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Risk and Risk Management in Geothermal Exploration and Development

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ABSTRACT

Risks encountered during geothermal exploration and development are identified and assessed and a generic geothermal risk model is described which is based on:

- a detailed appreciation of generic risks
- a formal methodology for undertaking geothermal exploration and development in a staged manner with considered decision making at key program points and with each new stage of work being undertaken only if and when the preceding stage proves to be successful.
- the use of assessed success probabilities for each stage in the geothermal exploration and development process based on an extensive review of geothermal developments around the world for a variety of geological terrains
- the use of a comprehensive database for geothermal exploration and development costs

To illustrate the use of the risk model, the risk profile of a proposed 64 MWe geothermal development in an East African Continental rift setting is described and assessed.

Introduction

Standard risk studies usually follow the following format and this is an appropriate framework within which to assess geothermal risks:

- establish the context within which risks needs to be assessed
- identify risks
- analyse risks qualitatively
- analyse risks in a quantitative manner, usually with the use of probabilistic risk models
- evaluate risks
- treat risks

Context of Geothermal Risk

The world-wide geothermal industry is long established with a history of a nearly 100 years use and there is now some 9000 MWe of geothermal power generation in operation. Much of this capacity was installed in the nineteen eighties for which there is now 20 years of operational history. This suggests that the overall risk profile of the geothermal industry is quite low.

In most countries, initial geothermal exploration studies, exploration drilling and resource proving has been traditionally undertaken by government agencies. In contrast there is strong interest today in the private sector taking over this role and most governments provide incentives (principally tax and reduced royally payments) to attract private sector participation. In spite of this, there has been little uptake by the private sector of the front-end exploration component of geothermal projects because of perceived high exploration risks. In contrast, there has been a strong involvement by the private sector in geothermal developments in countries where government has drilled at least a number of exploration wells and proved resource temperatures, fluid chemistries and steam output, thus significantly reducing development risk.

From this, it is clear that the private sector has little appetite for geothermal exploration and proving risk, given the relatively low financial returns from geothermal projects. It then appears that the necessary ingredients for ensuring that greenfield geothermal exploration and developments can be sustained are:

- rates of returns for geothermal projects be increased to levels acceptable by the private sector for the use of risk capital, or
- Governments need to remain in the business of geothermal resource proving and risk reduction to then then later transfer geothermal projects on to the private sector for commercial development.

Risk Terms

In order to discuss and assess geothermal risk, it is necessary to understand a number of key risk terms:

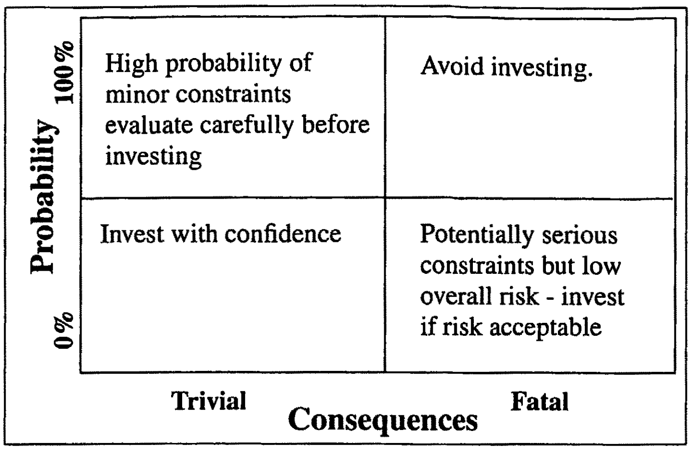

Figure 1. Risk Matrix Diagram.

"*Constraint*" - something which hinders a development or reduces its economic return. A constraint which is sufficiently severe to prevent a project from proceeding is termed a "fatal flaw".

"*Risk*" - the probability that a constraint will occur. In qualitative risk assessment, the probability of constraint is referred to in subjective terms such as high or low; in quantitative risk assessment, the probability of a constraint occurring is refereed to as percentage likelihood.

"*Consequence*" - the effects of a constraint. In risk analysis, a very useful means for assessing risk and probability is a risk matrix diagram in which risk probability is compared with consequence (see Figure 1). Constraints with low probability and low consequence are regarded favourably and those with high probability and high consequence are viewed as unfavourable to the point of probably constituting fatal flaws.

