FINAL REPORT

SOH PROGRAM REVIEW

FOR THE

DEPARTMENT OF BUSINESS,
ECONOMIC DEVELOPMENT AND TOURISM
ENERGY DIVISION

JANUARY 1991

TECHNICAL ADVISORY SERVICES

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PREPARED BY

R. A. PATTERSON & ASSOCIATES

R. O. Bowden　　K. P. Goyal

W. L. D'Olier　　R. A. Patterson

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EXECUTIVE SUMMARY

The Energy Division of the Department of Business, Economic Development And Tourism (DBED) provides leadership, funding and supervision for State programs including the vital Geothermal Resource Verification and Characterization Program (GRVC). The Hawaii Natural Energy Institute (HNEI), after consultation with other agencies and geothermal industry representatives interested in Hawaii's geothermal resource development, suggested that geological coring samples, flow test data, and fluid samples from proposed observation holes are the most critical information to be obtained from the Kilauea East Rift Zone (KERZ) in support of the GRVC. Based on these perceived needs, the Scientific Observation Hole (SOH) Program was proposed by HNEI and funded by the Legislature.

This SOH Program Review evaluated the Program objectives, performance and results during the drilling and completion of two initial Scientific Observation Holes, SOH 4 and SOH 1, during the 13-month interval from December 1989 through December 1990. SOH 4 commenced in mid December 1989 and was completed to a total depth of 6562 feet in late May 1990. SOH 1 commenced early in June 1990, and achieved a total depth of 5526 feet on 22 December 1990. Both SOH 4 and SOH 1 are located relatively close to active private geothermal drilling operations on geothermal mining leases in the Kilauea East Rift Zone (KERZ), Puna District, Hawaii County. (See location map following).

SOH 4 recorded a promising bottom hole temperature of 583°F at its location 3 miles distant from the True/Mid-Pacific Geothermal exploratory well which demonstrated high temperature fluid flows during flow tests in October-November 1990. These events may prompt additional drilling in this prospective area.

SOH 1 is approximately 2100 feet north of the productive geothermal reservoir where the Puna Geothermal Venture is constructing a 30 MW geothermal electric power project, adjacent to the long productive HGP-A geothermal well. However, SOH 1 has not penetrated this reservoir at the 5526-foot depth reached.

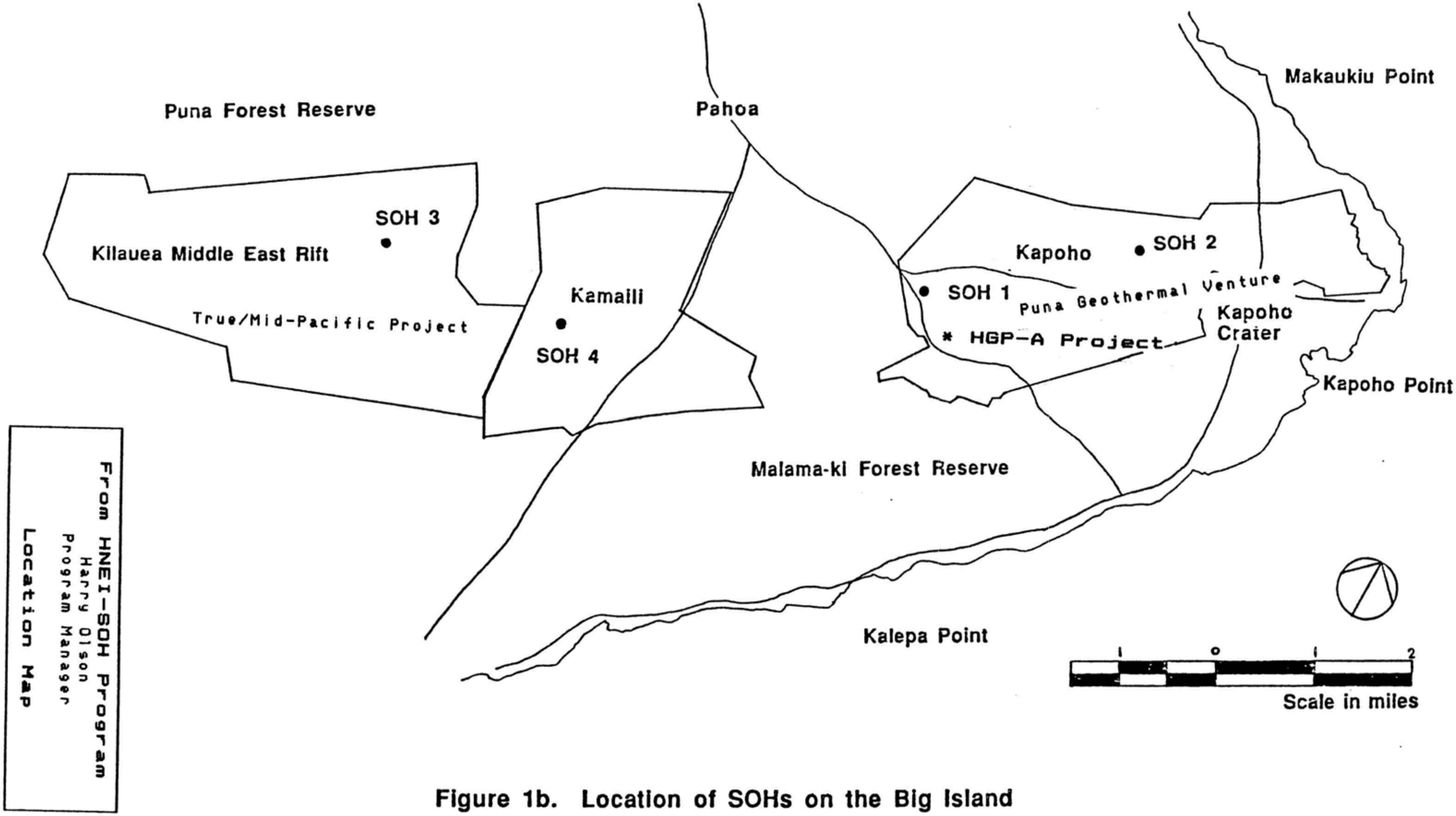


Figure 1b. Location of SOHs on the Big Island

This review was prompted by two important developments:

1. Both SOH 4 and SOH 1 have incurred major cost and time overruns beyond the estimates presented during the SOH Program approval process. This has raised questions about the value of continuing the SOH Program.

2. SOH flow testing, precluded by the existing permits, is increasingly seen by operators and others experienced in the Puna area as an essential evaluation process. Our conclusions are that flow testing can be safely executed at an SOH which has encountered a prospective geothermal reservoir. Limitations on proven exploration techniques, are detrimental when critical information is not collected in view of the total SOH Program cost and effort. The SOH Program is determining the quality and magnitude of the geothermal resource as a public asset. Flow testing of the successful SOHs will provide critically important information for this asset evaluation.

Our analyses focused on operational and management objectives, priorities, costs, and procedures used in the two initial SOHs, in an effort to improve future SOH operations. Scientific evaluations of SOH results were not included in this review. Any conclusions regarding the scientific results as they may affect future SOH activities are preliminary. A qualified subcontractor is evaluating the rock samples collected during continuous coring of SOH 4 and SOH 1. Additional geophysical surveys and injection tests are scheduled in both boreholes during January 1991.

This review is organized into seven specific tasks which look at separate but important areas of operational, cost, and management concerns. These tasks were set forth in the Revised Statement of Work, dated October 10, 1990, and are included in detail as Appendix A.

Task 1 evaluated the drilling-coring operations to date.

A single rig with adequate capacity to drill, case and core SOHs to 6500-foot depths has been utilized under a contract between Tonto Drilling Services, Inc. and The Research Corporation of the University of Hawaii (RCUH) on behalf of HNEI, Operator for the SOH Program. SOH 4 was completed to 6562' total depth in 151 days of rig operations, with total drilling costs of approximately $1,462,000. SOH 1 completed at 5526' total depth after 213 days of rig operations, with total drilling costs estimated at $1,700,000. Additional non-drilling costs for administration and management of the SOH Program were incurred; these have been estimated at about 20% of direct drilling costs.

Approved initial funding for the SOH Program was based on estimates that five SOHs could be completed in one year of operations at a total cost of $3,000,000. The chief causes of time and cost overruns were the continuous coring from the surface to total depth, and the hole opening requirements for the casing.

Task 2 found that the priority for continuous diamond coring from the surface drove the time and cost penalties, and subordinated the objective of assessing the geothermal resource. In spite of this, the active private operators continue to hold the SOH Program in high regard; other parties hold negative views, particularly with the existing limitations on flow testing. Many experienced in geothermal exploration believe that flow tests, along with pressure monitoring and injection testing, would yield information with a high value to the SOH Program as well as the broader GRVC objectives of the State.

In Task 3, refined SOH borehole plans were formulated to reduce construction time and costs and to allow safe flow testing. Rotary drilling and casing to 3000' depths, before coring from that point to 6500', should allow borehole completion in 80-84 days at total drilling costs of approximately $1,000,000. Heavier casing requirements are recommended for the flow testing candidates; lighter casing is proposed for SOH that would not be flow tested. SOH service objectives and the needed casing design can generally be determined when the location is selected. The recommended rotary drilling, casing and coring sequence of the new boreholes can be competitively and safely accomplished by the Tonto rig now under contract.

Task 4 prepared a complete guide to safe flow testing of SOHs, with key procedures and cost estimates. Initial 5-day flow tests, at an estimated cost of $80,000 or less, are proposed for a properly cased SOH which has been completed in a prospective geothermal reservoir. Safe shut-in retention or disposition options for flow tested SOHs are included.

In Task 5, the merits of an improved SOH Program, with flow tests, were compared with a full-hole exploration well program, and with a combination SOH/Exploration well program. Four new SOHs and two flow tests should be possible in 18 months, at estimated costs of $4,100,000. Four exploration wells and two flow tests should be possible in a period of 30 months at an estimated cost of $10,400,000. The combination SOH/Exploration program does not appear to be a logical path for an individual operator; its goals promise to be better achieved by cooperative actions between the State and private programs after specific drilling and testing successes, as seems now to be evolving around the True/Mid Pacific initial exploration well.

Task 6 analyzed how an improved SOH Program (with flow testing) could be integrated with revised rules that will allow SOH and exploratory well drilling and testing outside of Geothermal Resource Subzones, as authorized by Act 207, Session Laws of Hawaii 1990. Progress on the development of new rules should be aided by the conclusions presented in this review.

Task 7 assembled a perspective, rationale and values for safe flow testing as an important function in the SOH Program. Workshops are proposed, using information presented in Tasks 2 through 5, to cooperatively discuss and evaluate the benefits and impacts to the communities, county, and state regulatory agencies. The goal of an early, more accurate, and more efficient assessment of the KERZ geothermal resource can best be accomplished by such joint workshops.

TASK 1. **Evaluate SOH drilling-coring operations to date, with particular attention to the amounts and causes of time and cost overruns.**

Two Scientific Observation Holes, SOH 4 and SOH 1, have been cored and completed in the Kilauea East Rift Zone (KERZ) as of mid-December 1990. These holes comprise the first portion of an approved four hole SOH Program being conducted by the Hawaii Natural Energy Institute (HNEI) in support of the State of Hawaii's Geothermal Resource Verification and Characterization Program (GRVC). The drilling and coring operations on SOH 4 and 1 have extended over one year, utilizing a dual capacity single rig from Tonto Drilling Services, Inc., which was appropriately selected for the program.

The introduction of diamond cored, slim hole technology in the KERZ has substantially exceeded the original cost and time estimates for the holes. The following evaluation examines the reasons for these delays and cost overruns, providing the basis for subsequent analyses. It is believed that these analyses will show that this distinctive technology, with minor modifications, can be carried out at much lower cost and time requirements, and will be comparable with the original estimates.

1a. Work versus time profiles of each SOH from daily drilling reports.

Annotated Work versus Time Profiles for SOH 4 and SOH 1 are presented in Figures 1-1 and 1-2, respectively. The heavy line profiles the progress and history of each SOH by plotting the increasing depth of the hole (in feet) against the cumulative time (in days) from the start of operations. The steepest sloping line segments represent efficient rock penetration by continuous coring. The horizontal lines represent necessary supplemental activities, commonly hole opening and installation of the steel casing at selected depths to insure the safety and success of deeper coring operations. Diamond coring can recover 100% of the rock penetrated, as was consistently done in SOH 4. The gentle sloping line from 2671' to about 4600' in SOH 1 (Figure 1-2) indicates much lower core recovery and greater mechanical difficulties in highly

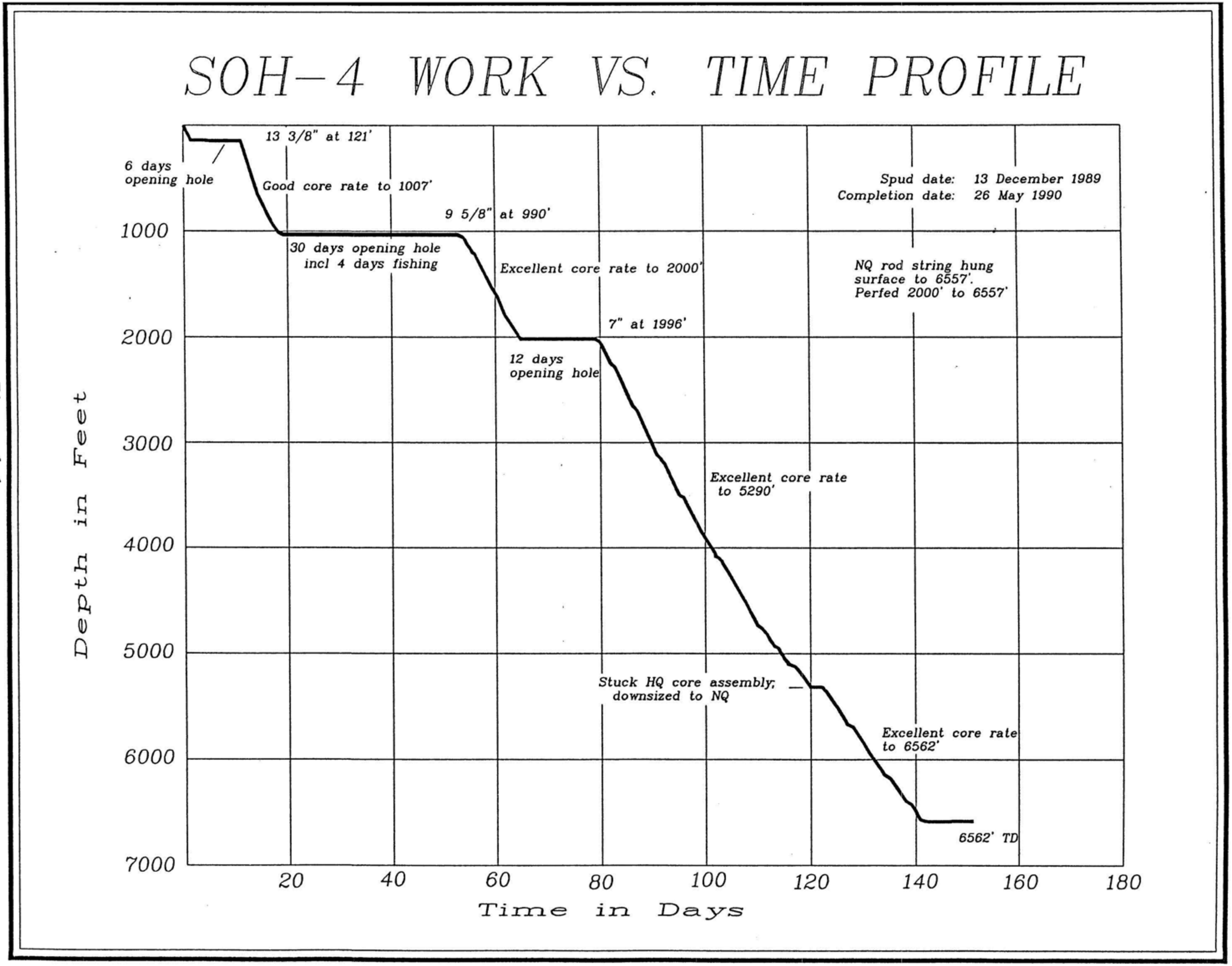
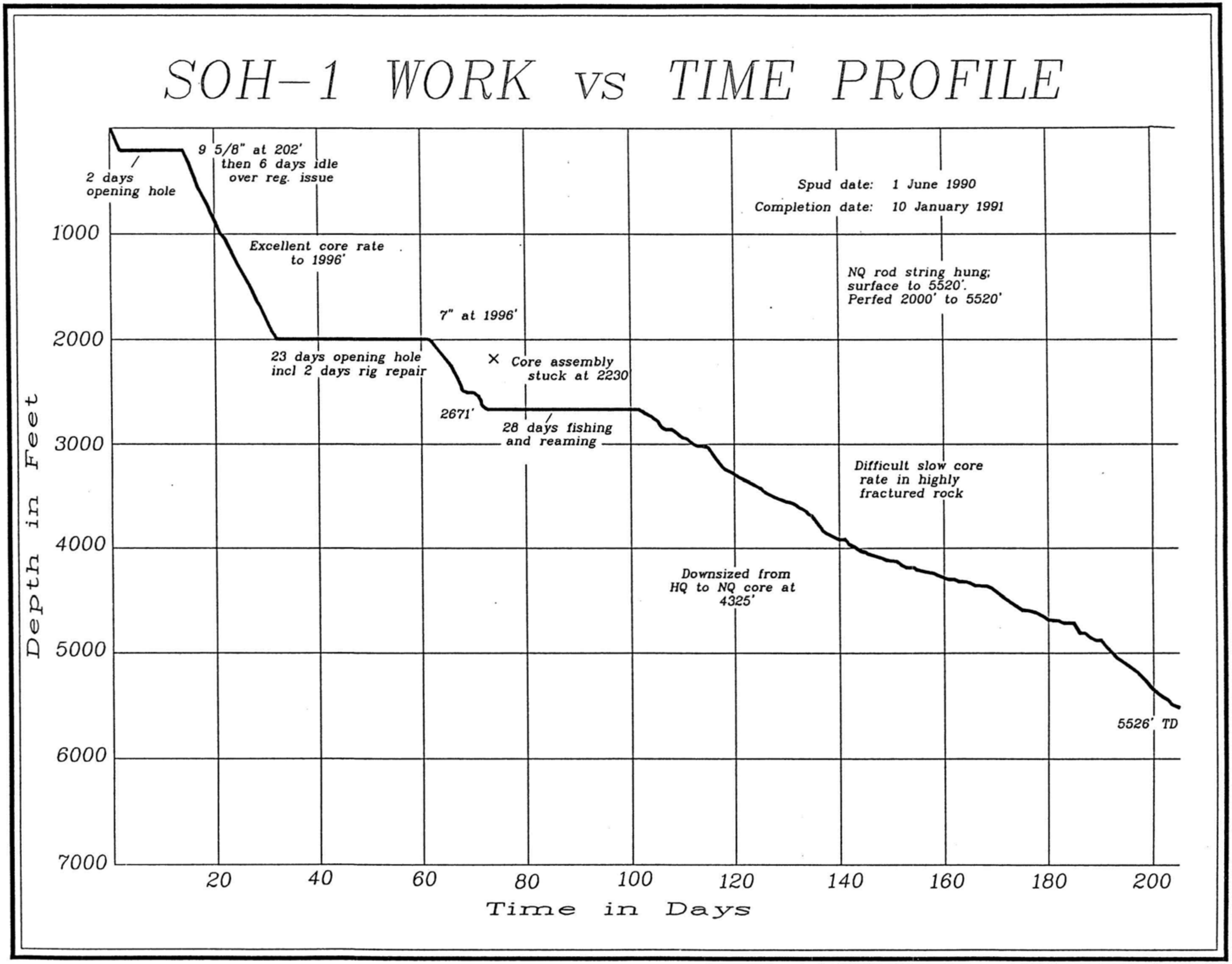
SOH-4 WORK VS. TIME PROFILE
6 days opening hole
13 3/8" at 121'
Good core rate to 1007'
9 5/8" at 990'
30 days opening hole incl 4 days fishing
Excellent core rate to 2000'
7" at 1996'
12 days opening hole
Spud date: 13 December 1989
Completion date: 26 May 1990
NQ rod string hung surface to 6557'. Perfed 2000' to 6557'
Excellent core rate to 5290'
Stuck HQ core assembly; downsized to NQ
Excellent core rate to 6562'
6562' TD
Depth in Feet
1000
2000
3000
4000
5000
6000
7000
20
40
60
80
100
120
140
160
180
Time in Days


Figure 1-1



SOH-1 WORK vs TIME PROFILE
2 days opening hole
9 5/8" at 202' then 6 days idle over reg. issue
Spud date: 1 June 1990
Completion date: 10 January 1991
Excellent core rate to 1996'
NQ rod string hung; surface to 5520'. Perfed 2000' to 5520'
7" at 1996'
23 days opening hole incl 2 days rig repair
Core assembly stuck at 2230'
2671'
28 days fishing and reaming
Difficult slow core rate in highly fractured rock
Downsized from HQ to NQ core at 4325'
5526' TD
Depth in Feet
1000
2000
3000
4000
5000
6000
7000
Time in Days
20
40
60
80
100
120
140
160
180
200

Figure 1-2

fractured rock. One reason for pressing on in SOH 1 was the strong expectation of encountering the geothermal reservoir below 4000' depth.

