GL02970-9

EG&G Idaho

INTEROFFICE CORRESPONDENCE

date December 22, 1978

to J. W. Morfitt

from L. G. Miller

subject RAFT RIVER WELL DRILLING SUMMARY - Mlr-51-78

Attached is the Well Drilling Summary requested by you some time ago. The Summary was delayed until costs were complete on RRGP-4. Costs for well drilling support in some cases were best estimates. In Figure 2, well cost per kW(e) are very sensitive to projected flows.

Number 5 well seems to be getting somewhat better and therefore, its cost per kW(e) will drop. I hope this summary contains the answers to your questions.

cs

cc: L. F. Burdge
    J. H. Ramsthaler

FORM EG&G-954
(Rev. 2-77)

EG&G Idaho

INTEROFFICE CORRESPONDENCE

date November 21, 1978

to J. W. Morfitt

from L. G. Miller

subject COMMENTS ON CEMENT PLUG AND FLOW TEST AT RRGP-5 - Mlr-49-78

John Griffith verbally requested a synopsis of the cement job on RRGP-5 well and further information on the flow test that was conducted before the salt incident. Several people have expressed that the measured flow was in error and nowhere near the reported 1100 gpm flow. John requested this information in order to give credence to his recommendation to multileg this well, expecially now that RRGP-4 has come up dry.

The initial plan was to kill No. 5 well during the running and cementing of the production casing. This was to be done by setting a 100 ft plug between the bottom of the casing and the producing zone, i.e. about 3700 ft. One hundred feet of cement can, in most cases, be drilled out. The formation is harder material than the cement and the bit will stay inside the old hole. If this did not hold, the well would then be backfilled with sand. A very effective method as was done in No. 1.

For an unknown reason, the plan was changed, 230 sacks (48 barrels of mixed cement) were pumped into the well through tubing set at 3720 ft. Which would have cemented 240 ft of hole. This did not shut off the well for unknown reasons. Instead of backfilling with sand to prevent any damage to the producing fracture system, 800 more sacks (165 barrels of mixed cement) were pumped into the well at the previous depth. This was a successful cement plug and the well was killed.

Since the bottom of the producing fracture zone is 4540 ft (from several spinner tests), the cement was pumped down the well and out into the producing fractures. Little cement would go below 4540 ft as it acts as a closed system. Therefore, with 213 barrels of cement, the well was cemented from 3735 ft to 4540 ft and 290 ft^3 of cement was forced out into the producing fractures cementing them closed out to some unknown radius.

When they came back to drill out the plug, the bit could not be kept within the old hole and drilled a new leg parallel to the old leg. The new leg was drilled to a depth of 4925 ft. Production from the new leg is-considerably less than the original leg. The first test after drilling Leg B indicated only about 100 gpm but further testing has indicated the well is developing. Flows of 300 gpm can be sustained for a period of time.

No one can say for certain why the second leg does not produce similar to the first leg. But with that much cement in the producing fractures and the two legs being only 16 ft apart in the producing zone, I am confident the second leg was drilled through the region where most of the fractures were cemented closed (see attached figure).

If one was to consider further drilling on this hole, two factors should be strongly considered. The first would be the value of a 274°F supply well. The value of this well to the power plant could be considerable considering the results of No. 4 even though the temperature is low. Mixing this water with other wells will lessen the low temperature effect and will reduce the plant efficiency somewhat. It would provide sufficient flow to allow operation of the plant with over design flow rates and would provide a reserve fluid capacity in the event of a failure of a production well.

The second factor is directionally drilling a new leg to penetrate the producing formation away from the cemented fractures. It is impossible to predict the distance from the original leg in which cement has penetrated. Possibly some reservoir engineering or hydrology people could make this estimate from previous flow data. If there is a real need for 274°F water, additional legs could be drilled at a relatively low cost which should bring the production back to near the original flow of 1100 gpm.

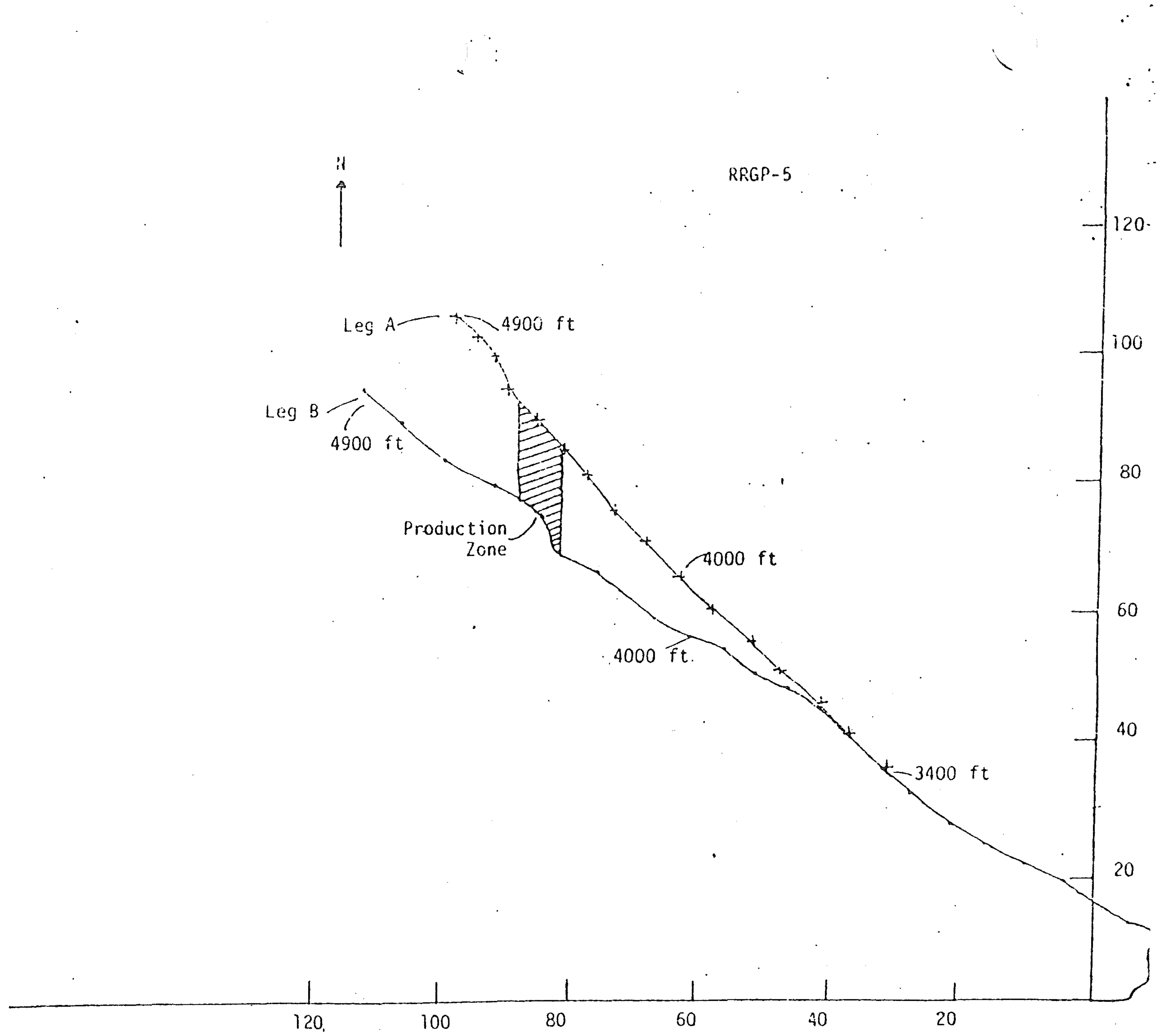
There seems to be a misunderstanding as to the flow capability of No. 5 well prior to the salt incident. Attached is a summary of the flow test along with substantiating information which supports the 1080 gpm flow measurement taken on June 10, 1978. The depth of the well at this time was 4505 ft. Using reserve pit fill up during the drilling from 4505 ft to 4911 ft or TD on Leg A indicated flow rates varied somewhat from 1000 to 2000 gpm.

With No. 4 coming up dry in both legs, it is much more important that No. 5 be returned to full production by drilling one or two more legs at a maximum distance from the original legs. The bottom of the No. 5 casing was kept high enough to provide sufficient distance to kick off two more legs.

cs

Attachments
As Stated

cc: w/attachments
L. F. Burdge
J. H. Ramsthaler


RRGP-5
N
Leg A
4900 ft
Leg B
4900 ft
Production Zone
4000 ft
4000 ft
3400 ft
120
100
80
60
40
20
120
100
80
60
40
20

RRGP-5 FLOW CAPABILITY
(Before Salt Incident)

Information is available which substantiates the accurately measured flows from RRGP-5. The rough estimates, impressions, and photographs all reinforce the measured flow. All of this is brought together in a synopsis starting June 1, 1978, when the rig twisted off a drill pipe while drilling at 4328 ft depth. On June 2, the wellhead was shut-in waiting for fishing tools.

At a depth of 4328 ft on June 5 and 6, after the fishing job was completed; flow tests were run using the mud pits. The two 15-minute tests measured 172 and 198 gpm. A temperature log measured a maximum downhole temperature of 275°F. Wellhead pressure had been previously recorded at 40 psi on the night of June 2, and 55 psi after being closed in all night.

From this information, we can conclude that the flow into the well bore from 1600 ft to 4328 ft was about 200 gpm and wellhead pressure of 55 psi. Some of this flow was probably from the 1600 to 2000 ft "thief zone.". There were no water disposal problems during this portion of the drilling. Percolation out the bottom of the pit kept the reserve pit water level low. Makeup water was pumped from site 1 up to the rig using the 125 HP 1200 gpm transfer pump. Transfer pumping was done almost half time around the clock while drilling.

Considerable increase in flow was experienced and they tripped out of the hole to change bits. A bleed-off line was installed on the flow nipple to bypass the large flow of water past the shale shaker directly to the reserve pit. A temperature log again only measured 275°F at the bottom of the hole.

The Hydrill would not hold the pressure due to the deteriorating rubber liner and a new Hydrill was ordered. On June 10, a flow line was set up with an orifice plate and a back pressure valve. Recommended straight pipe sections were used upstream and downstream of the orifice plate. Orientation of the orifice plate was verified upon insertion. A flow test was conducted by two very competent people; Bill Munger, an experienced piping hardware man; and Virgil Egan, a highly experienced instrument engineer.

RRGP-5 FLOW CAPABILITY

All instruments and gauges used on this test had previously been calibrated onsite using a Wallace Tiernan precision pressure gauge and a dead weight tester. Calibration was done under Egan's direction and instruments tagged. A 3.0-inch diameter orifice plate was first used but flows were too high and rubber from Hydrill kept plugging the hole. A 5.443-inch diameter Daniels 304SS orifice plate was installed in the 8-inch flow line. A 50 psi back pressure was maintained to prevent any chance of two phase flow through the orifice. After flow had nearly stabilized, four readings were taken over a 20-minute period. The volume of water and steam discharging from the flow line was so great that it hit the opposite reserve pit bank about 125-150 ft away depositing pieces of the Hydrill rubber liner. Attached are photographs taken while drilling prior to the bleed-off line installation on June 8, 1978.

Lynn Nelson conducted a flow test on No. 5 soon after this test. Part of the 550 gpm test was to observe the distance the discharge traveled across the reserve pit. With this flow, the discharge did not get beyond the middle of the reserve pit. Surface temperatures were about the same for both tests.

Time	Water Temperature	Back Pressure	ΔP	Calculated Flow
1630	260°F	50 psi	3.2 psi	1116 gpm
1640	262°F	51 psi	3.0 psi	1080 gpm
1645	263°F	51 psi	3.0 psi	1080 gpm
1650	264°F	51 psi	3.0 psi	1080 gpm

The above flow rates are calculated using the Crane Flow of Fluids equation

$$Q = 236\, d_1^2\; C\sqrt{\frac{\Delta P}{\rho}}$$

C was calculated by two methods, one using the Crane equation for Reynolds Number and plots; and the second using the equation from Fisher and Porters "Flow Meter Orifice Sizing Handbook." The two equations gave values of C within 1%. The above equation is for a standard orifice plate with taps one diameter upstream and one half diameter downstream. Orifice flanges were used in this experiment which could introduce less than 2% error.

RRGP-5 FLOW CAPABILITY

Since the flow had stabilized by 1650 hours, the test was terminated so that the well could be cooled and drilling resumed. This was the beginning of a series of serious water disposal problems.

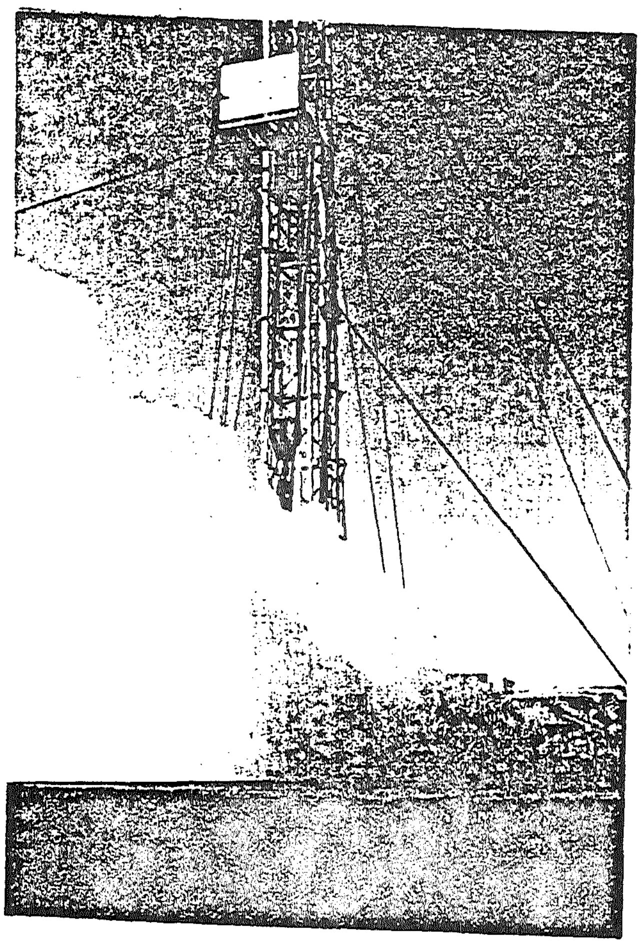
Cooler water from the reserve pit and site No. 1 was pumped into the mud pits and down the well. This lowered the return flow temperature below the flash point. The high water in the pond and the large volume of returning fluid caused the bank under the mud pits to erode. Rock was hauled for several days to build back the bank.

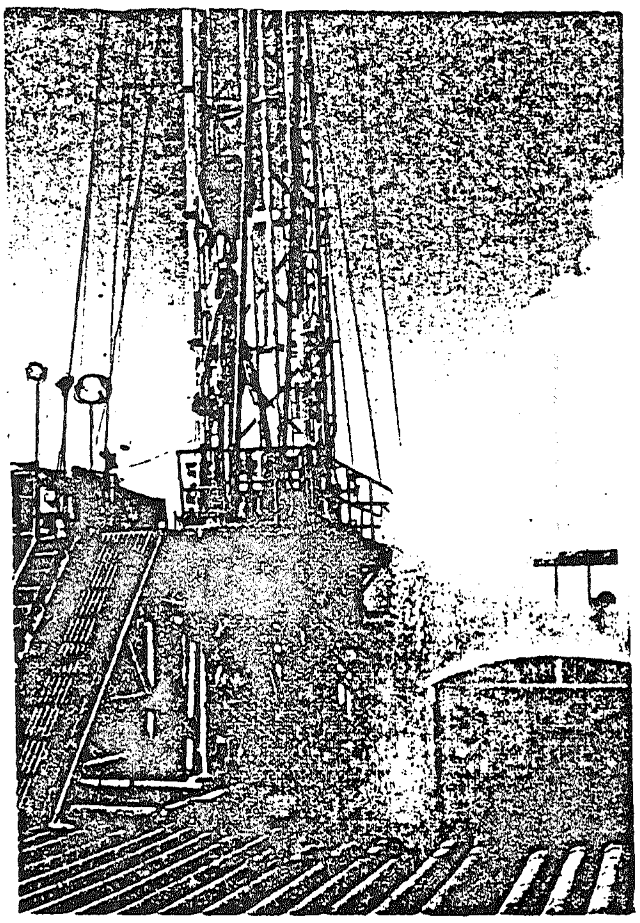
Two pumps were leased from Colorado Well Service, a pump was borrowed from the Raft River Highway District, a PTO pump and tractor was brought from site No. 1, and a 6-inch pump brought from the INEL site. One pump was used to pump water over to site No. 2 through a 6-inch aluminum line. (A second pump was added but the large flow caused the line to part.)

The water was checked for salinity and determined to be safe for surface disposal on the sagebrush. The additional pumps were then used to pump over the reserve pit berm into the sagebrush. The pumps were still not keeping up with the water. The drilling operation was halted periodically to allow the pumps to lower the reserve pit level.

A cut was made in the reserve pit berm and a large culvert installed to keep the water level about 3-ft below the top of the berm. This solved the drill site water problem. Even though the water spread out in the safebrush and percolated into the soil, water entered private land a quarter mile to the south. Trenches were dug in the sagebrush to slow the flow of water to the private land. Seven days after the flow test, the rig twisted off a drill pipe and drilling on this leg was terminated at 4911 ft.

Photographs were taken during the drilling of RRGP-5 prior to the installation of the bleed-off line on June 8, 1978. This line by-passed the flow across the shale shaker directly into the pond.





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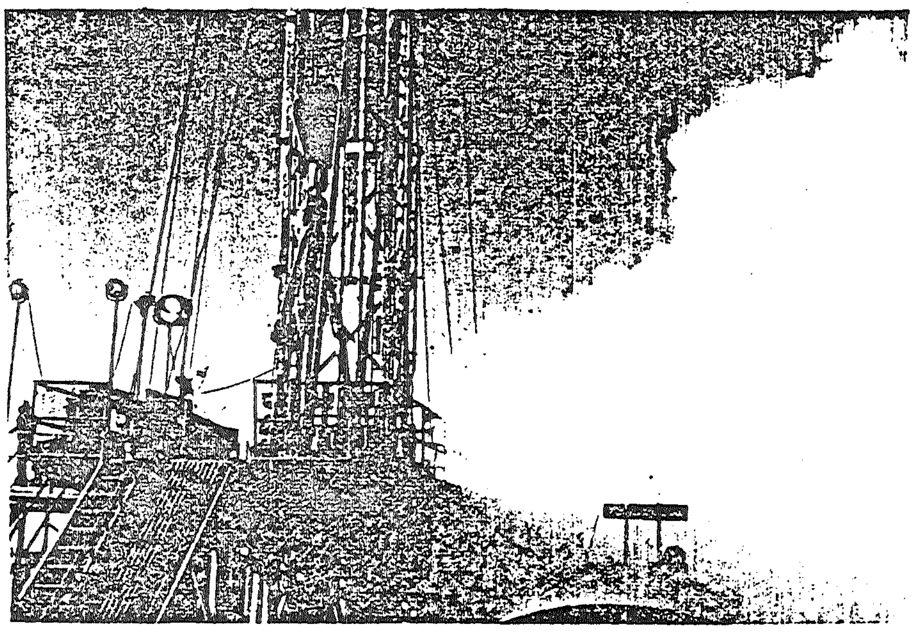

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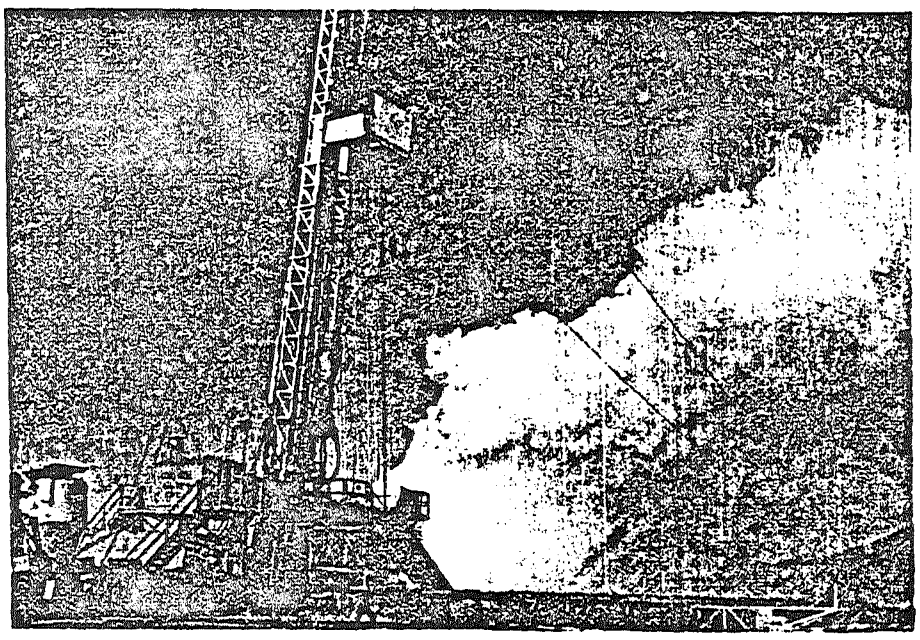

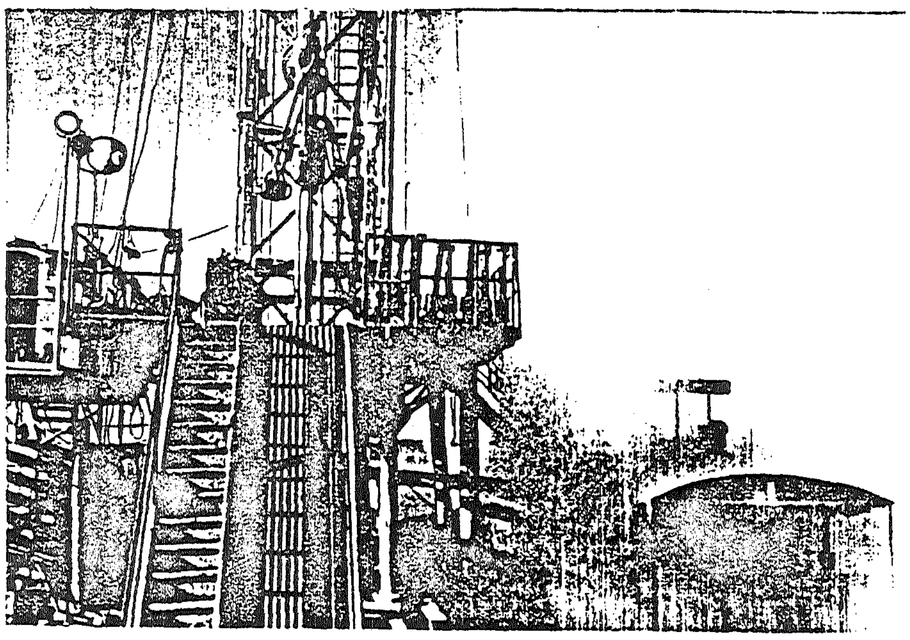

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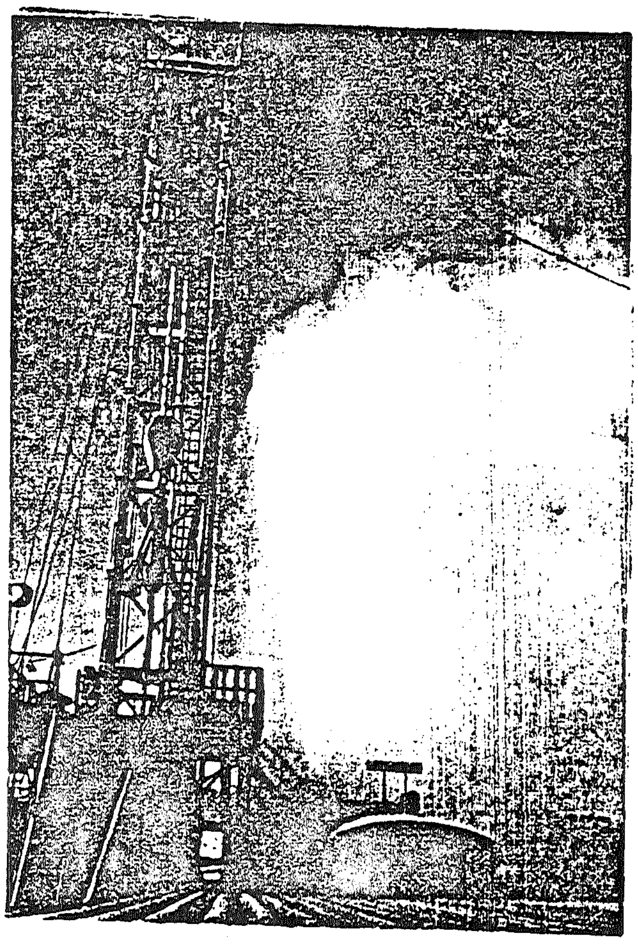

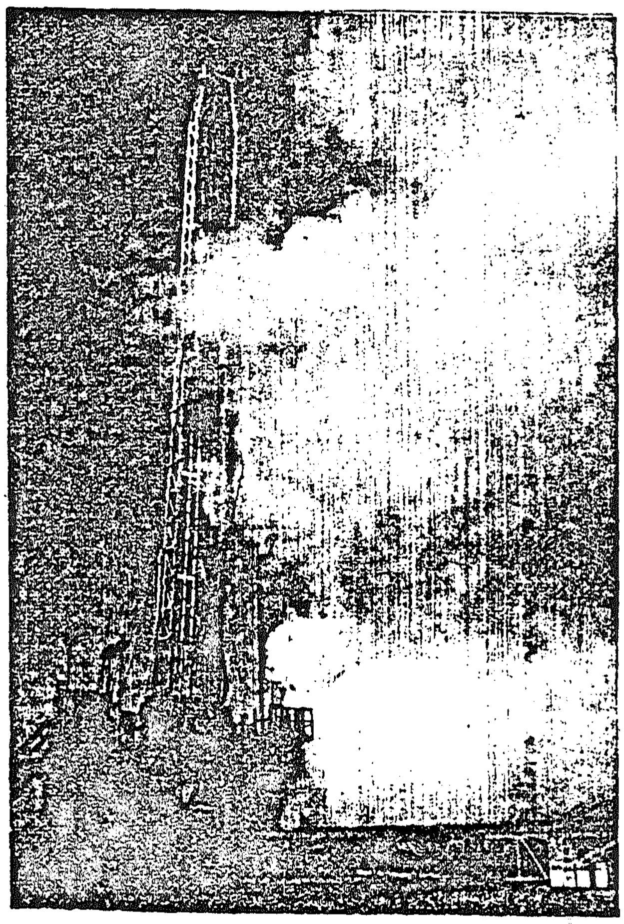

11-30-78

RAFT RIVER WELL DRILLING SUMMARY

L. G. Miller

INTRODUCTION

The drilling of the first well, early in 1975 in Raft River, verified the existence of a geothermal resource with a temperature of about 300°F. The pilot power plant was designed around this and the second well considering a few degrees temperature loss from resource to plant. Specifications were prepared for supply and injection system management plan, report GP-124, page 5. The system is to supply 2250 gpm of 290°F low salinity geothermal fluid to the pilot plant and inject 2125 gpm spent fluid into intermediate or deep injection wells, the depth of the injection zone to be determined by testing.

Initial estimates of flow from the first two wells indicated a need for three production wells and a standby well. Using initial injection tests on No. 2, two injection wells would be required with a standby well. As long term reservoir test data became available, it became apparent that after five years operation of the production and injection wells, their performance would be less than initially estimated. New five year production and injection estimates have been prepared and are shown in Table I. In the Table, No. 3 well is indicated as an injection well but the flow is shown in a production mode and may still be used for production.

SUMMARY OF WELLS DRILLED

RRGE-1

The first well was drilled by REECo (Reynolds Electric and Engineering Company, a subcontractor to the Nevada Operations Office), after Governor Andrus donated $200,000 in State funds to supplement the DOE (ERDA) funds. EG&G (ANC) had no drilling expertise at that time. The first two wells drilled by REECo were a learning experience for EG&G people. The third well drilled by REECo was then managed by EG&G people. All procurement actions and contracts were also set up and administered by EG&G people.

The first well was drilled in such a way that should no resource be encountered, minimal cost would be expended, i.e. production casing was not run and cemented until drilling was completed and well was found to be a success. This method worked exceedingly well. The bottom hole was backfilled with sand to shut off the resource during the casing and cementing operations.

Casing collapse during cementing was the only major problem encountered. Reaming was required to open the well bore. Production from this well is considered highest of any well drilled. Free flow from the well approaching 600 gpm.

RRGE-2

The second well was drilled in two parts and located along the same fault as No. 1 but further to the northeast. The well was to intercept the Bridge Fault at a greater depth than No. 1. The well was drilled with mud until a drill-stem-test (DST) measured temperatures exceeding 280°F. At this point, the casing was run and cemented. The well was drilled to basement rock at 6006 ft depth. During a major part of the next year, the drill rig set over the hole. Injection and flow tests were conducted during this period. Over 8-million gallons of cold aerated water were injected.

Drilling was resumed at USGS recommendation to determine if the quartz-monzonite basement rock was fractured and could produce fluids. No fractures were detected in the quartz-monzonite formation during the extremely hard drilling to 6561 ft.

RRGE-3

The third hole was drilled 9000 ft southeast across the river from the first two holes. This location was recommended by the USGS as this location would determine if the resource extended outside the fault zones. This well was planned to have three barefoot legs to increase the production by a calculated 50%. The first leg was drilled to basement rock. Formation temperature was above 294°F, but the first leg produced little fluid even after stimulation. The second leg was then drilled to the northeast and produced some increase in flow. The third leg was drilled to the north, toward the other production wells. Considerable flow was encountered in this leg. Maximum formation temperature was 301°F, but total production from the three legs is less than either of the first two wells. Major problem during the drilling of this well was the continued failure of the rubber components in the Dyna-drills during directional drilling.

RRGI-4

During the drilling of the first two wells, the intermediate zone from 1600 ft to 3000 ft appeared to have high permeability which could be utilized effectively for intermediate depth injection. A decision was made to drill an intermediate depth injection well for testing formation and interaction with the deep production zone. A location was selected by the USGS for this well with the plan to convert it to a production well after the injection test program. This well was located 2000 ft south of No. 1, a location considered to be a prime location for a production well. This location would be at the intersection of the Bridge Fault and the Narrows structure (possibly a fault structure).

A private rig was contracted and the well was drilled to 2900 ft. Cement failure at the casing shoe allowed the bottom two joints of casing to part from the main string causing a "trip in" problem. Maximum tempertaure at this depth was 252°F. Flow tests indicated formation permeability was less than predicted but temperature was considerably higher at this depth than any of the previous wells.

RRGI-6

No. 6 well was drilled as an intermediate injection well after completion of No. 4 initial injection tests. Location of the No. 6 and No. 7 injection wells was selected by DOE-ID, even though EG&G people recommended other areas. No. 3 had already proved that intermediate and deep formations were tight and would make a very poor injection well location. This well was drilled to 3888 ft at 30% less cost than estimated. Preliminary injection tests indicated somewhat tight formation. A recommendation was proposed to DOE-ID to drill the well deeper, i.e. opening up more formation which would reduce injection pump pressure. DOE-ID would not accept the recommendation and the drill rig was moved to No. 5.

RRGP-5

This well was located 3000 ft west of No. 1 well. Its location was selected by the USGS as being along the north edge of the Narrows structure. After drilling had commenced, Harry Covington, USGS Field Representative indicated that previous data had been analyzed which predicted a high basement in the region of No. 5. If this was true and No. 5 was cased to a depth indicated in the Management Plan, we would be casing a hole down to basement rock, a very costly mistake. A decision was made with ID concurrence to omit casing until the resource was verified.

A hot water resource of 274°F was encountered at about 4500 ft. Pilot plant use of this temperature water was considered marginal. The well could provide an important backup roll in the event of failure of a higher temperature well or be used to determine power plant characteristics with flow rates greater than the design. Drilling was resumed with DOE-ID concurrence to basement rock at 4911 ft. No additional hot water sources or higher temperatures were encountered.

At this depth, the hard quartz-monzonite was encountered and a drill pipe twisted off causing several weeks of fishing. Salt water was pumped into the hole intermittantly during the fishing job to keep the well "killed." During this period of fishing, DOE-ID was informed of the salt additions but they did not inform the Sate Water Resources until the salt injection was completed.

After the fishing job, the well was stimulated but initial characteristics did not return. DOE-ID agreed to allow the drill rig to move off No. 5 and drill No. 7 so that additional testing could be carried out on No. 5. The rig returned to complete the casing and cementing, but the two additional legs were not drilled as detailed in the test plant.

<u>RRGI-7</u>

This injection well was located 2300 ft southwest of No. 6 and drilled similar to No. 6. This well was drilled 40% below estimated cost. Initial injection tests indicated the permeability of No. 7 to be less than No. 6. EG&G recommended that this well be deepened while rig was over the hole,but the recommendation was not accepted.

During the completion of this well, DOE-ID assumed the management and direction of all drilling activities. Rig was moved back to No. 5 for well casing and completion.

RRGP-5 CASING AND COMPLETION

A cement plug was set below the proposed casing setting depth while the rig was drilling No. 7. Casing was then set and cemented to 3400 ft. Cementing failure required two remedial cement jobs. While drilling through the cement plug, hole was deviated out of original channel and a new hole was drilled to TD (4925 ft). Initial flow and temperature runs on the well indicate 100 gpm flow at 265°F maximum at the surface (274°F maximum temperature downhole). Flow measured prior to the salt incident and casing measured 1080 gpm. Most of this flow was attributed to the 4450 to 4500 ft producing zone.

RRGP-4 CASING AND COMPLETION

No. 4 was deepened to 3457 ft and 9-5/8 inch casing was run and cemented from TD up to casing hanger at 1512 ft depth. The Management Plan called for triple legs to this well, but after the first two legs produced nearly zero flow, the third leg was not attempted. The first leg was drilled to 5427 ft, 450 ft into the quartz-monzonite to determine if fractures and production could be located. Neither were intersected. A second leg was drilled to 5115 ft with similar results. Maximum downhole temperature was 288°F at 4900 ft, and bottom hole temperature was 273°F. Rig was removed from well and stacked in anticipation of drill rig use at INEL. Further drilling will be done after a thorough analysis of the present wells and further drilling funds are made available.

TABLE 1 WELL DRILLING SUMMARY

Well No.	Year Drill Complete	COST (Drilling Casing & Logging)		Total Well Costs[5]	Time (Drilling & Testing)	Name of Driller	Type of Well	Maximum DownHole Temperature	Wellhead Temperature	Projected FLOWRATE After 5 years gpm	DEPTH	Casing Size & Depth
		Drill and Mtls	Mgmt & Drill Support[3]									
1	1975	810	100	910	103 days	REECo	Prod	286°F	281-265°F	800	5007 ft	13-378" to 3624'
2	1976	800	70	870	82 days	REECo	Prod	291°F	282°F	400	6561 ft	13-3/8" to 4227'
3	1976	650	70	720	63 days	REECo	Inj	300°F	295°F	535	5853 ft[2] 5532 ft 5917 ft	13-38" to 1385' 9-5/8" to 4255'
4A	1977	305	25	330	26 days	Colo Well	Inj	252°F	--	--	2840 ft	13-3/8"to 1820'
4B	1978	830[1]	30	885[1]	45 days	Colo Well	Prod	288°F	282°F	30 to 100[4]	5427 ft[2] 5115 ft	9-5/8" to 3457'
5	1978	1140	60	1200	88 days	Colo Well	Prod	276°F	265°F	400 to 600[4]	4925 ft	
6	1978	325	35	360	25 days	Colo Well	Inj	160°F	--	--	3888 ft	13-3/8" to 1698'
7	1978	275	35	310	21 days	Colo Well	Inj	172°F	--	--	3858 ft	13-3/8" to 2044'

1 - Includes cost of 4A.

2 - Multilegged wells.

3 - Estimated.

4 - Very preliminary data.

5 - Nationwide well costs have escalated 25 to 40% per year.

11-30-78
LGM

IDAHO NATIONAL ENGINEERING LABORATORY

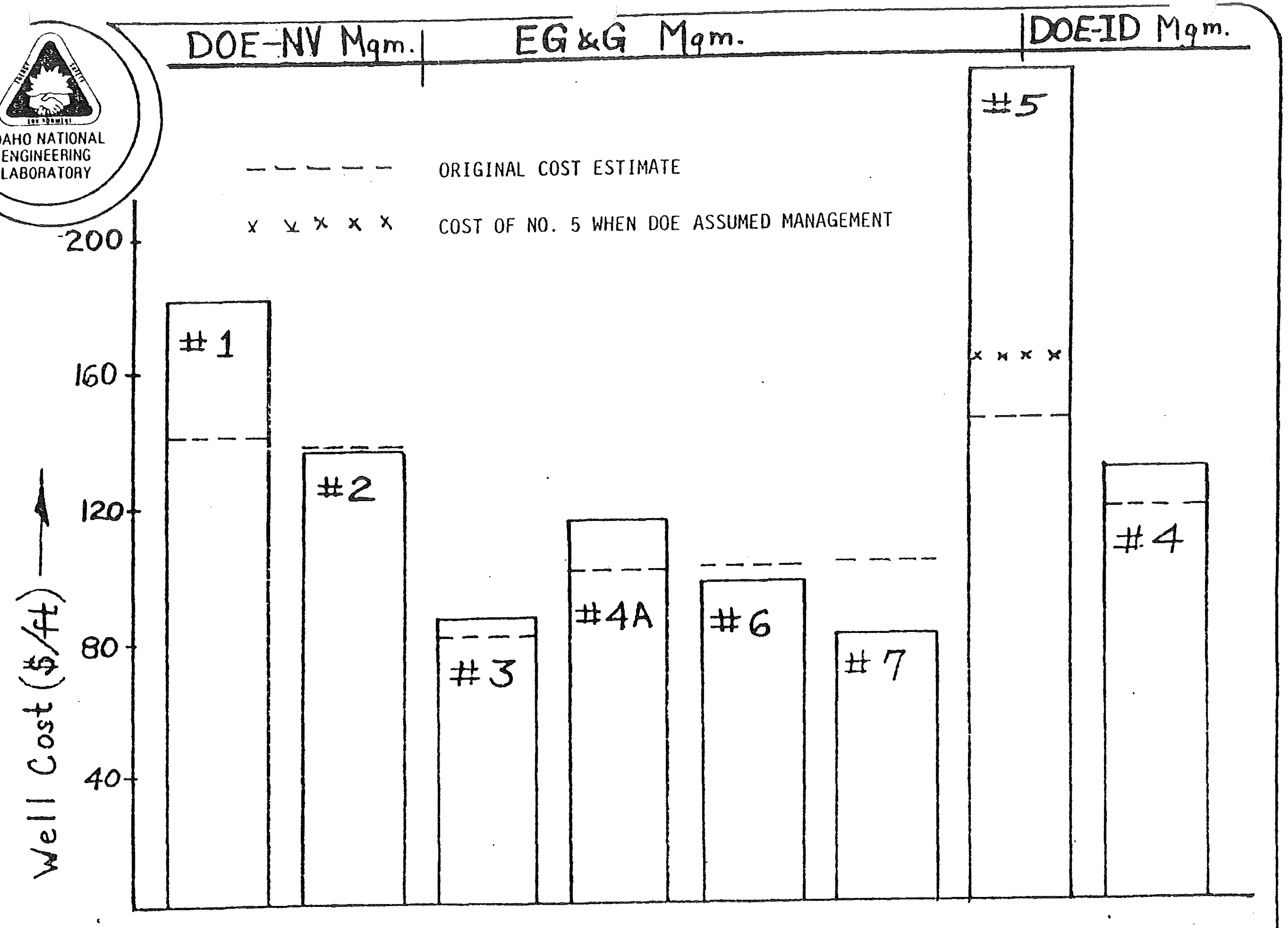

Figure 1. Raft River Well Cost

EG&G Idaho, Inc.

11-30-78
L.G.M

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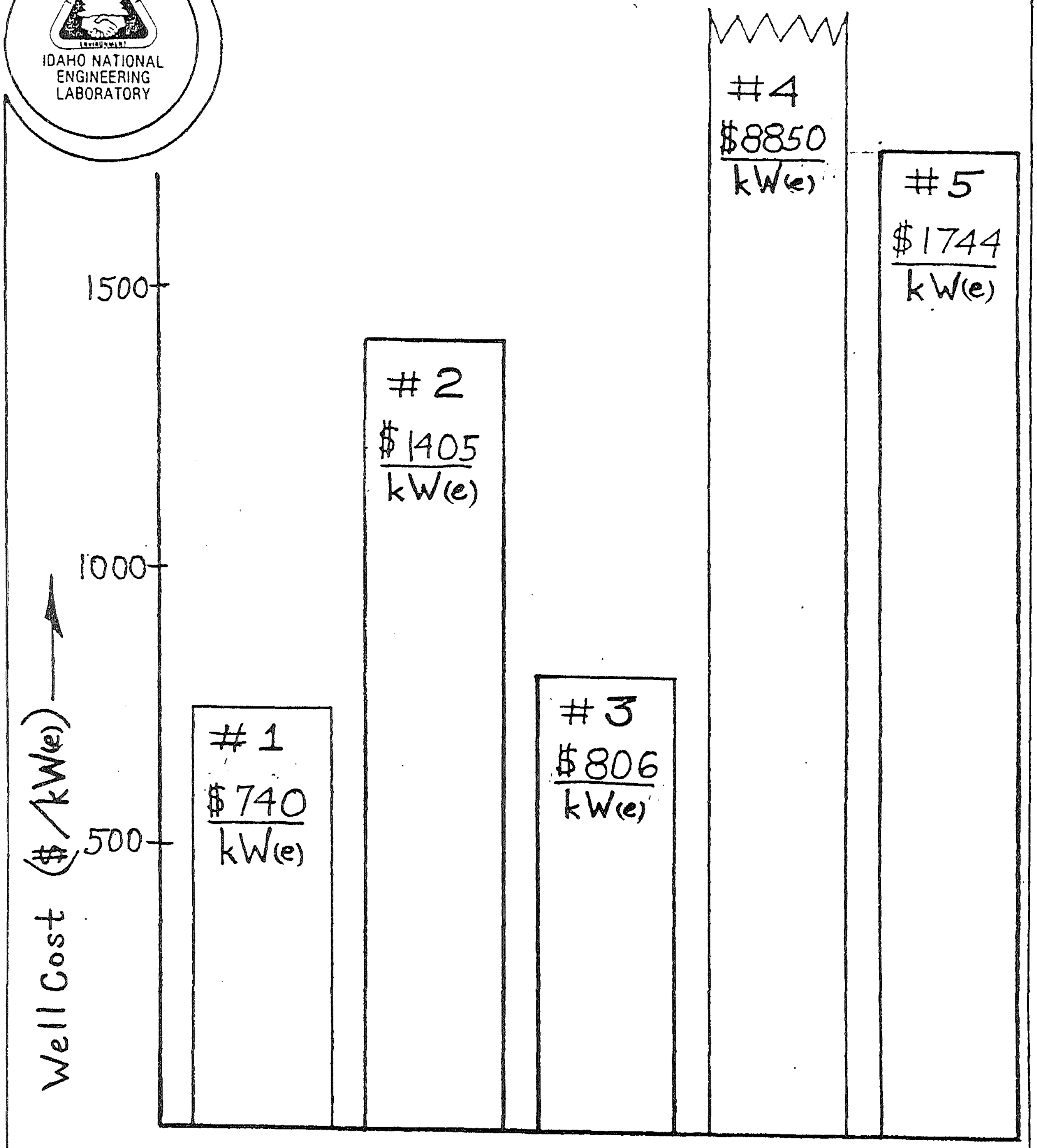

Figure 2. Raft River Well Cost.

