QUANTITATIVE RISK ANALYSIS FOR UNCERTAINTY QUANTIFICATION ON DRILLING OPERATIONS. REVIEW AND LESSONS LEARNED

Cunha, J. C., Demirdal B., Gui, P.
University of Alberta, Edmonton, AB, Canada

Abstract

This paper presents comments and some background on the use of risk analysis methods in the oil and gas industry. Particularly attention is given to applications developed specifically for drilling operations. A literature review emphasizing articles written specifically for risk analysis applications on oil & gas well drilling operation is presented.

Recommendations for procedures related to risk analysis methods implementation as well as an example of application and its results are presented.

A Monte Carlo simulation was run to predict a cumulative distribution function for a well drilling AFE (Authorization For Expenditure.) The simulation procedure as well as the resultant function is presented.

Introduction

Back in 1975, an article about “the use of new quantitative evaluation methods” was published[1]. The title of the article, “Risk Analysis - Is it Really Worth the Effort?”, somehow reflected the frustration of the author, one of the pioneers on the subject[2], with the fact that, by then, many would feel that decision making is a managerial process that could not be quantified by statisticians dealing with complex and hard-to-grasp concepts.

After thirty years it would probably be safe to assert that the use of quantitative risk analysis methods for investment decisions is widely adopted by oil companies. Also, certain petroleum engineering technical areas, like reservoir engineering, benefit of the use of risk analysis on the planning and development of oil fields and on reservoir management. Conversely, other technical areas that decidedly would benefit from the use of the same tools do not make use of it on a consistent way. In this paper specific risk analysis applications for drilling engineering processes will be analyzed. A literature review on some important applications as well as an example of application is presented. Some suggestions on how to implement risk analysis methods for drilling are discussed.

Literature Review

Risk analysis is a very powerful tool for certain engineering processes where decision under uncertainty is involved. Specifically for oil well operations, a number of articles have been presented illustrating how risk analysis methods can be used to maximize the possibility of adopting, for a certain operation, the correct decision. For drilling operations, even though not extensively used, a variety of applications have been developed. In this section a review of those important applications is presented.

Newendorp and Root[2] conducted a pioneer study on the possibility of using risk analysis methods while deciding on drilling investments, which involves a dedication of significant amount of capital under highly uncertain conditions. Authors suggested that, instead of reaching decisions qualitatively under the influence of subjective observations in a personal and intuitive process, a decision theory technique could be used making possible to asses and estimate the risks associated with drilling investments, quantitatively.

Since risks associated in drilling investments contain uncertainties due to geological and engineering factors that affect profitability of investment, it is wiser to estimate range and distribution of possible outcomes of a drilling investment to investigate the profitability of a prospect.

Authors stated that the method would minimize subjective decisions and conclusions for a drilling investment project. With the use of the method, effects of unlimited number of variables on drilling prospects can be analyzed, sensitivity analysis can be conducted and variables highly affecting the profitability could be isolated and better analyzed. The proposed method is much more sophisticated, objective and precise for assessment of drilling prospects than the type of qualitative analysis commonly used by the time of publication of the article.

Even though the article did not deal specifically with any particular drilling process or operation, it presented a method to handle uncertainties that clearly could be extrapolated for situations faced regularly on ordinary well operations.

Reference 1, from the same author, brought clarification to some misconceptions about risk analysis and emphasized the advantages of using decision analysis methods. Risk analysis can clearly examine various possible outcomes and compare different options for investment with different levels of risk and uncertainties.

Cowan[3] stated that the two distinctive characteristics of oil and gas exploration are high uncertainties involved and significant amount of capital expenditures. For that reason, possible outcomes from reserves should be analyzed carefully and risk analysis should be implemented on exploration prospects to measure the effects of uncertainties on the financial outcome. Cowan proposed a risk analysis model that could be used to quantify the elements of risks associated with exploring and developing a hydrocarbon prospect. Again, this article was not specifically aimed at drilling operations, but certainly pointed out some directions that would be used later on drilling engineering problems.

