Presented at Short Course on Geothermal Development in Central America – Resource Assessment and Environmental Management, organized by UNU-GTP and LaGeo, in San Salvador, El Salvador, 25 November – 1 December, 2007.

UNITED NATIONS
UNIVERSITY
GEOTHERMAL TRAINING PROGRAMME

LaGeo
LaGeo S.A. de C.V.

COMPUTER PROGRAMME FOR RESOURCE ASSESSMENT AND RISK EVALUATION USING MONTE CARLO SIMULATION

Zosimo F. Sarmiento[1] and Benedikt Steingrímsson[2]
[1]FEDCO- Filtech Energy Drilling Corporation
Muntinlupa City
PHILIPPINES
sarmiento@fedcophil.com
[2]ISOR- Iceland Geosurvey
Grensásvegur 9
108 Reykjavik
ICELAND
bs@isor.is

ABSTRACT

Calculation of the geothermal energy reserves based on the range of values of the various reservoir parameters can be carried out using Monte Carlo simulation. It applies a probabilistic method of evaluating reserves or resources that captures uncertainty. Given the complexity and heterogeneity of the geological formations of most geothermal reservoirs, this method is preferred as opposed to the usual deterministic approach which assumes a single value for each parameter to represent the whole reservoir. Instead of assigning a "fixed" value to a reservoir parameter, numbers within the range of the distribution model are randomly selected and drawn for each cycle of calculation over a thousand iterations. A Monte Carlo simulation handles this complex scenario, which allows extraction of each uncertain variable. The results are then analyzed in terms of the probability of occurrence of the reserves and/or equivalent power output in the range of values over the resulting population. The probability distribution function (pdf) quantifies the upside potential and downward risk in sizing up the field power potential, and gives indication on the probable range of proven, probable and possible reserves.

1. INTRODUCTION

Monte Carlo simulation is a numerical modelling technique, named after the city of Monte Carlo in Monaco, where the primary attractions are casinos that play games of chance like roulette wheels, slot machines, dice, cards and others. It is a technique that uses a random number generator to produce and extract an uncertain variable within a distribution model for calculation in a given formula or correlation. Monte Carlo simulation became popular with the advent and power of computers; because the simulations are too tedious to do repeatedly.

The random behaviour in a game of chance is how Monte Carlo selects the occurrence of an unknown variable in one calculation. The calculation is repeated over and over again until the specified iteration cycle is completed. In playing dice, 1, 2, 3, 4, 5 or 6 are possible outcomes, but we don't know which outcome is the result of each roll. The same is true for the various parameters used in calculating the geothermal reserves (e.g. area, thickness, porosity, reservoir temperature, recovery factors). They all vary within a certain range of values that is uncertain for a particular sequence in the calculation. To produce the desired results, unknown variables for each reservoir property are fitted into a chosen model distribution (e.g. normal, triangular, uniform and log normal) based on predetermined conditions or criteria of the area being evaluated. The simulation then proceeds by extracting numbers representing the unknown variable and using these as input into the cells in the spreadsheet until the process is completed.

2. THERMAL ENERGY CALCULATION

The volumetric method refers to the calculation of thermal energy in- the rock and the fluid which could be extracted based on specified reservoir volume, reservoir temperature, and reference or final temperature. This method is patterned from the work applied by the USGS to the Assessment of Geothermal Resources of the United States (Muffler, 1978). In their work, the final or reference temperature is based on the ambient temperature, following the exhaust pressures of the turbines. Many, however, choose a reference temperature equivalent to the minimum or abandonment temperature of the geothermal fluids for the intended utilization of the geothermal reservoir. For space heating the abandonment temperature is typically 30-40°C but for electricity generation the reference temperature is usually ca. 180°C for conventional power plants but as low as 130°C for binary plants.

The equation used in calculating the thermal energy for a liquid dominated reservoir is as follows:

$$Q_T = Q_r + Q_w \qquad \textit{Equation (1)}$$

, where:

$$Q_r = A \cdot h \cdot [\rho_r \cdot C_r \cdot (1 - \emptyset) \cdot (T_i - T_f)] \qquad \textit{Equation (2)}$$

$$Q_w = A \cdot h \cdot [\rho_w \cdot C_w \cdot \emptyset \cdot (T_i - T_f)] \qquad \textit{Equation (3)}$$

The question to be raised is: What if the reservoir has a two-phase zone existing at the top of the liquid zone? Theoretically, it is prudent to calculate the heat component of both the liquid and the two-phase or steam dominated zone of the reservoir. However, a comparison made by Sanyal and Sarmiento (2007) indicates that if merely water were to be produced from the reservoir, only 3.9 percent is contained in the fluids; whereas, if merely steam were to be produced from the reservoir, only 9.6 percent is contained in the fluids. If both water and steam were produced from the reservoir, the heat content in the fluids is somewhere between 3.9 and 9.6 percent. Conclusively, all the fluids are in the rock and it doesn't matter whether one distinguishes the stored heat in water and steam independently.