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EG&G Idaho, Inc.

Geothermal Resources Council, TRANSACTIONS, Vol. 1 May 1977

THE RAFT RIVER WELLS AND RESERVOIR PERFORMANCE

J. F. Kunze
L. G. Miller
R. C. Stoker

EG&G Idaho, Inc.

ABSTRACT

The three successful deep wells in Raft River have tapped a 300°F reservoir. The wells are artesian, but their use dictates pumping to achieve the maximum production rates. Well performance and production rates over many years indicate about 2 MW(e) per well using the binary cycle is predicted, and this at only 12% thermal efficiency. Use for non-electric direct heat represents 16 MW/well over the long term. Drilling technique and methods of determining the resource presence so as not to case it off have been the keys to getting the maximum production from these wells. Three channels in the bottom of the third well increased its production 5 times compared to one channel.

Three deep geothermal wells have been drilled in the upper Raft River Valley of Southern Idaho. The wells are producing moderately hot waters from nominally 300°F reservoirs, of which there appear to be two distinctly different types. The one reservoir is characterized as low salinity, 1250 ppm, The other reservoir has considerably higher salinity, 4000 ppm. Each reservoir now gives silica and Na/K/Ca geochemical(1) thermometer indices differing by about 15°C, consistent with each index, the high value applying to the higher salinity reservoir. The geothermometry on the surface "seeps" in the area (shallow wells delivering near boiling water) gave indicated reservoir temperatures 5 to 10°C lower than the actual temperatures of the reservoirs tapped, and 15 to 30°C less than indices derived from water extracted directly from the reservoir. Nevertheless, the relative nearness of the geochemistry predictions to actual temperatures in the reservoir is considered a major success of the current empirical formulas.(2)

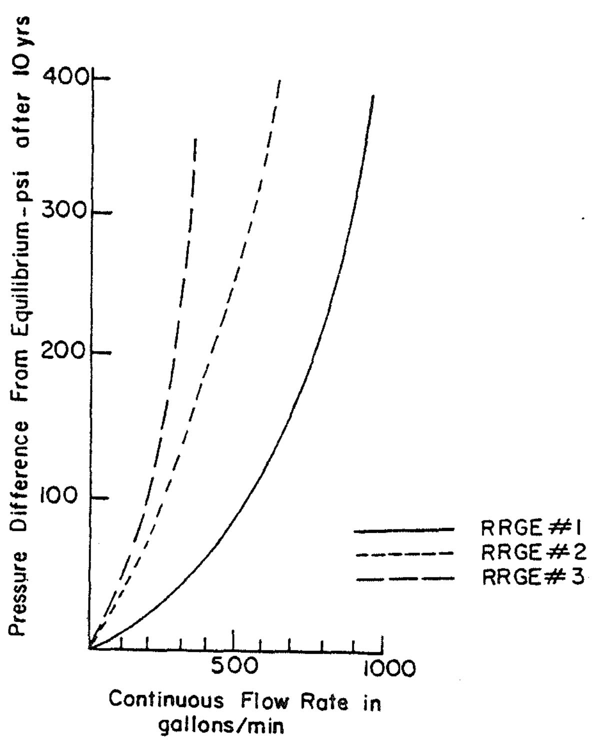
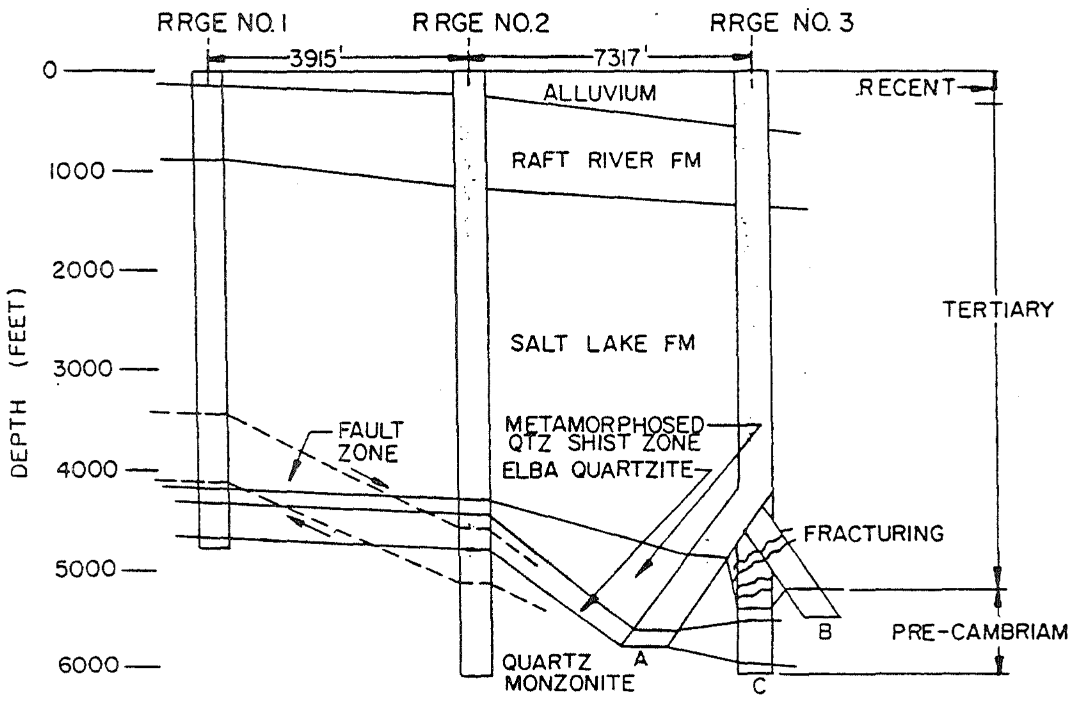


Figure 1, above, shows the productivity indices of each of the wells, based on extrapolations to ten years of steady state production conditions using the Theis Equation. The well cross sections are shown in Figure 2 on the following page.

This work was sponsored by the
Energy Research and Development Administration



This data indicates that, with pumping for a net 800 ft drawdown in the well after 10 years should produce 2200 gallons per minute from the three wells, enough for 6 MW with an efficient binary cycle. This requires use of downhole pumps set at about 1200 ft. Credit is taken for the 400 ft positive artesian head on the wells in their shutdown hot condition.

Of particular significance is the drilling technique used on all three wells. Water was used as the drilling fluid on all three wells in the producing region, but even so confirmation of a production zone was slow to develop due to the flushed cold water in formation near the well bore. A weighted mud column would have made detection of the reservoirs extremely difficult. The third well was planned for multiple branches beginning just below the casing. The main branch proved extremely disappointing, with very low kH values (less than 2000 millidarcy feet). The second and third branch provided significantly enhanced production, giving a net kH of nearly 10,000 millidarcy feet, for only a 20% increase in well costs compared to the single branch well.

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(1) USGS Circular 726 - Assessment of Geothermal Resources of the United States-1975

(2) (a) Procedure for Estimating the Temperature of a Hot-Water Component in a Mixed Water by Using a Plot of Dissolved Silica Versus Enthalpy
by: A. H. Truesdell and R. O. Fournier

(b) Geochemical Indicators of Subsurface Temperature Part I: Basic Assumptions
by: R. O. Fournier, D. E. White and A. H. Truesdell

Geothermal Resources Council, TRANSACTIONS, Vol. 2 July 1978

THE MULTI-PURPOSE GEOTHERMAL TEST AND EXPERIMENTAL ACTIVITIES AT RAFT RIVER, IDAHO

Robert N. Chappell, DOE-ID
John L. Griffith, DOE-ID
Wayne R. Knowles, DOE-ID
Robert J. Schultz, EG&G Idaho, Inc.

Department of Energy
Idaho Falls, Idaho 83401

SUMMARY

The largest variety of geothermal tests and experimental activities at any single location in the world are underway or developing at a remote geothermal test site in south-central Idaho. The majority of the DOE sponsored research conducted by scientists from the Idaho National Engineering Laboratory (principally EG&G Idaho employees) is devoted to investigating many uses of moderate temperature hydrothermal resources. The work also includes a significant environmental baseline and long-term effects program; resource discovery, production, control and disposal; fluid handling techniques from downhole pump to the miles of buried surface lines moving fluids between the production wells and the experimental facilities.

Work was initiated at the Raft River Test site in 1973 when the Raft River Electric Coop hired a geologist to investigate the geothermal resource which was manifested through a variety of 200 to 500 foot irrigation wells which had been drilled over a large section of the valley and had produced near boiling water for many years. A small group of farmers representing the Coop visited the DOE/INEL Idaho Office and arrangements were made for the Geothermal Guidance Committee to visit Raft River in August 1973. DOE sponsored work was first funded in December 1973 and 1974 was spent with a team from the U. S. Geological Survey and scientists from the INEL performing extensive geophysical exploration in the upper portions of the valley. In January 1975 deep drilling for geothermal water began near the narrows, a site just six miles north of the Utah border. The valley has Tetonic features characteristic of both the Snake River Plain volcanic rift zones with which it intersects and the older sedimentary characteristics of the Salt Lake - Old Lake Bonneville formations.

The site selected for the first exploratory drilling was approximately between two irrigation wells which have been producing boiling water from the 400 foot level for about 40 years. These shallow wells had been drilled for agricultural purposes and evidently had intersected faults along the edge of the valley. The geochemistry of wells predicted maximum reservoir temperatures between 140 to 150°C.

The scientists involved in this geothermal effort concluded that the Raft River reservoir characteristics would be ideal to determine the lower level of temperature for hydrothermal resources which may be utilized to produce economical electric energy and also would provide an excellent source of fluid to be used to conduct direct use experiments. In addition, the remote valley was essentially unmolested by any man-made developments with only a few farms and ranches in the area, which was advantageous for measuring environmental baseline conditions and the impact of geothermal development.

Now, four years later, the site contains a total of 17 geothermal wells. Every well drilled to date has encountered geothermal fluids -- even wells drilled exclusively for monitoring purposes unexpectedly have been producing geothermal fluids. Four of the wells drilled to about the 4,000 to 5,000 foot level are being used to produce the fluid, three wells drilled (or currently being completed) are being used as injection wells and five wells are being used to monitor the effects on the reservoir of producing and injecting fluids.

The test and experimental programs which are being conducted include facilities for testing advanced heat exchangers, a corrosion/deposition mobile test trailer, data collecting equipment and general laboratories. Figure 1. is a list of the activities at Raft River.

A large number of experiments have evolved from the requirements to produce and handle the geothermal fluids. These experiments have provided new insights on a variety of problems such as the use of transite pipe for transporting geothermal fluid. Tests indicate successful use of transite pipe for 150°C geothermal fluids at 1/2 the cost of steel lines. These lines have inherent expansion capability in the joints and can be buried for reduced heat loss. Another cost savings was realized with the use of polyurethane insulation on above ground steel pipe, as well as on the buried transite. The heat loss with 2" polyurethane insulation on a 10" transite pipe flowing 1,000 gpm is less than 1°C per mile of line. This becomes extremely important in using moderate temperature geothermal fluid for producing electrical energy where one degree loss in the transportation lines results in about one percent loss in plant efficiency. Another significant experiment in fluid handling was the use of submersible pumps. The submersible pumps have been found to be reliable for 150°C, with low salinity fluids. Cost of procuring and installing submersible pumps is about half the cost of lineshaft pumps and they are generally available for delivery in less time.

A large portion of the testing at Raft River is aimed towards the economic production of electricity from the moderate-temperature resource. The electrical power-related facilities now under development or on-line are a 60-kW binary test power plant, a 500-kW direct contact pilot plant, a 5 MW(e) geothermal pilot power plant, and a second advanced 5 MW(e) power plant. The 60-kW binary unit is now on-line and has been operating successfully for several months. The first 5 MW(e) pilot power plant is now scheduled for full-power operations in early 1980. In addition to the electrical power facilities, a comprehensive testing program is being undertaken for utilization of the moderate temperature resource in direct applications.

The direct applications program is divided into three elements: the beneficial uses element, the hardware systems element, and the heat dissipation/soil warming element. Since most of the known moderate-temperature geothermal resources of the United States are located in areas which frequently experience water shortages, the beneficial use of hydrothermal fluids, after energy extraction, may enhance the competitive economic position of geothermal energy. Geothermal water is being applied on a 25-acre agricultural plot at Raft River by sprinkler and flood irrigation to field crops of alfalfa, barley, and sugar beets. Results are being compared with control crops watered from existing shallow irrigation wells and from the Raft River. Analyses are being made of comparative yields, nutritional value, accumulation of fluorides and heavy metals, salt tolerance, and changes in soil chemistry. In the aquaculture facility at Raft River, channel catfish, tilapia, and freshwater shrimp are being cultured in a grow-out cycle in which the species are reared to marketable size in geothermal water. A subsequent phase of the work will study the reproduction and spawning phase of the species' life cycle. The three culture species will be evaluated for growth rates and biomass accumulation of minerals and fluoride. An intensive aquaculture program has the potential to economically produce high-quality protein on a year-round basis in temperature-controlled geothermal fluids. Future expansion of the direct applications of geothermal energy may, in some cases, depend upon advanced concepts in refrigeration, in heat exchangers, and also modification of industrial processes to operate at lower temperatures. Figure 2. is a partial list of the current Raft River experiments.

At the Raft River Test Site, work is being undertaken on a variety of projects aimed at developing technology which will enhance the possibility

of geothermal energy usage.

- ° Lithium bromide refrigeration units and ammonia absorption refrigeration/deep cooling units will be operated at the site using 140°C to 150°C fluids.
- ° Fluidized bed drying techniques using geothermal heat are undergoing tests with potato waste products, sugar beet pulp drying, grain drying, and alfalfa drying.
- ° Low-temperature heat exchangers are being tested to evaluate their use in domestic and commercial space heating.

A more unique series of tests being conducted at Raft River involve heat dissipation directly to the soil through soil warming using an underground cooling grid. Cooling low temperature geothermal power plants with conventional cooling towers would use three to ten times the amount of water needed for a high temperature fossil fired plant. This, of course, is inherent in the thermodynamics of heat engines. At Raft River heat is being dissipated into the top five to six feet of soil under tree and field crops. The objective is first to determine the economics of heat dissipation into the soil and second to determine the enhancement of plant growth as a result of the warmer soil. Success of this experiment will have far-reaching effects in arid parts of the world where hydrothermal reservoirs are often located.

As one can see, the Raft River facility is truly a multi-purpose facility. The attached summary details the current through 1984 test plans, including the number of engineering and direct applications experiments on-line.

Figure 1.

SUMMARY OF RAFT RIVER ACTIVITY

	78	79	80	81	82	83	84
NEW WELLS DRILLED	3	3	4				
OPERATIONAL PRODUCTION WELLS	4	6	8	8	8	8	8
OPERATIONAL INJECTION WELLS	3	4	6	6	6	6	6
MONITOR WELLS	7	10	10	10	10	10	10
ENGINEERING DEVELOPMENT EXPERIMENTS	24	27	35	35	30	28	22
DIRECT APPLICATION EXPERIMENTS	5	6	5	5	4	3	2
OPERATIONAL POWER SYSTEMS	1	2	3	3	3	4	4

Figure 2.

PRINCIPAL EXPERIMENTS AT RAFT RIVER

Soil Cooling
Soil Heating Agriculture
Aquaculture
Agriculture
Fluidized Bed Drying
Gas Air Conditioning
Component Testing
Tube & Shell Heat Exchanger
Direct Contact Heat Exchanger
60-kW Turbine-Generator
Environmental
Reservoir Engineering
Heat Dissipation (Pond Cooling)
Supply Well Mixing Tests
Injection Testing
Aerated Geothermal Water Corrosion
Cooling Tower Chemistry of Brine as Makeup Water
Sulfide Oxygen Scavenge Test
Asbestos Cement Pipe
Downhole Pump Test
500-kW Turbine-Generator Direct Contact

Geothermal Resources Council, TRANSACTIONS, Vol. 2 July 1978

DRILLING AND DIRECTIONAL DRILLING A MODERATE-TEMPERATURE GEOTHERMAL RESOURCE

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INTRODUCTION

The high cost of geothermal well drilling has caused great concern in the geothermal community, because of the direct relationship of well cost to power-on-line costs. The utilization of large quantities of moderate-temperature geothermal fluids (300°F, or 150°C) for electric power production at the Raft River, Idaho Geothermal Project creates even larger concerns about well costs. Various techniques were used during the exploration and drilling of the present wells, to improve resource detection and well production. These techniques will be utilized in all future drilling at Raft River.

Some resources have been overlooked because of the use of standard drilling methods. Each type resource will require unique techniques for detection and enhancement. The lower the temperature of the resource, the more difficult it will be to detect. Dry steam and high-temperature water-dominated resources are rare anomolies. Moderate-temperature resources, however, should be quite abundant throughout the West. It is necessary to detect such resources, enhance the production or injection capabilities of each well, and at the same time increase well lifetimes in order to keep moderate-temperature resources competitive with other forms of energy.

Three production and two injection wells have been drilled in the Raft River Valley, with an additional production and an injection well to be completed in the summer of 1978. This paper describes the techniques used in the drilling and testing of these high-fluid-volume wells.

Exploratory Drilling

During the exploratory phase, only the surface casing was run and cemented; if no resource was found, the cost invested in the dry well would then have been as small as practical. Below the casing, the well was drilled with water, rather than mud. This prevented the plugging of permeable producing zones and fractures and kept the fluid column as light as possible, so that geothermal water could enter the hole. Air or foam would lighten the column even more, but these measures have not been necessary at Raft River. Water drilling may not be a necessity with very high-temperature resources, but is the only recommended method for medium temperatures and lower artesian pressures. Care must be exercised in the use of water drilling.

After drilling and locating the resource, the well can, in many cases, be completed by cooling with injected cold water and by cementing in the production casing. This control method did not work at Raft River. A very permeable zone between 1600 and 2400 ft (490 to 730 m) accepted the hot water from the reservoir and all injected cold water. The well could not be "killed" with this method. An alternate method, that of filling the lower portion of the hole with sand, was very successful and resulted in effective control prior to casing the well during well completion. Sand was then drilled out to complete the well.

Cost again became a major factor for design of RRGE-3. Two major areas of well cost are casing and cementing. Casing calculations determined that over a 30-year production period, a 1000-gallon-per-minute well, with 9-5/8 in. (24.45 cm) production casing, would be more economical (including the cost of pump operation and the increased pressure drop in the casing) than a well with 13-3/8-in. (34 cm) production casing. The length of the production casing was reduced by hanging it from the bottom of the surface casing (at 1200 ft); thereby lowering the total well cost. Utilizing a Basch-Ross liner hanger with circulating ports allowed crews to squeeze cement from the top of the hung production string in the event of remedial cementing. This reduced the very costly perforating squeeze cementing and saved more than 50%. The use of this technique has been considered acceptable by the State for such moderate-temperature (low-pressure) wells.

Also because of costs, much time and planning have been devoted to cementing techniques. Perlite and silica cements have been used, and stage cementing tried--all with less than desirable results. We are still attempting to find a cement and technique which will be effective for Raft River hole conditions. This year, two different cements are to be used in the wells, so that the application and long-term retrogression of two cements can be compared.

Multiple-Leg Wells

Well RRGE-3 became an experiment in well stimulation to reduce well costs by directionally drilling open-hole legs through the production zone below the casing. This increased production for a minor increase in well cost. The first leg was drilled westwardly to a depth of 5853 G.L., with disappointing production results. Analysis showed an apparent lack of producing fractures, so the decision was made to drill two additional legs, in hopes of encountering production fractures. Leg B was drilled northeastwardly to a depth of 4432 ft (1351 m); Leg C, northwesterly to a depth of 5917 ft (1803.5 m). Production increased by 500% with the completion of the third leg.

Although we were unable to prove what would happen in a homogeneous producing layer, our calculations for the Raft River reservoir imply that an extra leg that gets as far away as 400 ft (122 m) will increase the cost 20%, while increasing production 50%.

A second multiple-leg production well, RRGP-5, will be drilled this June. Injection Well RRGI-4 will be deepened and completed as a multiple-leg production well in October.

Where formations are tight, or where formation plugging is a problem, producing well life time and well operating pressures can be improved by using multiple-leg wells. Formation plugging in wells with two phase then is apparently most likely to occur near the well bore. By directionally drilling multiple legs, penetrating the injection zone, the rate of plugging should be proportionately reduced.

SUMMARIES
THIRD WORKSHOP
GEOTHERMAL RESERVOIR ENGINEERING

December 14 - 16, 1977

Stanford Geothermal Program
INTERDISCIPLINARY RESEARCH
IN ENGINEERING AND EARTH SCIENCES
Stanford University, Stanford, California

UPDATE ON THE RAFT RIVER GEOTHERMAL RESERVOIR

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ABSTRACT

Since the last conference, a fourth well has been drilled to an intermediate depth and tested as a production well, with plans to use this well in the long term for injection of fluids into the strata above the production strata. The third, triple legged well has been fully pump tested, and the recovery of the second well from an injection well back to production status has revealed very interesting data on the reservoir conditions around that well.

Both interference testing and geochemistry analysis shows that the third well is producing from a different aquifer from that supplying the No. 2 well. There is an effective barrier, yet unidentified as to structure, making pressure communication between these aquifers quite negligible. These results have led to significantly different models for the aquifer system than those previously believed to apply.

E 4-WELL SYSTEM

The Raft River Geothermal Program now has 3 deep production wells, with producing zones between 3750 and 6000 ft. An intermediate depth well was recently drilled for injection testing into the zone between 1850 and 2500 ft. Figure 1 shows the location of the wells with respect to the major faults in the region. Figure 2 shows cross sections of each well. Additional details on these wells may be found in Reference 1 (last year's conference).

PRODUCTION TESTING

RRGE-1

This well has been used as a production well for the last 18 months, with greater than 95% capacity factor. It has been supplying fluids for a variety of heat exchanger tests, corrosion coupon tests, and water for several direct heat utilization experiments. Flow rates were deliberately throttled to supply only the fluids essential for these tests (150 to 300 gallons/minute (0 to 20 liters/sec), all using the artesian head. Pressures of 100 psig minimum have been maintained in all heat exchanger and coupon testing to prevent off-gasing and entry of air into these systems.

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* This work has been performed under contract to the U.S. Department of Energy, Division of Geothermal Energy, and Idaho Operations Office.

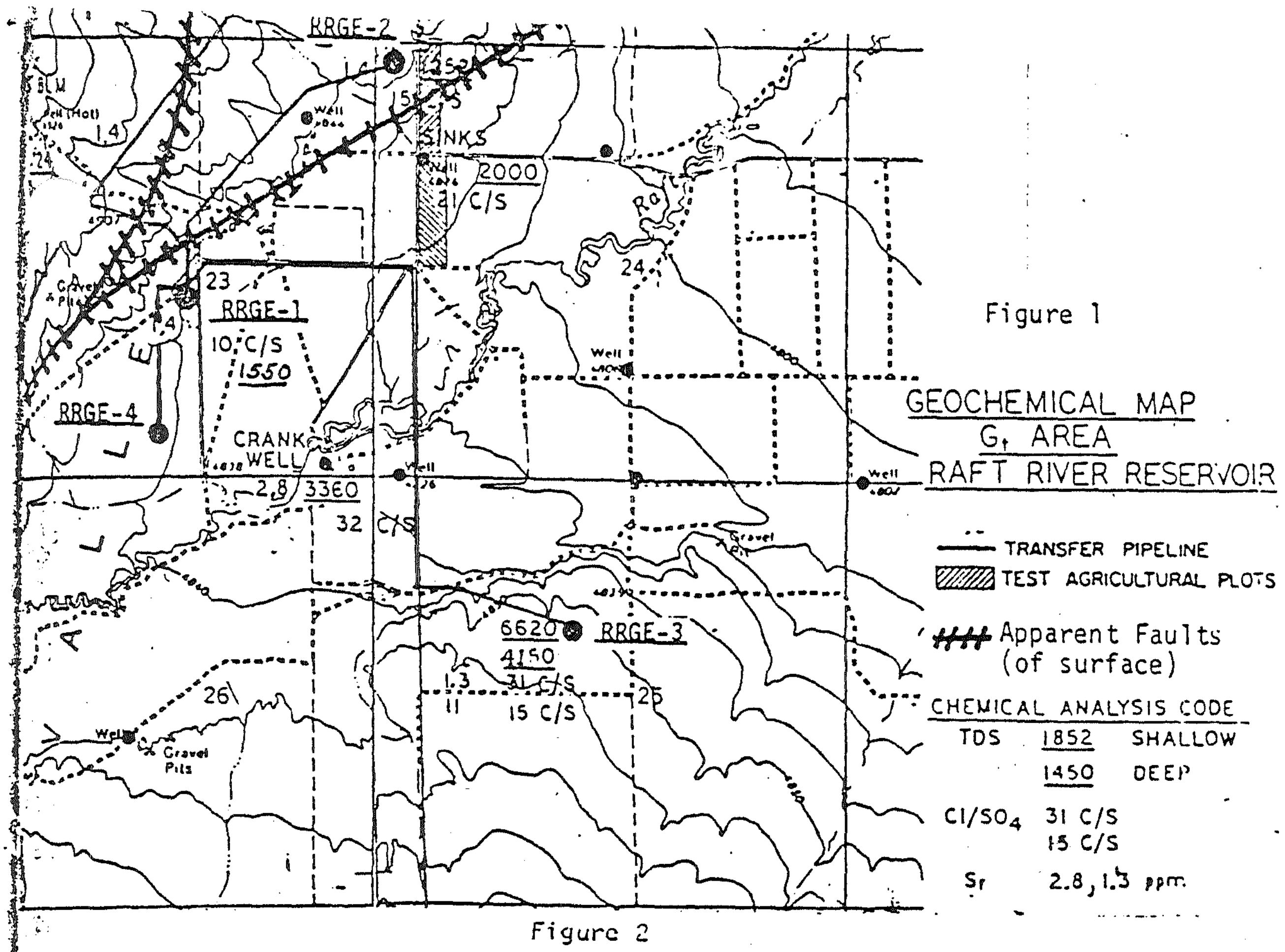
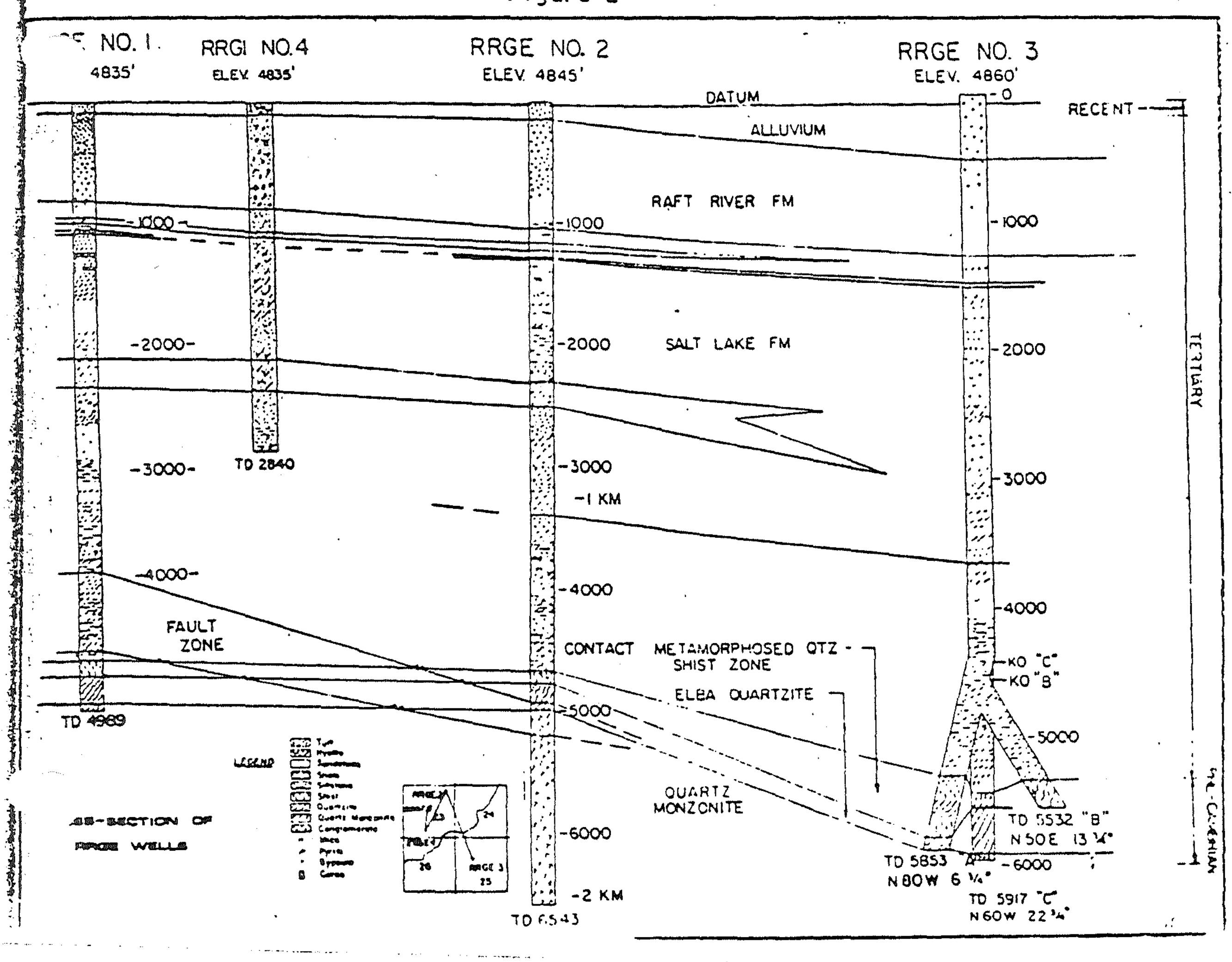


Figure 1

GEOCHEMICAL MAP
G, AREA
RAFT RIVER RESERVOIR

Figure 2



...SS-SECTION OF RRGE WELLS

The well performance data during the 18 months has shown no decrease in ctivity vs pressure, if anything a slight increase. The drawdown ince the start of the long term operation is so far, on the time logarithmic scale. Short term fluctuations in flow (and hence pressure) have occurred as demanded by the variety of experiments, and are the predominant variable change.

The apparent productivity curve for this well is as shown in Figure 3. It is the most productive well in the reservoir. The chemistry of the fluids have remained essentially the same as after the first thorough flow testing, 2-1/2 years ago. Dissolved solids are 1550 ppm (mg/liter). Temperature has shown no change during this period. At these low flow rates, with the large 13-3/8 in. casing, the temperature loss in the well bore is only approximately 12°C (22°F). At the nominal design flow rate of 1200 gal/min (80 liters/sec) planned for this well with a pump in place, temperature loss should be reduced by nearly a factor of 4. Production zone temperatures have held at 147°C (296°F).

RRGE-2

No significant flow testing during the last 12 months.

RRGE-3

A submersible pump was installed in this well at the 800 ft (244 m) level. Pump testing at 500 to 600 gal/min (90 l/sec) have been conducted for periods of several weeks to a month in duration. These have been at stant flow, using the Thies asymptotic semilogarithmic approach to obtain transmissivity and permeability thickness factors. Except for some possible early time effects before encountering a nearby boundary, the Thies analysis shows excellent linearly (semilog plot), giving a T = 850 ± 100 gal/day ft and kH - 8000 ± 1000 millidarcy-ft.

Pressure communication does not appear to occur, at least unambiguously over a two week period, with RRGE-2, 7000 ft away, as measured with a quartz transducer with ±0.01 psi sensitivity. Somewhat less ambiguous indication of pressure communication has been observed with the intermediate depth RRGI-4, 5000 ft away. The chemistry of the RRGE-3 well has been generally consistent throughout 1-1/2 years of limited testing (because of difficulty in disposing of the water) at 4150 ppm (mg/liter).

RRGI-4

This well was completed in May 1977, to be used for injection testing of the feasibility of disposing of water into the intermediate depth aquifer. It has 13-3/8 in. casing to 1835 ft, and is barefoot from there to its total present depth of 2840 ft. The relatively permeable section appears to extend from the casing bottom to about 2500 ft.* Though the well accepted

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* When drilling out the shoe, the lower two sections of casing (80 ft total) dropped off and are wedged between 1895 and 1975 ft, effectively blocking out the formation in this region.

ected water quite readily, the production testing (the well has a hot artesian head of about 40 psig at 250°F) gave a transmissivity of 1600 ± 200 gal/day ft. This value is not much different from RRGE-2. The well has about 2300 ppm (mg/liter) solids coming from the producing region. It has slight pressure communication with RRGE-3, quite noticeable communication with the USGS No. 3 well (1300 ft deep, 2200 ft away), and no detectable communication to date with RRGE-1 or 2.

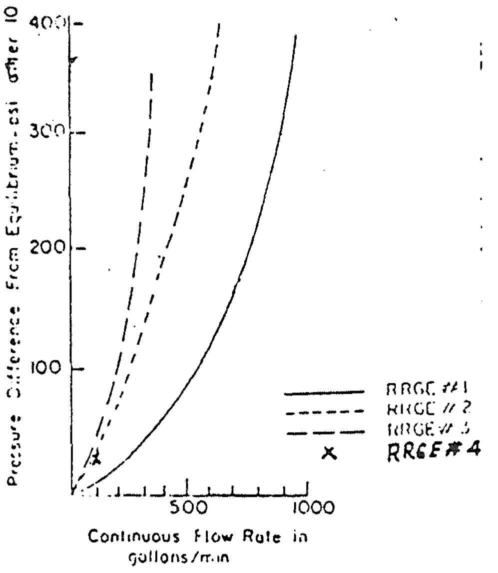

Figure 3 - Well productivity vs., drawdown after constant flow for 10 yr period. Note: Wells 1, 2, 3 have a positive (artesian) head of 150 psig when at hot"equilibrium." The 4th well has an artesian head of 40 psig.

GEOCHEMISTRY

The chemistry of the waters produced from the three deep wells and the Crank (400 ft or 122m) and BLM (500 ft or 152m) wells has shown that the chemical species in these wells seem to be originating from two quite different systems. The one has chemistry similar to RRGE-3 (4150 ppm), the other similar to RRGE-2 (1250 ppm). RRGE-1, the BLM, and the Crank wells appear to be mistures of these two systems, as shown in Table 1. In that Table, X_m represents the fractional contribution from the system representative of RRGE-2.

It thus appears that the most chemical laden waters and those with the highest indicated reservoir temperatures are upwelling in the region of RRGE-3 and the Crank well, and leaking into the area near RRGE-1 and the BLM well. Much purer waters are apparently feeding RRGE-2 (to the northeast) and leaking into the BLM and RRGE-1 areas. RRGI-4, for the little it has flowed, also seems to be composed of both waters.

CONCLUSIONS

The long hypothesized model of the geothermal heat source being located away from the immediate area, with the hot waters being fed into the region of the wells via the "narrows" structure to the southwest, is not supported by the geochemical analysis. Instead, it would seem that another model would be that of a hot plate effect under much of the valley, with a localized somewhat hotter, poorly convective region near RRGE-3.

TABLE I

TOTAL DISSOLVED SOLIDS AND MIXING FRACTIONS IN THE RAFT RIVER WELLS

	RRGE-2	RRGE-1	BLM	Crank	RRGE-3
TDS	1267	1560	1640	3720	4130
X_m	1	.898	.870	.143	0
Apparent Reservoir Temperature					
S_iO_2	158°C	155°C	--	--	165°C
Na/K/Ca	185°C	180°C	--	--	190°C

It does appear that a barrier of some type exists between RRGE-3 and the other two deep wells, restricting both pressure and flow communication, isolating the two systems with quite distinctly different chemistry.

Finally, the longer term test has not shown any major boundary restrictions or with significant regions of highly channelled flow (none isotropic). Based on these tentative conclusions and the information presented in Ref. 1, one can conclude the following about the known reservoir, that <u>within a mile</u> of the existing three wells.

Minimum area of <u>Known</u> reservoir ∿ 5 sq mi. (2)

Geothermal Aquifer Capacity - 300,000 acre-ft, with effective porosity of ∿ 0.15.

Near surface aquifer probably contains. 12 million acre ft, and sees annual precipitation of 200,000 acre ft (2)

Geothermal aquifer heat content (<u>known</u> reservoir only, heat above 250°F only) = 160 MW-Centuries (about 20 MW-Centuries net electrical output with binary-isobutane conversion system.

<u>REFERENCE</u>

1. D. Goldman, J. F. Kunze, L. G. Miller, R. C. Stoker, "Studies on the 3-Well Reservoir System in Raft River, 2nd Workshop on Geothermal Reservoir Engineering, Stanford University 1976.

2. Geothermal R&D Project Report for October 1976 to March 1977, TREE-1134, EG&G Idaho, Inc.

3. E. H. Walker, L. C. Dutcher, S. O. Decker, and K. L. Dyer, The Raft River Basin, Water Intermountain Bulletin No. 19, State Department of Water Resources (1970).

Lowell

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EG&G Idaho

FORM EG&G-954
(Rev. 9-76)

INTEROFFICE CORRESPONDENCE

date September 15, 1976

to J. F. Kunze
Office

from R. C. Stoker R. C. Stoker

subject RESERVOIR ENGINEERING SEMINAR SUMMARY - RCSt-25-76

A Raft River reservoir engineering seminar was held on May 21, 1976 at the Salt Lake City Airport Hawk's Nest Room. Those in attendance were as follows:

Steve Oriele, USGS, Denver
Harry Covington, USGS, Denver
Frank Trainer, USGS, Menlo Park
Manual Nathenson, USGS, Menlo Park
Dave Nichols, USGS, Sacramento
Jerry Crosthwaite, USGS, Boise
Ken Dunn, Idaho Dept. of Water Resources
Dale Ralston, Idaho Bureau of Mines and Geology
Roy Mink, Idaho Bureau of Mines and Geology
John Griffith, ERDA-Idaho
Jim Cotter, ERDA-Nevada
Gary Sandquist, University of Utah
Steve Swanson, University of Utah
Paul Witherspoon, LBL (Berkeley)
T. N. Narisimhan, LBL (Berkeley)
John Auten, REECo
Fred Huckabee, REECo
Arfon Jones, Terra Tek
Jay Kunze, INEL
Lowell Miller, INEL
Dennis Goldman, INEL
Bill Kettenacker, INEL
Jim Lofthouse, INEL
Susan Prestwich, INEL
Roger Stoker, INEL

Current work status and available data were presented by various people connected with the project and are summarized below. Open discussions were held in conjunction with the presentations and the resultant recommendations or observations concerning further work at Raft River are included under B. Summary and Future Plans on page 7.

A. Presentations

1. Well Status and Future Plans - Kunze

A short summary of the project and the experience acquired in drilling the three production wells was presented and discussed. Site locations were pointed out (Attachment 1) and a temperture profile of RRGE-2 (Attachment 2) was discussed in detail. This particular profile was taken after approximately eight million gallons of cool water had been pumped down the well and exhibits the temperature recovery after limited flow from the well.

The configuration and relationship of the three legs drilled in RRGE-3 were displayed (Attachment 3) and the temperature logs (Attachment 4) taken before production casing was installed were discussed. The flow tests and electric logs conducted prior to setting casing were shown to confirm the casing setting depth of 4,237 feet. Temperature logs (Attachment 5) and profiles (Attachment 6) from the leg "A" were presented and discussed. The poor flow (∿ 80 gpm) and geysering action from RRGE-3A were pointed out. The geysering action operated on a 9 1/2 minute cycle; 3 1/2 minutes of flow at ∿ 220 gpm and 6 minutes of no flow. A summary of drilling and testing RRGE-3 A and B is shown in Attachment 7.

NOTE: After all three legs were completed in RRGE-3, flow rates of 800 gpm (cold) and a bottom hole temperature of 298°F were recorded.

The chemical water analysis of all three wells was presented (Attachment 8) and the near term testing plan (Attachment 9) was reviewed.

2. Production and Reinjection Performance Data - Miller

A summary of well production and reinjection characteristics were presented. This included the early time cool water high production rates followed by lower hot water flow rates characterized by choking due to flashing steam within the wellbore. It also included more detailed information about RRGE-2 temperature recovery following the injection of cold water (eight million gallons). See Attachment 2.

The transfer line between RRGE-1 and -2 was discussed and the one proposed between RRGE-1 and -3 was outlined (Attachment 10). The favorable experience gained from the downhole pump employed at Raft River was discussed. The relatively minor modification to the lower pump motor seal should solve the problem of water leakage that was experienced in the lower motor. The total pump assembly was satisfactory except for the water leakage and there was no evidence of corrosion or erosion. The pump operated for about two weeks running time and delivered flows up to 1800 gpm from RRGE-1.

3. Lithology, Cover and Permeability Data - Stoker

The structural controls around all three wells were explained, through cross sections, as determined from USGS data (Attachment 11, 12, and 13).

The lithology of all three wells (Attachment 14) was presented and discussed in detail. Actual core samples were examined and the presence of extensive fracturing was noted to be associated with the production zones. Specific core permeabilities were presented from each of the three wells. These permeabilities were measured under "in situ" simulated conditions by Terr Tek and represent values as much as 10 to 100 times lower than if measured under atmospheric conditions. See Attachment 15.

It was reiterated that the RRGE-3 (leg "A" hole) was a very poor producer (80 gpm free flow and geysering) drilled through limited fracture zones. Leg "B" was drilled through more permeable fracture zones and production increased to 250 gpm. Leg "C" encountered extensive fracturing and a total cold flow rate of 800 gpm. In all three wells, the production zones have been located in the highly permeable fracture zones.

The gneisic fabric of the quartz monzonite in the upper portion indicates that the rock underwent a crushing action probably due to differential flow during emplacement (protoclastic). The alteration of the biotite and plagioclase indicates a high degree of late stage hydrothermal activities.

The phyllitic schist of the metamorphased zone occurring directly above the quartz monzonite is indicative of regional (widespread) metamorphism (rock recrystallization). The parent rock was obviously an argillaceous (clay) sediment. The metamorphism is probably not a result of the quartz monzonite emplacement but rather a widespread regional feature that occurred after the quartz monzonite emplacement.

4. Down-Hole Pressure Response and Interpretation - Witherspoon

The testing and monitoring procedure employed during the interference testing of RRGE-1 and RRGE-2 was reviewed and explained. A series of three drawdown tests were conducted in RRGE-1 and RRGE-2 during September and October, 1975 and shown in Attachment 16.

The acquired data was presented as follows:
a. Computation of reservoir characteristics for RRGE-2, Attachment 17.
b. Pressure response at RRGE-2, Attachment 18.
c. Computation of reservoir characteristics between RRGE-1 and RRGE-2, Attachment 19.
d. Lunar attraction effects in Raft River reservoir, Attachment 20.
e. Pressure response at RRGE-1, Attachment 21.

The interpretation of the interference testing was summarized as follows:
a. The Raft River reservoir is apparently very large.
b. The reservoir shows boundaries that must be located and defined through further testing.
c. The reservoir shows high permeability and Kh factors. Compared Raft River (Kh = 228,000 md ft) with East Mesa reservoir (Kh = 30,000 md ft, at best).
d. Further extensive reservoir testing should be accomplished involving additional wells for more detailed, precise and extensive

information based on better data.

e. The reservoir appears to be adequate to support a 10 MW power plant or greater based on this limited data.