The proposed model combined probabilistic geological, engineering and economic data to produce possible distribution functions related to potential outcomes of exploiting new reserves. The model is able to handle five different phases of prospect operation. First of these phases is the “exploration period” which incorporates the cost of the exploration studies in a given field. Following, comes the second phase which involves the analysis of wildcat drilling and analyzes the chance of finding hydrocarbon resources in a given location. If the chance of success in “drilling the wildcat” is high, then the model accounts for the third phase, which is “delineating the field”. Target rate and preliminary economic evaluation on development program are carried out in this stage of the model. Then, if the field has some potential value, phases 4 and 5 are applied. These phases are “developing the field” and “producing the field”, respectively. These last two phases are analyzed based on increasing production, stable production and declining production cases.

Cowan pointed out the superiority of using probabilistic methods compared to single value estimates. Probabilistic solution method enables to display possible outcomes depending on variation of various input elements and uncertainties and allows more realistic analysis.

Newendorp[4] pointed out that the awareness of industry on risk analysis increases with the increasing trend of the exploration activities towards smaller, harder to find traps, challenging environments and improved new technologies. There are many different ways for implementing risk analysis techniques for a drilling prospect and the paper aimed to classify them in five categories, Level 1 being the most basic one with two possible outcomes and Level 5 being the most comprehensive Monte Carlo simulation analysis. Based on the available data, he suggested using one of the five risk analysis models to analyze drilling prospects.

He considered the first three models (Level 1, Level 2 and Level 3) as “discrete-outcome models” while the latter two models (Level 4 and Level 5) are “continuous-outcome models.” Initially, due to lack of information, Level 1 can be used and one of two possible outcomes (hydrocarbons or no hydrocarbons) can be analyzed. As more data becomes available, Level 2 which accounts for four possible outcomes (three possible reserve values and no hydrocarbons) can be used. Level 3 provide six possible discrete outcomes, five being possible reserve values and one being no hydrocarbons. Newendorp stated that to go beyond five possible reserve outcomes, the model should be converted to a continuous outcome model so that the entire reserve distribution could be characterized. Level 4 is similar to Level 3 except by the fact that geology related probability distribution functions are determined using simulation and economic factors are obtained using deterministic methods. Finally, Level 5 is the most sophisticated model accounting for uncertainties in both geologic data and economic uncertainties.

The author stated that, depending on the risks accounted and uncertainties available, each level of risk analysis model provides valuable information in different stages of a drilling prospect analysis. He suggested using a higher level of risk analysis model as more data is obtained from the activities being implemented.

Another very interesting application, this one directed to a much common dilemma present in certain drilling operations was presented in Ref. 5. The author proposed a technique to determine whether the minimum cost while drilling is attained by (1) drilling the hole further with the drilling fluid currently in the hole, (2) with weighted drilling fluid, (3) quitting drilling and setting the casing to that depth or (4) even by abandoning the well if this is the most indicated due to safety and borehole integrity considerations. He pointed out that, during actual drilling operation these four options are always available. In the case that it is decided to drill further, then it is always possible to experience a kick or loss of circulation depending on formation pressures. This risk analysis model stated that, since all the decisions are related to the formation pressure and other drilling parameters, expected costs will also be ultimately related to the same factor (the formation pressure.)

Using a Monte Carlo simulation technique, the author developed a way to evaluate the risks associated with the given set of drilling parameters. Using the technique, it would be possible to estimate quantitatively the cost of drilling further with existing mud, weighted mud, setting a casing, abandoning the well and sidetracking. It should be noted that, the risk analysis model developed is very sensitive to cost distribution of the intractable kick and degree of uncertainty in formation pressure. For that reason, these two variables should be accounted accurately in order to estimate precisely the expected mean value, or loss, (EMV) of different drilling situations.

Ostebo et al.[6] presented a study on an area where qualitative and quantitative risk assessment can be implemented to a great extend. After the Piper Alpha accident, Norway and UK issued new regulations in which risk analysis has great importance. Knowing that offshore operations have potential safety and operational problems and after experiencing the Piper Alpha accident, neither the countries nor the companies would risk having another similar experience. As a result of that, risk analysis became a very useful tool in the process of decision making to enhance platform layout, operational procedures and orderliness together with safety and cost. Authors analyzed the regulations issued by the Norwegian Petroleum Directorate (NPD), to promote use of risk analysis techniques in offshore operations.

