CONF-820927--4

SAND--82-0671C

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THE IMPACT OF COMMON COMPLETION AND WORKOVER ACTIVITIES ON THE EFFECTIVE COSTS OF GEOTHERMAL WELLS

MASTER

SAND82-0671C

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ABSTRACT

Drilling and completing wells at minimum initial cost may not be the most cost effective way to exploit the geothermal resource. The impacts of completion practices on production and maintenance costs must also be considered. To evaluate alternative completion and workover technologies, a simple model has been developed that compares total well cost to total production or injection. This paper briefly discusses the model and focuses on results from its application to different completion and workover strategies.

The model development project had three aspects: 1) the establishment of a data base for the cost and effectiveness of various geothermal completion and workover activities; 2) the development of a computer model built around these data; and 3) application of the model to specific cases. The data collected include geothermal production characteristics; initial costs and completion practices for representative wells; estimated costs and effectiveness of common workover equipment and operations; the frequencies of and times required to perform workovers; etc. The model facilitates comparisons of completion and workover alternatives. Its primary purpose is the evaluation of potential impacts of proposed geothermal completion technologies in order to aid the management and direction of the DOE/Sandia Geothermal Technology Development Program.

The results discussed include an analysis of the impact of variations in well lifetime. Additional lifetime beyond 10 to 15 years adds little value to the well. A comparison of mechanical descaling of geothermal wells to chemical scale inhibition indicates that for certain conditions chemical inhibition is more cost effective. Results of an analysis of injectivity decline are also presented, as are studies of original well cost, initial flow, and productivity decline for production wells. Other results involving underreaming, changing casing profiles, perforating, and hydraulic fracturing are also discussed.

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INTRODUCTION

Sandia National Laboratories manages the U.S. Department of Energy Geothermal Technology Development Program.[1] This program includes the development of new completion technologies specifically for geothermal production and injection wells. In order to evaluate the potential effects of proposed new technologies, tools have been developed for analyzing technology impacts on well costs. Clearly, drilling and completing geothermal wells for minimum initial cost may not be the most cost-effective way to exploit a geothermal resource. The effectiveness of a completion technology depends on its impact on well production and lifetime, and so the analysis of it must include consideration of life-cycle costs and lifetime production. These are the essential elements of a computer-based model, GEOCOM (Geothermal Completion Technology Life-Cycle Cost Model), developed for Sandia by the BDM Corporation to assist in directing the Technology Development Program.[2]

The purpose in developing the model was to build a tool for evaluating and comparing the impacts of new completions technologies on the life-cycle costs of geothermal wells. The mathematics underlying the GEOCOM model are fairly simple, and its computer implementation is quite flexible. It contains a data base that defines the cost and effectiveness of many current completion and workover activities, and it allows evaluation of any technology for which a basic set of cost and performance parameters can be defined.

The model development project had three elements: 1) compilation of the data base defining existing technologies, 2) implementation of the data base and the costing mathematics in a computer code, and 3) application of the model to actual geothermal problems. This paper covers all three elements, with emphasis on the third. Documentation of the model development effort is available in Reference (2).

COMPLETION AND WORKOVER DATA BASE

The first step in compiling the data base for completion cost and effectiveness was to quantify the costs required for the initial drilling of geothermal wells. This was done using a set of representative well models for eight U.S. geothermal areas. These models are built around detailed operations sequences that describe the activities required for drilling the wells and the costs associated with those activities. The construction and use of these models has been described elsewhere.[3,4]

The same approach, built around representative models, was used for various completion and workover activities. Each common activity was broken down to a sequence of individual operations for which costs could be estimated. This was done for each of the twelve completion and workover activities shown in Table 1 for each of the six geothermal areas indicated. The sequence of operations defines the baseline completion activity. A new

or modified activity would change the baseline, and its cost impact could be estimated by determining its impacts on the appropriate operations sequence and on hardware costs. Table 2 presents a sample sequence, representing mechanical descaling at the Roosevelt Hot Springs, Utah, geothermal resource area.

In addition to providing the baseline for analyzing technology changes, the operations sequences were used to estimate the costs and times required for the standard completion and workover jobs. These costs and times for standard completions are built into the computer model as default values.

COMPUTER IMPLEMENTATION

Model Parameters

The data gathered in the analysis of completion activities enters the model as input parameters, along with other data determined from analysis of the characteristics of the geothermal resource areas. The parameters are divided into three groups according to function. Each parameter is assigned a default value in the baseline model and new or modified technologies are analyzed by changing the default values. The more important parameters are listed in Table 3. Analysis of a particular situation requires selection of the geothermal resource area, the well configuration and usage, and the completion activities of interest. As is indicated in the table many of the default parameter values depend on the area, the configuration, and the usage.

Cost Parameters. There are two types of cost parameters: one that defines the initial cost for the well and several that describe continuing costs for operating the well and performing workovers. Modifications to initial completion activities could change the initial cost parameter, and new workover or repair technologies change the appropriate continuing costs. These changes would be determined using the representative well and completion models.

Financial Parameters. There are two financial factors: the discount factor and the inflation factor. These are used in the present worth calculations.

Performance Parameters. There are two types of performance parameters: those that relate to well productivity or injectivity, and those that affect the production or injection schedule.

The productivity parameters define the initial well flow rate, the decline rates for the reservoir (due to draw-down, for example) and for individual wells (due to scaling or formation damage, for example), and the effectiveness of workover and repair operations.

The schedule parameters define the times related to costs and production by specifying the delay between initial completion and production and the times, frequencies, and durations of workovers and repairs. In addition, the schedule parameters include the well life and length of the study period.