Similar interference tests were conducted in the East Mesa area of California involving three wells rather than just the two wells as in Raft River. The test results show a superior performance by the Raft River reservoir although the data is more limited and not as precise.

5. USGS Summaries

a. Raft River Groundwater - Nichols

The model depicting the groundwater situation in Raft River was review and explained. Two cases were presented based on two different values of transmissivity. The first case (high transmissivity) requires an average annual net recharge and discharge of about 61,500 acre-feet. A vailable data states two different total available recharge rates; 42,130 acre-feet estimated by Walker and others (1960) and 74,930 acre-feet of Nace and others (1961). The net flux is given as a solution with this model not the total recharge and discharge. However, the total recharge and discharge will be greater than the net flux.

The computer model had 350 grid points for finite differential modeling, on a one mile spacing grid. It has predicted a maximum decline of 82 feet in the water table over a five year period if pumped at an additional rate of 19,000 gpm. This assumes a consumptive use of the water with no recharge or reuse as a means of providing once through cooling for a 10 MW plant. Although non-recharge of cooling water is not contemplated, the information provides base line predictive data.

From available data, it was determined that the water table has declined as much as 20 feet from 1952 to 1965 due to irrigation water consumption.

b. Raft River Valley Temperature Profiles - Nathenson
Several wells and holes have been monitored for temperature profiles by Urban and Diment of the USGS, Sacramento. This data was reviewed and is shown in Attachments 22 through 32.

Indications are that, for the shallow depths, the temperature profiles increase with depth toward the Narrows (southwest portion of the valley). I.D. No. 4 and 5 both display a temperature reversal within the first 200 feet of depth.

c. Near-Surface Aquifer Measurements and Analysis - Crosthwaite
The new-surface aquifer investigations being conducted were reviewed. D/O^{18} is being pursued as a means of determining the Raft River recharge and the Goose Creek as the discharge areas.

d. Raft River Lithology - Covington
In general, the area consists of gravels down to about 2,000 feet. The fault zone was encountered at 4,050 feet and caprock (siltstone) at ~ 4,500 feet in RRGE-1. The rock types were all encountered 50 to 200 feet deeper in RRGE-2 than RRGE-1. There is good correlation between the two wells.

6. <u>Permeability Measurements - Jones</u>

The core samples from RRGE-1 and -2 have been measured for permeabilities under "in situ" conditions (temperature and pressure). These results are a factor of 10 or more less than the results obtained under atmospheric conditions. Generally, the results obtained from the production zones of the wells have been above average. Moreover, the rocks exhibit high permeability values when fractures are included in the test sections.

7. Groundwater Measurement - Ralston

Data was presented which reflects on the groundwater system in Raft River. Transmissivity (T) factors are on the order of 100,000 - 200,000 gpd/ft. The storage coefficient (S) is about 0.001 and the leakage coefficient is 0.4 to 0.5. These factors apply to the valley proper while the area above the Narrows is a little lower in transmissivity values but about the same for storage and leakage coefficients.

8. INEL Raft River Reseroivr Computer Code - Kettenacker

This presentation was deferred due to time limitations and is presented here as Attachment 33 (Letter WCK-4-76).

B. Summary and Future Plans

Several consensus recommendations concerning future planning were made by the seminar participants and are summarized below:

1. Flow RRGE-3 for long period (∿ 30 days); monitor RRGE-1 amd -2 with the quartz crystal surface pressure instruments and RRGE-3 with the downhole pressure probe.
2. Repeat the three well test as above but flow RRGE-2.
3. Repeat the three well test as in 1. above but flow RRGE-1.
4. Conduct reinjection tests and monitor with the quartz crystal probe and surface instrumentation.
5. No reinjection well should be drilled at this time by REECo. REECo should demobilize and move out as soon as possible considering current budget restraints.

6. All three holes should be tested thoroughly and all plausible tests should be pursued for research reasons and to define the reservoir characteristics and boundaries.

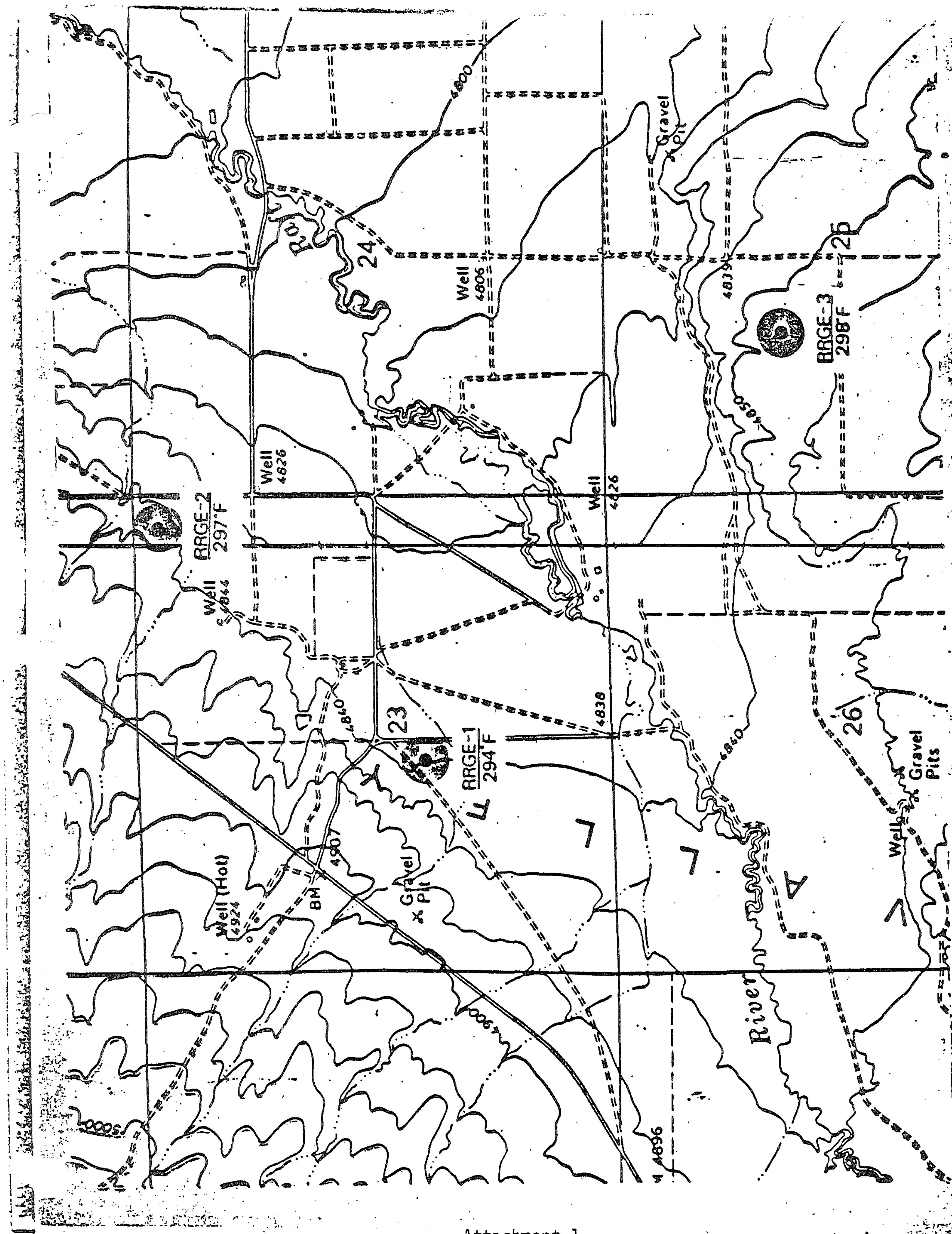
7. The reservoir appears to be limited by fracturing and faulting. That is:

   a. Permeability is reduced away from the fractured zones.
   b. There are localized zones, even around known faults, that lack the fracturing to transmit the existing geothermal fluids into the wellbore. This fact is exemplified by the lack of production in RRGE-3A.
   c. Near verical fracturing occurs in the area and appears to be associated with the major faulting. This fracturing is responsible for good production rates where it has been penetrated.

8. Development of the geothermal resource should be pursued as rapidly as possible.

nn

cc: SDGilliard
DGoldman
WWHickman
WCKettenacker
JHLofthouse
LGMiller
SJPrestwich

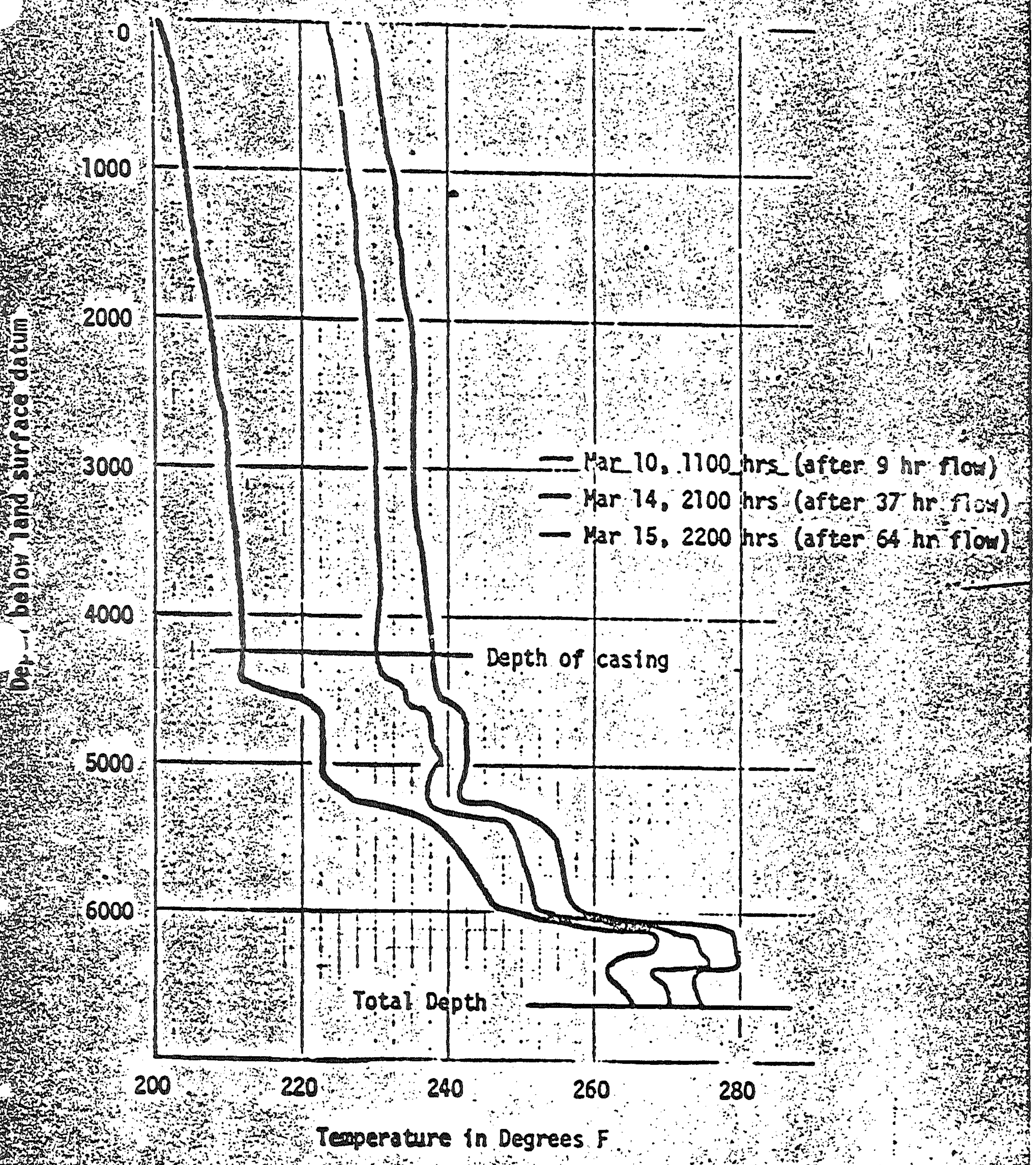


MAXIMUM DOWNHOLE TEMPERATURES OF WELLS

Attachment 1

RAFT RIVER GEOTHERMAL EXPLORATORY WELL NO. 2

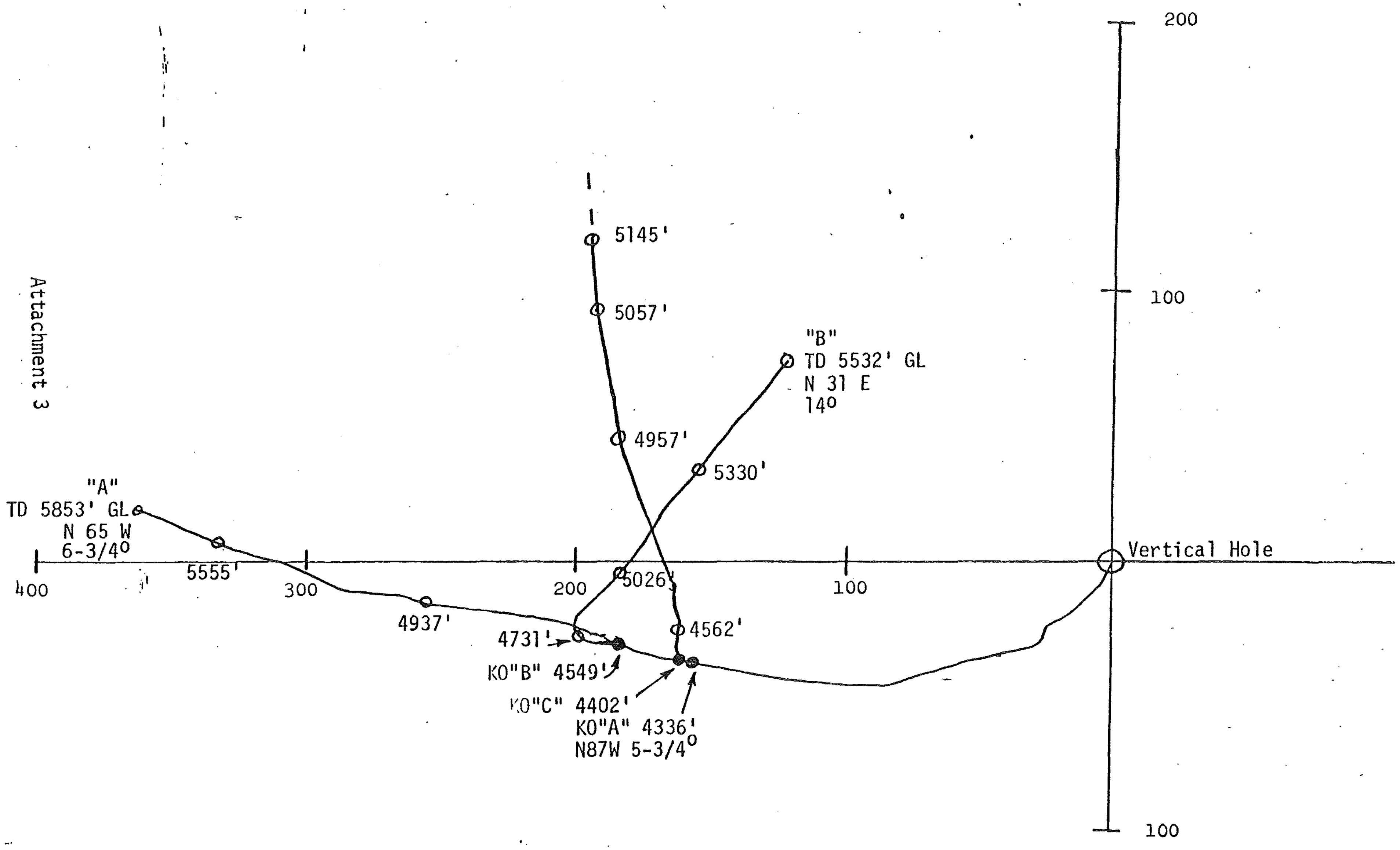
Temperature vs Depth

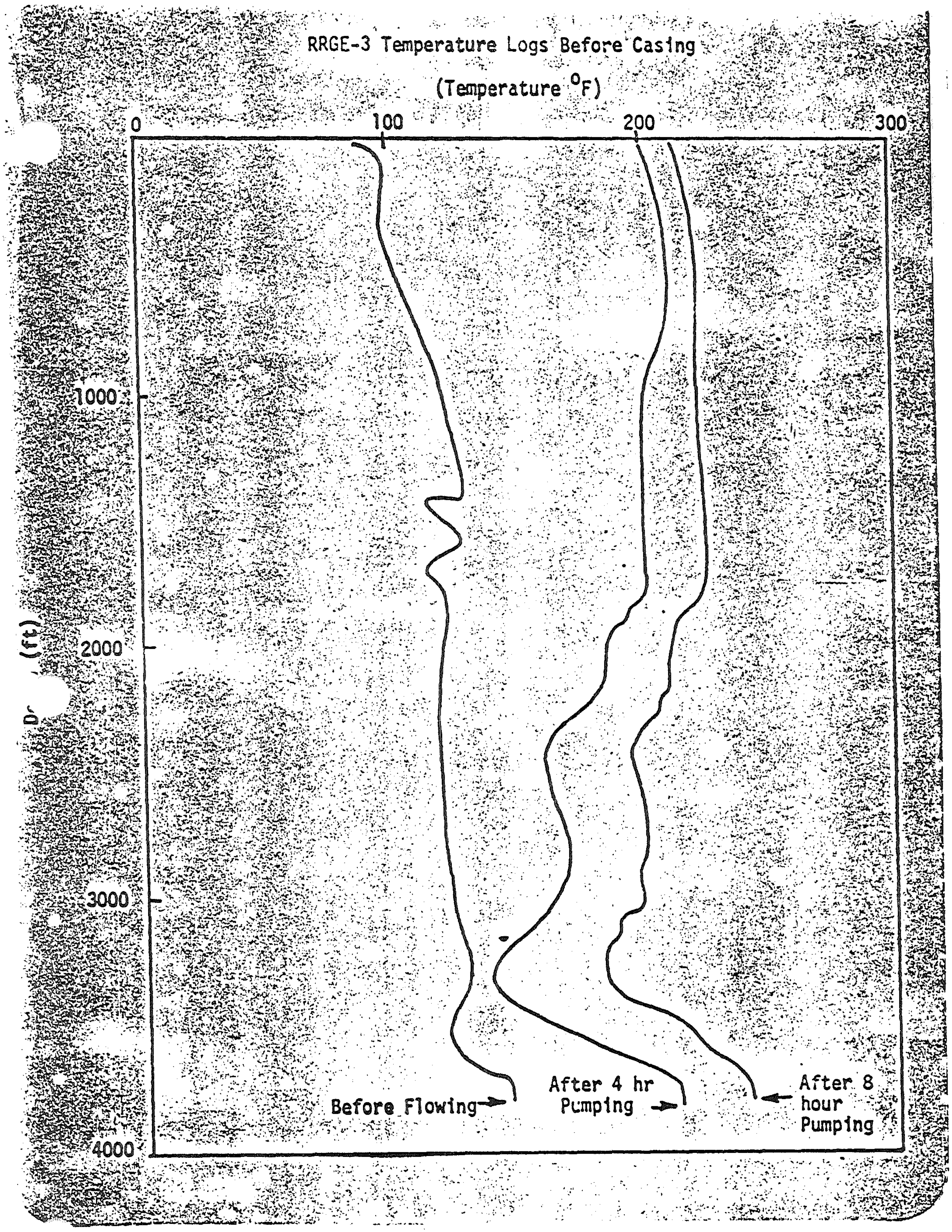


Attachment 2

Attachment 3

RRGE-3



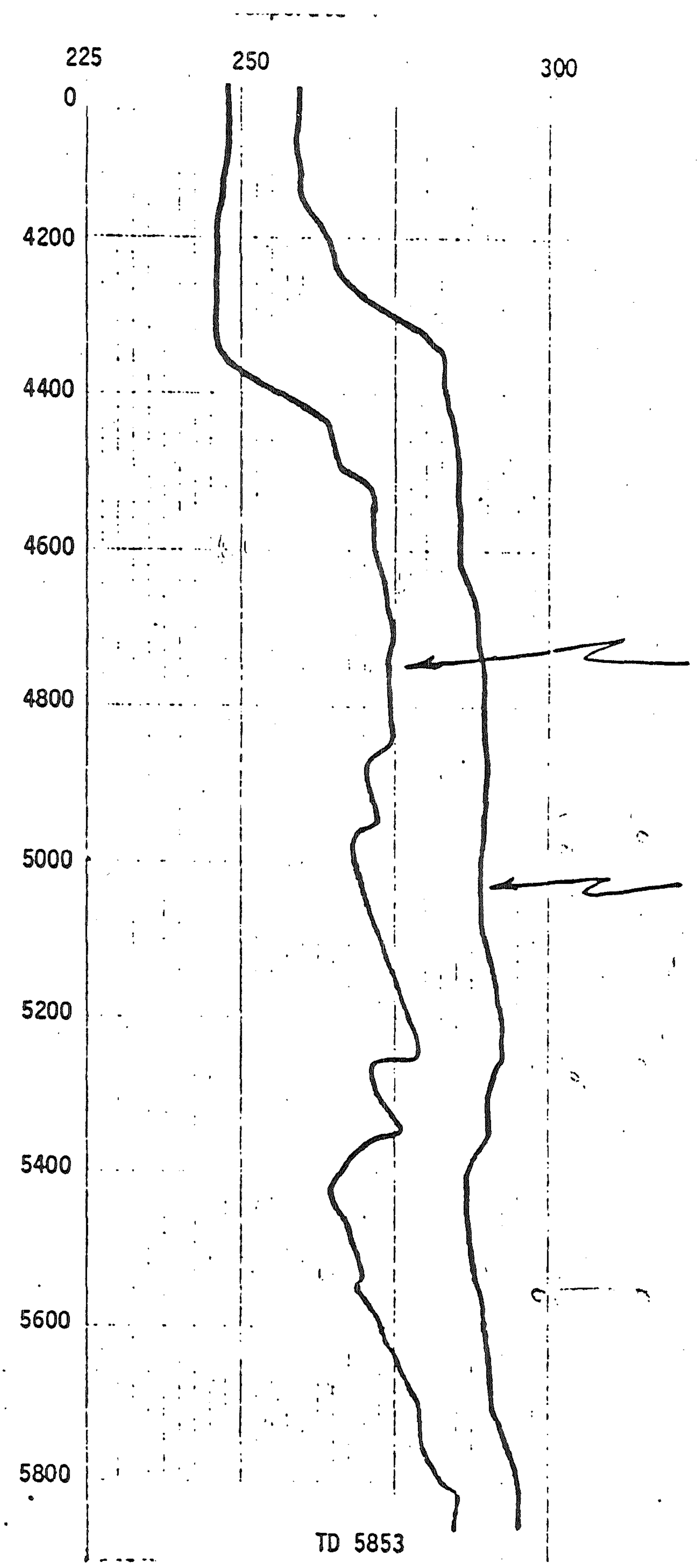


Attachment 4

RRGE 3-A

DRESSER ATLAS

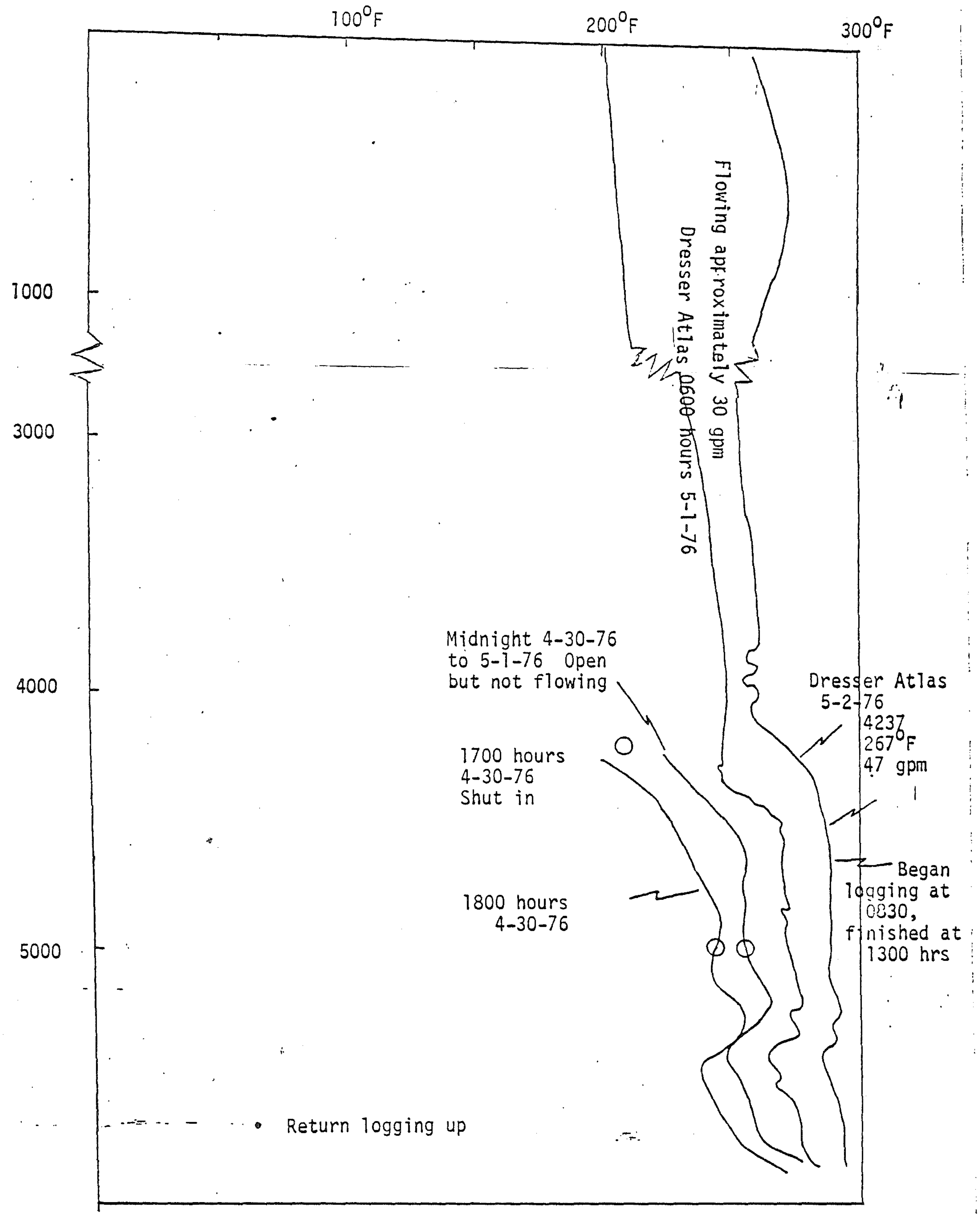
TEMPERATURE LOGS



Run 1 5/1/76
After Drilling Completed
Logging @ 0400
Well Flowing ~ 30 gpm Since 0130
BHT 285°F

Run 2 5/3/76
3 Days Later After 7 Hr. Airlift
Logging @ 0830, Finish @ 1600
Well Open Not Flowing, Flow Started
1730 Hrs.
BHT 295°F

Attachment 5



RRGE-3A - April 30 - May 1, 1976
Attachment 6

RRGE-3

SUMMARY OF DRILLING AND TESTING

SPUDDED IN ON MARCH 28

SURFACE CASING CEMENTED TO 1383 FT ON APRIL 1

DEPTH OF 4241 FT REACHED ON APRIL 16

3 DAYS OF FLOW TESTING AND LOGGING

CASING CEMENTING JOB COMPLETED, SECOND STAGE WORKING FROM
TOP, ON APRIL 21

FIRST LEG COMPLETED TO 5853 FT DEPTH ON APRIL 30 IN WESTERLY DIRECTION
OFFSET 363 FT FROM WELLHEAD, WEST, 2° NORTH
OFFSET 212 FT FROM KICKOFF POINT AT 4318 FT

BEGAN DYNADRILLING SECOND LEG KICKOFF AT 4531 FT
ON MAY 7

BOTTOM HOLE (5853 FT) TEMPERATURE ON MAY 3, 295°F

TEMPERATURE AT 4550 FT ON MAY 3 AND MAY 6, 286°F

TEMPERATURE AT 2000 FT ON MAY 6, 240°F

AS A RE-INJECTION HOLE, 1200 GPM REQUIRED 480 PSIG AT THE WELLHEAD
(HOT WATER VISCOSITY)

- -

AFTER DRILLING SECOND LEG TO 5530 FT IN NORTHEASTERLY DIRECTION

WELL HEAD PRESSURE COLD: 30 SPI
FLOW, WHEN COLD: APPROXIMATELY 250 GPM

Attachment 7

Attachment 8

TABLE I

Well #	Depth (ft.)	Sample Temperature (°C)	Pressure (psi)	SiO_2 (ppm)	Na (ppm)	K (ppm)	Ca (ppm)	Cl^- (ppm)	†HCO_3^-	Geochemical Thermometers (°C)	
										SiO_2	Na-K-Ca
3	3313	73	8	58	805	23	116	1480	---	107	132
3	3806	106	25	90	1790	43	280	3310	40.6	130	129
3	3986	112	8	92	1940	45	293	4210	32.5	131	131
3	4214	99	23	99	1940	46	283	3540	32.5	129	131
3	5700	60	0	56	430	21	75	770	47	66	113
2*	--	108	30	150	484	40	49	829	29	160	182
1*	--	137	150	126	523	37	52	850	45	149	175
Crank	--	--	--	111	1065	35	135	--	--	142	142
BLM	--	--	--	107	550	19	55	1139	83	140	140
Irrigation water for	--	--	--	45	--	--	--	--	--	96	--

---

* Data from most recent sampling was used.

† As μg/ml $CaCO_3$.

NEAR TERM TESTING PLAN

JUNE 1 - 15

FLOW TEST NO. 3, WITH DOWNHOLE INSTRUMENTATION IN NO. 1 AND NO. 2, EACH OF THOSE SHUT-IN

JUNE 15 - JULY 8

FLOW TEST NO. 2 AND DISPOSE OF WATER IN AREA

JUNE 15 - DURATION

FLOW NO. 1 FOR ENGINEERING TESTING

JUNE 20 - (IF POSSIBLE OR THEREABOUTS)

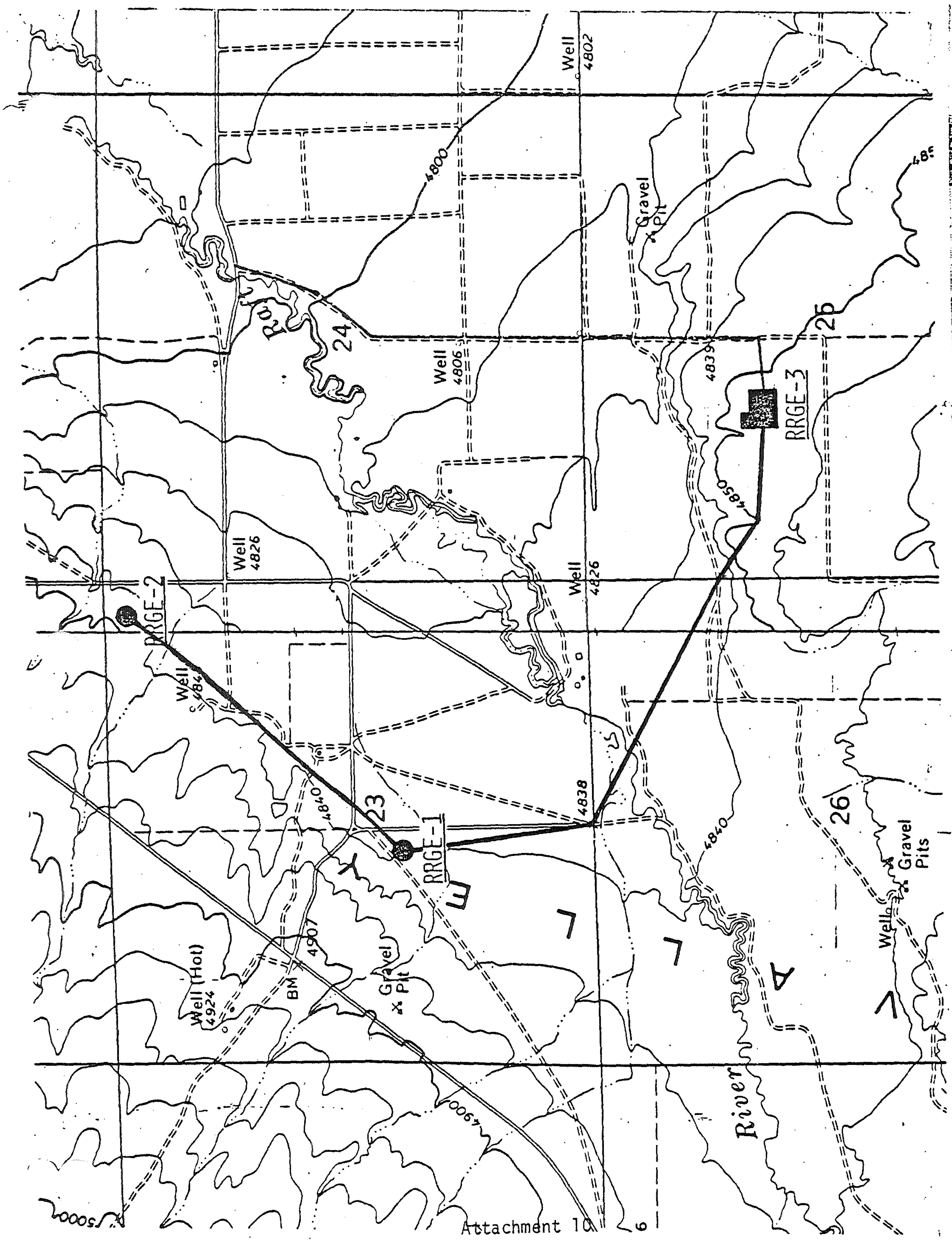
DOWNHOLE PUMP INSTALLATION IN NO. 3

JULY 6

BEGIN REMOVING DRILL RIG IF NO FUNDS FOR REINJECTION HOLE

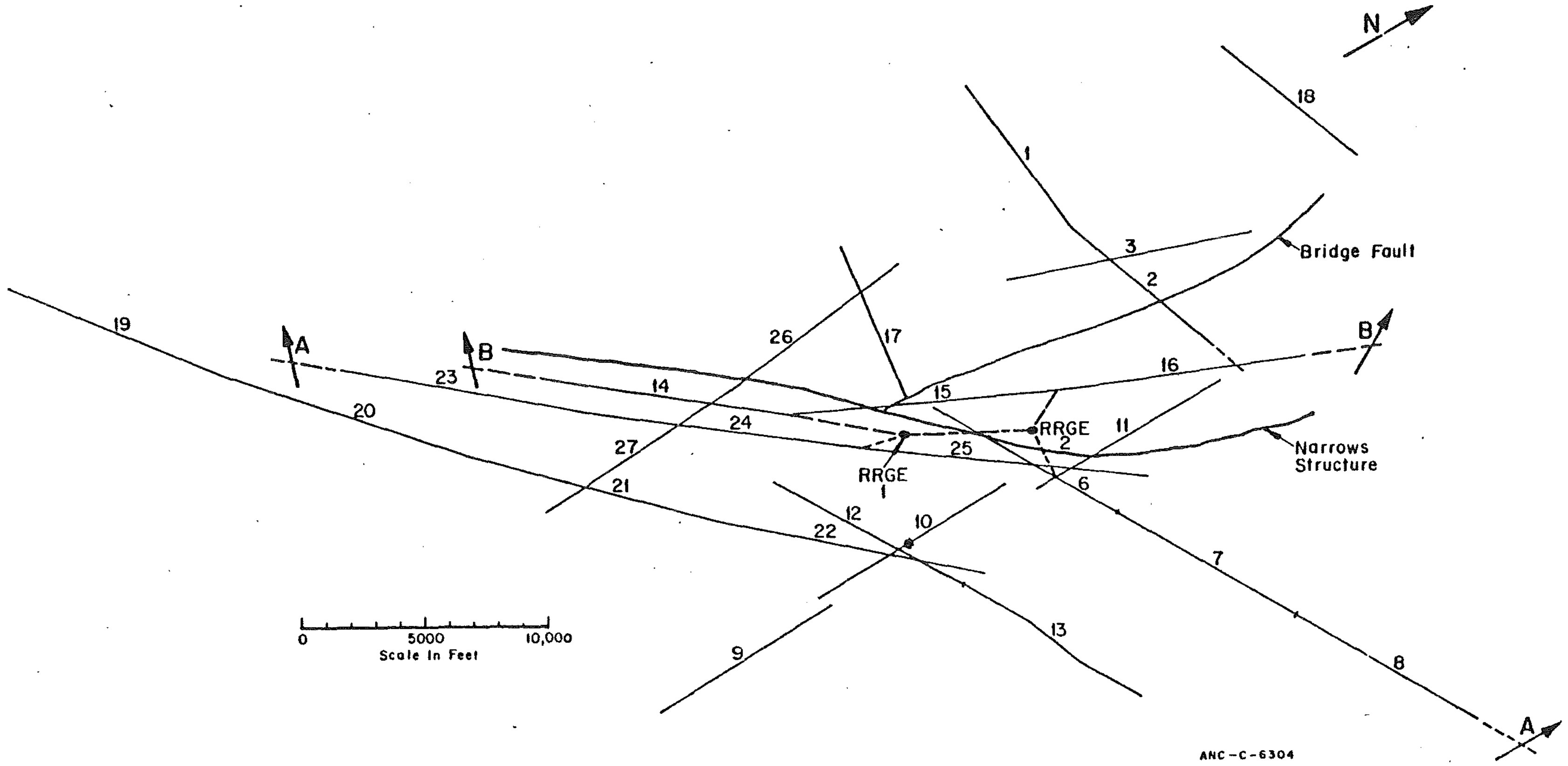
JFK:5-21-76

Attachment 9



Attachment 10

Attachment 11



ANC-C-6304

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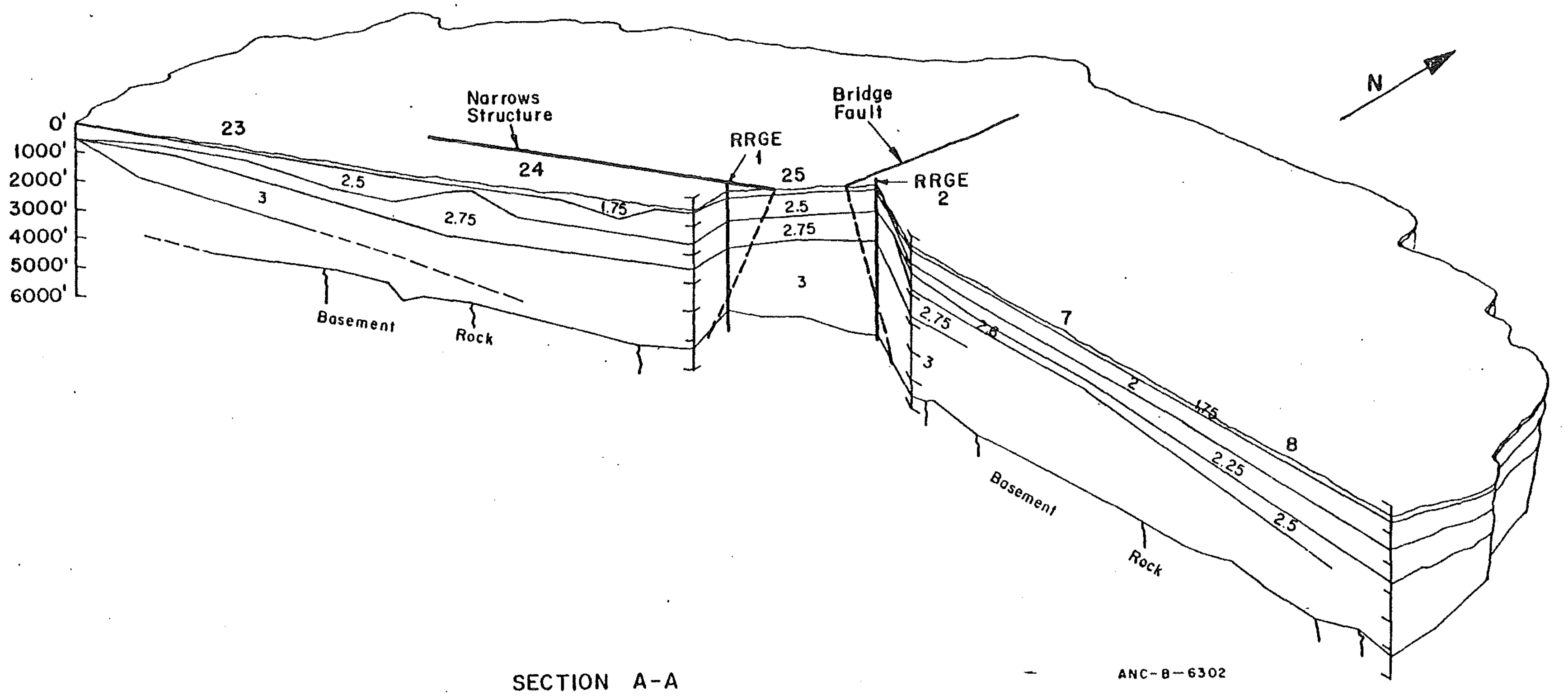
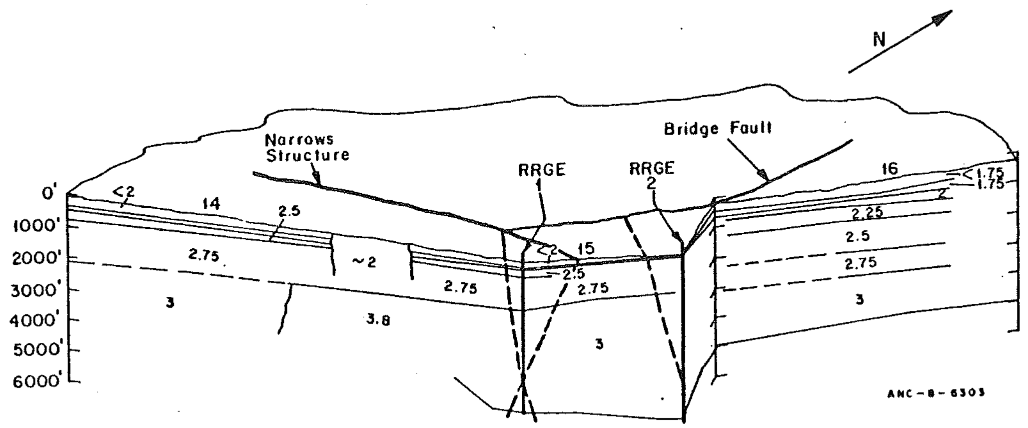


