UNITED STATES

DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

COMPLETION AND TESTING OF MADISON LIMESTONE TEST WELL 3, NW¼SE¼ SEC. 35, T. 2 N., R. 27 E., YELLOWSTONE COUNTY, MONTANA

By R. K. Blankennagel, L. W. Howells, and W. R. Miller

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JAMES G. WATT, Secretary

GEOLOGICAL SURVEY

Doyle G. Frederick, Acting Director

For additional information write to:

U.S. Geological Survey
Water Resources Division
Mail Stop 418, Box 25046
Denver Federal Center
Denver, Colorado 80225

For purchase, write to:

Open File Services Section
U.S. Geologcial Survey
Box 25425
Denver Federal Center
Denver, Colorado 80225

(303) 234-5888; FTS 234-5888

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CONVERSION FACTORS

In this report, figures for measures are given only in inch-pound units.[1] Factors for converting inch-pound units to metric units are shown in the following table:

Inch-pound	Multiply by	Metric
in (inch)	25.4	mm (millimeter)
ft (foot)	0.3048	m (meter)
mi (mile)	1.609	km (kilometer)
mi^2 (square mile)	2.590	km^2 (square kilometer)
gal (gallon)	3.785	L (liter)
ft^3 (cubic foot)	0.02832	m^3 (cubic meter)
bbl (barrel)	0.1590	m^3 (cubic meter)
gal/min (gallon per minute)	0.0631	L/s (liter per second)
(gal/min)/ft (gallon per minute per foot)	0.207	(L/s)/m (liter per second per meter)
ft^3/sec (cubic foot per second)	0.02832	m^3/s (cubic meter per second)
ft^2/d (foot squared per day)	0.0929	m^2/d (meter squared per day)
lb (pound)	0.4536	kg (kilogram)
lb/in^2 (pound per square inch)	6.8948	kPa (kilopascal)

[1]Temperature is reported in degrees Celsius. To convert to degrees Fahrenheit use: Temperature °F = 1.8 temperature °C + 32.

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ABSTRACT

Selected intervals in the lower and upper parts of the Mission Canyon Limestone of Mississippian age, and the Amsden Formation and Tensleep Sandstone of Pennsylvanian age, with water having dissolved-solids concentrations of 3,000 milligrams per liter or less, were perforated through 7-inch casing that was cemented to the walls of the borehole. Perforated intervals in the lower part of the Mission Canyon Limestone were developed and tested as a single unit, as were those in the upper part. The Amsden Formation and Tensleep Sandstone were tested as a single unit. Total flow from all perforated intervals after development of each unit by swabbing and flowing was 125 gallons per minute. Total flow increased to 2,900 gallons per minute after acidizing and fracturing each unit through perforations. Radioactive tracer surveys indicate about 65 percent of the flow was from perforations in the upper part of the Mission Canyon Limestone.

Based on analysis of data from a step-drawdown test performed about 1 month after completion of the well, the values of transmissivity and coefficient of storage considered as most reasonable are 5,090 square feet per day and 2×10^{-5} respectively. Maximum temperature of water, measured at land surface during a full-flow test of 24-hour duration, was 56.6 degrees Celsius.

INTRODUCTION

Madison Limestone test well 3, in the NW¼SE¼ sec. 35, T. 2 N., R. 27 E., Yellowstone County, Mont., (figs. 1 and 2) was spudded in alluvium on August 15, 1978, and bottomed 48 ft below the top of Precambrian gneiss rocks at 7,175 ft below land surface on November 16, 1978. The well was drilled as part of a study to determine the water-resource potential of the Madison Limestone and associated rocks to meet the future water needs in a 188,000-mi^2 region that includes the coal-rich area of the Northern Great Plains, and to evaluate these rocks as a source of water for industrial, agricultural, public, and domestic supplies.

Paleostructure and facies maps, prepared during development of a regional geologic model, were used as a guide for site selection. The well was drilled where these maps indicated: (1) A complete Mississippian section and a thick section of the Ordovician Red River Formation or Devonian section would be present; (2) the Precambrian contact would be 6,000 or

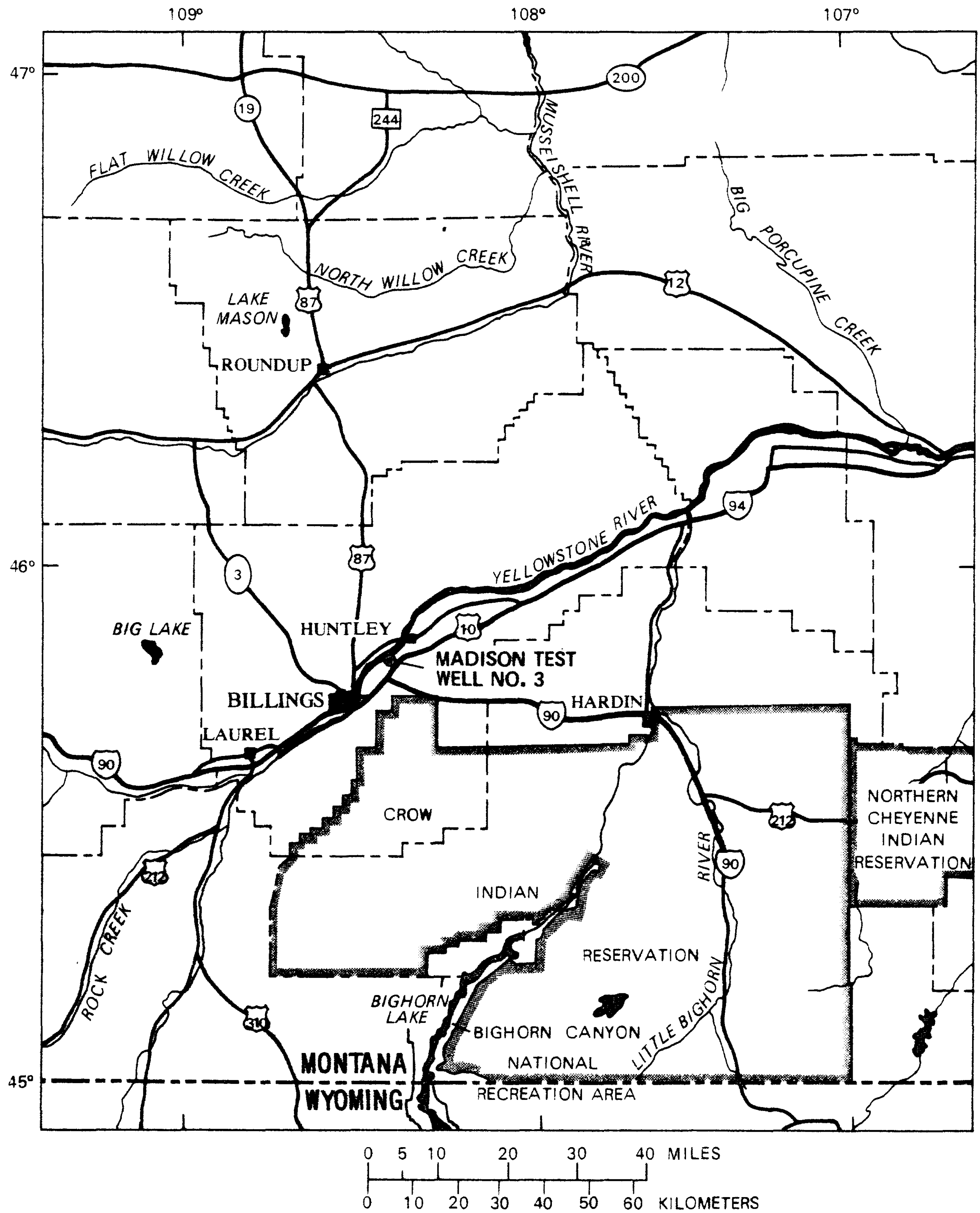

Figure 1.--Location of Madison Limestone test well 3 near Billings, Montana.

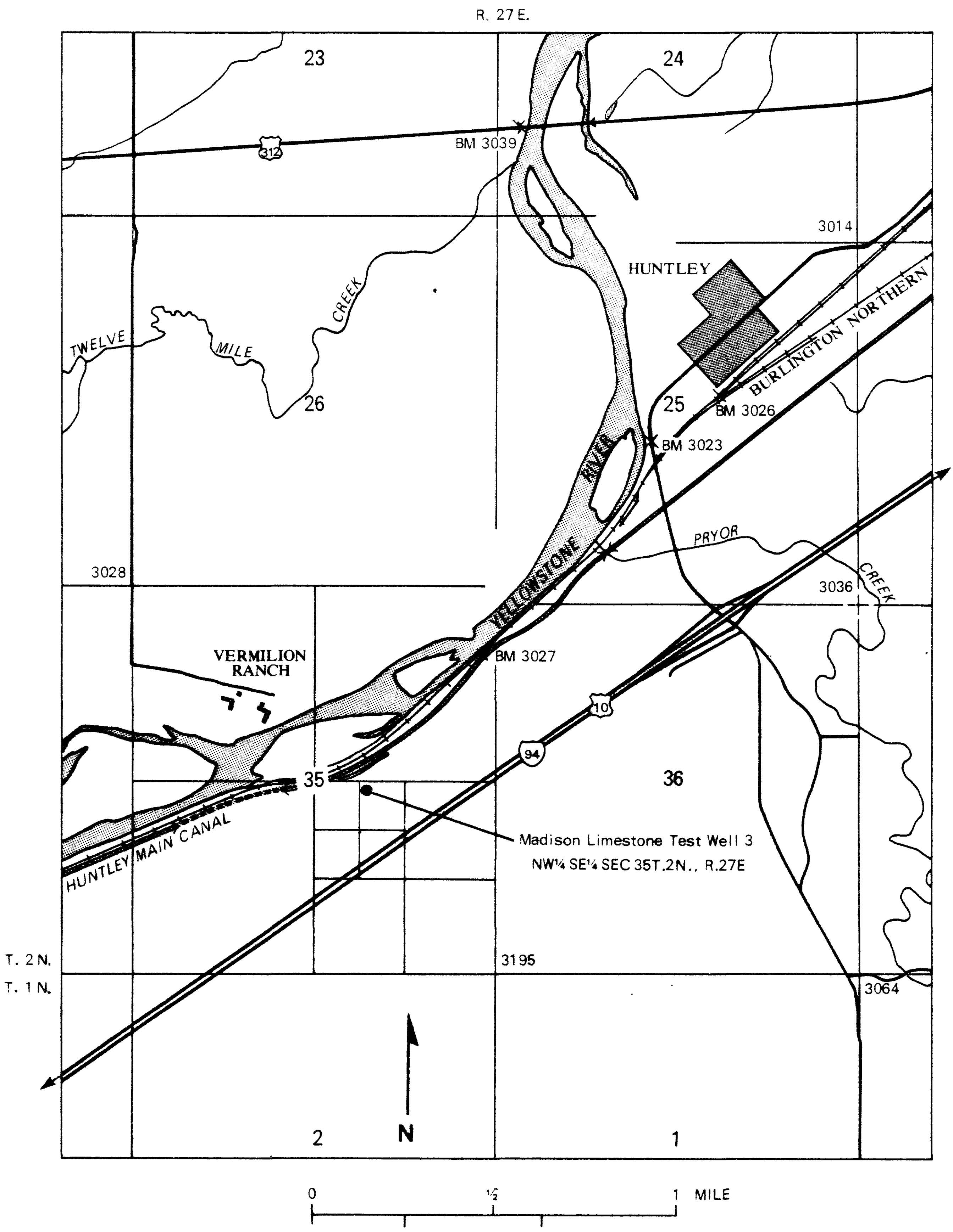

Figure 2.--Location of drill site for Madison Limestone test well 3.

7,000 ft below land surface; and (3) sufficient porosity and permeability would be present to provide relatively large water yields.

Drilling and testing were designed to yield a maximum of stratigraphic, structural, geophysical, and hydrologic information. Data from cuttings and cores from the well showed that the geologic model was valid. However, the development of primary and especially secondary interstitial porosity was minimal. Although primary porosity in the form of well-sorted oolites and vugs was formed during deposition, the oolite banks and vugs were mostly filled with anhydrite. Twelve conventional drill-stem tests were made in the open hole. Water flowed at land surface during nine of the tests. The sum of the flows from all producing intervals tested was about 560 gal/min. Freshwater--less than 1,000 mg/L (millimeters per liter) of dissolved solids--was not found in any of the intervals tested in the well. Dissolved-solids concentrations ranged from 2,660 to 19,800 mg/L.

Analysis of water samples, collected from drill-stem tests made in the exploratory hole during September and November 1978 (Blankennagel and others, 1979, table 3), showed that water having dissolved-solids concentrations of 3,000 mg/L or less (maximum permissible concentration for disposal at land surface near the wellsite) was available only from: (1) Lower part of the Mission Canyon Limestone of Mississippian age; (2) upper part of the Mission Canyon Limestone; and (3) Amsden Formation and Tensleep Sandstone of Pennsylvanian age. A 7-in casing liner, assembled with external casing packers, was run into the hole to a depth of 5,942 ft, and cemented to the borehole to isolate these intervals from overlying and underlying intervals having more mineralized water. The top of the liner was set at a depth of about 180 ft inside the 9-5/8-in casing (fig. 3).

Two intervals in the upper part of the Mission Canyon Limestone, 4,383 to 4,363 ft and 4,348 to 4,328 ft (depths adjusted on basis of geophysical logs made during completion operations), were perforated with four shots per foot. Additional water-bearing zones were not perforated because of bridges or other obstructions in the 13-3/8-in and 9-5/8-in casings. These bridges were attributed to sloughing of cement from the walls of the casing, after drilling mud in the casing had been displaced with water that entered through the perforations.

During July 1979, workover operations were begun to complete Madison Limestone test well 3. Primary objectives of the workover operations were to clean the cased hole, complete perforating of intervals with water having dissolved-solids concentrations of 3,000 mg/L or less, and to develop the perforated intervals by swabbing and flowing. Finally, the perforated intervals were to be stimulated by acidizing and fracturing to evaluate the effectiveness of the technique on water production.

U.S. Geological Survey personnel who assisted the authors in various phases of the operation included Thad Custis, Dave Flynn, Scott MacGarvie, Roger Lee, Joe West, Carol Janecke, Craig Joy, Elliott Cushing, Richard Feltis, and Jerry Wisnieski.

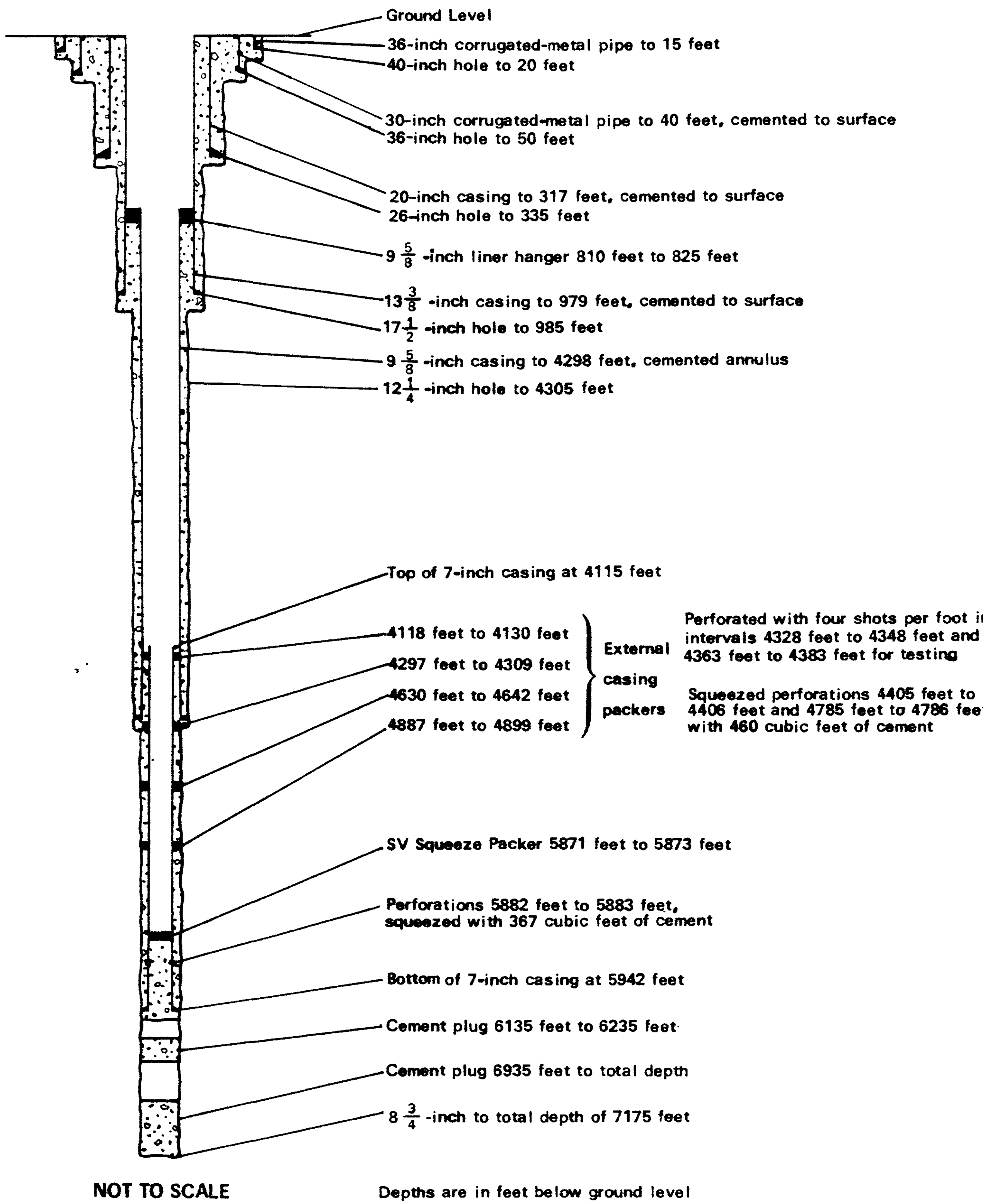

Figure 3.--Schematic diagram of Madison Limestone test well 3 showing construction of well before completion operations.

Fenix and Scisson, Inc., Tulsa, Okla., prime contractor for the U.S. Department of Energy, Nevada Operations Office, Las Vegas, Nev., assisted with the preparation of the well-completion specifications and provided a drilling specialist, Ray Herrington, at the drill site. Fenix and Scisson, Inc. also prepared the well history and assisted with the well-construction diagram (fig. 4) included in this report.

Rogers-Megargel Drilling Co., Olney, Tex., was awarded the contract for completing the well. Birdwell Division, Seismograph Service Corp., Tulsa, Okla., was awarded the geophysical logging contract; and Dowell Division of Dow Chemical U.S.A., Tulsa, Okla., was awarded the contract for the acidizing and fracturing treatments.

Equipment, supplies, and services were subcontracted by Rogers-Megargel Drilling Co. from "C" Brewer, Inc.; Baker Oil Tools; Halliburton Services; Weatherford/Lamb; Brown Oil Tools; Gearheart Owen Wireline Services; Dowell Mid-Continent Region Tools; Lynes, Inc.; Green Oil and Field Service, Inc.; and others. The use of named products in illustrations or in the report is for identification only and does not imply endorsement by the U.S. Geological Survey.

TEST WELL HISTORY

The following historical data on the test well, including hole history (rev. #1 additional work) and a daily log of additional work, were photocopied from the Fenix and Scisson report provided to the U.S. Geological Survey after the completion of Madison Limestone test well 3. The formation tops information was photocopied from the report provided to the U.S. Geological Survey by Irvin Kranzler and John R. Warne, consulting geologists, Billings, Montana (Blankennagel and others, 1979).

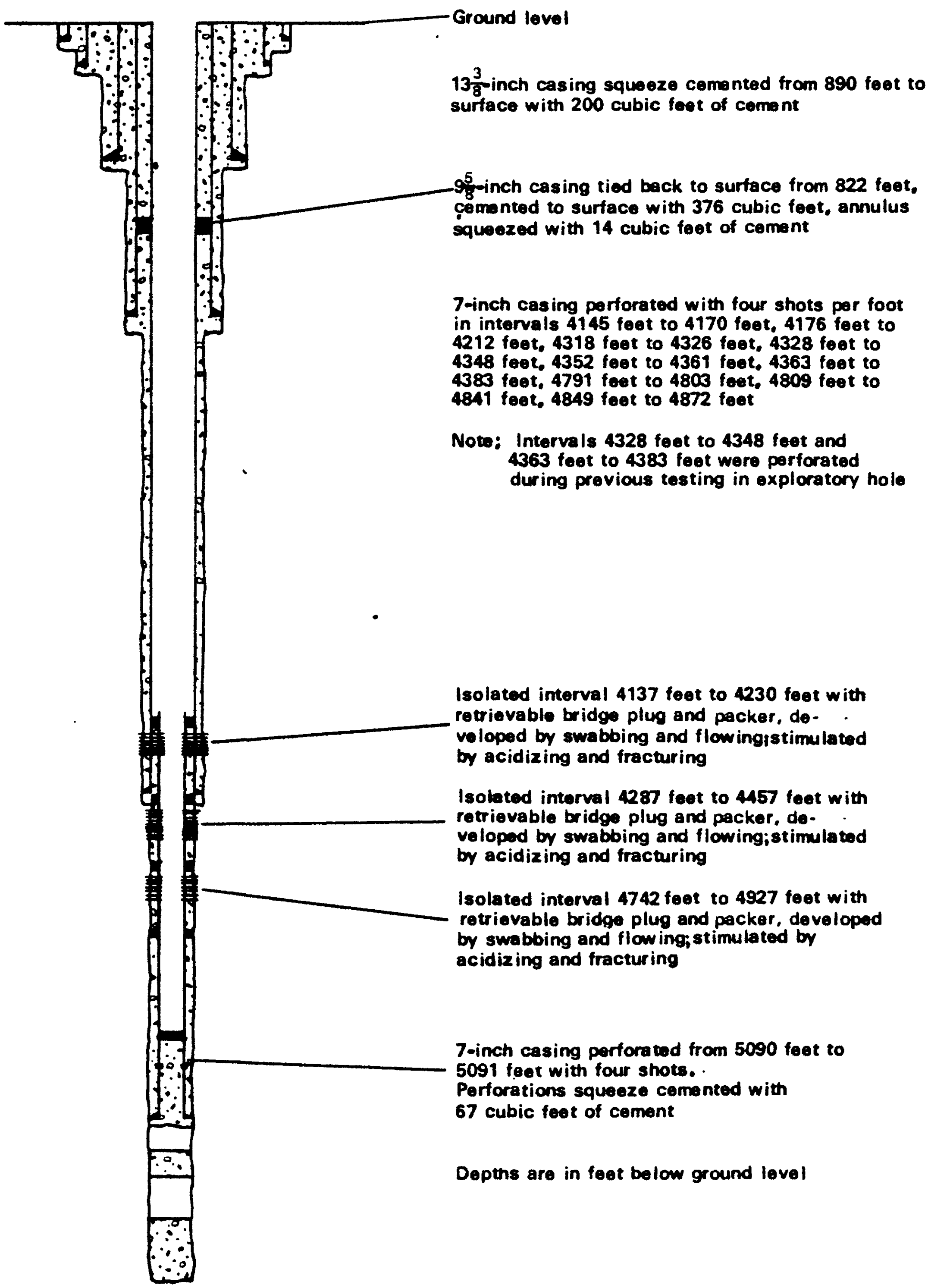

Figure 4.--Schematic diagram of Madison Limestone test well 3 showing construction of well after completion and briefly summarizing operations.