1b. and 1.c Segregation of costs by sectors and evaluation of primary cost elements. (Combined here for ease of reading.)

Drilling Costs

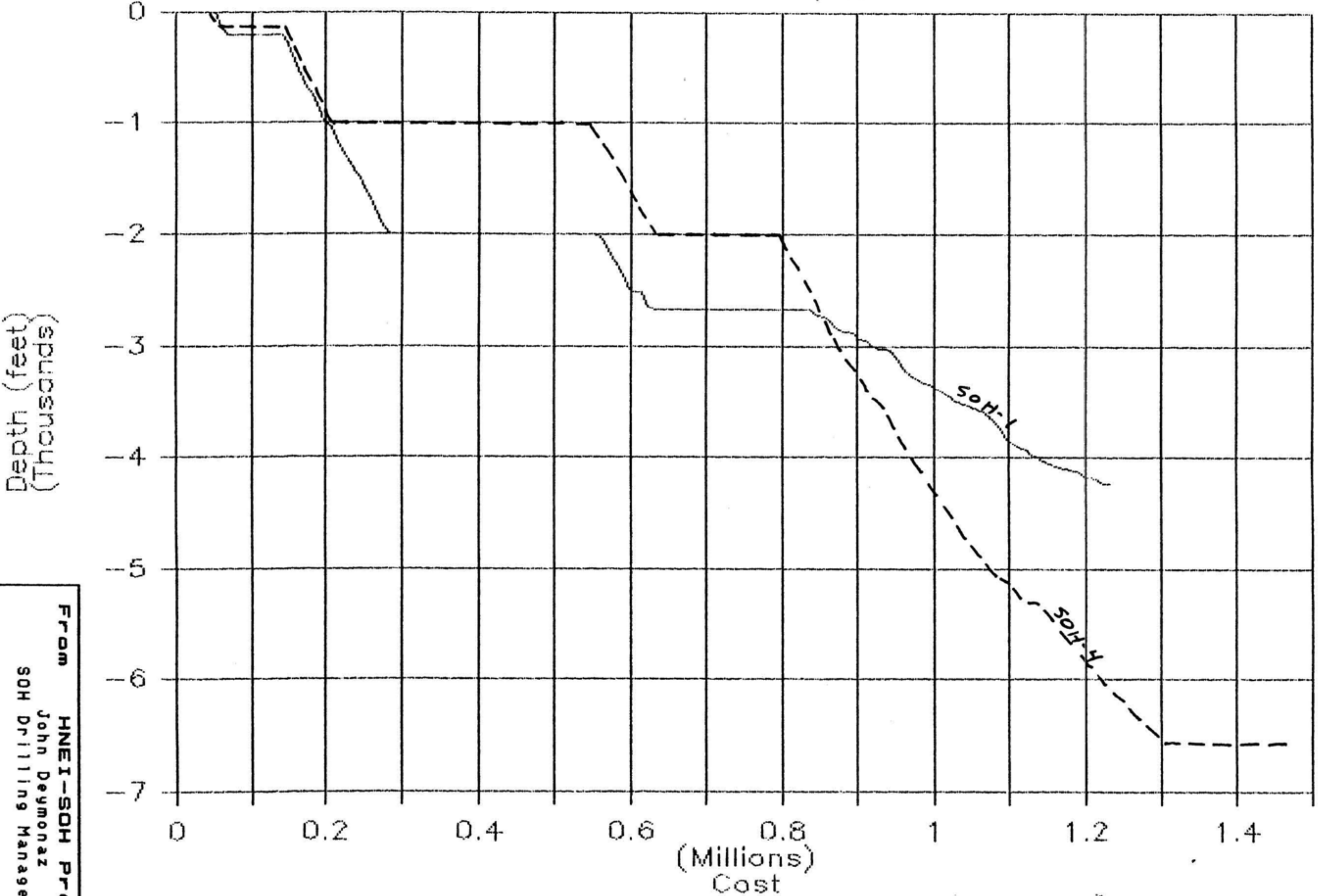
The HNEI drilling manager has accumulated excellent cost records of the drilling-coring operations for the two initial holes of the SOH Program. Figure 1-3 illustrates cumulative costs versus depth for both SOH 4 and SOH 1. The plots have a distinct similarity to the work versus time profiles (Figures 1-1 and 1-2) because the operating rig, with all support equipment and services, costs between $6800-7200 per day for any of the operations being performed.

The table of actual drilling costs (Table 1-1) separates these costs into two broad sectors: A-Cased hole to 2000 feet depth, and B-Cored hole below 2000 feet. Actual costs of the primary elements - coring, hole opening, casing, and fishing (for stuck tools in the borehole), are shown. The coring costs in sectors A and B were reasonable in SOH 4, as were the casing and cementing costs for the conservative casing design, which was accepted by HNEI as a result of the Hawaii County Geothermal Resource Permit (GRP) mediation process. Coring, casing and cementing costs in sector A were significantly improved in SOH 1; sector B costs of coring and fishing were high. However, Figure 1-3 and Table 1-1 show just how serious a penalty was sustained in the hole opening requirements. SOH 4 incurred $336,000 of costs and 48 days; SOH 1 incurred $170,000 of costs and 25 days at an average rate of $7000 per day. Hole opening was the biggest cost element in both holes. Largely due to a change in the casing design for SOH 1, HNEI significantly reduced the hole opening cost and time in this second hole.

The SOH Program objective of continuous coring from the surface to 2000 feet, and the subsequent need to install adequate casing in this same interval created the hole opening requirement.

SOH-1

Cost vs. Depth



From HNEI-SOH Program
John Deymonaz
SOH Drilling Manager

Figure 1-3

ACTUAL COSTS - By sectors A+B and primary element	SOH 4 REMARKS	SOH 4 COSTS	SOH 1 REMARKS	SOH 1 COSTS
A CASED HOLE AT 2000'				
Location & set-up		$42,000		$51,000
Surface Casing	to 121'	$93,000	to 202'	$89,000
Coring	121-2000'	$162,000	202-2000'	$137,000
Opening hole for all casing	48 days	$336,000	25 days	$170,000
Intermediate Casing	to 990'	$50,000		
7" Casing at 2000'; install wellhead		$81,000		$82,000
Cement & Cement Services		$36,000		$31,000
SUB-TOTAL:Hole cased @ 2000'; ready for deep coring		$800,000		$560,000
B CORED HOLE BELOW 2000'				
Coring - 2000' to TD	6562' TD	$510,000	5526' TD	$656,000
Fishing				$220,000
Completion & Evaluation		$152,348		$132,000*
TOTAL COSTS		$1,462,348		$1,700,000*

*(estimated)

Table 1-1

This is a secondary work procedure that contributes no new subsurface information and is not a tangible asset in the hole, as is the casing. When opening imposes such severe cost and time penalties on the SOH Program, it becomes a clear candidate for elimination.

Non-drilling costs

Non-drilling (administrative) costs have been kept in several places by different persons familiar with only their portion of the SOH Program. These costs have not been contemporaneously kept, and there is thus less confidence in their completeness and accuracy. These administrative costs are primarily from the monthly "Budget Status Report" (BSR) which is issued by the Research Center of the University of Hawaii (RCUH) for this project. As set up, the BSR has nine account categories:

1. Salaries (Account 01)
2. Fringe benefits (02)
3. Equipment (03)
4. Supplies (04)
5. Travel (05)
6. Consultants (06)
7. Publications (07)
8. Other (Miscellaneous) (08)
9. Drilling (11)

Some confusion as to what is, or should be, in each account category has arisen. Some costs that are properly drilling-related are entered in other categories. This has occurred in the Equipment, Supplies and Consultant categories. Charges properly attributed to drilling (rental equipment, drilling mud, etc.), as opposed to support of the project (administration, permitting, etc.), have been commingled. Unfortunately, once costs are placed into accounting classes, the procedures for shifting them to another account are cumbersome, and not readily followed by project management. In addition, BSR charges can be delayed from several weeks to months after they are actually incurred. As a result, tracking and analysis of project drilling costs and non-drilling costs for each SOH, or for a group of holes, is quite difficult.

One solution to this difficulty would be to review and re-classify all expenditures. This solution would be time consuming, and would probably require the services of an auditor familiar with the project, operational drilling accounting, and the RCUH accounting system. This is not recommended at this stage of the Program.

More practical, however, would be the following suggestions for the future:

1. Develop a more informed cost identification system at RCUH for future SOH Program accounting.
2. Conduct a brief management review of the cost accounting to date, with particular emphasis on reclassification of larger expenditures into either "drilling" or "non-drilling" categories. During this review, the drilling manager's cost accounting procedures should be reviewed, but a complete reworking of the accounting to date should be avoided. The current accounting should be retained for the first two SOH, except for reclassification of errors discovered.
3. In future operations, the costs tracked by the drilling manager should be better integrated with the costs under the direction of the HNEI Program Manager.
4. Conduct, with the HNEI Program Manager, the drilling manager, and RCUH accounting personnel, a regular quarterly review of all costs of the program, in order to identify and correct accounting problems and questions as they arise.
5. Consider preparing a monthly "Cost and Commitment Report" containing all RCUH-paid costs plus new purchase orders, current administrative costs and daily drilling costs. Although probably not fully reconcilable to the BSR, the "C & C Report" could provide management with more current cost tracking.

1d. Summary of SOH operational and cost performance.

Operational and cost results for the two SOH's now completed in the KERZ have demonstrated the difficulty of introducing an established technology in a new geologic environment. Major time and cost overruns have been incurred by hole opening requirements in the surface-to 2000-foot depth zones of both SOH 4 and 1. These procedures reflected the initial scientific objective of coring every foot of penetration in these holes, not just the anticipated deep geothermal reservoir interval. In the two holes remaining in the current SOH Program, and for future observation holes, these penalties can be avoided by revisions to the drilling, casing and coring plans.

Operational and cost performances at SOH 4 and 1 have certain other positive and negative aspects which are reviewed below.

SOH 4 DISCUSSION

151 days to completion at 6562'; total drilling cost of $1,460,000.

Positives:

a. The SOH 4 borehole reached a deep interval of interest (4000-6562') where temperatures increased from 330 to 583°F.

b. Quality performance of the coring method and the **Tonto UDR 5000** rig, was obtained during continuous coring in the 2000'-6562' interval. Average drilling rate was 73.5 feet per day and average cost was $112 per foot of core.

c. The high temperature rock section below 4000' has the same approximate depth below the ground surface as the geothermal reservoir interval in the three Kapoho-State wells approximately 5 miles downrift. Information is not available to suggest any correlation with the results of redrilling on the True/Mid-Pacific Site A-1.

d. The results outlined in a. and c. above may suggest considering directional redrilling at SOH 4, as at the True/Mid-Pacific site, to penetrate improved permeability zones.

Negatives:

a. The conductive nature of the temperature profile below 4000 feet suggests a lack of permeability or fractures in this hole.

b. Approximately 48 days of work and $336,000 of costs were spent in opening corehole. In order to meet casing requirements prompted by safety concerns, the operator had to open the initial SOH 4 corehole from a 3.0" diameter to 12.25" and 17.5" diameters. This proved to be a time and money expenditure which contributed little to the positive results cited above.

The experience gained in SOH 4 clearly indicates that coring between the surface and 2000' depth must be deleted in the future because of unacceptable time and cost overruns imposed by the hole opening- a most inefficient procedure in the basalt rock sections found in the KERZ. Major loss of drilling fluids occurs and repeated remedial cementing is needed during hole opening; this increases costs. The conclusion is evident; minimize or eliminate hole opening in all future SOH by rotary drilling to a casing point at 3000'; cement casing as directed and initiate continuous coring from that point.

SOH 1 DISCUSSION

224 days to completion at 5526'; total drilling cost of $1,700,000 (estimated).

Positives:

a. By obtaining approval for a revised casing program in SOH 1, hole opening requirements were reduced. HNEI installed its 7" casing at 2000' in 62 days, compared to the 80 days required in SOH 4. Cumulative expenditures to this point were approximately $560,000 at SOH 1 versus $800,000 at SOH 4, as shown in Figure 1-3.

Negatives:

a. Coring tools which became stuck in fractured rock at 2230', caused a 28-day fishing delay and $220,000 cost penalty on the SOH 1 operations.

b. SOH 1 at 5526' total depth did not penetrate the expected geothermal reservoir which is known below 4000' depth in the nearby Kapoho-State wells. This costly and extended operation provoked considerations of an early termination. However, termination proved not to be an acceptable option because of contract provisions (discussed below) and, at the time, the lack of final permits for the additional SOH locations.

SOH 1, the second hole of the Program, is located approximately 2100 feet north of the KS-1 and-1A wellpad, within the Puna Geothermal Venture's project area. A strong expectation attended the SOH 1 site selection for a coring penetration in the same permeable reservoir sectors which flow tested 72,000 and 65,000 pounds of steam per hour from well KS-1 and KS-1A, respectively. This productive reservoir was encountered below 4000-foot depths in the wells drilled by Thermal Power Company in the mid-1980's.

The failure to encounter the top of the reservoir at the 5526-foot total depth cored in SOH 1 is a serious disappointment. At a minimum, SOH 1 has shown that the depth to the top of the geothermal reservoir is decidedly variable in a cross rift direction. The 403 F bottom hole temperature, measured in SOH 1 on 5 January 1991, suggests that the geothermal reservoir may be present, at greater depth, under the 5526' borehole bottom.

The work versus time profile of SOH 1, presented in Figure 1-2, clearly reveals that coring progress fell to the margin of cost acceptability in the depth range between 2761' and 4650'; suspension of the SOH 1 was considered on several occasions. However, standby costs for the rig and equipment, at 70% of active operating costs (standby costs are commonly high percentages of operating costs, required by drillers to keep rigs in productive service), made the continuance of operations more appropriate, since approvals to move to SOH 2 or SOH 3 were not then available. The cause of this degraded coring performance was the intense fracturing of the rock encountered in the 2671'-4650' interval. Core recovery was substantially reduced to broken rock fragments and great difficulty was encountered in keeping the corehole clear. This fracturing intensity seems to confirm cross rift faulting in this locale, which may favor geothermal reservoir permeability at greater depths. The highly fractured 2671'-4650' interval is a low temperature zone (approximately 95 to 240 F). The existing water content and potential for injection should be evaluated in this interval; procedures are discussed in Conclusions and Recommendations (pp CR 3 and 4).

TASK 2. Assess current SOH performance.

2a. SOH Program objectives, as originally accepted.

In December 1989, a number of HNEI presentations revealed the following original multiple objectives for the SOH program in the KERZ.

- Subsurface geological conditions.
- Groundwater level, composition and quality.
- Subsurface temperatures and pressure.
- Drilling conditions.
- Assessment of possible mineral and geothermal resources.
- Eruptive history of the Island to the depth drilled.

The broad theme of scientific evaluation, observation, and monitoring in coreholes was emphasized for the SOH Program. This wide scope for the SOH activity, and an agreement not to flow fluids from these holes, was necessary to gain public acceptance and regulatory approval for the Program, especially from Hawaii County authorities.

With the completion of SOH 4 and SOH 1, some preliminary comments can be made about the original objectives. Subsurface geological conditions, temperatures, pressures and drilling conditions have been very clearly identified at both the SOH 4 and 1 sites. The HQ (2.5" diameter) and NQ (1.875" diameter) cores collected are being evaluated by a scientific staff subcontracted to the SOH Program. These studies will provide significant guidance to following geothermal drilling activity in these areas. The groundwater studies probably will be assisted by the detailed core analyses now in process.

The SOH 4 deep hot section is positive in comparison to the Kapoho-State wells 5 miles downrift. The seeming lack of permeability in SOH 4 is discouraging; however, True/Mid-Pacific, at its "A" site 3 miles uprift, overcame such an initial finding with redrilling. Assessment of the newly indicated geothermal resource in the True/Mid-Pacific exploration well needs further evaluation by additional drilling, coring, flow testing and interference testing. SOH 4, the planned SOH 3, and the next True/Mid-Pacific well should provide the basis for a proper initial evaluation of this area of the KERZ.