Geothermal Risks

Geothermal industry risks before and after development are quite different. Before development the risks are principally on the size, quality and certainty of the fuel supply (steam), whereas after development the main risk is in maintaining fuel supply for the life of the plant.

Pre Development Risks

- temperatures (and enthalpy)
- permeability
- resource size
- acidity of both deep magmatic origin and shallow near surface origin
- volcanic eruption
- seismicity
- initial gas content

Post Development Risks

- reservoir changes associated with mass extraction and pressure drawdown including cool influx, loss of surface thermal features and subsidence
- scaling in the formation and surface facilities
- reinjection returns
- changing gas content

Fatal flaws in geothermal development are mostly limited to resources with low temperature, poor permeability and acid magmatic fluids. If present these flaws should become apparent during the exploration program (up to and including exploration and delineation drilling) but before development drilling commences. The post development risks are usually non-fatal being more probable in occurrence but of manageable consequence due to application of appropriate scientific and/ or engineering interventions.

An example of a qualitative risk assessment of a geothermal exploration project using the risk matrix diagram is shown in Figure 2. As well as showing probability and consequence of possible risks, the diagram also attempts to show the magnitude of the risks based on the size portrayed for each risk and the extent to which the risk can or cannot be quantified.

Staged Exploration and Development Methodology

In geothermal risk analysis it is essential, to identify resource related risks as early as possible in the exploration and develop-

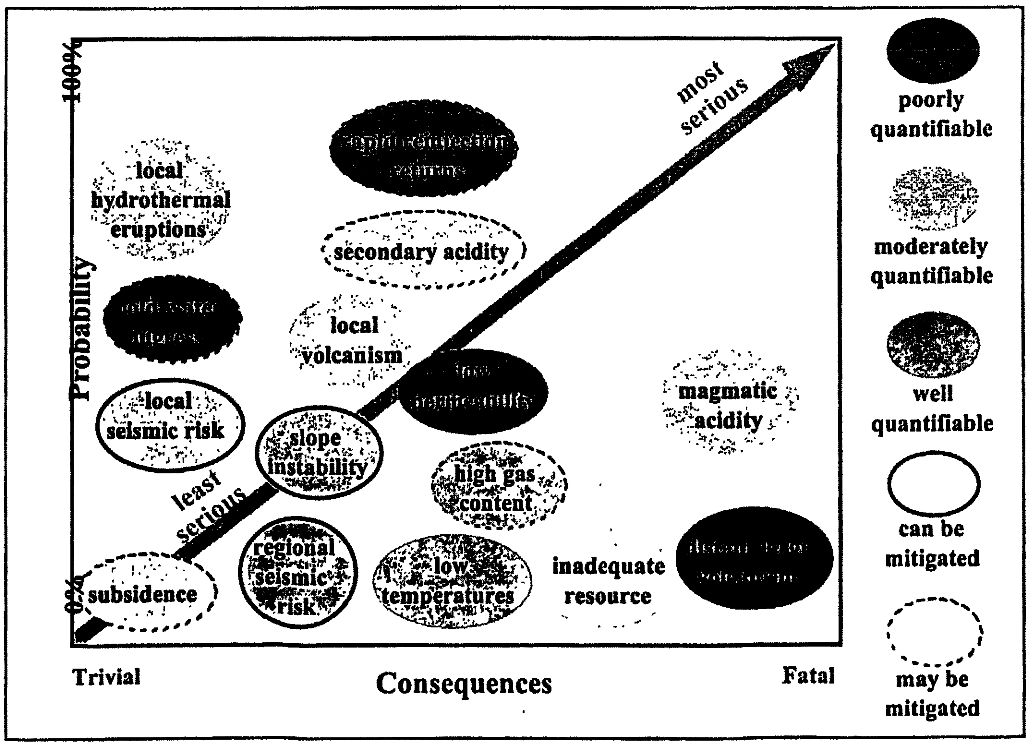

Figure 2. Qualitative Assessment of Geothermal Risks.