This approach is illustrated by the following set of equations to separately account for the liquid and steam components in the reservoir:

$$Q_T = Q_r + Q_s + Q_w \qquad \textit{Equation (4)}$$

, where:

$$Q_r = A \cdot h \cdot [\rho_r \cdot C_r \cdot (1 - \emptyset) \cdot (T_i - T_f)] \qquad \textit{Equation (2)}$$

$$Q_s = A \cdot h \cdot [\rho_{si} \cdot \emptyset \cdot (1 - S_w) \cdot (H_{si} - H_{li})] \qquad \textit{Equation (5)}$$

$$Q_w = A \cdot h \cdot [\rho_{li} \cdot \emptyset \cdot S_w \cdot (H_{li} - H_{li})]$$ *Equation (6)*

, and the following parameters as follows:

Q_T=*total thermal energy, kJ/kg*
Q_r= *heat in rock, kJ/kg*
Q_s= *heat in steam, kJ/kg*
Q_w = *heat in water, kJ/kg*
A= *area of the reservoir,* m^2
h= *average thickness of the reservoir, m*
$C_{r=}$ *specific heat of rock at reservoir condition, kJ/kgK*
$C_{l\,=}$ *specific heat of liquid at reservoir condition, kJ/kgK*
C_s *specific heat of steam at reservoir condition, kJ/kgK*

ø= *porosity*

$Ti_{=}$ *average temperature of the reservoir, °C*
Tc= final or abandonment temperature, °C
S_w = *water saturation*
ρ_{si} = *steam density,* kg/m^3
ρ_w = *water initial density,* kg/m^3
H_{li}= *initial water enthalpy, kJ.kg*
H_{li} = *final water enthalpy, kJ/kg*

3. POWER PLANT SIZING

The above calculations only provide for the total thermal energy in place in the reservoir. To size the power plant that could be supported by the resource, the following equation is further introduced.

$$P = \frac{(Q_t \cdot R_f \cdot C_e)}{P_f \cdot t}$$ *Equation (7)*

, *where:*

P = *power potential, MWe*
R_f = *recovery factor*
C_e = *conversion efficiency*
P_f = *plant factor*
t = *time in years (economic life)*

3.1 Recovery factor

Recovery factor refers to the fraction of the stored heat in the reservoir that could be extracted to the surface. It is dependent on the fraction of the reservoir that is considered permeable and on the efficiency by which heat could be swept from these permeable channels.

3.2 Conversion efficiency

The conversion efficiency takes into account the conversion of the recoverable thermal energy into electricity.

3.3 economic life

The economic life of the project is the period it takes the whole investment to be recovered within its target internal rate of return. This is usually 25-30 years.

3.4 plant factor

The plant factor refers to the plant availability throughout the year taking into consideration the period when the plant is scheduled for maintenance, or whether the plant is operated as a base-load or peaking plant. The good performance of many geothermal plants around the world places the availability factor to be from 90-97 %.

4. GUIDELINES FOR THE DETERMINATION OF RESERVOIR PARAMETERS

Recent developments in the geothermal industry require the establishment of guidelines on how reserves estimation is to be approached and reported in corporate annual reporting or financial statements. Sanyal and Sarmiento (2005) had proposed three categories for booking of reserves: proven, probable and possible; which are more appropriately estimated by volumetric methods. The reserves could be expressed in kW-h and/or barrels of fuel oil equivalent (BFOE). Conversion into MW unit should only be done when sizing up a power station for a period of time. Recently, Clothworthy et al. (2006) proposed to develop an agreed methodology for defining the reserves in order to increase market confidence in the industry and deter developers and consultants from quoting any figures they choose. The same categories of reserves are indicated except that the word inferred was used instead of the possible reserves. Lawless (2007) is similarly proposing guidelines on methodologies and other consideration when preparing reserves estimation in response to the requirement of investment companies, especially, those listed in the stock exchanges.