SECTION A-A

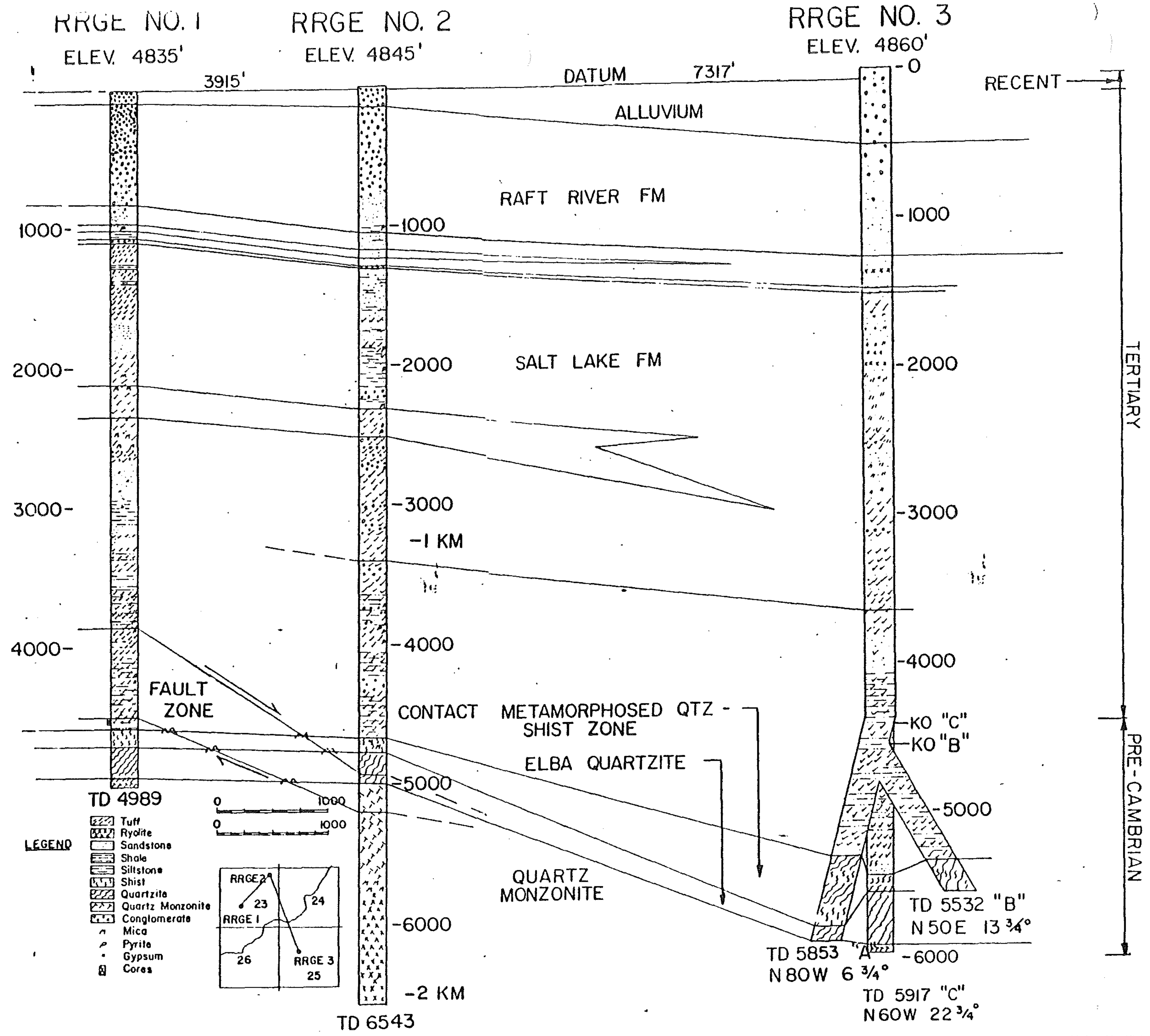
ANC-B-6302



SECTION B-B

Attachment 13

Attachment 14



RRGE WELL CORE PERMEABILITIES

Well	Depth, KB	Permeability (Millidarcies)	Rock Type
RRGE-1	4,227'	.003 - .04 (cap)	Siltstone
RRGE-1	4,506'	5.0	Tuffaceous Siltstone
RRGE-2	4,372'	0.0022 (cap)	Shale
RRGE-3	2,807'	.25	Sandstone
RRGE-3	3,365' lower	.04	Tuff
	3,365' upper	>35. (~100)	Tuff

Attachment 15

Attachment 16

Table I

Drawdown Tests

Test No.	Description	Duration Hours	Production Well No.	Production Flow Rate gpm	Pressure Gage in Well No.	Pressure Gage in Depth, feet	Maximum Pressure drop Well No.	Maximum Pressure drop Δp, psi
1	Short Term Test on RRGE #2	15	RRGE #2	210	RRGE #2	5200	RRGE #2	39
2	Long Term Test on RRGE #2	615-1/2	RRGE #2	400	RRGE #1	1000	RRGE #1	3.6
3	Short Term Test on RRGE #1	30	RRGE #1	26	RRGE #1	4700	RRGE #1	1.1

TABLE II

Characteristics of Reservoir as Deduced from Drawdown Measurements on RRGE-2 While Flowing RRGE-2

	Drawdown Data		Recovery Data
	Jacob's Method (Asymptote Solution)	Theis Method	Asymptote Solution
Transmissivity (gpd/ft^2 at 296°F)	4,667	4,696	4,718
kH md-feet	44,134	44,442	44,623
Storage Coefficient S	1.134×10^{-2}; $r_w = 1$ foot	1.09×10^{-2} $r_w = 1$ foot	-
ØCH (Porosity x Compressibility x Thickness)	2.82×10^{-2} ft/psi; $r_w = 1$ foot	2.71×10^{-2} ft/psi; $r_w = 1$ foot	-

Attachment 17

Attachment 1R

Fig. 7

DRAWDOWN DATA FROM RAFT RIVER TEST AT RRGE NO 2

(9/12/75 TO 9/13/75)

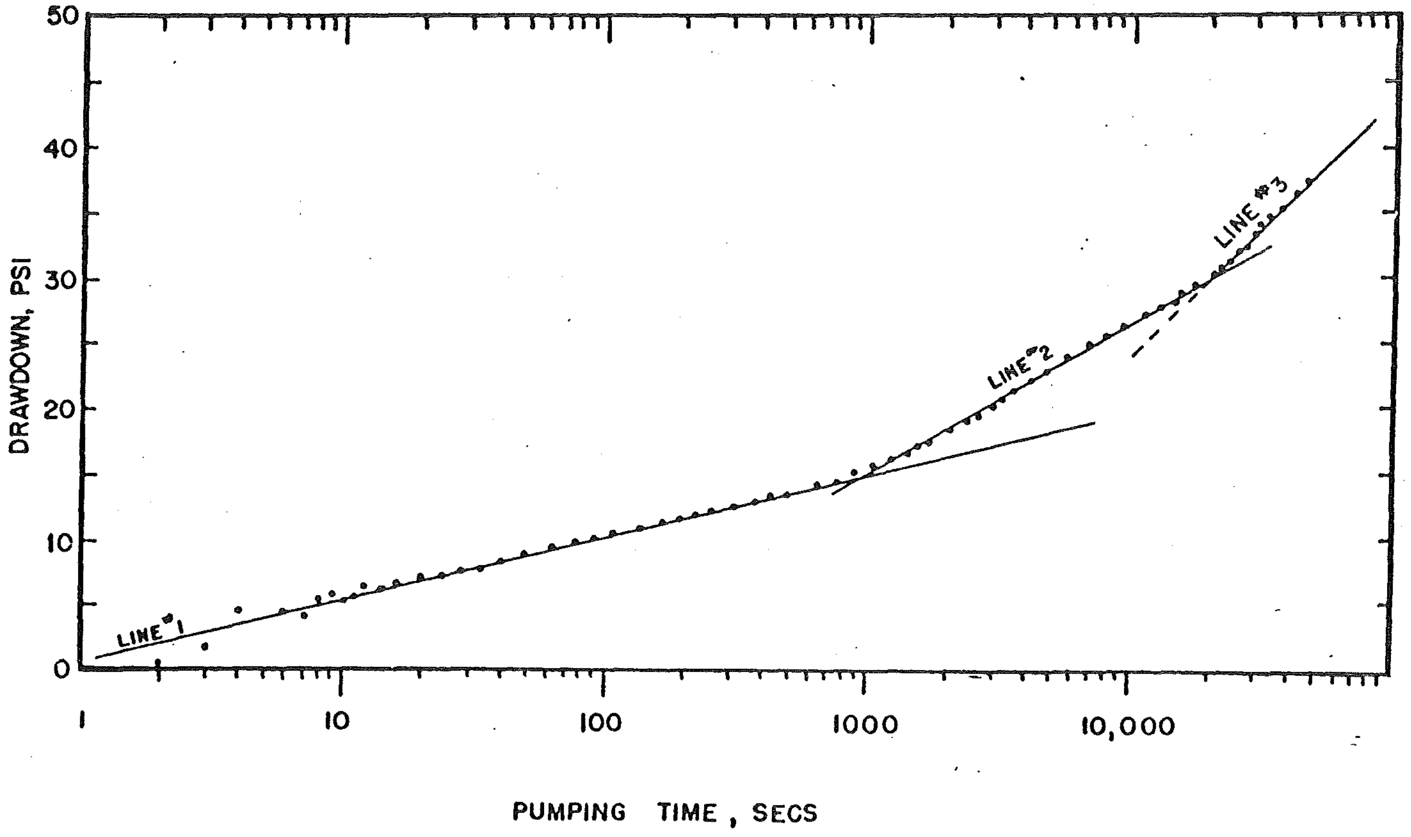


TABLE III

Results from Flowing RRGE-2 and Measuring Pressure in RRGE-1

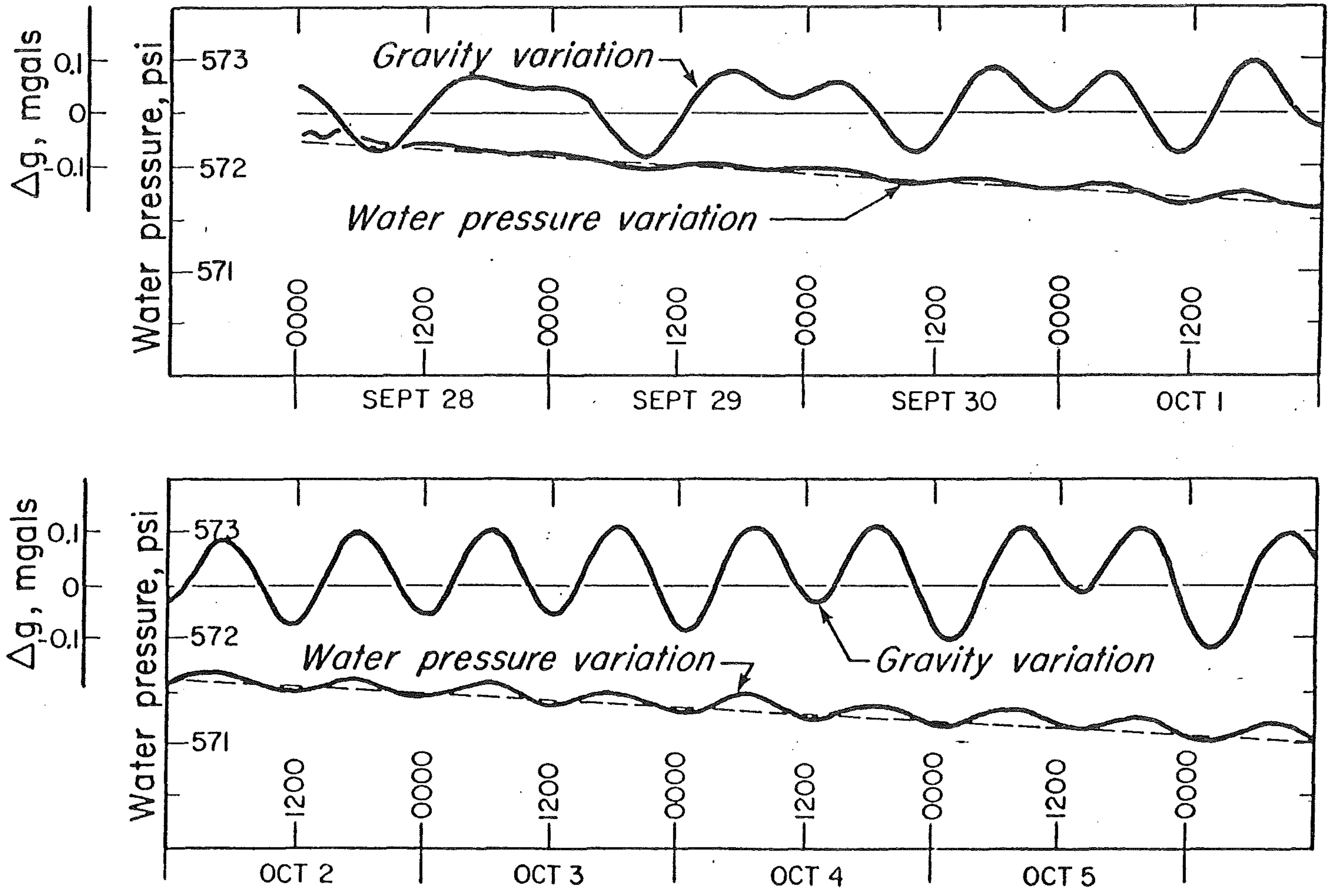
	Preliminary Test Sept. 14 to Sept. 17, 1975		Long Duration Test Sept. 20 to Oct. 16, 1975	
	Theis Curve Matching Procedure	Asymptotic Solu. (Jacob's Method)	Theis Curve Matching Procedure	Asymptotic Solu. (Jacob's Method)
kH, md feet	2.25×10^5	2.22×10^5	2.28×10^5	2.28×10^5
0CH, ft/psi (Porosity x Compressibility x Thickness)	5.74×10^{-4}	5.39×10^{-4}	1.19×10^{-3}	9.38×10^{-4}
Transmissibility gpd/ft at 296°F	2.37×10^4	2.34×10^4	2.41×10^4	2.37×10^4
Storage Coefficient S	2.31×10^{-4}	2.16×10^{-4}	4.78×10^{-4}	3.77×10^{-4}

Attachment 19

Attachment 20

Fig. 8

EFFECT OF LUNAR ATTRACTION ON WATER PRESSURE IN GEOTHERMAL RESERVOIR, RAFT RIVER VALLEY, IDAHO

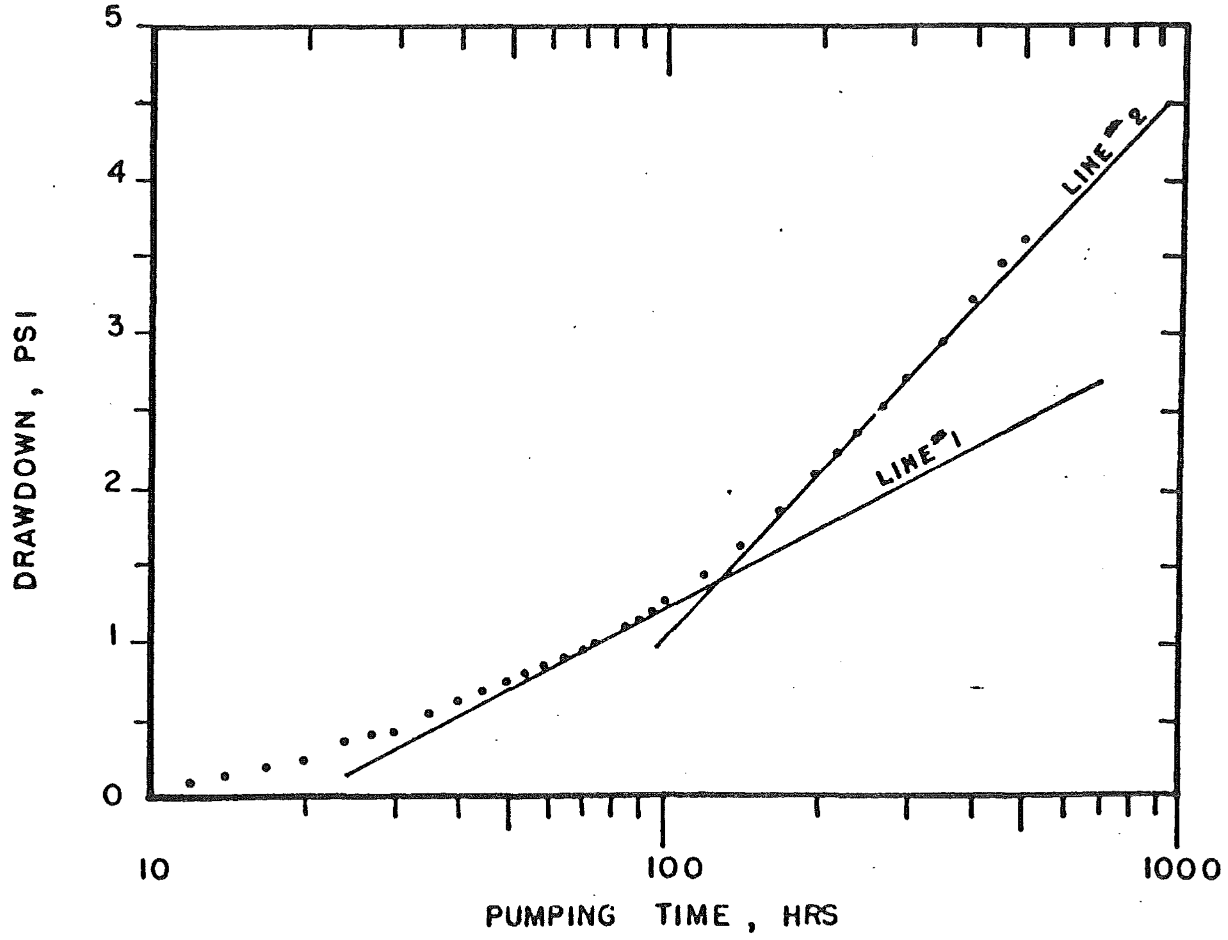


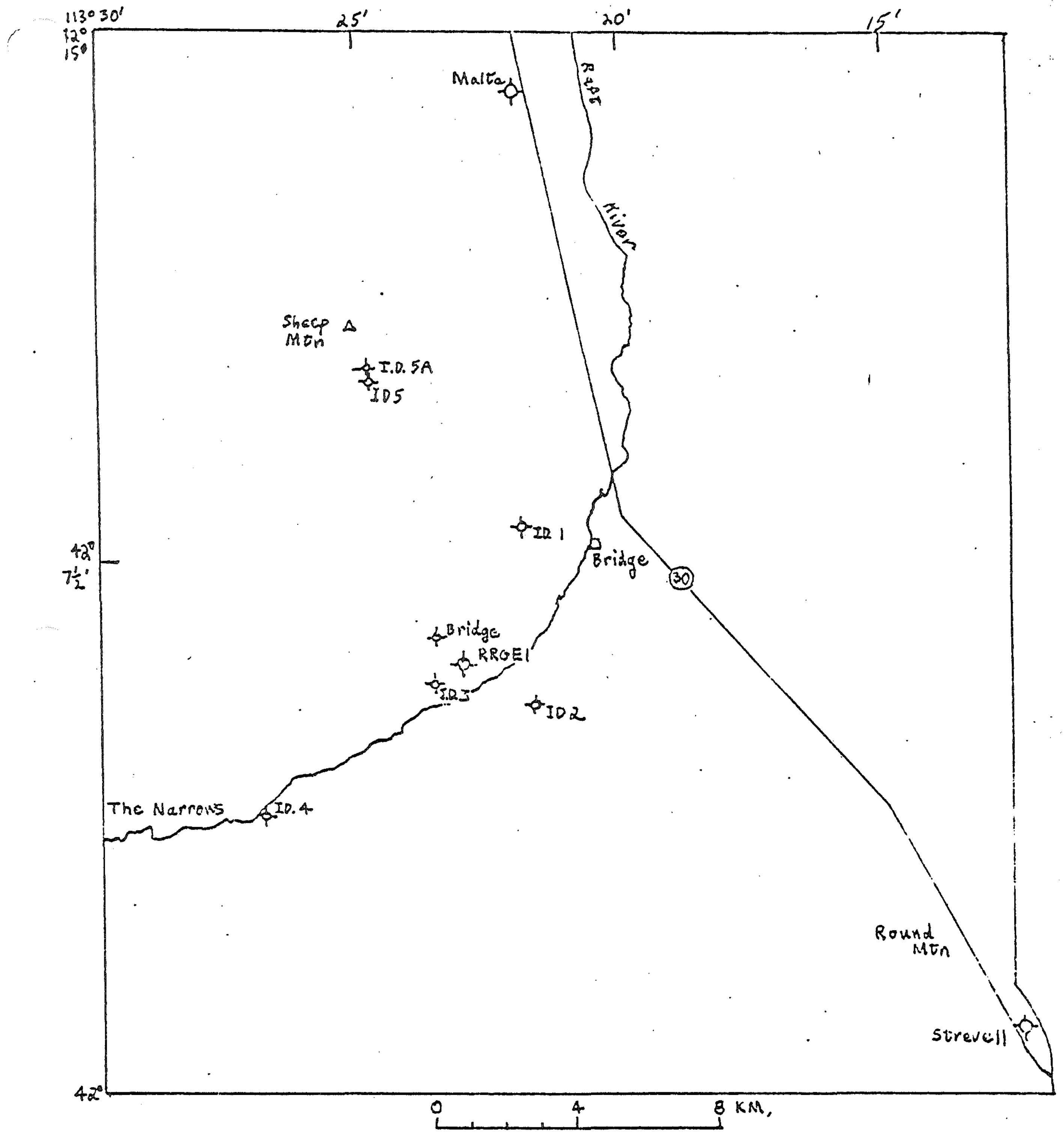
Attachment 21

Fig. 9

DRAWDOWN DATA FROM RAFT RIVER TEST AT RRGE NO. 1

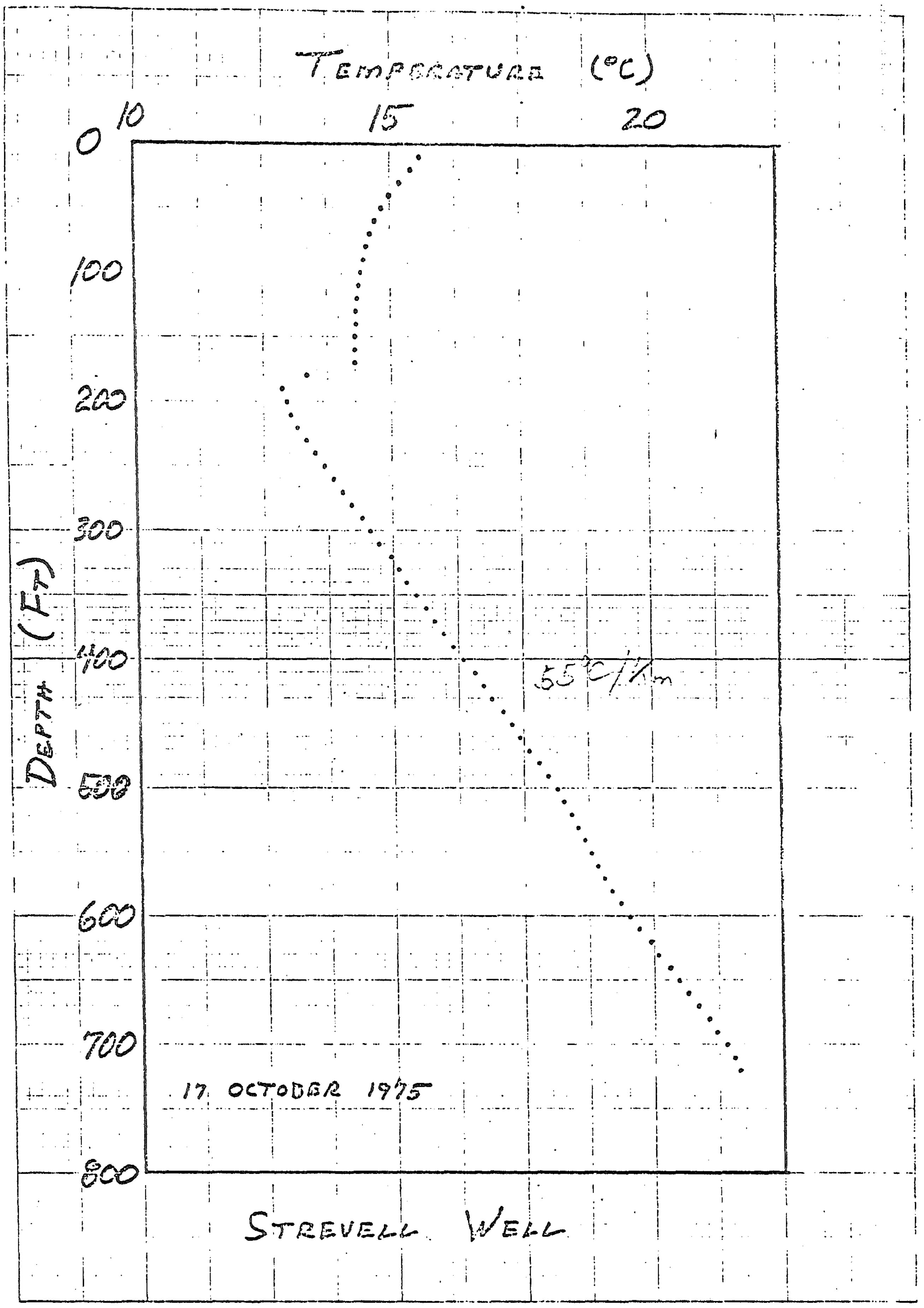
(9/20 TO 10/12)





southern Raft River Valley

Attachment 22



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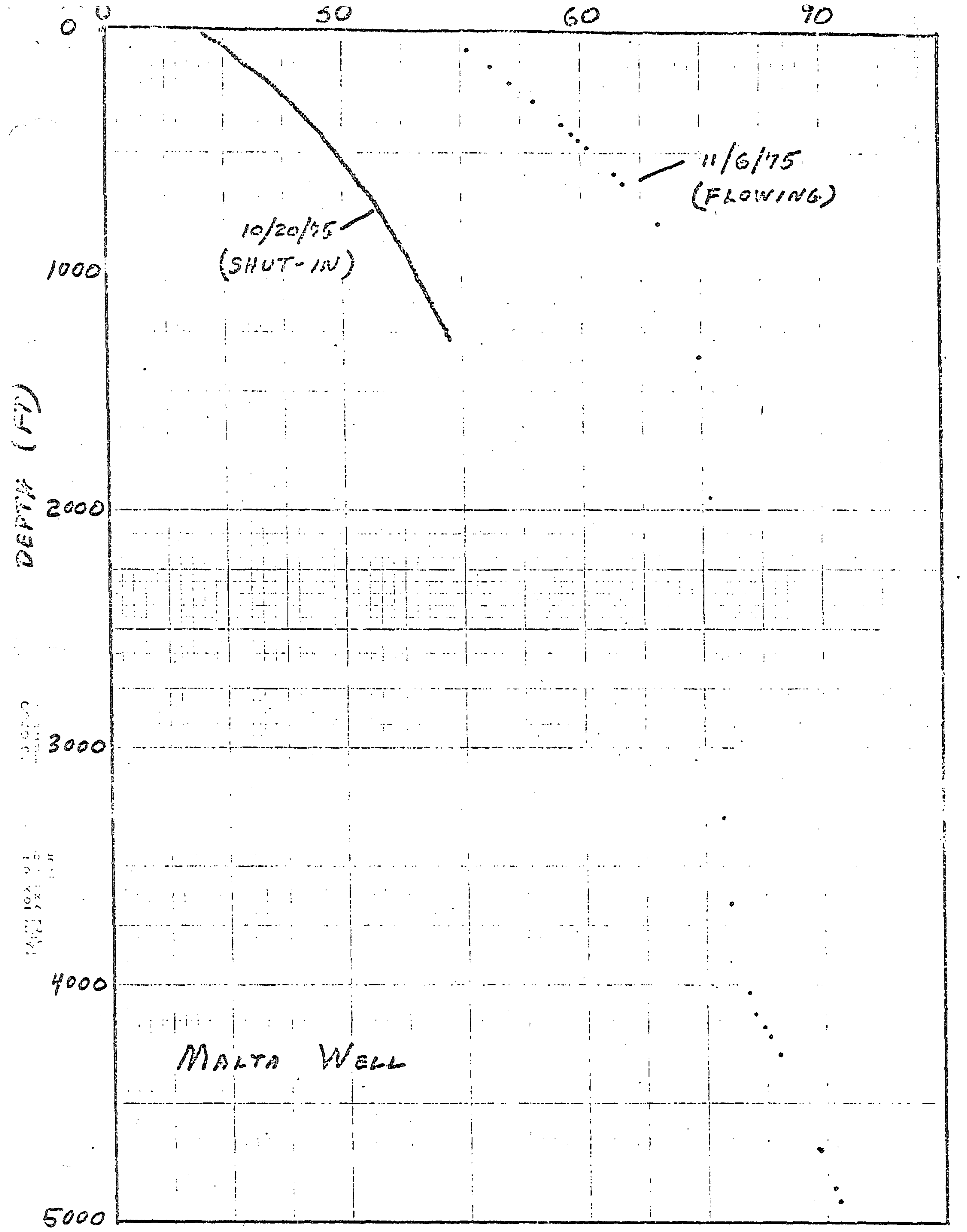

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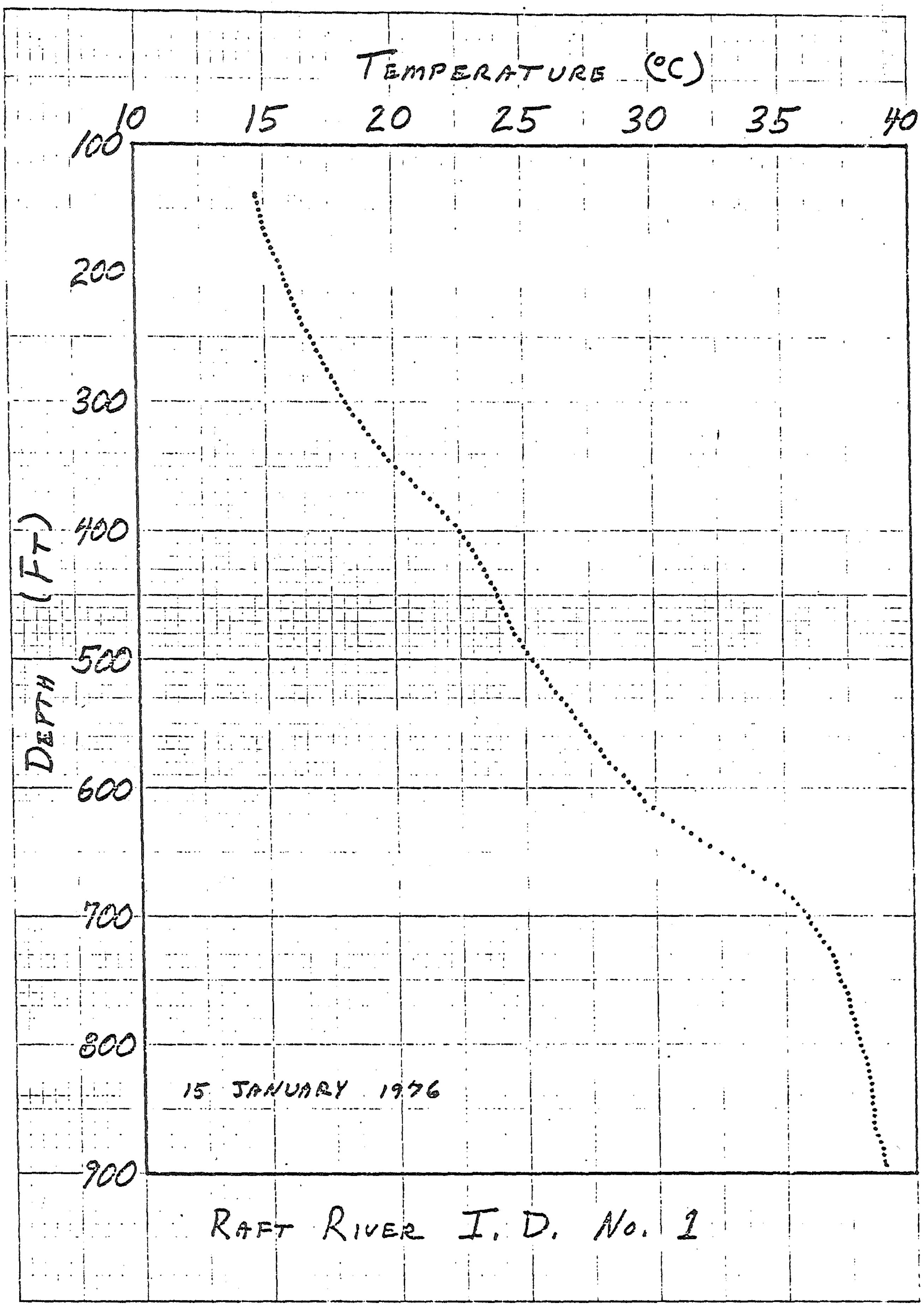
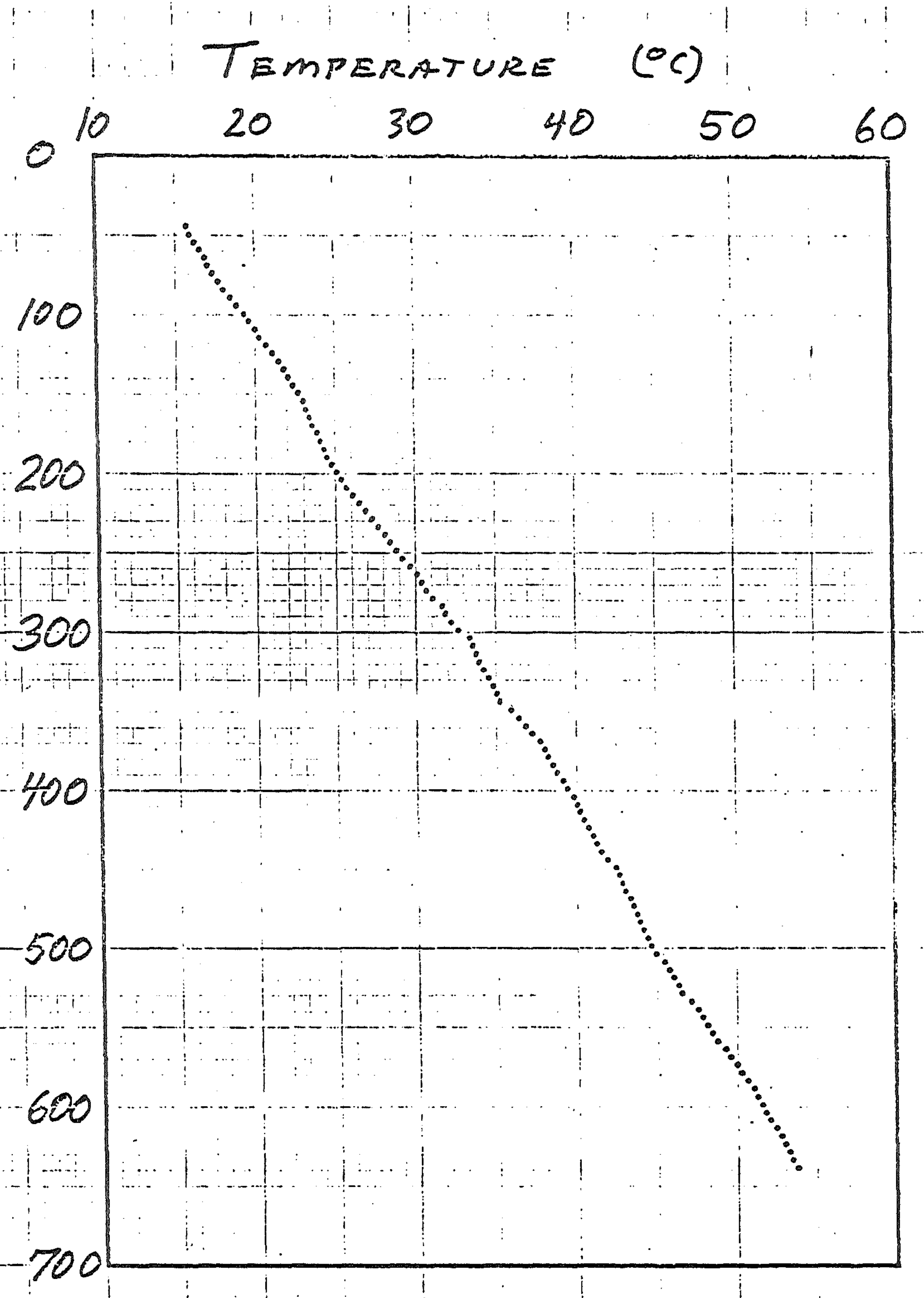


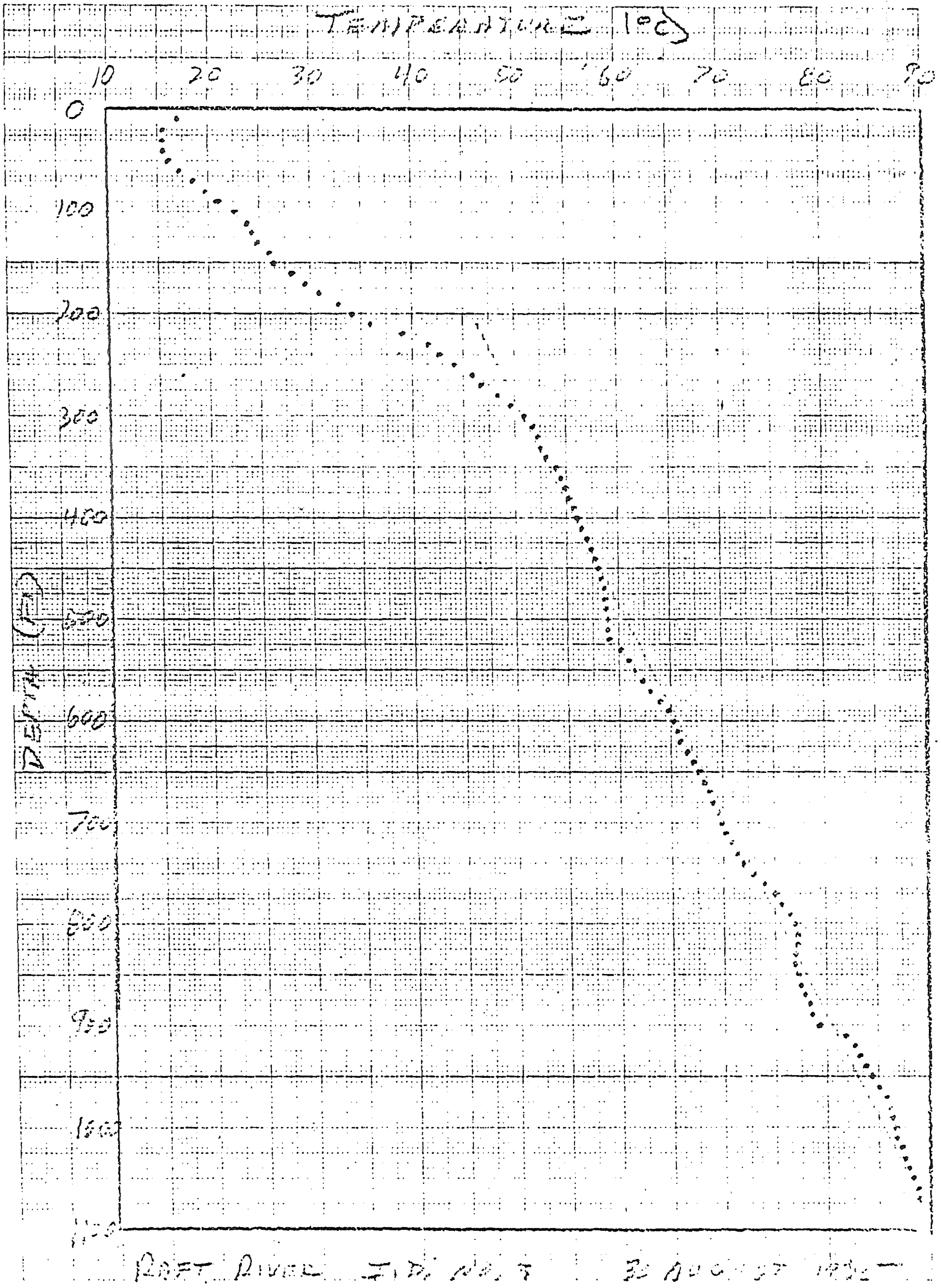
Attachment 25

RAFT RIVER I.D. No. 2
15 JANUARY 1976



Attachment 26

6/2/76



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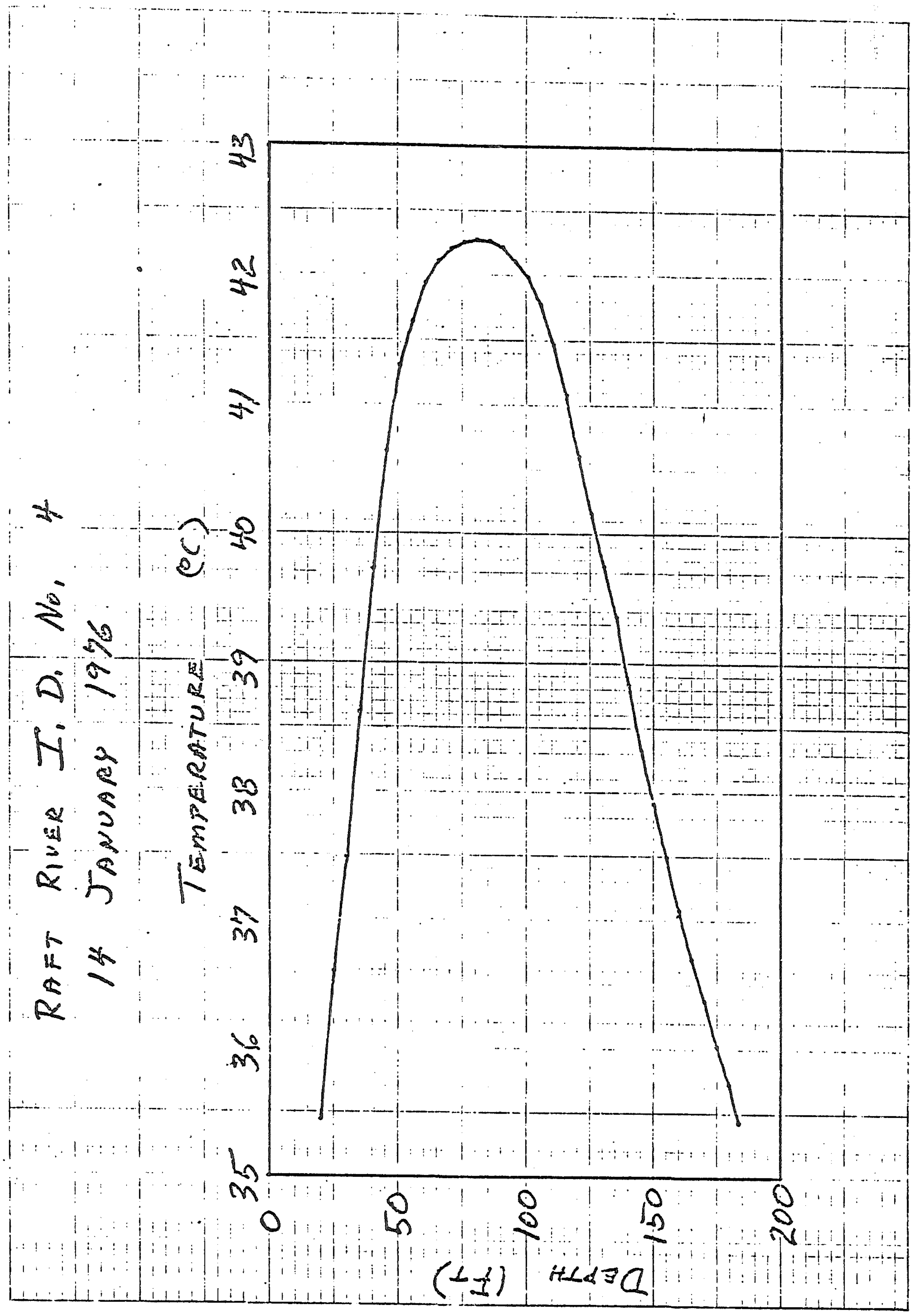
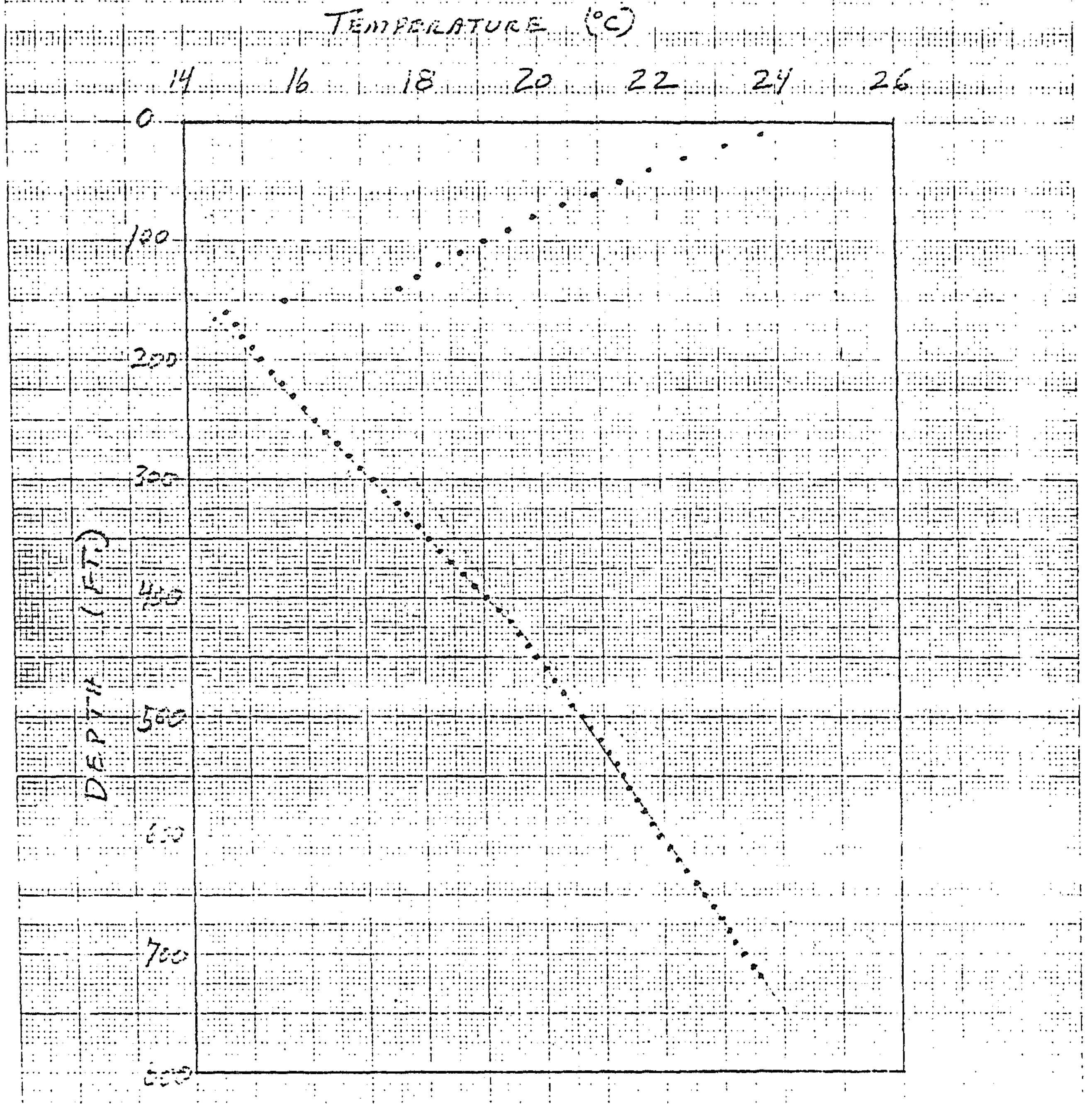