Mathematics

The entire completion and workover situation to be analyzed is specified by input parameters. There is a sequence of costs, for which the amounts and timing are specified, and there is a production or injection history. These are represented in Figure 1. The costs are converted, using standard treatments for the time value of money, to a present worth value that reflects the specified discounting and inflation rates. Unlike economic analyses, the amount of fluid produced or injected, and not a revenue, is the benefit derived from the expenditures. By using production quantities in this fashion, the assumed sale of geothermal fluid or assigning a dollar value to injected fluid can be avoided. The measure used to evaluate and compare technologies is the unit cost of the well and is either

$$\frac{\text{life cycle cost}}{\text{total BTUs produced}} \quad \text{or} \quad \frac{\text{life cycle cost}}{\text{total mass of fluid}}$$

The model allows production from a well to be discounted, just as is cash flow. In a situation in which the geothermal fluid is sold, discounting may be more realistic than not recognizing the time value of well production.

Since the mathematics is not complicated, the necessary computations could easily be done by hand; but the computer model was built for data storage and manipulation and to facilitate the

multiple, repetitive calculations necessary for parametric analysis and comparison of alternative technologies. With only a geothermal area and the completion activities of interest specified, the model will run a "base case". Then by changing parameter values to reflect changes in cost, effectiveness, scheduling, etc., the code can be used to analyze modified or new technologies. This procedure is illustrated by the applications discussed in the next section. The code itself is documented elsewhere.[2]

APPLICATIONS

Although developed primarily as a tool for internal evaluation of proposed completion technologies, the GEOCOM model has been used to study applications of general interest. Several, selected to illustrate a variety of forms of analysis, are included here.

Example 1: Well Lifetime

The model parameter for well lifetime denotes the mechanical and operational life of the well. It does not reflect declining production of the w^ll during its mechanical lifetime. Figure 2 shows the effect of this parameter on the cost effectiveness of production wells at The Geysers area in California. The different curves show the ratio between the life-cycle cost of a production well and the total quantity of steam produced, as a function of well operational lifetime for different flow decline rates. Using Using the default values for all parameters except well lifetime results in the indicated baseline curve. Changing only the

decline rate gives the other curves.

For the rapid decline case illustrated, the reservoir pressure in the neighborhood of the well declines so rapidly that well production is half its original value in 60 months. The other production "half lives" are indicated. As would be expected, the curves are asymptotic to the cost axis--that is, as operational lives get shorter, the cost per unit of production increases without bound. Similarly, in the case in which well production does not decline, increased lifetime reduces the unit cost.

Conclusions. For the baseline case, the well cost per pound of production is quite sensitive to lifetime for lives shorter than ten years and is insensitive for lifetimes greater than fifteen years. In fact, the unit cost increases slightly for well lifetimes greater than fifteen years. This means that minimum cost wells are not necessarily the longest life wells. This is true because, though the production declines, the costs for maintaining the well continue. This same result also holds for other geothermal areas and for injection wells.

The differences among the decline rate curves also support this conclusion. The more rapid the production decline, the less benefit or greater penalty there is in longer lifetimes. For rapid declines the minimum cost point becomes more clearly defined and the optimal lifetime is shorter. For the baseline case the optimum is at 180 months, while for the rapid decline case, the optimum is at 132 months.

Example 2: Wellbore Descaling

The buildup of scale in production wells is a severe problem

in many geothermal areas. In the Imperial Valley of California, scale can build up so rapidly that wells must be worked over every few months. Several methods for prevention or removal of scale have been used, among them chemical inhibition of scale, mechanical drilling or reaming of scale and waterjet removal of scale. These three methods have been included in the model data base.

Figure 3 presents results from an analysis of descaling at the Heber, California, geothermal area. The three horizontal lines represent the costs associated with mechanical descaling for different scale buildup rates. Each mechanical descaling operation costs $27,600 (the costs summarized in Table 2 are adjusted for the different well depth and mobilization expenses at Heber), and so the model can be used to determine, for any scale buildup rate, a scale cleanout frequency that results in minimum cost. For a scale buildup rate equivalent to a 2% flow reduction per month, a 12-month cycle is optimal, for a 6.5% monthly reduction a 6-month workover frequency is best.

The curve in Figure 3 plots unit cost as a function of chemical cost for the chemical scale inhibition option and allows comparison with mechanical descaling. The well costs for scale inhibition assume that a chemical concentration of 30 ppm is required to inhibit scale buildup and that at this concentration the inhibition is 100% effective. The baseline value for chemical costs is $ .87 per pound. Though chemical cost is the independent variable in Figure 3, the effects of concentration changes can

also be seen. Reducing the required concentration would have the same effect as reducing the chemical cost. Well costs for the zero-chemical-cost case are not equal to those for the no-required-descaling case because of the initial cost of the injection tubing and the reduction in flow due to the tubing in the casing.

Conclusions. For the baseline case, chemical scale inhibition is more expensive than mechanical descaling. However, this conclusion could easily be changed by one or more of the following departures from the baseline:

a. More expensive mechanical descaling,

b. More rapid scale buildup necessitating more frequent mechanical descaling,

c. Cheaper chemicals, and

d. More effective chemicals.

Figure 3 shows the sensitivity of the conclusion to all of these factors.

Example 3: Injectivity

Injection wells are used in geothermal development to dispose of spent fluids, to avoid environmental problems and to recharge the reservoir. Such wells have been common in selected geothermal fields outside the U.S. and their behavior is an active area of research. A concern for injection wells is the possible decline, of their injectivity (ability to receive fluids) due to formation or reservoir effects. Figure 4 shows the effect of injectivity decline on unit well cost for two geothermal reservoirs. The figure is not intended to show the actual costs of injecting

fluids but gives a relative indicator, the life cycle costs of the injection wells divided by the total amount of fluid injected through them.

Results. Figure 4 illustrates that the injectivity decline rate has a significant effect on unit well cost. For example, in the baseline Baca case, changing from no decline to a decline of 1% per month can double the effective cost of the well. The effect on the East Mesa costs is similar, but not as great due to the larger baseline costs for East Mesa. The East Mesa costs are higher primarily because of higher pumping costs. For injection wells the pumping costs are one of the largest components of life-cycle well costs.