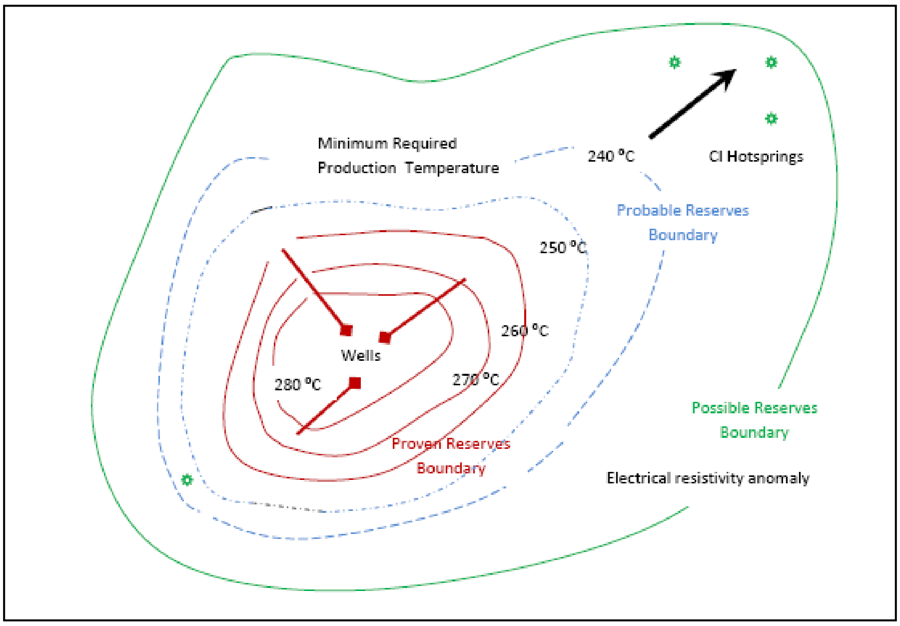


FIGURE 1: Illustration of the boundaries used in differentiating the three categories of reserves.

4.1 Definitions

The need for an industry standard is now imminent following the above developments, to create consistency in declaring the estimated reserves for a given project. Sanyal and Sarmiento (2005) uses the result of Monte Carlo simulation to determine the proven, probable and possible or inferred reserves based on the resulting percentiles obtained from the cumulative frequency or the probability density function. The percentile value indicates the value of probability that the quantities of reserves to be recovered will actually equal or exceed. The above and all other definitions in this paper conform with SPE (2001), where the ***proven*** reserves will have a P90 (90 percentile) probability, P50 for the ***proven*** + ***probable*** reserves and P10 for the ***proven*** + ***probable*** + ***possible*** reserves. The histogram of geothermal reserves calculated by Monte Carlo simulation is often highly skewed; hence, the ***proven + probable*** is better represented by the ***most likely*** or the ***mode*** instead of the P50.

4.2 Resource

Resource is the energy which can be extracted economically and legally at some specified time in the future (less than a hundred years).

4.3 Reserves

Reserves are defined as quantities of thermal energy that are anticipated to be recovered from known reservoirs from a given date forward. A reserve is the part of the resources, which can be extracted economically and legally at present and that is known and characterized by drilling or by geochemical, geophysical and geological evidence (Muffler and Cataldi, 1978; *Dickson and Fanelli,* 2002).

4.4 Proven

Proven reserves are quantities of heat that can be estimated with reasonable certainty based on geoscientific and engineering data to be commercially recoverable from the present to the future, from known reservoirs under current economic conditions and operating methods and government regulation. The definition by Clotworthy et al (2006) and Lawless (2007) give more specific descriptions, stating that a proven reserve is the portion of the resource sampled by wells that demonstrate reservoir conditions and substantial deliverability of fluids from the reservoir.

4.5 Probable

Probable reserves are unproven reserves which are most likely recoverable, but are less reliably defined than the proven reserves but with sufficient indicators of reservoir temperatures from nearby wells or from geothermometers on natural surface discharges to characterize resource temperature and chemistry.

4.6 Possible

Possible reserves have slighter chance of recovery than the probable reserves but have sound basis from surface exploration, such as springs, fumaroles, resistivity anomalies, etc., to declare that a reservoir may exist. Clotworthy et al. (2006) adopted the *inferred* resources from what could cover possible reserves based on McKelvey box as adopted by SPE (2001). Based on their graphic illustration, the probable reserve encompasses what could be categorized as only possible reserves in the Philippines (Figure 1). From ***probable*** to ***possible*** there is an increasing geoscientific and economic uncertainty whereas ***inferred*** connotes further geoscientific uncertainty only.

The following guidelines or set of criteria are followed in the resource assessment and reserves estimation in the Philippines.