SOH 1, failing to clearly encounter the expected geothermal reservoir before reaching a total depth of 5526', may have given Puna Geothermal Venture a deep geothermal fluid disposal target on its existing lease. Reliable **disposal,** by deep injection, of residual geothermal fluids from wellfields and plants, will be as vital as geothermal fluid **production** is in all future utilization of the KERZ resource. Lastly, the eruptive history of the Island and the extraordinary SOH 4 core finding of once shallow coral deposits, now at significant depths below sea level, will provide important new concepts to the structure of the KERZ when integrated with recent U.S. Geological Survey (USGS) evaluations of flank failures along Hawaiian rift zones.

2b. Perceptions of SOH Program results

Generally positive expectations attended the 1989 launching of the SOH Program; its results were expected to provide important inputs to the determination of the geothermal resource magnitude in the KERZ. This view was acknowledged by most of the parties in the five consortia that responded to the HECO Request for Proposals for the 500 MW geothermal power development. In October, 1989, DBED-Energy Division hosted a meeting in Santa Rosa, California for all interested parties to discuss the GRVC of the State. Strong group support was revealed to DBED on that occasion for the SOH concept if permitted and configured to include flow testing. Now, with completion of SOH 4 and 1, the reading of the Program results to date may be summarized as follows:

True/Mid-Pacific Geothermal and their technical consultants stated very strong support for the SOH Program in late August, 1990 meetings with DBED. They revealed an informed understanding of SOH usage in geothermal exploration and development activities, and of the Hawaii SOH Program's special potential to collect critical information in the KERZ. The deep hot section of SOH 4 probably filled one function which the State intended with the Program; it has helped encourage a private developer to continue his high risk drilling exploration with a full hole flow testable approach. True/Mid-Pacific has pursued three redrills at its "A" site.

Puna Geothermal Venture (ORMAT), equally strong in praise of the SOH concept, spoke of their present use of this technology in Nevada. They revealed an inclination to employ it at their own cost in the KERZ as a logical, integrated procedure with their full hole well drilling and appropriate geophysical programs. Interestingly, ORMAT obtained valuable information for their injection options from the SOH 1, even though the bore failed to clearly prove a northward extension of the geothermal reservoir known in the HGP-A and Kapoho-State wells.

HECO had high expectations that four SOHs, completed and evaluated by the fourth quarter of 1990, would be providing vital encouragement and guidance to negotiations for the 500 MW project. As a financial contributor to the SOH Program, they have a sense of discouragement about the results, the slow pace of the activity to date, and the permit prohibition of SOH flow testing.

ENEL holds a firm negative opinion of the SOH methodology. They claim that the procedure can create its own distinctive mechanical penetration problems, as encountered in SOH 1. ENEL also advocates that long flow tests (30 days or more) in full sized exploration wells are fundamental to factoring wellfield and plant requirements and economics. There is no challenge to this viewpoint, but approaching every exploration hole in the KERZ with "full sized" as the only basis on which to proceed seems not to recognize the high dry hole risk proven by drilling to date. Moreover, the local opposition to geothermal development would likely try to cripple the permit process for exclusive full-hole, big rig drilling in the presently contentious public arena.

Parties within the proposed 500 MW consortia expressed positive views about the SOH Program, stating that SOHs completed and evaluated at State cost and risk were good evidence of State support for geothermal development. Without this activity and the contributions of the SOH Program, any surviving consortium might well conclude that political events and the delays in private programs have put the geothermal concept in serious jeopardy.

2c: Relative value of flow testing

Most of the SOHs are expected to be drilled to total depths (TD) of about 6500' in the KERZ. Future boreholes merit completion with 3000' of steel casing cemented in solid from casing shoe to the surface, and a hanging, perforated liner extending through the geothermal reservoir, or interval of interest, to TD. Casing set to 3000' is preferable since it can better separate any shallow low temperature aquifers above 3000' from the deep geothermal zones. At present, SOHs are designed to provide geological and temperature information about the geothermal reservoir, and to act as pressure monitor or injection testing holes. Such small diameter, deep holes have not been flow tested to date. However, these holes provide a unique opportunity to flow test deep, hot, fractured rock. If successfully flow tested, the information obtained can guide and accelerate geothermal exploration and development in the KERZ. Flow testing would enhance the usefulness of the SOH program significantly beyond its presently intended function.

Comparisons of SOH flow testing values against pressure monitoring and injection testing are presented in the following Tables 2-1, 2-2, 2-3, and 2-4, for easier comprehension. These comparisons clearly indicate that a flowing SOH can yield more information about the geothermal reservoir than can interference or injection testing.

FLOW TESTING vs. INTERFERENCE TESTING

POSITIVE ELEMENTS

SOH FLOW TESTING	SOH INTERFERENCE TESTING
1. SOH deliverability and flow capacity of the surrounding area can be measured.	1. Cannot provide flow rate information for the SOH.
2. Reservoir temperatures, pressures and enthalpy of the produced fluids can be obtained.	2. Qualitative temperature, pressure, and enthalpy estimates can be obtained from T/P surveys.
3. Production zone depths and fluid volumes can be determined or estimated.	3. Such information cannot be obtained.
4. Chemical composition of liquid and gaseous phases of reservoir fluids can be obtained.	4. Reliable information cannot be obtained.
5. Reservoir kh(*) and borehole skin(**) can be estimated.	5. kh and storativity(#) may be obtained in a few weeks test, if the system is liquid dominated.
6. Radius of drainage and fluids disturbed by the flow tests can be estimated.	6. Pressure drawdown in SOHs offsetting a production well can provide an estimate of areal extent of reservoirs in a reasonable time frame in a liquid dominated system.
7. Production potential of full-sized wells can be estimated.	7. Such information cannot be obtained.
8. Production zone(s) and surrounding formation damaged by drilling can be cleaned by flow testing.	8. Such cleaning action on production zones or surrounding formation cannot be achieved by interference testing.
9. SOH flow testing is lower cost than full hole flow testing.	9. Interference testing with an SOH is best paired with full hole flow tests.

* - kh is the reservoir permeability-thickness product.
** - Skin is the measure of borehole damage caused by drilling.
\# - Storativity is the measure of the ability of rock to store fluids.

Table 2-1

FLOW TESTING vs. INTERFERENCE TESTING

NEGATIVE ELEMENTS

SOH FLOW TESTING	SOH INTERFERENCE TESTING
1. SOH may not flow, requiring pumping or other stimulation.	1. No flowing required.
2. Flow tests may be limited by permits.	2. Permit requirements are less stringent.
3. Lined sump may be needed to store effluent for disposal.	3. No sump required.
4. H_2S abatement may be needed for flow test.	4. No abatement needed.
5. High noise levels are incurred by initial vertical venting (stacking). However, venting is required to clean the borehole, and the fluid discharged, safely and rapidly before conducting flow tests.	5. No venting required.

Table 2-2

FLOW TESTING vs. INJECTION TESTING

POSITIVE ELEMENTS

SOH FLOW TESTING	SOH INJECTION TESTING
1. SOH deliverability can be measured.	1. Provides no information about flow rates.
2. Reservoir temperatures, pressures and enthalpy of the produced fluids can be obtained.	2. Such information cannot be obtained.
3. Production zone depths and fluid volumes can be determined or estimated.	3. Permeable zones can be located by temperature-spinner surveys.
4. Chemical composition of liquid and gaseous phases of reservoir fluids can be obtained.	4. Information not available from injection tests.
5. Reservoir kh and borehole skin can be estimated.	5. Reservoir kh and borehole skin can be estimated.
6. Radius of drainage and fluids disturbed by flow tests can be estimated.	6. Information not available from injection tests.
7. Production potential of full-sized well may be estimated.	7. Information not available from injection tests.
8. Production zone(s) and surrounding formation damaged by drilling can be cleaned by flow testing.	8. Injection testing may cause silica deposition and reduce permeability around the SOH.

Table 2-3

FLOW TESTING vs. INJECTION TESTING

NEGATIVE ELEMENTS

SOH FLOW TESTING	SOH INJECTION TESTING
1. SOH flow testing may require about a week of flowing.	1. Injection testing can be accomplished in a day.
2. SOH may not flow, requiring pumping or other flow inducements.	2. No flowing required.
3. Permitting considerations may severely limit SOH flow testing.	3. No specific permit required for injection testing.
4. A lined sump may be needed to collect the flow test effluent for disposal.	4. No sump required for injection tests.
5. H_2S abatement may be needed.	5. No abatement required for injection tests.
6. High noise levels are incurred by initial vertical venting (stacking). However, venting is required to clean the borehole, and fluid discharged, safely and rapidly before testing.	6. Injection testing does not produce flow noise.

Table 2-4

2d. Improving SOH Program performance.

The logic for using the slim hole, diamond coring technology lies in the challenge of understanding the internal complexities of an active volcanic rift zone. The critical envelopes of permeability, required for geothermal reservoirs, are poorly known in the KERZ. Compared to our confidence in the presence of abundant heat and fluids, there is little comprehension of causes and distribution of permeability. This lack of an ability to better predict permeability zones is the highest single risk to geothermal drilling in Hawaiian volcanic rocks.

Permeability in the KERZ can be expected in two primary modes. Horizontal distributions of permeability should exist in zones, between successive basalt flows. Vertical distributions of permeability should exist in the abundant faults and fractures created by the tensional stress field operating cross rift on both rift crests and flanks. KERZ geothermal reservoir targets also occur in the roof of a long, linear underlying magma conduit. Here, a constant interplay of magma intrusion in dikes, fracturing, faulting, sea and fresh water intrusion, and mineral deposition has made permeability a very difficult feature to forecast.

In this highly variable subsurface context, continuous rock cores are the unquestioned best available basis for determination of reservoir rock 'fabric' (lava flow versus dike), fracture and interflow plane distributions, and hydrothermal mineralization which may relate to open or closed fractures. Hard, factual knowledge of these features will provide the strongest basis to find permeable completion zones in the geothermal reservoirs.

Time is critical in the complex sequence of exploration and development events that must precede the development of reliable geothermal electric power production. Each separate task must be performed with an economy of time. Fortunately, the ability to accelerate the SOH Program is already indicated in the work versus time profiles of the first two SOHs. Combining the good deep core performance in SOH 4 with rotary drilling to casing setting points at 3000' depth, completion times of 80 to 84 days per SOH can be reasonably expected for the next holes of the Program, as discussed in Task 3. Further refinements should allow four SOHs per year with the current Tonto UDR 5000 rig.

The determination not to allow SOH flow testing is an extraordinary self imposed penalty. In the exploitation of any fluid resource, be it groundwater, oil, gas or geothermal fluids, the flow testing of each successful borehole or well is the next logical step to be taken. Without fully measuring the fluid production capacity, good effort is wasted; valuable integration with other data, allowing comprehension and reliable predictability to evolve, is impossible. The hard data from reservoir interval cores would be greatly magnified in value by subsequent flow testing. We find no reasons, in the detailed discussion presented in Tasks 3 and 4, why the flow testing of an appropriately cased SOH should pose any safety or health hazards. SOH flow testing will not approach the quality of flow testing in full sized exploration and production wells. However, both the value and cost of every drilled or cored permeable hot zone in the KERZ will be very high. Not to properly determine the fluid yielding capacities with appropriate flow testing procedures would extend a very poor policy. The State can ill afford to spend time and money on the SOH program and yet accept a serious constraint on its full capability to add to the knowledge sought.

TASK 3. Develop a refined SOH borehole plan and drilling-coring procedures to accelerate geothermal reservoir penetration at reduced time and costs, and to allow safe flow testing.

3a. Identify key changes required to better and faster accomplish the primary objectives; present the rationale for these improved procedures.

With the completion of SOH 4 and SOH 1, it is broadly recognized that the SOH Program must be refocused to move the diamond coring-slim hole technology to a more effective contribution. Time and cost penalties in the first two SOH's require a new approach of the SOH Program to KERZ geothermal reservoir evaluation below 4000 feet.

Continuous coring between the surface and 3000 feet should be eliminated from new SOH borehole plans. The upper 3000-foot interval would be rotary drilled and cased before initiating the continuous diamond coring intended to penetrate the geothermal reservoir. Rotary drilling can be accomplished effectively by the **TONTO UDR 5000** rig with certain equipment supplements; the proven rotary drilling capability of this rig was not effectively utilized in the SOH 4 and SOH 1 top hole sections. Rotary drilling in one pass of a tricone bit, under heavy weight drill collars, is the best penetration process in the KERZ. This is the primary change in the refined SOH borehole plans below.

3b. Write the new refined program for a flow-testable SOH in the KERZ.

A successful penetration of a geothermal reservoir interval in an SOH should allow two important options; pressure monitoring or flow testing. These ultimate functions, for the successful SOH continuously cored through permeable reservoir sections, are the "highest value added" activities used in defining the KERZ geothermal resource potential.

The **pressure monitor** and the **flow test** objectives for individual SOHs can be reflected in the site selection and borehole design as follows:

1. Pressure monitoring is the preferred function when an SOH is close to a full hole exploration well(s) which will

be flow tested, or where the SOH is sited near a production wellfield to observe reservoir pressure response due to production. This type of an SOH should not be subjected to the significant stress of flow testing. The objective is for a long lived SOH (> 10 years) in the pressure monitoring function.

2. Flow testing is the preferred option when an SOH is in a remote location, some distance from any other producing geothermal well. Flow testing this type of SOH can yield information of extraordinary value, as discussed in Task 4a., below. However, flow testing in the KERZ can impose substantial thermal, pressure, erosive, and corrosive stresses during and after the testing. In fact, the post-flow test dynamics in the borehole may present the greater hazard to long term borehole integrity. Considerations for safety in SOH flow testing relate directly to both testing and post-flow testing experiences in other KERZ geothermal wells. Safety considerations for the SOH that is to be flow tested require a larger, heavier casing geometry than does the SOH intended to serve only as a pressure monitor.

After flow testing of the SOH, an evaluation must be made of the severity of the flow stresses incurred, the follow on dynamics of the tested reservoir section, and possible fluid convection in the shut-in borehole. This evaluation can be used to select one of three options for disposition of the SOH.

1. Shut-in, for future long term flow testing or additional use, possibly as a pressure monitor.
2. Suspended, with deep cement plugs, for future additional use.
3. Promptly plugged and abandoned for lack of additional use and for elimination of the cost and risks of maintenance.

These options are further discussed and cost estimated in Task 4. Separate borehole plans are presented below for these two different objectives.

Borehole Plan for SOH Flow Testing

Rotary drilling, surface to 3000'; coring from 3000' to 6500'.

1. Air drill 12 ¼" hole to water level; convert to mud and drill to 1000' depth. Run and cement 9 5/8" casing to surface.
2. Rotary drill 8 ½" hole to 2000' depth. Run and cement 7" casing to surface. This casing preferably should be L-80, 23 pounds per foot, buttress coupled pipe; alternatively, it can be K-55, 26 pounds per foot, buttress coupled pipe.
3. Rotary drill 6" hole to 3000' depth. Run and cement 1200' of 4 ½" casing as solid liner in 1800-3000' depth interval.
4. Hang 4 ½" casing string, surface to 1800' to stabilize HQ core rods. Remove this string at completion of SOH.
5. Core HQ hole to 6500' depth. Downsize to NQ coring if required.
6. Complete cored section of hole with used HQ rods or equivalent used tubing in the 2800-6500' depth interval. Perforations should be limited to permeable reservoir interval(s) as determined from cores and temperature-pressure surveys. Hang this completion string in bottom of 4 ½" casing with a lead seal hanger.

Borehole Plan for SOH Pressure Monitor

Rotary drilling, surface to 3000'; coring from 3000' to 6500'

1. Air drill 9 ½" hole to water level; convert to mud and continue to 1000' depth. Run and cement 7" casing to surface.
2. Rotary drill 6" hole to 3000' depth. Run and cement 4 ½" casing to surface.
3. Core HQ hole to 6500' depth. Downsize to NQ coring if required.
4. Complete cored section of hole with used HQ rods

standing in the 2800-6500' depth interval. Perforations should be limited to permeable reservoir intervals.

The rotary drilling and casing requirements of both borehole plans are safely within the capacity of the **TONTO UDR 5000** rig. It is believed that this rig, supplemented with increased mud pump capacity and heavy drill collars, can perform the rotary drilling, casing and coring tasks on a competitive cost basis. Our investigation of using a separate rotary rig and drilling contractor for the top hole rotary task did not indicate any significant time or cost advantages over the **UDR 5000** equipment in completing the dual rotary-coring programs.

3c. Provide new work versus time profiles and new cost estimates for the refined flow testable SOH.

New Work versus Time Profiles for the two new types of SOH's are presented in Figure 3-1 following. Both profiles show the benefit of faster penetration by rotary drilling to 3000' depths for the cased portion of the holes. Coring is efficiently applied in the deeper intervals more likely to yield geothermal resources. These new plans indicate total times for drilling, coring and completing 6500-foot holes in 80-84 days.

New cost estimates are presented in the following pages. Detailed costs are shown for the rotary element and for the cored element, both of which should be accomplished by the **Tonto UDR 5000** rig. SOHs for flow testing are estimated to cost $1,010,400; SOHs for pressure monitoring are estimated to cost $945,600.

