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A PROBABILISTIC APPROACH TO FIELD PROVING AND STATION SIZING

Malcolm Grant and Tony Mahon

Geothermal Energy NZ Ltd., PO Box 9717
Newmarket, Auckland, New Zealand

ABSTRACT

Conventional approaches to proving a geothermal reservoir, and supporting the ultimate commitment to its development, are oriented toward proving some level of reserves: this is then followed, if successful, by the construction and operation of a power station.

We consider that there is always some level of uncertainty in the knowledge of the resource, and calculate the optimal level of development in the light of the present state of knowledge. This development accepts that there is some degree of risk and balances the risk of station over-sizing, and consequent over expenditure on plant, against undersizing, construction of additional plant, and delay in gaining possible revenue.

INTRODUCTION

"Proving" a geothermal resource involves collection of geoscientific and reservoir data to infer the size of the resource and its ability to support discharge. Some level of reserves are considered proven when a reasonable support exists for a judgement that they are proven.

The actual recent experience in some fields - for example, The Geysers - shows that some reserves considered to be proven did not in fact exist.

Rather than redouble efforts to establish ever-stricter criteria of proof, we consider that the appropriate response is to accept that knowledge of the reservoir is always imperfect to some degree. As with any management decision, a judgement must be made with what is known.

We consider the consequences of accepting that there is uncertainty in the proven resource.

PROBABILITY OF FIELD SIZE

Consider a field at some stage of exploration. It is known to be of at least 10 km^2 in area, has high temperature and good permeability in 2-3 discovery wells which are over a kilometer apart. Estimates of its capacity are around 100MW, with a low of 50MW and a high of 150MW.

Let us represent this state of knowledge by a triangular probability distribution of field size:

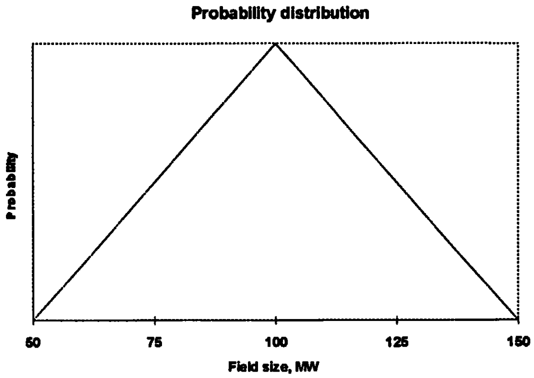

Figure 1. Triangular probability distribution of proven field capacity.

Given such knowledge of the resource, what size power station should be constructed? The proving approach would say that 50MW is the appropriate size, and if this is inadequate, continue field proving.

OPTIMISATION

It is a straightforward matter to optimise the station size, given field and station costs and steam or electricity price. Appendix 1 gives our cost and revenue assumptions. They are similar to other published costs, but of course any particular project will have site-specific considerations. The qualitative conclusions of this paper are not very sensitive to variations in these assumptions, although of course specific conclusions are site-specific.

Suppose that we choose to construct a station of size *S*, and that the actual size of the field is *M*. The future of the field is different depending on which is larger.

If $S<M$, then after 5 years of station operation this is apparent, and an additional unit or units are constructed of size S-M. These both operate until the field is depleted. We can compute the Net Present Value of this scenario. Let it be F_1.

If $S>M$, the station is somewhat oversized and runs down early. For simplicity we assume that it runs for 25 years at the actual field size, M, and then ceases generation. Let the NPV of this scenario be F_2.

Both NPVs depend on the actual field size M. The expectation value of the NPV is simply the integrated value over the distribution of field size:

$$E(NPV) = \int NPV(M)f(M)dM = \int_{50}^{S} F_2 f(M)dM + \int_{S}^{150} F_1 f(M)dM$$

Appendix 2 sketches the calculation. Figure 2 shows the NPV, and figure 3 the Internal Rate of Return, as functions of the initial station size S:

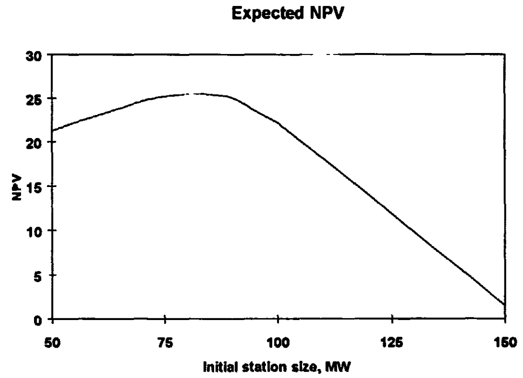

Figure 2. Expected Net Present Value of the project, in millions of dollars, , depending on the choice of initial station size.

