REPORT ON
DRILLING, DEVELOPMENT, AND TESTING
OF THE
VETERANS ADMINISTRATION
MEDICAL CENTER
GEOTHERMAL INJECTION WELL
BOISE, IDAHO

FEBRUARY 1987
REPORT ON DRILLING, DEVELOPMENT, AND TESTING

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THE VETERANS ADMINISTRATION MEDICAL CENTER

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CHAPTER 1

INTRODUCTION

BACKGROUND

Geothermal wells along the Boise Front have supplied hot water for space heating of residences since the late 1800's. Due to rising energy costs, interest in this resource increased in the late 1970's and early 1980's, and several wells were drilled in the vicinity of the Veterans Administration (V.A.) Medical Center by the U.S. Department of Energy, the State of Idaho, and Boise Geothermal Limited (BGL).

In 1983, a geothermal production well was drilled near the eastern boundary of the V.A. property for the purpose of space heating of the V.A. Medical Center. Total depth of this well is 1666 feet. Tests showed that it was capable of producing in excess of 1000 gpm of 160°F water.

Following drilling of the V.A. production well, a test injection well was drilled approximately 2100 feet northwest of the production well to a total depth of 1839 feet. This location was chosen to minimize thermal interference with the V.A. production well and BGL wells to the southeast, and the State Capitol Mall Wells to the south and southwest. Testing showed that this site was satisfactory for future injection of geothermal water from the V.A. space heating system. The test injection well was not capable of handling the anticipated flows, however, and the decision was made to construct a larger, deeper injection well at the same location.

ACKNOWLEDGEMENTS

Successful completion of this project is due in a large part to the competent and professional performance of Holman Drilling Company. Arnold "Skip" Holman and his crews were always helpful and accommodating through all phases of the project.

V.A. resident engineer Thomas Robinson was very helpful in many ways. The assistance of Larry Fettkether, of CH2M-Hill, is also appreciated.

Thanks are due to the Ada County Highway District for allowing disposal of development water in the storm sewer system. This resulted in more efficient development at a substantial cost savings.

A final acknowledgement is due the area residents who endured commotion and high noise levels, twenty-four hours per day, for more than a month. Their understanding was greatly appreciated.
CHAPTER 2

GEOLOGY

LOCAL GEOLOGY

Geology of the V.A. Medical Center area and the Boise Geothermal System is dominated by alternating lacustrine sediments and extrusive volcanics of Miocene to Pliocene age. These rocks and unconsolidated sediments are deposited upon, or faulted against, granitic rocks of the Idaho Batholith which make up the deep basement and the Boise Ridge.

The extrusive volcanics include flows and tuffs of both basaltic and silicic compositions. Silicic flows and tuffs, generally of rhyolitic composition, are part of the Miocene Idavada volcanic group. These silicic rocks are overlain by younger basalts of the Idaho group. Interbedded within and between these volcanic units are substantial thicknesses of sedimentary rocks and unconsolidated sediments. Above the Idavada volcanics, the sediments are considered to be part of the lower Idaho group. These sediments, both consolidated and unconsolidated, range in character from clay to coarse sand.

Volcanic and sedimentary units in the area are faulted along steeply dipping fault zones which parallel the break in slope between the foothills of the Boise Front and the floodplain of the Boise River. Fractures along these faults probably serve as conduits for deeply circulating thermal waters. Compartmentalizing of faulted units, a result of branching by these faults, results in complicated geologic environments.

WELL-SITE GEOLOGY AND HYDROGEOLOGY

Quaternary alluvial deposits were encountered during the first 82 feet of drilling. These sediments range from silts to coarse gravels. The upper 30 to 40 feet appear to be silts and sands of the Cottonwood Creek alluvial fan. Below this level, the sediments become coarser and cleaner, reflecting probable deposition by Boise River meandering and flooding. Static depth to water in this zone was approximately 32 feet.

Sediments of the lower Idaho group were encountered at 82 feet. These sediments, which consist of an alternating sequence of lacustrine (lake bed) sands, silts, and clays, extend to a depth of 549 feet, where the first basalt was encountered. Sand aquifers within these sediments are utilized as domestic aquifers, although the strong geothermal gradient in the area results in decreasing utilization with depth.

Basalt, first encountered at 549 feet, extends intermittently to a depth of about 1100 feet. Sediments of the lower Idaho group are found interbedded within and beneath the basalt. The basalt ranges in competence from hard, unaltered rock, to soft, clayey, weathered or altered rock.

Sedimentary clays were distinguished from altered basalt on the basis of gamma log response, as well as drilling rate and cuttings. Sedimentary clays are generally more radioactive than altered basalt because of the high potassium
feldspar content of the probable source—granitic rocks of the Idaho batholith. Altered basalt is low in radioactivity, drills slowly, and commonly contains basalt fragments.

The first silicic volcanics of the Miocene I davada group were encountered at about 1440 feet. As with the basalt encountered above, these volcanics range in competence from hard unaltered rock to soft weathered rock or ashy clays. The rock composition appears to range from dacite to andesite and varies from dark gray to gray in color. It is often porphyritic and contains abundant fracture filling material.

Medium- to coarse-grained, clean, arkosic sand was penetrated from 1800 to 1878 feet. This sand separates the dacites and andesites, above, from the more silicic rhyolitic volcanics found below 1878 feet. The rhyolite, probably a sequence of flows and welded tuffs, is light gray to white, often with small quartz phenocrysts. A very thick sequence, the rhyolite extends to an unknown depth below the bottom of the hole at 2300 feet.

Depth to water during development of the well ranged from several feet below ground surface, when the water column was cool, to about 12 feet above ground surface when the column was hot. The highest measured water temperature during development was 146°F.