TABLE 1: Guidelines followed in determining the various parameters for reserves estimation

Parameter	*Proven*	*Probable*	*Possible/Inferred*
Area	*Defined by drilled wells with at least 500 meters beyond the drainage of the outermost wells bounded by an extrapolated production temperature of 240°C. Enclosed by good permeability and demonstrated commercial production from wells. Acidic blocks excluded until demonstrability for utilization is achieved.*	*Defined by wells with temperature contours that would extrapolate to 240°C to the edge of the field. Acidic or reinjection blocks earlier delineated could be included. Areas currently inaccessible because of limited rig capacity and restriction imposed within the boundaries of national parks.* *Areas with wells which could be enhanced by stimulation like acidizing and hydro-fracturing, by work-over of wells, other treatments or procedures which have been proven to be successful in the future.* *Areas with extensive surface manifestations where geothermometers indicate consistent or constant? temperatures >250°C.*	*Areas include those not yet drilled but enclosed by geophysical measurements like Schlumberger electrical resistivity and magneto-telluric surveys. Defined by areas with thermal surface manifestations, outflow zones, high postulated temperatures based on geothermometers*
Thickness	*Depth between the 180°C and the maximum drillable depth of the rig that has demonstrated commercial production. Maximum depth should have at least 240°C to warrant commercial output of the well.*	*Defined by demonstrated productivity in nearby areas or adjacent wells. Depth beyond the deepest well drilled in the area +500 meters provided projected temperatures reached at least 240°C at the bottom*	*Defined by demonstrated productivity in nearby areas or adjacent wells*
Reservoir Temperature	*Taken from direct measurement in production wells, supplemented by enthalpy and chemical geothermometers.* *Reservoir temperature should be at least 240°C to allow the well to self discharge*	*Extrapolated from temperature gradients and temperature distribution across the field or results of geothermometers using water, steam and gas from hot springs and fumaroles*	*Results of geothermometers using water, steam and gas from hot springs and fumaroles.* *Resistivity anomaly where high resistivity anomaly is seen blow conductive cap, indicating chlorite-epidote alteration at depth.*
Base Temperature	*Similar to the abandonment temperature, usually @ 180°C or at ambient temperature*		

5. UNCERTAINTY DISTRIBUTION

The accuracy of the methods used in geothermal reserves estimation depends on the type, amount, and quality of geoscientific and engineering data, which are also dependent on the stage of development and maturity of a given field. Generally, the accuracy increases as the field is drilled with more wells and more production data become available. Volumetric estimation is most commonly applied during the early stage of field development to justify drilling and commitment for a specified power plant size. This method is better applied during the early stage than numerical modelling which requires significant number of wells and production history to be considered reliable. To be used for companies' annual reporting and to enhance corporate assets for valuation, booking of geothermal reserves could be performed during the maturity of the field (Sanyal and Sarmiento, 2005). However, because of the limited data and uncertainty on the assumptions on reservoir parameters, some degree of cautiousness and conservatism are also inputted. This approach which takes into account the risk factor in the decision making can be quantified with reasonable approximation using Monte Carlo Simulation.

Unlike a ***deterministic*** approach, where a single value representing a best guess value is used, the ***probabilistic*** method of calculation is considered to account for the uncertainty on many variables in geothermal reserves estimation. As seen from Table 1, a range of possible reserves estimates could be obtained depending on the assumptions included in the calculation. In general, the proven reserves refer to the minimum, the probable reserves as the most likely or intermediate, and the possible or inferred reserves as the maximum. The Monte Carlo simulation performs the calculation and determines the estimate based frequency distribution of the random variables, which are dependent on the number of times a value is extracted from the uncertainty models of the input parameters.