10-10-79 Rev. #1 Additional Work

FENIX & SCISSON, INC.
HOLE HISTORY DATA

DATE: 1-30-79

HOLE NO.: Madison #3		W. O. NO.:		I. D. NO.:	
USER: USGS		TYPE HOLE: Exploratory/Hydrologic			
LOCATION Montana		COUNTY: Yellowstone		AREA:	
SURFACE COORDINATES: NW, SE, Sec. 35, T2N, R27E					
GROUND ELEVATION: 3024'.3'		PAD ELEVATION:		TOP CASING ELEVATION:	
RIG ON LOCATION:		SPUDDED: 8-15-78		Recompleted: 9-17-79	
CIRCULATING MEDIA: Mud					
MAIN RIG & CONTRACTOR				NO. OF COMPRESSORS & CAPACITY:	

BORE HOLE RECORD			CASING RECORD							
FROM	TO	SIZE	I.D.	WT./FT.	WALL	GRADE	CPL'G.	FROM	TO	CU. FT. CMT
* 5'	20'	40"	36"			CMP		5'	15'	
* 20'	50'	36"	30"			CMP		5'	40'	118
50'	335'	26"	19.124"	94.00#		H-40	Butress	5'	317'	885
335'	985'	17-1/2"	12.615	54.50#		K-55	ST&C	0'	979'	1062
985'	4305'	12-1/4"	8.921"	36.00#		S-80	ST&C	0'	4298'	2584
4305'	7175'	8-3/4"	6.366"	23.00#		K-55	ST&C	4115'	5942'	* *

TOTAL DEPTH: 7175' GL | AVERAGE MANDREL DEPTH: | FROM REFERENCE ELEVATION @

JUNK & PLUGS LEFT IN HOLE:

SURVEYS PAGE: | CORING PAGE: | CU. FT. CMT. TOTAL IN PLUGS, ETC:

LOGGING DATA: Page 6

BOTTOM HOLE COORDINATES: | REFERENCE:

RIGS USED *(Site Prep Rigs *)*

RIG NO.	NAME	TYPE	CLASS	DAYS OPERATING	SECURED W CREW	SECURED W/O CREW	TOTAL DA ON LOC.
4	Molen Drilling Co.	National 50A		125.10	1.06	-	126.16
	Rogers-Megargel	Ideco BIR 3087		27.40	1.50	24.44	53.34
	(Additional Work)						

REMARKS: * *Site Prep Items:* 8' x 6' x 5' deep cellar.

* * See attached drawing for perforations and squeeze jobs

NOTE: Depths shown on this page are from ground level 15' below kelly bushing elevation.

PREPARED BY: WDS/it

MADISON #3

Additional Work

7-26-79 Completed rigging up Rogers - Megargel rig at 1000 hours. Mixed mud. Worked days only. All depths reported from ground level.

7-27-79 Continued mixing mud.

7-28-79 Continued mixing mud.

7-29-79 Continued mixing mud.

7-30-79 Completed mixing 550 barrels of mud. Rigged up to pump same.

7-31-79 Pumped 400 barrels of mud into the hole thru the 2" valve on the casinghead. Wellhead pressure at start was 450 psi to 255 psi after 400 barrels. Pump pressure was 750 to 650 psi. Mixed mud.

8-1-79 Wellhead pressure was 255 psi. Pumped in 50 barrels of mud at 650 psi, pressure remained at 255 psi. Mixed mud.

8-2-79 Flowed 10.7# mud from the hole and after 186 barrels, the hole started making water. Ran sand line in the hole and tagged bridge at 823'. Ran 6-1/8" bit in the hole to bridge at 788'. Worked thru bridge and ran bit to 918'. Top of 9-5/8" liner hanger at 810'. Pulled 6-1/8" bit and made trip with an 8-3/4" bit to 918', no obstructions.

8-3-79 Ran Lynes production injection packer in the hole on 3-1/2" drill pipe and set at 832'. Water flow was shut off. Pressured 13-3/8" casing to 500 psi and pressure held. Increased to 650 psi and pumped into formation at 1/2 barrel per minute for 5 minutes. Laid down Lynes packer and ran Baker bridge plug, set at 890'. Laid down 1 joint of drill pipe. Pumped 500# of 100 mesh sand mixed with 8 barrels of water on top of the plug. Pulled out of hole and closed the blind rams. Rigged up Halliburton to the 2" valve on the casinghead. Pumped in 15 barrels of water at 700 psi ahead of 200 ft^3 of neat cement and 2% calcium chloride at 900 to 950 psi. Displaced with 106 barrels of water at 4 barrels per minute with 950 to 1000 psi and pressure dropped to 0. Pressure built up to 700 psi after 2 barrels had been displaced and remained at that pressure until a total of 121 barrels had been displaced. Cement in place at 1815 hours.

8-4-79 2" valve on casinghead was leaking a 1" stream of water, pressure 275 psi, temperature 40.5° C. Ran 8-3/4" bit in the hole and worked thru bridge from 398' to 414' and hit solid bridge, unable to work lower. Pulled out of hole and found pieces of cement in the bit. Measured water flow at 90 gpm, temperature 42° C. Shut in pressure was 350 psi. Mixed mud.

8-5-79 Attempted to drill out bridge at 414' with reverse and conventional circulation. Bit plugged off with cement.

8-6-79 Drilled out cement from 414' to 424' and cement stringers to 439' with an 8-3/4" bit with jet ports blanked off and a hole cut in bottom of the bit. Laid down bit and ran Baker latch-on tool in the hole, could not get below 814'. Ran 8-3/4" bit in the hole to 800'.

8-7-79 Drilled out cement and sand from 814' to 885' and washed to 949'. Circulated hole clean. Pulled out of hole and ran Baker latch-on tool. Washed out 2' of fill and latched onto bridge plug at 948.33' that was set at 890'. Pulled out of hole and found cement lodged in slip segments.

8-8-79 Wellhead pressure was 350 psi. Ran 6-1/8" bit in the hole, worked thru bridge at 1163' and stopped at solid bridge at 4471'. Pumped 400 barrels of 10.7# mud in the hole at 450 psi holding 250 psi back pressure on the annulus.

8-9-79 Wellhead pressure was 0 psi. Attempted to break circulation at 4460'. Pulled to 4093' and broke circulation. Conditioned mud.

8-10-79 Wellhead pressure was 0 psi. Broke circulation at 4218', 4342' and 4466' and conditioned mud. Attempted to clean out fill using reverse circulation and lost 15 barrels of fluid after 1 hours. Pulled bit to 4093' and mixed mud.

8-11-79 Rigged up Emsco D-375 mud pump.

8-12-79 Broke circulation at 4093' using conventional circulation. Ran bit to 4505' and washed to 4566'. Circulated hole and washed to 5024', no cement, no fill. Changed back to Gardner-Denver triplex pump and circulated hole overnight.

8-13-79 Continued circulating hole at 5024'. Changed over to the Emsco pump and continued circulating to 1000 hours. Pulled bit to 2400' and mixed mud.

8-14-79	Pulled out of hole. Ran a sinker bar in the hole and tagged bridge at 4300'. Ran 7-3/4" swage in the hole on 3-1/2" drill pipe to 7" O.D. liner at 4115' and belled top of casing to 7-1/2". Laid down swage. Mixed 12# mud.
8-15-79	Wellhead pressure was 250 psi. Pumped 60 barrels of 12# mud in the hole under pressure and hole still flowed. Recovered 70 barrels of mud and hole flowed water at 50 gpm with 450 psi. Made trip with 9-5/8" casing scraper and 8-3/4" bit to 4115' and circulated with water, no cement or fill. Released Emsco pump.
8-16-79	Removed blow out preventer. Made trip to 800' with a 12-1/4" bit and 13-3/8" casing scraper, no bridges or cement. Ran a 12-1/4" tapered mill and dressed the top of the 9-5/8" liner hanger at 810'. Laid down mill and scraper. Install blow out preventer and closed in.
8-17-79	Ran sinker bar in the hole to 5345', no bridges. Ran Birdwell logs.
8-18-79	Continued logging.
8-19-79	Laid down drill pipe.
8-20-79	Reran Birdwell logs. Rigged up to run 2-7/8" O.D. tubing.
8-21-79	Picked up Halliburton 7" bridge plug and 9-5/8" packer with 3 joints of 2-7/8" O.D. tubing between the two. Ran in hole and set bridge plug at 4175'. Bridge plug probably not holding. Flowed 10 gpm thru the tubing and 7 gpm thru the annulus. Could not work bridge plug retrieving tool into the 7" O.D. casing. Pulled out of hole.
8-22-79	Changed out retrieving tool and added an additional joint of tubing between the packer and tool. Latched onto bridge plug and reset at 4205'. Reset packer at 4075'. Pressure tested 7" O.D. liner top to 2000 psi for 10 minutes. Reset 9-5/8" packer at 900' and pressure 9-5/8" O.D. casing to 1500 psi for 15 minutes. Pressures held. Laid down packer.
8-23-79	Ran 13-3/8" packer in the hole and set at 760'. Pumped into 9-5/8" liner hanger at 200 psi with a rate of 1 barrel per minute. Laid down packer and ran bridge plug retrieving tool to 4090'.
8-24-79	Washed 4' of fill off the bridge plug at 4175' and recovered same. Perforated 7" O.D. casing from 5090' to 5090.75' with 4 holes using GO International. Made up Halliburton retrievable squeeze packer and set at 5070'.

8-25-79 Rigged up Halliburton and pumped into the perforations at a rate of 2-1/4 barrels per minute. Squeezed with 10 barrels of water ahead of 67 ft3 (60 sacks) of neat cement. Displaced with 31 barrels of water at 1300 psi. Cement in place at 0915 hours. Laid down packer.

8-26-79 Rig secured waiting on 9-5/8" O.D. casing.

8-27-79 Ran sinker bar in the hole to 5070'. Set 9-5/8" retrievable bridge plug at 860' and pumped in 600# of 20-40 mesh sand on top of the plug. Ran a fluted mill in the hole and dressed the inside of the 9-5/8" O.D. liner hanger. Ran 20 joints (822.41') of 9-5/8" O.D., 36# casing with a Brown Oil Tool tie back seal assembly on bottom and seated inside the liner hanger. 9 centralizers were placed on the outside of the casing. Picked up casing and hung above the liner hanger. Cemented annulus using Halliburton with 376 ft3 of 50% neat cement and 50% Pozmix. Displaced with 63 barrels of water. Lowered seal assembly into the liner hanger. Cement in place at 1815 hours. Annulus started bleeding cement at 1930 hours and was flowing 3/4 gpm of water at 2130 hours.

8-28-79 Pressured up on casing to 500 psi and held for 10 minutes, no loss. Annulus flowed 3/4 gpm. Cut off 9-5/8" O.D. casing and welded a 3/4" plate to the casing and casinghead. Cut off 1-2" valve on the 13-3/8" casinghead and replaced nipple with a 2" bull plug. Rigged up Halliburton to the other 2" valve. Squeezed annulus with 14 ft3 of neat cement between 400 and 500 psi. Final squeeze pressure was 500 psi. Cement in place at 1515 hours. Installed a bull plug in the 2" valve.

8-29-79 Ran 8-3/4" bit in the hole to cement at 817'. Drilled out cement to 822' and circulated to 830'. Pressured casing to 1000 psi for 10 minutes, pressure held. Laid down bit and ran bridge plug retrieving tool, washed out 30' of sand and latched onto plug at 860'. Laid down bridge plug. Ran a sinker bar in the hole to 5070', no bridges. Closed pipe rams around 1 joint of tubing and flowed hole.

8-30-79 Made 3 trips with GO International perforating strip and could not get below 4712'. Checked depth with rig sand line after each run to 5000'. Ran GO line with 2 sinker bars and could not get below 4740'.

8-31-79 Ran 6-1/8" bit in the hole, cleaned out bridge at 4740' and ran to 5070'. Circulated hole clean and laid down bit. Perforated 7" casing with 580 shots in 10 runs from 4872' to 4849', 4841' to 4809', 4803' to 4791', 4361' to 4352', 4326' to 4318', 4212' to 4176' and 4170' to 4145'.

9-1-79 Made trip with 7" casing scraper and 6-1/8" bit to 5070'. Ran Dowell retrievable 7" bridge plug and packer in the hole. Set bridge plug at 4927' and packer at 4740'. Swabbed tubing and tested lower zone, flowed overnight.

9-2-79 Completed testing. Reset bridge plug at 4457' and packer at 4287'. Swabbed tubing and tested intermediate zone, flowed overnight.

9-3-79 Completed testing., Reset bridge plug at 4230' and packer at 4139'. Tested upper zone and flowed overnight.

9-4-79 Completed test. Laid down packer and bridge plug. Ran test with all zones open and shut in overnight.

9-5-79 Ran Birdwell logs and water test.

9-6-79 Completed logging.

9-7-79 Ran in hole and set a retrievable bridge plug at 4927' and packer at 4740'. Tested lower zone as directed by USGS.

9-8-79 Rigged up Dowell and fractured lower zone using 7500 gallons of 28% hydrochloric acid, 9000 gallons of YF4PSD crosslinked fluid, 12,000# of 100 mesh sand, 9000 gallons of Water-Frac 10 and 2 salt plugs consisting of 250 gallons of saturated salt water with 300# of granulated salt and 300# of rock salt followed by 100 barrels of water flush. The material was pumped in stages at a rate of 10 barrels per minute from 3000 to 900 psi. Flowed back frac fluid and ran water test as directed.

9-9-79 Continued testing.

9-10-79 Completed test. Shut in pressure was 457 psi in 15 minutes. Reset bridge plug at 4457' and packer at 4287'.

9-11-79 Rigged up Dowell and fractured the interval with the same amounts and materials as before. Pumped at a rate of 10 barrels per minute from 2300 to 200 psi. Flowed back frac fluid and ran water test as directed.

9-12-79 Continued testing.

9-13-79 Completed test. Reset bridge plug at 4230' and packer at 4137'. Acidized the interval with 600 gallons of 15% mud acid followed by 250 gallons of salt plug consisting of 300# of rock salt and 300# of granulated salt in WF/40. This was repeated two additional times followed by 600 gallons of mud acid and 26 barrels of water flush. Total material used was 2400 gallons of mud acid and 750 gallons of salt plug. Injection rates varied from 3 to 8 barrels per minute at pressures of 1200 to 2450 psi. Flowed back acid fluid and ran water test as directed.

9-14-79	Completed test. Released packer but could not get back into the 7" liner to retrieve bridge plug. Laid down packer. Removed blow out preventer and installed 10" WKM full opening valve.
9-15-79	Ran in hole with retrieving tool and released bridge plug at 4230' and recovered same. Hole flowed water at 58° C.
9-16-79	Ran Birdwell tracer log.
9-17-79	Laid down tubing and released rig. Bolted a 10" x 8" tee on top of the 10" WKM valve with the 8" side connected to a flow line and a 10" blind flange bolted on top with a 1/4" needle valve in the center. Additional work completed.

Log Index

TYPE LOG	DATE	RUN NO.	DEPTH DRILLER	DEPTH LOGGER	LOGGED FROM	LOGGED TO
BIRDWELL LOGS						
Caliper	9-18-78	1	4411	4415	930	4407
Casing Inspection	9-18-78	1	4411	4415	20	950
Temperature	9-18-78	1	4411	4417	300	4417
3-D Velocity	9-18-78	1	4411	4417	50	4415
Gammma-Caliper	8-17-79	1		5112	0	5110
Radioactive Tracer	9-05-79	1			4000	4890
	9-16-79	2		4891	4000	4891
Seisviewer	8-20-79	1		4400	0	4400
	9-04-79	2			4135	4230
					4315	4405
					4785	4885
Spinner	8-20-79	1		5106	100	5106
3-D with Casing Collar Locator	8-17-79	1		5109	18	5106
	9-05-79	2		5006	10	5002
Gamma-Temperature	8-18-79	1		5110	10	5110
DRESSER ATLAS LOG						
Caliper	10-12-78	1	4414	4310	939	4309
MCCULLOUGH LOGS						
Gamma Bond	12-04-78	1	7196	5884	800	4879
Temperature	12-03-78	1	7196		1000	5850
SCHLUMBERGER LOGS						
Caliper	8-26-78	1	1000	997	333	996
Casing Collar	12-02-78	1	5910	5909		
Cement Bond	11-09-78	1	7196	NR	143	4368
Compensated Formation Density	8-20-78	1	1000	996	298	995
	9-19-78	2	4411	4412	989	4411
Compensated Neutron-Formation Density	11-17-78	3	7196	7186	4308	7184
Fracture Identification (10" = 100') (5" = 100') (25" = 100')	11-19-78	1	7196	7186	4322	7185
Dual Induction-Laterolog	8-20-78	1	1000	996	332	990
	9-19-78	2	4411	4411	989	4405
	11-17-78	3	7196	7189	97	7183
Dual Laterolog	11-17-78	1	7196	7186	4318	7172
Sidewall Neutron Porosity	8-20-78	1	1000	996	10	995
	9-19-78	2	4411	4412	790	4411
	11-17-78	3	7196	7187	4300	7186
Borehole Compensated Sonic	8-20-78	1	1000	995	270	993
	9-19-78	2	4411	4411	950	4410
Borehole Compensated Sonic	11-17-78	3	7196	7186	4230	7185
Temperature	8-20-78	1	1000	996	130	996
	11-20-78	3	7196	7188	4310	7188

NOTE: Logs furnished F&S/Mercury.

Formation Tops

Formation and age[2]	Log depth (in feet)[1]	Datum
CRETACEOUS		
Eagle	245 (sample)	+2795
Telegraph Creek	700	+2340
Shannon	789	+2251
Colorado	823	+2217
Niobrara	938	+2102
Frontier	1796	+1244
Normal fault (90' cut out)	2143	+ 897
Mowry	2216	+ 824
Thermopolis	2457	+ 583
Muddy (?)	2833	+ 207
Skull Creek	2886	+ 154
Dakota silt	2993	+ 47
Dakota sand	3123	- 83
Kootenai	3208	- 168
Lakota	3390	- 350
JURASSIC		
Morrison	3442	- 402
Swift	3650	- 610
Rierdon	3788	- 748
Normal fault (90' cut out)	3830	- 790
Piper shale	3876	- 836
Piper limestone	3942	- 902
TRIASSIC		
Spearfish	4046	-1006
PENNSYLVANIAN		
Tensleep	4128	-1088
Amsden	4178	-1138
MISSISSIPPIAN		
Madison	4300	-1260
Lodgepole	4986	-1946
DEVONIAN		
Devonian	5368	-2328
ORDOVICIAN		
Stony Mountain	5612	-2572
Red River	5724	-2684
CAMBRIAN		
Snowy Range	5963	-2923
Dry Creek	6454	-3414
Pilgrim	6535	-3495
Gros Ventre	6642	-3602
Flathead	7073	-4033
PRECAMBRIAN		
Gneiss	7142	-4102
Total depth (Driller)	7190	-4150

[1]Depths are from KB (Kelly bushing), which is 15.5 ft above land surface and 3,039.8 ft above ses level.

[2]Driller's terminology. Some names do not follow U.S. Geological Survey usage.

WELL COMPLETION AND PERFORATION

An Ideco Back-in Rambler drilling rig, used to complete the well, was moved to the site on July 26, 1979. Efforts to control water flow with a pressure head greater than 450 lb/in^2 at the well-head from the perforated intervals, by pumping heavy mud into the hole, were unsuccessful. Mud losses, more than twice the volume needed to fill the cased hole, occurred while pumping mud from the surface into the well and again through tubing that had been lowered to the bottom of the well.

Geophysical logs, including temperature, six-arm caliper, and seisviewer; and pressure tests (using retrievable bridge plugs and hookwall and inflatable packers), indicated breaks in the 13-3/8-in casing near 350 ft and leakage around the 9-5/8-in liner hanger at 810 ft. These leaks permitted cement rubble and rock debris behind the casing to slough into the hole and create bridges and plugs. The problem was corrected by extending the 9-5/8-in casing to land surface, and then bonding the 13-3/8-in and 9-5/8-in casings with cement. A flush connection was made by use of a tie-back seal assembly on the bottom of the new section of 9-5/8-in casing. The casing was lowered to a depth just above the liner hanger before cementing of the annulus. The 3 ft-long seal assembly was lowered and seated inside the liner hanger immediately after completing cementing operations.

A 3-D cement-bond log with casing-collar locator and gamma-ray log showed little or no cement bonding of the 7-in casing liner and the borehole from 5,100 to 4,800 ft. Possible contamination from more mineralized water below 5,100 ft was minimized by perforating the liner with 4 shots at 5,090 ft, setting a retrievable squeeze packer at 5,070 ft, and squeezing cement through the perforations into the annulus.

Selected intervals in the lower and upper parts of the Mission Canyon Limestone were perforated through the 7-in casing between depths of 4,872 to 4,791 ft and 4,361 to 4,318 ft. The Amsden Formation and Tensleep Sandstone were perforated through two casings, 7 in and 9-5/8 in, in the intervals 4,212 to 4,176 ft and 4,170 to 4,145 ft. Perforated depths of the intervals are shown in table 1. Selection of these intervals was based upon porosity calculated from geophysical logs, including borehole compensated sonic, compensated formation density, and sidewall neutron porosity that were made in the uncased hole during exploratory drilling, and on densely fractured zones seen in cores. Other considerations were hole diameters determined from caliper logs made in the open hole, and casing collars and external casing packers recorded on the 3-D casing collar locator logs.

Perforations were made using 3½-in OD Strip Jet Guns having high strength glass charges mounted in semi-flexible, retrievable, sheet-steel carriers. Spacing of the charges was 4 shots per foot with 180 degree phasing (fig. 5). The section of seisviewer log on figure 5 indicates that some of the glass charges were broken (probably when the gun was maneuvered through the top of the 7-in liner) and did not explode. The charge weight in each glass container was 22.7 g (gram); average diameter of the perforations in the casing was 0.43 in; penetration depth (based on laboratory experiments) was in excess of 10.4 in. All charges loaded on a carrier were fired at one time. Positive perforating depth control was obtained with a magnetic-collar locator run with the gun. The length of the gun and associated equipment was limited by the length of the lubricator (an assembly of wireline pressure-control equipment) on the top of the well; the maximum gun length was 25 ft. After reeling the gun into the lubricator, the lubricator was bolted to the blow-out preventer. When the rams of the blow-out preventer were opened to permit entry of the gun into the well, the lubricator prevented flow at the surface and provided static conditions in the well. A total of 145 net ft was perforated. Total net perforated footage, including that done during December 1978, was 185 ft, which had 740 perforations.

HYDROLOGIC TESTS

Hydrologic tests were made of the perforated intervals. Perforated intervals in the lower part of the Mission Canyon Limestone were tested as a single unit (test 1), as were those in the upper part of the Mission Canyon Limestone (test 2). The Amsden Formation and Tensleep Sandstone were tested as one unit (test 3) because the distance between the two sets of perforations was only 6 ft. The probability of connection between these perforations was too great to justify isolating them as separate units (table 1).