Example 4: Well Cost Sensitivity

The model has been used to study the cost impacts of changes in the values of most input parameters. Critical parameters in determining the cost effectiveness of a workover-free well include: initial well cost, initial production delay, initial well flow rate, and reservoir productivity decline rate. For illustration, the following line values representing the Baca location were selected for these: a well cost of $1.075 million; an initial delay of 36 months between well completion and first production of electricity; an initial flow rate of 2×10^5 pounds per hour; and a productivity decline rate of .3% per month. Figure 5 shows the sensitivity of the cost effectiveness to changes in these baseline parameter values. The curves are generated by varying the parameters one at a time.

Results. The cost effectiveness of the well varies linearly with

initial well cost and initial production delay and its variation with productivity decline is nearly linear. The production of the well varies linearly with the initial flow rate, and so the cost effectiveness, which is cost divided by production, varies inversely with the initial flow rate. Figure 5 indicates that of the initial well parameters, well cost effectiveness is most sensitive to initial cost and initial flow rate.

Example 5: Workover Effects

The effects of downstream activities such as workovers on well cost effectiveness were studied by adding a recurring dummy workover to the Baca case used for the sensitivity study. The workover cost $28,000, was performed every four months, required 1/3 of a month to carry out, and completely restored a well flow loss of 12.5% per month. (It is assumed that the workover cannot correct the reservoir productivity decline of .3% per month).

Results. Figure 6 shows the sensitivity of the cost effectiveness to changes in these parameter values. The unit well cost varies linearly with workover cost and workover delay and nonlinearly with flow loss and workover frequency. The figure shows that the time it takes to perform the workover is not critical. In fact, increasing it by a factor of 6 would increase the unit well cost by 30%, the same increase that would accompany a doubling of workover cost. The unit cost is more sensitivie to the flow loss parameter. This parameter does not affect well costs but is important in determining total production. Increases in flow loss decrease production and thus increase the unit well cost.

The dependence of cost effectiveness on workover frequency is complicated. If the workover is performed too frequently, there will be a significant increase in cost but little additional production because the well does not lose much flow between workovers. On the other hand, if the workover is too infrequent, a time will be reached at which there is little production but there are still continuing costs. So for either extreme, the cost effectiveness is worse and thus there will be minimum unit cost at an optimum workover frequency. Figure 6 shows this time to be slightly more than 4 months.

A comparison of Figures 5 and 6 illustrates that, for the relatively inexpensive workover selected, the initial cost and productivity are still the most important parameters; but that workover parameters, such as flow loss and workover cost, are nearly as important.

Example 6: Initial Completion Activities

Several possible completion alternatives arise when a well is initially drilled. The impacts they have on the cost effectiveness of a well are determined by their costs and their effects on initial well flow and subsequent production decline rates. The sensitivity of unit well cost to these parameters was illustrated in Figures 5 and 6 and was discussed above. Only the costs of alternative initial activities are considered here.

Perforating. In the past, geothermal wells have generally been completed openhole or with slotted liners; however, cemented and perforated casing completions have recently been used at the Heber

resource. To be cost effective, geothermal wells must have very high flow rates (200,000 to 500,000 lbs/hour). Thus, a large number of shots are required in order that productivity not be limited by flow resistance through the perforations. A typical perforating job might be a 1,000 foot production interval with 4 shots per foot. Cost of such a perforation job from 4,000 to 5,000 feet at a bottom-hole temperature of 500° would be about $332,000, which is roughly 43% of the cost of drilling a Heber well. The cost effectiveness of cementing and perforating involves the tradeoff between higher initial cost and higher initial productivity. Figure 5 illustrated this tradeoff.

Hydraulic Fracturing. Hydraulic fracturing is another situation in which larger initial cost is incurred to achieve greater production. Hydrofracture of geothermal wells has been done in Japan and in the U.S.A. at Raft River, Baca location, East Mesa, Fenton Hill, and The Geysers. Though frequently considered a technical success in terms of performance of fracture fluids at high temperature, in general the results have been sub-economic. A geothermal hydrofracture job can vary considerably in scope from a small job designed to correct for skin damage to a large job designed to create a massive fracture. Costs range from $250,000 to $1.25 million. Figure 5 indicates that an initial flow increase of from 25% to 150% might be required to justify this expense. The GEOCOM model could be used for a detailed analysis for a specific geothermal area.

Casing Schedule Changes. The cost impacts of two kinds of casing

schedule changes from the representative well models were analyzed. The first involved keeping the same bottom-hole diameter but using a long production string back to the surface rather than hanging a production liner. This casing change resulted in well cost increases of less than 4%. The second casing change involved increasing the bottom-hole diameter to accommodate larger production casings. Starting with a 7-inch production string and increasing to a 8-5/8 9-5/8 resulted in a well cost increase of 15% or 24%. As indicated by the sensitivity analysis, the effects of these changes on productivity or well lifetime would determine their cost effectiveness.

Example 7: Underreaming

Underreaming has been proposed as a method of improving the productivity of a geothermal well. This improvement could come through removing formation damage or skin effect or by increasing the sand-face radius of the well. Laboratory tests on geothermal cores have shown invasion distances of 8" with permeability damage ratios of 1/2.[5] This results in a 17% loss in productivity index in a 8-3/4-inch hole. Underreaming the hole to 15-inches with a perfect drilling fluid would result in a 27% improvement in productivity index. A cost estimate for underreaming an East Mesa geothermal well with present day technology is $384,000 or 53% of the original well cost. Figure 5 shows that a 53% increase in cost for a 27% improvement in production is not cost effective. Thus, underreaming with present day technology is not an attractive completion alternative.

SUMMARY

The GEOCOM computer model was developed as a tool to aid in directing the Geothermal Technology Development Program. The model, and the data collected to construct it, have provided interesting insight into the impacts of completion and workover activities on the cost effectiveness of geothermal wells. Some of the conclusions drawn from its use include:

1. Completion strategies for achieving long production lifetimes for wells are not necessary and, in fact, may not be valuable. The rate of productivity decline for flow of the geothermal fluids into the well from the formation determines, to a large extent, the importance of long life.