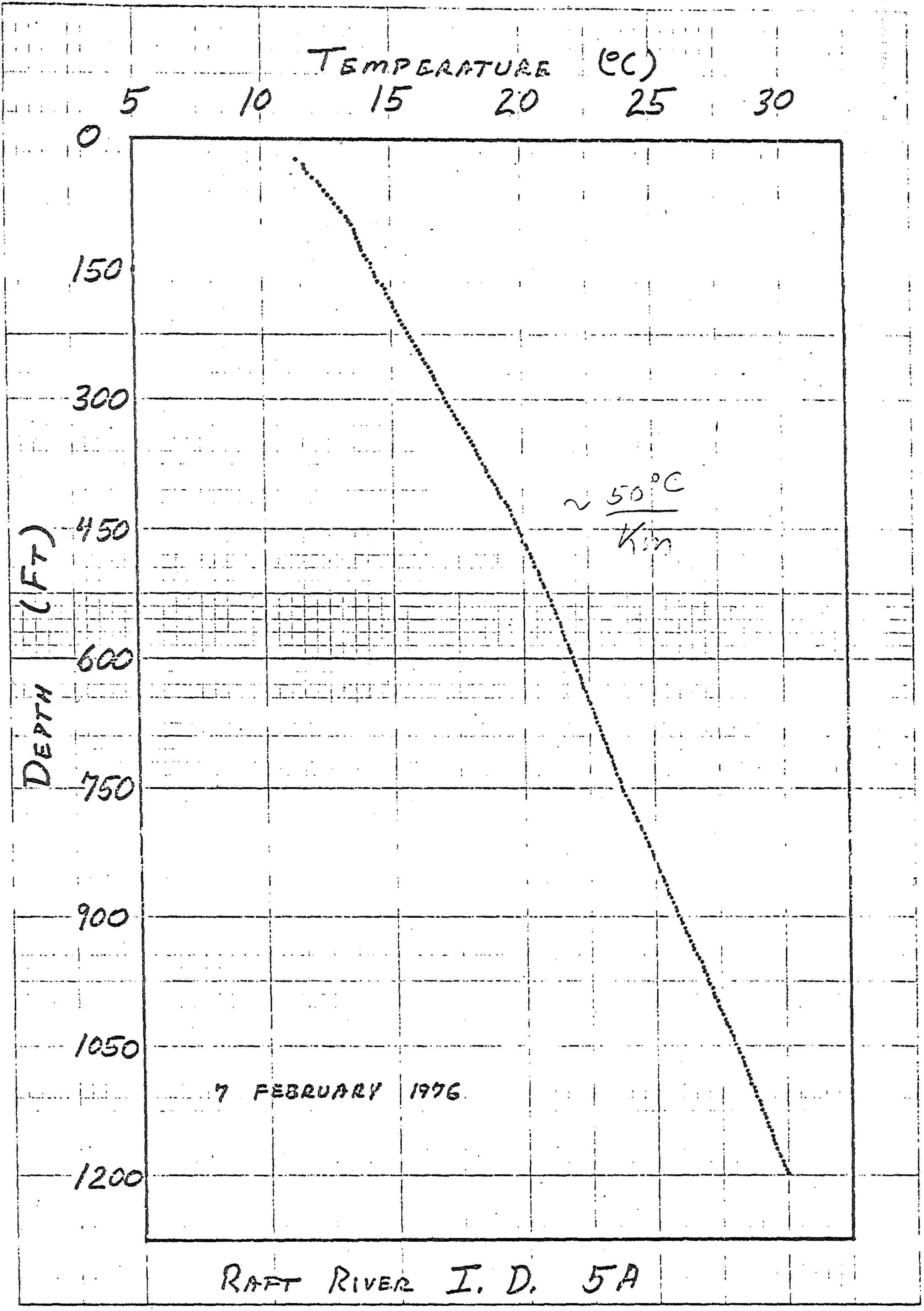
RAFT RIVER I. D. No. 4
14 JANUARY 1976

Attachment 28



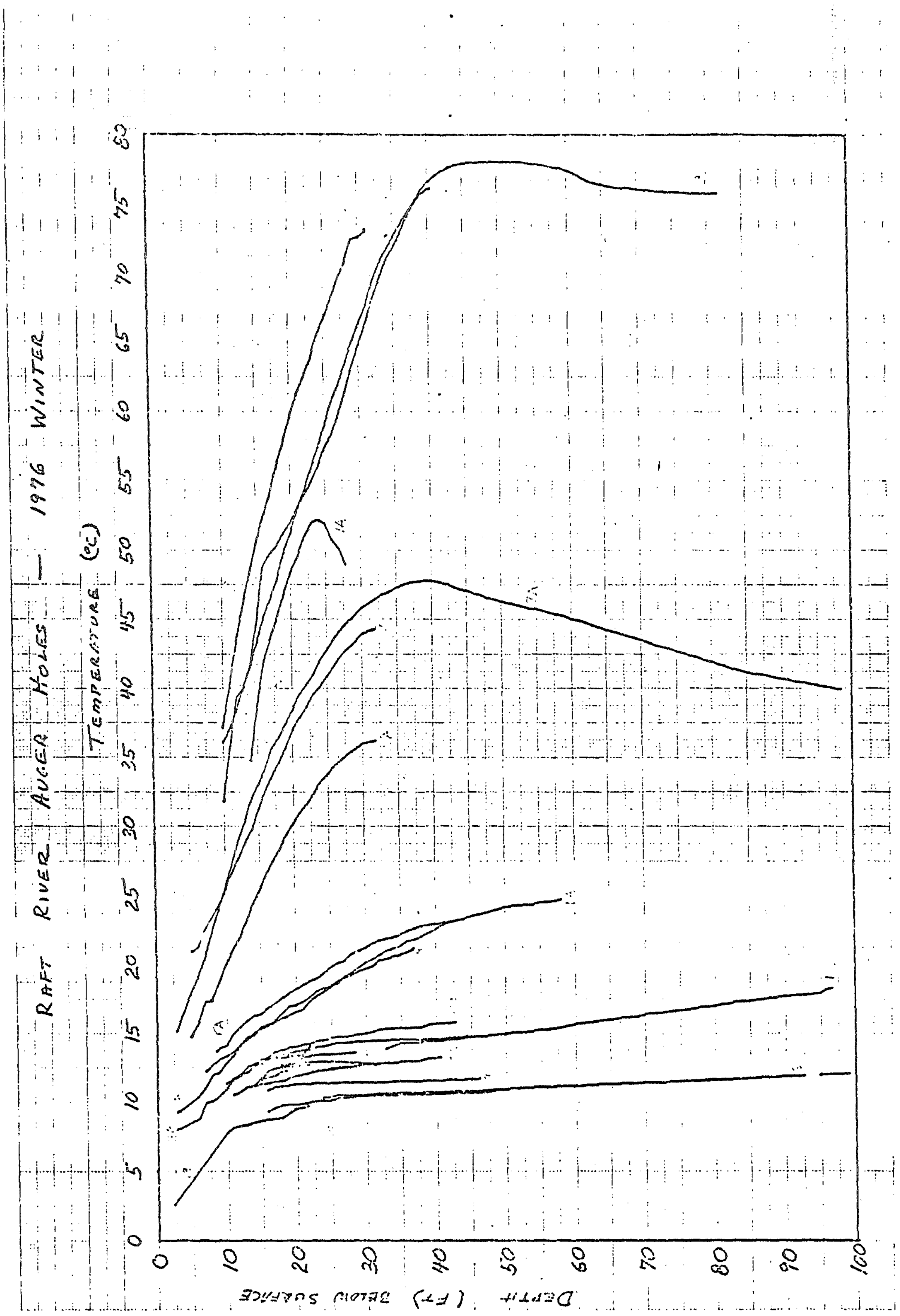
RAFT RIVER — I.D. NO. 5
19 OCTOBER 1975

Attachment 29



Attachment 30

4/7/76



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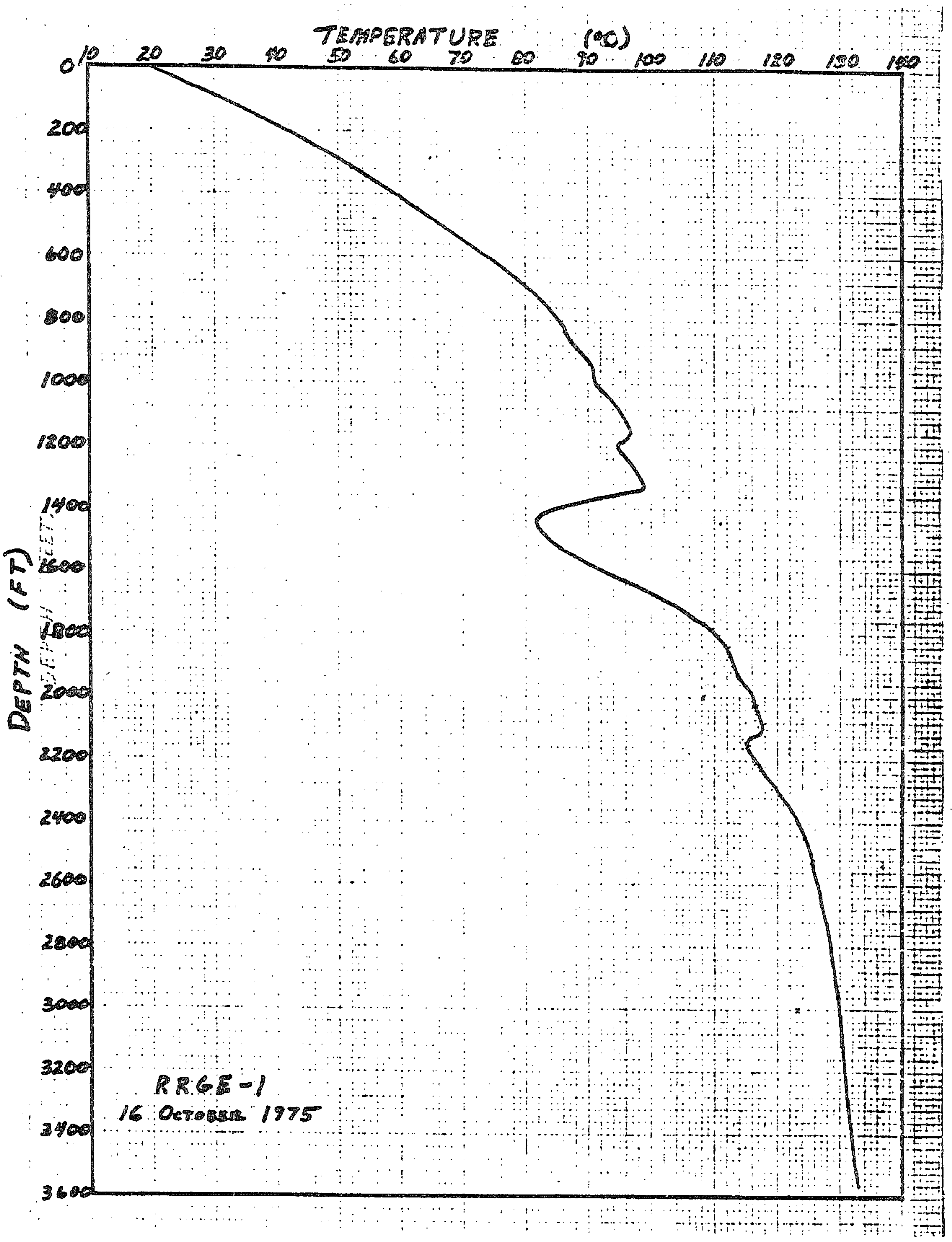


Attachment 32

Aerojet Nuclear Company

Interoffice Correspondence

June 26, 1976

J. F. Kunze
UPD

RESERVOIR ENGINEERING SEMINAR - SALT LAKE CITY - 5/21/76 - WCK-4-76

Because of time limitations at the SLC Reservoir Engineering Seminar, the ANC Thermal Analysis Branch reservoir engineering effort was not discussed. This effort has resulted in the development of a computer code to predict the long term pressure response of the Raft River Geothermal Reservoir and the long term temperature response of each of the wells. This computer code uses a modified heat-transfer code (SINDA-3G) which employs a finite-difference solution scheme.

Currently the code is able to match, with reasonable success, the test data taken at Raft River wells 1 & 2 using aquifer properties that are virtually unchanged from those determined by Dr. Paul Witherspoon. However, aquifer size and boundary locations are not known at this time thus making input boundary conditions to the computer code somewhat of a guessing game. Since the computer code now uses a very large aquifer model (8 miles X 10 miles), the boundary conditions have not as yet caused problems in matching the test data since test data is not of long enough duration to show significant effects from boundaries. Computer code predictions for times greater than 2 months will need accurate definition of aquifer boundaries.

Figures 1A-1E show the test data taken during the long term flow test of 9/75 to 10/75 and the corresponding computer predictions. Figure 1A is the actual flow rate for the flow test while a constant 415 gpm flow rate (not shown) was used for the computer predictions. The test data shown in Figure 1D was corrected to remove the sinusoidal tidal effects by taking only those data points approximately mid-way between the peaks and troughs. Figures 2A-2C show the test data for the pump test conducted during the early part of 1976 along with the computer predictions of this test. For this test prediction a constant 900 gpm flow rate was used in the computer model. Instrumentation on this test was not accurate enough to detect noticeable tidal effects and therefore no alteration of the test data was needed. Figure 3 shows a typical computer predicted well head temperature response curve resulting from flow initiation in an initially undisturbed well. This type of curve has no real test data counterpart since undisturbed wells are hard to come by at Raft River. Continuous flow from the wells to supply the various ongoing experiments at Raft River keep the wells relatively hot all the time.

The nature and location of the Raft River Geothermal Reservoir boundaries must be determined if meaningful long term pressure response predictions of the reservoir are to be made with confidence. These boundaries, at least with respect to the first 3 wells, could be found with long term testing of the 3 wells as outlined by Drs. Witherspoon and Narasimhan at the seminar. This would involve flow testing each well at 200 gpm to 400 gpm for approximately one month and monitoring all wells during each test. This type of flow test is essential in defining the reservoir boundaries since geological data alone cannot accurately determine them. Accurate long term reservoir pressure response prediction using the computer code developed by Aerojet's Thermal Analysis Branch is dependent upon the ability to define the boundaries.

W. C. Kettenacker
Thermal Analysis

jr

Attachments: As stated

cc: w/attachments
DGoldman
WCKettenacker
ECLemmon
JLLiebenthal
LGMiller
NEPace
RCStoker
JFWhitbeck

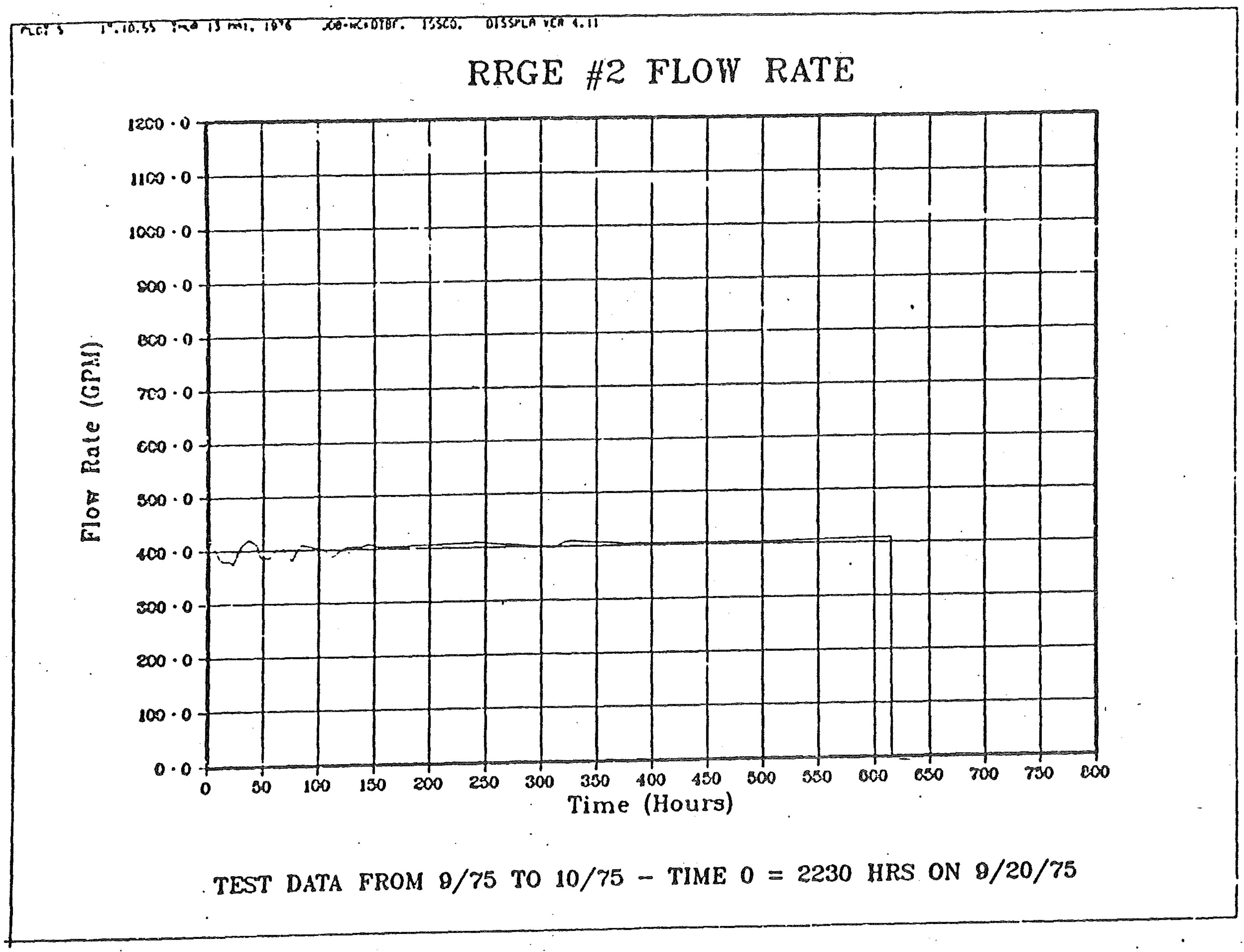


Figure 1A - Test Data Flow Rate from RRGE #2 - Flow Test of 9/75 to 10/75.

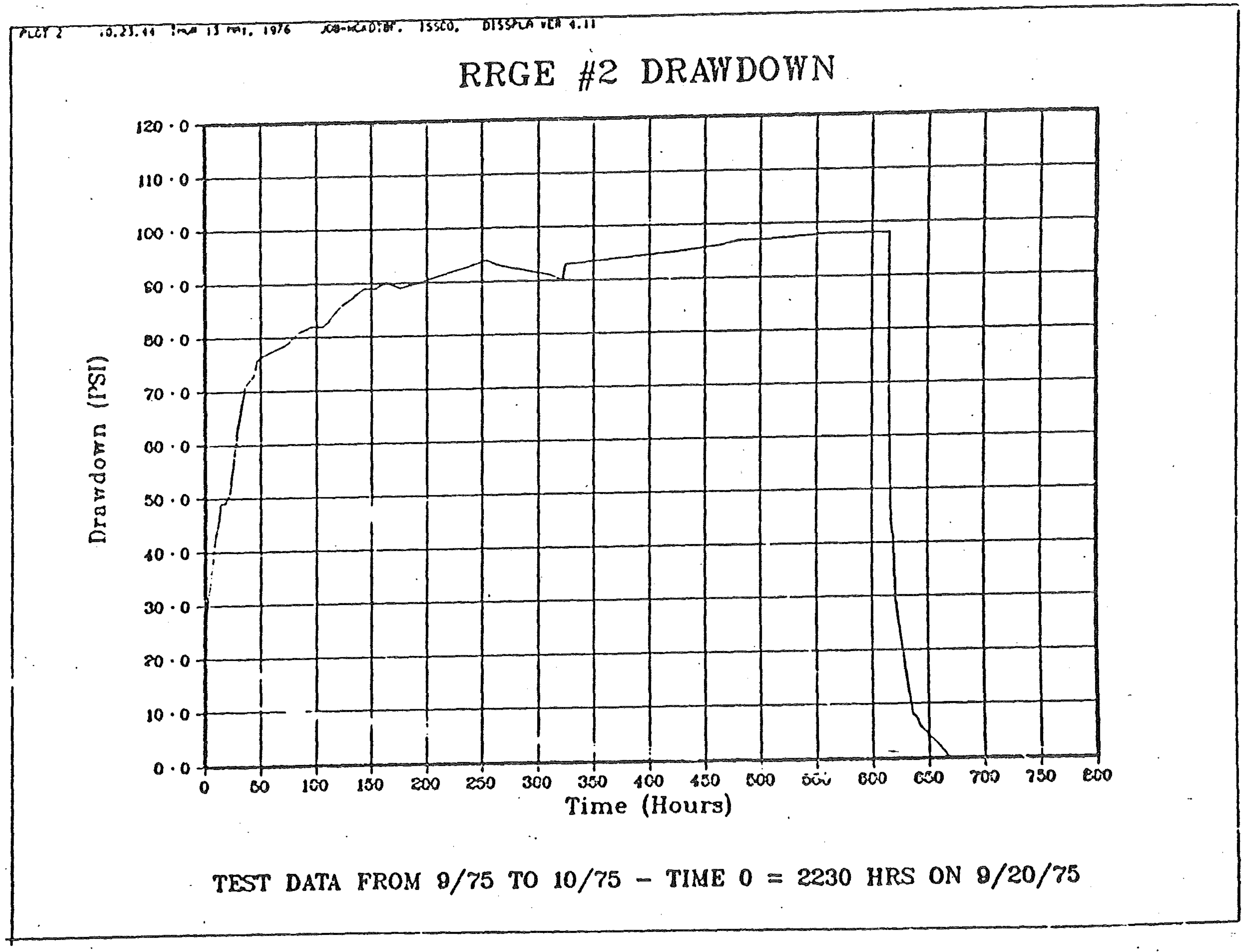


Figure 1B - Test Data Drawdown in RRGE#2 with Flow Rate of Figure 1A.

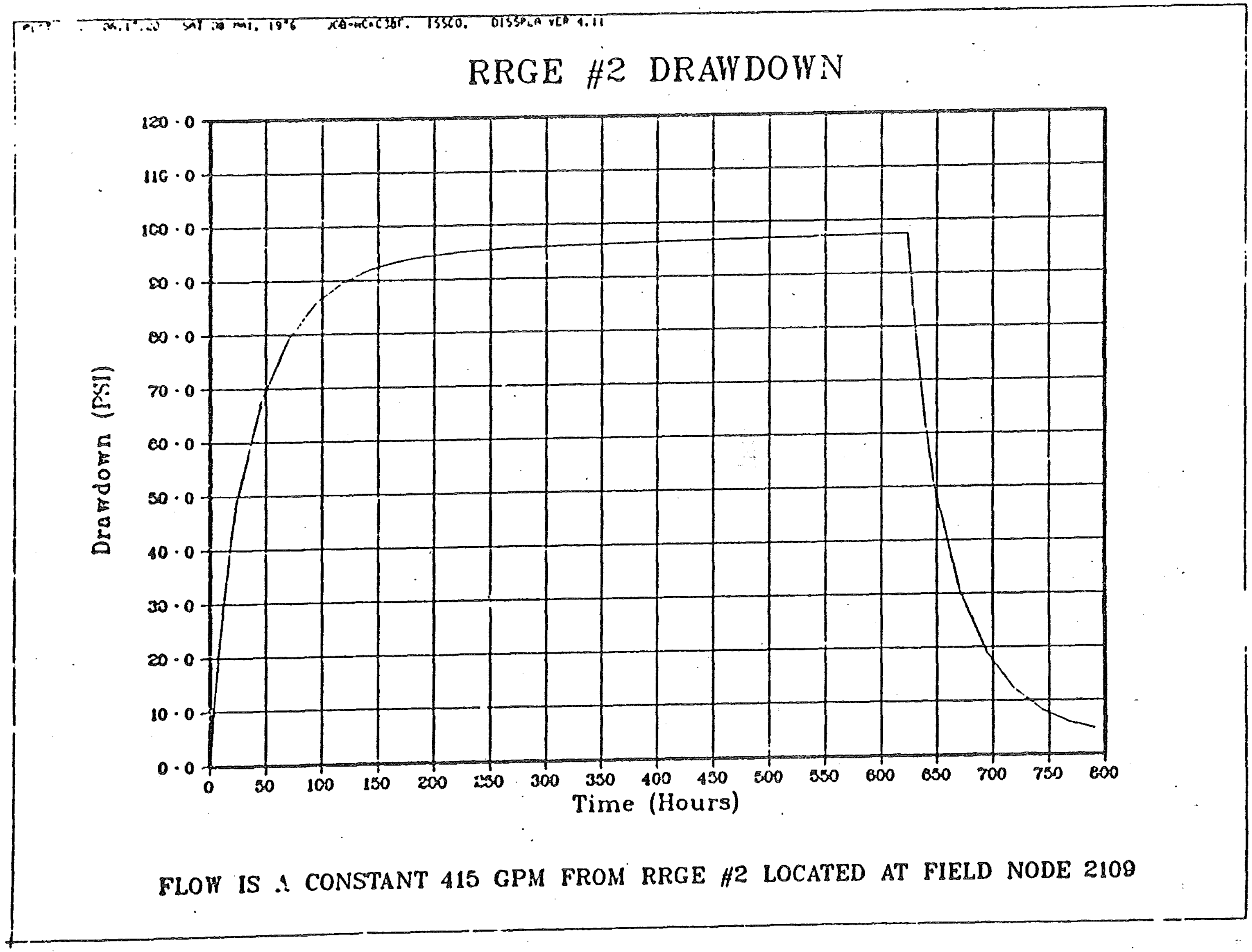


Figure 1C - Computer Predicted Drawdown in RRGE #2 with a 415 GPM Constant Flow Rate (This graph to match Figure 1B.).

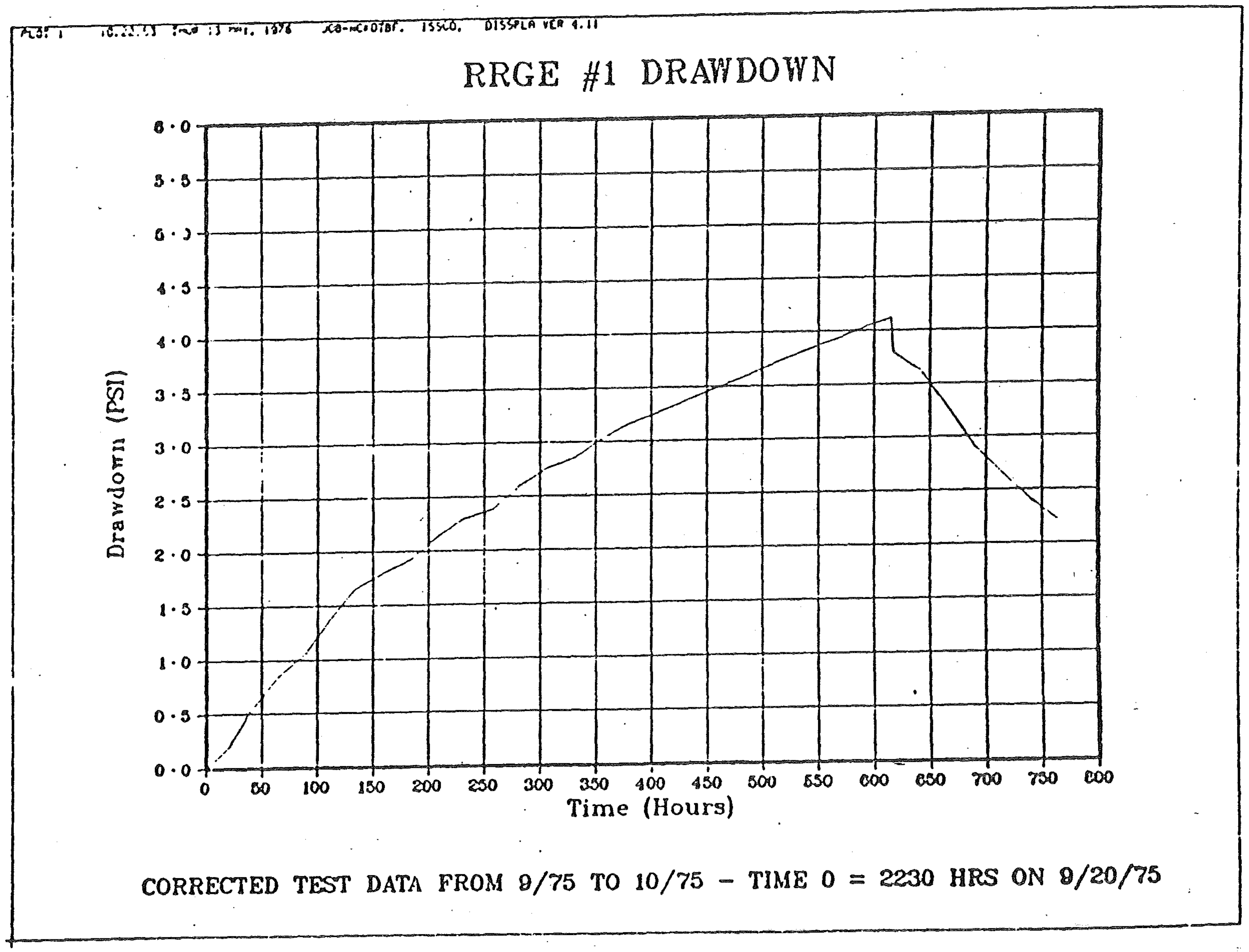


Figure 1D - Test Data Drawdown in RRGE #1 with Flow Rate of Figure 1A in RRGE #2 (Corrected to eliminate tidal effects).

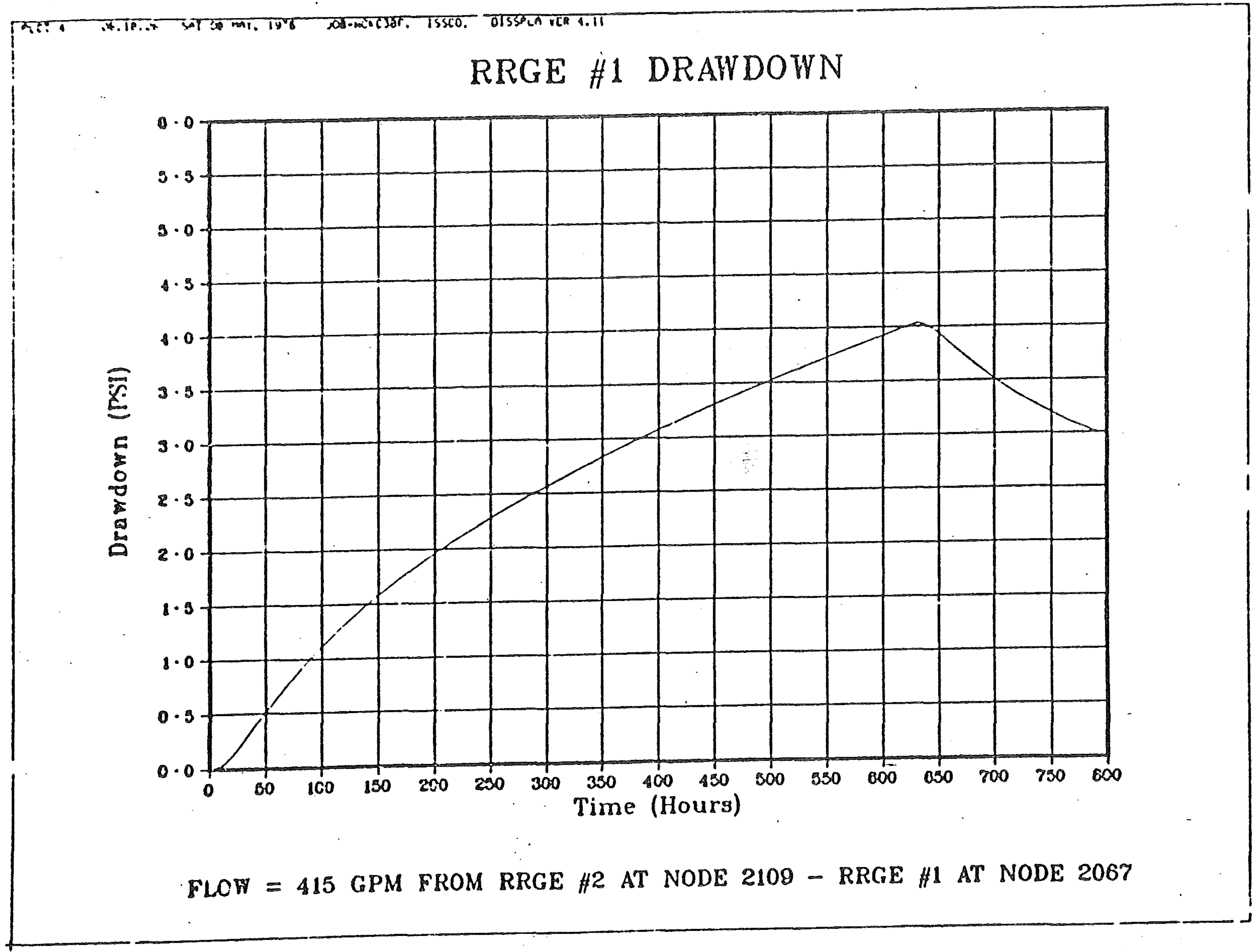
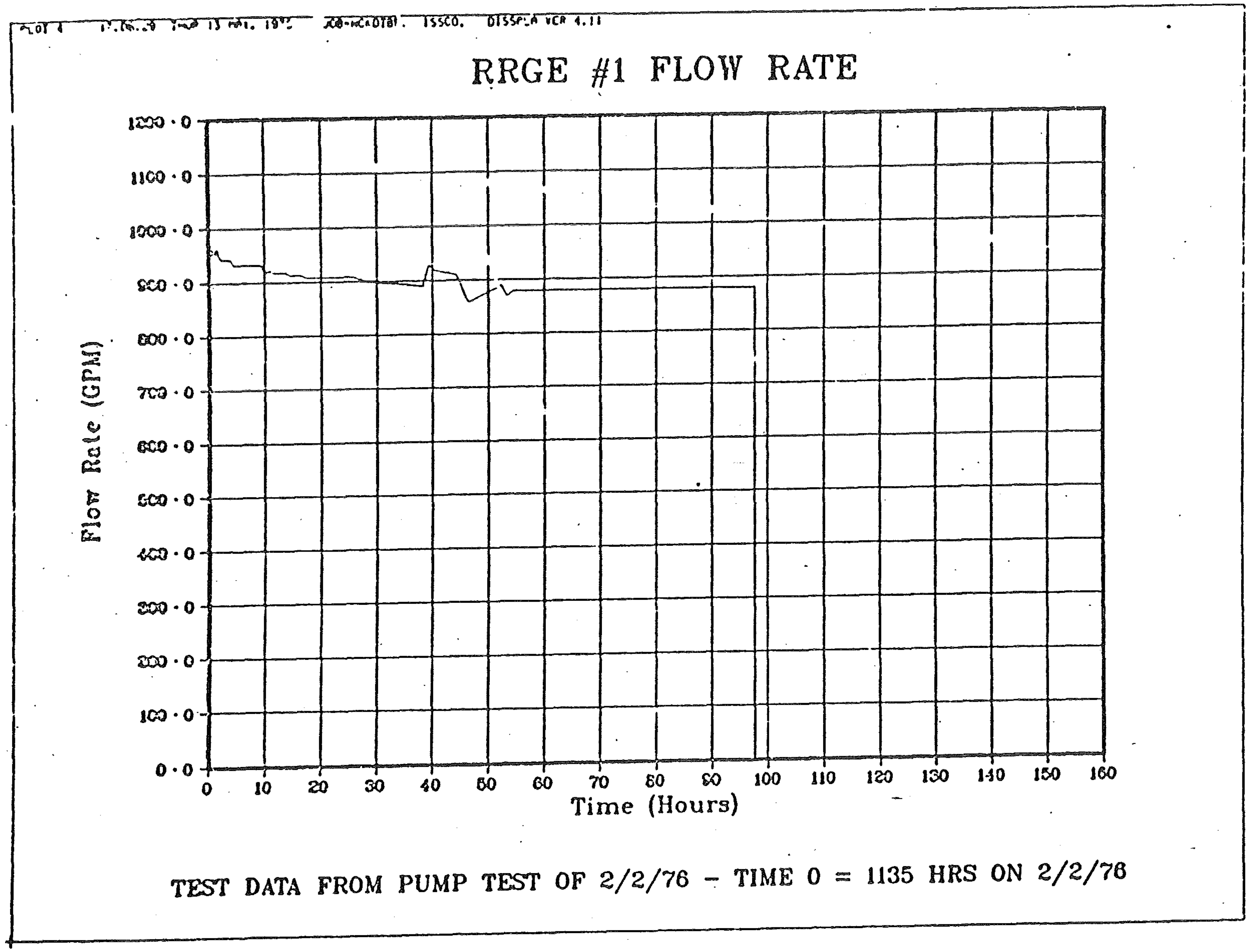


Figure 1E - Computer Predicted Drawdown in RRGE #1 with a 415 GPM Constant Flow Rate in RRGE #2 (This graph to match Figure 1D).

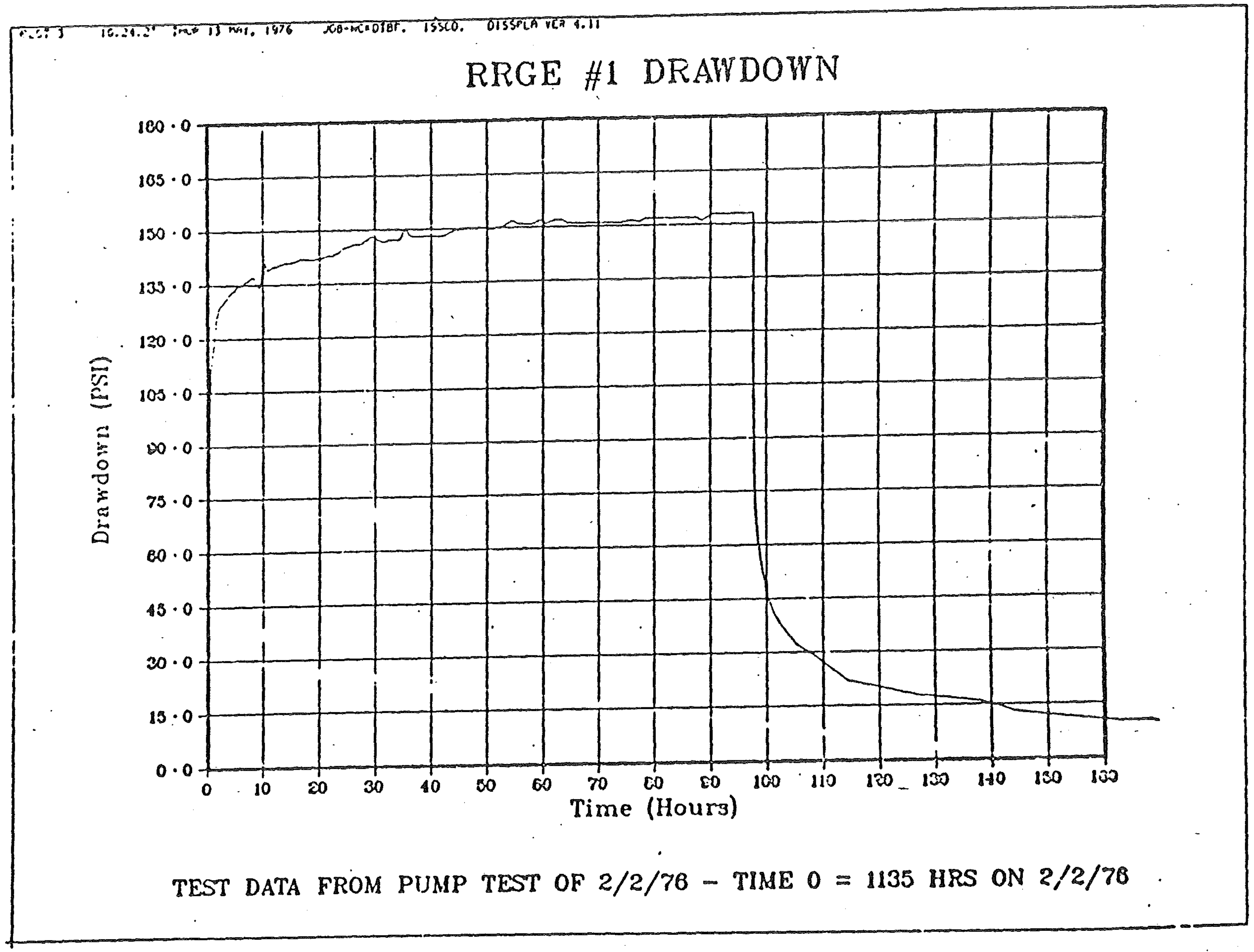


RRGE #1 FLOW RATE

TEST DATA FROM PUMP TEST OF 2/2/76 – TIME 0 = 1135 HRS ON 2/2/76

Figure 2A - Test Data Flow Rate in RRGE #1 - Pump Test of 2/76.