Each of the three units was isolated by using a retrievable bridge plug and packer in combination run on 2 7/8-in tubing (fig. 6). The retrievable bridge plug was set below the lower perforations. The packer assembly then

Table 1.--*Summary of flow from perforated intervals before and after stimulation by acidizing and fracturing*

[ft = feet; in = inch; gal/min = gallons per minute; lb/in² = pounds per square inch]

Test	Rock sequence	Perforated intervals[1] (ft below land surface)	Lithology of perforated intervals	Discharge from perforated intervals after development by swabbing (gal/min)		Discharge from perforated intervals after stimulation by acidizing and fracturing (gal/min)		Discharge from 8-in flow line at end of 24-hour flow test after acidizing and fracturing (gal/min)
				Isolated with bridge plug and packer. Flow to surface through 2-7/8-in tubing	Flow calculated from down-hole-radio-active-tracer survey	Isolated with bridge plug and packer. Flow to surface through 2-7/8-in tubing	Flow calculated from down-hole-radio-active-tracer survey	
1	Lower part of Mission Canyon Limestone	4,872-4,849 4,841-4,809 4,803-4,791 Total of 81 gross ft, 67 net ft	Limestone (64 percent). Dolomite and some anhydrite (36 percent). Intervals contain numerous fractures, mostly healed or lined with calcite.	13.3	15	>180 (with 90 lb/in^2 back pressure)	545	
2	Upper part of Mission Canyon Limestone	4,383-4,363 4,361-4,352 4,348-4,328 4,326-4,318 Total of 65 gross ft, 57 net ft	Dolomite, breccia and fine crystalline dolomite. Intervals are highly fractured and have vuggy porosity.	72 (with 8 lb/in^2 back pressure)	77	±200 (with 110 lb/in^2 back pressure)	1,838	
3	Amsden Formation	4,212-4,176	Dolomite (100 percent), fine crystalline, some anhydrite.	33	33	±150 (with 90 lb/in^2 back pressure)	311	
	Uppermost part of Amsden Formation and lower part of Tensleep Sandstone	4,170-4,145 Total of 67 gross ft, 61 net ft	Dolomite (50 percent), vuggy porosity; sandstone (25 percent) fine to coarse grained, shale and quartzitic sandstone (25 percent).					
			TOTAL FLOW	118.3	125	+530 (with 290 lb/in^2 back pressure)	2,694	2,900

[1] Four 0.5-in shots per foot

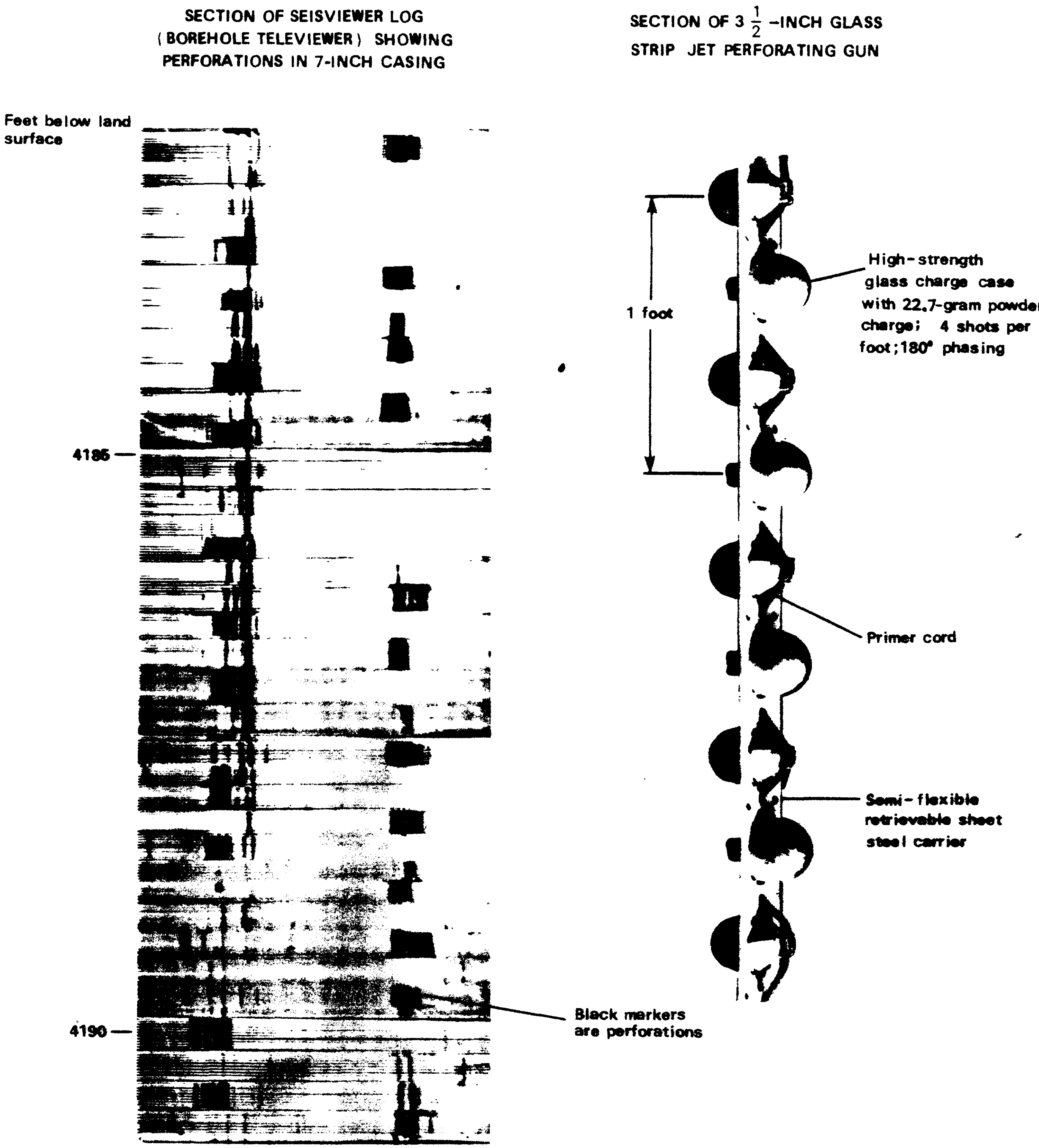

Figure 5.--Section of seisviewer log made in 7-inch casing in Madison Limestone test well 3 after perforating with strip jet gun (section of glass-strip jet gun after GO International, Inc.).

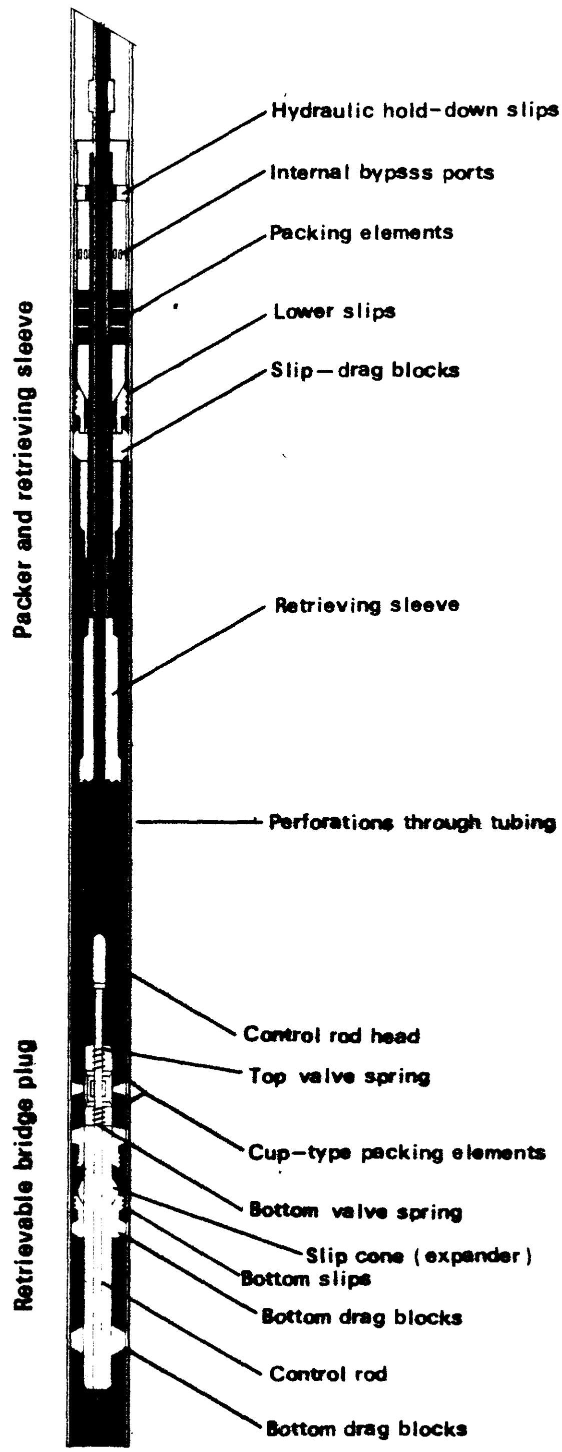

Figure 6.--Packer and retrievable bridge plug used to isolate perforated intervals in 7-inch casing for swab and flow tests and for acidizing and fracturing (courtesy of Dowell Division, Dow Chemical U.S.A.).

was disengaged from the bridge plug and moved up the well to a point above the upper perforations in the zone to be tested. Rotation of the 2 7/8-in tubing, and application of tubing weight, set the packer and permitted flow from the isolated perforations to the surface through the tubing. Flow at the surface was diverted from the tubing to a discharge line through a high-pressure manifold. The manifold contained valves to regulate flow, to simplify collection of water samples, to measure back pressures, and to measure final shut-in pressure. Upon completion of a test, the packer assembly was unseated, and then moved down the hole to unseat the bridge plug. The combination tool was moved to the next unit, and the same procedure was used to isolate and test that unit. It was not necessary to remove the equipment from the hole after each test. Depths to bridge plug and packer settings for the three tests are shown in table 2.

Swab and Flow Tests

Procedures for developing and testing each of the isolated units were similar. After the packer was set, initial flow was measured at the end of the discharge line volumetrically or by the trajectory method. The time for this step was relatively short, ranging from less than 1 to 3 hours. Following this, surface connections for swabbing the well were made, and a swab unit, consisting of a hollow supporting mandrel with an upward opening valve, rubber cups, and a sinker bar was lowered into the 2-7/8-in tubing. A sandline (a component of the drilling rig), attached to the swab unit, was marked at 200- and 400-ft depths. Because of high pressures, mineral deposits, slightly out-of-gage tubing, and equipment difficulties, the swabbing rate usually was slow and erratic. Greatest efficiency was obtained when swabs were pulled from depths no greater than 350 ft. Time for swabbing ranged from 1 to 5 hours. Periodic measurements of pH, specific conductance, and water temperature were made.

After swabbing, flow was diverted from the tubing through the manifold and discharge line. Flow periods for these tests were extended to permit collection of water samples representative of aquifer water in the perforated intervals isolated with bridge plugs and packers. Flow rates and measurements of pH, specific conductance, and water temperature were monitored throughout the flow period. After stabilization of these parameters, final suites of water samples for chemical analyses were collected. These analyses are shown in table 3.

Final shut-in pressures were measured at the end of flow periods. Shut-in pressure for the lower part of the Mission Canyon Limestone (test 1) was 451 lb/in^2, and those for the upper part of the Mission Canyon Limestone (test 2) and the Amsden Formation and Tensleep Sandstone (test 3) were 454 lb/in^2 (fig. 7).

Total flow from all perforated intervals, calculated from radioactive-tracer survey data, was 125 gal/min. Of this total, the lower part of the

Table 2.--*Acidizing and fracturing program*

[ft = feet; in = inch; bbl = barrel; bbl/min = barrels per minute; lb/in^2 = pounds per square inch; gal = gallons; lb/gal = pounds per gallon; lb = pounds; HCL = hydrochloric]

Intervals isolated for acidizing and fracturing					Acidizing and fracturing data[1]				
Test	Formation	Perforated intervals in 7-in casing liner (ft below land surface)	Retrievable bridge plug (ft below land surface)	Packer setting (ft below land surface)	Military clock time	Injection rate (bbl/min)	Accumulated volume injected (bbl)[2]	Pressure in 2-7/8-in tubing (lb/in^2)	Schedule
									Pressure test flow lines to 6,500 lb/in^2 (Sept. 8, 1979)
1	Lower part of Mission Canyon Limestone	4,872-4,849 4,841-4,809 4,803-4,791 Total of 81 gross ft, 67 net ft	4,927	4,742	1203	10		3,000	Start 500 gal 28 percent HCL acid (all 28 percent HCL contains 6 gal/1,000 gal acid corrosion inhibitor, 15 lb/1,000 gal iron sequestering agent, and 3 lb/1,000 gal acid friction reducer)
						10	12	3,000	Switch to 1,000 gal complex-low-residue guar (Dowell trade product name YF4PSD) mixed with 50 lb/1,000 gal clean water gelling agent (cross-linked)
						10	36	2,700	Switch to 2,000 gal complex-low-residue guar as above with 2 lb/gal 100-mesh sand
						10	84	2,500	Switch to 2,000 gal 28 percent HCL acid
						10	132	1,300	Switch to 3,000 gal water frac (Dowell trade product name WF10) consisting of 10 lb/1,000 gal clean water gelling agent (not cross-linked) and 10 lb/1,000 gal friction reducer
						10	204	1,700	Drop 250 gal salt plug (plugs consist of 5 lb clean water gelling agent (not cross-linked), 300 lb rock salt, and 300 lb granulated salt)
						10	210	1,500	Start 500 gal 28 percent HCL acid
						10	222	1,300	Switch to 1,000 gal YF4PSD
						10	246	1,200	Switch to 2,000 gal YF4PSD with 2 lb/gal 100-mesh sand
						10	294	1,200	Switch to 2,000 gal 28 percent HCL acid
						10	342	1,200	Switch to 3,000 gal WF10
						10	414	1,300	Drop 250 gal salt plug
						10	420	1,100	Start 500 gal 28 percent HCL
						10	432	1,100	Switch to 1,000 gal YF4PSD

Table 2.--*Acidizing and fracturing program*--Continued

Intervals isolated for acidizing and fracturing					Acidizing and fracturing data[1]				
Test	Formation	Perforated intervals in 7-in casing liner (ft below land surface)	Retrievable bridge plug (ft below land surface)	Packer setting (ft below land surface)	Military clock time	Injection rate (bbl/min)	Accumulated volume injected (bbl)[2]	Pressure in 2-7/8-in tubing (lb/in^2)	Schedule
						10	456	900	Switch to 2,000 gal YF4PSD with 2 lb/gal 100-mesh sand
						10	504	1,500	Switch to 2,000 gal 28 percent HCL acid
						10	552	900	Switch to 3,000 gal WF10
					1315	10	652	1,100	Flush to perforations with water
					1343				Begin flush back through manifold to steel holding tank
									Pressure test flow lines to 6,500 lb/in^2 (Sept. 11, 1979)
2	Upper part	4,383-4,363	4,457	4,287	0925[3]	10		2,200	Start 500 gal 28 percent HCL acid with additives as in test no. 1
	of	4,361-4,352				10	12	2,100	Switch to 1,000 gal YF4PSD with additives as in test no. 1
	Mission Canyon	4,348-4,328				10	36	2,400	Switch to 2,000 gal YF4PSD with 2 lb/gal 100-mesh sand
	Limestone	4,326-4,318				8	84	2,300	Switch to 2,000 gal 28 percent HCL acid
		Total of 63 gross ft,				7	132	1,100	Switch to 3,000 gal WF10
		57 net ft				6	204	600	Drop 250 gal salt plug
						6	210	1,000	Start 500 gal 28 percent HCL acid
						6	222	600	Switch to 1,000 gal YF4PSD
						6	246	800	Switch to 2,000 gal YF4PSD with 2 lb/gal 100-mesh sand
						7	294	1,150	Switch to 2,000 gal 28 percent HCL acid
						7.5	342	500	Switch to 3,000 gal WF10
						6	414	1,100	Drop 250 gal salt plug
						7	420	1,100	Start 500 gal 28 percent HCL acid
						8	432	700	Switch to 1,000 gal YF4PSD
						6	456	1,000	Switch to 2,000 gal YF4PSD with 2 lb/gal 100-mesh sand
						6	504	200	Switch to 2,000 gal 28 percent HCL acid
						8	552	1,200	Switch to 3,000 gal WF10
					1200	7	652	1,200	Flush to perforations with water
					1207				Begin flush back through manifold to steel holding tank

Table 2.--*Acidizing and fracturing program*--Continued

Intervals isolated for acidizing and fracturing					Acidizing and fracturing data[1]				
Test	Formation	Perforated intervals in 7-in casing liner (ft below land surface)	Retrievable bridge plug (ft below land surface)	Packer setting (ft below land surface)	Military clock time	Injection rate (bbl/min)	Accumulated volume injected (bbl)[2]	Pressure in 2-7/8-in tubing (lb/in^2)	Schedule
3	Amsden	4,212-4,176	4,230	4,137	1029	4		1,200	Pressure test flow lines to 6,500 lb/in^2 (Sept. 13, 1979).
	Formation	4,170-4,145							Start 600 gal 15 percent mud and silt remover acid (HCL base)
	and	Total of 67 gross ft,							(all acid contains 4 gal/600 gal acid corrosion inhibitor--
	lower part	61 net ft				3	14	2,450	Dowell trade product name 15 percent MSR)
	of								Drop 250 gal salt plug (plugs consist of same additives as in
	Tensleep					6	20	2,100	tests 1 and 2
	Sandstone					3	34	1,950	Start 600 gal 15 percent MSR acid
						8	40	2,000	Drop 250 gal salt plug
						3	54	1,950	Start 600 gal 15 percent MSR acid
						8	60	2,000	Drop 250 gal salt plug
					1044	8	74	2,000	Start 600 gal 15 percent MSR acid
					1047				Flush to perforations with water
									Begin back through manifold to steel holding tank

[1] Modified from Dowell Well Stimulation and Well Treatment reports.

[2] For conversion purposes, Dowell uses 24 bbl equals 1,000 gal.

[3] Tubing malfunction after injecting 27 bbls. Approximately ½ hour to repair before continuing.

Table 3.--*Chemical analyses of water and acid flush-back fluid from Madison Limestone test well 3*

[Analyses by U.S. Geological Survey unless otherwise indicated; chemical constituents, in mg/L. ft = feet; min = minutes; µmhos/cm at 25°C = micromhos per centimeter at 25 degrees Celsius; °C = degrees Celsius; mg/L = milligrams per liter]

Formation	Sample interval (ft below land surface)	Drill-stem test (DST) or sample number	Date sampled	Time since flow began (min)	Specific conductance (µmhos/cm at 25°C) Onsite	Specific conductance Laboratory	Onsite pH (units)	Water temp. (°C)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Alkalinity ($CaCO_3$)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Dissolved solids (Calc.)	Dissolved solids (Residue on evap.)
Lower part of Mission Canyon Limestone------	4783-4973	DST-10[1/]	11-27-78	---	---	3,300	6.9	48.1	530	110	240	39	170	---	2,100	60	3.3	3,100	---
Do.	4791-4872	---[2/]	9-02-79	---	2,950	2,940	7.3	38.4	480	110	97	34	170	140	1,800	40	3.5	2,700	2,890
Do.	do.	2[3/]	9-09-79	827	19,000	16,100	7.0	53.0	3,000	490	240	35	---	260	1,600	5,900	29	11,500	13,200
Do.	do.	3[3/]	do.	977	16,000	12,700	7.0	50.0	1,900	330	170	35	---	330	---	4,000	2.6	6,640	9,410
Do.	do.	4[3/]	do.	1,997	5,400	6,620	7.0	53.0	1,100	200	110	---	---	330	2,000	1,400	3.9	5,360	5,520
Do.	do.	5[3/]	9-10-79	2,237	5,600	5,960	7.0	53.0	980	140	100	35	---	310	1,500	1,100	3.4	4,080	4,880
Do.	do.	6[3/]	do.	3,017	4,800	4,930	7.0	55.7	780	110	90	33	---	180	1,400	700	3.2	3,260	---
Upper part of Mission Canyon Limestone------	4287-4477	DST-12[1/]	11-28-78	---	---	3,900	7.0	49.5	480	88	500	41	220	---	2,300	74	3.4	3,600	---
Do.	4275-4399	DST-2[4/]	9-02-78	---	---	2,880	6.8	51.8	490	100	95	39	155	---	1,800	39	.7	2,660	---
Do.	4328-4348, 4363-4383	---[1/5/]	1- 7-79	---	---	2,700	7.0	48.8	540	99	84	40	146	---	1,800	35	3.2	2,670	---
Do.	4318-4383	---[2/]	9-03-79	---	2,900	2,870	7.0	50.4	460	120	81	38	159	130	1,700	35	3.6	2,560	2,620
Do.	do.	1[6/]	9-11-79	54	55,000	52,500	5.5	33.0	6,700	3,900	710	37	---	1	1,600[7/]	26,000	1.7	37,500	44,100
Do.	do.	1A[6/]	do.	114	30,000	32,700	6.2	41.5	4,100	2,500	530	38	---	210	---	14,000	2.7	21,300	26,800
Do.	do.	2[6/]	do.	174	30,000	24,600	5.7	43.0	3,300	1,700	490	38	---	270	1,900	9,500	2.8	17,100	19,000

Table 3.--*Chemical analyses of water and acid flush-back fluid from Madison Limestone test well 3*--Continued

Formation	Sample interval (ft below land surface)	Drill-stem test (DST) or sample number	Date sampled	Time since flow began (min)	Specific conductance (μmhos/cm at 25°C) Onsite	Specific conductance (μmhos/cm at 25°C) Laboratory	Onsite pH (units)	Water temp. (°C)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Alkalinity ($CaCO_3$)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Dissolved solids (Calc.)	Dissolved solids (Residue on evap.)
Upper part of Mission Canyon Limestone------	4318-4383	2A[6]	9-11-79	234	21,000	20,000	6.5	49.0	2,200	1,200	330	38	---	270	---	7,700	2.9	11,600	15,400
Do.	do.	2B[6]	do.	314	15,500	16,400	5.7	50.0	1,900	970	300	36	---	280	1,500	5,200	2.8	10,100	12,700
Do.	do.	3[6]	do.	479	12,100	11,800	5.5	51.8	1,300	580	190	38	---	220	---	3,000	3.9	5,250	---
Do.	do.	3A[6]	9-12-79	729	8,500	8,730	5.5	53.5	1,000	470	160	35	---	170	1,500	2,300	3.4	5,570	6,760
Do.	do.	3B[6]	do.	834	8,000	8,100	6.0	54.0	910	390	140	---	---	210	1,600	2,000	3.2	5,680	6,170
Do.	do.	3C[6]	do.	954	7,100	7,310	6.0	54.0	920	380	130	35	---	69	1,600	1,800	2.9	4,950	5,670
Do.	do.	3D[6]	do.	1,074	6,900	6,990	6.5	54.1	820	340	130	34	---	160	1,600	1,500	3.4	4,530	5,470
Do.	do.	3E[6]	do.	1,249	7,300	7,350	6.5	52.3	820	330	130	36	---	230	1,300	1,500	3.6	4,310	5,750
Do.	do.	3F[6]	do.	1,509	6,000	6,170	6.5	54.5	920	280	110	35	---	220	1,600	1,300	3.2	4,420	4,660
Do.	do.	3G[6]	do.	1,614	5,200	5,990	6.8	54.0	750	290	120	40	---	210	1,600	1,200	3.5	4,180	4,760
Do.	do.	3H[6]	do.	1,734	5,600	5,790	6.8	54.3	780	290	110	35	---	210	1,600	1,200	3.0	4,180	4,570
Do.	do.	4[6]	9-13-79	2,214	4,700	5,310	5.8	54.2	680	250	100	36	---	200	1,700	940	3.5	3,830	4,090
Amsden Formation and Tensleep Sandstone------	4135-4219	DST-3	9-24-78	---	---	2,300	6.9	49.7	500	110	84	40	151	---	1,800	41	4.5	2,700	---
Do.	4145-4212	---[2]	9-04-79	---	2,900	2,912	7.2	47.0	470	88	82	40	159	130	1,800	35	3.6	2,640	2,800
Do.	do.	1[8]	9-13-79	25	113,000	124,500	2.3	43.8	15,000	8,200	17,000	94	---	1	1,500[7]	74,300[7]	.1	116,000	154,000
Do.	do.	2[8]	do.	72	34,400	34,000	6.0	49.0	3,400	1,800	2,900	57	---	420	1,700	14,000	2.6	24,100	27,500

Table 3.--*Chemical analyses of water and acid flush-back fluid from Madison Limestone test well 3*--Continued

Formation	Sample interval (ft below land surface)	Drill-stem test (DST) or sample number	Date sampled	Time since flow began (min)	Specific conductance (µmhos/cm at 25°C) Onsite	Specific conductance (µmhos/cm at 25°C) Laboratory	Onsite pH (units)	Water temp. (°C)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Alkalinity ($CaCO_3$)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Dissolved solids (Calc.)	Dissolved solids (Residue on evap.)
Amsden Formation and Tensleep Sandstone------	4145-4212	3[8/]	9-13-79	123	16,500	13,000	6.0	52.0	1,400	590	870	45	---	280	1,800	4,300	3.9	9,180	9,540
Do.	do.	4[8/]	do.	168	11,800	14,200	6.0	53.0	1,100	490	650	40	---	290	460	4,300	2.8	7,220	---
Do.	do.	4A[8/]	do.	273	6,500	6,600	6.0	53.3	720	260	350	39	---	190	1,700	1,400	3.5	4,630	5,010
Do.	do.	4B[8/]	do.	333	5,600	5,160	6.0	53.0	470	200	230	34	---	140	1,100	900	2.9	3,050	3,270
Do.	do.	4C[8/]	do.	403	4,640	4,940	6.2	53.5	450	170	140	37	---	120	1,200	680	3.0	2,780	2,970
Do.	do.	4D[8/]	do.	513	3,900	3,980	6.4	53.0	600	170	180	37	---	150	1,700	430	3.4	3,210	3,530
Do.	do.	4E[8/]	do.	633	3,200	3,950	6.2	53.0	440	150	130	37	---	150	1,500	340	2.8	2,730	2,820
Do.	do.	4F[8/]	do.	693	3,100	3,710	6.3	53.0	510	100	130	35	---	160	1,500	330	3.4	2,740	---
Do.	do.	4G[8/]	9-14-79	753	3,300	3,580	6.1	51.0	520	100	130	37	---	77	1,600	300	3.4	2,770	3,260
Do.	do.	4H[8/]	do.	828	3,200	3,620	6.2	50.5	420	130	110	36	---	92	1,400	250	3.4	2,450	2,730
Do.	do.	5[8/]	do.	991	3,200	3,380	6.7	52.9	560	140	110	35	---	140	1,700	200	3.5	2,870	3,040
Sample from all perforated intervals-----			9-15-79	---	2,870	2,870	6.8	47.0	510	110	80	36	---	370	1,500	32	3.4	2,520	2,820
Sample at end of fall-flow test----------			10-26-79	1,430	2,920	---	---	56.6	500	120	75	40	---	110	1,700	46	3.6	2,590	---

1/ Analysis by EERC (Energy and Environmental Resource Consultants, Inc.), Billings, Mont.
2/ Sample collected after swabbing and before stimulation by acidizing and fracturing.
3/ Sample of flush-back fluid after acidizing and fracturing test 1.
4/ Long duration flow test, water clear when collected.
5/ Sample collected after well flowed for several days; well flowing from perforations made in December 1978.
6/ Sample of flush-back fluid after acidizing and fracturing test 2.
7/ Concentration of constituent from analysis of duplicate sample by EERC, Billings, Mont.
8/ Sample of flush-back fluid after acidizing and fracturing test 3.