Highly fractured silicic volcanics are generally the most productive aquifers of the Boise Geothermal System. Transmissivity in these volcanics is probably dependent on the fault-related fracture density. Additional aquifer transmissivity is found in sands, interbedded with the volcanics. At the V.A. injection well, transmissivity is thought to be approximately 60,000 gpd/ft. This value may be somewhat lower than the transmissivity found at other wells in the geothermal system. Possible explanations for this include lower fracture density in the volcanics and thinner sand interbeds.
CHAPTER 3
CHAPTER 3
WELL DRILLING AND CONSTRUCTION

UPPER HOLE DRILLING

Drilling of the V.A. Medical Center geothermal injection well began on October 23, 1986, approximately 100 feet east of the test injection well drilled in 1983. Holman Drilling of Spokane, Washington was the drilling contractor. A cable-tool drill rig was used to install a 22-inch diameter temporary surface casing. Installation of this casing to a total depth of 57 feet below ground surface was completed on November 3.

Set up of the direct circulation, mud rotary drill rig was completed on November 20. Rotary drilling began on November 21 when a 20-inch diameter hole was drilled from the bottom of the temporary surface casing to a depth of 140 feet.

Permanent 16-inch surface casing was set on November 22. This casing was cemented the next day using 175 sacks of Type I & II Portland Cement pumped through a float shoe. The 22-inch temporary surface casing was removed immediately after cementing. The cement then was allowed 56 hours to cure before drilling proceeded.

Drilling resumed on November 25 with a 12¾-inch bit. Drilling progressed rapidly through the Idaho Group sediments. The penetration rate averaged 1.95 min/ft from 140 to 546 feet.

Basalt was encountered from 546 feet to 719, and again from 872 to 1074. The basalt ranged in character from black, unaltered rock to weathered gray clay. Alternating beds of clay and sand were found both between and beneath the two basalt sections. The basalt drilled slowly, with penetration rates as low as 21 min/ft, but averaging 8.5 min/ft.

The bottom of the 12¾-inch hole at 1245 feet was reached at 1700 hours on November 30. No circulation losses were detected during drilling. Upon completion of that drilling phase, drilling fluid was circulated for two hours to clean the hole of cuttings. Drilling fluid viscosity and weight also were increased during this time to help stabilize the formations and prevent fluid loss. After the two hour circulation period, the hole was reamed to insure full diameter and alignment. After reaming, drilling fluid was circulated for two hours to further clean and condition the borehole.

Casing was run after cleaning and conditioning of the hole. The casing is 10-3/4 inch O.D. welded pipe with 0.365 inch wall thickness. Three weld passes were made at each connection to ensure a strong weld. Centralizers were installed at 100 foot intervals from the surface to 1220 feet. A 2-foot long, 10-5/8 inch O.D. float shoe was welded on the bottom of the casing string. Total length of the casing string was 1252.04 feet.

CEMENTING

The initial cementing job used the "stinger" method. This method involves the use of small diameter (2-3/8 inch) cement tubing or "stinger pipe" which is run down the
casing and plugs into the float shoe. A float shoe has a check valve which allows cement or fluid to be pumped outward into the borehole but will not allow the cement or fluid to enter the casing after the stinger pipe is removed. The advantage of this method is that cement can be pumped out the bottom of the casing string and up the annulus of the borehole until a good cement return is visible at the surface.

Halliburton Services began cementing at 0400 hours on December 2. At this time, the casing was hanging free enough in the borehole that it could be rotated by hand. Circulation to the surface through the stinger pipe was achieved with approximately 50 psi pressure. The pressure gradually increased as the cement began to rise in the borehole annulus. This pressure increase is due to the density difference between Halliburton Light cement (13.1 lb/gal) and the lighter drilling mud (9.3 lb/gal). After approximately 20 minutes of pumping time, a rapid increase in pressure followed by a sharp decrease in pressure was detected. Circulation to the surface was immediately lost at this time. Cement pumping continued until 160% of the calculated cement volume required for the job was expended, without restoring circulation.

A possible explanation for the pressure response and lost circulation is that cement encountered a bridge or barrier to flow which caused a pressure surge. This surge, along with the already high pressure due to the hydrostatic head of the cement column, caused the cement to break out into the formation, probably along a major fracture or discontinuity near the lower portion of the hole. A deep lost circulation zone is indicated because relatively low pressure was needed to pump the remaining cement after the circulation loss.

Flow to the surface before circulation loss appeared to be a mixture of drilling fluid and cement. A sample of this material did not contain enough cement to harden.

Because of the loss of circulation encountered during cementing, a cement-bond log was required by the State Department of Water Resources. This log, along with a natural gamma ray log, was run on December 4 at 1800 hours by Petrolog. This time lag allowed approximately 60 hours for cement curing. The gamma ray log was included to give a better definition of formation geology.

Results of the cement-bond logging indicated that a bond existed from 1005 to the bottom of the hole, with good bonding from 1098 to 1132. Above 1000 feet, cement bridges (possibly weak) were indicated at 952 to 957 feet and 740 to 750 feet.

Re-Cement Attempt No. 1

Because of the lack of grout seal between 1000 feet and the ground surface, indicated by the cement-bond log, the State required re-cementing of this zone. Re-cementing a zone such as this requires "squeezing", where perforations are made in the casing and cement is forced into the annulus under pressure. Pressure is achieved by placing a removable packer or drillable retainer above the perforations to prevent upward flow. Cement is pumped through the packer or retainer, down to the perforations, out into the annulus, and then upward to the surface.

Eight perforations (0.48 inch nominal diameter) were "shot" in the casing between 993 and 995 feet using an explosive perforating tool at 2100 hours on December 4. The rig went on stand-by at 12:00 A.M. on December 5th while waiting for Halliburton to arrive with a retainer or packer.
Halliburton arrived with a drillable retainer at 1800 hours on December 5. The retainer was set at 948 feet. Halliburton attempted to circulate to the surface with 500 psi but was unsuccessful. The formation was taking some fluid, therefore 50 sacks (14 bbls) of thixotropic cement were used to cement the perforated zone. Thixotropic cement is a fast setting cement which is drillable after twelve hours of curing time. Cementing was completed at 2230 hours.