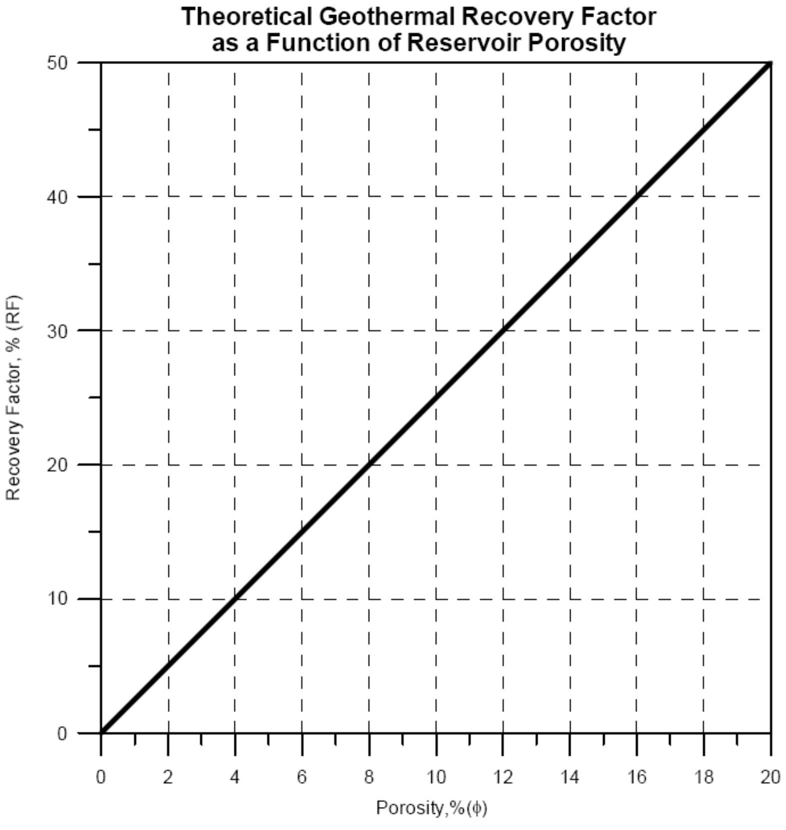


FIGURE 2: Correlation between recovery factor and porosity (After Muffler, 1978)

The area and the thickness of the reservoir are usually assigned the triangular distribution because these parameters are obtained directly from drilling and well measurements. There is a good approximation of the resource area based on the temperature contours and electrical resistivity measurements; while drilling depths and indication of permeability and temperature are directly measured from the well. There has been good evidence from wells currently drilled that permeability still exists at depths below 3,400 meters in the Philippines, (Golla et al, 2006) and down to 4000 meters in Larderello (Capetti and Cepatelli, 2005; Capetti, 2006) which could justify an addition of 500 meters beyond currently drilling depth range of 2500-3000 meters. The successful drilling in Tanawon located at the southernmost edge of Bacman proves a point that geothermal resource may really extend within or beyond the fence delineated by a geophysical anomaly, i.e., Schlumberger resistivity anomaly. The distribution model for these two parameters could be skewed appropriately depending on one's knowledge of the area.

Earlier volumetric estimation in the Philippines defined the lateral and vertical resource boundaries on the basis of the ability of many wells to flow unaided at minimum required temperature of 260 °C. However, recent findings from the country's maturing geothermal fields indicate that this minimum temperature limit could be lowered to 240 °C. Wells were recently observed to sustain commercial flow rate at this temperature, after the field had been produced sufficiently to cause boiling and expansion of two-phase zones in the reservoir. In New Zealand, wells are drilled to intersect temperatures of 180°C at shallower levels of the reservoir as the fluid has the ability to flow to the surface (Lawless, 2007b).

The porosity is usually assigned a log normal distribution following the observations of Cronquist (2001) quoting Arps and Roberts (1958) and Kaufmann (1963) giving that, in a given geologic setting, a log normal distribution is a reasonable approximation to the frequency distribution of field size, i.e., to the ultimate recoveries of oil or gas and other geological or engineering parameters like porosity, permeability, irreducible water saturation and net pay thickness. The mean and the standard deviation are however needed to be defined. All other parameters like fluid densities and specific heat are dependent on temperatures (Table 2).

The correlation between the recovery factor and porosity is shown in Figure 2, while the conversion efficiency and reservoir temperature correlation is shown in Figure 3.

It has been practice to slice the reservoir into several layers to capture the variation in temperature, porosity, permeability and productivity. This full representation of the various properties of the entire field does not make the whole process more precise than when treating it as a single block in a Monte Carlo simulation, and is not necessary because all of the values in a given range for every parameter are inputted in the calculation.

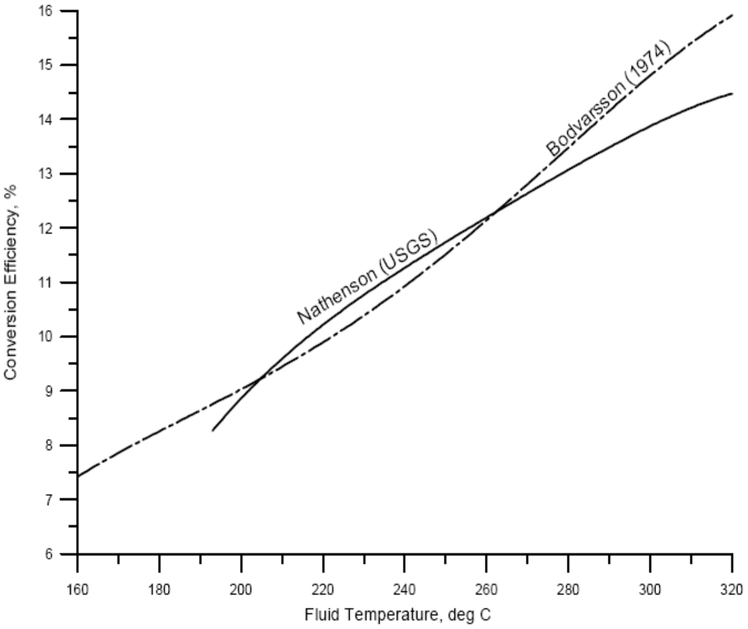


FIGURE 3: Correlation between thermal conversion efficiency and reservoir temperatures (From Nathenson, 1975 and Bodvarsson, 1974).