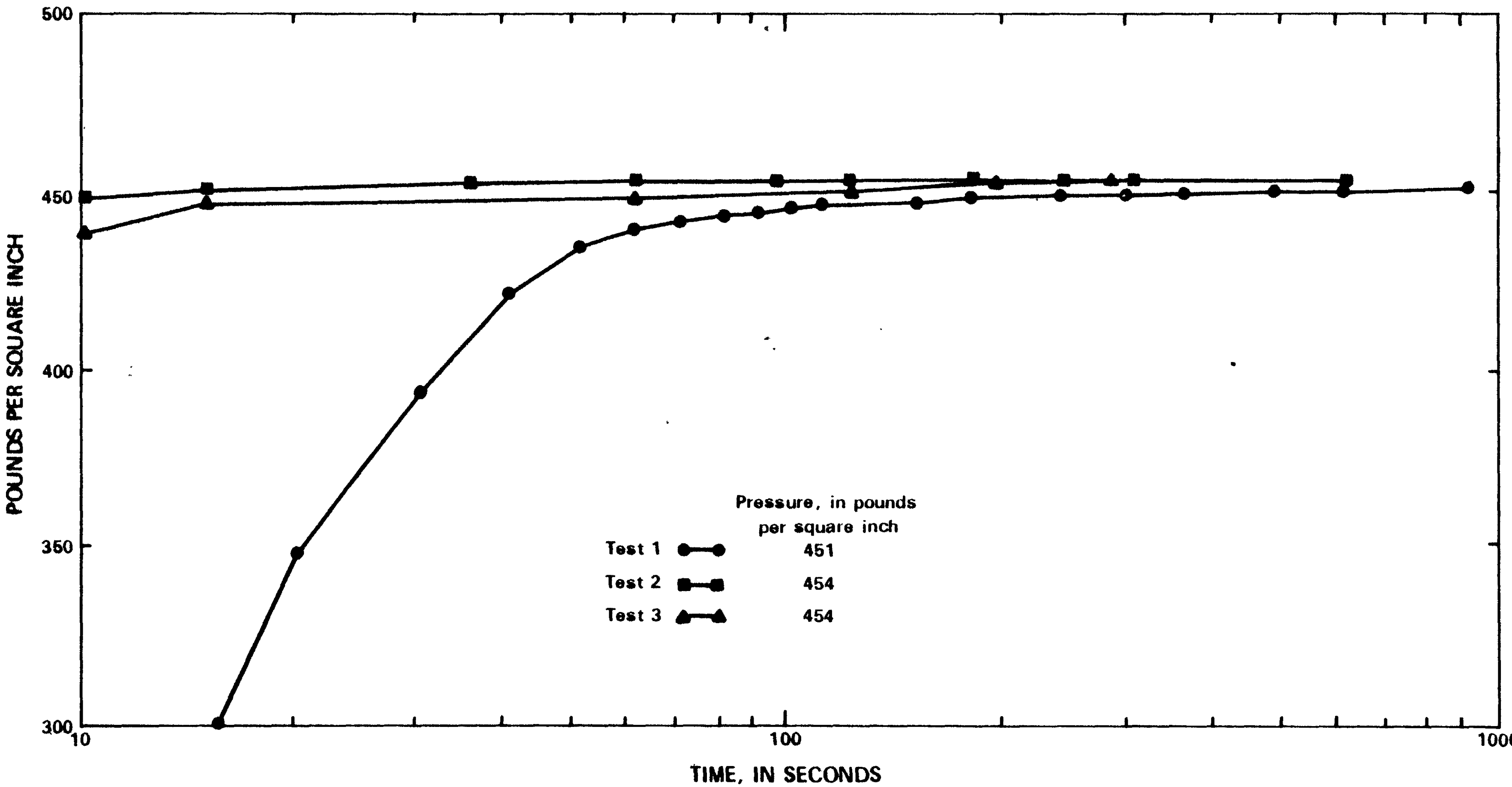

Figure 7.--Surface shut-in pressure curves before acidizing and fracturing perforated intervals isolated with bridge plugs and packers.

Mission Canyon contributed 15 gal/min; the upper part contributed 77 gal/min; and the Amsden-Tensleep contributed 33 gal/min (table 1).

The perforated intervals are representative of selected zones within the intervals that were isolated and tested using straddle packers in the open hole (drill-stem tests 2, 3, and 10) during the original testing in Madison Limestone test well 3 (Blankennagel and others, 1979). Combined flow at the surface from these drill-stem tests was greater than flow through the perforations by a factor of 2. Probable reasons for the smaller production and transmissivity in perforated zones were: (1) Sealing of water-bearing fractures during the cementing of the 7-in casing, (2) increased friction through perforations, and (3) perforation of less than 50 percent of the zones isolated during the open-hole drill-stem tests.

Throughout the prolonged flow in each of the tests, there was no consistent change in either the rate of discharge or back pressure. Specific capacities, ranging from 0.01 to 0.07 (gal/min)/ft of drawdown, are meaningless in terms of the capacity of the aquifer to yield water. Swabbing, to clean perforations, did not improve flow rates.

Acidizing and Fracturing Stimulation

Drill-stem tests made in carbonate rocks in the open hole during exploratory drilling of Madison Limestone test well 3 showed that intervals containing fractures (seen in cores) produced greater volumes of water than unfractured intervals with more than 15 percent interstitial porosity (calculated from geophysical logs). Most fractures seen in cores were sealed and contained calcite, calcite crystals, or anhydrite. The amount of rock with open fractures was indeterminate, because the broken rock commonly jammed the core barrel, resulting in minimal core recovery.

Reasons for including a program of acidizing and fracturing stimulation in the workover completion program were: (1) Probability of unrealistically small production through perforated intervals in the untreated hole because of sealing of open fractures with cement; (2) the carbonate section, containing fractures as well as some interstitial porosity, was ideally suited for stimulation by acidizing and fracturing; and (3) results of the stimulation program, positive or negative, would have excellent transfer value for holes drilled in other areas having similar subsurface geologic conditions.

Following completion of total-flow measurements and collection of water samples for chemical analyses, each of the three intervals tested in the untreated hole was again isolated, using retrievable bridge plug and packer, and stimulated by acidizing and fracturing. The acidizing and fracturing schedule was one recommended by personnel of various major companies specializing in these services that had previous experience in the area. Dowell Division of Dow Chemical, U.S.A., performed the work.

The primary purpose of acidizing and fracturing is to increase productivity beyond natural reservoir capability. This may be achieved by opening and extending existing fractures; creating new fractures to open new permeability paths, interconnect existing permeability zones, or break into an unpenetrated part of the reservoir; or both. The significant increase in water production from each interval that was stimulated showed that the primary purpose was achieved (table 1).

The lower and upper parts of the Mission Canyon Limestone (tests 1 and 2) were stimulated with similar acidizing and fracturing treatments. More than 26,000 gal of fluid were injected at various rates and pressures into each isolated interval. The fluids consisted of 7,500 gal of 28 percent hydrochloric acid, 9,000 gal of complex low-residue guar (crosslinked)* fluid, 9,000 gal low-residue guar (not crosslinked) fluid, and 500 gal containing salt plugs. About 12,000 lb of 100-mesh sand was pumped with the low-residue guar fluid.

All of the 28 percent hydrochloric acid contained the following:

1. 6 gal/1000 gal acid corrosion inhibitor to provide metal protection for tubing, casing, and tools used to isolate the test intervals;
2. 15 lb/1000 gal iron-sequestering-complexing agent to prevent deposition of ferric iron hydroxide, a gelatinous material that can plug formation pores; and
3. 3 lb/1000 gal acid friction reducer to change fluid-flow behavior by reducing turbulence as the acid moves through the tubing, thereby reducing drag or friction pressure.

All low-residue-guar-starter solution was prepared by thickening fresh water with 50 lb/1000 gal clean-water gelling agent. The resulting cross-linked-fracturing fluid is designed to produce very wide fractures and carry large volumes of propping agents much farther into the fractures than conventional fluids. This nonreactive-pad fluid flows into the acid-enlarged flow channels and secondary fractures. Because it is a slow-moving fluid, it temporarily blocks the channel or secondary fracture and keeps the acid in the main fracture. Sand (100 mesh), used in the fluid, also bridges the secondary, or hairline, fractures, thus providing more effective acid control.

Water-frac fluid is a flushing agent prepared by mixing fresh water with 10 lb/1000 gal of clean-water gelling agent (not crosslinked) and 10 lb/1000 gal of a friction reducer. This nonreactive-pad fluid is injected after each of three episodes of acid and low-residue guar containing 100-mesh sand has been pumped. It reduces friction pressure and permits a greater injection rate at the same pressure, thus increasing fluid efficiency. This increases the ability of the fracturing fluid to create more fracture voids in the reservoir.

Salt plugs contain saturated salt water consisting of 5 lb/250 gal of clean-water-gelling agent (not crosslinked), 300 lb of rock salt, and 300 lb

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*Networks of bonds between linear polymers.

of granulated salt. The plugs are pumped into the isolated intervals after the first and second episodes of acid and pad treatments to temporarily plug those perforations taking most or all of the fluids because of preferred permeability paths. Plugging these perforations causes the acid and pad fluids to enter those perforations that penetrated less permeable rocks.

The schedule for the alternating stages of acid, pad, flush, and salt-plug pumping; and the injection rates, volumes, and tubing pressures are shown in table 2. This table also shows intervals perforated, depth settings of the retrievable bridge plugs and packers, times for each operation, and the Dowell Division of Dow Chemical (U.S.A.) trade names for products used.

The final step in each stimulation treatment was to flush the perforations with fresh water. This was followed 28 minutes after test 1, and 7 minutes after test 2 by flushing back the spent acid and other chemicals through the manifold to 500-bbl holding tanks.

Water samples for chemical analysis were collected from each isolated perforated interval before acidizing in order to characterize the natural waters in the rocks and to evaluate the effect of acidization. Analyses of water collected from drill-stem tests of similar intervals also are listed for comparison in table 3. The analyses indicate that about 90 percent of the major chemical constituents in water from the three zones are calcium, magnesium, and sulfate; the dissolved-solids concentration ranged from 2,820 to 2,890 mg/L.

Chemically, acid stimulation consists of dissolving carbonate rocks with hydrochloric acid. Experimental data have shown that 1,000 gal of 28 percent by weight of hydrochloric acid will dissolve approximately 3,600 lb of limestone and produce about 13,000 ft^3 of carbon dioxide. The resulting solution, assuming no dilution and including the salt plugs, will be a calcium sodium chloride brine. The effect of the propping and flushing agents and dilution of the solution by formation waters, tends to decrease the concentration. The approximate volumes, weights, concentrations of acid, propping agents, salt plugs, and the resulting solution before dilution are listed in table 4.

Chemical analyses of the samples collected during the flush-back periods for the three tests also are listed in table 3. The amount of foam contained in the flush-back fluid, probably due to outgassing of the carbon dioxide, and some of the additive contained in the acidizing-fracturing fluids, made it difficult to collect a sufficient volume for analysis. Large volumes of the foaming flush-back fluid were collected, and after the foam had dissipated, a sample of the resultant liquid was analyzed. The following section summarizes the water chemistry of the acidizing and fracturing episodes.

Flush back of fluids containing spent acid and other chemicals following test 1 contained large amounts of gas, and because of the dissolved constituents in the fluid, it contained about 75-percent foam for the first 700 minutes. The amount of foam produced with liquid precluded accurate

Table 4.--*Volumes, weights, and concentrations of materials injected and removed from each zone*

[lb = pounds; gal = gallons; mg/L = milligrams per liter; HCl = hydrochloric]

MISSION CANYON ZONES I AND II (per zone)

Item	Weight of material		Total Volume (gal)	Concentration of resulting solution (mg/L, rounded)
	Injected (lb)	Removed (lb)		
1. Acid, 28-percent HCl--	20,000	30,430	7,500	483,000
Plus additions--------	220	220	-----	-------
Sub total-------------	20,220	30,650	7,500	490,000
2. Propping agent (Guar)-	540	540	9,000	7,200
3. Salt plugs------------	2,490	2,490	500	597,000
4. Water frac------------	180	180	9,000	2,400
Sub total (1-4)-------	23,430	33,860	26,000	156,000
Sub total (zones I and II)-------	46,860	67,720	52,000	156,000
TENSLEEP				
1. Acid, 15-percent HCl--	3,230	4,915	2,400	245,000
Plus mud and silt remover--------	200	200	-----	-------
Sub total-------------	3,430	5,115	2,400	245,000
2. Salt plugs------------	3,735	3,735	750	597,000
Sub total (1 and 2)---	7,165	8,850	3,150	337,000
Grand total-------------	54,025	76,570	55,150	167,000

discharge measurements. After about 1,700 minutes, the flow was approximately 200 gal/min, and contained about 2-percent foam. After about 2,850 minutes, final flow of clear fluid was greater than 180 gal/min, with a back pressure of 90 lb/in^2 (table 1). Samples of the flush-back fluid were collected periodically at the manifold, and onsite measurements for pH, specific conductance, and water temperature were made. The change in onsite specific conductance with time is shown in figure 8. Initial conductance values show the dilution effect of the final flush with fresh water after the acid had been injected. A maximum specific conductance of 110,000 μmhos (micromhos per centimeter at 25 degrees Celsius) was measured after 40 minutes. The specific conductance remained fairly constant for about 10 minutes, then decreased, with minor fluctuations, to 11,000 μmhos after 1,100 minutes. At the conclusion of the test, 2,860 minutes, the specific conductance was 4,800 μmhos or about 1,800 μmhos greater than the specific conductance of fluid from the interval before acidizing and fracturing. The temperature of the fluid at the end of the flow period was 55.7°C (degrees Celsius), whereas that from the pre-acidizing and fracturing flow was 38.4°C. Final shut-in pressure at the surface for the isolated interval after discharging an estimated 375,000 gal of fluid was 454 lb/in^2.

Characteristics of the flush-back fluid containing spent acid and other chemicals following test 2 were similar to those from test 1. The amount of foam produced with the liquid was equal to that of test 1; however, the percentage of foam decreased in a much shorter time. This probably was due to the greater flow rates. Flow during and near the end of the test was estimated at 200 gal/min with a back pressure of 110 lb/in^2 (table 1). The change in onsite specific conductance with time is shown in figure 9. A peak of 85,000 μmhos was measured after 22 minutes. This value decreased rapidly to 15,000 μmhos at 300 minutes. After 300 minutes, the slope of the curve was less steep, and at the end of the test, 2,068 minutes, the specific conductance was 4,700 μmhos, about 1,800 μmhos greater than the water flowing from the interval before acidizing and fracturing. The temperature of the fluid at the end of the flow period was 54.2°C, whereas that of the pre-acidizing and fracturing flow was 50.4°C. Final shut-in pressure at the surface after discharging an estimated 380,000 gal of fluid was also 454 lb/in^2.

The chemical analyses of flush-back fluid collected during test 2 were plotted to illustrate the relative changes in dissolved constituents during the test (fig. 10). The shapes of the curves are similar to the shape of the specific conductance graph (fig. 9). This graph also shows that the increase of reacting values of chloride and of calcium and magnesium were nearly equal. The reacting values of calcium and magnesium exceeded that for chloride by 20 to 30 meq/L (milliequivalent per liter) throughout most of the flush-back period; in the pretest analysis, calcium and magnesium exceeded chloride by 30 meq/L. The sulfate concentration remained almost constant throughout the flush-back period. The sodium and potassium was 31 meq/L in the first sample collected during the flush-back period, compared to a preacidation value of 5 meq/L. The last sample collected contained 6 meq/L.

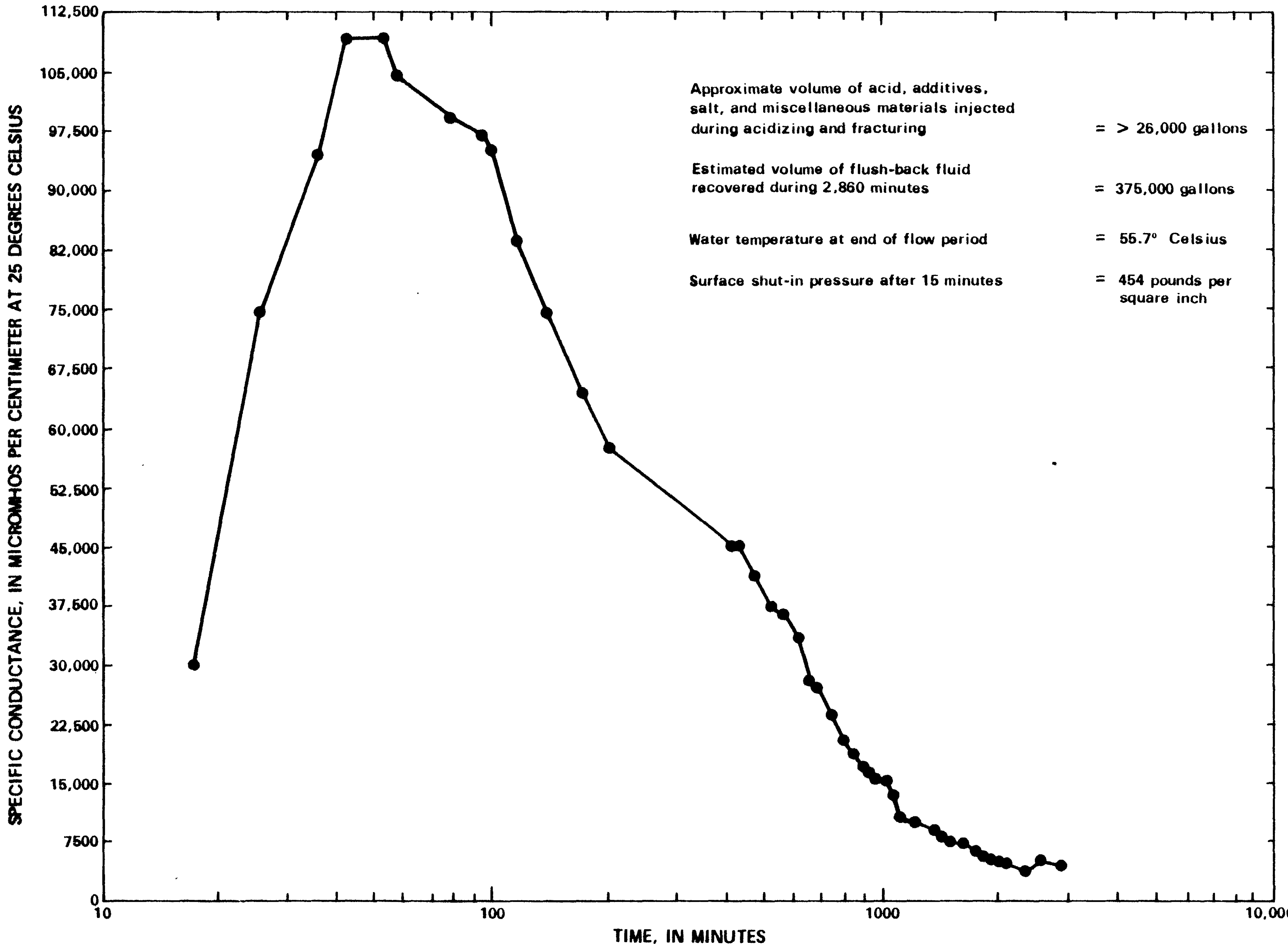


Figure 8.--Variation with time of specific conductance in the flush-back fluid after acidizing and fracturing test 1.

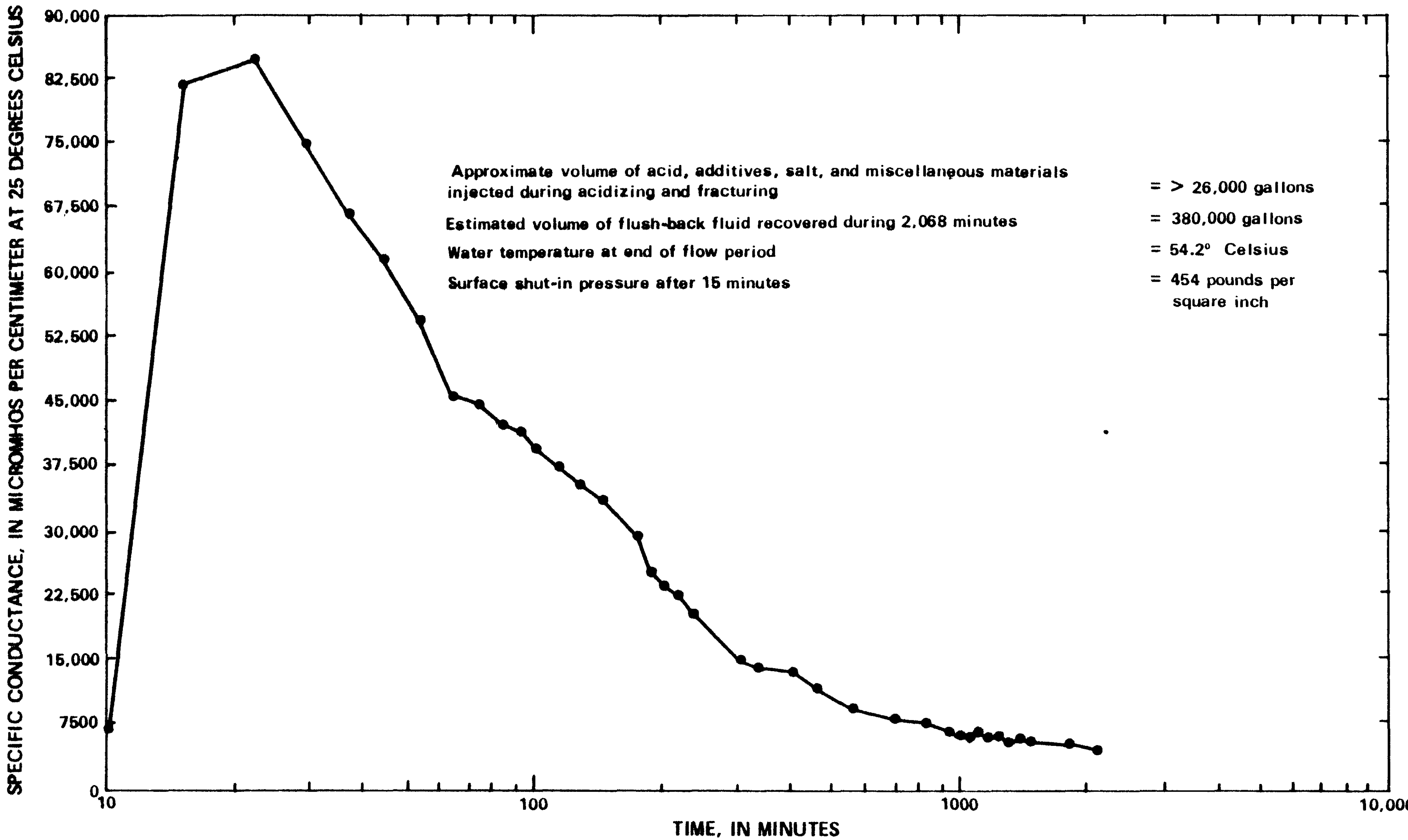


Figure 9.--Variation with time of specific conductance in the flush-back fluid after acidizing and fracturing test 2.