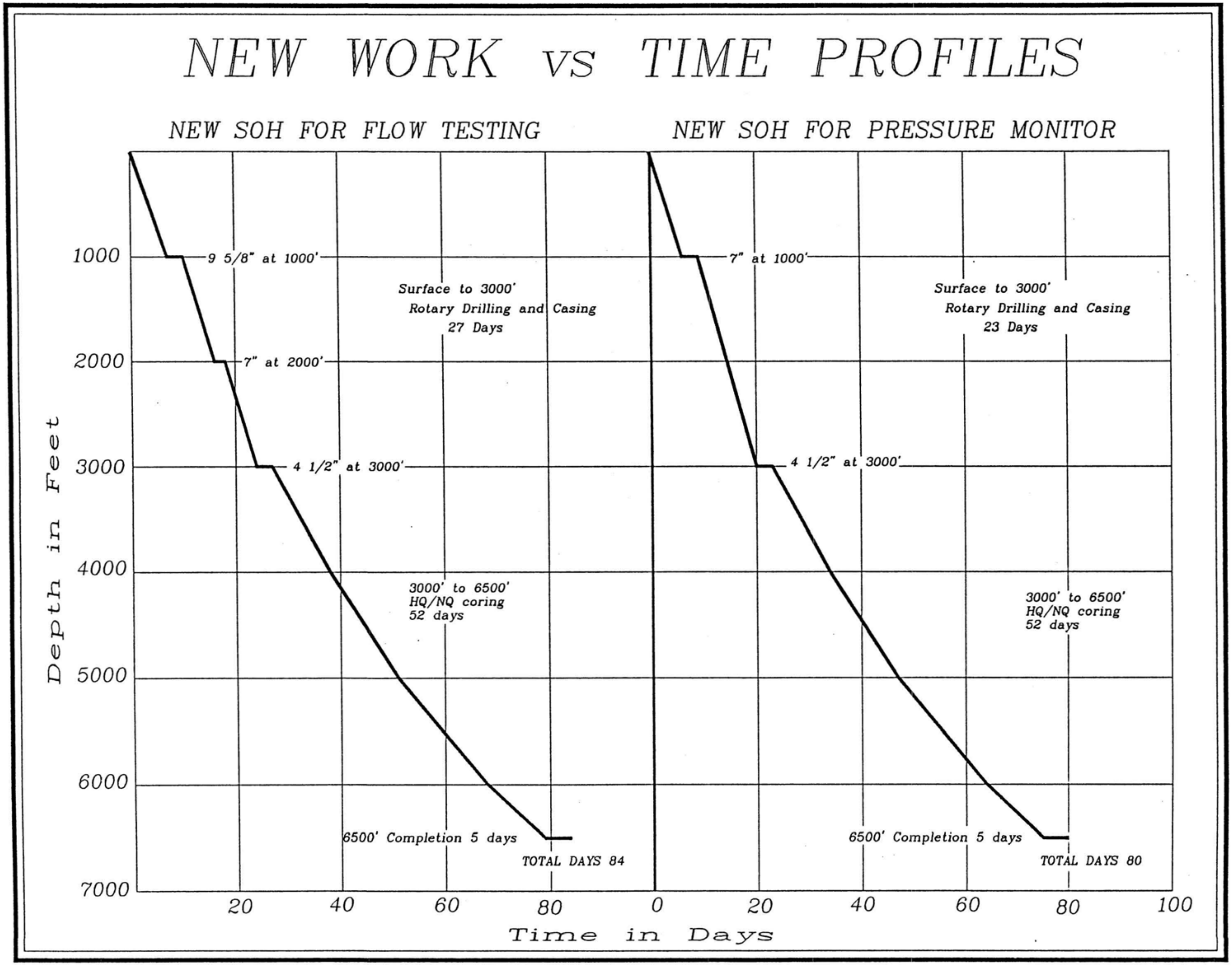

NEW WORK vs TIME PROFILES
NEW SOH FOR FLOW TESTING
NEW SOH FOR PRESSURE MONITOR
9 5/8" at 1000'
7" at 2000'
4 1/2" at 3000'
Surface to 3000'
Rotary Drilling and Casing
27 Days
3000' to 6500'
HQ/NQ coring
52 days
6500' Completion 5 days
TOTAL DAYS 84
7" at 1000'
4 1/2" at 3000'
Surface to 3000'
Rotary Drilling and Casing
23 Days
3000' to 6500'
HQ/NQ coring
52 days
6500' Completion 5 days
TOTAL DAYS 80
Depth in Feet
1000
2000
3000
4000
5000
6000
7000
20
40
60
80
0
20
40
60
80
100
Time in Days

Figure 3-1

COST ESTIMATE: SOH DESIGNED FOR FLOW TESTING

Rotary drilling to 3000'; cement 9 5/8", 7" and 4 ½" casing, as shown on Figure 3-1.

HQ coring 3000' to 6500' TD; NQ back up

ROTARY ELEMENT

Location and access	$20,000
Rig move in	22,000
9 5/8" casing 1000' $15/ft	15,000
7" casing 2000' $16/ft	32,000
4 ½" casing 1200' $10/ft	12,000
Casing accessories	15,000
Rig $7200/day 27 days [1]	194,400
Cement and cementing services	50,000
Wellhead	30,000
Bits, tools and drill collars [2]	35,000
Mud [3]	39,000
Water	50,000
	$514,400

CORED ELEMENT

HQ/NQ coring per SOH 4 actual costs (3000' to 6500' 52 days)	$440,000
HQ rods or used tubing ± 3600' [4]	20,000
GP logs (1000-6500') USGS	?
Completion: $7200/day - 5 days	36,000
	$496,000
Estimated total time: 84 days	
ESTIMATED TOTAL COSTS	$1,010,400

[1] TONTO UDR 5000 rig, crew, supervisor, and equipment, including rentals.

[2] Includes additional heavy drill collars

[3] Includes 800 gpm mud pump for rotary drilling

[4] Lead seal hanger in bottom 4 1/2" casing

COST ESTIMATE: SOH DESIGNED FOR PRESSURE MONITORING

Rotary drilling to 3000'; cement 7" and 4 ½" casing, as shown on Figure 3-1.

HQ coring 3000' to 6500' TD; NQ back up.

ROTARY ELEMENT

Location and access	$20,000
Rig move in	22,000
7" casing 1000' $16/ft	16,000
4 ½" casing 3000' $10/ft	30,000
Casing accessories	12,000
Rig $7200/day 23 days. [5]	165,600
Cement and cementing services	40,000
Wellhead	25,000
Bits, tools and drill collars [6]	30,000
Mud [7]	39,000
Water	50,000
	$449,600

CORED ELEMENT

HQ/NQ coring per SOH 4 (3000' to 6500' 52 days)	$440,000
HQ rods or used tubing ± 3600' [8]	20,000
GP logs 3000' to 6500' USGS	?
Completion: $7200/day - 5 days	36,000
	$496,000
Estimated total time: 80 days	
ESTIMATED TOTAL COSTS	$945,600

[5] TONTO UDR 5000 rig, crew, supervisor and equipment, including rentals.

[6] Includes additional heavy drill collars

[7] Includes 800 gpm mud pump for rotary drilling

[8] Lead seal hanger in bottom 4 ½" casing

TASK 4. Formulate an appropriate flow test program, equipment, objectives, key procedures, time, and cost estimates for the optimal evaluation of the KERZ geothermal reservoir intervals.

The SOH program provides a unique opportunity to flow test geothermal fluids in deep, hot fractured rock. Successful flow testing of an SOH will enhance the usefulness of this Program substantially and accelerate geothermal exploration and development in the KERZ.

4a. Confirm the logic and practicality of flow testing SOHs in the KERZ. (The integration of safety and community concerns is discussed in Task 7).

SOH 4 proves that diamond cored slim holes can penetrate the 4000'-6500' depth intervals, equivalent to the high temperature production zone in the HGP-A and Kapoho State geothermal wells. An SOH, properly cased and cemented to 3000' depth, affords a safe opportunity to flow test geothermal fluids, if fractured or permeable prospective hot zones are encountered. When conditions promising production are encountered, the high information value of such a successful SOH can be substantially increased by flow testing.

Flow testing can provide an opportunity to collect samples and measure the flow rates of geothermal fluids to help estimate the productivity of the surrounding area. SOH flow testing should establish a strong correlation of the geothermal production zones with the fractures and mineral alterations identified in the rock cores of the same interval. SOH flow test data can be used to estimate the flow potential of a full size well, which are commonly completed with a perforated 7" steel liner in an 8½" diameter drilled hole through the productive zone(s). SOH flow testing can provide information about reservoir temperatures, pressures, enthalpy (heat content) of produced fluids and the chemical composition of the liquid and gaseous phases of the fluids.

Not all SOHs would be flow tested because,

(a) Some would not find fractures or permeability in the prospective hot zones.

(b) Some would be better utilized as pressure monitors for nearby full size wells that will be flow tested or placed in production service.

However, successful SOHs at new locations, distant from another well or SOH, should be flow tested to maximize the value and ability to interpret the results of the entire SOH Program.

Slim holes will yield smaller quantities of geothermal fluids compared to full size wells. Scaled down equipment and surface requirements can be used to flow test SOHs, saving dollars and minimizing land areas used.

<u>4b. Identify critical data and fluid samples to be collected in flow tests and key sampling procedures. Cite fluid disposal and emission mitigation options.</u>

It is proposed that qualified SOHs be flow tested for an initial interval of 5 days by using the James tube method. This simple, short duration test is designed to provide initial estimates of flow rate and the enthalpy (heat content) of the reservoir fluids and be economical in cost. The proposed test equipment will be provided with a port to collect both gas and liquid phase samples in a small hand held separator. The initial 5-day flow test can be followed by a 15-30 day long test with a larger separator to obtain quality data and the more detailed information about the reservoir, if so desired.

Data Collection

Collect the following data at each hour during the test.

a. Wellhead pressure (WHP)
b. Wellhead temperature (WHT)
c. Lip pressure and weir flow rate
d. Effluent enthalpy or separator pressure
e. Steam and brine flow rates
f. Atmospheric pressure and temperature

Have draeger tubes, pH meter and conductivity meter available on site. Collect brine and steam samples at hourly intervals to obtain the following information.

a. H_2S concentration
b. Brine pH
c. Condensate pH
d. Brine conductivity

e. Condensate conductivity

Fluid Samples and Sampling Procedure

Samples of liquid (brine and steam condensate) and gas phases should be collected in the middle and towards the end of the flow test. Each liquid sample should be analyzed for major cations, anions, silica and isotopes (oxygen 18 and Deuterium). A set of three one litre containers should be used for each brine sample. The first sample should be preserved with HCl to determine cation content. The second sample should be diluted with distilled water in a ratio of 1:9 to subsequently obtain silica concentration. The third sample should be collected with no preservatives to determine anion composition. Only two containers are required for each steam condensate sample since a container with distilled water is not needed.

The non-condensible gas (NCG) sample should be collected in a glass vessel containing NaOH solution. Both NCG and steam condensate should be collected in the glass vessel. Air contamination should be avoided while collecting the sample because it will be analyzed for the following gases:

Carbon dioxide, hydrogen sulphide, ammonia, oxygen, nitrogen, hydrogen, methane, radon, water vapor and total non condensible gases.

Fluid Disposal and Emission Mitigation Options

Geothermal effluent obtained in the flow testing may be injected back into the same SOH after the flow test or may be transferred to an injection facility in an operating geothermal wellfield, provided a sump can contain the effluent until the end of the flow test. At some locations, small volumes of geothermal effluent produced in an initial 5-day flow test might be disposable on the ground surface.

Hydrogen sulphide (H_2S) concentration should be measured periodically during the flow test. H_2S should be abated when its emission rate exceeds 5 lbm/hr **(pounds (mass) per hour)**.

4c. Determine equipment needs, sizes, modifications or new construction requirements for the mass flow volumes anticipated. Present a graphic layout of equipment on a small drilling location during the test periods.

In the absence of the flow test information from any SOH, the anticipated flow rate is estimated from the data provided by (i) full size wells and (ii) the SOH 4. Some useful points of these data are:

1. Geothermal wells in the KERZ produce fluids with a wide range of enthalpy, fluid phase mixes and flow rates. Wells, producing 100% steam, or varied stream-brine mixtures, have been reported.[9] Geothermal fluid production from an SOH may also have a similar range.
2. The total mass flow rate of KERZ wells range from 33,000 pounds per hour steam to 110,000 pounds per hour steam-water effluent at wellhead pressure (WHP) of 150 psig or more. Most of these wells produce through a 7" perforated liner and 9-5/8" production casing. The production rate and WHP of SOHs are expected to be lower due to small casing sizes and higher friction losses.
3. The temperatures in the reservoir interval of the full size production wells range from 575^{0}F to 665^{0}F (Figure 4-1). A high temperature of 583^{0}F was also measured in SOH 4 at TD, seven weeks after the hole completion (Figures 4-1 and 4-2).
4. The shape of the SOH 4 temperature-depth curve is quite different compared to other KERZ production wells (Figure 4-1). A linear temperature-depth profile in SOH 4 indicates a conduction type heat transfer (tight rock) compared to a the convective type isothermal profile of the HGP-A, KS 1 and KS 2 wells. This seems to suggest that there is not enough permeability to flow SOH 4.
5. The SOH 4 pressure data presented in Figure 4-2 show a low (two phase) pressure gradient at 4200'-4400' depth. A

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[9] Iovenitti, J. L. and D'Olier, W. L. "Preliminary Results of Drilling and Testing in the Puna Geothermal System, Hawaii", Proceedings: Tenth Workshop on Geothermal Reservoir Engineering, Stanford University, Palo Alto, CA, January 1985, pp. 65-71.

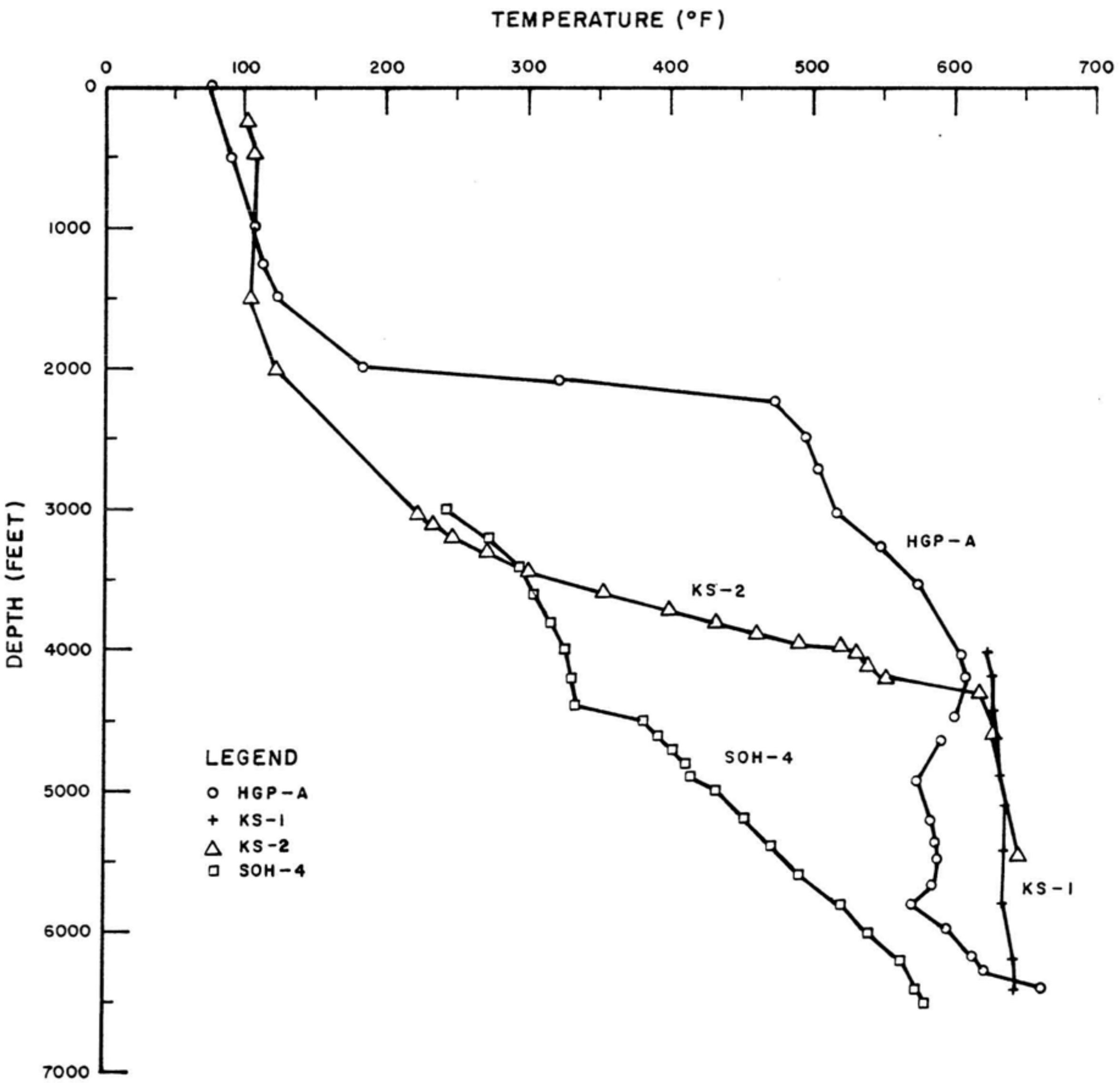

FIGURE 4.1: TEMPERATURES OF SOME DEEP WELLS IN THE KERZ
(FROM IOVENITTI AND D'OLIER, 1985)

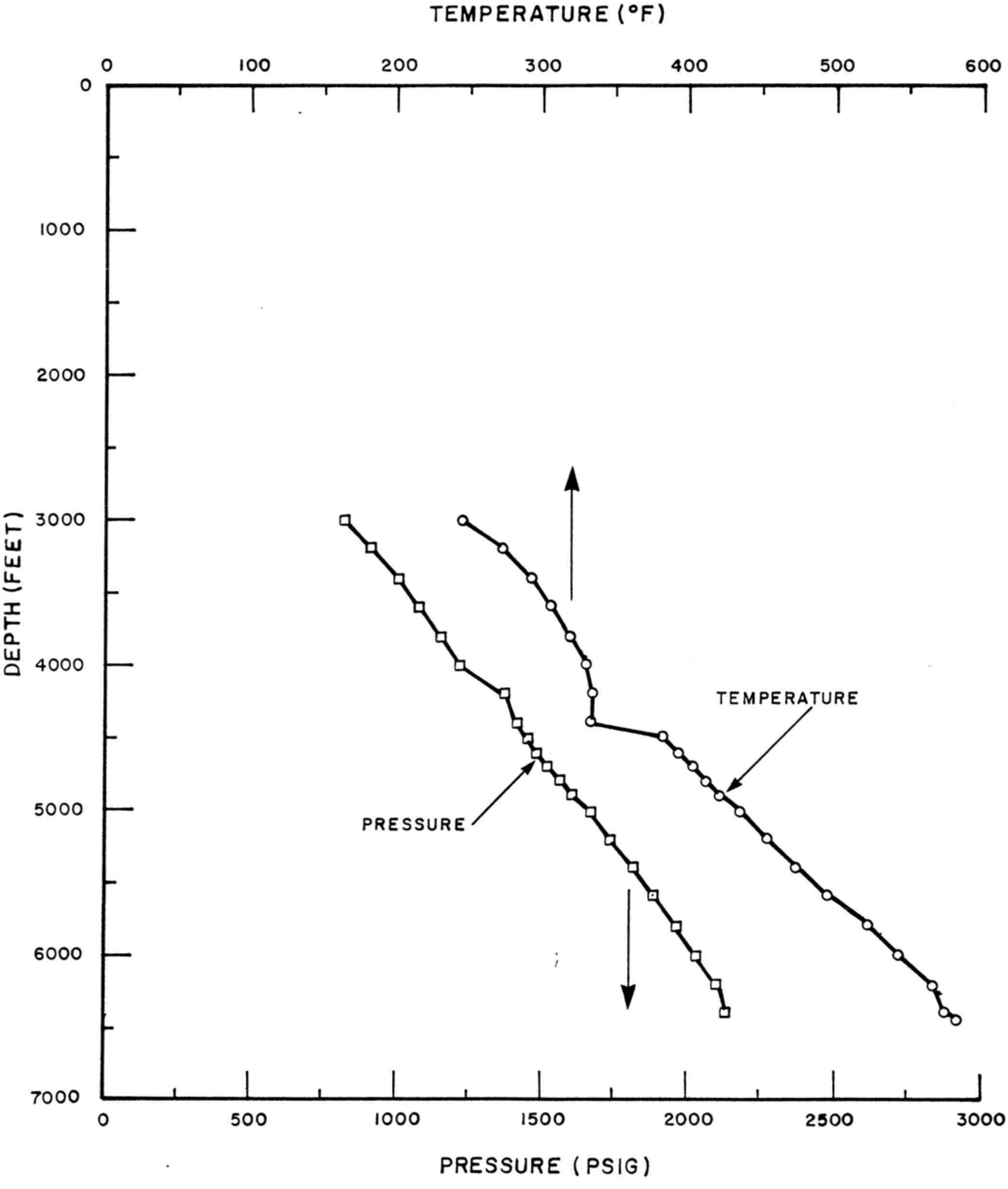

FIGURE 4.2: SOH-4 TEMPERATURE AND PRESSURE VS DEPTH

temperature change of about 50°F is also indicated at 4400'-4500' depth interval (Figure 4-2). Another temperature/pressure should be run in SOH 4 to verify these measurements and the existence and significance of these preliminary findings.