Attachment
WCK-4-76
Page 6 of 9



RRGE #1 DRAWDOWN

TEST DATA FROM PUMP TEST OF 2/2/76 – TIME 0 = 1135 HRS ON 2/2/76

Figure 2B – Test Data Drawdown in RRGE #1 with Flow Rate of Figure 2A.

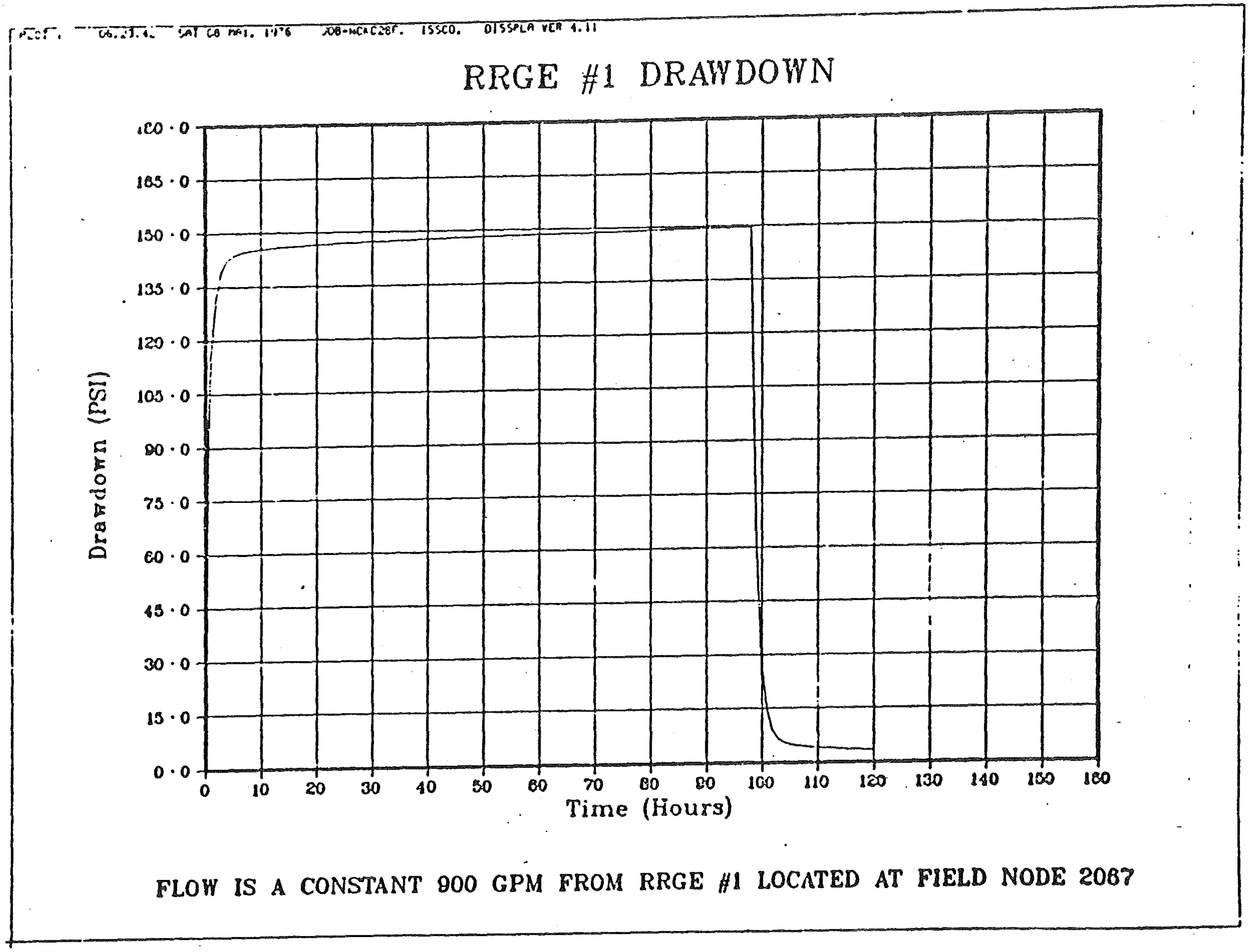


Figure 2C - Computer Predicted Drawdown in RRGE #1 with a 900 GPM Constant Flow Rate (This graph to match Figure 2B).

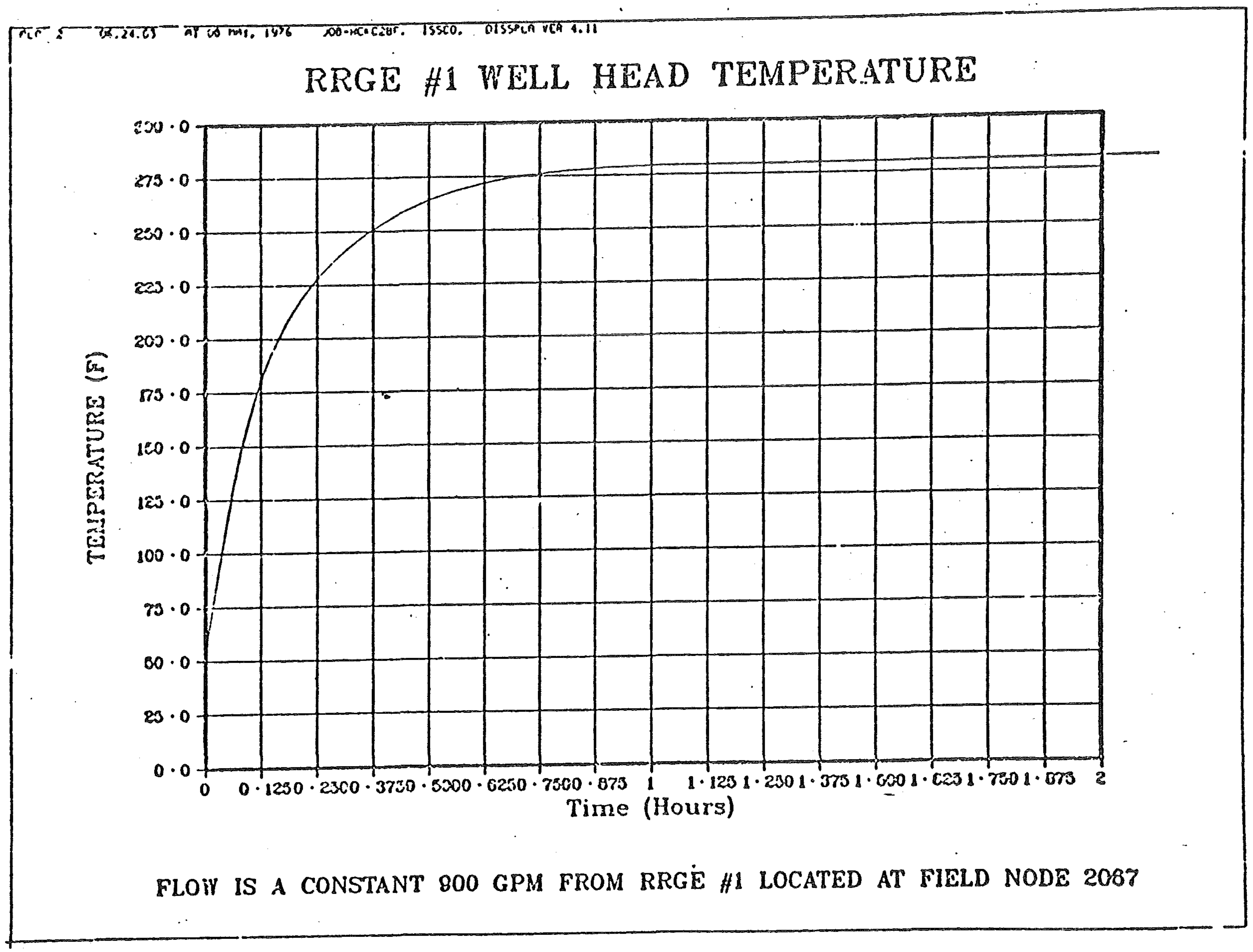


Figure 3 - Computer Predicted Well Head Temperature from Undisturbed Well
(Results taken from computer run to generate Figure 2C).

Subsidence

Surveys of historical subsidence in the Raft River Valley (Lofgren, 1975) determined that as much as 0.9 m of subsidence had occurred in the lower Raft River Valley as a result of irrigation pumping. In June 1975, 169 points on a 400 m grid were established and tied into the USGS grid for the purpose of checking elevations in the geothermal development area. In 1975 and 1976, two sets of levels were run on a 2.4 km square in the center of the original grid and closed in segments. In October 1977 and June 1978, 59 elevation points were surveyed over an area encompassing the five wells drilled or located at that time. With the exception of five points, the changes in elevation from the 1975 survey were within the expected error of the level runs. Three of the five points are in cultivated fields and may have been disturbed. To date, there is no indication of any settlement; however, none of the geothermal wells have been tested at high fluid volumes over a long period of time.

At the current time, the production wells are clustered on the northwest side of the Raft River, while the injection wells are located 1.5 to 2.5 km to the southeast. Long-term production and injection during the operation of various facilities, including the 5 MW power plant, may result in significant hydrologic changes because of this "polarization" of well locations with respect to known fault structures. Because the geothermal resource is not a closed system, pressure changes are not necessarily confined to the source aquifer(s). In some areas, these pressure changes may be transmitted to shallower aquifers of unconfined sediments.

As long-term production and injection tests are conducted on the geothermal wells in Raft River, several specific elevation surveys will be made and the data will be correlated with changes in water level or artesian pressure in monitor wells (see pages 21 through 29).

Water Quality

The water quality monitoring program can be divided into four parts: 1) routine field monitoring of irrigation wells and the Raft River, 2) detailed sampling of geothermal wells, 3) independent semi-annual sampling of shallow groundwater and surface water supplies, and 4) the injection well monitoring efforts. The injection monitoring is detailed in the following section.

Using field laboratory facilities in Raft River, weekly analyses are performed on samples from five water sources near the geothermal development area. The data are used to provide a "warning signal" if significant changes occur in these water sources. Analyses include pH, fluoride, chloride, calcium carbonate, alkalinity, and conductivity. The mean and standard deviations for these components for each water source are shown in Table IV. In general, the variances in the data collected so far are within expected values. The Raft River shows some of the widest fluctuations as a result of spring runoff, low summer flows, and irrigation return flows.

Detailed analyses of fluids produced from the geothermal wells are conducted during flow tests. The results are used to determine potential environmental consequences of utilizing the fluids in various experiments and tests, to determine fluid "incompatibilities" and corrosion-scaling potential, and to provide input to theories on the source(s) and extent of the geothermal resource. The currently available analyses of the seven deep geothermal wells drilled in Raft River valley are shown in Table V. There has been relatively little sampling of RRGI-7 because the well is not artesian at the wellhead. Therefore, the results shown may not be entirely indicative of the composition of the fluids at depth.

The Idaho Department of Water Resources conducts semi-annual surveys of irrigation wells and the Raft River to provide independent information on the quality of water in these sources. To date, eight surveys have been completed. The quality of the Raft River exhibits significant seasonal

TABLE IV

Water Quality - Raft River Water Sources

	Cond.	pH	F	Cl	$CaCO_3$	Alk.
Crank						
$\bar{x}$	5684	7.88	7.06	1790	300	26
s	632	0.28	.83	129	16	9
BLM						
$\bar{x}$	3100	7.57	7.66	850	140	45
s	360	0.26	1.11	80	40	33
Udy						
$\bar{x}$	2550	7.5	5.0	630	300	130
s	430	0.2	1.45	170	40	50
RRGE-1						
$\bar{x}$	2100	7.79	5.92	574	159	89
s	180	0.45	1.1	76	34	16
Raft River						
$\bar{x}$	1200	7.86	0.96	236	300	144
s	400	0.4	0.26	170	50	67

$\bar{x}$ - mean
s - standard deviation

TABLE V

Available Chemical Analyses of Raft River Geothermal Water
(in mg/l unless otherwise noted)

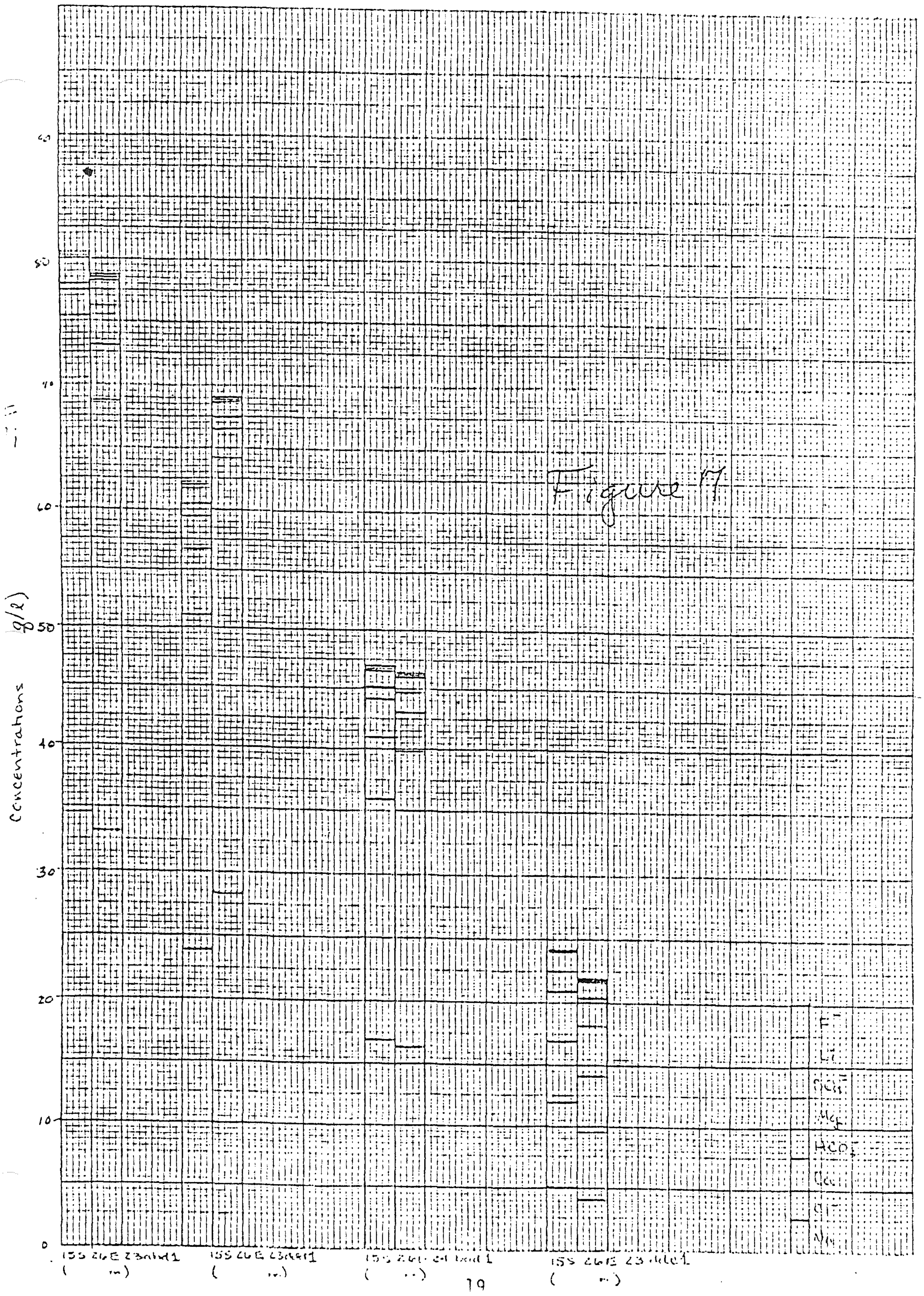
	RRGE-1	RRGE-2	RRGE-3	RRGP-4	RRGP-5	RRGI-6	RRGI-7
Ca	53.5	35.3	193	150	40	157	315
K	31.3	33.4	97.2	28	--	--	--
Li	1.5	1.2	3.1	3.1	--	--	--
Mg	2.4	0.6	0.6	0.2	--	--	1.6
Na	445	416	1185	1525	--	--	2,100
Si	57	61	74	51	67	--	39
Sr	1.6	1.0	6.7	6.5	--	--	--
Cl^-	776	708	2170	2575	900	3,150	4,085
F^-	6.3	8.3	4.6	4.5	8.4	8.5	5.0
HCO_3^-	64	41	44	24	--	37	26
NO_3^-	<0.2	<0.2	<0.2	--	--	--	--
$S^=$	--	0.3	--	--	--	--	--
$SO_4^=$	60	54	53	61	--	--	64
pH	8.4	7.6	7.3	7.4	8.1	7.3	--
Conductivity (μmhos/cm)	3370	2740	9530	7280	2150	10,500	12,000
TDS	1560	1270	4130	4470	--	--	--

variation but varies only slightly by location. The quality of irrigation wells, which generally produce from the 30-150 m depth, varies significantly with location and depth. The quality of water in shallow (<40 m) wells approximates that of the Raft River in most locations. Deeper wells west of the geothermal development and to the north toward Malta produce relatively good quality water (specific conductance averages 1400 μmhos).

Within 3-5 km of the geothermal development, irrigation wells show the influence of the geothermal resource: temperatures increase by approximately 10 °C, silica content increases, and overall water quality decreases (specific conductance averages 3000 μmhos).

Selected results from the 1978 surveys are compared to previous surveys in Figure 7. The 1978 values are within the expected range of natural fluctuations for the wells shown, all of which are near the geothermal development. One irrigation well 7 km northwest of the development has shown significant changes in water quality during the past three years (Table VI). The conductivity of this well more than doubled between August 1975 and August 1977. Most of this was due to an increase in chloride, with calcium, magnesium, sodium, and sulfate also showing significant increases. Nearby wells did not show similar fluctuations during the same period, indicating that geothermal development was probably not the cause. Subsequent chemical analyses of water from that well and nearby domestic and irrigation wells have not yielded an explanation for the fluctuations.

Between June 18, 1978, and June 29, 1978, a total of 90 MT of salt (NaCl) were used to "kill" RRGP-5 during fishing operations for lost drill pipe. Additionally, 30 MT of NaCl were dumped directly into the reserve pits. Of the total amount of 120 MT salt used, an estimated 5 MT were removed from the hydrologic system. Because the well was only cased to 460 m, concern arose that shallow and intermediate depth aquifers could be contaminated, either as a result of seepage from the reserve pit or by seepage into thief zones in the uncased section of the borehole. Depth-dependent changes in the conductivity of RRGP-5 provided a model of groundwater flow in and around the well. Estimates (McAtee, TREE-1295, 1978) indicate that at least 16 MT of salt entered the aquifer at a depth of 490 m.


Concentrations g/l)
0
10
20
30
40
50
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90
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(m)
F⁻
Li
SO₄⁼
Mg
HCO₃⁻
Ca
Cl⁻
Na

Figure 17

TABLE VI

Water Quality - Irrigation Well 14S 27E 32bdd1
(in mg/l unless otherwise noted)

	8/75	6/77	9/77	8/78
Ca	206	542	363	287
K	10	13	10	278
Li	0.16	0.21	0.23	0.26
Mg	37	103	68	4
Na	193	378	254	575
SiO_2	49	51	38	44
Cl^-	525	1402	966	1266
F^-	0.72	0.61	0.47	0.58
HCO_3^-	278	352	301	341
$SO_4^=$	111	408	194	322
Conductivity (μmhos/cm)	2250	5300	3500	4750

Seventeen domestic and irrigation wells were sampled up to three times weekly, beginning five days after the salt was first used. These samples were analyzed in the field for conductivity, chloride, and sodium. Trends in these water quality parameters during the sampling period were compared to baseline conditions. To date, none of the data show any indication of salt contamination.

Monitor Wells

As geothermal development progressed in Raft River, it became apparent that there is hydraulic communication between the geothermal system(s) and the shallower aquifers that have been developed for irrigation and domestic water supplies. Because of this natural communication, there is some concern that the development of the geothermal resources in the valley may adversely affect the chemical quality or supply of water in the shallower aquifers.

Historically, declining water levels in the shallower aquifers indicated that recharge to these aquifers was not adequate to meet demand (Walker *et al.*). As a result, the State closed the basin to further water resource development. Currently, the geothermal system is included in that closure.

In November 1977 an aquifer monitoring program was initiated and seven monitor wells drilled. The objectives of this monitoring program are: 1) to evaluate the natural communication between aquifers, 2) to provide information to be used by the State in deciding if the geothermal system should be excluded from the closure of the basin, and 3) to quantify the effects of production and injection of geothermal fluids on shallow aquifers.

The monitor wells were drilled to varying depths in the shallower aquifers and were located around the injection well field (Figure 8). Their locations were selected on the assumption that injection of geothermal fluids at depths of 600 m to 1000 m, not deeper production, would have the greatest potential for adversely affecting shallower aquifers. The construction, temperature logs, and initial water quality for the monitor wells are shown

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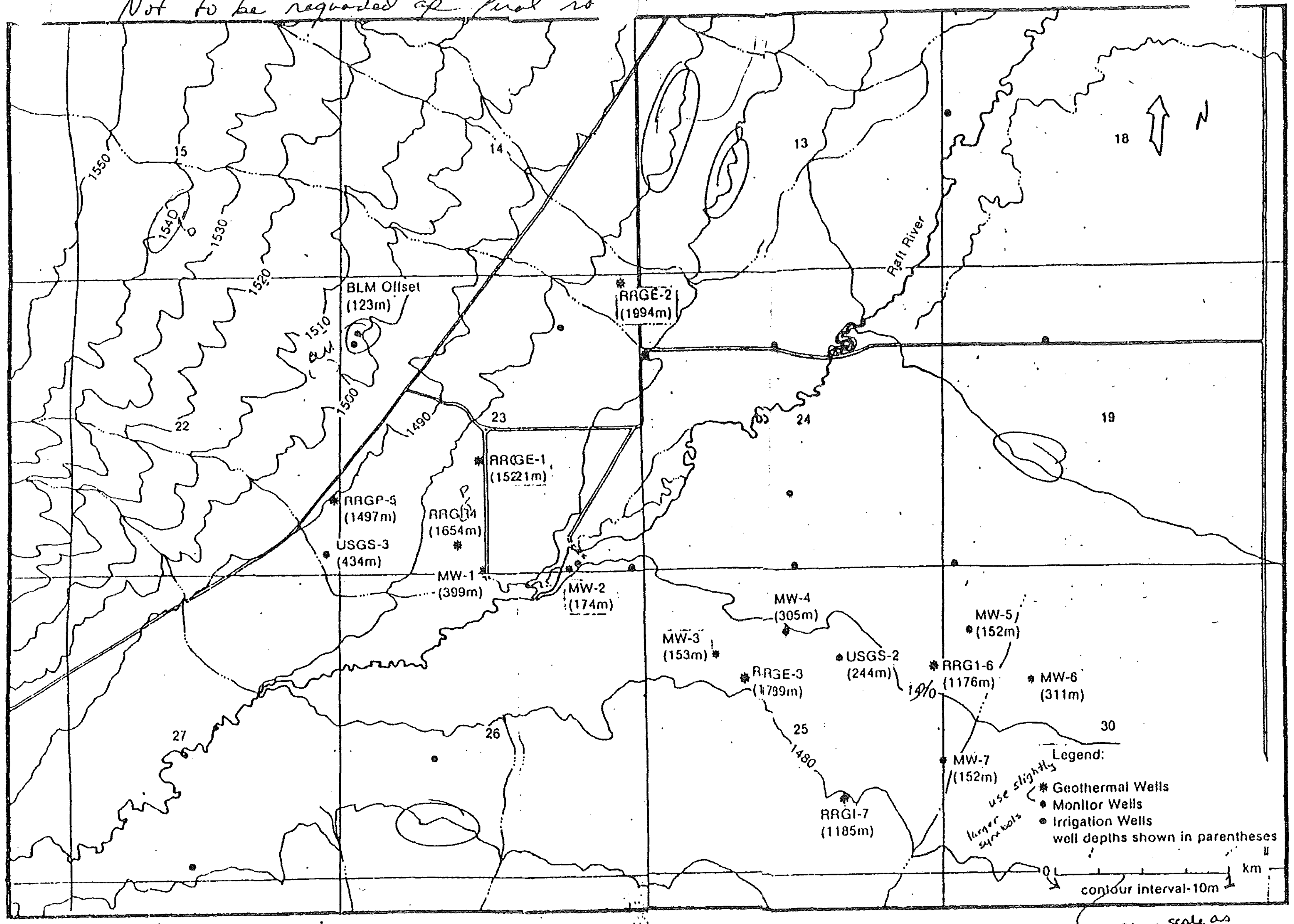


use slightly larger symbols

use same scale as other map.

Figure 8

in Figures 9 and 10 and in Table VII. MW-1 is the deepest of the wells, with a total depth of 399 m. Three of the wells are 150 m deep, corresponding to the deepest irrigation well in the vicinity. The temperature profiles indicate that MW-3 and MW-4 have similar thermal characteristics, as do MW-5, MW-6, and MW-7 as a group. MW-1 and MW-2 have the highest thermal gradients, indicating the greatest influence from the deeper geothermal system.

MW-1 and MW-2 were equipped with pressure transducers to monitor injection tests on RRGI-4 during the spring of 1978. In addition, water levels, wellhead pressures, and/or artesian flow rates were monitored on fourteen other wells: the USGS-3 corehole (434 m), the BLM flowing well (126 m), the BLM offset well (122 m), the Crook greenhouse well (165 m), seven irrigation wells, the USGS-4 corehole (77 m), and two USGS auger holes (11 and 26 m) The last three wells are upgradient, hydrologically, from the geothermal development and were used to monitor natural fluctuations of the water table.

During the period from March 21, 1978, to June 10, 1978, a total of 12,800 m^3 of water was injected into RRGI-4 at rates ranging from 16 l/s to 51 l/s. The longest test lasted for 13,300 minutes, during which the injection rate was 44 l/s. A pressure response was seen in MW-1 and USGS-3 during each of the injection tests (Figure 11). During the longest test, pressure increases of 34 kPa and 97 kPa were seen in MW-1 and USGS-3, respectively. The water level in the BLM offset well rose over 1 m during the same period. The responses at USGS-3 and the BLM offset well were much larger than expected and indicate that the intermediate-depth aquifer system is heterogenous and/or anisotropic. The response of USGS-3 to injection was also much larger than the well's response to seasonal hydrologic changes or to past geothermal activity (Figure 12). Comparison of well logs and well locations with known fault systems indicates that USGS-3 and RRGI-4 penetrate the same fracture system, while MW-1 penetrates unfractured rock adjacent to the fracture system (Niemi and Nelson, 1978).

Water samples were taken from each of the monitor wells before and after the injection tests and from the flowing BLM and Crook wells during the tests. No change in water quality was detected.

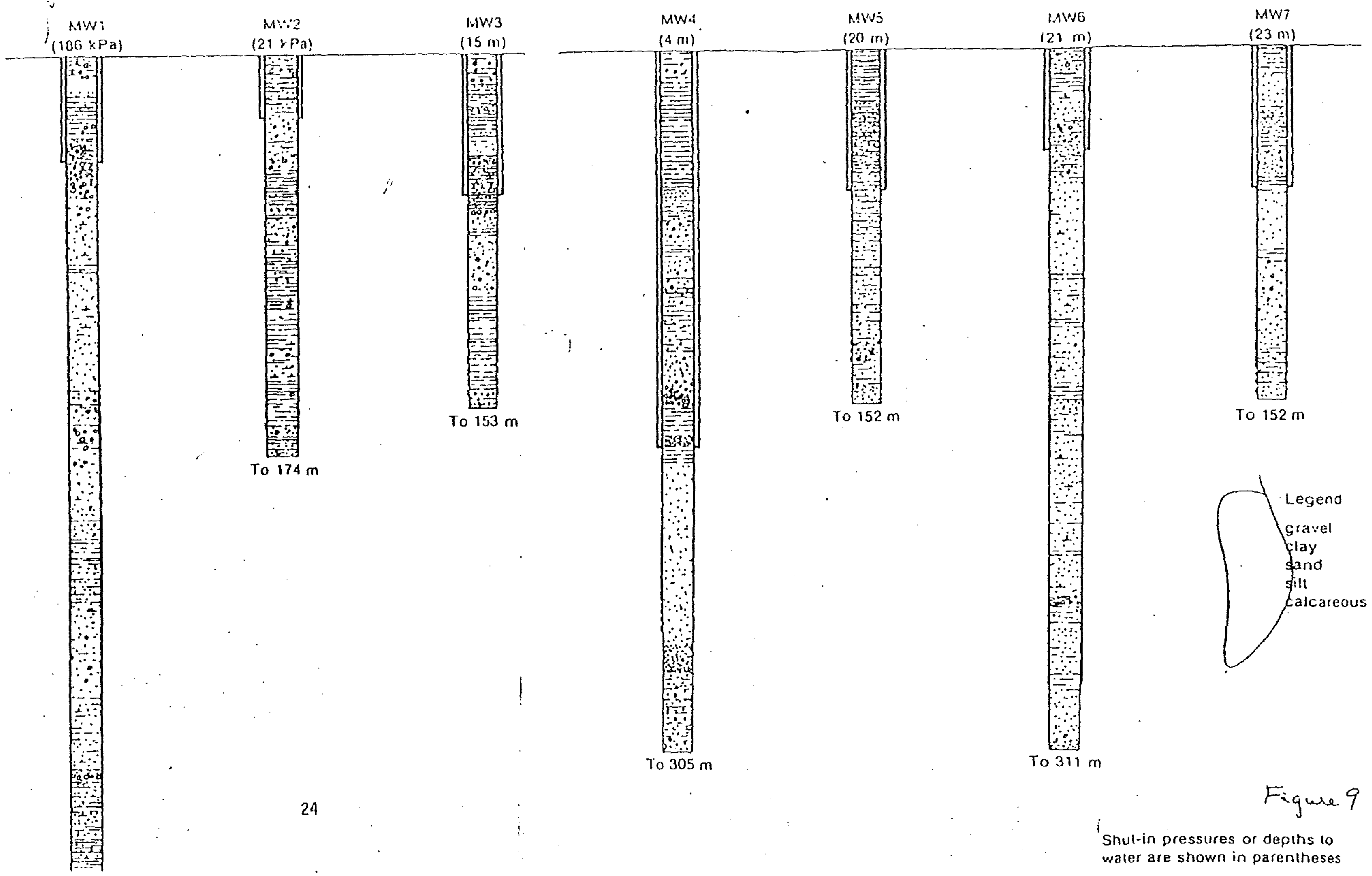
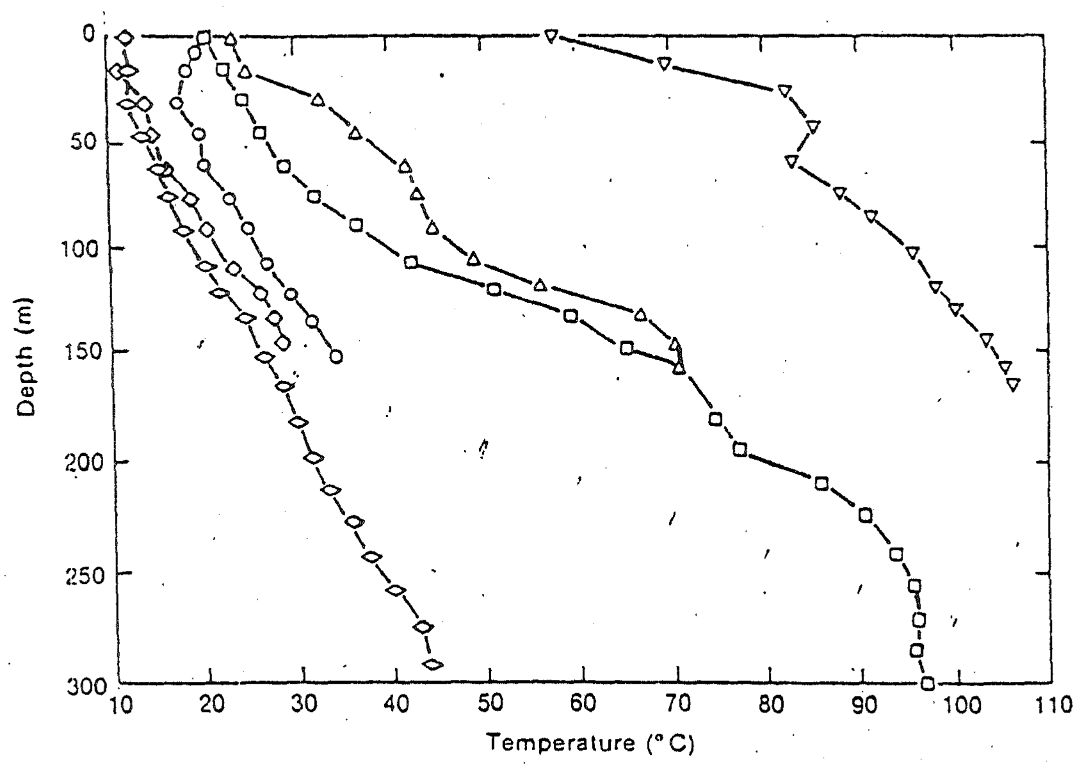


Figure 9

Shut-in pressures or depths to water are shown in parentheses

Temperature profiles Raft River monitor wells



Bottom Hole Temperature

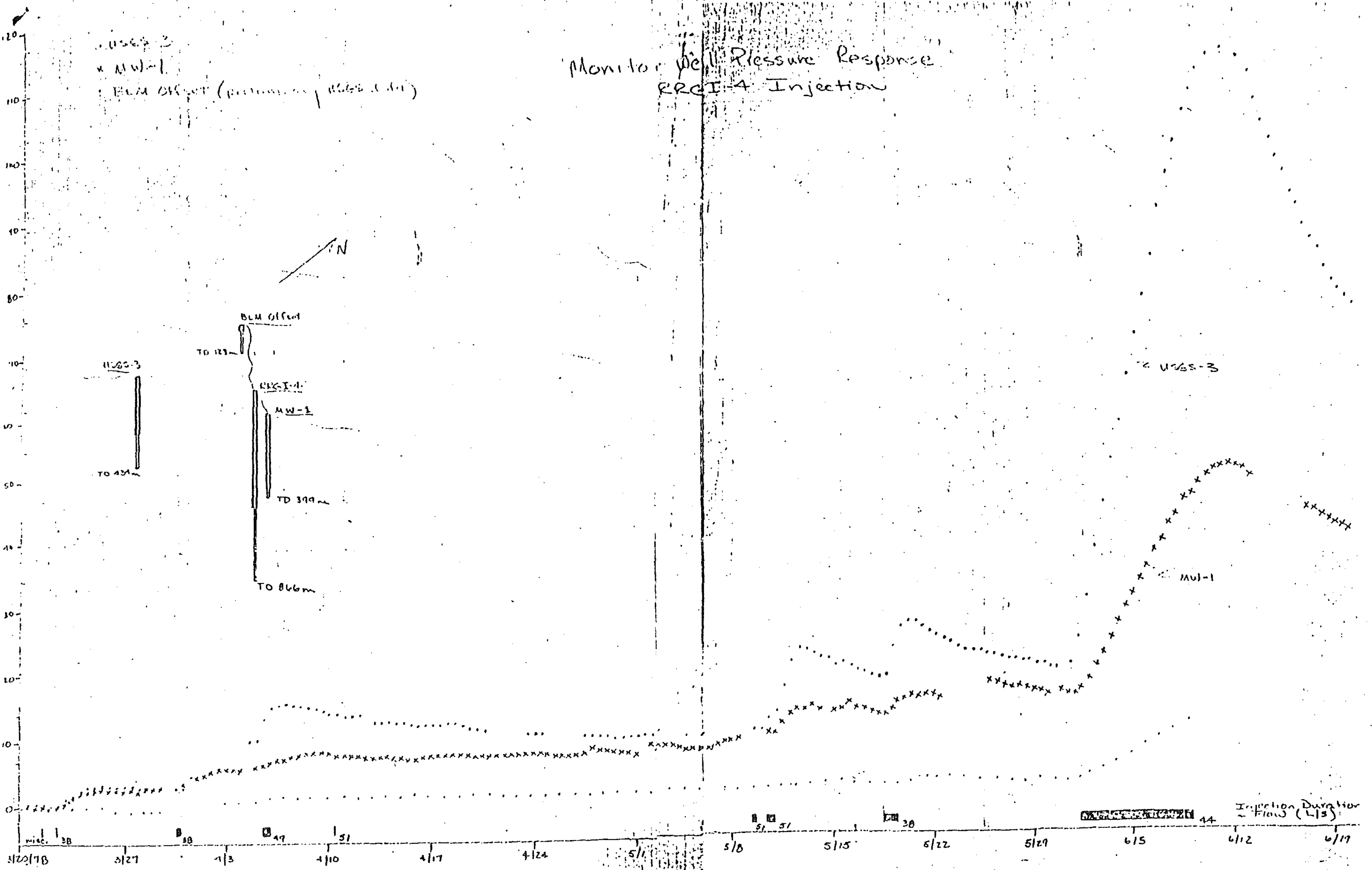
▽	MW-2	106°C	at	178 m
△	MW-3	71°C	at	162 m
□	MW-4	98°C	at	305 m
◇	MW-5	29°	at	146 m
◇	MW-6	44°C	at	293 m
○	MW-7	34°C	at	152 m

Figure 10

TABLE VII

Initial Water Quality - Monitor Wells
(in mg/l unless otherwise noted)

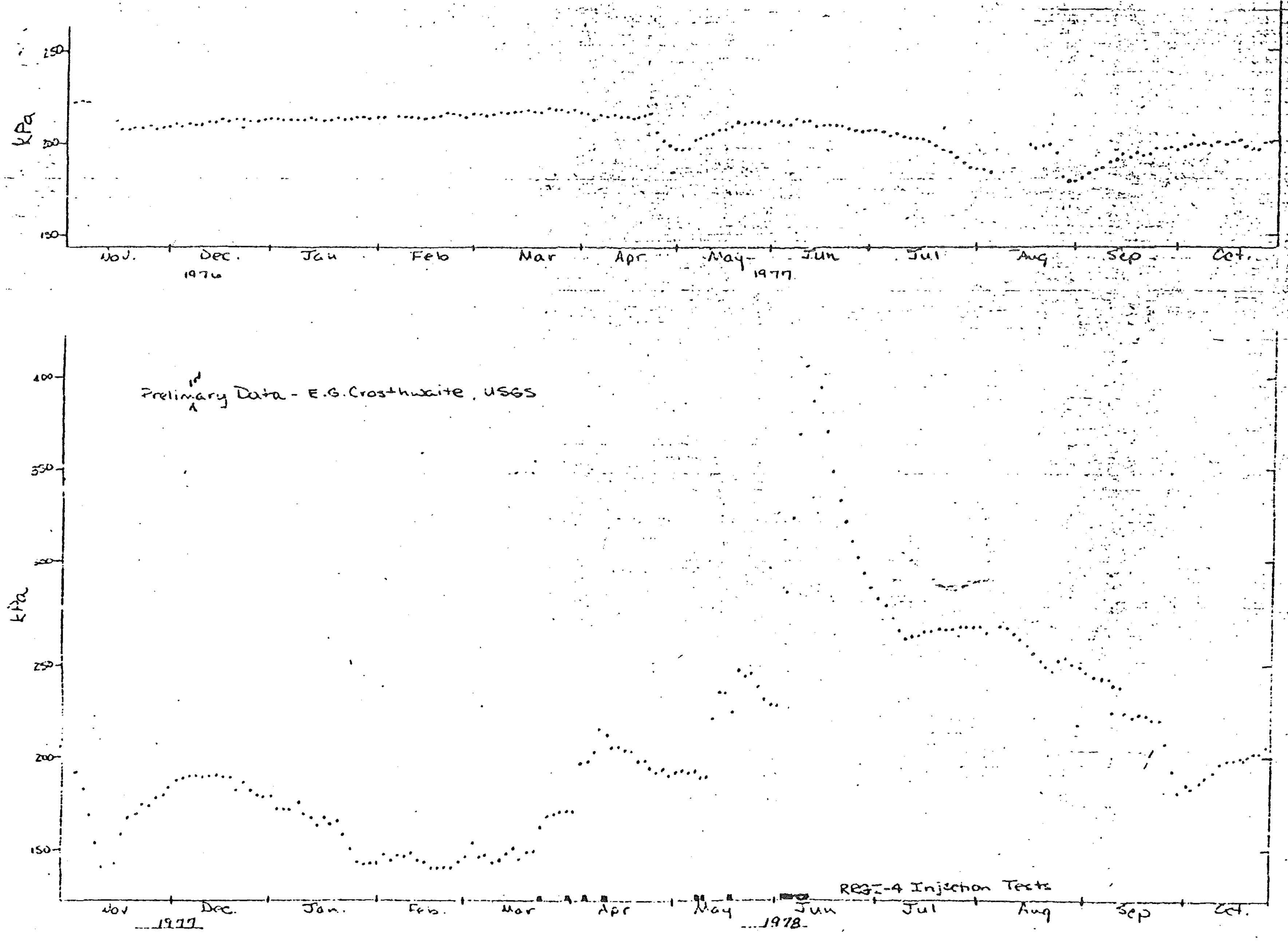
	MW-1	MW-2	MW-3	MW-4	MW-5	MW-6	MW-7	USGS-3	BLM	Crook's
Ca	193	118	173	189	164	193	102	60	42	108
Fe	0.3	0.5	7.6	12.8	5.7	0.3	7.6	--	<0.1	0.1
K	31	25	54	25	20	58	13	16	21	30
Li	3.8	2.6	2.9	3.4	2.5	2.6	1.1	2.1	1.5	2.5
Mg	0.36	0.6	4.0	--	--	--	23	0.3	0.2	0.4
Na	2,060	1400	1290	1390	210	1230	340	1090	570	1170
SiO_2	78	86	97	74	59	36	39	62	82	91
NH_4^+	1.4	0.08	0.62	1.7	<0.05	--	0.06	--	0.4	0.3
Cl^-	3,590	1640	2410	2440	610	2380	650	1870	890	1770
$CO_3^=$	<1	<0.1	--	<1	--	<1	--	0	<1	<1
F^-	2.7	5.6	5.1	6.2	0.5	3.7	1.0	4.9	6.7	5.6
HCO_3^-	25	28	50	40	--	--	104	50	35	33
NO_3^-	0.6	0.02	0.09	0.09	0.4	--	2.9	--	0.5	0.9
$SO_4^=$	68	60	50	43	44	63	28	62	55	49
pH	8.1	7.5	7.6	7.9	7.8	9.8	7.8	8.1	7.7	8.1
Conductivity (μmhos/cm)	11,200	5740	6100	7700	2000	7020	2250	6600	3200	6000
TDS	6,330	3200	4350	4000	1240	4660	1380	3360	1700	3300



Monitor Well Pressure Response
RRGI-4 Injection

Figure 11

Injection tests in RRGI-6 and RRGI-7 will begin in early 1979. The monitor wells, nearby irrigation wells, and USGS wells will be monitored for changes in water quality, pressure, or water level. RRGI-4, MW-1, MW-2, and USGS-3 will be used to monitor production tests later this year. All wells will be monitored during hydrofracturing and well stimulation tests planned for mid-1979. Upon completion of initial resource testing in early 1980, a report on the results and initial conclusions from monitoring injection and production tests will be issued.



