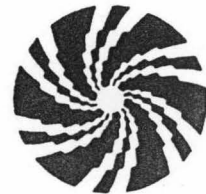


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DIV. OF WATER &
LAND DEVELOPMENT

April 28, 1991

Dr. John Lewin, M.D.
Director
State of Hawaii
Department of Health
P.O. Box 3378
Honolulu, Hawaii 96801

Dear Dr. Lewin:

Pursuant to Underground Injection Control (UIC) Permit Application No. 1529, Puna Geothermal Venture (PGV) is required to submit to and receive approval from DOH for a Casing Monitoring Program (CMP). PGV is herewith submitting the CMP for all existing and planned wells in the PGV well field. The enclosed plan is designed to assure well casing integrity during drilling, testing, and routine operations so that ground water contamination from geothermal brine or injectate is prevented.

If you have any questions that may assist in your review and approval, please do not hesitate to contact me.

Respectfully,
PUNA GEOTHERMAL VENTURE

William Teplow
Field Manager

cc: Chauncey Hew, DOH
✓ Dean Nekano, DLNR
Eric Tanaka, DLNR
M. Richard
N. Clark
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PRODUCTION AND INJECTION WELL
CASING MONITORING PROGRAM

1 INTRODUCTION

1.1 Background

Pursuant to Underground Injection Control (UIC) Permit No. UH-1529, the Hawaii State Department of Health (DOH) requires Puna Geothermal Venture (PGV) to develop a Casing Monitoring Program (CMP). This program is to be submitted to and approved by DOH prior to start of operation of injection wells drilled under permit UH-1529.

1.2 Purpose

The purpose of this CMP is to specify the observations, tests, drilling operations, and if necessary, remedial actions required to insure that the integrity of production and injection casing remains intact throughout the drilling, testing, and operation of PGV wells. The cemented and hung casing strings that are used in the PGV wells are designed to prevent contamination of shallow aquifers by either reservoir fluid in production wells or power plant effluent in injection wells. Contamination of the shallow aquifers might occur if the casing strings are breached due to corrosion or mechanical failure thus allowing the escape of geothermal brine or injectate to the formation. The casing monitoring program described below is designed to indicate the presence of casing leaks and accurately define their location. Remedial actions required to fix the casing leaks are also described.

1.3 Scope

This CMP covers all production and injection wells drilled by PGV and all existing wells that were drilled by previous operators on the 500 acre PGV site which to date have not been plugged and abandoned.

1.4 Hydrogeologic Basis for the Casing Monitoring Program

The hydrogeologic basis for the CMP is derived from data available from the drilling of 5 production wells to depths ranging from 6500' to 8000' and by two shallow monitoring wells drilled to depths of 640' and 720' (Figure 1).

Based on static temperature profiles, well testing, and behavior of drilling fluid during drilling, it is possible to divide the hydrologic regime in the project area into five major horizontally extensive zones. These zones are reflected in the typical temperature-depth profiles measured in the deep production wells (Figure 2).

- 1.4.1 The shallowest zone extending from surface to about 6' above sea level is unsaturated and consists of a highly permeable sequence of subareal basalt flows and interflow breccias. Within the project area this zone varies in thickness from 600' to 720' depending on the surface elevation. Numerous cracks with widths of up to 2' traverse the area. These cracks are vertical or very steeply dipping and reach from the surface to at least the top of the warm unconfined aquifer described below. This is evidenced by the discharge of warm, moist air from many of these cracks. The cracks trend parallel to the major structures and lineaments of the Lower East Rift Zone.
- 1.4.2 The zone below the unsaturated surface rock consists of an unconfined aquifer which contains relatively fresh ground water with varying degrees of natural contamination from the underlying geothermal system. This zone is approximately 1400' thick with the water surface elevation controlled by sea level according to the Ghyben-Herzberg model. The temperature of this zone ranges from 95 to 130 deg.F in the project area and tends to be nearly isothermal throughout the entire interval indicating good vertical mixing. A detailed description of this aquifer is given in the Puna Geothermal Venture Hydrologic Monitoring Program submitted to DOH in April 1990.
- 1.4.3 The interval from 1400' below sea level to 2400' below sea level is characterized by an extremely steep thermal gradient in the range of 30 deg.F/100' or more. This zone appears to have very low permeability and hence a very high conductive thermal gradient. The zone appears to be an effective aquitard separating the high temperature geothermal fluid below from the low temperature unconfined aquifer overlying it. Locally the aquitard may be breached as in the area of KS-7 and GTW-III where anomalously high shallow ground water temperatures and salinities are observed.
- 1.4.4 Between the depth interval 2400' and 3400' below sea level, the temperature profile indicates that existence of a transition zone which consists of alternating