Re-Cement Attempt No. 2

A meeting between representatives of Montgomery Engineers and the Department of Water Resources was held at 1000 hours on December 6 to decide the next step. The results of re-cementing attempt No. 1 indicated a good seal existed both above and below 995 feet, as indicated by the very low volume flow at 500 psi. However, the State required that the higher warm-water and domestic zones be isolated from each other. For this reason, and in the interest of better casing integrity and corrosion resistance, the decision was made to squeeze again above the bridge indicated by the cement-bond log at 745 feet.

Petrolog perforated the casing with 8 holes from 728 to 730 feet at 1230 hours on December 6. Halliburton began installation of a retrievable packer at 1300 hours. After several attempts to set this packer, it was pulled out of the hole. Subsequent examination of the packer revealed that it was the wrong size. Another packer was ordered at this time. Halliburton also agreed to compensate the V.A. for delays caused by the incorrect tool size.

The correct size retrievable packer arrived on-site at 0800 hours on December 7. It was set at 609 feet and a pump pressure of 300 psi was applied at 0915. The formation appeared to be taking water at a rate of about one barrel per minute (42 gpm) without circulating to the surface. The decision was made to cement the perforated zone and as much of the borehole annulus as possible above the perforations using 100 sacks (28 bbls) of thixotropic cement. Cementing was completed at 1050 hours.

Re-Cement Attempt No. 3

Due to the inability to circulate to the surface during re-cement attempt No. 2, a cement bond log was ordered to evaluate the cement bond above the perforations at 728 to 730 feet. This bond log was run at 1800 hours on December 7. It showed that the top of the cement-bond was at 610 feet, with no bonding between 610 feet and the surface. Since this amount of bonding was not acceptable to the State officials, a third squeeze cement attempt was ordered.

Following the bond logging, the perforating tool was used to shoot eight holes in the casing between 573 and 575 feet. The packer then was set and pumping began at 2015 hours. Pressure immediately built up to 400 psi without any flow. This indicated that the perforated zone may have already been cemented, but that the bond did not show on the bond log. Since the formation would not take any flow, it was assumed that this zone was adequately sealed. No cement was used because the perforated zone would not accept any flow.

Re-Cement Attempt No. 4

Although a probable bond was located around 575 feet by re-cement attempt No. 3, there was no reason to believe a bond existed opposite the V.A. domestic water
supply aquifer (above 475 feet). Therefore, in the interest of isolating this zone from the other domestic zones, as well as from any injection contamination, the decision was made to cement from the bottom of the V.A. domestic aquifer upward. Eight perforations were made between 468 and 470 feet at 2115 hours on December 7. The packer then was set and a pump pressure of 150 psi was applied with no flow. Flow was obtained by increasing the pressure to 250 psi. As with the other re-cementing attempts, no surface circulation was achieved. The decision was made to pump in 75 sacks (21 barrels) of thixotropic cement to seal off the V.A. domestic aquifer zone and as much borehole annulus as possible above that. Cementing was completed at 2315 hours.

Re-Cement Attempt No. 5

Immediately following re-cement attempt No. 4, representatives from Montgomery Engineers proposed to the Department of Water Resources officials on-site that cementing be completed by pressure cementing, from the surface, the annulus between the 10-3/4 inch casing and the 16-inch surface casing. If pressure cementing did not work, cement could be poured from the surface or injected using a 1-inch diameter tremie pipe after drilling was completed. This final cementing job would provide a seal to prevent groundwater contamination from the surface. This plan was approved shortly before midnight on December 7.

Pressure was applied to the annular space between the 10-3/4 inch and 16-inch casings at 0930 on December 8. No flow was obtained at 450 psi, therefore the decision was made to pour in a surface seal after drilling was completed. Halliburton Services was released at this time.

The final cementing took place after completion of the well on January 13, 1987. Portland cement was pumped down a 42-foot drop pipe until a return was visible at the surface.

Post-Cementing Procedure

Drilling of the drillable retainer and cement plugs within the 10-3/4 inch casing began at 1200 hours on December 8. Drilling was stopped at a depth of 1250 feet, just above the cement float shoe, at 0700 hours on December 9 in order to run a pressure test. This test was run in order to evaluate potential leakage through the various perforated zones. The test began at 1115 hours with 210 psi pressure, valves closed and pump off. After 30 minutes the pressure had gradually fallen to 150 psi, a drop of 2 psi/minute. It is unknown where leakage was occurring, through the perforations or through the float shoe. A minor amount of leakage from surface valves also was detected.

Assuming that the leakage rate is equivalent to the expansion of water at a pressure change of 2 psi/min., the amount of water leaking from the casing would be approximately .034 gal/min. This is calculated using the equation dVw = BVwdp:

Where
- \( dVw \) = volume change of water
- \( B \) = coefficient of compressibility of water
- \( Vw \) = initial volume of water
- \( dp \) = change in pressure

This calculation ignores any changes in pressure due to temperature changes. It also does not compensate for the higher than normal hydrostatic pressure lower in
the hole due to the density difference between the drilling fluid in the casing and the lighter water in the formation. However, it does indicate the low rate of leakage, which is acceptable because much of it may have been from surface valves and through the float shoe valve.

LOWER HOLE DRILLING

Drilling resumed at 1430 hours on December 9 with a 9 7/8-inch bit. Alternating zones of clay and sand were encountered from 1245 to 1330 feet. Volcanic rocks (basalt, andesite, and dacite) were penetrated from 1330 to 1800 feet. The rock varied in competence from hard, unaltered rock to soft, ashy clays.

Rhyolite of the lower volcanic zone was encountered at 1878 feet. This zone is separated from the more mafic upper volcanic zone by 80 feet of sand. Drilling was completed in this zone at a depth of 2300 at 1545 hours on December 13.

Installation of 1060 feet of slotted casing and 60 feet of blank 7-inch casing was completed on December 14 at 0600 hours. Slots are 3 inches long and 1/8-inch wide, with 16 slots per foot.
CHAPTER 4
DEVELOPMENT AND TESTING

DEVELOPMENT

Development began almost immediately after installation of the 7-inch diameter slotted casing. Initial development consisted of pumping approximately 12,000 gallons of clear water from the bottom of the hole upwards, to displace the drilling fluid. This water then was circulated for 12 hours to further clean the hole. Circulation of a second 12,000 gallons of clean water began at 0930 hours on December 15. Circulation was completed at 1530 hours. The static depth-to-water was 14 feet below ground surface at that time.