2. The most cost effective way to combat scale in a geothermal well may vary from resource area to resource area. The best choice depends primarily on the scale buildup rate and on the cost and effectiveness of mechanically removing scale from the well.

3. The effective cost of wells for reinjecting geothermal brines is quite sensitive to declines in injectivity. Formation damage, or other mechanisms that reduce injectivity, can greatly increase injection costs. A major component of the cost of an injection well is the required pumping cost.

In addition to being used to analyze specific completion situations, the model has been used to study the relative importance to well cost effectiveness, of various performance and cost parameters. The sensitivity of well cost per pound of production to changes in various parameters was investigated.

For relatively inexpensive or infrequent workovers, the unit well cost was most sensitive to initial well cost and initial fluid flow; but for cases, such as injection, in which the continuing activities are frequent or expensive, their effect dominates that of the initial parameters.

The model will continue to be used in the types of analyses described to aid evaluation of the potential impacts of proposed completion technologies.

ACKNOWLEDGEMENT

This work was performed under the auspices of U.S. Department of Energy Contract No. DE-AC04-76PK00789.

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TABLE 1. COMPLETION ACTIVITIES AND GEOTHERMAL AREAS MODELED

Activities	Geothermal Areas
Logging	Brawley
Perforating	Heber
Mechanical Descaling	Geysers
Hydrojet Descaling	Baca Location
Chemical Scale Inhibition	Roosevelt Hot Springs
Injection Pumps	East Mesa
Submersible Pumps	
Line Shaft Pumps	
Remedial Cementing	
Underreaming and Gravel Pack	
Slotted Liner Replacement	
Well Repair with a Liner	

Table 2. Sample Operations Sequence--Mechanical Descaling

	UNIT	RATE	COST	TOTAL COST
MOBILIZATION-DEMOBILIZATION				
Workover Rig	20 hrs	$105.00	$2,100.00	
Fuel Cost Adjustment	20 hrs	3.50	70.00	
Ten-Ton Winch Truck, Float & Driver	20 hrs	55.00	1,100.00	
Pickup, Crew Transport	20 hrs	75.00	1,500.00	
Subsistence/Man/Day (4 men)	2 days	45.00	360.00	
				$ 5,130.00
RIG UP AND RIG DOWN				
Workover Rig	12 hrs	$105.00	$1,260.00	
Fuel Adjustment	12 hrs	3.50	42.00	
Ten-Ton Winch Truck, Float & Driver	12 hrs	55.00	660.00	
Pickup, Crew Transport	1 day	75.00	75.00	
				$ 2,037.00
DESCALING				
Pick-up First Joint, Makeup BHA	.25 hrs	$105.00	$26.25	
Strip in Hole @500'/hr	7.50 hrs	105.00	788.00	
Wash & Ream Scale @150'/hr.	8.00 hrs	105.00	840.00	
P.O.O.H. Laying Down @500'	10.00 hrs	105.00	1,050.00	
Lay down BHA	.25 hrs	105.00	26.25	
Fuel Cost Adjustment	26.00 hrs	3.50	90.50	
				$ 2,821.00
SUPPLEMENTAL EQUIPMENT				
Drill Collars 4-4 3/4" OD	5.0 Days Min.		$ 100.00	
Power Swivel S-2.5	3.0 Days	$475.00	1,425.00	
Duplex Pump	3.0 Day Min.	375.00	1,125.00	
BOP 6", 3,000# DBL Hydraulic	5.0 Day Min.	40.00	200.00	
Hydraulic Stripper Head 3,000#	5.0 Day Min.	37.00	185.00	
100 bbl Circ. Tank	5.0 Day Min.	40.00	200.00	
Thread Dope per trip		22.00	22.00	
Bit (purchased)		520.00	520.00	
Casing Scraper (rental)	Per Run	300.00	300.00	
*Casing Scraper Drayage	650 Miles	.80	520.00	
5,000', 2 3/8", 6.65#, "E" Drill (Pipe Per Foot/Day)	4 Days	0.0725	1,450.00	
Round Trip Drayage - Drill Pipe & Collars	73,000#	5.25/cwt.	3,833.00	
Pipe Racks (2 sets)	4 Days	16.00	128.00	
Wet Pay (4 Men)	4 Days	12.00	192.00	
Subsistence (4 Men)	4 Days	45.00	720.00	
Permits, Replacement Elastomers	(Contingencies)		900.00	
				$11,820.00

*NOTE: If Brought With Rig Delete

Table 3. GEOCOM Parameters and Default Values

PARAMETER	VALUE	TYPE OF PARAMETER
INITIAL WELL FLOW	1	PRODUCTIVITY
RESERVOIR DECLINE RATE	1	PRODUCTIVITY
DISCOUNT FACTOR	0.00878/MO	FINANCIAL
INFLATION FACTOR	0.00695/MO	FINANCIAL
WELL LIFE	1	SCHEDULE
STUDY PERIOD	360.MO	SCHEDULE
WELL FLOW LOSS	0.125/MO	PRODUCTIVITY
INITIAL DELAY	0.0 MO	SCHEDULE
CAPITAL COSTS		CAPITAL COSTS
- WELL	1	
- OTHER	2	
WORKOVER		
- COSTS	2	CONTINUING COSTS
- FREQUENCY	2	SCHEDULE
- DURATION	2	SCHEDULE
- EFFECTIVENESS	2	PRODUCTIVITY
ROUTINE O&M		CONTINUING COSTS
- WELL	1	
- OTHER	2	
PER POUND PRODUCTION COSTS	2	CONTINUING COSTS
REPAIR	$121,000.	
- COST		CONTINUING COSTS
- TIME	999. MO	SCHEDULE
- DURATION	0.33 MO	SCHEDULE
- EFFECTIVENESS	40%	PRODUCTIVITY
ABANDONMENT COST	$18,000.	CONTINUING COST