In summary, SOHs have not been flow tested to date; however, a flow test can be conducted safely with an appropriate casing, cemented to 3000' depth. Flow test requirements demonstrate a need for the largest casing diameter consistent with dual drilling-coring capacity of the **TONTO UDR 5000** rig. Casing of 7" diameter is preferred in SOH flow test candidates because it would allow higher fluid flow volumes and pressures at the surface evaluation facilities.

The amount of fluid produced from an SOH will be uncertain until one is flow tested. However, from the information discussed above, an SOH flow rate of less than 50,000 pounds per hour is anticipated. A simple 4" diameter James tube testing method is appropriate to run an initial 5 day flow test, as shown in Figure 4-3.

4d. Specify the pre test preparations; borehole temperature-pressure survey; bleed-flow heating of borehole and casing, and opening to full flow for safe geothermal fluid cleanup.

Pre-test preparations include the following:

- Define flow test objectives.
- Determine geothermal effluent disposal method and establish appropriate sump capacity, if required.
- Setup flow test equipment on SOH location.
- Prepare SOH for the flow test.

Flow Test Objectives

1. Obtain the samples of the uncontaminated reservoir fluid.
2. Confirm the permeable zones in the geothermal reservoir as indicated by cores and T/P/S surveys.
3. Characterize the reservoir with regard to temperature, pressure, fluid state and the fluid composition.
4. Flow at stepped rates to obtain a deliverability curve

for an SOH with 7" casing, if possible. Predict equivalent flow rate for a full size well.

5. Develop a standard flow test program for SOHs.

Flow Test Equipment Setup

As a first attempt to flow test an SOH, we propose a simple test of a short duration at minimum cost. A schematic of the test equipment for the 5 day flow test is presented in Figure 4-3. This simple test setup is designed to provide preliminary estimates for the mass flow rate, WHP, WHT and fluid enthalpy. Data collection and sampling points are also indicated in Figure 4-3.

SOH Pre-test Preparation

The activity-time line for the proposed 5-day flow test with and without an air blanket are presented in Figures 4-4 and 4-5 respectively. It is assumed that fluid disposal facilities are available to run the test for 5 days or more. The pre-test sequences are as follows:

1. After hole completion, with the rig on the hole, run a 2" tubing to 500' below the water level in the hole. Remove cold water from the borehole by pumping air through the tubing for 30 minutes. This procedure is intended to produce early fluid flow from the borehole. Measure the temperature of the produced water.
2. Wait for 30 minutes and make a qualitative estimate of the reservoir permeability by measuring the water level in the hole.
3. Run the tube deeper to 1800' (top of the $4\frac{1}{2}$" casing), if deemed necessary. Unload the hole again (by pumping air) for 30 minutes and measure the temperature of the produced water.
4. Shut-in the hole if it tries to flow. In this event, move the rig off the hole and set up the flow test equipment as shown in Figure 4-3. Go to Step 8.
5. Move the rig off the hole and allow borehole to warm up for 1 to 2 weeks by retaining SOH in a shut-in, static mode. Perform the activities listed below.

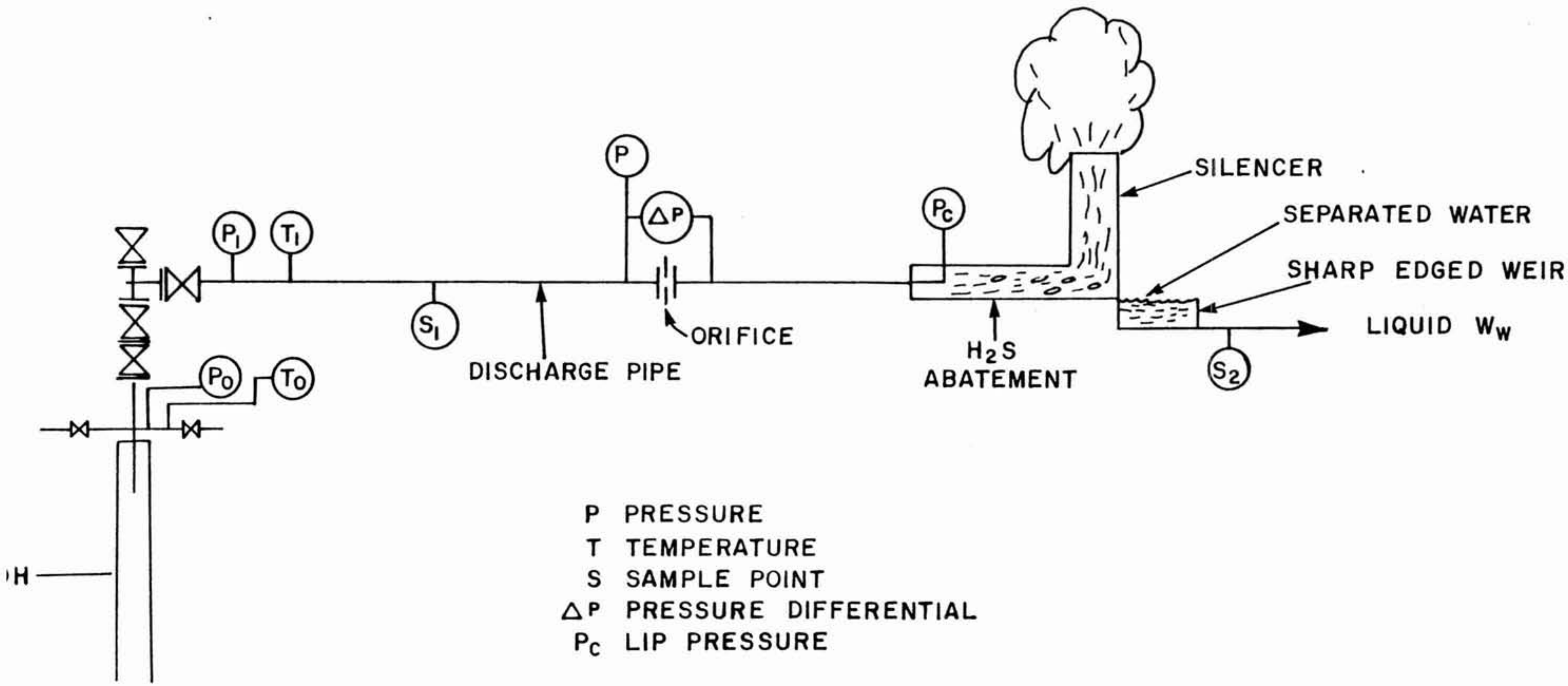

FIGURE 4.3: JAMES TUBE TEST SETUP

6. Run static temperature/pressure (T/P) surveys 24 hours, 3 days and 5 days after unloading the hole (Figures 4-4 and 4-5). Determine permeable horizons from these surveys and compare them with the cores and lithology log.

7. Measure water level in the hole by an olympic probe every 24 hours after the hole completion. Determine the rate of water rise or heating up of the borehole and estimate whether or not a positive WHP can be obtained in a reasonable time frame. If a positive WHP cannot be developed in the next 5 days then go to Step 10.

8. Heat the borehole and casing by bleed flowing the SOH at approximately 20 gpm for 24 hours (Figure 4-4). Measure bleed flow rate (M) with a bucket and a stop watch. Also obtain wellhead pressure (WHP) and wellhead temperature (WHT) data. Have pH meter, conductivity meter and draeger tubes on site to measure pH, conductivity and H_2S concentration of the effluent. H_2S abatement may be required if emission rate is higher than 5 lbm/hr.

9. Make proper notifications in accordance with noise and air permits. Clean the hole by stacking it vertically for 2 to 3 hours (Figure 4-4). Go to Task 4e. for the 5-day flow test.

10. Push water level down below the 4½" casing shoe at 3000' depth by air injection, assisted by gas sticks, if required. Keep water level down for 10 days (Figure 4-5).

11. Release the air blanket by vertically stacking the hole for 2 to 3 hours on the 16th day (Figure 4-5). If the hole flows, go to Task 4e. A non flowing hole is a candidate for injection testing and utilization as a pressure monitor in the geothermal reservoir. Test such an SOH as per procedure outlined under "Injection Testing."

<u>4e. Write the preferred flow test program for SOHs in the KERZ to meet GRVC criteria and goals. Specify the test activities and sampling points and sequence on a flow test time line.</u>

1. Divert the flow from vertical to horizontal by opening the valves to the two phase (James tube) line. Close the

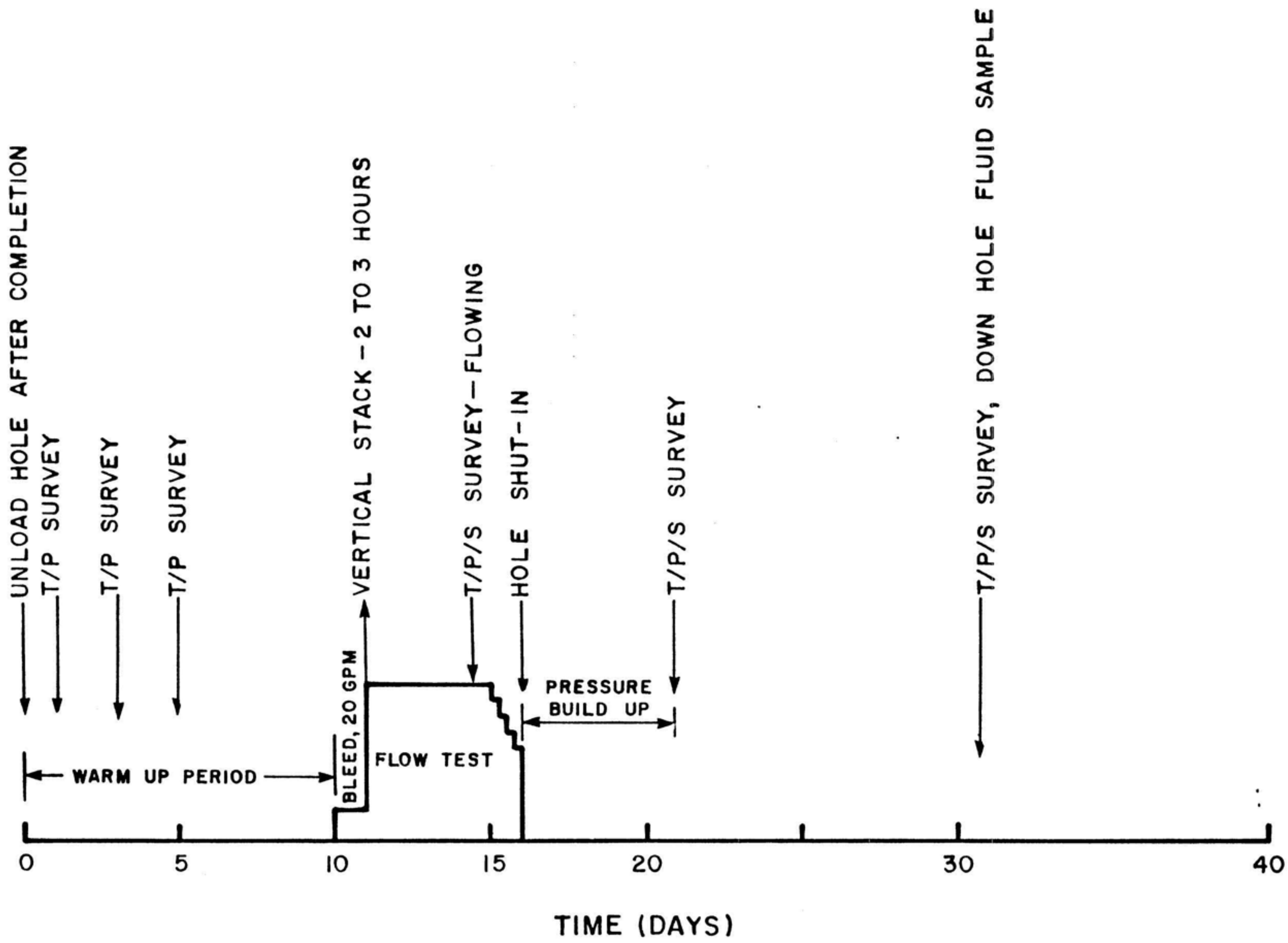

FIGURE 4.4: ACTIVITY—TIME LINE FOR 5 DAY SOH FLOW TEST

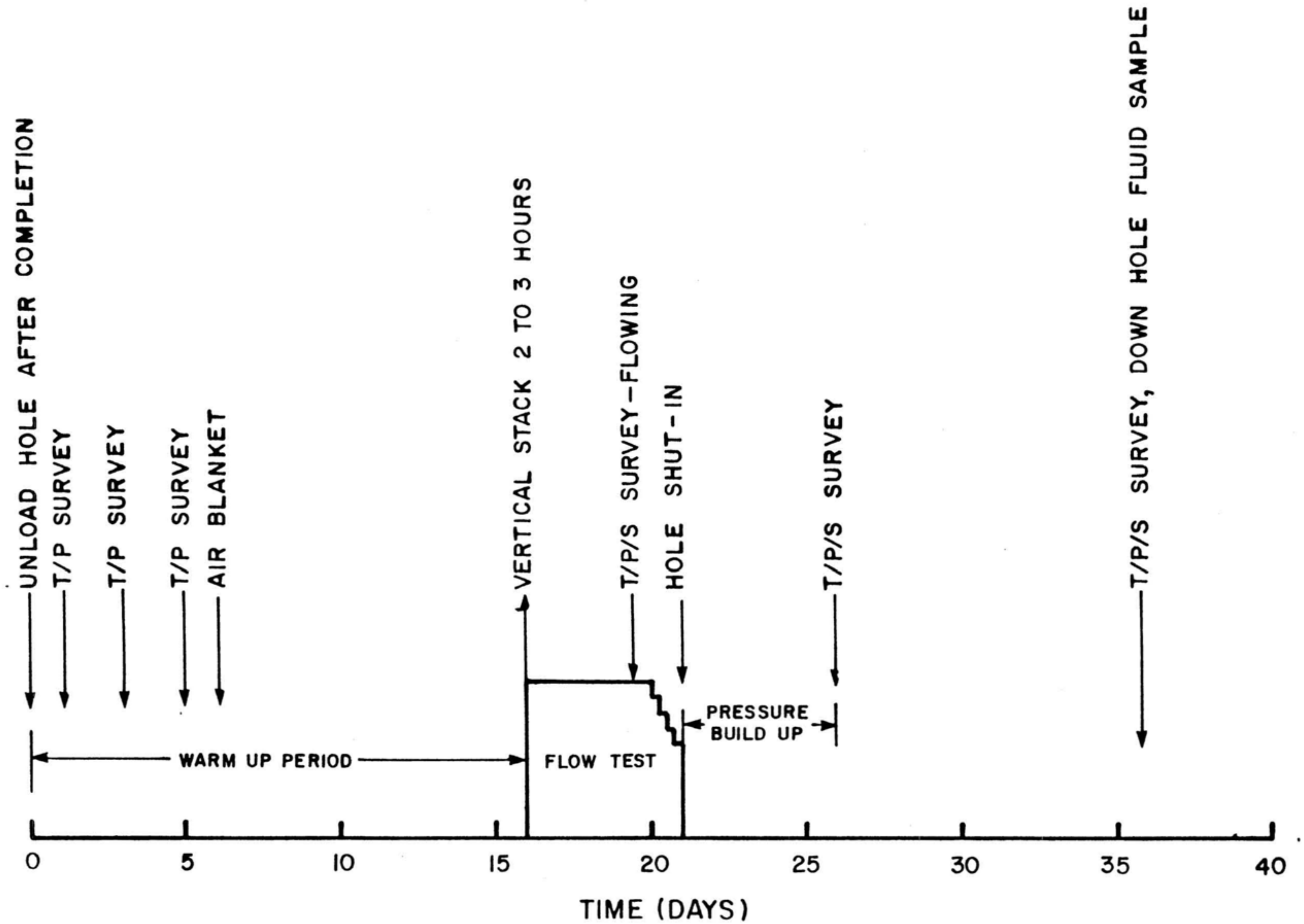

FIGURE 4.5: ACTIVITY–TIME LINE FOR 5 DAY SOH FLOW TEST WITH AIR BLANKET

stack valve slowly to obtain a smooth transition from vertical flow to the James tube.

2. Flow the hole at constant flow rate for the next 4 days (Figures 4-4 and 4-5). Measure WHP, WHT, water flow rate, pressure differential across the orifice plate, lip pressure and H_2S concentration on hourly basis. Estimate enthalpy and flow rate from Figure 4-6. Abate H_2S, if released at more than 5 lbm/hr. Collect brine and steam samples in a small separator from the James tube as suggested in Task 4b. Run a T/P/S survey on the 4th day under flowing conditions and determine the location of the steam producing zones.

3. Run a 24-hour deliverability test on the 5th day by measuring stabilized flow rates at 5 different WHP (stepped rates).

4. Run a T/P tool in the hole and set it at 6000' depth. Shut-in the hole.

4f. Specify the post-flow test pressure buildup, temperature-pressure surveys and wellbore fluid sampling procedures.

1. Monitor downhole pressure buildup for 12 hours and then remove the T/P tool from the hole. Collect WHP and WHT data at 5, 10, 15, 30, 60 minutes and then at 1 hour intervals for 24 hours. Use circular chart to obtain hourly data.

2. Monitor and record WHP for 5 days; use circular charts. Run a T/P/S survey after 5 days of shut-in to analyze wellbore conditions.

3. If WHP continues to rise, expect gas cap formation in the upper borehole. After 15 days of shut-in, run another T/P/S survey and collect samples of gas and brine (Figures 4-4 and 4-5). See "Post Flow Test Issues and Options" for future shut-in actions.