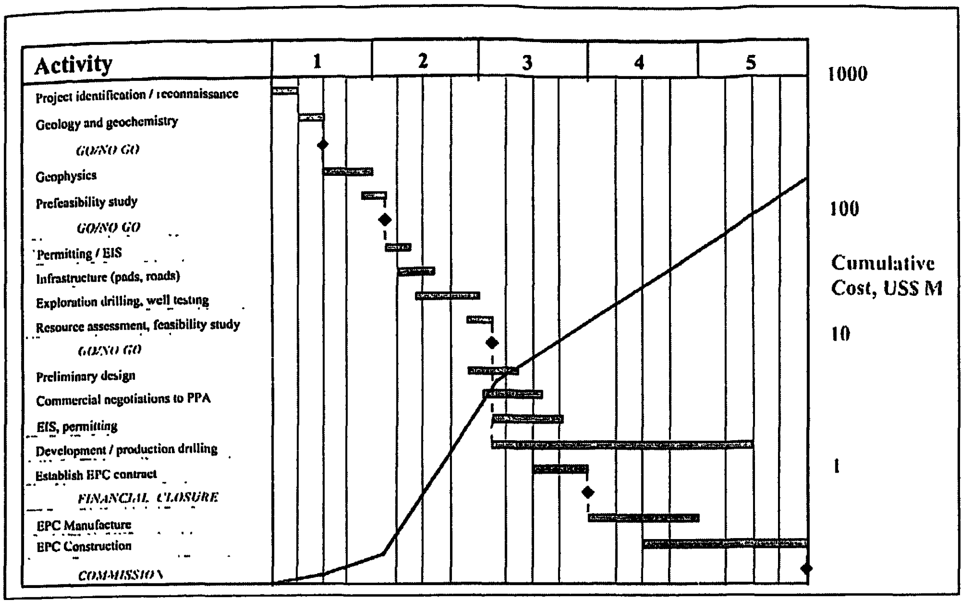

Figure 3. Staged Geothermal Exploration and Development Methodology.

ment program, especially for possible fatal constraints. This requires that early qualitative and/or semi quantitative analysis be undertaken to assess if there are fatal flaws and to then use this information to drive a decision whether to abandon or to proceed with the project.

It is most desirable to adopt a similar approach throughout the exploration and development program in the form of a staged evaluation procedure in which each new stage of work is undertaken only as and when each preceding stage proves to be successful. The procedure is detailed in Figure 3 and includes:

- a total of 11 work stages, from desktop review through to power plant construction and commissioning
- considered decision making exercised throughout each stage with expert review and assessment at the conclusion of a number of critical GO / NO-GO.decision points

The procedure provides a most effective means for controlling and reducing geothermal exploration and development risk and provides increasing confidence with time for a successful project outcome.

Quantitative Risk Assessment

SKM has developed a geothermal Risk Model based on the foregoing concepts, in particular:

- a staged methodology for geothermal exploration and development
- success probabilities at each project stage, initially assigned from the results of a world wide review of geothermal data
- a detailed knowledge of geothermal industry costs

In a world-wide review of geothermal data recently undertaken by SKM, 94 geothermal power developments at 89 geothermal fields were assessed for the following key exploration and development indicators:

- geological and tectonic environments
- temperature
- field size
- energy extraction rates (in MWe /km^2)

The key indicators were assessed for each of 9 geo-tectonic environments and probability distribution functions established for each indicator. These were incorporated in a probabilistic risk model based on Excel with calls to the @Risk software package for Monte Carlo simulations based on the defined probability distribution functions.

The risk model is structured with inputs based on the 11 project stages referred to above and the following output data is presented:

- probability of achieving a successful project outcome at any project stage
- the likely number of wells and costs required at each stage to achieve a stated development target size (in MWe)
- estimated time to undertake each project stage
- actual costs to any stage and likely costs to complete the project

Example Risk Model Results

Data from a geothermal prospect area in East Africa located in a Continental Rift geo-tectonic environment have been analysed using the model. Three exploration wells have been drilled at this prospect and a program of six delineation wells is now proposed.

An analysis of the risks and potential costs involved are shown in Figures 4 to 6 (5 and 6 overleaf). Important conclusions from these figures include the following:

- exploration and development risk progressively reduces as each project stage is successfully completed.

