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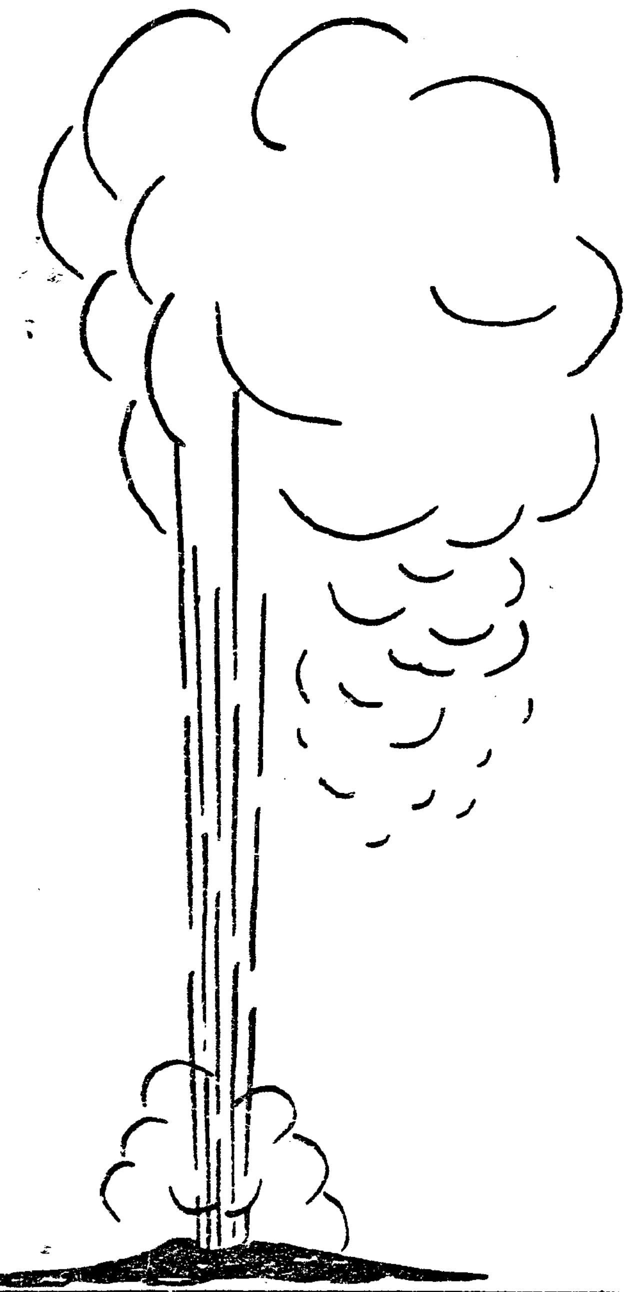

DIRECT UTILIZATION OF GEOTHERMAL ENERGY FOR PAGOSA SPRINGS, COLORADO

Final Report
June 1979 - June 1984

Prepared by
Coury and Associates, Inc.
Lakewood, Colorado 80226

Under Subcontract to
The Town of Pagosa Springs, CO

For
The U.S. Department of Energy
Idaho Operations Office
Under Cooperative Agreement
No. DE-FC07-78ET27030

U. S. DEPARTMENT OF ENERGY

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FINAL REPORT

DIRECT UTILIZATION OF GEOTHERMAL ENERGY FOR PAGOSA SPRINGS, COLORADO

Steven W. Goering
Kenneth L. Garing
Glenn Coury

August 1984

COURY AND ASSOCIATES, INC.
7400 West 14th Avenue
Lakewood, Colorado 80215

Under Subcontract to the

TOWN OF PAGOSA SPRINGS, COLORADO

Sponsored by the

UNITED STATES DEPARTMENT OF ENERGY
Division of Geothermal and Hydropower Technologies
Washington, D.C. 20585

Under DOE-ID Cooperative Agreement No. DE-FC07-78ET27030

ABSTRACT

The Pagosa Springs Geothermal District Heating System was conceptualized, designed, and constructed between 1979 to 1984 under the U.S. Department of Energy Program Opportunity Notice (PON) program to demonstrate the feasibility for utilizing moderate temperature geothermal resources for direct-use applications. The Pagosa Springs system successfully provides space heating to public buildings, school facilities, residences, and commercial establishments at costs significantly lower than costs of available conventional fuels. The Pagosa Springs project encompassed a full range of technical, institutional, and economic activities. Geothermal reservoir evaluations and testing were performed, and two productive ~140°F geothermal supply wells were successfully drilled and completed. Transmission and distribution system design, construction, startup, and operation were achieved with minimum difficulty.

The geothermal system operation during the first two heating seasons has been fully reliable and well respected in the community. The project has proven that low to moderate-temperature waters can effectively meet required heating loads, even for harsh winter-mountain environments. The principal difficulty encountered has been institutional in nature and centers on the obtaining of the geothermal production well permits and the adjudicated water rights necessary to supply the geothermal hot water fluids for the full operating life of the system.

ACKNOWLEDGMENTS

Numerous individuals made significant contributions to the success of this project. We wish to express our appreciation for their assistance.

First, throughout the program duration, Pagosa Springs community officials provided the necessary leadership, support, and coordination for the project to be completed. Special thanks are extended to Messrs. Fred Ebeling, William Ray, Jr., Worthe V. Crouse, Ronald Backus, and Joe Dan Martinez for their efforts in this regard. In addition, Mr. Frank W. Childs of EG&G Idaho, Inc. provided important program coordination and technical input throughout the project duration.

Additionally, special acknowledgment is expressed to J. D. Dick, Chaffee Geothermal Ltd.; Ronald Halley and Kurt Mahnken, HydroTriad, Ltd.; and David A. Sommers, HydroSciences, Inc., for their professional contributions to the Pagosa Springs program.

PON FINAL REPORT FORMAT

This report follows a general outline which has been developed for PON project final reports. The intent of the outline is to provide general uniformity in reporting format and content. Since the scopes of the projects vary, some sections of the general outline may not be applicable. This accounts for gaps in the section numbering because consistent numbering has been maintained for each subject which is presented. A list of PON projects which are expected to use this final report format follows. The DOE report number will be of the format: DOE/ET/XXXXX-N, where the X's are the last five digits of the contract number (given below) and N is determined by the number of reports issued by the subject contract.

Contract Number	Project Name	Location	DOE Office
DE-FC07-78ET27054	Monroe	Monroe, Utah	ID
DE-FC07-78ET27080	Haakon School	Philip, South Dakota	ID
DE-FC07-78ET28419	Diamond Ring Ranch	Haakon County, South Dakota	ID
DE-AC07-78ET28424	Ore-Ida Foods	Ontario, Oregon	ID
DE-FC07-78ET28441	St. Mary's Hospital	Pierre, South Dakota	ID
DE-FC07-79ET27027	Utah State Prison	Draper, Utah	ID
DE-FC07-79ET27028	Madison County	Rexburg, Idaho	ID
DE-FC07-79ET27030	Pagosa Springs	Pagosa Springs, Colorado	ID
DE-AC07-79ET27033	Elko Heat Company	Elko, Nevada	ID
DE-FC07-79ET27053	Boise	Boise, Idaho	ID
DE-AC07-79ET27055	Warm Springs State Hospital	W.S.S.H., Montana	ID
DE-AC07-79ET27056	Utah Roses, Inc.	Sandy, Utah	ID
DE-AC03-78ET27154	Klamath Falls	Klamath Falls, Oregon	SAN
DE-AC03-79ET27029	Moana, Reno	Reno, Nevada	SAN
DE-AC03-79ET27040	Susanville	Susanville, California	SAN
DE-AC03-79ET27045	El Centro	El Centro, California	SAN
DE-AC03-79ET27047	Aquafarms	Dos Palmas Area, California	SAN
DE-AC08-78ET27059	T-H-S Hospital	Marlin, Texas	NV
DE-FC08-79ET27058	Navarro College	Corsicanna, Texas	NV

PROJECT REPORTS - PAGOSA SPRINGS, COLORADO PON

1. Garing, Kenneth L., Direct Utilization of Geothermal Energy for Pagosa Springs, Colorado, Semi-Annual Progress Report, June-December 1979, Report IDO-7031-1, Contract No. DE-FC07-79ET27030.

2. Hydrosciences, Inc., Geohydrological Analysis of the Geothermal Reservoir, Pagosa Springs, Colorado, Cooperative Agreement No. DE-FC07-79ET27030, October 18, 1979.

3. Coury and Associates, Inc., An Environmental Report on the Construction and Operation of a Geothermal District Heating System in Pagosa Springs, Colorado, Contract No. DE-FC07-79ET27030, January 1980.

4. Coury and Associates, Inc., Chaffee Geothermal, Ltd., and Hydrosciences, Inc., Geothermal Resources Report, Pagosa Springs, Colorado, Contract No. DE-FC07-79ET27030, January 1980.

5. Coury and Associates, Inc., Direct Utilization of Geothermal Energy for Pagosa Springs, Colorado, Preliminary Design Report, Contract No. DE-FC07-79ET27030, February 1980.

6. Coury and Associates, Inc., Direct Utilization of Geothermal Energy for Pagosa Springs, Colorado, Final Design Report, Contract No. DE-FC07-79ET27030, September 1980.

7. Chaffee Geothermal, Ltd., Direct Utilization of Geothermal Energy for Pagosa Springs, Colorado, Geothermal Drilling Activities, 1980, Contract No. DE-FC07-79ET27030, November 1980.

8. Hydrosciences, Inc, 1980 Hydrological Testing Program at Geothermal Production Wells PS-3 and PS-5, Pagosa Springs, Colorado, Contract No. DE-FC07-79ET27030, February 10, 1981.

9. Coury and Associates, Inc., Summary Report--Pagosa Springs Geothermal Heating System, System Testing: October 1, 1983 - February 29, 1984, Prepared for the Town of Pagosa Springs, Colorado, for submittal to the Colorado Oil and Gas Conservation Commission and the Colorado Department of Natural Resources, Division of Water Resources, State Engineer, March 30, 1984.

DOE DIRECT-USE GEOTHERMAL PON PROJECT

1. Project Title: Direct Utilization of Geothermal Energy for Pagosa Springs, Colorado.

	Contract/Cooperative Agreement	
2.	Number:	DE-FC07-79ET27030
3.	Former No:	None
4.	Period:	03/23/79 to 08/31/84
5.	Value:	$1,487,620
6.	DOE Share:	$1,213,000 82%
7.	Participant Share:	$ 274,620 18%

8. Project Application: A district heating system for about 10 public buildings, 54 businesses, and private residences. An isolation heat exchanger, two recirculating loops and disposal into the San Juan River are used. The two production wells are 131°F and 149°F, and are 300 and 274 feet deep.

9. Project Location: Pagosa Springs, Colorado (60 miles east of Durango).

10. Well Name/Loc.: PS-3 and PS-5, SE 1/4, NE 1/4, SW 1/4, Sec. 13, T35N, R2W.

11. Peak Heat Load: 9.14 Million Btu/hr (800 gpm, 23°F)
12. Annual Heat Load: 23.2 Billion Btu/yr (load factor = 29%)
13. Simple Payback (Cash): 20 years

14. Project Status: System operable November 1981. Operation prevented; no State permit in 1981-1982. System was successfully operated on 450-500 gpm flows during the 1982-1983 and 1983-1984 heating seasons with temporary production permits. Final adjudicated rights are being pursued.

15. Principal Investigator: Joe Dan Martinez, Manager, Water Department. (Previously Ronald Backus, Worthe Crouse, Bill Ray and Fred Ebeling)

16. Firm: Town of Pagosa Springs, Colorado
17. Address: Box 265, Pagosa Springs, CO 81147 (486 San Juan Street)
18. Phone: 303-264-4151 (FTS DIR-DIAL)
303-264-5851 for Ebeling, PI through drill/test

OTHER PARTICIPANTS:

19. Firm/Activity: Coury and Associates, Inc. /Overall project engineering.
20. Address: 7400 W. 14th Avenue, Lakewood, CO 80215
21. Phone/Contact: 303-232-3823. Glenn Coury or Steven W. Goering (FTS DIR-DIAL)

22.	Firm/Activity:	Hydrosciences, Inc. /Hydrological test and analysis.
23.	Address:	12687 W. Cedar Drive, Lakewood, CO 80226
24.	Phone/Contact:	303-989-3055/David A. Sommers; Phil E. Gagnard (FTS DIR-DIAL)
25.	Firm/Activity:	Chaffee Geothermal, Ltd. /Geology, site and drilling.
26.	Address:	1776 S. Jackson, Suite 1000, Denver, CO 80210
27.	Phone/Contact:	303-692-9496/Jay Dick (FTS DIR-DIAL)
28.	Firm/Activity:	Hydro-Triad Ltd. /Piping and system design.
29.	Address:	12687 W. Cedar Dr., Suite 100, Lakewood, CO 80226
30.	Phone/Contact:	303-989-1264/Eric Will; Kurt D. Mahnken (FTS DIR-DIAL)

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1.0 INTRODUCTION

1.1 OBJECTIVES

1.1.1 U.S. Department of Energy "Program Opportunity Notice" (PON) Programs

Private sector use of geothermal energy for direct heat purposes within the United States has been limited, yet there is a large potential market for thermal energy in such areas as industrial processing, agri-business, and space and water heating of commercial and residential buildings. Technical and economic information is needed to assist in identifying prospective direct heat users and to match their energy needs to specific geothermal reservoirs. Technological uncertainties and associated economic risks have influenced potential user perception of profitability to the point of limiting private investment in geothermal direct heat applications.

In September 1977 and April 1978, the Department of Energy, Division of Geothermal Energy (now the Division of Geothermal and Hydropower Technologies), issued two Program Opportunity Notices (PONs). These solicitations were part of DOE's national geothermal energy program plan, which had as its goal the near-term research and development of hydrothermal resources by the private sector. Encouragement was given to the private sector by DOE offering to share a portion of the front-end financial risk in a limited number of field experiment projects. After competitive evaluations, twenty-three PON projects were selected from the two Project Opportunity Notice Solicitations. Subsequent events caused four of these projects to withdraw from the program.

This report documents the DOE Direct-Use Geothermal PON Project at Pagosa Springs, Colorado.

1.1.2 Demonstration Project

The objective of this project was to demonstrate the technical and economic feasibility for utilizing moderate temperature geothermal resources for space heating. To accomplish this objective, the Town of Pagosa Springs, Colorado, initiated the design, construction, and operation of a geothermal-based district heating system to serve the core business area, Municipal and Archuleta County public buildings, Archuleta School District Joint-50 school buildings, and additional residential buildings.

1.2 PRE-PROJECT BACKGROUND

Pagosa Springs is located in the San Juan Basin in the southwestern Colorado mountains approximately 300 miles southwest of Denver and 60 miles east of Durango; this location is shown in Figure 1-1. Pagosa Springs is the County seat of Archuleta County, Colorado, and had a 1983 service population of about 1,500. Historically, the regional economy has been closely tied to both tourism and to the utilization of its natural resources, including mining, agriculture and wood products.

Natural hot waters of the Pagosa Springs area have been used since the early 1800's. Indians named the area Pagosa, meaning "boiling waters," and used the hot springs for medicinal purposes and religious ceremonies. When white settlers came to the region in the later 1800's they also used the springs for medicinal purposes as well as for a recreational novelty. Between 1900 and 1910 the first hot water well was drilled in the community of Pagosa Springs and this began natural hot water heating in the area.

The main hot spring is located south of downtown Pagosa Springs and across the San Juan River. This spring is the largest hot spring in Colorado and is 25 to 30 feet in diameter. At 136°F and with a discharge

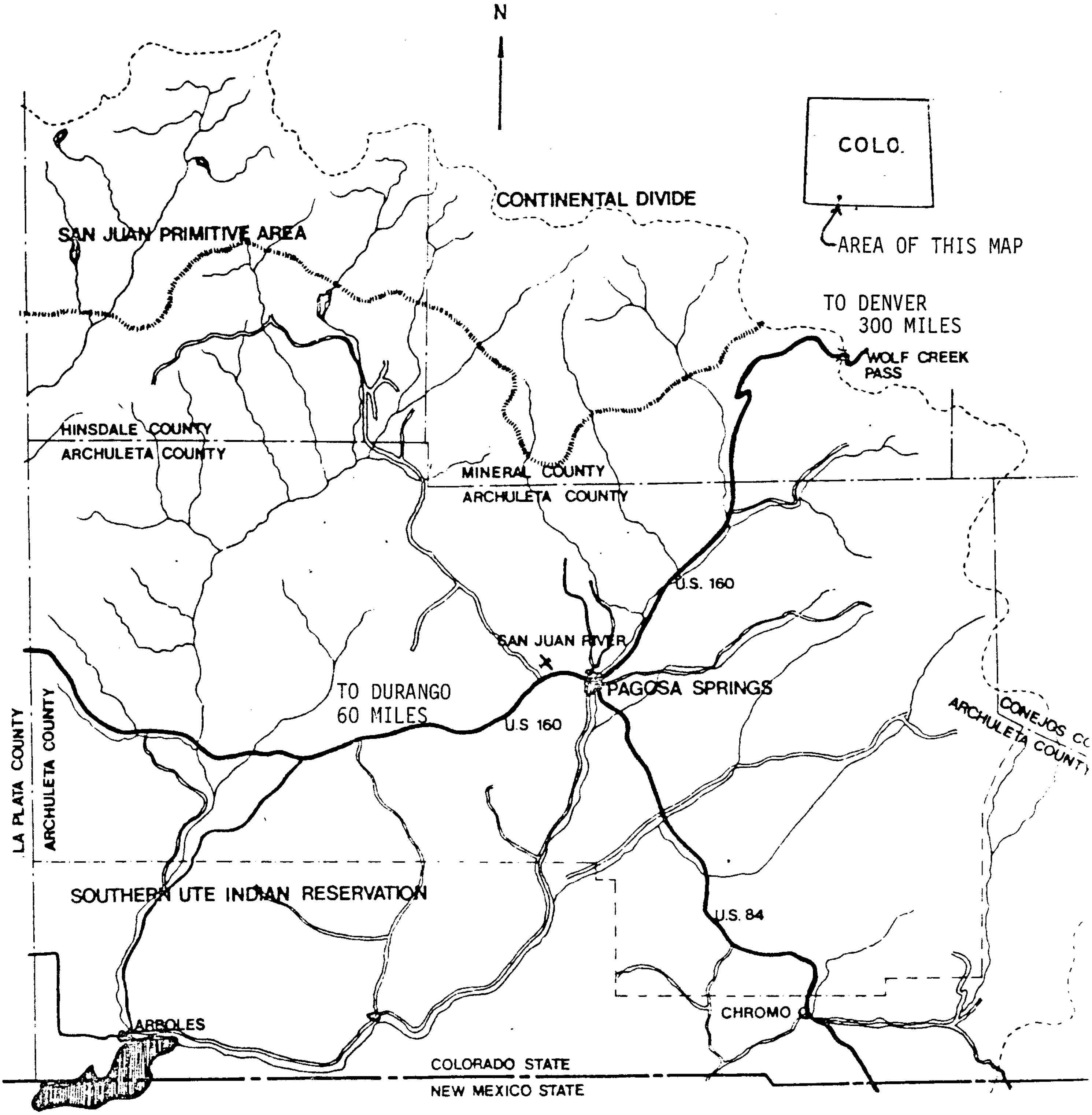


Figure 1-1. Location Map

of 300 to 700 gpm (Barrett and Pearl, 1976; Lynn, 1978), Pagosa Hot Springs is neither the hottest nor highest flowing hot spring in Colorado. However, there is no hot spring in the State that has both greater temperatures and discharge, inclusive. In the 1950's the local blacksmith lowered a 30-foot section of railroad iron into the hot spring. The iron descended over 100 feet prior to becoming entangled in travertine deposits (Crouse, 1977).

During the early 1900's hot wells began to be drilled in the area to utilize natural hot water for space heating. The first well drilled in Pagosa Springs was the present Adobe Inn Well (formerly the Pagosa Hotel or Los Banos Hotel). There are 30 known hot wells in Pagosa Springs and of these 13 were being used prior to the current project; seven were operational but not in use, and ten have been abandoned. Many of the older wells are no longer in good operating condition due to lack of brine chemistry control, which has led to excessive scale and corrosion of well and piping systems. Figure 1-2 presents the locations of the majority of the hot wells in the area. As of 1980, a number of the hot wells in downtown Pagosa Springs were still being used to heat commercial businesses and public buildings; others were merely used to melt snow in the winter or for aesthetic tourism purposes. Figure 1-2 also shows the hot wells and which buildings are utilizing the hot waters (or have in the past).

In the midst of energy shortages, and rapidly increasing conventional fuel costs, the Town of Pagosa Springs, Archuleta County, and Archuleta School District Joint-50 officials recognized the potential for the low-cost utilization of the area's hydrothermal resource through the establishment of a professionally designed and constructed district heating system that would consolidate the older, multiple individual systems. Therefore, these entities jointly applied for U.S. DOE cost-shared funding under

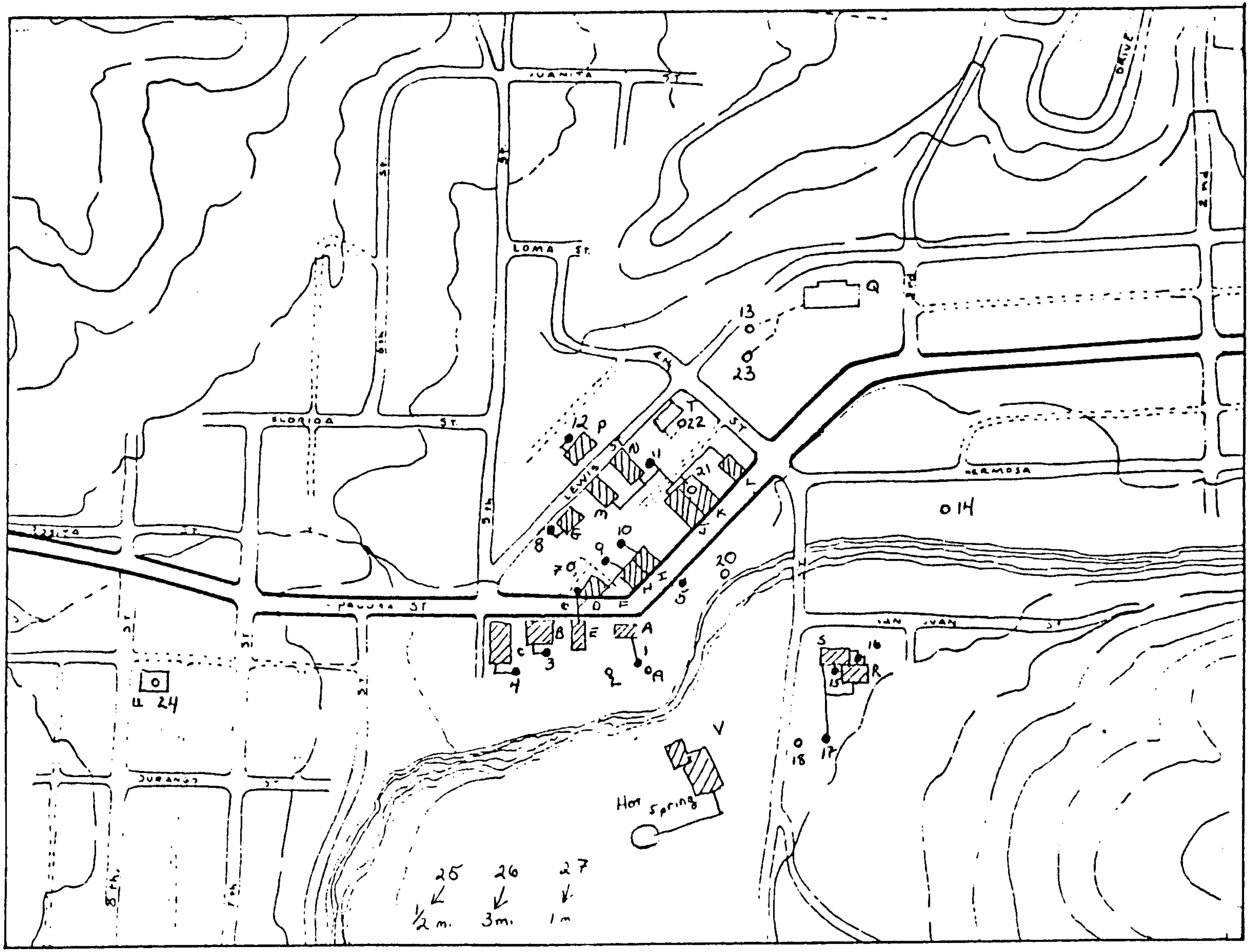


Figure 1-2. Location and Utilization of Hot Water Wells in Pagosa Springs, Colorado. Well Numbers and Building Letters are Indexed to Page 6.
(Chaffee Geothermal, Ltd., 1978.)

KEY AND INDEX TO FIGURE 1-2

● Hot well in operation

o Hot well not in use or abandoned

▨ Building presently utilizing hot water

☐ Building formerly utilizing hot water

—— Flowline from operating well to building (schematic)

- - - - Flowline from non-operating well to building (schematic)

HOT WELLS	
1	Courthouse Well
2	County-2 Well
3	Texaco Well
4	Poma-2 Well
5	City-1 Well
6	Amoco Well
7	Bank Well
8	Adobe Inn Well
9	Brown Well
10	Montroy Well
11	Rumbaugh Well
12	Methodist Church Well
13	High School Well
14	Sanders Well
15	Spa Motel-1
16	Spa Motel-2
17	Spa Motel-3
18	Spring Inn Well
19	County-3 Well
20	City-2 Well
21	Rexall Well
22	Phone Company Well
23	School District-2 Well
24	County Garage Well
25	School District-3 Well
26	Perkins Well
27	Catchpole Well
28	Pagosa Hot Springs

BUILDINGS	
A	County Courthouse
B	Texaco Station
C	Poma Building
D	Buhler's Garage
E	Gunrunners CB
F	Citizens Bank
G	Adobe Inn
H	Wilsey Professional Building
I	Pagosa Sun Building
J	Pagosa Hardware
K	Jackisch Drugs
L	Superior Automotive
M	Catholic Church
N	Parish Hall
P	Methodist Church
Q	Old High School
R	Spa Motel - bathhouse
S	Spa Motel - pool
T	Universal Telephone Company
U	County Garage
V	Spring Inn Motel

the PON program to establish such a system. The cooperative Agreement with DOE was executed in June 1979 and the project began thereafter.

1.3 PROJECT SCOPE

The original project scope included the following component tasks:

--Evaluate and develop the hydrothermal resource using existing, previously drilled geothermal wells.

--Design and construct a geothermal-based district heating system to effectively serve the core commercial sector, the municipal and county buildings, school buildings and selected residential areas.

--Attract and develop the service utilization rate necessary for the system to be cost-effective as compared to alternate fuels.

The project scope changed only slightly during the course of the project development. New production wells were drilled to centrally supply the new system with adequate geothermal resource flow; second, significant efforts have been required to establish adjudicated water rights for these production wells under Colorado Water Law; and third, the size of the installed system was reduced, due to escalation of costs during the course of the project. This eliminated practically all residential service.

1.4 GROWTH POTENTIAL

The constructed system has established a trouble-free, well-respected operation during the past two heating seasons. The public sector buildings were the first to utilize the system during the 1982-1983 winter season. Based on that demonstrated successful operation, additional school buildings and several private sector hookups were achieved for the 1983-1984 season. Utilization is expected to grow to current system capacity by 1985.

In addition, the following new uses are being considered:

--Light industrial greenhouse space heating.

--Process heating for styrofoam manufacture.

--Snow and icing control of currently unsafe road intersections.

--Snow and icing control of a Shopping Center parking lot.

The Town of Pagosa Springs intends to utilize the developed geothermal resource and associated energy supply to promote additional tourism activity and to promote the locating of new businesses to the area.

2.0 SUMMARY

The objectives of the Pagosa Springs Geothermal project were to evaluate and develop the Pagosa Springs hydrothermal resource, and subsequently design, construct, and initially operate a geothermal-based district heating system to serve the Pagosa Springs community. The technical, institutional, and economic feasibilities of direct-use geothermal energy utilization for this type of system could then be demonstrated based on concrete program experience and on documented, full-scale operational performance.

The necessary activities to successfully accomplish these objectives are presented in Table 2-1, which serves as an effective summary for the project and for this report.

The project as finally completed was consistent with the proposed system and the program objectives. Certain of the original project concepts were modified, and improved as the component task completions progressed. These changes included:

--The drilling of new production wells to supply the system with geofluids rather than to utilize previously existing wells. Existing wells either lacked capacity or temperature, or were in poor operating condition;

--A plate heat exchanger was utilized to isolate the geothermal waters from user systems. Even though geothermal water quality is comparatively high, H_2S concentrations would have been corrosive to copper found in most user systems;

--Substantial system cost escalations forced a reduction in system service area. This eliminated most residential services;

--Water rights issues, principally concerns for possible interference with previously existing well flows, may limit the ultimate capacity of the system. This is not resolved as of the date of this report.

TABLE 2-1

SUMMARY--PAGOSA SPRINGS GEOTHERMAL DISTRICT HEATING PROJECT

Activity	Completion Date	Summary
Resource Assessment--Existing Wells	January 1980	The hydrogeological regime and production characteristics of the Pagosa Springs geothermal reservoir were assessed utilizing historical evidence, review of existing geological and hydrological mapping and reports, and hydrological flow testing of selected existing wells.
Production Well Drilling and Completion	Summer 1980	Permits were obtained and two wells, PS-3 and PS-5, were successfully drilled and completed for full-scale production. Depths were to 300 feet and 275 feet, respectively. A third well produced insufficient water and temperature and was abandoned. Drilling difficulties were experienced due to large river bed boulders encountered in the drill hole at shallow well depths.
Production Well Testing and Assessment	February 1981	Production wells PS-3 and PS-5 were hydrologically flow tested and the overall reservoir evaluated for its ability to support the proposed district heating system. Production capabilities were placed at 600 gpm at 131°F and 1200 gpm at 149°F, respectively. Interference with existing wells was noted. Water quality was good with TDS levels of ~3000 mg/l.
Environmental Assessment and Permitting	July 1979	An environmental assessment indicated no significant adverse impacts of water quality and air quality were anticipated as a result of the proposed activities. The Colorado Department of Health permitted surface disposal of the cooled geothermal fluid to the San Juan River.
System Design	December 1980	Design heat load basis was established, and geothermal water quality and materials were evaluated for compatibility. A plate heat exchanger was specified to isolate geofluids from system users. Instrumentation and controls were specified to achieve optimum system performance and extend the geothermal reservoir life.
Bidding, Construction and Startup	October 1982; Summer 1983	Bid documents, including plans and specifications, and quality assurance requirements were issued to contractors through open bidding process. Project was reduced in scope due to higher than expected cost. Contractors were selected on the basis of price and qualifications. Project proceeded on schedule and acceptance tests were completed in late 1981. Final startup was not achieved until Fall 1982 due to water rights questions. An additional system expansion was completed in August 1983 to access additional customers.
Institutional Issues--Water Rights	Ongoing	Substantial difficulty was encountered in obtaining production permits from the Colorado State Water Engineer. This is necessary for obtaining adjudicated water rights in Colorado Water Court. Permanent production permits have not been obtained to date. System operated with temporary one-year permits for the 1982-1983 and 1983-1984 heating seasons while additional well data were collected.
Operational Experience	1982-1984	The constructed system established trouble-free, well-respected operation during the 1982-1983 and 1983-1984 heating seasons. Based on this good experience, additional customers hookups are being realized.
Economic Analysis	1982-1984	The geothermal system is marketing heat-energy to customers at a cost less than 80% of current natural gas cost service to the area. As utilization factors increase through increased customer attachment, charged rates can be decreased further. Studies performed by ICF, Inc. indicated attractive private sector development potential.
Public Awareness and Education	Continuous	Extensive efforts were made, through Advisory Committees and community meetings, to convey to the public the advantages of the geothermal system to the community. These were generally well received. Formal dedication ceremonies with tours were held in February 1982. In 1982, Coury and Associates, Inc., the prime contracting engineer won the Consulting Engineers Council of Colorado Grand Award in Statewide Engineering Excellence Competition.

3.0 CONCLUSIONS AND RECOMMENDATIONS

The Pagosa Springs geothermal project has encompassed a broad range of technical, institutional and economic activies. Much of this documented experience is directly applicable to future geothermal development and the program's specific results, conclusions, and recommendations should prove useful to the economic utilization of similar resources at other geographic locations. The principal conclusions and recommendations are presented below, organized in technical, institutional, and economic categories.

3.1 Technical Conclusions and Recommendations

--The Pagosa Springs geothermal reservoir is capable of supporting substantial district heating system energy utilization. Produced reservoir water temperatures of 131°F to 149°F have been confirmed.

--The constructed geothermal system utilizing 135°F to 140°F water can effectively provide space heating for diverse system customers such as private sector businesses, schools, churches, and for public, municipal, and private-residential buildings. Substantial fossil fuel energy savings, of the range of 23 X 10^9 Btu annually, is being realized as a result.

--The project has proven that low to moderate temperature waters can effectively meet required heating loads, even for harsh winter-mountain environments with low temperatures in the range of -30°F to -40°F.

--Candidate industrial processes which can effectively utilize these moderate temperature operating ranges should be considered for direct-use geothermal application.

--The system, as designed and constructed, is not complex, high technology. It is rather similar in nature to typical water supply/distribution systems. It can, therefore, be successfully operated by municipal water plant personnel.

--Production well flow controls which regulate producing flows as a function of seasonal heating demands, are important and can effectively conserve reservoir longevity through increased system efficiency. Although designed for the system, these controls were not ultimately installed in the Pagosa case.

--Excellent construction management, adequate system "as built" documentation, and development of effective startup and operating manuals is essential to the successful operation and longterm maintenance of the operating system.

--Process design and materials selection must consider geothermal water quality corrosion and/or scaling characteristics if long-term, trouble-free system operation is to be maintained.

--The geothermal system operation has been trouble-free and well-respected in the community. Reliability and dependability has been excellent; no service interruption attributable to the geothermal system has been experienced. This is mandatory for continued public acceptance and for achieving continued hookups of new customers.

--Simplicity of design is an essential ingredient to this trouble-free operation.

--Predicting the existence of geothermal fluid underground, and especially quantification, is not reliable even in close proximity to existing wells. The only dependable way to determine the existence of, and to quantify, geothermal sources is by means of test holes.

In this project, a new well located only 30 feet from a previously drilled test well produced fluid $10^{o}F$ cooler than had been obtained from the test well at comparable depth. A second new well located 350 feet southwest of the first one did not produce fluid quantity or temperature comparable to the first new well, nor as expected from geological analysis of the substrata. The well could not be used and was cemented up. A third new well located 180 feet east of the first one, and about 30 feet south of an existing old well, produced much greater quantity of fluids than either of them, $17^{o}F$ hotter and at a depth considerably less than predicted by geological analysis of the substrata.

--Drilling geothermal wells, particularly artesian wells, presents problems and situations not encountered in usual water well drilling. This applies not only to the temperatures and pressures involved but also to the subsurface strata which may have been affected by the geothermal conditions. Anomalies from usual geologic situations should be expected.

3.2 Institutional, Environmental, and Construction Management Conclusions and Recommendations

--Obtaining the appropriate permits for this system required the interfacing with multiple State agencies including the Colorado Department of Natural Resources, State Engineer's Office; Colorado Oil and Gas Conservation Commission; Colorado Department of Health, Air and Water Quality Control Divisions; and, in certain instances, State legislators regarding proposed legislation. Most of the permits were readily obtained and if done in a systematic and organized way, the effort required to secure them should not be considered a deterrant to potential geothermal developers.

--In Western United States regions, the water rights issue is highly visible and extremely important to the public. Since geothermal energy is a developing energy source with new implications for water use patterns, the regulatory authority governing water permitting has not always been clearly identified. Rigorous efforts should be extended to insure the successful and timely resolution of permitting issues.

--Keeping State agencies and local government bodies informed on the progress of the project, and particularly about well drilling, is of great value in assisting various permitting and approval requirements.

--Many of the laws and regulations pertaining to geothermal are new and leave many holes regarding their interpretation. Plan on spending more time than initially anticipated in dealing with these. Precedence has not always been set for these new laws.

--Keeping the public informed of project progress is important for successful acceptance, and to minimize erroneous information and rumors. Interviews by media reporters frequently result in partial, misleading information being published or broadcast. Carefully written news releases are best, but even then media space or time limitations result in editing which often changes the context. If at all possible, a person should be designated to communicate with the media and the public on a regular basis.

--If possible, a local contractor with interest in the project should be used. Since the contractor's reputation will be under close scrutiny, it is likely he will do a better job.

--Extensive background checks should be made on all contractors by contacting the owner of their two or three most recent jobs. Past reputation may not always be accurate.

3.3 Economic Conclusions and Recommendations

--The Pagosa Springs system is utilizing a moderate temperature resource to reliably and economically supply heat energy in direct-use application for space heating purposes.

--Additional light industrial, year-around process heat utilization would substantially improve the economics of the overall system since geothermal systems are capital intensive.

--Private sector economic incentives currently exist to make direct-use geothermal utilization economically attractive in the Pagosa Springs service region, provided the prospective user's needs match up well to the Pagosa Springs moderate 135°F to 140°F water temperatures.

4.0 PROJECT DESCRIPTION

4.1 TASK BREAKDOWN

Figure 4-1 presents the principal tasks and subtasks and the schedule for completion of these tasks. The final completion schedule for the program was extended up to two years beyond normal project completion dates due to legal constraints relating to the permitting and the adjudication of water rights for the geothermal production wells.

4.2 ORGANIZATION AND PARTICIPATION

The Town of Pagosa Springs, the lead proposer and prime contractor, and project associates Archuleta County and Archuleta County School District 50-Joint constituted the project team under the Cooperative Agreement effort. Messrs. Fred Ebeling, County Planning Administrator, and William Ray, Jr., Worthe Crouse, Ronald Backus, and Joe Dan Martinez, Pagosa Springs Town officials, were the Geothermal Program Managers during the project timeframe. In addition, the following subcontractors were instrumental to the success of the project;

--Coury and Associates, Inc.
--Chaffee Geothermal Ltd.
--Hydro-Triad Ltd.
--Hydrosciences, Inc.
--B&B Drilling, Inc.
--Petroleum Engineers, Inc.
--Roseberry Plumbing and Heating, Inc.
--Triad-Western,Inc.
--Sam Maynes, Attorney (Water Law)

An organization chart showing the participating organizations and principals, and the roles they performed, is presented in Figure 4-2.

Figure 4-1. Major Project Task and Work Schedule

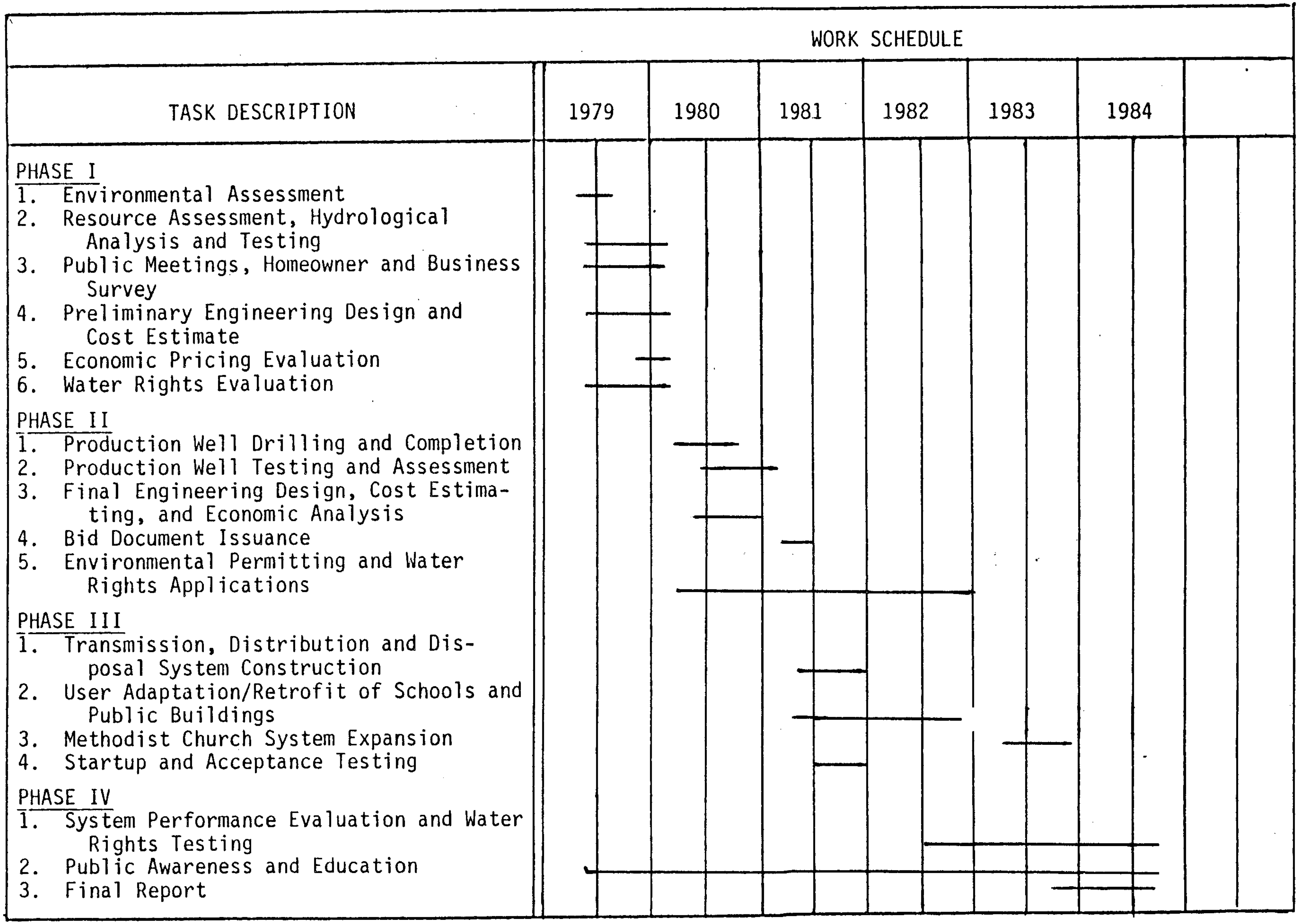


FIGURE 4-2 -- PROJECT ORGANIZATION

U.S. Department of Energy
Idaho Operations Office

EG&G Idaho, Inc.

Frank C. Childs

Town of Pagosa Springs
Archuleta County, CO
Archuleta School District
Joint-50

Fred Ebeling
William Ray, Jr.
Worthe V. Crouse
Ronald Backus
Joe Dan Martinez

- Program Management
- Construction Management
- Water Rights

Pagosa Springs
Geothermal Advisory
Committee

B&B Drilling, Inc.

- Production Well Drilling & Completion

Roseberry Plumbing & Heating, Inc.

Don Roseberry

- System Construction
- System Expansion Design--1983

Coury & Associates, Inc.

Kenneth L. Garing
Glenn Coury
Steven W. Goering

- Geothermal Consulting
- System Engineering Design
- Program Management and Reporting

Triad-Western, Inc.

- Distribution System Construction

Sam Maynes

- Attorney--Water Law

Hydro-Triad, Ltd.

Ronald Halley
Kurt P. Mahnken

- Civil Engineering Design

Chaffee Geothermal, Ltd.

Jay D. Dick

- Resource Assessment
- Permitting
- Drilling Consultant

Hydrosciences, Inc.

David A. Sommers

- Geothermal Reservoir Evaluation

Petroleum Engineers Inc.

- Production Well Design

4.3 COST BREAKDOWN

The cost breakdown for the project is presented in Table 4-1. The initial program budget was estimated at $963,200. Due to higher than anticipated production well costs, program delays, construction cost inflation, and significant expenditures for water rights acquisition, the final program expenditures were $1,487,620. The Town of Pagosa Springs cost shared to the extent of $274,620 in the form of property rights-of-way, in-kind services, and construction materials and labor. Table 4-1 presents the budget expenditures by task for the project as of June 1984.

Table 4-1. PROGRAM BUDGET SUMMARY

I.	Resource Assessment and Preliminary Design	$ 106,780
II.	Production Wells Costs	290,832
III.	Final Design and Construction	999,980*
IV.	G&A Expense	40,000
V.	DOE Program Costs, Publicity, Technology Transfer, Reporting	40,028
VI.	Pagosa Springs Retrofit Assistance	10,000
	TOTALS	$1,487,620*

* Includes $115,500 of in-kind facility values contributed to the project by Pagosa Springs.

5.0 RESOURCE ASSESSMENT

5.1 PRE-PROJECT ASSESSMENT

Prior to the current project, the geothermal resources at Pagosa Springs were analyzed extensively over the past 50 years primarily by government financed projects and university research programs. Detailed geological studies have been undertaken by Wood and others (1948), Dunn (1964), Hail (1965), and more recently by the Colorado Geological Survey, Colorado School of Mines and Chaffee Geothermal, Ltd. Under contract to the Colorado Geological Survey the Geophysics Fund, Inc., a subsidiary of the Colorado School of Mines Geophysical Department, conducted extensive dipole-dipole and dipole-bipole (roving dipole) electrical resistivity studies within a two-mile radius of Pagosa Springs. Under the same contract they also undertook a vibroseis survey which resulted in questionable results. The Colorado Geological Survey also drilled and temperature probed six shallow temperature gradient wells throughout the Pagosa Springs area. Amax Exploration, Inc., Geothermal Branch, also temperature probed and computer modeled these same temperature gradient wells. Chemical analysis and geothermometry modeling has been done on the Pagosa Hot Springs and several hot wells throughout town. The Geophysics Fund, Inc. conducted a detailed soil mercury survey of the Pagosa Springs area under contract to the Colorado Geological Survey.

Under contract to the U.S. Department of Energy, the Colorado Geological Survey drilled two exploration geothermal wells during the summer of 1978. Downhole geological and geophysical data were also acquired during these operations. In summary, extensive geological, geophysical, and hydrogeological studies were conducted prior to the initiation of the geothermal program. The following discussions summarize those findings.

a) Geothermal resources at Pagosa Springs are known to exist by surface manifestations at Pagosa Hot Springs and hot water wells throughout the area. These hot wells have been used since the early 1900's to heat commercial businesses and public buildings, melt snow and de-ice streets, and for aesthetic tourism purposes Figure 1-2, previously presented, shows the locations of the majority of hot wells in the area. Temperatures of these wells range from 93°F to 153°F, with most wells averaging 131°F. Depths of the hot wells range from 85 to 468 feet, with an average depth being 300 to 400 feet. All hot wells produce from either the Dakota Sandstone or the Mancos Shale which are dipping to the northeast. Because of this natural dip, wells in the eastern portions of town are much deeper than those to the southwest. Dipping Dakota Sandstone is capped by impermeable Mancos Shale and this causes artesian flow in all hot wells in Pagosa Springs.

The town of Pagosa Springs is located within the San Juan Basin which is bounded to the north and east by the San Juan Mountains of volcanic and sedimentary origin. The geology of Pagosa Springs is characterized by outcrops of Mancos Shale and Dakota Sandstone dipping to the northeast at 46° to 50°. The dipping sedimentary units are the result of the Archuleta Anticlinorium, a regional tectonic feature west of Pagosa Springs. At the crest of the anticlinorium are smaller anticlinal features that alter the regional dip. Two miles southwest of Pagosa Springs is an extension of the Nacimiento Fault zone which trends from north-central New Mexico into the San Juan Basin. Locally, the Nacimiento Fault uplifts the Dakota Sandstone into contact with the younger Mancos Shale. There are several smaller faults splaying in a northerly direction from the Nacimiento Fault. Figure 5-1 is a geologic map of Pagosa Springs.

At Pagosa Springs 1300 to 1500 feet of Upper Cretaceous to Upper Triassic sediment rests unconformably on Precambrian igneous and metamorphic rocks. The geologic column of the Pagosa Springs area is:

Tertiary Intrusives (exact age of emplacement not known)--intermediate to silicic dikes.
Lewis Shale (Upper Cretaceous)--clay shale with thin sandstone beds.
Mesaverde Formation (Upper Cretaceous)--interbedded thin sandstone with dark shale.
Mancos Shale (Upper Cretaceous)--light to dark calcareous shale.
Dakota Sandstone (Upper Cretaceous)--quartzitic sandstone with dark shale.
Morrison Formation (Upper Cretaceous)--variegated to white sandstone.