Air lifting began at 1930 hours on December 15 and continued intermittently until 2120 hours. Air lifting then was stopped because storage capacity for development water had been reached. At this time, the well was flowing approximately 50 gpm of cloudy, 140°F water. At 2230 hours, the well was shut in and the static water level rose to the height of the kelly bushing, or about 12 feet above ground surface. Development operations were shut down pending the removal of approximately 40,000 gallons of development water from the mud tanks and reserve pit.

Air lifting resumed at 1315 hours on December 16. Air lifting produced approximately 600 to 800 gpm for 15 minutes at 200 psi. At 1400 hours, the well was flowing slightly cloudy, 142°F water. At 1530 hours, the temperature was 137°F and the flow was clear.

Due to the lack of storage for air-lifted water, it was decided that circulation would be the most efficient method to further clean the well while the air-lifted water was being hauled away for disposal. Circulation might also indicate the extent of development in the lower portion of the well.

Circulation of clean, air-lifted water began at 1600 hours. At 1620 hours, the return flow became very muddy. This indicates that the clear water flowing from the well was probably coming from an upper part of the injection zone while the lower portion of the injection zone contained substantial amounts of drilling mud and fine formation material.

The circulation water cleared as the well began to clean up. Circulation continued until 1940 hours, with brief shutdowns as clean water was transferred from the doghouse reservoir to the mud tanks.

Following circulation, the well was air lifted for 22 minutes at 150 psi to flush out muddy circulation water. After air lifting, the well flowed 60 gpm at 134°F. At 2140 hours, the well was shut in and the mud tanks were dumped and cleaned.

At 2217 hours, air lifting resumed in order to fill the mud tanks with clean water for the injection test. Air lifting continued until 2243 hours at an average pressure of 175 psi and an approximate flow of 400 gpm. Following air lifting, the well was allowed to flow (65 gpm at 142°F) as the doghouse reservoir was filled. The well was shut in at 0100 hours on December 17.
An injection test was run intermittently from 0830 to 1130 hours. The results of
this test indicated that the well would not take the desired injection flow and
required further development.

The well was air lifted intermittently for 30 minutes between 1245 and 1420
hours, after the injection test. This relatively clear, air-lifted water was then
used to circulate through the hole from 1600 to 1900 hours. As with the previous
round of circulation, large amounts of clay and sand were produced from the
lower part of the hole, indicating that it had not cleaned up and might be plugged
by drilling fluid.

On December 18, the rig was shut down for the holidays. The total amount of
water used or produced during initial development was approximately 140,000
gallons.

Development was resumed on January 5, 1987. Circulation of CONDET, a
phosphate detergent and wetting agent, began at 1530 hours. CONDET is ef-
fec tive in breaking down drilling mud which has invaded the formation. Approx-
imately 15,000 gallons of CONDET solution was circulated for 15 hours. An
estimated 2000 gallons were injected into the formation.

Following CONDET circulation the hole was intermittently air lifted on January
6. Approximately 150,000 gallons of fluid was produced, of which 33,000 gallons
(which contained a considerable amount of mud and CONDET) were trucked
away for landfill disposal. The remaining clear water produced was piped into a
storm drain at 6th and Fort Streets.

A second batch of CONDET began circulating at 2130 hours on January 6. A
total of 8000 gallons of this solution was injected into the formation before air
lifting resumed at 1045 hours on January 7. A small amount of mud and a
considerable amount of fine sand was produced by air-lift pumping. On this date
240,000 gallons of fluid were produced by air lifting. Approximately 30,000
gallons of this fluid was trucked to the landfill for disposal.

TESTING

Due to limitations of adequate water supply, both from quantity and quality
standpoints, long-term or high rate injection testing was not possible. Instead,
short step-tests were run at rates of up to 580 gpm.

Testing equipment consisted of duplex mud pumps which pumped water stored in
the mud tanks. Total mud tank volume available for short-term testing was
approximately 9,000 gallons. Additional water storage was available in the
20,000 gallon reservoir beneath the doghouse. However, the maximum rate of
water transfer from the doghouse reservoir to the mud tanks was only 125 gpm,
which severely limited the amount of available water at high injection rates.

Injection flow rates were estimated on the basis of mud tank volume drop during
the tests. Rates were held constant by keeping the pump stroke rate constant.

Pressures were measured using a 200 psi pressure gage. This gage was initially
mounted on the drilling platform, between the kelly hose and the mud pumps.
However, in order to avoid the friction losses in the kelly hose and drill pipe, the
pressure gage was mounted on the blow-out-preventer for the final test. Injection pressures were estimated by averaging the high and low values of pressure gage needle fluctuations. These fluctuations, caused by pump piston strokes, were substantial. For instance, at 580 gpm, the pressure gage needle fluctuated between 34 and 60 psi at 11 minutes into the test.

The first injection test was run on December 17, 1986. A constant rate of 165 gpm was maintained for 68 minutes. Injection pressure increased steadily through this test, reaching a peak of 162 psi at 68 minutes. This test indicated the need for further development. Following this test, a test was run which determined that the head loss through the 5⅛-inch injection pipe was only 8 psi.

Following secondary development operations after the holiday break, an injection test was run beginning at 2100 hours on January 7. This test showed remarkable improvement in well performance in comparison to tests run before using CONDET. The test was run by injecting at rates of 240 gpm and 320 gpm through the 3⅜-inch drill pipe used for air lifting. Since high friction losses through the 3⅜-inch drill pipe were detected following this test, a final test was conducted injecting through the 5⅛-inch drill pipe with the pressure gage mounted on the blow-out-preventer.