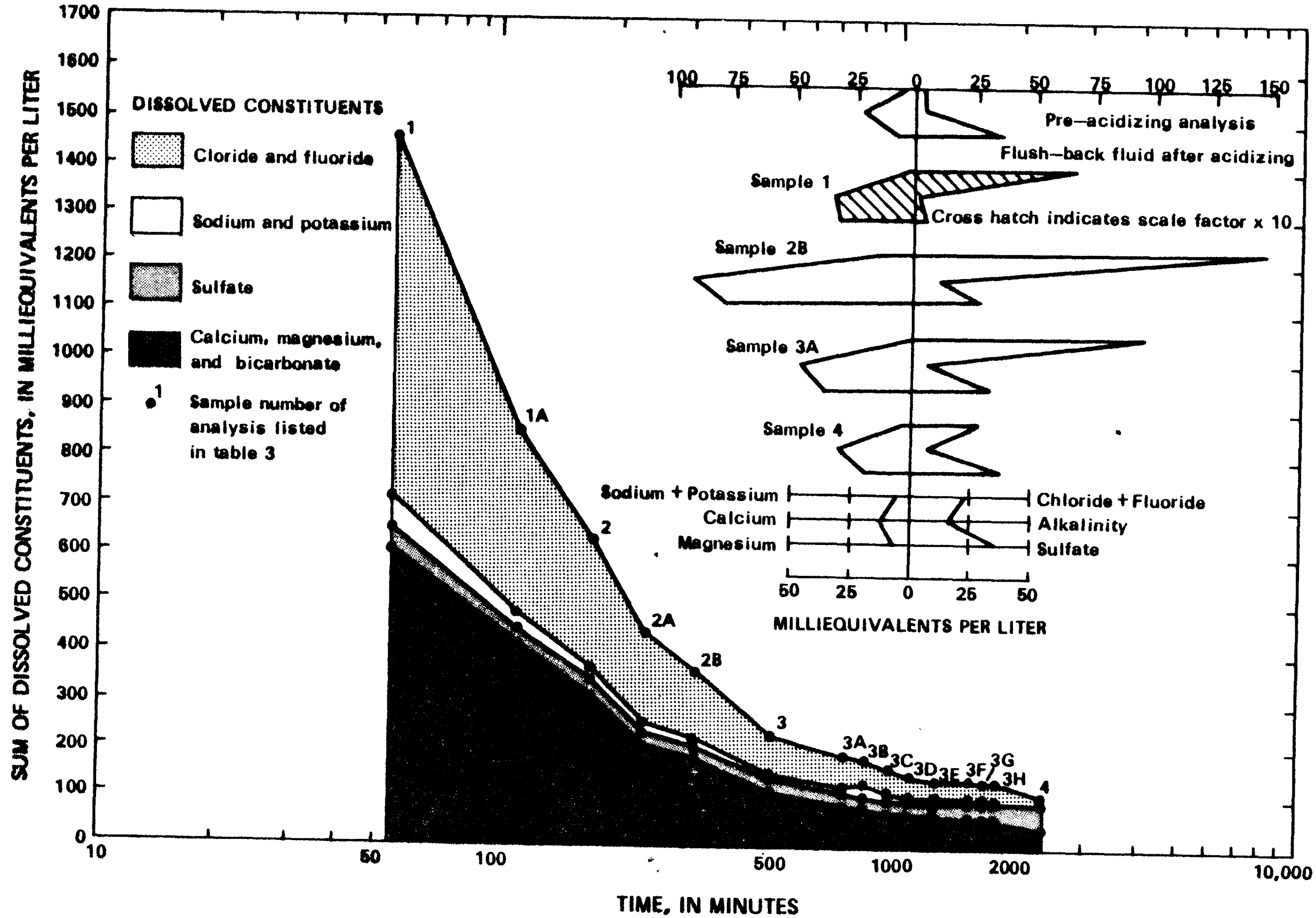


Figure 10.--Variations of dissolved constituents in the flush-back fluid after acidizing and fracturing test 2 and diagrams showing water-quality from the upper part of the Mission Canyon Limestone before and after acidizing.

The water-quality diagrams (fig. 10) also show the relative changes of various constituents with time during the flush-back period. They indicate that calcium, magnesium, and chloride did not return to equilibrium, but that the other constituents did.

The Amsden Formation and Tensleep Sandstone (test 3) were stimulated using different chemicals and techniques. The upper part of the Amsden is 100 percent dolomite, and the lower part of the Tensleep, the major aquifer of the two rock units, is more than 50 percent sandstone. If treated separately, the Amsden would have been stimulated using the same procedures as those in tests 1 and 2, and the Tensleep would have been stimulated using an acid-base mud and silt remover. Using 28-percent hydrochloric acid on the Tensleep would cause a problem if the sand were dislodged; the cementing material holding the grains of sand in place would be dissolved, and the sand grains could migrate.

The vertical distance between perforations in the upper part of the Amsden and those in the lower part of the Tensleep is only 6 ft. Even with a perfect cement bond between the casing and borehole, the distance between the sets of perforations is such that there probably would be hydrologic connection between the upper and lower perforations during the stimulation treatments. So, the Amsden and Tensleep were isolated and treated as a single unit (test 3). The method used was one designed to stimulate both sandstone and carbonate rocks.

The interval was stimulated by alternately pumping 600 gal of 15-percent acid-base mud and silt remover and 250 gal of salt plugs. The final acid stage was followed by flushing with fresh water. A total of 2,400 gal of mud and silt remover and 750 gal of salt plugs was injected. In excess of 1,000 gal of fresh water was used in the flush (table 2). The mud and silt remover is an acid-base well-treating solution that contains a clay dispersing and suspending agent and iron-chelating chemicals. The acid base was inhibited 15-percent hydrochloric acid. The composition of the salt plugs was similar to those used for tests 1 and 2.

The flush back of spent acid and other chemicals following test 3 differed from that of tests 1 and 2. The change in onsite specific conductance with time is shown in figure 11. A peak of 170,000 μmhos was measured after 11 minutes of flow. The specific conductance decreased rapidly to 8,000 μmhos at about 230 minutes. Thereafter, the decline was gradual to 3,200 μmhos at 635 minutes, and this value remained constant until the test was concluded after about 900 minutes of flow. Final specific conductance was about 300 μmhos greater than that from the interval before acidizing and fracturing. The final temperature was 53°C, whereas that prior to treatment was 50.3°C. Flow during and near the end of the test was about 150 gal/min with a back pressure of 90 lb/in^2 (table 1). Final shut-in pressure at the land surface after discharging about 140,000 gal of fluid was 454 lb/in^2.

Characteristics of the time and specific conductance graphs plotted from data collected during flush back of spent acid from tests 1 and 2 are similar

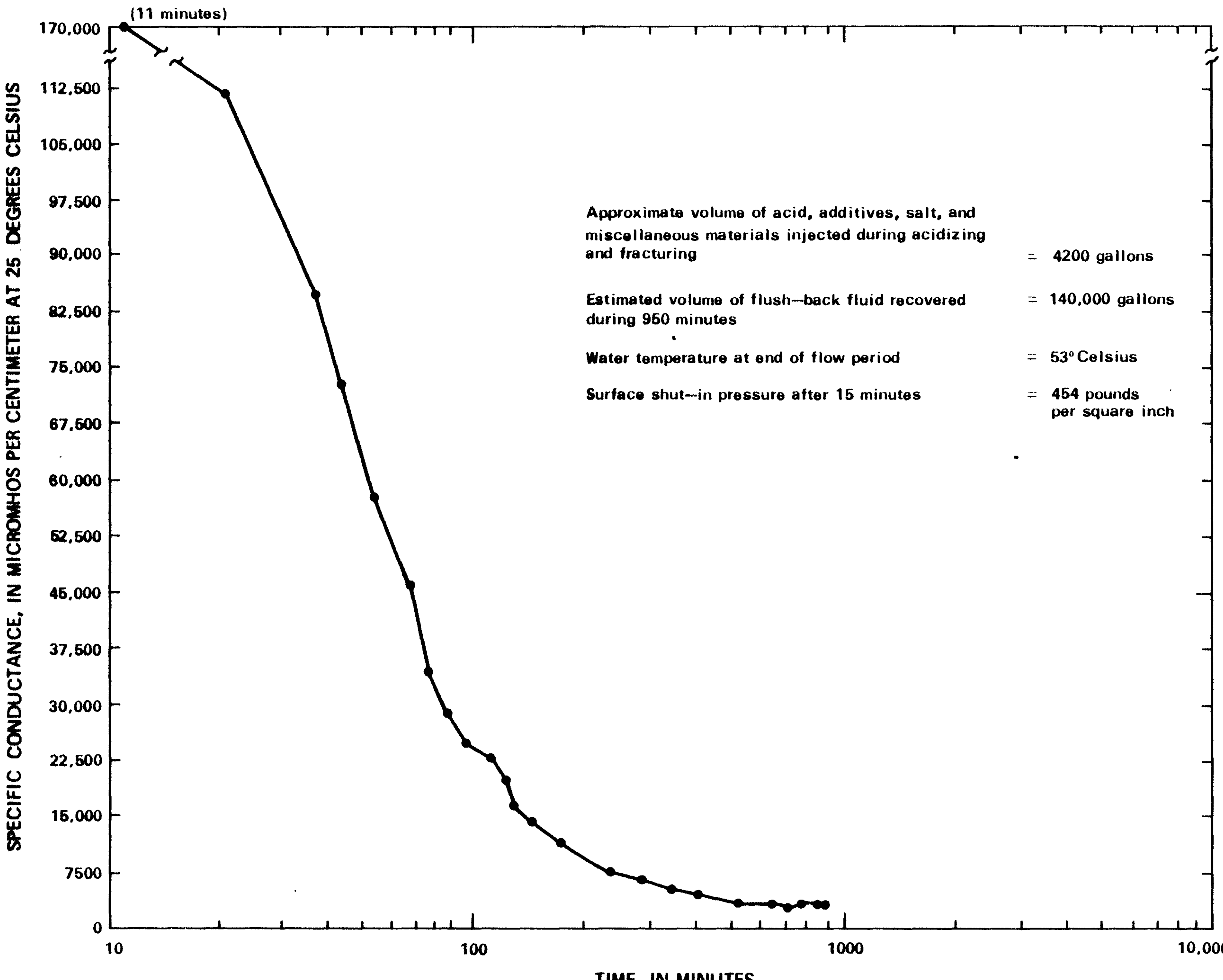


Figure 11.--Variations with time of specific conductance in the flush-back fluid after acidizing and fracturing test 3.

(figs. 8 and 9). The carbonate rocks isolated in these tests are similar (except for a greater percentage of limestone in test 1), and the acidizing and fracturing stimulation schedule was identical. The graph for test 3 (fig. 11) differs in many aspects. The peak of the specific conductance is greater, but the decrease in specific conductance to a value near that of the specific conductance of water from the untreated interval is more rapid. This is attributed to the different stimulation treatment used in test 3, mixed lithology (dolomite and sandstone), and less penetration of acid into the formation. Although initial injection pressures used in test 3 were adequate to open existing fractures or create new fractures; low-residue guar, propping agents (100-mesh sand), and other additives used in tests 1 and 2 were not used in test 3. The density of perforations in the Amsden Formation and Tensleep Sandstone may be considerably less than those in the Mission Canyon Limestone, because the charges in test 3 had to penetrate the 7-in and 9 5/8-in casings.

Deeper penetration of acid in tests 1 and 2 is indicated by the volume of flush-back fluid and the time required to stabilize specific conductance of the fluid to pre-acidizing and fracturing values. Estimated penetration of acid were about 600 ft for test 1 and about 500 ft for test 2, as determined by Dowell Division of Dow Chemical (U.S.A.) personnel using a computer program. These estimates, made before the acidizing and fracturing tests, were based on lithologic data, number of feet perforated, injection rate, and treatment schedule. No computer estimate was made for test 3.

The relative changes of the dissolved chemical constituents during the flush-back period of acidizing and fracturing test 3 are shown in figure 12. The shape of the curves are similar to the shape of the specific conductance curve. Samples 1 and 2 were plotted at a different scale in order to show the difference between the two samples; sample 2 also was plotted with the rest of the samples at the same scale on figure 10 so that they would be compatible.

The curves show that at the beginning of the test the reacting value of chloride was greater than the reacting values of calcium and magnesium by 50 percent, but after 100 minutes, they were nearly equal. During this flush-back period, the reacting values of sodium and potassium also were large, but decreased to near the pre-acidizing level before the end of the test; the pH also was minimal at the start of the flush-back period.

Radioactive-Tracer Surveys

Radioactive-tracer surveys were made with the well flowing at maximum capacity, before and after stimulation by acidizing and fracturing, to determine the effectiveness of the stimulation treatments on each of the perforated intervals. Background data on radioactive-tracer logs, techniques (time-drive and depth-drive), and general testing procedures are discussed by Blankennagel (1967 and 1968).

The tracer ejector tool electronically measures the travel time of radioactive-tracer material between gamma detectors of known spacing above

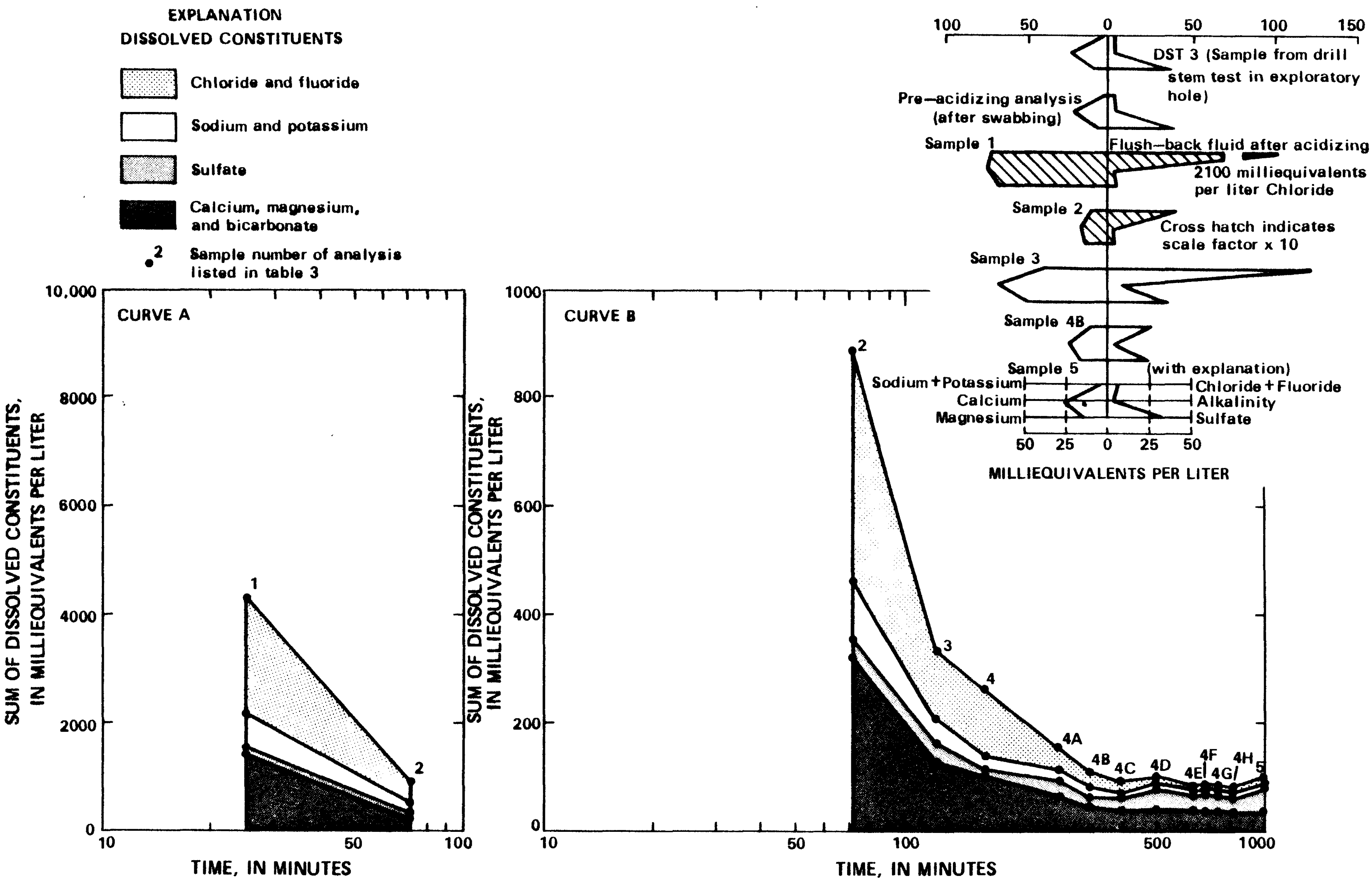


Figure 12.--Variations of dissolved constituents in the flush-back fluid after acidizing and fracturing test 3 and diagrams showing water-quality from the Tensleep Sandstone and Amsden Formation before and after acidizing.

an ejector. The tools used for each of the surveys (figs. 13 and 14) were identical, except for the distance between the detectors. The major differences in the surveys were in the electronics and surface-recording equipment. The equipment used for the first survey had been in operation since the 1960's. The detectors were connected to a single channel, and the peak (response) at each detector was recorded by a single pen on a paper recorder in time drive. The maximum gear speed for the paper recorder yielded markers at a scale of 1.3 in of logging paper for each minute (fig. 15). Because of slow flow rates in the untreated well, the peaks were adequately separated; and, using a Gerber Variable Scale, the time in minutes between peaks could be measured. Had the total flow rate in the well been two or three times greater, the peaks would have been superimposed, precluding any measurement.

After stimulation by acidizing and fracturing, when total flow increased about 22 times, a radioactive survey was made using a computerized logging truck. The peak at each detector was recorded on film on a separate channel. For very fast flow rates, the gear speed of the film recorder could be increased to expose 10 in of film every 6 seconds, or 100 in of film each minute. This recording speed yields excellent separation of sharp peaks at flow rates in excess of 3,500 gal/min, and accurate measurement of times less than 0.01 minute between peaks.

Iodine-131 was used as the radioactive tracer because it has a short half-life (7 days) and is miscible in water. The volume of tracer material ejected at each station was controlled at the surface. The average ejector release time was less than 1 second, ejecting less than 0.2 millicurie of iodine-131. The time-drive method was used with the tool stationary in the hole. Each station was tested at least two times, and the flow recorded at that station was the average of the flows. Repeatability of flow measurements was within 96 to 100 percent. Such excellent results usually are not common in open-hole testing because of hole rugosity and possible shifting of the tool. The depth for each station was from land surface to the lower detector.

A depth-drive radioactive-tracer survey under static conditions (no flow of water from well), using a lubricator bolted on the blow-out preventer, was made to investigate possible cross flow between perforations in the untreated well. Results showed little or no movement of water in the well, probably because of similar hydraulic heads in each of the perforated intervals.

Spinner surveys were conducted during early episodes of logging. Results were disappointing, and under slow flow rates, the log could not be interpreted. Better results probably could have been obtained with a tool having a larger diameter impeller, or if the surveys had been made during the final period of the flows. However, based on previous experience, more accurate flow rates can be obtained from radioactive-tracer surveys.

The yield of water from each isolated interval before and after stimulation by acidizing and fracturing through perforations is shown in

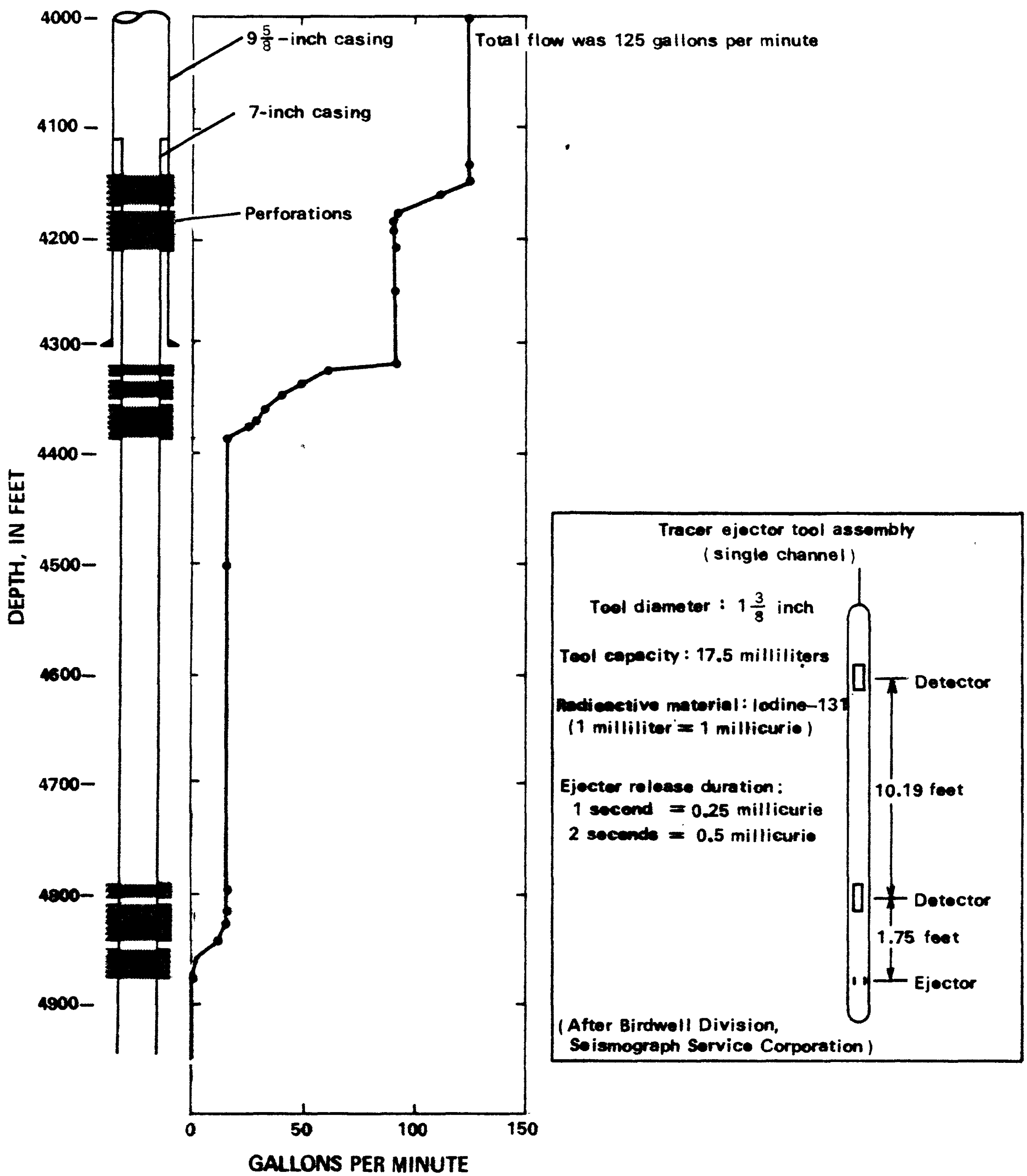


Figure 13.--Radioactive-tracer survey after development of perforated intervals before acidizing and fracturing.

