly water temperature, pH and flow available with ambient temperatures and precipitation data collected 1.5 miles above Redondo Station. Blanks in graphs indicate no data.

Table 4 indicates hourly flow changes in Redondo Creek. Total daily flow change is recorded as an activity index (sum of changes without regard to sign x 100). The activity index pinpoints those days of peak activity. Field notes and the station log can be checked or interviews of field personnel conducted to determine the cause of activity. Activity during June through October can usually be traced to precipitation in Redondo Canyon. Data from the 200' MET tower rain gauge have not been compared to flow data for analysis. Activity November through February/ March are typically caused in early mornings by ice buildup below the station and in mid-day by snow melt. Sunny days all winter produced runoff from south facing slopes. Beginning in March through June spring runoff produced very large activity indexes due to almost hourly flow changes.

The magnitude of fluctuations in flow due to runoff caused problems with setting the ISCO sampler.

The ISCO is triggered by a transducer placed above ambient water level. As water touches the transducer an electric impulse triggers the sampler to begin collecting. As water subsides, the trigger stops the sampler. Frequency of collection is determined by a clock inside the sampler.

The trigger was set during the winter months at a point about .05 feet above the stream on the flume scale. During periods of runoff, the trigger and timer were moved regularly in an attempt to be sensitive to flow increases without being overly sensitive. ISCO sample collections are indicated on Table 4.

Representative aliquots were regularly selected from the sampler and analyzed for the following constituents:

TDS (mg/l)
TSS (mg/l)
pH
Conductivity µmhos/cm
SO_4 (mg/l)
Cl "
B "
Br "
As "
Hg "
Si "

Grab samples were taken from Redondo Creek between periods of peak flow in an attempt to characterize Redondo's waters. Table 6 lists the constituents tested for in samples and values for each. ISCO samples are indicated by an ISCO # in the table. If no number is present, the values represent a grab sample collected at Redondo Station. Possible reasons ISCO was triggered are listed below specific samples.

The only convenient way to ensure that potential samples from a geothermal spill are collected during periods of runoff would be to set a series of samplers with triggers set at increasing distances above base flow. A single sampler may be set so it is filled before such a spill would reach it, or that samples might not be collected from a small spill.

Ensuring against the first case with a single sampler would require a full time 24 hour surveillance. Ensuring against the second case could produce the first case.

During spring runoff for 1980, the field technician regularly checked the ISCO no more than once a week. The sampler frequently was full and out of operation for over half a week at a time. Increasing the number of sample bottles available and training additional staff should prevent such problems in 1981. A laboratory will be available in Redondo Canyon from spring 1981 so that ISCO sample bottles may be cleaned on site. Turbidity measurements could also be made of samples on site.

The majority of problems with data collection at the Redondo Creek Station are technician related. The work supports only a part time position which limits the availability of personnel. Initially, the technician in charge of the WSSI air quality MET towers was to check the water station. Problems arose when the technician was called away frequently without notifying supervisors that the water station would not be monitored.

It was decided to hire a technician to strictly work with the water station and collect monthly water shed samples. The technician selected was a UNM student who had several years experience collecting water samples.

Problems again arose from periods when the technician was not available to monitor the station when charts required change. Two additional people have, therefore, been hired to monitor the station on a more regular basis. Both persons work at other activities in the vicinity of the water station. Since the additional personnel have been acquired, data loss is expected to drop significantly.

CONCLUSION

Since the Redondo Creek Station has been operational all equipment at the station has had some down time, but generally equipment has operated satisfactorily for the first year. The companies selling equipment, with the exception of Beckman, have been helpful and have provided speedy assistance when necessary.

The major problems with operating the water station relate to the difficulty of finding a qualified technician to monitor the station daily. Two technicians are presently monitoring the station. One checks the instruments nearly daily. A second is available to bring samples to Albuquerque.

The thorniest problem with the collection of data is the setting of the ISCO sampler so that critical samples are not missed.

The water budget for 1980 was overrun. Analysis of ISCO samples accounted for about 1/3 of the total cost of water analysis. Runoff water has been sufficiently analyzed so that analysis of few ISCO samples should be necessary for 1981.

The critical questions that water samples should clarify are whether flow increase in Redondo Creek carries geothermal water, and secondly whether runoff is carrying an increased salt load over time. Silt load changes in Redondo Creek should also be monitored. A technique that samples all increased flows, allowing for analysis of any sample, has yet to be successfully worked out.

TABLE 1: REDONDO CREEK pH/WATER TEMPERATURE (T)i (^{o}C) DECEMBER 1 - 15, '79

DATE:	1		2		3		4		5		6		7		8		9		10		11		12		13		14		15		
TIME	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	
0000	7.2	1^{o}	7.2	1^{o}	7.2	1.5	7.1	1.7	7.1	2.0	7.1	2.2	7.0	2.0	7.0	2.0	7.0	2.5	7.0	2.5	7.0	2.6	7.0	3.0	7.0	3.0	6.8	2.0	6.8	2.0	
01	↓	↓	↓	↓																						2.9					
02																										2.7				2.1	
03																										2.6					
0400																						2.7				2.5				2.2	
05																										2.4					
06												2.1												2.8		2.3				2.3	
07																								2.4		2.1					
0800																2.1						2.8		2.5		2.0				2.4	
09																								2.6							
10																2.2								2.8						2.5	
11																								2.9							
1200						1.6		2.0		2.1		7.1				2.3						2.9				6.9				2.6	
13				1.1																											
14				↓																										2.7	
15																															
1600																														2.8	
17				1.2																											
18				↓																										2.9	
19																															
2000				1.3												2.5						3.0		3.0						3.0	
21				↓																											
22																															
23				1.4																											
MEAN	7.2	1^{o}	7.2	1.2	7.2	1.6	7.1	1.9	7.1	2.0	7.1	2.1	7.0	2.0	7.0	2.3	7.0	2.5	7.0	2.5	7.0	2.8	7.0	2.7	7.0	2.5	6.8	2.0	6.8	2.5	
HI	7.2	↓	"	1.4	"	1.6	"	2.0	"	2.1	"	2.2	"	"	"	2.5	"	"	"	"	"	2.9	"	3.0	7.0	3.0	"	"	"	3.0	
LO	7.2	↓	"	1^{o}	"	1.5	"	1.7	"	2.0	"	2.1	"	"	"	2.0	"	"	"	"	"	2.6	"	2.4	6.9	2.0	"	"	"	2.0	
RANGE	ø	ø	ø	.4	ø	.1	ø	.3	ø	.1	ø	.1	ø	ø	ø	.5	ø	ø	ø	ø	ø	.3	ø	.6	.1	(1.0)	ø	ø	ø	(1.0)	

FLOW CHANGE FLOW

TABLE 1 (CONT'D): REDONDO CREEK pH/WATER TEMPERATURE (T) (^{o}C) DECEMBER 16 - 31 '79

DATE:	16		17		18		19		20		21		22		23		24		25		26		27		28		29		30		31	
TIME	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T
0000	6.8	3.0	6.8	3.0	6.8	2.5	6.9	3.0	6.9	3.0	6.9	3.0	6.8	3.0	6.9	3.0	6.9	2.0	6.8	2.5	6.9	3.0	6.9	3.0	6.8	2.0	6.8	2.2	6.9	3.0	6.8	2.5
01																			2.6											2.9		
02				2.9												2.9				2.7										2.8		
03																2.8				2.8										2.7		
0400				2.8												2.7				2.9										2.6		
05																2.6				3.0				2.9						2.5		
06		3.0		2.6												2.5								2.7						2.4		
07		2.2														2.2								2.6						2.2		
0800		2.6		2.4												2.0								2.4						2.0		
09		2.6																						2.2				2.3		2.2		
10		2.7																						2.0				2.4		2.3		
11	6.9	2.8		2.2																								2.5		2.4		
1200						2.6												2.1					6.8	2.0				2.6	6.8	2.5		2.6
13																		2.2										2.7				
14																												2.8				
15																		2.3										2.9				
1600																		2.4										3.0				2.7
17						2.7																										
18		2.9				2.8																					6.9					
19		3.0				2.9																										
2000				2.3														2.5	6.9						2.1						2.8	
21																																2.9
22																																
23				2.4																												
MEAN	6.8	2.8	6.8	2.6	6.8	2.7	6.9	3.0	6.9	3.0	6.9	3.0	6.8	3.0	6.9	2.5	6.9	2.3	6.9	2.8	6.9	3.0	6.9	2.5	6.8	2.0	6.8	2.6	6.8	2.5	6.8	2.7
HI	6.9	3.0	"	3.0	"	2.9	"	"	"	"	"	"	"	"	"	3.0	"	2.5	6.9	3.0	"	"	6.9	3.0	"	2.1	6.9	3.0	6.9	3.0	"	2.9	
LO	6.8	2.2	"	2.2	"	2.5	"	"	"	"	"	"	"	"	"	2.0	"	2.0	6.8	2.5	"	"	6.8	2.0	"	2.0	6.8	2.2	6.8	2.0	"	2.5	
RANGE	.1	.8	Ø	.8	Ø	.4	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	(1.0	Ø	.5	.1	.5	Ø	Ø	.1	(1.0	Ø	.1	.1	.8	.1	(1.0)	Ø	.4

FLOW ↑ FLOW ↑ ?

TABLE 1 (CONT'D): REDONDO CREEK pH/WATER TEMPERATURE (T) (°C) JANUARY 1 - 15, '80

DATE:	1		2		3		4		5		6		7		8		9		10		11		12		13		14		15		
TIME	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T
0000	6.8	3.0	6.9	3.0	6.8	2.0	6.8	2.0	6.9	2.6	6.8	2.6	6.8	2.6	6.8	2.8	6.9	3.0	6.8	3.0	6.8	2.2	6.9	3.0	7.0	3.2	6.9	3.0	7.0	3.3	
01																				2.9											
02																				2.8		2.3									
03																				2.7											
0400								2.1							6.9	3.0				2.6		2.4									
05																															
06				2.9																2.5		2.5									
07				2.8																											
0800				2.6				2.2												2.4		2.6									
09				2.5																											
10				2.3				2.3												2.3											
11				2.1																											
1200	6.9			2.0				2.4												2.2	6.9										
13																															
14								2.5																							
15																															
1600			6.8				6.9	2.6									6.8					2.7				3.1					
17																															
18																						2.8									
19																															
2000													2.7									2.9									
21																															
22																							7.0	3.1			7.0	3.1			
23																												3.2			
MEAN	6.9	3.0	6.9	2.5	6.8	2.0	6.8	2.3	6.9	2.6	6.8	2.6	6.8	2.6	6.9	2.9	6.8	3.0	6.8	2.6	6.9	2.6	6.9	3.0	7.0	3.1	7.0	3.1	7.0	3.3	
HI	6.9	"	6.9	3.0	"	"	6.9	2.6	"	"	"	"	"	2.7	6.9	3.0	6.9	"	"	3.0	6.9	2.9	7.0	3.1	"	3.2	7.0	3.2	"	"	
LO	6.8	"	6.8	2.0	"	"	6.8	2.0	"	"	"	"	"	2.6	6.8	2.8	6.8	"	"	2.2	6.8	2.2	6.9	3.0	"	3.1	6.9	3.0	"	"	
RANGE	.1	Ø	.1	(1.0)	Ø	Ø	.1	.4	Ø	Ø	Ø	Ø	Ø	.1	.1	.2	.1	Ø	Ø	.8	.1	.7	.1	.1	Ø	.1	.1	.2	Ø	Ø	

TABLE 1 (CONT'D): REDONDO CREEK pH/WATER TEMPERATURE (T) (°C) JANUARY 16 - 31 '80

DATE:	16		17		18		19		20		21		22		23		24		25		26		27		28		29		30		31	
TIME	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T
0000	7.0	3.3	7.0	3.0	7.0	3.0	7.0	2.8	7.0	3.0	7.1	3.0	7.0	2.0	7.0	2.0	7.2	2.0	7.2	2.0	7.1	2.0	7.0	2.0	7.1	2.0	7.2	2.5	7.1	2.2	7.0	2.0
01																										2.1						
02												2.9														2.2						
03																										2.3						2.1
0400												2.8														2.4						2.2
05																																2.3
06												2.7																				2.4
07																																
0800												2.6			7.1											2.5						
09																																
10																																
11																																
1200		3.2							7.1														7.1								7.1	2.5
13																																
14																																
15																																
1600		3.1						2.9																								
17																																
18						2.9																										
19												2.5																				
2000		3.0																										2.4				
21																												2.3				
22											7.0	2.4																				
23												2.2																				
MEAN	7.0	3.2	7.0	3.0	7.0	3.0	7.0	2.9	7.1	3.0	7.1	2.6	7.0	2.0	7.1	2.0	7.2	2.0	7.2	2.0	7.1	2.0	7.1	2.0	7.1	2.3	7.2	2.4	7.1	2.2	7.0	2.3
HI	"	3.3	"	"	"	3.0	"	2.9	7.1	"	7.1	2.2	"	"	7.1	"	"	"	"	"	"	"	7.1	"	"	2.5	"	2.5	"	"	"	2.5
LO	"	3.0	"	"	"	2.9	"	2.8	7.0	"	7.0	3.0	"	"	7.0	"	"	"	"	"	"	"	7.0	"	"	2.0	"	2.3	"	"	"	2.0
RANGE	Ø	.3	Ø	Ø	Ø	.1	Ø	.1	.1	Ø	.1	.8	Ø	Ø	.1	Ø	Ø	Ø	Ø	Ø	Ø	Ø	.1	Ø	Ø	.5	Ø	.2	Ø	Ø	Ø	.5

TABLE 1 CONT'D): REDONDO CREEK pH/WATER TEMPERATURE (T) (°C) FEBRUARY 1 - 15, '80

DATE:	1		2		3		4		5		6		7		8		9		10		11		12		13		14		15		
TIME	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T
0000	7.2	2.5	7.1	2.5	7.0	2.0	7.1	2.5	7.2	3.0	7.1	2.2	7.0	2.0	7.0	2.2	7.1	2.8	7.1	2.0	7.0	1.2	7.0	1.5	7.1	2.0	7.1	2.0	7.0	2.0	
01																		2.7						1.6							
02				2.4										2.1				2.6						1.7							
03																								1.8							
0400				2.3										2.2		2.3		2.5						1.9							
05				2.2																				2.0							
06				2.1																											
07																															
0800				2.0												2.4															
09																															
10																2.5				1.9											
11										2.9										1.8											
1200								2.6		2.8						2.6		2.4		1.6				7.1							
13										2.7								2.2		1.4											
14								2.7		2.6								2.0		1.3											
15										2.5										1.2											
1600			7.0					2.8		2.4		2.1			7.1	2.7			7.0												
17																															
18						2.1		2.9														1.3									
19						2.2				2.3												1.4									
2000						2.3	7.2	3.0		2.2						2.8						1.5									
21						2.4																									
22						2.5																									
23																															
MEAN	7.2	2.5	7.1	2.3	7.0	2.3	7.1	2.8	7.2	2.6	7.1	2.2	7.0	2.1	7.0	2.5	7.1	2.4	7.1	1.6	7.0	1.4	7.1	1.8	7.1	2.0	7.1	2.0	7.0	2.0	
HI	"	"	7.1	2.5	"	2.5	7.2	3.0	"	3.0	"	2.2	"	2.2	7.1	2.8	"	2.8	7.1	2.0	"	1.5	7.1	2.0	"	"	"	"	"	"		
LO	"	"	7.0	2.0	"	2.0	7.1	2.5	"	2.2	"	2.1	"	2.0	7.0	2.2	"	2.0	7.0	1.2	"	1.2	7.0	1.5	"	"	"	"	"	"		
RANGE	Ø	Ø	.1	.5	Ø	.5	.1	.5	Ø	.8	Ø	.1	Ø	.2	.1	.6	Ø	.8	.1	.8	Ø	.3	.1	.5	Ø	Ø	Ø	Ø	Ø	Ø		

TABLE 1 (CONT'D): REDONDO CREEK pH/WATER TEMPERATURE (T) (^{o}C)

FEBRUARY 16 - 29 '80

TIME	DATE: 16 pH	16 T	17 pH	17 T	18 pH	18 T	19 pH	19 T	20 pH	20 T	21 pH	21 T	22 pH	22 T	23 pH	23 T	24 pH	24 T	25 pH	25 T	26 pH	26 T	27 pH	27 T	28 pH	28 T	29 pH	29 T	30 pH	30 T	31 pH	31 T
000	7.0	2.0	7.1	2.5	7.0	2.5	7.0	2.5	7.0	2.0	7.0	2.0	7.0	2.0	7.0	2.0	7.0	2.0	7.0	2.0	7.0	2.0	6.9	2.0	6.9	2.0	6.9	2.5				
1		2.1						2.4																								
2		2.2						2.3																								
3		2.3						2.2																								
400		2.4						2.1																								
5		2.5						2.0																								
6																																
7																																
800																																
9																																
0																																
1																																
200	7.1																															
3			7.0																													
4																																
5																																
600																																
7																										2.1						
8																										2.2						
9																										2.3						
2000																					6.9					2.4						
1																										2.5						
2																																
3																																
MEAN	7.1	2.3	7.1	2.5	7.0	2.5	7.0	2.3	7.0	2.0	7.0	2.0	7.0	2.0	7.0	2.0	7.0	2.0	7.0	2.0	7.0	2.0	6.9	2.0	6.9	2.3	6.9	2.5				
HI	7.1	2.5	7.1	"	"	"	"	2.5	"	"	"	"	"	"	"	"	"	"	"	"	7.0	"	"	"	"	2.5	"	"				
LO	7.0	2.0	7.0	"	"	"	"	2.0	"	"	"	"	"	"	"	"	"	"	"	"	6.9	"	"	"	"	2.0	"	"				
RANGE	.1	.5	.1	Ø	Ø	Ø	Ø	.5	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	.1	Ø	Ø	Ø	Ø	.5	Ø	Ø				

TABLE 1 (CONT'D) REDONDO CREEK pH/WATER TEMPERATURE (T) (°C) MARCH 1 - 15, '80

TIME	DATE: 1 pH	1 T	2 pH	2 T	3 pH	3 T	4 pH	4 T	5 pH	5 T	6 pH	6 T	7* pH	7* T	8 pH	8 T	9 pH	9 T	10 pH	10 T	11 pH	11 T	12 pH	12 T	13* pH	13* T	14 pH	14 T	15 pH	15 T	pH	T
0000	6.8	2.5	6.8	2.5	6.8	2.5	6.8	3.0	6.8	2.5	6.8	2.5	6.8	3.0	7.1	3.0	7.4	3.0	7.1	3.0	(8.4)	3.0	7.2	3.0	7.2	3.0	7.6	2.2	8.0	3.0		
0100																	(7.0)															
0200																	(7.5)				7.2						7.7					
0300																	(7.6)				7.2						7.8'					
0400																	(7.8)				(8.0)						7.9					
0500																	(7.9)				(8.2)						8.0	2.3				
0600																	(8.0)				(8.3)							2.4				
0700																	(8.2)				(8.4)							2.5				
0800								2.9									(7.1)		7.1		(8.5)							2.6				
0900								2.8									(8.2)		(8.0)		(8.4)							2.7	7.9			
1000								2.7											(8.1)		7.2								7.7			
1100								2.6									(8.3)		(8.2)										7.6			
1200					2.6		2.5				2.6						(8.4)		(8.2)								7.9		7.9			
1300					2.7						2.7						(8.4)		(8.2)								7.8					
1400					2.8						2.8						(7.2)		7.0									2.8				
1500					2.9						2.9						(7.1)		(8.2)									2.9				
1600					3.0												(7.2)		(8.3)								8.0	3.0				
1700											3.0				7.0										7.5	2.2						
1800																			(8.4)						7.6							
1900															7.1				(8.4)													
2000															7.2		7.1		7.0													
2100																7.3			(8.4)													
2200																7.4			(8.5)													
2300																																
MEAN	6.8	2.5	6.8	2.5	6.8	2.8	6.8	2.8	6.8	2.5	6.8	2.8	6.8	3.0	7.3	3.0	7.8	3.0	7.8	3.0	7.9	3.0	7.2	3.0	7.4	2.6	7.8	2.6	7.3	3.0		
HI	"	"	"	"	"	3.0	"	3.0	"	"	"	3.0	"	"	7.4	"	8.4	"	8.5	"	8.5	"	"	"	7.6	3.0	8.0	3.0	8.0	"		
LO	"	"	"	"	"	2.5	"	2.5	"	"	"	2.5	"	"	7.1	"	7.1	"	7.0	"	7.2	"	"	"	7.2	2.2	7.6	2.2	7.6	"		
RANGE	Ø	Ø	Ø	Ø	Ø	.5	Ø	.5	Ø	Ø	Ø	.5	-	-	.3	Ø	(1.3)	Ø	(1.5)	Ø	1.3)	Ø	Ø	Ø	.4	.8	.4	.8	.4	Ø		

* CALIB. 7 MAR. 1500

(7.0 @ 0030) (7.0 @ 0730) FLOW FLUX (7.0 @ 1400) (7.0 @ 1930) (7.2 @ 0830)

* CALIB. 13 MAR. 1700

TABLE 1 (CONT'D): REDONDO CREEK pH/WATER TEMPERATURE (T) (°C) MARCH 16 - 31 '80

DATE:	16		17		18		19		20		21		22		23		24		25		26		27		28		29		30		31	
TIME	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T
0000	7.8	3.0	7.6	3.0	7.6	2.8	7.6	2.8	7.4	3.0	7.4	(3.0)	7.3	3.0	7.3	3.5	7.2	3.5	7.2	3.0	7.2	3.0	7.2	3.0	7.2	3.0	7.2	3.0	7.2	3.0	7.2	3.0
01											7.0	(4.0)																				
02												(5.0)					3.4															
03											7.4	(3.0)																				
0400			7.5								7.3						3.3															
05																																
06																																
07																																
0800			2.9																													
09			2.7																													
10			2.5										3.1				3.2															
11			2.2										3.2				3.1															
1200	7.7		2.0				7.5						3.3				3.0															
13													3.4																			
14													3.5																			
15																																
1600																																
17																																
18																																
19																																
2000			2.1				7.4								7.2																	
21			2.3																													
22			2.4																													
23			7.6	2.5																												
MEAN	7.7	3.0	7.6	2.5	7.6	2.8	7.5	2.8	7.4	3.0	7.3	4.0	7.3	3.3	7.3	3.5	7.2	3.3	7.2	3.0	7.2	3.0	7.2	3.0	7.2	3.0	7.2	3.0	7.2	3.0	7.2	3.0
HI	7.8	"	7.6	3.0	"	"	7.6	"	"	"	7.4	5.0	"	3.5	7.3	"	"	3.5	"	"	"	"	"	"	"	"	"	"	"	"	"	"
LO	7.7	"	7.5	2.0	"	"	7.4	"	"	"	7.0	3.0	"	3.0	7.2	"	"	3.0	"	"	"	"	"	"	"	"	"	"	"	"	"	"
RANGE	.1	Ø	.1	(1.0)	Ø	Ø	0.2	Ø	Ø	Ø	(.4)	(2.0)	Ø	.5	.1	Ø	Ø	.5	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø

FLOW ↑ ?

TABLE 1 (CONT'D): REDONDO CREEK pH/WATER TEMPERATURE (T) (°C) APRIL 1 - 15, '80

DATE:	1*		2*		3		4		5*		6		7		8		9		10		11		12		13		14		15	
TIME	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T
0000	7.2	3.0	7.2	2.0							7.1	3.8	7.7	4.0	7.6	4.0	7.2	3.6	7.1	4.0	7.5	4.0	7.2	4.0	7.1	3.0	7.0	3.0	7.1	4.0		
01													7.6	3.9		3.9																
02			STOP TAPE											3.8	7.5	3.8					7.4			3.9								
03												3.7		3.6	7.4	3.7																
0400												3.6		3.4	7.3	3.6				3.9				3.8								
05												3.5		3.2				3.5						3.7								
06														3.0				3.4		3.8				3.6								
07																7.2		3.2		3.7												
0800		2.8																3.0		3.6			7.1	3.5								
09		2.6												3.1							7.3											
10		2.5												3.2																		
11													7.5	3.5																		
1200		2.4										3.4	7.4	3.6							7.2			3.4								
13		2.2										3.5		3.8				3.1														
14		2.0										3.6		4.0				3.2	(7.6)	(6.0)												
15		1.5							1st * READING @ 1730			3.8	7.3					3.3														
1600		1.0										4.0	(7.9)	4.5		3.8	7.1	3.4		5.9				3.3				(4.0)				
17		1.5							7.1	4.0	(7.8)	4.5	7.8	4.4	7.1	4.0		3.5		5.1												
18		1.7										4.4	7.7	4.3			7.0	3.6		4.8										(4.5)		
19		1.8										4.2	7.6	4.1				3.8		4.5										(5.0)		
2000		2.0										4.0		4.0		3.9	7.1	4.0		4.3				3.2						(7.4)	(5.2)	
21										3.9	7.7					3.8				4.2										(7.5)	(5.0)	
22										3.8						3.6				4.1										(4.5)		
23																			7.5	4.0				3.1						(4.2)		
MEAN	7.2	2.0	7.2	2.0	NO		NO		7.1	3.9	7.1	3.9	7.6	3.7	7.4	3.8	7.1	3.5	7.4	4.1	7.3	4.0	7.2	3.5	7.1	3.0	7.0	3.5	7.3	4.6		
HI	"	3.0	"	"	CHART		CHART		"	4.0	7.8	4.5	7.9	4.5	7.6	4.0	7.2	4.0	7.6	6.0	7.5	"	"	4.0	"	"	"	4.0	7.5	5.2		
LO	"	1.0	"	"	IN		IN		"	3.8	7.1	3.4	7.3	3.0	7.1	3.6	7.0	3.0	7.1	3.6	7.2	"	"	3.1	"	"	"	3.0	7.1	4.0		
RANGE	Ø	(2.0)	Ø	Ø	RECORDER		RECORDER		Ø		(.7)	(1.1)	(.6)	(1.5)	.5	.4	.2	(1.0)	(.5)	(2.4)	.3	Ø	Ø	.9	Ø	Ø	Ø	(1.0)	.4	(1.2)		

* END OF TAPE 2 APR FLOW

* START NEW TAPE FLOW

?

ICE BUILD-UP

TABLE 1 (CONT'D): REDONDO CREEK pH/WATER TEMPERATURE (T) (°C) APRIL 16 - 30 '80

DATE:	16		17		18		19		20		21		22		23		24 *		25		26		27		28		29		30	
	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T
	7.5	4.2	7.4	4.0	7.4	4.5	7.4	4.0	7.3	4.0	6.9	4.0	6.8	4.0	6.8	4.6	6.8	5.0	6.7	4.4	7.2	4.0	7.3	4.6	7.5	4.6	7.6	5.0	7.6	5.0
	7.4	4.1						3.9	7.2			3.9								4.3			7.4							7.3
		4.0			7.3			3.8				3.8							6.8	4.2				4.7	7.6	4.7				7.2
	7.3						7.3	3.7	7.1			3.6								4.1										
					7.2	4.4	7.2	3.6		3.9		3.2								4.0				4.8		4.8				
	7.2				7.1			3.4		3.8		3.0																		7.3
			7.3		7.0			3.2		3.7																				
	7.1							3.0	7.0	3.6								4.9						4.7						7.4
		3.9	7.2			4.3	7.1			3.5								4.8						4.6						
	7.0	3.8				4.2				3.4														4.5		4.7				
		3.7				4.1				3.2								4.9						4.4		4.6				7.5
		3.6	7.1	3.9						3.0								5.0						4.3		4.5				
			7.0	3.8		4.0	7.0											4.8						4.2		4.4				
								3.4		3.5	6.8	3.3					(11.7)	4.6	(7.4)							4.2				
								(4.0)		4.0		(4.0)					(8.8)	4.8	(7.2)							4.1				7.6
		3.7						4.4		4.5		4.5					(7.2)	4.6												
		3.9						4.8		4.8		5.0					6.9	4.5				4.1		4.3		4.0				
		4.0		3.9		4.1		5.0	6.9	5.0		5.5					6.8					4.2	7.5	4.4						
		(5.0)		4.0	(7.4)	(5.0)		(6.0)		(6.0)		6.0		4.1				4.4			7.3	4.3		4.5	7.8					
	(7.4)	5.6		(5.0)		(6.0)	7.2	6.5		(7.0)		5.5		4.2		4.7		4.3			7.4			4.6	7.6	4.2				
		5.4	7.1				7.3			6.5		5.0		4.4		4.8	6.7	4.4							7.5	4.4				
		5.0	7.2	4.9		5.5		6.0		6.0				4.5		4.9					7.3	4.4				4.6				
		4.2	7.3	4.8		(4.5)		5.5		5.5		4.3		4.6		5.0						4.5				4.8				
		4.1	7.4	4.6		4.0		4.5		(4.5)		4.1										4.6			7.6	4.9	7.4		7.7	
	7.3	4.6	7.2	4.4	7.2	5.0	7.2	4.5	7.1	5.0	6.8	4.5	6.8	4.3	6.8	4.8	(9.2)	4.7	7.1	4.2	7.3	4.3	7.4	4.5	7.6	4.5	7.5	5.0	7.5	5.0
	7.5	5.6	7.4	5.0	7.4	6.0	7.4	6.5	7.3	7.0	6.9	6.0	"	4.6	"	5.0	(11.7)	5.0	7.4	4.4	7.4	4.6	7.5	4.8	7.8	4.9	7.6	"	7.7	"
	7.0	3.6	7.0	3.8	7.0	4.0	7.0	3.0	6.9	3.0	6.8	3.0	"	4.0	"	4.6	6.7	4.3	6.7	4.0	7.2	4.0	7.3	4.2	7.5	4.0	7.4	"	7.2	"
	(.5)	(2.0	.2	(1.2)	.4	(2.0)	.4	(3.5)	.4	(4.0)	.1	(3.0)	Ø	.6	Ø	.4	(5.0)	.7	(.7)	.4	.2	.6	.2	.6	.3	.9	.2	Ø	.3	Ø

SNOW MELT

"PH RECORDER NOT RESPONDING PROPERLY" RP

TABLE 1 (CONT'D): REDONDO CREEK pH/WATER TEMPERATURE (T) (°C) MAY 1 - 15 '80

DATE:	1		2		3		4		5		6		7		8		9		10		11		12		13		14		15		
IME	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T
000	7.7	5.0	7.7	5.0	7.7	5.0	7.7	5.0	7.8	5.3	7.8	5.5	7.8	5.0	7.7	5.5	7.8	6.0	7.8	6.0	7.8	6.0	7.8	6.0	7.8	6.0	7.8	5.2	7.8	5.6		
01										5.4						5.6												5.3		5.8		
02										5.6					7.8	5.8												5.4		6.0		
03										5.8					7.6	5.9												5.6				
0400														5.1	7.7	6.0											7.7	5.7				
05			7.8		7.6					5.9				5.2	7.6													5.8				
06															7.8													6.0				
07							7.8			6.0																						
0800					7.7																											
09												5.4																				
10					7.8				7.9			5.3		5.3												6.2						
11							7.9		7.8			5.2		5.4												6.4						
1200					7.9							5.1		5.5												6.5						
13							8.0			5.9															7.9							
14					7.8		7.9			5.8															7.8							
15										5.7																6.4						
1600					7.7					5.6		5.0														6.2						
17			7.7				7.8	5.1		5.5																6.0		5.9		5.5		
18			7.8																							5.7		5.8		5.0		
19			7.7																							5.5		5.7				
2000																										5.4		5.6				
21																										5.3	7.6	5.5				
22								5.2																		5.2	7.8	5.5				
23													7.7															5.6				
EAN	7.7	5.0	7.7	5.0	7.8	5.0	7.9	5.1	7.8	5.7	7.8	5.3	7.8	5.3	7.7	5.8	7.8	6.0	7.8	6.0	7.8	6.0	7.8	6.0	7.8	5.9	7.7	5.6	7.8	5.5		
HI	"	"	7.8	"	7.9	"	8.0	5.2	7.9	6.0	"	5.5	7.8	5.5	7.8	6.0	"	"	"	"	"	"	"	"	7.9	6.5	7.8	6.0	"	6.0		
LO	"	"	7.7	"	7.6	"	7.7	5.0	7.8	5.3	"	5.0	7.7	5.0	7.6	5.5	"	"	"	"	"	"	"	"	7.8	5.2	7.6	5.2	"	5.0		
RANGE	Ø	Ø	.1	Ø	.3	Ø	.3	.2	.1	.7	Ø	.5	.1	.5	.2	.5	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	.1	(1.3)	.1	.8	Ø	(1.0)		

RAIN, SLEET, SNOW ⟶

TABLE 1 (CONT'D): REDONDO CREEK pH/WATER TEMPERATURE (T) (^{o}C) MAY 16 - 31 '80

DATE:	16		17		18		19		20		21		22*		23		24		25		26		27		28		29		30		31	
E	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T
0	7.8	5.0	7.7	5.2	7.7	6.0	7.8	6.0	7.8	7.0	7.7	7.0	7.6	7.0	7.6	9.5	7.6	9.0	7.7	8.5	7.7	8.5	7.8	9.0	7.8	9.0	7.8	9.0				
				5.3				6.3		7.2	7.8	7.2				9.0	7.7			8.0		8.0										
				5.4			7.7	6.6		7.4	7.7	7.4						8.5		7.5				8.5		8.5		' 8.5				
				5.5				6.8		7.6		7.6			7.5	8.5				7.0		7.5										
00				5.6	7.6			7.0		7.8		8.0				8.0		8.0				7.0		8.0		8.0		8.0				
							7.6		7.7	7.9								7.5		6.5												
									7.6								7.6		7.6	6.0	7.6			7.5	7.7	7.5		7.5				
			7.6				7.5									7.5		7.0	7.5			6.5										
00					7.5		7.4		7.5	7.8		7.9				7.0				7.4	5.5			7.0		7.0	7.7	7.0				
				5.5					7.4	7.6	7.6	7.7						6.5	7.5	5.0		6.0						6.5				
				5.4				6.9		7.4	7.5	7.5			7.6	(7.5)								6.5		6.5	NO DATA					
				5.3		5.8		6.8		7.2		7.4	CALIB.			(8.5)		7.0								6.0						
00				5.2	7.4	5.6		6.2		7.0	7.4		AT 1400		7.7	(9.5)		(8.0)	7.6	5.5	7.7		7.7		7.9	(10.5)						
				5.1	7.5	5.2	7.5	6.0		6.8		7.3	BY RP			(10.5)		(9.0)		(6.5)		6.5										
				5.0	7.6	5.1	7.6		7.5	6.6		7.0	7.6 (13)	*	7.8	(11)		9.5		(7.5)		7.0		7.0								
					7.7	5.0	7.7		7.6	6.4	7.5					11.5	7.7	10	7.7	(8.5)		(8.0)		7.5								
00			7.7		7.8		7.8		7.7	6.2	7.6	6.9				12		10.5	7.8	9.0	7.8	(9.0)	7.8	8.0								
						5.1				6.0		6.8			7.7			11		9.5		9.5		(9.0)								
			7.8			5.2								12.5	7.6	11.5		10.5	7.7		7.9				7.8	10						
	7.7					5.3				6.1				12		11	7.6	10		10		10		9.5								
00				5.2		5.4				6.2				11.5		10.5			7.6	9.5	7.8											
			7.7	5.4		5.6				6.4				11		10	7.7	9.5														
				5.6		5.3		6.5		6.6		6.9		10.5				9.0	7.7	9.0	7.7	9.5	7.7									
				5.8		6.0		6.8		6.8		7.0		10		9.5				8.5						9.5						
AN	7.8	5.0	7.7	5.4	7.6	5.5	7.6	6.5	7.6	7.0	7.6	7.4	7.6	11.5	7.6	9.5	7.7	8.8	7.6	7.5	7.7	8.0	7.8	8.0	7.8	8.0	7.8	8.0				
	7.8	"	7.8	5.8	7.8	6.0	7.8	7.0	7.8	7.9	7.8	8.0	"	13	7.8	12	7.7	11	7.8	10	7.9	10	7.8	9.5	7.9	10.5	7.8	9.0				
	7.7	"	7.6	5.0	7.4	5.0	7.4	6.0	7.4	6.0	7.4	6.8	"	10	7.5	7.0	7.6	6.5	7.4	5.0	7.6	6.0	7.7	6.5	7.7	6.0	7.7	6.5				
NGE	.1	Ø	.1	.8	.4	(1.0)	.4	(1.0)	.4	(1.9)	.4	(1.2)	Ø	(3.0)	.3	(5.0)	.1	(4.5)	.4	(5.0)	.3	(4.0)	.1	(3.0)	.2	(4.5)	.1	(2.5)				

*CALIB. PH BY RP

END OF CONTINUITY IN TAPE ?