They have defined and explained the Concept Safety Evaluation (CSE), which is a method of quantified risk analysis. CSE is being applied to all production platform design in Norway and its main goals are to determine areas where problems might occur and evaluate those areas to reduce the possibility of accidents. In addition, the authors showed different ways of applying risk analysis in the areas of reliability and availability analysis, safety management techniques and human and organizational factors during offshore operations.

Ottesen et al.[7] developed a new wellbore stability analysis method, which combines a classical mechanical wellbore stability model with viability operational limits, for example, hydraulics necessary to allow efficient cuttings transport in highly deviated wells. Those limits are determined by quantitative risk analysis (QRA) principles. The authors have defined the limits for failure and success and generated a limit state function to create a link between classical wellbore stability model and operational failure. The proposed wellbore stability analysis method is not only capable of quantifying the risks associated with the operational failure but also enables the engineer to choose the appropriate mud density to avoid wellbore instability problems.

Liang[8] presented a method to determine pore pressure and fracture gradient using quantitative risk analysis (QRA). It was stated on this study that it is possible to approximate the probabilistic distribution of pore pressure, equivalent mud weight and fracture gradient using Gaussian distribution, which would be possible due to the randomness of the statistical ranges of those parameters at any given depth. By using probabilistic distribution functions for pore pressure, fracture gradient and equivalent mud weight, risks associated with taking a kick or loss-return can be analyzed quantitatively.

QRA methods presented in the paper makes possible to identify risks associated to having a kick or circulation loss. Such risks can be minimized or controlled by changing some of the drilling parameters such as mud weight, mud rheological properties, flow rate, tripping speed, penetration rate, etc. In addition, more realistic information for casing design and more accurate selection of casing shoe depth is attained using pore pressures and fracture gradients calculated with QRA approach.

McIntosh[9] emphasized the need for use of probabilistic methods to manage well-construction performances effectively under challenging conditions where uncertainties exist all the time. As more exploration activities are taking place in increasingly hostile areas such as deeper waters and remote locations, risks and uncertainties associated with the operations are also escalating and operators should look for more reliable and cost-effective models for oil well drilling activities.

Compared to deterministic models, probabilistic modeling/processing does not only take into account the planned order of events, but also accounts for unplanned/undesired events. By doing so, operators are able to manage most critical and unexpected events, and “non-productive time” decreases effectively. It is also possible to model the applicability of new technology and compare the possible outcome of new technologies with the conventional methods for a given project. It is recommended to build a probabilistic model at the early stages of the operation and evolve the model continuously as more data is obtained from successive operations. As a result of that, actual events in well-construction operations are described more precisely, numbers of unexpected events are decreased and consequently better development/execution can be achieved.

With the increasing use of risk analysis to analyze problems closely related to drilling operations, more specific applications started to be developed. Thorogood et al.[10] presented a risk-analysis based solution to the subsurface well collisions problem. The method included a mathematical analysis of the probability of collision combined with a decision tree to describe the consequences.

The results of the collision risk analysis can be compared with the predefined limits on the probabilities of the various outcomes, which depend on the assessment of the tolerable risk. For daily use, the drilling engineers can plan their well operations with a flow chart of the directional-drilling procedures. Clearly defined levels of risk can be properly established.

Virine and Rapley[11] presented a practical approach to use risk analysis toolsets in economic evaluation applications for the oil and gas industry. They described the integration of decision and risk analysis tools with economic engineering application.

The paper emphasized the importance of data input as well as analysis result. An example case was presented.

Alexander and Lohr[12] summarized seven essential elements for a successful risk analysis project. They emphasized that the commitment and endorsement from both management and technical teams are essential to the risk analysis progress. A good risk analysis process is always supported by well prepared guidelines, adaptable evaluation software, good understanding of dependency between variables and the proper result interpretation. Even though risk analysis can not replace professional judgment, it can improve the evaluation and help to reach the correct decision.

Coopersmith et al.[13] described applications of decision-tree analysis in the oil and gas industry through a case study where a deepwater production system was analyzed. After defining some parameters of the project, such as reservoir size, production rates, number of wells and drilling schedule, the high-level decision trees were constructed for two different designs. Through the comparison of final NPV calculations of both designs under consideration the one with the best result could be chosen.