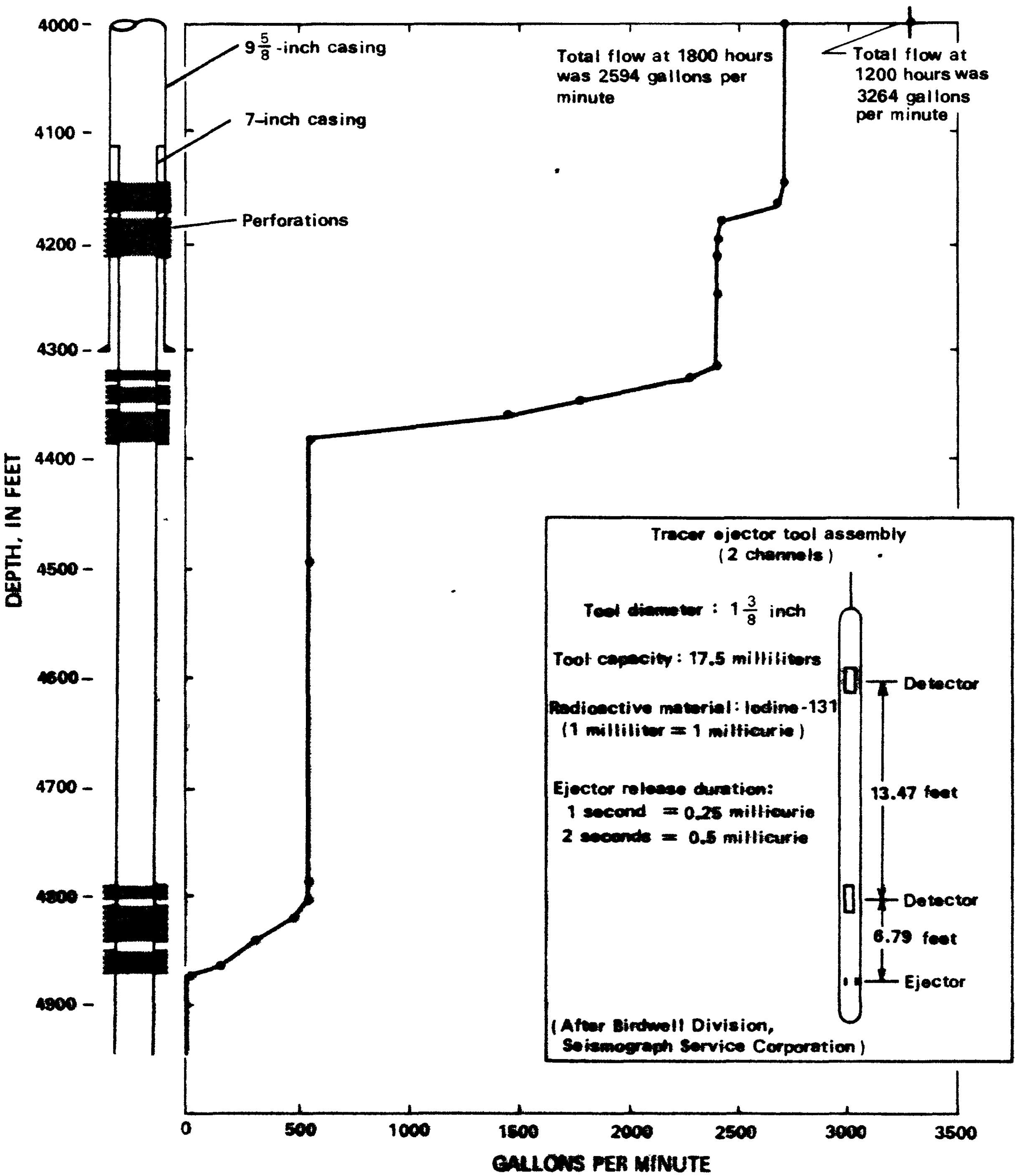
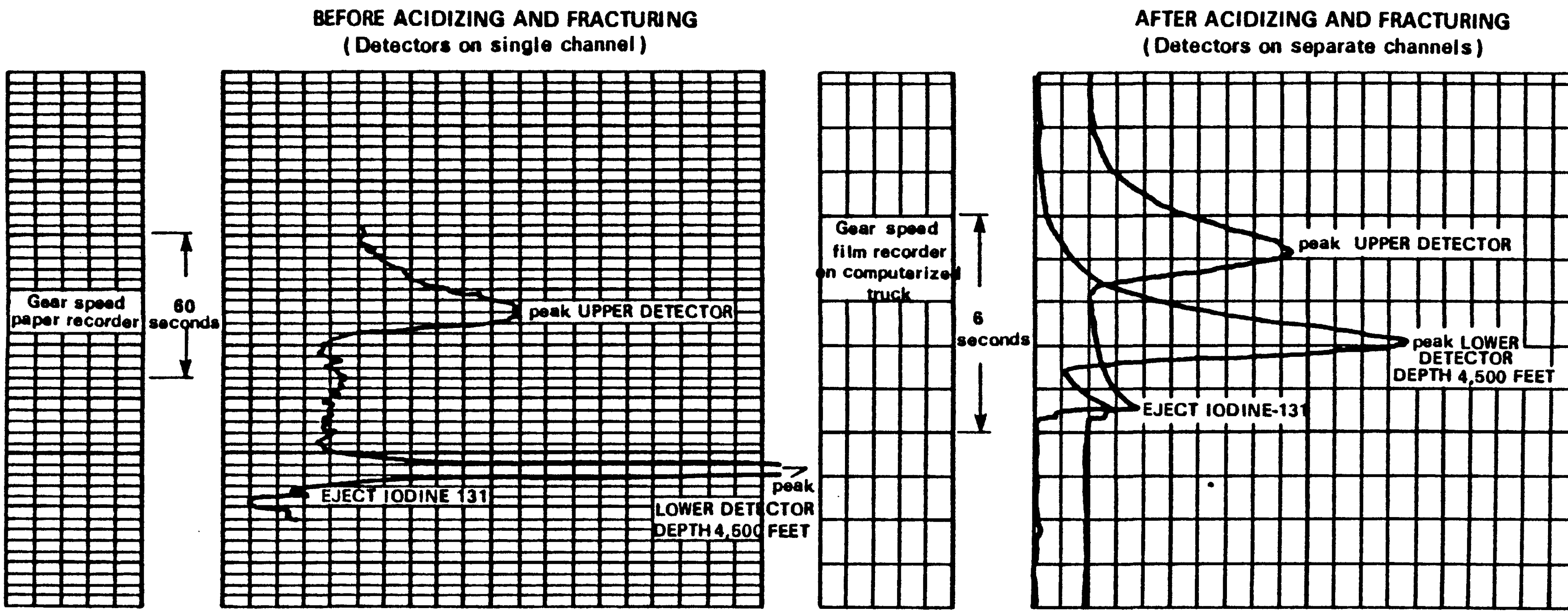


Figure 14.--Radioactive-tracer survey after acidizing and fracturing through perforated intervals.



Time drive method

$$\frac{*\,10.19}{1.10} = 9.26 \text{ feet per minute}$$

$9.26 \times 1.65 = 15.3$ gallons per minute

$$\frac{\text{distance, in feet, between detectors}}{\text{time, in minutes, between peaks}} = \text{velocity, in feet per minute}$$

$$\left(\begin{array}{c}\text{velocity, in}\\ \text{feet per minute}\end{array}\right)\left(\begin{array}{c}\text{volume of casing,}\\ \text{in gallons per linear foot}\end{array}\right) = \begin{array}{c}\text{flow rate, in gallons}\\ \text{per minute}\end{array}$$

$$\frac{*\,13.47}{0.04} = 336.75 \text{ feet per minute}$$

$336.75 \times 1.65 = 555.6$ gallons per minute

(Average of repeat stations was 545 gallons per minute)

(* see figures 13 and 14 for tool assembly)

Figure 15.--Radioactive-tracer survey in 7-inch casing (6.366-inch ID) before and after acidizing and fracturing perforated intervals 4,872 to 4,849, 4,841 to 4,809, and 4,803 to 4,791 feet. Station depth 4,500 feet.

table 1. Contributions from specific sets of perforations are shown in figures 13 and 14. The distance between stations positioned in perforated intervals generally is equal to the distance between the detectors of the tool that was used. Deviations from this general rule are not uncommon, and are the result of decisions made in the logging truck after a cursory review of the data at each station.

The most significant increase in water production after stimulation by acidizing and fracturing was from the lower part of the Mission Canyon Limestone. The least increase was from the Amsden Formation. No production was obtained through perforations from 4,212 to 4,182 ft either before treatment or after. Improvement did occur, however, through the perforations between 4,170 to 4,157 ft, where production increased from 29 to 264 gal/min. Prior to treatment, the Amsden-Tensleep yielded 33 gal/min, and after acidizing and fracturing it yielded 311 gal/min. This increased production probably occurs at or near the contact of the Amsden Formation and Tensleep Sandstone, logged at 4,162 ft. Prior to treatment, the lower part of the Mission Canyon yielded 15 gal/min, and after acidizing and fracturing, it yielded 545 gal/min.

After a prolonged shut-in period and prior to the radioactive-tracer surveys, initial flow from the treated well was greater than stabilized flow after 4 or more hours. As shown in figure 14, total flow, measured in the 9-5/8-in casing at 1200 hours was 3,264 gal/min, a rate that was confirmed by a pigmy current meter measurement made in a trench at the end of a reserve pit. Radioactive-tracer surveys, beginning above the lower set of perforations in the 7-in casing and progressing downward, were started about 4 hours after the large initial total flow measurements. This delay was caused by turbulence at the juncture of the 7-in and 9-5/8-in casings, which, in turn, resulted in misalinement of the light-weight tool and impeded its entrance into the 7-in casing. Modifications to the tool were time-consuming; however, the time loss was beneficial, in that the flow in the well was more stable. Final flow at the end of the survey was 2,694 gal/min.

If surveys were made immediately after the well was opened, and after 12 hours of uninterrupted flow, intervals where total initial production was not sustained could be clearly defined. For reasons stated before (under the heading, Acidizing and Fracturing), it is likely that the loss in production occurs in the Amsden Formation and Tensleep Sandstone.

Based on estimates of acid penetration in the Mission Canyon Limestone, and the amount of fracturing seen in cores cut through the intervals that were perforated, it is probable that production would be sustained. It is also probable that new permeability paths were developed and interconnected. A prolonged flow test, about 2 weeks, would be required to determine the length of time that total production of 2,900 gal/min could be sustained.

Step-Drawdown Test

On October 31 and November 1, 1979, a step-drawdown test, consisting of eight flow rates, was made of the well to determine well and aquifer response and hydrologic characteristics. A schematic diagram of the well head and flow line are shown in figure 16. The duration of each step of the flow test was 120 minutes. Shut-in pressure and back pressure were measured at two points at the well head; also measured at the well head were temperature (certified mercury thermometers in overlapping 20°C ranges reading to 0.05°C and a digital thermometer meter accurate to 0.5°C) and specific conductance. Flow measurements were made, as appropriate, in three ways: (1) A Haliburton electrically-powered in-line flow meter near the well head; (2) volumetrically, using 10- and 20-gallon containers; and (3) the trajectory method. Measurements used in analysis are given in supplemental information at the end of this report. Vibration caused by flow of water through the open 8-in gate valve made it difficult to obtain accurate readings from the pressure gages on steps 4 to 7. Gage-needle oscillations ranged from ±10 lb/in^2 on step 4 to greater than ±20 lb/in^2 on step 7.

Hydraulic-head measurements were corrected for the effects of temperature changes on fluid density. The need for such corrections is obvious from the data for step 1 (see supplemental information). During this flow step, temperature at the measuring point increased from 12 to 27°C, and the back pressure increased from 446 to 451 lb/in^2. The temperature at the top perforation (depth of 4,145 ft) was estimated as 65.6°C from the temperature logs. A linear approximation, based on this temperature and depth, was used to correct the hydraulic-head measurements.

As performance of the test well was crucial to evaluation of aquifer characteristics, hydraulic-head losses and well efficiency were calculated by the Rorabaugh (1953) modification of Jacob's (1947) method. The resulting equation, $s_w = 28\ Q_n + 38.5\ Q_n^{1.67}$ (where, for each step, s_w = drawdown in the well in feet, and Q_n = pumping rate, in cubic feet per second), predicted drawdowns at the end of each step ranging from -6 to +1.2 percent of the values measured; for 4 of the 8 steps, computed values were within ±0.05 percent of measured values. The results of this analysis, plus other data and the results of other calculations relating to hydraulic-head loss, are shown in table 5. The results of the Jacob-Rorabaugh method appear reasonable and were assumed to be correct in subsequent analysis.

Hydraulic-head losses caused by turbulent flow in the casing (including the affect of the enlargement from 7- to 9-5/8-in casing) also are shown in table 5. Hydraulic-head losses in the aquifer due to turbulent flow are less than 0.1 ft even at a flow rate of 2,900 gal/min, a hydraulic-head loss that is less than the accuracy of hydraulic-head measurement. For all practical purposes, all turbulent-flow hydraulic-head loss is in flow through the perforations and up the casing. Of the turbulent-flow hydraulic-head losses, losses from flow through the perforations ranged from 84 percent for step 1 to 54 percent for step 8, and the hydraulic-head loss up the casing ranged from 16 percent for step 1 to 46 percent for step 8.

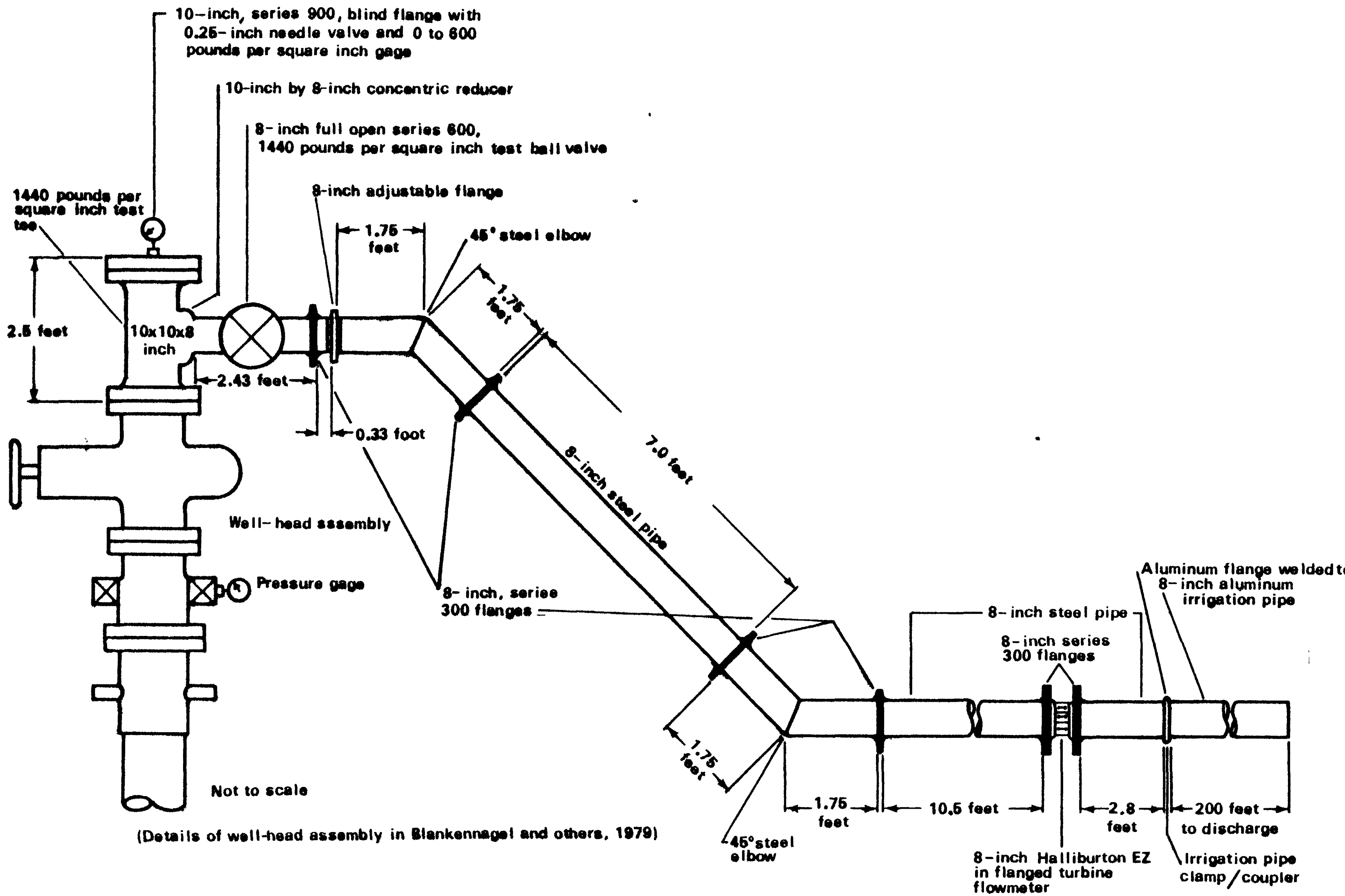


Figure 16.--Schematic diagram of well head and flow line during full-flow and step-drawdown tests.

Table 5.--*Step-drawdown test--comparison of measured drawdowns with those predicted by the Jacob-Rorabaugh and the Birsoy and Summers methods, and with pipe-friction calculations*

[gal/min = gallons per minute; ft = feet]

Test step	Step flow (gal/min)	Measured[1] drawdown (ft)	Drawdown predicted by the Jacob-Rorabaugh method: Laminar flow loss in the aquifer (ft)	Drawdown predicted by the Jacob-Rorabaugh method: Turbulent flow loss in the aquifer and well (ft)	Drawdown predicted by the Jacob-Rorabaugh method: Total predicted drawdown (ft)	Drawdown predicted by the Birsoy and Summers method: Laminar flow loss in the aquifer (ft)	Drawdown predicted by the Birsoy and Summers method: Turbulent flow loss in the aquifer and well (ft)	Drawdown predicted by the Birsoy and Summers method: Total predicted drawdown (ft)	Hydraulic-head loss[2] in flow in the well (ft)	Hydraulic-head loss[3] from turbulent flow in the well perforations (ft)
1	33.3	2.59	2.08	0.50	2.58	1.39	1.15	2.54	0.08	0.42
2	164.1	17.9	10.2	7.14	17.4	4.04	13.6	17.7	1.66	5.48
3	519	86.4	32.3	48.9	81.2	4.08	81.7	85.8	14.2	34.6
4	1,049	219.5	65.0	157.2	222.2	-24.8	242.6	217.9	54.3	102.9
5	1,700	460.9	105.8	354.4	460.1	-65.8	517.1	451.3	140.3	214.1
6	2,220	679.8	136.9	545.1	681.9	-107.1	772.1	664.9	231.8	313.3
7	2,670	903.3	165.5	748.4	913.9	-145.0	1,037.3	892.3	336.5	411,9
8	2,900	1,044.5	180.4	864.6	1,045.0	-142.4	1,186.4	1,044.0	397.3	467.3

[1]Corrected for temperature.

[2]Includes pipe friction losses in the 7-in and 9 5/8-in casing and from the enlargement between the casings.

[3]Assumes that the turbulent-flow head loss calculated by the Jacob-Rorabaugh method is correct.

Of the total hydraulic-head loss measured, 81 percent of the drawdown in step 1 was caused by laminar-flow losses in the formation, and 19 percent was caused by turbulent-flow losses in the well. Thus, well efficiency for this step was 81 percent. For step 8, 17 percent of the drawdown was caused by laminar-flow losses in the formation, and 83 percent was caused by well losses. Well efficiency for this step was 17 percent.

Another approach to calculating hydraulic-head losses and well efficiency is that of Birsoy and Summers (1980). This approach, though related to that of Jacob and Rorabaugh, appears to be based on evaluation of empirical data. The equation developed for the Madison 3 step-drawdown test by this method is $s_w = BQ_n + 0.0049\ Q_n^{1.55}$ (where s_w = feet of drawdown at the end of a step, Q_n = flow, in gallons per minute, for any step n, and B is a constant). This equation predicted drawdown at the end of each step with an accuracy of -0.05 to -2 percent of the measured values. The equation can be modified to predict drawdowns at any time within a given step. Although the equation can predict total drawdown with reasonable accuracy, it cannot be used to differentiate hydraulic-head losses caused by laminar and turbulent flow because: (1) The "constant" B has a value that varied from step to step and, (2) for several steps, B was negative, which indicates a hydraulic-head gain, rather than a hydraulic-head loss, from laminar flow in the aquifer. The most likely reason for these results is that one or more of the basic assumptions of the method are not met.

Transmissivity (T) was calculated by the specific capacity method (Brown, 1963), by a method developed by Birsoy and Summers (1980), and by a method developed by Stallman (1962). For the first two methods, transmissivity was determined both with the "raw" data (corrected for temperature affects), and with drawdowns corrected to a "100 percent efficient" well. The third method was used only with data corrected for a "100 percent efficient" well. The turbulent hydraulic-head loss calculated by the Jacob-Rorabaugh method was used to correct the drawdowns for a "100 percent efficient" well. The results are shown in table 6. For the specific capacity method, the average transmissivity is 1,740 ft^2/d if the coefficient of storage (S) is 2×10^{-5} for the "raw" data or 5,090 ft^2/d for a "100 percent efficient" well. The Birsoy and Summers method gave an average transmissivity of 5,760 ft^2/d for the "raw" data, and a transmissivity of 5,090 ft^2/d and a coefficient of storage of about 2×10^{-6} for the "100 percent efficient" well. The Stallman method gave a transmissivity of 5,090 ft^2/d and a coefficient of storage of about 4×10^{-5} for a "100 percent efficient" well. The values of transmissivity and coefficient of storage considered as most reasonably representing this test are 5,090 ft^2/d and 2×10^{-5} respectively.

A full-flow (constant-head variable-discharge) test of 24-hour duration was made prior to the step-drawdown test. Preliminary analysis of data from the full-flow test (Jacob and Lohman, 1952) resulted in transmissivities of 1,460 ft^2/d, uncorrected for well losses, and 8,040 ft^2/d for a "100 percent efficient" well. Pressure measurements were obtained during well recovery, but the data were not suitable for analysis.

Table 6.--*Step-drawdown test--aquifer transmissivity (T) and coefficient of storage (S) determined by the specific capacity and the Birsoy and Summers methods*

[gal/min = gallons per minute; (gal/min)/ft = gallons per minute per foot of drawdown; ft^2/d = feet squared per day]

Test site	Flow (gal/min)	Drawdowns corrected for temperature: Specific capacity [(gal/min)/ft]	Specific-capacity method: T_1 (ft^2/d) S assumed $2X10^{-4}$	T_2 (ft^2/d) S assumed $2X10^{-5}$	T_3 (ft^2/d) S assumed $2X10^{-6}$	Birsoy and Summer's method[1]: T (ft^2/d)	Drawdowns corrected for temperature and for a "100 percent efficient" well: Specific capacity [(gal/min)/ft]	Specific-capacity method: T_1 (ft^2/d) S assumed $2X10^{-4}$	T_2 (ft^2/d) S assumed $2X10^{-5}$	T_3 (ft^2/d) S assumed $2X10^{-6}$	Birsoy and Summer's method: T (ft^2/d)	S
1	33.3	12.9	3,350	4,020	4,489	3,537	16.03	4,489	5,051	5,534	3,886	$1.6X10^{-2}$
2	164.1	9.17	2,546	2,867	3,189	3,725	15.20	4,355	4,703	5,346	3,162	$8.4X10^{-2}$
3	519	6.01	1,608	1,809	2,010	7,865	13.84	3,886	4,355	4,850	7,691	---
4	1,049	4.78	1,313	1,380	1,608	11,792	16.78	4,730	5,427	5,963	10,720	---
5	1,700	3.69	1,045	1,179	1,313	3,725	15.97	4,596	5,132	5,762	3,886	$2.2X10^{-2}$
6	2,220	3.27	884	1,018	1,085	4,422	16.34	4,757	5,360	5,949	3,805	$6.2X10^{-2}$
7	2,670	2.96	804	911	1,005	5,534	17.18	5,025	5,708	6,298	5,132	$1.2X10^{-3}$
8	2,900	2.78	737	871	938	----	16.13	4,690	5,400	5,949	---	---
Average-------		5.69	1,527	1,755	1,956	5,788	15.93	4,569	5,145	5,708	5,132	$1.9X10^{-6}$

[1]As T's are calculated from the slopes of the adjusted T curves, an average can be calculated by averaging the slopes of the curves; slope of curve for step 8 is 0. By plotting the curve of average slope through the last point of step 8, T can be found for $s/Q_n = 0$.

SUMMARY AND CONCLUSIONS

Analyses of water samples, collected from drill-stem tests made in Madison Limestone test well 3 during September and November 1978, showed that water having dissolved-solids concentrations of 3,000 mg/L or less was available only from the lower and upper parts of the Mission Canyon Limestone, and the Amsden Formation and Tensleep Sandstone. Two intervals in the upper part of Mission Canyon Limestone were perforated during testing of the exploratory well. Other water-bearing zones were not perforated because of bridges and other obstructions in the casings.

During July 1979, workover operations were begun to complete the well. Primary objectives of the workover operations were to clean the cased hole, to complete perforating of selected intervals, and to conduct various hydrologic tests before and after stimulation of the well by acidizing and fracturing.

Geophysical logs, which included temperature, six-arm caliper, seisviewer, and pressure tests, indicated breaks in the 13-3/8-in casing near 350 ft, and leakage around the 9-5/8-in liner hanger at 810 ft. These leaks enabled cement rubble and rock debris behind the casing to slough into the hole and create bridges and plugs. The problem was corrected by extending the 9-5/8-in casing to land surface, and then bonding the 13-3/8-in and 9-5/8-in casings with cement.

Selected intervals in the lower and upper parts of the Mission Canyon Limestone were perforated through the 7-in casing between depths of 4,872 to 4,791 ft and 4,361 to 4,318 ft. The Amsden Formation and Tensleep Sandstone were perforated through two casings, 7 in and 9-5/8 in, in the intervals 4,212 to 4,176 ft and 4,170 to 4,145 ft. Total net perforated footage, which included that completed during December 1978, was 185 ft and had 740 perforations.

Hydrologic tests were made of the perforated intervals. Perforated intervals in the lower part of the Mission Canyon Limestone were tested as a single unit (test 1), as were those in the upper part (test 2). The Amsden Formation and Tensleep Sandstone were tested as one unit (test 3).

Each of the units was isolated by using a retrievable bridge plug and packer in combination run on 2-7/8-in tubing. Each of the isolated units was developed by swabbing and then flowing. Flow periods for the tests were extended to permit collection of water samples representative of aquifer water.