TABLE 1 (CONT'D): REDONDO CREEK pH/WATER TEMPERATURE (T) (°C) JULY '80

TIME	DATE: 16 pH	T	17 pH	T	18 pH	T	19 pH	T	20 pH	T	21 pH	T	22 pH	T	23 pH	T	24 pH	T	25 pH	T	26 pH	T	27 pH	T	28 pH	T	29 pH	T	30 pH	T	31 pH	T
0000																															8.0	14
01																															7.8	
02																															8.0	
03																															7.8	
0400																																
05																															7.6	
06																															7.8 7.6	
07																															7.4	
0800																															7.5	
09																																13
10																																
11	←										NO DATA																→		START			
1200																													7.6	13		
13																															7.6 7.5	
14																																
15																															7.4	
1600																													7.7			
17																																
18																																
19																																
2000																																
21																														14		14
22																																
23																													7.6			
MEAN																													7.6	13	7.7	14
HI																													7.7	14	8.0	14
LO																													7.6	13	7.4	13
RANGE																													.1	1.0	.6	1.0

TABLE 1 (CONT'D): REDONDO CREEK pH/WATER TEMPERATURE (T) (^{o}C) AUG. 1 - 15 '80

	1		2		3		4		5		6		7		8		9		10		11		12		13		14		15	
TIME	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T
0000	7.4	14															7.8	14	7.3	14	7.2	14	7.3	14	7.2	14	7.2	14	7.4	14
01																			7.2										7.3	
02																	7.7												7.4	
03																	7.6				7.3									
0400	7.5																		7.3											
05																			7.4											
06		13															7.5													
07	7.6																7.6													
0800																	7.5		7.3						7.3		7.3			
09	END																		7.4		7.4									
10	OF																				7.3				13		7.2		13	
11	CHART																7.4	13				13		13	7.2					
1200																			13		7.2									
13					NO DATA												7.5		7.3								7.3			
14															START		7.4													
15															7.4	13			7.2											
1600															7.6	14							7.2				7.4			
17															7.8				7.3											
18															7.0															
19															7.0		7.3	14	7.2								7.3		14	
2000															7.8				14		14		14		14		7.4			
21																	7.2										7.3			
22															7.7		7.3										7.5		7.3	
23															7.8						7.3						7.4		7.4	
MEAN	7.5	14													7.4	14	7.5	14	7.3	14	7.3	14	7.3	14	7.2	14	7.3	14	7.4	13.6
HI	7.6	14													7.8	14	7.8	14	7.4	14	7.4	14	7.3	14	7.3	14	7.5	14	7.4	14
LO	7.4	13													7.0	13	7.2	13	7.2	13	7.2	13	7.2	13	7.2	13	7.2	14	7.3	13
RANGE	.2	1.0													.8	1.0	.6	1.0	.2	1.0	.2	1.0	.1	1.0	.1	1.0	.3	0	.1	1.0

TABLE 1 (CONT'D): REDONDO CREEK pH/WATER TEMPERATURE (T) (^{o}C) AUG. 16 - 31 '80

TIME	DATE: 16		17		18		19		20		21		22		23		24		25		26		27		28		29		30		31	
	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T
000	7.4	14	7.4	14	7.4	13	7.2	13	7.5	13	7.4	13	7.4	12	7.3	13	7.6	13	7.2	13	7.2	13	7.2	13								
1							7.3								7.4																	
2				13								12																				
3							7.4										7.5															
400																																
5																																
6		13															7.4		7.3													
7										12										12												
800																			7.2													
9												11										12										
0																12								12								
1											7.5																					
200				12			7.3				7.6																					
3			7.3		7.3	12					7.5						7.3															
4							7.4																									
5					7.4						7.6						7.2															
600			7.4				7.5				7.4	12					7.4															
7																																
8							7.6		13							13	7.3			13			7.2	12								
9				13	7.3	13	7.5																									
000		14							7.6					13	7.2							13										
1							7.6		7.4						7.4								END OF TAPE									
2	7.3						7.5								7.6																	
3	7.4				7.2								7.3				7.2															
EAN	7.4	13.5	7.4	13	7.4	13	7.4	13	7.5	12.5	7.4	12	7.4	12	7.4	13	7.4	13	7.2	12.5	7.2	12.5	7.2	12.5								
I	7.4	14	7.4	14	7.4	13	7.6	13	7.6	13	7.6	13	7.4	13	7.6	13	7.6	13	7.3	13	7.2	13	7.2	13								
0	7.3	13	7.3	12	7.2	12	7.2	13	7.4	12	7.4	11	7.3	12	7.2	12	7.2	13	7.2	12	7.2	12	7.2	12								
ANGE	0.1	1.0	0.1	2.0	0.2	1.0	0.4	0	0.2	1.0	0.2	2.0	0.1	1.0	0.4	1.0	0.4	0	0.1	1.0	0	1.0	0	1.0								

TABLE 1 (CONT'D): REDONDO CREEK pH/WATER TEMPERATURE (T) (^{o}C) SEPT. 1 - 15 '80

DATE:	1		2		3		4		5		6		7		8		9		10		11		12		13		14		15	
TIME	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T
0000							7.3	12	7.2	12	7.3	12	7.0	12	7.0	13	7.1	13	7.2	12.5	7.0	12	7.0	12.5	7.0	12	7.0	12	7.0	12	
01													7.2																		
02											7.2		7.4						7.1												
03																	7.2														
0400									7.4 7.3				7.3																		
05													7.2																		
06							11.5												7.0												
07																															
0800							11								12.5		7.1	12.5													
09					START TAPE								7.1				7.0														
10					7.4	11									7.1					12					11.5		11.5				
11							7.2		7.2				7.0			12							11.5		11		11		11.5		
1200					7.3												7.1														
13							7.3																11								
14																															
15									7.3								7.2	12	6.9												
1600																	7.4														
17																															
18							7.2	11.5	7.2		7.1 7.2												12						12		
19					7.2	11.5					7.3 7.2				12.5		7.3								12		12				
2000					12								12.5																		
21							12		7.3								7.2				12.5										
22															13																
2230 23					7.3						7.1	12.5	13				12.5														
MEAN					7.3	11.5	7.3	11.5	7.3	12	7.2	12	7.1	12	7.1	12.5	7.2	12.5	7.0	12	7.0	12	7.0	12	7.0	11.5	7.0	11.5	7.0	12	
HI					7.4	12	7.3	12	7.3	12	7.3	12.5	7.4	13	7.1	13	7.4	13	7.2	12.5		12.5		12.5		12		12		12	
LO					7.2	11	7.2	11	7.2	12	7.1	12	7.0	12	7.0	12	7.0	12	6.9	12		12		11		11		11		11.5	
RANGE					0.2	1.0	0.1	1.0	0.1	0	0.2	0.5	0.4	1.0	0.1	1.0	0.4	1.0	0.3	0.5	0	0.5	0	1.5	0	1.0	0	1.0	0	0.5	

TABLE 1 (CONT'D): REDONDO CREEK pH/WATER TEMPERATURE (T) (^{o}C) SEPT. 16 - 30 '80

DATE:	16		17		18		19		20		21		22		23		24		25		26		27		28		29		30		31	
	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T	pH	T
	7.0	12.5	7.0	12	7.1	12	7.1	12	7.2	12	7.2	11.5			7.2	11	7.2	11	7.1	10.5	7.1	10	7.1	10.5	7.1	10.5	7.0	10	7.0	10		
											STOP																					
							7.2										7.1															
		12																			10.5											
						11.5													10						7.0	10						
																		10.5						10								
				11.5																												
								11.5		11.5																						
						7.2	11											10														
								11					START											9.5								
		11.5		11												10.5										9.5						
						10.5				11			7.2	10																		
		11														10				9.5												
																		9.5														
																				9												
																								10		10						
		11.5	7.2			11																										
									7.3															10.5								
		12		11.5					7.2					10.5																		
				12				11.5						11						9.5												
						11.5		12		11.5						10.5		10														
			7.1		7.1											11				10												
	7.0	11.5	7.0	11.5	7.2	11.5	7.2	11.5	7.2	11.5	7.2	11.5	7.2	10.5	7.2	10.5	7.1	10.5	7.1	9.5	7.1	10.5	7.1	10	7.0	10	7.0	10	7.0	10		
	7.0	12.5	7.2	12	7.2	12	7.2	12	7.3	12	7.2	11.5	7.2	11	7.2	11	7.2	11	7.1	10.5	7.1	10.5	7.1	10.5	7.1	10.5	7.0	10	7.0	10		
	7.0	11	7.1	11	7.1	10.5	7.1	11	7.2	11	7.2	11.5	7.2	10	7.2	10	7.1	9.5	7.1	9	7.1	10	7.1	9.5	7.0	9.5	7.0	10	7.0	10		
E	0	1.5	0.1	1.0	0.1	1.5	0.1	1.0	0.1	1.0	0	0	0	1.0	0	10	0.1	1.5	0	1.5	0	0.5	0	1.0	0.1	1.0	0	0	0	0		

TABLE 2: REDONDO CREEK WATER TEMPERATURE - BARTON METER (CONVERTED TO °C)

JUNE '80

TIME DATE:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
0000																											13	13	13	13	
01																											12	12	12		
02																														12	
03																											11	11	11		
0400																															
05																											10	10			
06																														11	
07																												9	10		
0800																										START					
09																										V					
10																										11	11	10	11	12	
11																										12	12	12	12		
1200																										13	13	13	13	13	
13																										14	15	14	15	15	
14																										17	16	16	16	16	
15																										18	17	17		17	
1600																												18	17		
17																															
18																													16		
19																										17		17			
2000																											16			16	
21																										16		16	15		
22																										15	15	14	14	14	
23																										13	13	13	13	13	
MEAN																															
HI																															
LO																															
RANGE																															

TABLE 2 (CONT'D) REDONDO CREEK WATER TEMPERATURE - BARTON METER (CONVERTED TO °C) JULY '80

TIME DATE:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
0000	13	13	12	12	11	13	13	12	13	13	14	13	12	13	13	12	12	12	13	13	12	11	11	11	12	13	13	13	13	13	13
01	12						12		12		13			12	12																
02		12	11	11	10	12				12		12				11			12	12	11								12		
03								11	11		12				11			11							12	12	12			12	12
0400	11		10	10	9	11							11				11			11					11				11		
05											11			11										10				11			
06			9		14											10						10								11	
07				9				10	10	11						9	10	10			10		10	9	10	11	11				11
0800		11		10	9	10												11										12			
09				11	10	11		11	11	12	12					10	11			12	11	11	11	10	11	12	12				
10	12		10	12	11	12	13		12		13	13	12	12	12	11		12	13		12			11				13	12		12
11		12	11	13	12	13		12	13	13	14	14	13	13		12	12	13		13		12	12	12	12	13	13		13	12	
1200	13		12				14	13	14	14	16	16		14	14	13	13	14	14	14	14	13	13	13	13	14	14	14	14	13	13
13	14	13	13	14	13	16		14		16			14	16	16	16	14	16	16		15	14	14	14	16	16	14	16	16	14	14
14	16	15	14	16	16	17	16	16		17		17	16		17	18	16		17		(13)				17	17	16	17	17		16
15	17	16	16	17	17	18				18						17	17					13	13	16			17		16		
1600		17	17				17				17	16		17										17					14		
17																		15					14	16				18			
18	16						16				16		15	16				14	16			14			16			17	16		
19		16	16	16	16	17				17		15	14			16						13				16	16				
2000	15					16	15	15			15	14			16		16						13	15	15				15		
21	14	15	14	14	14	14	14	14		16	14			15	14	14	14		15					14	14	15	15	15	14	14	15
22		14	13	13			13		13	15		13	13	14	13	13	13	13	14	13	12	12	12			14	14	14		13	14
23	13	13	12	12		13		13		14	13			13					13					13	13			13			
MEAN	13	13.5	12.5	13	13	14	13	13	12.5	14	14	14	13	14	14	12.5	13	13	14	13	13	12	12	12.5							
HI	17																														
LO	11																														
RANGE	6																														

TABLE 2 (CONT'D): REDONDO CREEK WATER TEMPERATURE - BARTON METER (CONVERTED TO ^{o}C) AUG. '80

TIME DATE:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
0000	13	14	13	14	13	14	14	13	13																						
01				13		13																									
02	12	13					13																								
03				12	12																										
0400																															
05							12		12																						
06	11		12																												
07		12				12																									
0800			11.5	11			11.5	12																							
09	11.5	13	12	11.5			12																								
10	12		13	12		13	13																								
11	13	14.5		13	13				13																						
1200	14.5	15.5	14.5	14.5		14.5	14.5	13																							
13	15.5	17	15.5	15.5	14	17	15.5		14.5																						
14			17	17	14.5	16	17	14.5	15.5																						
15	16		18	18	15.5		(11)*		17																						
1600	17	16			17		(13)*	15.3	18																						
17									17																						
18		15.5																													
19	16		17	17	16	15.5		15																							
2000		15			15.5	15		14.5																							
21	15.5	14.5	16	16	15	14.5			15.5																						
22	15	14	15.5	15.5	14.5	14	14	14	15																						
23	14.5		15				13		14.5																						
MEAN	14	14	14.5	15	13	14	13	13.5	14																						
HI	17	17	18	18	17	17	17	15.5	18																						
LO	11	12	11.5	11	12	12	11	12	12																						
RANGE	6	5	6.5	7	5	5	6	2.5	6																						

TABLE 3: REDONDO CREEK AVERAGE DAILY FLOW RATE (cfs)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
AUG.'79																						START/	2.0	2.0	2.0	2.0	1.9	1.8	1.7	1.7	1.8
SEP.'79					2.0	1.9	1.8	1.9	1.8	1.7	1.8	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0					2.0	2.0	1.7	1.6	1.4	1.2	1.2	
OCT.'79	1.2		1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.5	1.4	1.4	1.4	1.4	1.4	1.6	1.6	1.7	1.7	1.7
NOV.'79	1.6	1.6	1.55	1.6	1.6	1.6	1.6	1.6	1.6			1.9	1.9	1.8	1.6	1.6	1.6	1.6	1.6	1.6	1.9	2.9	5.1	5.1	1.9	1.6	1.62	3.6	8.6	3.9	
DEC.'79	1.9	1.6	1.6	1.6	1.52	1.56	1.56	1.56	1.56	1.6	1.56	1.56	1.56	2.4	1.9	1.5)	1.5	1.5	1.5	1.65	1.7	1.75	1.8	3.4	1.9				1.9	1.9	1.9
JAN.'80	1.9	1.9	2.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	2.9	3.9	2.9	1.9	1.9	1.9	1 9	1.9	1.9	1.9
FEB.'80	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	(3.4	3.9	2.4)	1.9	1.9	1.9	1.9	1.9	1.9	(2.4	3.0	2.4)	1.9	1.9	1.6	1.6	1.6	1.6	1.9	3.4			
MAR.'80	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.6	3.8	3.9	3.4	5.1	3.4	3.9	3.9	3.4	5.7	4.5	3 4	3.4	3.9	3.9	3.4	3.4	2.8	2.8	2.8	2.8	2.8	3.4	3.4
APR.'80	5.7	3.4	3.4	3.4	4.5	5.7	6.8	7.8	7.8	9.2	8.6	8.2	8.2	8.2	8.2	8.5	10.0	12.4	15.0	17.8	21.0	29.1	27.4	25.0	4.2	23.5	22.2	21.8	22.1	22.4	
MAY '80	22.4	20.9	20	20.6	21.8	22.4	23.5	25.0	24.5	Drive Stopped					25.0	26	24.5	24.8	24.9	24.4	23.9	22.9	21.8	20.5	19	17.8	16.9	16.0	15	14.8	15
JUNE'80	15	15	14.8	14.6	14.2	14.2	14	14	13.3	12.4	11.6	11.0	10.8	10.5	10.3	10.3	10.3	10.0	9.8	9.8	9.6	9.4	9.2	9.0	8.5	8.5	8.4	8.2	8.2	8.2	
JULY'80	7.8	7.8	7.1	7.1	(6.4	5.7	5.1	4.5	3.9)	3.9	3.9	3.9	3.9	3.8	3.4	3.3	3.2	3.2	3.2	3.1	3.2	3.2	3.3	3.1	3.1	3.1	3.1	3.1	4.0	3.2	3.2
AUG.'80	3.1	3.4	3.3	3.1	3.1	3.1	4.0	4.5	5.1	3.0	2.5	2.5	2.8	2.7	2.7	2.7	2.6	2.6	2.6	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3
SEP.'80	2.3	2.3	1.9	1.7	1.7	1.8	1.8	1.8	1.9	2.0	2.0	2.0	2.0	2.1	2.1	2.1	2.1	2.1	2.1	2.3	2.1	2.1	2.1	2.1	2.1	2.1	2.3	2.3	2.3	2.3	

*1 "Removed stones from flume" RP

*3 Based on slope of flume readings

** Thunderstorms

** "Heavy thunderstorm upper watershed" RP

** Thunderstorm?

EMPTY SPACES INDICATE MISSING DATA

TABLE 4: REDONDO CREEK

GROSS FLOW FLUCTUATIONS
NET CHANGES(FEET)

AUG. '79

TIME DATE:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
0000																										+.02					
01																										-.01					
02																										-.01					
03																															
0400																															
05																															
06																															
07																											+.01	+.01		+.01		
0800																														+.01	
09																															
10																															
11																															
1200																															
13																															
14																															
15																															
1600																															
17																															
18																										-.01	-.01	-.01			
19																															
2000																															
21																															
22																															
23																															
ACTIVITY INDEX (Sum of Changes x 100)																			START 8/23			0		0	0	(5)	2	2	1	1	0
ISCO TAKEN (X)																															

TABLE 4 (CONT'D): REDONDO CREEK

GROSS FLOW FLUCTUATIONS
NET CHANGES(FEET)

SEPT. '79

TIME DATE:	1 2 3	4 5 6	7 8 9	10 11 12	13 14 15	16 17 18	19 20 21	22 23 24	25 26 27	28 29 30	31
0000			-.01	-.03							
01				-.01						+.01	
02											
03									+.01		
0400											
05											
06										+.01	
07									+.01		
0800										+.01	
09											
10		-.01				-.01					
11											
1200											
13											
14									-.01	-.01	
15			+.01								
1600			+.01						-.01 -.01	-.01 -.01	
17									+.01		
18											
19											
2000											
21											
22				(+.08)							
23			-.01	-.03						+.01 +.01	
ACTIVITY INDEX (Sum of Changes x 100)	NO DATA 1		0 (3) 1	0 (11) 4	0 0 0	0 0 1	0 0 NO DATA		2 3 1	3 3 2	
ISCO TAKEN (X)				X							

TABLE 4 (CONT'D): REDONDO CREEK — GROSS FLOW FLUCTUATIONS NET CHANGES(FEET) — OCT. '79

TIME DATE:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
0000						+.01																									
01																						-.02	+.01								
02																						+.02	-.01								
03					+.01																	-.02									-.01
0400																						+.02									
05							+.01			+.01												-.02									
06																					+.01	+.02									
07																					+.01	-.02									
0800																															
09																						-.02 +.02									
10																						-.02 +.02									+.02
11																						-.02	-.01								-.02 +.03
1200																						+.02									
13																							+.01								-.01
14																															-.01
15						-.01																									
1600						+.01			-.01																					+.02	
17																														-.01	
18				-.01	-.01		-,01			-.01											-.01		+.01							-.01	
19				+.01	+.01					+.01	-.01		-.01								+.01										
2000								-.01					+.01								-.01	+.01									
21			-.01					+.01													+.01	+.01									
22																							+.01								
23			+.01			-.01+.01			+.01			+.01																			
ACTIVITY INDEX (Sum of Changes x 100)	0	0	2	2	(4)	(4)	2	2	2	1	2	2	2	0	0	0	0	0	0	0	(6)	(28)	4	2	0	0	0	0	0	(4)	(10)
ISCO TAKEN (X)																						X									

TABLE 4 (CONT'D): REDONDO CREEK — GROSS FLOW FLUCTUATIONS NET CHANGES(FEET) — NOV. '79

TIME DATE:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
0000			-.01																												
01													+.01																		
02		-.01						-.01						+.01 -.01								+.01	+.01		-.02			+.06			
03																	-.01					+.02	+.02		-.02		-.01	+.06			
0400															+.01 -.01	+.01 -.01						+.02	+.02		-.02			+.06			
05													+.01								+.01	+.02	+.02		+.01			+.06			
06					-.01	-.01							-.02								+.01	+.02	+.02								
07													+.01									+.01	+.02								
0800						+.01							+.01									+.01	+.01								
09						-.01							-.01		-.01	-.01						+.01	+.01								
10					+.01								-.01				+.01					-.01	+.01	+.01							
11		+.01	+.01		+.02	+.02							-.01		+.02	+.02	+.02					-.02	+.01	-.01					-.05		
1200		+.01	+.02	+.03		+.01						+.01 -.01	+.04 -.04	+.01 -.01 +.02		+.01 -.01						-.01	+.01	+.01					-.05		
13		+.01	-.02		-.02							+.03	+.01	-.01	-.01		-.01				-.01 -.01	-.01 -.02	-.01	-.02							
14		-.02	-.01	-.02		-.02						-.01	-.01	-.01								-.02	-.01	-.02				-.08			
15												-.01										-.02	-.02				-.01				
1600																						-.02	-.02		-.01 +.01			-.02			
17																						-.02						-.02			
18			+.01 -.01				+.01																								
19																															
2000																															
21																															
22																															
23												-.01																			
ACTIVITY INDEX (Sum of Changes x 100)	(5)	(7)	(8)	0	(6)	(8)	1	1	0	NO DATA		(8)	(19)	(8)	(6)	(7)	(5)	0	0	0	(4)	(28)	(17)	(11)	(7)	2	2	(32)	(4)	(10)	
ISCO TAKEN (X)						X															Moderate ice build-up up-and-down-stream from building							X			

TABLE 4 (CONT'D): REDONDO CREEK — GROSS FLOW FLUCTUATIONS NET CHANGES(FEET) — DEC. '79

TIME DATE:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
0000																															
01																															
02																			-.01					+.14							
03	+.01														+.04		-.01	-.01						+.01							
0400	+.01													+.02	+.04									+.01							
05	+.01													+.02	+.02					-.01			-.01	+.02							
06	+.01													+.02	-.02																
07	+.01												+.02	+.04	-.02																
0800	+.01												+.02	+.02	-.02																
09	+.01												-.04	.02	-.04			+.02					+.02								
10	-.04													-.02			+.02	-.01					+.02								
11	-.03												+.02	-.02			+.01						-.02	-.08							
1200													+.01	-.02									-.02	-.02							
13										+.01			-.01	-.02										-.02							
14										+.01				-.02										-.02							
15					-.01					-.02	+.02 -.02			+.02										-.02							
1600						+.01 -.01																		+.02 -.03							
17																															
18																															
19						+.01																									
2000			+.01 -.01																												
21																															
22																															
23																															
ACTIVITY INDEX (Sum of Changes x 100)	(14)	0	2	0	1	3	0	0	0	4	4	0	(12)	(26)	(20)	0	3	4	1	1	0	0	(9)	(39) Ice build-up RP	0	0	0	0	0	0	0
ISCO TAKEN (X)																												X			

TABLE 4 (CONT'D): REDONDO CREEK — GROSS FLOW FLUCTUATIONS NET CHANGES(FEET) — JAN. '80

TIME \ DATE:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
0000																															
01																															
02																						-.01									
03																															
0400																					-.01		+.10				-.01				
05																							+.02								
06			.14																				+.02								
07			.04																				+.02								
0800			-.02																				+.02								-.01
09			+.01																				+.02	+.02							
10			-.06																			+.06	+.02	+.02	+.02 -.02						
11			-.06							-.01 +.01												-.01 +.03	-.10								
1200			+.02				-.01 +.01														+.01	-.05	-.08				+.01				+.02
13			-.02 -.04							-.01				+.04							+.01		-.02	-.02 -.01							
14									+.01					-.03							-.01		+.02 -.02								
15																															-.01
1600																															
17																															
18										-.01																					
19																															
2000																															
21																															
22																															
23																															
ACTIVITY INDEX (Sum of Changes x 100)	0	0	(42)	0	0	0	0	2	1	(5)	0	0	0	(7)	0	0	0	0	0	0	(4)	(20)	(46)	7	4	0	2	0	0	0	(4)
	HOH back-up caused by ice																					Ice layer above shed indicates									
ISCO TAKEN (X)	blocking culvert under road. Remains of ice seen in flume" RP																					an ice back-up (prob. Wed.) RP									

TABLE 4 (CONT'D): REDONDO CREEK — GROSS FLOW FLUCTUATIONS NET CHANGES(FEET) — FEB. '80

TIME DATE:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
0000																			-.01						-.01						
01																															
02	-.01	-.01			-.01	-.01													-.01												
03									+.02																						
0400								-.01	+.02										-.01												
05									+.04	+.08																					
06								+.01	+.02	+.05	+.01																				
07								-.01	+.01	+.05	+.01														+.01						
0800									+.01	+.05	+.02														+.02						
09					+.01			-.01	-.04	-.04	+.02									+.02					+.01	+.01					
10	+.01	+.01			+.01	+.01			-.03	-.04	+.02								+.02				+.02	+.01	-.02 +.01		+.01				
11	-.01								+.02 -.03	-.05	-.04	+.02	+.01						-.01	-.02			+.01	+.02	+.01	+.02	-.01 +.01				
1200					-.01	-.01			-.04	-.05	-.02		-.01						-.01			+.01	+.01	+.01			+.02				
13										-.02	+.01 -.02	-.02							+.01			-.01	-.01	-.01	-.01	-.02					
14																+.01				-.01 +.01			-.01	-.01	-.01						
15																-.01							-.01	-.01	-.01		-.01				
1600								+.01										+.01	-.01				-.01								
17																															
18								-.01										+.01													
19																															
2000																		+.01													
21																															
22																		+.01													
23																															
ACTIVITY INDEX (Sum of Changes x 100)	3	2	0	0	4	3	0	(6)	(28)	(43)	(17)	(4)	2	0	0	2	0	4	(9)	(4)	2	2	(8)	(7)	(12)	(5)	(6)				
ISCO TAKEN (X)																															

TABLE 4 (CONT'D): REDONDO CREEK — GROSS FLOW FLUCTUATIONS NET CHANGES(FEET) — MARCH '80

TIME DATE:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
0000																															
01										-.01																		+.01			
02								-.01					+.14				+.10														
03														-.02			+.01	+.12													
0400													-.04				+.01	+.02													
05													+.01				+.01														
06	-.02	-.01					-.01						-.04				+.01	-.02													
07													-.07				-.02													+.02	
0800		+.01			-.01					+.01		-.01					-.10						+.02			+.02		-.01		+.02	
09		+.01			+.01		+.01	+.01	+.01	+.01		+.01	+.02				-.02			+.02	+.02		+.02			+.02	-.01			-.02	
10	+.02	+.01					+.01	+.02	+.02	-.01			+.02	+.02			-.10			-.02	-.02		-.02			-.01	-.01		+.02	-.02	-.01
11	+.02						-.01	-.01	-.01	-.01			-.02	+.02			-.02	+.01								-.01			+.02	+.02	
1200	-.02	-.02						-.01	-.01								+.02		+.02										-.02	+.03	
13														-.02			+.04	-.01	-.02										-.02	-.02	+.02
14						+.01								+.03			-.02	-.02												-.02	-.01
15														-.02			-.01											+.02			
1600																	-.01		+.01												
17																			-.01												
18																															
19																															-.01
2000												-.01	-.01	-.01														-.01			
21																															
22																-.01									-.01						
23							-.01																			-.01			-.01		
ACTIVITY INDEX (Sum of Changes x 100)	(8)	(6)	0	0	2	1	(5)	(5)	(6)	(5)	0	3	(37)	(14)	0	1	(36)	(34)	(6)	(4)	(4)	0	0	(6)	1	(5)	(5)	(5)	(9)	(17)	(5)
ISCO TAKEN (X)													X					RP						X							pp

Ice build-up at culvert under road

Some ice at road culvert and above stream upstream side of shed- probably ice back-up

TABLE 4 (CONT'D): REDONDO CREEK — GROSS FLOW FLUCTUATIONS NET CHANGES(FEET) — APRIL '80

TIME DATE:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
0000																					-.01	+.03									
01	+.01																		-.01		-.01	+.03		-.01							
02	+.02	-.01		-.01								-.01									-.01	+.03		-.01							
03	+.02							-.01								-.01			-.01	-.01		+.03		-.01							
0400	+.02			-.01				-.01			-.01			-.01									-.06	-.01	-.01		-.01	-.01		-.01		
05	+.02		-.01										-.01				-.01		-.01			+.02 -.04	-.01	-.01							
06	+.02	+01						-.01	-.01	-.01												+.02	-.01		-.01					-.01	
07	+.02								+.01					+.02							-.01	-.01									
0800	+.02												+01	+.01 -.01						-.01		-.02	-.01								
09	-.03			+.02				+.02						-.02								-.02				-.01					
10	-.03			+.02	-.01			+.02				+.01		+.01								-.02	-.01	-.01	-.01			-.01			
11	+.02							+.01 -.01						+.01		-.01						-.02									
1200	-.05	+.01	+.02	-.03				+.01		+.02		-.01	+.01								-.01	-.01	-.01	+.01		+.01	+.01			-.01	
13	-.03							-.03	+.02	+.02				+.01		+.02								-.01						+.01	
14	+.01 -.02		-.01	+.01		+.01				+.02				+.01		+.02	+.02	+.03	+.02	+.02			+.01		+.01	+.01	+.01	+.01		+.01	
15			+.02	+.01	+.01	+.01	+.02	+.02							+0.2	+.02	+.01	+.03	+.01	+.01										+.01	
1600				+.01	+.01	+.01				-.01					+.01	+.02	+.01		+.01	+.01		-.01	+.01			+.01	+.01		+.01	+.01	
17						+.01				-.01					+.01		+.01	+.02	+.02	+.01	-.01										
18										-.01	-.01			-.01		-.01	+.01	+.02 -.02	+.02	+.01		+.02							+.02		
19						-.01	-.01							-.01		-.01		+.02	+.02	+.01		+.02	+.01							+.01	
2000						-.01		-.01		-.01	-.01			-.01	-.01	-.01	-.01	-.02		+.01	+.03	+.02	+.01	-.01	-.01				+.02	-.01	
21						-.01		-.01		-.01						-.01		-.02	-.01	+.01	+.03	+.02	+.02						+.01		
22			-.02			-.01			-.01			-.01	-.01		-.01	-.01	-.01	-.02	-.02	+.01	+.03		+.02					+.01			
23					-.01												-.01			-.01	+.03			-.01	-.01	-.01	-.01			-.01		
ACTIVITY INDEX (Sum of Changes x 100)	(34)	3	(8)	(12)	4	(8)	3	(17)	5	(12)	3	4	4	(13)	(6)	(15)	(10)	(20)	(16)	(15)	(18)	(49)	(14)	(10)	5	6	5	4	8	8	
	Ice build-up																		Snow melt						Approx. 5 cm deep stones have washed into E. side of flume at measuring point			RP			
ISCO TAKEN (X)								X											X			X								

TABLE 4 (CONT'D): REDONDO CREEK — GROSS FLOW FLUCTUATIONS NET CHANGES(FEET) — MAY '80

TIME DATE:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
0000																-.01	-.01										+.01				
01																															
02																-.01															
03																															
0400		-.01		-.01													-.01														
05																															
06			-.01						-.01																						
07																															
0800																-.01						-.01	+.01						+.01		
09																														-.01	
10																														-.01	+.01
11																															
1200								-.01	-.01							+.01															
13																															
14																+.01				-.01			-.01	-.01	-.01	-.01	-.01	-.01			
15							+.01		+.01					+.01		+.01															
1600		+.01		+.01		+.01	+.01		+.01					+.01		+.01	+.01									-.01	-.01		-.01	-.01	
17							+.01		+.01					+.01	+.01														-.01		
18				+.01		+.01	+.02							+.01															+.01	-.01	-.01
19							+.01							+.01	+.01															+.01	
2000				+.01		+.01								+.01	+.01		+.01														
21										DRIVE STOPPED																					
22			+.01											+.01	-.01	-.01							-.01								
23	-.01	-.01																													
ACTIVITY INDEX (Sum of Changes x 100)	1	3	2	4	0	3	(6)	1	(5)				(7)	4		(8)	4	0	0	0	1	1	3	2	2	2	2	2	3	(5)	1
													RAIN SLEET SNOW																		
ISCO TAKEN (X)	X							X						X	X	X			X		X		X								

* Rocks & stones continually washing into flume (PP)

TABLE 4 (CONT'D): REDONDO CREEK — GROSS FLOW FLUCTUATIONS NET CHANGES(FEET) — JUNE '80

TIME DATE:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
0000																															
01																															
02																															
03																															
0400		+.01			+.01																										
05																															
06			+.01			+.01	+.01	+.01		+.01			+.01	+.01				+.01			+.01	+.01	+.01	+.01	+.01	+.01	+.01	+.01	+.01	+.01	
07																															
0800																+.01	+.01		+.01												
09				+.01																											
10									-.01																						
11																							-.02								
1200							-.01					-.01						-.02	-.02												
13																		+.02	-.02												
14								-.01			-.01				-.01	-.01	-.01	+.02	+.03	-.01		-.01	+.01	-.01							
15													-.01					-.04			-.01					-.01					
1600	-.01	-.01	-.01	-.01	-.01				-.01	-.01				-.01	+.01			+.02				-.01	-.01		-.01						
17																							+.01				-.01	-01	-.01	-.01	
18																		Working on S.W. tank, filling and emptying RP					Tank fill and overflow								
19																															
2000																															
21																															
22																															
23	+.01																														
ACTIVITY INDEX (Sum of Changes x 100)	1	2	2	2	2	1	2	2	2	2	1	1	2	2	2	2	2	(13)	(10)	1	1	3	(6)	2	2	2	2	2	2	2	
ISCO TAKEN (X)					X					X		X				X				X				X							

TABLE 4 (CONT'D): REDONDO CREEK — GROSS FLOW FLUCTUATIONS NET CHANGES(FEET) — JULY '80

TIME \ DATE:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
0000							-.01	-.02																							+.02
01								+.02																							
02																												+.01			
03																															
0400																															
05																															
06	+.01	+.01				+.01					+.01				+.01		+.01				+.01										
07			+.01	+.01	+.01											+.01		+.01		+.01						+.01	+.01				
0800																															
09																															
10																															
11			-.01												-.01									-.01							
1200			-.01				-.01								+.01	-.01					-.01	-.01	-.01	+.01		-.01					
13			-.01									+.02				+.01			-.01		+.02	+.01		+.01		+.01				-.01	
14					-.01	-.01					-.04	-.02		-.01				-.01	+.01		-.01	+.01								+.01	
15					-.01									+.01								-.01									
1600	-.01					-.01		-.02										•					+.03				-.01		+.05		
17		-.01	-.01	-.01				+.02		-.01													-.03						-.01		
18										+.01							+.02			-.01									-.01		-.02
19					+.01	+.01										-.01							+.01						-.01		+. 1
2000						+.01										+.01	-.01				-.01								-.01		
21					-.01												+.01									-.01						
22			+.01																							+.01					
23																															

F.W. being pumped to Bill drill rig on

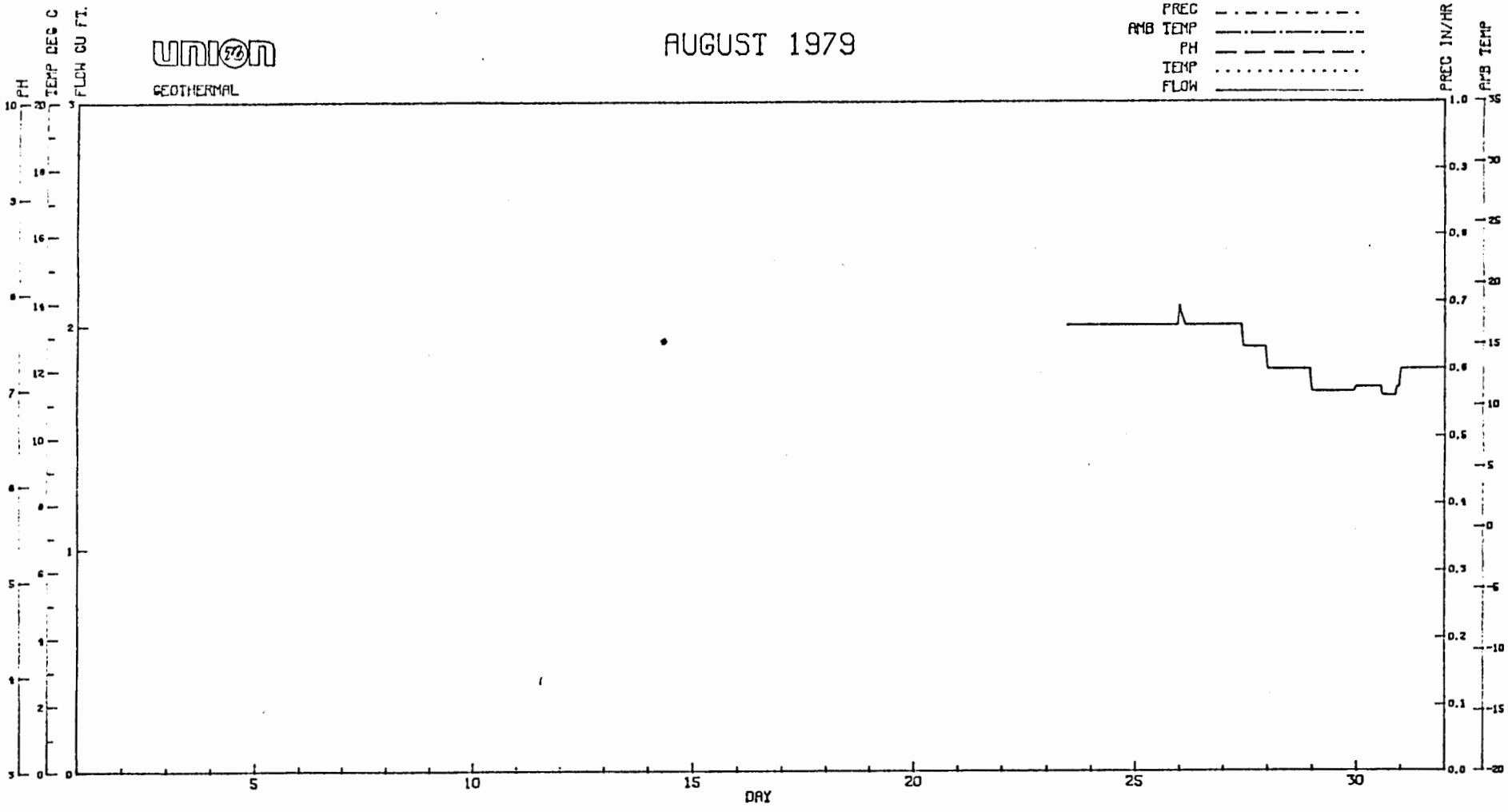
work on flume

ACTIVITY INDEX (Sum of Changes x 100)	2	2	(5)	2	(5)	(5)	2	(8)	0	2	(5)	(4)	0	2	3	(5)	3	(4)	2	2	(6)	4	(9)	2	2	3	2	1	(9)	2	(5)
								?			?							?					?							?		
ISCO TAKEN (X)			X									X											Heavy thunder-storm upper watershed RP						Probably thunder-storms	X	

TABLE 4 (CONT'D): REDONDO CREEK — GROSS FLOW-FLUCTUATIONS NET CHANGES(FEET) — AUG. '80

TIME DATE:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
0000																															
01			-.01				+.02		-.02			+.01																			
02							-.01		-.02																						
03			-.01				-.01		-.02																						
0400		-.01							-.02																						
05		+.01																													
06					+.01																										
07																															
0800									-.01																						
09																															
10																															
11							+1.7		-.01																						
1200								-.01																							
13							-1.0																								
14		-.01	-.01		-.01			+.04		-.01																					
15		+.01	+.01		+.01		-.01	+.03																							
1600							-.01	-.03			-.01																				
17							-.02	-.01																							
18		+.03		-.01			-.01	-.01				-.01																			
19								+.02																							
2000		+.02				-.01		-.02			-.01																				
21						+.01						+.01																				
22								+.03																							
23		-.01						+.04																							
ACTIVITY INDEX (Sum of Changes x 100)	0	(10)	(4)	1	3	2	(36)	(25)	(10)	1	2	3																			
		?																													
ISCO TAKEN (X)						X		X																							