For the case presented the key uncertainty was the reservoir size and the most important factor influencing the investment payback was the development timing steps. Using decision-tree analysis, the oil company could analyze the range of possible outcomes.

Use and Implementation of Risk Analysis

Reference 14 established that implementation of risk analysis involves three basic steps: “identifying an opportunity” (or event) where the tool can be applied, “quantifying the consequences of various possible decisions” and “assessing, within the possible outcomes, the estimated best economic or operational result.” The first step was considered the simplest part of the process since it is recognized that many are the decisions under uncertainty occurring during well drilling operations. The second and third steps are more complex and involve issues related to data availability and reliability, cost analysis, probability determination and economic assessment. In the next section an example of application is presented.

Example of Application – Well Cost Estimation

Engineers involved in well planning and budgeting know how sensitive this subject is. A poorly prepared well budget or AFE (Authorization for Expenditure) will have effect on the company's internal functioning as well as in its relation with possible partners. Internally, the accounting department will rely on the recommendation from engineers to prepare the company's budget. Externally, partners will do the same and, only to a certain extent, will allow deviation from the proposed AFE.

Normally, in certain high-risk exploration ventures, it is very common for oil companies to look for partners to share the risks involved, potential losses and, of course, the possible gains. In this case, following clauses established in a Joint Operating Agreement (JOA), an AFE will have to be approved by all partners before drilling operation takes place. It is regular in these cases to allow a 10% over spending on the planned costs. Any amount above this limit will require mandatory approval from the partners, which may cause operational delays and doubts about the operating partner's technical proficiency.

Since cost estimation for drilling operations naturally carries a great deal of uncertainty, this area appears to be suitable for risk analysis application.

Table 1 presents an actual AFE for a vertical offshore well. The total estimated cost is $6,456,000. Let us assume now that the engineer in charge of well planning has uncertainties related to 16 items (see Table 2) on the proposed AFE. The normal approach, of considering a "best case" with all the lower costs occurring at the same time and a worst scenario with all the higher costs happening simultaneously cannot be applied here. There is no guarantee that, let us say, rig costs, will be in the lower side at the same time that supervision and P&A costs reach a minimum.

Assuming that all cost variations are independent, which may not be the case with certain related item like casings with different diameters, we can further assume that the costs will vary according to a triangular distribution where the minimum, maximum and mode value are known (as given in Table 2).

From that premise, a Monte Carlo simulation can be performed, with all uncertain costs being randomly varied combined with the other costs. The simulation is run consecutively, every time taking one possible cost from the distribution of each of the 16 uncertain variables. Those values are added with the fixed costs, variables where no uncertainty exist, resulting in a total cost for the well. In this case the simulation was repeated 500 times and the results used to form a cumulative distribution function (CDF) for the well.

The resulting CDF is presented in Fig. 1.

Analysis of Results

After establishing the distribution of possible costs for the well, the engineer now has a much more reliable tool to be used on the AFE's preparation. Notice that the analysis itself does not substitute the engineer's evaluation or company's policy. On the other hand it provides the professional with means to best estimate contingency costs and determine P(10), P(50) and P(90) costs, in our case, $6.32, $6.54 and $6.83 millions.

Conclusions and Final Remarks

An overview on most important works relating use of risk analysis applications for drilling operations was presented.

Use of risk analysis on oil and gas investment decision is a common procedure in all major oil companies, however, use of QRA methods as an auxiliary tool for decisions under uncertainty in well engineering process is not as prevalent as it should be.

A simple example for application in well cost estimation was presented. Monte Carlo simulation was used to determine a cumulative distribution function for the expected well costs.

The application presented here, as well as the ones presented in Refs. 6, 7, 8 and 13 can be extrapolated or adapted for various drilling engineering processes.

Use of decision methods with risk analysis required reliable database and careful analysis of possible outcomes. However, once the method is implemented, its use is simple and will provide great benefit for the company.

Acknowledgement

The Natural Sciences and Engineering Research Council of Canada (NSERC) has been for 26 years a major sponsor of research and education in engineering. Particularly at the School of Mining and Petroleum Engineering at the University of Alberta, NSERC has contributed to a number of research projects including this one. NSERC continuous support is acknowledged by the authors.