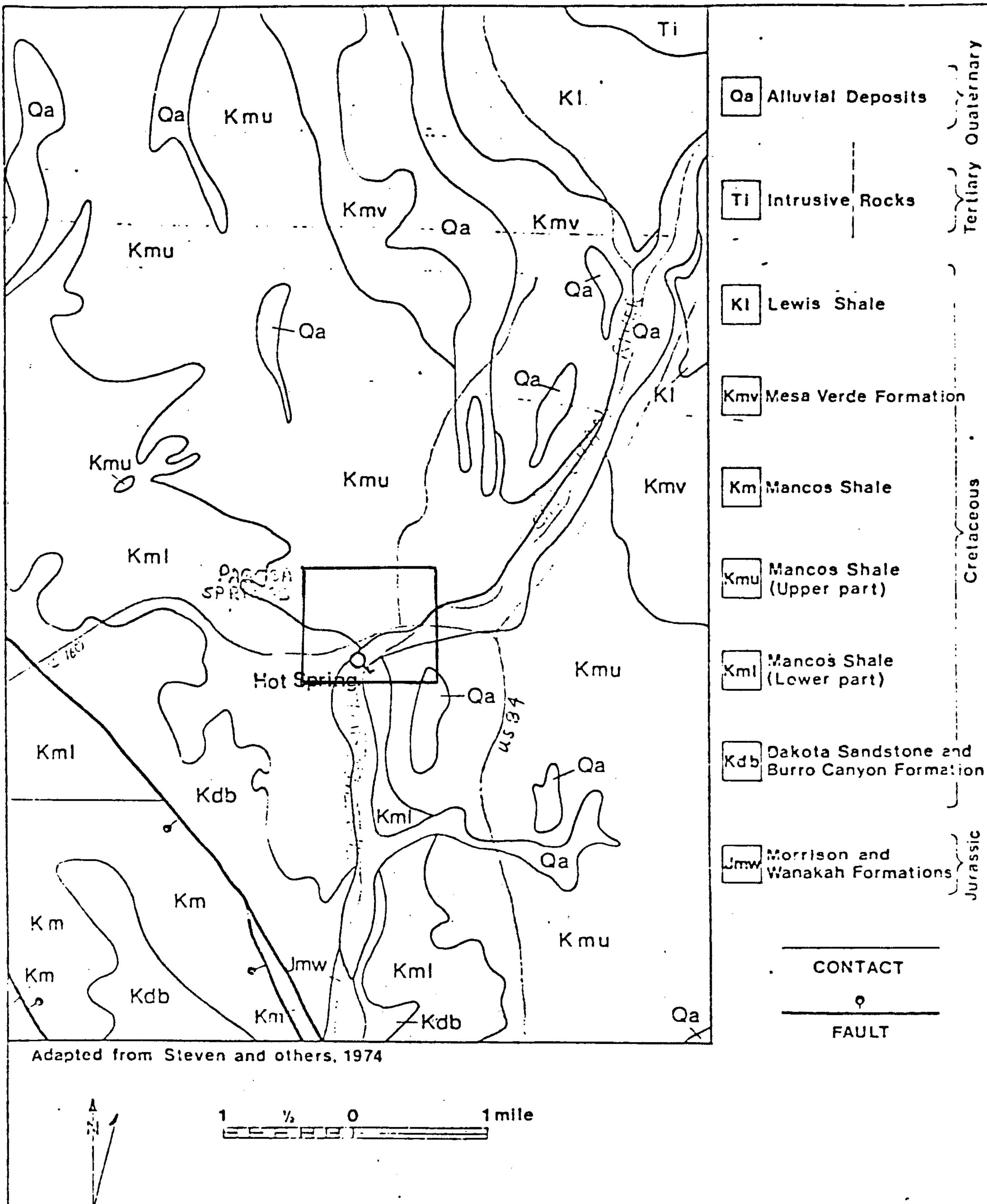


Figure 5-1. Simplified Geologic Map of the Pagosa Springs Area

Wanakah Formation (Upper Jurassic)--gypsiferous limestone and shale.
Entrada Formation (Upper Jurassic)--quartz sandstone.
Dolores Formation (Upper Triassic)--red shale with sandstone.
Precambrian (age unknown)--several igneous and metamorphic units.

b) The Colorado Geological Survey obtained samples from wells and springs in the region and performed standard geothermometry modeling to estimate reservoir temperatures at depth. The best estimate of subsurface reservoir temperatures was calculated at 176^{o}F to 302^{o}F. Reservoir temperatures obtained through well drilling were projected at up to 160^{o}F.

c) Isotopic determinations for oxygen-18 and deuterium performed on the geothermal fluids indicated the fluids were meteoric in origin and were not trapped in place for several million years.

d) Tritium analysis of wells indicated geothermal fluids have a residence time greater than 25 years.

e) Slightly anomalous concentrations of soil mercury at Pagosa Springs indicated presence of low-temperature geothermal resources.

f) Both dipole-dipole and dipole-bipole electrical resistivity surveys indicated a well-defined zone of low resistivity probably representing the area of the reservoir feeding the hot springs. Mapped results of these surveys are presented in Figures 5-2 and 5-3.

g) Colorado Geological Survey temperature gradient wells to measure temperature profiles are shown in Figure 5-4. The average thermal gradient of the earth is 35^{o}C/km (approximately 2.9^{o}F/100 feet); many of the gradient holes at Pagosa Springs were in excess of 100^{o}C/km (6.5^{o}/100 feet). Average terrestrial heat flow for the Western United States is 1.5 Heat Flow Units (HFU). Some gradient holes have heat flow values in excess of 4.0 HFU and nearly all gradient holes have twice normal heat flow values.

h) Chemical analyses of geothermal fluids from wells indicated a consistent and relatively good quality geothermal fluid. Analyses results are presented in Table 5-1.

i) The Colorado Geological Survey drilling program conducted in 1978 drilled two wells of 640 feet (observation well O-2) and 1475 feet (production well P-1). The deeper well produced only 113^{o}F water and temperatures were not significantly increased with depth. Figure 5-5 illustrates the temperature profile of P-1.

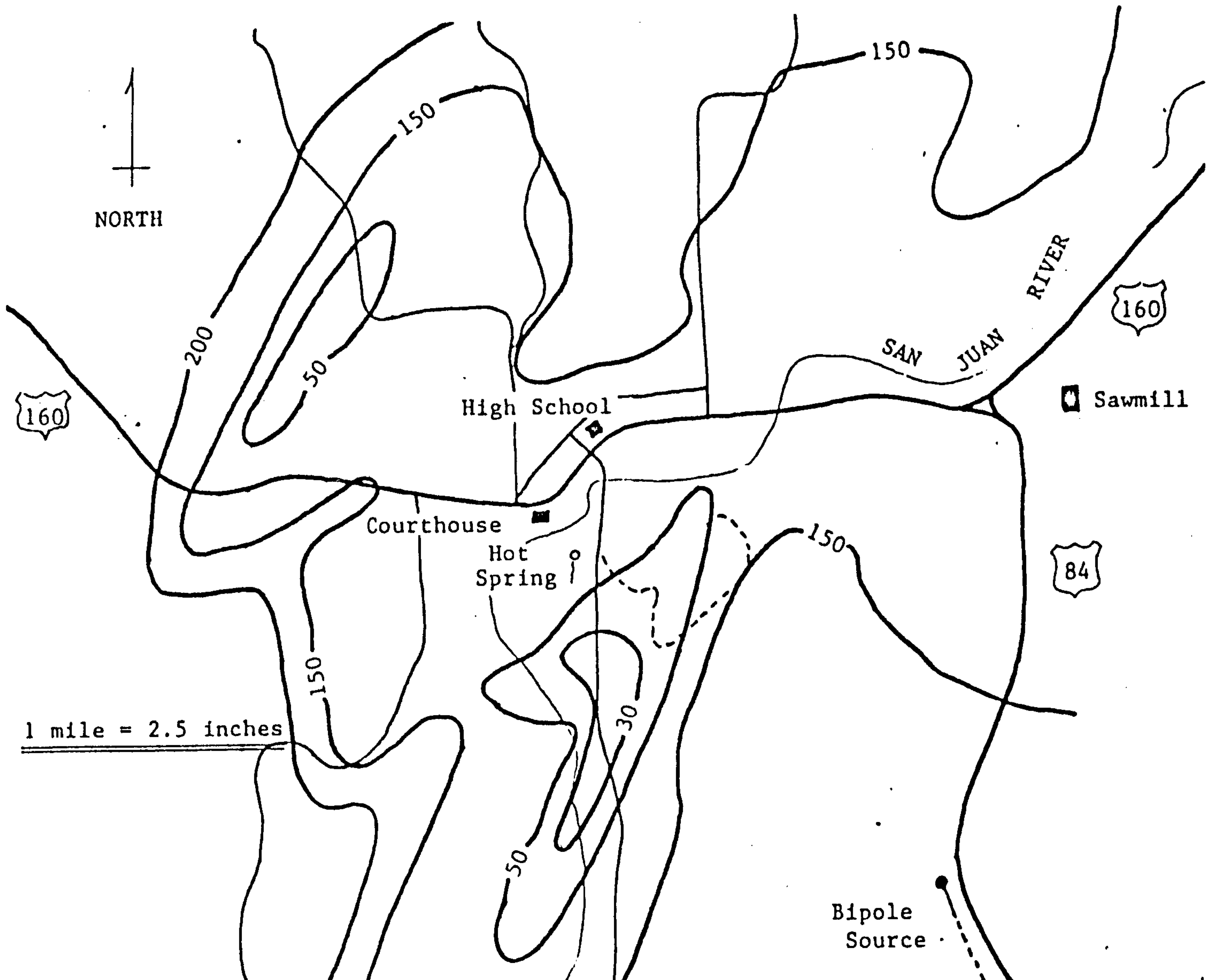


Figure 5-2. Dipole-Bipole Electrical Resistivity Map of Pagosa Springs, Colorado (Keller, 1977).

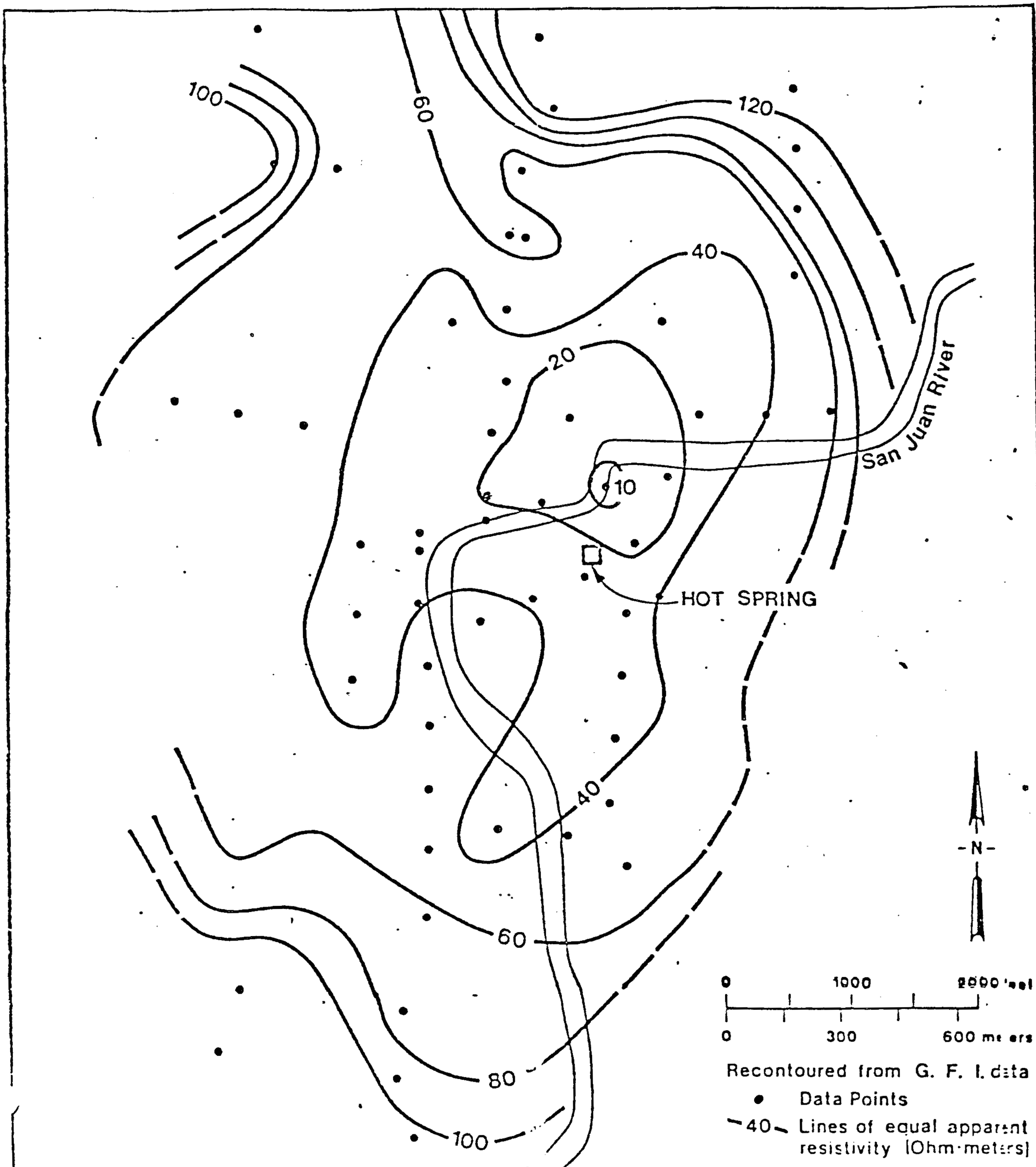


Figure 5-3. Mapped Results of a Dipole-Dipole Electrical Resistivity Survey at Pagosa Springs, Colorado (Keller, 1977).

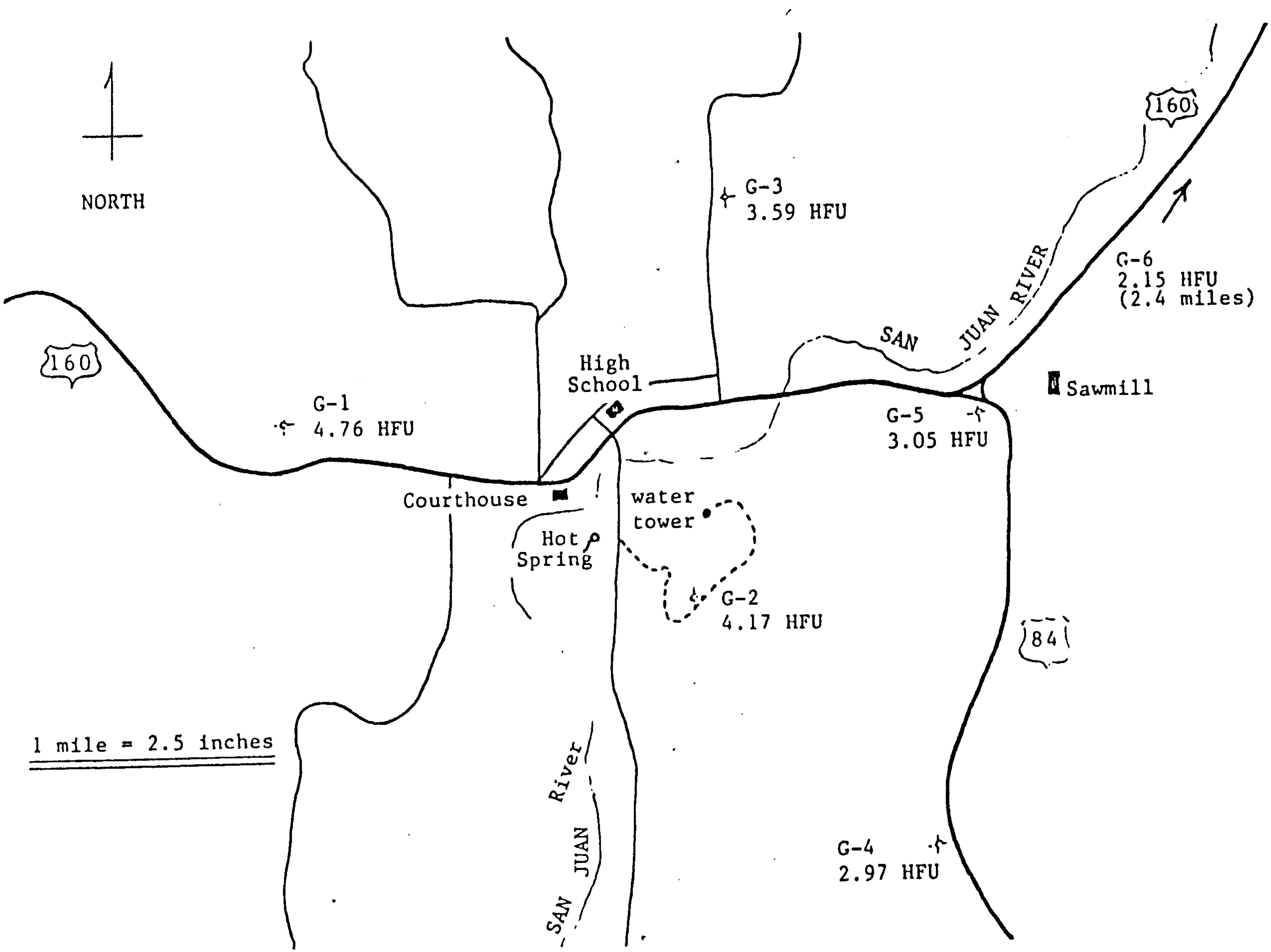


Figure 5-4. Location and Heat Flow Values of Colorado Geological Survey Gradient Holes, Pagosa Springs, Colorado.

Table 5-1. Chemical analyses of Pagosa Hot Spring and selected hot water wells in Pagosa Springs, Colorado (Barrett and Pearl, 1976). All units are in mg/l unless otherwise noted.

constituents	Pagosa Hot Spring	Courthouse Well (#1)	Spa Motel-1 (#15)
Date Sampled	8/75	8/75	8/75
Sodium	790	780	780
Potassium	90	89	91
Calcium	230	250	230
Magnesium	25	25	24
Silica	54	52	51
Chloride	180	170	160
Fluoride	4.3	4.5	4.4
Arsenic	0.12	0.093	0.08
Boron	1.8	1.8	1.9
Cadium	-0-	-0-	-0-
Iron	0.08	0.02	0.21
Lithium	2.9	2.8	2.9
Manganese	0.23	0.27	0.25
Mercury	0.0001	-0-	-0-
Nitrogen	0.02	0.01	-0-
Selenium	-0-	-0-	-0-
Sulfate	1400	1500	1600
Zinc	0.01	0.01	0.01
Bicarbonate	855	858	753
pH	6.5	6.5	6.5
Temperature (°C)	58	56	53
Total Dissolved Solids	3200	3300	3320
Discharge (gpm)	265	30	-

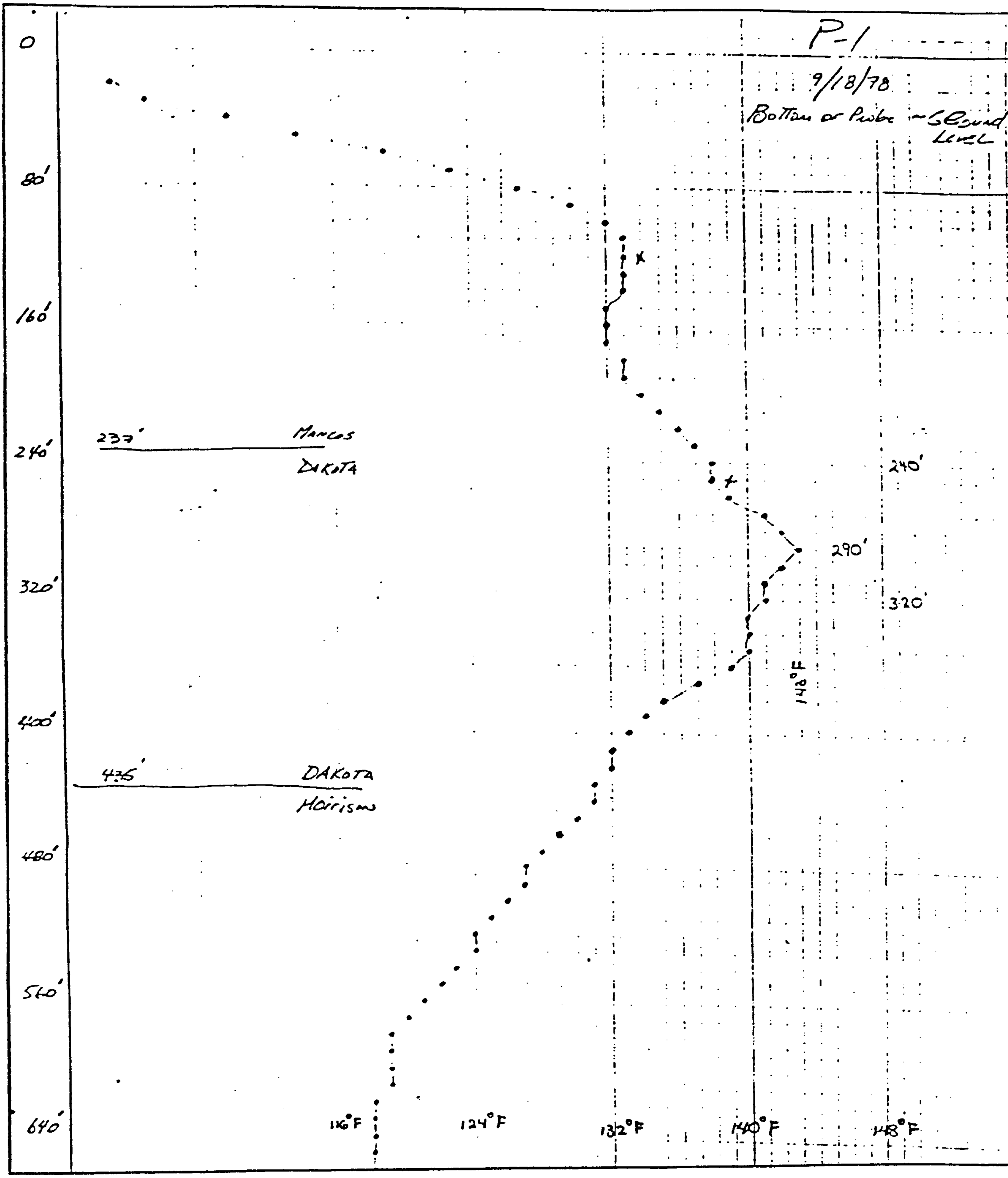


Figure 5-5. Temperature Profile of Well P-1 Conducted Under Shut-In, Static Conditions.

j) Groundwater flow in the Mancos Shale is the result of intergranular and fracture porosity. The Dakota Sandstone flows are confined and are the result of fracture porosity. Pagosa Springs may be an area of regional discharge from the Dakota Sandstone. A theorized cross-section of possible water movement in the Dakota Sandstone, south of Pagosa Springs, is shown in Figure 5-6.

k) Previous, multiple wells producing substantial water flows indicated the geothermal resource was entirely sufficient to support extensive district heating system development. The exact reservoir model describing the resource was not known.

5.2 PRE-DRILLING ASSESSMENT

Hydrosciences, Inc., a Denver-based hydrogeological company, conducted preliminary hydrological testing and evaluated the geothermal reservoir system beneath the town of Pagosa Springs as part of the pre-drilling assessment. The main objectives of Hydrosciences' reservoir testing program were to determine aquifer characteristics such as transmissivity, permeability and the storage coefficient, to model the relationships between the local ground water system and the geothermal heat source, to provide estimates of reservoir life. and to project feasible production flow rates.

To ascertain the most reliable reservoir model, Hydrosciences designed a two-step testing plan. A series of short-term pulse tests were conducted on the Colorado Geological Survey's well 0-2 while monitoring reservoir response and pressure equilibration at wells P-1, County-2, Courthouse, Buhler, Edmonds (Montroy), Methodist Church, Giordano-1 (Spa Motel-1), Town 1, and several discharge vents at the Pagosa Hot Spring. After the pulse test a 24-hour flow and recovery test was also run on well 0-2. The full, comprehensive discussion of the testing details is given in Project Report No. 2, Hydrosciences, Inc., October 1979.

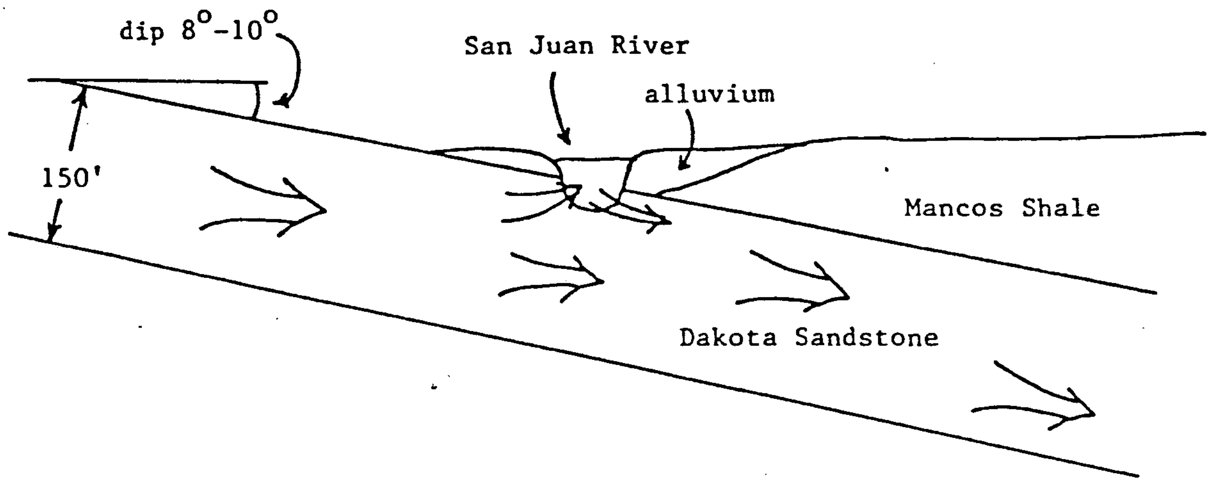


Figure 5-6. Theorized Cross-Section of Possible Groundwater Movement in the Dakota Sandstone, South of Pagosa Springs, Colorado.

Based on the analysis and interpretation of the available data derived from these tests, Hydrosciences made the following conclusions:

1) In order to provide the desired quantity of hot water required for a maximum planned peak demand of 2000 gpm it would be necessary to drill new production wells. No single existing well can supply 2000 gpm.

2) Based on interpretation of the results of one 24-hour flow test of well 0-2, it can be stated that on a continuous basis well 0-2 would be capable of yielding 500 gpm for a period of 25 years with a calculated reduction in pressure at the wellhead of about 105 feet (45.5 psi). This pressure reduction would still allow the well to flow at the land surface, but the available pressure head will only be ten feet (4.3 psi). If well 0-2 were allowed to flow at 750 gpm, the wellhead pressure was estimated to gradually decline to zero pressure (land surface datum) after about eight years of continuous flow. At a continuous flow rate of 1000 gpm the wellhead pressure was estimated to decline to zero pressure (land surface datum) within one week of flow. When the wellhead pressure falls below the land surface datum it would be necessary to install a pump in the well to maintain flow out of the well bore.

3) The probable maximum yield of well 0-2 under pumping conditions would be 350 gpm or less, assuming a maximum lift of 200 feet, because of the limitations on the pump size and lift capacity at maximum drawdown posed by the 7 1/2-inch OD well casing.

4) Based upon the behavior of the flow test of well 0-2 and interpretation of the flow test data, it appears that the local subsurface flow system in the Mancos Shale and Dakota Sandstone at the geothermal "hot spot" near Pagosa Springs behaves analogously to porous media. That is, the local hot spring area likely is controlled by the intersection of two or three major linear structural features. The zone of fracturing (perhaps several hundred to a thousand feet in width) within this fracture intersection area is believed to be so well developed and extensive that the rock matrix mass in the area transmits fluids in the same manner as porous media.

5) The average temperature of the discharge water from well 0-2 during the 24-hour flow test was a fairly constant 119^{o}F. Water of 138^{o}F is available from the Courthouse Well which reportedly flowed continuously at 150 gpm for a period of 24 hours during a short test by personnel of Coury and Associates, Inc. The possible changes in discharge water temperature from these wells that might occur during long-term periods of continuous flowing/pumping are unknown.

6) The relationship between the geothermal reservoir system in the Mancos Shale and the Dakota Sandstone beneath Pagosa Springs and the actual source of the geothermal heat at depth is unknown.

Multiple theories were projected to model the geothermal reservoir at Pagosa Springs but it is not definitely known which model is correct or which portions of different models tie together into the actual geothermal system. It has been sufficiently proven that the geothermal reservoir in the area is probably a secondary reservoir restricted to fractures throughout the Dakota Sandstone and lower Mancos Shale. Where the primary geothermal reservoir is, and how the waters migrate to Pagosa Springs, has not been positively determined. One model theorizes that hot waters may ascend the Nacimiento Fault zone and mix with ground water in the Dakota Sandstone and Mancos Shale. Cold ground water would mask the hot waters while moving them under Pagosa Springs. A second model projects that hot waters are carried to the surface at Pagosa Springs via a fault which splays from the Nacimiento Fault, or from dike swarms to the east and south. A third model projects the heat source may be east of town. Terrestrial heat is ascending the Dakota Sandstone enough to manifest thermal waters at the surface. None of the above models in themselves adequately explain the documented reservoir characteristics, however.

The pre-drilling evaluations suggested that no geologic intrusions are providing heat to the reservoirs. It was judged more likely that the geothermal system may originate in the Precambrian crystalline basement complex and then migrate to Pagosa Springs via the Dakota Sandstone and Mancos Shale sedimentary units. One of the major questions regarding the nature of this system is whether the thermal water is flowing laterally through the Dakota Sandstone and Mancos Shale or is fed vertically to the shallow reservoir via fractures. Location of hot water wells in the town of Pagosa Springs indicates the lateral extent of the thermal water is very limited as shown by wells which have encountered cold water just on the perifery of downtown. Also, the electrical resistivity surveys (Figures 5-2 and 5-3) traced the limited area of known hot water wells. Lateral geothermal movement would be within the depth and penetration of the dipole-bipole survey and the saline chemistry of geothermal fluids should easily allow detection by electrical resistivity surveys; this was not the case, however.

Another strong argument for a system controlled by a vertical feature is the high flow encountered in the Dakota Sandstone in well P-1, but not in 0-2 only 88 feet away. The vertical feature encountered in P-1 is probably a small displacement vertical fault which may be either the major conduit, as suggested by its strong control over pressures in all thermal wells and springs, or it may be one of many related, interconnected vertical faults. If this type of fault were to continue well into the basement, it would explain why high, hot flows were not encountered in basement rocks. The high volume, hot water might be restricted to fault zone(s) and then mix with cold ground water over larger volumes of the aquifers.

Hydrosciences proposed that based upon the behavior of the wells during the flow test and subsequent analysis and interpretation of the data, that the local geothermal reservoir system is highly fractured and acts as a porous medium in a relatively narrow zone near the intersection of two or more major fracture ("fault") systems which intersect underneath Pagosa Springs. The relationship of the geothermal reservoir (i.e., the shallow, porous-media portion which provides hot water to local wells less than 700 feet in depth) with the geothermal heat source at depth is not certain, but is believed to be a type of convection cell with a circulation pattern within the fracture system by continuous discharge of hot water at the Pagosa Hot Springs and underneath the San Juan River Valley in the alluvium. A convection cell could explain the cause of a higher temperature fluid zone becoming isothermal or inversed with depth as is the case in well P-1 (Figure 5-5). The recharge probably originates as percolation from snow melt and precipitation in the outcrop areas of the Dakota Sandstone and migrates downdip toward town.

As seen from the above discussion, many theories have been projected to model the geothermal reservoir at Pagosa Springs and each has its own deficiencies. None of the existing theories affect the fact that significant flow has been continually withdrawn from the reservoir for the past 50 years. Additionally, the past historical use has been sufficient for the heating needs of the proposed distribution system.

5.3 DRILL SITE SELECTION

Based on the pre-project knowledge and the pre-drilling resource assessment, two production wells were drilled on sited land immediately south of the Archuleta County Courthouse. The new site was in the immediate proximity of already existing wells P-1 and O-2 such that subsurface conditions were well known. The new site was chosen based on objectives to penetrate the Dakota Sandstone for production flows at depths of 250 to 300 feet. Public ownership of the site and the well-resource (both later questioned), and its central location to the distribution system were also important criteria in the locating process. Figure 5-7 shows the selected drilling site relative to the Core business area, the County Courthouse, and the principal Town geographic features including the Pagosa Hot

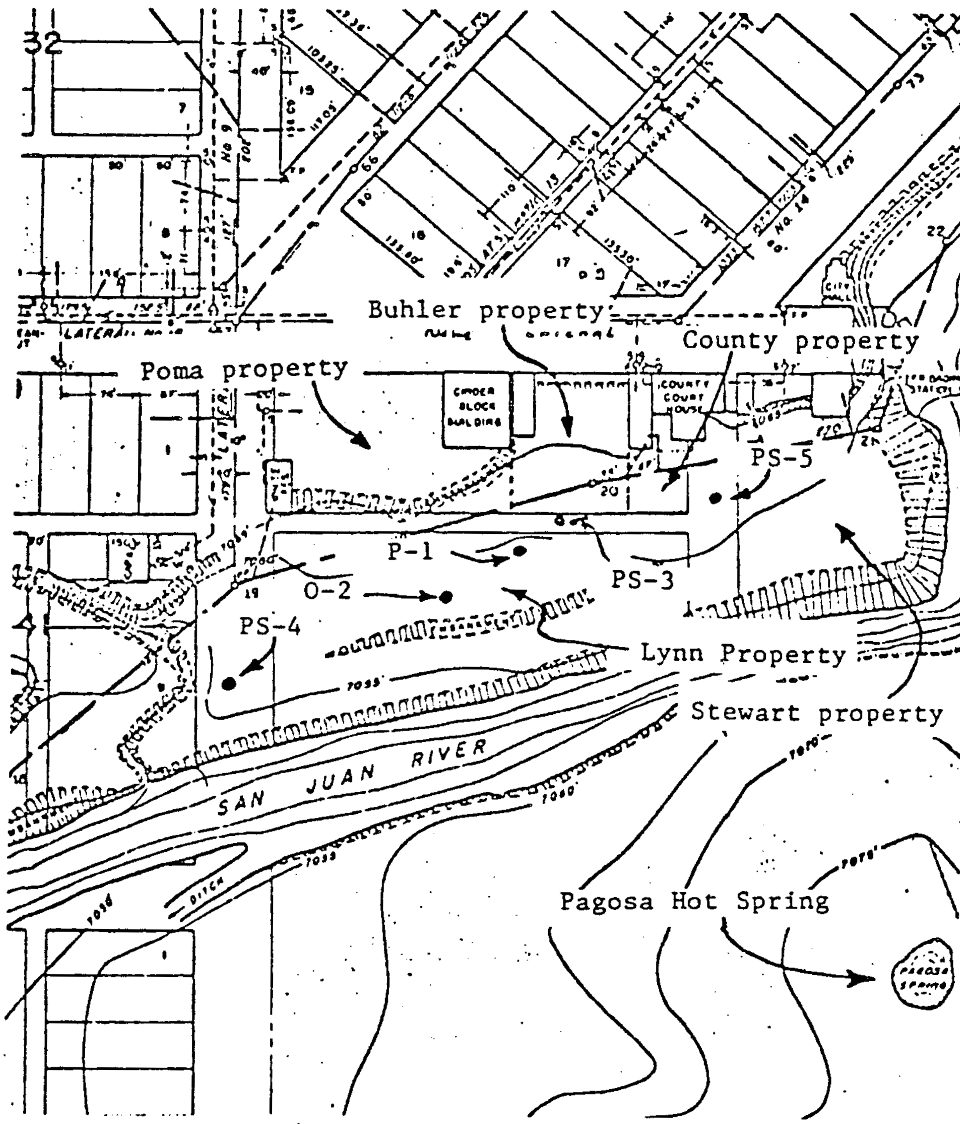


Figure 5-7. Location of wells drilled by this Project (PS-3, -4, and -5) and Wells Drilled Previously by the Colorado Geological Survey (P-1 and O-2). Also shown are the Landowners Within 100 Feet of the New Wells.

PAGOSA SPRINGS, COLORADO

Hot Springs and the San Juan River. Subsequent to the drilling of the two wells, it became apparent that the production well site was in reality located on the Lynn family private land and a land exchange was then executed to legally assume ownership of the wells for the geothermal system.

6.0 ENVIRONMENTAL ISSUES

6.1 PRE-DRILL

An environmental assessment of the impacts of establishing a geothermal district heating system at Pagosa Springs was completed in 1979 by Coury and Associates, Inc.; this study concluded that the impacts resulting from such a system would be minimal and that any specific issues of concern could be reasonably mitigated. The report addressed the effects of production well drilling, utilization of existing wells, construction of the distribution and collection system, and the disposal of the spent fluids. Potential impacts of the system on geology, soils, water resources, air quality, noise, flora and fauna, human environment (land use, socio-economics, and safety), and archaeology were all considered in the review. The assessment highlighted the following points:

--The overall impact of the physical and human environment should not be significant.

--The geothermal resource in the area has been utilized for decades; the proposed system does not sharply change the existing environment and current residents are already acclimated to the proposed activity.

--Effects of drilling and construction activities will be minor and temporary; surface disturbances will be restored at project completion.

--Drilling and construction noise will be mitigated to the extent possible and will primarily be kept to daytime hours.

--The potential for surface water contamination from distribution system leakages will be minimized by effective design practices.

--Disposal of the cooled geothermal fluid will be by discharge to the San Juan River or through reinjection to the producing aquifer. Water of similar quality and quantity has been surface discharged to the San Juan River for several decades, and this discharge has caused no noticeable adverse effects to the environment and and water quality standards have been met. Since the new system will utilize or replace existing wells, continuation of surface discharge is anticipated.

--Air quality will not be adversely affected by the project. The primary source of H_2S gas is from the natural hot springs and seeps. Since geothermal fluid production of the new system will be comparable to flow of existing wells, there should be no significant increase in H_2S levels.

--Groundwater production rates in existing wells, not tied to or replaced by the new system, should not be significantly affected. Adjudicated Water Rights will be obtained through the Colorado Department of Natural Resources, State Engineer's Office.

6.2 POST-DRILL

Subsequent to the geothermal resource assessment performed in 1979 and 1980, two production wells to supply the district heating system were drilled and completed. No significant, new environmental impacts were experienced as a result of this project requirement.

Since the discharge of cooled fluids to the San Juan River was comparable in quality and quantity to previous discharges which were to be replaced by the new wells, the Colorado Department of Health, Water Quality Control Division, approved the surface discharge option and did not require a formal NPDES discharge permit.

Finally, the impact of the new production wells on nearby existing wells became a visible and public issue in later project stages. All water-property rights of those well owners have been protected and adjudication procedures for rights from the new wells are in progress.

7.0 INSTITUTIONAL ISSUES AND PERMITS

7.1 PRIVATE

The Pagosa Springs production wells were originally located such that the production wells, transmission piping, heat exchanger-control house, distribution piping and the disposal piping were all on public lands and public rights-of-way; therefore, no purchase or leasing of land or rights-of-way was initially pursued or required. Midway through the project, it was realized that original county platting maps had been misinterpreted and, as a consequence, the production wells were located on private land. The Town then exchanged public land for this privately held land such that clear title was established. No other private acquisitions or lease agreements were necessary during the duration of the project.

7.2 CITY/COUNTY

Permitting at the local level was not significant. No special city or county zoning permits were required.

7.3 STATE

The principal permitting agency governing geothermal energy development during the project timeframe (1979-1984) was the Colorado Oil and Gas Conservation Commission. The Colorado State Water Engineer, Groundwater Section, provided input to the Oil and Gas Commission related to the protection of groundwater and surface water supplies. Colorado Geothermal legislation was changed in 1984 and the State Engineer now governs geothermal developments similar to the Pagosa Springs project.

For production wells PS-3, PS-4, and PS-5, drilling permits were obtained from the Oil and Gas Commission.

If the geothermal well is on state, federal, or private lands, these permits must be filed with the State of Colorado. General Rule G303(a) of Colorado's "Rules and Regulations for the Development and Production of Geothermal Resources" states as follows:

> Before any person shall commence operations for the drilling of a well, such person shall file with the Director an application on GT Form 2, for a permit to drill, along with a filing and service fee of Seventy-Five Dollars (75.00), and must secure the Director's approval before proceeding with such operation.

In accordance with General Rule G303(a), GT Form 2's (geothermal drilling permits) were filed with the Colorado Oil and Gas Conservation Commission on April 28, 1980 and July 18, 1980.

Property boundaries at Pagosa Springs are very close to the well sites. Drilling sites were very restrictive and all well sites were located within 20 to 30 feet of property lines. General Rule G318(a) of Colorado's "Rules and Regulations for the Development and Production of Geothermal Resources" states as follows:

> .....provided and except that in drilling to a known common source of supply that is less than a depth of 1000 feet below the surface, the well shall be located not less than 100 feet from any lease line, and not less than 150 feet from any other producible geothermal resources well, or drilling well, in said source of supply, unless authorized by order of the Commission; .....

In order to conform with General Rule G318(a), a waiver was requested from the Colorado Oil and Gas Conservation Commission. This Commission granted the Pagosa Springs Geothermal Project a waiver based on written permission from the surrounding landowners to drill within 100 feet of their property lines.

Upon completion of drilling operations the appropriate forms and permits must again be filed with the State regulatory agencies. General Rule G306(a) of Colorado's "Rules and Regulations for the Development and Production of Geothermal Resources" states as follows:

> Within sixty (60) days after the completion or recompletion of any well, the owner or operator shall transmit to the Director the well completion or recompletion report and log, GT Form 5.....

In accordance with G306(a), well completion permits were filed for PS-3, PS-4, and PS-5 on September 17, 1980.

Since only one well was determined to be unsuccessful, abandonment and plugging procedures were relatively easy. General Rule G305(c) requires a GT Form 4: Sundry Notices to be filed with the Oil and Gas Conservation Commission, and to include the following information:

> .....a report on the operation shall be filed with the Commission on GT Form 4..... The abandonment details shall include an account of the manner in which the abandonment or plugging work was carried out, including the nature and quantities of materials used in plugging and the location and extent (by depth) of the plugs of different materials; records of the amount, size and location (by depth) of casing and junk left in the well; and a detailed statement of the volume and weight of mud fluid used. No plugging report will be approved until pits have been filled and location cleared and restored to the satisfaction of the Director.

GT Form 4 was filed on September 17, 1980.

Originally, permanent production well permits for PS-3 and PS-5 were also to be obtained through the Oil and Gas Commission. In 1982, those permit applications were denied due to objections by the State Engineer; those objections were advanced due to potentials for water-right interferences. Because of legislative changes, all future permitting will be directly through the State Engineer only. During the 1982-1983 heating season, a temporary nine-month production permit was issued. Again, during the 1983-1984 heating season, a second temporary production permit was granted conditional on the performing of a geothermal system testing program designed to identify interference which the new system may have on previously existing wells with established water rights. Appendix 1 presents the results of that testing effort, while Appendix 3 summarizes the data from a second test period during 1984 and 1985.

The overall water rights issue is a complex, visible issue, especially in the arid Western United States, and professional, legal and engineering consultation is recommended at all project stages. Legal issues relating to reservoir modeling and testing, utilization of water rights from existing wells, historical beneficial use of adjudicated flows from existing wells and transference of rights to new wells all played a role in the denial of the permanent production permits for the Pagosa system. Throughout the course of the project development, Pagosa Springs town management, along with the engineer's consultant team, continuously communicated with State officials. At one point, verbal production approval was given to Town officials. At various times, lack of definition with respect to State Agency regulation and decision-making authorities has complicated the process. All parties are currently cooperating to resolve this important issue such that the system can operate efficiently and at design capacity in the future. The adjudication of water rights for the Pagosa system is scheduled for Fall 1984.

In order to discharge geothermal fluids to the San Juan River during drilling operations, and on a long-term production basis, the appropriate environmental permits had to be filed with the Colorado Department of Health, Water Quality Control Division, granting Pagosa Springs a waiver of the required discharge permits. Such a waiver was obtained. The waiver of this permit means that the Town of Pagosa Springs can discharge geothermal effluent to the San Juan River for an indeterminate amount of time, providing that the volume of fluids and total dissolved solids (mineral content) does not increase measurably over the ensuing years.

7.4 FEDERAL

A project environmental report was prepared for the U.S. Department of Energy. That effort concluded that project impacts would be minimal. Details of that report are discussed in greater detail in Chapter 6.

8.0 PRODUCTION DRILLING AND LOGGING

8.1 SUMMARY

During June-August 1980, two geothermal wells were drilled to approximate depths of 300 feet and then cased with 9 5/8-inch production casing. Targeted production rates from each of the two geothermal wells were 135^{o}F fluids at 500 gpm. These production rates would be sufficient to supply the demands of the first phase of the municipal heating district. From drilling records of two geothermal wells at Pagosa Springs drilled by the Colorado Geological Survey, it was determined that the lower geothermal aquifer in the Dakota Sandstone was most suitable for large-scale production. Drilling records of the state wells show that the shallow aquifer in the Mancos Shale does not yield adequate flow rates and has significant impact upon the privately-owned geothermal wells in town.

Extensive drilling difficulties were encountered in well PS-3 due to large amounts of river gravels and boulders at shallow depths. The drilling rig used in this job would have been adequate to drill a 26-inch bore in boulders if the driller had been aware of drilling conditions. The driller did not have a sufficiently large Kelly to handle a 26-inch bit and consequently "twist-offs" were numerous. After four weeks of continual efforts, PS-3 reached a total depth of 300 feet. Reservoir tests showed artesian production rates of 600 gpm at 131^{o}F. Though a lower temperature was encountered than anticipated, the good flow rates proved this well to be a success.

Reservoir testing of the Dakota Sandstone aquifer in well PS-3 showed minor interference with the Pagosa Hot Spring and privately-owned hot water wells in town. In order not to impact other hot water wells, PS-4 was sited several hundred feet southwest of the known geothermal anomaly. Geologists realized there was a greater "dry-hole" risk at this location; however, they felt there was sufficient evidence to indicate chance for success and that production flows may not significantly impact existing hot water wells in town. Similar drilling problems were encountered with boulders and a 26-inch bit, as in PS-3; additional problems were the result of vandalism. Thirty to forty pounds of cast iron and steel scrap had been dumped down the borehole to a depth of 37 feet while drilling operations had been down for the night. It took three days to drill out this steel and clean up the borehole. A total depth of 299 feet was reached on July 16, 1980, after twelve days of drilling. Because large flow rates at elevated temperatures were not encountered in PS-4, reservoir testing was not conducted. Cumulative flow rates of 228 gpm at 118^{o}F were the total production of this well. Because this well did not produce sufficient quantities of geothermal fluids it was considered a "dry hole"and therefore plugged and abandoned.

Because of inadequate total geothermal production, a third well was required to meet the engineering specifications required for a municipal heating district. To reduce "dry hole" risks, well PS-5 was sited immediately behind the County Courthouse in an area where it was "known" geothermal fluids would be encountered. After only ten days of drilling operations a total depth of 274 feet was reached in the Dakota Sandstone aquifer. Reservoir tests on well PS-5 yielded production at 1,200 gpm with temperatures of 149^{o}F. These flow rates and temperatures make PS-5 both the hottest and greatest flowing geothermal well in the Pagosa Springs area.

Results of the drilling program during the summer of 1980 at Pagosa Springs were successful. Two successful wells were drilled with combined flow rates greater than 1,500 gpm. Well PS-3 has a production temperature of 131^{o}F and PS-5 has temperatures of 149^{o}F. Production rates of these wells are sufficient to supply the demands of a municipal heating district for the Town of Pagosa Springs.

8.2 ORGANIZATION

Production wells PS-3, PS-4, and PS-5 were drilled by B&B Drilling Company, Grand Junction, Colorado. Technical management of drilling activites was provided by Chaffee Geothermal, Ltd., Petroleum Engineers, Inc., and Coury and Associates,Inc. The temperature logging was performed by the Town of Pagosa Springs, assisted by Chaffee Geothermal, Ltd., and Coury and Associates, Inc.

8.3 DRILLER BIDDING, SELECTION, AND CONTRACT

A bid package was sent to qualified drilling contractors in May 1980. Two contractors responded with bids which were then evaluated on the basis of cost, contractor equipment, and previous experience. Based on that evaluation, the drilling contract was awarded to B&B Drilling Co., Grand Junction, Colorado. Under the contract, the drilling contractor was reimbursed as follows:

--Drilling-related expendable items were paid at actual cost;

--Mobilization and demobilization costs were paid on basis of $.75/mile from Casper, Wyoming.

--Drilling, standby with crew, and standby without crew was paid on predetermined agreed-to hourly charge basis.

8.4 DRILLING SUMMARY

The well was drilled with a Speedstar 2,000 drill rig equipped with a 5 X 10 mud pump and Gardner-Denver 667 air compressor.

The general drilling procedures for drilling wells PS-3, PS-4 and PS-5 were as follows.

1. Construct drill pad, excavate mud pits and flow lines, and set 36-inch culvert to the top of the Km.

2. Move in rotary tools and rig-up.

3. Drill a 6 3/4-inch pilot hole to 30 feet, or through the river boulders and several feet into the Km.

4. Ream the hole to 30 feet with a 6 3/4-inch pilot/12 1/4-inch cutter. Ream again with a 12 1/4-inch pilot/17 1/2-inch cutter. The final ream should be to 30 feet with a 17 1/2-inch pilot/26-inch cutter bit.

5. Set 30 feet of 20-inch conductor pipe and cement with 2 yards of Redi-mix. WOC.

6. Drill out cement in conductor pipe with 17 1/2-inch bit.

7. Drill a 6 3/4-inch pilot hole to 80 feet. Ream the bore to 80 feet with a 6 3/4-inch pilot/12 1/4-inch cutter bit. Ream with 12 1/4-inch pilot/17 1/2-inch cutter.

8. Set and cement 80 feet of 13 3/8-inch surface casing with 100 sx of class "B" + 2% CaCl additive. Grout casing annulus if returns are not obtained.

9. Drill out cement in surface casing with 12 1/4-inch drag bit.

10. Pressure-up casing with 100 psi to test casing joints.

11. Pick up 12 1/4-inch bit and drill out 5 feet of formation. Text casing seat with 100 psi for 1 hour. Observe pressure gauge for leak-off. If pressure bleeds off, rig-up to squeeze.

12. Pick up RTTS packer and go into well to 75 feet and set packer. Pump 20 sx of class "B" cement and squeeze casing shoe. Do not exceed 250 psi during squeeze. WOC 12 hours.

13. Pick up 12 1/4-inch bit and drill out bore to 85 feet. Retest casing seat to 100 psi. Resqueeze if does not test.

14. After obtaining a good test, weld a 14-inch casinghead flange onto surface casing and nipple-up BOP, rotating head, blooie line and the remainder of the drilling stack. Figure 8-1 shows the drilling stack used to control the well during the remainder of drilling operations.

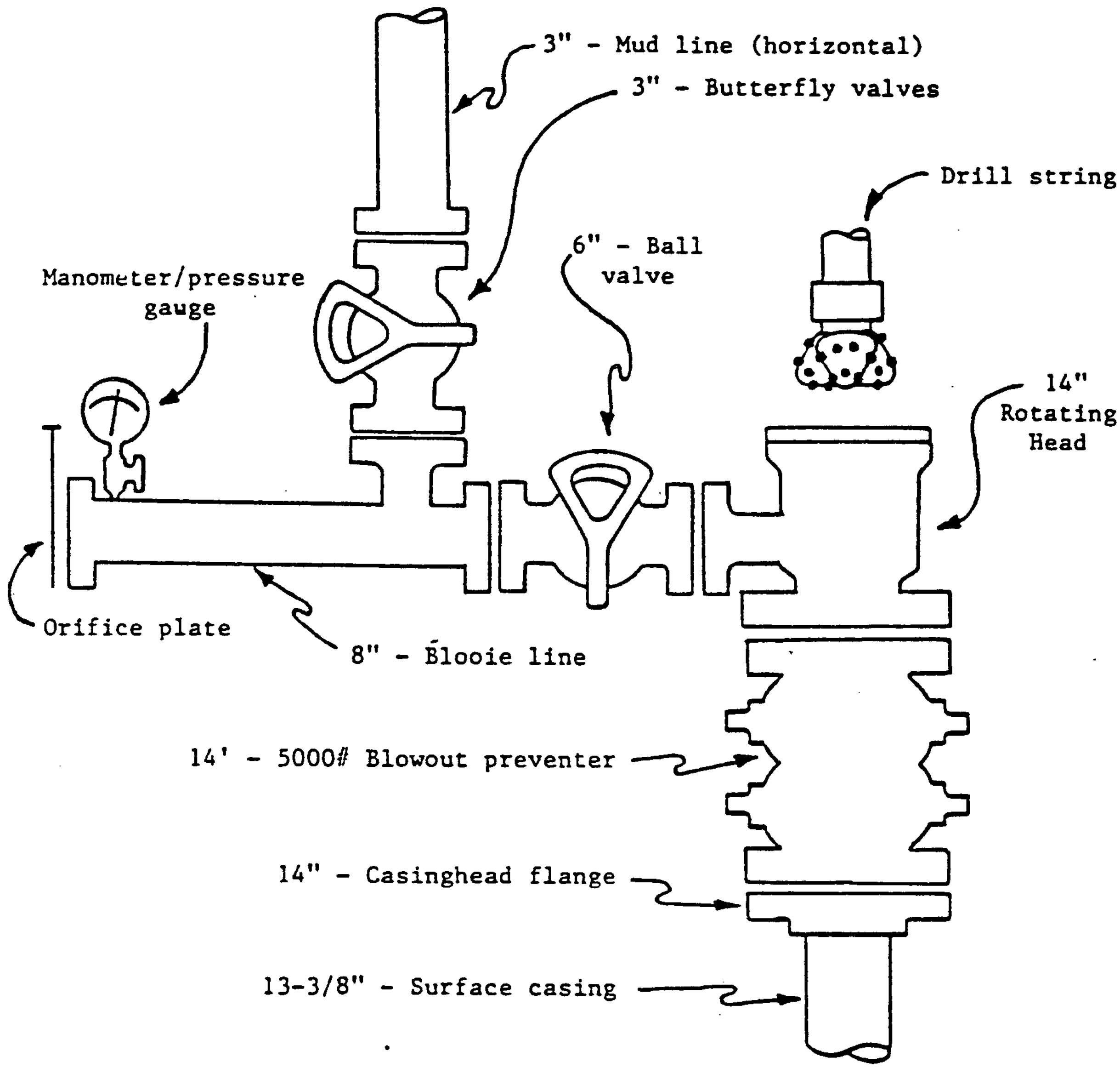


Figure 8-1. Drilling Stack Assembly for Downhole Fluid Control in Geothermal Wells PS-3, PS-4 and PS-5, Pagosa Springs, Colorado.