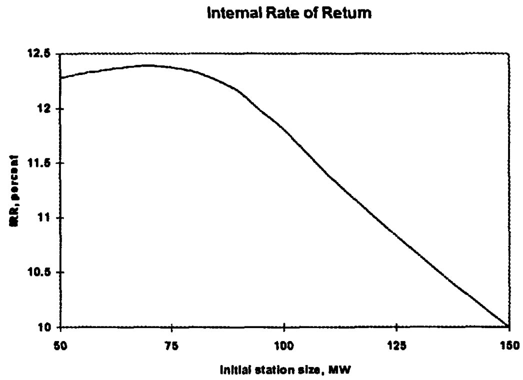

Figure 3. Internal Rate of Return depending on initial station size.

The NPV and IRR are optimised at a value somewhat above the proven minimum, the IRR at a somewhat lower value, and in fact neither vary greatly over a range toward the lower end of the probability distribution. The choice of the proven minimum is not the best, because with this choice there is almost certainly a loss of profit due to the delayed revenue from the additional plant. Further, the fact that the NPV and IRR do not vary greatly over a surprisingly wide range argues that it may not be worth excessive effort in refining the resource estimate, as opposed to proceeding and getting some revenue. Additional exploration effort would cost the developer a delay in station construction and generation. The delay in earning revenue is probably much more important than the cost of additional exploration work.

Similar conclusions were reached by Girelli et al (1995), based solely on the economics of construction and development but without any consideration of uncertainty in resource size. Likewise Danar (1993) argues for modular development. Consideration of the uncertainty in field size strengthens further the argument for modular development, with rapid installation of the first unit in a field.

The specific cost assumptions of the example financially demanding: the power price is marginal. Different cost produce different specific results but the same qualitative behavior. Instead of NPV it is possible to use the cost of power or the internal rate of return as the objective function. This again produces changes in specific results but not qualitative changes.

CONCLUSIONS

We conclude that field proving should be regarded as an exercise in judgement with imperfect knowledge. Station size should be set at a value that balances the risks of undersizing and oversizing, in the light of the present state of knowledge.

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APPENDIX 1

We take the following costs, in US$:

Exploration costs	$10m
Wells, inclusive of failures and reinjection	$1.5m
Separation and pipework, per well	$0.7m
Plant and substation, per MW	$1.2m
Operation and maintenance,	3%pa
Well productivity	5MW
Power price	4.5c/kWh
Discount rate:	10%
Plant availability	90%

These are similar to the assumptions of Girelli et al (1995) and Liguori (1995), and also to Sanyal et al. (1989) for well costs.

APPENDIX 2

The costs of exploration C_0 are incurred in year 1. Steamfield development takes place in years 2-5, and costs a total of C_1 per station MW for each of these years. This is assumed to cover the costs of drilling wells - production, injection, failures and makeup wells - plus the costs of pipelines and pumps. The power station costs C_2 per MW and this happens in year 6.

Revenue, net of O&M, starts in year 7, and is R_1 per MW-yr.

If the station size exceeds the actual capacity ($S > M$), then the station is assumed to produce at capacity M for 25 years. If the station size is smaller than capacity, this is known after 5 years operation and an additional station of size M-S is constructed in year 12, and both stations run until year $L_1 = 32 - S/5M$ depleting the reservoir, with allowance for the five years of operation of the first station.

If $S>M$: $F_2 = -C_0 - S\sum_{2}^{5} C_1(1-I)^n - SC_2(1-I)^6 + S\sum_{7}^{32} R_1(1-I)^n$

which is the sum of the costs of exploration, the costs of field development, the cost of station construction, and the revenue from power generation.

If $S<M$ we have the revenue from the first station:

$NPV_1 = -C_0 - S\sum_{2}^{5} C_1(1-I)^n - SC_2(1-I)^6 + S\sum_{7}^{L_1} R_1(1-I)^n$

plus the revenue from the addition, of size $S_1 = M-S$:

$NPV_2 = - S_1\sum_{9}^{12} C_1(1-I)^n - S_1C_2(1-I)^{12} + S_1\sum_{13}^{L_1} R_1(1-I)^n$

$F_1 = NPV_1 + NPV_2$