FIGURE 1



SUPERSEDES

FIGURE 2

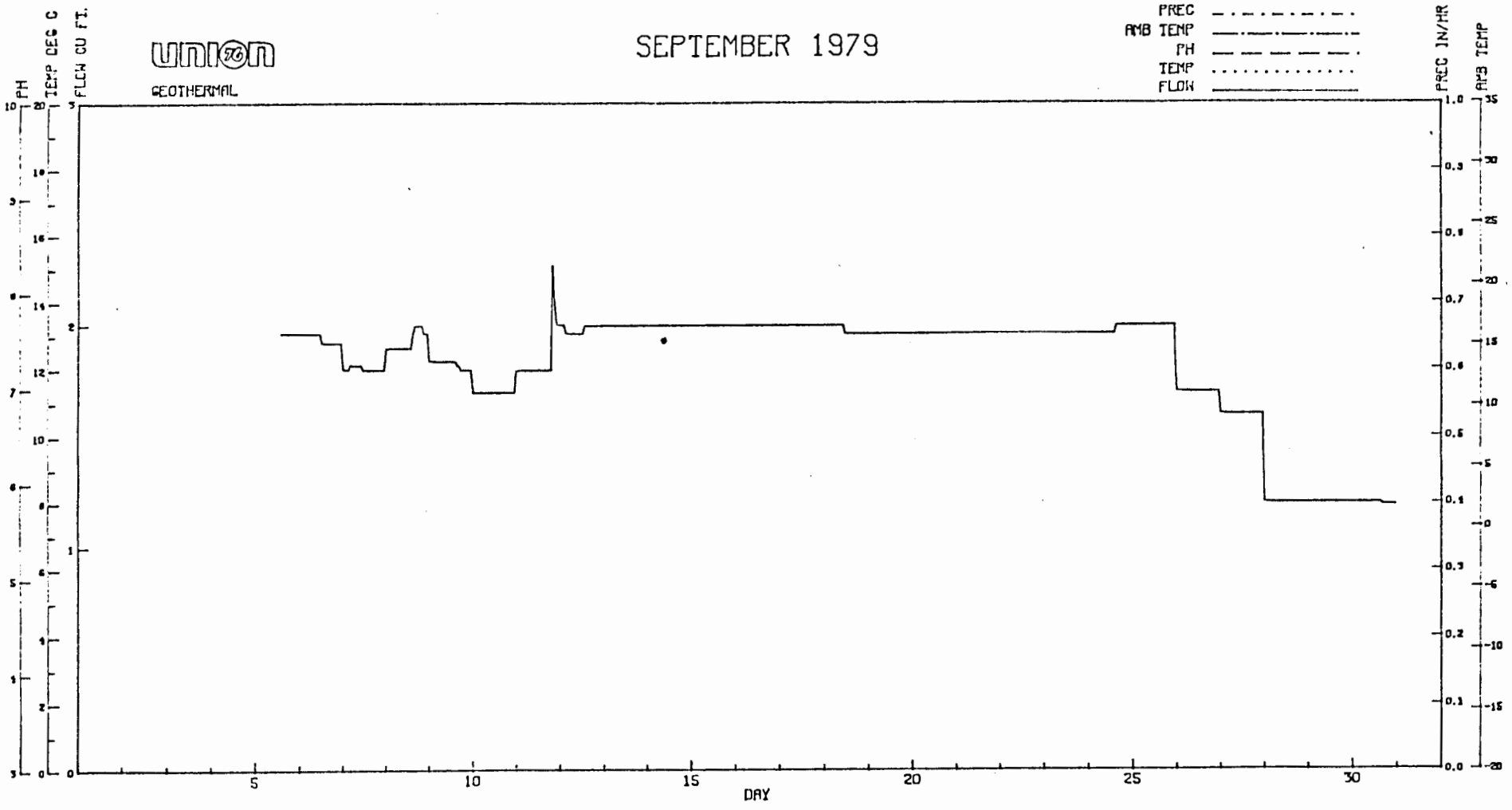
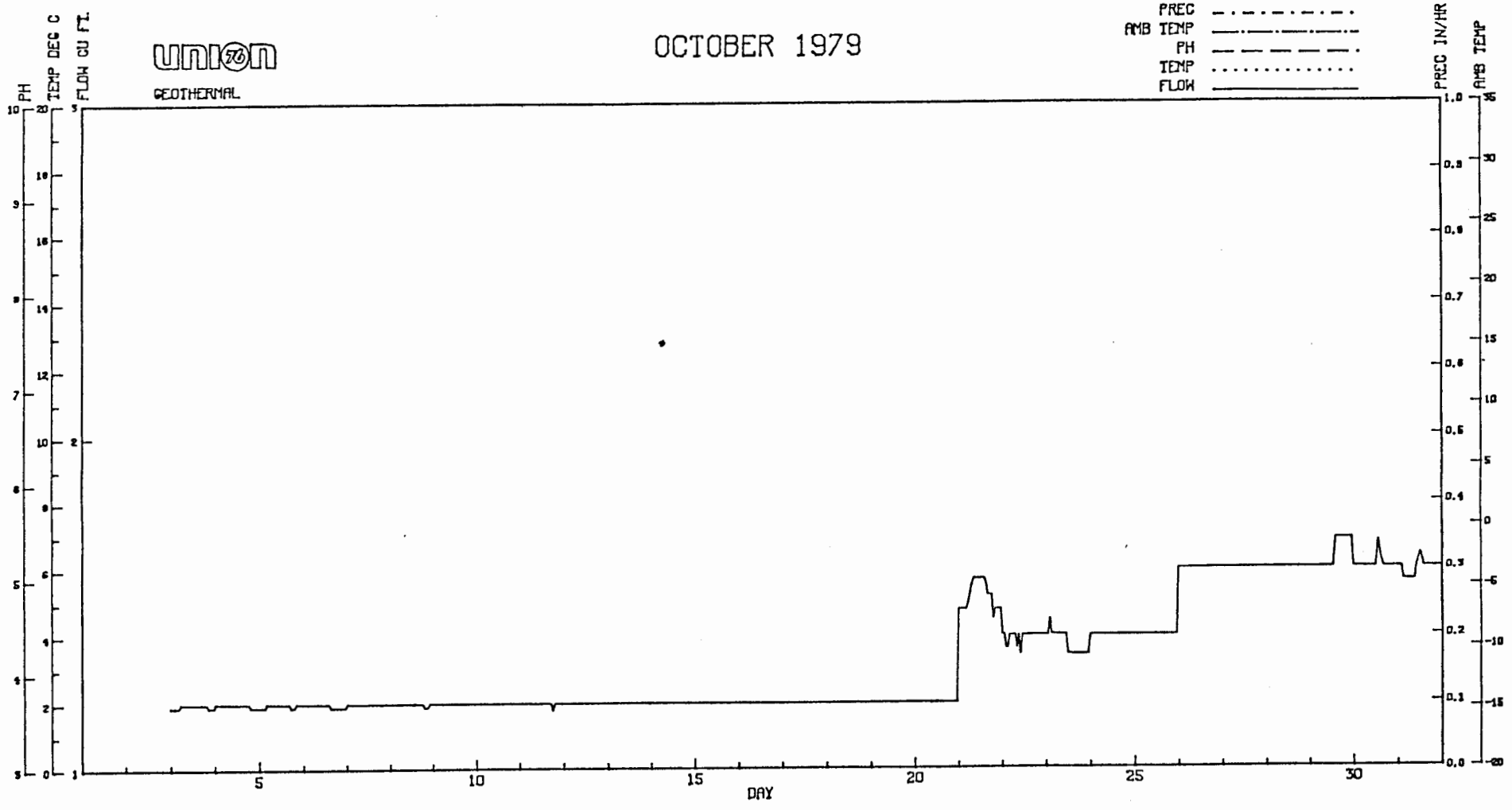
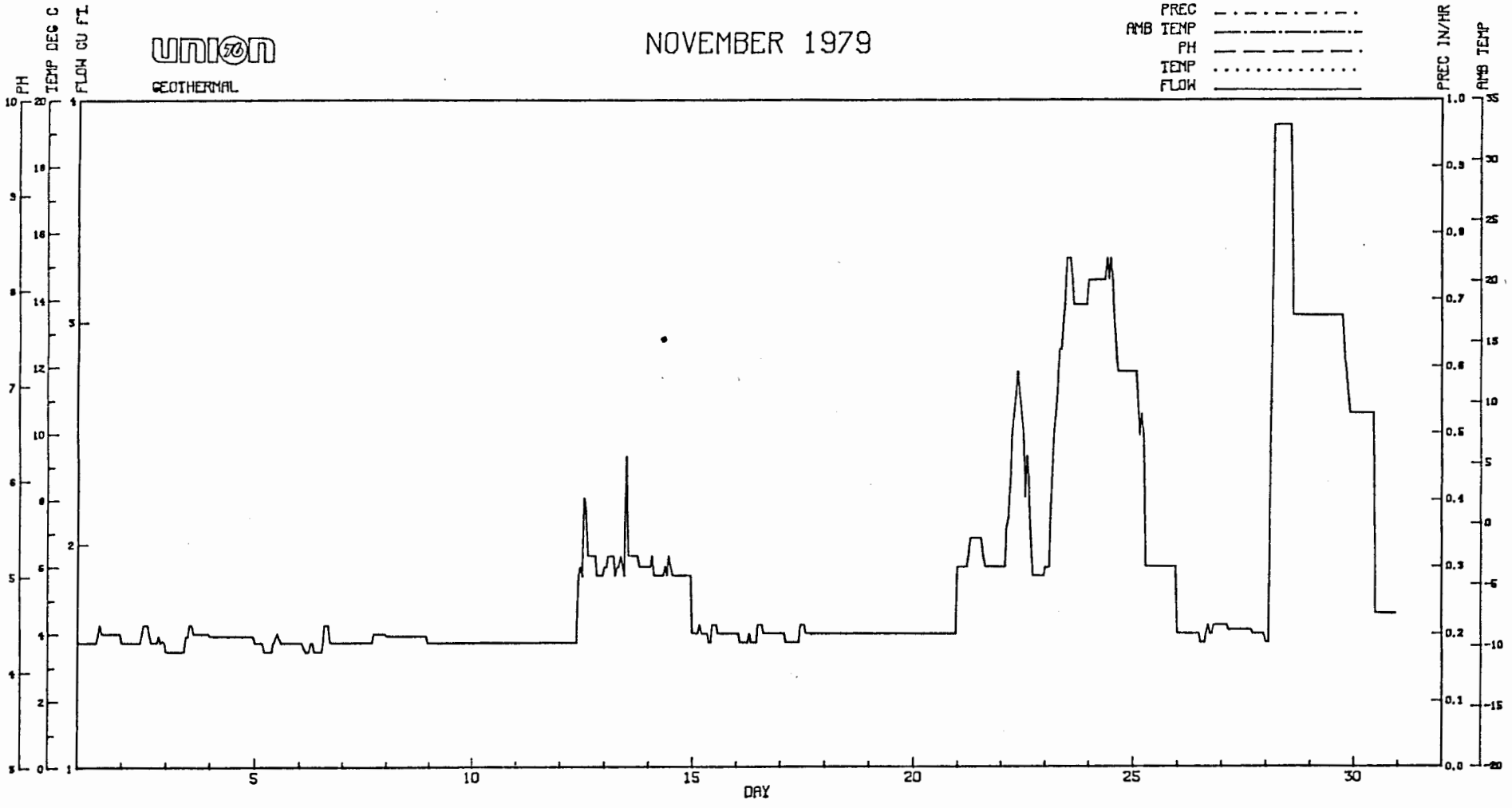

union 76
GEOTHERMAL
SEPTEMBER 1979
PREC
AMB TEMP
PH
TEMP
FLOW
PH
TEMP DEG C
FLOW CU FT.
PREC IN/HR
AMB TEMP
DAY
5
10
15
20
25
30

FIGURE 3



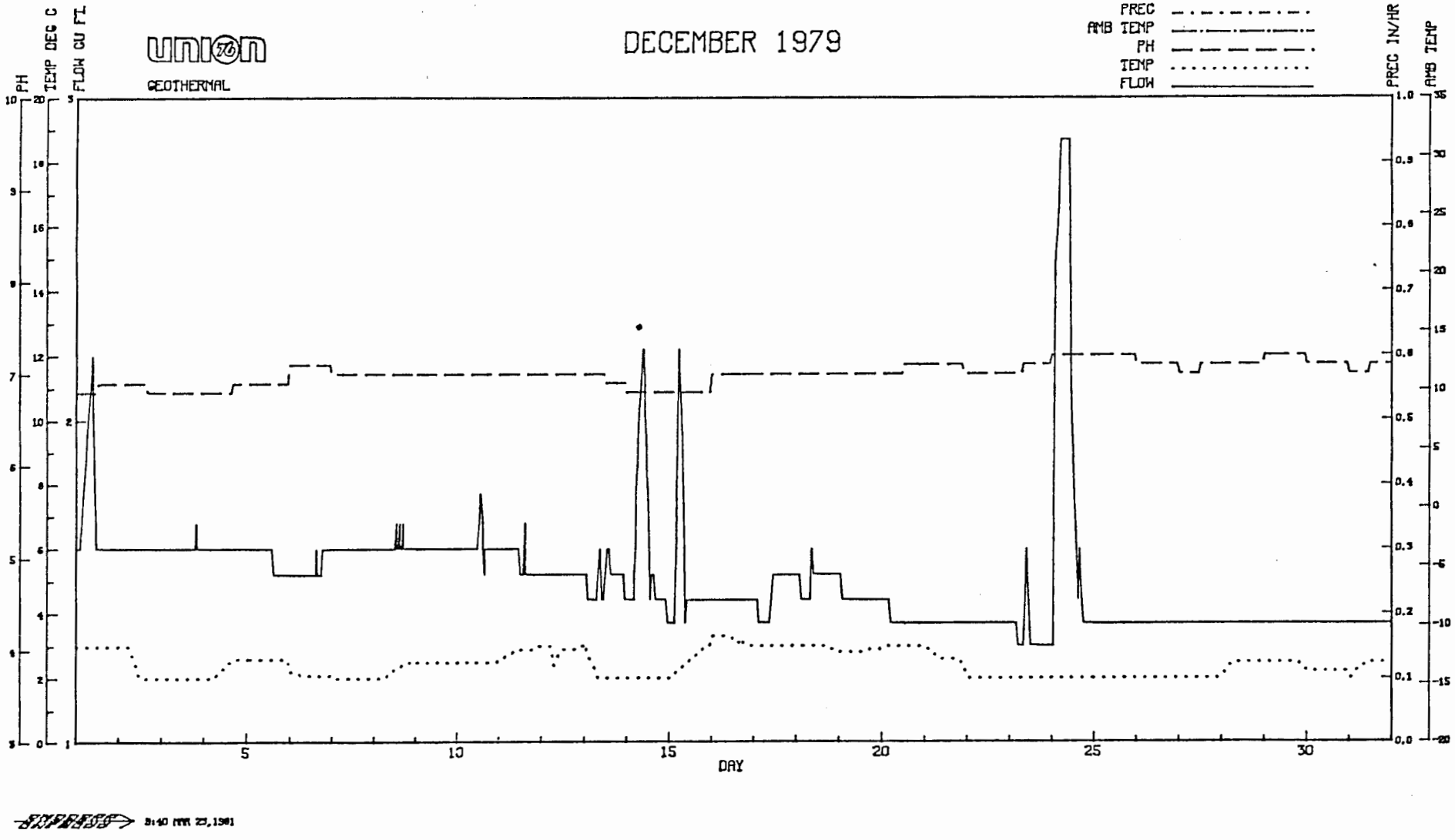
EXPRESS 10:05 MAR 25, 1981

FIGURE 4



EXPRESS> 9:31 MAR 23,1981

FIGURE 5



3:40 MAR 25,1981

FIGURE 6

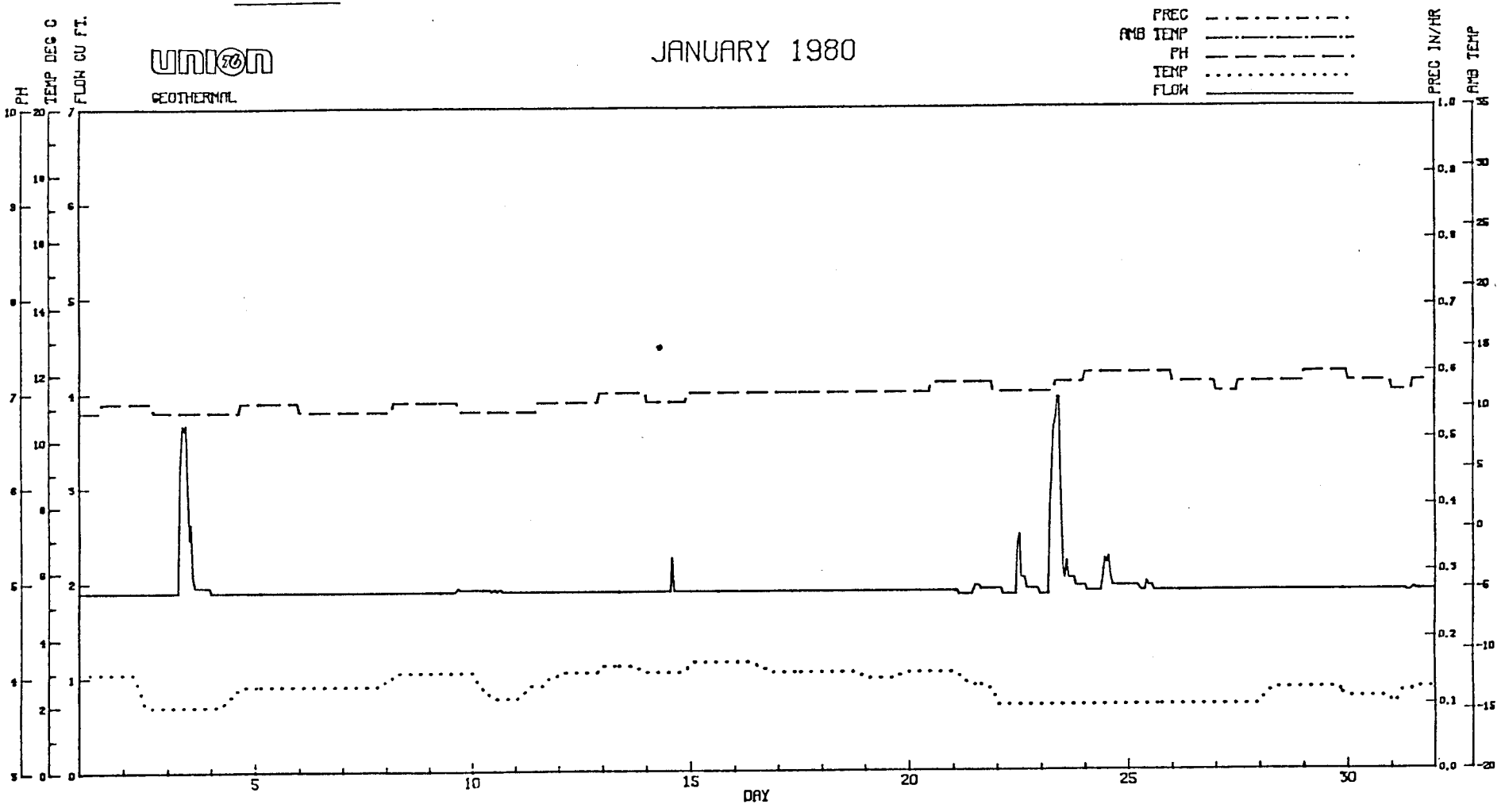
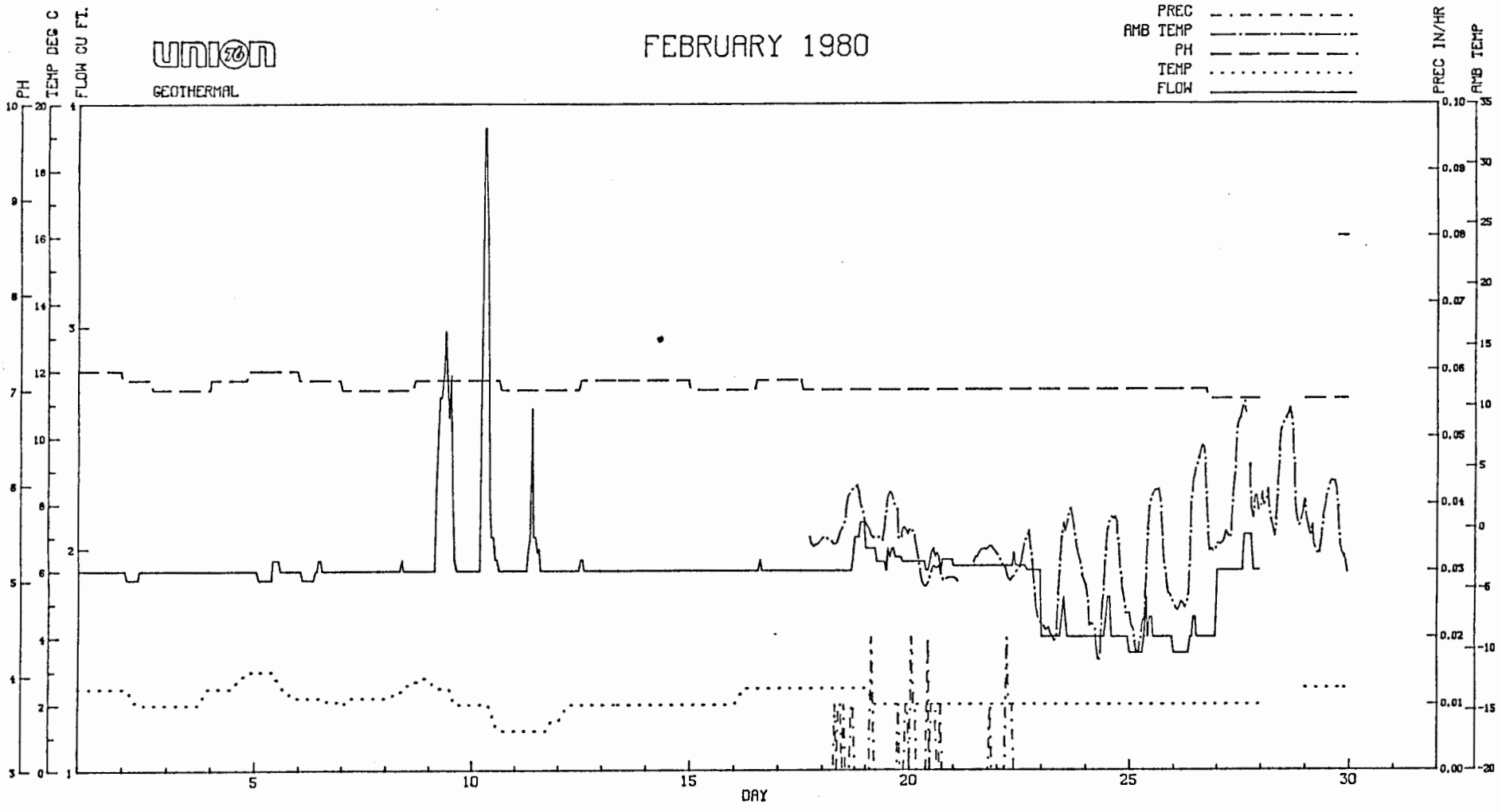
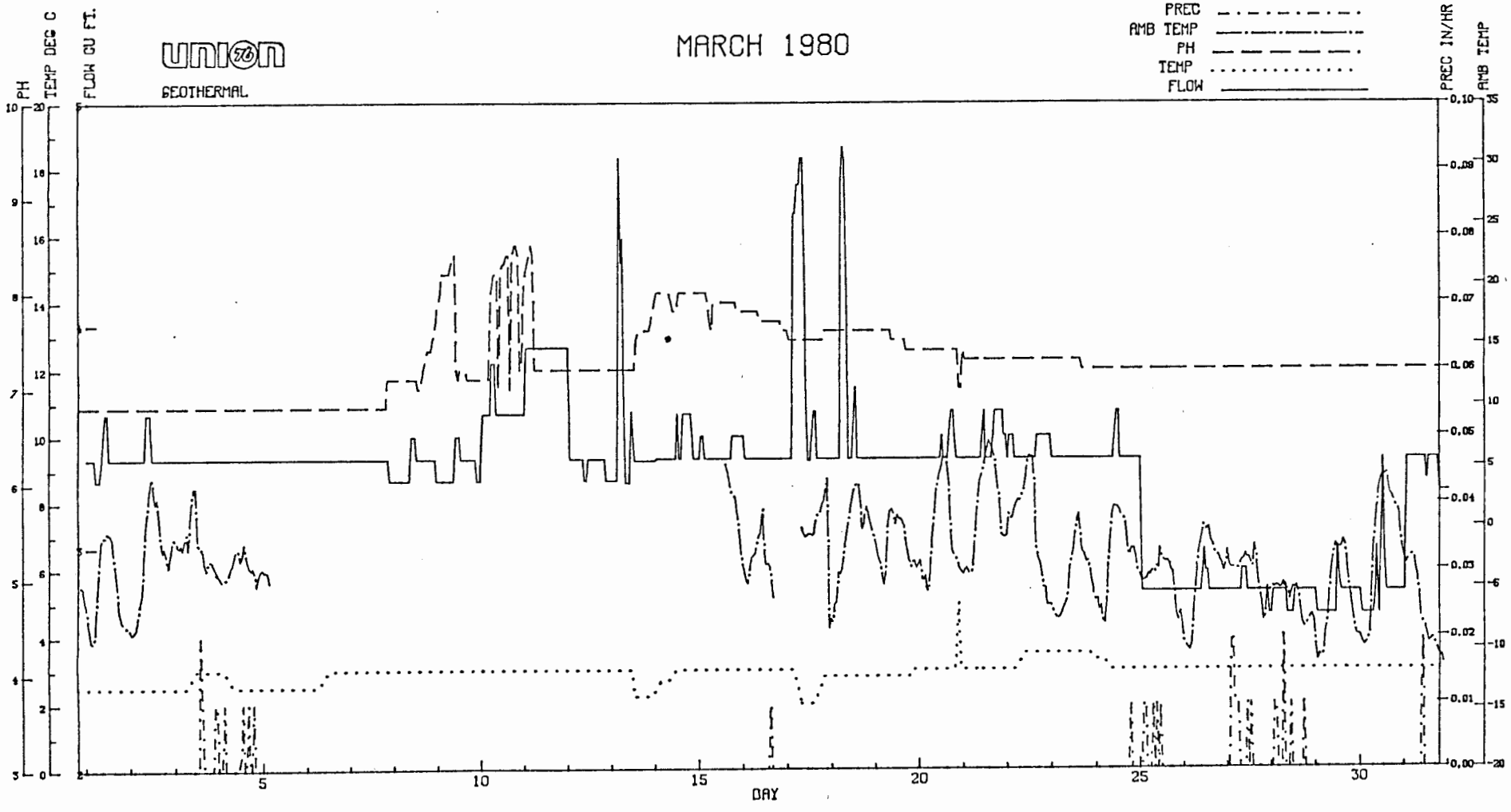

UNION
GEOTHERMAL
JANUARY 1980
PREC
AMB TEMP
PH
TEMP
FLOW
PH
TEMP DEG C
FLOW CU FT.
PREC IN/HR
AMB TEMP
DAY
5
10
15
20
25
30

FIGURE 7



ENDRESS+HAUSER 13:40 MAY 12,1981

FIGURE 8



EXPRESS 7:08 THU 13,1981

FIGURE 9

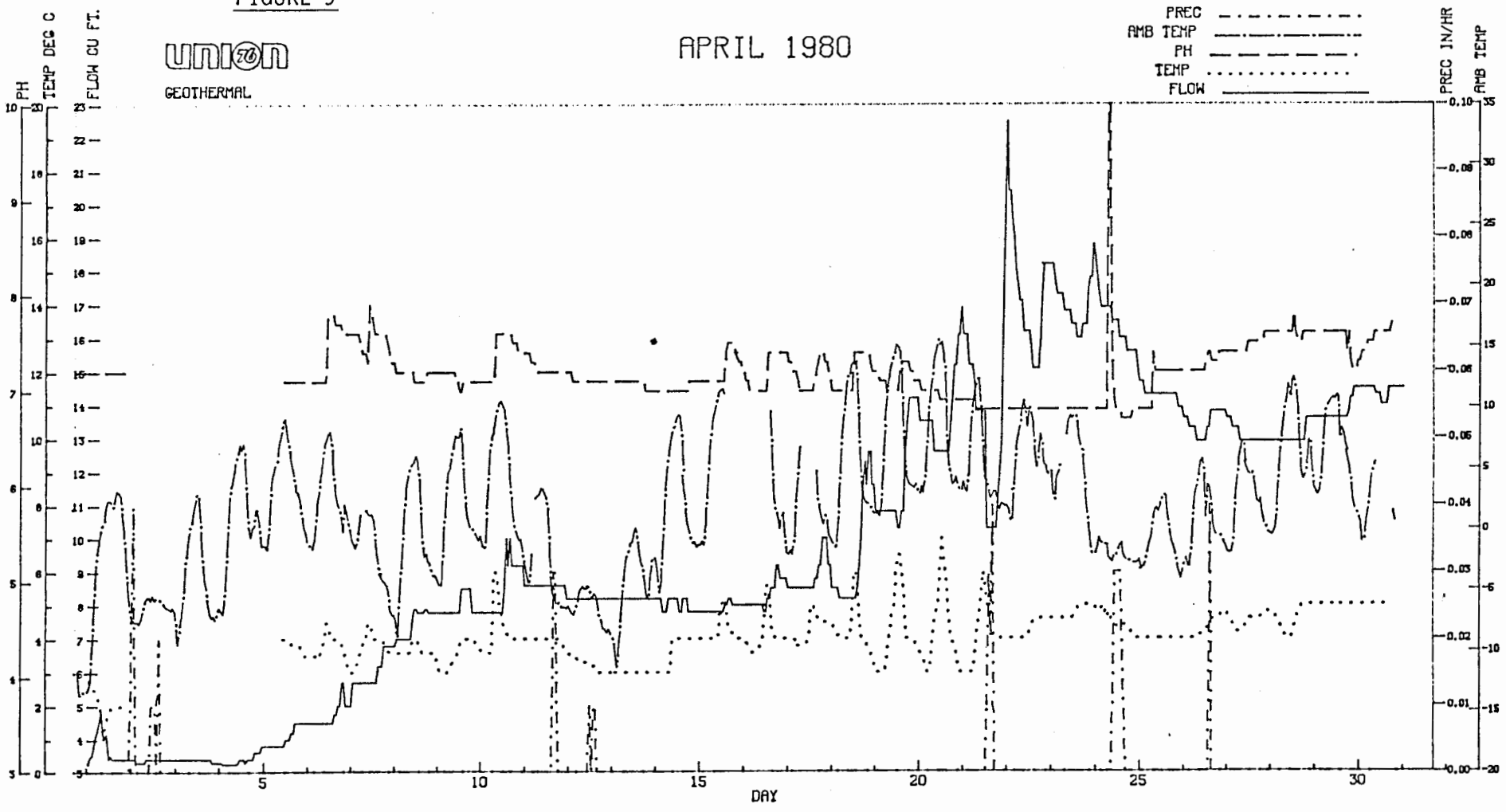
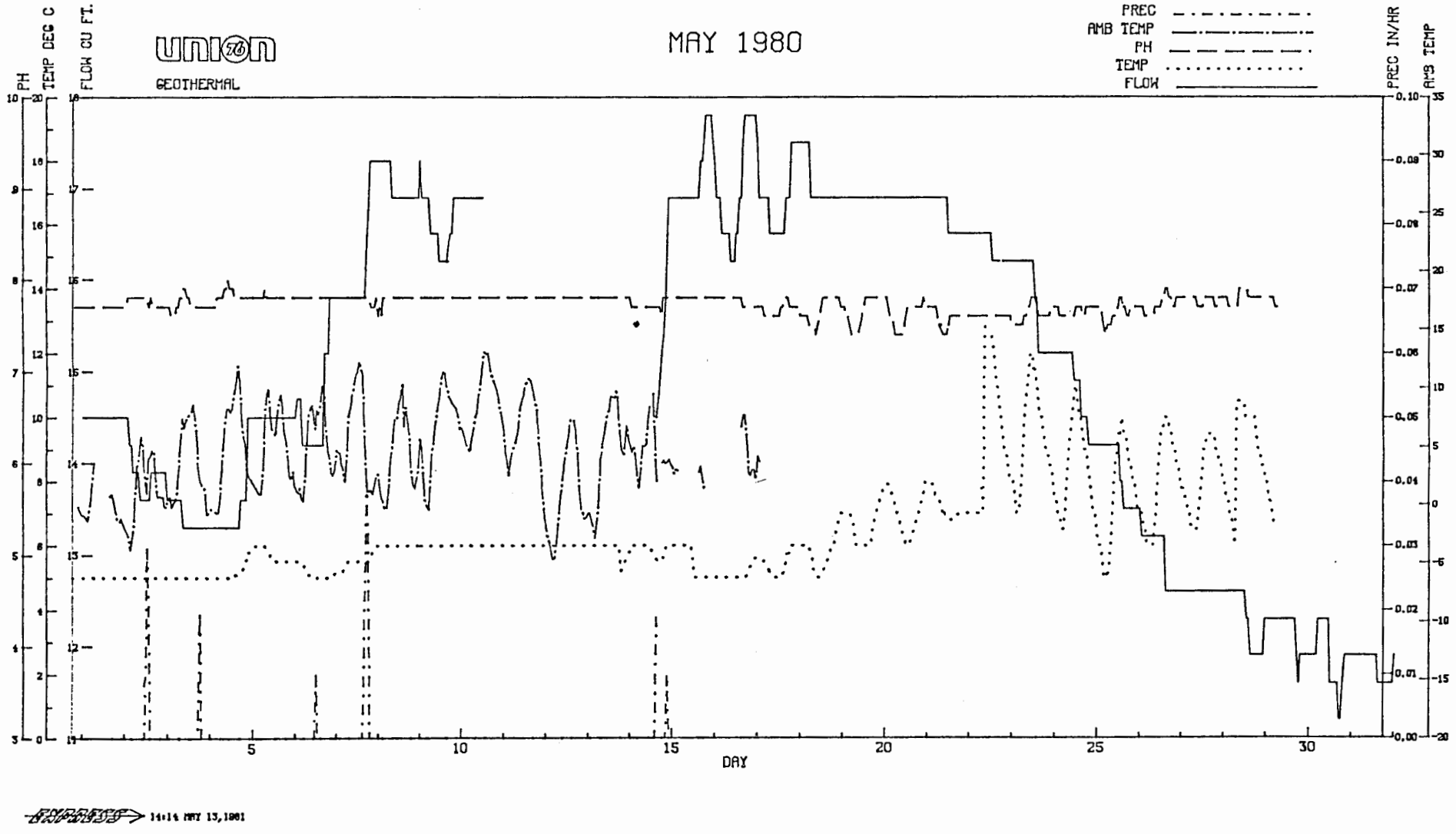
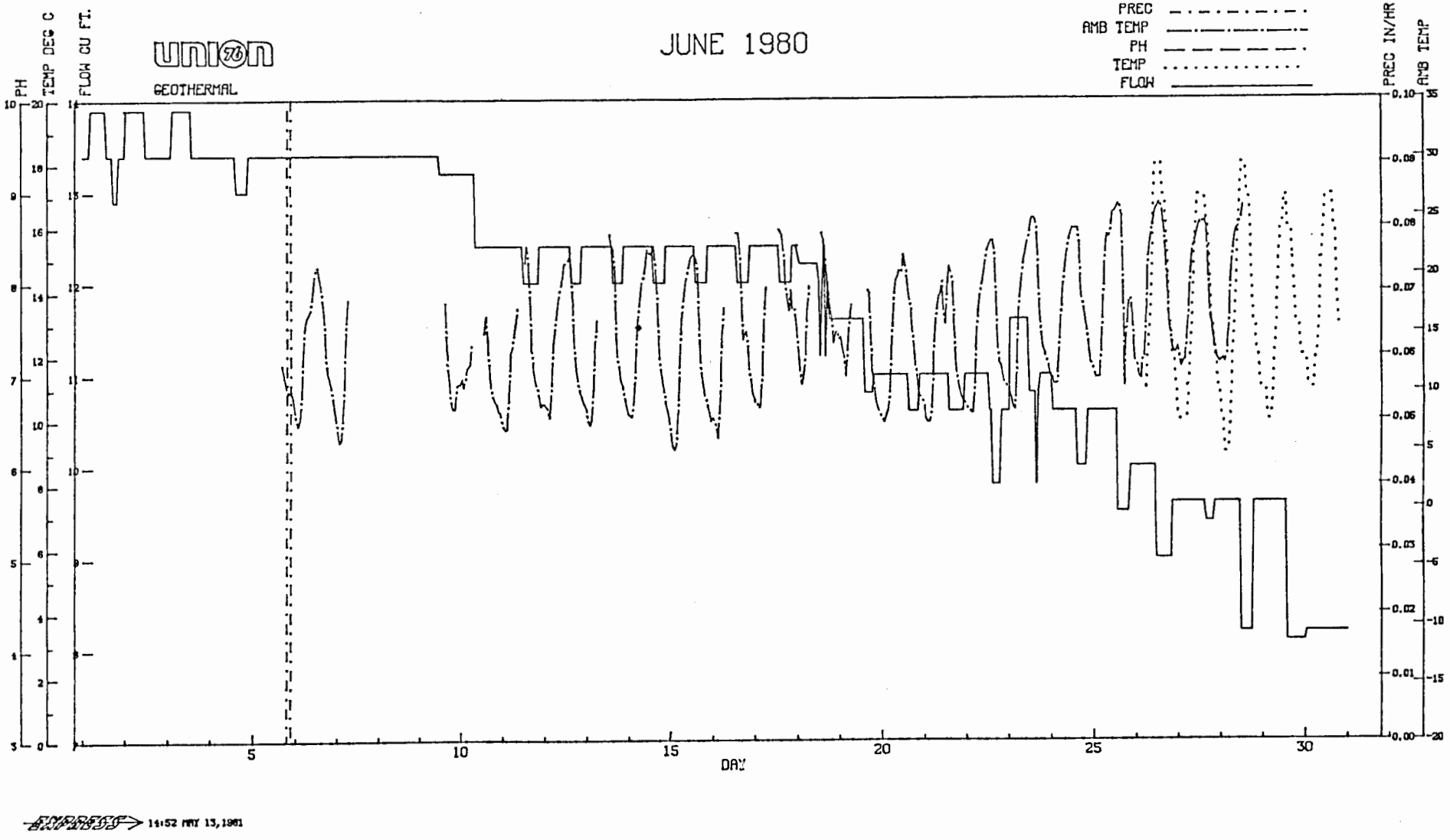

UNION 76
GEOTHERMAL
APRIL 1980
PREC
AMB TEMP
PH
TEMP
FLOW
PH
TEMP DEG C
FLOW CU FT.
PREC IN/HR
AMB TEMP
DAY
5
10
15
20
25
30