6. THE MONTE CARLO SIMULATION SOFTWARE

The reserves estimation is done using commercial software that provides for a probabilistic approach of calculating uncertainty in the occurrence of events or unknown variables. The most common commercial software are Crystal Ball (2007) and @Risk which are used in assessing risks in investment, pharmaceuticals, petroleum reserves and mining evaluation. Monte Carlo simulation can also be programmed using an Excel or Lotus spreadsheet but the use of commercial software allow the user to take advantage of all the features required in a statistical analyses as follows:

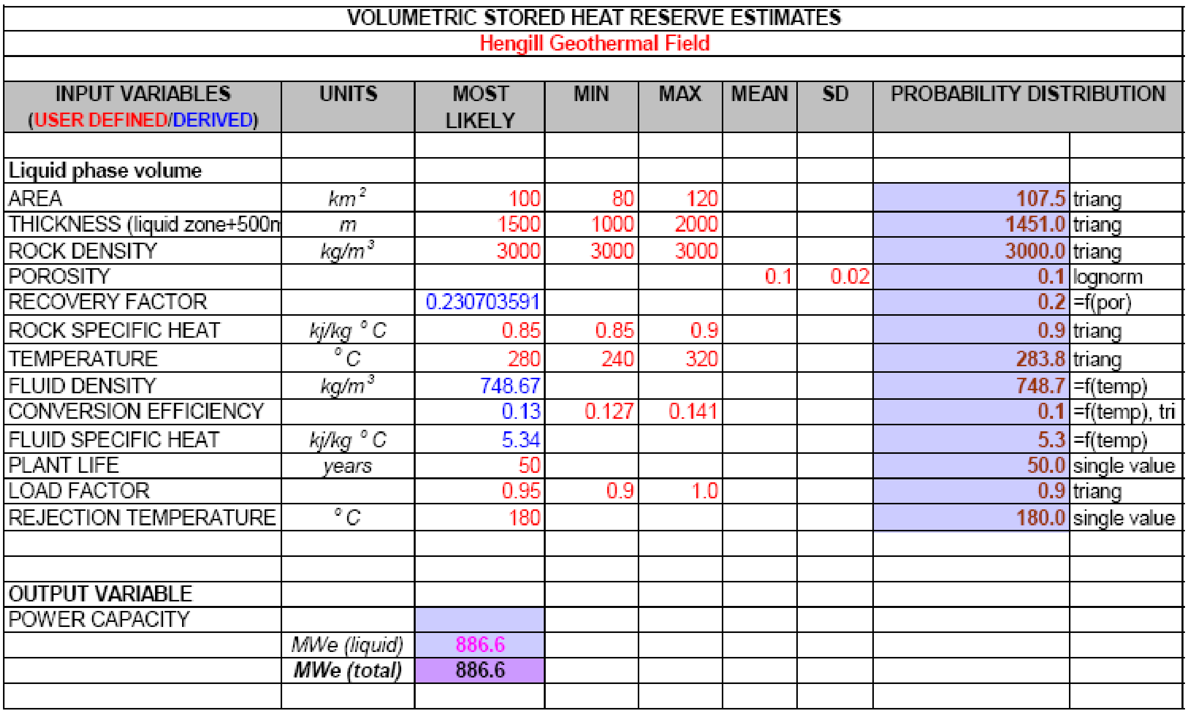
- Graphs of input parameters and output, frequency, cumulative frequency, linear plot etc.
- Statistics: minimum, mean, median, mode, maximum, standard deviation and others
- Sensitivity test

To obtain a good representation of the distribution sampling is done through 1000 iterations with continuous calculation.

6.1 The Input Cells

The Monte Carlo Simulation program is embedded in MS Excel spreadsheet and, like other programs, various cells that have links to the main output or target reserves need to be filled-up. Atypical worksheet for volumetric reserves estimation is shown in Table 2.