15. Drill a 6 3/4-inch pilot bore to 125 feet or through the shallow hot water artesian aquifer. Let the formation produce through the blooie line while drilling continues.

16. Ream the bore with a 6 3/4-inch pilot/12 1/4-inch cutter bit to 125 feet.

17. Run a short-term (12 to 24 hours) flow test to determine if the shallow aquifer meets the production criteria. If not, continue drilling operations.

18. There are two options for continued drilling. The produced formation water can be allowed to flow during drilling and turned to the flow line via the blooie line or heavy mud can be mixed and circulated to kill the flows. Herein, drilling under static well conditions is described. However, this method is not necessarily recommended because any additional hot water flows can be easily masked during drilling.

19. Mix and circulate 13.5 #/gal drilling mud until the wellhead pressure has been reduced to "0" psi.

20. Continue mixing and circulating heavy drilling mud while drilling a 6 3/4-inch pilot bore to 235 feet, or the top of the Kd.

21. Ream the bore to 235 feet with a 6 3/4-inch pilot/12 1/4-inch cutter bit.

22. While the well is under static conditions set 235 feet (or to the top of the Kd) of 9 5/8-inch production casing with 100 sx of Class "B" cement + 2% CaCl. Grout annulus if returns are not obtained.

23. With an 8 3/4-inch bit repeat steps 9 through 13.

24. After obtaining a good test, thread a 9 5/8-inch/10-inch swedge into the top casing collar and nipple-up a 10-inch master valve, BOP, rotating head, blooie line, casinghead flange, etc., as in step 14.

25. Re-enter the well with a 6 3/4-inch pilot bit and drill out the Kd to 300 feet, or until adequate hot water production is achieved. All produced fluids can be turned out the blooie line.

26. When adequate production is achieved trip-out of the well, shut-in the master valve and nipple-down the drilling stack.

27. Move off rotary tools.

28. Open the well and let produce for 12 to 24 hours to clean out borehole.

29. Conduct extensive reservoir testing on the 235-foot to 300-foot producing zone.

The drilling activities for the three wells are summarized in Table 8-1.

TABLE 8-1
DRILLING SUMMARY

	PS-3	PS-4	PS-5
Date Spudded:	6/19/80	7/ 8/80	7/22/80
Date Completed:	7/ 2/80	7/16/80	7/31/80
Depth of 20-inch Conductor Pipe:	18'	26.5'	7'
Depth of 13 3/8-inch Surface Casing:	84'	50'	80'
Depth of 9 5/8-inch Production Casing:	230'	--	200'
Total Depth	300'	299'	274'
Boulders/Mancos Shale Contact:	24'	16'	18'
Mancos Shale/Dakota Sandstone Contact	234'	201'	200'
Cumulative Flow:	835 gpm	228 gpm	1000 gpm
Temperature:	130^{O}F	118^{O}F	148^{O}F
Sustained Flow:	600 gpm	--	1200 gpm
Temperature:	131^{O}F	--	149^{O}F

8.5 COMPLETION

During well drilling on PS-3, difficulties were encountered using a 26-inch bit in large boulders. In order to expedite setting the 20-inch conductor pipe through the boulders a drill-and-drive technique was used by drilling a 17 1/2-inch bore and forcing sections of 20-inch conductor pipe down within the collapsing borehole wall. When four to five feet of casing had been forced down to ground level then another section was spot welded onto the conductor pipe already in the hole. As can be seen in Figure 8-2, the final conductor pipe was only set to a depth of 18 feet and the Mancos Shale did not begin until 24 feet. From drilling reports of the Colorado Geological Survey's wells P-1 and O-2, the first hot water flows were anticipated from 90 to 100 feet in depth. Therefore, the 13 3/8-inch surface pipe was set and cemented at 84 feet so as to control and kill the flows when they were encountered. The first production zone was encountered at 110 feet with flow rates of 660 gpm at temperatures of 138^{O}F. A

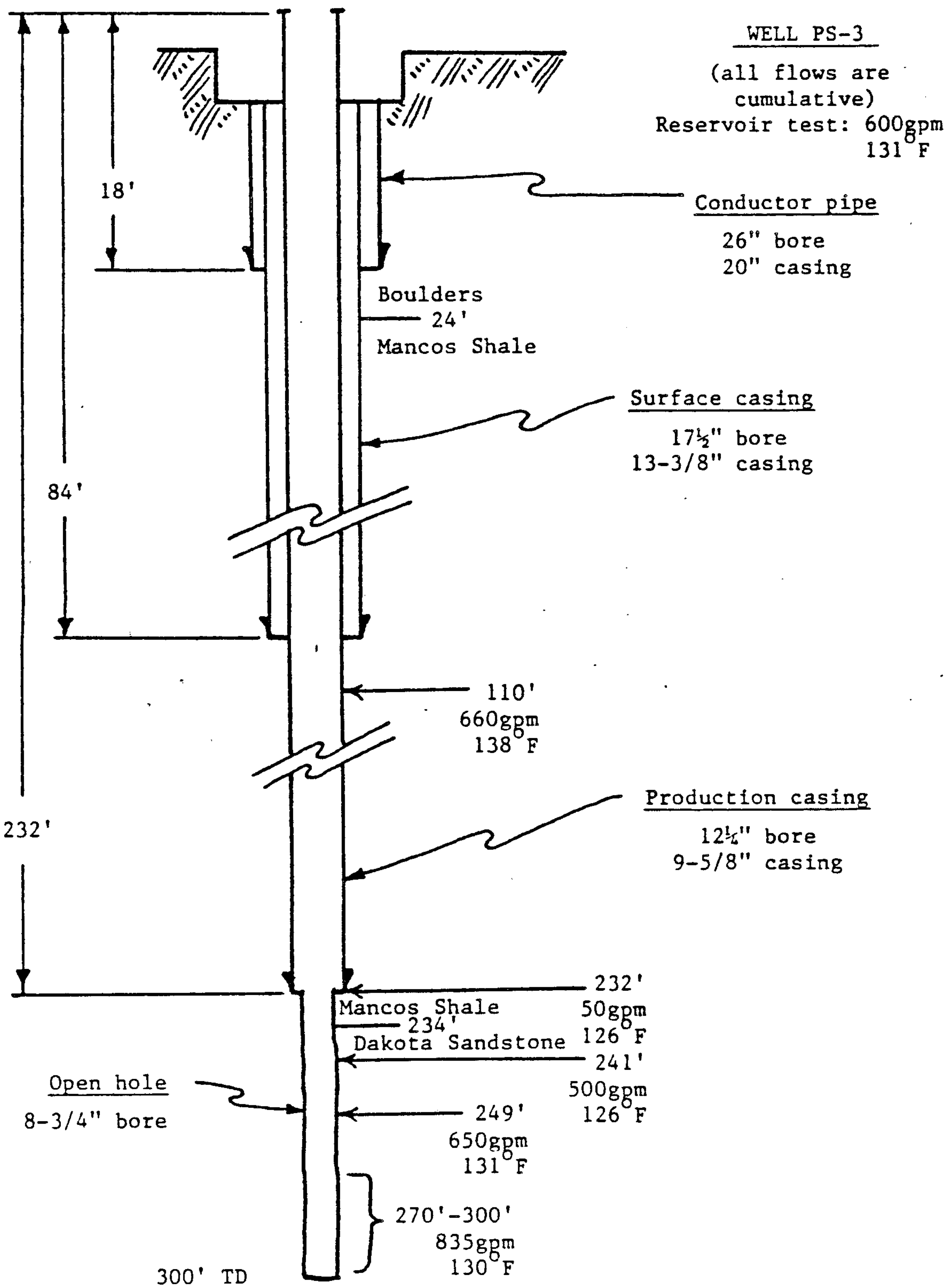


Figure 8-2. Completion and Casing Profile of Well PS-3, Pagosa Springs, Colorado

12 1/4-inch bore was then drilled to the Mancos Shale/Dakota Sandstone contact at 234 feet and 9 5/9-inch production casing was set and cemented. Due to the competence of the borehole wall in the Dakota Sandstone, the production zone was left uncased as open-hole from 232 feet to the total depth of 300 feet.

By projecting a 10° regional up-dip to the southwest of the subsurface formations, production zones at 90 to 100 feet in PS-3 could occur as shallow as 30 to 50 feet in well PS-4 (tangent 10° x 400 feet of lateral distance = depth shallower than PS-3). Very cautious operations were undertaken during drilling, setting and cementing the 26.5 feet of conductor pipe and the 50 feet of 13 3/9-inch surface casing. Drilling continued through the shallow flow zone at 80 feet and to the Mancos/Dakota contact at 201 feet. Since the shallow flow zone was much smaller and colder than in PS-3 it was decided to continue drilling in the Dakota Sandstone and not set 9 5/8-inch production casing. At 285 to 290 feet of depth, extremely hard drilling conditions occurred. Total flows of only 228 gpm at 118°F had been encountered by 299 feet so the well was classified a "dry hole" and abandoned. Class B + 2% CaCl cement, weighing 17.5 pounds/gallon was pumped into PS-4 to a depth of 195 feet to form a solid cement plug back to within 30 feet of the surface. When the cement had hardened, ten sacks of barite were dumped into the upper 30 feet of the 13 3/8-inch surface casing and a steel cap was welded over the well.

Well PS-5 was drilled and completed very similar to PS-3. The 20-inch conductor pipe was drilled-and-driven within a 17 1/2-inch bore. Due to very difficult drilling conditions in the river boulders only seven feet of conductor pipe could be set. As in PS-3, 80 feet of 13 3/8-inch surface casing was set and cemented and then the shallow production zone was encountered at 99 feet (300 gpm at 138oF). As shown in Figure 8-3,

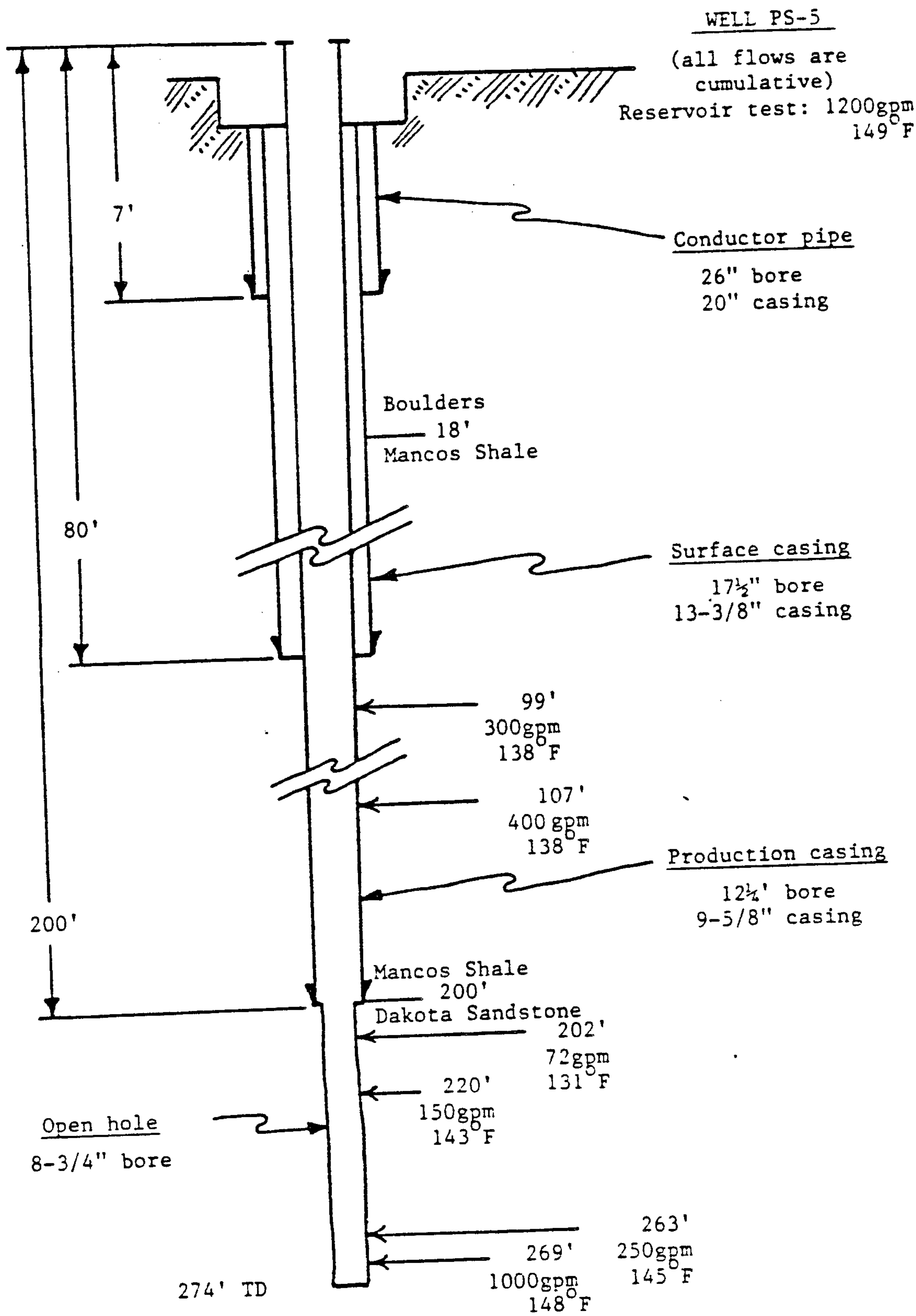


Figure 8-3. Completion and Casing Profile of Well PS-5, Pagosa Springs, Colorado.

the 9 5/8-inch production casing was set in the Dakota Sandstone and an 8 3/4-inch open hole was drilled to a total depth of 274 feet. Massive hot water flows were encountered at 269 feet with production rates of 1200 gpm at 149^{o}F.

On wells PS-3 and PS-5 a threaded casing collar was welded onto the top of the 9 5/8-inch production casing. Then a 9 5/8-inch/10-inch swedge was threaded into the collar and a 10-inch casinghead flange was threaded onto the swedge (Figure 8-4). A 10-inch iron with brass workings slab-gate valve is bolted onto the casinghead flange and this is used as a master valve. A second identical water well valve is placed on the master valve for a backup safety system. On top of the wellhead completion assembly is a "T" with a blind flange which is used as an elbow to turn produced fluids to a blooie line for testing. Upon completion of pipeline construction an elbow was be bolted onto the safety valve and in turn welded onto the connecting pipeline.

Additional drilling details, well testing procedures, drilling fluids utilized, and other well service information are discussed in full detail in Project Report No. 7, Chaffee Geothermal, Ltd., November 1980.

8.6 STIMULATION METHOD--Not Applicable.

8.7 WELL LOGGING SUMMARY

Stratigraphy analysis was performed on PS-3, PS-4, and PS-5. Temperature logging was performed on PS-3, PS-4, and County Well No. 1. Figure 8-5 represents the stratigraphic section of Production Well PS-5, based on drill cuttings and sample descriptions. The formations found in each of the three wells were similar.

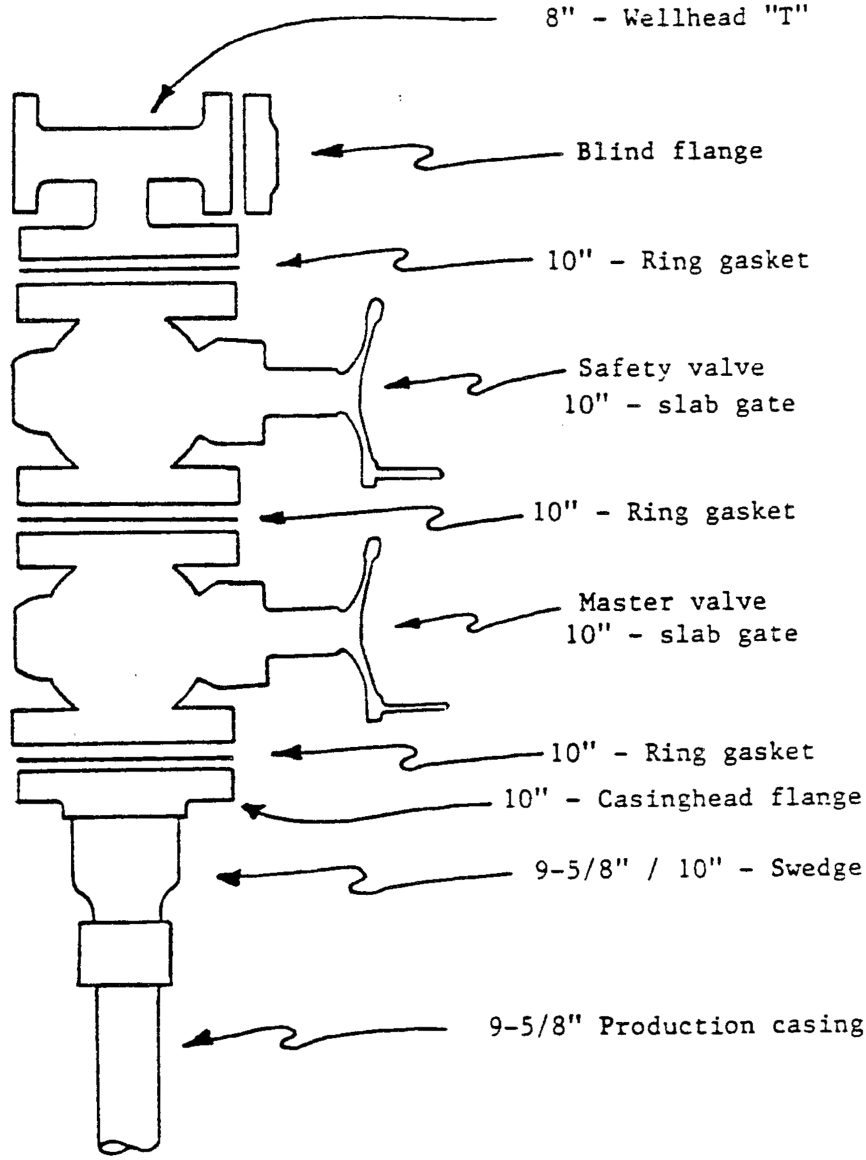


Figure 8-4. Wellhead Completion Assembly for Geothermal Wells PS-3 and PS-5, Pagosa Springs, Colorado.

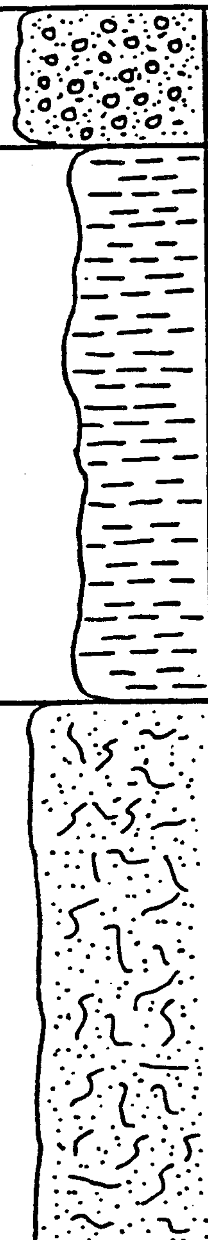
AGE	FORMATION	THICKNESS (feet)	LITHOLOGY	DEPTH (feet)	DESCRIPTION
Quaternary	Alluvium	18		18	River gravels and boulders up to 12" - 18" in diameter. Apparently not a welded zone as in PS-3 and PS-4, but numerous travertine chips throughout cuttings.
Upper Cretaceous	Mancos Shale	182		200	Dark gray, fine-grained, soft, fissle shale. Lenses of very clayish, muddy shale.
	Dakota Sandstone	74		274	Light gray to white, medium-grained, extremely hard, quartzitic sandstone

Figure 8-5. Stratigraphic Section of Well PS-5.

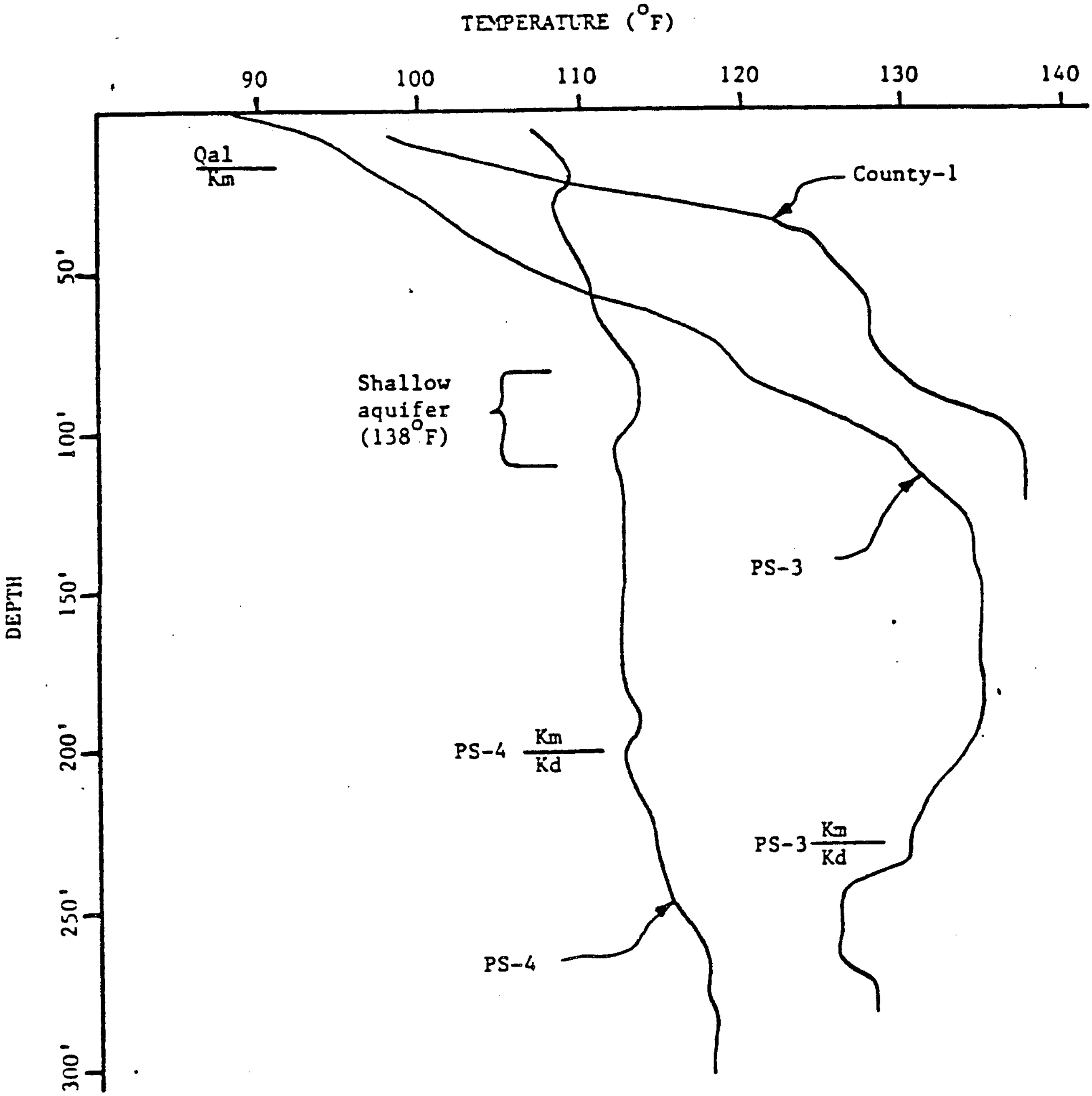


Figure 8-6. Temperature Profiles for Hot Water Wells at Pagosa Springs, Colorado.

The value of temperature gradient logs is their relevant temperature profiles compared to borehole conditions. Figure 8-6 shows the temperature profiles for wells PS-3, PS-4, and County-1. To date, a temperature profile has not been measured for well PS-5. Because of well PS-5's close proximity to County-1 (less than 30 feet), it is projected that the upper 100 feet has an identical temperature gradient profile as that for County-1 as shown in Figure 8-6.

The temperature gradient for well PS-3 is very high (34.5^{o}F/ 100 feet) above the shallow hot water aquifer and then becomes isothermal throughout the remainder of the Mancos Shale (Km). Temperatures within the Dakota Sandstone (Kd) begin to elevate again but surprisingly not until over 30 feet of the formation has been penetrated. The temperature log of PS-4 shows similar temperature profiles only at much lower absolute temperatures and gradients. Though the County-1 well is only 115 feet deep it has a very similar temperature profile with increasing temperatures up to, and through, the shallow aquifer and then apparently isothermal into the remainder of the Mancos Shale. Though the temperature log shown in Figure 8-6 represent true and accurate geothermal temperature gradients, they do not show absolute temperatures. Inadequate equilibration times did not allow the downhole temperatures to stabilize prior to the temperature logs.

9.0 RESOURCE TESTING

9.1 HYDROLOGIC TESTING

The objectives of the 1980 hydrologic testing program were to provide information on the following:

1) Estimates of the aquifer characteristics of the geothermal reservoir system and reservoir life.
2) Interference effects between the two new production wells and the pressure reductions that would occur at selected flow rates necessary to meet the projected needs of the heating system.
3) Potential effects of long-term production from the new wells on existing "hot water" wells.
4) Future monitoring requirements for detecting and evaluating possible changes in the geothermal reservoir system and assessing potential impacts on other wells.

The stated objectives were accomplished by collecting, analyzing and interpreting field data from 12- and 72-hour flow tests conducted at each of the production wells, PS-3 and PS-5, and from a 7-day multiwell flow test conducted at both wells simultaneously. Prior to the initiation of the flow tests, pressure gages (100 psi) were installed at production wells PS-3 and PS-5 and selected observation wells throughout the town, including County #1, Town, Buhler, Edmonds, Superior Automotive and the Methodist Church well. For each flow test, pressure reductions versus time were monitored. In addition, the water level fluctuations were monitored at the Pagosa Hot Spring throughout the testing program using staff gages installed in the main pool. The discharge from each test well was measured using selected orifice plates and a manometer installed near the control valve.

Short-term flow tests (up to 12 hours) were planned for the upper (Mancos Shale) and lower (Dakota Sandstone) zones that would be penetrated during the drilling of each production well. The flow tests were conducted to obtain a general idea of the production capabilities of each zone and to show the effects on nearby existing "hot water" wells and the Pagosa Hot Spring. If either of the flow tests in the upper zone would have adversely affected nearby wells, the tests would have been terminated before the scheduled flow period had elapsed. Discharge rates for each short-term flow test were determined by projecting data collected during "pulse" tests, where flow rates were increased during each one (1) hour pulse step. During the drilling of both PS-3 and PS-5, flow testing in the upper zone did cause immediate reductions in pressure in nearby observation wells and the Pagosa Hot Spring. Therefore, the tests were stopped and the wells were drilled and completed in the lower zone, the Dakota Sandstone, where sufficient quantities of water of suitable temperature were obtained. The flow rates at PS-3 and PS-5 for the 120-hour flow tests were chosen at 600 and 1,150 gpm, respectively. During the flow test at PS-5 (1,150 gpm), it was necessary to open the gate valve completely to maintain a constant flow rate near the end of the test.

Subsequently, 72-hour flow tests were performed at each production well in order to obtain better estimates of the aquifer characteristics of the reservoir system in the vicinity of the production wells. Prior to the start of the 72-hour flow test at well PS-3, the static pressure readings at wells PS-3 and PS-5 were 47.3 and 49.3 psi, respectively. For the 72-hour flow test at well PS-5, the static pressure readings at wells PS-3 and PS-5 were 47.5 and 49.7 psi, respectively. The flow rates at PS-3 and PS-5 were chosen at 425 and 800 gpm, respectively. Each test was run separately to obtain information on the characteristics of each well in the event the entire heating system flow requirement would be taken from a single well. These estimates of aquifer characteristics could then be used to predict pressure reductions versus time over extended periods of time as well as for different flow rates.

In addition to the 72-hour flow tests at the production wells, a 7-day multiwell flow test was made by flowing PS-3 and PS-5 simultaneously at selected flow rates of 212 and 700 gpm, respectively, and pressure reductions were monitored at the production wells, selected observation wells and the Pagosa Hot Spring. Prior to the start of the multiwell flow test, the static pressure readings at wells PS-3 and PS-5 were 47.5 and 49.4 psi, respectively. The multiwell test was conducted to show the interference effects that would occur between the two wells when both wells would be used to supply water for the central heating system.

During the 12- and 72-hour flow tests at PS-3 and PS-5 and the 7-day multiwell test, the temperature of the discharge waters was monitored at reasonable time intervals by field personnel using a glass-mercury thermometer. The temperature measurements at PS-3 and PS-5 remained relatively constant at 131^{o}F and 149^{o}F, respectively. Because of the difference of 18^{o}F between the production wells, the discharge rates for the hydrological analysis were adjusted to provide adequate quantities of water that would meet the design heating requirements.

After the 12- and 72-hour and multiwell flow tests were performed, the appropriate test well(s) were shut-in and pressure recovery in the test wells and selected observation wells were monitored until the wells had recovered to within a minimum of 95% of static pressure heads. Based on the analyses and interpretation of data collected during the 12- and 72-hour and 7-day multiwell flow test at wells PS-3 and PS-5, the following conclusions are presented:

1) The calculated average values of transmissivity at production wells PS-3 and PS-5 are 17,270 and 23,100 gpd/ft, respectively.

2) Measured temperatures of the discharge waters from production wells PS-3 and PS-5 remained constant during the testing program at 131^{o}F and 149^{o}F, respectively.

3) Calculations of the "life of the reservoir" at production well PS-3 at selected, continuous flow rates of 200 and 400 gpm indicate that the well can be flowed at these rates for a period of 100 years without the necessity of installing a pump, under conditions the same as during the flow test. However, the theoretical calculations show that there is only 8.4 psi of pressure head remaining at the well after 100 years at the higher flow rate of 400 gpm.

4) Calculations of theoretical pressure reductions at production well PS-3 at flow rates of 200 and 400 gpm indicate that more than 100 psi (231 feet) of pressure head will be available after 100 years and, therefore, the reservoir system will not be depleted.

5) Calculations of the "life of the reservoir" at production well PS-5 at a selected, continuous flow rate of 700 gpm indicate that the well can be flowed at this rate for a period of at least 25 years without the necessity of installing a pump, whereas, at a higher flow rate of 1,400 gpm, the pressure at well PS-5 would drop to zero in a matter of minutes. However, the pressure heads available using a flow rate of 700 gpm are very near land surface. Therefore, depending on the well efficiency, it may be necessary to install a pump after flowing the well for several years.

6) Calculations of theoretical pressure reductions at production well PS-5 at flow rates of 700 and 1,400 gpm indicate that more than 80 and 30 psi, respectively, of pressure head will be available after 100 years and, therefore, the reservoir system will not be depleted.

7) Extrapolated estimates of pressure reductions indicate that both PS-3 and PS-5 could be flowed simultaneously at system design rates of 200 and 700 gpm, respectively, for approximately 50 years without having to install a pump at either well. However, the pressure heads at both wells would be very near land surface at that time.

8) It is important to realize that the calculations of "reservoir life" do not account for additional pressure reductions at the production wells that may occur due to withdrawals from nearby "hot water" wells.

9) Calculations of theoretical pressure reductions indicate that PS-3 and PS-5 could be flowed at equal rates of 300 gpm for approximately 100 years without installing a pump; but, at higher rates of 1,000 gpm each, the pressures at the production wells would drop to zero within a few days. However, a flow rate of 1,000 gpm at each well could possibly be withdrawn provided the proper pumps were installed near the bottom of the casing in each well. The "life of the reservoir," in this instance, would depend on the added stress imposed on the reservoir system as fractures are dewatered in the overlying strata in the vicinity of the production wells.

10) Calculations of theoretical pressure reductions while flowing both production wells simultaneously at a rate of 300 gpm indicate that more than 90 psi (208 feet) of pressure head will be available after 100 years and, therefore, the reservoir system will not be depleted. However, if both wells are flowed at a continuous rate of 1,000 gpm, it is possible that the reservoir system could be depleted after many years of pumpage depending on the well efficiency and the presence of boundaries, if any, in the reservoir system. Nonetheless, in all likelihood, this will not occur because the production wells will not be flowed continuously, 24 hours per day, for the time period simulated.

11) Field data collected during the 1980 hydrologic testing program indicate that the nearby "hot water" wells and the Pagosa Hot Spring are affected to some degree, regardless of the flow rates at PS-3 and PS-5. The pressure reductions and water level decline are directly related to the flow rate (i.e., withdrawal) at the production well and the time period, with some wells affected to a greater extent than others.

9.2 1983-1984 FIELD TESTING FOR WATER RIGHTS PURPOSES

The one-year 1983-1984 production permit for PS-5 was granted to the Town by the Colorado State Engineer's Office contingent on the preparation and the performing of a geothermal system test plan. The test plan objectives were as follows:

--Document geothermal system operational data to establish the important system operating variables, and to facilitate the long-term optimized performance of the system, including geothermal well withdrawals, heat exchanger performance, energy requirements, and user energy demand.

--To the extent possible, document data showing the impact of PS-5 and PS-3 geothermal well withdrawals on other already existing hot water wells representing a cross section of wells in the Pagosa Springs geothermal reservoir.

--Document PS-5 and PS-3 geothermal withdrawal requirements related to ambient weather conditions, including heating degree days.

--Document operational characteristics of the geothermal distribution system, as a function of hot water and cold water return temperatures, and as related to heating degree days and ambient weather conditions.

--The test objectives did not include reservoir evaluation, projections of geothermal reservoir life, or projections of long-term impacts on nearby wells.

Results of the initial tests are presented in Appendix 1, and they are discussed in Section 26, Production System Performance, and in Section 29, Distribution System Performance. The results of later tests are summarized in Appendix 3.

9.3 WATER CHEMISTRY--ANALYSIS OF CORROSION AND SCALING POTENTIALS

Water chemistry samples of the Pagosa Springs resource were obtained and evaluated for materials compatibility purposes by Radian Corporation, Austin, Texas. The key conclusions of that water chemistry evaluation are as follows:

--Hydrogen sulfide levels of the resource water preclude the use of copper or copper-alloy materials in piping in contact with geothermal fluids.

--For the pH range noted (6.6 to 7.3), the corrosion of carbon steel is largely a function of chloride ion concentration, dissolved oxygen, and temperature. Corrosion rates of carbon steel in similar fluid ranged from 6 to 16 mils per year. These corrosion rates are constant with time and are based on the absence of oxygen.

--Contamination of the geothermal fluid by atmospheric oxygen is to be strongly avoided, as general corrosion rates can increase up to tenfold.

--Vented tanks should be avoided.

--External protection of buried carbon steel pipe from aerated groundwater is recommended.

--High strength, low alloy steels and 12 Cr stainless may be susceptible to sulfide stress cracking (SSC) if they are under stress.

--Given suitable precautions, carbon steel will be generally suitable for use.

--CPVC and PVC (although marginal due to temperature) may be suitable for certain system components.

--Fiber reinforced plastic pipe with either polyester or epoxy resin is also attractive.

--The Pagosa fluid contains enough sulfate to be aggressive to those cement grades not rated for sulfate service.

--Carbon steel should be acceptable for valve bodies, but internals should be corrosion resistent, for example, T316 or Alloy 20. Seals of austentitic steel, viton, or a TEE polymer should be satisfactory.

--Heat exchanger materials T316 stainless or Incoloy 825 should be appropriate; the latter is about one-third more expensive.

--Buna and Viton gasket materials are recommended.

--Calcium carbonate scaling tendencies of the geothermal fluid is judged as light and gypsum scaling and silver scaling should not be a problem.

--For the secondary loop, any competent water treatment vendor can define a specific treatment program, if required, to adequately protect the system.

10.0 DISPOSAL DRILLING AND LOGGING

Since no disposal well was drilled for this project, this Section is not applicable.

11.0 DISPOSAL TESTING

No disposal testing was performed for this project; therefore, this Section is not applicable to the Pagosa Springs project.

12.0. APPLICATION ANALYSIS

The primary objective of the Pagosa Springs district heating system project is to provide low cost space heating and possibly hot water heating services to businesses, public buildings, and residences served by the new system. This objective did not change during the course of the project.

The basic temperature and flow characteristics of the two production wells were established through the resource testing efforts (Section 9.0). Subsequent to that determination, analyses were performed to verify that the proposed applications and heating loads could be addressed with the established geothermal resource. Temperature and flow requirements of proposed users were reviewed and checked against the heating source and the proposed technology.

The attractiveness of geothermal space heating had previously been demonstrated during the several decades of individual well water use at Pagosa. The current project efforts were technically more rigorous in nature. Figure 12-1 illustrates the different types of space heating systems for residential, commercial, and public buildings, and outlines each system's applicable temperature operational range. The 131°F to 149°F production well temperatures are entirely adequate for normal 70°F space heating and 100°F to 110°F hot water heating needs. This has been confirmed during the successful two-year test operation of the system.

Other secondary light industrial process-oriented applications were periodically considered during the course of the project development. These process applications were limited in scope by the low to moderate

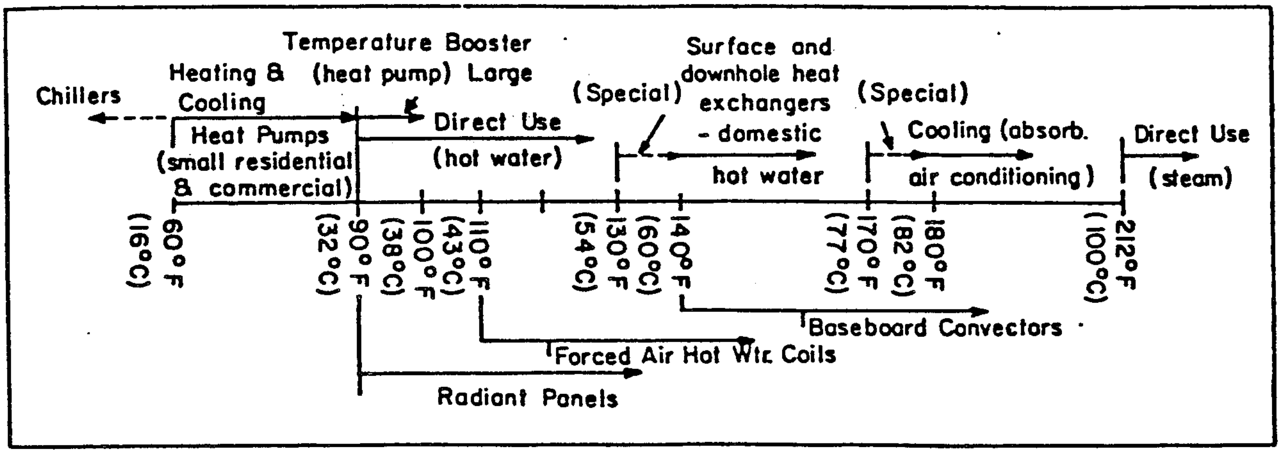


Figure 12-1. Temperature Ranges for Different Space Heating and Cooling Methods.

resource temperature range of the resource. Analyses of these secondary uses were conceptual in nature and were based on identified, future potential uses of the resource which might enhance both the economic attractiveness of the installed system and create additional employment opportunities in the region. Detailed engineering and economic assessments of these aplications were not performed. These secondary uses included:

--Heating of new, large public swimming pools as part of developing tourism facilities.

--Space heating of greenhouses.

--Shopping center parking lot snow melting.

--Snow and ice melting for unsafe public intersection.

--Styrofoam manufacturing process heating.

13.0 OBTAINING USER COMMITMENT

13.1 SUMMARY--INITIAL STRATEGY

From the onset of the project, there was clear recognition by project participants that high utilization of the system will be necessary for the system to be economic. To confirm the potential for this necessary utilization, the initial proposal efforts identified commercial, public, and private candidate users. Later, during preliminary design efforts, candidate users were contacted by questionnaire to help ascertain their interest in hooking up to the system. Figure 13-1 presents a copy of this contact questionnaire. As incentive for customers to hook up to the system, $50,000 of program budget monies was set aside for fifty $1,000 grants to help defray costs customers might incur to tie into the system. This offering was later deleted due to program budget constraints.

As part of the initial contact, heat-load analyses were encouraged; building fuel use was documented by type (wood, natural gas, fuel-oil). Finally, candidate users were encouraged to bring in conventional fuel-use histories to help quantify their probable geothermal needs and to set aside appropriate geothermal demand capacity for their service.

During final design stages, prospective users were then asked to sign letters of interest to reserve space on the system. Figure 13-2 presents such an agreement.

Throughout this entire project effort, the potential benefits for hooking up to the system were disseminated through the local media, through advisory committee participants, and in public meetings.

Original energy pricing efforts by Pagosa Springs Town officials estimated delivered energy costs of $3.35 per million Btu. Final User Agreements were developed in 1981-1982, a copy of which is presented in

Date: ______________

Interviewer: __________

Name: ______________________________ Phone: __________________
(where can be reached during the day)

Mailing Address: ____________________

Address of Building to be retrofitted: ________ Lot ____________ Block

Street Number __________

Is the applicant the owner _____ or renter _______ ?

Type of Building _____ residence _____ one business commercial

_____ apartments _____ multi-commercial ___ church

_____ other: describe _________________________

Approximate square footage: __________ sq.ft.

Type of Heat: ______________________________

____
(please describe as fully as possible

Does the applicant consider the building to be adequately insulated? _______________

Is the applicant interested in using geothermal for water heating purpose? __________

Is the applicant interested in having a heat-load analysis done on the building? _______ yes _________ no

If yes when can the applicant bring his/her last 12 months heating bills? _________________________

If yes, what is the best day(s) and time to have an inspection of the house done? ______________________________

Figure 13-1. Geothermal User Initial Contact Sheet

PRELIMINARY AGREEMENT
FOR USE OF THE PAGOSA SPRINGS
GEOTHERMAL MUNICIPAL HEATING DISTRICT

I, ____________________________ , do hereby make application to
(please print name)
hook on to the Pagosa Springs Geothermal Municipal Heating District for the building located at:

____________________________ ________ ____________
street address lot block

and hereby agree to the following TERMS AND CONDITIONS:

1) I agree that I will purchase heat from the Town's geothermal municipal heating district when such heat becomes available to me, and thereafter will pay for such heat monthly at rates to be determined from time to time by the Town.
2) I agree to comply with, and I understand that I will be bound by such rules and regulations for the geothermal municipal heating district as the Town may adopt and amend from time to time.
3) I understand, that by signing this Preliminary Agreement, I will become eligible for user retrofit assistance. This assistance will include the following material at no cost to me: the corporation stop; curb stop; flow control meter; metering device, and the inlet and outlet pipes from the distribution mains to my building for a distance not to exceed one hundred (100) feet. Further, the Town will supply to me at no cost technical assistance to determine specific equipment, material and installation techniques I will need to retrofit the interior of my building. The total dollar equivalent of this user retrofit assistance shall not exceed one thousand dollars ($1,000.00). The Town reserves the right to install inlet and outlet lines from the distribution lines to my property line and to bill the cost of such installation against my retrofit assistance allocation.
4) I understand that the cost of installing the material supplied by the Town for user retrofit assistance, and the entire cost of the equipment, material and installation of retrofitting the interior of my building will be at my own expense.
5) I agree that, in the event I decide to design and install my own interior retrofit system without technical assistance from the Town, I shall receive approval from the Town on my design prior to beginning installation, and that I shall permit periodic inspections on the interior retrofit during installation. FAILURE TO ADHERE TO THIS SECTION SHALL RELIEVE THE TOWN OF ANY IMPLIED OR EXPLICIT OBLIGATION AND RESPONSIBILITY TO SUPPLY GEOTHERMAL HEAT TO MY BUILDING.
6) In the event that the initial monthly billing charge for heat supplied by the Town's municipal geothermal heating district exceeds $.71 per thousand gallons or $3.35 per million BTUs, or if the costs for the interior retrofit of my building is in my sole opinion unacceptably high, I reserve the right to cancel this Agreement in writing. I agree that in the event I cancel this agreement after the Town has supplied the user retrofit material described in Item #3 above, I shall reimburse to the Town the entire cost of such materials.

Applicant: ____________________________
name (please print)

____

____
mailing address

____
signature

____
date

For the Town: ____________________________

Figure 13-2. Preliminary User Agreement

Figure 13-3. Each of the final agreements were properly executed, some with individual modification, to suit the customer's special circumstance. Most hookups were established during the 1983-1984 heating season. Currently there are nine users hooked into the system, representing a peak loading of between 6 million to 7 million Btu per hour. The current users and the dates at which they hooked into the geothermal system are given below:

TABLE 13-1. PAGOSA SPRINGS GEOTHERMAL HEAT USERS

1.	Superior Automotive	October 5, 1983
2.	Empire Savings & Loan	October 12, 1983
3.	Pagosa Springs Middle School	October 18, 1983
4.	Pagosa Springs High School	October 18, 1983
5.	Pagosa Springs Town Hall	October 19, 1983
6.	Hub Dairy Queen	October 31, 1983
7.	Spring Realty	October 31, 1983
8.	Methodist Church	November 11, 1983
9.	Pagosa Hotel	November 12, 1983

The Archuleta County Courthouse and the Pagosa Elementary School are expected to be hooked up to the system in the future. This would represent an additional peak loading of approximately 3 million Btu per hour.

Energy costs were set at 80 percent of the ongoing price of natural gas. In each case, energy consumption is measured by metered water use combined with an assumed or measured temperature differential. The overall consumer response has been very good. This is in large part due to very reliable and dependable geothermal system operation during the past two heating seasons.

Figure 13-3. Example--Final User Agreement

FINAL USER AGREEMENT

FOR THE

PAGOSA SPRINGS

GEOTHERMAL MUNICIPAL HEATING SYSTEM

THIS AGREEMENT, dated this day of , 1982, by and between the Town of Pagosa Springs (the "Town") and (hereinafter referred to as the "User") sets forth the terms, conditions, respective responsibilities, and limits of liability concerning the sale and purchase of geothermal energy.

1. The User being the owner of the building(s) and property located at:

(Street)

(Block) (Lot(s))

does by signing this Agreement agree to purchase geothermal energy from the Town, and the Town does in turn agree to sell such geothermal energy to the User.

2. The User agrees to comply with and abide by the written rules and regulations for the Town's Geothermal Municipal Heating System (the "rules and regulations") as may be adopted and from time to time amended by the Town. A copy of said rules and regulations shall be available for inspection at the Town Hall during normal business hours.

3. The Town has assigned to the User's property noted in Item 1 above an initial flow of ### gallons per minute (gpm) of geothermally heated water to meet the User's space heating and/or domestic hot water pre-heating needs of the building(s) as constructed at the time of this Agreement on the property listed in Item 1 above. This gpm assignment is an initial allocation based on the best information available to the Town, and may be adjusted up or down, by the process described in the rules and regulations. The Town shall deliver geothermally heated water at a temperature not to exceed one hundred sixty

degrees Fahrenheit (160 F) and at a maximum operating pressure not more than one hundred fifty pounds per square inch (150 psi) as measured at the point where such water leaves the geothermal control house (located near Fifth Street and US Highway 160).

4. The User agrees to allow periodic inspections of the geothermal application within the User's building(s) noted in Item 1 above by the Town upon reasonable advance notice given to the User. The User's geothermal application as completed must be inspected and approved by the Town prior to the commencement of service. It is required that said application be installed in accord with a design approved by the Town; if not so installed the Town shall be relieved of any further obligation for service to the User.

5. The User may elect to use part(s) of the heating system which existed in said building(s) prior to the geothermal application and utilize same for geothermal energy. Should the user so elect, the Town may require the User to, insofar as feasible, demonstrate to the Town's satisfaction that the portion of the pre-existing heating system being so utilized is capable of and sufficient to safely withstand the temperatures and pressures of the geothermally heated water being delivered to said building(s). Any part found by the Town to be unsatisfactory shall not be approved and the User shall not be allowed to purchase geothermal energy from the Town until such deficiencies are corrected.

6. The User should elect to install and/or maintain a backup heating system in the building(s) described in Item 1 above for emergency situations. The Town strongly encourages the User to do so. If the User declines to do so, the User specifically understands and agrees to indemnify and hold the Town harmless from any consequential damages, injury, or loss, resulting from such lack of backup heating system in the event the Town in unable to deliver geothermal energy for any of the reasons outlined in Item 14 below.

7. The Town may furnish to the User as a part of this Agreement various equipment, service pipe, and other materials, hereinafter referred to as "exterior equipment." It is expressly understood that the User shall be responsible to assure that the installation of said exterior equipment is to be in accordance with the manufacturers' written specifications, and that the cost of installing said exterior equipment is the sole responsibility of the User.

8. Beginning the first day of the month following the date first written above the Town shall begin charging the User an availability fee in order to meet operating expenses and to serve to the User the ### gpm assignment mentioned in Item 4 above. The availability fee shall be due and payable on the tenth day of the second month following the date first written above and the tenth day of every succeeding month until the User's geothermal application and exterior equipment has been installed and approved by the Town for service. The amount of the availability fee shall be five dollars ($5.00) per gpm assigned per month.

This availability fee shall continue to be charged to the User until actual service is begun, at which time the User shall be billed for the actual BTU's consumed and the availability fee for the month pro rated accordingly. The governing body of the Town may waive payment of the availability fee upon showing that the User has exerted sufficient good faith efforts toward installing the geothermal facilities and/or the exterior equipment but has not been able to due to unavailability of proper equipment, unavailability of earthwork equipment, weather conditions, or Acts of God which prevent completion of the geothermal application or installation of the exterior equipment.