Total flow from all perforated intervals, calculated from radioactive-tracer survey data, was 125 gal/min. Of this total, the lower part of the Mission Canyon contributed 15 gal/min, the upper part contributed 77 gal/min, and the Amsden-Tensleep contributed 33 gal/min.

Final shut-in pressures were measured at the end of flow periods. Shut-in pressure for the lower part of the Mission Canyon Limestone was

451 lb/in^2, and those for the upper part of the Mission Canyon Limestone and the Amsden Formation and Tensleep Sandstone were 454 lb/in^2.

Each of the three intervals developed and tested again was isolated and stimulated by acidizing and fracturing. The lower and upper parts of the Mission Canyon Limestone were stimulated with similar acidizing and fracturing treatments. Fluids and propping material, pumped under pressure into each isolated interval, consisted of 7,500 gal of 28 percent hydrochloric acid, 9,000 gal of complex low-residue guar (cross linked), 9,000 gal of low-residue guar (not cross linked), 500 gal of salt plugs, and 12,000 lb of 100-mesh sand.

The Amsden Formation and Tensleep Sandstone were stimulated using different chemicals and techniques, because the lower part of the Tensleep, the major aquifer of the two rock units, consisted of more than 50-percent sandstone. The interval was treated by alternately pumping 600 gal of 15-percent acid-base (hydrochloric) mud and silt remover, and 250 gal of salt plugs. A total of 2,400 gal of mud and silt remover and 750 gal of salt plugs was injected.

Total flow from all perforated intervals, calculated from radio-active-tracer survey data, was 2,694 gal/min. Of this total, the lower part of the Mission Canyon contributed 545 gal/min, the upper part contributed 1,838 gal/min, and the Amsden-Tensleep contributed 311 gal/min.

Full-flow (constant-head variable-discharge) and step-drawdown tests were performed approximately 1 month after well completion. The most reasonable values of transmissivity and coefficient of storage, based on interpretation of data from the step-drawdown test, are 5,090 ft^2/d and 2 X 10^{-5} respectively. Maximum flow, after 24 hours of full flow, was 2,900 gal/min.

The primary purpose of acidizing and fracturing is to increase productivity beyond natural reservoir capability. This may be achieved by opening and extending existing fractures, and creating new fractures to open new permeability paths, interconnect existing permeability zones, or break into an untapped portion of the reservoir. The significant increase in water production from each interval that was treated showed that the primary purpose was achieved.

Based on computer estimates of acid penetration in the Mission Canyon Limestone, and the amount of fracturing seen in cores cut through the intervals that were perforated, it is probable that production of the well could be sustained. However, a prolonged flow test of approximately 2 weeks would be required to determine the length of time that total production of 2,900 gal/min could be sustained.

The transfer value of the acidizing and fracturing schedule (as used in Madison Limestone test well 3) for holes drilled in other areas having similar rock types and structure is apparent. Although the increase in production may not be as great as that of the Madison well, it probably would be sufficient to justify the expense of a stimulation treatment.

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SUPPLEMENTAL INFORMATION

Table 7.--*Data from full-flow test of Madison Limestone test well 3, October 25-26, 1979*

[min = minutes; in = inches; gal/min = gallons per minute; lb/in^2 = pounds per square inch; °C = degrees Celsius]

Date	Clock time (24 hours)	Elapsed time (min)	Trajectory (in)	Yield (gal/min)	Pressure (lb/in^2)	Temperature (°C)
10-25-79	0915	0	-----	----	449	15.2
	0916	1	68.25	3460	26	16.3
	0917	2	65.50	3320	23.5	23
	0918	3	63.75	3240	22.5	45
	0919	4	61.25	3110	22	----
	0920	5	61.50	3120	22	50
	0921	6	62.88	3190	22	----
	0922	7	63.25	3210	22.5	----
	0923	8	61.75	3130	21.5	----
	0924	9	61.00	3100	21	----
	0925	10	60.88	3090	21	----
	0926	11	60.00	3050	20.5	----
	0927	12	66.75	3390	20.5	----
	0928	13	63.25	3210	20.5	----
	0929	14	63.00	3200	20.5	----
	0930	15	61.63	3130	20.5	----
	0932	17	62.38	3170	20.5	----
	0934	19	61.75	3130	20.4	----
	0936	21	61.25	3110	20.3	----

Table 7.--*Data from full-flow test of Madison Limestone test well 3, October 25-26, 1979*--Continued

Date	Clock time (24 hours)	Elapsed time (min)	Trajectory (in)	Yield (gal/min)	Pressure (lb/in^2)	Temperature (°C)
10-25-79	0938	23	60.88	3090	20.1	----
	0940	25	61.00	3100	20	----
	0942	27	61.00	3100	20	----
	0944	29	61.38	3120	20	----
	0946	31	61.13	3100	20	----
	0949	34	60.88	3090	20	----
	0952	37	62.00	3150	20	----
	0955	40	60.63	3080	20	----
	0958	43	60.38	3060	20	----
	1001	46	60.13	3050	20	----
	1005	50	59.88	3040	20	----
	1010	55	59.56	3020	20	----
	1015	60	59.75	3030	20	----
	1020	65	60.00	3050	20	----
	1025	70	61.13	3100	20	----
	1030	75	60.00	3050	20	----
	1035	80	59.75	3030	20	----
	1045	90	60.00	3050	20	----

Table 7.--*Data from full-flow test of Madison Limestone test well 3, October 25-26, 1979*--Continued

Date	Clock time (24 hours)	Elapsed time (min)	Trajectory (in)	Yield (gal/min)	Pressure (lb/in^2)	Temperature (°C)
10-25-79	1055	100	59.63	3030	20	----
	1105	110	59.25	3010	20	----
	1115	120	59.38	3010	20	----
	1125	130	59.13	3000	20	----
	1135	140	59.25	3010	20	----
	1150	155	59.38	3010	20	----
	1205	170	59.63	3030	20	----
	1220	185	59.00	2990	20	----
	1255	220	-----	----	20	56.4
	1302	227	58.75	2980	20	----
	1305	230	-----	----	20	56.4
	1315	240	58.75	2980	20	56.3
	1330	255	58.50	2970	20	56.3
	1345	270	-----	----	20	56.3
	1400	285	58.25	2960	20	56.3
	1415	300	58.50	2970	20	56.3
	1430	315	-----	----	20	56.3
	1442	327	58.00	2940	20	----
	1445	330	-----	----	20	56.3
	1515	360	57.50	2920	20	56.3

Table 7.--*Data from full-flow test of Madison Limestone test well 3, October 25-26, 1979*--Continued

Date	Clock time (24 hours)	Elapsed time (min)	Trajectory (in)	Yield (gal/min)	Pressure (lb/in^2)	Temperature (°C)
10-25-79	1545	390	58.00	2940	20	56.5
	1610	415	-----	----	20	56.6
	1615	420	57.50	2920	20	----
	1630	435	-----	----	20	56.5
	1645	450	57.50	2920	20	----
	1700	465	-----	----	20	56.5
	1715	480	57.25	2910	20	----
	1743	508	-----	----	20	56.5
	1800	525	56.75	2880	20	----
	1835	560	-----	----	20	56.4
	1903	588	56.75	2880	20	----
	1935	620	-----	----	20	56.3
	2000	645	57.00	2890	20	----
	2039	684	-----	----	20	56.3
	2055	700	56.75	2880	20	----
	2200	765	57.25	2910	20	56.4
	2300	825	57.13	2900	20	56.3

Table 7.--*Data from full-flow test of Madison Limestone test well 3, October 25-26, 1979*--Continued

Date	Clock time (24 hours)	Elapsed time (min)	Trajectory (in)	Yield (gal/min)	Pressure (lb/in^2)	Temperature (°C)
10-25-79	2400	885	57.00	2890	20	56.4
10-26-79	0100	945	57.00	2890	20	56.2
	0200	1005	57.00	2890	20	56.2
	0300	1065	57.00	2890	20	56.3
	0400	1125	57.00	2890	20	56.1
	0500	1185	56.75	2880	20	56.1
	0600	1245	57.00	2890	20	55.5
	0700	1305	57.00	2890	20	55.3
	0800	1365	57.00	2890	20	55.3
	0900	1425	57.00	2890	20	55.8

Table 8.--*Yields, flowing pressures, and temperatures for Madison Limestone test well 3, step-drawdown test--step 1, October 31-November 1, 1979*

[min = minutes; in = inches; gal/min = gallons per minute; lb/in^2 = pounds per square inch; °C = degrees Celsius]

Observation number	Clock time (24 hours)	Cumulative time: This step (min)	Cumulative time: Total test (min)	Discharge data: Trajectory (in)	Discharge data: Free board (in)	Discharge data: Yield (gal/min)	Flowing pressure (lb/in^2)	Temperature (°C)
	1030	0	0	-----	----	----	446	12.3
1	1031	1	1	-----	----	----	445.5	12.0
2	1032	2	2	-----	----	----	445.5	14.0
3	1033	3	3	-----	----	----	445.5	16.0
4	1034	4	4	-----	----	----	446.0	18.5
5	1035	5	5	-----	----	----	446.0	19.6
6	1036	6	6	-----	----	----	446.0	20.2
7	1037	7	7	-----	----	----	446.0	20.8
8	1038	8	8	-----	----	----	446.0	21.1
9	1039	9	9	-----	----	----	446.0	21.5
10	1040	10	10	3.75	6.75	19.8	446.0	22.0
11	1041	11	11	4.75	6.50	31.8	446.0	22.0
12	1042	12	12	5.00	6.50	33.5	446.0	22.1

Table 8.--*Yields, flowing pressures, and temperatures for Madison Limestone test well 3, step-drawdown test--step 1, October 31-November 1, 1979*--Continued

Observation number	Clock time (24 hours)	Cumulative time: This step (min)	Cumulative time: Total test (min)	Discharge data: Trajectory (in)	Discharge data: Free board (in)	Discharge data: Yield (gal/min)	Flowing pressure (lb/in^2)	Temperature (°C)
13	1043	13	13	4.75	6.50	31.8	446.0	22.4
14	1044	14	14	5.00	6.50	33.5	446.0	22.5
15	1045	15	15	5.00	6.50	33.5	446.0	22.7
16	1046	16	16	4.875	6.375	35.1	446.0	22.7
17	1047	17	17	4.875	6.50	32.7	446.0	22.7
18	1048	18	18	5.00	6.50	33.5	446.0	22.7
19	1049	19	19	5.00	6.50	33.5	446.5	22.7
20	1050	20	20	5.00	6.50	33.5	446.5	22.7
21	1051	21	21	4.875	6.50	32.7	-----	----
22	1052	22	22	5.00	6.50	33.5	446.5	22.5
23	1054	24	24	-----	----	----	446.5	22.6
24	1056	26	26	5.00	6.50	33.5	447.0	22.6
25	1058	28	28	5.00	6.50	33.5	447.0	22.7
26	1100	30	30	4.75	6.375	34.2	447.0	22.7
27	1102	32	32	4.75	6.50	31.8	447.0	22.9
28	1104	34	34	4.875	6.50	32.7	447.5	22.9

Table 8.--*Yields, flowing pressures, and temperatures for Madison Limestone test well 3, step-drawdown test--step 1, October 31-November 1, 1979*--Continued

Observation number	Clock time (24 hours)	Cumulative time: This step (min)	Cumulative time: Total test (min)	Discharge data: Trajectory (in)	Discharge data: Free board (in)	Discharge data: Yield (gal/min)	Flowing pressure (lb/in^2)	Temperature (°C)
29	1106	36	36	4.875	6.50	32.7	447.5	23.0
30	1108	38	38	4.875	6.50	32.7	447.5	23.1
31	1110	40	40	5.00	6.50	33.5	448.0	23.1
32	1112	42	42	5.125	6.50	34.3	-----	----
33	1114	44	44	5.125	6.50	34.3	448.0	23.2
34	1116	46	46	5.125	6.50	34.3	-----	----
35	1118	48	48	-----	----	----	448.0	23.5
36	1120	50	50	5.125	6.50	34.3	-----	----
37	1122	52	52	-----	----	----	448.0	23.6
38	1124	54	54	5.125	6.50	34.3	-----	----
39	1126	56	56	-----	----	----	448.0	23.9
40	1128	58	58	5.125	6.50	34.3	-----	----
41	1130	60	60	-----	----	----	448.5	24.0
42	1132	62	62	4.875	6.50	32.7	-----	----

Table 8.--*Yields, flowing pressures, and temperatures for Madison Limestone test well 3, step-drawdown test--step 1, October 31-November 1, 1979*--Continued

Observation number	Clock time (24 hours)	Cumulative time		Discharge data			Flowing pressure (lb/in^2)	Temperature (°C)
		This step (min)	Total test (min)	Trajectory (in)	Free board (in)	Yield (gal/min)		
43	1135	65	65	-----	----	----	449.0	24.3
44	1136	66	66	5.00	6.50	33.5	-----	----
45	1140	70	70	4.875	6.50	32.7	449.0	24.4
46	1145	75	75	5.00	6.50	33.5	449.5	24.8
47	1150	80	80	5.00	6.50	33.5	450.0	25.0
48	1155	85	85	5.00	6.375	33.5	450.0	25.7
49	1200	90	90	5.00	6.375	33.5	450.0	25.6
50	1205	95	95	5.00	6.375	33.5	450.0	25.8
51	1210	100	100	5.00	6.50	33.5	450.5	26.0
52	1215	105	105	5.00	6.50	33.5	451.0	26.4
53	1220	110	110	5.125	6.50	34.3	451.0	26.5
54	1225	115	115	5.125	6.50	34.3	451.0	26.8
55	1229	119	119	5.125	6.50	34.3	-----	----
56	1230	120	120	-----	----	----	451.0	27.0

Table 9.--*Yields, flowing pressures, and temperatures for Madison Limestone test well 3, step-drawdown test--step 2, October 31-November 1, 1979*

[min = minutes; in = inches; gal/min = gallons per minute; lb/in^2 = pounds per square inch; °C = degrees Celsius]

Observation number	Clock time (24 hours)	Cumulative time		Discharge data			Flowing pressure (lb/in^2)	Temperature (°C)
		This step (min)	Total test (min)	Trajectory (in)	Free board (in)	Yield (gal/min)		
0	1230	0	120	8.5	4.50	182.9	451.0	27.0
1	1231	1	121	8.5	4.75	166.5	447.5	26.9
2	1232	2	122	8.5	4.75	166.5	447.5	27.4
3	1233	3	123	8.5	4.75	166.5	447.5	27.8
4	1234	4	124	8.375	4.75	164.1	447.5	28.1
5	1235	5	125	8.375	4.75	164.1	447.5	28.4
6	1236	6	126	8.25	4.75	161.7	448.0	28.7
7	1237	7	127	8.375	4.75	164.1	447.5	29.1
8	1238	8	128	8.375	4.75	164.1	448.0	29.4
9	1239	9	129	8.25	4.75	161.7	448.0	29.7
10	1240	10	130	8.375	4.75	164.1	448.0	29.9
11	1241	11	131	8.25	4.875	150.8	448.0	30.2
12	1242	12	132	8.25	4.75	161.7	448.0	30.5
13	1243	13	133	8.375	4.75	164.1	448.0	30.8

Table 9.--*Yields, flowing pressures, and temperatures for Madison Limestone test well 3, step-drawdown test--step 2, October 31-November 1, 1979*--Continued

Observation number	Clock time (24 hours)	Cumulative time: This step (min)	Cumulative time: Total test (min)	Discharge data: Trajectory (in)	Discharge data: Free board (in)	Discharge data: Yield (gal/min)	Flowing pressure (lb/in^2)	Temperature (°C)
14	1244	14	134	8.375	4.75	164.1	448.0	31.0
15	1245	15	135	8.375	4.75	164.1	448.0	31.2
16	1246	16	136	8.375	4.75	164.1	448.5	31.5
17	1247	17	137	8.25	4.75	161.7	449.0	31.9
18	1248	18	138	8.25	4.75	161.7	449.0	32.1
19	1249	19	139	8.25	4.75	161.7	449.5	32.5
20	1250	20	140	8.25	4.75	161.7	449.5	32.7
21	1252	22	142	8.375	4.75	164.1	449.5	33.1
22	1254	24	144	8.375	4.75	164.1	450.0	33.7
23	1256	26	146	8.375	4.75	164.1	450.0	34.2
24	1258	28	148	8.375	4.75	164.1	450.0	35.1
25	1300	30	150	8.25	4.75	161.7	450.0	35.6
26	1302	32	152	8.375	4.75	164.1	450.0	36.3
27	1304	34	154	8.375	4.75	164.1	450.5	36.8
28	1306	36	156	8.375	4.75	164.1	450.5	37.2
29	1308	38	158	8.375	4.75	164.1	451.0	37.8

Table 9.--*Yields, flowing pressures, and temperatures for Madison Limestone test well 3, step-drawdown test--step 2, October 31-November 1, 1979*--Continued

Observation number	Clock time (24 hours)	Cumulative time: This step (min)	Cumulative time: Total test (min)	Discharge data: Trajectory (in)	Discharge data: Free board (in)	Discharge data: Yield (gal/min)	Flowing pressure (lb/in^2)	Temperature (°C)
30	1310	40	160	8.375	4.75	164.1	451.0	38.1
31	1315	45	165	8.375	4.75	164.1	451.5	39.1
32	1320	50	170	8.375	4.75	164.1	451.5	40.9
33	1325	55	175	8.375	4.75	164.1	451.5	42.2
34	1330	60	180	8.375	4.75	164.1	451.5	43.0
35	1335	65	185	8.375	4.75	164.1	451.5	43.8
36	1340	70	190	8.375	4.75	164.1	451.5	44.7
37	1345	75	195	8.375	4.75	164.1	451.5	45.5
38	1350	80	200	8.375	4.75	164.1	451.5	46.0
39	1355	85	205	8.375	4.75	164.1	451.5	46.6
40	1400	90	210	8.375	4.75	164.1	451.5	47.0
41	1405	95	215	8.375	4.75	164.1	451.5	47.0
42	1410	100	220	8.375	4.75	164.1	452.5	47.7
43	1415	105	225	8.375	4.75	164.1	452.5	48.1
44	1420	110	230	8.375	4.75	164.1	452.5	48.3
45	1425	115	235	8.375	4.75	164.1	452.5	48.1
46	1430	120	240	8.375	4.75	164.1	452.5	47.6

Table 10.--*Yields, flowing pressures, and temperatures for Madison Limestone test well 3, step-drawdown test--step 3, October 31-November 1, 1979*

[min = minutes; in = inches; gal/min = gallons per minute; lb/in^2 = pounds per square inch; °C = degrees Celsius]

Observation number	Clock time (24 hours)	Cumulative time: This step (min)	Cumulative time: Total test (min)	Discharge data: Trajectory (in)	Discharge data: Free board (in)	Discharge data: Yield (gal/min)	Flowing pressure (lb/in^2)	Temperature (°C)
0	1430	0	240	13.5	2.25	536.6	452.5	47.6
1	1431	1	241	13.5	2.50	511.9	430.0	47.6
2	1432	2	242	13.5	2.50	511.9	428.0	47.7
3	1433	3	243	13.25	2.375	510.5	428.0	48.0
4	1434	4	244	13.5	2.50	511.9	428.0	48.4
5	1435	5	245	13.75	2.50	521.4	427.0	48.6
6	1436	6	246	13.5	2.50	511.9	427.0	48.6
7	1437	7	247	13.5	2.25	536.6	427.0	48.9
8	1438	8	248	13.5	2.50	511.9	426.0	49.1
9	1439	9	249	13.5	2.50	511.9	427.0	49.0
10	1440	10	250	13.25	2.375	510.5	427.0	49.6
11	1441	11	251	13.25	2.375	510.5	427.0	49.3
12	1442	12	252	13.25	2.375	510.5	427.0	49.8
13	1443	13	253	13.25	2.375	510.5	427.0	49.9

Table 10.--*Yields, flowing pressures, and temperatures for Madison Limestone test well 3, step-drawdown test--step 3, October 31-November 1, 1979*--Continued

Observation number	Clock time (24 hours)	Cumulative time		Discharge data			Flowing pressure (lb/in^2)	Temperature (°C)
		This step (min)	Total test (min)	Trajectory (in)	Free board (in)	Yield (gal/min)		
14	1444	14	254	13.25	2.25	526.6	427.0	50.5
15	1445	15	255	13.125	2.50	497.7	426.0	51.4
16	1446	16	256	13.5	2.25	536.6	426.0	51.6
17	1447	17	257	13.375	2.375	515.3	426.0	51.5
18	1448	18	258	13.25	2.50	502.4	426.0	52.0
19	1449	19	259	13.50	2.25	536.6	426.0	52.0
20	1450	20	260	13.375	2.50	507.2	426.0	52.3
21	1452	22	262	13.25	2.50	502.4	426.0	52.2
22	1454	24	264	13.25	2.375	510.5	426.0	52.4
23	1456	26	266	13.25	2.375	510.5	426.0	52.4
24	1458	28	268	13.5	2.375	520.1	426.0	52.7
25	1500	30	270	13.375	2.375	515.3	426.0	52.8
26	1502	32	272	13.5	2.25	536.6	426.0	52.6
27	1504	34	274	13.375	2.50	507.2	426.0	53.0
28	1506	36	276	13.5	2.50	511.9	426.0	53.0
29	1508	38	278	13.375	2.375	515.3	426.0	53.0

Table 10.--*Yields, flowing pressures, and temperatures for Madison Limestone test well 3, step-drawdown test--step 3, October 31-November 1, 1979*--Continued

Observation number	Clock time (24 hours)	Cumulative time		Discharge data			Flowing pressure (lb/in^2)	Temperature (°C)
		This step (min)	Total test (min)	Trajectory (in)	Free board (in)	Yield (gal/min)		
30	1510	40	280	13.25	2.25	526.6	426.0	53.0
31	1512	42	282	13.75	2.25	546.5	-----	----
32	1514	44	284	13.875	2.50	526.1	-----	----
33	1515	45	285	-----	-----	-----	426.0	53.2
34	1516	46	286	13.75	2.25	546.5	-----	----
35	1520	50	290	13.625	2.625	500.0	426.0	53.3
36	1524	54	294	13.75	2.25	546.5	-----	----
37	1525	55	295	-----	-----	-----	426.0	53.4
38	1528	58	298	13.625	2.625	500.0	-----	----
39	1530	60	300	-----	-----	-----	426.0	53.4
40	1532	62	302	13.625	2.50	516.6	-----	----
41	1535	65	305	-----	-----	-----	426.0	53.4
42	1536	66	306	13.625	2.375	524.9	-----	----
43	1540	70	310	13.5	2.375	520.1	426.0	53.4
44	1545	75	315	13.75	2.50	521.4	426.0	53.5

Table 10.--*Yields, flowing pressures, and temperatures for Madison Limestone test well 3, step-drawdown test--step 3, October 31-November 1, 1979*--Continued

Observation number	Clock time (24 hours)	Cumulative time		Discharge data			Flowing pressure (lb/in^2)	Temperature (°C)
		This step (min)	Total test (min)	Trajectory (in)	Free board (in)	Yield (gal/min)		
45	1550	80	320	13.625	2.25	541.5	426.0	53.5
46	1555	85	325	13.75	2.50	521.4	426.0	53.7
47	1600	90	330	13.75	2.50	521.4	426.0	53.9
48	1605	95	335	13.5	2.375	520.1	426.0	53.7
49	1610	100	340	13.5	2.375	520.1	426.0	53.7
50	1615	105	345	13.5	2.50	511.9	426.0	53.8
51	1620	110	350	13.5	2.25	536.6	426.0	54.0
52	1625	115	355	13.375	2.375	515.3	426.0	54.0
53	1627	117	357	13.5	2.375	520.1	-----	----
54	1630	120	360	-----	-----	-----	426.0	54.0

Table 11.--*Yields, flowing pressures, and temperatures for Madison Limestone test well 3, step-drawdown test--step 4, October 31-November 1, 1979*

[min = minutes; in = inches; gal/min = gallons per minute; lb/in^2 = pounds per square inch; °C = degrees Celsius]