The final injection test consisted of short steps at rates of 180, 220, 300, and 580 gpm. The 580 gpm step was maintained for eleven minutes. Injection pressure at the end of the 580 gpm step was estimated at 47 psi. Recovery was very rapid.
CHAPTER 5
CHAPTER 5
CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

No conclusive data is available to accurately predict how this well will behave at high injection rates during long-term injection periods. However, results of the final step-test indicate that the well should accept a flow of 900 gpm at an injection pressure of about 100 psi for a short period of time. Above 900 gpm, injection pressures will increase rapidly. A short term injection pressure range of 120 psi to 150 psi might be expected at 1000 gpm. At 1100 gpm, pressures of 160 to 180 psi are likely. Pressure responses at these high rates are difficult to predict due to turbulent flow losses in the aquifer(s) and high friction losses in and through the 7-inch casing.

Injection pressures can be expected to increase with time at a logarithmic rate. For instance, at the measured flow rate of 580 gpm, injection pressure increased at a rate of 18 psi per log cycle. Therefore, if this rate of pressure increase remains constant, the pressure of approximately 40 psi that was measured at 10 minutes might be expected to be 58 psi at 100 minutes, 76 psi at 1000 minutes, and so forth. At this rate, a pressure of 115 psi might be expected after 70 days (100,000 minutes) of continuous injection at 580 gpm. However, because transmissivity is shown to be higher locally, as observed in the test injection well, the rate of pressure increase over time may decline to less than 18 psi per log cycle.

RECOMMENDATIONS

Since the construction schedule for the V.A. heating system calls for a gradual switch to geothermal heat, high flow-rate injection testing, for a sustained time, should be made during the first year of operation before peak flows are required for space-heating purposes. The test should be designed to simulate typical operation of the heating system.

Monitoring of injection well pressures and flow rates should be done to discern any changes in well performance. Performance can be expected to decrease in the future if plugging of the aquifer occurs. Consequently, the geothermal water should stay in a closed system, with no contact with the atmosphere, and the only change to the water being a lowering of the temperature.
APPENDIX A

WELL SUMMARY DATA SHEET

Owner: Veterans Administration

Well: V.A. Medical Center Injection Well

Location: SW¼, NW¼, SW¼, Sec. 2, T3N, R2E, B.M.

Elevation: 2720 Ground Surface (Topo. Map)
2732 Kelly Bushing

Contractor: Holman Drilling Co.
Tool Pusher: Arnold Holman

Geologist: Terry Scanlan

Casing: 16-inch O.D.; 0.250-inch wall thickness; set at 151.0' K.B.;
cemented to surface with 175 sacks of Portland Type I & II
cement.

10-3/4-inch O.D.; 40.5 lb/ft set at 1252.0 K.B.; cemented from
bottom with 361 sacks of Halliburton light cement and 145 sacks
of Class H cement; squeeze cemented with 50 sacks of thixotropic
cement at 995 feet; squeeze cemented with 100 sacks of
thixotropic cement at 730 feet; squeeze cemented with 75 sacks
of thixotropic cement at 470 feet.

7-inch O.D.; 23 lb/ft; 1120 feet set at 2300; perforated 1240 to
2300; 16 slots per foot; 1/8-inch by 3-inch slots.

Logging: Petro-Log, Inc., Evanston, Wyoming

Drilling
Commenced: October 23, 1986

Drilling
Completed: December 13, 1986

Rig Released: January 8, 1987
APPENDIX B
PORTLAND CEMENT GROUT

16" O.D., 0.250" WALL THICKNESS CASING

10-3/4" O.D., 0.365" WALL THICKNESS CASING; CENTRALIZERS AT 100' INTERVALS

CEMENT GROUT TO 1240' (MAY BE INTERMITTENT)

LEFT HAND THREADS WITH CASING CENTRALIZER

7", 0.317" (23 lb) CASING, MILL SLOT PERFORATED WITH 16 PERFORATIONS PER FOOT AT 1/8" x 3"; CENTRALIZERS AT 100' INTERVALS

VETERANS ADMINISTRATION GEOTHERMAL INJECTION WELL
BOISE, IDAHO
## APPENDIX C

### DEVIATION AND TEMPERATURE RECORD

<table>
<thead>
<tr>
<th>Depth (ft. below K.B.)</th>
<th>Deviation (degrees from vertical)</th>
<th>Mud Temp. of (Down Hole)</th>
<th>Mud Temp. of (Return Flow)</th>
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</thead>
<tbody>
<tr>
<td>157</td>
<td>0°</td>
<td>72</td>
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<tr>
<td>251</td>
<td>3/4°</td>
<td>78</td>
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<tr>
<td>345</td>
<td>1/2°</td>
<td>90</td>
<td></td>
</tr>
<tr>
<td>469</td>
<td>7/8°</td>
<td>87</td>
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<td>569</td>
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<td></td>
<td>90</td>
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<tr>
<td>715</td>
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<td>96</td>
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<tr>
<td>864</td>
<td>1 1/2°</td>
<td>100</td>
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<tr>
<td>903</td>
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<td>1050</td>
<td>2°</td>
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<td>1618</td>
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<td></td>
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<td>1700</td>
<td>1 3/4°</td>
<td>118</td>
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<td>1745</td>
<td></td>
<td></td>
<td>104</td>
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<td>2281</td>
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<tr>
<td>2275</td>
<td>2 1/4°</td>
<td>134</td>
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<td>2312</td>
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**Note:** Peak temperature of air-lifted water during development was 146°F.
# APPENDIX D

## BIT RECORD

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<tr>
<th>Bit Number</th>
<th>Date</th>
<th>Footage In (K.B.)</th>
<th>Footage Out (K.B.)</th>
<th>Total Footage</th>
<th>Total Hours</th>
<th>Size and Type</th>
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<tr>
<td>1</td>
<td>11/21/86</td>
<td>59</td>
<td>152</td>
<td>93</td>
<td>10</td>
<td>20-inch, HTC 3J</td>
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<tr>
<td>2</td>
<td>11/25/86</td>
<td>152</td>
<td>913</td>
<td>761</td>
<td>39 1/4</td>
<td>12 1/4-inch, Smith F4</td>
</tr>
<tr>
<td>3</td>
<td>11/28/86</td>
<td>913</td>
<td>1257</td>
<td>344</td>
<td>59</td>
<td>12 1/4-inch, Smith F33</td>
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<td>4</td>
<td>12/09/86</td>
<td>1257</td>
<td>2132</td>
<td>875</td>
<td>67 3/4</td>
<td>9 7/8-inch, Smith F4</td>
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<td>5</td>
<td>12/13/86</td>
<td>2132</td>
<td>2312</td>
<td>180</td>
<td>12 1/2</td>
<td>9 7/8-inch, Reed Sm 62J</td>
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## APPENDIX E