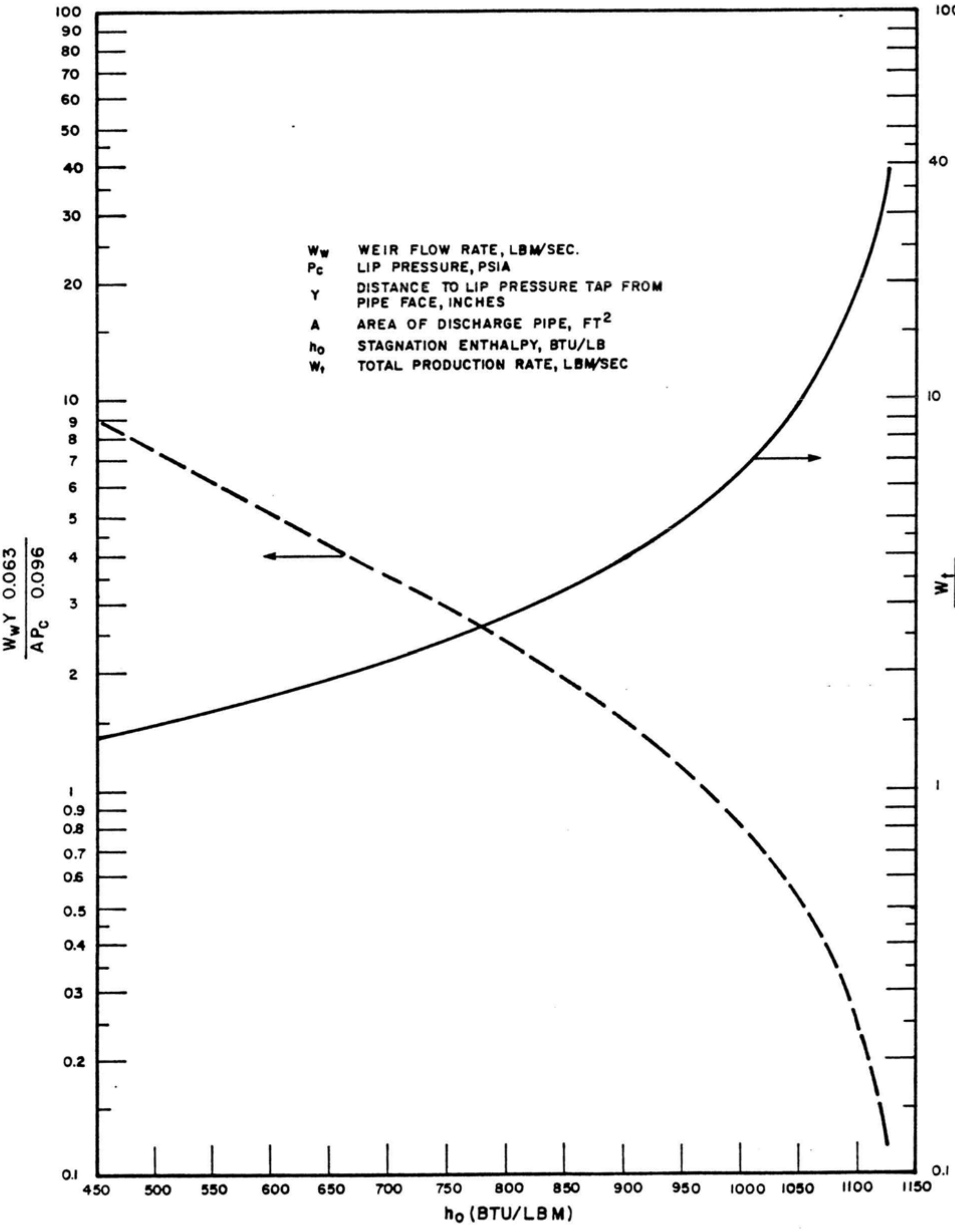

FIGURE 4.6: PLOTS TO DETERMINE ENTHALPY AND FLOW RATE BY LIP PRESSURE METHOD

<u>4g. Present a preliminary cost and time estimate of a SOH flow test. Segregate into preparation, flow testing and post flow test activity/disposition.</u>

Portable Test Equipment; Fabrication (One Time Cost)

Materials and Fabrications of Test Setup	$ 10,000
Materials and Fabrications of Silencer	$ 25,000
Materials and Fabrications of Weir Box	$ 7,000
Shipping Charges	$ 5,000
Technician air fare (Round trip)	$ 1,300
Technician per diem (3 days)	$ 600
Technician daily charges (5 days)	$ 2,000
Air Time (2 days)	$ 800
One Time Test Equipment Cost: Total	**$ 51,700**

Pre-Test Costs

T/P surveys (3)	$ 1,050
Field charges 5 days -2 men	$ 4,000
Wire line unit rental charges (5 days)	$ 500
Truck rental charges (5 days)	$ 500
Per diem 5 days - 2 men	$ 1,250
Air Fare - 2 men (Round trip)	$ 1,300
Technician-Bleed flow (24 hours)	$ 1,000
Air Blanket (if needed)	$ 1,000
Pre-Test Cost: Total	**$ 9,600 to $ 10,600**

Flow Test Costs (5-day test)

Technician Charges (24 hrs./day, 5 days)		$ 5,000
	Subtotal	**$ 5,000**
Flowing T/P/S survey		
Survey Data Plotting		$ 300
Field Charges, 1 day - 2 men		$ 800
Per Diem, 2 days 2 men		$ 500
Truck rental, 1 day		$ 100
Unit rental, 1 day		$ 100
Air Fare, 2 men (Round trip)		$ 1,300
	Subtotal	**$ 3,100**
H_2S Abatement (If needed)		
Unit Shipping		$ 1,000
Unit rental, 5 days		$ 1,000
Unit standby, 10 days		$ 1,000
Chemicals (NaOH and FeSO4)		$ 14,500
Air Fare, 2 men (Round trip)		$ 1,300
Air time, 2 days, 2 persons		$ 800
Lodging 6 days 2-persons		$ 500
Car rental, 6 days		$ 300
Per diem, 6 days		$ 500
Technician charges		$ 2,000
H_2S wet test (2 samples/day)		$ 350
	Subtotal	**$ 23,250**

Fluid Sampling (2 samples)

Prepared sample bottles	$ 300
Sample analysis	$ 800
One Isotope Analysis	$ 120
Subtotal	$ 1,220

Flow Test Total $ 9,320 to $ 32,570

Post Flow Test

Pressure buildup (12 hours)	$ 300
Field charge 2-men	$ 1,000
Per diem 2-men	$ 250
Truck rental, 1 day	$ 100
Unit rental, 1 day	$ 100
Technician charges, 24 hrs	$ 1,000
Post Flow Test Total	**$ 2,750**

Safe shut-in option (No rig required)

T/P/S survey (1 day)	$ 3,100
Wellbore liquid sample (1)	$ 400
Set drillable plug	$ 15,000
Safe shut in Total	**$ 18,500**

Hole Abandonment option (Rig required)

Plug and Abandon (P & A)	$ 100,000

Flow Test Cost Summary

Test Equipment	$ 51,700
Pre-Test	$ 9,600 to $ 10,600
Flow Test	$ 9,320 to $ 32,570
Post Test	$ 2,750
Shut-in Options	$ 3,500 to $ 18,500
Abandon	$ 100,000

4h. Survey the post flow test issues and options; borehole conditions or new requirements may pose shut-in, plugging or prompt abandonment.

The continuous monitoring of WHP, T/P/S survey and the fluid sample collected from the borehole on the 15th day after shut-in, may indicate one of the following conditions:

The borehole fluids are active (convecting) and the fluid pH is low. A continuous rise in WHP may indicate the formation of a gas cap in the upper part of the casing. Such a hole requires close attention as it poses a threat due to high WHP and casing degradation. After the initial use, a drillable cement plug should be set at the bottom of the casing to allow a future use of the hole. The hole should be permanently plugged and abandoned (P&A), if not needed for future use.

The borehole fluids are active, the pH is neutral and the WHP continues to rise. Measure the highest WHP the gas cap generates. Collect a gas sample and determine whether the partial pressures of individual gases are a threat to the casing or not. Set a drillable plug if the gases are considered to be a threat; otherwise inspect the hole from time to time. P&A the hole if not needed for the future use.

The borehole is not active and the pH is neutral. The WHP does not increase after reaching a maximum buildup value after the flow test. Such a hole should be inspected and WHP monitored from time to time.

The WHP is zero and the pH is low. A drillable plug should be set in such a hole because low pH poses a casing degradation threat.

The WHP is zero and pH is neutral. This type of hole poses the least safety risk in the shut-in static mode. Such a hole should be inspected from time to time.

4i. Other Testing Options

15 day Flow Test

To confirm a more accurate potential of an SOH, a 15 day flow test can be run to obtain quality data and a deliverability curve. The flow measurements of steam and brine should be made by using a large separator with the James tube. Steam and brine samples should be collected from two phase and single phase lines at the times indicated in Task 4b.

1. Run a T/P/S survey in the hole at 20' per minute to determine wellbore condition before the test.
2. Warm up the hole slowly by bleeding it through a 4" line at about 20 gpm for 4 hours. Measure M (flow rate), WHP, WHT and H_2S concentration at 60 minute intervals. Abate H_2S if its release rate is more than 5 lbm/hr.
3. Stack the hole vertically for 2 to 3 hours to clean it.
4. Divert the flow from vertical to horizontal by opening the valves to the two phase (James tube) line. Close the stack valve slowly to obtain a smooth transition from vertical flow to the James tube. Take flow rate and H_2S measurements. Abate H_2S if its release rate is more than 5 lbm/hr.
5. Divert the flow through the separator after 2 hours. Separate the flow at 150 psig or any suitable separator pressure.
6. Flow the hole at constant flow rate for next 14 days. Measure WHP, WHT, steam and brine flow rates. Collect brine and steam samples as suggested in Task 4b. Run a T/P/S survey on the 14th day under flowing conditions and determine the location of the steam producing zones.
7. Run a 24-hour deliverability test on the 15th day by measuring stabilized flow rates at 5 different WHPs (stepped rates).
8. Run T/P tool to 6000' depth. Shut-in the hole and monitor downhole pressure buildup for 12 hours. Collect WHP and WHT data at 5, 10, 15, 30, 60 minutes and at 1 hour intervals for 24 hours. Use circular charts to obtain hourly data.
9. Monitor WHP for 20 days by using circular charts. Run a T/P/S survey after 5 days of shut-in to analyze wellbore conditions.
10. If WHP continues to rise then probably a gas cap is forming in the upper part of the casing. Run another T/P/S

survey after 30 days and collect samples of gas and brine. See "Post Flow Test Issues and Options" for future shut-in actions.

Injection Testing

Non flowing SOHs can be injection tested to determine the formation permeability and the permeable zones, if any. Two 500 bbl tanks, filled with water, should be ready before the start of the injection test. Water inflow to both tanks should continue during the injection test. Assuming no electricity at site, a diesel pump with a 250 gpm capacity against 500 psig pressure should be connected to the tank and to the kill line in the hole.

1. Run a T/P survey from surface to TD at 20' per minute just before the injection test. Stop 15 minutes at the top, to stabilize the tools, 5 minutes at every 1000', and 10 minutes at the bottom.
2. Rerun the wireline T/P/S tools to 3000' depth. Start injection at 250 gpm. After 30 minutes of injection, run the tools from 3000' to TD at 20 feet per minute with 5 minute stops at every 1000'. Measure WHP and water injection rate at every 15 minute interval. Measure the temperature of the injected water.
3. Come out of the hole and rerun the T/P/S tools to 6000' depth. Shut-in the well. Collect pressure falloff data for 5 to 8 hours after shut-in.
4. Locate permeable zones. Analyze injection and fall off data for kh and wellbore skin.

TASK 5. Compare expected benefits, critical issues and cost estimates of an SOH Program, modified as recommended, versus an exploration well program in the KERZ in the context of reservoir evaluation goals, existing permit procedures, and pending DLNR rule changes for exploration drilling.

5a. Review existing permits and approval history of SOH Program, True/Mid-Pacific and PGV (ORMAT) operations as they apply to GVRC goals.

Existing permits and approval history on the SOH Program, and the True/Mid-Pacific and Puna Geothermal Venture (ORMAT) full sized exploration and production wells, reflect a very difficult and protracted process. Prospective drilling locations are within approved Geothermal Resource Subzones, yet fall in areas of different land use categories, with varied requirements for permits and approvals. Continuing difficulties with permit coordination and cooperation between county and State agencies, and a dauntless opposition which effectively uses statutory public hearings and conflict resolution options, have effectively constrained drilling by both private developers and the State. This situation continues to delay and retard the Geothermal Resource Verification and Characterization Program of the State.

In spite of smaller operational scale, lesser environmental impacts and voluntary forfeiture of the flow testing option, the SOH Program approval was deferred repeatedly for additional conditions: lower noise and air emissions limits, limits on truck traffic to and from the site, etc. Existing permits and approvals for both the SOH Program and True/Mid-Pacific are again uncertain, if not effectively suspended, by late additional stipulations on medicinal herb flora and possible ancient Hawaiian burials in sub-surface lava tubes. Operators recognize that the State must expose all credible issues in the matter of exploration wells and SOHs drilling permits. However, the outcome of present procedures is putting every individual exploration well and SOH, specifically located and logistically prepared within a Program approval, at risk of serious delay or elimination from final drilling. This clearly obstructs an efficient and early determination of the magnitude of the geothermal resource in the KERZ.

5b. Assess the merits of 1) a modified SOH-hole program; 2) a full-scale exploration well drilling and testing program; and 3) a combination of the above with enhanced tests that might be accomplished.

Refined SOH Program

1. Analysis of SOH 4 and 1 and requirements for an improved rotary drilling-deep coring sequence indicates that 80-84 days per SOH at approximate $1,000,000 cost is achievable with the **TONTO UDR 5000** rig. This is the lowest geothermal reservoir finding cost now available in the KERZ.

2. Flow testing can be safely accomplished with appropriate casing cemented in the upper 3000' of hole.

3. SOH technology can provide an optimal data package from a geothermal reservoir interval; continuous rock cores, supplemented by borehole logs and capped by flow testing or pressure monitor service.

4. The SOH optimal data package is obtainable at less than half the cost of full hole exploration well option.

5. The SOH optimal data package offers the strongest inducement available to prompt private developers to follow with full hole well drilling. It decidedly reduces their drilling risk and it assists their casing design to better isolate the geothermal reservoir for flow testing procedures.

6. The SOH optimal data package provides the strongest technical basis on which to attempt to qualify the airborne and surface geophysical procedures which might delineate the critical permeability envelopes (reservoir) in the KERZ geothermal system.

7. It is believed that in the existing circumstances a package of four SOH with flow test rights can be moved through the permit process in 9 months. A package of four exploration wells with flow test rights is expected to require 12 to 18 months.

Exploration Well Drilling and Testing Program

1. The full hole exploration well allows long-term (30 days or more), detailed flow testing to confidently measure well production capacity. It can more precisely determine reservoir pressure and temperature, steam-water ratios and chemical composition of the geothermal effluent. This is essential procedure for geothermal wellfield and plant design; however, it is appropriately the task of the party intending to proceed to commercial development.

2. Geothermal exploration well time and costs in the KERZ are reasonably established: 60 days to completion in a successful 6500-foot vertical wellbore and a minimum cost of approximately $2,400,000 per well. The same costs would be incurred in a dry hole, which is a significant risk in the KERZ.

3. Flow testing costs are significant and will involve H_2S abatement, large sumps and substantial fluid disposal costs. Logic would indicate targets of long term flow and high quality data at a successful exploration well in the KERZ. Initial flow test costs are conservatively estimated at $400,000 per long term test. Much of the heavy flow test equipment might be constructed in Hilo; expert welding and fabrication, on specified steels for high temperature, pressure and corrosive stresses, are required.

Combination SOH and Exploration Well Program

1. The combination program approaches its first hurdle, the "reservoir finding problem" with the dual use of both the low cost (SOH) and high cost (full hole well) drilling approaches. A prudent drilling operator would not likely do this; rather, one approach as the best suited to his purpose. The State's purpose, to determine the magnitude and extent of the geothermal resource throughout the KERZ, fits with a consistent use of the lower cost SOH program.

2. Simultaneous use of two different rigs and drilling technologies poses new levels of complexity and difficulty in permitting, logistics, and operational management.

3. Simultaneous operations might be replaced by sequential operations. If the combination program were selected by the State for its wholly funded, exclusive approach to the GRVC Program, an extended and disjointed sequence would be incurred. SOHs would be completed as the first phase, to avoid the $2,400,000 costs of unsuccessful full hole exploration wells. The degree of success in the SOH phase would then guide the second phase of full hole exploration wells. The location, permit restrictions, and logistical requirements for the second phase would impose at least a one year hiatus in the sequence.

4. The issues discussed in 1, 2, and 3 above indicate that the combination program is not logical or sensible. It is not recommended for further consideration by DBED.

5. The presumption may exist that the combination program offers an early advantage of paired SOH and exploration wells, when both have successfully penetrated the geothermal reservoir, being used to determine permeability in a large volume of productive reservoir rock. With the full hole well in the flowing mode, the offset SOH can measure fluid pressure responses caused by the flow event. However, the issues discussed in 2 and 3 above indicate that the combination program is not likely to achieve a paired interference test at an early date, on its own doing.

6. It is likely that the intended SOH 3 would be sited close to the geothermal reservoir permeability and production now indicated in the True/Mid-Pacific exploration well. Indeed, a successful True/Mid-Pacific confirmation well and SOH 3 may first establish the ideal paired conditions and opportunity discussed in 5. above. Here is the realization that the highest benefit of a combination program is now being opened by coincident State and private developer activities. This appears to be an optimal approach to the goals of any combination program; it affords a viability to cooperatively respond more quickly to indicated drilling successes.

5c. Prepare a time and cost forecast for each alternative. Assume equal dry hole penalties and equal flow test opportunities on each path.

The expected events and consequent time and cost estimates in the two and a half year interval, January 1991-June 1993 are shown in Figure 5-1. The SOH Program should reasonably complete four new 6500-foot holes and flow test two of them by October 1992 at a total cost of $4,072,000. The exploration well program should complete four new 6500-foot full sized holes and flow test two of them by mid year 1993 at a total cost of $10,400,000. The combination path now evolving between the True/Mid-Pacific exploratory drilling operations and SOH 4 (completed) and SOH 3 (planned) might yield an initial successful flow test measurement of bulk reservoir permeability by November 1991.