FIGURE 10



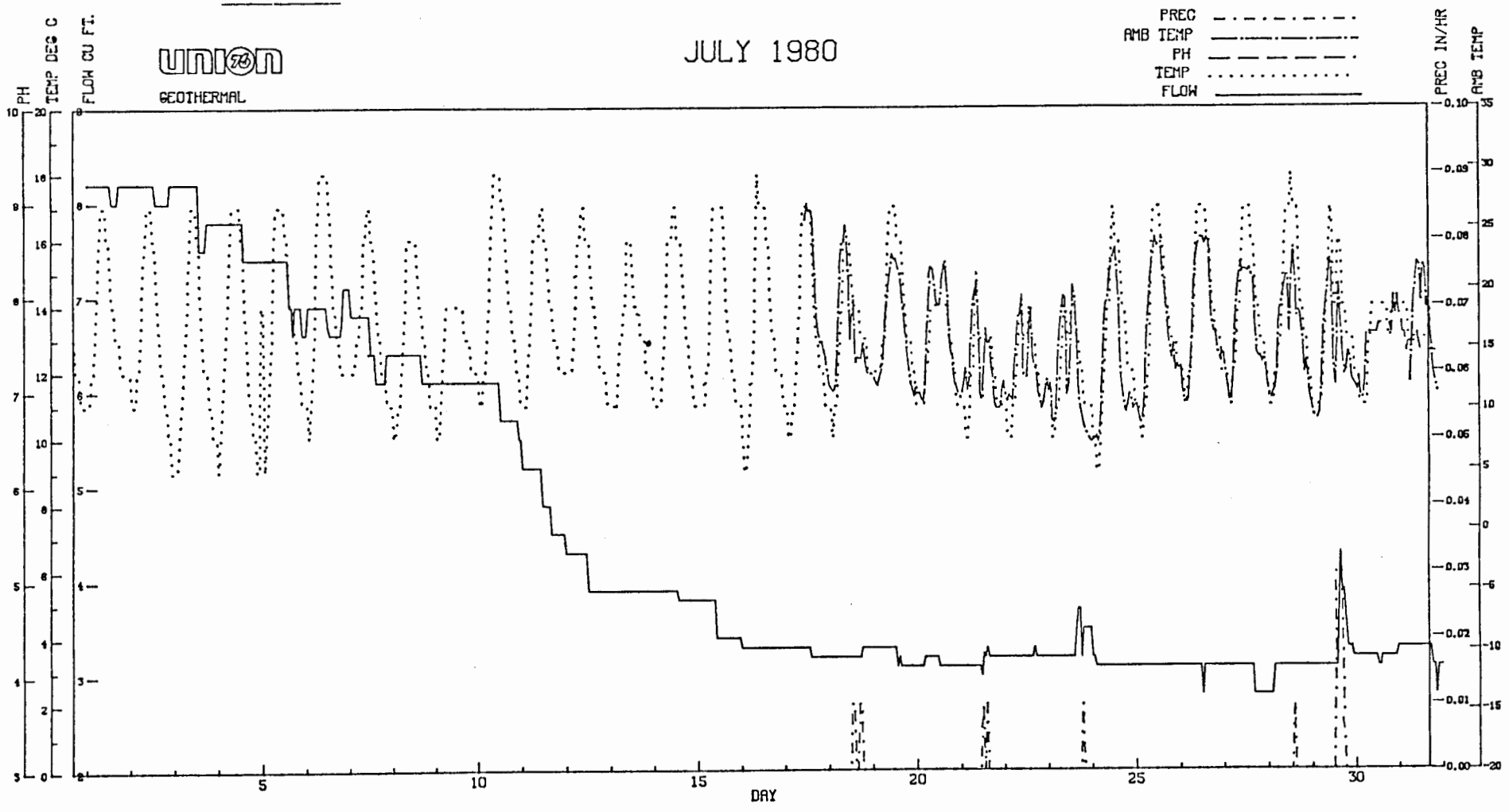
EXPRESS 14:14 MAY 15,1981

FIGURE 11



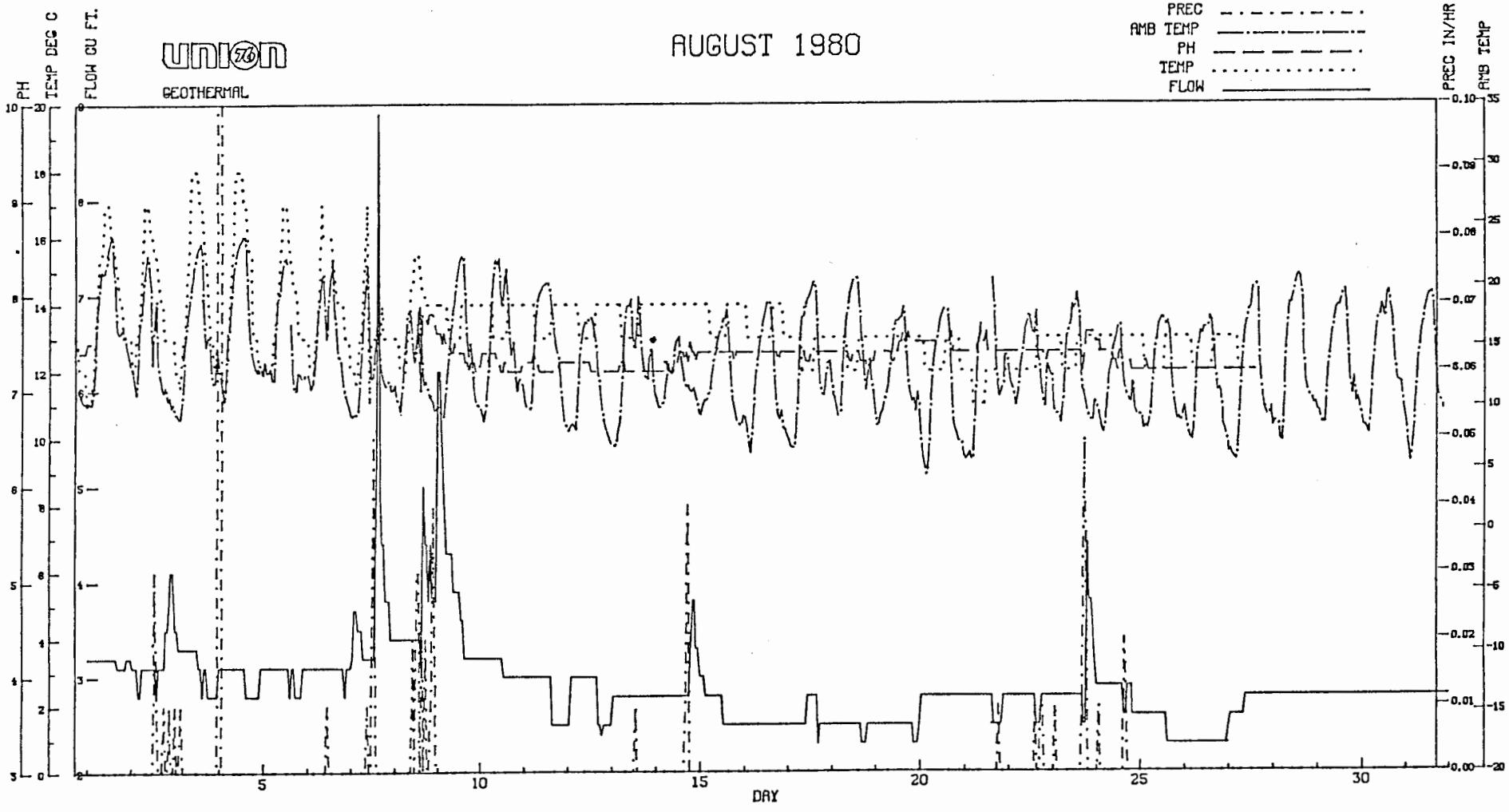
14:52 MAY 13,1981

FIGURE 12



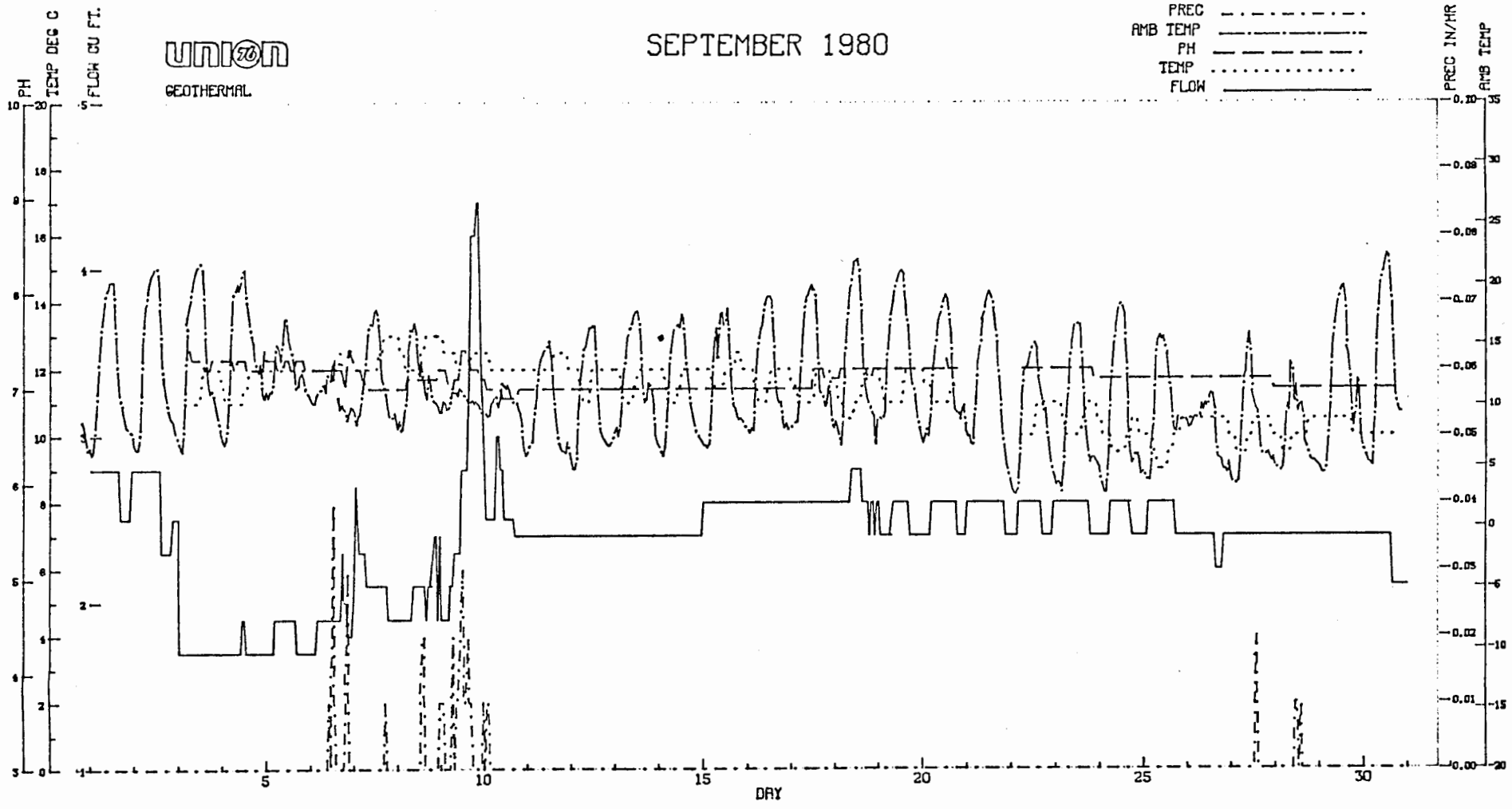
EXPRESS 15:07 MAY 13,1981

FIGURE 13



15:27 MAY 13,1981

FIGURE 14



EXPRESS 7:06 MAY 14,1981

TABLE 5: REDONDO CREEK WATER QUALITY DATA

REDONDO		AUGUST 79	SEPTEMBER 79	OCTOBER 79	NOV. 79	DEC. 79	JAN. 80	FEB. 80	MARCH 80	MAY 80	June 80	July 80	AUG. 80	SEPT. 80
BOD_5	mg/l							6.3		3.0	5.0	5.0	2.4	0.25
As	"	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	0.01	<0.02	0.05	0.01	0.01	<0.01	<0.01
Ba	"	----	----	----	----	----	2.5	2.0	1.5	----		0.01	<0.01	0.02
Hg	"	0.00012*	<0.00001*	0.00025*	0.00054*	0.00012*	<0.00001*	<0.001	<0.00001*	<0.001	0.001	0.001	<0.001	<0.001
NO_3	"	0.48	0.05	0.005	0.34	1.5	0.5	0.5	0.7	0.78	0.58	0.10	0.03	<0.01
F	"	0.47	0.6	0.28	0.6	0.47	<0.1	0.14	0.22	0.05	0.10	0.42	0.10	0.05
B	"	0.2	0.3	0.02	1.1	0.25	1.75	0.2	0.1	0.03	0.10	0.02	0.50	0.16
HCO_3	"	45.2	29.1	31.9	19.5	30.0	37.5	33.4	48.0	45.0	41.1	37.4	37.3	37.3
Ca	"	7.6	4.8	8.8	35.4	7.6	16.7	15.0	18.7	11.0	7.4	7.9	18.0	20.6
Cl	"	13.4	12.0	16.0	109.8	18.8	44.0	18.1	23.0	15.9	6.0	17.9	76.4	24.8
Fe	(diss)	<0.02	0.05	0.09	<0.02	<0.02	<0.02	.30	<0.02	0.35	0.02	0.09	0.07	0.17
Mg	"	0.8	1.1	1.3	6.7	0.8	1.8	1.4	2.3	1.1	0.79	0.78	2.0	1.20
K	"	1.6	2.0	1.8	12.4	1.6	4.7	2.8	2.9	3.8	1.2	1.8	4.6	1.90
Na	"	6.0	6.9	6.4	50.8	6.0	26.6	13.0	15.7	7.1	11.0	4.0	31.0	8.70
SO_4	"	11.0	7.0	10.0	135.0	12.0	6.0	8.0	10.0	6.6	0.8	0.1	4.0	<0.1
pH		6.4+	6.4+	7.2	5.4	7.7	7.3	6.8	7.5	7.2	7.6	7.1	7.8	7.0
umhos	conductance	50	40	70	440		130	79	112	70	63	78	245	
Temp	°C	17°	8°	7°	13°	0°	2°	3.5°	5°	7°	13°	15°	13°	10°0
PO_4	"	.09	0.45	0.23	0.05	0.24	0.1	0.11	<0.1	0.13	0.07	0.08	0.07	0.12

* data questionable - no known technique assures such accuracy
\+ pH electrode questionable
pH, conductance and water temperature are field data

TABLE 6: SELECTED WATER SAMPLES COLLECTED FROM REDONDO CREEK WATER YEAR 1979-1980

TSS	5	33	1	3	12	3	20	7	2	2	80	25	4	2	<1	20	12	3	5	7	
TDS	116	3940	148	104	84	52	244	448	120	128	133	140	50	140	175	128	136	140	132	124	
pH	7.1	8.0	6.5	7.1		8.0	7.2	6.6	7.7	7.6	7.5	7.6	7.9	7.8	7.5	7.6	7.8	7.8	7.7	7.7	
µmhos	188	5550	100	110	168	148	380	450	240	250	170	220	145	100	185	151	159	175	196	106	
B	.2	<.02	.03	<.02	0.1	<.02	.15	1.1	.45	<.02	.15	.45	<.02	.1	.05	<.02	0.1	<.02	.05	.25	
Br																					
Cl	13.4	406	12	16	16.2	16.2	21.4	109.8	17.8	17.6	15	15.2	16.8	30	18.8	20.4	19.6	31.4	34.4	18.8	
Si		20	22	3.4	28	28	27.8	48.5	28.5	31.5	28	26.5	27.8	6.5	26.5	32.5	28	30	27.5	28.5	
SO_4	11	2550	7	10	8	10	11	135	9.5	7.0	5.5	8.0	8.0	9.0	.12	8	7	8	7	7	
As	<.02	<.02	<.02	<.02	<.02	<.02	<.02	<.02	<.02	<.02	<.02	<.02	<.02	<.02	<.02	<.02	<.02	<.02	<.02	<.02	
Hg	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	
DATE 1979	8/24	9/11	9/28	10/19	10/22	10/26	11/6	11/28	11/28	11/28	11/28	11/28	11/29	12/6	12/8	12/28	12/28	12/28	12/28	12/31	
* ISCO Sample #		#1			#1		#1		#1	#4	#8	#12				#2	#11	#20	#28		

TSS	5	13	13	6	4	8	15	107	277	781	19	9										28	460	164	104		
TDS	164	144	156	104	108	164	368	216	224	286	132	204						180	182	156	162	204	174	160	224	194	174	
pH	6.4	7.4	7.5	7.5	7.6	7.4	7.6	6.9	6.8	6.9	7.3	7.2	7.2	6.8	6.9	6.5	6.6	7.5	7.7	10.3	7.8	7.5	7.4	7.0	7.0	7.0	7.1	
µmhos	140	250	140	120	159	220	450	230	280	410	200	250	151	136	132	108	105	109	132	73	132	138	138	100	100	100	100	
B	1.1	.15	1.75	.05	.2	<.02	1.2	<.02	.05	.4	.04	.01	.14	.09	.09	.09	.16	.08	.20	.13	.25	.05	.14	.06	.06	.07	.07	
Br	<.1	.2	<.1															.03	<.01	.04	.03	<.01	.02	.10	.09	.11	.09	
Cl	18	30.2	44	22.4	28.4	29.2	23	25.8	50.8	90.8	28	27.2	25.8	22.8	25.8	10.9	3	13.9	10.9	12.9	8.9	8.9	7.9	17.9	15.9	23.8	17.9	
Si	29	27.5	30	27	32	32.5	26	28.5	25.5	28	28.5	30	17	13	14	12	11	11	11	10	11	13	13	1.9	15	16	17	
SO_4	12	9	16	9	12	11	10	12	17	18	13	14						9.9	25	23	20	30	29	12	9	16	10	
As	<.02	<.02	<.02	<.02	<.02	<.02	<.02	<.02	<.02	<.02	<.02	<.02	<.01	<.01	<.01	<.01	<.01	.01	<.01	.02	.01	<.01	<.01	.03	.02	.02	.01	
Hg	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	
DATE 1980	1/2	1/11	1/18	2/2	2/7	3/4	3/14	3/17	3/17	3/18	3/21	3/28	4/2	4/2	4/2	4/19	4/19	4/22	4/22	4/22	4/22	4/22	4/22	4/24	4/24	4/24	4/24	
* ISCO Sample #							#2	#2	#14				#2	#15	#26	#1	#2	#4	#10	#14	#19	#23	#27	#1	#10	#17	#27	
							Runoff	Runoff								Runoff		Runoff &						Runoff &			

* IF NO ISCO # IS GIVEN WATER WAS COLLECTED BY HAND AT ISCO SITE.

TABLE 6 (cont'd)

TSS	14	26	154	184	40	104	479	844	735	1031	373	308	381	92	120	74	49	100	74	41	171	89	44	33	25	22	27
TDS	154	156	136	136	128	148	92	96	114	100	92	98	86	108	124	146	119	103	123	131	111	120	126	113	127	132	127
pH	7.0	7.6	7.3	7.3	7.3	7.5	7.1	7.1	7.1	7.1	7.2	7.1	7.2	7.3	7.2	7.2	7.1	7.2	7.2	7.2	7.1	7.2	7.2	7.1	7.4	7.3	7.3
µmhos	100	110	99	95	100	80	90	88	90	90	88	92	93	100	100	100	110	110	120	115	125	125	130	130	120	120	120
B	0.11	.06	.07	.08	.06	.09	.07	.05	.06	.08	.05	.06	.05	.05	.06	.06	.06	.04	.04	.06	.08	.08	.09	.09	.12	.09	.08
Br																											
Cl	15.9	11.9	7.9	15.7	6.0	13.9	10.9	10.9	9.9	10.9	7.9	11.9	9.9	7.9	11.9	17.9	15.9	16.9	19.9	18.9	21.8	22.8	19.9	20.8	19.9	16.9	15.9
Si	18	15	18	15	18	16	20	22	15	14	13	16	17	17	17	17	17	15	17	16	16	17	17	16	17	17	16
SO_4	6.6	7.0	10.0	13	13	3.0	15	13	17	18	17	17	16	14	10	13	12	9	12	7	7	9	12	12	10	9	8
As	0.05	<0.01	.06	.03	.01	.02	.02	.02	.02	.03	.04	.01	.03	.03	.01	.01	.01	.01	<.01	.01	<.01	<.01	.02	<.01	<.01	.01	<.01
Hg	<.001	< .001	<.001	<.001	<.001	<.001	<.001	.004	<.001	.002	<.001	.001	.001	.001	.001	<.001	.001	.001	.001	.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001
DATE 1980	5/1	5/ 7	5/7	5/ 7	5/7	5/8	5/10	5/10	5/10	5/10	5/10	5/10	5/10	5/14	5/14	5/14	5/16	5/16	5/16	5/16	5/19	5/19	5/19	5/19	5/21	5/21	5/21
* ISCO SAMPLE #		#2	#12	#20	#28		#2	#6	#12	#6	#20	#24	#26	#1	#4	#28	#1	#9	#17	#23	#1	#5	#16	#24	#1	#11	#23
		Runoff & T_b					Unkown At least partially runoff							Runoff & T_b			Runoff				Runoff				Power Surges		

TSS	18	25	21	22	2
TDS	179	109	141	105	117
pH	6.9	6.9	7.0	7.1	7.6
µmhos	103	103	102	101	86
B	.08	.08	.03	.03	.03
Br					
Cl	73.5	14.9	11.9	14.9	4.0
Si	17	17	17	17	15
SO_4	8	8	8	11	3
As	.02	.01	.02	.01	0.01
Hg	<.001	<.001	<.001	<.001	<.001
DATE 1980	5/23	5/23	5/23	5/23	5/29
* ISCO Sample #	#1	#10	#24	#28	
	Power Surges				

* IF NO ISCO # IS GIVEN, WATER WAS COLLECTED BY HAND AT ISCO SITE.

TABLE 6 (cont'd)

TSS	34	87	24	26	32	55	14	14	47	36	50	04	75	98	45	53	41	32	19	13	(067)
TDS	102	96	61	70	65	92	84	04	01	06	94	110	107	00	80	81	71	42	00	00	72
pH	7.6	7.2	7.6	7.8	7.6	7.5	7.7	7.7	7.5	7.0	7.4	7.2	7.3	7.1	7.5	7.4	7.3	6.9	7.1	7.2	7.2
µmhos	84	84	86	85	87	90	63	63	82	84	86	88	90	90	87	90	87	76	78	90	88
B	.07	.05	0.03	.03	.02	.04	.10	.10	.03	.04	.04	.04	.04	.03	.04	.04	.04	.05	.06	.02	.04
Br	<.01	<.01	.01	.06	.08	<.01			<.01			.05	.02	<.01	<.01	.03	<.01	.03	.05		<.01
Cl	9.9	7.9	5	5	5	4	6	6	7.9	5	6	5	5	6	5	7	6	3	6.9	17.9	6
Si	15	14	15	14	15	14	15	15	16	14	14	14	14	.9	1	3.2	1.3	5.8	15	15	13
SO_4	3	3	8	8	7	(.8)	(.8)	(.8)	(.8)	6	5	3.3	(<0.1)	2	3	.8	<.1	<.1	<.1	.1	4
As	.02	.01	.01	.01	<0.01	<.01	.01	.01	.04	.01	.04	<.01	<	.02	.02	.01	.01	.01	.01	<.01	.01
Hg	<0.001	<0.001				0.001		<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001
DATE 1980	6/3	6/3	6/10	6/10	6/10	6/11	6/16	6/16	6/16	6/20	6/20	6/23	6/24	7/3	7/3	7/3	7/3	7/10	7/10	7/22	7/29
* ISCO SAMPLE #	#1	#2	#1	#15	#28	#1		#1	#2	#8	#10	#11	#14	#16	#18	#22	#28	#1	#28		#2 + 3
	%		Power Surge?			%		Power Surge		Field Activity Draining Pipeline Fresh Water		Field Activity Overflow Fresh Water Storage Tank		Field Activity				Field Activity?			%

TSS	46	7494	3496	1872	2188	23	446	721	306	1730	6100	4232	15	8.3
TDS	128	103	167	166	156	228	223	219	256	192	203	232	121	250
pH	7.2	6.8	7.2	6.3	6.6	7.2	7.1	7.1	7.3	6.9	7.5	7.4	7	7
µmhos	140	116	200	200	185	275	300	300	375	240	265	320	152	400
B	.1	.39	.16	.16	.14	.50	.49	.45	.56	.32	.26	.36	.16	.64
Br	<.01	<.01	<.01	<.01	<.01		<.01	<.01	<.01	.02	.02	.02		
Cl	16.9		55	22.3	21.1	76.4	72.5	68.5	91.3	53.6	37.7	58.6	24.8	96
Si	14	8.1	13	12	14	13	12	11	13	12	7.9	12	15	14
SO_4	.4	<.1	7	40	31	4	4	5	7	4	12	9	<.1	11
As	.02	<.01	.02	.01	.04	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.07	.02
Hg	<	<	<.001	.001	<.001	<.001	<.001	<.001	<.001	<.001	.069	<.001	<.001	< .001
DATE 1980	8/4	8/8	8/11	8/11	8/11	8/19	8/14	8/14	8/14	8/24	8/24	8/24	9/29	10/31
ISCO SAMPLE #	#4	#8	#18	#25	#28		#1	#2	#4	#6	#7	#8		
	%	%	Field Activity Leaking Pump				%			%				

* IF NO ISCO # IS GIVEN WATER WAS COLLECTED BY HAND AT ISCO SITE.

PRESSURE TRANSIENT ANALYSIS

FOR HOT WATER AND TWO-PHASE GEOTHERMAL WELLS: SOME NUMERICAL RESULTS

PREPARED BY:

SYSTEMS, SCIENCE AND SOFTWARE

UNDER CONTRACT TO:

WESTEC Services, Inc.

PUBLIC SERVICE COMPANY OF NEW MEXICO

UNION GEOTHERMAL COMPANY OF NEW MEXICO

UNITED STATES DEPARTMENT OF ENERGY

Carl Ulvog

DOE/ET/27163-5
Distribution Category UC-66f

BACA GEOTHERMAL DEMONSTRATION PROJECT

PRESSURE TRANSIENT ANALYSIS FOR HOT WATER AND TWO-PHASE GEOTHERMAL WELLS: SOME NUMERICAL RESULTS

TOPICAL REPORT

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Date Published - October 1980

Prepared Under Subcontract to

WESTEC Services, Inc.

Prepared For

UNION GEOTHERMAL COMPANY OF NEW MEXICO

AND

PUBLIC SERVICE COMPANY OF NEW MEXICO

UNDER CONTRACT NO. GEO-CSL-25

Work Sponsored By

THE U.S. DEPARTMENT OF ENERGY

DIVISION OF GEOTHERMAL ENERGY

UNDER COOPERATIVE AGREEMENT NO. DE-FC03-78ET27163

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Printed in the United States of America

Available from:

WESTEC Services, Inc.
505 Marquette, N.W., Suite 1000
Albuquerque, NM 87102

ABSTRACT

A geothermal reservoir simulator has been employed in a series of calculations which describe the response of geothermal reservoirs to fluid production/injection from a single well. The numerical solutions were analyzed to generate interpretation techniques for pressure transient data from either single-phase or two-phase geothermal reservoirs. The investigations include (1) the drawdown/buildup response of hot water wells, (2) the drawdown/buildup behavior of initially two-phase (liquid water/steam) reservoirs, (3) the drawdown/buildup response of initially single-phase reservoirs which undergo flashing as a result of fluid production and (4) the effect of cold water injection into single-phase and two-phase reservoirs.

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SECTION 1: INTRODUCTION

1.1 Introduction

The line source solution (or Theis solution) has been traditionally used in hydrology and petroleum engineering to analyze pressure transient data from isothermal single-phase (water/oil/gas) and isothermal two-phase (oil with gas in solution, free gas) reservoir systems. For a constant flow rate well test, a plot of pressure drop versus logarithm of time asymptotes to a straight line after a short initial period. The slope and intercept of this line yield the mobility-thickness product and the total formation compressibility. The total formation compressibility depends upon, among other variables, fluid compressibility. Although very often it is not explicitly stated, the fluid compressibility in traditional applications is the one measured at constant temperature.

Extension of the Theis solution to analyze pressure transient data from geothermal reservoirs involves several difficulties. Geothermal reservoirs by their very nature contain fluid at elevated temperatures. Very often the in situ fluid is either boiling or near boiling. For single-phase hot liquid reservoirs, it is not self-evident whether or not the isothermal fluid compressibility is the appropriate one. (This question will be examined in detail in Section 2, and it will be shown that the isothermal fluid compressibility should be replaced by isenthalpic fluid compressibility at elevated temperatures.) In recent years, several investigators (Garg [1978], Grant [1978], Moench and Atkinson [1977]) have examined the production (or drawdown) behavior of two-phase geothermal reservoirs. The geothermal reservoir may be initially two-phase or may evolve into a two-phase reservoir as a result of fluid production. The plot of pressure drop versus logarithm of time asymptotes to a straight line after an initial non-linear period; the slope of the straight line can be used to calculate the kinematic mobility-thickness product. The intercept

of the straight line, however, provides a very poor approximation of the total formation compressibility which is primarily governed by phase change effects. Sorey, et al. [1980] have also numerically examined the buildup behavior in initially two-phase reservoirs; the plot of pressure versus log $[(t+\Delta t)/\Delta t]$ (t = production time, Δt = shutin time) gives a straight line. The slope of this straight line again can be related to the kinematic mobility-thickness product; the kinematic mobility-thickness product calculated from buildup data is, however, different from that obtained from drawdown data due to nonlinear effects in two-phase non-isothermal flow. These nonlinear effects imply that the superposition principle does not apply in two-phase geothermal systems. As the present time, there exists little or no information in the literature on either the (1) buildup response of initially single-phase reservoirs which undergo flashing as a result of fluid production, or (2) the effect of cold water fluid injection into two-phase geothermal reservoirs.

The numerical results presented in the report form a theoretical framework which will be used in interpreting the flow data from the production/injection wells at the Baca Geothermal Demonstration Power Plant (GDPP) Project. The application of the techniques to the data from the Baca wells will be the subject of a separate topical report. The results contained herein, however, are of fundamental interest to geothermal reservoir engineers and applicable to other geothermal systems.

1.2 Scope of the Report

The main purpose of this report is to develop interpretation techniques for pressure transient data from either single-phase or two-phase geothermal reservoirs. More specifically, the Systems, Science and Software (S^3) reservoir simulator CHARGR (Pritchett [1980]) will be employed in a series of one-dimensional radial flow problems to investigate (1) the drawdown/buildup response of hot water wells, (2) the drawdown/ buildup behavior of initially two-phase reservoirs, (3) the drawdown/buildup response of initially

single-phase reservoirs which undergo flashing as a result of fluid production and (4) the effect of fluid injection into single-phase and two-phase reservoirs. The numerical results are employed to generate guidelines for calculating mobility-thickness product from pressure transient data.

1.3 Summary and Conclusions

The numerical simulations presented herein demonstrate some of the difficulties associated with analyzing pressure transient data from hot water and two-phase geothermal reservoirs. It is demonstrated that production data (drawdown/buildup) from single-phase hot water and initially two-phase reservoirs may be analyzed in the usual manner to yield absolute permeability/kinematic mobility provided the total formation compressibility is defined differently from its conventional usage in petroleum engineering and hydrology. Drawdown data from initially single-phase reservoirs which undergo flashing during production can be made to give two-phase kinematic mobility; the buildup data from such reservoirs offers the possibility of determining absolute formation permeability. It is further shown that injection data for single-phase and two-phase reservoirs can be interpreted in a straightforward manner to give absolute formation permeability; the fall-off data (especially in two-phase systems) appear, however, to be of lesser utility.

1.4 Recommendations for Future Study

This report contains the results of theoretical calculations simulating transient production and injection testing of single-phase and two-phase reservoirs. The simulations provide a quantitative understanding of the phenomena which may be expected to occur during the pressure testing of wells in such a reservoir. The results are of direct relevance to the Baca reservoir system and will be used by S^3 in evaluating the available flow test data for the Baca wells.

SECTION 2: THEORETICAL PRODUCTION BEHAVIOR ANALYSES

2.1 Introduction

In this section numerical simulations are presented which describe the production data (drawdown/buildup) for a single well producing fluid from a geothermal reservoir. The S^3 geothermal reservoir simulation CHARGR is used to study all-liquid reservoirs, initially two-phase reservoirs and initially single-phase reservoirs which undergo flashing as a result of fluid production.

2.2 Summary

It is demonstrated that production data from single-phase hot water and initially two-phase reservoir may be analyzed, respectively, to yield absolute formation permeability and two-phase kinematic mobility. Drawdown data from initially single-phase reservoirs which undergo flashing during production can be made to give kinematic mobility; the buildup data may be used to determine absolute permeability.

2.3 Production Behavior of Hot Water Reservoirs

The classical methods of analyzing groundwater and petroleum fluid production data may be extended to interpret single-phase geothermal fluid production data. However, the extension requires a careful examination of the fluid compressibility factor which occurs in the classical solution. In this section it is shown that for hot water reservoir flow data it is necessary that the isoenthalpic fluid compressibility be used instead of the isoenergetic or isothermal fluid compressibility. Both drawdown and buildup flow tests are simulated.

2.3.1 Background of Theory

In groundwater hydrology and petroleum engineering, the line source solution to the linearized diffusivity equation is used to interpret pressure transient data. For constant rate of mass production M, the pressure at the bottom of the well $p_w(t)$ is given by

$$p_w(t) = p_i + \frac{M\nu}{4\pi Hk} Ei\left[-\frac{r_w^2 \phi \rho C_T \nu}{Hkt}\right], \tag{2.1}$$

where

p = initial reservoir pressure
ν = kinematic fluid viscosity
H = formation thickness
r_w = well radius
ρ = fluid density
k = absolute formation permeability
ϕ = porosity
t = time
C_T = total formation compressibility
$\left(= \frac{1-\phi}{\phi} C_m + C\right)$
C_m = uniaxial formation compressibility
C = fluid compressibility

If $\frac{4tk}{\phi r_w^2 \rho \nu C_T} > 100$, Equation (2.1) can be approximated as follows:

$$p_w(t) = p_i - \frac{1.15\ \nu M}{2\pi Hk}\left[\log \frac{kt}{\phi r_w^2 \nu \rho C_T} + 0.351\right] \tag{2.2}$$

Equation (2.2) implies that a plot of p_w versus log t should be a straight line. If m denotes the slope of this straight line, then

$$k = \frac{1.15\ \nu M}{2\pi Hm} \tag{2.3}$$

$$C_T = \frac{kt}{\text{antilog}\left[\frac{p_i - p_w(t)}{m} - 0.351\right]} \cdot \frac{1}{\phi r_w^2 \nu \rho} \qquad (2.4)$$

Superposition can be utilized to construct solutions for buildup (i.e., shutin after production for time t). The solution implies that a plot of p versus $\log(t+\Delta t/\Delta t)$ (Δt = shutin time) should be a straight line. The slope of the straight line can be used, together with Equation (2.3), to calculate formation permeability. (In the above, consideration of skin effect and well storage have been ignored. These effects, while important in practical well testing, are not germane to the present discussion.)

The fluid compressibility C can be defined in a number of ways (at constant internal energy C_E; at constant temperature C_t; at constant enthalpy C_h).

$$C_E = \frac{1}{\rho}\left(\frac{\partial \rho}{\partial p}\right)_E \qquad (2.5)$$

$$C_t = \frac{1}{\rho}\left(\frac{\partial \rho}{\partial p}\right)_T \qquad (2.6)$$

$$C_h = \frac{1}{\rho}\left(\frac{\partial \rho}{\partial p}\right)_h \qquad (2.7)$$

Table 2.1 gives liquid water compressibilities as a function of pressure and temperature. (Note that the data in Table 2.1 are based on S^3 CHARGR equation-of-state for water (Pritchett [1980]), and may be in error by a few percent. Nevertheless, it is believed that the relative values of C_E, C_t and C_h are approximately correct.) At 0°C, all three compressibilities are practically identical; thus for groundwater or petroleum reservoirs it is of little concern as to which fluid compressibility is used. However, at elevated temperatures characteristic of geothermal systems, substantial differences do exist between the different

Table 2.1

CONSTANT ENERGY (C_E), ISOTHERMAL (C_t), AND ISENTHALPIC (C_h) COMPRESSIBILITIES FOR LIQUID WATER AS GIVEN BY THE S^3 CHARGR EQUATION-OF-STATE.

All compressibilities are in GPa^{-1} ($1GPa^{-1} = 10^{-9}\ Pa^{-1}$)

T(0°C)	0			50			100			150			200			250			300		
P(MPa)	C_E	C_t	C_h	C_E	C_t	C_h	C_E	C_t	C_h	C_E	C_t	C_h	C_E	C_t	C_h	C_E	C_t	C_h	C_E	C_t	C_h
0.1	0.491	0.491	0.495	0.411	0.424	0.512	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2.5	0.490	0.490	0.497	0.411	0.424	0.512	0.416	0.465	0.597	0.499	0.602	0.753	0.624	0.820	0.970	-	-	-	-	-	-
5.0	0.490	0.490	0.498	0.410	0.423	0.512	0.415	0.464	0.595	0.498	0.600	0.750	0.622	0.815	0.964	0.831	1.27	1.32	-	-	-
7.5	0.489	0.489	0.498	0.410	0.423	0.512	0.415	0.463	0.594	0.497	0.598	0.747	0.620	0.810	0.959	0.826	1.25	1.31	-	-	-
10.0	0.488	0.488	0.499	0.409	0.422	0.512	0.414	0.462	0.592	0.496	0.596	0.744	0.618	0.806	0.954	0.821	1.24	1.30	1.24	2.49	2.01
12.5	0.488	0.488	0.500	0.409	0.422	0.512	0.413	0.461	0.590	0.495	0.594	0.741	0.616	0.801	0.948	0.817	1.23	1.28	1.22	2.42	1.97
15.0	0.487	0.487	0.501	0.409	0.422	0.512	0.413	0.460	0.589	0.493	0.592	0.738	0.614	0.797	0.943	0.812	1.21	1.27	1.21	2.35	1.94

compressibilities. One may speculate that for hot water reservoirs, isenthalpic fluid compressibility C_h is the appropriate one to use in the definition for total formation compressibility.

Hot water flow in geothermal reservoirs follows a complex thermodynamic path. Although the variations in internal energy, temperature, and enthalpy are small, they do nevertheless occur. The fluid flow cannot be simply treated as isoenergetic, isothermal or isenthalpic. The flowing enthalpy does, however, approach a definite limit as $r \to 0$ or $t \to \infty$. (It is worth emphasizing that the constancy of enthalpy means that internal energy and temperature must be varying.) The equations governing one-dimensional radial flow will now be considered to prove that

$$\lim_{\substack{r\to 0 \\ \text{or } t\to\infty}} h_f \to h_{fo} \quad .$$

Assuming that (1) the rock porosity depends only on the fluid pressure, (2) the rock matrix and the fluid are in local thermal equilibrium (3) the global heat conduction is negligible, and (4) the fluid flow is governed by Darcy's law, the balance equations for mass and energy in radial geometry can be written as follows:

Mass (liquid)

$$\frac{\partial}{\partial t}(\phi\rho) - \frac{1}{r}\frac{\partial}{\partial r}\left[\frac{rk}{\nu}\frac{\partial p}{\partial r}\right] = 0 \qquad (2.8)$$

Energy

$$\frac{\partial}{\partial t}\left[(1-\phi)\rho_r h_r + \phi\rho h - \phi p\right] - \frac{1}{r}\frac{\partial}{\partial r}\left[\frac{rk}{\nu} h \frac{\partial p}{\partial r}\right] = 0 \qquad (2.9)$$

where

ρ_r = rock grain density,

h_r = rock enthalpy.

The differential equations (2.8) and (2.9) are subject to the following boundary and intial conditions:

Boundary Conditions

$$\lim_{r \to 0} \; r \frac{\partial p}{\partial r} = - \frac{M\nu}{2\pi Hk} \tag{2.10}$$

$$\lim_{r \to \infty} \; p = p_i, \; h = h_i \tag{2.11}$$

Initial Conditions

$$t = 0: \quad p = p_i, \; h = h_i \tag{2.12}$$

Following O'Sullivan [1980], the similarity variable η is introduced:

$$\eta = r^{0.5}/t \tag{2.13}$$

Substituting from (2.3) into (2.8)-(2.12), one obtains the following transformed equations:

Mass

$$\frac{d(\phi\rho)}{d\eta} + \frac{2}{\eta^2} \frac{d}{d\eta} \left[\frac{k}{\nu} \eta \frac{dp}{d\eta} \right] = 0 \tag{2.14}$$

Energy

$$\frac{d}{d\eta} \left[(1-\phi)\rho_r h_r + \phi\rho h \right] - \phi p + \frac{2}{\eta^2} \frac{d}{d\eta} \left[\frac{k}{\nu} h\eta \frac{dp}{d\eta} \right] = 0 \tag{2.15}$$

Boundary and Initial Conditions

$$\lim_{\eta \to 0} \; \eta \frac{dp}{d\eta} = - \frac{M\nu}{2\pi Hk} \tag{2.16}$$

$$\lim_{\eta \to \infty} \; p = p_i, \; h = h_i \quad . \tag{2.17}$$

Also, note that

$$\frac{d\phi}{dp} = (1-\phi)C_m, \tag{2.18}$$

$$h = c_r T \tag{2.19}$$

where T is the common local temperature of the rock matrix and the pore fluids, and c_r is the rock grain heat capacity.

Regarding p and h as independent thermodynamic variables and utilizing (2.18) and (2.19), Equations (2.14) and (2.15) may be algebraically manipulated to yield:

$$\phi\rho \left\{ \frac{1-\phi}{\phi} C_m + C_h - \frac{1}{\rho}\left(\frac{\partial \rho}{\partial h}\right)_p \frac{(1-\phi)\ \rho_r c_r \left(\frac{\partial T}{\partial p}\right)_h - (1-\phi)\ C_m(\rho_r h_r + p) - \phi}{(1-\phi)\ \rho_r c_r \left(\frac{\partial T}{\partial h}\right)_p + \phi\rho + \frac{2}{\eta}(k/\nu)\frac{dp}{d\eta}} \right\}$$

$$\cdot \frac{dp}{d\eta} + \frac{2}{\eta^2}\frac{d}{d\eta}\left[\left(\frac{k}{\nu}\right)\eta \frac{dp}{d\eta}\right] = 0 \tag{2.20}$$

$$\frac{dh}{d\eta} = -\frac{\left\{(1-\phi)\ \rho_r c_r \left(\frac{\partial T}{\partial p}\right)_h - (1-\phi)\ C_m(\rho_r h_r + p) - \phi\right\}}{(1-\phi)\ \rho_r c_r \left(\frac{\partial T}{\partial h}\right)_p + \phi\rho + \frac{2}{\eta}\left(\frac{k}{\nu}\right)\frac{dp}{d\eta}} \cdot \frac{dp}{d\eta} \tag{2.21}$$

Equations (2.16) and (2.21) can be combined to give:

$$\lim_{\eta \to 0} \frac{dh}{d\eta} = 0 \tag{2.22}$$

Equation (2.22) demonstrates that the fluid enthalpy approaches a constant value in the limit $\eta \to 0$ (i.e., in the limit $r \to 0$ or $t \to \infty$). Since

$$\lim_{\eta \to 0} \eta \frac{dp}{d\eta} \neq 0 \quad ,$$

Equation (2.22) also implies that internal energy E and temperature T are varying even as $t \to \infty$.