### DRILLING RATES

(Minutes/Foot)

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<th>30-40</th>
<th>40-50</th>
<th>50-60</th>
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<th>70-80</th>
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<td>100-200</td>
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</table>
APPENDIX F
WATER QUALITY

A water sample was collected on the morning of January 3, following air lifting. Representative water quality constituents were determined using a Hach Chemical Co. DR-EL/4 portable test kit. Results of this analysis are shown below.

Silica  -  115 mg/l
Sulfate  -  18 mg/l
Fluoride  -  14 mg/l
Hardness  -  7 mg/l
Alkalinity (methyl orange)  -  80 mg/l
pH  -  8.3
Specific conductance  -  420 micromhos/cm
## APPENDIX G

### LITHOLOGIC LOG

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<thead>
<tr>
<th>Depth</th>
<th>Description</th>
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<td>0</td>
<td>Kelly Bushing (K.B.); elevation 2732 (assumed).</td>
</tr>
<tr>
<td>12</td>
<td>Ground Surface.</td>
</tr>
<tr>
<td>12-22</td>
<td>Silt and sand - brown silt with medium grain sand; poorly sorted with occasional pebble or rock fragment; primarily quartz sand.</td>
</tr>
<tr>
<td>22-32</td>
<td>Silty sand - course, oxidized, angular; mainly quartz and feldspar grains with some lithic grains.</td>
</tr>
<tr>
<td>32-42</td>
<td>Sand - medium to coarse, poorly sorted, abundant rock fragments; silty.</td>
</tr>
<tr>
<td>42-52</td>
<td>Sand - coarse, poorly sorted; quartz and feldspar with abundant lithic (granite and basalt) fragments; angular; oxidized feldspar grains; 30 percent pea gravel from 34-35 feet.</td>
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<tr>
<td>52-60</td>
<td>Sandy gravel to gravelly sand - 50 percent coarse sand, 50 percent gravel; sand is as above; gravel is primarily angular rock fragments (granite and basalt).</td>
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<tr>
<td>60-80</td>
<td>Lithic sand - coarse, gravelly, angular, clean; 50 percent rock fragments (granite and basalt) and 50 percent quartz sand.</td>
</tr>
<tr>
<td>80-94</td>
<td>Sandy gravel - poorly sorted, clean, broken; primarily granite with lesser amounts of basalt.</td>
</tr>
<tr>
<td>94-110</td>
<td>Sand - medium grain quartz sand; unoxidized, fair sorting, minor amounts of muscovite; top of Idaho Group lacustrine sediments.</td>
</tr>
<tr>
<td>110-130</td>
<td>As above - but slightly clayey and coarser (medium to coarse grained).</td>
</tr>
<tr>
<td>130-151</td>
<td>As above - with minor amounts of interbedded dark brown silt.</td>
</tr>
<tr>
<td>151-210</td>
<td>Clayey silt - dark brown, slightly sandy, soft.</td>
</tr>
<tr>
<td>210-220</td>
<td>As above - with less clay and sand; dark gray brown.</td>
</tr>
<tr>
<td>220-250</td>
<td>As above - dark gray, soft, with some sand.</td>
</tr>
<tr>
<td>250-260</td>
<td>As above - brownish gray color; becomes more plastic below 260.</td>
</tr>
</tbody>
</table>
260-270  Silty clay - as above.
270-300  As above - less than 10 percent sand.
300-310  As above - slightly firmer.
310-326  As above - very little sand.
326-346  Sand - coarse quartz sand; clean; well sorted; subrounded to subangular; gray to white color.
346-364  Sandy clay - gray silty clay with 20 percent quartz sand (may be mixed in from 326-346 zone).
364-408  Sand - medium to coarse grain quartz sand with a trace of muscovite; clean; fair sorting; subrounded to subangular grains; gamma log shows clay from 381-383.
408-414  Silty clay - gray, soft; abundant sand.
414-432  Sand - coarse quartz sand; poorly sorted with sub-rounded grains; minor fragments of basalt and granite.
432-437  Clayey sand - gray clayey quartz sand; medium to coarse grained with abundant lithic fragments.
437-476  Sand - medium to fine grain sand; poorly sorted; subangular; abundant lithic fragments (mainly dark gray basalt); 80 percent quartz grains.
476-510  Silty clay - soft, gray, silty clay with minor amounts of sand.
510-520  Clay - firm gray clay with little or no sand.
520-532  Sandy clay - soft, gray clay with approximately 20 percent medium grain sand.
532-546  Sandy clay - greenish gray clay with less than 20 percent sand; soft; trace pyrite.
546-561  Sand - medium to coarse quartz sand; subangular; gray; minor amounts of green siliceous grains and basalt fragments.
561-602  Basalt - black basalt; hard, unaltered; abundant green and white siliceous vesicle and fracture fillings; rock is fine grained to aphanitic.
602-624  Basalt - altered, dark reddish brown to black color; slightly clayey at times; abundant green and white siliceous fracture filling as above; also some rust colored coatings or fillings.
624-630  Clay - gray, soft, probably altered or weathered basalt.
630-638 Basalt - hard, black; abundant clay; altered.

638-670 Clay - soft dark gray with varying amounts of basalt fragments; probably altered or weathered basalt; gamma shows sedimentary clay (?) from 656-664.

670-697 Basalt - hard, black; slightly altered with minor amounts of pyrite and white fracture filling material.

697-712 Clay - probably highly altered basalt; redish gray clay with soft green (calcareous?) fracture fillings, white coatings or fillings and reddish brown siliceous (?) fragments.