TIME AND COST FORECASTS – FUTURE PROGRAM OPTIONS

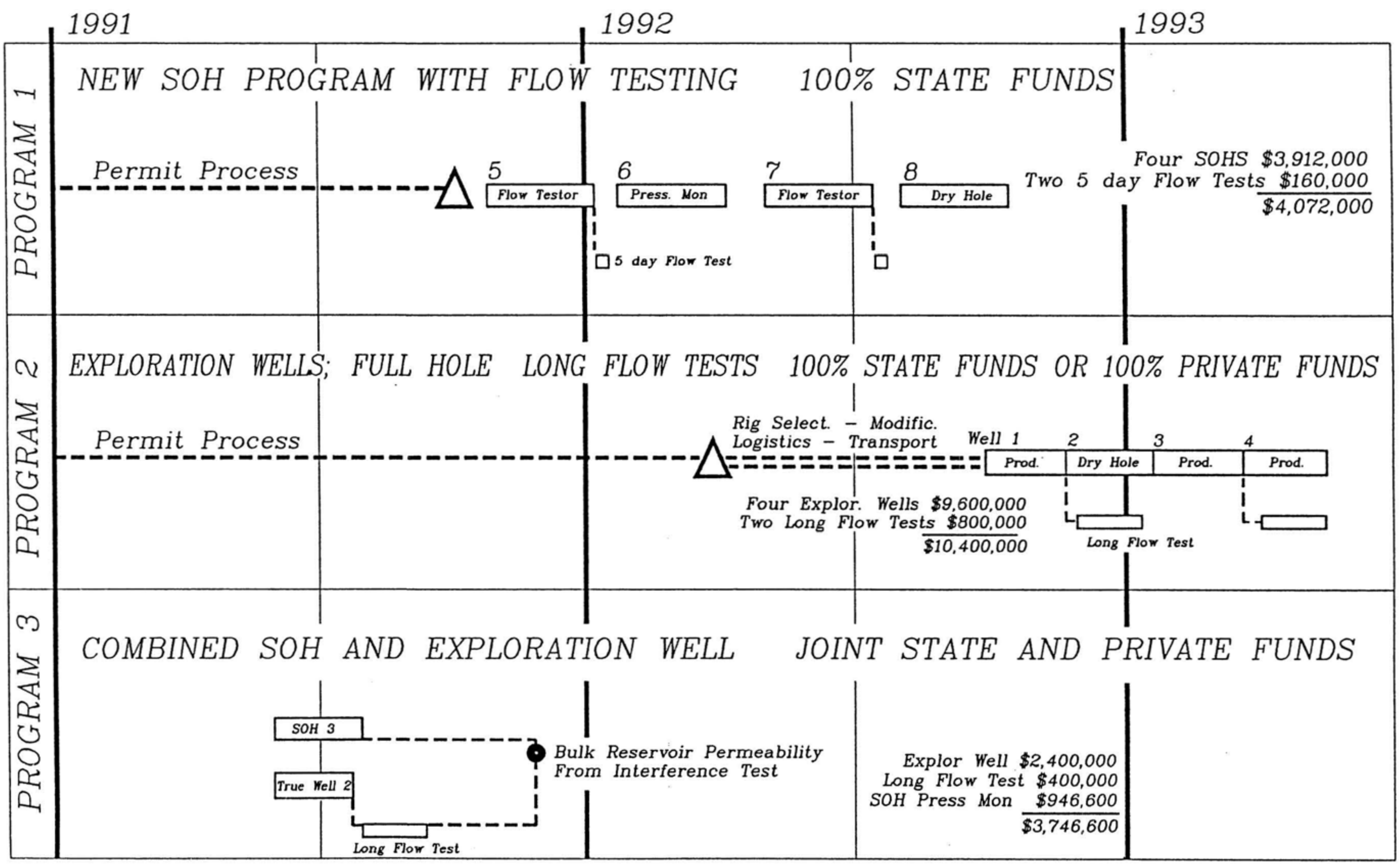

Figure 5-1

<u>TASK 6.</u> Assist DBEDT with technical and practical considerations for pending revisions to DLNR rules for exploratory wells outside of Geothermal Resource Subzones, in accordance with Act 207 of the 1990 Legislature.

The 1990 Hawaii Legislature passed a revision to the laws regarding exploration well drilling outside of designated Geothermal Resource Subzones (GRS). This revision also changed the definition of "geothermal resources" to <u>exclude</u> any "*water, mineral in solution,or other product obtained from naturally heated fluids, brine, associated gases, and steam* (sic) *located below the ground with a temperature of 150 degrees Fahrenheit or less.*" This legislation, passed as SB 3285, C. D. 1, was signed by the Governor and became Act 207.

The Department of Land and Natural Resources (DLNR) is presently drafting revisions to the basic state geothermal regulations (Title 13, Chapter 183 and Chapter 184, DLNR Administrative Rules) in order to implement Act 207. The current wording of the rules does not permit any "geothermal development activities" outside a properly designated GRS. The rules also do not currently define a geothermal exploratory well in sufficient detail to allow permitting of such wells in contrast to other types of geothermal wells.

There are two basic problems - the need for rules to define an exploratory well (and probably other types of wells) in any location, and the need for State and County rule changes to implement Act 207, which will allow exploration wells **outside** of a designated GRS.

<u>6a. Review DLNR drafts for rule changes.</u>

A meeting to discuss our draft recommendations, and review the DLNR approach, was held in mid-December.

DLNR has not completed a draft of proposed rule changes to all the affected regulations. In general, they have begun the process to change as few of the regulations as possible in order to effect Act 207; this will require careful coordination of affected agencies, as discussed below. Revisions to this report will reflect the direction provided by DLNR staff.

<u>6b. Develop and discuss the proposed rule changes with DBED</u>

Geothermal Program personnel, operators, and others.

RULES AFFECTED

The following agency permits and rules may be affected by Act 207:

PERMIT	AGENCY	RULE REFERENCE
Geothermal Exploration	DLNR	Administrative Rules, Title 13, Chap. 183.
Geothermal Mining Lease	DLNR	Administrative Rules, Title 13, Chap. 183.
Geothermal Plan of Operations	DLNR	Administrative Rules, Title 13, Chap. 183.
Conservation District Use Permit	DLNR	Administrative Rules, Title 13, Chap. 183.
Geothermal Well Drilling	DLNR	Administrative Rules, Title 13, Chap. 183.
Geothermal Resource Permit	COUNTY	Rule 12 (Hawaii); Maui pending.
Authority to Construct	DOH	Administrative Rules, Title 11, Chap. 59 & 60.
Permit to Operate	DOH	Administrative Rules, Title 11, Chap. 59 & 60.
Grading, Grubbing	HI COUNTY	Hawaii County Code, Chap. 10, Art. 2 & 3.

DEFINITIONS - GEOTHERMAL WELLS AND OTHER ACTIVITIES

In the present rules, there are no definitions of geothermal well types. Except for a brief mention of "*shallow temperature test holes*," defined as "*less than five hundred feet in depth*," [1] one well is considered the same as another. In actual practice, however, the different purposes for exploration, development, production, injection and other types of wells associated with geothermal activities seem to call for different regulations and considerations for permits, land use elements, etc. The legislature recognized this by exempting exploratory wells from the "GRS-only" requirement.

This lack of clear separation between the several possible stages of geothermal development has caused confusion on the part of the developers, the public, and the regulating agencies; correction of some of these confusing elements should be the aim of rule changes to be considered in implementation of Act 207.

Industry practice in other areas, notably California, has developed several working definitions, [2] including those for:

- Development wells
- Exploratory wells
- Geothermal wells
- High-temperature wells
- Injection wells
- Idle wells
- Low-temperature wells
- Observation wells
- Shallow wells
- Intermediate wells
- Deep wells
- Commercial Low-temperature wells
- Noncommercial Low-temperature wells

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[1] §13-183-7, Exploration permit required on state and reserved lands.

[2] "Drilling and Operating Geothermal Wells in California", Publication No. PR7S; California State Department of Conservation, Division of Oil and Gas. Fourth Edition, 1986

Service wells

Suspended wells

While some of these definitions have overlapping elements (a Service well, for instance, might include Injection wells), nearly all of these definitions have been needed in the definition and regulation of geothermal activities. None of these types of wells are now defined in the Hawaii rules.

Other useful definitions might include those for exploratory projects and development projects, in order to better differentiate purposes and limitations for these collective activities.[3]

OTHER NEEDED RULE CHANGES

Several other changes need to be considered in the rule revisions. First, the present regulations for exploration permits (which do not include provisions for the drilling of deep wells), apply only to State lands. No exploration permit is needed for private or county-owned lands. In developing new rules, the expanded exploration rules should cover all geothermal exploration activities.

Secondly, the review of an application, and issuance of an exploration permit seems properly to be the responsibility of the BLNR, regardless of what land use zone (urban, rural, agricultural, or conservation) is to be the site of the exploration activities. The parallel is found in the fact that the Board has the sole responsibility to designate Geothermal Resource Subzones under the revised chapter 205-5.1, HRS. Since the Board has the basic responsibility for regulating and managing the geothermal resources of Hawaii, under 182-26.15, HRS, the location and evaluation of the resources is properly entrusted to the BLNR. We realize, however, that the county governments may well not agree to this control of exploration activities. Pending more thorough discussions with the DLNR and Hawaii County staffs involved, it is difficult to make complete suggestions for rule revisions. Several

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[3]According to California DOG definitions, ALL of Hawaii's geothermal activities, until the Puna Geothermal Venture development well drilling begun in November, 1990, could be classed as exploratory.

approaches could be discussed, but it is probably repetitive to do so here without input from the agencies mentioned above.

Thirdly, matters related to surface owners permission, occupier rights, and the relationship of exploration well permits to the holders, if any, of state or private mining leases, need to be clarified in any new rules. These relationships are sometimes complex from a legal standpoint and will require careful review by counsel familiar with the current status of mineral claims and leases in Hawaii before the proposed rules are presented for public comment.

Fourth, issues concerned with limits on the locations of exploratory wells, particularly those outside designated GRS, will have to be spelled out. We have in mind the need to protect schools, hospitals and the like from unreasonable disturbances brought on by exploration drilling and testing. These should not unfairly limit exploration activities just because they involve geothermal matters. Limitations on the depth, diameter and flow testing of the wells must be avoided if the State is to realize maximum benefits from such exploration drilling.

Finally, the rules should contain some discussion of what well logs or tests will be required, and how the information gained will be made available to the State, to other parties interested in geothermal development, and to the general public. Current rules for protection of information gathered under exploration permits appear to be too restrictive under the evolving State resource evaluation policies and programs.

PROPOSED CHANGES - REVIEW

Insofar as possible under freedom of information rules, proposed geothermal rule changes should be thoroughly reviewed by the various state and county agencies that will be affected before they are released to the public for review and comment at public hearings. This review could go a long way to insure that the process will be as smooth as possible.

In connection with the release of the rules for comment and hearings, a carefully crafted public information program, going beyond the usual (and required) published legal notice in the back pages of the paper is suggested. These steps can make the final result better, and better understood, by the public and the agencies charged with regulation of the activities.

<u>6c. Make specific recommendations for rule changes that can be brought to the Public Hearings stage later in 1990.</u>

The following specific rule changes, to the indicated references, are suggested:

TITLE 13, DEPARTMENT OF LAND AND NATURAL RESOURCES, SUB-TITLE 7. WATER AND LAND DEVELOPMENT.

CHAPTER 183
RULES ON LEASING AND DRILLING OF GEOTHERMAL RESOURCES.
Subchapter 1.

<u>Add</u> the following to §13-183-3 <u>Definitions:</u>

"Development project" means a project composed of any combination of geothermal wells, pipelines, production equipment, roads, and other facilities necessary to supply geothermal energy to any electrical generation or heat utilization equipment for its productive life, within an area delineated by the operator or applicant.

"Exploratory project" means a project composed of not more than six wells and associated drilling and testing equipment, whose chief and original purpose is to evaluate the presence, characteristics, and economic viability of geothermal resources. Wells included in an exploratory project must be located at least one-half mile from the surface location of any existing geothermal well(s) capable of commercial production.

"Geothermal well" means a well drilled for the discovery or production of geothermal resources, or a well drilled on lands producing geothermal resources or reasonably presumed to contain geothermal resources; or any special well, converted producing well, or reactivated or converted abandoned well, which is used as an injection well.

"Exploratory well" means a well located at least one-half mile from the surface location of any existing geothermal well(s) capable of commercial production, and drilled for the purpose of evaluating the presence and characteristics of geothermal resources.

"Development well" means a well drilled for the commercial production of geothermal resources and located within one-half mile of the surface location of any existing geothermal well(s) capable of commercial production.

"Injection well" means a well used for geothermal fluid disposal, reservoir pressure maintenance, reservoir fluids augmentation, or for any other purpose authorized by the board.

"Deep well" means a well drilled to a depth exceeding 1,000 feet (305 meters) for the purposes of recovering geothermal resources, or for use as an injection well.

"Shallow well" means a well drilled to a depth less than 1,000 feet (305 meters) for the purposes of recovering geothermal resources, or for use as an injection well.

"Idle well" means a well, other than a suspended well, that has not been officially abandoned, but where the operator has ceased all activity, including but not limited to drilling, production, or injection.

"Suspended well" means a well that is temporarily abandoned pursuant to requirements of the board. The operations necessary for such temporary abandonment shall have been completed by the operator and approved by the board.

"Observation well" means a well drilled to monitor pressure and other physical properties of the reservoir or formation penetrated by the well.

Change the following in §13-183-3 Definitions as indicated:

"Geothermal resources" means the natural heat of the earth, including the energy, in whatever form, below the surface of the earth and present in, resulting from, or created by, or which may be extracted from the natural heat of the earth, and all minerals in solution or other products obtained from naturally heated fluids, brine, associated gases and steam, in whatever form, above 150 degrees Fahrenheit as measured at the surface outlet of the energy, fluids, brine, etc., found below the surface of the earth, but excluding oil, hydrocarbon gas or other hydrocarbon substances.

Subchapter 2. Geothermal Exploration Permits

Change §13-183-7 and §13-183-8 as indicated:

§13-183-7 Exploration permit required ~~on state and reserved lands~~. An exploration permit is required to conduct any exploration activity for evidence of geothermal resources. Exploration activity includes, but is not limited to, geophysical operations, drilling ~~of shallow temperature test holes less than five hundred feet in depth, or deeper as may be determined by the board~~, construction of roads and trails, and crosscountry transit by vehicle over state lands, and any combination of the above under a described exploration project. ~~All other d~~Drilling~~s on state or reserved lands~~ shall be regulated as provided for in subchapters 8 through 13 herein.

§13-183-7 <u>Application for exploration permits.</u> Any person may apply for an exploration permit ~~on any state or reserved land~~ by submitting a written application to the board containing the following:

(1) The name and................(8).securing the consent.

CHAPTER 184
DESIGNATION AND REGULATION OF GEOTHERMAL RESOURCE SUBZONES

<u>Add</u> the following to §13-183-3 <u>Definitions:</u>

"Development project" means a project composed of any combination of geothermal wells, pipelines, production equipment, roads, and other facilities necessary to supply geothermal energy to any electrical generation or heat utilization equipment for its productive life, within an area delineated by the operator or applicant.

"Exploratory project" means a project composed of not more than six wells and associated drilling and testing equipment, whose chief and original purpose is to evaluate the presence and characteristics of geothermal resources. Wells included in an exploratory project must be located at least one-half mile from the surface location of any existing geothermal wee(s) capable of commercial production.

"Geothermal well" means a well drilled for the discovery or production of geothermal resources, or a well drilled on lands producing geothermal resources or reasonably presumed to contain geothermal resources; or any special well, converted producing well, or reactivated or converted abandoned well, which is used as an injection well.

<u>Change</u> the following in §13-184-2 <u>Definitions</u> as indicated:

"Geothermal development activities" means ~~the exploration, development, or production of electrical energy~~ the establishment of productive wellfields and related electrical generation or heat utilization facilities using ~~from~~ geothermal resources.

"Geothermal resources" means the natural heat of the earth, including the energy, in whatever form, below the surface of the earth and present in, resulting from, or created by, or which may be extracted from the natural heat of the earth, and all minerals in solution or other products obtained from naturally heated fluids, brine, associated gases and steam, in whatever form, above 150 degrees fahrenheit as measured at the surface outlet of the energy, fluids, brine, etc., found below the surface of the earth, but excluding oil, hydrocarbon gas or other hydrocarbon substances.

Add the following section as indicated:

§13-184-2.2 Geothermal exploration. Exploration projects or exploration wells may be permitted within urban, rural, agricultural, and conservation land use districts in accordance with Chapter 205, Hawaii Revised Statutes, rules of the appropriate county authority, and these administrative rules.

The provisions of these administrative rules shall not abrogate nor supersede the provisions of chapter 182, entitled "reservation and disposition of government mineral rights" and 183, entitled "forest reservations, water development, zoning", Hawaii Revised Statutes, and chapter 183 of title 13, department administrative rules entitled "rules on leasing and drilling of geothermal resources".

Permits for exploration wells or exploration projects shall not abrogate nor supersede the provisions of chapters 342 and 343, Hawaii Revised Statutes, and administrative rules promulgated thereunder shall apply as appropriate.

Additional specific changes to regulations should be developed as the discussions proceed with various affected agencies. It is important to include the County administration and Council in these ongoing deliberations.

TASK 7. Develop a perspective and rationale on the value of safe, controlled flow testing of SOH boreholes which encounter reservoir fluids.

7a. Develop an approach designed to assist in the acceptance of SOH flow tests by the communities and regulatory agencies involved. Provide information requirements to support discussions with County officials (and community leaders, as feasible) to determine the specific objections to limited SOH flow testing.

A basic perspective and rationale for safe flow testing of SOHs lies in the values for the people of Hawaii in knowing, measuring and qualifying the natural resources existing within the State. The State and counties of Hawaii consistently collect groundwater data, especially water well production information, to better comprehend the magnitude of an excellent indigenous resource and to allow the development of improved water resource management. The high value of abundant, clean groundwater to Hawaiian communities and agriculture is nearly immeasurable. The SOH Program performs a similar function for the critical need to understand the reality and practical factors that will affect the management of the geothermal resources in the KERZ.

The State of Hawaii is providing public funds to help determine the extent and size of productive geothermal reservoir(s). Well drilling by private developers is also directed at proving resources, but expressly for commercial development. The State objective is properly an "asset inventory" of the total geothermal resource in the KERZ. While the objective of the private developers is distinctly different from the more general State objectives, they are interdependent. Any geothermal well or SOH which penetrates geothermal reservoir rock containing a permeable zone provides a critical additional data point of great value to both objectives. There is no other acquisition process available; geophysics is not yet able to define productive geothermal reservoir below depths of 4000 feet in the KERZ.

Every geothermal well and SOH adding to KERZ geothermal reservoir knowledge is completed at high cost. Private developers have utilized full-hole exploratory wells at minimal costs of $ 2,400,000 to perhaps $ 3,000,000 per well. When success is encountered geothermal fluid production capacity must be measured in flow tests which are estimated to cost at least $ 400,000 per test. The state, utilizing a refined SOH drilling-coring plan, should be able to complete a successful 6,500-foot hole at approximately $1,000,000 costs and conduct a 5-day flow test for $80,000 or less per test, as presented in Tasks 3, 4 and 5 of this evaluation.