Wellhead Pressure - USGS-3

Figure 12

~~1.4~~ 2.9

Aerojet Nuclear Company
Interoffice Correspondence

January 31, 1976

F. H. Tingey
Rogers

MILESTONE-10, RESERVOIR ANALYSIS - Kun-47-76

Completion of Milestone 10 specified a preliminary draft report be available and with review sign-off by the end of January.

The attachments, I believe, satisfy this milestone, as documented under this letter transmittal. The final version of this report will be prepared as soon as this program office has been able to fully integrate the contributions just recently received from Lawrence Berkeley Lab, with our own report material.

J. F. Kunze, Manager
Advanced Programs

rp

Attachments

cc: RCStoker
LGMiller
File

ATTACHMENTS

1. Outline of Final Report with summary material for each section including detailed Background and Summary Information.

2. Draft Report by Dr. Paul A Witherspoon and Dr. T. N. Narasimhan, edited by R. C. Stoker.

3. Letters documenting flow characteristics under pumped conditions.

4. Preliminary Report prepared by Dr. Paul A Witherspoon for the October 17, 1975 Senate Hearings in Idaho Falls.

5. Completion Report, "Raft River Geothermal Exploratory Hole No. 1 (RRGE-1)," October 1975, IDO-10062, NVO-410-30, Reynolds Electrical and Engineering Company, Inc.

Attachment 1

PRELIMINARY DRAFT REPORT

ADVANCED PROGRAMS

A COLLECTION OF INFORMATION ON THE RAFT RIVER GEOTHERMAL AREA

RESERVOIR POTENTIAL FOR PILOT PLANT AND SUBSEQUENT DEMONSTRATION PLANT DEVELOPMENT

Prepared by:

R. C. Stoker
J. F. Kunze

Idaho National Engineering Laboratory

With Contributions from:

P. A. Witherspoon
T. N. Narashimhan

Lawrence Berkeley Laboratory

Reviewed and Approved:

L. G. Miller
L. G. Miller, Manager
Geothermal Field Operations

J. F. Kunze 1/31/76
J. F. Kunze, Manager
Advanced Programs

RAFT RIVER VALLEY RESERVOIR ENGINEERING REPORT

1.0 INTRODUCTION AND BACKGROUND

The Raft River Valley of Southcentral Idaho appears to be one of the most promising areas in the United States for near surface economically recoverable geothermal energy. As a typical site of the Western States, this area was selected in 1973 by the Idaho National Engineering Laboratory (INEL) and the U.S. Geological Survey (USGS) as a prime location for the possible establishment of a medium temperature-low salinity geothermal research and development power plant project. The geological, geophysical and shallow well information gathered by the USGS, indicated that the Raft River Valley is a complex fault-controlled feature typical of the Basin and Range Physiographic Province. It appears to be one of the promising areas in the United States for near surface, economically recoverable geothermal energy, typical of the many such areas, and hence appropriate for the siting of the pilot-demonstration facility.

The correct interpretation of geothermal reservoir characteristics is of utmost importance if the reservoir is to be efficiently utilized in the support of a nominal 10 MW(e) net, pilot plant. The plant requirements of 300°F water at 5,000 gpm flow, dictate that four or five wells will be necessary, all logicially and judically located such that the reservoir can sustain the flows and temperature over a long (>20 year) period of time. In addition, the water must be reinjected into the reservoir at the appropriate depth and location to maintain reservoir fluid pressures with a minimum long-term delerious effect on the producing well temperatures.

Drilling was completed on the first two wells in the spring of 1975. The wells afforded the opportunity to gather data on the reservoir characteristics. This report describes the tests conducted, the data gathered, the analysis and the conclusions reached concerning the reservoir.

2.0 SUMMARY AND CONCLUSIONS

Two geothermal wells have been drilled in the Raft River Valley in winter-spring 1975. These reached a depth sufficient to tap undiluted geothermal water of the expected reservoir temperature (nominally 300°F). Both wells delivered substantial artesian flow of 600 to 900 gpm once completed and cased. (The first well delivered 1400 gpm before ooler waters were cased out). The wells have, over the subsequent 6 to 9 months, received an extensive variety of flow testing and pressure monitoring, both for production and reinjection purposes. From the results of these tests, the characteristics of the reservoir between and surrounding them have been deduced.

In brief, the following statements are appropriate:

1. Both wells are successful producers of water of the desired temperature.

2. Pumping of the wells yields approximately the flow increase expected (once equilibrium is obtained), based on the standard pressure drop law for flow with frictional losses. This is partly due to the high effective permeability of the reservoir (see 3 below).

3. Both the dimensionless storage coefficient and the transmissivity coefficient, for the basic two-dimensional reservoir diffusion theory model, are quite encouraging for a reservoir expected to yield flow sufficient to operate a pilot plant (5000 gpm from 1 to 2 square mile area), and even a demonstration plant (25,000 gpm from 4 to 8 square mile region).

4. The total dimensions of the "reservoir" cannot be established from just two wells. But the three week drawdown test indicated but a few reflecting boundaries, and no apparent total reservoir enclosure limit from that test period.

5. The longevity of the reservoir has been estimated from the reservoir parameters, based on reinjection within a mile of the producing wells. Lifetimes of nearly a century with only a few degrees degradation of the production well temperatures seem likely.

6. From the testing to date, neither well has shown evidence of degradation. If anything, artesian flow and shut-in pressures have increased.

7. Neither well has been designed specifically for reinjection. Pressure and pumping power requirements to use these wells for reinjection are higher than anticipated, and future wells must be considered, designed specifically for reinjection.

In summary, the evidence is very convincing that production of 5,000 gpm can be obtained from 4 to 5 wells, 2 to 3 more than the present excellent producers. It appears that the success of future wells drilled near the present faults, and within a one mile radius of the present wells, are virtually certain to be excellent producers. The chance of success of obtaining about 20 producing wells for the 50 MW demonstration plant cannot be estimated with certainty from the present two wells. However, there is no data to date to indicate that problems are to be anticipated in obtaining 20 producing wells.

3.0 WELL SITING

The sites for two deep geothermal exploratory wells were selected primarily on the geological and geophysical data available for the Raft River area. The first site, RRGE-1, was selected such that the well would encounter the projected intersection of the Narrows Structure and the Bridge Fault at depth. The second site, RRGE-2 was selected to encounter the Bridge Fault at depth but be close enough to the Narrows Structure so that production would be influenced by this feature.

4.0 WELL DRILLING

4.1 RRGE-1

RRGE-1 was drilled to a total depth of 4989 feet during January, February, and March, 1975. Details of the drilling are included in a Completion Report. The well was completed as a successful production well.

4.2 RRGE-2

RRGE-2 was drilled to a total depth of 5988 feet during April, May, and June, 1975. The well will be deepened by 500 feet during March 1976. It is already a successful production well.

5.0 FLOW TESTING

Both RRGE-1 and RRGE-2 have undergone extensive flow testing during active drilling and over extended periods of time (5 weeks at 200-400 gpm). RRGE-1 discharges approximately 650 gpm under artesian conditions and RRGE-1 approximately 800 gpm.

A downhole temperature recorder was run in RRGE-2 several times under flow and static shutin conditions. Maximum temperatures in RRGE-1 and RRGE-2 is 294°F and 297°F, respectively.

6.0 WELL LOGGING

Several standard and special well logs were run in both wells and include temperature caliper, natural gamma, compensated neutron formation density, dual induction-laterology, spontaneous potential, dipmeter, compensated gamma density, sonic televiewer and flowmeter. The logging interpretation agrees to a large extent with the lithology of the sections and the geophysical data of the area.

7.0 DRAWDOWN PRESSURE TESTING

Drawdown tests were conducted in September and October on each individual well and with one well producing while the pressure change was observed in the other.

Following nearly two weeks of steady flowing from RRGE-2, the pressure in RRGE-1 dropped approximately 1-2/3 psig compared to its initial downhole pressure of 2003 psi. The interpreted results indicate high effective permeability and substantial storage coefficients.

It should be noted the tidal effect pressure changes are being observed with the pressure monitoring instrumentation. This phenomenon has magnitude (peak-to-peak) of typically 0.1 psi and occasionally as large as 0.2 psi. The observed tides correspond exactly to those predicted for "land-tides" created by the sun and moon in this area.

8.0 PUMPING TEST

Under pumped conditions, the No. 1 well performed about as expected, with reference to the artesian flow conditions. Flow is 650 gpm with an artesian head of 175 psi. With a pump operating with additional drawdown of 550 ft of water (at 290°F), an additional 220 psi head is developed. The flow increased to 980 gpm steady state. Approximately the increase expected for a highly permeable reservoir with "infinite" boundaries.

9.0 RESERVOIR SYSTEM

Based on the data gathered to date, it appears that the majority of geothermal water originates in the Almo Basin (the valley immediately west of the Raft River Valley). A larger portion of this water (78%) apparently flows underground through the Narrows and feeds a large and permeable reservoir underlying much of the southern portion of the Raft River Valley. Only about 22% of the annual precipitation in the Almo Basin can be accounted for by the observed surface runoff. Further investigation is continuing to affirm this concept of the total system.

Attachment 2

Raft River Valley Reservoir Testing - P. A. Witherspoon, and
T. N. Narasimhan, Edited by R. C. Stoker

A series of three drawdown tests were conducted in RRGE-1 and RRGE-2 during September and October as shown in Table 1. The instrument used to record the pressure changes was a highly accurate device employing a quartz crystal downhole and a frequency recorder on the surface. The INEL logging truck was used to lower and retrieve the tool from the two wells.

A coordinated effort involving INEL and the University of California Lawrence Berkeley Laboratory (Dr. Paul A. Witherspoon and T. N. Narasimhan) was accomplished during the testing. Analysis and interpretation of the data was accomplished by Witherspoon and Narasimhan.

The computation of permeability and storage coefficient result in the following data for RRGE-2.

TABLE 1

Test No.	Description	Duration Hours	Production		Pressure Gage in		Maximum Pressure drop	
			Well No.	Flow Rate gpm	Well No.	Depth, feet	Well No.	Δp, psi
1	Short Term Test on RRGE #2	215	RRGE #2	210	RRGE #2	5200	RRGE #2	39
2	Long Term Test on RRGE #2	615-1/2	RRGE #2	400	RRGE #1	1000	RRGE #1	3.6
3	Short Term Test on RRGE #1	30	RRGE #1	26	RRGE #1	4700	RRGE #1	1.1

	Drawdown Data		Recovery Data
	Jacob's Method (Asymptote Solution)	Theis Method	Asymptote Solution
Transmissivity (gpd/ft^2 at 296°F)	4,667	4,696	4,718
kH md-feet	44,134	44,442	44,623
Storage Coefficient S	1.134×10^{-2}; r_w = 1 foot	1.09×10^{-2}; r_w = 1 foot	-
ØcH (Porosity x Compressibility x Thickness)	2.82×10^{-2} ft/psi; r_w = 1 foot	2.71×10^{-2} ft/psi/ r_w = 1 foot	-

The analysis of the RRGE-2 drawdown data reveal the following:

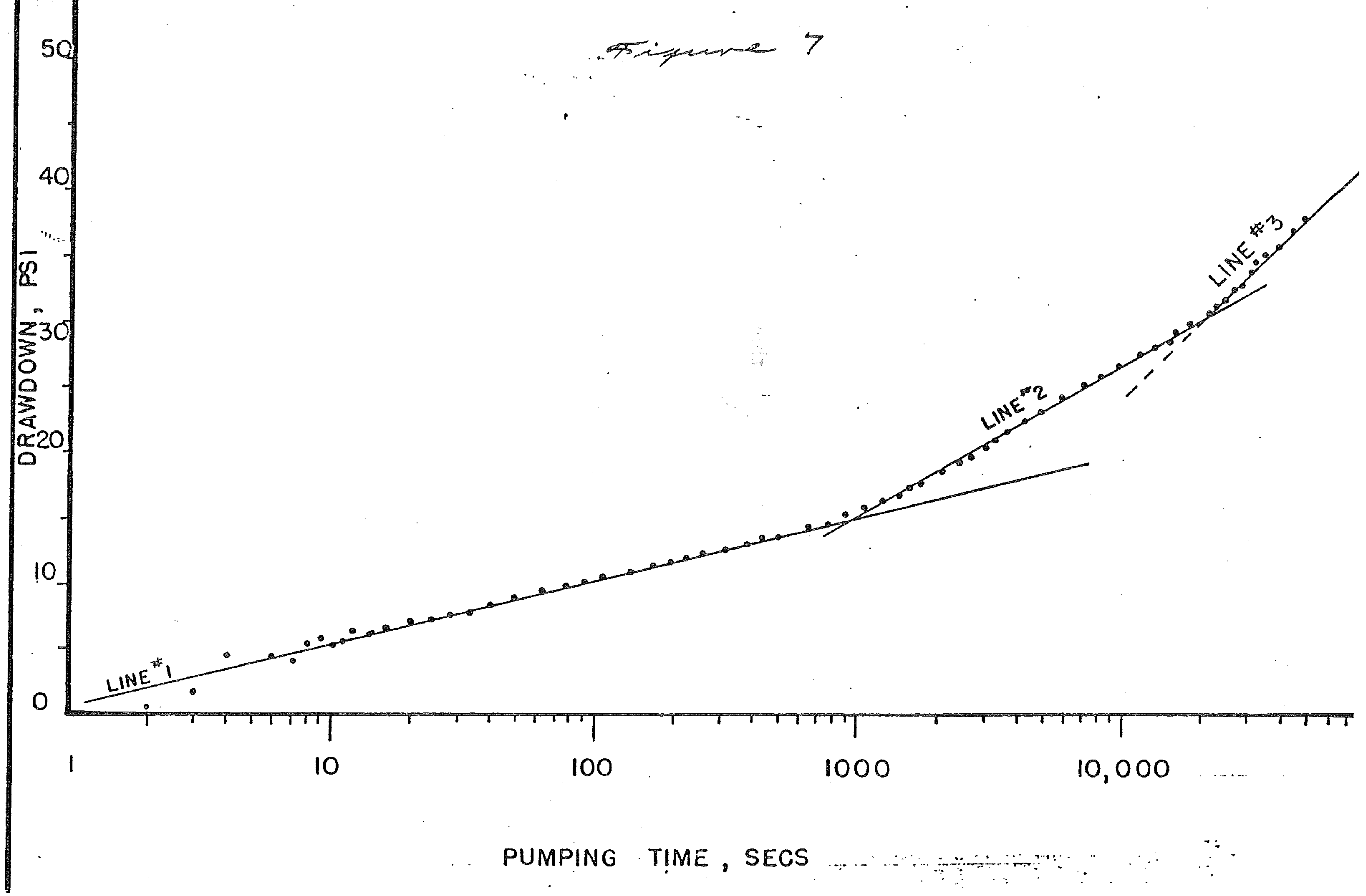
1. The semilog plot (Jacob's plot), Figure 7, of drawdown data indicates the presence of <u>more than one</u> barrier boundary, as evidenced by the three distinct straight line segments. The ΔP_{10} intercepts of these straight line segments are:

<u>Line 1</u>	0 to 800 seconds	ΔP_{10} = 4.75 psi/cycle
<u>Line 2</u>	800 to 20,000 seconds	ΔP_{10} = 11.3 psi/cycle
<u>Line 3</u>	20,000 to 46,000 seconds	ΔP_{10} = 20 psi/cycle

DRAWDOWN DATA FROM RAFT RIVER TEST AT RRGE#2

(9/12/75 TO 9/13/75)

Figure 7



If line 2 were controlled by only one boundary, it should have a ΔP_{10} equal to 2 x ΔP_{10} of line 1 = 2 x 4.75 = 9.50 psi/cycle. The fact that the ΔP_{10} of line 2 is found to be greater than 9.50 psi/cycle, suggests that the pressure drop beyond 800 seconds is controlled by more than one barrier boundary.

2. The log-log plot (Figure 8) of drawdown data also indicates the presence of more than one barrier boundary. It is seen from the plot that the data beyond 800 seconds departs from the Theis Curve and cuts across the type curves for $r_i = 50\ r_r$ and $r_i = 20\ r_r$ This fact also suggests the presence of more than one boundary barrier with the first image well about 50 effective radii away from the pumped well.

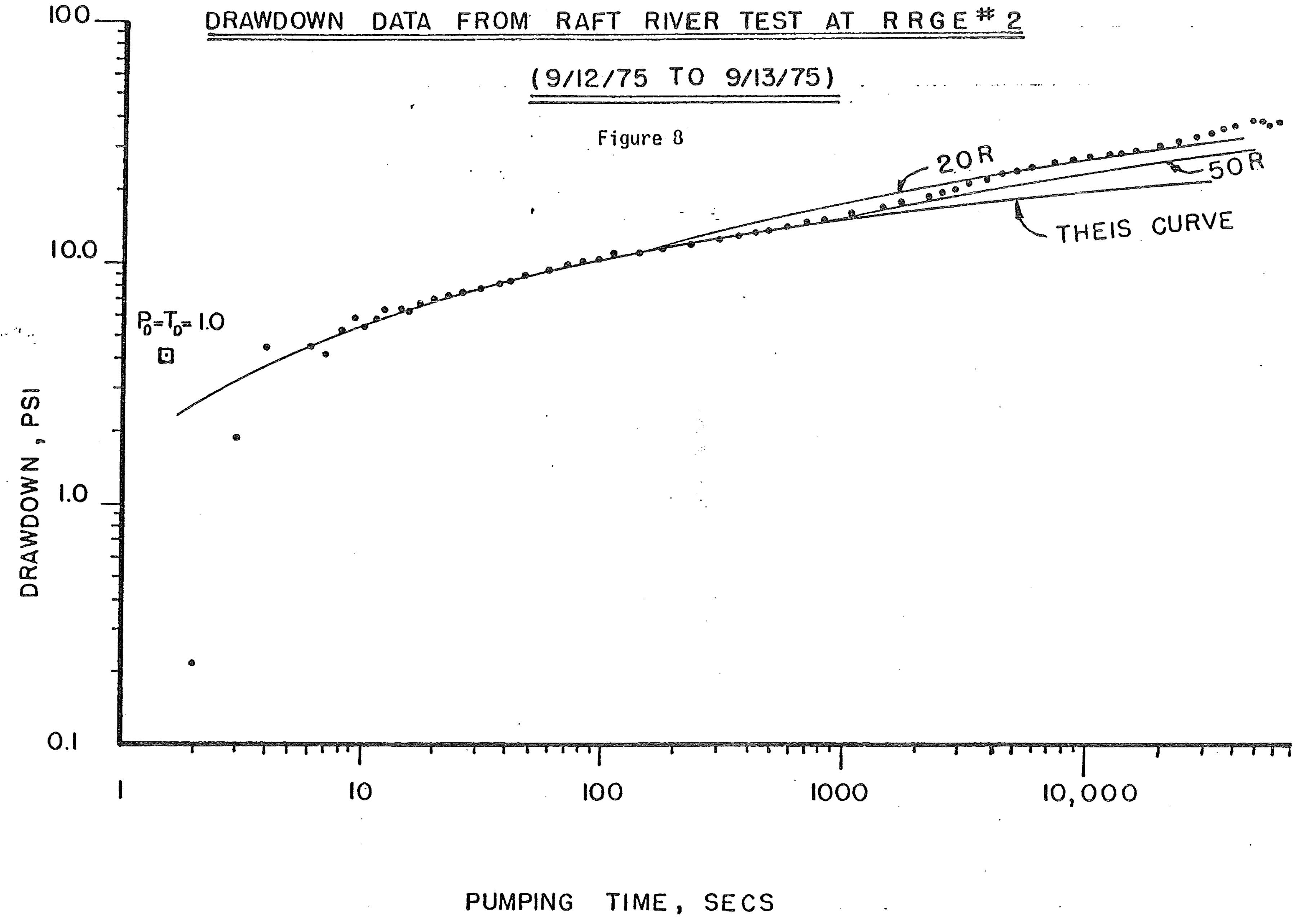
3. The calculation of the distance to the boundary depends on r_w in the case of this test. Using the Jacob's Plot, the following results have been obtained:

Assumed Effective r_w, ft (radius of wellbore)	r_i, ft (distance to image well)	Distance to boundary ($1/2\ r_i$)
1	23.5	11.75
3	70.5	35.25
5	117.5	58.75

The analysis of buildup data taken during the drawdown testing reveal the following:

1. The log-log plot (Figure 8) does not reveal any unit slope or half slope segments. This indicates neither wellbore storage nor large fractures have influenced the buildup data.

	Preliminary Test Sept. 14 to Sept. 17, 1975		Long Duration Test Sept. 20 to Oct 16, 1975	
	Theis Curve Matching Procedure	Asymptotic Solu. (Jacob's Method)	Theis Curve Matching Procedure	Asymptotic Solu. (Jacob's Method)
kH, md feet	2.25×10^5	2.22×10^5	2.28×10^5	2.28×10^5
Ø cH, ft/psi (Porosity x Compressibility x Thickness)	5.74×10^{-4}	5.39×10^{-4}	1.19×10^{-3}	9.38×10^{-4}
Transmissibility gpd/ft at 296°F	2.37×10^4	2.34×10^4	2.41×10^4	2.37×10^4
Storage Coefficient S	2.31×10^{-4}	2.16×10^{-4}	4.78×10^{-4}	3.77×10^{-4}



DRAWDOWN DATA FROM RAFT RIVER TEST AT RRGE # 2

(9/12/75 TO 9/13/75)

Figure 8

The analysis of the RRGE-1 drawdown data reveal the following:

1. The numbers for the permeability of the reservoir are fairly consistent. The average permeability characteristic appears to be:

   $kh \approx 2.25 \times 10^5$ md feet $\approx$23,700 gpd/ft at 296°F

2. The preliminary test and the long duration test give the same order of numbers individually for S and ϕcH but the preliminary test gives S and ϕcH values only about 50% of those yeilded by the long duration test. This inconsistancy is probably a result of the flow varying between 400 and 900 gpm during the early part of the long duration test.

The analysis of the RRGE-1 drawdown data reveal the following:

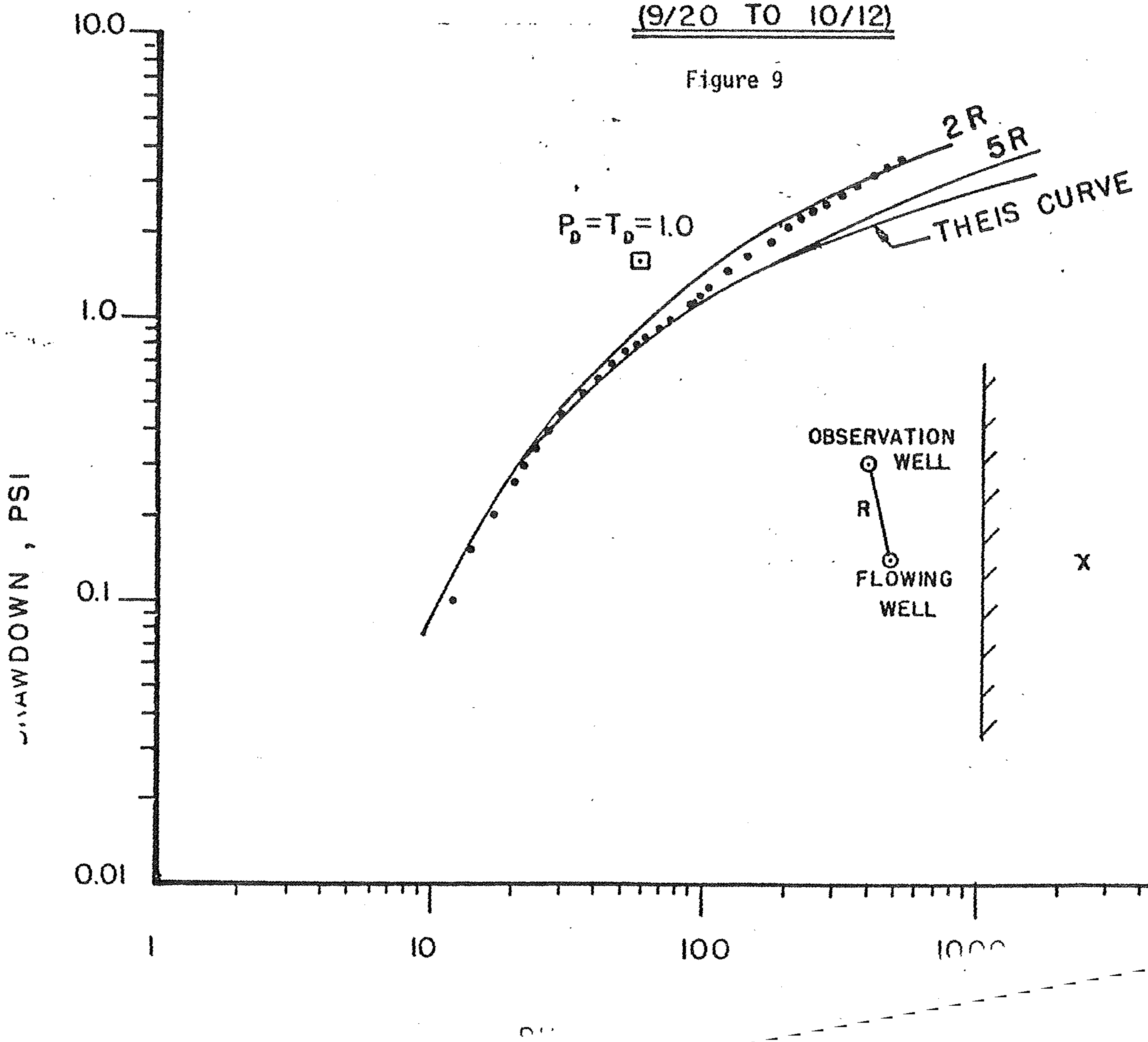
1. The total duration of production during the preliminary test was about 70 hours. Neither the Jacob's Plot or Theis Plot of this test indicate the effects of any barrier boundary close to RRGE-1.

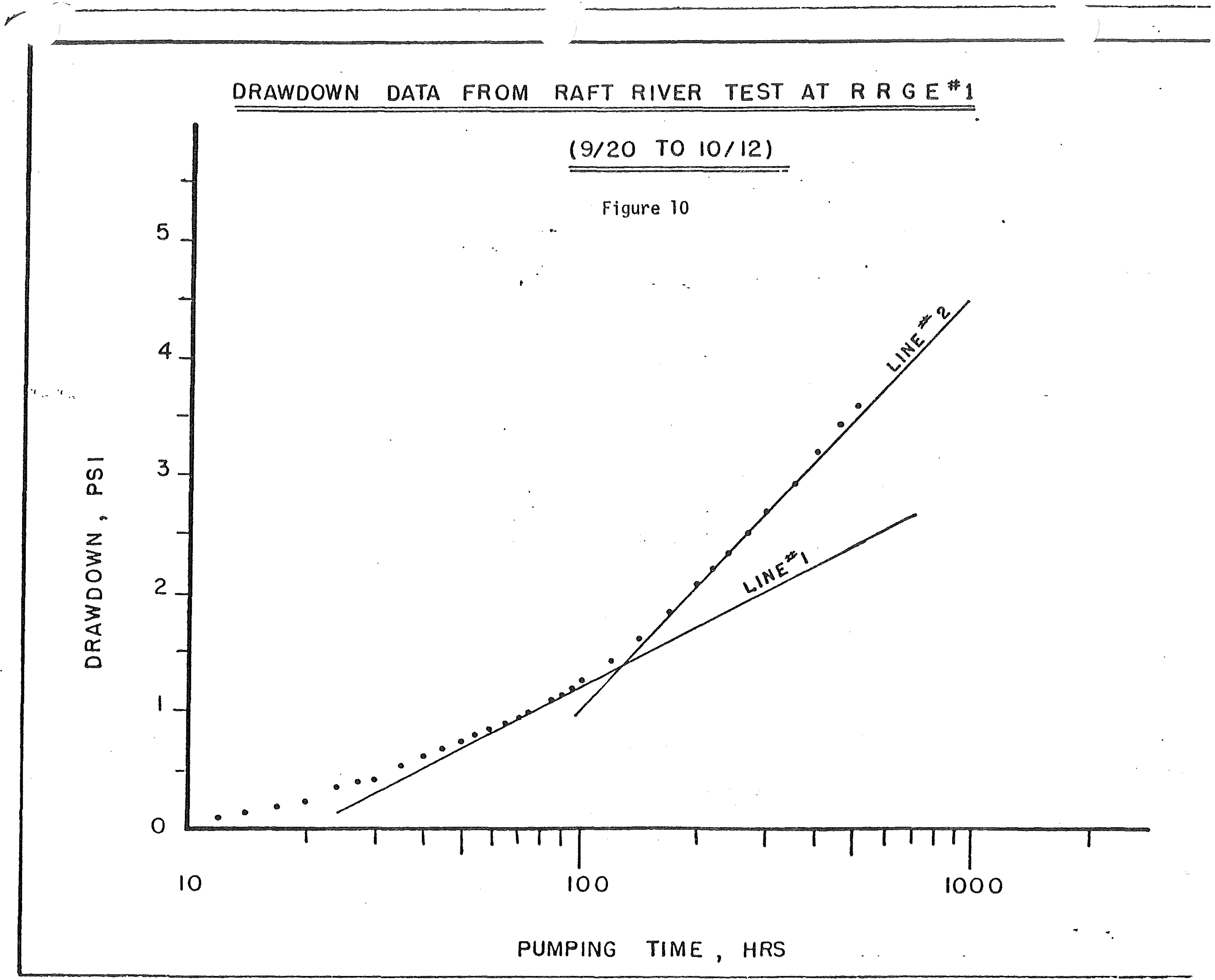
2. The Theis (log-log) Plot, Figure 9, of the long duration test data shows clear evidence of barrier boundary effects commencing from about 80 hours. Comparison with barrier boundary type curves indicate that the radius to the image well from the observation well (RRGE-1) is between 2 and 5 times the distance rr (4000 feet) to the real producing well (RRGE-2). The comparison also shows that the observed data gradually shifts towards and cuts across the type curve for ri = 2rr. This suggests that there is possibly more than one barrier boundary influencing the pressure drawdown.

DRAWDOWN DATA FROM RAFT RIVER TEST AT RRGE #1

(9/20 TO 10/12)

Figure 9





DRAWDOWN DATA FROM RAFT RIVER TEST AT R R G E #1

(9/20 TO 10/12)

Figure 10

3. The Jacob's (semi-log) Plot, Figure 10, of the long duration test data also shown the effects of barrier boundaries. The first boundary manifests itself as a change in straight line slope after about 80 hours. The slope of this line is 3.58 psi/log cycle, whereas the slope of the reservoir itself is 1.75 psi/log cycle. The fact that the ratio (3.58/1.75) is greater than 2 suggests that there is more than one boundary present. If only one boundary were present, the slope of line 2 should be twice that of line 1. The straight line plot also indicates the effect of more boundaries after 400 hours.

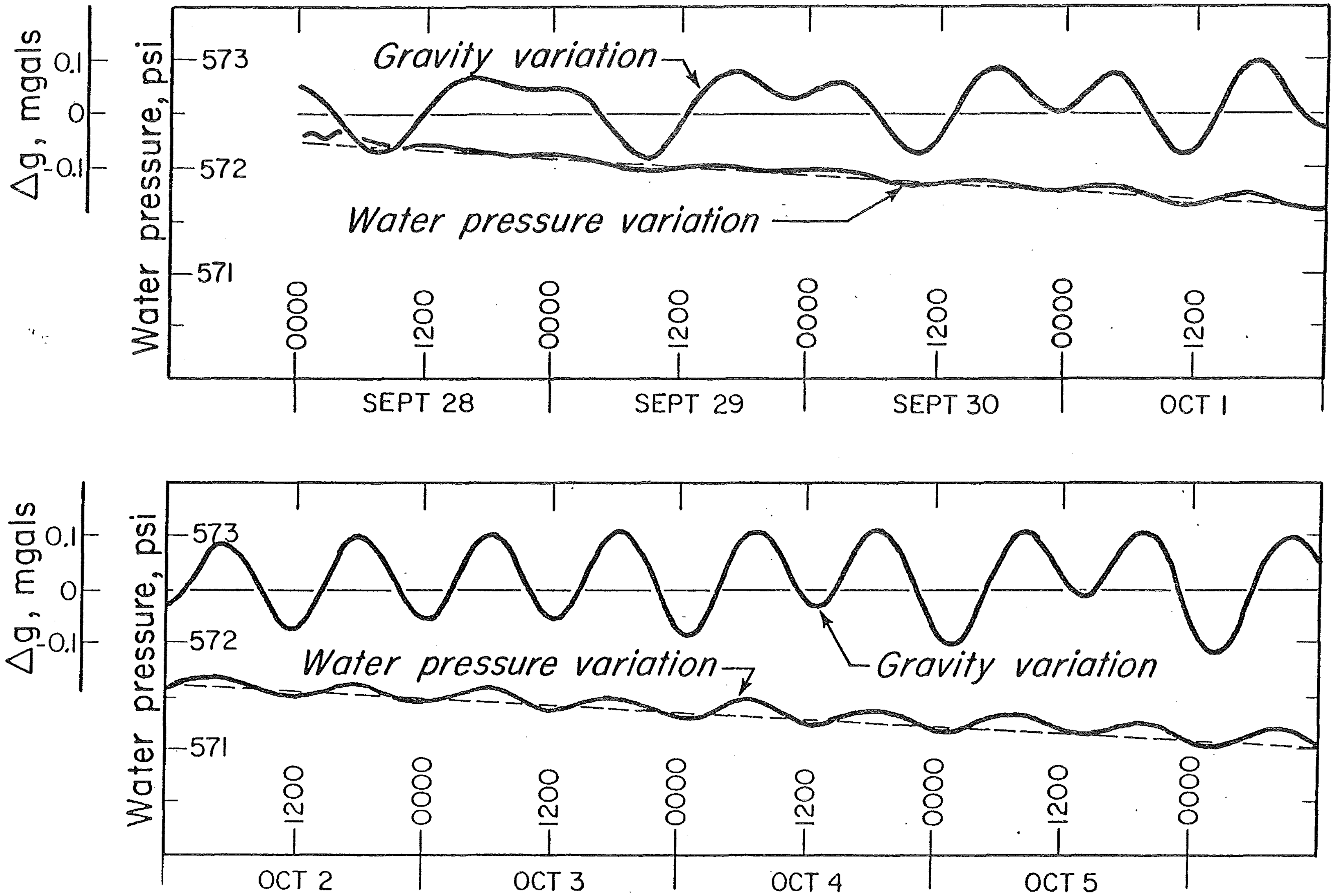
4. Calculations based on the Jacob's Plot data, show that the image well is located about 10,600 feet (2 miles) from RRGE-1. However, with only two wells it is not possible to fix the location of the image well as to direction and hence not possible to fix the location of the boundary.

The calculated parameters based on the short term test conducted in RRGE-1 are as follows:

kh = 115,000 md feet
T = 12,300 gpd/ft at 296°F
$\phi cH = 22 \times 10^{-4}$ ft/psi
$S = 8.1 \times 10^{-4}$

During the pressure testing, a slowly flucuating pressure variation was noted in the data. This was traced to lunial attraction effects and is shown in Figure 11. The fact that lunar effects are exhibited by the reservoir indicate the reservoir is rather large and has high permeability.

Figure 11



EFFECT OF LUNAR ATTRACTION ON WATER PRESSURE IN GEOTHERMAL RESERVOIR, RAFT RIVER VALLEY, IDAHO

XBL 7512-9504

Attachment 3

J. B. Hunger

Aerojet Nuclear Company

Interoffice Correspondence

December 24, 1975

DEC 30 1975

L. G. Miller
Rogers 326

RRGF #1 SUPPLY PUMP INSTALLATION - PROJECT NO. 82801-008, 552 - WLG-23-75

The down hole supply pumping system installation at RRGF #1 was completed November 22, 1975. The installation procedure, exact location of the downhole equipment, and the check out tests are described in this document.

The well was shut-in with the installation of a Model "KB" packer supplied by the Baker Oil Tool Company. The packer was set at 850 feet below grade level in the 13-3/8 inch well casing. The installation was accomplished with an electric line unit by Schlumberger, Incorporated. The packer installation was preceeded by a casing collar log and a gauge ring and junk basket run. This insured that the packer setting location was between casing collars and the casing was free from debris that might prevent the packer insertion.

The existing casing head spool, and master valve was removed and replaced with WKM Brewster Wellhead Company components. The new well head Christmas tree includes a new casing head with a guide bushing and secondary packing assembly to insure complete environmental protection for the upper aquifers and the well. The environmental expansion spool contains the primary packing assembly and allows up to 30-inches of production casing growth. A 12-inch through-conduit master valve completes the basic Christmas tree assembly.

The down hole supply pump system is comprised of three basic components. These are the 4-1/2 inch stinger, the Reda pump, and the 8-5/8 inch production tubing. The 4-1/2 inch stinger was installed in nominal 30 feet joints totaling 179.62 ft. The first section of the stinger was slotted to permit flow through the packer and into the annulus above the packer (Ref: Dwg. #406514).

The stinger is attached to the pump motor with a 4-1/2" x 2-1/2" swage. The pump is suspended from a hanger spool on the Christmas tree assembly. Fifteen joints of 8-5/8 inch casing totaling 609.98 feet was installed locating the pump inlet at 623.06 feet below the master valve flange. The stinger penetration through the production packer is 6.19 feet.

The remaining components of the Christmas tree assembly were installed and connected to the flow loop piping completing the supply pump installation (Ref: Dwg. #406494).

The initial checkout test lasted only 30 minutes. The unit and system performed as expected; however, the well drew down very rapidly and appeared to drop to approximately 500 ft. below the surface. The flowrate was approximately 1400 gpm. Additional drawdown studies will be made as pumping tests continue.

W. L. Godare

W. L. Godare
Special Projects Section
Design Engineering Branch

gh

cc: HWCampen (r) S. Cohen
JFKunze ←
LSMasson
RSMcPherson
JWNeitzel
RWGould (r) RBRinger
RDSanders
JFWhitbeck

Attachment 3

Aerojet Nuclear Company

Interoffice Correspondence

December 29, 1975

L. G. Miller
Rogers 326

RRGF #1 PUMP AND WELL TEST SUMMARY THROUGH DECEMBER 24, 1975 - WLG-24-75

Four short-duration tests have been conducted at RRGF #1 to evaluate pump performance and to characterize the well and reservoir. Each test is described in detail, and the data sheets for each is attached.

Test 101

This test was the initial checkout run for the pump and flow loop. The "dead-head" conditions for the pump were established prior to opening the flow control valve. It was determined that the flow control valve was not adequate for throttling the flow and should be changed before the next test.

The test lasted only 20 minutes, and no conclusive data was obtained, however, it was noted that the well drawdown was more than anticipated.

Test 102

Prior to starting the pump, an artesian flow test was conducted to establish a head versus flow curve for RRGF #1. This data is presented graphically in Figure 1.

The pump was started and the initial flowrate was in excess of 2000 gpm. However, after only 20 minutes, the flow and discharge pressure had dropped drastically. The throttle valve was completely opened and the well could not sustain flows in excess of 1055 gpm.

Test 103

The well was left flowing overnight prior to this test. The average flowrate during this period was 550 gpm and the maximum temperature reached was 274°F. The well head pressure was approximately 40 psig.

The initial drawdown occurred very quickly, dropping the water level to 554 feet below the surface in only five minutes. The drawdown seemed to reach semi-stable conditions after five hours of pumping at an average flowrate of 1020 gpm although the trend was still downward. At these conditions, the pump discharge pressure was 60 psig. Assuming this well would stabilize at 1000 gpm, the pump inlet could be lowered to 845 feet to regain the additional discharge pressure.

The 3-inch side valves were opened to bypass part of the flow in an effort to regain sufficient NPSH without decreasing total pump flowrate. The well did recover to produce a pump discharge pressure of 120 psig at a net flowrate from the well of 520 gpm. These conditions may not be an accurate indication of well performance due to the cascading of water back into the well.

Test 104

In an attempt to determine the amount of flow that could be pumped from the well, steady-state conditions from the artesian flow upward were studied. The initial flow condition achieved was 658 gpm. At this flowrate, the water level in the well dropped 66 feet.

The flowrate was then increased to approximately 740 gpm. The water level dropped to 167 feet before semi-steady state conditions were reached. At 818 gpm, the level dropped to 253 feet, and at 917 gpm the level dropped to 370 feet and the pump discharge presssure was 162 psig. The well could not sustain any flowrate above 920 gpm.

It must be emphasized that all points in this test were maintained for a very short time and, in most cases, there continued to be a downward trend in the water level in the well.

The data for this test is shown versus drawdown in Figure 2, and a pump performance comparison is shown in Figure 3. The pump is performing as expected, however, the well performance seems to be much less than predicted. In addition to the lack of capacity, the well is much cooler than predicted averaging only 270°F. There has been no casing expansion detected in any of the above tests.

Recommendations for Further Testing

The next logical test must be of longer duration. The well should be pumped at approximately 900 gpm for several days to determine whether or not this flowrate can be maintained for a significant length of time. If not, lower flowrates should be examined to find the capacity at which the well can be pumped.

Before this longer test can be made, suitable calibrated instrumentation should be installed to monitor discharge temperature and flowrates. Recorders should be avoided unless a controlled atmosphere and recalibration procedures can be maintained. A sketch showing the location of the instrumentation for Tests 101 through 104 is shown in Figure 4.