TABLE 2: Typical worksheet and input parameters for Monte Carlo Simulation



VOLUMETRIC STORED HEAT RESERVE ESTIMATES

Hengill Geothermal Field

INPUT VARIABLES (USER DEFINED/DERIVED)	UNITS	MOST LIKELY	MIN	MAX	MEAN	SD	PROBABILITY DISTRIBUTION	
Liquid phase volume								
AREA	km^2	100	80	120			107.5	triang
THICKNESS (liquid zone+500n	m	1500	1000	2000			1451.0	triang
ROCK DENSITY	kg/m^3	3000	3000	3000			3000.0	triang
POROSITY					0.1	0.02	0.1	lognorm
RECOVERY FACTOR		0.230703591					0.2	=f(por)
ROCK SPECIFIC HEAT	kj/kg °C	0.85	0.85	0.9			0.9	triang
TEMPERATURE	°C	280	240	320			283.8	triang
FLUID DENSITY	kg/m^3	748.67					748.7	=f(temp)
CONVERSION EFFICIENCY		0.13	0.127	0.141			0.1	=f(temp), tri
FLUID SPECIFIC HEAT	kj/kg °C	5.34					5.3	=f(temp)
PLANT LIFE	years	50					50.0	single value
LOAD FACTOR		0.95	0.9	1.0			0.9	triang
REJECTION TEMPERATURE	°C	180					180.0	single value
OUTPUT VARIABLE								
POWER CAPACITY								
	MWe (liquid)	886.6						
	MWe (total)	886.6						

6.2 Output

To obtain the required output, the user has to specify the targeted input and output to print and plot. In reserves estimation, the most important output of the program is related to the frequency plot of the thermal energy or its equivalent power plant size capacity.

The thermal energy or the plant capacity is usually plotted using the relative frequency histogram and the cumulative frequency distribution. The relative frequency of a value or a group of numbers (intervals or bins) is calculated as a fraction or percentage of the total number of data points (the sum of the frequencies). The relative frequencies of all the numbers or bins are then plotted, as in Figure 4, to show the relative frequency distribution.

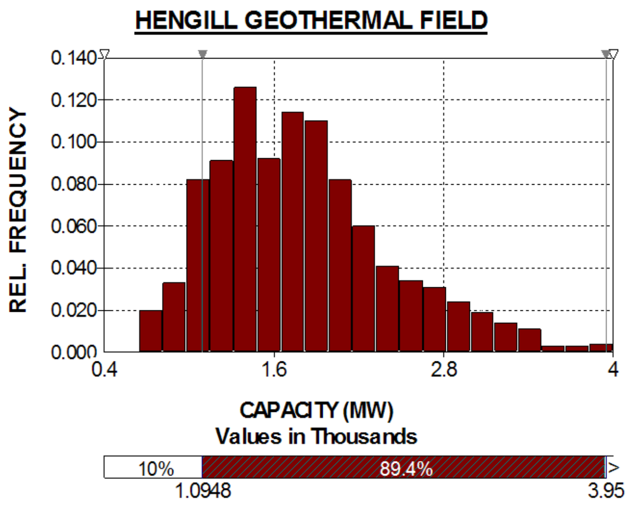


FIGURE 4: Relative frequency plot of the volumetric reserves estimation of the Hengill field (After Sarmiento and Bjornsson, 2007)

On the other hand, the cumulative frequency distribution is similar to a probability density function. It is plotted by cumulating the frequency or adding incrementally the relative frequency of each number or bins. Figure 5 is plotted by cumulating the frequency distribution from maximum value of the random variable to the minimum random variable. The vertical axis is then interpreted as representing the cumulative frequencies greater than or equal to given values of the random variable. The same plot could be represented in a reverse order, from minimum to maximum, but the vertical axis would then be interpreted as the cumulative frequency equal or less than the given values of the random variable. The cumulative frequency greater than or equal to the maximum value is always 1 and the cumulative frequency greater than or equal the minimum value is always 0. In Figure 5, the probability that the output is greater than or equal to 1,095 MW is 90 percent (***Proven*** reserves); the probability that the capacity is greater than or equal to 1,660 MW is 55 percent (***Proven*** + ***Probable*** Reserves, Mode or Most Likely); and the probability that the output is greater than or equal to 2720 MW is 10 percent (***Proven*** + ***Probable*** + ***Possible*** or Maximum Reserves). These results imply that the field could initially support a 1,095 MW power plant for 25 years; possible expansion to 1660 MW will be subject to further delineation drilling and availability of field performance data. The risk that the field could not sustain 1,095 MW is equal to or less than 10 percent.