1 RESOURCE DEPENDENT VALUE

2 CONFIGURATION AND USAGE DEPENDENT VALUE

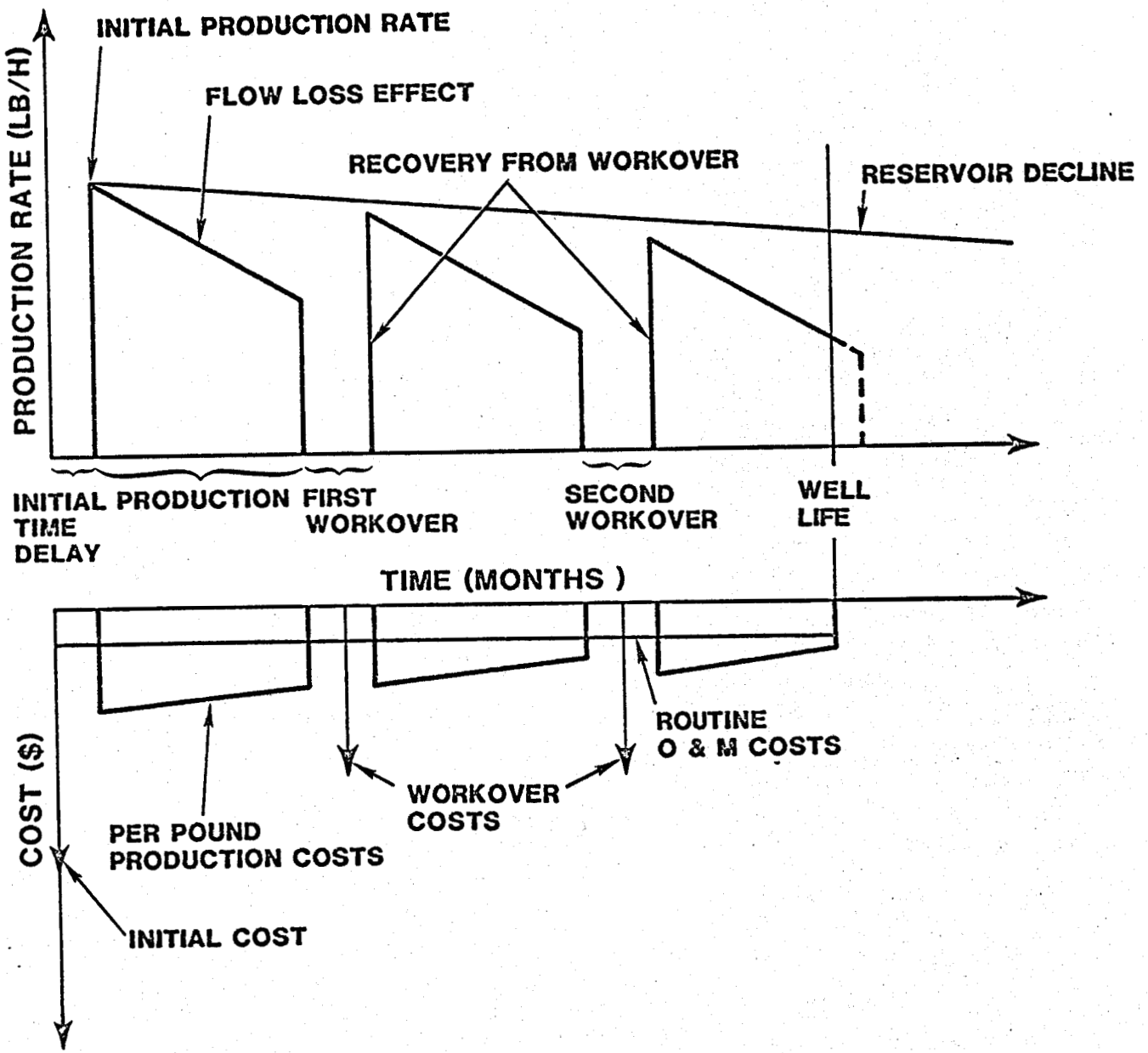

Figure 1. Schematic Representation of Production and Cost Sequences