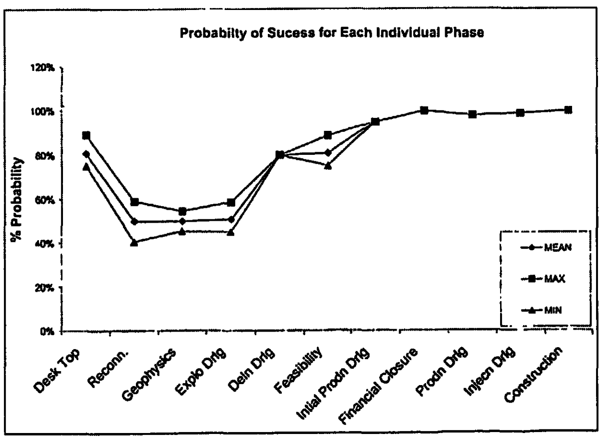

Figure 4. Probability of Success for Each Project Phase.

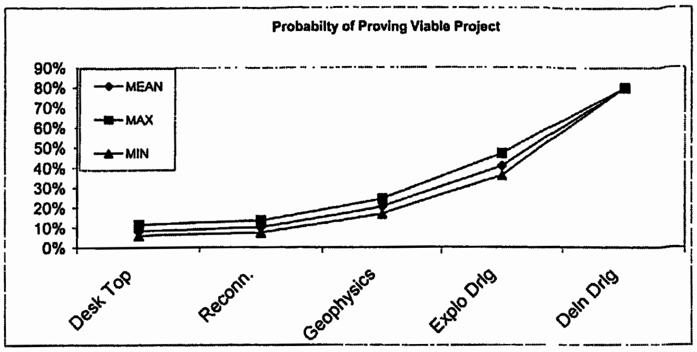

Figure 5. Cumulative Probability of Proving a Viable Project.

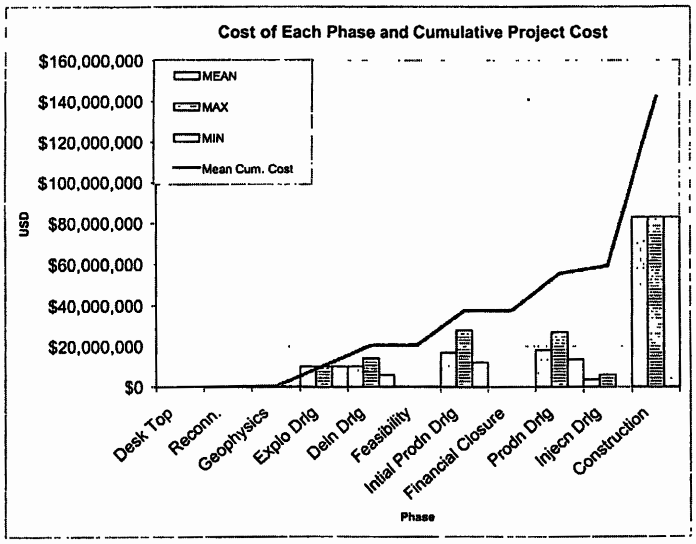

Figure 6. Likely Cost for Each Project Phase.

- at the completion of field surface studies the probability of a successful project is quite low (at 20%).
- the probability of project success then doubles with the completion of exploration drilling (40%) and doubles again after completion of delineation drilling (80%)
- it is probably only after completion of the delineation well drilling program that the level of project risk has dropped to a level (with an 80% success probability) that would be acceptable to the private sector for taking up a project for development.

Conclusions

Geothermal resource risks cannot be eliminated but their impact can be minimised by a combination of qualitative and quantitative risk assessment.

Risks that most frequently pose fatal constraints on geothermal projects are limited to:

- low temperature
- poor permeability
- pervasive acid magmatic fluids

Other project technical risks can generally be mitigated or are of sufficiently low probability that in spite of potentially serious consequences they don't pose fatal flaws e.g. volcanic eruptions.

The concept of staged development is very important in reducing risk and this ensures that constant review and appraisal of incoming data is undertaken and that key GO-NO GO decisions are undertaken in a timely manner and considered manner.

Quantitative risk assessment using probability modelling methods provides a very useful tool for examining:

- key areas of exploration and development risk
- cost of reducing risk
- commercial issues such as when the risk profile of an exploration project might become acceptable to the risk adverse private sector