permeable and impermeable strata. Within this zone are two or more alternating zones of high thermal gradients and isothermal intervals. The high average thermal gradient though this zone indicates that vertical fluid circulation is very limited.

- 1.4.5 Below a depth of 4400' below sea level, the temperature profile becomes nearly isothermal. This interval is within the geothermal reservoir in which significant vertical movement of fluid is taking place at temperatures above 620 deg.F.

The casing program planned for the production and injection wells calls for cemented casing to reach from ground surface to a depth of 3400 below sea level (Figures 3 and 4). This allows the casing to be anchored securely within the transition zone described in 1.4.4 and to fully isolate the geothermal reservoir from the shallow aquifer with a cemented interval through the aquitard. Within the shallow aquifer zone, two cemented casing strings are installed. Three cemented strings pass through the top of the shallow aquifer and the unsaturated zone. The production and injection casing programs are designed to prevent leakage of geothermal fluid from the wellbore into the shallow aquifer above a depth of 1400' below sea level. The CMP discussed below provides the methods and procedures necessary to detect any leakage and to repair those leaks if detected.

2. PRODUCTION WELL CASING MONITORING PROGRAM

2.1 Pressure testing during drilling.

Each production well is completed with three casing strings cemented to the surface (Figure 3). Immediately upon completion of cementing each casing string and prior to drilling out the cement shoe, the casing will be pressure tested. The test will consist of pressurizing the casing to 600 psi and holding for 30 minutes. The pressure drop during the 30 minute period shall not exceed 10%. In the event that significant bleed-off occurs that is not attributable to surface equipment leakage, a cement plug will be set at the casing shoe and the casing retested. If the leak persists, casing inspection logs will be run. These logs will include a temperature survey while injecting and a magnetic and multi-arm caliper casing inspection tool. After identification of the point of leakage, a cement squeeze job will be performed and the casing retested. Results of each pressure test will be reported to the Department of Land and Natural Resources (DLNR) and DOH.

2.2 Monitoring During Injection Testing.

Upon completion of each production well an injection test may be performed to give an initial indication of reservoir permeability. The injection test consists of pumping cool fresh water into the wellbore at several controlled rates while monitoring downhole and wellhead pressure. Temperature-pressure-spinner (TPS) logs are also run during the test. These logs can be used to locate leaks in the casing by noting a sudden rise in temperature with depth within the casing string. Also a temperature reversal within the casing string that remains after cessation of injection may be indicative of leakage. In the event that a leak is indicated by the temperature profile during or after injection, a magnetic and multi-arm casing inspection log will be run to more precisely locate the casing defect.

2.3 Monitoring During Flow Testing.

During flow testing of each production well, wellhead temperature and pressure along with steam and brine flow rate and chemistry are continuously monitored. After the initial 24 hours of flow, flow characteristics tend to be stable. Sudden changes in the wellhead pressure, temperature, brine/steam ratio, or brine chemistry during stabilized flow can be indicative of a casing failure which is allowing cool water leakage into the wellbore.

Also during flow testing, TPS logs are periodically run. Leakage of cool water into the well bore or loss of fluid due to casing failure may be seen in the TPS logs as a sharp change in flow rate and temperature above or below a certain point in the casing. In the event that wellhead or logging data indicate casing failure during the flow test, the well will be shut in and a magnetic and multi-arm casing inspection tool will be run to aid in precisely locating the leak.

2.4 Monitoring During Production.

Wellhead pressure and temperature will be monitored daily during normal production. Brine and steam chemistry will also be analyzed for each production well. Initially samples will be taken weekly to establish a baseline geothermal fluid chemistry. The sampling frequency will then be reduced to monthly and quarterly as stabilization of the fluid chemistry is confirmed.