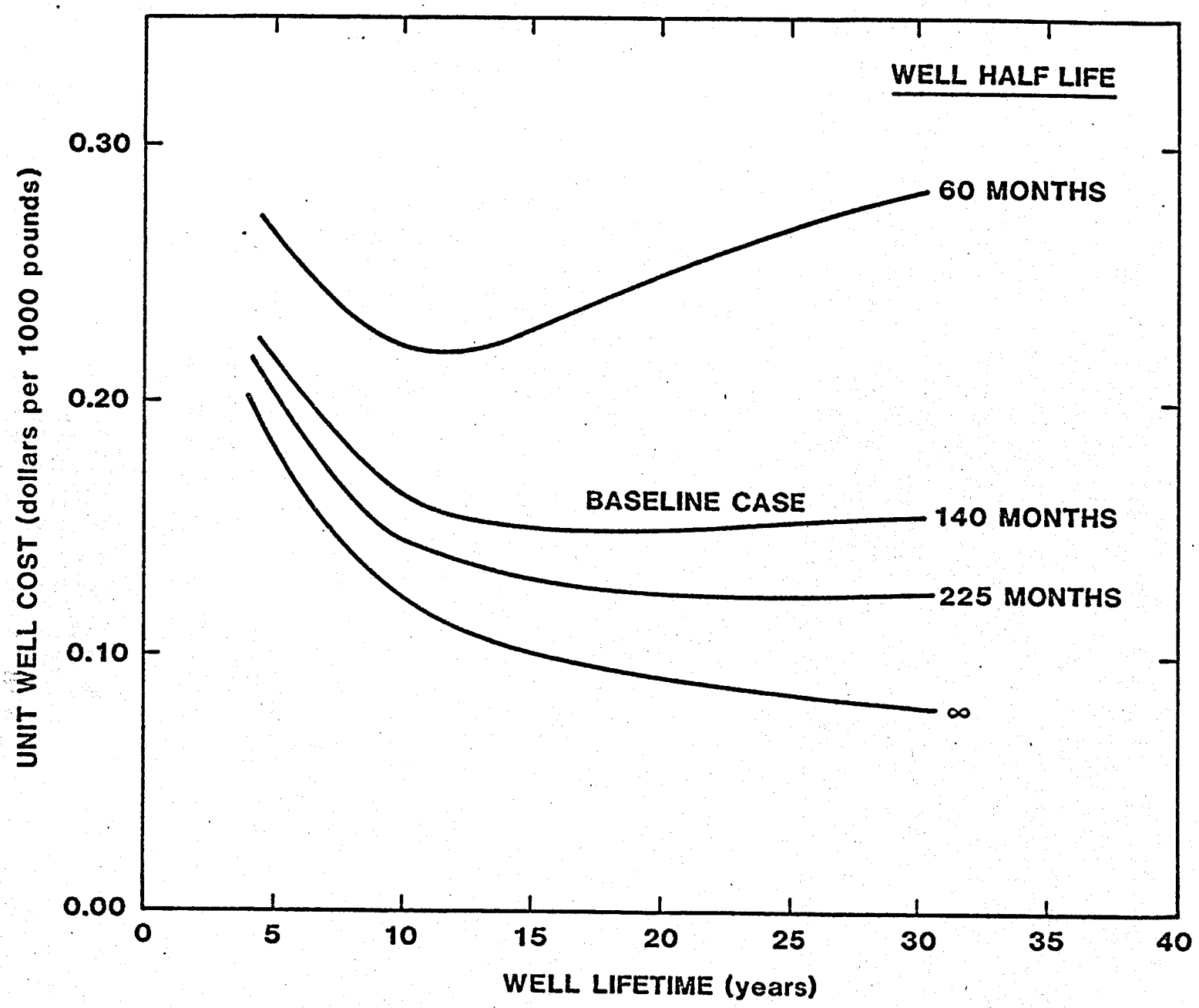

Figure 2. Unit Well Cost As A Function of Well Lifetime

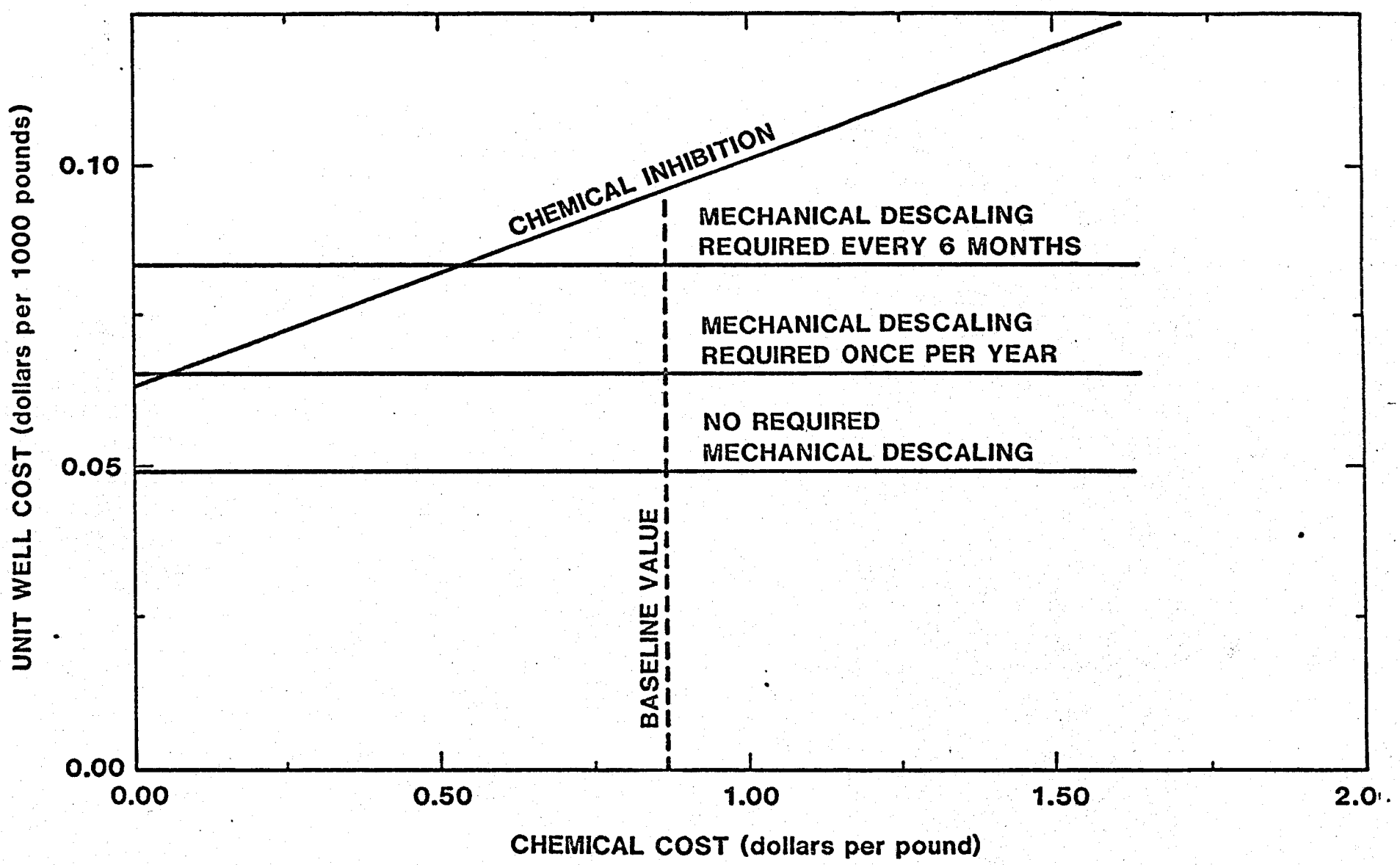

Figure 3. Cost Comparison of