Although Equation (2.22) is only valid as $\eta \to 0$, it is now assumed that $dh/d\eta = 0$ is a reasonable approximation to use in interpreting pressure transient data. With Equation (2.22) and taking k/ν to be constant, Equation (2.21) leads to the usual diffusivity equation:

$$\phi \rho C_T \frac{dp}{d\eta} + \frac{2}{\eta^2} \frac{k}{\nu} \frac{d}{d\eta} \eta \frac{dp}{d\eta} = 0 \qquad (2.23)$$

with

$$C_T = \frac{1-\phi}{\phi} C_m + C_h \qquad (2.24)$$

The solution of Equation (2.23) subject to the boundary conditions, Equations (2.16 and (2.17), is identical with the classical Theis solution.

2.3.2 Single-Phase Reservoir Production Behavior

To test the validity of the preceding theory, the S^3 reservoir simulator CHARGR was exercised in its one-dimensional radial mode. The radially infinite reservoir was simulated using a 60-zone [$\Delta r_1 = 0.11$ m; $\Delta r_2 = 1.2\ \Delta r_1$; $\Delta r_3 = 1.2\ \Delta r_2$, ..., $\Delta r_{60} = \Delta r_{59}$] radial grid. The outer radius of the grid is 25,825 m and is sufficiently large such that no signal reaches this boundary for production/shutin periods. The formation thickness is H = 250 m. The well is assumed to be coincident with Zone 1. (In the CHARGR code, a well can be represented as an integral part of the grid by assigning to the well-block sufficiently high permeability and porosity.) The reservoir rock is assumed to be a typical sandstone. The relevant rock properties are given in Table 2.2. (Although the present problem is purely single-phase, Table 2.2 also lists relative permeabilities, and residual liquid and

Table 2.2

ROCK PROPERTIES EMPLOYED IN NUMERICAL SIMULATION

	Well-Block ($i = 1$)	Rock Matrix ($2 \leq i \leq 60$)
Porosity, ϕ	0.9999	0.1
Permeability, $k(m^2)$	50×10^{-12}	5×10^{-14}
Uniaxial Formation Compressibility, $C_m(MPa^{-1})$	0	0
Rock Grain Density, $\rho_r(kg/m^3)$	1	2650
Grain Thermal Conductivity, $K_r(W/m-^\circ C)$	0	5.25
Heat Capacity, $c_r(kJ/kg^\circ C)$	0.001	1
Relative Permeability (k_{rl}, k_{rg})	Straight Line*	Corey**
Residual Liquid Saturation, S_{lr}	0	0.3
Residual Gas Saturation, S_{gr}	0	0.05

* $k_{rl} = S_l$, $k_{rg} = S_g = 1-S_l$, $S_l(S_g)$ = liquid (gas) volume fraction.

** $k_{rl} = (S_l^*)^4$, $k_{rg} = (1-S_l^{*2})(1-S_l^*)^2$, $S_l^* = (S_l-S_{lr})/(1-S_{lr}-S_{gr})$.

vapor saturations for later use in sections on two-phase flow.) The mixture (rock/fluid) thermal conductivity is approximated by Budiansky's formula (Pritchett [1980]).

The initial formation pressure and temperature are 9.3917 MPa and 300°C respectively. The reservoir is produced at a constant rate of 35 kg/s for t = 5.868×10^5 s, and is then shutin for Δt = 1.3932×10^6 s+. Figures 2.1 and 2.2 show the calculated drawdown and buildup response of the well. The drawdown curve has a slope m of 0.0644×10^6 Pa/~. With $\nu = 1.244 \times 10^{-7}$ m^2/s (= kinematic viscosity of fluid at initial reservoir pressure and temperature), we obtain for formation permeability k

$$k = \frac{1.15\ \nu M}{2\pi\ H\ m} = \frac{1.15 \times 1.244 \times 35 \times 10^{-7}}{2\pi \times 250 \times 0.0644 \times 10^6} \sim 4.95 \times 10^{-14}\ m^2$$

The slope of the buildup curve (~ 0.0653×10^6 Pa/~) yields k = 4.88×10^{-14} m^2. Both drawdown and buildup data thus yield permeability values in close agreement with the actual permeability of 5.00×10^{-14} m^2. With ρ = 713.9 kg/m^3 (fluid density at initial reservoir conditions), the following is obtained for total formation compressibility C_T (= fluid compressibility C since C_m = 0):

$$C_T = \frac{1}{\phi r_w^2 \nu \rho} \frac{kt}{\text{antilog}\left[\frac{p_i - p_w(t)}{m}\right] - 0.351}$$

$$= \frac{1}{0.1\ (0.11)^2\ 1.244 \times 10^{-7} \times 713.9} \frac{4.95 \times 10^{-14} \times 5 \times 10^5}{\text{antilog}\left[\frac{9.3917 - 8.8490}{0.0644} - 0.351\right]}$$

$$= 1.93\ GPa^{-1}$$

+ For the various cases discussed in the following sections, the grid, formation properties, production (injection) rate, drawdown (injection) time and shutin (falloff) time specified in this section will be used. The initial fluid state will, however, vary from case to case.

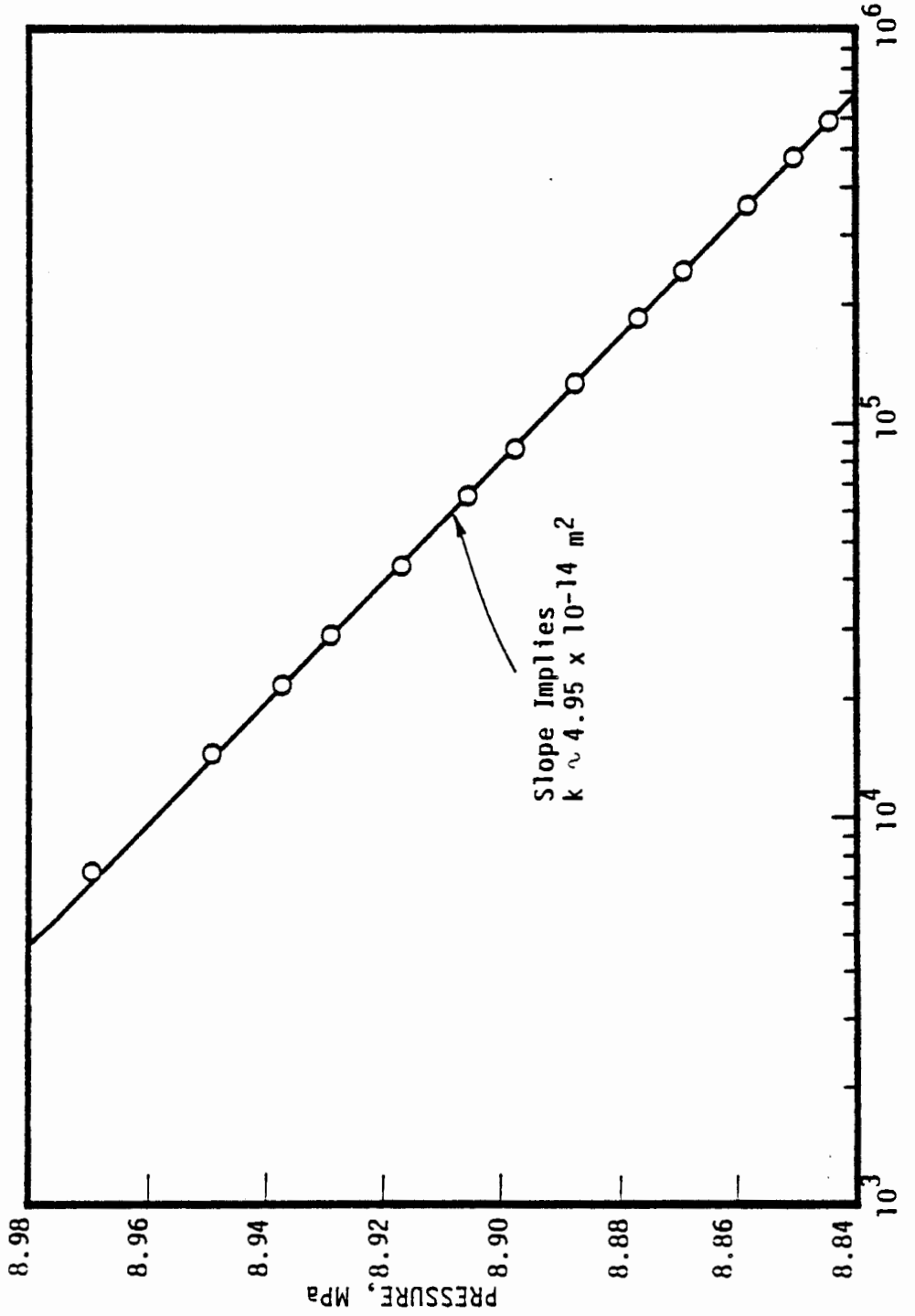

Figure 2.1. Drawdown data for hot water geothermal reservoir (p_i = 9.3917 MPa, T_i = 300°C).

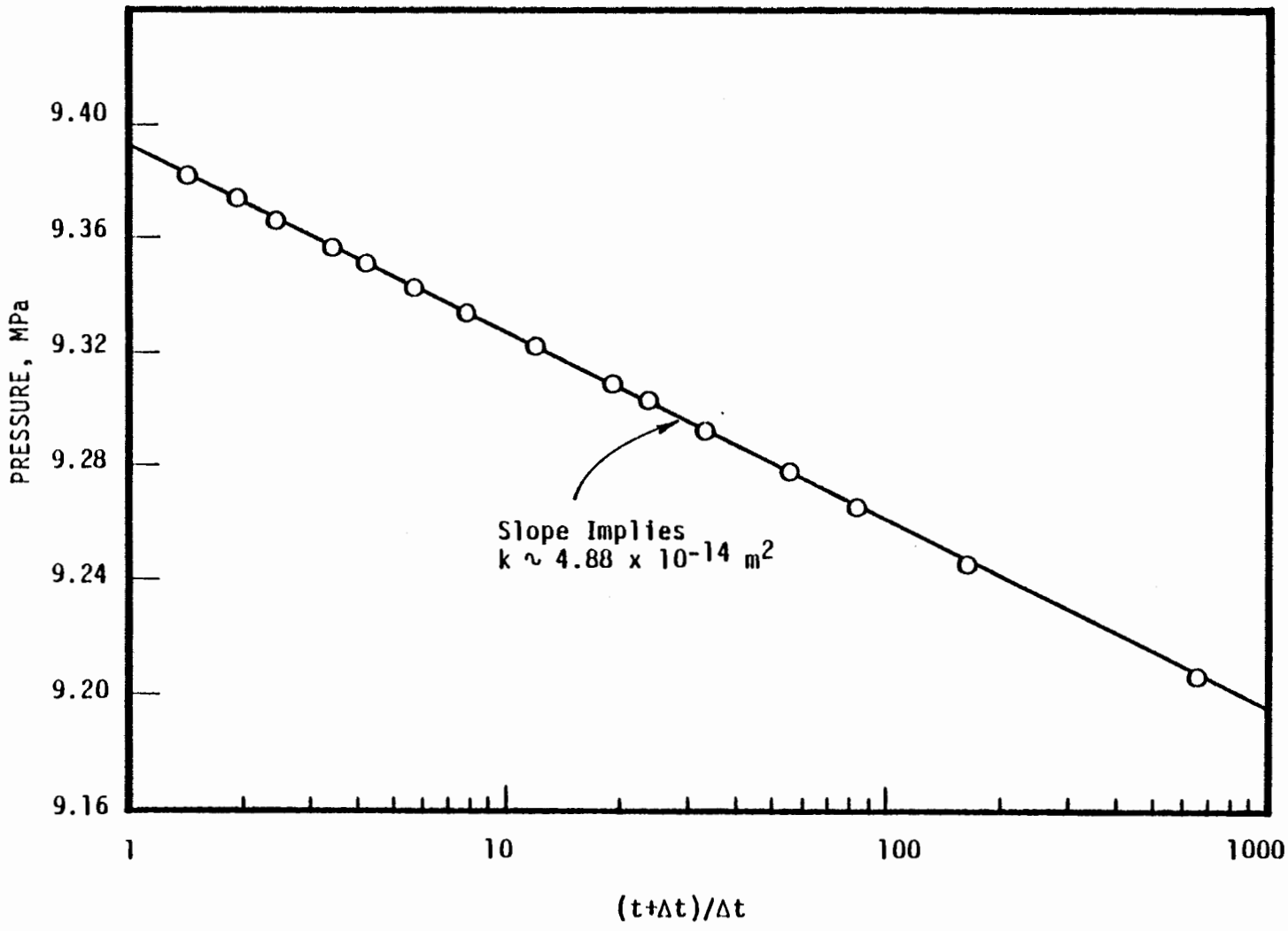

Figure 2.2. Buildup data for hot water geothermal reservoir (p_i = 9.3917 MPa, T_i = 300°C).

The calculated fluid compressibility value is in reasonable agreement with the isenthalpic fluid compressibility (~ 2.01 GPa^{-1}) but is considerably different from the isoenergetic (~ 1.24 GPa^{-1}) and isothermal (~ 2.49 GPa^{-1}) compressibilities. This verifies the speculation that the isenthalpic fluid compressibility should be used in the definition for total formation compressibility. Finally, for the sake of completeness, Figure 2.3 shows the enthalpy variation with $1/\eta^2$. Although $\max|\Delta h/h|$ (0.20/1344 ~ 1.5×10^{-4}) is very small, the fluid does undergo enthalpy changes. Furthermore, Δh (and hence h) approaches a constant value for $1/\eta^2 > 10^4$ (or $\eta < 10^{-2}$).

2.4 Production Behavior of Initially Two-Phase Geothermal Reservoirs

Approximate analytical solutions of limited applicability have been presented for cases in which a geothermal reservoir, initially boiling everywhere is produced at a constant rate. In this section detailed numerical results are presented for two cases simulating the response of such two-phase geothermal reservoirs. The bottomhole fluid pressure and temperature variations with time are examined as well as the radial distributions of flowing kinematic viscosity and steam saturation at selected times. Both drawdown and buildup flow tests are simulated.

2.4.1 Background of Theory

Recently Garg [1978], Grant [1978] and Moench and Atkinson [1977] have examined the drawdown response of initially two-phase geothermal reservoirs. The plot of pressure drop versus logarithm of time asymptotes to a straight line after an initial nonlinear period; the slope m of the straight line is related to the kinematic mobility as follows:

$$(k/\nu)_t = \frac{1.15\ M}{2\pi\ H\ m} \tag{2.25}$$

where

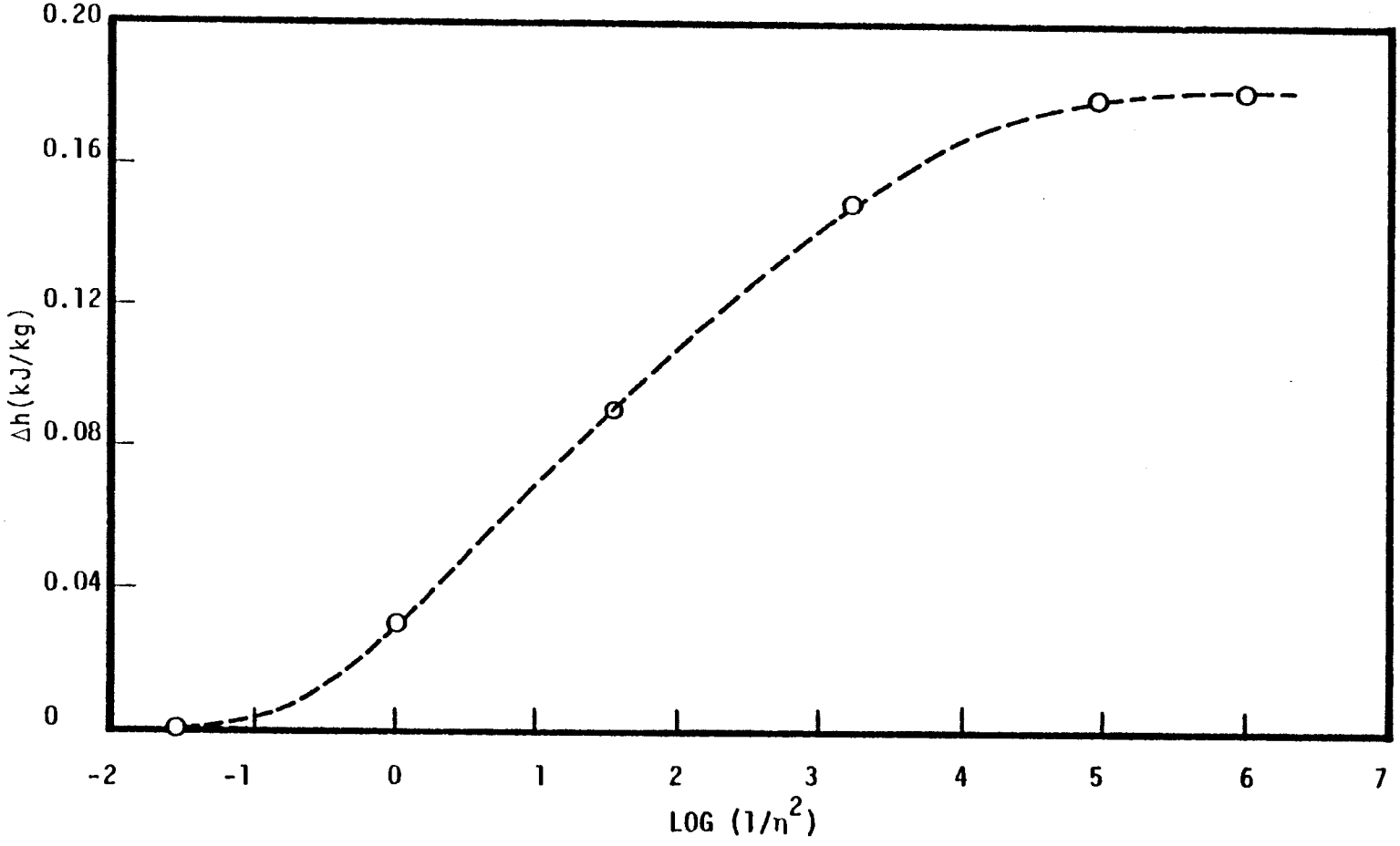

Figure 2.3. Enthalpy variation as a function of $1/\eta^2$ for hot water reservoir.

$$(k/\nu)_t = k/\nu_t \tag{2.26}$$

$$\frac{1}{\nu_t} = \frac{k_{r\ell}}{\nu_\ell} + \frac{k_{rg}}{\nu_g} \tag{2.27}$$

Given flowing enthalpy h_f, it also is possible to obtain the separate liquid- and vapor-phase kinematic mobilities.

$$\frac{kk_{r\ell}}{\nu_\ell} = (k/\nu)_t \left[\frac{h_g - h_f}{h_g - h_\ell}\right]; \quad \frac{kk_{rg}}{\nu_g} = (k/\nu)_t \left[\frac{h_f - h_\ell}{h_g - h_\ell}\right] \tag{2.28}$$

The intercept of the straight line can be used to calculate an effective total formation compressibility C_T; however, as noted by Garg [1978] and Sorey, et al. [1980], the inferred value often provides a very poor approximation to the actual value.

Sorey, et al. [1980] have numerically investigated the buildup behavior in initially two-phase reservoirs; the plot of pressure versus logarithm of time gives a straight line. The slope of the straight line can be used to calculate total kinematic mobility from Equation (2.25). The kinematic mobility inferred from the buildup data is, however, different from the one given by drawdown data; this illustrates the nonlinear nature of two-phase flow in porous media. Sorey, et al. also observed over-recovery of liquid saturation near the wellbore during buildup.

2.4.2 Two-Phase Reservoir Production Behavior

In the following, two cases will be considered in which the reservoir, initially boiling everywhere, is produced at a constant rate. The initial fluid state is given in Table 2.3.

Table 2.3
INITIAL FLUID STATE FOR TWO-PHASE CASES

Case No.	Pressure, MPa	Steam Sat.	Enthalpy (kJ/kg)
A.1	8.5917	0.28	1466
A.2	8.5917	0.05	1345

Figures 2.4 and 2.5 show the drawdown and the flowing enthalpy data. The drawdown data closely fit a straight line; the slope of the straight line m yields the flowing kinematic viscosity ν_t.

$$\nu_t = \frac{2\pi\ H\ m}{1.15\ M}\ k \tag{2.29}$$

The inferred values of ν_t (Figures 2.4 and 2.5) are representative of a large region surrounding the producing well (see Figures 2.8 and 2.9) wherein $\partial S_g/\partial r$ is small (Figures 2.10 and 2.11). After an initial nonlinear period, the flowing enthalpy approaches a more or less constant value (Figures 2.4 and 2.5) as predicted by the linear theory of Grant [1979a]; the flowing enthalpy does, however, undergo small fluctuations even at late times. With h_ℓ = 1345 kJ/kg and h_g = 2749 kJ/kg (values corresponding to 8.5917 MPa), the separate liquid- and vapor-phase relative permeabilities as calculated from Equation (2.28) are given in Table 2.4.

The calculated relative permeability values are representative of the reservoir region wherein $\partial S_g/\partial r$ is small. Agreement between the calculated and inferred values (especially gas) could be improved by evaluating ν_ℓ and ν_g at actual bottom-hole conditions.

The pressure and temperature buildup data are given in Figures 2.6 and 2.7. For the high saturation case (case A.1), pressure buildup data fit a straight line; the inferred ν_t from the straight line is characteristic of the two-phase region (see Figure 2.8). In the low-saturation case (case A.2), more than one straight line can be fit to the pressure buildup data indicating a nonlinear buildup response; the calculated ν_t's can, however, still be identified with those obtained in the two-phase region (Figure 2.9). Figures 2.10 and 2.11 show the vapor saturation distribution at different times; during buildup substantial liquid over-recovery is seen. The condensation front (Figures 10 and 11) eventually engulfs most of the reservoir region affected during the

Table 2.4

CALCULATION OF LIQUID- AND VAPOR-PHASE RELATIVE PERMEABILITIES

Case	h_f(kJ/kg)	h_ℓ(kJ/kg)	h_g(kJ/kg)	$\frac{kk_{r\ell}}{\nu_\ell}$ (s)	$\frac{kk_{rg}}{\nu_g}$ (s)
A.1	2158	1345	2749	1.41×10^{-8}	1.95×10^{-8}
A.2	1414	1345	2749	7.70×10^{-8}	0.40×10^{-8}

Case	ν_ℓ(m^2/s)*	ν_g(m^2/s)*	$k_{r\ell}$	k_{rg}	$k_{r\ell}$(actual)	k_{rg}(actual)
A.1	1.245×10^{-7}	4.283×10^{-7}	0.035	0.167	0.033 - 0.056	0.27 - 0.20
A.2	1.245×10^{-7}	4.283×10^{-7}	0.192	0.034	0.18 - 0.25	0.69 - 0.042

* Values at P ∿ 8.5917 MPa, T ∿ 300°C

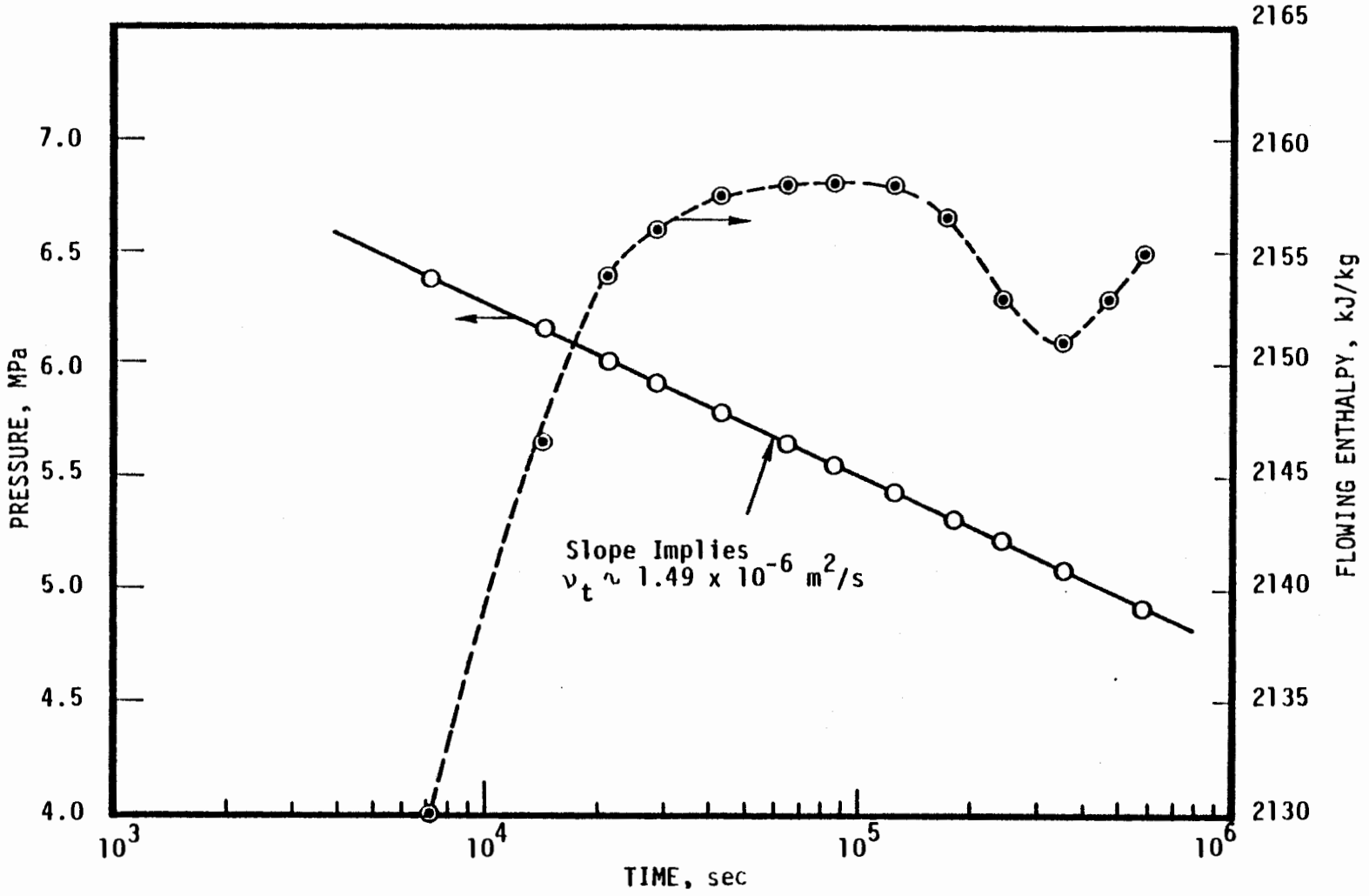

Figure 2.4. Pressure drawdown and flowing enthalpy for case A.1 (p_i = 8.5917 MPa, S_{gi} = 0.28, h_i = 1466 kJ/kg).

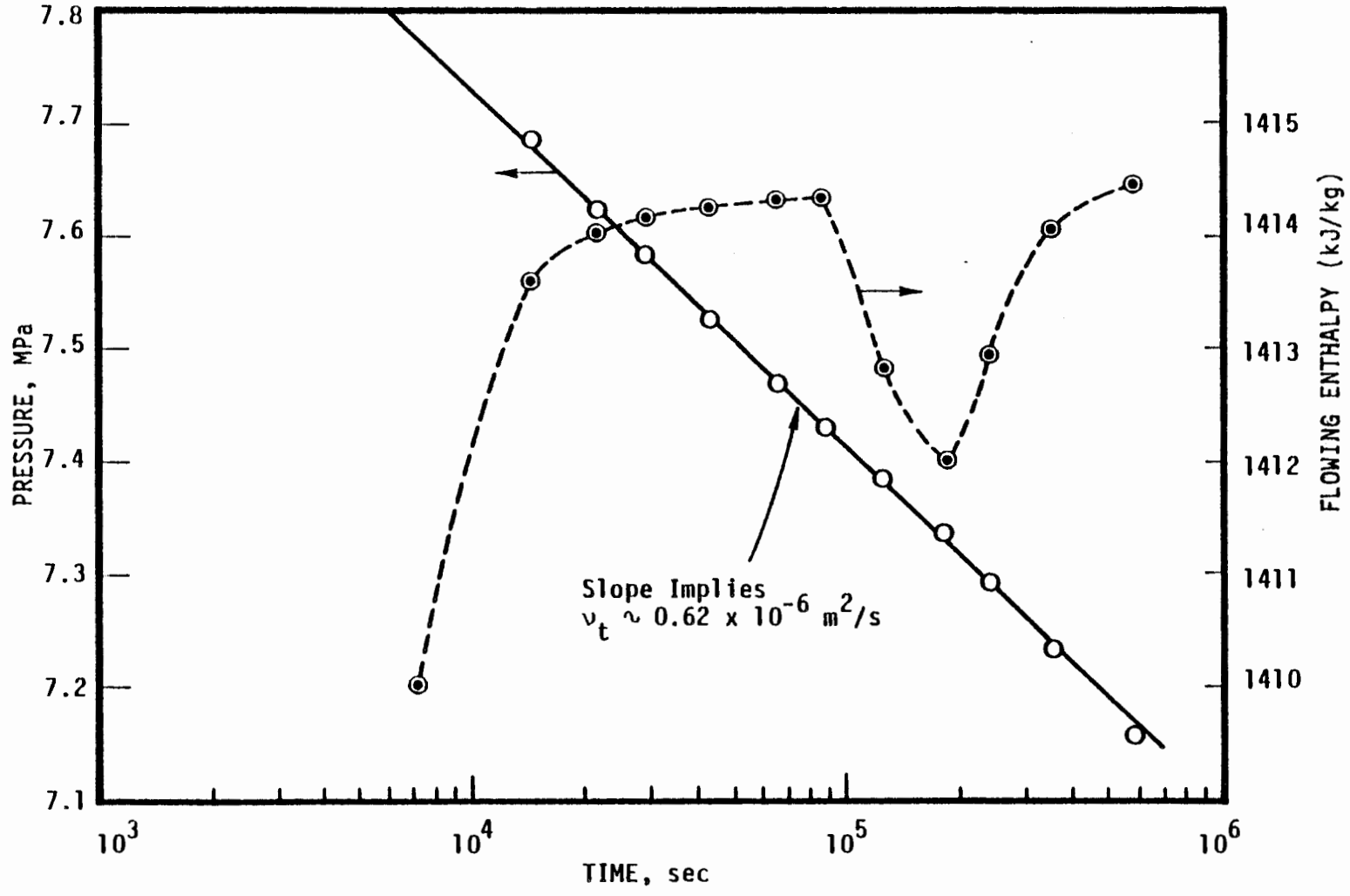

Figure 2.5. Pressure drawdown and flowing enthalpy for case A.2 (p_i = 8.5917 MPa, S_{gi} = 0.05, h_i = 1345 kJ/kg).

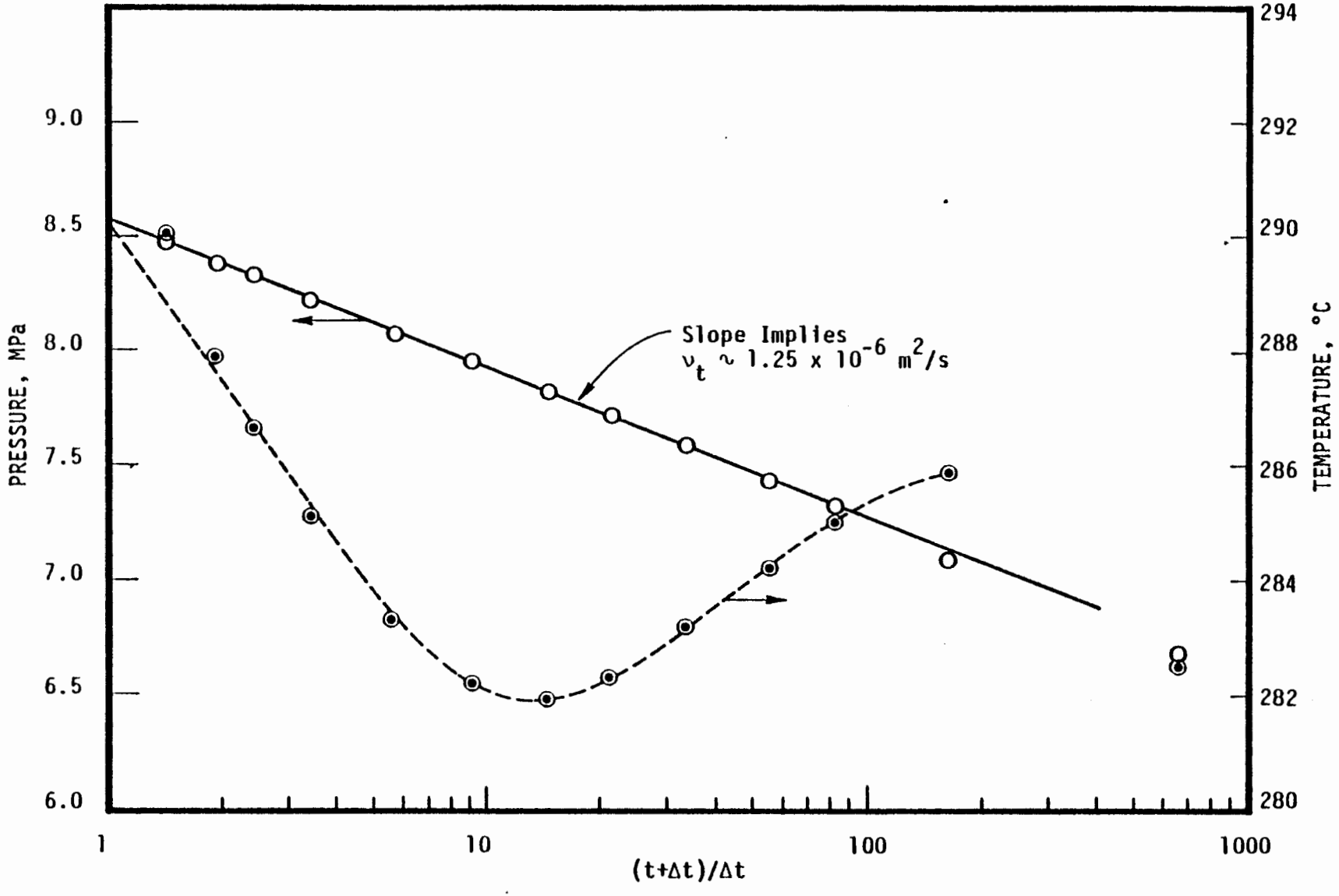

Figure 2.6. Pressure and temperature buildup data for case A.1.

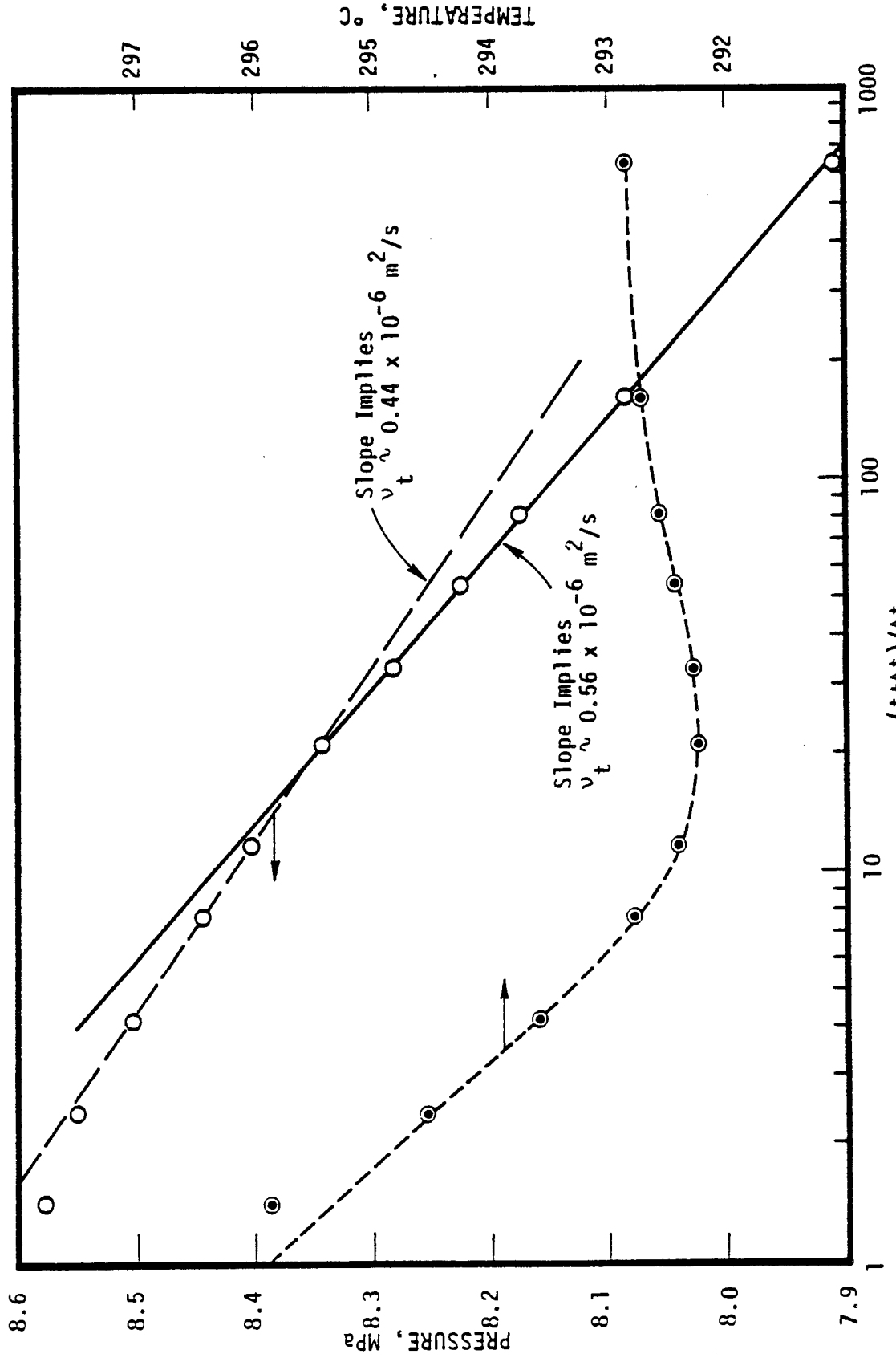

Figure 2.7. Pressure and temperature buildup data for case A.2.