Casing failure causing leakage of cool ground water into the wellbore or loss of geothermal fluid to the formation may be manifested as a pressure and temperature drop at the wellhead. Fluid chemistry changes may also indicate ground water leakage. Wellhead pressure, temperature, and chemistry data will be reported to the DOH quarterly on a routine basis.

In the event that anomalous production parameters are observed, a TPS survey will be run with the well flowing. The TPS profiles will be used to determine whether the observed changes are due to changes in reservoir characteristics or are caused by casing failure and leakage. In the event of casing leakage, the TPS surveys will be used to locate the point of failure.

2.5 Casing Repair.

Once a casing failure causing leakage is identified and approximately located, casing repair procedures will be initiated. These procedures may include any or all of the following activities depending on whether the well is being produced or is still in the testing phase or shut-in:

- 2.5.1 Shut in well and run magnetic and multi-arm casing inspection tools to precisely locate leak.
- 2.5.2 Rig up workover rig on well. Use casing packer to pressure test suspected leaking interval.
- 2.5.3 Execute cement squeeze job in leaking interval.
- 2.5.4 Repeat pressure test. If good, move rig off well and return well to production.
- 2.5.5 In the event of major casing failure, a 7" cemented liner may be installed through the damaged interval.
- 2.5.6 Prior to drilling out the 7" shoe, the liner will be pressure tested to 600 psi for 30 minutes.

3 INJECTION WELL CASING MONITORING PROGRAM

3.1 Pressure Testing During Drilling.

The cemented casing string design in PGV injection wells (Figure 4) is similar to that of production wells. Pressure testing of each string will proceed as described in 2.1 above.

3.2 Monitoring During Injection Testing.

Prior to installation of the stainless steel hangdown liner, an injection test will be performed to measure injectivity of the open formation below the cemented 9-5/8" casing. During the test, TPS traverses will be made. The resulting data will confirm whether all the injected fluid is exiting the casing shoe or is leaking through the casing into the formation. If the results of the injection test confirm that the casing is intact, then the stainless steel 7" liner will be hung from the casing head. If

leakage is found, repair procedures as described in 3.4 will be performed.

3.3 Monitoring During Routine Injection.

During routine injection the 7" X 9-5/8" annulus will be continuously purged with deoxygenated water at a constant flowrate and pressure. A TPS survey will be run annually in the 7" liner. This survey will verify that all injectate is exiting the 7" liner at the shoe. Leakage may also cause an anomalous temperature profile which can be observed by the survey. Once annually a pump-down test will be performed on the 7" X 9-5/8" annulus. Compressed air will be injected into the annulus to a pressure of 600 psi and shut in for 30 minutes. Bleed-off of the pressure will be observed. If bleed-off exceeds 10% in the 30 minute period then leakage in the pumped-down interval may be occurring.

In addition, purge pressure and flowrate into the liner annulus at the wellhead will be monitored weekly. Leakage in the 9-5/8" casing will cause a drop in annular wellhead pressure as well as in the wellhead pressure of the main injection stream passing through the 7" liner.