W. L. Godare
Special Projects Section
Design Engineering Branch

gh

Attachments - As stated

Distribution

cc: *HWCampen (r) SCohen
RWGould (r) RBRinger
JFKunze
LSMasson
RSMcPherson
GLMines
JWNeitzel
RDSanders
JFWhitbeck

*With Attachment I only

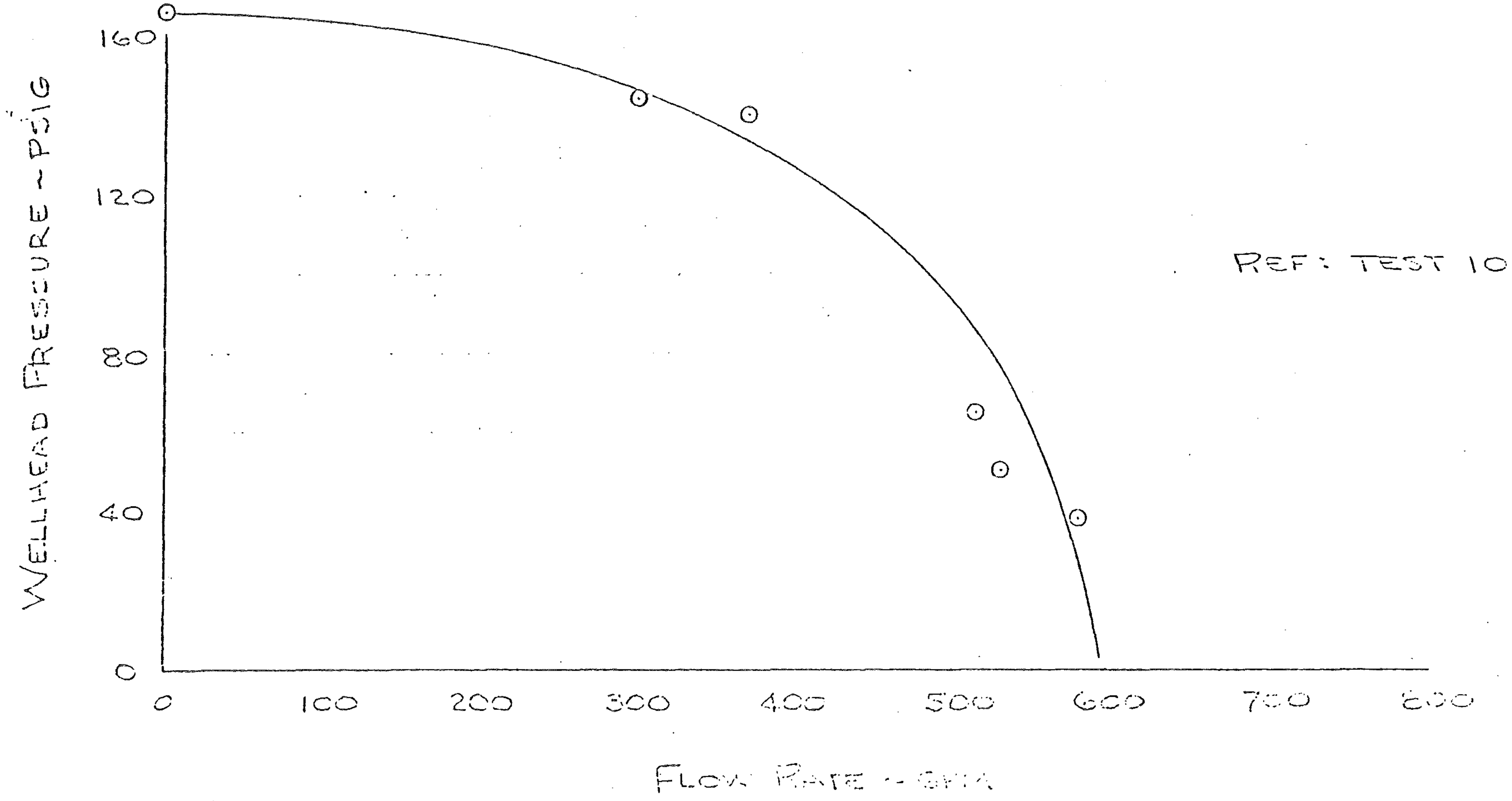
DATA SHEET TERMINOLOGY

E.T.	Time, HRS
QΔP	Orifice Plate ΔP, psid
QF	Flowrate, gpm
PWH	Wellhead Pressure (annulus) psig
PDT	Drawdown Tube Pressure - psig
ρW	Liquid Density - lb/ft^3
NPSH	Net Positive Section Head, ft.
PPD	Pump Discharge Pressure, psig
TPI	Pump Inlet Temperature, ^{o}F
TPD	Pump Discharge Temperature, ^{o}F
AMP	Pump Power - amps

FIGURE. 1

RRGF WELL No 1

ARTESIAN HEAD VS FLOW

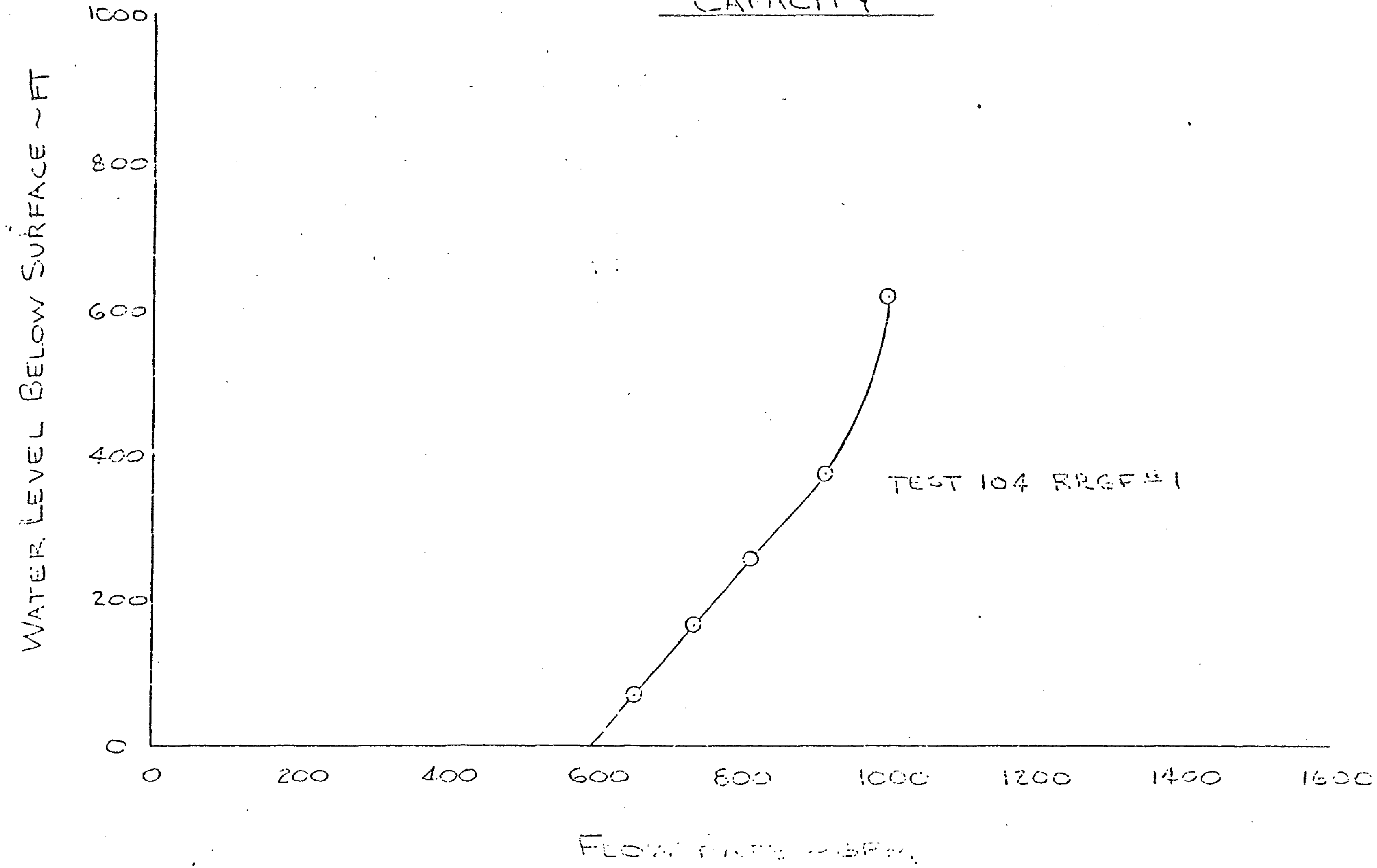


REF: TEST 102

12-30-75 [illegible]

FIGURE 2

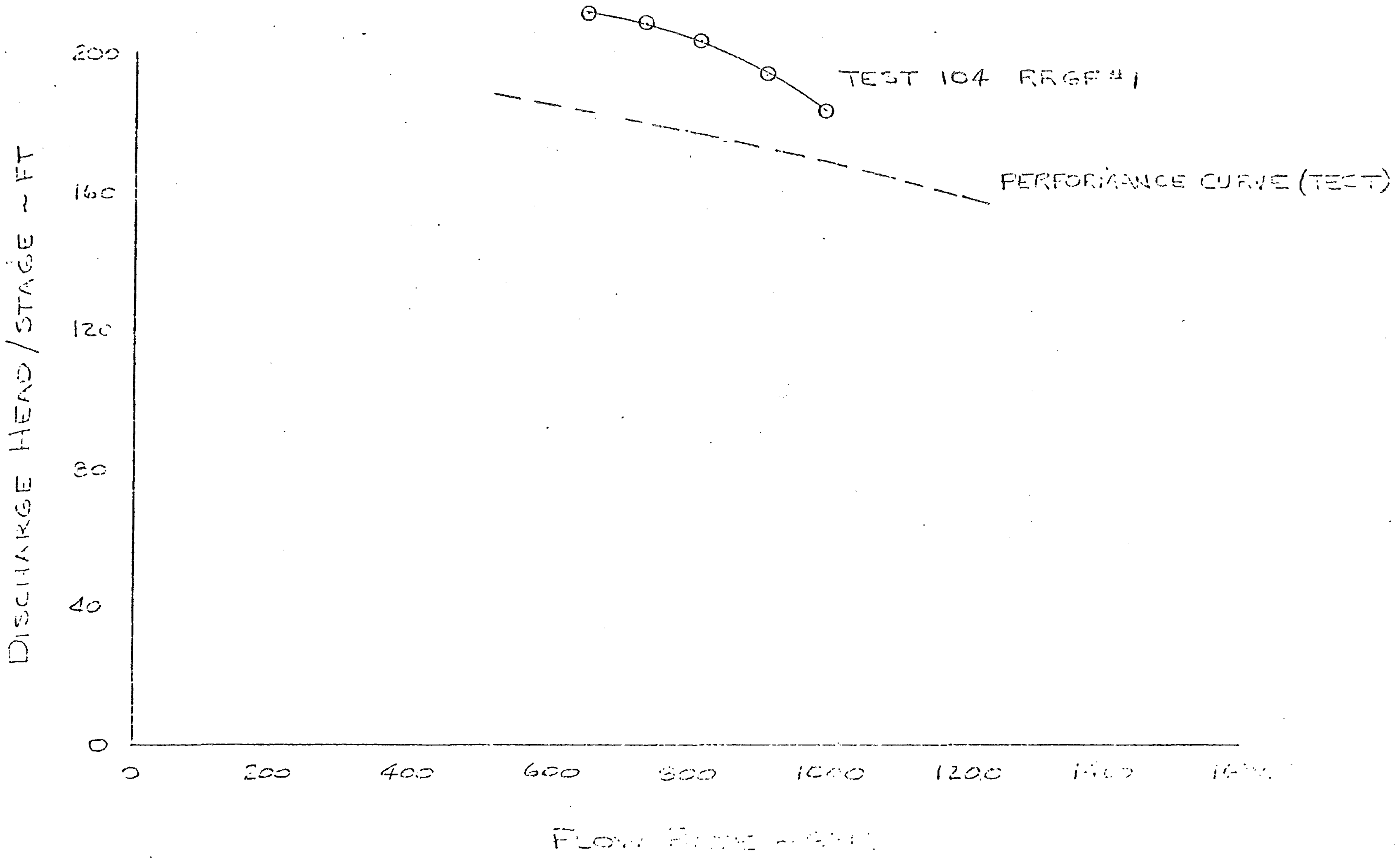
RRGF WELL No. 1
DRAWDOWN
VS
CAPACITY



12-18-75

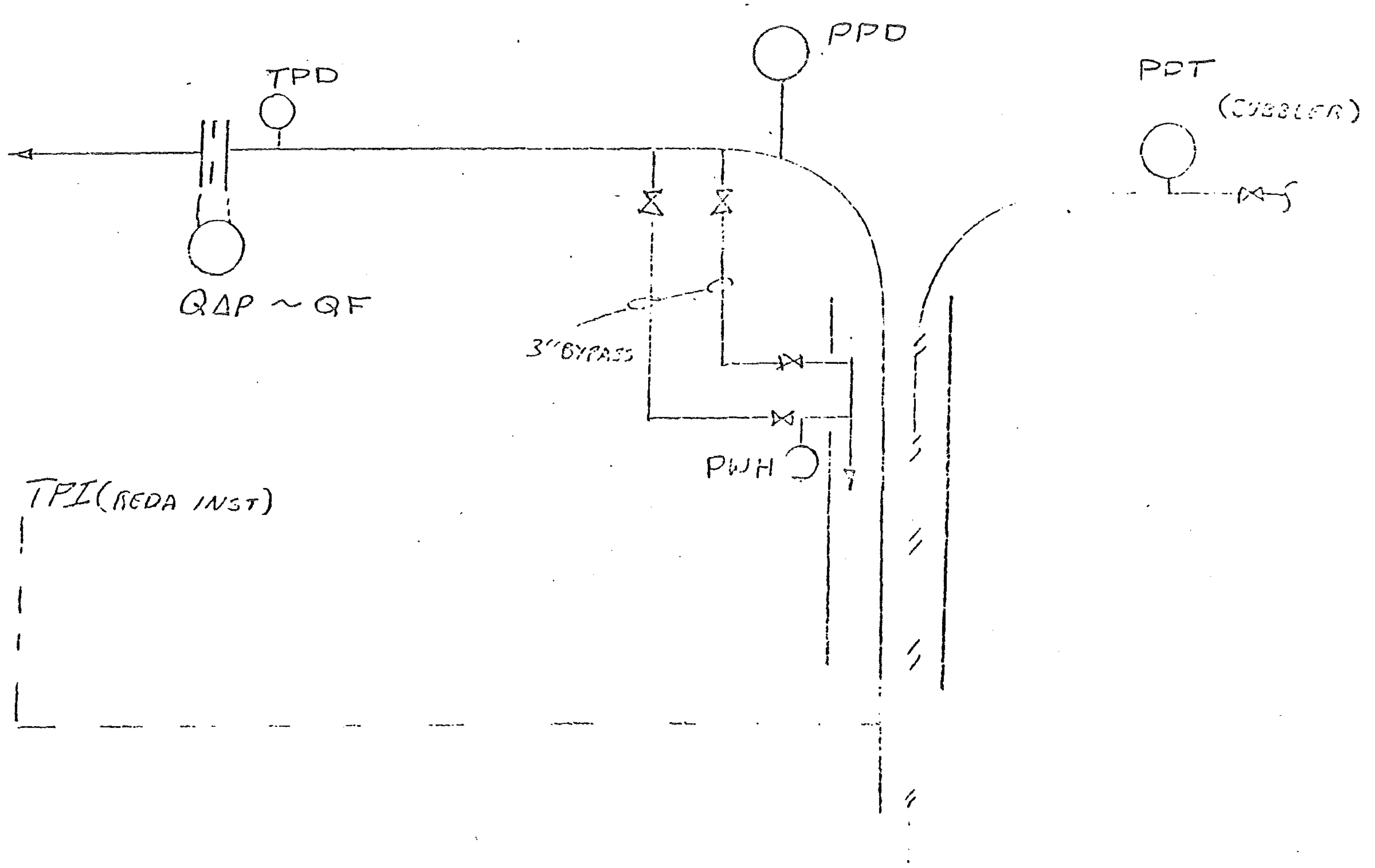
FIGURE 3

PUMP PERFORMANCE COMPARISON



12-18-75

FIGURE 4



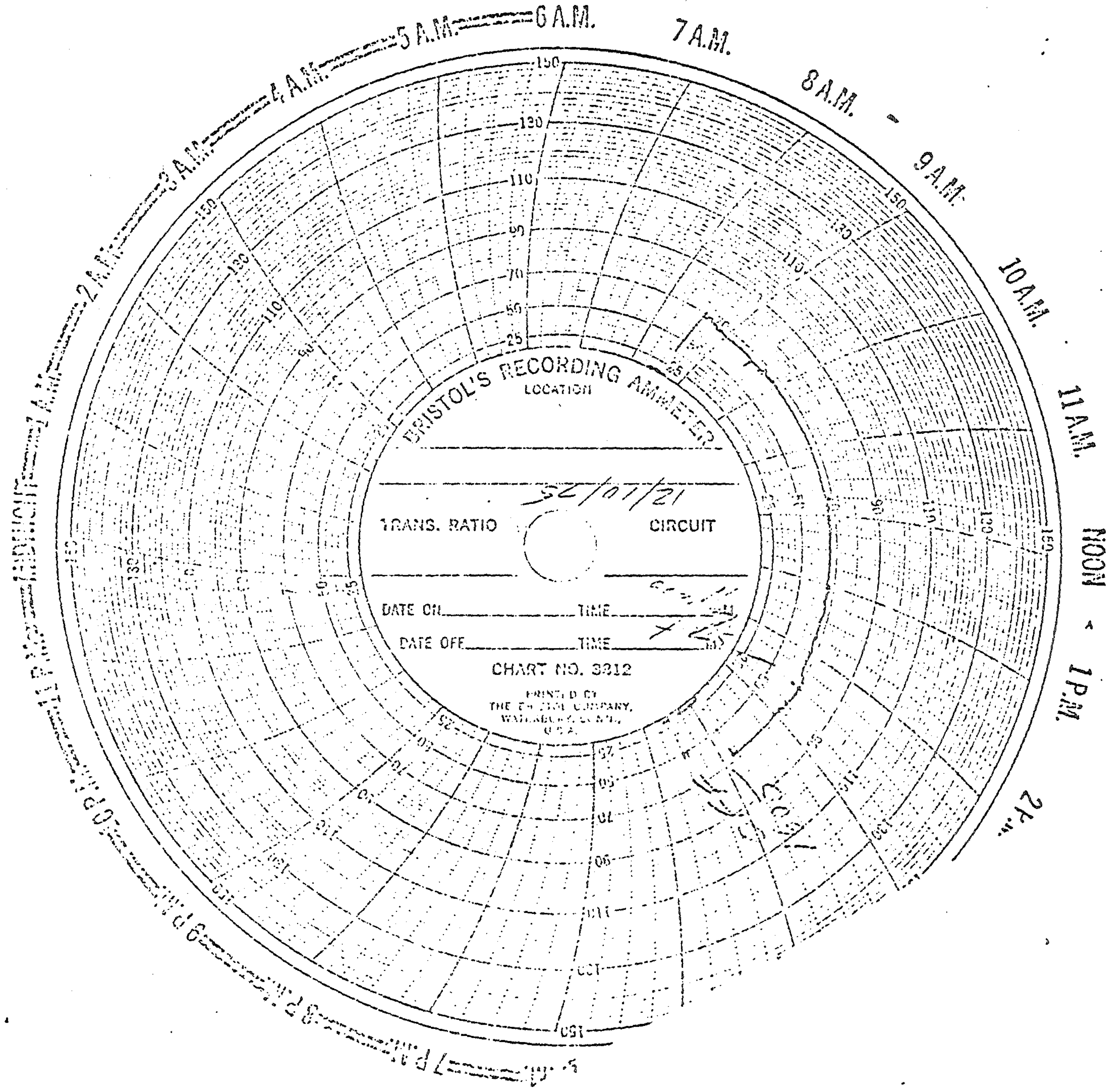
RRGF WELL #1 INSTRUMENTATION LOCATIONS

FORM ANC-656 (REV. 12-72)

START TIME: 0840 (Pump On)

AEROJET NUCLEAR COMPANY

T.	QΔP	QF	PWH	PDT	CW	WH	PPD	TPI	TPD	AMP
HRS	PSID	GPM	PSIG	PSIG	lb/ft^3	ft	PSIG	°F	°F	AMPS
0810	1.6	550	40	235	—	—	—	—	271	—
0814	Shut-in									
0830	0	0	160	2882	(BAD)	—	—	—	—	—
0840	Pump On									
0845	10	1370	32	60	58.18	69.3	48	—	270	[illegible]
0850	7.6	1190	20	45	58.18	37.1	48	—	272	[illegible]
0855	7.1	1153	28	42	58.18	34.7	48	—	272	67
0900	6.8	1129	28	40	58.18	29.7	48	—	272	[illegible]
0905	6.6	1110	26	40	58.18	[illegible]	48	—	[illegible]	[illegible]
0915	[illegible]	965	26	42	58.18	39.6	[illegible]	—	[illegible]	[illegible]
0930	[illegible]	1057	26	42	58.18	39.6	62	—	[illegible]	[illegible]
1000	5.80	1048	25	41	58.18	39.6	62	—	[illegible]	[illegible]
1030	[illegible]	1040	25	41	58.18	39.6	60	—	272	[illegible]
1100	5.65	1030	25	41	58.18	39.6	60	—	[illegible]	[illegible]
1145	5.6	1027	25	42	58.18	42.1	60	—	[illegible]	[illegible]
30	5.45	1012	25	38	58.35	32.1	60	—	268	[illegible]
30	5.40	1010	24	38	58.35	34.6	60	—	[illegible]	[illegible]
1430	Begin Bypassing							—		
1450	2.2	640	34	103	58.22	192.9	98	—	270	70
1520	1.5	520	35	250	58.22	556.5	120	—	270	68
1700	0	0	150	340	58.22	779.1	510	—	—	—


BRISTOL'S RECORDING AMMETER
LOCATION
12/10/75
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TIME
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CHART NO. 3812
PRINTED BY
THE BRISTOL COMPANY,
WATERBURY, CONN.
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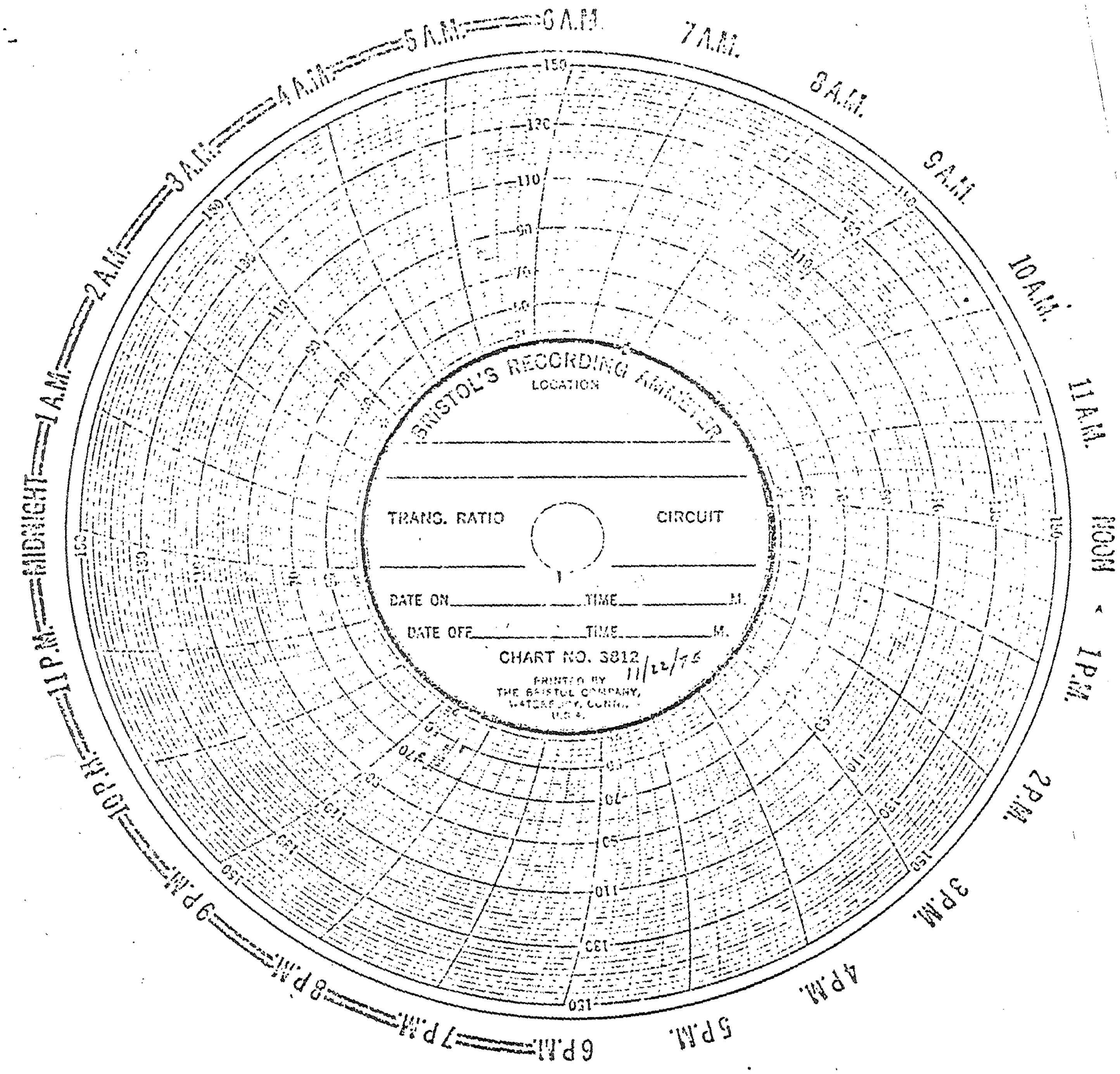
FORM ANC-656 (REV. 12-72) ATTACHMENT II
To WLG-24-75

START TIME: 2025

AEROJET NUCLEAR COMPANY

[illegible]	QΔP	QF	PWH	PDT	ρW	NPSH AVAIL	PPD	TPI	TPD	AMP
HRS	PSID	GPM	PSIG	PSIG	lb/ft³	ft	PSIG	°F	°F	AMPS
2025	0	0	—	—	—	—	520	261	—	55
2030	11.5	1470	—	—	—	—	350	—	—	—
2035	8	1220	—	—	—	—	150	—	—	70
2040	7	1145	—	100	—	—	110	—	—	63
2045		SHUTDOWN.								


BRISTOL'S RECORDING AMMETER
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CIRCUIT
DATE ON
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CHART NO. 3812
PRINTED BY
THE BRISTOL COMPANY,
WATERBURY, CONN.
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11/22/75

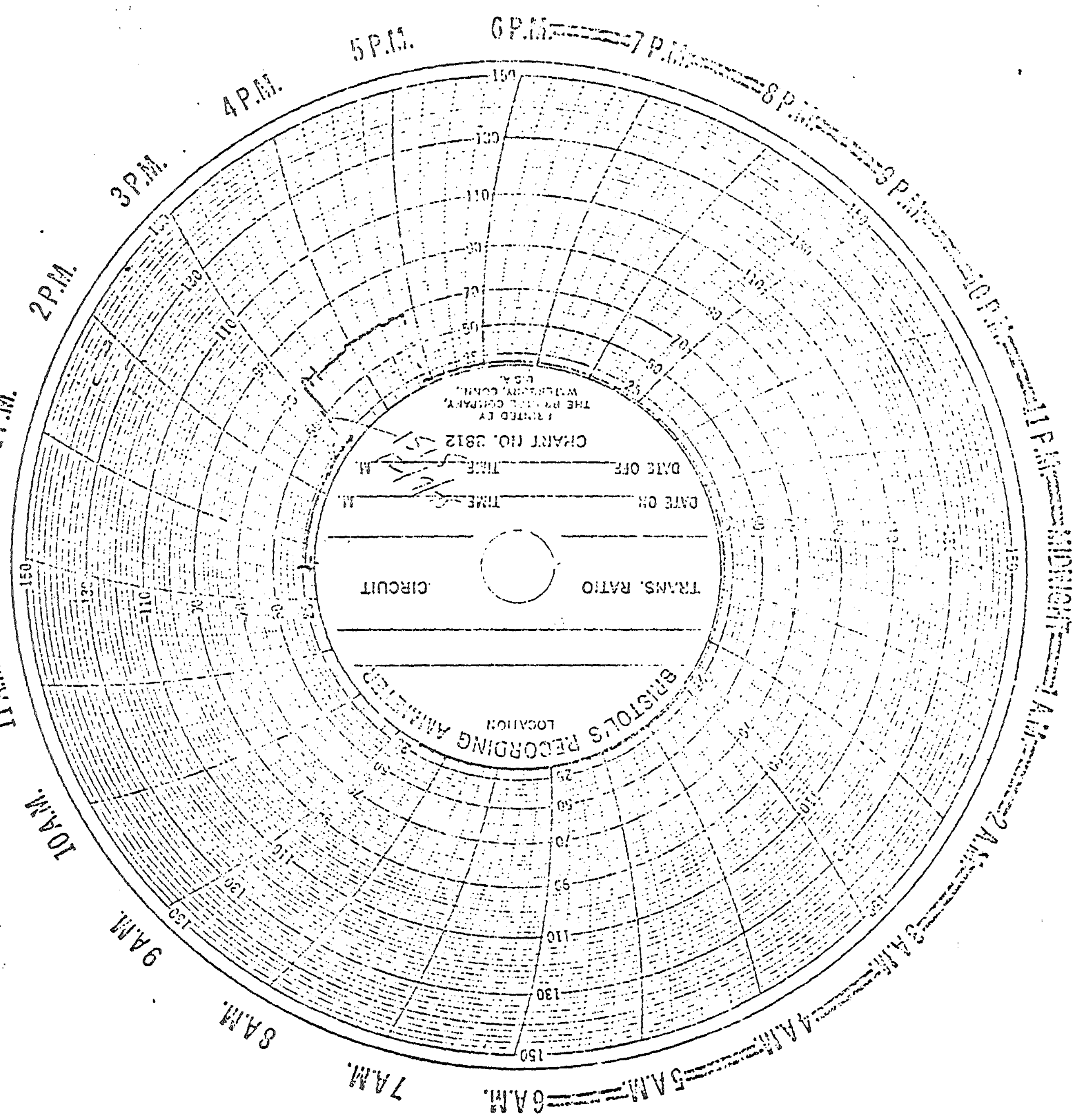
FORM ANC-650-(REV. 12-72)

START TIME: 1510 (Pump On)

AEROJET NUCLEAR COMPANY

T.	QΔP	QF	PWH	PDT	CW	NPSH ~~ΔH~~	PPD	TPI	TPD	AMP
HRS	PSID	GPM	PSIG	PSIG	lb/ft³	ft	PSIG	°F	°F	AMPS
(FREE FLOW)										
1230	.50	300	144	290	—	—	—	—	—	—
1350	.75	370	140	220	—	—	—	—	—	—
1415	1.4	515	65	220	—	—	—	—	—	—
1420	1.5	[illegible]	50	210	—	—	—	245	—	—
1445	1.8	580	32	185	—	—	—	250	—	—
1450	0	0	125	262	—	—	—	[illegible]	—	—
1510	Pump	On								
1530	5.7	1055	25	110	58.49	209.3	140	255.5	—	6.8
1600	6.7	1120	25	90	58.49	160.0	95	258	—	[illegible]
1625	5.7	1035	25	68	58.49	105.9	95	260	—	[illegible]
1630	6.1	1070	25	57	58.49	83.7	75	261	—	6.5
1639	5.9	1055	25	55	58.49	73.9	70	262	—	6.8
1642	6.1	1070	25	51	58.49	64.0	65	262	—	6.8
1650	5.7	1055	25	50	58.49	61.5	65	[illegible]	—	6.7
1655	SHUT	DOWN								

INCREASING FLOW / OPENING THROTTLE VALVE.



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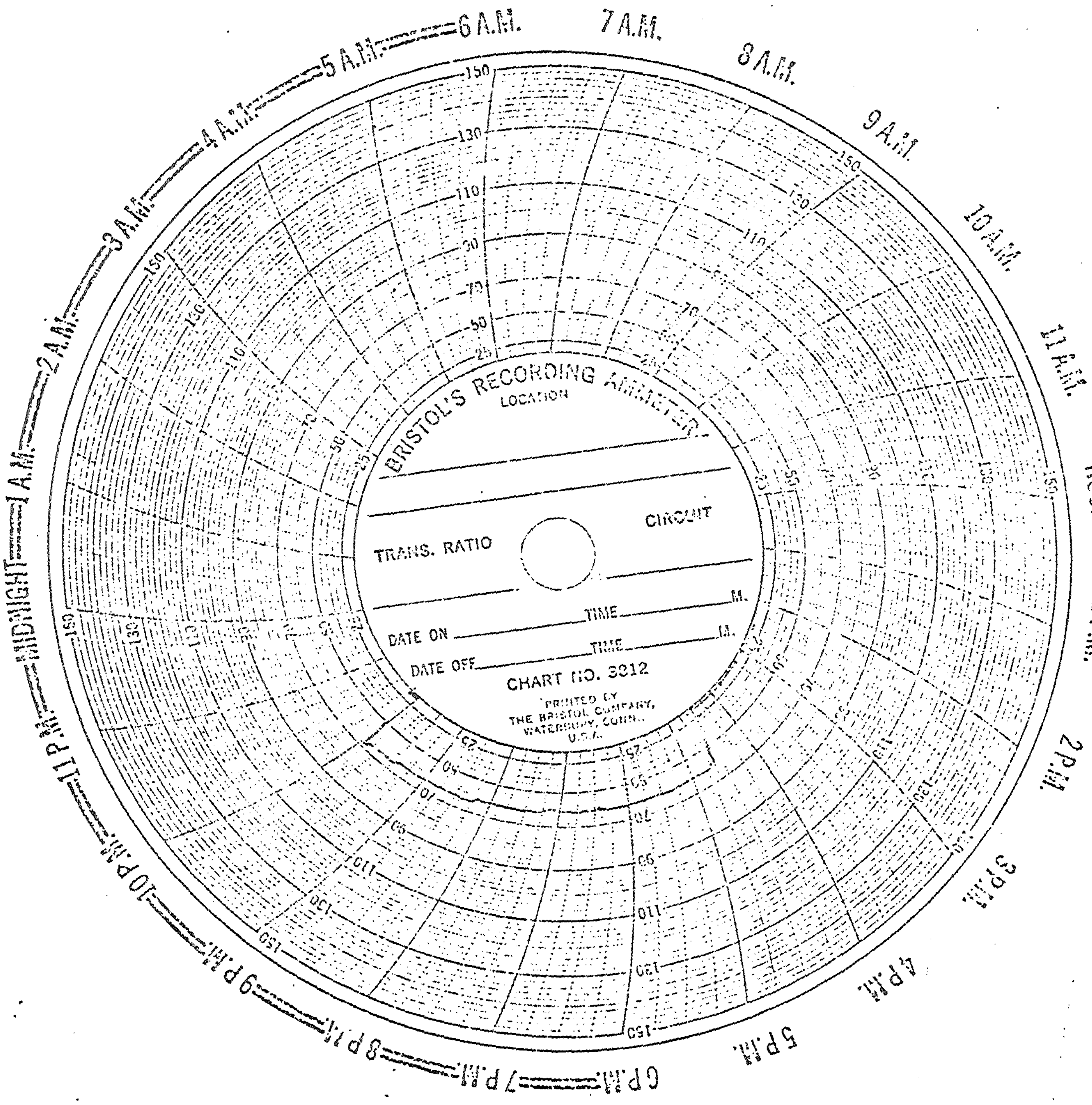
BRISTOL'S RECORDING AMMETER
LOCATION
TRANS. RATIO
CIRCUIT
DATE ON
TIME
M.
DATE OFF
CHART NO. 2812
THE BRISTOL COMPANY,
WATERBURY, CONN.
U.S.A.

FORM ANC-556 (REV. 12-72)

START TIME: 1625

AEROJET NUCLEAR COMPANY

T.	GΔP	QF	PWII	PDT	ρW	WR	PPD	TPI	TPD	AMP
HRS	PSID	GPM	PSIG	PSIG	lb/ft³	ft	PSIG	°F	°F	AMPS
1630	2.4	673	31	268	58.22	576.5	300	—	270	60
1645	2.3	658	29	252	58.22	576.1	315	—	270	55
1700	2.3	658	29	252	58.22	576.9	315	—	270	55
INCREASING	FLOW									
1705	3.2	725	29	239	58.22	574.7	295	—	270	58
1720	3.0	750	27	218	58.22	475.3	270	—	270	55
1730	3.0	750	27	218	58.22	475.3	270	—	270	55
1745	3.0	750	27	215	58.22	470.3	270	—	270	57
1800	3.0	750	27	212	58.22	462.9	270	—	270	57
1815	2.85	733	27	211	58.22	460.4	270	—	270	57
1830	2.90	740	27	209	58.22	455.5	268	—	270	57
1900	2.85	733	26	207	58.22	457.9	268	—	270	57
INCREASING FLOW										
1907	3.75	840	28	185	58.22	[illegible]	225	—	270	58
1920	3.55	818	28	178	58.22	[illegible]	225	—	270	58
1940	3.55	818	28	176	58.22	371.4	225	—	270	58
[illegible]	3.55	818	28	175	58.22	368.9	225	—	270	57
INCREASING		FLOW								
2005	4.95	925	28	140	58.22	[illegible]	[illegible]	—	270	[illegible]
2030	4.50	920	28	128	58.22	252.6	[illegible]	—	270	[illegible]
2045	4.45	917	28	128	58.22	252.6	162	—	270	[illegible]
2110	4.45	917	27	127	58.22	252.6	162	—	270	57
INCREASING		FLOW								
2120	5.20	989	27	105	58.22	188.2	120	—	270	57
2135	4.95	965	27	100	58.22	185.9	150	—	270	57
2150	SHUTDOWN.									
2200	0	0	125							
2205	0	0	140							
2210	0	0	145							
2214	0	0	147							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BRISTOL'S RECORDING AMMETER
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CHART NO. 3312
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Attachment 4

LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720 ▫ TEL. (415) 843-2740

October 15, 1975

PRIORITY MESSAGE

Dr. James C. Bresee
Division of Geothermal Energy
U. S. Energy Research & Development
Administration
Washington, D. C. 20545

Dear Jim:

As per your request, I have prepared the following statement on the Raft River testing program for you to use as you see fit.

RAFT RIVER GEOTHERMAL PROJECT
RESERVOIR ASSESSMENT

At the request of Dr. Jay Kunze, Director Raft River Geothermal Project, Idaho National Engineering Laboratory (INEL), the Lawrence Berkeley Laboratory (LBL) Geothermal Group was asked to provide technical assistance in assessing the size and producing capabilities of the geothermal reservoir at the Raft River Project near Malta, Idaho. Two wells about 4,000 feet apart have been drilled in Section 23-15S-26E of Cassia County and were used in this reservoir assessment work.

The geological and geophysical exploration work performed by the U. S. Geological Survey has revealed that a complex fault system is present in the Raft River basin. The locations of the first two wells were selected to intersect these faults and to determine if a geothermal reservoir of significant size is present. The first well, RRGE #1, was drilled to a depth of 4,618 feet and the second well, RRGE #2, was drilled to a depth of 6,004 feet.

The results were very satisfactory. After the wells were completed and shut in, they had bottom hole temperatures of about 296°F and closed in pressures at the surface of about 150 psi (pounds per square inch). The bottom hole pressures at a depth of 5,000 feet were about 2,200 psi. This suggests that the wells have tapped a large body of hot water that is under artesian pressure, controlled by the vast groundwater system of that area. Because of the artesian conditions, each well can flow up to 800 gpm (gallons per minute) simply by opening it to the atmosphere. This is an indication of a very satisfactory well productivity.

With two successes, the next obvious step would appear to be to continue drilling more wells. The critical problem, however, is where? One must bear in mind that in planning an efficient power plant, optimum locations for the required number of producing wells have to be determined, and the total development must also provide for appropriately placed reinjection wells. These problems require detailed information on reservoir properties. In view of the fault system that is present, a very critical question is whether the first two wells are producing from the same aquifer or are separated from each other by some barrier, such as a tight fault.

Such questions can only be determined by a flow test wherein hot water is produced from one well and the pressure response is observed at the other. If the two wells have been drilled into a common aquifer, there will be a signal in the form of a pressure drop that can be measured at the observation well. Once the pressure communication is proven, a continuation of the flow test provides data that can be used in determining the reservoir parameters that control well productivity. If any reservoir limits lie beyond the area of the present two wells, such limits may also be detected depending on the duration of the flow test.

Accordingly, it was important to carry out a series of flow tests to gather information on reservoir properties. These tests were set up by LBL in cooperation with INEL and were carried out during September and October, 1975. A key piece of equipment was a quartz pressure sensor that could be placed in either wellbore deep underground. This special apparatus was used to measure pressures with a sensitivity of 0.001 psi. The instrument is so sensitive that the combined gravitational pull of the sun and moon on the earth, which caused pressure changes twice a day of up to 0.2 psi, was clearly evident throughout the test. To our knowledge, this is the first time that such a sensitive pressure gauge has been used in evaluating a geothermal reservoir.

The most important test was to flow RRGE #2 at approximately 400 gpm for 22 days. Pressures were monitored continuously 4,000 feet away in RRGE #1, and by the end of that period, the total pressure drop was about 3.6 psi. An analysis of the data has given the following results.

The important reservoir parameter that controls flow of water to a well is the product of permeability (k) and aquifer thickness (h). We obtained a value of kh = 210,000 millidarcy-feet, which indicates a very high permeability for the reservoir. We do not yet have an accurate measurement of aquifer thickness, but the drilling data suggest several hundred feet. If h is 500 feet, then the reservoir permeability is 420 millidarcies, which is very favorable. Water viscosity is also a significant factor in controlling flow. At 296°F and 2,200 psi, the viscosity of the reservoir water is 0.18 centipoise, which means it is five times less viscous than water at ordinary temperatures and thus flows five times more easily through the formation.

Another important reservoir parameter is the ability of the formation to release water from the internal void spaces of the rock when pressures decrease. Water is a very slightly compressible liquid and the void spaces within the rocks are also deformable when pressures change. The combined effect of these factors is called the storage coefficient (S). We obtained a value of S = 0.001 per psi drop in pressure, which is a satisfactory result and on the high side for aquifers of this kind. This value means that a significant volume of water will come out of storage because of the vast size of the aquifer. This "stored" water simply joins the water moving by virtue of the imposed pressure gradients and augments the total flow to the producing wells.

Another valuable result is the fact that we detected the presence of at least two barrier boundaries or flow discontinuities. It is not possible to determine the location of these boundaries with only two wells, but one of them appears to be located within a few hundred feet of RRGE #2. A more precise location of these boundaries must be made as soon as possible because this will affect the final selection of sites for the producing wells.

Finally, these tests have enabled us to design conditions for further investigations of this kind. For example, with the reservoir data we now have, we can predict that if a third well is drilled about two miles from the present wells and the flow tests are repeated, the pressure drop at such a distance will be about 1 psi, which can easily be measured with the system we have devised. Such a step-out distance to the next well seems appropriate in terms of the problems that must now be faced.

In summary, the recent flow tests have served a very useful purpose. The first two wells have enabled us to determine that a large and productive geothermal reservoir with a high permeability has been discovered. Both wells produce from a common aquifer but, in view of the complex fault system in this region, it is not surprising that barriers or discontinuities to flow have been detected. Further drilling and testing will be necessary to locate these boundaries more accurately. This should be done as soon as possible because such information will be needed in selecting optimum locations for producing and reinjection wells.

Paul A. Witherspoon

Paul A. Witherspoon, Director
Geothermal Development Project
Lawrence Berkeley Laboratory

PAW:mp

cc: J. Hollander
J. Kunze
K. Mirk