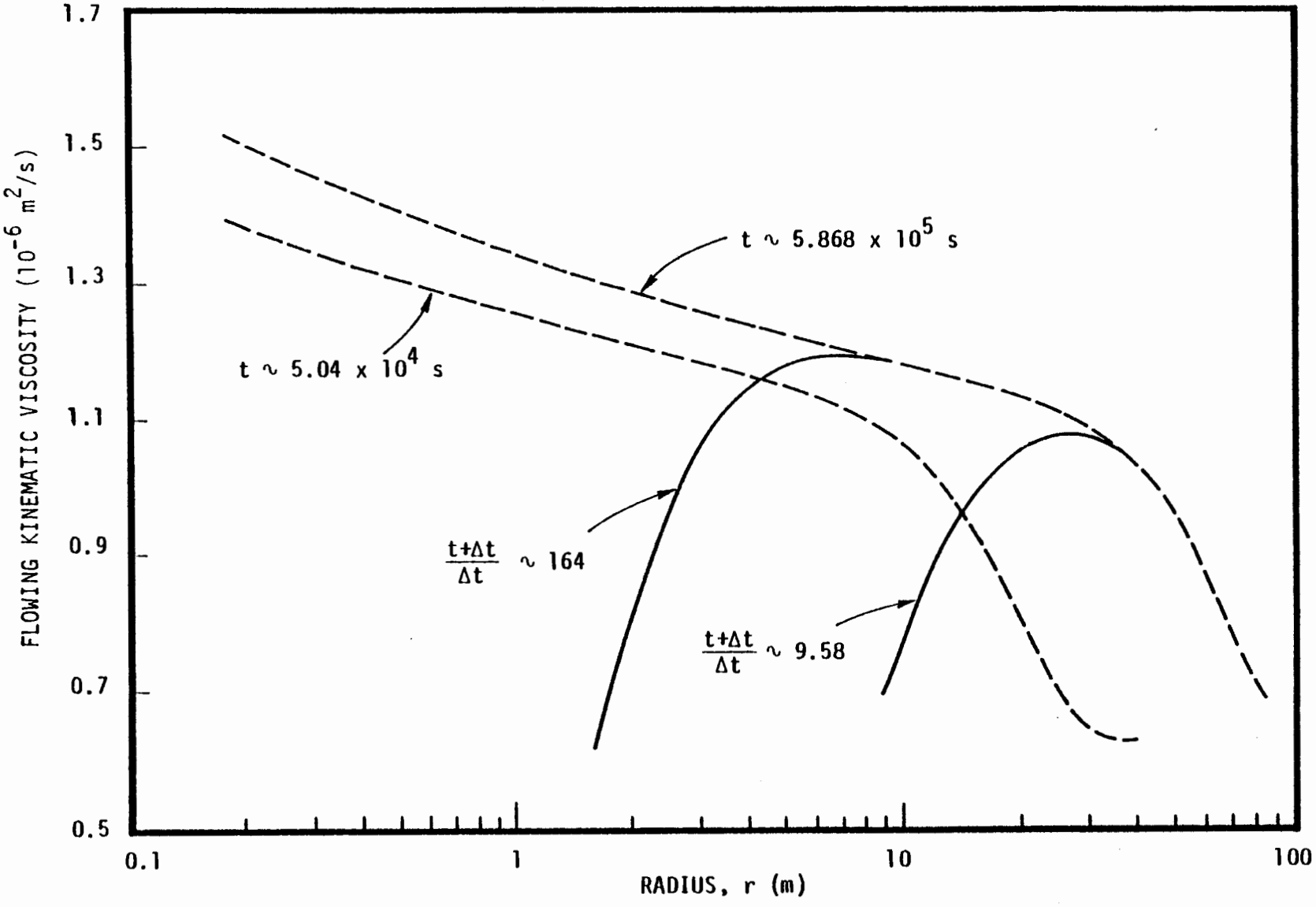

Figure 2.8. Radial distribution of flowing kinematic viscosity ν_t at selected times for case A.1.

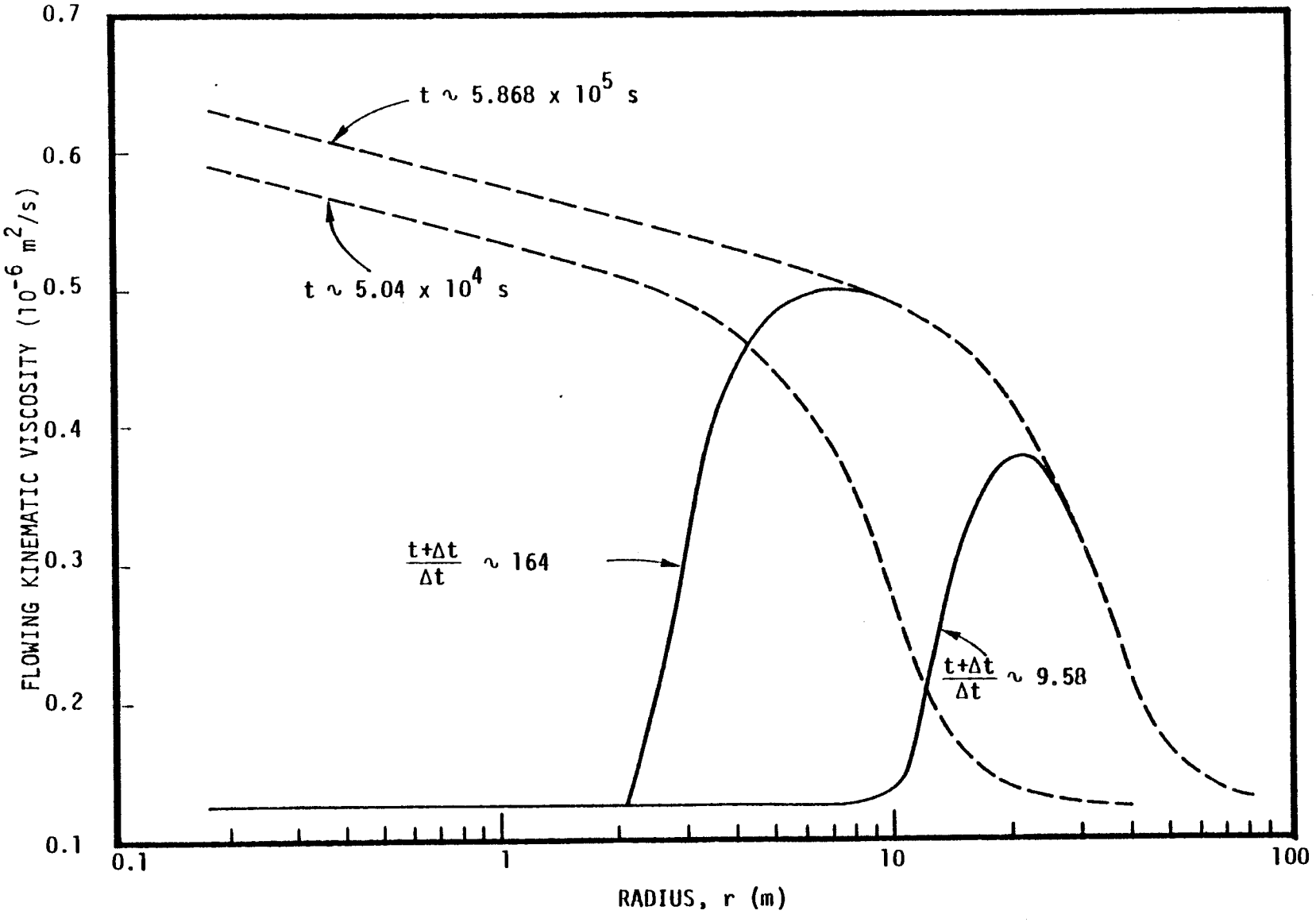

Figure 2.9. Radial distribution of flowing kinematic viscosity ν_t at selected times for case A.2.

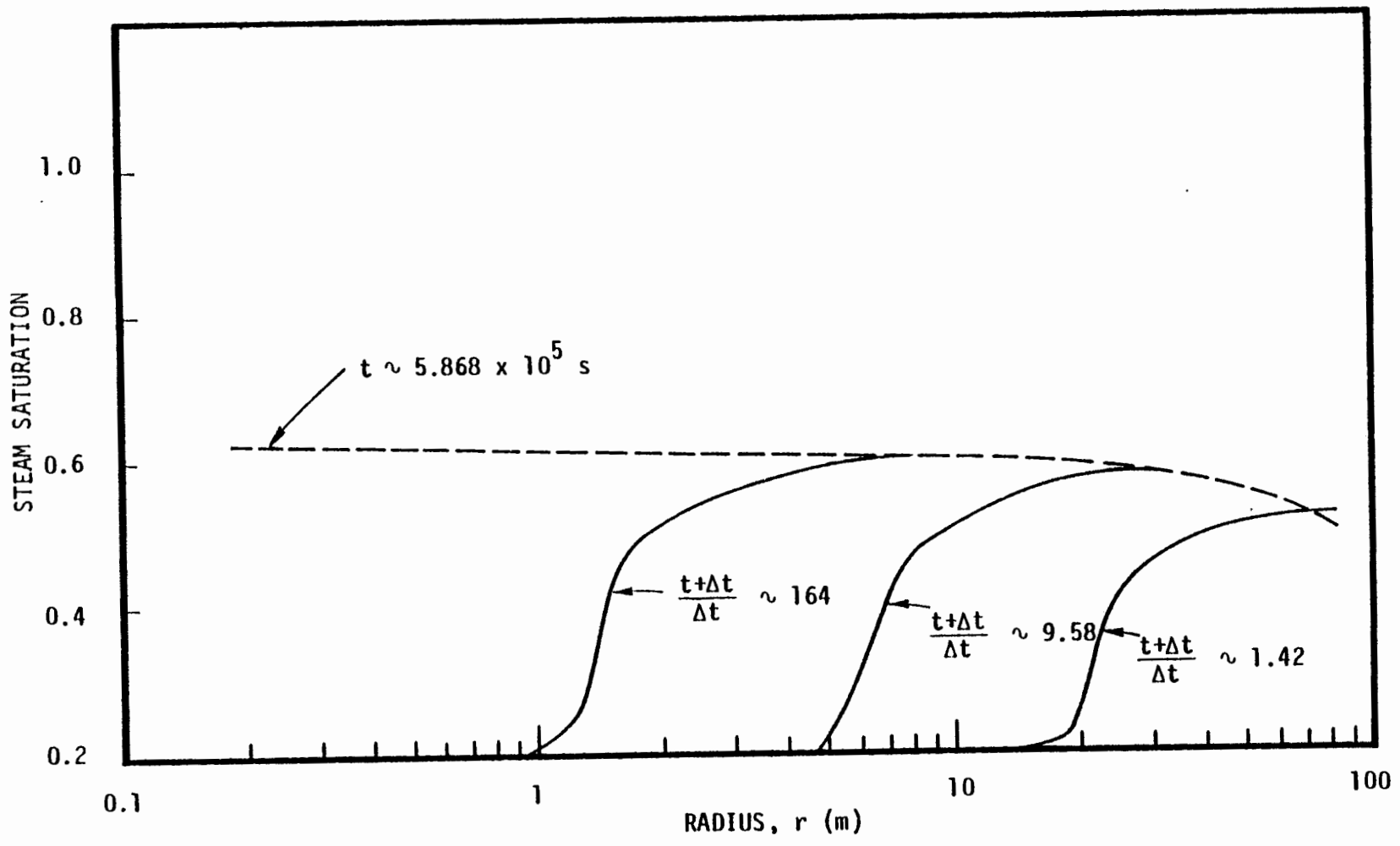

Figure 2.10. Radial distribution of steam saturation S_g at selected times for case A.1.

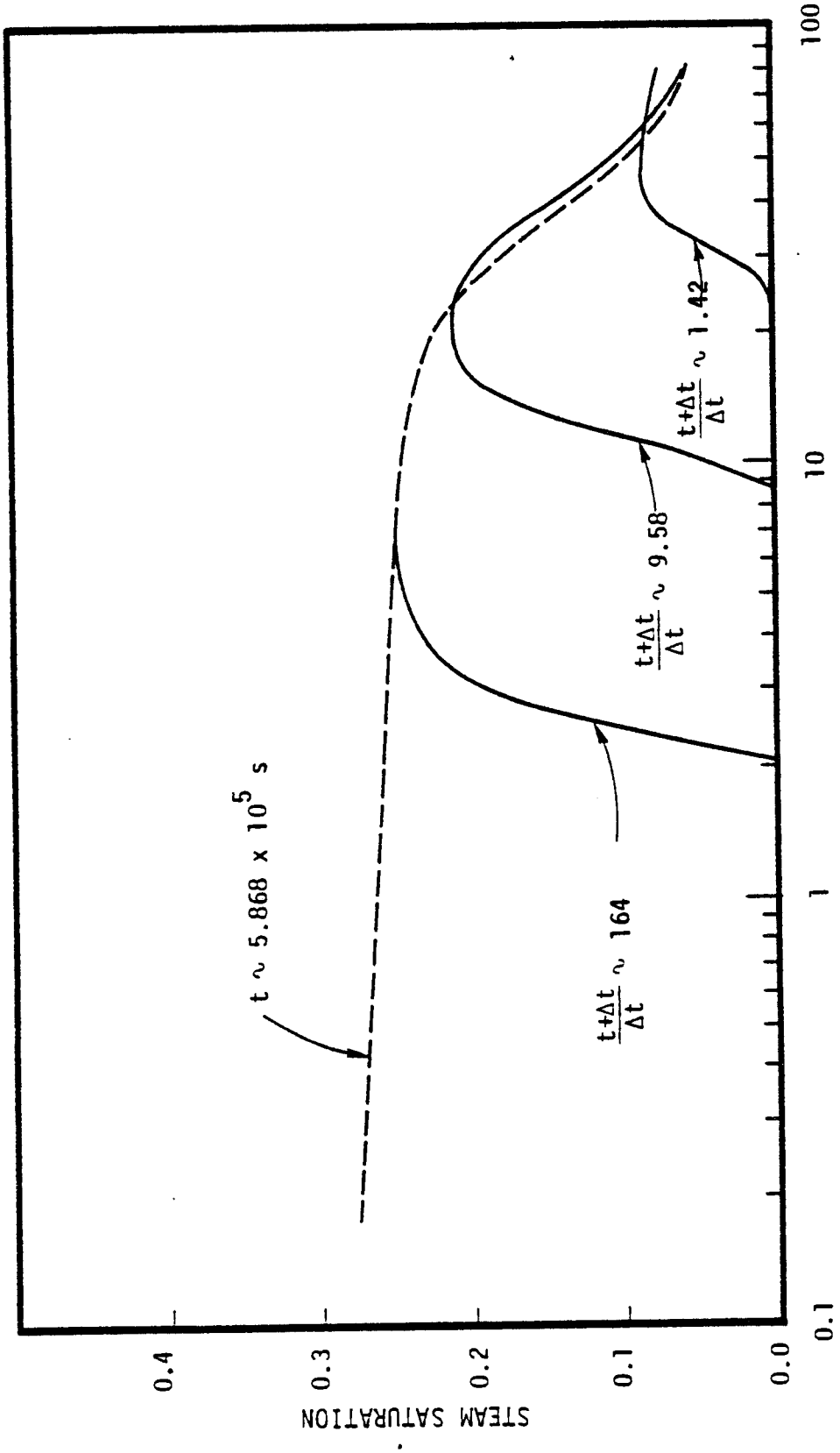

Figure 2.11. Radial distribution of steam saturation S_g at selected times for case A.2.

drawdown period. The reason for liquid-phase over-recovery during buildup is fairly straightforward. During drawdown, a decrease in pressure is accompanied by a corresponding reduction in temperature. (Note that pressure and temperature in two-phase flow are not independent.) On shutin, the pressure tends to recover to the initial formation pressure. The temperature recovery beyond the saturation point at local reservoir conditions occurs on a much longer time scale than the one for pressure recovery. (Temperature recovery is mainly governed by heat conduction.) A puzzling aspect of pressure recovery is that it appears to be essentially governed by the two-phase region in the reservoir. The reason for the latter behavior must be sought in the great difference between the liquid- and two-phase compressibilities. Since the liquid compressibility is much smaller (by 2 to 3 orders of magnitude) than the two-phase compressibility, the liquid-phase will reach pressure equilibrium (i.e., zero pressure gradient) on a much faster time scale than the two-phase region. Numerical calculations show that the liquid-region pressure gradients are essentially zero for the entire buildup period. Finally, it is noted that the condensation front does not obey the law ($R \alpha t^{1/2}$); this demonstrates that the similarity solution (see e.g., O'Sullivan [1980]) does not apply to buildup in two-phase reservoirs.

2.5 Production Behavior of Hot Water Reservoirs which Flash on Fluid Withdrawal

In this section the response of an initially single-phase reservoir which undergoes flashing on fluid production is considered. Detailed numerical results are presented which simulate both the propagation of the flash front during production and the propagation of a condensation front, during buildup. The presence of these fronts is shown to greatly complicate the interpretation of the well test data.

2.5.1 Background of Theory

Garg [1978] has considered the drawdown response of an initially single-phase reservoir which undergoes flashing on fluid production. In this case, the reservoir exhibits single-phase response until some time t_f when the well pressure falls below the saturation pressure at the local reservoir temperature; for $t > t_f$, a flash front starts propagating into the formation. The reservoir (for $t > t_f$) is two-phase for $r < R$ [$R = R(t)$ denotes the location of the flash front], and is single-phase for $r > R$. The drawdown curve ($t > t_f$) asymptotes to a straight line; the slope of the straight line yields the total kinematic mobility $(k/\nu)_t$ (c.f., Equation (2.25)). The buildup behavior of such reservoirs has apparently not been previously investigated.

2.5.2 Hot Water Reservoirs which Undergo Flashing

To study the drawdown/buildup behavior of hot water reservoirs which undergo flashing on production, two cases will be considered. The initial fluid-state for these cases is given in Table 2.5.

Table 2.5
INITIAL FLUID-STATE FOR HOT-WATER RESERVOIRS WHICH UNDERGO FLASHING ON PRODUCTION

Case No.	Pressure, MPa	Temperature, °C
B.1	8.7917	300
B.2	8.9917	300

Figures 2.12 and 2.13 show the simulated drawdown histories for the two cases; these figures show only the two-phase part of the drawdown response. In case B.1 (low pressure case), the flash front propagates to approximately 20 m at the end of the drawdown period (Figure 2.18); for the high-pressure case (B.2), the flash front

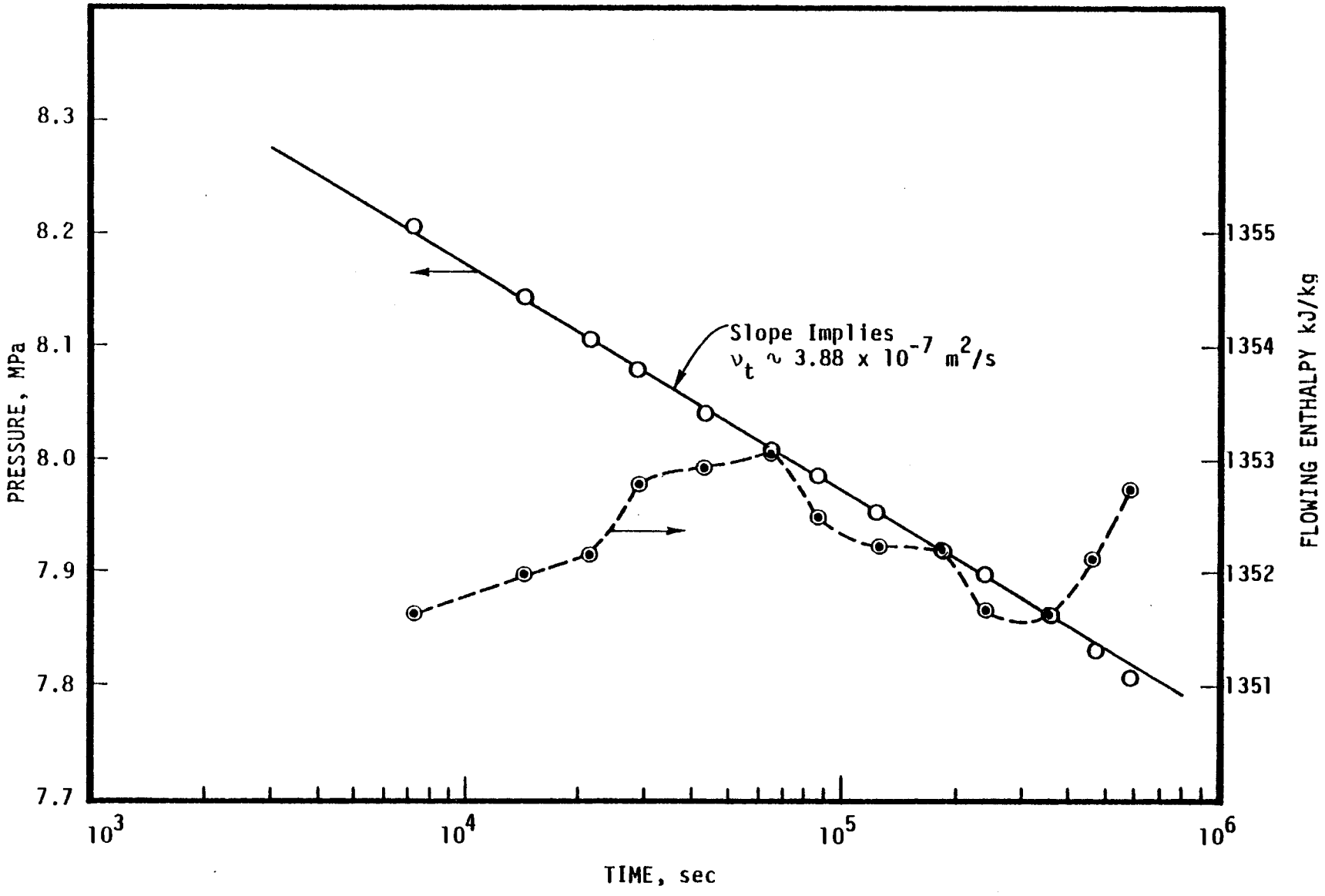

Figure 2.12. Pressure drawdown and flowing enthalpy for case B.1 (p_i = 8.7917 MPa, T_i = 300°C)

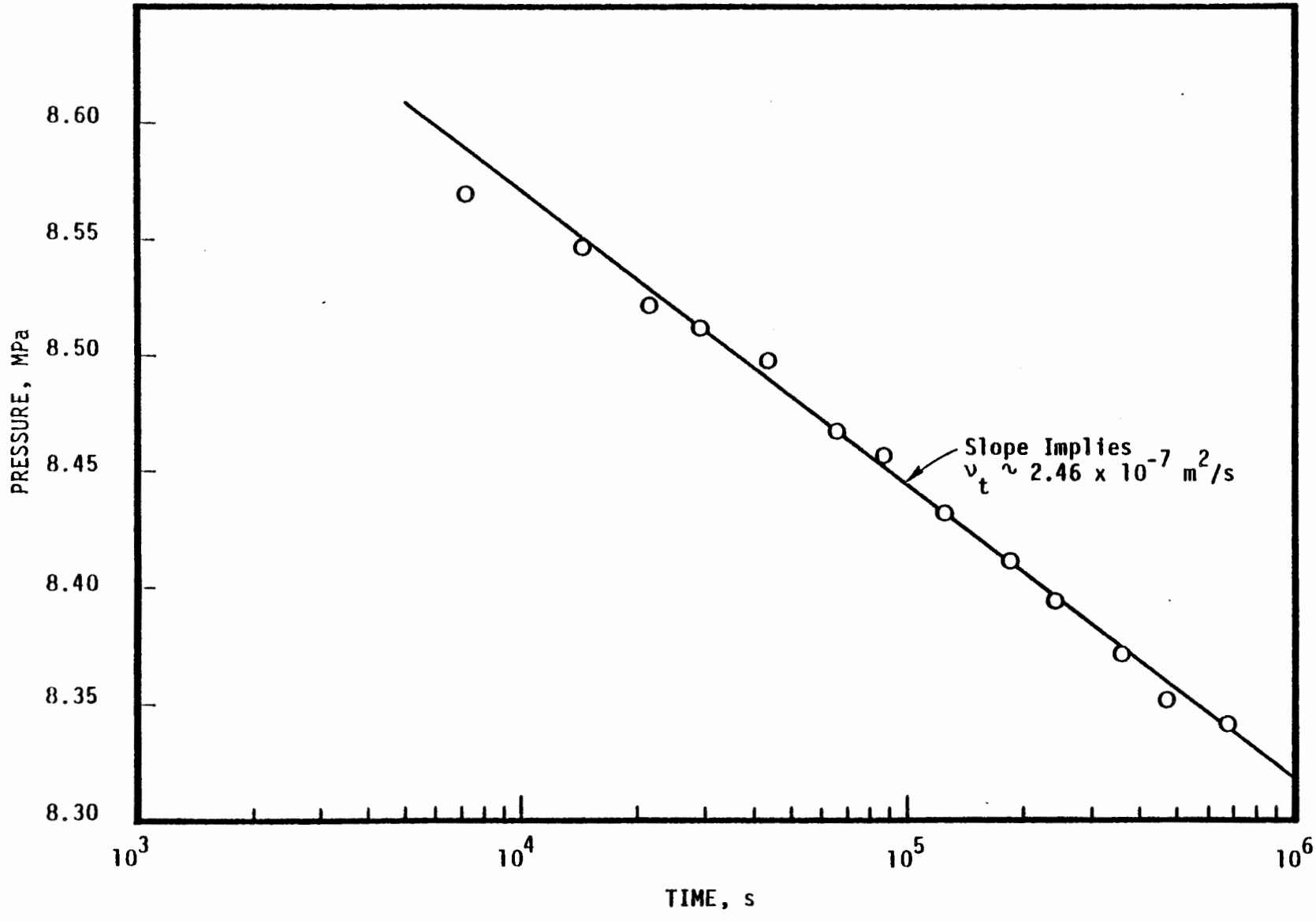

Figure 2.13. Pressure drawdown for case B.2 (p_i = 8.9917 MPa, T_i = 300°C)

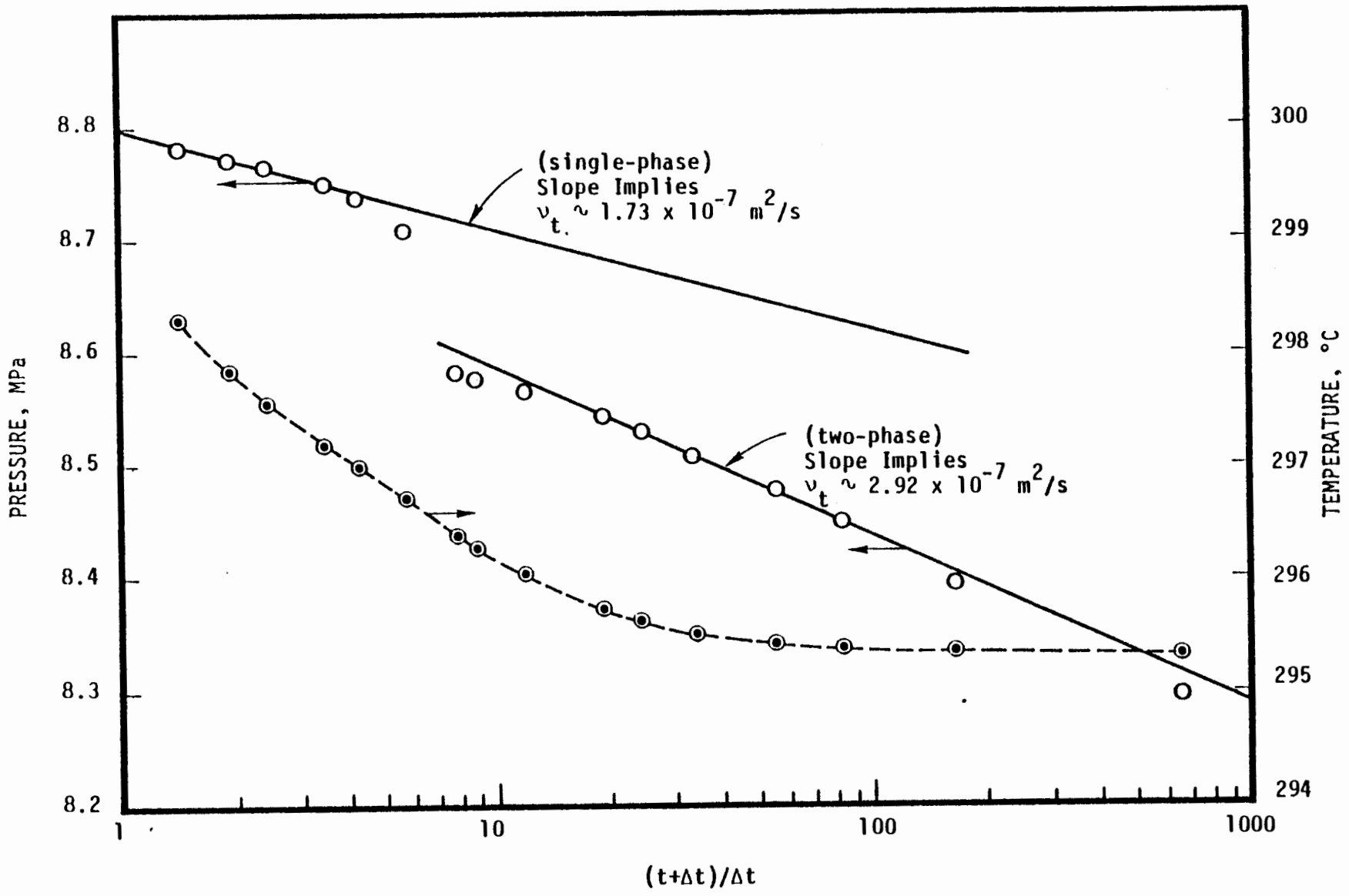

Figure 2.14. Pressure and temperature buildup data for case B.1.

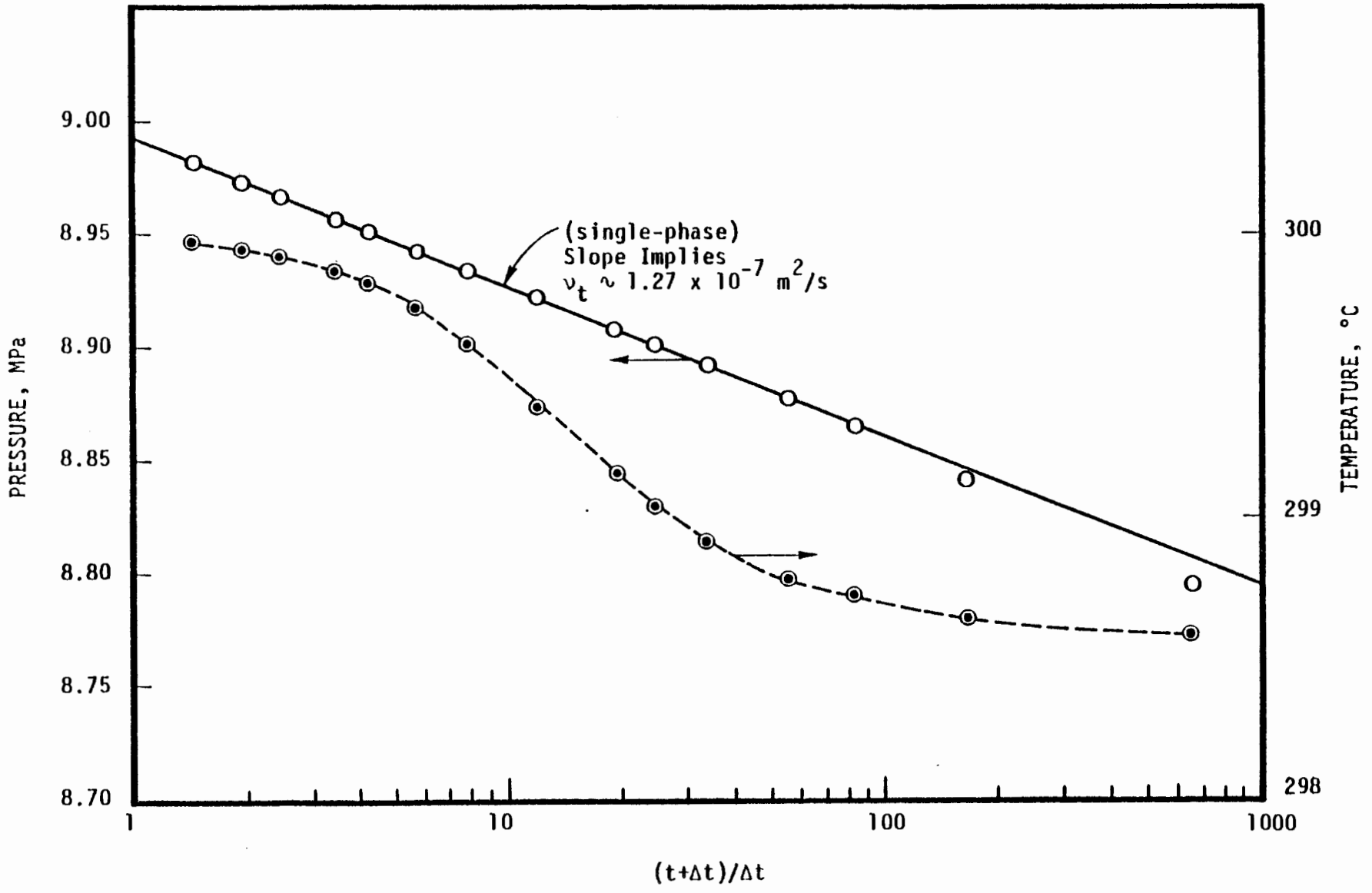

Figure 2.15. Pressure and temperature buildup data for case B.2.

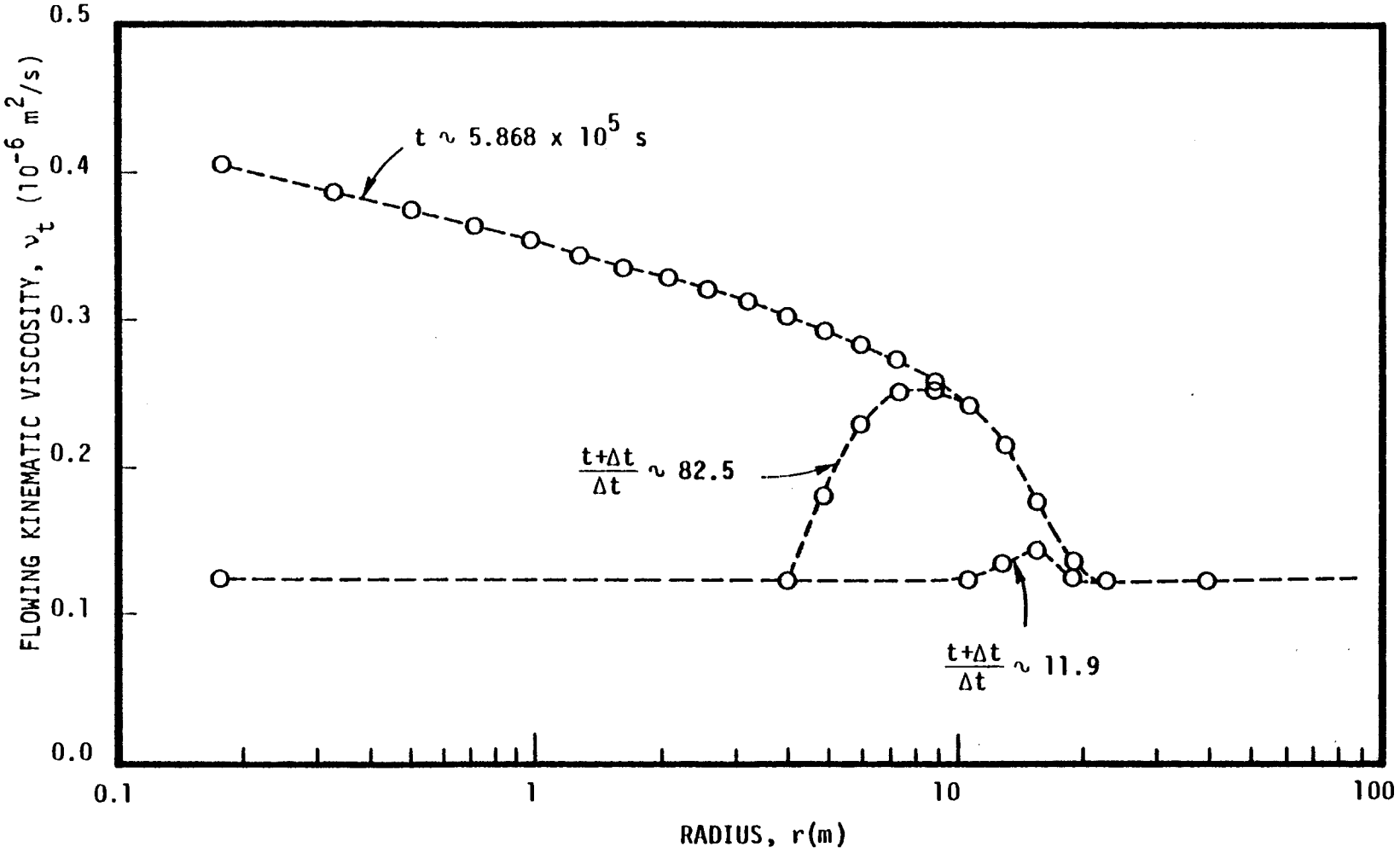

Figure 2.16. Radial distribution of flowing kinematic viscosity ν_t at selected times for Case B.1.

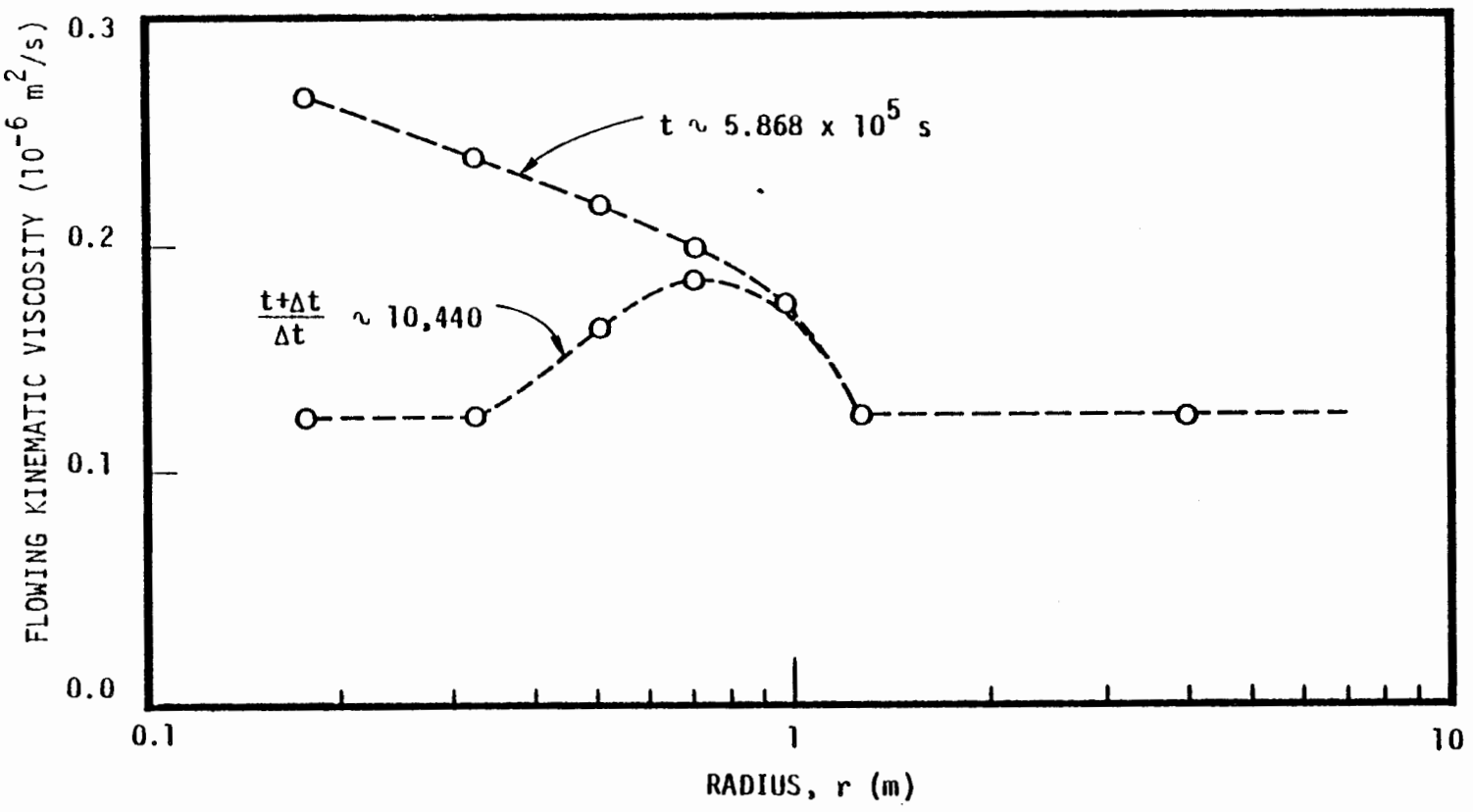

Figure 2.17. Radial distribution of flowing kinematic viscosity ν_t at selected times for case B.2.