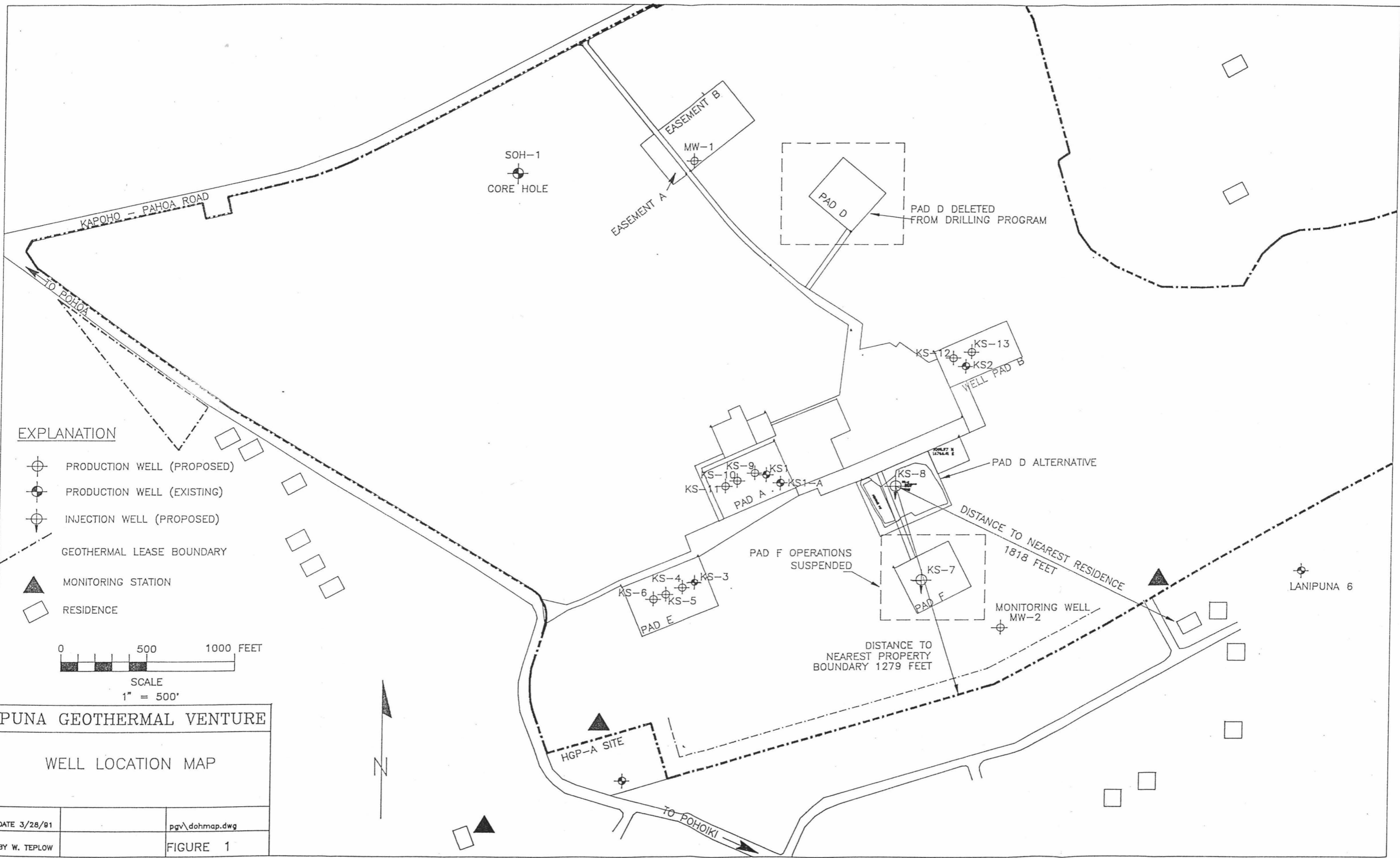
3.4 Casing Repair.

In the event that wellhead monitoring, pressure testing and TPS logs indicate that leakage is occurring, the following procedures will be followed:

- 3.4.1 Take well out of service and move rig on the well.
- 3.4.2 Pull the 7" stainless liner.
- 3.4.3 Run TPS and magnetic and multi-arm casing inspection tools.
- 3.4.4 Perform cement squeeze job in the leaking interval identified by the logging.
- 3.4.5 Pressure test casing to 600 psi using an inflatable casing packer.
- 3.4.6 Reinstall 7" liner and return the well to service.

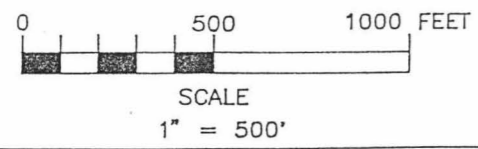
4 LIST OF FIGURES

- 4.1 Figure 1: Location Map Showing Wells
- 4.2 Figure 2: Typical Production Well Temperature Profile
- 4.3 Figure 3: Production Well Casing Schematic
- 4.4 Figure 4: Injection Well Casing Schematic



EXPLANATION

- PRODUCTION WELL (PROPOSED)
- PRODUCTION WELL (EXISTING)
- INJECTION WELL (PROPOSED)
- GEOTHERMAL LEASE BOUNDARY
- MONITORING STATION
- RESIDENCE