Notwithstanding any of the above, if the User is not capable of receiving service by July 1, 1982, the Town shall have the option of termination hereof without further obligation. If the option is exercised, the User shall have no further obligation to pay the monthly availability charge.

9. It is agreed that after normal service has begun, the User shall pay a monthly charge, based on BTU's consumed, at the rates established from time to time by the Town Board of Trustees (The "Town Board"). These rates shall be based on actual and anticipated operational, maintenance and other reasonable expenses. There shall also be a miminum monthly charge of $5.00; the User shall pay either the minimum monthly charge or the charge based on actual BTU's consumed, whichever is greater. Prior to any change in either the monthly charge or the monthly minimum, a public hearing shall be scheduled before the Town Board or its designee. Any User shall present evidence to the Town Board prior to any final action taken on such changes in accordance with the rules and regulations.

10. It is mutually understood and agreed by both parties that the quantity of geothermally heated water assigned by the Town to the User's property noted in Item 1 above shall not be transferred to another property without the express written permission of the governing body of the geothermal project. A record of the gallons per minute assigned to said property shall be kept and maintained by the Town. This record is open and available for inspection at the Town Hall during normal business hours. It is further mutually understood and agreed by both parties that the Town's records shall be the sole and final source of information regarding the gallons per minute assigned to said property. It is further mutually understood and agreed that the User shall not sell, lease, give or in any other way convey or attempt to convey the gallons per minute assigned to said property without the prior written permission of the Town Board.

11. The User reserves the right to voluntarily discontinue purchasing geothermal energy from the Town at any time, provided thirty (30) days prior written notice is given to the Town. If such notice is given in less than thirty days, the User's final bill shall be determined by the actual amount of BTU's consumed since previous payment plus one month due based on the availability fee as defined in Item 10 above plus any and all other fees or charges due to the Town. In the event the User, subsequent to voluntarily discontinuing service, decides to again purchase geothermal energy from the Town, the User shall be placed at the bottom of the customer waiting list.

12. Penalties for late payment or non-payment of any fee, charge, or other payment due the Town shall be as required in the rules and regulations. Prior to disconnection for non-payment, notice shall be given a reasonable period in advance. Such notice may be given by mail to the user addressed to address of user herein or by posting a copy on the property or any other reasonable method.

13. The User shall hold the Town harmless from any and all damage, loss or injury including but not limited to: damages to persons, real property and personal property, business losses resulting from the use, application, operation, purchase, sale or activity of the geothermal energy system of the Town.

The Town assumes no responsibility as to the design quality of materials or quality of workmanship of the User's geothermal application, nor does the Town assume any responsibility for leaks, material failures, mechanical failures , or any other failures due to poor on inadequate installation of the existing heating system being converted to geothermal energy, or of any new equipment being installed. If damage results to the User's geothermal application due to pressures and temperatures being delivered from the geothermal control house in excess of system specifications as note in Item 4 above, the Town agrees in lieu of any other or additional liability to pay for repairs and/or replacment for such materials and/or equipment at no cost to the User. The Town shall be subrogated to any insurance proceeds or claims covering such loss(es).

Further, User agrees to hold harmless the Town, its agents, officers and employees in the event the Town is not able to deliver geothermally heated water to the User due to power failures, injunction issued by a court of competent jurisdiction enjoining or limiting the Town's operation of the geothermal system, Acts of God, war whether declared or not, civil insurrection, loss of municipal water pressure, or other circumstances beyond the control of the Town. Should the Town be unable to deliver geothermally heated water for extended periods of time, the Town may waive payment of monthly user charges or availability fees.

14. This document constitutes the entire agreement of the parties and supercedes any and all previous documents executed between the User and the Town. This Agreement is binding upon all successors, heirs and assigns of both parties. This Agreement may be amended at any time by mutual written consent.

15. The Town reserves the right upon reasonable notice to cease operation of the geothermal system and/or to cause the operation of the same to be transferred to a private, public, quasi-public or other appropriate entity, if the Town Board deems it in the best interest of the Town of Pagosa Springs to do so.

16. Should any portion of this Agreement be declared to be invalid by a decision of any court of competent jurisdiction, such decision shall apply only to the portion involved, and shall not affect, impair or nullify this Agreement as a whole or any other portion thereof.

Signature of User:

Name of User:

Attest: ____________________
Town Clerk

Town of Pagosa Springs

by: ____________________
Authorized Signature

____
(Capacity)

14.0 SYSTEM LOADS

The discussion of system loadings given here is presented in two basic parts. First, the initial sections 14.1 to 14.4 present the design methodology utilized for the design of the full capacity system at Pagosa Springs. Currently, however, the constructed system capacity is limited due to water rights issues. System loads and estimated cost savings for the reduced system capacity are presented in Section 14.5.

The peak load design for the Pagosa Springs system is a combined determination of the peak loading of the residential sector, the public sector, and the commercial-business sector. The starting point for determining the contributing loads of each of these components was different. For residential users, the design approach was to select a typically constructed home to be served and to then calculate the peak demand based on accepted American Society of Heating, Air Conditioning, and Refrigerating Engineers (ASHRAE) standards. Second, for the County and municipal buildings and for commercial buildings, annual, documented conventional fuel use was collected and peak demand was calculated from that basis. The peak load design is based on a factor of 3.5 times the annual load expressed on an hour-by-hour basis. In each case, the probable users were then identified and the peak load summed to arrive at system design criteria. The design peak heat load is summarized in Table 14-1 for the major user groups. The required geothermal water flow requirement was based on a 25 Btu/pound of water energy extraction rate.

TABLE 14-1--HEAT LOAD REQUIREMENTS FOR MAJOR USER GROUPS

User Group	No. of Users	Annual Heat Load 10^6 Btu/yr	Flow Requirement Annual GPM	Design GPM
Residential	63	11,800	108	378
Commercial*	54	33,000	301	1055
Public	10	11,900	108	379
Total		56,700	517	1812

* Includes additional heat load expected from near-term future users.

14.1 PEAK LOAD -- MAXIMUM DESIGN

The annual heat load, the peak flow rates, and the annual flow rates for each of the potential users are presented in Table 14-2. A code number for each user was assigned and is also presented in Table 14-2 for locating purposes on core city mappings.

Based on the distribution of the users relative to the heating source, two independent loops were then located, as shown on Figure 14-1. The first loop is designed to carry 1000 gpm and extends west from the courthouse, in an existing easement, to the Elementary School. The second loop is designed to carry 1350 gpm east from the Courthouse. Actual utilized capacities are less than those listed, however, due to water rights issues. A summary of the specific technical approaches to the residential peak heat load calculation is reviewed below.

The initial step in determining the expected single residence peak heat load is to ascertain the style, construction characteristics, and size of an "average" home. Most of the homes in Pagosa to be heated by this heating district are older than 30 years. As such, few have adequate insu-

Table 14-2. Heat Load Requirements of Individual Users

Business	Annual Heat Load 10^6 BTU/yr	Flow Average (GPM)	Flow Peak (GPM)
Circle K	159	1.4	5
San Juan Motel	2348	21.4	75
Griffitts			
Silver Dollar	125	1.1	4
River Center	1001	9.1	32
River Center			
Al's Cafe	313	2.9	10
Colorado Can Sports			
Museum	313	2.9	10
San Juan Chevron	391	3.4	12
New Horizon Book	187	1.7	6
Biggens Barn	187	1.7	6
Forest Service	663	6	21
Dr. Davis	188	1.7	6
Harvey's Motel	1315	12	42
Pioneer West	94	0.8	3
Trading Post	125	1.1	4
Solar Mall	1722	15.7	55
Masonic Hall	341	3.1	11
Church of Christ			
Morning Star Bakery	778	7.1	25
United Farm	188	1.7	6
Jr. High School			
Sr. High School	6769	62.6	217
Goodmans	470	4.3	15
Larsen's Law Office	187	1.7	6
Post Office	470	4.3	15
Rays Hair Care	187	1.7	6
Mortuary	187	1.7	6
Parish Hall			
Rectory	1001	9.1	32
Catholic Church			
Natural Gas Office	125	1:1	4
Adobe	1589	14.5	51
Town Hall	626	5.7	20
Citizen's Bank	137	1.2	5
Pagosa Bar	313	2.8	10
La Cantino	282	2.6	9
Total Sports	940	8.6	30

Table 14-2. Continued

Business	Annual Heat Load 10^6 BTU/yr	Flow	
		Average (GPM)	Peak (GPM)
Barber Shop	156	1.4	5
TV Repair	150	1.4	5
Montoya Hardware	498	4.5	16
Jackish Drugs			
Lister Building (Pagosa Hotel)	1941	17.1	62
Sears	150	1.4	5
Hub	471	4.3	15
Mesa Verde Savings & Loan	471	4.3	15
Courthouse	2661	24.3	85
Poma Building	939	8.6	30
Joslen's Chevrolet	2473	22.6	79
Gambles & Groc.	1566	14.3	50
Middle Earth Deli	219	2	7
Taxidermy	142	1.3	5
Conoco Service Station	1753	16	56
County Shop	939	8.6	30
Pagosa Plaza	2504	22.8	80
Elementary Bus Garage			
Methodist Church	782	7.1	25
Alley's	188	1.7	6
Future Building East of Town	3134	28.6	100
Private Residences (63 units)	11800	108	378
TOTAL	56,658	517	1812

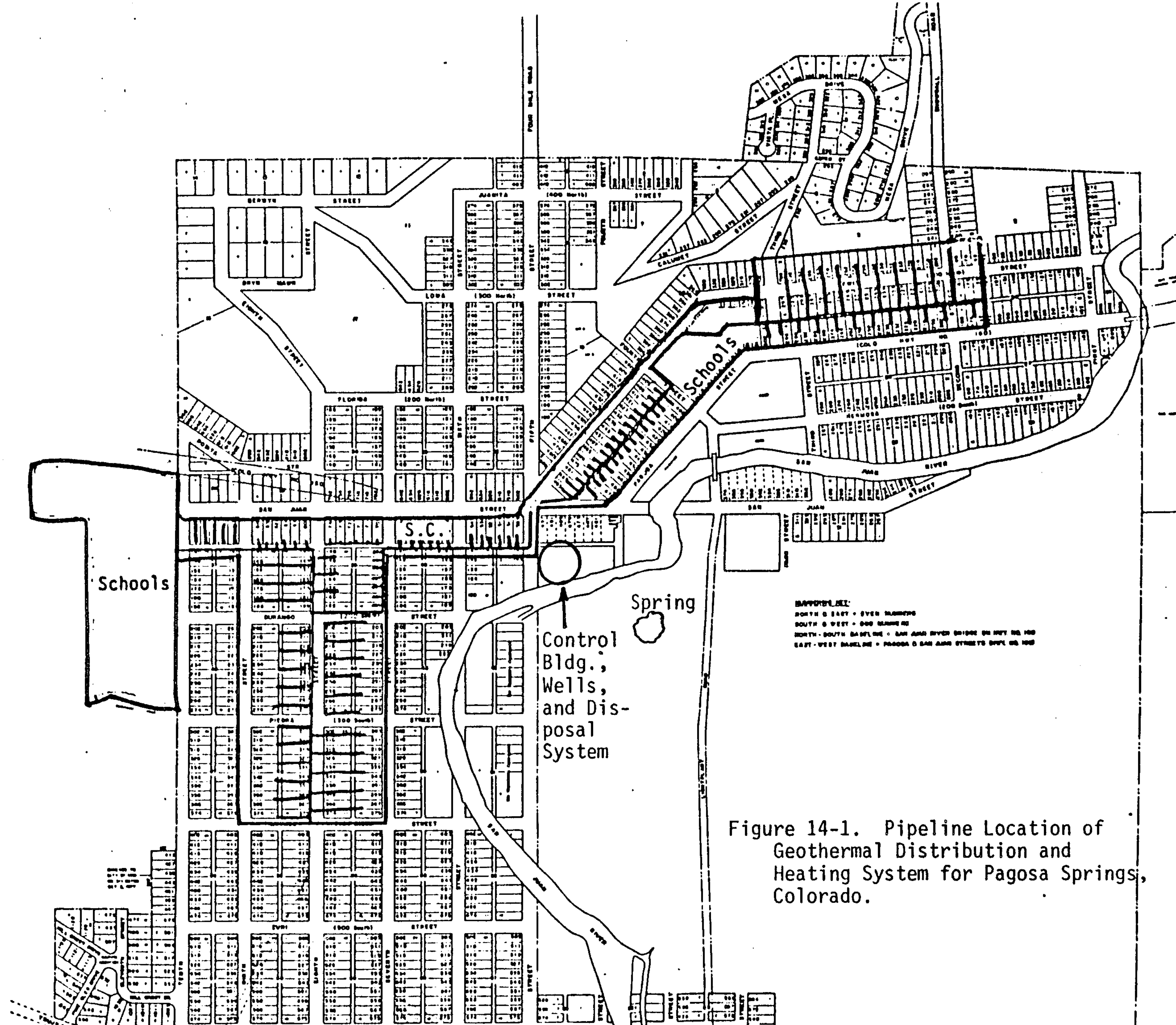


Figure 14-1. Pipeline Location of Geothermal Distribution and Heating System for Pagosa Springs, Colorado.

lation and as a result heat losses are large. The structure on which our heat load figures are based is one-story with approximately 1,200 square feet. The floor surface area, dimensions, height, insulation, and construction materials are important since the heat load analysis used the basic heat transfer relationship as given in Equation 1 to calculate the heat loss through the walls, doors, windows, floor, and ceiling of the home.

That equation is of the form: $Q = U \times A \times \Delta T$ (1)

where
Q = Peak residential heat loss in Btu/hour
U = Heat transfer coefficient in Btu/hour-^{o}F-ft^2
A = Exposed surface area, ft^2
ΔT = Temperature difference between inside and outside conditions, ^{o}F

A -9^{o} design temperature was adopted based on documented weather data for the area. Assuming a 70^{o}F inside temperature level, the ΔT would equal 79^{o}F.

The total outside exposed wall surface area of such a home is 950 square feet. Construction is with 2 x 4's supporting 1/2-inch sheetrock on the interior, dead air space, 5/8-inch plywood outside covered with a wood siding. Table 14-3 shows the the wall construction and the R values of each of the building materials.

TABLE 14-3. WALL CONSTRUCTION AND RESISTANCES

(R = hour - ^{o}F - ft^2/Btu)

Outside film coefficient	R = 0.17
Outside wall siding	R = 0.81
5/8-inch plywood	R = 0.78
Air space	R = 0.97
1/2-inch sheetrock	R = 0.45
Inside film coefficient	R = 0.68
Total	3.86

Thus, the R value is the reciprocal of U, or R = 1/U; therefore, the overall heat transfer coefficient is 0.26 Btu/hour-^{0}F-ft^{2}. Since the walls are of 2 x 4 construction, with wood studding occupying up to 20 percent of interior wall space, the overall wall coefficient should be increased by about 10 percent, giving a U value of 0.28. The total peak load calculated from Equation 1 is 21,014 Btu/hour.

Similar computational procedures were used for the doors, windows, ceiling, and floor. Windows were all designated as single pane; ceiling insulation was to R-11 values. Finally, outside air infiltration was assumed to equal 9.6 Btu/hour per square foot of floor surface, based on ASHRAE standards.

The sum total home peak heat loss was then found by adding the six components as summarized in Table 14-4. The total calculated loss came to 0.071 million Btu/hour.

TABLE 14-4. PROJECTED RESIDENTIAL PEAK HEATING LOADS

Component	Heat Loss (Btu/hour)
Walls	21,014
Doors	1,559
Windows	10,712
Floor	15,168
Ceiling	11,520
Infiltration	11,520
Total	71,493

14.2 ANNUAL HEATING REQUIREMENTS

The previous section discussed the design conditions to supply heating requirements during peak winter conditions. However, in determining the payback period for the project it is also necessary to define the annual fuel consumption. Annual heating requirements are related to both the annual degree days of 8,416 and the design heating load of 71,493 Btu/hour. For the purposes of this study, two different methods were utilized and then checked for consistency. The first calculational method is from ASHRAE and is as follows:

$$F = U \times N_b \times D \times C_f \times C_d$$

where

F = Fuel consumption in therms (1 therm = 100,000 Btu)
U = Unit fuel consumption (from ASHRAE table). For our case, U = .00392 for a 100-percent energy efficient system.
N_b = Design heating load in 1000 Btu/hr
D = Number of degree days
C_f = Temperature correction factor
C_d = Correction factor for additional degree days

This approach gave a calculated annual heat load of 184×10^6 Btu/year or on an hourly basis, a value of 21,000 Btu/hour.

These calculated annual heating requirements were then compared with actual heating bills from residents living in the development. This effort met with limited success. For homes using propane, the actual heating bills were approximately 20 percent less than the calculated value. For homes utilizing electric heating there was a larger difference, of between 30 to 50 percent, between the calculated and actual heating loads.

The factor between design to annual heat load is about 3.5 as determined from the 21,000 average and 71,000 peak heating loads. This factor is used in calculating the peak flow requirements in Tables 14-1 and 14-2, presented previously.

14.3 LOAD FACTOR

Based on the seasonal heating loads and the peak heating loads, as discussed in the preceding sections, the load factor, defined as the average load as percentage of peak load, is 28.6 percent.

14.4 FUEL REPLACED

Based on the above annual energy delivery, total system delivery would be 56.7 x 10^6 Btu/year. Assuming 75% furnace efficiency due principally to heat loss up the flue, this represents an equivalent replacement of 66,700 MCF of natural gas.

14.5 SYSTEM LIMITATIONS APPLICABLE DUE TO WATER RIGHTS ISSUE

Current well testing indicates that peak load, geothermal well flows may be limited to approximately 800 gallons per minute. Based on current user agreements and energy use efficiency (see Section 13.0), the peak system capacity is 9.14 million Btu per hour. Seasonal energy delivery is estimated at 23.2 X 10^9 Btu. Based on a delivered geothermal energy pricing structure of $0.52 per therm, estimated customers savings will be $37,835 annually.

15.0 PRODUCTION SYSTEM DESIGN

15.1 OVERVIEW AND SYSTEM DESCRIPTION

The geothermal system design calls for geothermal fluid to heat city water, which in turn will be piped to individual users to heat homes and buildings. The geothermal fluid will not require pretreatment since it will be kept under pressure to prevent scaling. The city water will pass through individual heating units and then will be recycled to a central location for reheating and reuse. The geothermal fluid will be discharged directly to the river after heating the city water. The schematic diagram of the overall design is shown in Figure 18-1.

15.2 PRODUCTION DESIGN OVERVIEW

The production system of the Pagosa Springs geothermal system is defined to include the production well, the well piping and valving, the well pumps, and the production system controls. This section describes the production well pump design and controls approach. The production well designs and associated valving were discussed earlier in Section 8.0.

15.3 DESIGN CONSIDERATIONS AND SPECIFICATIONS

The bid document included technical specifications for component hardware; as part of that task, the water chemistry-scaling and corrosion potentials, and any unusual or significant materials requirements were identified. Based on the resource water chemistry evaluations discussed in Section 8.0, scaling and corrosion potentials were judged minimal if the system is kept under pressure and that concept is integrated into the design.

The well pumps were specified to pump the artesian geothermal fluid to the control building housing the heat exchangers, through the heat exchangers, and on to the San Juan River for disposal. Surface centrifugal pumps could be specified since the natural artesian pressure can supply adequate flows at acceptable NPSH. Each pump was specified to deliver 800 gpm at 90 feet of head with an available NPSH of 11.5 feet. Cast iron casing and cast iron impellar materials were specified. A split case design allowing the removal of the rotating element without disturbance of the piping connections was specified for ease of maintenance.

The flow from the geothermal wells was designed for control by the discharge temperature of the circulating fluid. This temperature controller was to operate a throttling valve on the geothermal supply line to maintain the desired discharge temperature from the heat exchangers. The design instrumentation and control schematic for the overall system is presented in Figure 18-3.

16.0 DISPOSAL SYSTEM DESIGN

Reservoir testing and water quality evaluation and discussions with the Colorado Department of Health, Water Quality Control Division, indicated that surface discharge of the cooled geothermal fluids was an acceptable and, in fact, the preferred alternate for the disposal of these fluids (see Sections 6.0 and 7.0). The surface discharge option is very clearly less complex, less energy intensive, and at least environmentally equal to alternates involving reinjection of the cooled fluids.

Given that decision, the disposal system is a simple one consisting of approximately 300 feet of ten-inch diameter steel and asbestos concrete transite pipe to transport the used waters from the control-heat exchanger building to the San Juan River. A four-inch steel and asbestos concrete drain line running directly from the geothermal wells to the river was also specified. A flow measuring wier was to be installed at the end of the line immediately prior to discharge to the river channel for system monitoring purposes.

17.0 TRANSMISSION SYSTEM DESIGN

The transmission system to transport the geothermal fluids from the PS-3 and PS-5 wellheads to the heat exchanger control building is straightforward in design due to the short distance involved. An eight-inch diameter asbestos concrete line was specified for the 165-foot distance between PS-5 and PS-3; from PS-3 to the control-heat exchanger building a 340-foot, ten-inch diameter asbestos concrete pipe was specified to carry the maximum flow from the two wells.

18.0 DISTRIBUTION SYSTEM DESIGN

18.1 SELECTION PROCESS

The distribution system, including the heat exchangers, controls, and the distribution and return piping was conceptualized and designed according to the following criteria.

--Geothermal flows were minimized to conserve the resource and to minimize water rights requirements.

--The system focused on serving high density heat loads including the commercial and public sectors at lowest distribution system capital costs.

--Geothermal waters were segregated from the circulating system serving the individual users, allowing the use of copper piping and copper heating system components which are standard in off-the-shelf heating units and in existing user systems.

--The system was designed with two independent distribution loops which can be isolated and each can be maintenanced with the other in continuous operation.

--The system was sized for future expansion.

18.2 DESIGN

The initial design description presented below is for a completed, full-scale system at Pagosa Springs. Due to water rights issues and budget constraints, portions of the system were deleted during construction. For example, only two of the four circulating pumps and only one heat exchanger were actually installed. A full description of the system "as built" is presented in Sections 20 through 23.

18.2.1 General Description

The proposed closed distribution system includes two independent loops--one for the east side of town and the other for the west side--to provide a safety factor in the event of a pipeline breakage. The east loop is designed to carry 1350 gpm. The west loop is designed for 1000 gpm; however, initially, it carries only 500 gpm. This is to permit future expansion of the distribution system into the growth areas of Pagosa Springs. A schematic diagram of the overall design is shown on Figure 18-1. Briefly, the system operates as follows:

--Clean city water is heated with the geothermal fluid using plate heat exchangers. The geothermal fluid leaving the plate heat exchangers is then discharged to the San Juan River.

--The clean heated city water is circulated in each of two closed loops by means of one to four pumps, depending on user demand. Each of the loops consists of large diameter, 6 to 10 inch, concrete asbestos pipes, referred to as trunklines, and smaller diameter service pipes carrying the water to the individual users. Two parallel trunklines are in each loop. An insulated supply trunkline carries the heated circulating water, and an uninsulated return trunkline directs the cooled circulating water back to the heat exchanger.

--At the terminal point of the supply line, in each loop, there are flow control valves to ensure a minimal amount of hot water being circulated at all times.

--The circulating water is collected in the return trunkline and then routed to the heat exchangers where the entire process is repeated.

18.2.2 Component Design and Operating Conditions

Table 18-1 shows the design operating conditions for the heating system. The flow conditions will not be realized for the first several years, since initially the system is used to only partial capacity.

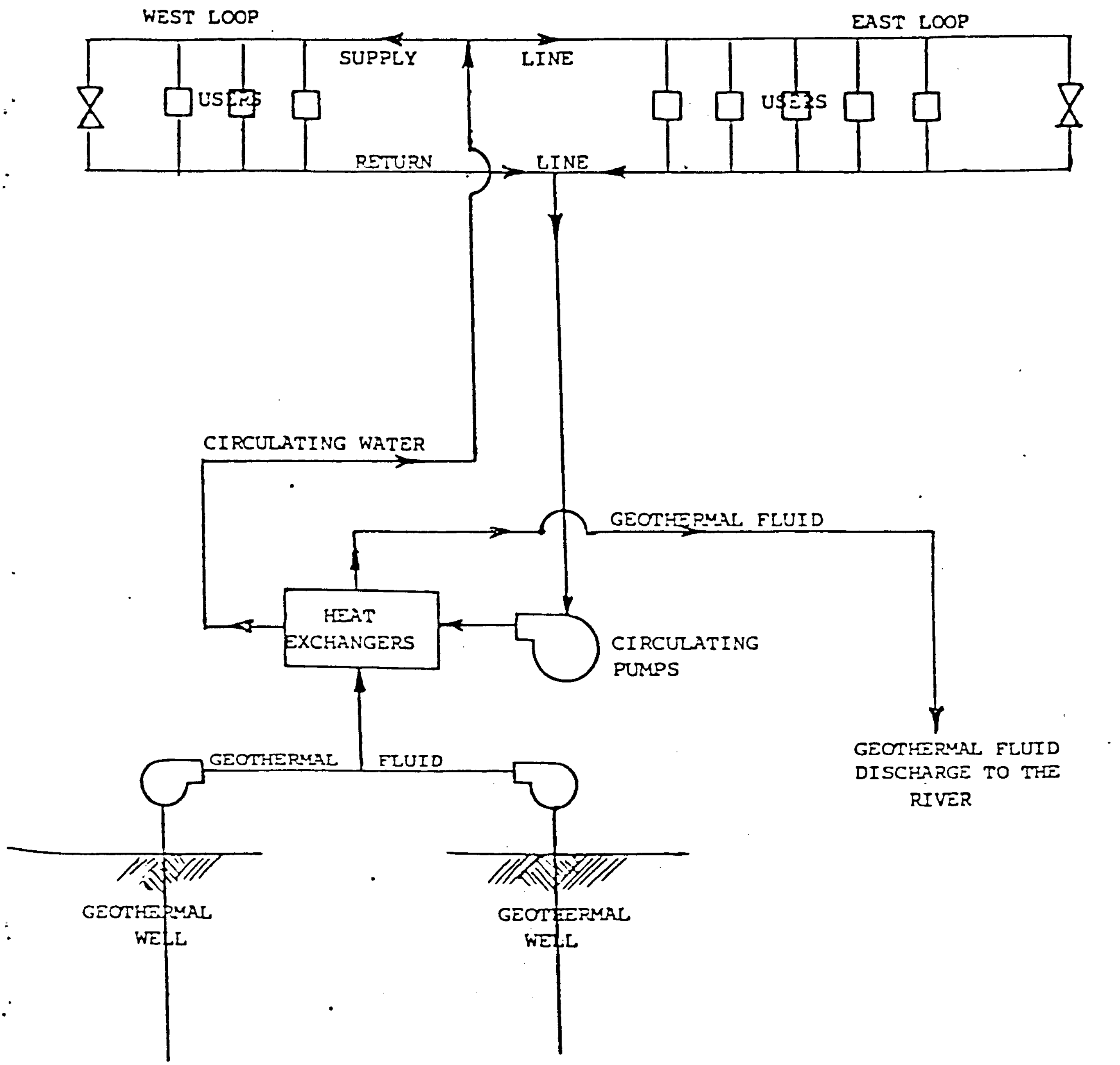


Figure 18-1. Schematic Diagram of the Town Geothermal Heating System

TABLE 18-1. DESIGN OPERATING CONDITION

	Geothermal Fluid			Circulating Fluid		
	Temp. (^{o}F)	Pressure (psi)	Flow (gpm)	Temp. (^{o}F)	Pressure (psi)	Flow (gpm)
Inlet heat exchanger	140	30	2000	107	101	1800
Outlet heat exchanger	114	15	2000	136	130	1800

Figure 18-2 shows values of the piezometric head, in psi, at various points in the distribution loops. The circulating water at the suction side of the pump is at a pressure of 60 psi. To assure the constant 60 psi suction pressure, city water supply is cross-connected into the return lines of the distribution loops and maintained using a pressure-reducing valve. This pressurizes the system and also is the source of makeup water. Two back check valves are installed at this point to avoid the possibility of water backflowing into the City water supply system. Pressure release valves and vacuum valves are also installed in the system.

The pumps at design flow rates add 70 psi of head, for a net of 130 psi. Valving and other losses drop the pressure to 113 psi and the heat exchanger further reduces it by 12.1 psi to 101.0 psi. The 101.0 psi is reduced to 98 psi and 87 psi at the supply end of the West and East loops, respectively. This is due to the frictional losses of the pipeline flow. The return end of each loop is 60 psi plus the frictional losses in the pipe. This value is 73.0 psi for the West Loop, and for the East loop the value is 74.0 psi.

The pressure drop available for the West loop is the difference between 98.0 and 63.0, or 35.0 psi. This value is the pressure to be absorbed by the user's heating system and the flow control valve.

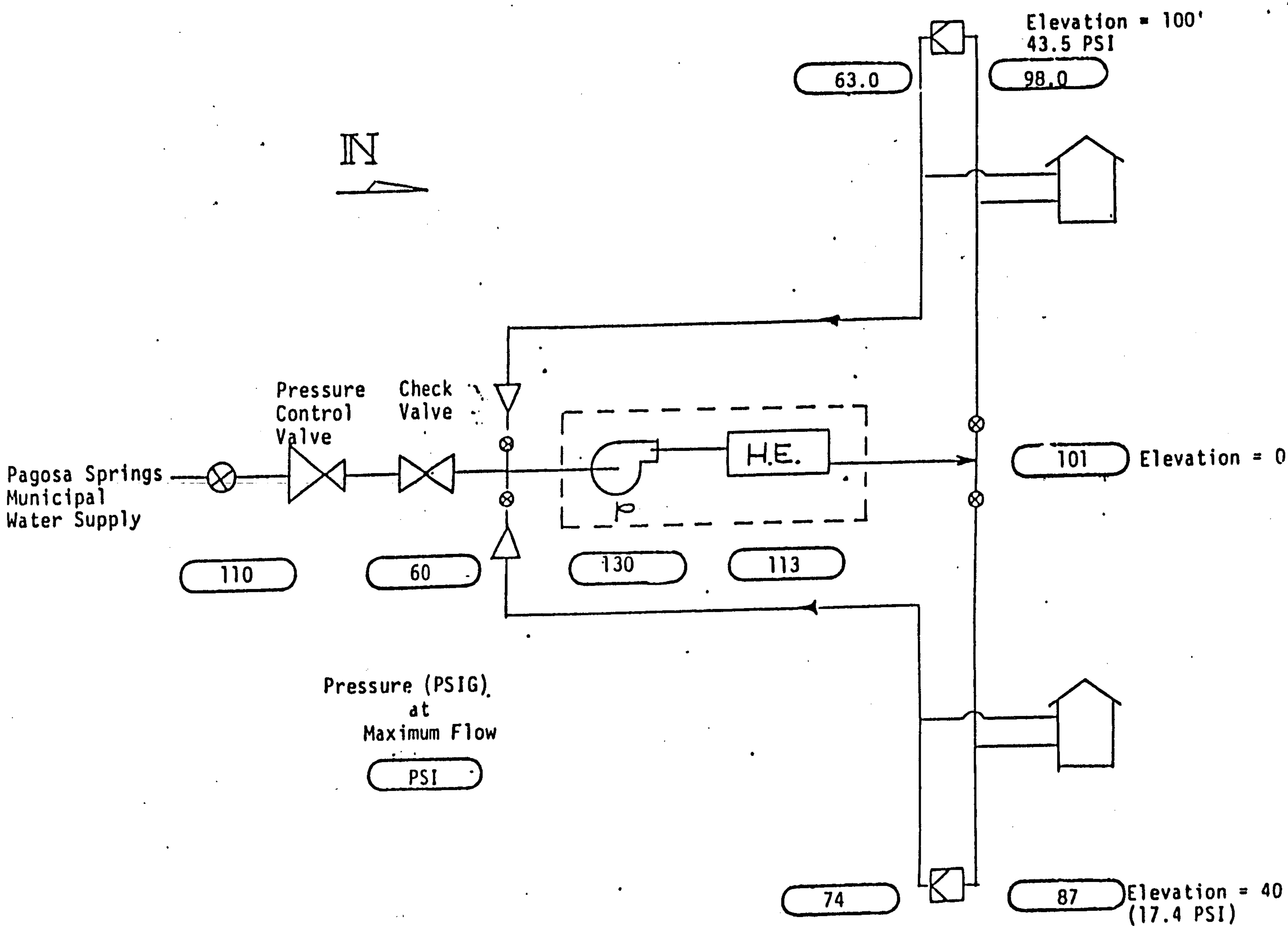


Figure 18-2. Operating Conditions of Heating System

The heating system will not be operated at design conditions for the first several years since all users are not expected to be on-line. This does not influence the normal operation conditions or the control scheme described below. The distribution system operates over a broad range of conditions that will fluctuate daily as well as seasonally. The seasonal flow ratios vary from 200 to 2000 gpm, and daily fluctuations by 250%.

Principal component design is as follows:

1) Trunkline Pipeline--The trunkline portion of each of the distribution loops consists of two large diameter parallel pipelines. One of the pipelines is to supply heated water to the users and the other returns the cooled water to the heat exchangers. The lengths and diameters required for each loop, which are designed to allow for future expansion of the system, are presented in Table 18-2 and depicted on Figure 18-3.

TABLE 18-2. PIPE SIZES AND LENGTHS FOR THE TRUNKLINE DISTRIBUTION LOOP

	West Loop	
	Supply (ft)	Return (ft)
8-inch	1,450	1,450
6-inch	1,000	1,000
	East Loop	
10-inch	2,000	2,000
8-inch	2,300	2,300
6-inch	1,600	1,600

2) Feeder Piping--Small feeder pipes transport the heating fluid from the main supply trunkline to the user and then carry the cooled water into the return trunkline. These smaller feeder lines range in size from 1 inch for the private residences to 3 inches for larger commercial users.

All pipelines are buried below frost line, which is 4 feet at Pagosa Springs. Both the supply and return pipelines are buried in the same trench with a separation of 1 foot. Provisions to drain the lines, in case of prolonged down times or breaks, consist of opening valves and allowing the lines to drain by gravity flow. The pumps and heat exchange equipment are located at the low elevation point of the entire system and affords an ideal location for draining the system.

3) Heat Exchangers--Two 316 SS plate heat exchangers were specified. Each exchanger is rated at 13 million Btu/hour and is capable of heating 1800 gpm of circulating fluid from 107°F to 136°F.

4) Circulating Pumps--The circulating pumps are rated at 500 gpm and 160 feet of head. They are vertical inline centrifugal pumps of carbon steel construction.

5) Control House--A control building houses the heat exchange equipment, pumps, instrumentation, and control equipment. The building is 30 x 40 feet, with a 12-foot ceiling.

18.2.3 Distribution Control System

The distribution system operates over a broad range of conditions that fluctuate daily as well as seasonally. The main intent of the control system is to minimize both the operating costs and manpower requirements to operate the system. The control scheme regulates the circulating pumps, the number of heat exchangers in operation, flow from the geothermal wells, and temperature of the circulating water leaving the heat exchangers. The control system schematic is presented in Figure 18-2.

The circulating pumps are operated based on user demand plus 150 gpm, which will be continuously circulated through the piping system. Initial design was for the pumps to operate in the following sequence; note that only two pumps were finally installed.

Flow Rate	
150 to 500 gpm	1 pump
500 to 1000 gpm	2 pumps
1000 to 1500 gpm	3 pumps
1500 to 2000 gpm	4 pumps

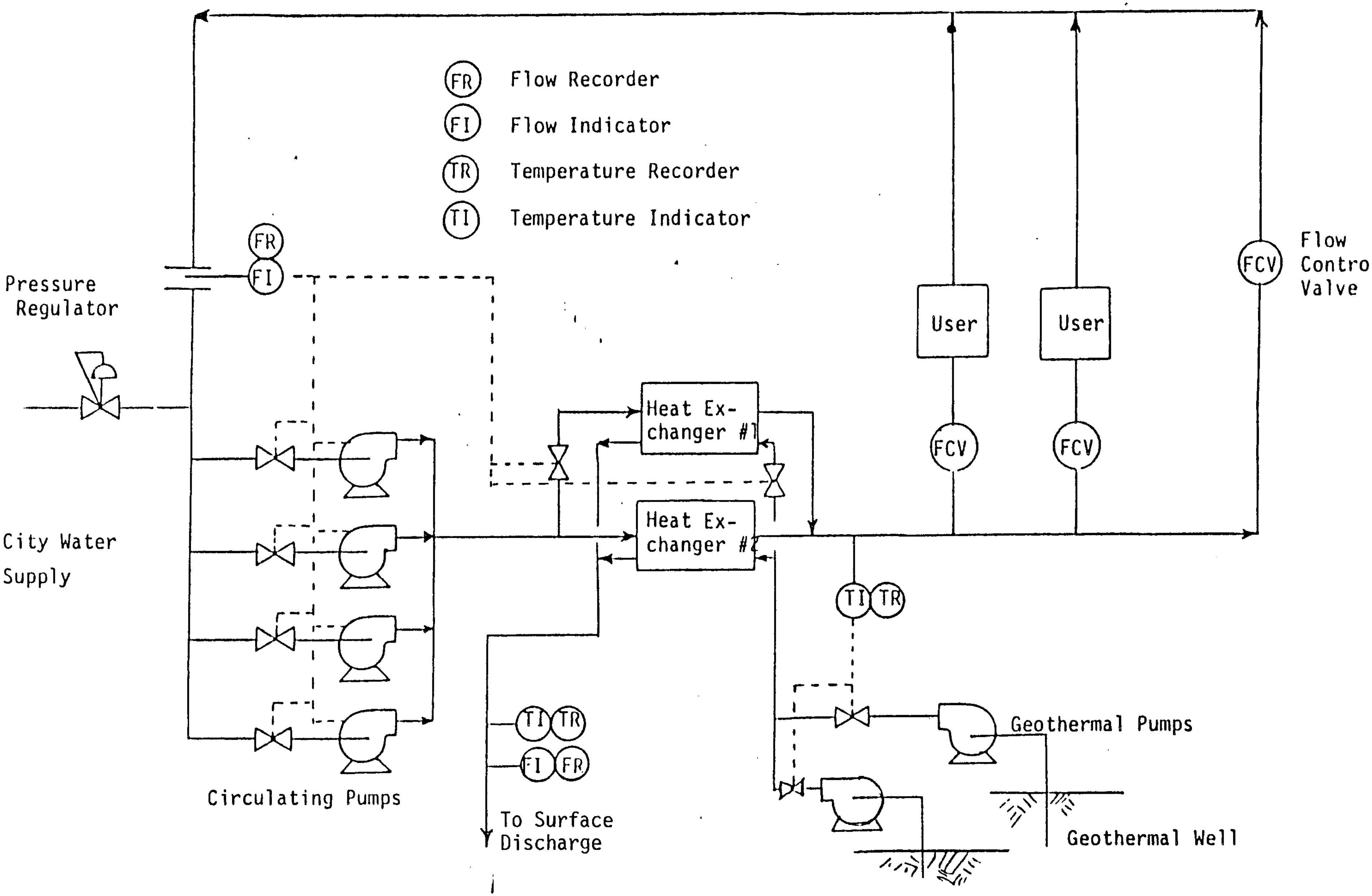


Figure 18-3. Schematic Diagram of Control System

There is manual switching for rotating the use of the pumps. This feature permits an even utilization of all four pumps.

The flow requirements were designed to be sensed by a flow indicator on the return portion of the piping network. In addition to determining the number of circulating pumps to be in operation, the flow instrument was to control the number of heat exchangers in operation. At flows of less than 1000 gpm, only one heat exchanger was to be in service. At flows greater than 1000 gpm, both heat exchangers should be in service.

The flow indicator was also to determine the number of geothermal pumps in operation. With flows of less than 1000 gpm, one well pump is to be operational. At flows greater than 1000 gpm, both wells and associated pumps are in operation. To minimize equipment wear and to allow the system to reach equilibrium operating conditions, a minimum cycle time was specified between on and off modes of the pumps and heat exchangers.

Flow from the geothermal wells is to be controlled by the discharge temperature of the circulating fluid. This temperature controller is to operate a throttling valve on the geothermal supply line to maintain a constant discharge temperature from the heat exchangers.

18.2.4 Instrumentation and Data Collection

A control panel monitoring the different components of the distribution system is located in the building housing the heat exchangers and pumps. The panel indicates which distribution pumps, well pumps, and heat exchangers are in operation.

The flow rates of both the geothermal and circulating fluids were to be measured and recorded. The flow rates were designed to be indicated locally and also totalized to allow a comparison to be made with users' meter readings to act as a check. At the heat exchangers, the inlet and outlet temperature of the geothermal and circulating fluids were designed to be measured and recorded. The geothermal fluid discharge into the San Juan River again was to be measured and recorded continuously for temperature and flow.

19.0 APPLICATION SYSTEMS DESIGN

19.1 APPLICATION SYSTEMS OVERVIEW

The geothermal heating system program did not actively participate in the design of the residential, commercial and public sector users which hooked onto the system. This was instead performed by each individual customer. Nevertheless, to encourage an adequate understanding of the types of systems users may need to use to augment existing systems or for new systems necessary in new building, conceptual reviews of user system designs were performed and cost estimates for these systems were then developed. These conceptual presentations are given in the following text for residential users, commercial users, and for public buildings. A 20^{o}F temperature drop was assumed for all users within each individual system. Figure 19-1 illustrates the operating principles of the forced-air and convective systems discussed below.

A. RESIDENTIAL USERS--There are four basic approaches, outlined below, for retrofitting private residences. The choice of which retrofitting scheme to use for each individual home will be dictated by the type of heating equipment in use. Sizing of the residential heating equipment was based on a heat demand of 75,000 Btu/hour.

1) Heating Coil in Existing Forced-Air System--This type of retrofit conversion is perhaps the easiest and least costly to homeowners. All that is required for this conversion is to replace the burner element from the furnace with a heating coil. This type of conversion is suitable to homeowners who have either a gas or propane central forced-air system. This type of equipment is commercially available and has approximate dimensions of 20 inches high by 20 inches long by 2 1/2 inches deep.

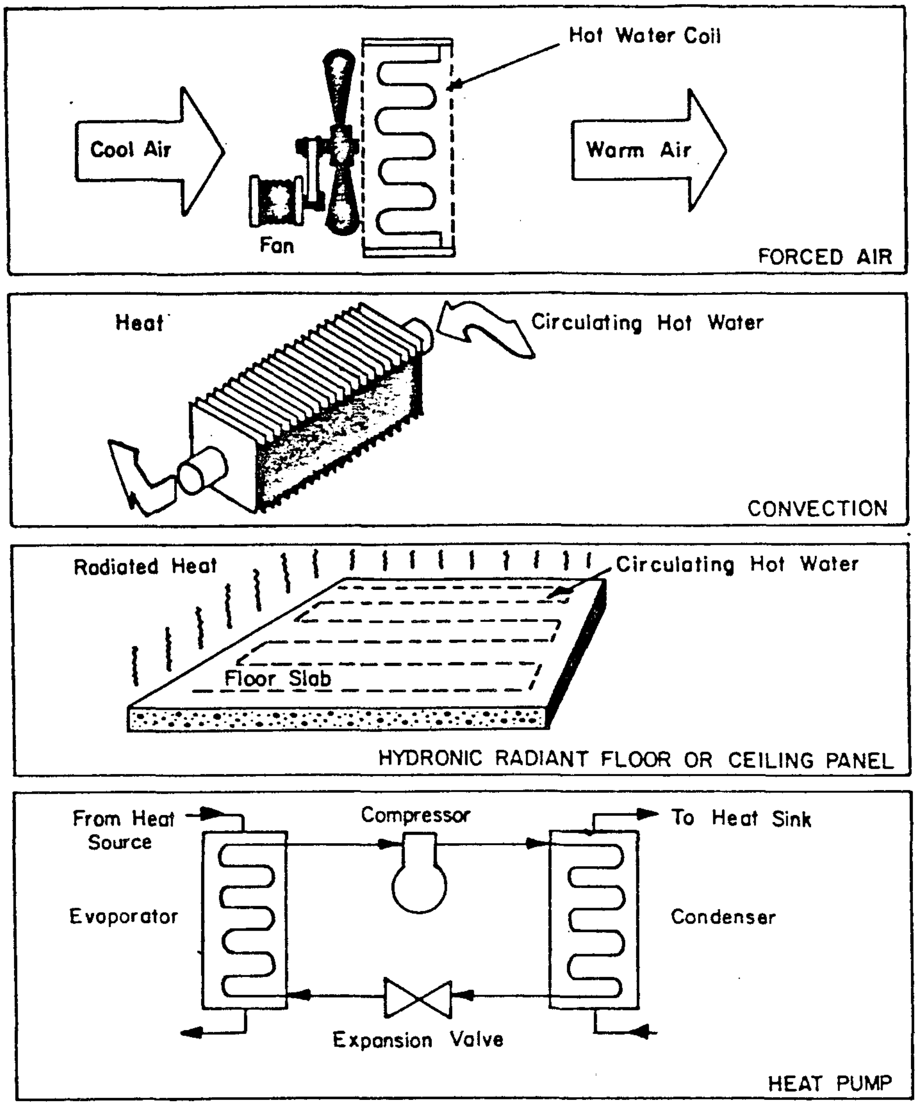


Figure 19-1. Space-Heating Systems Suitable for Geothermal Applications. (Source: EG&G Idaho, Inc.)

2) Baseboard Radiators -- This type of conversion involves the installation of small baseboard radiators. Due to relatively low supply temperature, approximately 250 linear feet of baseboard radiator will be required. Additional piping is also required to get the warmed water to the various independent radiators. This type of heating conversion would be applicable to homes which currently have space heaters in individual rooms.

3) Convector Units-This type of conversion is similar to the baseboard radiator conversion but with fan capacity to assist in heat exchange distribution. The only difference is that small heating units will replace the long linear baseboards. This heating system consists of three or four heating units standing about 2 feet tall, 3 feet in length, and 8 inches in depth. These units are also commercially available.

4) New Forced-Air System--An alternative to either the baseboard radiators or convector units is to install a new central forced-air system in the home. This type of conversion is available to all users who have either a crawl space or attic area in their home.

B. COMMERCIAL USERS--The same type of conversion schemes are available to commercial users. As was the case with the private residences, the approach for conversion of the commercial users will be based on the existing heating equipment.

C. PUBLIC BUILDINGS--Six of the public buildings to be heated by the system currently used hot water heating. In each of these buildings water was heated in a gas furnace to 150°F to 200°F. The heated water was then circulated throughout the structure. The buildings using hot water heating are:

1. Town Hall
2. County Courthouse (new addition)
3. Post Office
4. Elementary School
5. Middle School
6. High School

The hot water heating temperature of each building was lowered to 140°F for the 1980-1981 winter. The building was then evaluated to see if comfortable temperatures could be maintained. If so, then no retrofitting equipment would be required. The only expense would be in connecting their hot water system into the supply pipeline.

If the building temperature could not be maintained at the $140^{o}F$ set point, then the temperature set point was to be increased until comfortable levels were maintained. Using this approach the peak heat loads were to be obtained for the 1980-1981 heating season and converted to design conditions. The actual retrofitting equipment needs would then be known and the cost determined. These costs could then be weighed against the cost of using their existing furnaces for supplying peak demands. The actual testing during the 1980-1981 winter indicated that only minimal modification would be necessary.

19.2 ENERGY MONITORING SYSTEM-METERING

A metering scheme for the geothermal system is depicted on Figure 19-2. The scheme consists of two block valves, one located on both the supply and return pipeline. This allows isolation of home heating systems for any routine maintenance or servicing. A constant flow valve assures a uniform flow of entering the home. A water meter is then used to measure usage. The thermostatic controller will operate a solenoid valve which controls the flow of hot water into the house.

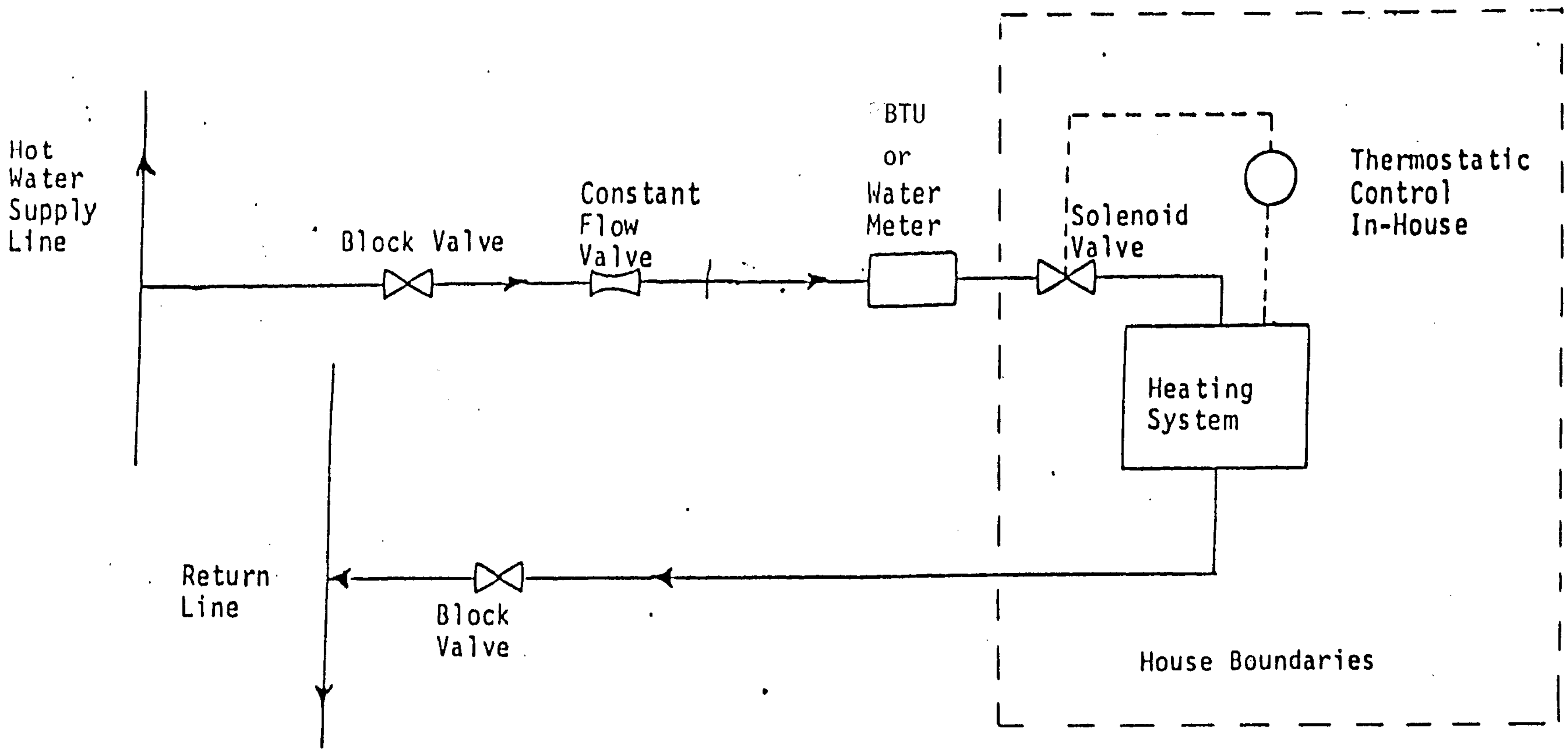


Figure 19-2. Schematic Diagram of Flow Metering System

20.0 PRODUCTION SYSTEM CONSTRUCTION

Production system construction at Pagosa Springs was completed in two separate efforts. The first was the 1980 well drilling, completion and testing. This effort was described in Sections 8 and 9. The second effort, which incuded installation of the production pumps and controls, occurred concurrently with the transmission and distribution systems in 1981.