712-728 Basalt - black to dark gray basalt; hard; abundant soft (calcareous?) and hard (siliceous?) fracture filling material; also abundant reddish brown siliceous fragments.

728-734 Clay - gray with abundant basalt fragments and fracture fillings; may be altered basalt.

734-748 Sand - coarse, very clean, well sorted quartz sand; sub-rounded grains; un cemented; drills very fast.

748-780 Sandy clay - gray and brown silty clay with varying (10-50%) amounts of sand; sand is quartz sand and lithic fragments.

780-818 Clay and sand - probably interbedded; gamma log shows clay at 776-780, 792-803, 808-811, 816-818; clay is gray and brown silty clay; sand is gray, poorly to moderately sorted, fine to coarse quartz sand with abundant lithic fragments; subangular.

818-840 Sand - poorly sorted, medium grain quartz sand with minor amounts of lithic fragments and muscovite.

840-876 Sandy clay - soft, brownish-gray clay with 30 to 40 percent sand below 850 feet.

876-884 Clay - greenish-gray and reddish-gray in color.

884-905 Altered basalt - clay with basalt fragments; firm; drills slow.

905-919 Basalt - black, clayey; slightly altered; drills slow.

919-1005 Basalt - black, hard; unaltered; drills slow; minor amounts of green and red siliceous (?) fracture filling material; drills faster from 946-952.

1005-1008 Clay - reddish brown altered basalt (flow top or cinders?); abundant basalt fragments.

1008-1015 Basalt - hard, black, as above; abundant red basalt fragments.
Clay - dark gray clay; probably altered basalt; red and light gray clay common (to 1040 and below 1060) with abundant basalt fragments; blue gray and green gray clay common from 1040 to 1060 with minor rock fragments.

Clay - gray with lesser amounts of blue gray and green gray clay; firmer; drills up in "chunks" with no sand or rock fragments; drills faster.

Sand - fine to coarse grained quartz sand; slightly clayey; poorly sorted.

As above - with 40 percent clay.

Sandy clay - grades from 40 percent to 80 percent clay.

Clay - dark gray clay with minor basalt fragments; may be altered basalt.

As above - but lighter gray; minor amounts of blue-gray clay.

As above - with mudstone or highly altered basalt fragments.

As above - with minor amounts of gray, altered basalt (?) and fracture filling material.

As above - with increased basalt fragments; some reddish-gray and light gray clay.

As above - with 10 percent basalt and green andesite (?) fragments.

Sand - coarse, poorly sorted quartz and lithic sand; clayey.

Clay - brown, sandy.

Clay and sand - soft green gray and blue clay with interbedded (?), poorly sorted, angular quartz sand; clay becoming mainly reddish-brown color below 1275.

Sand - clean, medium to coarse quartz sand with minor muscovite.

Clay - soft sandy clay; blue-gray to green-gray in color.

Clay - gray-brown silty clay; very soft, low plasticity; with lesser amounts of firm, plastic, blue clay; grades into clayey sand below 1330.

Basaltic tuff (?) - weathered; clayey; dark brown grading into black less weathered basalt tuff below 1350; in red clay matrix; primarily red clay 1380-1390, 1410-1420; black clay matrix below 1430; considerable amounts of intermixed sand at times.
1440-1470  Clay – altered volcanic rock or tuff; gray with abundant fracture filling material (red, green and white).

1470-1510  Dacite (?) – light gray volcanic rock; porphyritic with abundant fracture filling material (red).

1510-1520  Clay – altered volcanic rock (as above).

1520-1530  Basalt (?) – black volcanic rock; grades into andesite (?).

1530-1560  Andesite (?) – Dark gray volcanic rock with lesser amounts of light gray volcanic rock; porphyritic with abundant red siliceous fracture fillings and lesser amounts of green fracture filling.

1560-1570  Clay – volcanic rock altered to gray clay; possibly tuff or ash.

1570-1645  Basalt – glassy, black, hard basalt with minor amounts of gray clay and red fracture filling; below 1610, minor amounts of gray porphyritic rhyolite and abundant red, green, and brown fracture fillings.

1645-1700  Andesite or Dacite (?) – dark gray volcanic rock with abundant fracture fillings.

1700-1710  Clay – gray altered volcanic; may be tuff or ash; soft; some volcanic rock fragments.

1710-1791  Dacite (?) – Gray volcanic rock with abundant red siliceous fracture filling; dark and glassy at 1710-1720; becoming slightly clayey below 1780.

1791-1798  Clay – altered gray volcanic rock (as above) with numerous rock fragments; very soft; non-plastic.

1798-1812  Clay – very soft, brown-gray clay with abundant volcanic rock fragments; probably altered rhyolite or tuff.

1812-1890  Sand – medium grain arkosic sand with abundant lithic fragments; clean; grades to coarse sand below 1840.

1890-2312  Rhyolite – light gray to white rhyolite; may be welded tuff; becoming gray below 2000; chips occasionally show some flow banding; occasional small quartz phenocrysts; occasional thin beds or bands of dark chocolate brown fracture filling; hard; drills relatively fast (2–6 min/ft).
APPENDIX H