Observation number	Clock time (24 hours)	Cumulative time		Discharge data			Flowing pressure (lb/in^2)	Temperature (°C)
		This step (min)	Total test (min)	Trajectory (in)	Free board (in)	Yield (gal/min)		
0	1630	0	360	20.5	.50	1020	426.0	54.0
1	1631	1	361	21.125	1.00	1010	378.0	53.6
2	1632	2	362	24.0	----	1070	375.0	53.7
3	1633	3	363	21.25	1.00	1010	375.0	53.9
4	1634	4	364	23.875	1.00	1060	374.0	53.6
5	1635	5	365	23.75	----	1050	374.0	54.0
6	1636	6	366	23.625	----	1050	374.0	53.6
7	1637	7	367	23.75	----	1050	374.0	53.6
8	1638	8	368	23.75	----	1050	374.0	54.0
9	1639	9	369	23.625	----	1050	374.0	53.9
10	1640	10	370	23.50	----	1040	374.0	53.6
11	1641	11	371	23.50	----	1040	374.0	53.6
12	1642	12	372	23.625	----	1050	374.0	54.0
13	1643	13	373	23.625	----	1050	374.0	54.2

Table 11.--*Yields, flowing pressures, and temperatures for Madison Limestone test well 3, step-drawdown test--step 4, October 31-November 1, 1979*--Continued

Observation number	Clock time (24 hours)	Cumulative time		Discharge data			Flowing pressure (lb/in^2)	Temperature (°C)
		This step (min)	Total test (min)	Trajectory (in)	Free board (in)	Yield (gal/min)		
14	1644	14	374	23.5	----	1040	374.0	54.0
15	1645	15	375	23.625	----	1050	374.0	54.1
16	1646	16	376	23.75	----	1050	372.0	54.2
17	1647	17	377	23.625	----	1050	372.0	54.1
18	1648	18	378	23.75	----	1050	372.0	54.1
19	1649	19	379	23.75	----	1050	372.0	53.4
20	1650	20	380	23.625	----	1050	372.0	54.0
21	1652	22	382	23.75	----	1050	372.0	53.9
22	1654	24	384	23.625	----	1050	372.0	54.0
23	1656	26	386	23.5	----	1040	372.0	54.1
24	1658	28	388	23.625	----	1050	372.0	54.0
25	1700	30	390	23.625	----	1050	372.0	54.2
26	1702	32	392	23.75	----	1050	370.0	54.0
27	1704	34	394	23.625	----	1050	370.0	54.2
28	1706	36	396	23.5	----	1040	370.0	54.0
29	1708	38	398	23.625	----	1050	370.0	54.0

Table 11.--*Yields, flowing pressures, and temperatures for Madison Limestone test well 3, step-drawdown test--step 4, October 31-November 1, 1979*--Continued

Observation number	Clock time (24 hours)	Cumulative time		Discharge data			Flowing pressure (lb/in^2)	Temperature (°C)
		This step (min)	Total test (min)	Trajectory (in)	Free board (in)	Yield (gal/min)		
30	1710	40	400	23.625	----	1050	370.0	54.0
31	1712	42	402	23.5	----	1040	-----	----
32	1714	44	404	23.5	----	1040	-----	----
33	1715	45	405	------	----	----	370.0	54.2
34	1716	46	406	23.5	----	1040	-----	----
35	1720	50	410	23.625	----	1050	370.0	54.2
36	1724	54	414	23.5	----	1040	-----	----
37	1725	55	415	------	----	----	370.0	54.5
38	1728	58	418	23.5	----	1040	-----	----
39	1730	60	420	------	----	----	370.0	54.3
40	1732	62	422	23.625	----	1050	-----	----
41	1735	65	425	------	----	----	370.0	54.6
42	1736	66	426	23.625	----	1050	-----	----
43	1740	70	430	23.5	----	1040	370.0	54.7
44	1745	75	435	23.875	----	1060	370.0	54.9

Table 11.--*Yields, flowing pressures, and temperatures for Madison Limestone test well 3, step-drawdown test--step 4, October 31-November 1, 1979*--Continued

Observation number	Clock time (24 hours)	Cumulative time		Discharge data			Flowing pressure (lb/in^2)	Temperature (°C)
		This step (min)	Total test (min)	Trajectory (in)	Free board (in)	Yield (gal/min)		
45	1750	80	440	23.5	----	1040	370.0	54.9
46	1755	85	445	23.625	----	1050	370.0	54.1
47	1800	90	450	23.5	----	1040	370.0	54.3
48	1805	95	455	23.625	----	1050	370.0	54.6
49	1810	100	460	23.875	----	1060	370.0	54.6
50	1815	105	465	23.625	----	1050	370.0	54.7
51	1820	110	470	23.625	----	1050	370.0	54.6
52	1825	115	475	23.875	----	1060	370.0	54.6
53	1830	120	480	23.625	----	1050	370.0	53.2

Table 12.--*Yields, flowing pressures, and temperatures for Madison Limestone test well 3, step-drawdown test--step 5, October 31-November 1, 1979*

[min = minutes; in = inches; gal/min = gallons per minute; lb/in^2 = pounds per square inch; °C = degrees Celsius]

Observation number	Clock time (24 hours)	Cumulative time		Discharge data			Flowing pressure (lb/in^2)	Temperature (°C)
		This step (min)	Total test (min)	Trajectory (in)	Free board (in)	Yield (gal/min)		
0	1830	0	480	23.625	----	----	370.0	54.6
1	1831	1	481	38.375	----	1800	284.0	53.2
2	1832	2	482	38.25	----	1790	278.0	54.5
3	1833	3	483	37.75	----	1760	278.0	54.6
4	1834	4	484	36.75	----	1710	276.0	54.4
5	1835	5	485	36.75	----	1710	276.0	54.9
6	1836	6	486	36.5	----	1700	274.0	54.4
7	1837	7	487	36.625	----	1710	274.0	54.2
8	1838	8	488	36.5	----	1700	273.0	53.7
9	1839	9	489	36.625	----	1710	273.0	54.2
10	1840	10	490	36.5	----	1700	273.0	54.4
11	1841	11	491	36.625	----	1710	272.0	54.7
12	1842	12	492	36.625	----	1710	274.0	54.3
13	1843	13	493	36.625	----	1710	273.0	53.5

Table 12.--*Yields, flowing pressures, and temperatures for Madison Limestone test well 3, step-drawdown test--step 5, October 31-November 1, 1979*--Continued

Observation number	Clock time (24 hours)	Cumulative time		Discharge data			Flowing pressure (lb/in^2)	Temperature (°C)
		This step (min)	Total test (min)	Trajectory (in)	Free board (in)	Yield (gal/min)		
14	1844	14	494	36.5	----	1700	272.0	54.7
15	1845	15	495	36.375	----	1690	272.0	55.0
16	1846	16	496	36.5	----	1700	272.0	54.9
17	1847	17	497	36.375	----	1690	273.0	54.9
18	1848	18	498	36.375	----	1690	272.0	54.8
19	1849	19	499	36.25	----	1690	270.0	54.5
20	1850	20	500	36.375	----	1690	272.0	54.3
21	1852	22	502	36.25	----	1690	272.0	55.1
22	1854	24	504	36.125	----	1680	273.0	54.6
23	1856	26	506	36.0	----	1680	271.0	55.4
24	1858	28	508	36.25	----	1690	270.0	54.7
25	1900	30	510	36.5	----	1700	272.0	55.6
26	1902	32	512	36.25	----	1690	270.0	55.8
27	1904	34	514	36.5	----	1700	270.0	55.7
28	1906	36	516	36.375	----	1690	270.0	55.9
29	1908	38	518	36.5	----	1700	270.0	55.8

Table 12.--*Yields, flowing pressures, and temperatures for Madison Limestone test well 3, step-drawdown test--step 5, October 31-November 1, 1979*--Continued

Observation number	Clock time (24 hours)	Cumulative time		Discharge data			Flowing pressure (lb/in^2)	Temperature (°C)
		This step (min)	Total test (min)	Trajectory (in)	Free board (in)	Yield (gal/min)		
30	1910	40	520	36.5	----	1700	270.0	55.8
31	1914	44	524	36.375	----	1690	-----	----
32	1915	45	525	------	----	----	270.0	56.0
33	1918	48	528	36.5	----	1700	-----	----
34	1920	50	530	------	----	----	270.0	55.8
35	1922	52	532	36.375	----	1690	-----	----
36	1925	55	535	------	----	----	270.0	55.9
37	1926	56	536	36.125	----	1680	-----	----
38	1930	60	540	36.25	----	1690	270.0	55.7
39	1934	64	544	36.25	----	1690	-----	----
40	1935	65	545	------	----	----	270.0	55.6
41	1938	68	548	36.125	----	1680	-----	----
42	1940	70	550	------	----	----	270.0	55.7
43	1942	72	552	36.25	----	1690	-----	----
44	1945	75	555	------	----	----	270.0	55.6

Table 12.--*Yields, flowing pressures, and temperatures for Madison Limestone test well 3, step-drawdown test--step 5, October 31-November 1, 1979*--Continued

Observation number	Clock time (24 hours)	Cumulative time		Discharge data			Flowing pressure (lb/in^2)	Temperature (°C)
		This step (min)	Total test (min)	Trajectory (in)	Free board (in)	Yield (gal/min)		
45	1946	76	556	36.375	----	1690	-----	----
46	1950	80	560	36.25	----	1690	270.0	55.6
47	1955	85	565	36.25	----	1690	270.0	55.6
48	2000	90	570	36.125	----	1680	270.0	55.3
49	2005	95	575	36.125	----	1680	270.0	56.0
50	2010	100	580	36.0	----	1680	268.0	56.1
51	2015	105	585	36.25	----	1690	270.0	56.1
52	2020	110	590	36.125	----	1680	270.0	56.2
53	2025	115	595	36.25	----	1740	268.0	56.1
54	2030	120	600	36.25	----	1690	268.0	56.2

Table 13.--*Yields, flowing pressures, and temperatures for Madison Limestone test well 3, step-drawdown test--step 6, October 31-November 1, 1979*

[min = minutes; in = inches; gal/min = gallons per minute; lb/in^2 = pounds per square inch; °C = degrees Celsius]

Observation number	Clock time (24 hours)	Cumulative time: This step (min)	Cumulative time: Total test (min)	Discharge data: Trajectory (in)	Discharge data: Free board (in)	Discharge data: Yield (gal/min)	Flowing pressure (lb/in^2)	Temperature (°C)
0	2030	0	600	36.25	----	1690	268.0	56.2
1	2031	1	601	47.75	----	2270	188.0	55.9
2	2032	2	602	47.25	----	2250	186.0	55.9
3	2033	3	603	46.75	----	2220	184.0	55.9
4	2034	4	604	46.0	----	2230	184.0	55.9
5	2035	5	605	46.0	----	2230	182.0	56.0
6	2036	6	606	46.25	----	2250	180.0	56.0
7	2037	7	607	46.0	----	2230	182.0	56.1
8	2038	8	608	46.25	----	2250	-----	----
9	2039	9	609	46.25	----	2250	180.0	56.1
10	2040	10	610	46.25	----	2250	182.0	56.0
11	2041	11	611	46.25	----	2250	182.0	56.0
12	2042	12	612	46.0	----	2230	182.0	56.1
13	2043	13	613	46.0	----	2230	183.0	56.1

Table 13.--*Yields, flowing pressures, and temperatures for Madison Limestone test well 3, step-drawdown test--step 6, October 31-November 1, 1979*--Continued

Observation number	Clock time (24 hours)	Cumulative time: This step (min)	Cumulative time: Total test (min)	Discharge data: Trajectory (in)	Discharge data: Free board (in)	Discharge data: Yield (gal/min)	Flowing pressure (lb/in^2)	Temperature (°C)
14	2044	14	614	46.0	----	2230	183.0	56.0
15	2045	15	615	46.0	----	2230	181.0	56.1
16	2046	16	616	46.0	----	2230	180.0	56.0
17	2047	17	617	46.0	----	2230	182.0	56.2
18	2048	18	618	46.875	----	2230	183.0	56.0
19	2049	19	619	46.75	----	2220	182.0	56.1
20	2050	20	620	46.875	----	2230	182.0	56.0
21	2052	22	622	46.25	----	2250	180.0	55.9
22	2054	24	624	46.0	----	2230	182.0	56.0
23	2056	26	626	46.75	----	2220	182.0	55.9
24	2058	28	628	46.75	----	2220	180.0	56.0
25	2100	30	630	46.75	----	2220	180.0	55.8
26	2102	32	632	46.625	----	2210	180.0	55.9
27	2104	34	634	46.75	----	2220	180.0	55.9
28	2106	36	636	46.875	----	2230	180.0	55.9
29	2108	38	638	46.75	----	2220	182.0	55.9

Table 13.--*Yields, flowing pressures, and temperatures for Madison Limestone test well 3, step-drawdown test--step 6, October 31-November 1, 1979*--Continued

Observation number	Clock time (24 hours)	Cumulative time		Discharge data			Flowing pressure (lb/in^2)	Temperature (°C)
		This step (min)	Total test (min)	Trajectory (in)	Free board (in)	Yield (gal/min)		
30	2110	40	640	46.625	----	2210	182.0	55.8
31	2114	44	644	46.5	----	2210	------	----
32	2115	45	645	------	----	----	182.0	56.0
33	2118	48	648	46.625	----	2210	------	----
34	2120	50	650	------	----	----	180.0	56.0
35	2122	52	652	46.5	----	2210	------	----
36	2125	55	655	------	----	----	182.0	56.0
37	2126	56	656	46.625	----	2210	------	----
38	2130	60	660	46.5	----	2210	181.0	56.1
39	2134	64	664	46.5	----	2210	------	----
40	2135	65	665	------	----	----	179.0	56.1
41	2138	68	668	46.5	----	2210	------	----
42	2140	70	670	------	----	----	178.0	56.1
43	2142	72	672	46.375	----	2200	------	----
44	2145	75	675	------	----	----	179.0	56.1

Table 13.--*Yields, flowing pressures, and temperatures for Madison Limestone test well 3, step-drawdown test--step 6, October 31-November 1, 1979*--Continued

Observation number	Clock time (24 hours)	Cumulative time		Discharge data			Flowing pressure (lb/in^2)	Temperature (°C)
		This step (min)	Total test (min)	Trajectory (in)	Free board (in)	Yield (gal/min)		
45	2146	76	676	46.25	----	2200	-----	----
46	2150	80	680	46.25	----	2200	178.0	56.2
47	2155	85	685	46.25	----	2200	178.0	56.0
48	2200	90	690	46.125	----	2190	176.0	56.0
49	2205	95	695	46.375	----	2200	176.0	56.0
50	2210	100	700	46.5	----	2210	177.0	55.9
51	2215	105	705	46.5	----	2210	178.0	56.0
52	2220	110	710	46.25	----	2200	176.0	56.1
53	2225	115	715	46.25	----	2200	176.0	56.1
54	2230	120	720	46.25	----	2200	175.0	56.2

Table 14.--*Yields, flowing pressures, and temperatures for Madison Limestone test well 3, step-drawdown test--step 7, October 31-November 1, 1979*

[min = minutes; in = inches; gal/min = gallons per minute; lb/in^2 = pounds per square inch; °C = degrees Celsius]

Observation number	Clock time (24 hours)	Cumulative time		Discharge data			Flowing pressure (lb/in^2)	Temperature (°C)
		This step (min)	Total test (min)	Trajectory (in)	Free board (in)	Yield (gal/min)		
0	2230	0	720	46.25	----	2200	175.0	56.2
1	2231	1	721	57.5	----	2770	87.0	55.8
2	2232	2	722	57.0	----	2740	85.0	55.6
3	2233	3	723	56.0	----	2690	85.0	55.7
4	2234	4	724	55.75	----	2680	85.0	55.9
5	2235	5	725	56.25	----	2700	84.0	55.8
6	2236	6	726	56.0	----	2690	84.0	55.8
7	2237	7	727	55.75	----	2680	84.0	55.9
8	2238	8	728	56.25	----	2700	84.0	55.9
9	2239	9	729	55.75	----	2680	84.0	55.9
10	2240	10	730	55.875	----	2680	84.0	56.0
11	2241	11	731	56.125	----	2700	82.0	55.9
12	2242	12	732	56.25	----	2700	84.0	56.0
13	2243	13	733	55.5	----	2660	83.0	56.0

Table 14.--*Yields, flowing pressures, and temperatures for Madison Limestone test well 3, step-drawdown test--step 7, October 31-November 1, 1979*--Continued

Observation number	Clock time (24 hours)	Cumulative time		Discharge data			Flowing pressure (lb/in^2)	Temperature (°C)
		This step (min)	Total test (min)	Trajectory (in)	Free board (in)	Yield (gal/min)		
14	2244	14	734	56.0	----	2690	84.0	56.0
15	2245	15	735	56.0	----	2690	84.0	55.9
16	2246	16	736	55.75	----	2680	83.0	55.8
17	2247	17	737	56.125	----	2700	84.0	56.0
18	2248	18	738	56.25	----	2700	84.0	55.9
19	2249	19	739	56.25	----	2700	84.0	56.0
20	2250	20	740	56.25	----	2700	83.0	56.0
21	2252	22	742	56.125	----	2700	82.0	56.1
22	2254	24	744	56.125	----	2700	83.0	56.0
23	2256	26	746	56.0	----	2690	82.0	55.9
24	2258	28	748	56.0	----	2690	82.0	56.0
25	2300	30	750	55.75	----	2680	83.0	56.0
26	2302	32	752	56.0	----	2690	82.0	55.8
27	2304	34	754	56.0	----	2690	82.0	55.9
28	2306	36	756	55.875	----	2680	82.0	56.0
29	2308	38	758	56.0	----	2690	83.0	56.0

Table 14.--*Yields, flowing pressures, and temperatures for Madison Limestone test well 3, step-drawdown test--step 7, October 31-November 1, 1979*--Continued

Observation number	Clock time (24 hours)	Cumulative time: This step (min)	Cumulative time: Total test (min)	Discharge data: Trajectory (in)	Discharge data: Free board (in)	Discharge data: Yield (gal/min)	Flowing pressure (lb/in^2)	Temperature (°C)
30	2310	40	760	55.875	----	2680	84.0	55.9
31	2314	44	764	55.0	----	2640	-----	----
32	2315	45	765	------	----	----	83.0	55.8
33	2318	48	768	55.25	----	2650	-----	----
34	2320	50	770	------	----	----	84.0	55.9
35	2322	52	772	55.0	----	2640	-----	----
36	2325	55	775	------	----	----	84.0	55.6
37	2326	56	776	55.0	----	2640	-----	----
38	2330	60	780	55.0	----	2640	82.0	55.8
39	2334	64	784	54.5	----	2610	-----	----
40	2335	65	785	------	----	----	80.0	56.0
41	2338	68	788	54.5	----	2610	-----	----
42	2340	70	790	------	----	----	82.0	55.9
43	2342	72	792	54.625	----	2620	-----	----
44	2345	75	795	------	----	----	81.0	55.9

Table 14.--*Yields, flowing pressures, and temperatures for Madison Limestone test well 3, step-drawdown test--step 7, October 31-November 1, 1979*--Continued

Observation number	Clock time (24 hours)	Cumulative time		Discharge data			Flowing pressure (lb/in^2)	Temperature (°C)
		This step (min)	Total test (min)	Trajectory (in)	Free board (in)	Yield (gal/min)		
45	2346	76	796	54.875	----	2630	-----	----
46	2350	80	800	55.0	----	2640	82.0	56.0
47	2355	85	805	54.5	----	2610	82.0	55.9
48	2400	90	810	54.5	----	2610	81.0	55.9
49	2405	95	815	54.5	----	2610	81.0	56.0
50	2410	100	820	54.5	----	2610	82.0	55.8
51	2415	105	825	54.5	----	2610	80.0	56.0
52	2420	110	830	54.25	----	2600	81.0	56.1
53	2425	115	835	54.0	----	2590	82.0	56.0
54	2430	120	840	54.75	----	2630	80.0	56.8

Table 15.--*Yields, flowing pressures, and temperatures for Madison Limestone test well 3, step-drawdown test--step 8, October 31-November 1, 1979*

[min = minutes; in = inches; gal/min = gallons per minute; lb/in^2 = pounds per square inch; °C = degrees Celsius]

Observation number	Clock time (24 hours)	Cumulative time		Discharge data			Flowing pressure (lb/in^2)	Temperature (°C)
		This step (min)	Total test (min)	Trajectory (in)	Free board (in)	Yield (gal/min)		
0	2430	0	840	54.75	----	2630	80.0	56.8
1	2431	1	841	62.75	----	3030	20.0	56.8
2	2432	2	842	60.75	----	2930	20.0	56.0
3	2433	3	843	60.5	----	2920	19.0	56.0
4	2434	4	844	60.375	----	2910	19.0	56.0
5	2435	5	845	60.5	----	2920	19.0	56.1
6	2436	6	846	60.5	----	2920	19.0	56.1
7	2437	7	847	60.625	----	2930	20.0	56.1
8	2438	8	848	60.25	----	2910	20.0	56.2
9	2439	9	849	60.5	----	2920	20.0	56.1
10	2440	10	850	60.5	----	2920	20.0	56.1
11	2441	11	851	60.375	----	2910	20.0	56.1
12	2442	12	852	60.25	----	2910	20.0	56.2
13	2443	13	853	60.0	----	2890	20.0	56.2

Table 15.--*Yields, flowing pressures, and temperatures for Madison Limestone test well 3, step-drawdown test--step 8, October 31-November 1, 1979*--Continued

Observation number	Clock time (24 hours)	Cumulative time		Discharge data			Flowing pressure (lb/in^2)	Temperature (°C)
		This step (min)	Total test (min)	Trajectory (in)	Free board (in)	Yield (gal/min)		
14	2444	14	854	60.0	----	2890	20.0	56.1
15	2445	15	855	60.25	----	2910	20.0	56.1
16	2446	16	856	60.5	----	2920	20.0	56.1
17	2447	17	857	60.25	----	2910	20.0	56.0
18	2448	18	858	60.25	----	2910	20.0	56.1
19	2449	19	859	60.0	----	2890	20.0	56.2
20	2450	20	860	60.0	----	2890	20.0	56.1
21	2452	22	862	60.125	----	2900	20.0	56.0
22	2454	24	864	60.0	----	2890	19.0	56.0
23	2456	26	866	60.375	----	2910	20.0	56.0
24	2458	28	868	60.0	----	2890	20.0	56.0
25	0100	30	870	60.0	----	2940	20.0	56.0
26	0102	32	872	61.25	----	2960	20.0	56.0
27	0104	34	874	61.25	----	2960	19.0	56.0
28	0106	36	876	60.25	----	2910	19.0	56.0
29	0108	38	878	60.0	----	2890	20.0	56.0

Table 15.--*Yields, flowing pressures, and temperatures for Madison Limestone test well 3, step-drawdown test--step 8, October 31-November 1, 1979*--Continued

Observation number	Clock time (24 hours)	Cumulative time		Discharge data			Flowing pressure (lb/in^2)	Temperature (°C)
		This step (min)	Total test (min)	Trajectory (in)	Free board (in)	Yield (gal/min)		
30	0110	40	880	60.0	----	2890	20.0	56.0
31	0114	44	884	60.25	----	2910	-----	----
32	0115	45	885	------	----	----	19.0	56.0
33	0118	48	888	59.75	----	2880	-----	----
34	0120	50	890	------	----	----	18.0	56.0
35	0122	52	892	59.5	----	2870	-----	----
36	0125	55	895	------	----	----	20.0	56.0
37	0126	56	896	59.5	----	2870	-----	----
38	0130	60	900	59.625	----	2870	20.0	56.0
39	0134	64	904	59.25	----	2860	-----	----
40	0135	65	905	------	----	----	20.0	56.0
41	0138	68	908	59.0	----	2840	-----	----
42	0140	70	910	------	----	----	20.0	56.0
43	0142	72	912	59.5	----	2870	-----	----
44	0145	75	915	------	----	----	20.0	56.0

Table 15.--*Yields, flowing pressures, and temperatures for Madison Limestone test well 3, step-drawdown test--step 8, October 31-November 1, 1979*--Continued

Observation number	Clock time (24 hours)	Cumulative time		Discharge data			Flowing pressure (lb/in^2)	Temperature (°C)
		This step (min)	Total test (min)	Trajectory (in)	Free board (in)	Yield (gal/min)		
45	0146	76	916	59.5	----	2870	-----	----
46	0150	80	920	59.5	----	2870	20.0	56.0
47	0155	85	925	59.25	----	2860	20.0	56.0
48	0200	90	930	59.5	----	2870	20.0	56.0
49	0205	95	935	59.25	----	2860	19.0	56.0
50	0210	100	940	59.5	----	2870	19.0	56.0
51	0215	105	945	59.0	----	2840	19.0	56.0
52	0220	110	950	59.25	----	2860	20.0	56.0
53	0225	115	955	59.5	----	2870	20.0	56.0
54	0230	120	960	59.25	----	2860	20.0	56.0