The production system as installed has three significant deviations from that designed and specified in the original bid package. First, production well PS-3 has never formally been hooked into the system. The exact reasons for this are not entirely clear. The significance of this is that currently there is no backup for production well PS-5 should that well experience flow problems. This could create significant hardships on system customers in the case of decreasing well production.

Second, all production flow is currently artesian and adequate for the reduced system flow capacity as limited by water rights issues. Production pump problems on PS-5 required the removal of the centrifugal pump for maintenance and it has not been reinstalled into the system.

Third, the production system controls were not installed as specified in the original technical design. These production controls were to automatically control geothermal well flow rates based on the outlet temperature of the heated city water exiting the plate heat exchanger. For example, if the heated city water to the distribution loop was at lower than required temperature, the geothermal fluid flow rate was to automatically increase. If the heated water was higher in temperature, the geothermal flows would be decreased. This control system and instrumentation was also tied to the circulating water distribution controls which were designed to automatically control the water flows to their most efficient levels such that the greatest possible heat energy could be extracted from the geothermal fluid.

The key component to this control system was a remotely located microcomputer which was to monitor and control the various temperatures,

pressures, and flows; this specific design scheme was developed at Pagosa Springs' directive. Due to program budget constraints, however, the microcomputer was never connected into the system. System controls now are manual only and system performance during the 1983-1984 season, although very reliable, has been less efficient than would have been the case had the controls been installed.

The "As Built" flow and instrumentation schematic is given in Figure 20-1.

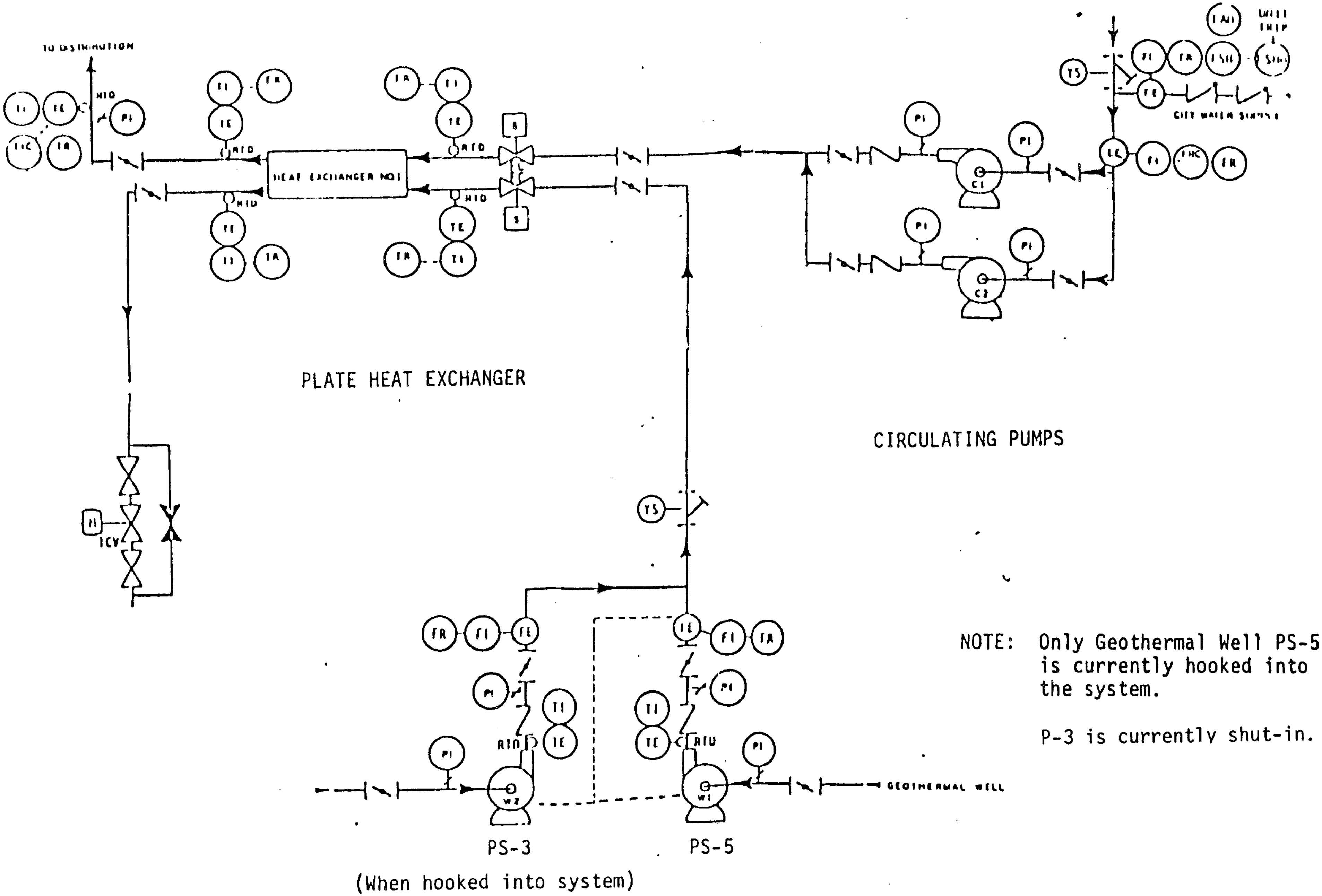


Figure 20-1. Flow and Instrumentation Schematic

21.0 DISPOSAL SYSTEM CONSTRUCTION

The Pagosa Springs disposal system was constructed as specified in the bid package, with two exceptions. First, the piping materials of construction from the plate heat exchanger to the San Juan River were changed from concrete asbestos to fiberglass. Second, the flow control valve of the geothermal fluid discharge stream is a manual control and not automatic as originally designed. The control systems were not installed as originally designed due to the deletion of the key microcomputer control component. This is discussed in greater detail in Section 20.

22.0 TRANSMISSION SYSTEM CONSTRUCTION

The transmission system for carrying geothermal fluids from the production wells to the plate heat exchanger was constructed as specified except for one factor. The piping materials of construction from the production wells to the exchanger were changed from concrete asbestos piping to fiberglass piping.

23.0 DISTRIBUTION SYSTEM CONSTRUCTION

The Pagosa Springs distribution system as constructed differed from the final design and the original bid package in several ways. First, it should be noted that the original design was prepared with system objectives such that system capacity could be expanded as the system achieved good operating experience during early years. Piping was sized to accommodate those increasing flows; also, design drawings contain placement and space for two heat exchangers and four circulating, distribution pumps. In actuality, only one heat exchanger and two circulating pumps were bid.

Second, the initial bid costs were over the budgeted funds. Since additional funding was not available, selected portions of the system were deleted and the Town performed parts of the construction with in-house staff. For example, the control room building was bid separately to save money; also, the building location was offset approximately 20 feet as compared to original design placement. The final constructed size of the system was, however, also expanded in two areas. The Town applied for and received a Federal appropriate technology grant for $50,000. This was used to expand the system south to low-income housing units and the Senior Citizens' Center. Also, during April to October 1983, a distribution system expansion to serve the Methodist Church and other businesses on Lewis Street was constructed. The exact routing of this expansion is presented in the "As Built" drawings, Appendix 2. This Methodist Church expansion loop was necessary to serve important interested customers and to thereby increase the overall utilization of the system.

As noted previously in the production system and disposal system cases, the control systems originally specified were not installed per the bid package due to the deletion of the microcomputer control package.

24.0 APPLICATION SYSTEM CONSTRUCTION

Early in the Pagosa Springs project, fifty thousand dollars ($50,000) of program money were designated to assist individual users to retrofit their business or residence and hook the facility into the geothermal system. The money was proposed for distribution in the form of 50 $1,000 grants. The proposal objective was to generate interest and advertise the geothermal system, encourage preliminary commitments to the system, and assist those with high retrofit costs, all three of which would help the system achieve high utilization factors.

During the course of the project, however, the program budget became extremely tight--even for the sole objective of completing the district system exclusive of user assistance. Therefore, retrofit assistance was provided only to public buildings; these buildings already utilized hot water heating systems and retrofit requirements were minimal. All other user application money previously proposed was withdrawn and utilized to complete the remaining system construction.

The geothermal district's policy is to extend distribution system lines to the user property boundary. User installations have included both hot water and forced-air heating systems; each has performed well and without significant problems using these moderate temperature waters.

25.0 SYSTEM MANAGEMENT AND ORGANIZATION

The Town of Pagosa Springs, Colorado, is the sole owner and operator of the Pagosa Springs Geothermal District Heating System. The Geothermal System Manager, designated by the Town Manager with Town Board approval, manages and operates the system and is responsible for all maintenance. Municipal water system operators and maintenance crews perform all necessary O&M functions. No additional staff personnel are required.

Customer billings are distributed monthly; billings are based on water flows within the user facility.

26.0 PRODUCTION SYSTEM PERFORMANCE

Since production startup and acceptance testing in Fall 1981, geothermal fluid production has been maintained without interruption during heating season periods. Only minor difficulties have been experienced and include the following: First, the Pacific split casing centrifugal production pump experienced vibrational problems subsequent to approximately six months' operating experience. The pump was taken out of service and repaired under contract warranty. The reservoir artesian flow from PS-5 is sufficient to meet all system heat energy requirements and, even though repaired, the pump has not been reinstalled into the system. Other smaller operational problems included the delivery and installation of pumps lacking proper packings and without certified curves. Also, a wire strainer located in the line from the geothermal wells to the plate heat exchanger is collecting considerable shale from the well production flows. Originally, a manual wash has been used to clean the screen. In the future, this will be changed to an automatic wash conducted at intervals of one to two hours, or as needed.

Again, it is noteworthy that systems controls were not installed per specifications, and system efficiency defined at the Btu of heat energy extracted per pound of water, has been variable. This is not an equipment malfunction, but rather a systems control task. System efficiency for extracting heat is an important factor when considering long-term reservoir life.

Operator satisfaction for the system is high. No unusual or difficult operating or maintenance problems have surfaced. System performance data for the period October 1983 to February 1984 are summarized in Sections 27 to 29. They are also included in the in the special report "Pagosa Springs Geothermal System, System Testing--October 1, 1983-February 29, 1984," which is attached as Appendix 1. A second series of tests were made during the period of July 1984 through February 1985. These results are summarized in Appendix 3.

27.0 DISPOSAL SYSTEM PERFORMANCE

Disposal of the cooled geothermal fluids is by surface discharge to the San Juan River through approximately 300 feet of fiberglass piping. Flow control is manual; flow measurement is accomplished using a standard parshall flume.

All of the above components have performed well and without difficulty during the two-year performance period.

28.0 TRANSMISSION SYSTEM PERFORMANCE

The geothermal fluid transmission piping consists only of 10-inch fiberglass piping from the PS-5 production well to the plate heat exchanger in the control building. This piping segment has operated without difficulty during the two-season operating period.

29.0 DISTRIBUTION SYSTEM PERFORMANCE

The geothermal distribution system has performed very well and without significant problems during the two heating season periods. Several operational problems were noted during initial startup and acceptance testing in late 1981. The first problem related to construction techniques used in laying the trunkline distribution piping. The trunkline piping is of large-diameter asbestos-cement construction; large o-rings provide the seal between the individual pipe sections. During construction, certain of the o-rings either were damaged or were not sealed properly due to "stabbing methods" used to bring the pipe sections together. The resulting poor seal was soon apparent in the pressurized pipeline testing, where high leakage was immediately noted. The contractor was required to identify and correct the faulty joints prior to system acceptance.

A second problem related to pressure fluctuations in the system was noted during first-year operation of the system. During initial operations, pressure gauges recorded a continual upward creep in the distribution and collection system pressures. Ultimately, the pressure relief valves, which are preset at 150 psi, activated automatically for system protection. Review of the problem, coupled with field inspection, indicated that control valves, which are located in the flow lines between the supply and return lines, and which have both flow and, indirectly, pressure maintenance functions, had not been installed. This problem has been solved and the system is no longer experiencing operational difficulties.

To summarize, the system has mechanically performed very well during initial heating seasons. No significant operation problems have been experienced in the pipes, pumps, and heat exchanger systems. The 316 Stainless Steel heat exchanger has performed well, with approach temperatures consistent with design specifications. The system has not been taken from service and inspected for presence of scale. The good operation indicates scale is not significant, however. Control systems are manual. They have operated without difficulty; however, the deletion of automatic controls has hurt day-to-day operating efficiencies as discussed in subsequent sections.

29.1 GEOTHERMAL SYSTEM OPERATIONAL EFFICIENCY

A system efficiency analysis was performed for the October 1983-February 29, 1984 test period. This analysis was performed to meet requirements of the one-year production permit issued by the Colorado Department of Natural Resources, State Water Engineer, Groundwater Section. The testing results are summarized below and presented in greater detail in Appendix 1. The data from a later test period (July 1984 through February 1985) are presented in Appendix 3.

29.1.1 Efficiency Significance

The efficiency at which heat energy is extracted from geothermal waters and utilized throughout the system is significant in that low heat utilization efficiencies require larger geothermal fluid withdrawals. This, in turn, may affect overall reservoir pressures and reservoir longevity.

Current system operating objectives are to extract 30 Btu of heat energy from each pound of geothermal water produced. To document system operational performance, weather data, geothermal well flows and temperatures, and the geothermal distribution system, hot and cold water flows and temperatures were recorded daily during initial system operation and twice weekly subsequent to system stabilization in early 1984. In addition, data were taken two times daily during the specified periods of October 17-22, 1983, and February 6-11, 1984. Finally, additional attention and analysis were given the data taken during the coldest winter temperature period of January 16-January 23, 1984.

29.1.2 Results

The geothermal operational data is summarized in Table 29-1, which presents typical data from each month. The data indicate that the system is operating at low utilization factors. While acknowledging that temperature measurements may reflect inaccuracies, it is clear that as compared to the operational goal of extracting heat and thereby lowering geothermal water temperatures 30°F, only a 16°F to 19°F temperature differential is being achieved during peak demand periods. On many other occasions and especially during February, the heat energy extraction rate was much smaller, often of the order of 8 Btu per pound of water. On January 19, which reflected the most severe heating demand of any day in the test period, 40 percent more heat could have been able to have been extracted from the geothermal fluid. To accomplish this may require changes in the current system to allow lower pumped circulation rates.

The significance of the above analysis is that with system flow rate control, geothermal well withdrawals might be able to be reduced, subject to system design constraints. Conversely, the Town could hook up to a 40 percent greater heating load and substantially improve system economics without further increasing the required geothermal well withdrawals.

The two one-week test periods of October 17-22 and February 6-11 showed no significant variation of system temperatures or pressures with time of day. Readings were taken at 6:30 a.m. and 5:30 p.m. This is a somewhat surprising result since user heating demand would be expected to

TABLE 29-1. PAGOSA SPRINGS GEOTHERMAL SYSTEM OPERATING DATA

Date	1 Lowest Temperature (°F)	2 Degree Days	3 PS-5 Flow (gpm)	4 Geothermal Water Temperature Drop (°F)	5 Percent Utilization	6 Distribution System Flow (gpm)	7 Distribution System Water Temperature (Gain)	8 Distribution System Energy Delivered (Btu/hour)
10/18/83	35	16	347	7*	.23	625	10	3.12
10/31/83	33	18.5	347	19*	.63	450	11	2.47
11/15/83	13	33	347	19*	.63	450	16	3.6
11/30/83	1	49.5	347	19*	.63	450	16	3.6
12/15/83	4	45.5	347	16	.53	450	8	1.8
1/01/84	19	38.5	347	17	.56	450	11	2.47
1/19/84	-29	70.5	347	18	.60	450	10	2.24
1/23/84	-16	55	450	5	.16	450	7	1.57
1/30/84	-3	43	450	4	.13	450	4	.9
2/15/84	22	34	450	8	.26	450	8	1.8
2/29/84	8	37.5	450	8	.26	450	8	1.8

* Temperature difference is estimated, corrected value subsequent to gauge calibration.

vary at least somewhat with time of day. As noted earlier, the 345 gpm geothermal flow rate was more than adequate to serve current user loads during the peak demand period of January 16 to January 23, 1984.

30.0 APPLICATION SYSTEM PERFORMANCE

30.1 PERFORMANCE SUMMARY

Retrofit assistance to customer heating systems has been limited to public buildings with already installed hot water heating systems. Assistance was minor and consisted only of miscellaneous piping connections. Available information indicates these user systems have performed efficiently and without significant operational problems.

31.0 CONSTRUCTION COSTS

The construction costs for the Pagosa Springs geothermal program are presented in Table 31-1. These include both the reservoir evaluation and well drilling costs, and also the 1981-1982 transmission, distribution, and disposal system costs. Costs related to the establishing of adjudicated water rights and all other permitting are also included. Complete and final system costs are not available as of the report date due to ongoing program activities related to water-rights issues and minor equipment additions/ charges. Total program costs as of June 1984 were $1,487,620.

TABLE 31-1
PAGOSA SPRINGS GEOTHERMAL
PROGRAM COSTS AS OF JUNE 1984

I.	RESOURCE ASSESSMENT AND PRELIMINARY DESIGN		
	--Feasibility Study and Conceptual Design	$ 33,000	
	--Permitting	59,900	
	--Geological and Geophysical Survey	10,000	
	--Environmental Report	3,880	
	Totals		$106,780
II.	PRODUCTION WELL COSTS		
	--Tangible	$ 28,526	
	--Intangible	262,306	
	Totals		$290,832
III.	SYSTEM FINAL DESIGN AND CONSTRUCTION		
	--Final Design and Bidding	$ 70,412	
	--Construction	929,568	
	Totals		$999,980
IV.	G&A EXPENSES		$ 40,000
V.	DOE PROGRAM COSTS, PUBLICITY, TECHNOLOGY TRANSFER, REPORTING		$ 40,028
VI.	PAGOSA SPRINGS SCHOOL SYSTEM AND MUNICIPAL BUILDING RETROFIT ASSISTANCE		$ 10,000
JUNE 1984--TOTAL PROGRAM COSTS			$1,487,620

32.0 OPERATING AND MAINTENANCE COSTS

Operating and Maintenance (O&M) costs include those related to electric power, labor, and repair or replacement of materials. System power costs are primarily related to pumping requirements; since the production wells are artesian, the pumping costs are solely distribution pumping costs. These are billed on a demand basis and have averaged approximately $660 per month. Negotiations are in progress to change the billing basis to a kilowatt hour consumption basis.

Pagosa Springs Water Department personnel operate the system; one additional full-time employee is required to operate the system.

Materials replacement costs have also been minimal. Reserve funding will be gradually accumulated from operating revenues to pay for long-term equipment replacement.

The originally estimated operating and maintenance costs are presented in Table 32-1, and were developed on the following basis.

It is anticipated for the first several years the system will be used to only 40 percent capacity and thereafter usage will increase to its final design. For this reason, O&M costs have been estimated in current dollars for both partial and full utilization of the system.

1. Pumping--The pumping for the circulating loop will consist of two to four pumps, each requiring a 25-hp motor. For the first year of operation, it is estimated that one pump will be used continuously and a second will be used only during four months of the year. When full capacity is achieved, the following is the estimated pump operation.

TABLE 32-1
OPERATING AND MAINTENANCE COSTS ($/YR)

	First Year Operation (675 GPM)	Full Capacity (1800 GPM)
Pumping	15,600 (348,000 kWh)	23,800 (531,000 kWh)
Maintenance	6,000	15,000
Billing	4,000	6,000
Treatment and Miscellaneous	2,000	4,000
TOTAL	27,600	48,800

Four pumps for one month
Three pumps for three months
Two pumps for six months
One pump for two months

A 1000 GPM pump requiring a 20-hp motor will transport the geothermal fluid from the well to the heat exchange equipment. One such pump will be located at each of the two wells. When the heating district is utilized to partial capacity for the first year, one pump will operate continuously. At full capacity one pump will operate continuously and the second for three months.

Electrical costs for operating the motors were calculated with the following commercial rate schedule, and assuming the installed horsepower.

First 40 kWh--------------------------$0.3066
Everything over 1000 kWh-------------- 0.4416

2. Maintenance--From information presented in the preliminary design and subsequent discussions with the Town of Pagosa Springs, a value of $15,000 was arrived at, based on the equivalent of one full-time employee operating the system.

3. Billing Costs--The billing costs will be agreed on by the Town, based on expenses incurred by the Town in the billing of the City water system. These estimates are based on the assumption that users will read their own meters and a computer will be used in the billing process.

4. Treatment and Miscellaneous Costs--These treatment costs include chemicals for controlling algae and minimizing corrosion. Items such as lighting and supplies for a computer are also included.

33.0 SYSTEM ECONOMICS

33.1 ECONOMIC SUMMARY

Rigorous system economic evaluations were not performed by the Town during the project duration. Capital cost, anticipated revenues, and anticipated O&M costs are presented in Table 33-1.

TABLE 33-1

SYSTEM ECONOMICS COST SUMMARIES

Capital Cost*	$1,394,000
Anticipated Revenues	120,710
Anticipated O&M Costs	27,600
Annual Net Revenues*	93,110

Debt service is not a listed expense since all capital construction was accomplished through grant money.

* June 1984. Total Program Cost minus DOE Program Cost and Municipal and School System Retrofit assistance.

33.2 CONSULTANT ECONOMIC ASSESSMENTS

ICF, Inc., a Washington based consulting company, performed an economic evaluation of the different DOE demonstration programs. The results of those evaluations, including the Pagosa Springs case, are found in the following reports:

--Resource Assessment for Geothermal Direct Use Applications, DOE/ET/12099-3, Prepared by ICF, Inc., Washington, D.C., and EG&G Idaho, Inc., Idaho Falls, Idaho (April 1984).

--Resource Development; System Design, Cinstruction, and Operation for Geothermal Direct Use Applications, DOE/ET/12099-4, Prepared by ICF, Inc., Washington, D.C., and EG&G Idaho, Inc., Idaho Falls, Idaho (September 1983).

APPENDIX 1

SUMMARY REPORT

PAGOSA SPRINGS GEOTHERMAL HEATING SYSTEM
SYSTEM TESTING: October 1, 1983 - February 29, 1984

Prepared For
Town of Pagosa Springs, Colorado

For Submittal to the
Colorado Oil and Gas Conservation Commission
and the
Colorado Department of Natural Resources
Division of Water Resources
State Engineer

Coury and Associates, Inc.
Lakewood, Colorado 80226

March 30, 1984

SUMMARY REPORT

PAGOSA SPRINGS GEOTHERMAL DISTRICT HEATING SYSTEM
SYSTEM TESTING: October 1, 1983 - February 29, 1984

I. INTRODUCTION AND TEST PLAN OBJECTIVES

In October 1983, the Colorado Oil and Gas Conservation Commission working with the Colorado Division of Water Resources approved a nine-month production permit for Pagosa Springs geothermal wells PS-3 and PS-5. This permit covered the time period of October 1983 to June 1984, and was conditional on the Town of Pagosa Springs performing additional testing of the geothermal system during the 1983-1984 heating season. A formal test plan was drawn up and submitted to the State Engineer's Office, Division of Water Resources. Since permit approval in October 1983, testing has been performed consistent with provisions of that plan, to the extent possible given the field conditions. This summary report reviews the testing results for the time period of October 1983 through February 1984.

The test plan objectives are as follows:

1. Document data, to the extent possible, showing the impact of PS-5 and PS-3 geothermal well withdrawals on other already existing hot water wells representing a cross section of wells in the Pagosa Springs geothermal reservoir.

2. Document PS-5 and PS-3 geothermal withdrawal requirements related to ambient weather conditions, including heating degree days.

3. Document geothermal system operational data to establish the important system operating variables, and to facilitate the long-term optimized performance of the system, including geothermal well withdrawals, heat exchange performance, and user energy use.

4. Document operational characteristics of the geothermal distribution system, as a function of hot water and cold water return temperatures, and as related to heating degree days and ambient weather conditions.

5. The test objectives do not include reservoir evaluation, projections of geothermal reservoir life, or projections of long-term impacts on nearby wells.

II. SYSTEM DESCRIPTION

The Pagosa Springs geothermal district heating system provides space heating to public buildings, school facilities, and commercial establishments. A schematic diagram of the system design and controls is shown in Figure 1. During system operation, geothermal water is withdrawn from the hot water reservoir through production well PS-5. Production well PS-3 has not been hooked into the distribution system and is currently shut-in. The geothermal waters are then directed through a plate heat exchanger where heat is extracted and transferred to circulating City water which is then pumped to Town users. The cooled geothermal fluid leaving the plate heat exchanger is discharged to the San Juan River in accordance with Colorado Department of Health agreement.

The system users individually extract heat for space heating purposes at their point of use; the cooled water is circulated back to the heat exchanger and is then reheated by the geothermal water.

Currently there are nine users hooked into the system, representing a peak loading of as high as 6 million to 7 million Btu per hour. The system equipment is capable of extracting up to 30 Btu per lb. from the geothermal waters.

The current users and the dates at which they hooked into the geothermal system are given below:

TABLE 1. PAGOSA SPRINGS GEOTHERMAL HEAT USERS

1.	Superior Automotive	October 5, 1983
2.	Empire Savings & Loan	October 12, 1983
3.	Pagosa Springs Middle School	October 18, 1983
4.	Pagosa Springs High School	October 18, 1982
5.	Pagosa Springs Town Hall	October 19, 1983
6.	Hub Dairy Queen	October 31, 1983
7.	Spring Realty	October 31, 1983
8.	Methodist Church	November 11, 1983
9.	Pagosa Hotel	November 12, 1983

The U.S. Forest Service Complex and the Pagosa Elementary School are expected to be hooked up to the system in the future. This would represent an additional peak loading of approximately 3 million Btu per hour.

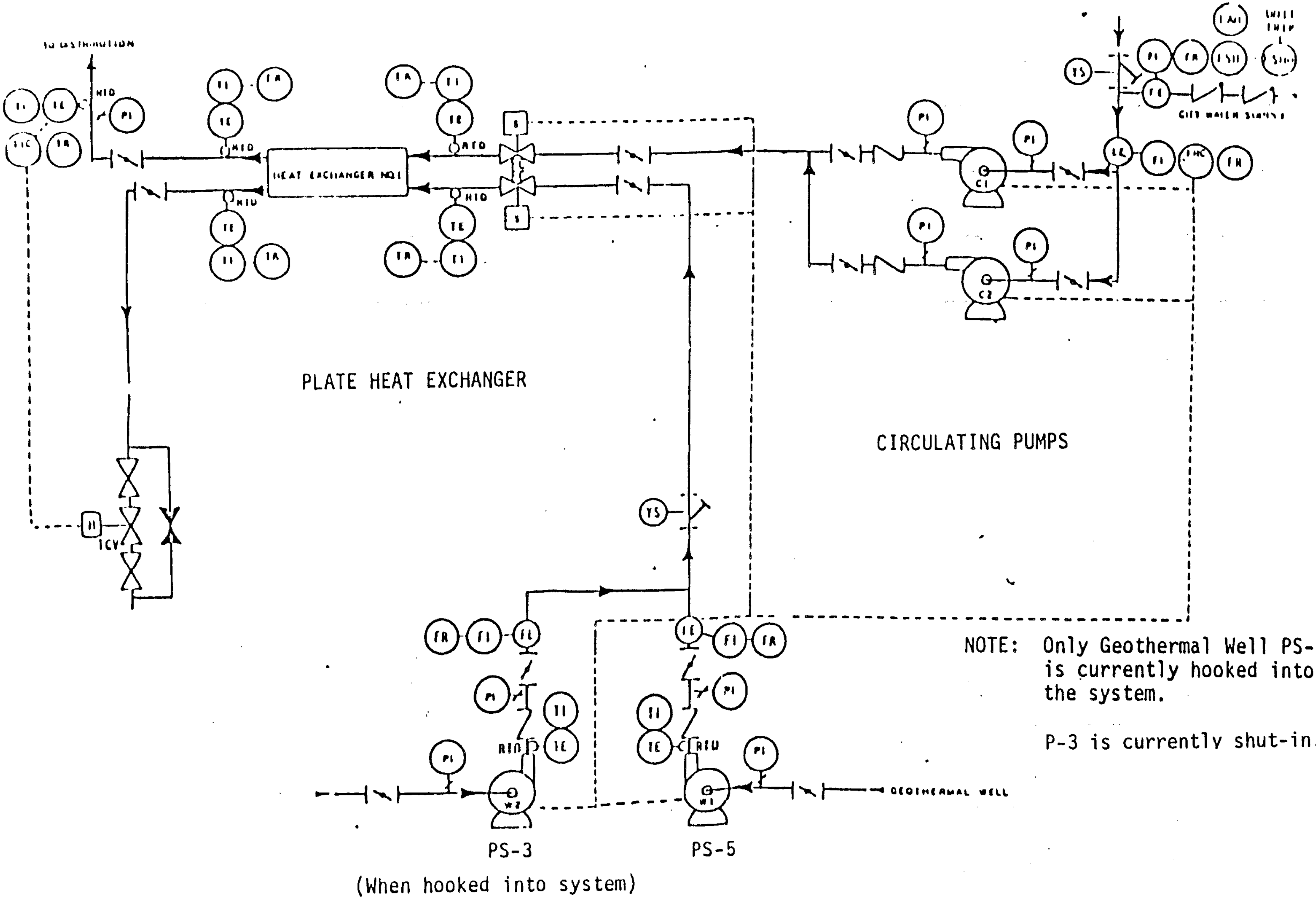


Figure 1
Flow and Instrumentation Schematic

III. GEOTHERMAL SYSTEM TESTING

A. Field Data Taking

The current testing included data taking from selected wells and Pagosa Hot Spring, as presented in Figure 2 and Table 2. The test data were generally obtained in accordance with the original test plan with the following exceptions. First, the ultrasonic flow meter originally purchased by the Town did not give accurate flow measurement readings due to lack of entrained suspended solids, due to lack of gas bubbles, and due to the deteriorated condition of many of the old, existing wells. Flow rates for PS-5 were measured by parshall flume. Flows of other Town wells, in combination with other streams, were measured by installation of six 90^{0} V-notch wiers. These wiers are installed at various locations around the Town, and the individual well flows are not easily isolated and are thus not available for review at the current time. Wier readings are continually being taken, however. During the spring of 1984, after space heating requirements have passed, the individual wells will be shut down and their respective contributions to the total wier flows will be calculated. This approach was discussed with and approved by Chuck Liles, District Engineer.

Second, well-pressure data for the Adobe Inn well, the Poma well, and the Giordano No. 1 well were not able to be taken due to the very poor condition of the original well manifolding and previously installed gauges, or due to the absence of authorization to perform the data-taking. The High School well and the old Methodist Church well are not in use; the High School well was frozen and was not able to be tested for significant portions of the test period.

A circular, dial bourdon pressure gauge and a Marshall Type E407 thermometer were utilized for the pressure and temperature data-taking of the individual wells. These instruments were connected utilizing pre-plumbed fittings on the wellhead.

B. System Impact on Surrounding Wells

PS-5 production flows were initiated on October 4, 1983 and were documented throughout the test period. Pressure readings were likewise obtained for PS-5 and a cross section of previously existing wells

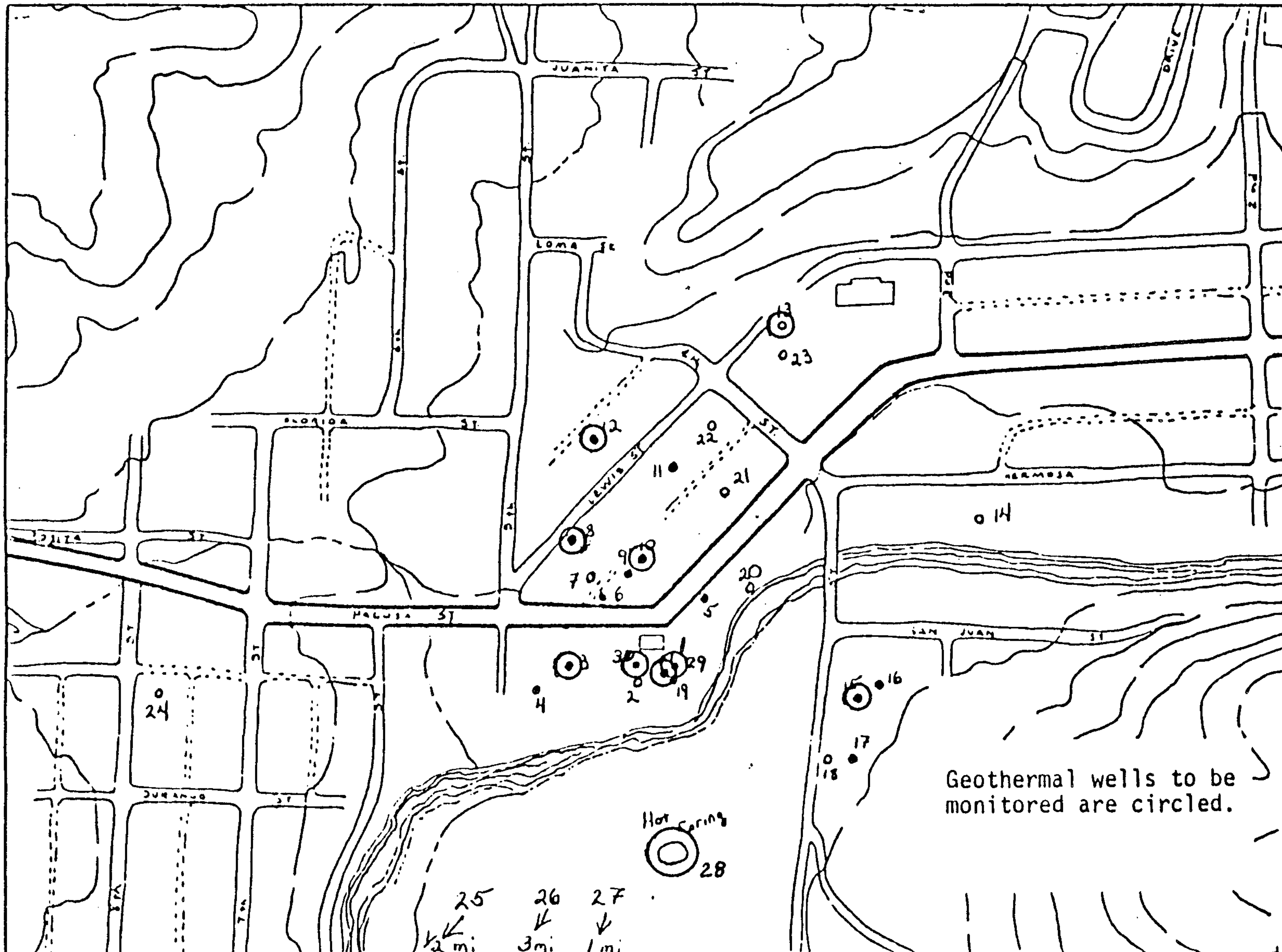


Figure 2. Locations of hot water wells in Pagosa Springs, Colorado. Well numbers are indexed to page 6. (Taken from "An Appraisal of Natural Hot Water Utilization in Pagosa Springs, Colorado, Chaffee Geothermal Ltd., June 1978.)

INDEX TO FIGURE 2

● Hot well in operation

o Hot well not in use or abandoned

HOT WELLS TO BE MONITORED

1. County Well (Courthouse Well)
2. *Poma Well (Lacked Authorization Without Additional Support and Modification
8. *Adobe Inn Well
10. Montroy Well (Edmonds)
11. Rumbaugh Well (Added to List)
12. *Methodist Church Well
13. High School Well
15. *Giordano No. 1 (Spa Motel-1)
28. Pagosa Hot Springs (Level)
29. Pagosa Springs Geothermal District Heating System Well PS-5
30. Pagosa Springs Geothermal District Heating System Well PS-3

* These wells were not monitored in current testing due to the poor condition of the existing wellhead manifolding which precluded the connecting of the instrumentation or, secondly, due to lack of authorization of well owners.

near PS-5. These flow and pressure data are charted graphically on Figures 3 and 4; these have been smooth-curve fitted to illustrate the general trends of the data.

PS-5 flow rates initially were set at 395 gpm on October 4, 1983; there was an unplanned reduction of these rates to 347 gpm on October 4. The 347 gpm flow rate was then constantly maintained until January 20, 1984. On January 20, the flow rate was increased to 450 gpm and maintained at that flow through the duration of the test period.

The pressure response to this geothermal water production for both PS-5 and the nearby wells and the Spring is as seen in Figures 3, 4, and 5. All pressures dropped at the point of initial production startup. On January 16, all wells showed consistent pressure drops which are not completely explainable, since PS-5 flows were not increased on that date. Weather data, which are presented in degree day format in Figure 6, indicate that very cold temperatures ($-16^{o}F$ to $-30^{o}F$) were experienced between January 16 to January 21, 1984. This itself does not explain the decreasing well pressures, however, unless flows from other nearby wells were either initiated or increased substantially during this period. Nearby well operations were checked. No such increase of flow is currently known, although full knowledge of each well operation is not available. A second possible factor giving these readings and which is potentially responsible for the noted pressure drop is the possibility of a malfunctioning pressure gauge. Pagosa Springs personnel felt this to be likely at the time and changed pressure gauges in the January 16 to 17 time period. The old gauge was thrown away and there is currently no way to check that assumption.

Given the above analysis, there is no clear understanding regarding exact causes for the pressure decrease seen on January 16.

A second decrease in well pressures is noted on January 20; this suggests a correspondence with the increase of PS-5 production flows to 450 gpm on that date. Again, this direct relationship is called into question by the unexplained pressure decrease discussed earlier on January 16. Subsequent to January 20, all well pressures and the Spring level stabilized throughout the remainder of the test period.

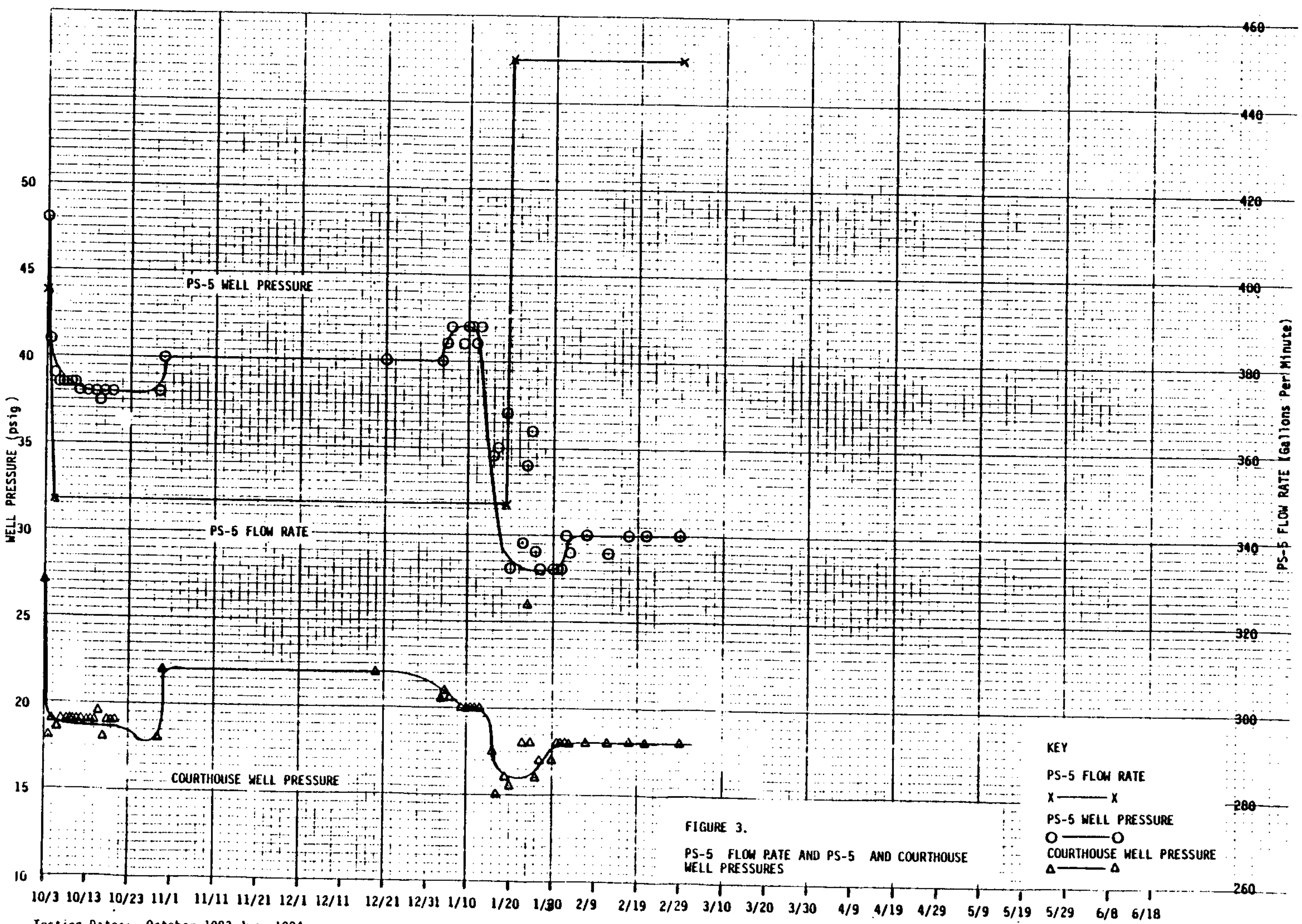


FIGURE 3.

PS-5 FLOW RATE AND PS-5 AND COURTHOUSE WELL PRESSURES

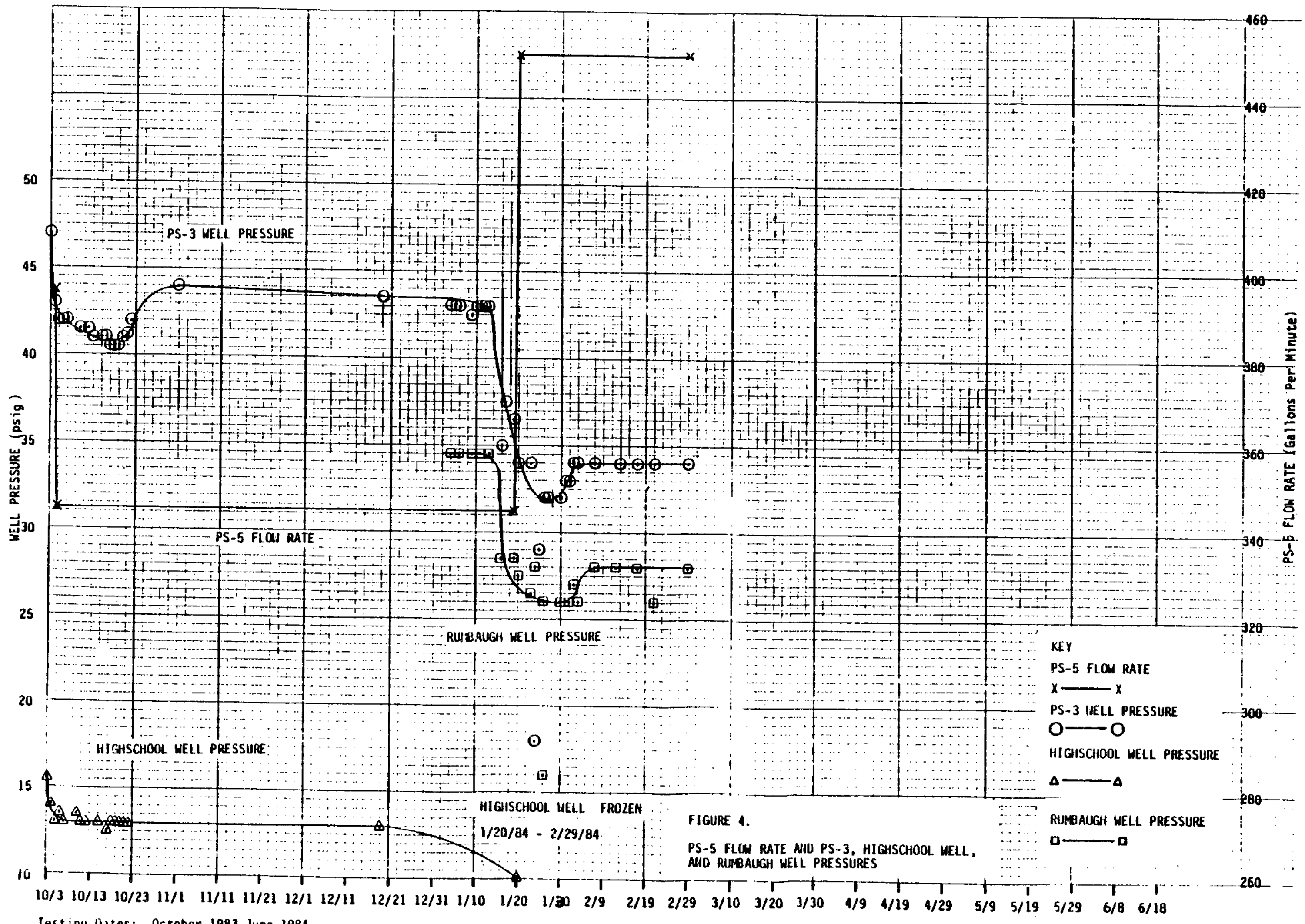


FIGURE 4.

PS-5 FLOW RATE AND PS-3, HIGHSCHOOL WELL, AND RUMBAUGH WELL PRESSURES

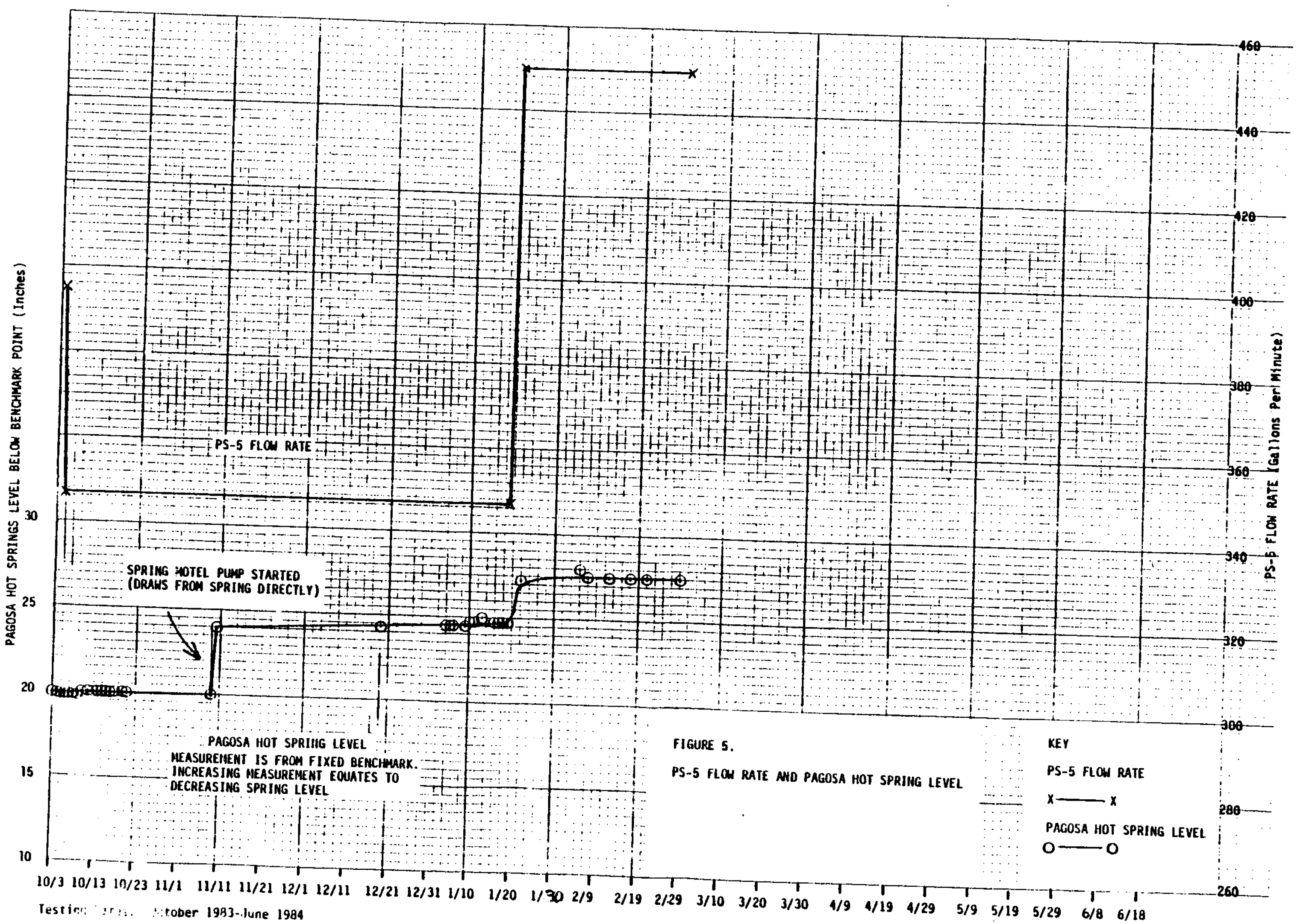


FIGURE 5.
PS-5 FLOW RATE AND PAGOSA HOT SPRING LEVEL

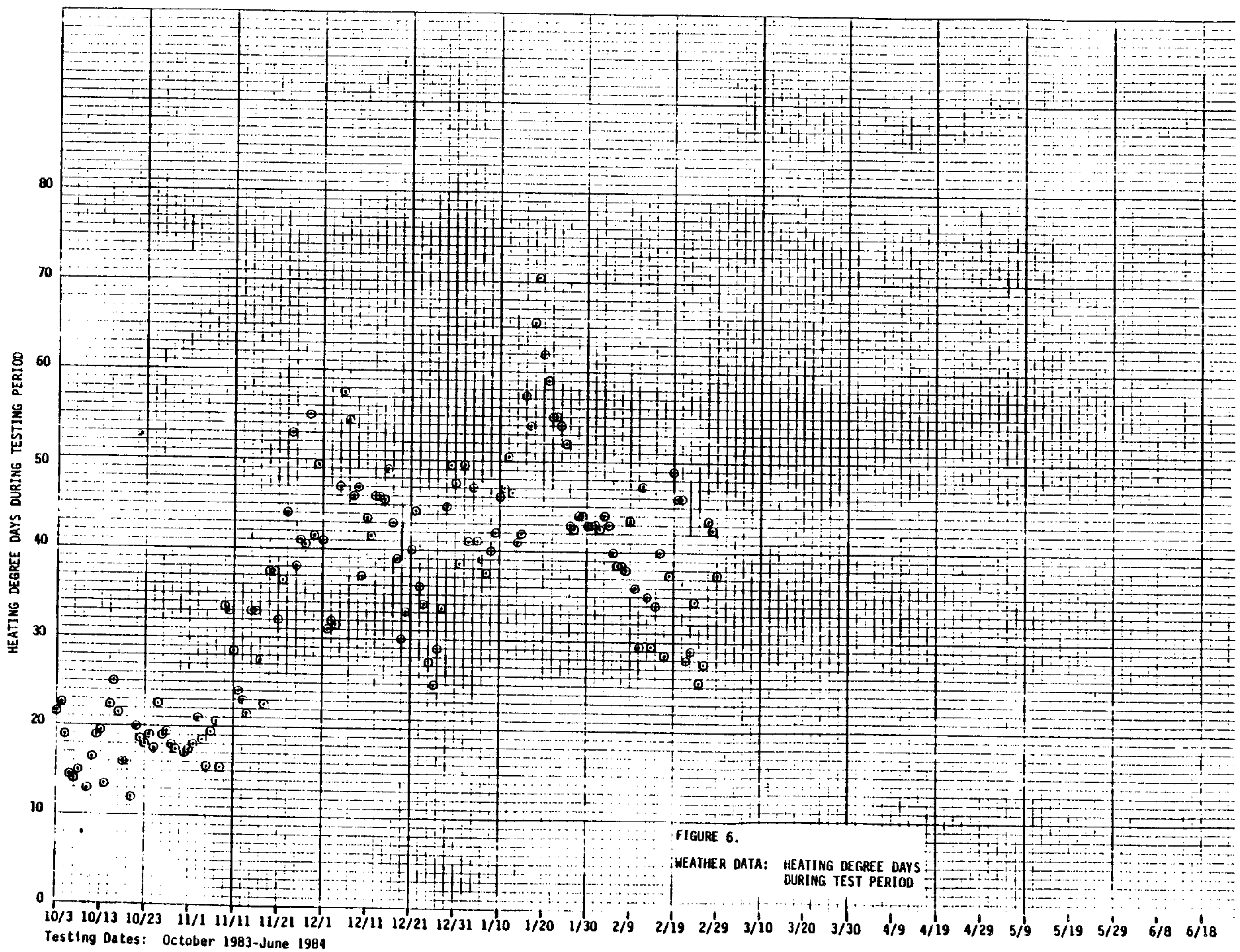


FIGURE 6.