PUNA GEOTHERMAL VENTURE

WELL LOCATION MAP

DATE 3/28/81	pgv\dohmap.dwg
BY W. TEPLow	FIGURE 1

PUNA GEOTHERMAL VENTURE KS-3 STATIC AND FLOWING TEMPERATURE PROFILES

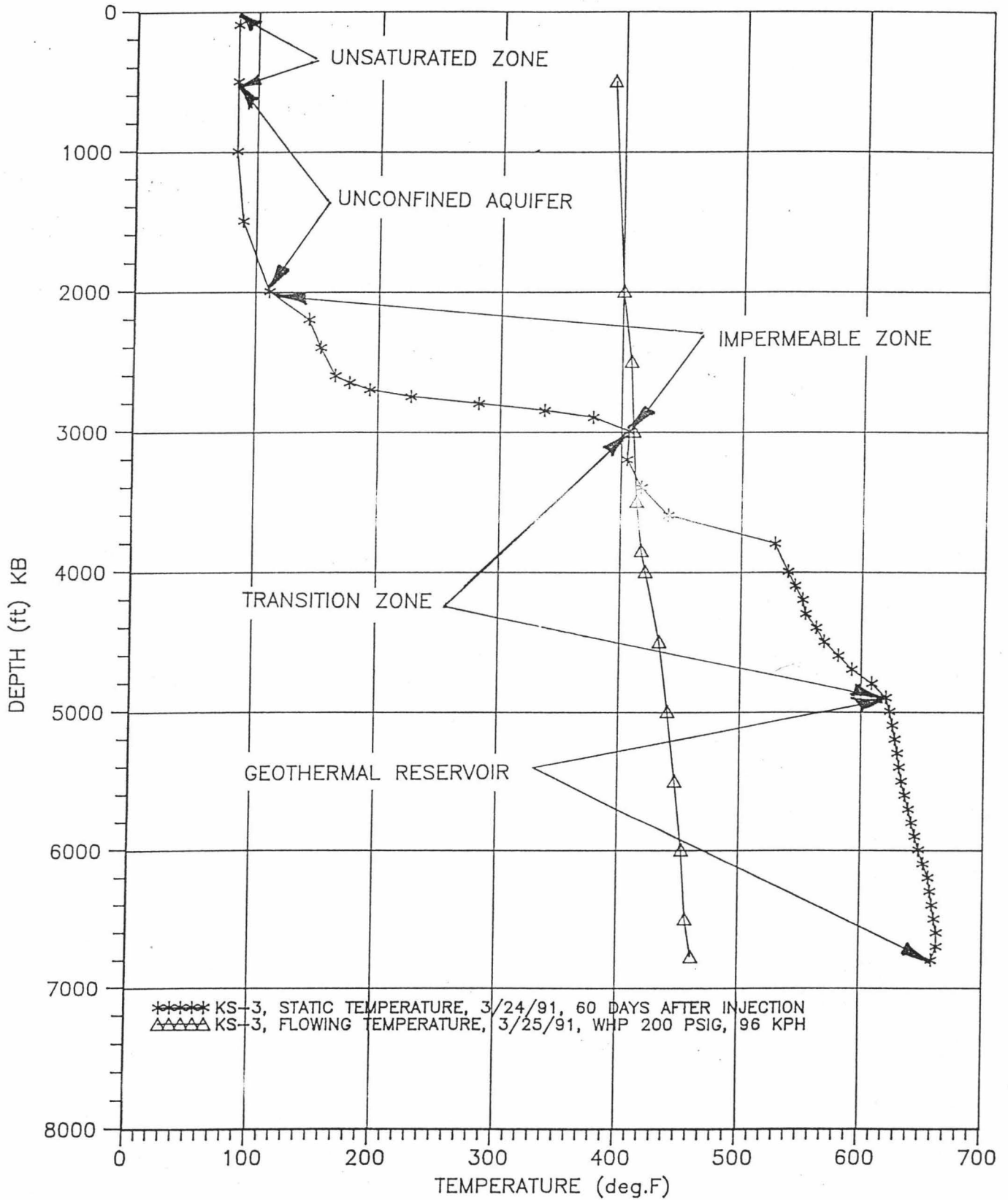
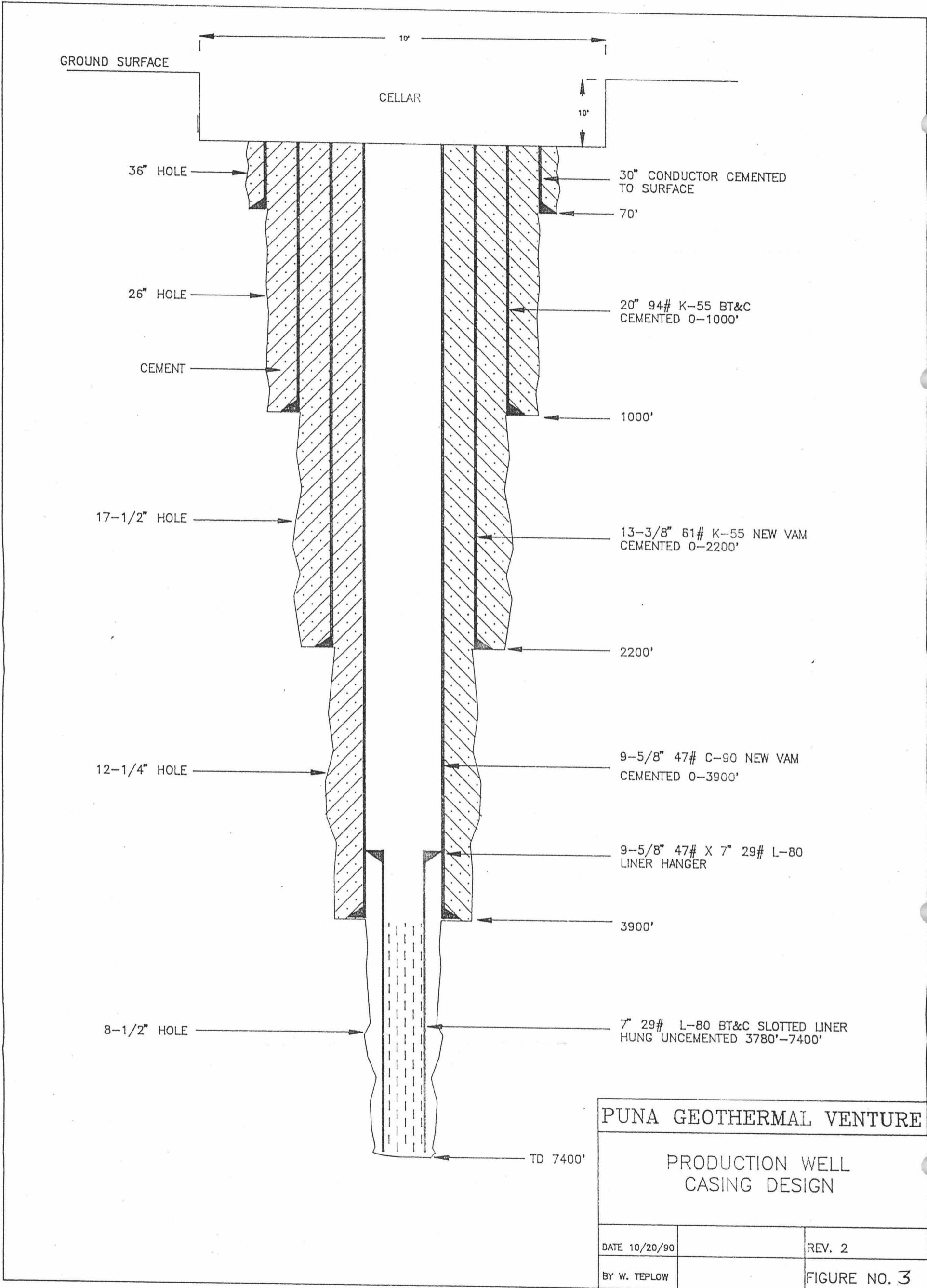