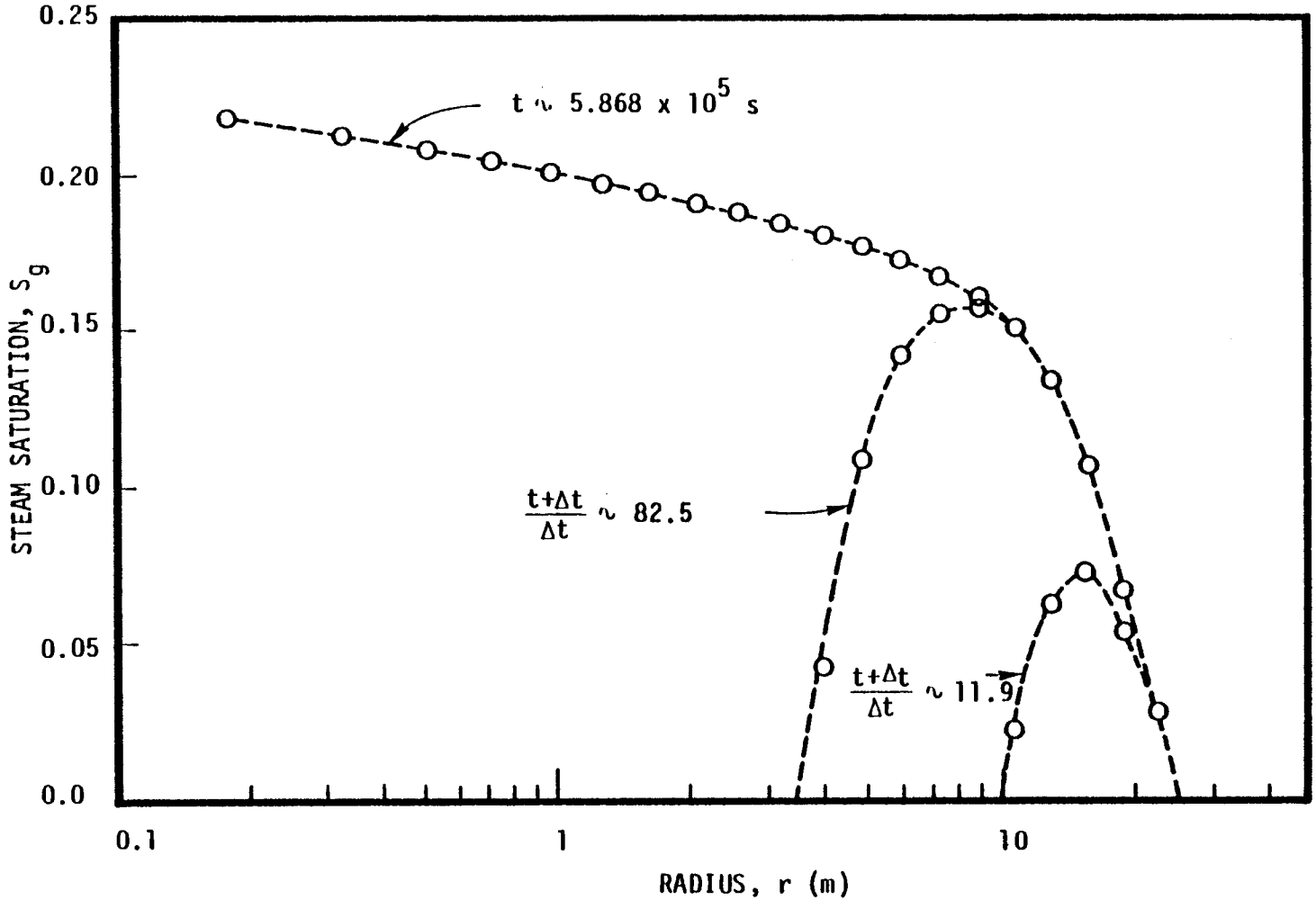

Figure 2.18. Radial distribution of steam saturation S_g at selected times for case B.1.

advances to only 1 m (Figure 2.19). The drawdown data closely fit straight lines; the slopes of the straight lines yield flowing kinematic viscosities which are representative of the two-phase part of the reservoir wherein $\partial S_g/\partial r$ is small (see Figures 2.12, 2.13, 2.16 and 2.17).

The buildup behavior is shown in Figures 2.14 and 2.15. Referring to Figure 2.14, it may be seen that in the low pressure case, the initial buildup behavior is governed by the two-phase region of the reservoir; the slope of this curve yields ν_t which is characteristic of the two-phase region created during drawdown (see Figure 2.14 and 2.16). The pressure buildup is accompanied by the propagation of a condensation front, originating at the well, into the formation (Figure 2.18); the condensation front eventually engulfs the entire two-phase region after which the buildup behavior is essentially that of a single-phase fluid. The two-buildup segments (single-phase and two-phase) are separated by approximately one log cycle (Figure 2.14). The single-phase buildup behavior (Figure 2.14) extends over less than one-half cycle; the slope of this straight line yields a kinematic viscosity $\nu_t \sim 1.73 \times 10^{-7}$ m^2/s which is approximately 40 percent larger than the actual value of 1.245×10^{-7} m^2/s. The divergence between the inferred and actual values of ν_t is really not surprising in view of the fact that single-phase buildup response in this particular instance is observed for less than one-half log cycle. In the high pressure case (B.2), the two-phase buildup behavior lasts for only a very brief period (at most a few minutes, see Figures 2.17 and 2.19); the single-phase buildup, however, lasts for approximately two-log cycles (Figure 2.15). The slope of the straight line in case B.2 yields a ν_t in good agreement with the actual value of 1.245×10^{-7} m^2/s.

The above discussion of buildup behavior illustrates the importance of selecting the correct straight line. If sufficiently long (at least one-log cycle) straight line segments can be identified, then the buildup data may be interpreted to give both

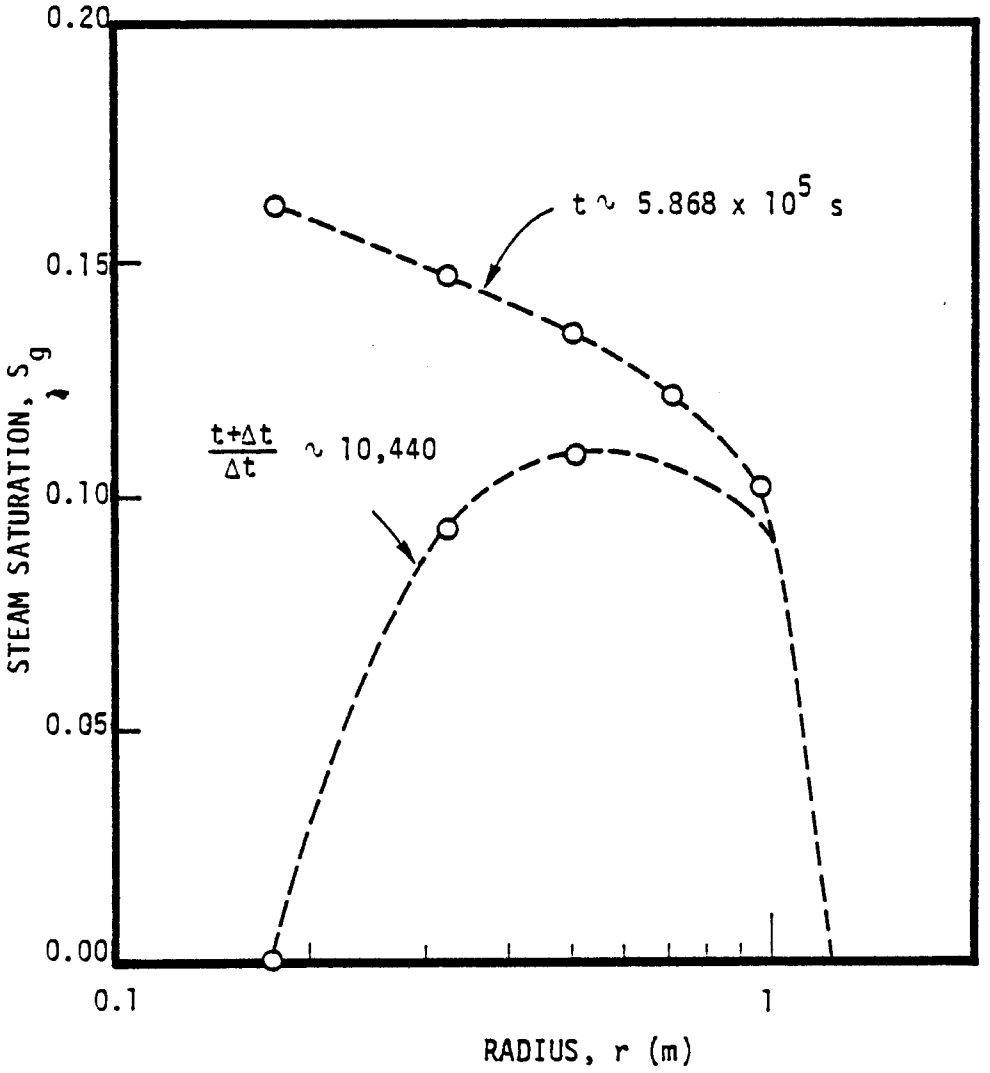

Figure 2.19. Radial distribution of steam saturation S_g at selected times for case B.2.

single- and two-phase kinematic mobilities. In many practical situations, however, it is likely that the buildup data will not be such as to make possible the unambiguous determination of both single- and two-phase mobilities.

SECTION 3: THEORETICAL INJECTION BEHAVIOR ANALYSES

3.1 Introduction

In this section numerical simulations are presented which describe the injection data for a single well injecting into a geothermal reservoir. The S^3 geothermal reservoir simulator CHARGR is used to analyze single-phase and two-phase reservoirs.

3.2 Summary

It is demonstrated that injection data for single-phase and two-phase geothermal reservoirs can be interpreted to yield absolute formation permeability. The pressure fall-off data subsequent to injection are of lesser utility.

3.3 Cold Water Injection into a Hot Water Well

In this section, a case is considered wherein cold water is injected into a single-phase (all liquid) hot water well. The initial formation pressure and temperature are 8.7917 MPa and 300°C respectively; the temperature of the injected fluid (injection rate = 35 kg/s) is approximately 151°C. The pressure buildup (Injection) data are seen to fit a straight line (Figure 3.1); the slope of this straight line yields $\nu_t \sim 1.985 \times 10^{-7}$ m^2/s which is in good agreement with the kinematic viscosity of the injected fluid ($\sim 1.955 \times 10^{-7}$ m^2/s). Figure 3.2 shows the radial distribution of ν_t and temperature T at the end of the injection period ($\sim 5.868 \times 10^5$ s); the thermal front is seen to have propagated approximately 6 m into the formation. The fall-off (shutin) data are plotted in Figure 3.3; the fall-off data asymptote to a straight line whose slope yields a value of $\nu_t \sim 1.20 \times 10^{-7}$ m^2/s which is in good agreement with the kinematic viscosity of hot water ($\sim 1.25 \times 10^{-7}$ m^2/s). No straight line corresponding to cold water pressure fall-off can, however, be identified on Figure 3.3; the reason for this is tied to the relatively small radius (~ 6 m) affected by cold

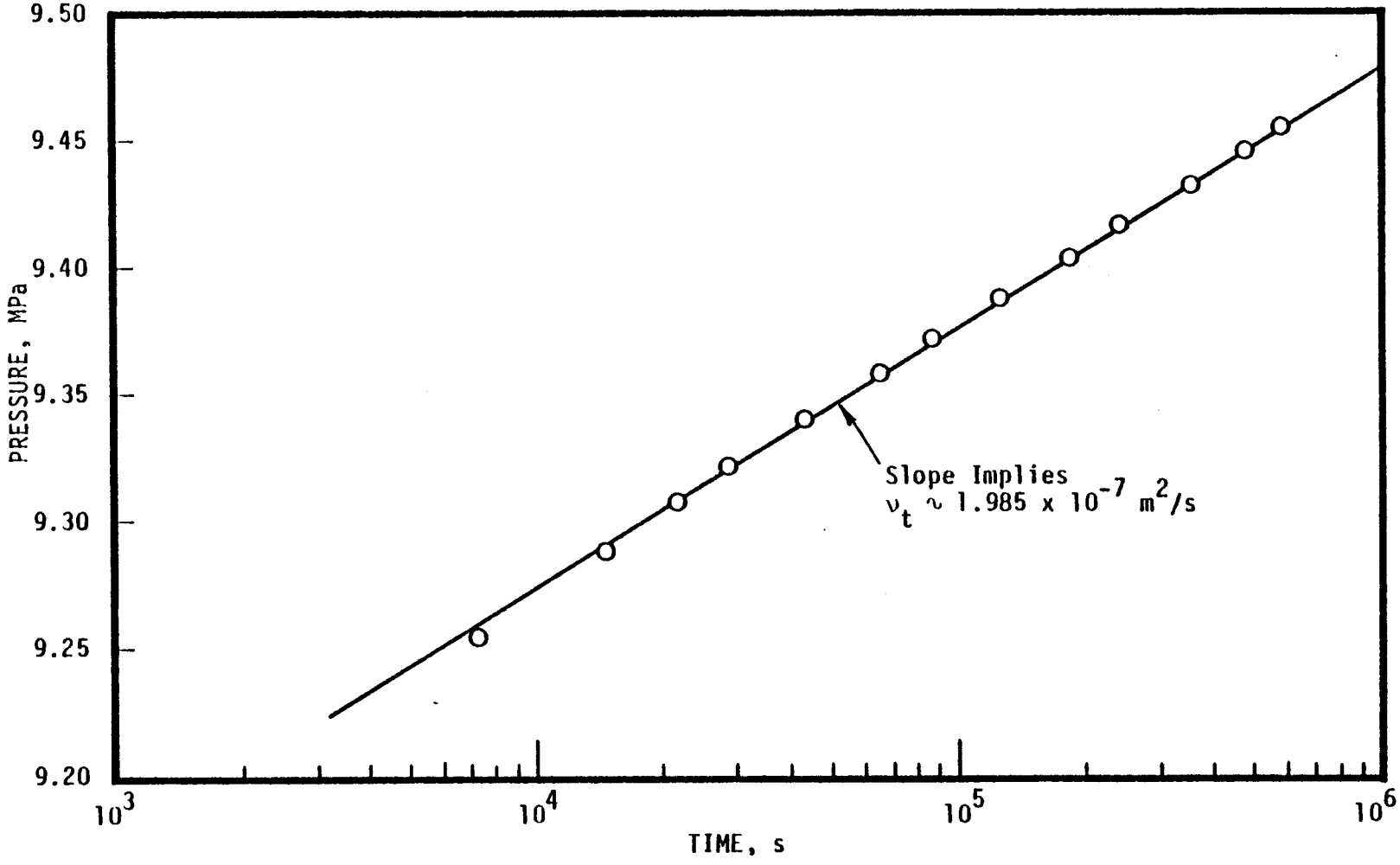

Figure 3.1. Pressure buildup (Injection) data for cold water injection into a hot water well (p_i = 8.9917 MPa, T_i = 300°C, $T_{injection} \sim 151$°C).

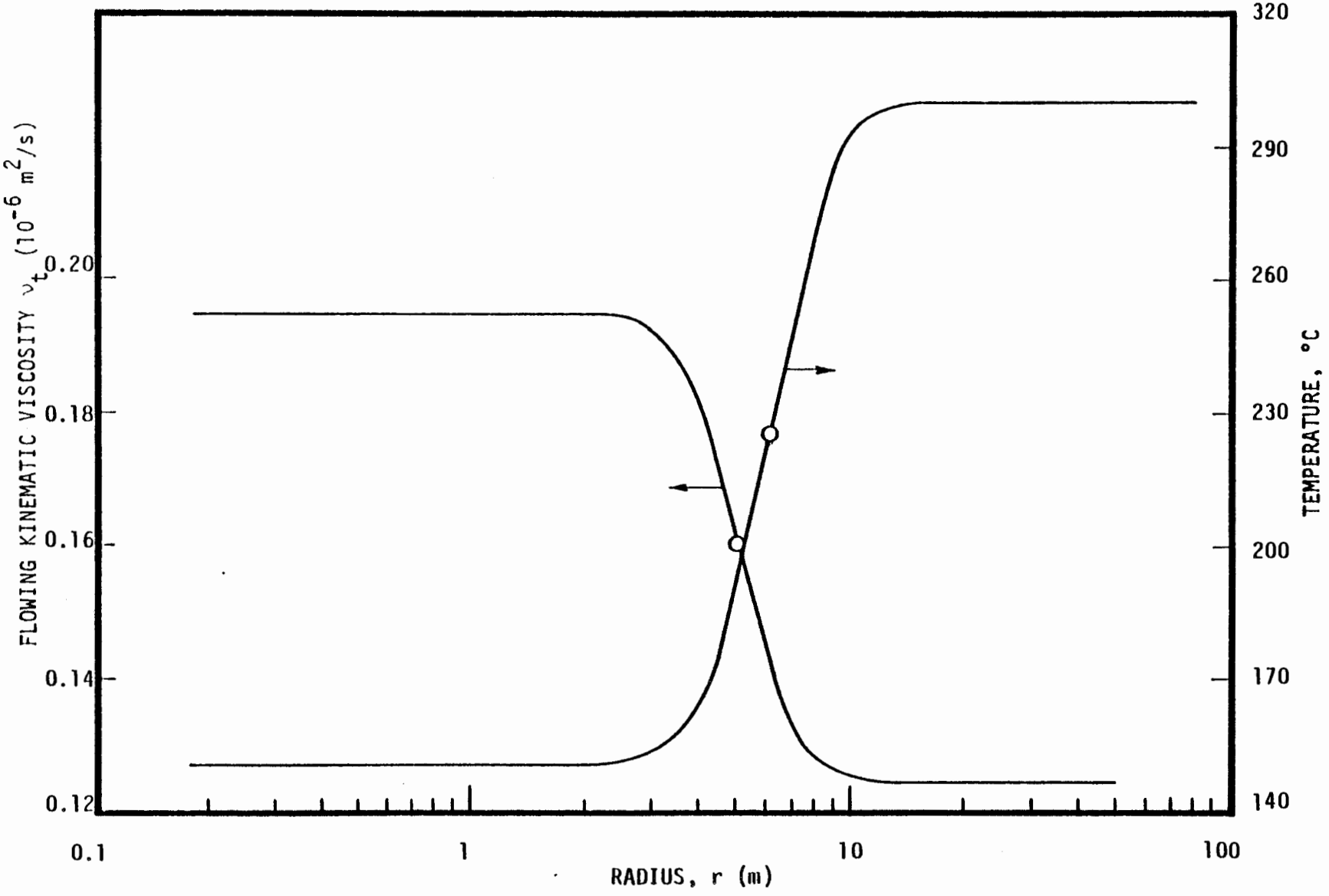

Figure 3.2. Radial distribution of flowing kinematic viscosity and temperature at $t \sim 5.868 \times 10^5$ s (end of injection period). O denotes the location of the front (defined as the mid point).

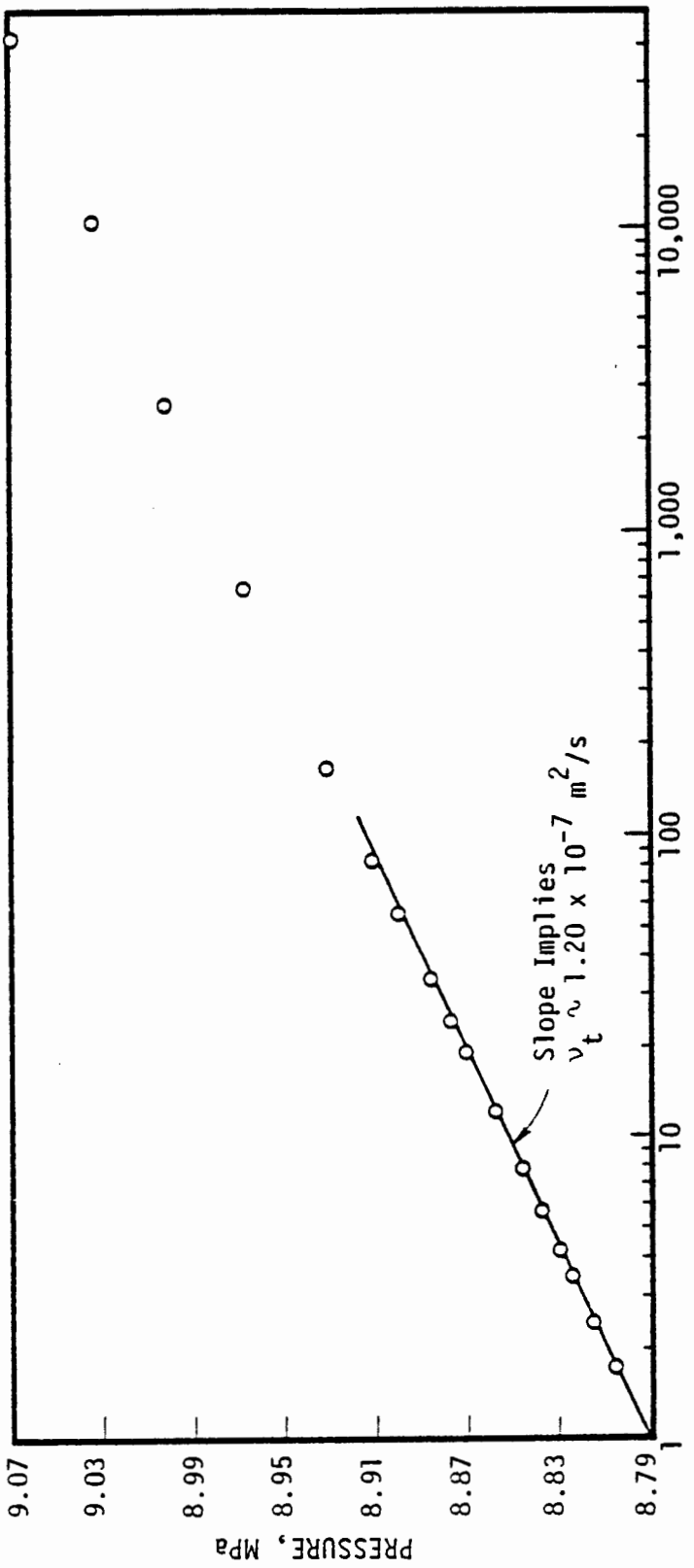

Figure 3.3. Pressure fall-off data for cold water injection into a hot water well.

water injection. The time to investigate a particular radius r during fall-off is approximately given by (see e.g., Matthews and Russell [1977]):

$$\Delta t = \frac{r_{inv}^2}{4} \frac{\phi \mu C_T}{k} \tag{3.1}$$

where

Δt = Fall off time in sec
r_{inv} = Radius of investigation in meters
μ = Dynamic fluid viscosity in Pa-s
C_T = Total formation compressibility in Pa^{-1}
k = Formation permeability in m^2

with r_{inv} = 6 m, ϕ = 0.1, $\mu \sim 1.8 \times 10^{-4}$ Pa-s, $C_T \sim 0.075 \times 10^{-8}$ Pa^{-1} (μ and $C_T = C_h$ are evaluated at 151°C), we have $\Delta t \sim 2.4$ s. The first point on the fall-off curve corresponds to a Δt of 14 s.

3.4 Cold Water Injection into Two-Phase Reservoirs

Although cold water injection into two-phase reservoirs has been suggested by several investigators for evaluating formation properties (see e.g., Grant [1979b]), yet theoretical analyses of pressure buildup/fall-off data are currently unavailable in the published literature. In order to investigate the effects of cold water injection into two-phase reservoirs, two cases will be considered. The initial fluid state for these cases is given in Table 3.1; the fluid injection rate (35 kg/s) and the injected fluid temperature, are identical with those employed in the preceding section.

Table 3.1
INITIAL FLUID STATE FOR COLD WATER INJECTION INTO TWO-PHASE RESERVOIRS

Case No.	Pressure, MPa	Temperature, °C	Steam Sat.
C.1	8.5917 MPa	300	0.28
C.2	8.5917 MPa	300	0.05

The pressure buildup (injection) data (Figures 3.4 and 3.5) closely fit straight lines with identical slopes. The slope implies a flowing kinematic viscosity of 2.02×10^{-7} m^2/s which is in good agreement with the kinematic viscosity of the cold injected water ($\nu \sim 1.96 \times 10^{7}$ m^2/s). Figures 3.6 and 3.7 show the radial distribution of steam saturation and temperature at the end of the injection period ($t \sim 5.868 \times 10^{5}$ s). The condensation front (especially in the low steam saturation case C.2) is seen to have advanced further into the formation than the edge of the thermal front. The latter effect is due to the fact that pressure changes are experienced over a much larger portion of the reservoir than the one undergoing cooling as a result of cold fluid injection.

Horner plots of pressure fall-off data are given in Figures 3.8 and 3.9. Three regions can be identified on these plots:

(i) for large $(t + \Delta t)/\Delta t$ (i.e., small shutin times), pressure falls off relatively rapidly

(ii) for moderate values of $(t + \Delta t)/\Delta t$, pressure is essentially constant

(iii) for small values of $(t + \Delta t)/\Delta t$ (i.e., large buildup times), pressure again starts to fall rather rapidly.

The first region (i.e., $(t + \Delta t)/\Delta t$ large) of the fall-off curve is governed by the pressure response of the condensed fluid region. Due to the large contrast in single-phase and two-phase compressibilities, the two-phase region remains practically unaffected during this time period (see e.g., steam saturation

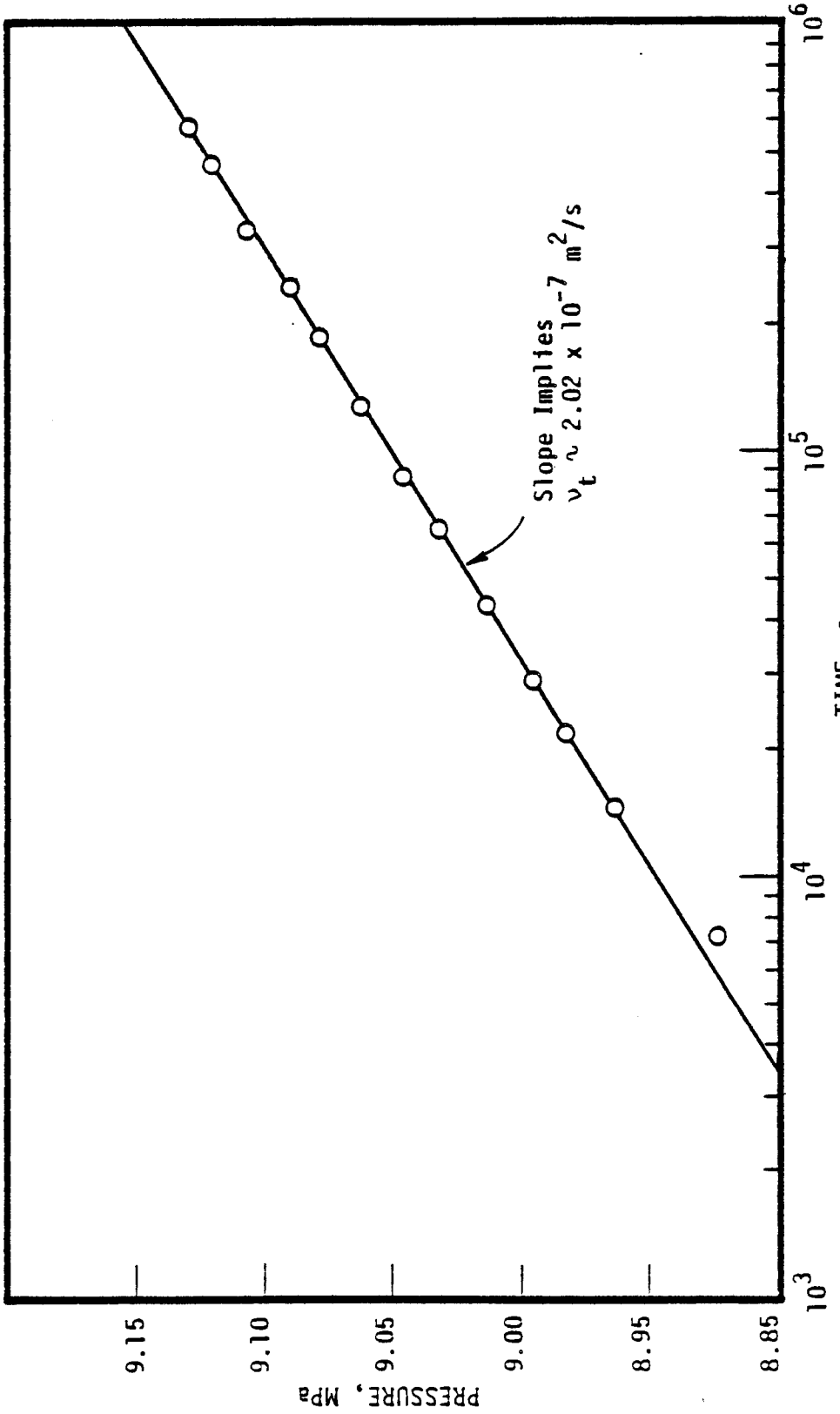

Figure 3.4. Pressure bulldup (Injection) data for case C.1.

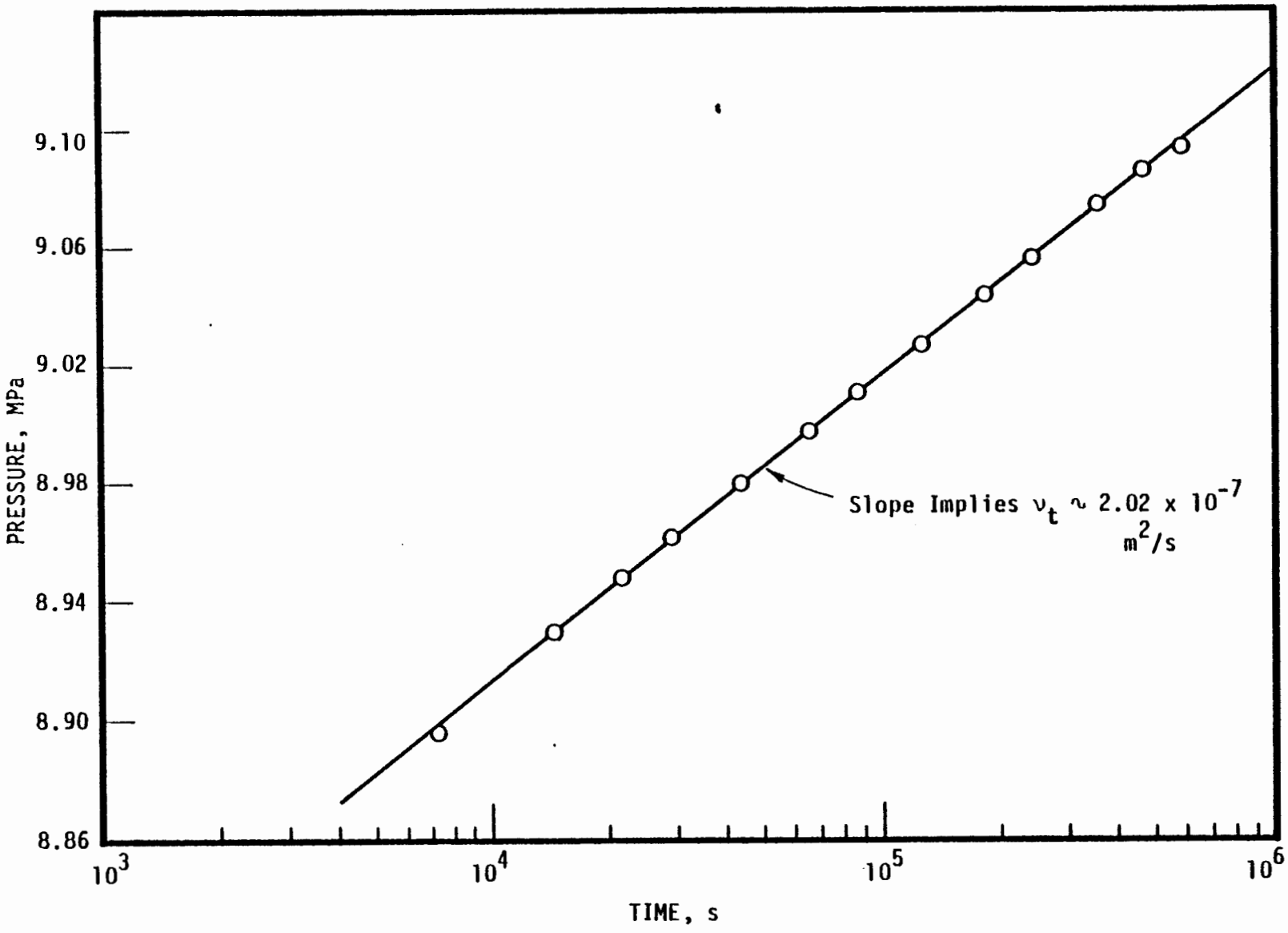

Figure 3.5. Pressure buildup (Injection) data for case C.2.

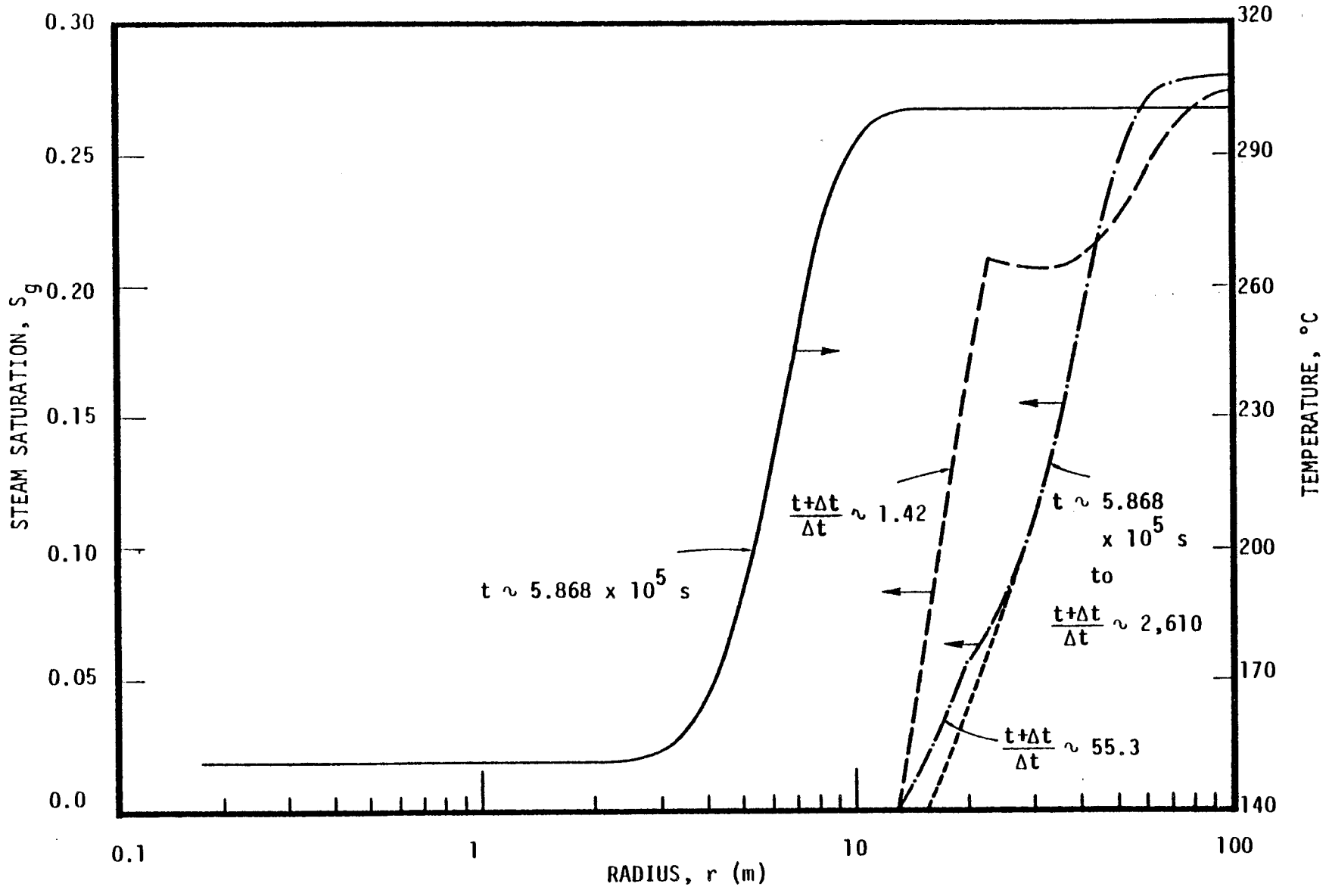

Figure 3.6. Radial distribution of temperature and steam saturation at selected times for case C.1.

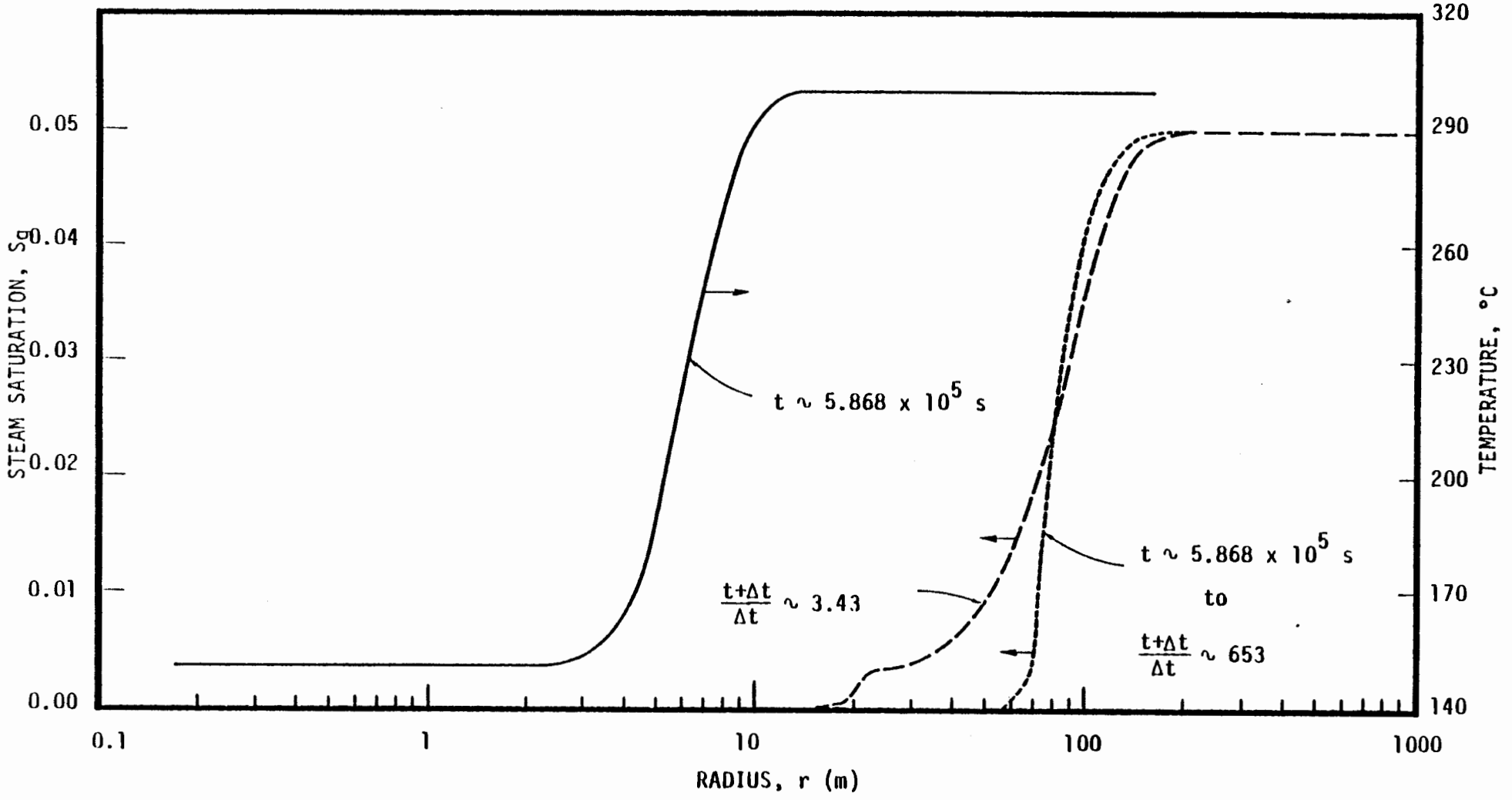

Figure 3.7. Radial distribution of temperature and steam saturation at selected times for case C.2.