WEATHER DATA: HEATING DEGREE DAYS DURING TEST PERIOD

Well temperature data for PS-5 are charted in Figure 7, and are presented as representative of other well data. No significant degradation of well temperatures is evident. Initial PS-5 temperatures are estimated to be of the order of 8°F high due to the utilizing of an uncalibrated gauge early in the testing.

Throughout all of this testing, Town of Pagosa Springs personnel have been in contact with the various individual well owners near the PS-5 production well. To our knowledge, although flows were not able to be precisely measured, no significant flow reductions in these surrounding wells have been documented or otherwise attributed to PS-5 operation. In addition, no complaints are known to have been registered either with the Town or State agencies with regards to impacts which the geothermal system might have had on any nearby well operation and use.

C. Goethermal System Operational Efficiency

1. Efficiency Significance

The efficiency at which heat energy is extracted from geothermal waters and utilized throughout the system is significant in that low heat utilization efficiencies require larger geothermal fluid withdrawals. This, in turn, may affect overall reservoir pressures and reservoir longevity.

Current system operating objectives are to extract 30 Btu of heat energy from each pound of geothermal water produced. To document system operational performance, weather data, geothermal well flows and temperatures, and the geothermal distribution system hot and cold water flows and temperatures were recorded daily during initial system operation and twice weekly subsequent to system stabilization in early 1984. In addition, the required data were taken two times daily during the specified periods of October 17-22, 1983, and February 6-11, 1984. Finally, additional attention and analysis were given the data taken during the coldest winter temperature period of January 16-January 23, 1984.

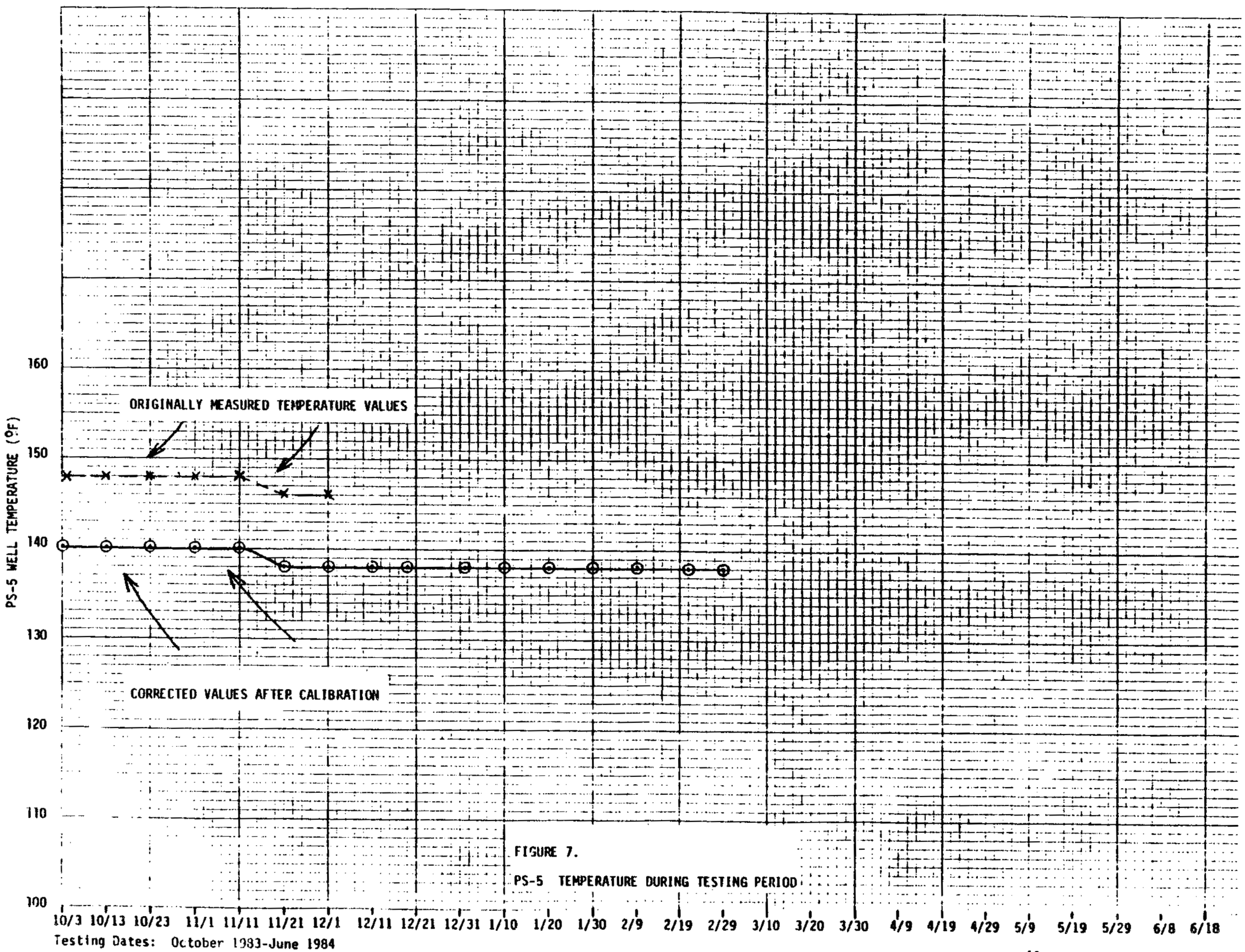


FIGURE 7.
PS-5 TEMPERATURE DURING TESTING PERIOD

2. Results

The geothermal operational data is summarized in Table 3, which presents typical data from each month. A review of Table 3 indicates that the desired data consistency is lacking. For example, if all data are consistent, the energy distributed to the system (column 8) should increase and decrease comparably with the degree day data (column 3). This is not the case, however, as seen by the calculated energy delivered on January 19. The 2.24 million Btu per hour is less than the calculated heat delivered for numerous other days with considerably lower heating demands.

Additionally, the calculated energy delivered decreases substantially during February to levels significantly below values in October when degree day heating demands were considerably less. (The very low values noted on January 23 and January 30 are likely the result of significantly decreased load due to the schools temporarily disconnecting from the system.) The calculated value of the energy delivered is dependent on flow and temperature. It is especially sensitive to accurate temperature measurement, where temperature variations of 1 to 3 degrees could increase or decrease the calculated distributed energy by as much as 40 percent. This suggests additional need for calibration of temperature-taking instrumentation and also suggests additional care be taken procedurally when obtaining the temperature data.

Flow is the other major variable utilized in the delivered energy calculation. Again, additional care will have to be taken to insure accurate flow readings are being obtained, both in flumes and wiers, and in fixed flow meter instrumentation.

The data indicate that the system is operating at low utilization factors. While acknowledging that temperature measurements recorded may reflect inaccuracies, it is clear that as compared to the operational goal of extracting heat and thereby lowering geothermal water temperatures 30°F, only a 16°F to 19°F temperature differential is being achieved during peak demand periods. On many other occasions and especially during February, the heat energy extraction rate was much smaller, often of the

TABLE 3. PAGOSA SPRINGS GEOTHERMAL SYSTEM OPERATING DATA

Date	1 Lowest Temperature (°F)	2 Degree Days	3 PS-5 Flow (gpm)	4 Geothermal Water Temperature Drop (°F)	5 Percent Utilization	6 Distribution System Flow (gpm)	7 Distribution System Water Temperature (Gain) (°F)	8 Distribution System Energy Delivered 10^6(Btu/hour)
10/18/83	35	16	347	7*	.23	625	11	3.44
10/31/83	33	18.5	347	17*	.57	450	11	2.47
11/15/83	13	33	347	19*	.63	450	16	3.6
11/30/83	1	49.5	347	19*	.63	450	16	3.6
12/15/83	4	45.5	347	16	.53	450	8	1.8
1/01/84	19	38.5	347	17	.56	450	11	2.47
1/19/84	-29	70.5	347	18	.60	450	10	2.24
1/23/84	-16	55	450	5	.16	450	7	1.57
1/30/84	-3	43	450	4	.13	450	4	.9
2/15/84	22	34	450	8	.26	450	8	1.8
2/29/84	8	37.5	450	8	.26	450	8	1.8

* Temperature difference is estimated, corrected value subsequent to gauge calibration.

order of 8 Btu per lb. of water. On January 19, which reflected the most severe heating demand of any day in the test period, 40 percent more heat could have been extracted from the geothermal fluid. To accomplish this may require changes in the current system to allow lower pumped circulation rates.

The significance of the above analysis is that with additional system flow rate control, geothermal well withdrawals might be able to be reduced, subject to system design constraints. Conversely, the Town could hook up to a 40 percent greater heating load and substantially improve system economics without further increasing the required geothermal well withdrawals. To run at high system efficiencies will lessen the impact on nearby well owners, help prolong reservoir longevity, and reduce system energy pumping costs.

The two one-week test periods of October 17-22 and February 6-11 showed no significant variation of system temperatures or pressures with time of day. Readings were taken at 6:30 a.m. and 5:30 p.m. This is a somewhat surprising result since user heating demand would be expected to vary at least somewhat with time of day. As noted earlier, the 347 to 450 gpm geothermal flow rates were more than adequate to serve current user loads during the peak demand period of January 16 to January 23, 1984.

D. Initial Drawdown Data

Production flows through PS-5 were initiated on October 4, 1983; initial flows were 395 gpm. Flows were adjusted to 347 gpm on October 5, 1983. Drawdown data for PS-5, PS-3, the Courthouse well, and the High School well are presented in Figures 8 to 13. A detailed hydrological analysis of these data is not within the scope of the current testing effort; rather, these data represent backup should additional data analysis prove desirable at a later date. The unplanned change of PS-5 flow within the initial 24-hour production period will add complexity to these drawdown analyses. Figures 12 and 13 show 8-hour drawdown data collected when PS-5 flows were increased from 347 gpm to 450 gpm on January 20, 1984. Data were not collected beyond eight hours; also a 600 gpm drawdown was not performed.

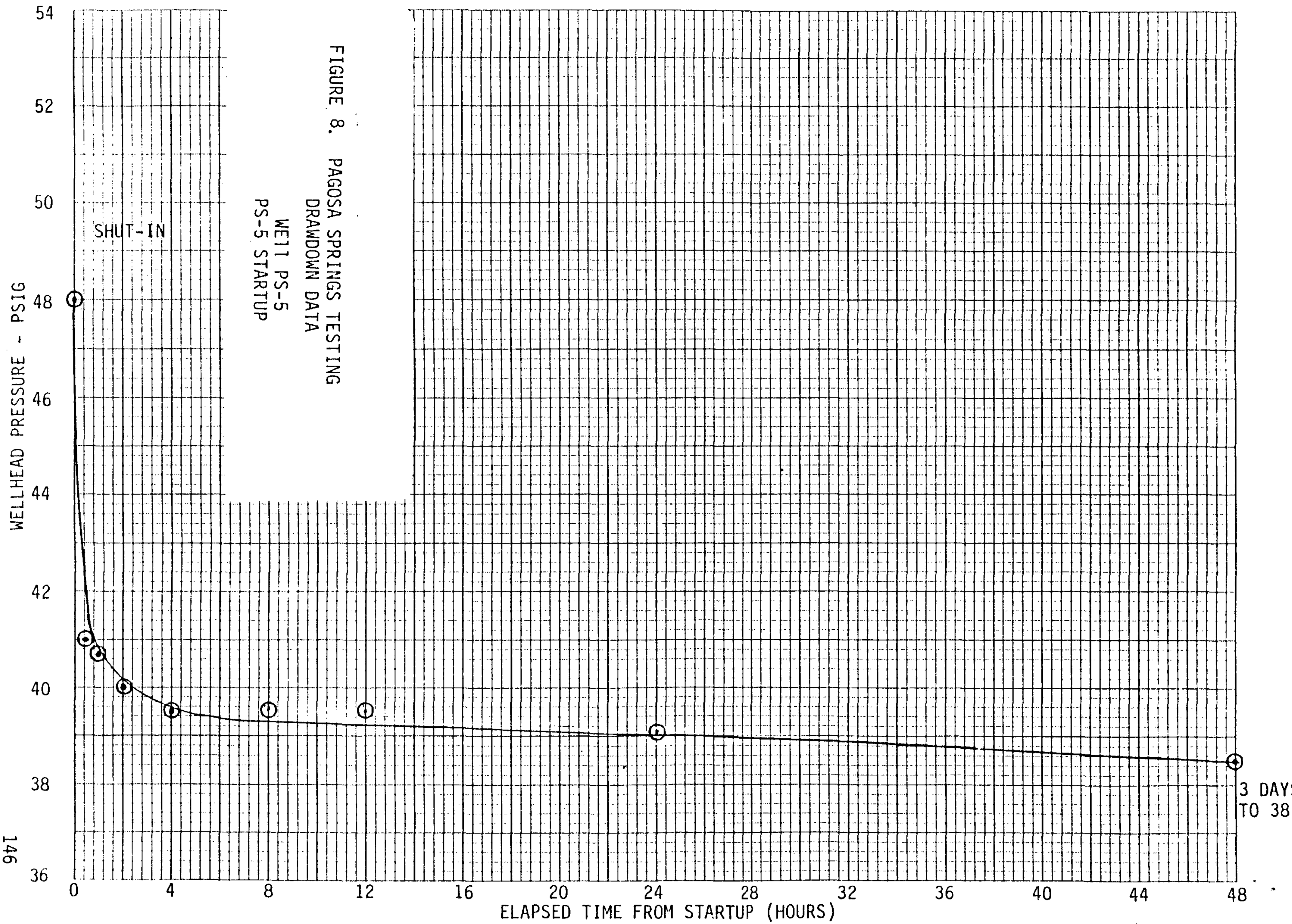


FIGURE 8. PAGOSA SPRINGS TESTING
DRAWDOWN DATA
Well PS-5
PS-5 STARTUP

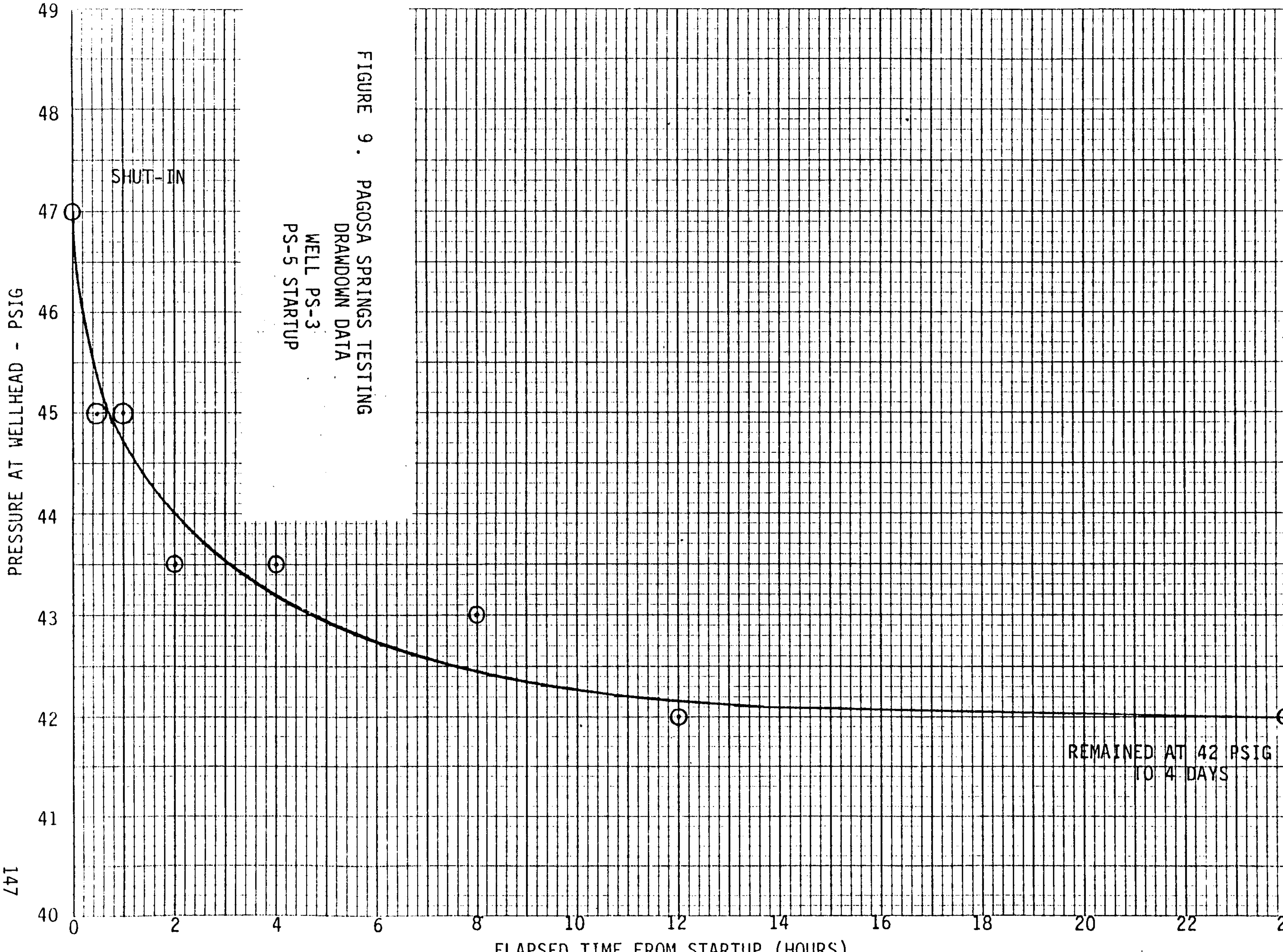


FIGURE 9. PAGOSA SPRINGS TESTING
DRAWDOWN DATA
WELL PS-3
PS-5 STARTUP

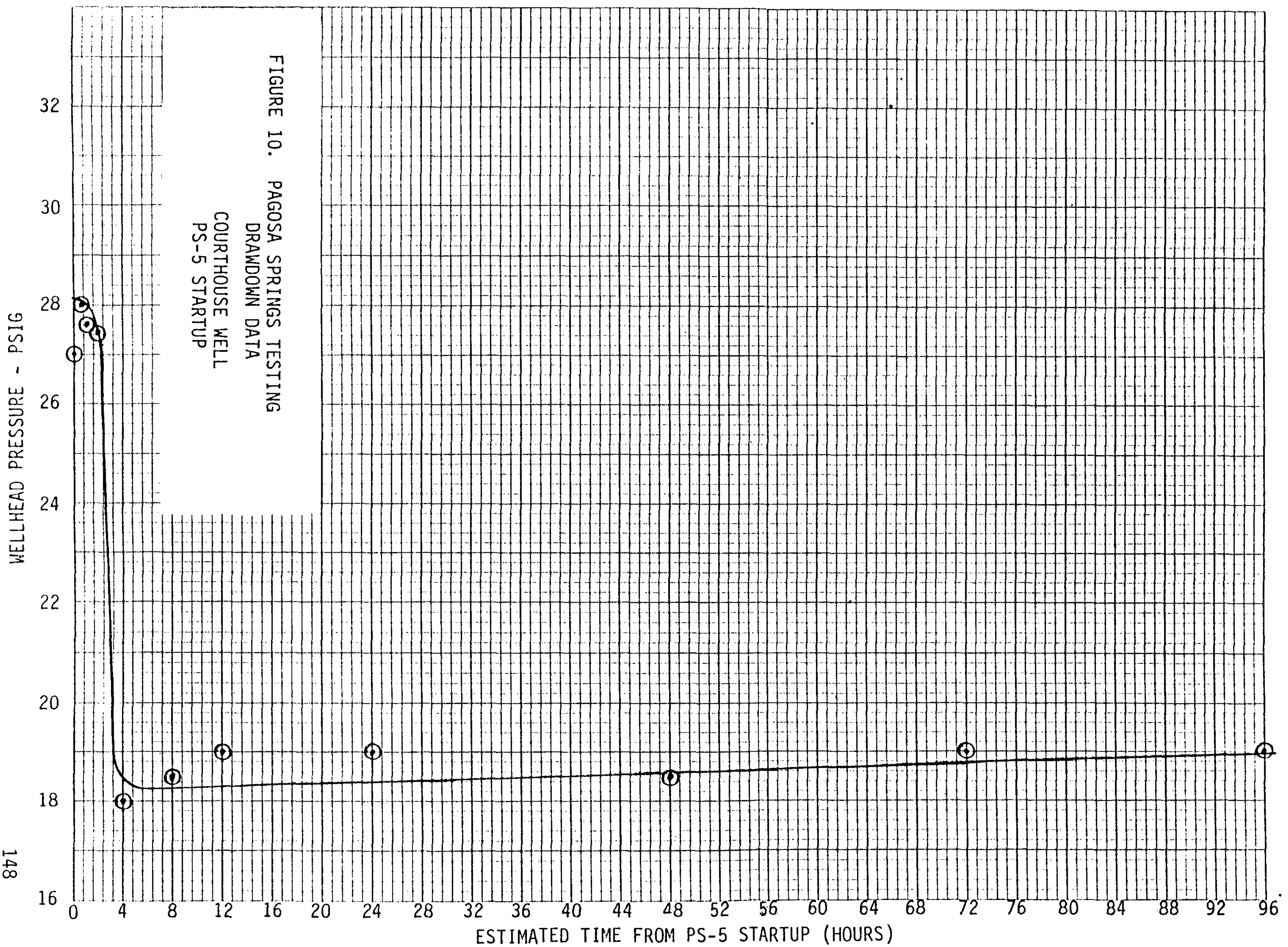


FIGURE 10. PAGOSA SPRINGS TESTING
DRAWDOWN DATA
COURTHOUSE WELL
PS-5 STARTUP

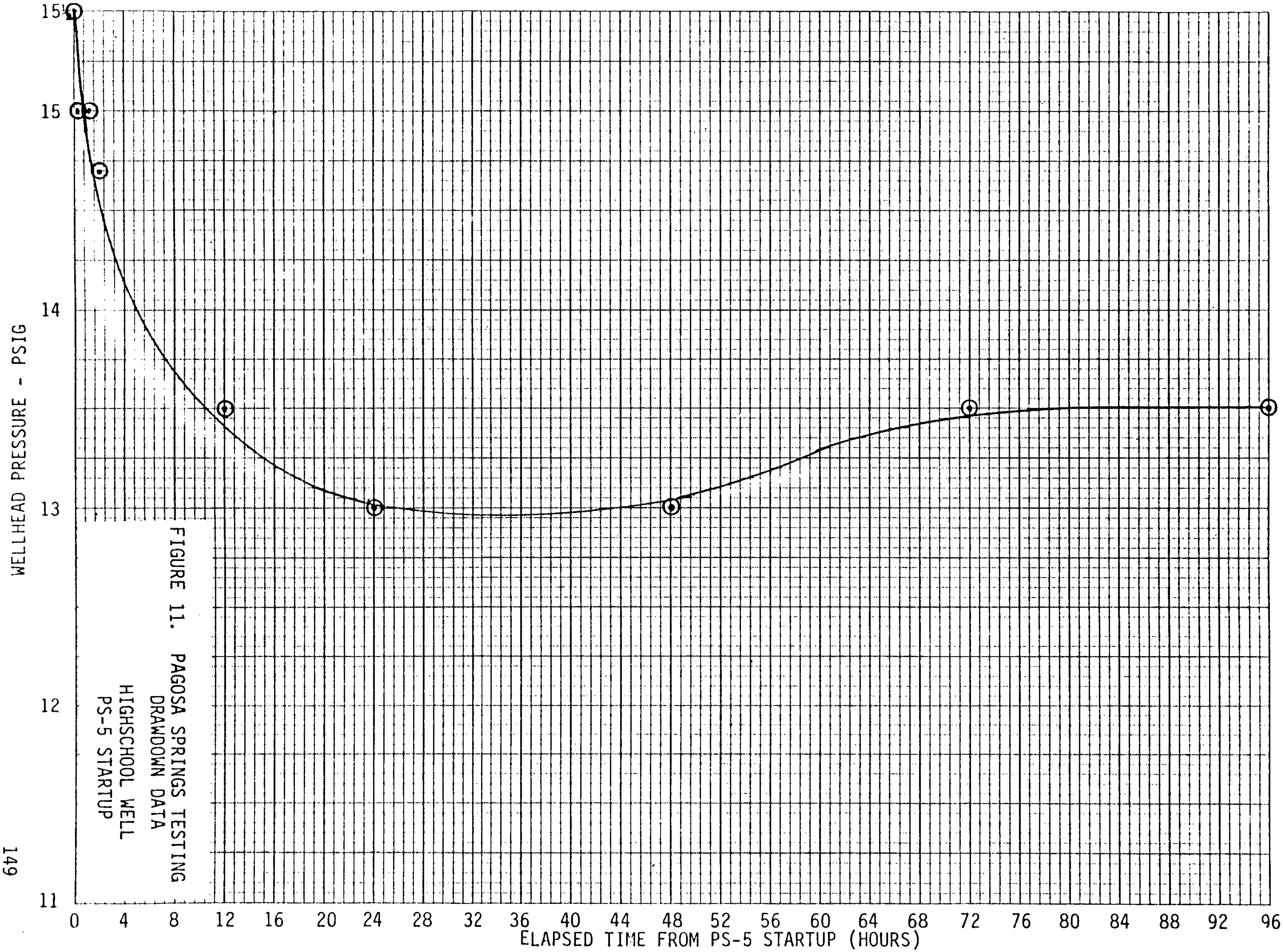


FIGURE 11. PAGOSA SPRINGS TESTING
DRAWDOWN DATA
HIGHSCHOOL WELL
PS-5 STARTUP

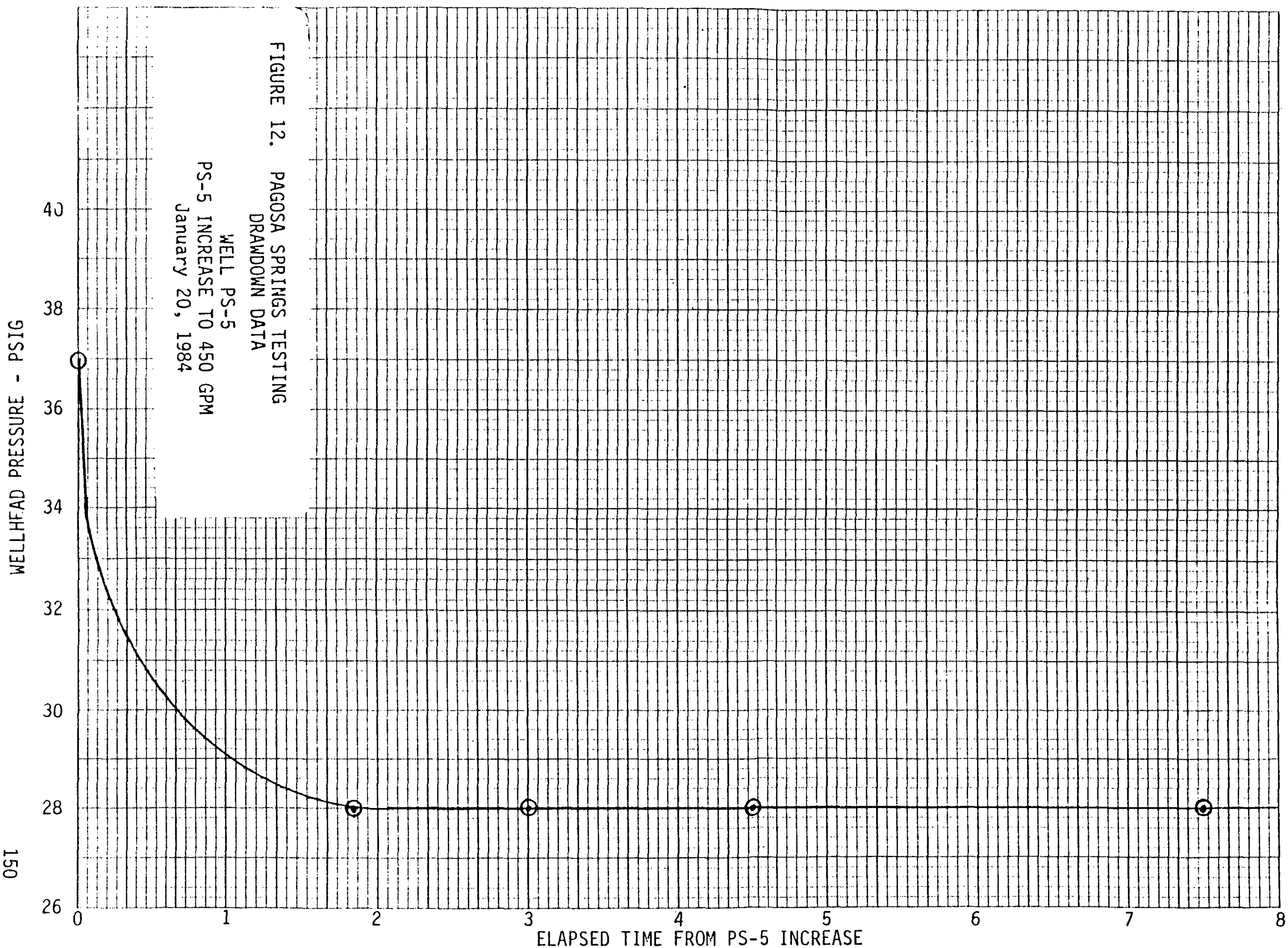


FIGURE 12. PAGOSA SPRINGS TESTING
DRAWDOWN DATA
WELL PS-5
PS-5 INCREASE TO 450 GPM
January 20, 1984

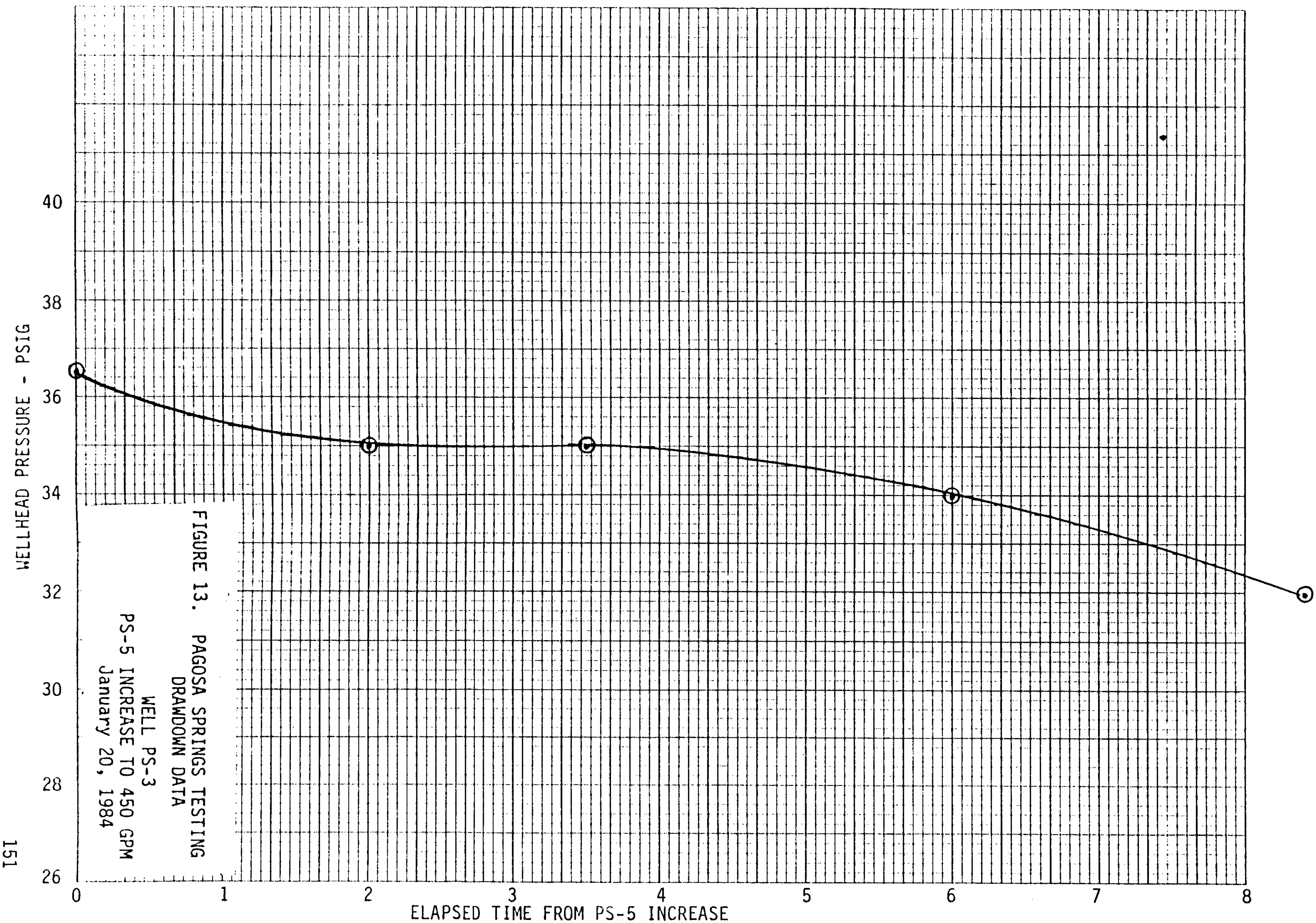


FIGURE 13. PAGOSA SPRINGS TESTING
DRAWDOWN DATA
WELL PS-3
PS-5 INCREASE TO 450 GPM
January 20, 1984

IV. RECOMMENDATIONS FOR FUTURE TESTING

Based on current testing results, the following recommendations for continued testing are suggested:

1. The current testing effort should be continued as planned until shutdown of the system in June 1984.

2. Specific attention should be given both to the calibration of temperature and flow measurement instrumentation and also to the procedural steps for obtaining the required data to insure the highest accuracy possible while obtaining these data.

3. Flow measurement data using the six V-notch wiers should be continued to be obtained. The individual flows of these wells should be isolated and quantified to the greatest accuracy possible at the earliest date possible.

4. The geothermal wells should be flow tested to rates of 800 to 1200 gpm during late April to early May to ascertain impacts on the reservoir and nearby wells. These tests should be carefully planned in advance and performed to insure that the most useful testing information possible will be obtained.

5. These data along with the other data collected should be summarized and submitted to the Colorado Oil and Gas Conservation Commission and the State Engineer's Office prior to July 15, 1984.

APPENDIX 2

AS-BUILT DRAWINGS

PAGOSA SPRINGS, COLORADO

PAGOSA SPRINGS GEOTHERMAL PROJECT

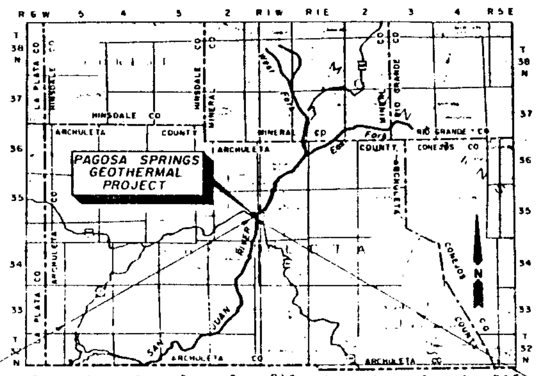
ARCHULETA COUNTY, COLORADO

Sec. 13, T 35 N, R 2 W &
Sec. 18, T 35 N, R 1 W, 6th P.M.

INDEX OF DRAWINGS

GENERAL NOTES

1. Topographic mapping obtained from the "San Juan River Flood Study" prepared by: Nelson, Haley, Patterson and Quirk, Engineering Consultants, Greely, Colorado, 1975.
2. Underground utilities in the area of construction have been located in plan only from field data and available utility records. All water lines are approximately 4 feet deep and gas lines are approximately 18 inches deep. Sewer lines vary in depth, but can be expected to be encountered. The contractor shall assume responsibility for the protection of the utilities affected by the execution of this contract.
3. The drawings and details of the distribution pipelines are shown for asbestos-cement type pipe. If another type pipe is used some drawings and details may be required to be revised, by the contractor, at no additional cost to the owner.
4. All distribution piping, as shown is approximate. Actual alignment to be done in the field by the owner.
5. Control house to be field located by owner.



VICINITY MAP
SCALE 1:500,000

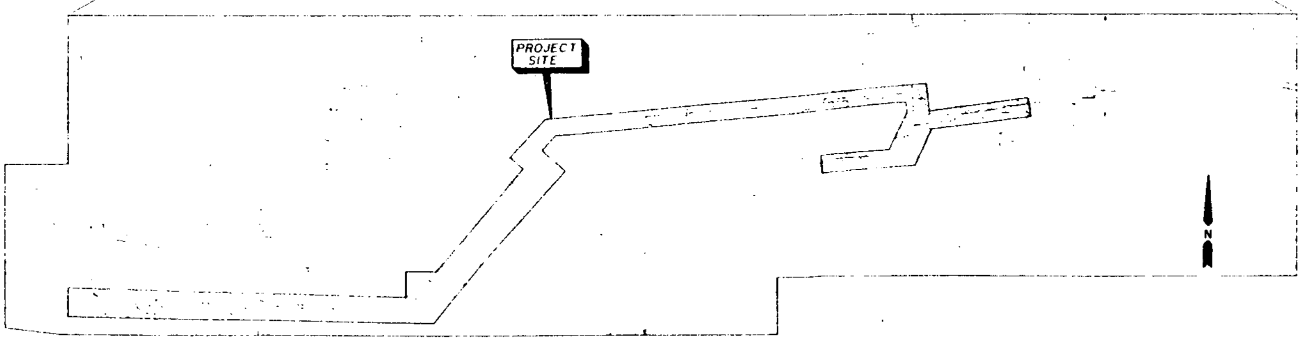
I certify that these plans were prepared under my direct supervision:

Eric Will, Project Manager — Date

Kurt D Mohnken, Project Engineer — Date

AS-BUILT DRAWINGS
PREPARED BY
ROSEBERRY PLUMBING AND HEATING, INC.
DURANGO, COLORADO
SEPTEMBER 1983

'AS BUILTS' — SEPT. 12, 1983

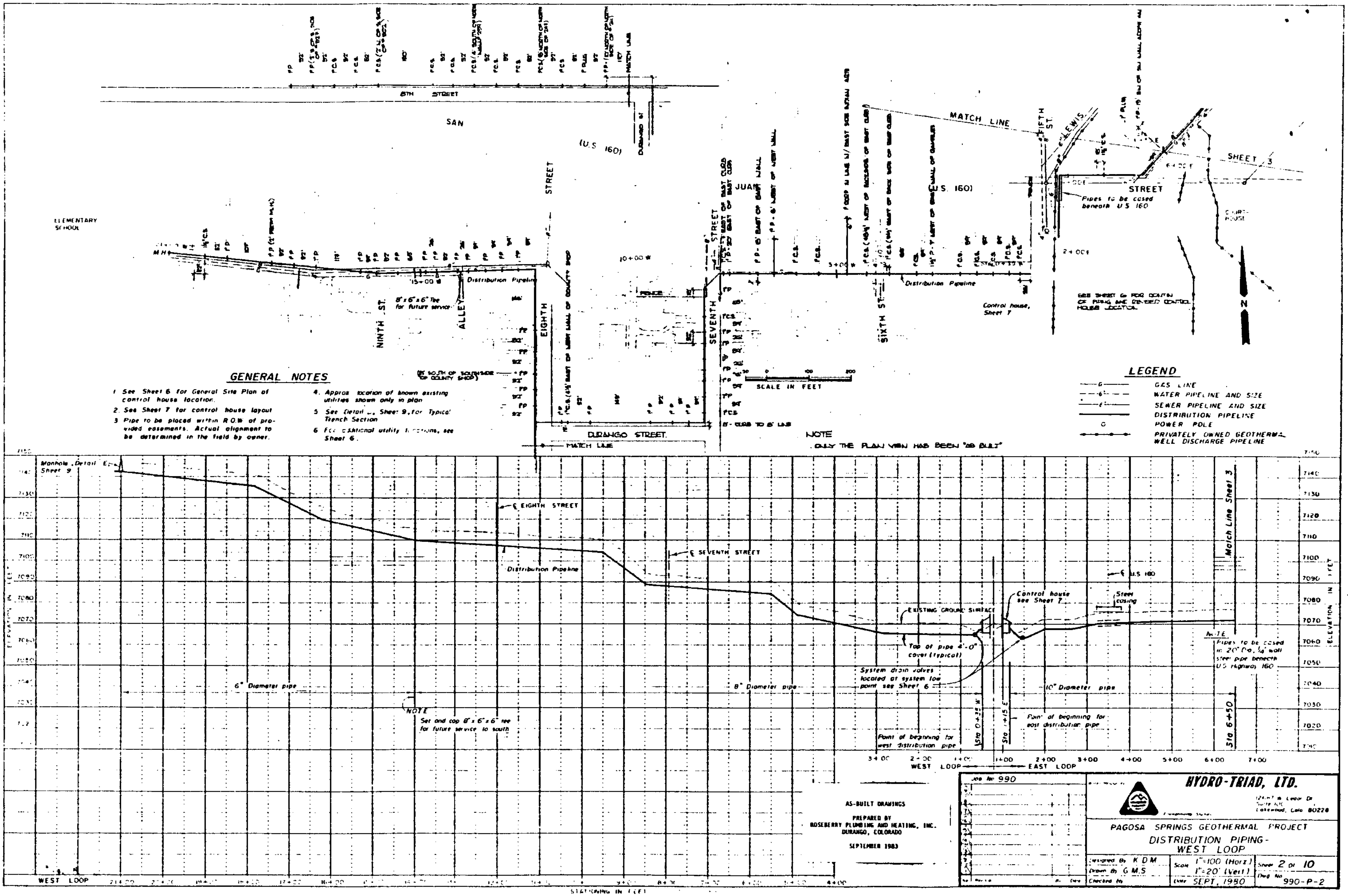


GENERAL LOCATION MAP
SCALE 1":400'

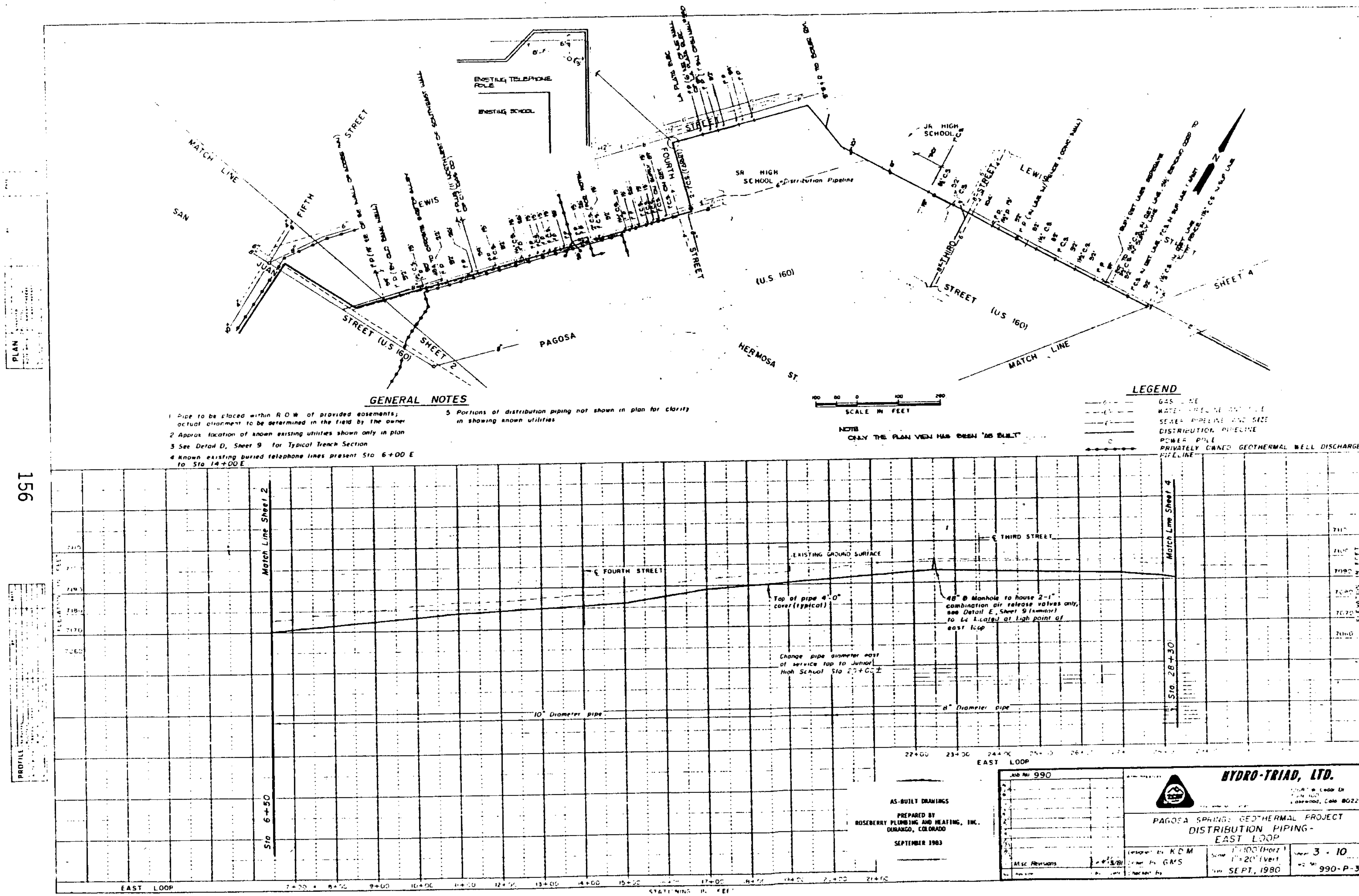
HYDRO-TRIAD, LTD.
WATER RESOURCE ENGINEERS
12687 W Cedar Dr
Suite 100
Lakewood, Colo 80228