Mechanical Descaling and Chemical Scale Inhibition

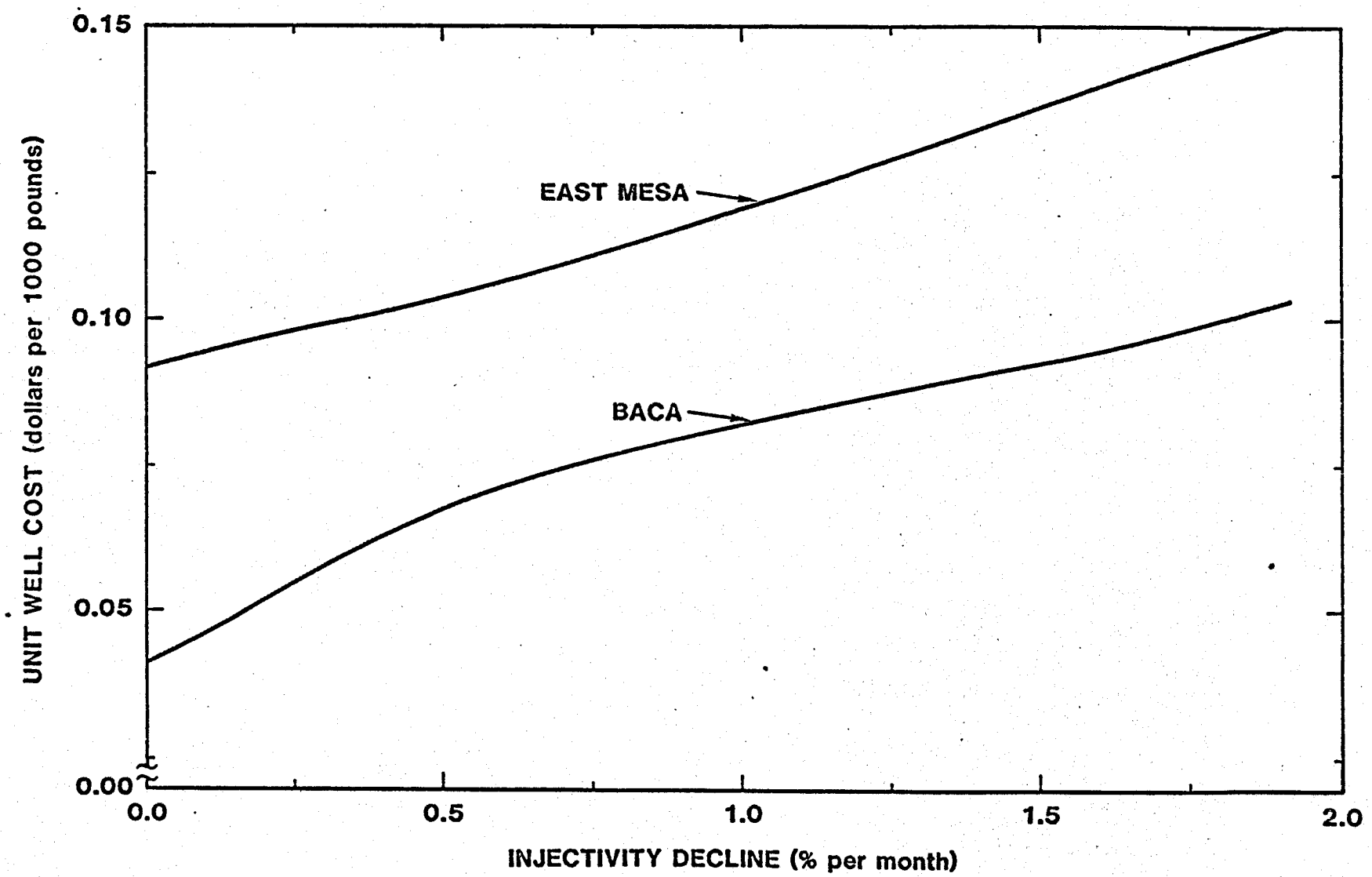

Figure 4. Unit Well Cost For Injection Wells

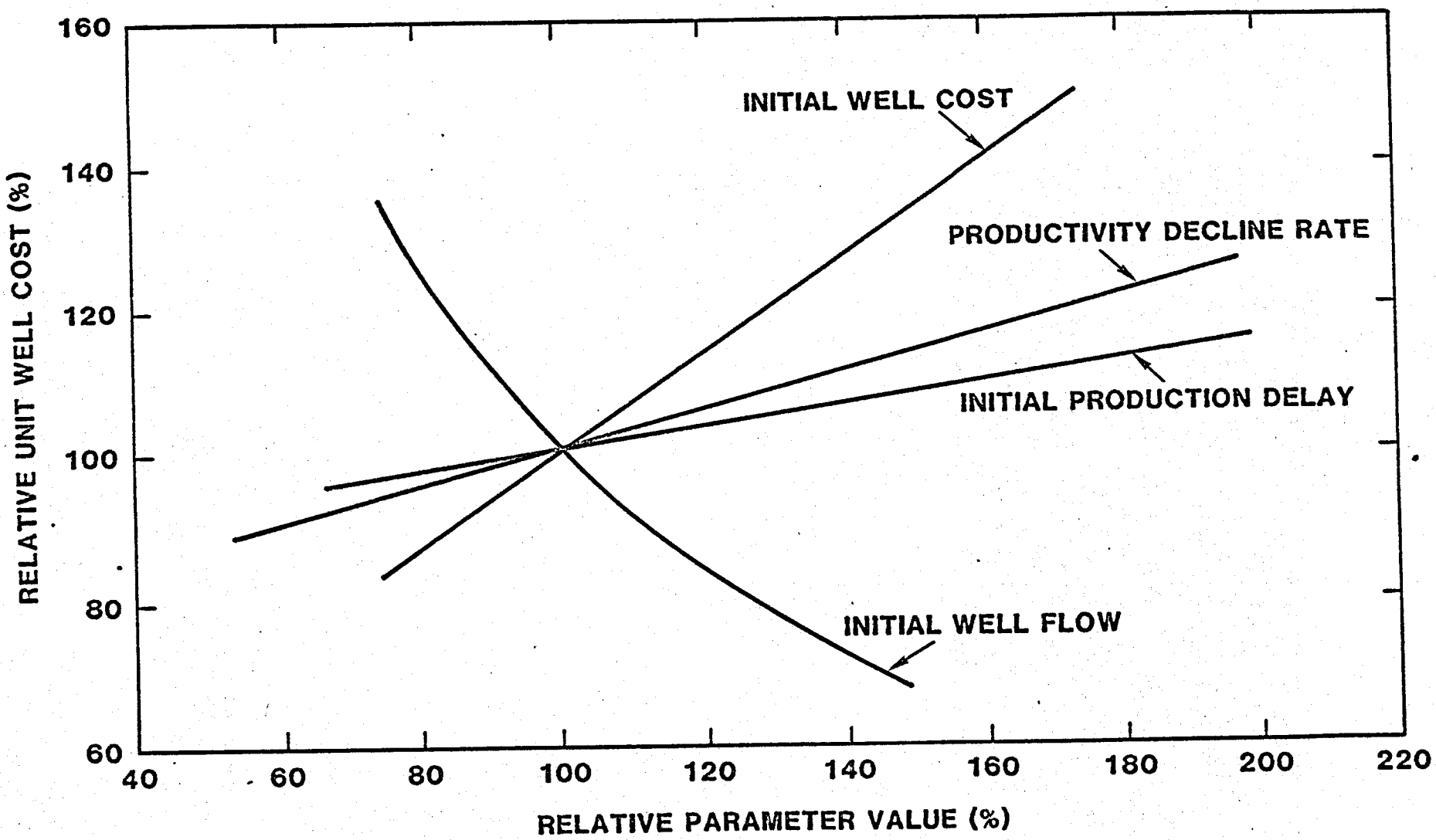