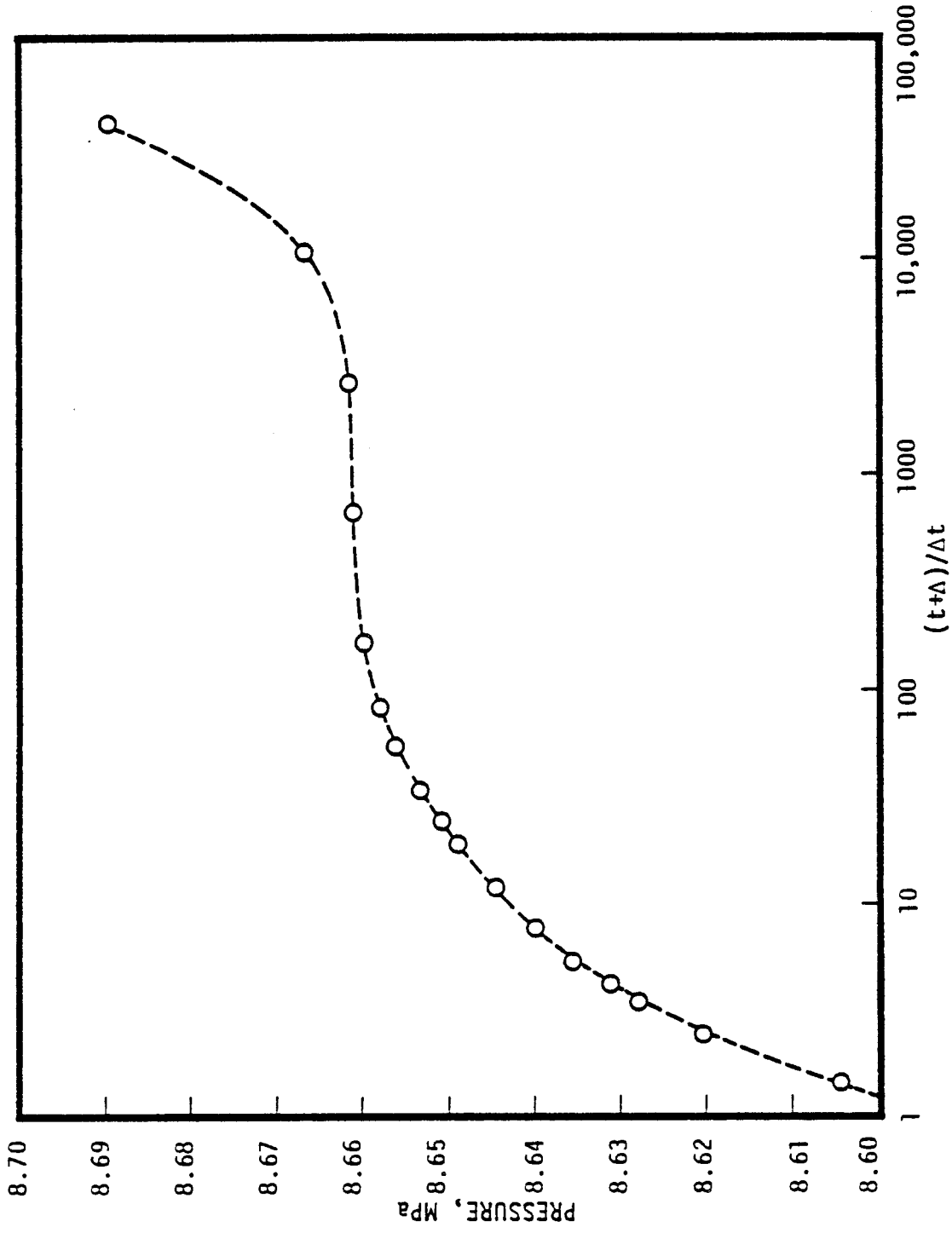

Figure 3.8. Pressure fall-off data (Horner plot) for case C.1.

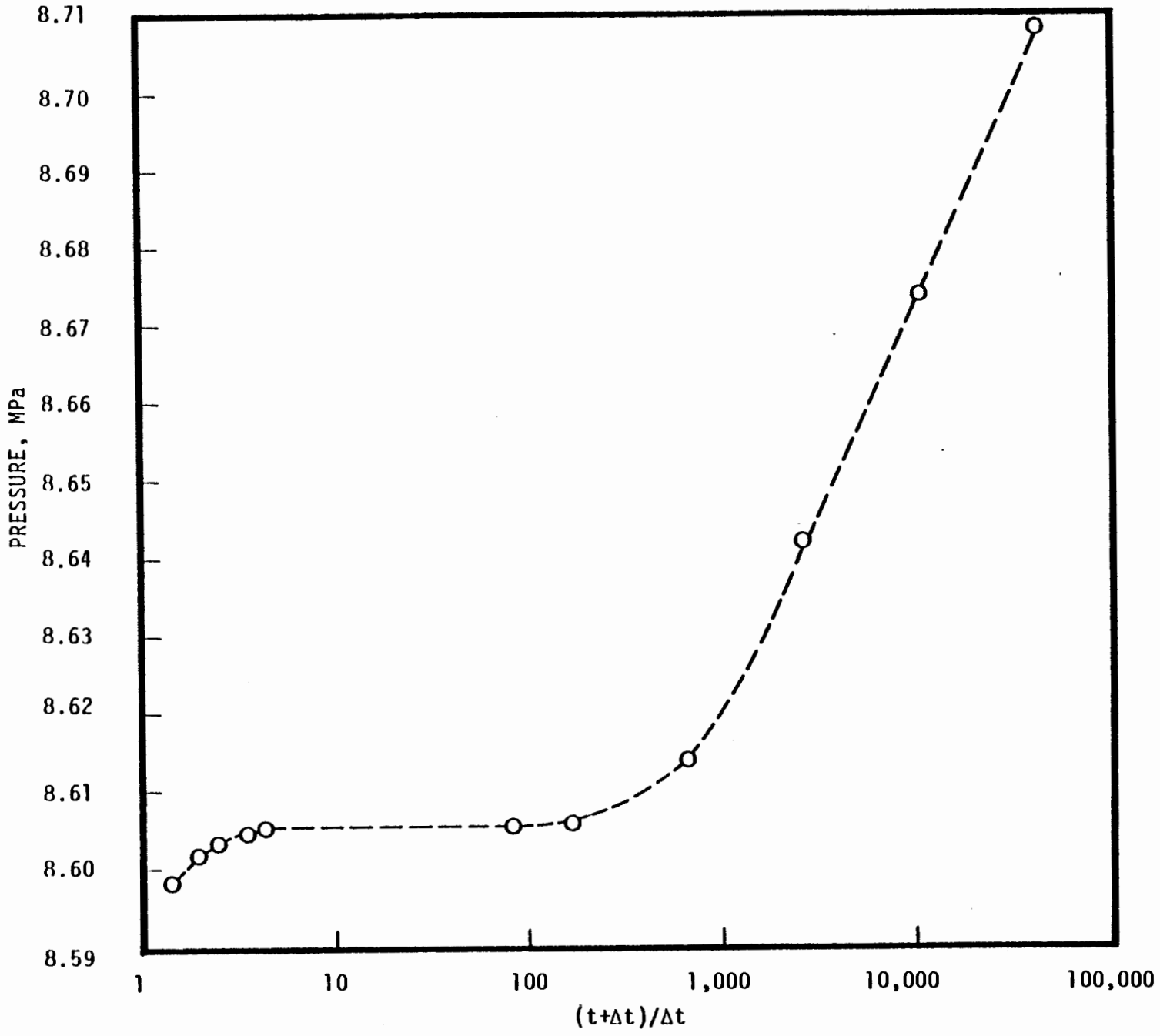

Figure 3.9. Pressure fall-off data (Horner plot) for case C.2

profiles in Figures 3.6 and 3.7). The condensed fluid region behaves like a reservoir with a constant pressure (= pressure at the edge of the condensation front) boundary. These early pressure fall-off data are replotted in Figures 3.10 and 3.11; these figures clearly demonstrate that the early fall-off behavior in the present cases resembles that of a reservoir with a constant pressure boundary. The condensation front radius, r_e, can, therefore, be calculated from the formula (Earlougher [1977]):

$$r_e = \left(\frac{k \, \Delta t_s}{1.25 \, \phi \, \mu \, C_T} \right)^{0.5} \tag{3.2}$$

where

- k = formation permeability
- Δt_s = time to startup of semi-steady reservoir behavior (time at which pressure curve bends over)
- μ = viscosity of injected liquid water
- C_T = Total formation compressibility in the condensed region.

The condensation front radii inferred from Equation (3.2) and data of Figures 3.10 and 3.11 are compared with the actual values in Table 3.2.

Table 3.2
CONDENSATION FRONT RADII
($\mu = 1.8 \times 10^{-4}$ Pa-s; $C_T = 0.075 \times 10^{-8}$ Pa^{-1})

Case No.	Δt_s	r_e (inferred)	r_e(actual)
C.1	72 s	14.6 m	(15.5 $\pm$ 1.5) m
C.2	753 s	47.2 m	(57.1 $\pm$ 5.2) m

Although the inferred values for r_e are in reasonable agreement with the actual values, a note of caution is in order here. In practical situations, the early fall-off data (such as that utilized

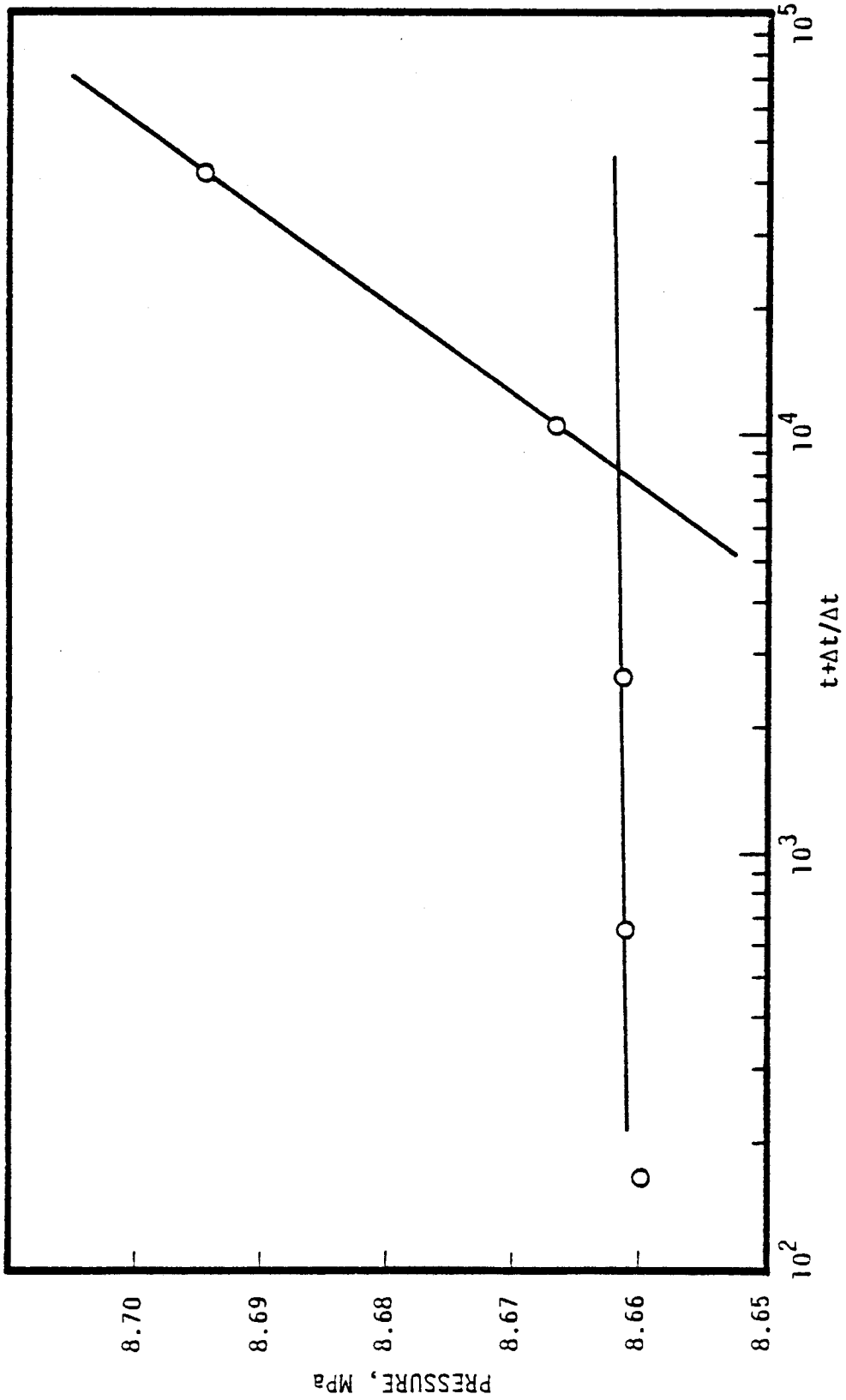

Figure 3.10. Early pressure fall-off data for case C.1.

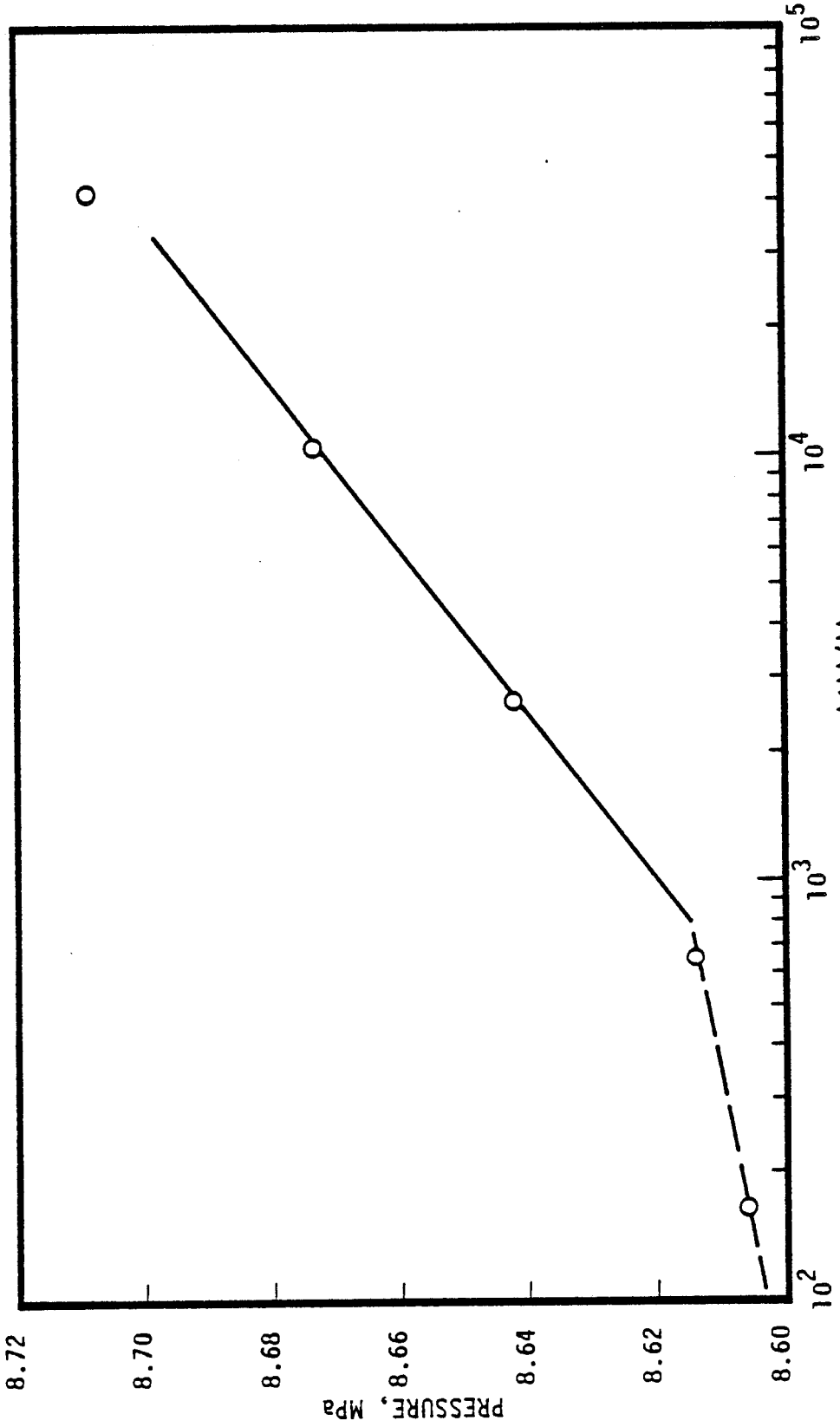

Figure 3.11. Early pressure fall-off data for case C.2.

in the above calculation for r_e) are liable to be dominated by wellbore storage, and it may well be impossible to identify the time at which the well starts exhibiting "semi-steady" response.

An examination of the numerical results shows that at the end of the first part of the fall-off curve, the pressure gradient in the single-phase (condensed) region is essentially zero whereas the pressure at the edge of the condensation front remains at its value at $\Delta t = 0$ (start of shutin period). Also, the edge of the condensation front is stationary throughout this initial period (Figures 3.6 and 3.7 - See steam saturation profiles for $t = 5.868 \times 10^5$ s to $(t + \Delta t)/\Delta t$ - (2610 in Figure 3.6, and 653 in Figure 3.7)).

During the middle fall-off period, the condensation front starts moving towards the wellbore. This part of the well response is characterized by an essentially constant pressure. At the end of this period, the condensation front becomes coincident with the edge of the thermal front (see e.g., steam saturation curve labeled $(t + \Delta t)/\Delta t \sim 3.43$ in Figure 3.7). The condensation front once again becomes stationary at this point.

For large fall-off times (i.e., for the third fall-off period), the well response is governed by the two-phase region. As can be seen from Figures 3.8 and 3.9, the pressure fall-off data do not, however, asymptote to a straight line. It is convenient to plot the fall-off data in a somewhat different manner. Figures 3.12 and 3.13 are plots of log Δp ($\Delta p = |p_w(\Delta t) - p_f|$ where p_f is the last flowing pressure) versus log Δt. Referring to Figure 3.13, it may be seen that the two-phase fall-off data lie on the unit slope line. A unit slope line can also be identified on Figure 3.12. It is well known that the presence of a unit slope line indicates that the well response is controlled by storage effects; this part of the fall-off data is useless for analysis purposes in the absence of data regarding the location of the condensation front (~ effective wellbore radius for two-phase fall-off regime). For

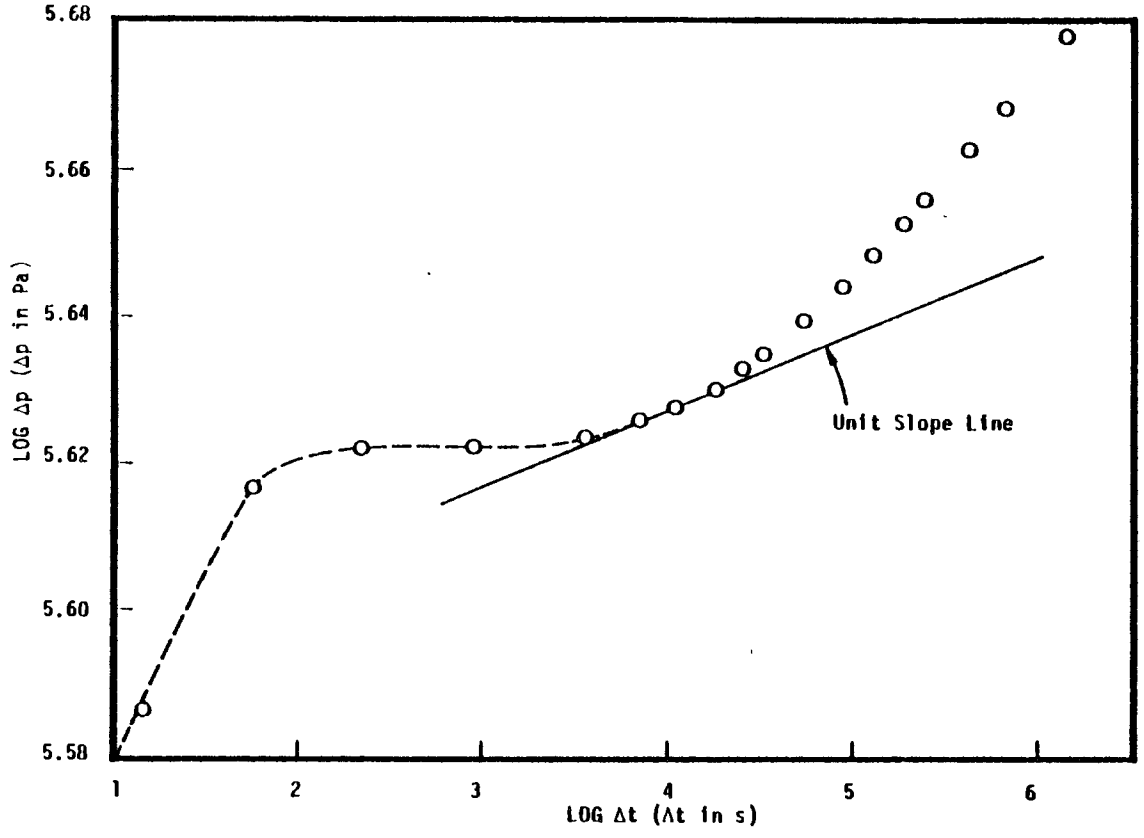

Figure 3.12. Plot of log Δp versus log Δt for case C.1. ($\Delta p = |p_w - p_f|$; p_w is the well pressure at Δt and p_f is the last flowing pressure.) Note that the vertical and horizontal scales are different.

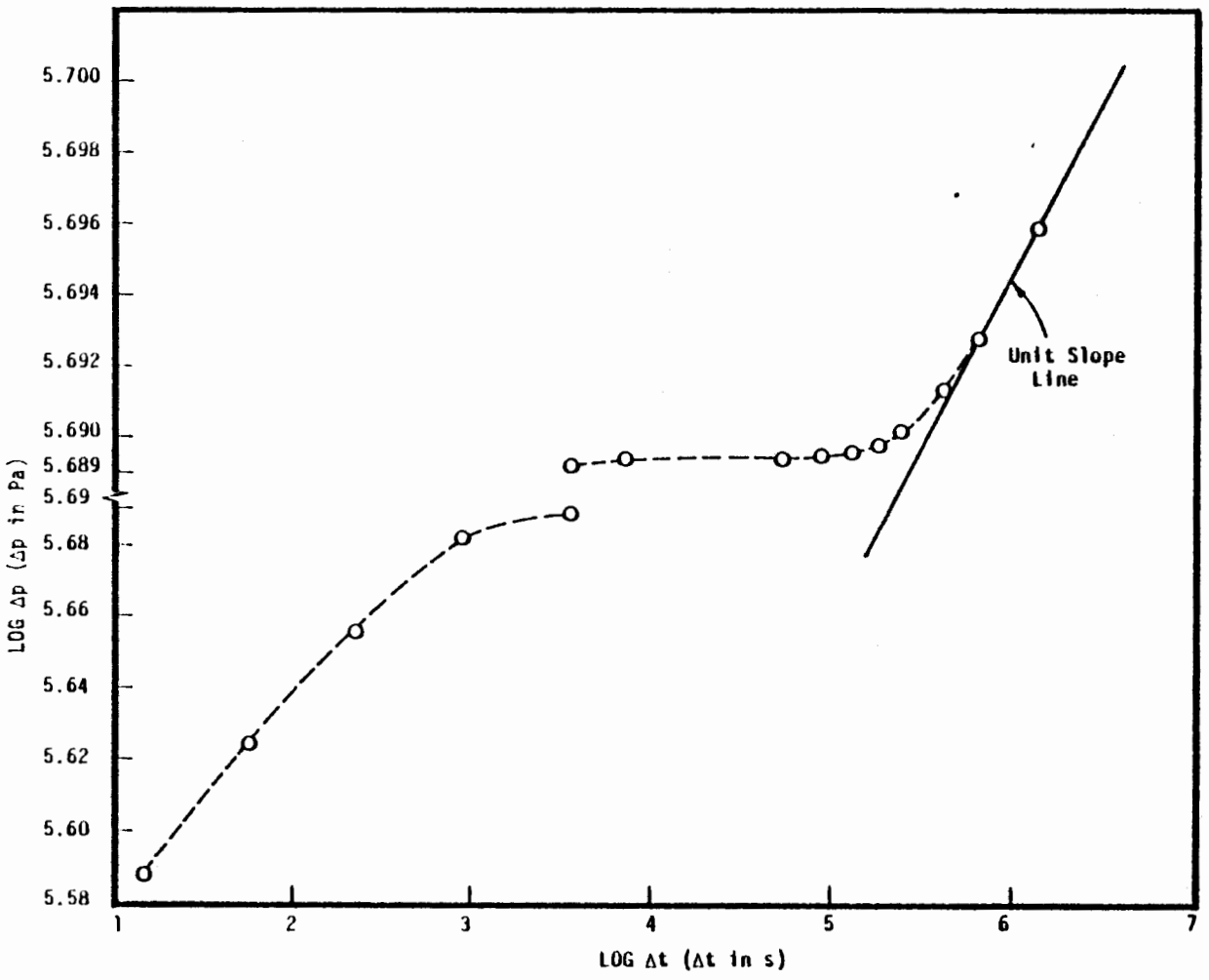

Figure 3.13. Plot of log Δp versus log Δt for case C.2. ($\Delta p = |p_w - p_f|$; p_w is the well pressure at Δt and p_f is the last flowing pressure.) Note that (1) the vertical and horizontal scales are different, and (2) the vertical scale is discontinuous.

single-phase flow, a rough rule of thumb is that the semi-log straight line starts at a time which is one and one-half log cycles removed from the time at which the pressure data begins to deviate from the unit slope straight line. Utilizing the latter criterion, it is seen from Figure 3.12 that only the last point or two may be expected to lie on the semi-log line. In view of the nonlinear nature of two-phase flow in porous media, especially prior to the start of semi-log straight line, it would very likely be futile to try to analyze the two-phase fall-off data of Figure 3.12 to derive kinematic mobility.

REFERENCES

EARLOUGHER, R. C., Jr., Advances in Well Test Analysis, Monograph Series, Vol. 5, Society of Petroleum Engineers, Dallas, TX, 1977.

GARG. S. K., "Pressure Transient Analysis for Two-Phase (Water/Steam) Geothermal Reservoirs," Society of Petroleum Engineers, Paper No. 7479, 1978. Also SPEJ, pp. 206-214, June 1980.

GRANT, M. A., "Two-Phase Linear Geothermal Pressure Transients: A Comparison With Single-Phase Transients," New Zealand J. Sci., Vol. 21, pp. 355-364. 1978.

GRANT, M. A., "Quasi-Analytic Solutions for Two-Phase Flow Near a Discharging Well," Applied Mathematics Division - DSIR, New Zealand, Report No. 86, June 1979a.

GRANT, M. A., "Interpretation of Downhole Measurements in Geothermal Wells," Applied Mathematics Division - DSIR, New Zealand, 1979b.

MATTHEWS, C. S. and D. G. Russell, Pressure Buildup and Flow Tests in Wells, Monograph Series, Vol. 1, Society of Petroleum Engineers, Dallas, TX, 1967.

MOENCH, A. F. and P. G. Atkinson, "Transient Pressure Analysis in Geothermal Steam Reservoirs With an Immobile Vaporizing Liquid Phase - Summary Report," Proc. Third Stanford Workshop on Geothermal Reservoir Engineering, Stanford, CA, pp. 64-69, 1977.

O'SULLIVAN, M., "A Similarity Method for Geothermal Well Test Analysis," to appear in Water Resources Research, 1980.

PRITCHETT, J.W., "Geothermal Reservoir Engineering Computer Code Comparison and Validation Calculations Using MUSHRM and CHARGR Geothermal Reservoir Simulators," Systems, Science and Software Report SSS-R-81-4749, November 1980.

SOREY, M. L., M. A. Grant and E. Bradford, "Nonlinear Effects in Two-Phase Flow to Wells in Geothermal Reservoirs," Water Resources Research, August 1980.

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UNION 76

October 15, 1979

Mr. Carl Ulvog
New Mexico Energy Resources Board
Oil Conservation Commission
P.O. Box 2088
Santa Fe, New Mexico 87501

Dear Mr. Ulvog:

Enclosed are location data, lithologic summaries, and geophysical logs for our wells in the Redondo Creek area of the Valles Caldera. These data may be made available upon request to interested parties as per Union's agreement with the U. S. Department of Energy. Data for two wells outside Redondo Creek, Baca 7 and Baca 8, are also included.

Very truly yours,

R. O. Engebretsen
Area Manager

RD:dp

Enclosure

B- #4
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Operator: Union Geothermal Company of New Mexico

Lease: Baca

Well No.: Baca 4

Location: 1,778,980'N 404,915'E NM State Plane Co-ordiantes

Elevation: 9318'

County: Sandoval

Total Depth of Well: 6376'

Lithologic Units

Formation	Age	Interval - Feet	
		Measured Depth	Elevation Above Sea Level
Caldera Fill	Quaternary	0-200	9318-9135
Bandelier Tuff	Quaternary	200-5980	9135-3355
Paliza Canyon	Tertiary	5980-6376	3355-2959

Operator: Union Geothermal Company of New Mexico

Lease: Baca

Well No.: Baca 5A

Location: 1,774,670'N 403,285'E NM State Plane Co-ordinates

Elevation: 9320'

County: Sandoval

Total Depth of Well: 6973'

Lithologic Units

Formation	Age	Interval - Feet	
		Measured Depth	Elevation Above Sea Level
Caldera Fill	Quaternary	0-450	9320-8870
Bandelier Tuff	Quaternary	450-6610	8870-2710
Paliza Canyon	Tertiary	6610-6973	2710-2347

Operator: Union Geothermal Company of New Mexico

Lease: Baca

Well No.: Baca 6

Location: 1,778,490'N 401,580'E NM State Plane Co-ordinates

Elevation: 8726'

County: Sandoval

Total Depth of Well: 4810'

Lithologic Units

Formation	Age	Interval - Feet	
		Measured Depth	Elevation Above Sea Level
Caldera Fill	Quaternary	0-500	8726-8226
Bandelier Tuff	Quaternary	500-4750	8226-3976
Paliza Canyon	Quaternary	4750-4810	3976-3916

Operator: Union Geothermal Company of New Mexico

Lease: Baca

Well No.: Baca 7

Location: Projected: NE1/4, SE1/4, NW1/4 Sec 26; T20N; R 3E NMPM

Elevation: 8724'

County: Sandoval

Total Depth of Well: 5532'

Lithologic Units

Formation	Age	Interval - Feet	
		Measured Depth	Elevation Above Sea Level
Valles Rhyolite	Quaternary	0-1400	8724-7324
Caldera Fill	Quaternary	1400-2300	7324-6424
Bandelier Tuff	Quaternary	2300-3300	6424-5424
Sediments-Undivided	Tertiary	3300-3960	5424-4764
Red Beds	Permian	3960-4840	4764-3884
Limestone, Sandstone	Pennsylvanian	4840-5460	3884-3264
Granite	Pre-Cambrian	5460-5532	3264-3192

Operator: Union Geothermal Company of New Mexico

Lease: Baca

Well No.: Baca No. 8

Location: Projected NE ¼, SE ¼, SW ¼ Sec 35; T20N; R3E NMPM

Elevation: 8631'

County: Sandoval

Total Depth of Well: 4384'

Lithologic Units

Formation	Age	Interval - Feet	
		Measured Depth	Elevation Above Sea Level
Caldera Fill	Quaternary	0-580	8631-8070
Bandelier Tuff	Quaternary	580-3100	8070-5550
Sediments-Undivided	Tertiary	3100-4000	5550-4650
Red Beds	Permian	4000-4384	4650-4226

Operator: Union Geothermal Company of New Mexico

Lease: Baca

Well No.: Baca 9

Location: Approximately 1,776,400'N 400,270'E NM State Plane Co-ordinates

Elevation: 8605'

County: Sandoval

Total Depth of Well: 5303'

Lithologic Units

Formation	Age	Interval - Feet	
		Measured Depth	Elevation Above Sea Level
Caldera Fill	Quaternary	0-80	8605-8525
Bandelier Tuff	Quaternary	80-5303	8525-3302

Operator: Union Geothermal Company of New Mexico

Lease: Baca

Well No.: Baca 10

Location: 1,777,860'N 400,715'E NM State Plane Co-ordinates

Elevation: 8735'

County: Sandoval

Total Depth of Well: 6001'

Lithologic Units

Formation	Age	Interval - Feet	
		Measured Depth	Elevation Above Sea Level
Caldera Fill	Quaternary	0-520	8735-8235
Bandelier Tuff	Quaternary	520-5220	8235-3555
Paliza Canyon	Tertiary	5220-5390	3555-2848
Sediments-Undivided	Tertiary	5390-6001	2848-2777

Geophysical Logs

Type	Interval (ft. KB)	Date
Temperature	50-2421	9-14-79
Gamma Ray	2445-surface	9-12-79

Operator: Union Geothermal Company of New Mexico

Lease: Baca

Well No.: Baca 11

Location: 1,781,120'N 403,450'E NM State Plane Co-ordinates

Elevation: 9065'

County: Sandoval

Total Depth of Well: 6924'

Lithologic Units

Formation	Age	Interval - Feet	
		Measured Depth	Elevation Above Sea Level
Caldera Fill	Quaternary	0-320	9605-8765
Bandelier Tuff	Quaternary	320-5300	8765-3811
Paliza Canyon	Tertiary	5300-6560	3811-2585
Sediments-Undivided	Tertiary	6560-6924	2585-2239

Operator: Union Geothermal Company of New Mexico

Lease: Baca

Well No.: Baca 12

Location: 1,773,160'N 399,360'E NM State Plane Co-ordinates

Elevation: 8430'

County: Sandoval

Total Depth of Well: 9212'

Lithologic Units

Formation	Age	Interval - Feet	
		Measured Depth	Elevation Above Sea Level
Caldera Fill	Quaternary	0-160	8430-8290
Bandelier Tuff	Quaternary	160-6460	8290-1998
Paliza Canyon	Tertiary	6460-7380	1998-1080
Abiquiu Tuff	Tertiary	7380-7575	1080-886
Red Beds	Permian	7575-9210	886-(-)750

Geophysical Logs

Type	Interval (ft. KB)	Date
Temperature	1453-3495	7-7-74

Operator: Union Geothermal Company of New Mexico

Lease: Baca

Well No.: Baca 13

Location: 1,781,685'N 405,725'E NM State Plane Co-ordinates

Elevation: 9292'

County: Sandoval

Total Depth of Well: 8228'

Lithologic Units

Formation	Age	Interval - Feet	
		Measured Depth	Elevation Above Sea Level
Caldera Fill	Quaternary	0-560	9292-8752
Bandelier Tuff	Quaternary	560-5712	8752-3686
Paliza Canyon	Tertiary	5712-8090	3686-1340
Red Beds	Permian	8090-8228	1340-1204

Geophysical Logs

Type	Interval (ft. KB)	Date
Induction	3485-1470	9-18-74
Induction	6813-3494	10-28-74
Temperature	1150-3499	9-18-74
Temperature	2640-8228	10-27-74
Sonic	7240-3494	10-28-74
Neutron/Density	6809-3494	10-28-74

Operator: Union Geothermal Company of New Mexico

Lease: Baca

Well No.: Baca 14

Location: 1,776,450'N 400,320'E NM State Plane Co-ordinates

Elevation: 8605'

County: Sandoval

Total Depth of Well: 6824'

Lithologic Units

Formation	Age	Interval - Feet	
		Measured Depth	Elevation Above Sea Level
Caldera Fill	Quaternary	0-280	8605-8345
Bandelier Tuff	Quaternary	280-5800	8345-3060
Paliza Canyon	Tertiary	5800-6140	3060-2736
Undivided-Sediments	Tertiary	6140-6700	2736-2204
Red Beds	Permian	6700-6824	2204-2085

Geophysical Logs

Type	Interval (ft. KB)	Date
Temperature	470-5300	10-7-75
Neutron/Density	5830-3068	2-10-75

Operator: Union Geothermal Company of New Mexico

Lease: Baca

Well No.: Baca 15

Location: 1,780,590'N 402,160'E NM State Plane Co-ordinates

Elevation: 9117'

County: Sandoval

Total Depth of Well: 5505'

Lithologic Units

Formation	Age	Interval - Feet	
		Measured Depth	Elevation Above Sea Level
Caldera Fill	Quaternary	0-140	9117-8997
Bandelier Tuff	Quaternary	140-5300	8997-4003
Paliza Canyon	Tertiary	5300-5505	4003-3833

Operator: Union Geothermal Company of New Mexico

Lease: Baca

Well No.: Baca 16

Location: 1,784,290'N 405,630'E NM Plane Co-ordinates

Elevation: 9622'

County: Sandoval

Total Depth of Well: 7002'

Lithologic Units

Formation	Age	Interval - Feet	
		Measured Depth	Elevation Above Sea Level
Caldera Fill	Quaternary	0-380	9622-9242
Redondo Creek Rhyolite	Quaternary	380-880	9242-8742
Bandelier Tuff	Quaternary	880-5560	8742-4155
Paliza Canyon	Tertiary	5560-6880	4155-2931
Undivided-Sediments	Tertiary	6880-7002	2931-2820

Operator: Union Geothermal Company of New Mexico

Lease: Baca

Well No.: Baca 17

Location: 1,782,690'N 402,980'E NM State Plane Co-ordinates

Elevation: 9361'

County: Sandoval

Total Depth of Well: Original Hole: 5791'
Redrill: 6254'

Lithologic Units

Formation	Age	Interval - Feet	
		Measured Depth	Elevation Above Sea Level
Original Hole:			
Redondo Creek Rhyolite	Quaternary	0-400	9361-8982
Caldera Fill	Quaternary	400-980	8982-8402
Bandelier Tuff	Quaternary	980-5500	8402-3931
Paliza Canyon	Tertiary	5500-5791	3931-3647
Redrill:			
Bandelier Tuff	Quaternary	3175-5520	6211-3949
Paliza Canyon	Tertiary	5520-6254	3949-3266

Geophysical Logs

Type	Interval (ft. KB)	Date
Induction	1168-238	8-31-78
Induction	2763-1171	9-22-78
Induction	5801-3000	10-12-78
Induction (Redrill)	6270-3000	11-10-78
Temperature	250-2755	9-22-78
Temperature	100-4615	10-12-78
Borehole Geometry	2755-1181	9-22-78
Caliper	3500-3000	10-12-78