SEPTEMBER, 1980

155



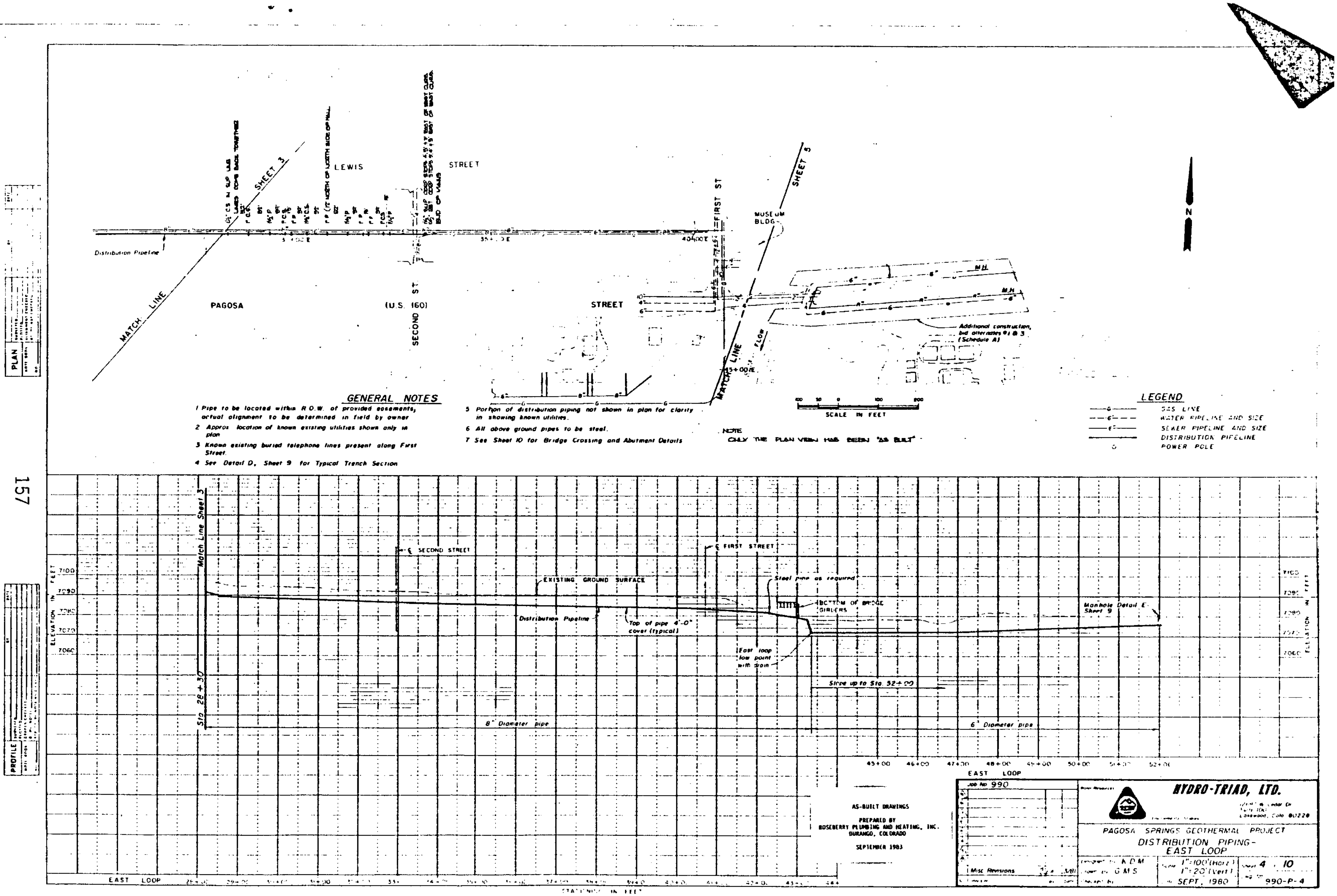
PLAN
PROFILE
8TH STREET
SAN
JUAN
(U.S. 160)
MATCH LINE
SHEET 3
FIFTH ST.
LEWIS
STREET
Pipes to be cased beneath U.S. 160
COURT HOUSE
ELEMENTARY SCHOOL
MH
15+00 W
10+00 W
5+00 W
2+00 E
Distribution Pipeline
8" x 6" x 6" Tee for future service
NINTH ST.
ALLEY
EIGHTH STREET
SEVENTH STREET
SIXTH ST.
FENCE
Control house, Sheet 7
SEE SHEET 6 FOR ROUTING OF PIPING AND REVISED CONTROL HOUSE LOCATION
N
SCALE IN FEET
0
100
200
DURANGO STREET
MATCH LINE
NOTE
ONLY THE PLAN VIEW HAS BEEN "AS BUILT"
GENERAL NOTES
1 See Sheet 6 for General Site Plan of control house location.
2. See Sheet 7 for control house layout
3 Pipe to be placed within R.O.W. of provided easements. Actual alignment to be determined in the field by owner.
4. Approx location of known existing utilities shown only in plan
5 See Detail _, Sheet 9, for Typical Trench Section
6 For additional utility locations, see Sheet 6.
LEGEND
GAS LINE
WATER PIPELINE AND SIZE
SEWER PIPELINE AND SIZE
DISTRIBUTION PIPELINE
POWER POLE
PRIVATELY OWNED GEOTHERMAL WELL DISCHARGE PIPELINE
Manhole, Detail E, Sheet 9
℄ EIGHTH STREET
℄ SEVENTH STREET
℄ U.S. 160
Distribution Pipeline
EXISTING GROUND SURFACE
Control house see Sheet 7
Steel casing
Top of pipe 4'-0" cover (typical)
System drain valves located at system low point see Sheet 6
NOTE
Pipes to be cased in 20" Dia. 1/4" wall steel pipe beneath U.S. Highway 160
6" Diameter pipe
8" Diameter pipe
10" Diameter pipe
NOTE
Set and cap 8" x 6" x 6" tee for future service to south
Point of beginning for west distribution pipe
Point of beginning for east distribution pipe
Sta 0+25 W
Sta 1+15 E
Sta 6+50
Match Line Sheet 3
ELEVATION IN FEET
7140
7130
7120
7110
7100
7090
7080
7070
7060
7050
7040
7030
7020
3+00
2+00
1+00
1+00
2+00
3+00
4+00
5+00
6+00
7+00
WEST LOOP
EAST LOOP
WEST LOOP
4+00
STATIONING IN FEET
AS-BUILT DRAWINGS
PREPARED BY
ROSEBERRY PLUMBING AND HEATING, INC.
DURANGO, COLORADO
SEPTEMBER 1983
Job No 990
HYDRO-TRIAD, LTD.
Lakewood, Colo 80228
PAGOSA SPRINGS GEOTHERMAL PROJECT
DISTRIBUTION PIPING - WEST LOOP
Designed By K D M
Drawn By G M.S
Checked By
Scale 1"=100 (Horz.) 1"=20' (Vert)
Date SEPT, 1980
Sheet 2 of 10
Dwg No 990-P-2

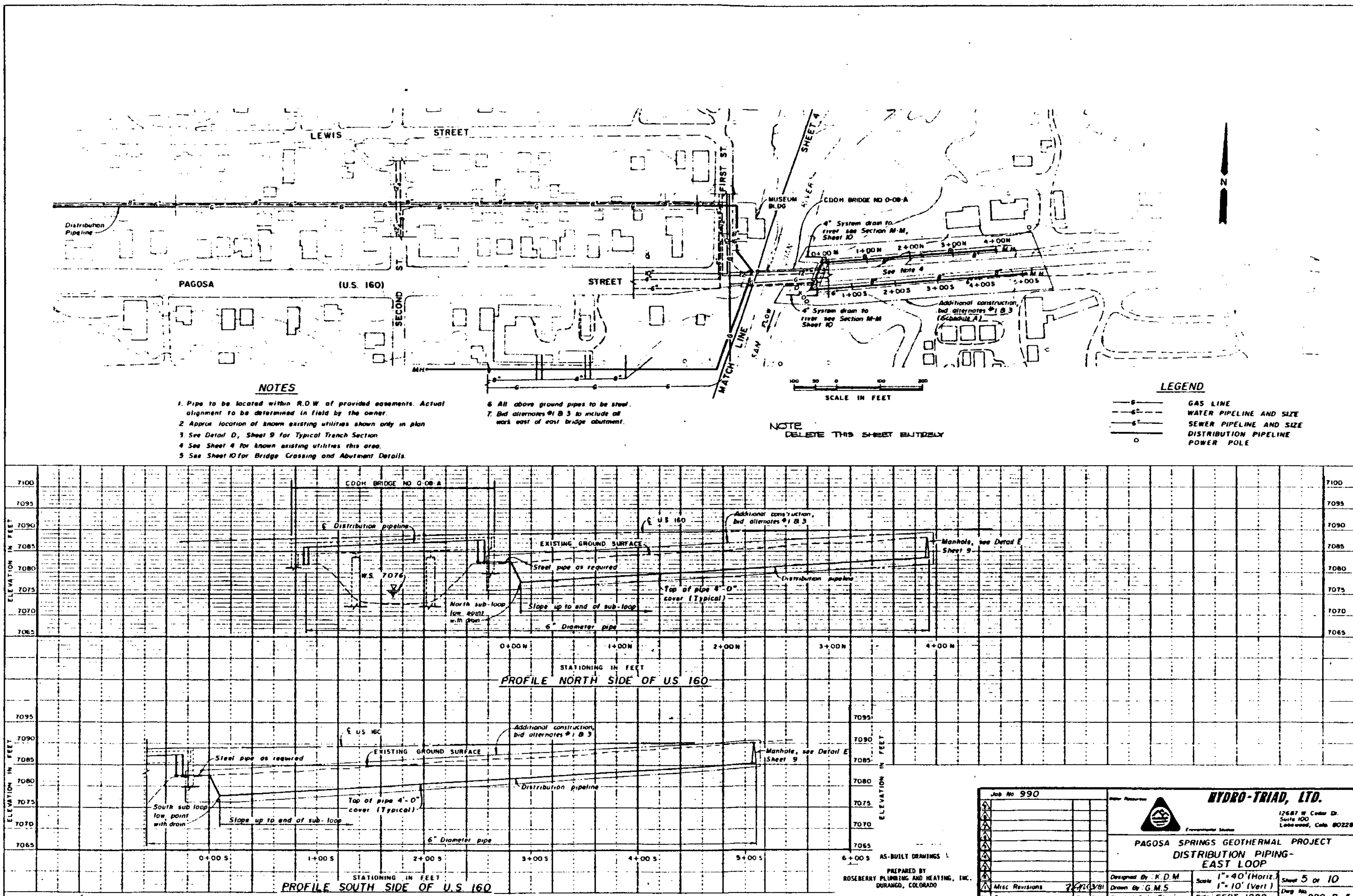


GENERAL NOTES

1. Pipe to be placed within R.O.W. of provided easements; actual alignment to be determined in the field by the owner
2. Approx. location of known existing utilities shown only in plan
3. See Detail D, Sheet 9 for Typical Trench Section
4. Known existing buried telephone lines present Sta 6+00 E to Sta 14+00 E
5. Portions of distribution piping not shown in plan for clarity in showing known utilities

157


LEWIS
STREET
PAGOSA
(U.S. 160)
STREET
SECOND ST
FIRST ST
MUSEUM BLDG.
MATCH LINE
SHEET 3
SHEET 5
Distribution Pipeline
FLOW
Additional construction, bid alternates #1 & 3 (Schedule A)
SCALE IN FEET
GENERAL NOTES
1 Pipe to be located within R.O.W. of provided easements, actual alignment to be determined in field by owner
2 Approx location of known existing utilities shown only in plan
3 Known existing buried telephone lines present along First Street.
4 See Detail D, Sheet 9 for Typical Trench Section
5 Portion of distribution piping not shown in plan for clarity in showing known utilities.
6 All above ground pipes to be steel.
7 See Sheet 10 for Bridge Crossing and Abutment Details
NOTE
ONLY THE PLAN VIEW HAS BEEN "AS BUILT"
LEGEND
GAS LINE
WATER PIPELINE AND SIZE
SEWER PIPELINE AND SIZE
DISTRIBUTION PIPELINE
POWER POLE
PLAN
PROFILE
Match Line Sheet 3
Sta 28+30
℄ SECOND STREET
℄ FIRST STREET
EXISTING GROUND SURFACE
Steel pipe as required
BOTTOM OF BRIDGE GIRDERS
Distribution Pipeline
Top of pipe 4'-0" cover (typical)
East loop low point with drain
Manhole Detail E Sheet 9
Slope up to Sta. 52+00
8" Diameter pipe
6" Diameter pipe
ELEVATION IN FEET
7100
7090
7080
7070
7060
45+00
46+00
47+00
48+00
50+00
EAST LOOP
STATIONING IN FEET
AS-BUILT DRAWINGS
PREPARED BY
ROSEBERRY PLUMBING AND HEATING, INC.
DURANGO, COLORADO
SEPTEMBER 1983
Job No 990
Misc Revisions
HYDRO-TRIAD, LTD.
Lakewood, Colo 80228
PAGOSA SPRINGS GEOTHERMAL PROJECT
DISTRIBUTION PIPING-
EAST LOOP
K D M
G M S
1"=100'(Horz)
1"=20'(Vert)
SEPT, 1980
Sheet 4 of 10
990-P-4



LEWIS STREET
PAGOSA (U.S. 160) STREET
SECOND ST.
FIRST ST.
SHEET 4
MATCH LINE
SAN JUAN RIVER
FLOW
MUSEUM BLDG
CDOH BRIDGE NO 0-08-A
Distribution Pipeline
4" System drain to river see Section M-M, Sheet 10
0+00N 1+00N 2+00N 3+00N 4+00N
See Note 4
0+00S 1+00S 2+00S 3+00S 4+00S 5+00S
Additional construction, bid alternates #1 & 3 (Schedule A)
SCALE IN FEET
N
NOTES
1. Pipe to be located within R.O.W. of provided easements. Actual alignment to be determined in field by the owner.
2. Approx. location of known existing utilities shown only in plan
3. See Detail D, Sheet 9 for Typical Trench Section
4. See Sheet 4 for known existing utilities this area.
5. See Sheet 10 for Bridge Crossing and Abutment Details.
6. All above ground pipes to be steel.
7. Bid alternates #1 & 3 to include all work east of east bridge abutment.
NOTE
DELETE THIS SHEET ENTIRELY
LEGEND
GAS LINE
WATER PIPELINE AND SIZE
SEWER PIPELINE AND SIZE
DISTRIBUTION PIPELINE
POWER POLE
PLAN
PROFILE
ELEVATION IN FEET
7100 7095 7090 7085 7080 7075 7070 7065
CDOH BRIDGE NO 0-08-A
℄ Distribution pipeline
℄ US 160
Additional construction, bid alternates #1 & 3
EXISTING GROUND SURFACE
Manhole, see Detail E Sheet 9
Steel pipe as required
W.S. 7076
Distribution pipeline
Top of pipe 4'-0" cover (Typical)
North sub-loop low point with drain
Slope up to end of sub-loop
6" Diameter pipe
0+00N 1+00N 2+00N 3+00N 4+00N
STATIONING IN FEET
PROFILE NORTH SIDE OF U.S. 160
℄ US 160
Additional construction, bid alternates #1 & 3
EXISTING GROUND SURFACE
Steel pipe as required
Manhole, see Detail E Sheet 9
Distribution pipeline
South sub loop low point with drain
Top of pipe 4'-0" cover (Typical)
Slope up to end of sub-loop
6" Diameter pipe
0+00S 1+00S 2+00S 3+00S 4+00S 5+00S 6+00S
STATIONING IN FEET
PROFILE SOUTH SIDE OF U.S. 160
AS-BUILT DRAWINGS
PREPARED BY
ROSEBERRY PLUMBING AND HEATING, INC.
DURANGO, COLORADO
SEPTEMBER 1983
Job No 990
HYDRO-TRIAD, LTD.
12687 W. Cedar Dr. Suite 100 Lakewood, Colo. 80228
PAGOSA SPRINGS GEOTHERMAL PROJECT
DISTRIBUTION PIPING-
EAST LOOP
Misc. Revisions
Designed By: K.D.M
Drawn By: G.M.S
Checked By:
Scale 1"=40' (Horiz.) 1"=10' (Vert.)
Date SEPT. 1980
Sheet 5 of 10
Dwg No. 990-P-5

158

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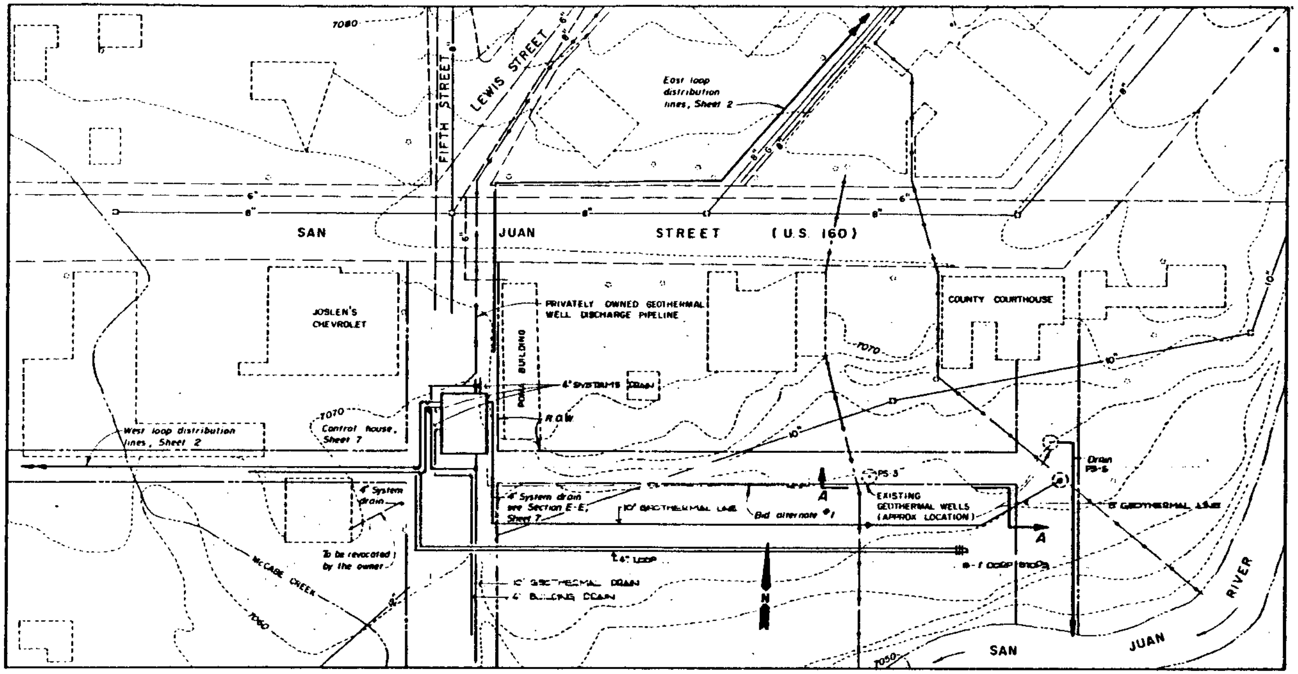


CONTROL HOUSE GENERAL SITE PLAN

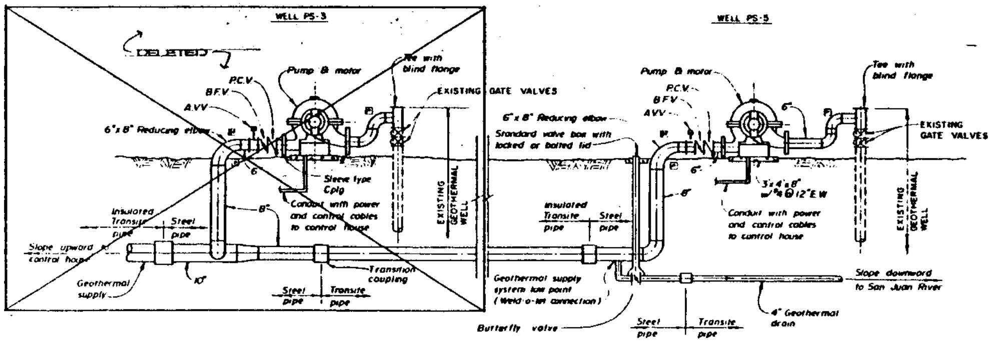
NOTES

1 Control house to be field located by owner. Finished floor elevation to be at El 7066.00 or higher

2 See Sheet 2 for additional utilities information

LEGEND

——8——	GAS LINE
——6"——	WATER PIPELINE AND SIZE
——8"——	SEWER PIPELINE AND SIZE
———	DISTRIBUTION PIPELINE
○	POWER POLE
—•—•—	PRIVATELY OWNED GEOTHERMAL WELL DISCHARGE PIPELINE



SECTION A-A
No Scale

NOTES
B.F.V. = Butterfly valve
A.V.V. = Air release / vacuum valve
P.C.V. = Pump check valve
(E) - Field tap location for pressure probe, Detail O
(F) Field location for flow meter to be located 10 pipe diameters from all valves, elbows, or other restrictions

NOTE
CONTROL HOUSE & PS-5 DRAWINGS WERE 'AS BUILT' AT JOB COMPLETION AND SENT TO OWNER UNDER SEPERATE COVER.

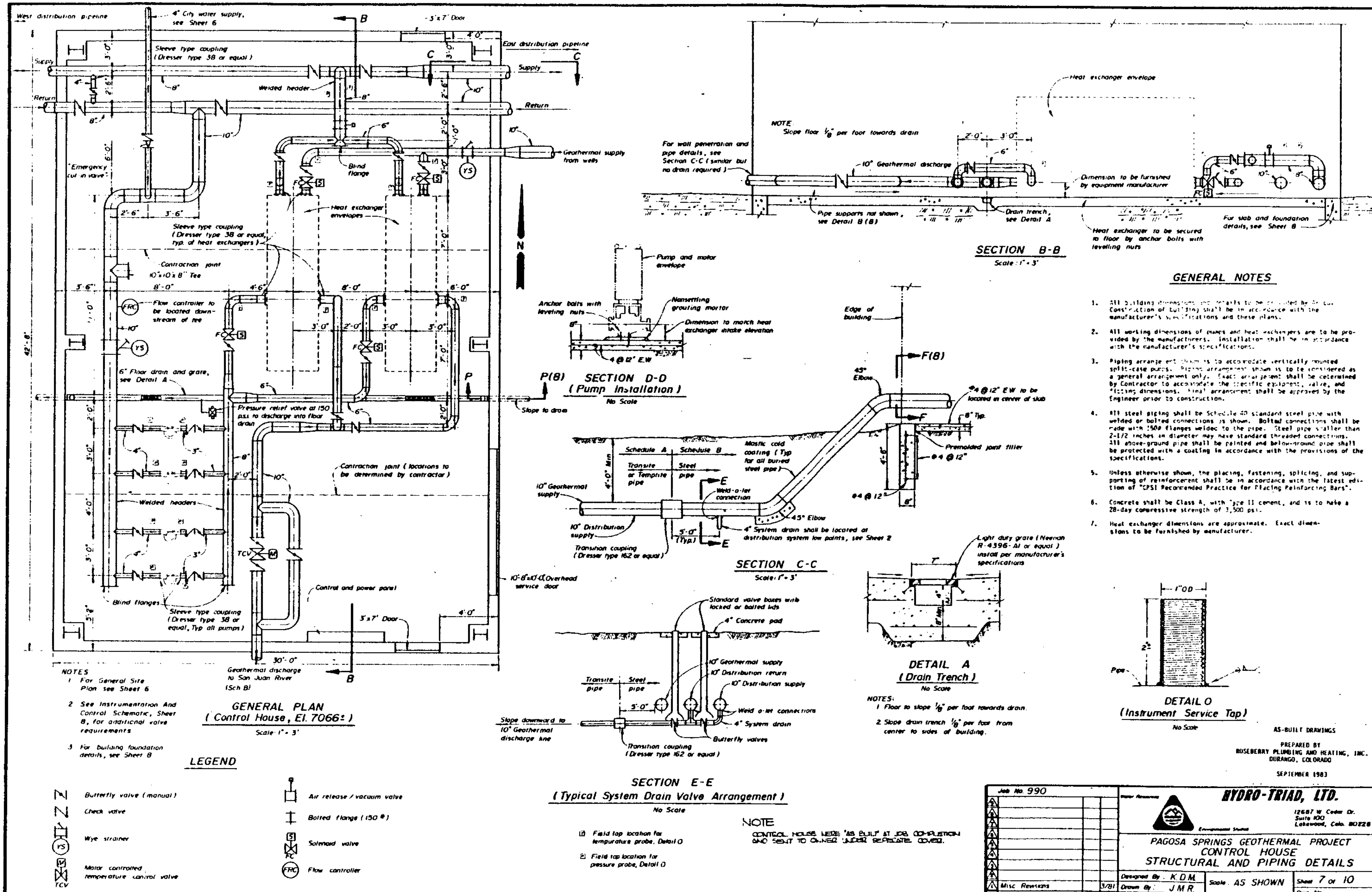
AS-BUILT DRAWINGS
PREPARED BY
ROSEBERRY PLUMBING AND HEATING, INC.
DURANGO, COLORADO
SEPTEMBER 1983

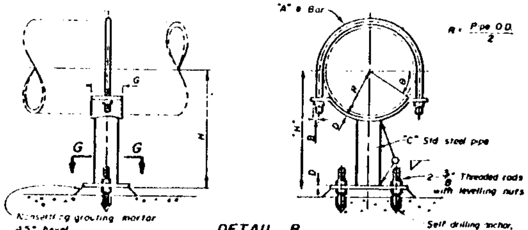
Job No 990
Misc. Revisions 3/81

HYDRO-TRIAD, LTD.
Water Resources — Environmental Studies
12687 W Cedar Dr, Suite 100, Lakewood, Colo 80228

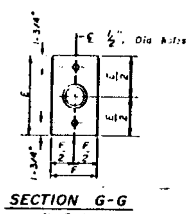
PAGOSA SPRINGS GEOTHERMAL PROJECT
GENERAL SITE PLAN
CONTROL HOUSE AND WELLS

Designed By K.D.M. | Scale AS SHOWN | Sheet 6 of 10
Drawn By J.M.R.
Checked By E.
Date SEPT. 1980 | Dwg No 990-P-6


GENERAL PLAN
(Control House, El. 7066±)
Scale 1" = 3'
NOTES
1 For General Site Plan see Sheet 6
2 See Instrumentation And Control Schematic, Sheet 8, for additional valve requirements
3 For building foundation details, see Sheet 8
LEGEND
Butterfly valve (manual)
Check valve
Wye strainer
Motor controlled temperature control valve
Air release / vacuum valve
Bolted flange (150 #)
Solenoid valve
Flow controller
SECTION D-D
(Pump Installation)
No Scale
SECTION C-C
Scale: 1" = 3'
SECTION B-B
Scale: 1" = 3'
SECTION E-E
(Typical System Drain Valve Arrangement)
No Scale
① Field tap location for temperature probe, Detail O
② Field tap location for pressure probe, Detail O
NOTE
CONTROL HOUSE WERE "AS BUILT" AT JOB COMPLETION AND SENT TO OWNER UNDER SEPERATE COVER.
DETAIL A
(Drain Trench)
No Scale
NOTES:
1 Floor to slope 1/8" per foot towards drain.
2 Slope drain trench 1/8" per foot from center to sides of building.
DETAIL O
(Instrument Service Tap)
No Scale
GENERAL NOTES
1. All building dimensions and details to be provided by Arc... Construction of building shall be in accordance with the manufacturer's specifications and these plans.
2. All working dimensions of pumps and heat exchangers are to be provided by the manufacturers. Installation shall be in accordance with the manufacturer's specifications.
3. Piping arrangement shown is to accommodate vertically mounted split-case pumps. Piping arrangement shown is to be considered as a general arrangement only. Exact arrangement shall be determined by Contractor to accommodate the specific equipment, valve, and fitting dimensions. Final arrangement shall be approved by the Engineer prior to construction.
4. All steel piping shall be Schedule 40 standard steel pipe with welded or bolted connections as shown. Bolted connections shall be made with 150# flanges welded to the pipe. Steel pipe smaller than 2-1/2 inches in diameter may have standard threaded connections. All above-ground pipe shall be painted and below-ground pipe shall be protected with a coating in accordance with the provisions of the specifications.
5. Unless otherwise shown, the placing, fastening, splicing, and supporting of reinforcement shall be in accordance with the latest edition of "CRSI Recommended Practice for Placing Reinforcing Bars".
6. Concrete shall be Class A, with Type II cement, and is to have a 28-day compressive strength of 3,500 psi.
7. Heat exchanger dimensions are approximate. Exact dimensions to be furnished by manufacturer.
AS-BUILT DRAWINGS
PREPARED BY
ROSEBERRY PLUMBING AND HEATING, INC.
DURANGO, COLORADO
SEPTEMBER 1983
Job No. 990
HYDRO-TRIAD, LTD.
12687 W. Cedar Dr. Suite 100 Lakewood, Colo. 80228
PAGOSA SPRINGS GEOTHERMAL PROJECT
CONTROL HOUSE
STRUCTURAL AND PIPING DETAILS
Designed By: KDM
Drawn By: JMR
Checked By:
Scale: AS SHOWN
Date: SEPT. 1980
Sheet 7 of 10
Dwg No. 990-P-7
Misc Revisions 3/81



DETAIL B
(Control House Pipe Supports)
No Scale



SECTION G-G
No Scale

NOTES

Pipe supports not shown on control house plans & sections. Pipe supports shall be located by the contractor as follows.

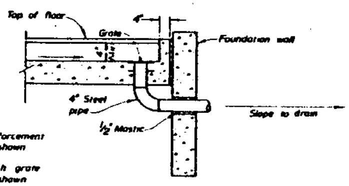
1. Place support at elbows & tees
2. Place support at flanges & valves
3. Distance along pipe between supports shall be less than 8'-0"

The engineer shall review support locations prior to construction and make revisions to and/or require resubmittal of contractor's proposed support layouts. Construction of supports and piping shall not begin until the engineer has approved contractor's final layout drawings.

"H" To be determined by pumps and heat exchangers furnished

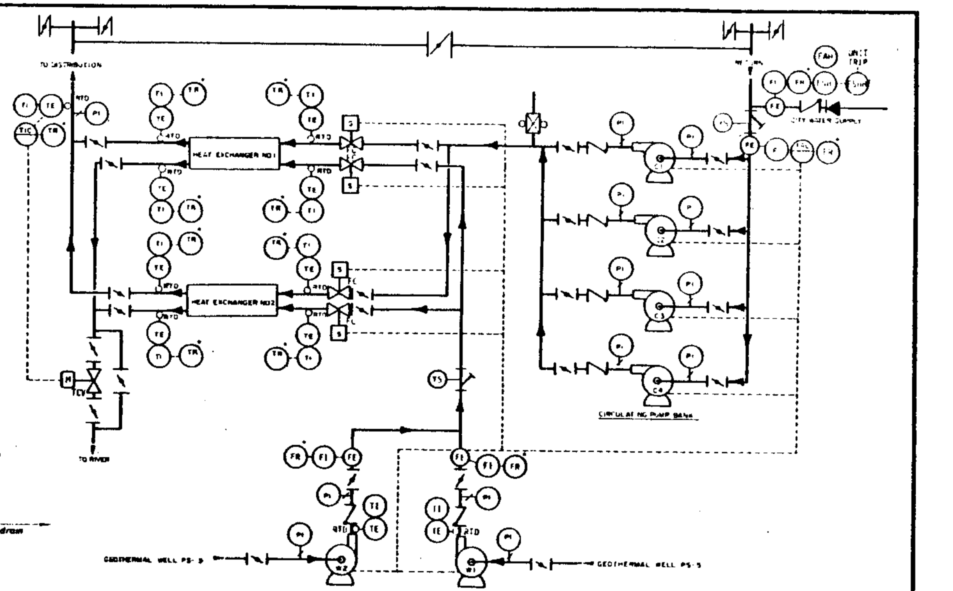
PIPE SUPPORT DIMENSIONS

PIPE I.D.	PIPE O.D.	A	B	C	D	E	F	G	θ
6"	6 [illegible]"	[illegible]	[illegible]	2"	[illegible]	10"	6"	3"	40°
8"	8 [illegible]"	[illegible]	1"	2	[illegible]	10"	6"	4"	40°
10"	10 [illegible]"	[illegible]	1"	2 [illegible]	[illegible]	10"	6"	4"	35°



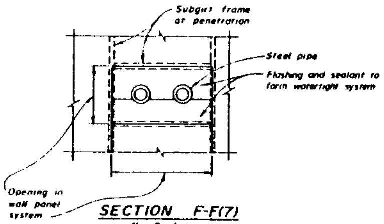
NOTES.
1 Reinforcement not shown
2 Trench grate not shown

SECTION P-P
(Drain Detail)
No Scale

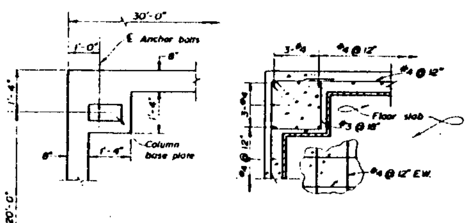


INSTRUMENTATION AND CONTROL SCHEMATIC
NO SCALE

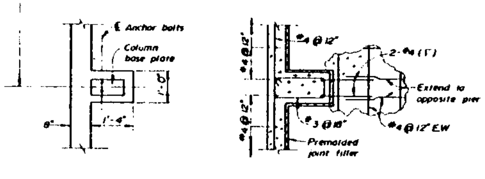
REVISED DWG By COURY AND ASSOCIATES, INC.
19/SEPT/80



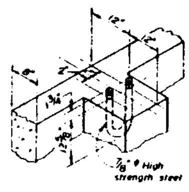
SECTION F-F(7)
No Scale



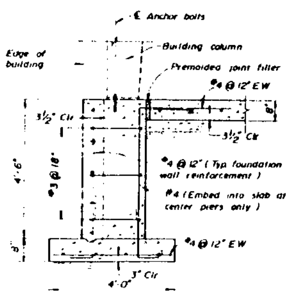
TYPICAL CORNER COLUMN
No Scale



TYPICAL INTERIOR COLUMN
No Scale



ANCHOR BOLT ASSEMBLY
No Scale



FOOTING AND PIER DETAILS
No Scale

LEGEND

(PI) Local Pressure Indicator	(FI) Local Flow Indicator
(TE) Temperature Element	(FR) Flow Recorder
(TI) Local Temperature Indicator	(FRC) Flow Controller
(TR) Temperature Recorder	(FSH) Flow Switch High
(TIC) Temperature Controller	(FAH) Flow Alarm High
(FE) Flow Element	(FSHH) Flow Switch High High
Solenoid Valve	(YS) Wye Strainer
Motor Controlled Temperature Control Valve	Check Valve
Butterfly Valve	* All output signals to the recorder shall be 4-20 ma. Owner shall furnish computer to be used as recorder.
Panel mounted	

City water supply cut-in valve

Pressure relief valve

AS-BUILT DRAWINGS
PREPARED BY
ROSEBERRY PLUMBING AND HEATING, INC.
DURANGO, COLORADO
SEPTEMBER 1983

NOTE
CONTROL HOUSE 'AS BUILTS' WERE SENT TO OWNER AT JOB COMPLETION UNDER SEPARATE COVER.

Job No 990

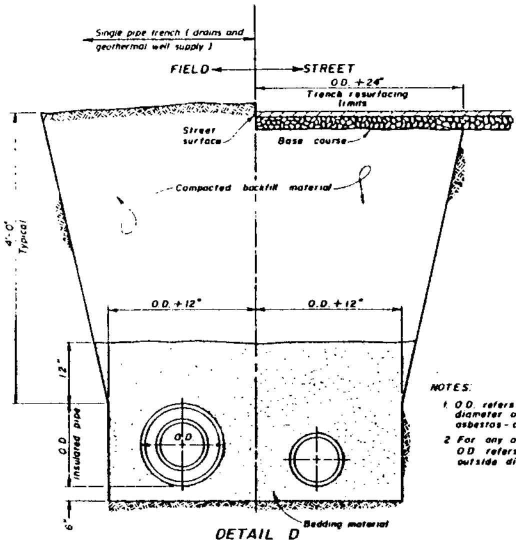
Misc. Revisions

HYDRO-TRIAD, LTD.
12687 W Cedar Dr.
Suite 100
Lakewood, Colo. 80228

PAGOSA SPRINGS GEOTHERMAL PROJECT
MISCELLANEOUS DETAILS

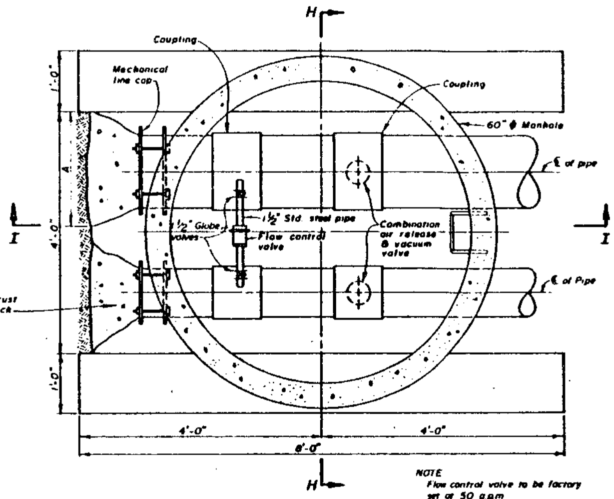
Designed By: K D M
Drawn By: J M R
Checked By:
Scale: AS SHOWN
Date: SEPT. 1980
Sheet 8 of 10
Dwg No 990-P-8

161



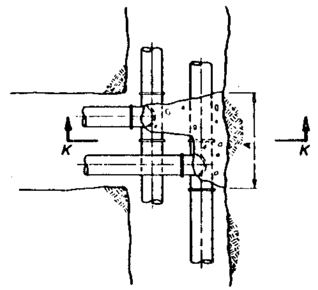
DETAIL D
(Typical Trench Section)

NOTES:
1. O.D. refers to the outside diameter of the insulated asbestos - cement pipe
2. For any other type of pipe O.D. refers to the nominal outside diameter

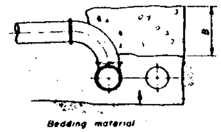


NOTE
Flow control valve to be factory set at 50 gpm

DETAIL E
(Typical Manhole)



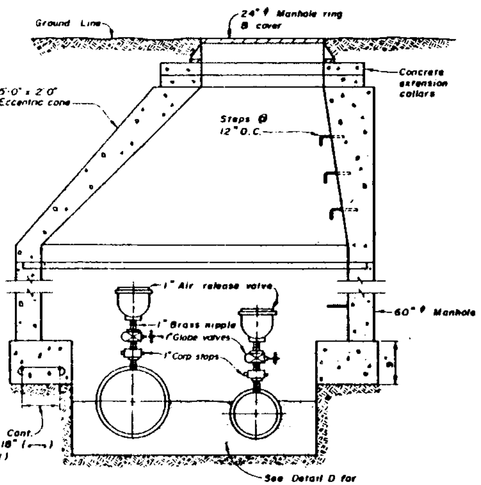
DETAIL G
(Thrust Block Details)



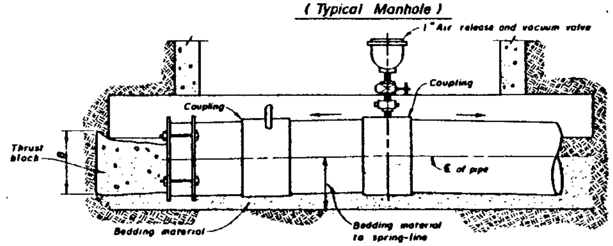
SECTION K-K

GENERAL NOTES

1. All thrust blocks to be Class "B" concrete with 28 day compressive strength of 2500 psi.
2. At option of contractor, a precast concrete manhole base may be used. Blockouts shall be seperated from pipe by joint filler material.



SECTION H-H

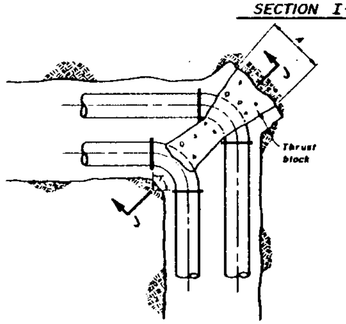


SECTION I-I

AS-BUILT DRAWINGS

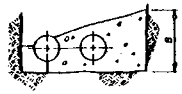
PREPARED BY
ROSEBERRY PLUMBING AND HEATING, INC.
DURANGO, COLORADO

SEPTEMBER 1983



DETAIL F
(Thrust Block Details)

NOTE
1 Thrust block to bear against undisturbed soil



SECTION J-J

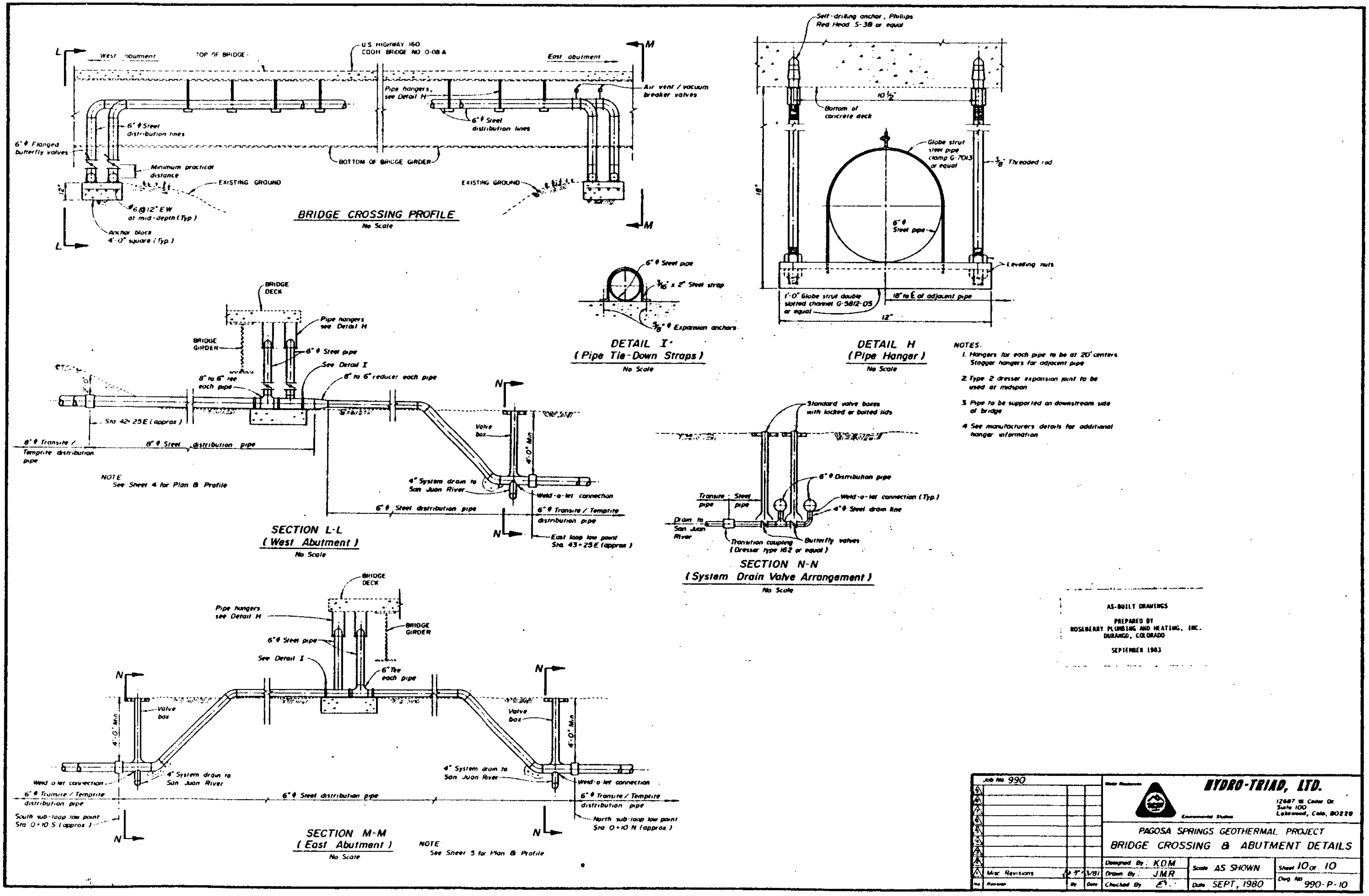
		A (ft)	B
10"	T	5-0	2-6
	90°	6-0	3-0
	45°	4-0	2-6
	22½°	2-6	2-6
8"	T	3-0	2-6
	90°	4-0	3-0
	45°	2-6	2-6
	22½°	2-6	2-6
6"	T	2-6	2-6
	90°	2-6	2-6
	45°	2-6	2-6
	22½°	2-6	2-6

Job No 990			
1	Misc. Revisions	KDM	
No	Revision	By	Date

HYDRO-TRIAD, LTD.
Water Resources · Environmental Studies
12687 W. Cedar Dr.
Suite 100
Lakewood, Colo. 80228

PAGOSA SPRINGS GEOTHERMAL PROJECT
TRENCH DETAILS

Designed By K D M	Scale NONE	Sheet 9 of 10
Drawn By G M S		Dwg No 990-P-9
Checked By [illegible]	Date SEPT, 1980	



BRIDGE CROSSING PROFILE
No Scale
West abutment
TOP OF BRIDGE
U.S. HIGHWAY 160
COOH BRIDGE NO. O-08-A
East abutment
Pipe hangers, see Detail H
Air vent / vacuum breaker valves
6" ϕ Steel distribution lines
6" ϕ Flanged butterfly valves
Minimum practical distance
BOTTOM OF BRIDGE GIRDER
EXISTING GROUND
#6 @ 12" EW at mid-depth (Typ.)
Anchor block 4'-0" square (Typ.)
DETAIL I
(Pipe Tie-Down Straps)
No Scale
6" ϕ Steel pipe
3/16" x 2" Steel strap
5/8" ϕ Expansion anchors
Self-drilling anchor, Phillips Red Head S-38 or equal
Bottom of concrete deck
Globe strut steel pipe clamp G-7013 or equal
3/8" Threaded rod
6" ϕ Steel pipe
Leveling nuts
1'-0" Globe strut double slotted channel G-5812-05 or equal
18" to ℄ of adjacent pipe
DETAIL H
(Pipe Hanger)
No Scale
NOTES:
1. Hangers for each pipe to be at 20' centers. Stagger hangers for adjacent pipe.
2. Type 2 dresser expansion joint to be used at midspan.
3. Pipe to be supported on downstream side of bridge.
4. See manufacturers details for additional hanger information.
SECTION L-L
(West Abutment)
No Scale
BRIDGE DECK
BRIDGE GIRDER
Pipe hangers see Detail H
6" ϕ Steel pipe
See Detail I
8" to 6" tee each pipe
8" to 6" reducer each pipe
Sta. 42+25E (approx.)
8" ϕ Transite / Tempite distribution pipe
8" ϕ Steel distribution pipe
Valve box
4'-0" Min.
4" System drain to San Juan River
Weld-o-let connection
6" ϕ Steel distribution pipe
6" ϕ Transite / Tempite distribution pipe
East loop low point Sta. 43+25E (approx.)
NOTE
See Sheet 4 for Plan & Profile
SECTION N-N
(System Drain Valve Arrangement)
No Scale
Standard valve boxes with locked or bolted lids
6" ϕ Distribution pipe
Weld-o-let connection (Typ.)
4" ϕ Steel drain line
Transite pipe
Steel pipe
Drain to San Juan River
Transition coupling (Dresser type 162 or equal)
Butterfly valves
SECTION M-M
(East Abutment)
No Scale
Pipe hangers see Detail H
6" ϕ Steel pipe
See Detail I
6" Tee each pipe
Valve box
4" System drain to San Juan River
Weld-o-let connection
6" ϕ Transite / Tempite distribution pipe
6" ϕ Steel distribution pipe
South sub-loop low point Sta. 0+10 S (approx.)
North sub-loop low point Sta. 0+10 N (approx.)
NOTE
See Sheet 5 for Plan & Profile
AS-BUILT DRAWINGS
PREPARED BY
ROSEBERRY PLUMBING AND HEATING, INC.
DURANGO, COLORADO
SEPTEMBER 1983
Job No. 990
Misc. Revisions
HYDRO-TRIAD, LTD.
12687 W. Cedar Dr. Suite 100 Lakewood, Colo. 80228
PAGOSA SPRINGS GEOTHERMAL PROJECT
BRIDGE CROSSING & ABUTMENT DETAILS
Designed By: KDM
Drawn By: JMR
Checked By
Scale AS SHOWN
Date SEPT. 1980
Sheet 10 of 10
Dwg. No. 990-P-10

APPENDIX 3

SUMMARY OF MEASUREMENTS

ON THE PAGOSA SPRINGS GEOTHERMAL SYSTEM

FOR THE PERIOD OF JULY 1984 THROUGH FEBRUARY 1985

Prepared by:
Coury and Associates, Inc.
Lakewood, Colorado

June 1985

BACKGROUND

The Town of Pagosa Springs conducted initial tests on the in-service performance of its geothermal heating system during the period of October 1983 through February 1984. The data taken during those tests are summarized in Appendix 1, on page 129. In general, the system pressures stabilized soon after production rates from Well PS-5 were changed. This is shown on Figures 3 and 4 of Appendix 1 for various wells. The measurements of the water level in the Pagosa Hot Spring (Figure 5 of Appendix 1) also shows a stabilizing trend. The level fell significantly after pumping directly from the Spring was initiated in November 1983. A gradual decline continued until the flow rate from Well PS-5 was increased in late January. At that time the level at first decreased again, but then appeared to stabilize within two or three weeks, as the test period came to an end.

A second test period was undertaken by the Town over the period of July 1984 through February 1985. Well PS-5 was run at an essentially constant flow rate during the summer preceeding the 1984-1985 heating season. During this period, a data baseline was established on the basis of daily measurements for seven wells (including PS-5) and for the Hot Spring. A small uncertainty exists with respect to this data, because it is not known if other wells were operated for short periods during the tests.

The measurements of the Spring level and of wellhead pressures continued during most of the heating season. In addition, the performance of the heat exchanger in the geothermal loop was measured at startup, and for several days thereafter. The measurements for the second test period are summarized in this Appendix 3. Where appropriate, the results are compared with the 1983-1984 tests.

DATA TABULATIONS

The original data log sheets, that were filled out in the field, were examined and organized. Some discrepancies were found that were able to be corrected by consulting with the Town. For example, during one time period, the temperatures as recorded on the log sheets were switched. In other cases, faulty gauges or erroneous readings were assumed. In general, the data show a high level of consistency.

The measured values were reorganized, and then tabulated on Tables 1 through 4. These tables show the data as presented on the log sheets, except that the temperature inversions mentioned above were corrected. Table 1 lists the wellhead pressures and the Spring level for the summer months of July and August. Table 2 shows the temperatures around the heat exchanger during the startup on October 4. Many measurements were made on that day to keep track of the rapid changes. Table 3 summarizes the temperature readings over the following month during which conditions stabilized. Finally, Table 4 continues the summary of pressure readings for the end of the summer, through the system startup, and for most of the heating season.

The results are then presented graphically so that any trends can be more readily determined. The temperature measurements are shown on Figures 1 and 2, corresponding, respectively, to the data on Tables 2 and 3. Figures 3, 4 and 5 summarize the pressure data on Table 1. Figures 6, 7 and 8 cover the pressure data from Table 4.

HEAT EXCHANGER PERFORMANCE

The heat exchanger is not being loaded to its design capacity because the number of users hooked onto the system is not yet at the level anticipated. Therefore, the reduction in temperature of the geothermal fluid, between the wellhead and the discharge point from the heat exchanger, was only in the range of 10°F to 18°F during the test period. This value is the difference between the values shown in the second and third columns of Table 3. In contrast, the design of the system called for a temperature reduction of almost 30°F, and this was to occur with a flow rate from the well of more than double the flow rate used during the tests. Thus, the potential heating capabilities of the system can be expected to be more than four times the load experienced during the tests. (That is, the load can about double by increasing the flow rate, and then about double again by increasing the temperature change.)

However, in order for this higher rate of heat extraction actually to occur, the performance of the heat exchanger must be adequate. The level of performance is indicated by the heat transfer coefficient, and the heat exchanger in use would be expected to have a very high coefficient. If this were actually the case, it would be evident by a small difference in temperature between the discharged geothermal water and the loop return water. That is, Columns 3 and 5 on Table 3 would show almost the same temperature. The average difference between these two columns on Table 3 is between 6°F and 7°F. However, this temperature approach would be expected to be closer to 1°F at the heating load being experienced, based on the specifications of the heat exchanger supplier.

Several reasons could explain the relatively high temperature approach that was measured during the tests. These should all be carefully evaluated, so that a good estimate can be made of the system capabilities before the heating district is greatly expanded. The simplest explanation would be an inaccuracy in the thermometers used to make the measurements. These should be calibrated, and test procedures should be carefully evaluated. Another possible reason is related to the normal decline in the heat transfer coefficient that is always experienced when the water flow rate is less than the design value. Thus, performance would be expected to improve simply by increasing the flow rates. A test should be scheduled as soon as it is convenient to determine if this is the entire cause of the currently low coefficient. A third possibility is that the plates of the heat exchanger have been fouled by dirt or scale. The plates should be inspected to determine if this has occurred, and they should be cleaned if necessary.

SYSTEM PRESSURES

The pressures across the system are shown in Figures 3, 4 and 5 for the early summer months. These data are taken from Table 1. Measurements were usually made on a daily basis. In some cases, however, more than one measurement was made during one day. When this occurred, an average value of all of the readings for that day is reported on the Table. In one case, almost two weeks elapsed without any measurements being made. This period is shown by a dashed line on the Figures.