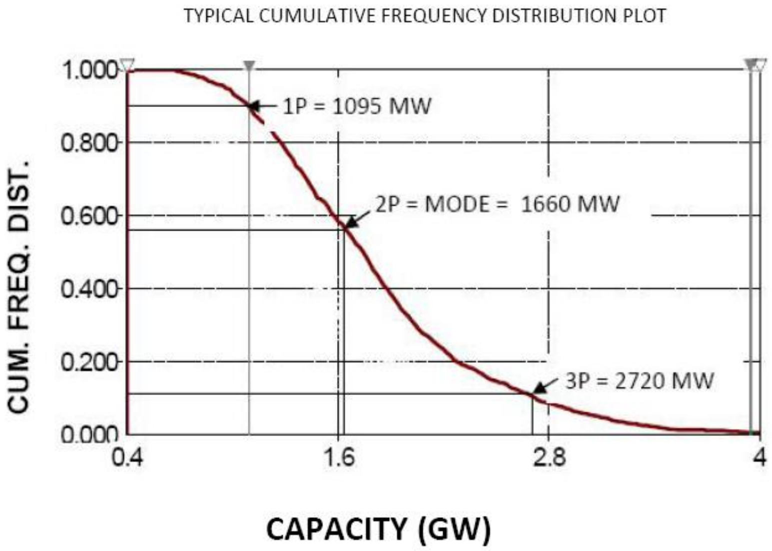


FIGURE 5: Illustration of a typical cumulative frequency plot of the volumetric reserves estimation.

7. CONCLUSION

Through the aid of a computer program using Monte Carlo simulation, a probabilistic approach of estimating geothermal reserves becomes less demanding. . Some guidelines in the selection of the various reservoir parameters are needed to have consistency in the estimation. By this method, the risks associated with overestimating the size of a geothermal field could be quantified. Moreover, future expansion in the field could be planned in advance while drilling gets underway to confirm the available reserves.

8. REFERENCES

Arps, J. J. and Roberts, T.G., 1958: Economics of Drilling for Cretaceous Oil on East Flank of Denver Julesberg Basin. *AAPG Bulletin. 42*, 2549.

Bodvarsson, G., 1974: Geothermal Resource Energetics. *Geothermics, V.3.*

Capetti, G. and Cepatelli, L., 2005: *Geothermal Power Generation in Italy 2000-2004 Update Report*. Proceedings: World Geothermal Congress 2005. Antalya, Turkey, 2005.

Cappetti , G., 2006: *How EGS is investigated in the case of the Larderello geothermal field ?* Engine Launching Conference, Orleans, France 12-15 February 2006.

Clothworthy, A.W., Ussher, G.N.H., Lawless, J.V. and Randle, J.B., 2006: *Towards An Industry Guideline for Geothermal Reserves Determination*. Proceeding: 28th New Zealand Geothermal Workshop 2006.

Cronquist, 2001: *Estimation and Classification of Reserves of Crude Oil, Natural Gas and Condensate. Society of Petroleum Engineers. 2001.*

Crystal Ball, 2007: *Inside Crystal Ball 7 Standard Edition* http://www.crystalball.com/crystal_ball/index.html

Golla, G.U., Sevilla. E.P., Bayrante, L.F., Ramos, S.G. and Taganas, R.G., 2006: *Geothermal Energy Exploration and Development in the Philippines after 35 years*. Proceedings: 28th NZ Geothermal Workshop 2006. Auckland, New Zealand.

Kaufman, G.M.., 1963: Statistical *Decision and Related Techniques in Oil Exploration*. Prentice Hall Inc. Englewood Cliffs, New Jersey.

Lawless, J. V., 2007a: *Discussion Paper on Guidelines for Geothermal Reserves Definition*. AUSTRALIAN GEOTHERMAL ENERGY GROUP. August 2007.

Lawless, J. V., 2007b: Personal email communication.

Muffler, P.L., 1978: Assessment of Geothermal Resources of the United States—1978. *Geological Survey Circular 790.*

Muffler, L.J.P., 1978: 1978 USGS *Geothermal Resource Assessment*. Proceedings: Stanford Geothermal Workshop. Stanford University, Stanford, California. 1977.

Muffler, P and Cataldi, R., 1978: Methods for regional assessment of geothermal resources. *Geothermics, V.7,* pp 53-89.

Nathenson, M., 1975: *Physical Factors Determining the Fraction of Stored Heat Recoverable from Hydrothermal Convection Systems and Conduction Dominated Areas*. USGS Open File Report 38.

Palisade Corporation, 2007: @Risk and Decision Tools suite. *Risk Analysis, Decision Analysis and Statistical Analysis*. http://www.palisade-europe.com/. Oct 17,2007.

Sanyal, S. K., and Sarmiento, Z. F., 2007: *Booking Geothermal Energy Reserves*. Transaction, Geothermal Resources Council, 2005.

SPE, 2001: *Guidelines for the Evaluation of Petroleum Reserves and Resources, A Supplement to the SPE/WPC Petroleum Reserve Definitions and the SPE/WPC/AAPG Petroleum Resources Definitions*.