References

1. Newendorp, P. D. and Campbell, John M.: "Risk Analysis - Is it Really Worth the Effort?" paper SPE 5578 presented at the 50th SPE Annual Fall Meeting, Dallas, TX, USA, 28 September-01 Oct. 1975.
2. Newendorp, P. D. and Root, P. J.: "Risk Analysis in Drilling Investment," *Journal of Petroleum Technology*, Vol. 20, No. 6, pp. 579-585, June 1968.
3. Cowan, J.V.: "Risk Analysis as Applied to Drilling and Developing an Exploration Prospect", Paper SPE 2583, Presented at the 44th Annual Fall Meeting of SPE of AIME, Denver, CO, 28 September-01 October, 1969.
4. Newendorp, P.D.: "A Strategy for Implementing Risk Analysis", Paper SPE 11299, Presented at the SPE Hydrocarbon Economics and Evaluation Symposium, Dallas, TX, 3-4 March, 1983.
5. Turley, J.A.: "A Risk Analysis of Transition Zone Drilling", Paper SPE 6022, Presented at the 51st Annual Fall Technical Conference and Exhibition of the SPE of AIME, New Orleans, LA, 3-6 October, 1976.
6. Ostebo, R.; Tronstad, L.; and Fikse, T.: "Risk Analysis of Drilling and Well Operations", Paper SPE/IADC 21952, Presented at the 1991 SPE/IADC Drilling Conference, Amsterdam, Holland, 11-14 March, 1991.
7. Ottesen, S., Zheng, R.H. and McCann, R.C.: "Borehole Stability Assessment Using Quantitative Risk Analysis", Paper SPE/IADC 52864, Presented at the 1999 SPE/IADC Drilling Conference, Amsterdam, Holland, 9-11 March, 1999.
8. Liang, Q.J.: "Application of Quantitative Risk Analysis to Pore Pressure and Fracture Gradient Prediction", Paper SPE 77354, Presented at the SPE Annual Technical Conference and Exhibition, San Antonio, TX, 29 September – 2 October, 2002.
9. McIntosh, John: "Probabilistic Modeling for Well-Construction Performance Management", *Journal of Petroleum Technology* (JPT), November, 2004.

10. Thorogood, J. L., Hogg, T. W. and Williamson, H. S.: ”Application of Risk Analysis Methods to Subsurface Well Collisions” paper SPE 23941, SPE Drilling Engineering pp.299-304, December, 1991.
11. Virine, L. and Rapley L.: ”Decision and Risk Analysis Tools for the Oil and Gas Industry,” paper SPE 84821 presented at the SPE Eastern Regional/AAPG Eastern Section Joint Meeting, Pittsburgh, Pennsylvania, U.S.A, Sept.6-10, 2003.
12. Alexander, J. A. and Lohr, J.R.: ”Risk Analysis: Lessons Learned” paper SPE 49030 presented at the 1998 Annual Technical Conference and Exhibition, New Orleans, Louisiana, Sept.27-30, 1998.
13. Coopersmith, E., Dean, G., McVean, J. and Storaune, E.: ”Making Decisions in the Oil and Gas Industry,” *Oilfield Review,* Winter 2000/2001, pp.2-9.
14. Cunha, J. C.: “Risk Analysis Application for Drilling Operations,” paper CIPC 2004-148 presented at the Petroleum Society’s 5th Canadian International Petroleum Conference (55th Annual Technical Meeting), Calgary, Alberta, Canada, June 8 – 10, 2004.