Essentially all wells showed a drop in pressure, to a new approximately constant level, on about August 7 (about 32 days after the start of the tests). This pressure drop occurred because the flow rate from Well PS-5 was increased by about 60%, from 400 gpm to 650 gpm. The increased flow rate was maintained for a period of about 10 days, after which it was returned to the 400 level. After this time, the pressures in general increased back to their previous levels or, in some cases, to higher values.

During this same period of higher flow rates from Well PS-5, the level in the Hot Spring dropped by two to four inches. (Note that the scale on Figure 5 is inverted, so that a falling line represents a falling level in the Spring.) The exact value of the drop in the Spring level related to the increased flow rate is difficult to determine. Only one data point, taken on the day before the flow rate changed, indicates that the drop could have been four inches. The several prior days passed with no measurements.

It is also significant, as shown on Figures 3, 4 and 5, that the pressures and the Spring level quickly stabilized to an essentially constant value after the flow rate increase. The Giordano well, however, exhibited an ambiguous behavior. Its pressure did not show the characteristic decline, except for one low reading on day 34. Then, the pressure increased significantly after completion of the high flow rate test. This behavior was apparently not real, but rather the result of a faulty and erratic pressure gauge that was eventually replaced.

Figures 6 and 7 show wellhead pressures, and Figure 8 shows the Spring level, for the period just before, and for the four months following, the startup of the district heating system. These figures are based on the data summarized in Table 4. Startup occurred on October 4, which corresponds to the "41 day" point on the Figures. In general, the pressures all fell following startup, and then stabilized rather quickly at essentially constant values. It should be pointed out again that there is some uncertainty with respect to the impact of these data since the actual water withdrawal rates from the reservoir are not known. The flow at well PS-5 remained at 400 gpm. However, the average flow rates, and day-to-day changes in the flow, from the other wells or from the Spring are not known.

In particular, the pressure at Well PS-5 declined gradually over a period of 40 to 50 days after the startup, and then stabilized at about 35 psig. The pressure decline occurred sooner, and was steeper, for the Courthouse and Montroy wells, but these pressures stabilized within about 20 days after startup. This behavior was paralleled in general by the PS-3 and Rumbaugh wells, except that the decline was not as steep. The School well showed very little, if any, pressure decline in the weeks following system startup. The data variation is too great to determine whether actual pressure declines occurred, or whether erroneous readings or faulty gauges were involved. A specific pressure decline did occur, however, about 60 days later, but this decline rapidly stabilized. The latter behavior was paralleled at the Giordano well, but the problem with the pressure gauge at this well makes the data suspect. The Hot Spring, on the other hand, was essentially unaffected by the startup. The level dropped, at most, by one inch.

COMPARISON WITH PRESSURE DATA FROM THE FIRST TEST PERIOD

The results of this second test period are generally consistent with the results reported in Appendix 1 for the first tests. The comparison cannot be made in great detail, however, since the flow rates were not the same in both cases. From Well PS-5, the production was 450 gpm during the first tests, and 400 gpm during the second. However, no data are available to allow a comparison of flows from the other wells, or from the Spring, during the two test periods.

Based on the available data, the general results of the two tests are summarized here. At the PS-5 wellhead, the stabilized pressure was about 30 psig during the first tests, and about 35 psig during the recent rests. The comparable values for Well PS-3 are 34 and 37 psig; for the Rumbaugh well, they are 28 and 31 psig, respectively. At the Courthouse well, the pressure after test 1 was slightly higher, at 18 psig, compared to the 16 psig measured more recently. The School well was similar with values of 10 and 8 psig. The Hot Spring level appeared to stabilize at 21.5 inches below the mark during the 1984 to 1985 tests, compared to 28 inches during the first test period.

TABLE 1.--BASELINE DATA
WELLHEAD PRESSURES AND HOT SPRING LEVEL

KEY

WELL DESIGNATION	WELL NAME
PS-3	PS-3
PS-5	PS-5
CH	Courthouse
M	Montroy
R	Rumbaugh
S	School
G	Giordano

TABLE 1 (Continued)

DATE	WELLHEAD PRESSURES (psig) PS3	PS5	CH	M	R	S	G	LEVEL OF SPRINGS (inches)
7/ 6/84	36	30	28	22	32	8	9	25.5
7/ 7/84	36	30	28	--	32	8	9	25.5
7/ 8/84	--	--	--	23	31	--	--	--
7/ 9/84	36	30	28	23	30	8	9	25.5
7/10/84	36	30	28	23	30	8	9	25.5
7/11/84	36	30	28	23	30	8	9	25.5
7/12/84	36	30	28	23	30	8	6	25.5
7/13/84	30	30	28	23	30	8	8	25.5
7/14/84	36	30	28	23	30	8	8	25.5
7/15/84	36	30	28	23	30	8	8	25.5
7/16/84	30	30	28	23	30	8	8	25.5
7/17/84	36	30	28	23	30	8	8	25.5
7/18/84	36	30	28	23	30	8	8	25.5
7/19/84	36	31	30	24.5	30	9.5	10	24.8
7/20/84	36	28	30	24.5	31.5	10	8	24
7/21/84	36	28	--	--	31	--	--	--
7/22/84	36	28	30	24.5	31	10	8	24
7/23/84	36	29.5	29	24	31.5	9.8	9	24.5
7/24/84	36	28	29.8	24	31	9	9.5	24
7/25/84	--	--	--	--	--	--	--	--
8/ 6/84	37	23	29.5	24.5	30	8.8	9.8	23.5
8/ 7/84	35.8	22.8	28.8	23.8	29.5	7	9.5	25.2
8/ 8/84	34.5	17	27.5	22.5	27.8	6.8	9.8	27.2
8/ 9/84	33.8	17	26.5	21.8	27.2	6.5	8	27.5
8/10/84	32.8	17	27	22	27.2	6.2	9.5	27.8

TABLE 1 (Continued)

DATE	WELLHEAD PRESSURES (psig)							LEVEL OF SPRINGS
	PS3	PS5	CH	M	R	S	G	(inches)
8/11/84	32.5	17	27.5	22	26.8	6.5	10	27.5
8/12/84	32.5	17	27.5	22	26.5	6.2	10	27.5
8/13/84	32.5	17.2	27.5	22	26.5	6	10	27.5
8/14/84	32.5	17	27.5	22	26.5	6.5	10	27.5
8/15/84	32.5	17	27.5	22	26.5	6.5	10	27.5
8/16/84	32.5	17	27.5	22	26.5	6.8	11	27.5
8/17/84	32.5	17	27.5	22	26.5	7	11	27.5
8/18/84	--	--	--	--	--	--	--	--
8/19/84	--	--	--	--	--	--	--	--
8/20/84	36.5	36.5	29.5	23.5	31	9	12.8	26.8
8/21/84	40	39.2	30.5	25.5	33.2	10	13.5	22.5
8/22/84	40	39.8	30	25.5	33.2	10.2	14	22.5
8/23/84	40	37.5	30	25	33.5	10.2	14	20.5

TABLE 2.--HEAT EXCHANGER STARTUP (OCTOBER 4, 1984): TEMPERATURE DURING THE TRANSITION PERIOD

	TEMPERATURE BY TIME (^{o}F)				PRESSURE (psig)	
TIME	WELL WATER	DISCHARGE	LOOP SUPPLY	LOOP RETURN	OUT	IN
1007	141	---	128	114		
1008	141	---	88	54		
1013	141	78	88	58	50	40
1015	141	76	91	62		
1017	141	66	93	63		
1020	141	65	93	64		
1023	141	64	92	64		
1027	141	63	92	63		
1033	141	65	92	63		
1039	141	64	92	62		
1053	141	65	93	64		
1055	141	66	94	65		
1057	141	66	94	66		
1100	141	67	94	66		
1105	141	68	96	67		
1110	141	69	96	68		
1115	141	71	97	70		
1120	141	73	98	73		
1125	141	74	99	74		
1130	141	74	101	74		
1135	78	--	102	78		
1140	140	78	102	78		
1145	140	81	104	81		
1150	140	82	105	82		
1155	140	83	106	83		
1200	140	85	107	85		
1230	140	90	110	90	56	48
1240	140	92	110.5	92	56.5	48
1245	140	94	112	93	57	48.5
1250	140	94.5	112	94	57.5	49
1305	140	96	113	96		
1310	140	97	114	97		
1315	140	86	114	97		
1320	140	98	115	98		
1325	140	99	115	99		
1330	140	100	115	100	59	50
1335	140	100	116	100		
1340	140	101	116	101		
1350	140	102	117	102		
1355	140	102	117	102	59	51

TABLE 2 (Continued)

TIME	TEMPERATURE BY TIME (°F) WELL WATER	DISCHARGE	LOOP SUPPLY	LOOP RETURN	PRESSURE (psig) OUT	IN
1400	140	103	118	103		
1405	140	103	118	103		
1410	140	104	118	103		
1415	140	105	118	103	60	52
1420	140	105	119	104		
1425	140	105	119	104		
1430	140	106	119	104		
1435	140	106	119	104		
1440	140	106	120	104		
1445	140	107	120	105		
1450	140	107	120	105		
1455	140	108	120	105	61	52
1500	140	108	121	105		
1505	140	108	121	105		
1510	140	109	121	106		
1515	140	109	121	106		
1520	140	110	121	106		
1525	140	110	122	107		
1530	140	110	122	107		
1535	140	111	122	107		
1540	140	111	122	107		
1545	140	111	122	107		
1550	140	111	123	107		
1555	140	111	123	107		
1600	140	111	123	107		
1605	140	112	123	107		
1610	140	112	123	108		
1615	140	112	123	108		
1620	140	113	124	109		
1625	140	113	124	109		
1630	140	113	124	109		
1635	140	114	124	110		
1640	140	114	124	110		
1645	140	114	124	110		
1650	140	114	124	110		
1655	140	115	125	111		
1745	140	116	126	113		
1938	140	120	128	114		

TABLE 3--HEAT EXCHANGER OPERATION
TEMPERATURE PROFILES OVER TIME

DATE	TEMPERATURE BY DATE (^oF)			
	WELL WATER	DISCHARGE	LOOP SUPPLY	LOOP RETURN
10/10/84	140	125	131	119
	140	127	132	121
10/18/84	140	128	132	120
10/19/84	140	129	133	122
10/20/84	140	130	134	122
10/21/84	--	--	--	--
10/22/84	140	130	133	122
10/23/84	140	128	132	118
10/24/84	140	126	130	118
10/25/84	140	126	130	118
10/26/84	140	126	130	118
10/27/84	140	126	130	118
10/28/84	--	--	--	--
10/29/84	140	126	130	118
10/30/84	140	128	132	120
10/31/84	--	--	--	--
11/ 1/84	--	--	--	--
11/ 2/84	140	124	128	118
11/ 3/84	--	--	--	--
11/ 4/84	--	--	--	--
11/ 5/84	140	124	128	118
11/ 6/84	140	124	128	118
11/ 7/84	140	124	128	118
11/ 8/84	140	124	128	118
11/ 9/84	140	124	128	116
11/10/84	140	122	126	116
11/11/84	140	123	126	116

TABLE 4 -- SUMMARY OF OPERATING DATA (PRE- AND POST-STARTUP) FOR PRODUCTION WELLS PRESSURE AND HOT SPRING LEVEL

KEY

WELL DESIGNATION	WELL NAME
PS-3	PS-3
PS-5	PS-5
CH	Courthouse
M	Montroy
R	Rumbaugh
S	School
G	Giordano

TABLE 4 (Continued)

DATE	TIME RANGE*	WELLHEAD PRESSURES (psig) PS3	PS5	CH	M	R	S	G	LEVEL OF SPRINGS (inches)
8/24/84	1000 to 1035	40	37.5	29.8	25.5	34	9.8	14	20.2
	1105 to 1140	40	37.8	29.8	25.8	33.2	10	14	20.2
	1545 to 1615	40.2	37.8	29.8	25	34.2	10	14	--
8/25/84	805 to 840	41	37.5	29.8	25	34	10.5	14	20.5
	1305 to 1335	40.8	37.5	30	25.5	34	10	14	--
	1615 to 1645	41	37.8	29.5	25.2	34	10	14	--
8/26/84	730 to 805	40.5	37.5	30.5	25.8	34	10.5	14	20.5
	1600 to 1650	40.5	37.5	30.5	25.8	34	10.5	14	--
8/27/84	830 to 905	40	37.8	31	26	33.5	10.8	14.5	20.5
	1100 to 1130	40.5	37.5	30.2	25.2	33.5	10	14.2	--
	1605 to 1635	40	37.8	30.8	25.2	33.5	10.2	14.2	--
8/28/84	830 to 905	40	37.8	31	26	34.2	10.2	14.2	20.5
	930 to 1005	40	37.5	30.5	25.5	34.2	10.2	14.5	20.5
8/29/84	905 to 940	40.2	37.2	30	25.2	33.5	10	14	20.5
	1630 to 1700	40.5	37.8	30.5	25.8	33.8	10.5	14.2	--
8/30/84	825 to 900	40	37.8	30.8	25.5	33.5	9.8	12.5	20.5
	1615 to 1645	40.2	37.5	30.2	26	33.5	10	14	--
8/31/84	820 to 855	40	37.5	31	25.2	33.8	10	11.8	20.5
	1610 to 1645	40.2	37.8	30.8	25.2	33.5	10	11.5	20.5
9/ 1/84	820 to 855	40	37.8	30	26	33.5	10	14	20.5
	1405 to 1440	40.5	37.3	30	25.8	33.8	10	14	20.5

*This is the time period over which all the readings were made, beginning with the Well PS3 pressure and ending with the springs level.

TABLE 4 (Continued)

DATE	TIME RANGE*	WELLHEAD PRESSURES (psig) PS3	PS5	CH	M	R	S	G	LEVEL OF SPRINGS (inches)
9/ 2/84	825 to 900	40	37.8	30	25.8	33.5	10	14	20.5
	1330 to 1403	40.2	37.8	30	25.8	33.8	10	14	20.5
9/ 3/84	820 to 855	40	37.5	29.8	25.5	33.5	10	14	20.5
	1500 to 1535	40.5	37.8	30.2	25.8	33.5	10	14	20.5
9/ 4/84	805 to 840	40.5	38	31	26	33.8	10.8	14	20.4
9/ 5/84	810 to 845	40.5	38.2	30.2	25.5	34.5	11	14	20.4
	--	41	37.8	30.2	26.2	34.2	11	14	20.4
9/ 6/84	820 to --	40.2	38.2	30	26.2	34.2	10.8	14.2	20.2
9/ 7/84	820 to 855	40.2	38	29.5	25.2	34.2	10.5	14.2	20.5
9/ 8/84	530 to 905	40.2	38	30	26.2	34.2	10.8	14.2	20.5
	1605 to 1640	40.2	38	29.8	26.2	34.2	10.5	14.2	20.5
9/ 9/84	820 to 855	40.2	38	30.2	26	34.2	10.8	14.5	20.5
	1605 to 1640	40.2	38.2	30.2	26	34.2	10.5	14	20.5
9/10/84	820 to 855	40.5	38.2	30	25.8	33.8	10	14	20.5
	1610 to 1645	40.8	38.2	30.5	25.5	34	10.2	14	20.5
9/11/84	--	41	37.8	30	26.2	34.2	10.2	14	20.5
9/12/84	820 to 855	40.2	37.8	30	25.8	34.8	10.5	14.2	20.5
9/13/84	--	40.5	37.8	30	26	33.8	10.8	14.2	20.5

*This is the time period over which all the readings were made, beginning with the Well PS3 pressure and ending with the springs level.

TABLE 4 (Continued)

DATE	TIME RANGE*	WELLHEAD PRESSURES (psig) PS3	PS5	CH	M	R	S	G	LEVEL OF SPRINGS (inches)
9/14/84	805 to 840	40.5	37.5	30.2	26	33.2	10.8	14.2	20.5
9/18/84	815 to 850	41.2	37.8	30	26	33.2	10	14.5	20.5
9/20/84	815 to 855	40.8	37.5	30.2	26	33.5	10.2	14.5	20.2
9/21/84	830 to 905	40.8	38	30	26.2	33.5	10.2	14.2	20.2
9/24/84	830 to 905	41.2	37.8	30.2	26	33.5	10.5	14.2	--
9/28/84	845 to 935	40.5	37.5	29.5	25.5	33.2	10.2	14.2	20.8
9/29/84	810 to 845	40.5	37.5	29.2	25.5	33.2	10.2	14.5	20.8
9/30/84	840 to 915	40.2	37.5	29.5	25.5	33.2	10.5	14.2	20.8
10/ 2/84	820 to 855	39.2	36.8	26.5	22.2	31.2	10	14.2	21
10/ 3/84	820 to 855	39	36.5	22	21	31.2	9.8	14.2	21
10/ 5/84	905 to 930	38.5	36	18.5	18.2	30.8	8.8	--	--
10/ 6/84	835 to 910	38.5	36	19.5	18.2	30.2	8.8	13	21
10/ 7/84	840 to 915	38.8	36	19.2	18.8	30.5	8.8	13.2	21
10/10/84	1600 to 1650	39.2	36.8	22	19	31.8	10.8	14.5	--
10/11/84	810 to 845	38.5	36.5	21.5	18.8	30.8	10.5	14.2	21

*This is the time period over which all the readings were made, beginning with the Well PS3 pressure and ending with the springs level.

TABLE 4 (Continued)

DATE	TIME RANGE*	WELLHEAD PRESSURES (psig)							LEVEL OF SPRINGS
		PS3	PS5	CH	M	R	S	G	(inches)
10/24/84	1620 to 1755	38.2	36	19.2	17.5	30	9	12	22.5
10/25/84	815 to 850	37	36	18.8	16	31.2	9.2	12	21
11/ 7/84	915 to 955	38	36	19.8	18.8	30.8	9.2	13	21
11/ 8/84	910 to 945	38	35.8	19.5	16.8	30.2	9.8	13	21
11/ 9/84	910 to 945	38.5	36	19.2	16	30	9.2	13	21
11/26/84	1045 to 1120	38	35.2	19.5	17.2	30.5	10	12	21.5
11/29/84	935 to 1005	38.2	35.8	20.2	16.2	30	9	12	21.5
11/30/84	--	38	35.2	19.8	17	30.5	10	12	21.5
12/ 3/84	1415 to 1450	37.8	35.2	19.5	17	30.5	8.8	11.5	21.5
12/14/84	1025 to 1100	37.8	35.2	20	17.2	29.8	7.2	8.5	21.2
12/17/84	825 to 900	38.5	35.2	20	17.2	30	--	8.5	21.5
12/18/84	935 to 1010	38.2	35	19.8	17	30.5	--	8.8	21.5
12/19/84	835 to 910	38	35.5	14.5	17	31	--	8	21.2
1/ 2/85	815 to 850	37.2	35.5	19	17	29.5	7.5	8.5	21.5
1/16/85	810 to 840	37.2	35.2	19.5	17	31	8.2	9	21.5

*This is the time period over which all the readings were made, beginning with the Well PS3 pressure and ending with the springs level.

TABLE 4 (Continued)

DATE	TIME RANGE*	WELLHEAD PRESSURES (psig) PS3	PS5	CH	M	R	S	G	LEVEL OF SPRINGS (inches)
1/18/85	815 to 850	37.5	35.5	19	16.8	30.5	8.2	9	21.5
1/21/85	805 to 840	37.5	35.5	19.2	17.2	30.8	8.2	9	21.5
1/23/85	810 to 845	37.8	35.2	18.8	16.5	30.5	8.8	8.8	21.5
1/25/85	1000 to 1055	37.2	35.2	19.2	17.2	30.2	8.5	8	21
1/30/85	820 to 900	37.8	35.8	18	17.2	31.2	8.5	8	21.5
2/ 1/85	830 to 905	37.2	35.5	18.5	17	31	--	9	21.5
2/ -/85	815 to 850	37	35.5	18.8	17.5	31.2	8	6	21.5
2/ 6/85	1305 to 1340	38	35.8	19.5	17.2	30.8	8.2	8	21.5
2/ 8/85	815 to 850	37.5	35.2	18.2	15	30.8	8.5	18	21.5
2/11/85	830 to 905	37.2	35	18	13.8	30.8	--	--	21.5
2/13/85	1100 to 1135	37.5	35.5	17.5	14	30	8.2	38	21.5
2/19/85	--	37.5	35.5	17.8	16.5	31.5	9	39	21.5

*This is the time period over which all the readings were made, beginning with the Well PS3 pressure and ending with the springs level.

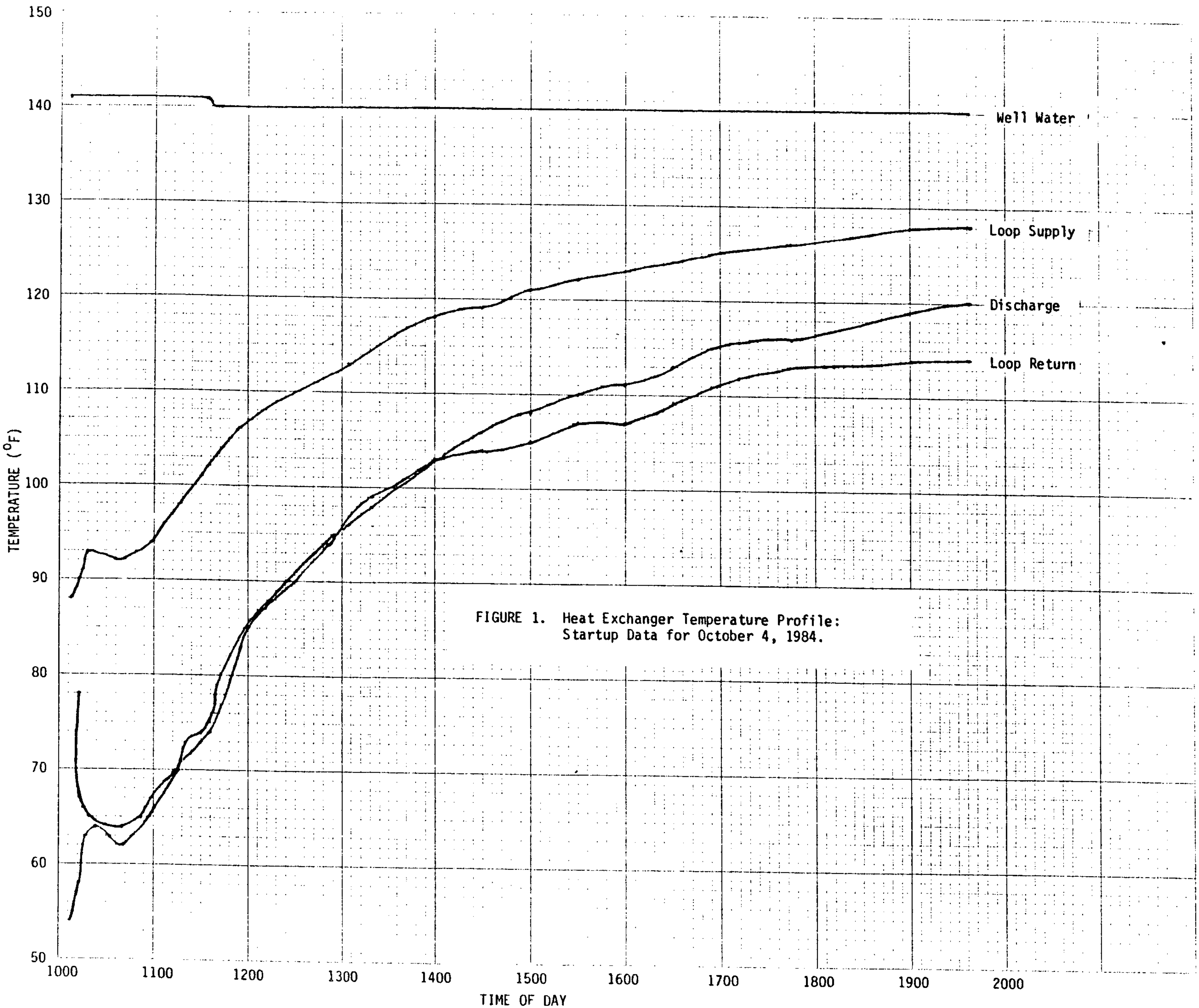


FIGURE 1. Heat Exchanger Temperature Profile: Startup Data for October 4, 1984.

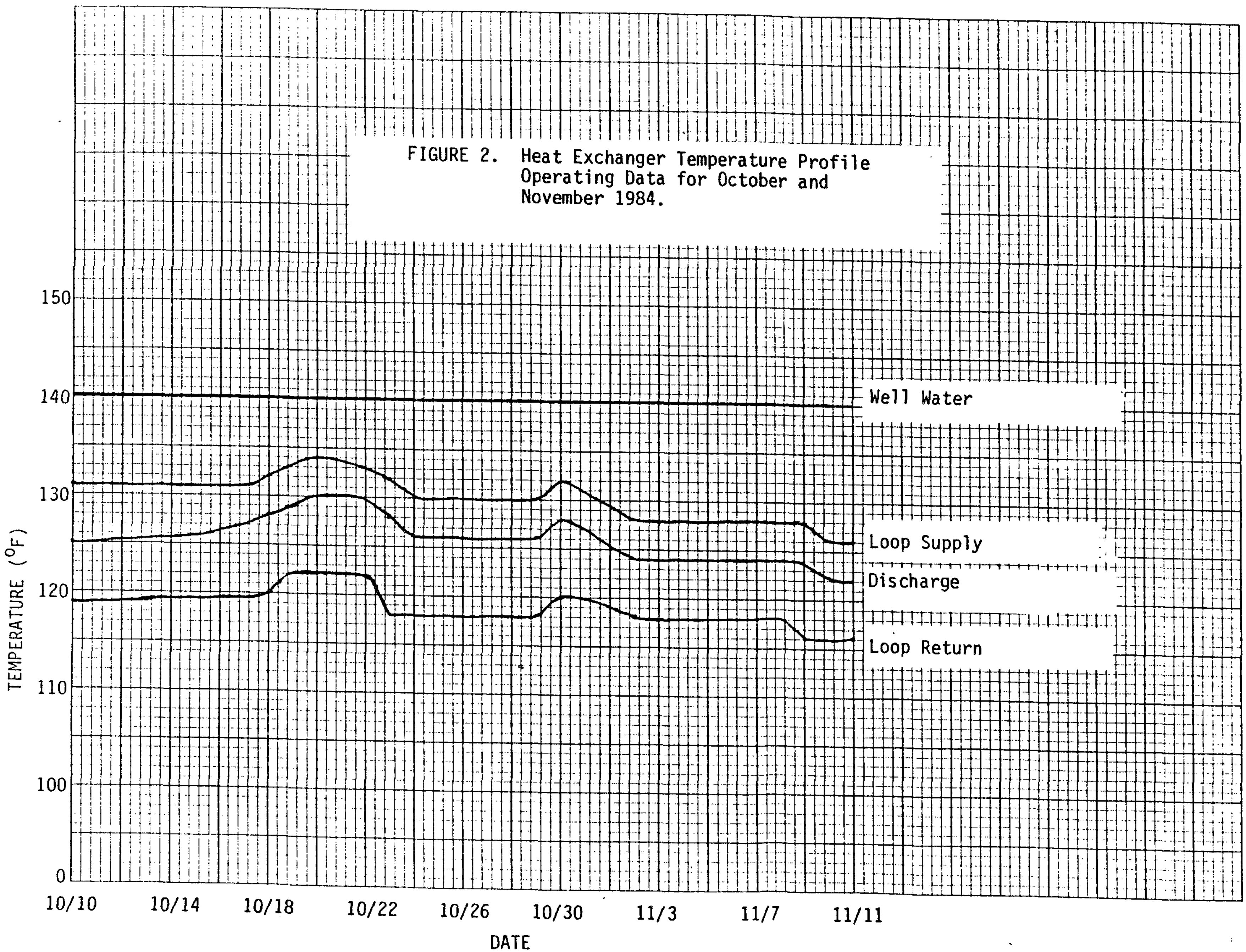


FIGURE 2. Heat Exchanger Temperature Profile Operating Data for October and November 1984.

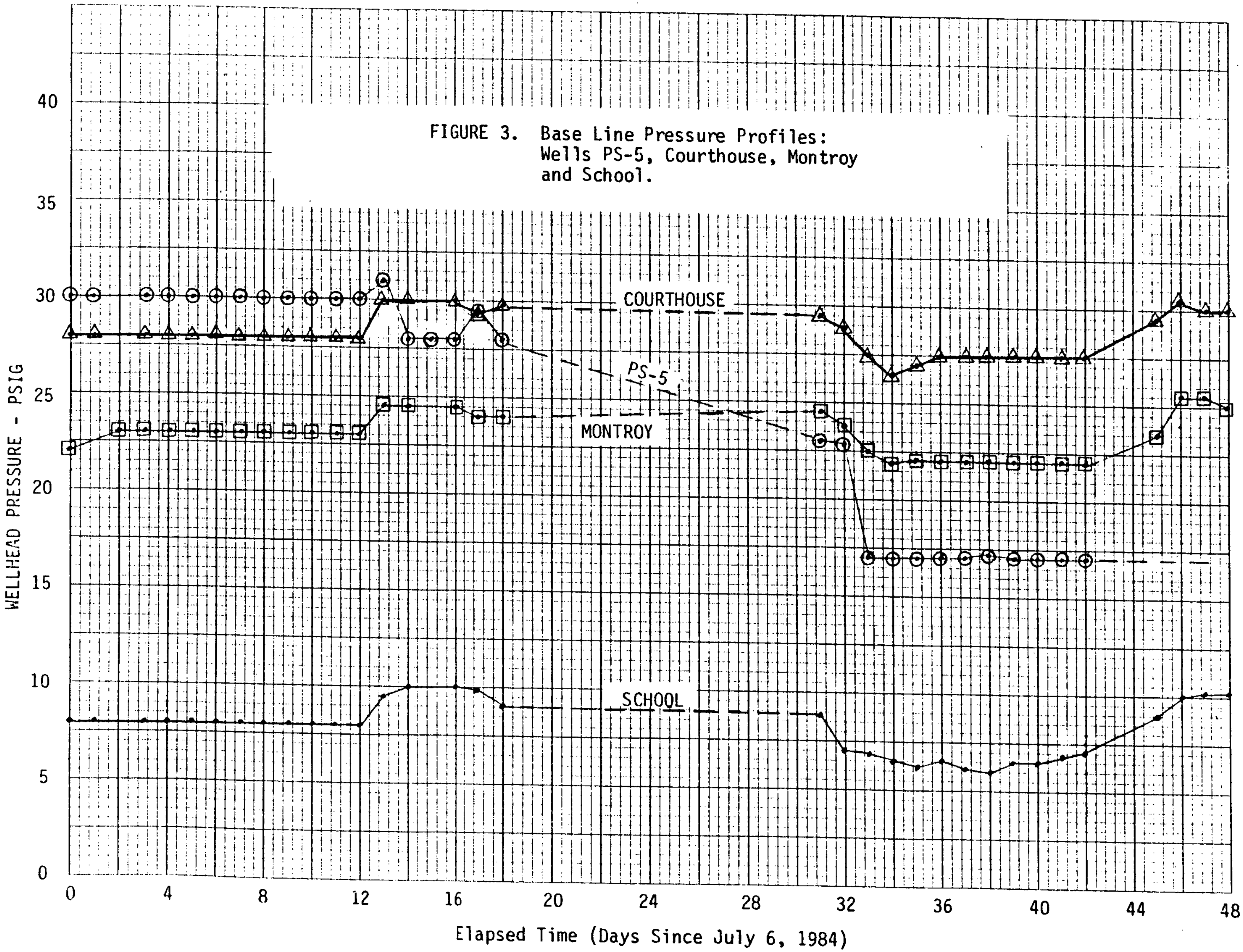


FIGURE 3. Base Line Pressure Profiles: Wells PS-5, Courthouse, Montroy and School.

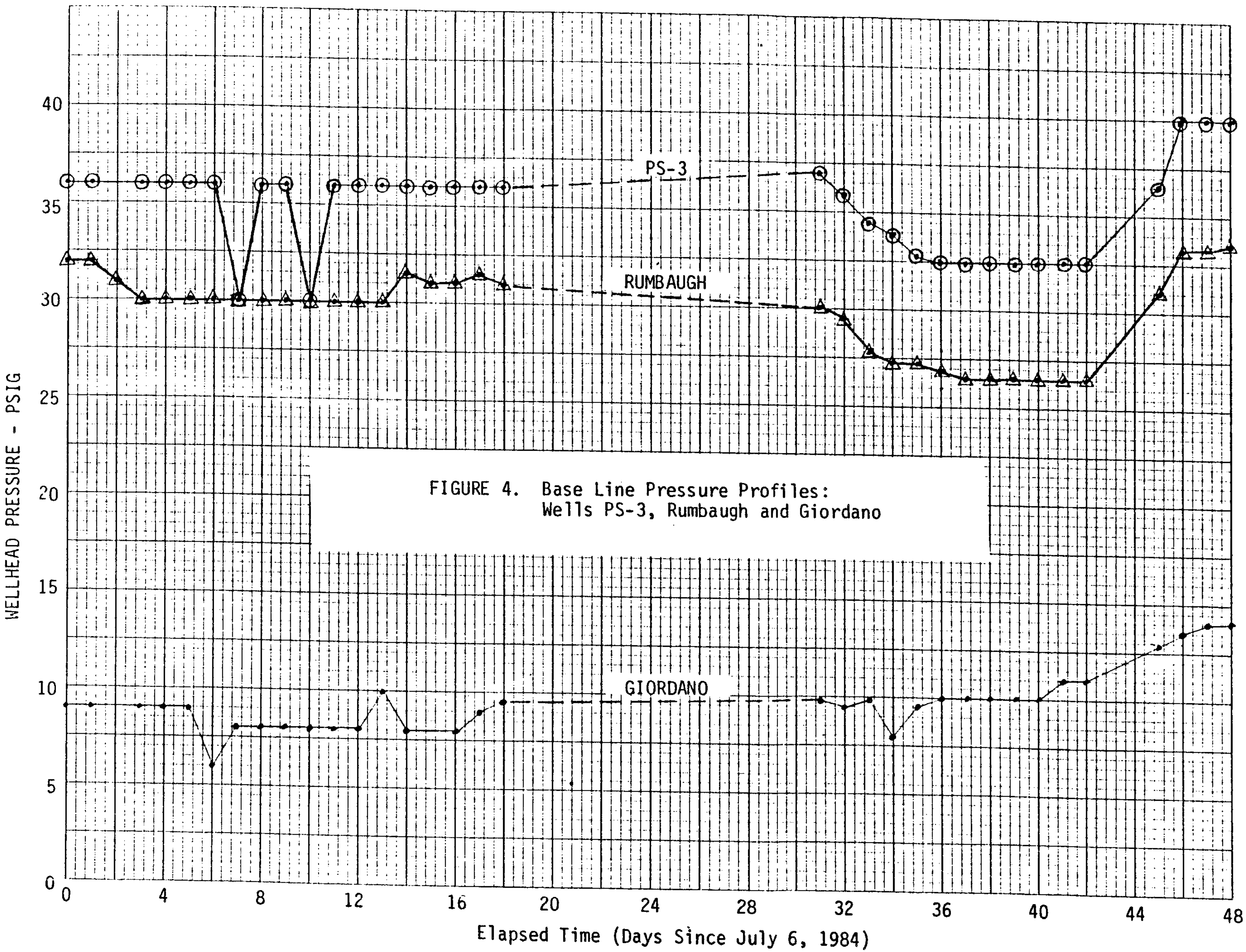


FIGURE 4. Base Line Pressure Profiles: Wells PS-3, Rumbaugh and Giordano

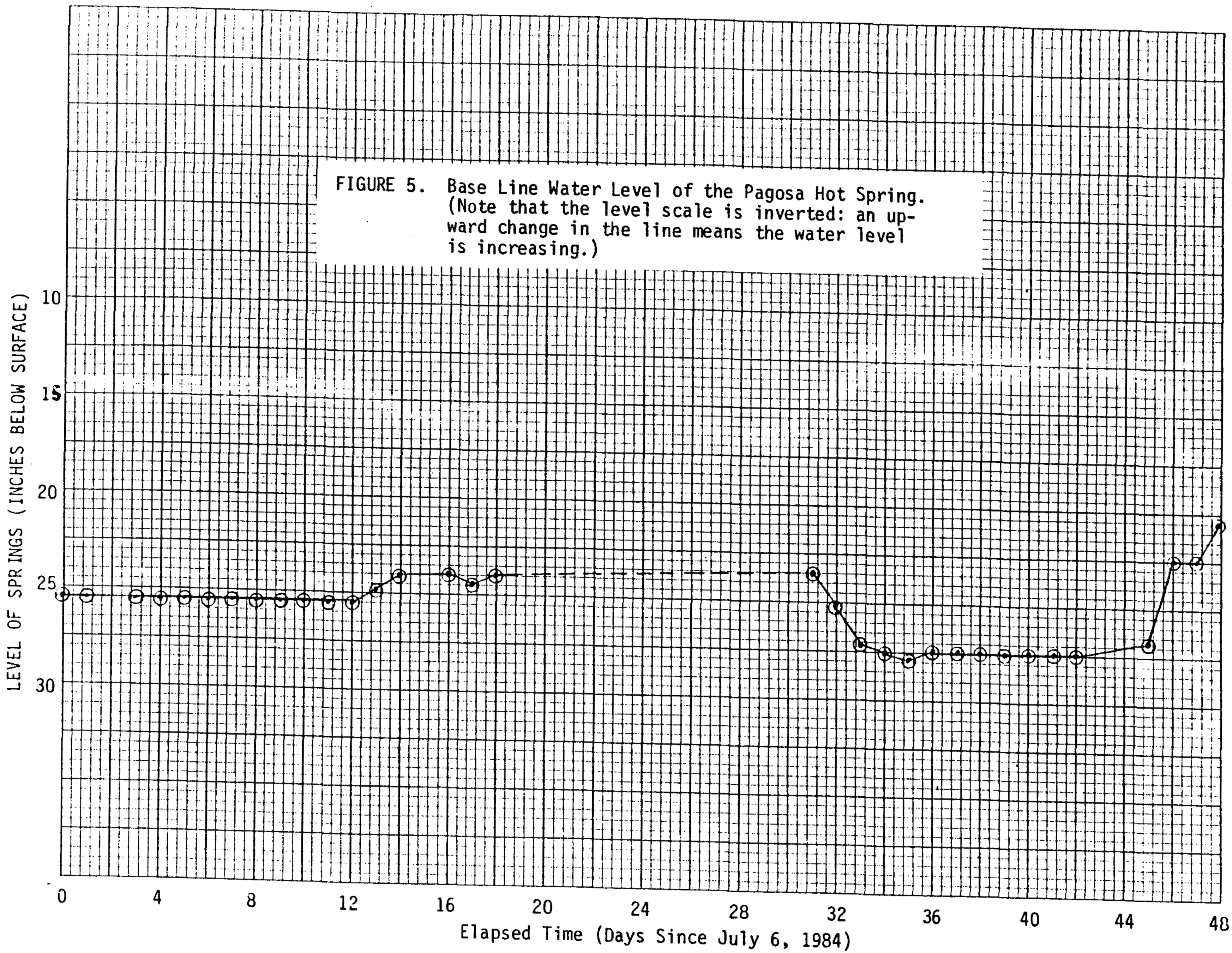


FIGURE 5. Base Line Water Level of the Pagosa Hot Spring. (Note that the level scale is inverted: an upward change in the line means the water level is increasing.)

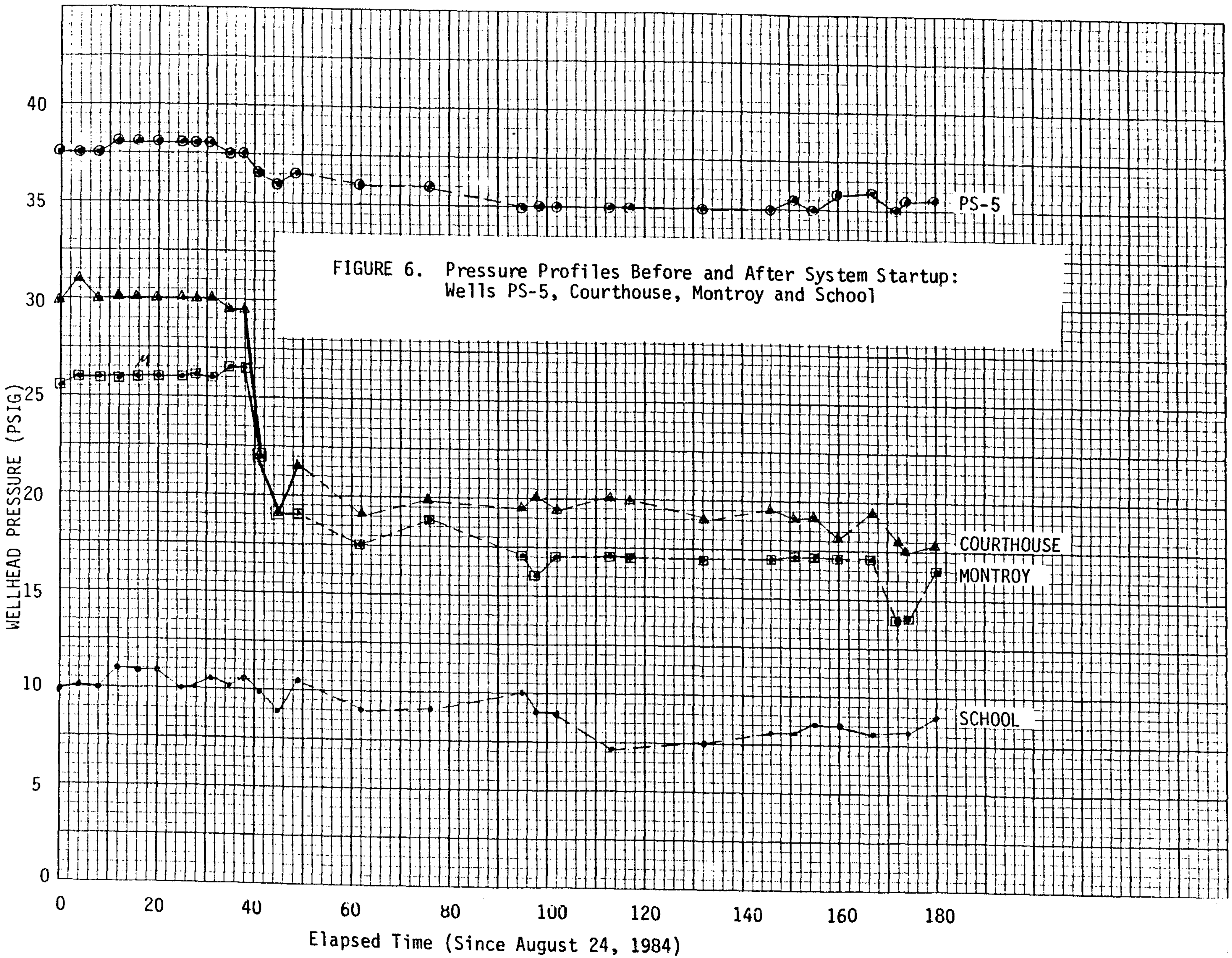


FIGURE 6. Pressure Profiles Before and After System Startup: Wells PS-5, Courthouse, Montroy and School

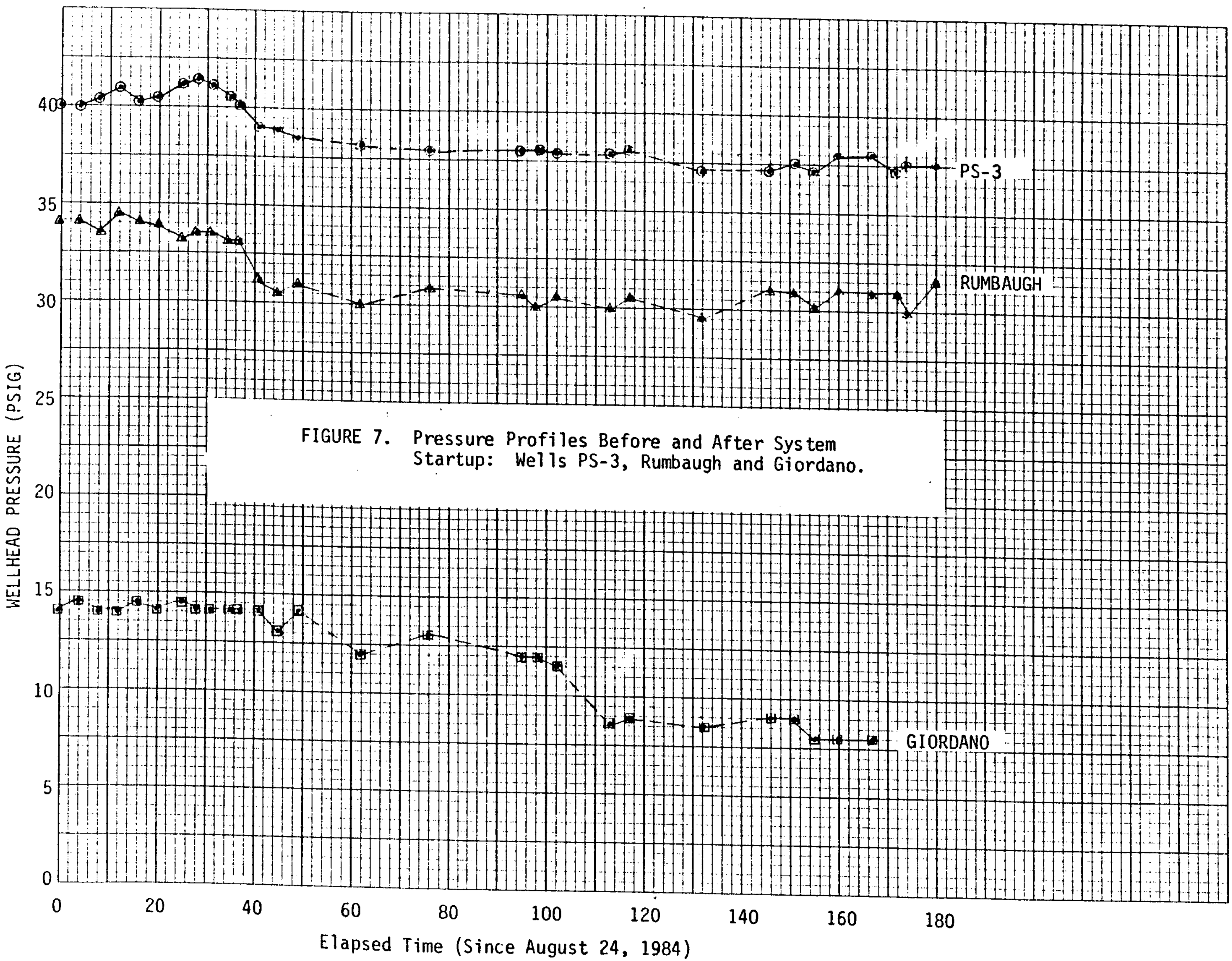


FIGURE 7. Pressure Profiles Before and After System Startup: Wells PS-3, Rumbaugh and Giordano.

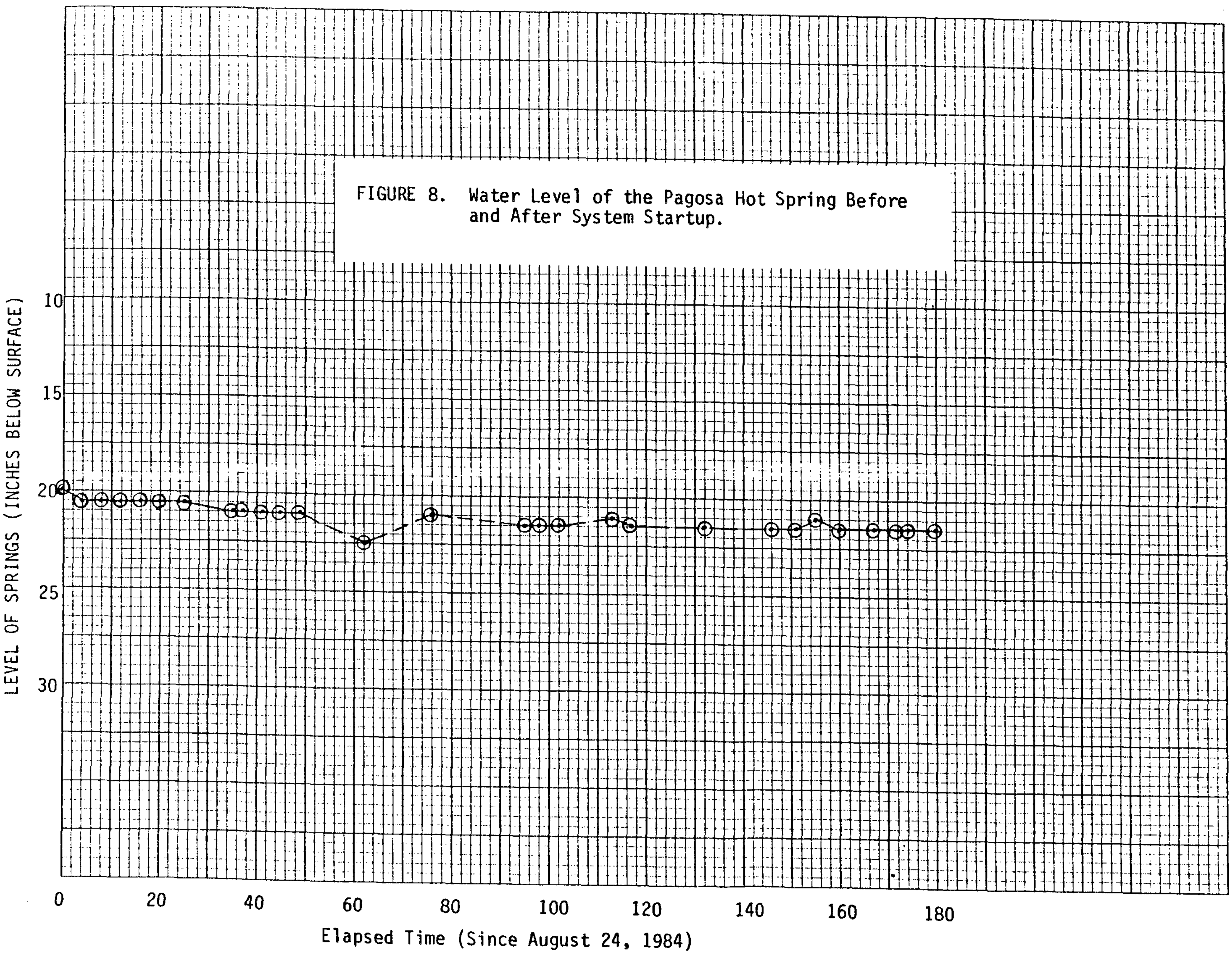


FIGURE 8. Water Level of the Pagosa Hot Spring Before and After System Startup.