The composite data package obtained in a successful SOH, penetrating a permeable geothermal reservoir zone, becomes an exceptional value if flow tested. The diamond coring process can deliver continuous rock cores through the productive interval; the cores reveal fracturing, primary porosity and mineral alteration, while the core hole provides access for temperature, pressure and other geophysical surveys. Flow testing, by measuring the productive capacity and fluid contents of the cored and surveyed reservoir zone, enhances the data package to an optimal value. Each such borehole achievement provides unequivocal new facts about the magnitude of the geothermal resource, better guiding all subsequent drilling. It also offers a proper basis for evaluating geophysical measurement techniques that might eventually assist in confident reservoir prediction. In addition, there are distinct environmental advantages from testing the smaller SOHs as opposed to full scale wells. Smaller mass flows, smaller drilling pads, less operating noise, and less large equipment would have significantly less impact.

<u>7b. Develop a planned approach to flow test operations that will satisfy permit requirements, community needs, and program goals.</u>

Presentations to State and county regulatory agencies in support of SOH flow testing should include three components:

1) Rationale and value of flow testing in designated SOHs, as presented in Task 4.

2) SOH borehole and test design and procedures for safe flow testing, as discussed in Tasks 3 and 4.

3) Detailed descriptions of the flow test process and post test disposition of the SOH, with emphasis on safety and other community and regulatory concerns, as discussed

here and in Task 4.

The presentations might best be made in the quiet give and take atmosphere of informal workshops, separately with DLNR and with the Hawaii County Planning Department. The questions, comments and criticisms of these regulatory staffs must be drawn out and met with constructive discussions and explanation. The workshop process and product must determine the specific objections to SOH flow testing and the basis for the preclusion of flow testing in the permit for the first SOHs. The workshops must establish a creditable rationale for including flow testing in future SOHs which are safely designed for this purpose.

A planned approach to flow test operations would be integral with a new application for a second group of SOHs. Flow test candidates, specified by location and special casing requirements, should be identified, and flow test procedures detailed, as in Task 4. They must be related to community concerns and to the goals of the SOH and Geothermal Resource Verification and Characterization programs.

It is believed that the workshops could be prepared for presentation in March or April 1991. Permit application for four enhanced additional SOH, including flow tests, could be ready for submission by May 1991 if workshops can be held first and personnel are available to prepare the applications.

The identification of community needs for acceptance of flow testing in SOHs will require perceptive analysis and careful presentation. The public will want to know important specifics; how SOH flow testing can be safely done; that H_2S will not be released in any significant quantities; that noise will be minimized; that not every SOH will qualify for flow testing. These, and other specifics must be in a rationale for flow testing that will show testing will provide important highest values to the SOH Program, and will afford better delineation and measurement of a major public asset.

Presentation opportunities, using existing forums recognized in Hawaii County regulations, community organizations, or specially structured workshops, need to be carefully considered and planned. This will be an extraordinary task, one that must follow and benefit from all that has been learned in the presentations on geothermal development in the past.

SOH Program Review: Overall Conclusions, Integration of Concepts, and Recommendations

The SOH Program uses slim hole, diamond coring technology to gather important subsurface information on the character and magnitude of the geothermal resource in the KERZ. The initial hole of the Program, SOH 4, continuously cored potential reservoir rock in a 330°-583°F temperature range between depths of 4000 and 6562 feet. The SOH 4 location and the True/Mid-Pacific Geothermal discovery well are respectively 5 and 8 miles, respectively, uprift from the productive HGP-A well and the Puna Geothermal Venture 30 MW geothermal electric power project now under construction. Through the SOH Program, the State of Hawaii is an active participant in the deep geothermal drilling which is fundamental to measuring the extent and characteristics of this important indigenous energy resource.

An excellent rig and competent contractor were selected for the dual drilling and coring requirements of the SOH Program. However, actual costs and time inputs in the first two SOHs are more than double the original estimates. These cost and time overruns are clearly the consequences of emphasizing one scientific objective, continuous diamond coring from the surface to total depth, among several other major objectives for the SOH Program. If the program is to survive and make the positive contribution it can make to the Geothermal Resource Verification and Characterization Program in the KERZ, it should be refocused on that target.

The diamond coring-slim hole technology can obtain hard, in-situ geothermal reservoir data by the combination and sequence of:

1) continuous rock cores,
2) borehole geophysical surveys,
3) flow testing to sample geothermal fluids and measure flow rates, or
4) perform monitoring of nearby geothermal wells which are under flow test or are in production service.

The cross correlation and factual confirmation of the resource characteristics that can be achieved in such evaluations, linked where possible to other drilling and testing, allows the SOH Program to provide critical geothermal reservoir knowledge at reasonable cost.

SOH Program Review: Recommendations

Our review found that rotary drilling and casing to the 3000-foot depth in each SOH is the effective launch point for deep continuous coring into the prospective geothermal zones. The **Tonto UDR 5000** rig, with heavier drill collars and a larger mud pump, should efficiently handle the top hole rotary and the deep hole coring in 80-84 days of total operating time. These new SOHs, completed at 6500-foot depths, should approximate $1,000,000 per hole in total drilling costs.

The inclusion of the flow test option is necessary to enable the SOH Program to meet its high potential to help inventory the KERZ geothermal resource. The SOH Program will do this best by working in concert with full-hole well drilling by private developers. We have defined the safety requirements in casing design, detailed flow test procedures, and post flow test actions, to allow safe flow testing of the SOH holes. Flow testing should be done; both the State and private developers recognize it as an advantageous, cost competitive procedure in the exploration and development of Hawaii's geothermal energy.

Specific recommendations for the completed SOH's are as follows:

SOH 4

Evaluate this borehole further for the presence of some permeability at depth(s) which would allow an optimal use of SOH 4 as a pressure monitor hole in support of True/Mid-Pacific drilling operations and flow testing in full sized wellbores.

The distinctive linear temperature increase, from approximately 330 F at 4000' to a 563 F maximum at total depth, indicates a conductive heat transfer zone within generally impermeable rock, in this deepest portion of the SOH 4 borehole. However, pressure and temperature surveys repeatedly show anomalies in the thin interval between 4000-4500 feet, which may indicate permeability (see Figure 4-2). Additional surveys and a second injection test, accomplished in SOH 4 on or about 12 January 1991, were quite appropriate actions that should resolve this important possibility of permeability.

The significant options for SOH 4, in order of consideration, are:

1. Use SOH 4 as a pressure monitor, in concert with the planned SOH 3, when True/Mid-Pacific runs a long term flow test in a successful new confirmation well, or in its existing discovery well. This important interference test may yield a creditable determination of bulk reservoir permeability in this general locale.
2. If permeable below 4000 feet, consider flow testing SOH 4 on a demonstration basis if a waiver of the permit restrictions can be obtained. The superior casing and the remote location of SOH 4 favor this idea. The 330 -380 F indicated temperature range of the suspected permeability zone, while not as hot as the HGP-A and Kapoho-State geothermal production zones, could yield important fluid and reservoir information.
3. With permeability proven, and even after possible flow testing, SOH 4 should afford a long term pressure monitor service in connection with other wells in the area.
4. Directional drilling or coring from the shoe (bottom) of the 7" casing at 2000 feet depth in a direction that is judged more meaningful as the cumulative knowledge of structure, hydrology and reservoir permeability increase as a result of other drilling and testing.

SOH 1

Though the expected geothermal reservoir penetration was not achieved in this borehole, at its 5526 foot total depth, SOH 1 data can and should make a valuable contribution to the first KERZ cross-rift geologic section that can be constructed on hard data from appropriate deep holes. The logs of Lanipuna 1, HGP-A, KS-1, and SOH 1 will provide an important opportunity to construct cross rift subsurface correlations of rock structure, hydrology, temperatures, and geothermal reservoir extent.

The marked improvement in rock competence, increasing temperatures, sealed fractures and mineral alteration in the bottom of SOH 1 (5250 to 5526 feet) appears quite similar to the geothermal reservoir caprock in the 3600-4000 foot depth in the Kapoho-State wells located about 2100 feet south. The highly fractured mid section of SOH 1 (2670 to 4650 feet) is consistent with major transverse (cross rift) faulting in this locale. Identification of the low-temperature fluid content of this fractured section in SOH 1 should provide important new hydrologic knowledge next to the deeper geothermal reservoir.

Appropriate options for SOH 1 are:

1. Use as a pressure monitor during the initiation of geothermal wellfield production to the Puna Geothermal Venture's (PGV) new generating plant, expected later in 1991 on the Kapoho-State leasehold. Pressure monitoring in the SOH 1 borehole should also be done during any future flow testing or return to production of the HGP-A well.

2. Because of low temperatures in the fractured mid section of SOH 1 and the 7" casing to 2000 foot depth, flow testing should be considered to identify the fluids resident in the extensively fractured interval. Is it fresh (deep groundwater), saline (seawater), or mixed waters? Flow testing SOH 1, as now completed, could yield important information on the hydrologic interface between the geothermal reservoir fluids and external waters. Waiver of the permit preclusions would be required, but flow testing of the low temperature, fractured zone in SOH 1 is a valuable option.

3. After considering and executing 2. above, SOH 1 merits consideration as a high-volume injection test to determine if the highly fractured midsection (2670 to 4650' depth interval) is a potential fluid disposal zone of large capacity. This could establish important economic and operational advantages for PGV; they should be requested to fully fund this test.

3. Deepening, with downsized BQ coring assembly, or

redrilling from the 7" casing shoe are also possibilities for SOH 1, if geothermal reservoir penetration can be judged to be possible for these options. Substantial funding support from the PGV might be essential to justify the costs and risks of this option.

GEOPHYSICAL LOGGING IN THE SOH PROGRAM

BACKGROUND

Following the submission of our Draft Final Report on the SOH Program, DBED requested comments on the role of geophysical logging in the Program and for the general advancement of geothermal resource assessment. Geophysical logging provides evaluations of rock penetrated by the borehole using a series of electrical, acoustic, radioactive and other procedures and devices. These can measure a very broad array of physical parameters of the rock and the surrounding fluids.

In geothermal exploration to date in the KERZ, the use of geophysical logging has been uneven; some government and private efforts have been made, but there has been little or no coordination of the efforts. The have been no standards of geophysical logging applied to the wells and observation holes drilled, and there has been little or no analyses performed on those procedures that have been employed.

LOGGING TECHNIQUES AND APPLICATION

Geophysical logging is extensively used in the world wide petroleum industry, which usually seeks its valuable resource in sedimentary rocks and in lower temperature formations. Petroleum industry applications have been the prime driver of exceptional technical advances made in geophysical logging in recent years. However, geothermal resources are usually found in hard, altered, or crystalline rocks at much higher temperatures. In this more difficult subsurface environment, simple temperature and pressure surveys have proven to be the most reliable, cost effective, interpretable, and repeatable procedures for all types of geothermal wells and boreholes.

The lag in application of broader, state-of-the-art geophysical logging procedures by the geothermal industry reflects the higher costs, risks and uncertainties involved. This situation is being addressed by tool improvements; by increasing temperature tolerances for all components and by down sizing much of the hardware. However, technical improvements need to be matched by better awareness among geothermal resource developers of new opportunities to apply carefully selected geophysical logging procedures.

APPLICATION TO THE SOH PROGRAM

It should be noted that the SOH Program did not identify geophysical logging as a scientific target or as a priority technical adjunct to the primary objective of continuous rock coring. However, the program managers are aware that successful geophysical logging in the cored intervals would provide a valuable guide to log type selection, applications and interpretation in future KERZ rotary drilled geothermal exploration and production wells. If the SOH program seems to offer an opportunity here, it also presents a number of mechanical difficulties.

Most procedures must be, or are best conducted, in the open (uncased) section of the bore hole. Open hole logging windows can suddenly be lost in SOHs when core rods become stuck unexpectedly in the hole. There were also concerns that geophysical survey tools could get stuck in the open corehole by dislodged rock debris in both SOH 4 and SOH 1, due to the conditions encountered. An open hole caliper survey in SOH 1 indicated a number of areas where corehole enlargement, beyond the 8" diameter measuring limit of the tool, had occurred from the loss of wall rock.

In the SOH cored intervals, the small open hole diameters (HQ hole diameter of 3.98" and NQ hole diameter of 3.04") put a significant constraint on geophysical logging. Hothole Instrument Co. was brought to the SOH 4 location with specially downsized tools; yet they accomplished only a small interval of open hole survey when an electric resistivity measuring device failed. Such malfunctions are more frequent in small diameter logging tools.

Obviously, an assortment of risks confronts geophysical logging in the cored intervals of the SOHs. The Operator's caution in SOH 4 and SOH 1 was rewarded by the fact that no survey tools of any kind were lost downhole, allowing perforated liners to be installed to total depth in both holes.

FUTURE SOH LOGGING

ENEL (December 1989) has recommended a specific suite of geophysical logs for both geothermal exploration wells and SOHs in the KERZ. The electric resistivity, formation density and sonic (acoustic) logs specified by ENEL comprises a general log set which is used worldwide, frequently by the petroleum industry and to a lesser extent by the geothermal industry. These logs are run in full sized open holes (6" diameter and larger) before casing or liners are installed, in both exploration and production wells.

It is appropriate to now consider a selected geophysical log program for the rotary drilled top portion of SOH 2 and 3. Unfortunately, California-based state-of-the-art equipment would be cost prohibitive for these next two SOH's. The geophysical logging truck recently provided in Puna by the Water Resources Division, U. S. Geological Survey (WRD-USGS), presents an opportunity for the logging of 2000 to 3000 feet of the open 8½" rotary drilled hole before running the 7" casing in SOH 2 and 3. A tophole geophysical logging program should be worked up with the full participation of WRD-USGS professional expertise in groundwater evaluation by these methods. The common interests of the SOH Program, the USGS, DLNR, and the active geothermal developers in the KERZ are nearly identical in the need to understand how groundwater interfaces and interacts with the underlying geothermal fluids which are escaping the reservoir at some locales in the KERZ.

Furthermore, Dr. Thomas of HIG is hopeful that USGS borehole televiewer surveys may provide sufficient details of rock fracturing in this tophole interval to assist in stress analysis and possible permeability prediction at greater depths.

Finally, the challenge of supplementing the deep coring of the SOH Program with carefully selected geophysical logging procedures should be addressed. It is suggested that a thorough review and enumerated summary be made of the geophysical logging events of SOHs 4 and 1, and then distributed to a small group of informed persons for review and comment. Following this, discussion of the past applications of SOH geophysical logging, and the potential for the future, in a carefully planned work session would allow the full discussion of risks against expected advantages to the SOH Program and the broader GRVC. The risks are significant, yet the correlation of geophysical logs to the hard geologic information from cores should be of major importance to the active drilling evaluation of the KERZ geothermal resource.

APPENDIX A

REVISED STATEMENT OF WORK - October 10, 1990

TASKS

<u>TASK 1.</u> Evaluate SOH drilling-coring operations to date, with particular attention to the amounts and causes of time and cost overruns.

a. Construct work versus time profiles of each SOH from daily HNEI/contractor drilling reports.

b. Segregate actual costs by sectors.

c. Evaluate the primary cost elements: coring, drilling, hole opening, casing, cementing, etc. Identify elements posing the greatest time penalties and serious mechanical risks.

d. Summarize SOH operational/cost performance to date.

<u>TASK 2.</u> Assess current SOH performance against those multiple objectives which won the initial program approval and funding, particularly in light of the concerns about time and results shortfalls against GRVC goals.

a. Review the SOH Program multiple objectives, as originally accepted.

b. Summarize the perceptions of results anticipated from SOH; consider the views of HECO, ENEL, other operators, etc.

c. Evaluate the relative value of flow testing the SOH holes against the conduct of 1) interference testing between SOH holes and other wells/boreholes and, 2) single SOH injection testing.

d. Present the logic for improving SOH Program performance to accelerate the process and incorporate flow testing.

<u>TASK 3.</u> Develop a refined SOH borehole plan and drilling-coring procedures to accelerate geothermal reservoir penetration at reduced time and costs, and to allow safe flow testing.

a. Identify key changes required to better and faster accomplish the primary objectives; present the rationale for these improved procedures.

b. Write the new refined program for a flow-testable SOH in the KERZ.

c. Provide new work versus time profiles and new cost estimates for the refined, flow testable SOH.

TASK 4. **Formulate an appropriate flow test program, equipment, objectives, key procedures, time, and cost estimates for the optimal evaluation of the KERZ geothermal reservoir intervals.**

a. Confirm the logic and practicality of flow testing SOHs in the KERZ. Stress the integration of safety and community concerns.

b.Identify critical data and fluid samples to be collected in flow tests and key sampling procedures. Cite fluid disposal and emission mitigation options.

c. Determine equipment needs, sizes, modifications or new construction requirements for the mass flow volumes anticipated. Present a graphic layout of equipment on a small drilling location during the test periods.

d. Specify the pre test preparations; borehole temperature-pressure survey; bleed-flow heating of borehole and casing, and opening to full flow for safe geothermal fluid cleanup.

e. Write the preferred flow test program for SOHs in the KERZ to meet GRVC criteria and goals. Specify the test activities and sampling points and sequence on a flow test time line.

f. Specify the post-flow test pressure buildup, temperature-pressure surveys and wellbore fluid sampling procedures.

g. Present a preliminary cost and time estimate of a SOH flow test. Segregate into preparation, flow testing and post flow test activity/disposition.

h. Survey the post flow test issues and options: borehole conditions or new requirements may pose shut-in, plugging or prompt abandonment.

TASK 5. **Compare expected benefits, critical issues and cost estimates of an SOH Program, modified as recommended, versus an exploration well program in the KERZ in the context of reservoir evaluation goals, existing permit procedures, and pending DLNR rule changes for exploration drilling.**

a. Review existing permits and approval history on SOH Program, True/Mid-Pacific and PGV (ORMAT) operations as they apply to GVRC goals.

b. Asses the merits of 1) a modified SOH-hole program; 2) a full-scale exploration well drilling and testing program; and 3) a combination of the above with enhanced tests that might be accomplished.

c. Prepare a time and cost forecast for each alternative. Assume equal dry hole penalties and equal flow test opportunities on each path.

<u>TASK 6.</u> Assist DBEDT with appropriate technical and practical considerations for the pending revisions to DLNR rules to enable, among other things, the flow testing of SOHs and exploratory wells outside of Geothermal Resource Subzones, in accordance with of Act 207 (Senate Bill 3285) of the 1990 Legislature.

a. Review DLNR drafts for rule changes.

b. Develop and discuss the proposed rule changes with DBEDT Geothermal Program personnel, operators, and others.

c. Make specific recommendations for rule changes that can be brought to the Public Hearings stage later in 1990.

<u>TASK 7.</u> Develop a perspective and rationale on the value of safe, controlled flow testing of SOH boreholes which encounter reservoir fluids.

a. Develop an approach designed to assist in the acceptance of SOH flow tests by the communities and regulatory agencies involved. Provide information requirements to support discussions with County officials (and community leaders, as feasible) to determine the specific objections to limited SOH flow testing.

b. Develop a planned approach to flow test operations that will satisfy permit requirements, community needs, and program goals.