Figure 5. Sensitivity of Unit Well Costs To Initial Well Parameters

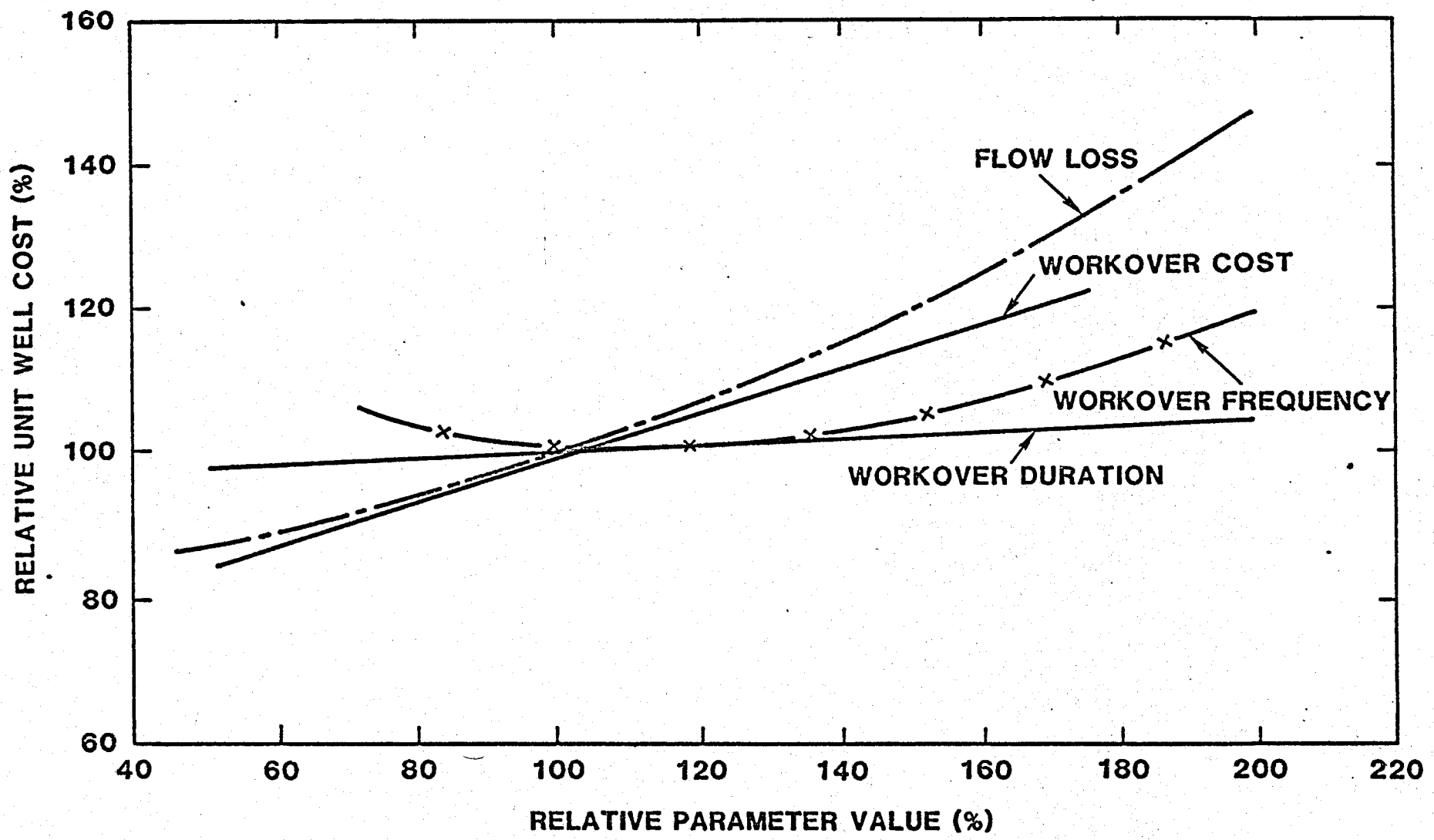

Figure 6. Sensitivity of Unit Well Costs To Workover Parameters