DAILY WELL HISTORY

10/21 - 10/22  Move on to site with cable tool rig and set up.
10/23 - 11/3  Drill and drive 22-inch temporary surface casing to 57 feet.
11/17 - 11/19 Move on to site with rotary rig and set up.
11/20        Complete set up and drill rat hole; static depth to water is 32 feet.
11/21        Drill to 140 with 20-inch bit.
11/22        Ream hole and set 16-inch surface casing.
11/23        Cement casing using float shoe and 175 sacks of Type I & II Portland cement; 56 hours allowed for cement set-up.
11/25        Drill 140 to 333 with 12 3/4-inch bit.
11/26        Drill 333 to 588; trip out to check bit at 585; bit judged satisfactory.
11/27        Drill 588 to 901; trip out for bit change at 901.
11/28        Trip in with bit #3; drill 901-1009.
11/29        Drill 1009 to 1125.
11/30        Drill 1125 to 1245; circulate to condition hole 2 hours, short trip, circulate to condition hole 2 hours; trip out.
12/1         Run 10 3/4-inch casing; centralizer every 100 feet.
12/2         Halliburton attempts to cement casing through float shoe; circulation lost after 20 minutes; cement appears to have broken out in lower part of the hole.
12/3         Waiting on cement.
12/4         Cement bond and natural gamma logs run by Petrolog. First attempt to run tools blocked by heavy mud at 568 feet. Trip in and circulate clear water to clean out casing. Second attempt to run logs is successful. Cement bond log shows very little cement above 1000 feet and mediocre bond below 1000 feet. Petrolog runs casing perforator tool and perforates two rounds of four holes (0.48-inch nominal diameter) each at 993 to 995. Attempt is made to circulate but flange gasket on well head blows at 300 psi. Crews go on standby at midnight.
Set a retainer (EZDRILL Squeeze Packer) at 948 feet. Pumped water at 500 psi through perforations at 995-993 without pumping to the surface. Pumped in 14 bbls (50 sacks) of thixotropic cement.

Perforated casing at 728-730 feet with 8 holes (0.48-inch nominal diameter). Attempted to set a packer but found that Halliburton had brought the wrong size.

Correct size packer arrives at 0800 hours and is set at 609 feet. Packer is a RTTS (Retrievable Treat Test Squeeze) Packer. Began pumping water through the 728-730 feet perforations at 0915 hours at 300 psi and approximately 1 bbl per minute. Water followed by 100 sacks (28 bbls) of thixotropic cement. No surface return.

Packer removed at 1730 hours. Cement bond log run at 1800 hours showing top of cement at 610 feet. Ran perforating tool and shot 8 holes at 575-573. Set packer and pressured up to 400 psi with no flow at 2015 hours.

Pulled packer and ran perforating tool. Shot 8 holes a 468-470 at 2115 hours. Set packer and pressured up at 150 psi with no flow. Flow began at 250 psi but with no surface return. Pumped 75 sacks (21 bbls) of thixotropic cement at 2245 hours.

Pulled out packer at 0830 hours. Attempted to pressure cement the annulus from the surface at 450 psi without any flow. Trip in with bit #4; drill retainer from 1530 hours to 2400 hours.

Finish drilling retainer and cement at 0700. Pressure test casing from 1115 to 1200 hours at 210 psi. Pressure dropped to 150 psi after 30 minutes. Trip in hole at 1200 hours and drill to 1442 with 9 7/8-inch bit.

Drill 1442 feet to 1678 feet.

Drill 1678 feet to 1898 feet.

Drill 1898 feet to 2132 feet. Trip out for bit #5.

Trip in bit #5. Drill 2132 to 2312. Begin running 7-inch casing at 2200 hours.

Finish setting 7-inch at 0600 hours. Trip in 3 1/2-inch drill pipe and begin mud displacement at 2130 hours.

Circulate until 1530 hours; 24,000 gallons of water used for mud displacement and circulation. Air lift for 50 minutes between 1930 hours and 2120 hours. Well flowing approximately 50 gpm of cloudy, 140°F water at 2120 hours. Suspend development at 2230 pending water disposal.

H-2
12/16 Resume air lifting at 1315 hours for 15 minutes at 600-800 gpm. Circulate from 1600 to 1940 hours. Air lift for a total of 48 minutes between 1940 and 2300 to clean hole and fill mud tanks with clean water.

12/17 Run injection test from 0830 to 1130 hours. Air lift for 30 minutes between 1245 and 1420 hours. Circulate from 1600 to 1900 hours. Run injection head loss test from 2230 to 2300 hours. Shut down at 2300 hours.

1/5/87 Resume development operations. Begin circulating CONDET (25 gallons blended with 15,000 gallons water) at 1530 hours. Pressure inject 2000 gallons of CONDET mixture into information at 2100 hours. Continue circulation.

1/6 Stop circulation at 0630 hours. Begin air lifting at 0850 hours. Dispose of approximately 30,000 gallons of soapy water to landfill. Begin air lifting for storm drain disposal at 1145 hours. Pumping +325 gpm to Fort Street storm drain. Injection test at 1500-1600 hours. Continue intermittent air lift development until 2015 hours. Trip to bottom of hole. Begin circulation of batch #2 of CONDET at 2130 hours. Pressure inject 4000 gallons of mixture into formation at 2330 hours. Continue circulation of CONDET. Total amount of water produced by air lifting on 1/6/87 is 150,000 gallons.

1/7 Inject 4000 gallons of CONDET mix at 0830. Short trip for air lift. Air lift 30,000 gallons of soapy water for landfill disposal at 1045 hours. Begin intermittent air lift and storm drain disposal (325 gpm) at 1200 hours. Injection test 2100-2330 hours. Total air lifted water produced on 1/7/86 is 240,000 gallons.

1/8 Run friction loss test 0030 to 0115 hours. Resume air lifting and storm drain disposal at 0145. Run final injection test 0830 to 0930. Begin rigging down at 1200 hours.

1/13 Cement annular space between 16-inch casing and 10 3/4-inch casing from the surface through a 42-foot drop pipe.
**WELL TEST**

Date: January 8, 1987  
Tested by: Holman Drilling  

Well: V.A. Injection Well  
Supervised by: TMS/GEK  

Pumping Equipment: One duplex mud pump through 60 feet of 5 1/2-inch drill pipe  

Measuring Device: Volumetric for flow; 200 psi gage for pressure  

<table>
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<th>Time</th>
<th>Pressure</th>
<th>Discharge</th>
<th>Remarks</th>
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<td>10</td>
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<td>0906</td>
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<td>Gage bottomed</td>
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**WELL TEST**

Date: January 8, 1987

Tested by Holman Drilling

Well: V.A. Injection Well

Supervised by TMS/JEK

Pumping Equipment: Two duplex mud pumps through 60 feet of 5 1/2-inch drill pipe

Measuring Device: Volumetric for flow; 200 psi gage for pressure

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I-2