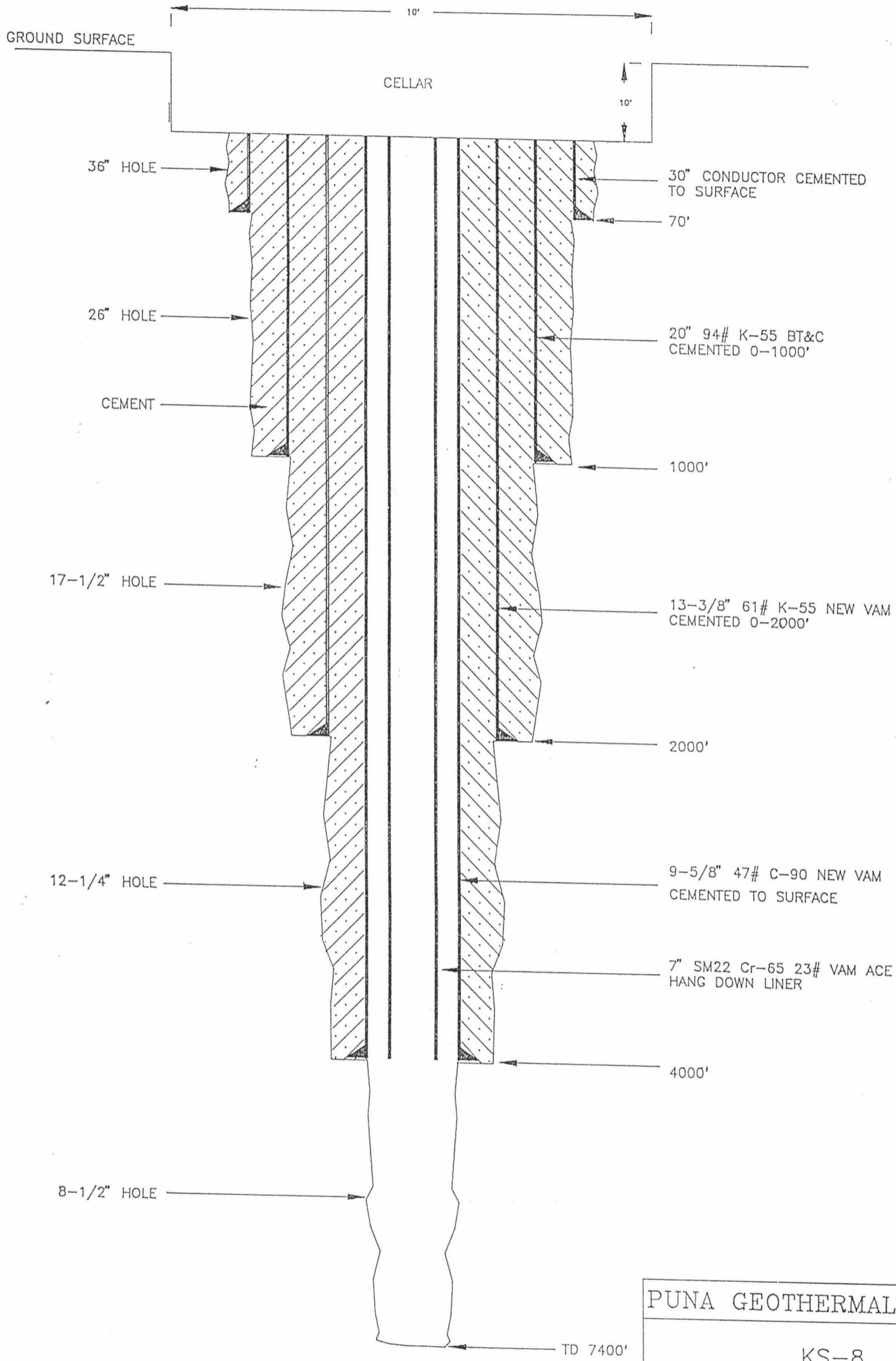
FIGURE 2



PUNA GEOTHERMAL VENTURE

PRODUCTION WELL CASING DESIGN

DATE 10/20/90	REV. 2
BY W. TEFLOW	FIGURE NO. 3



PUNA GEOTHERMAL VENTURE		
KS-8 CASING DESIGN		
DATE 4/1/91	File pgv\ks8cas.dwg	REV. 1
BY W. TELOW		FIGURE NO. 4