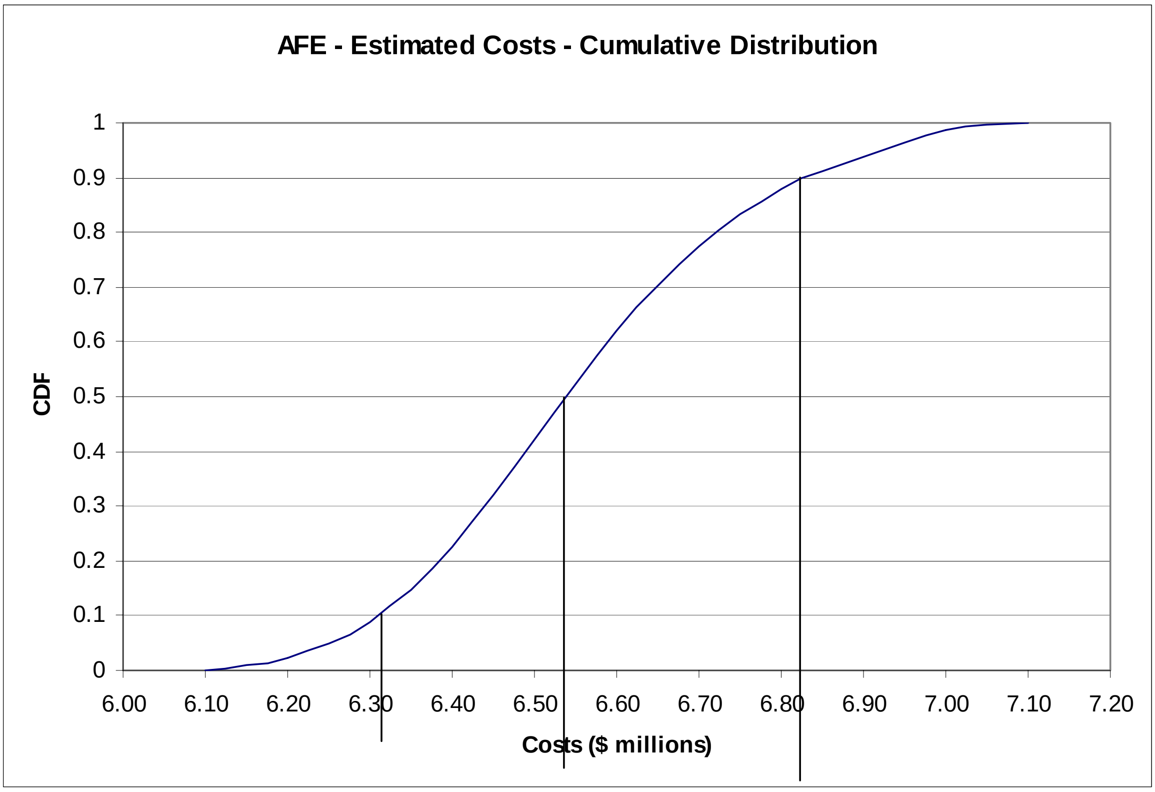

Figure 1 – Cumulative Distribution for AFE

TABLE 1 – Authorization for Expenditure (AFE)

Preliminary Estimate for a 9000 ft Straight Hole Precompletion Estimate Included				DRILLING COST	PRECOMPL. COST	TOTAL AFE
ESTIMATED INTANGIBLE COSTS						
Surveys and Permits/Environmental				$20,000	$5,000	$25,000
Location Cleanup	Rate	Days	Days			
Rig Move (Mob. & Demob.)	$75,000	7		$525,000	$0	$525,000
Drilling - Daywork	$75,000	31	6	$2,325,000	$450,000	$2,775,000
Fuel, Lubes and Water	$2,000	31	6	$62,000	$12,000	$74,000
Rental Equipment	$3,000	31	6	$93,000	$18,000	$111,000
Drill Bits				$50,000	$5,000	$55,000
Drilling Mud & Chemicals		31	6	$400,000	$0	$400,000
Mud Logging	$800	5		$4,000	$0	$4,000
Cement & Squeeze Services				$130,000	$50,000	$180,000
Casing Crews & Tools				$40,000	$25,000	$65,000
OH Logging+MWD/LWD				$350,000	$0	$350,000
Cores & Analysis				$15,000	$0	$15,000
Transportation	$13,100	31	6	$406,100	$78,600	$484,700
Labor + Dock Charges	$2,000	31	6	$62,000	$12,000	$74,000
Supervision	$850	31	6	$26,350	$5,100	$31,450
P&A Costs	$120,000	5	0	$600,000	$0	$600,000
Pipe Inspection				$25,000	$10,000	$35,000
Overhead	$750	31	6	$23,250	$4,500	$27,750
Insurance	$570	31	6	$17,670	$3,420	$21,090
Communications	$300	31	6	$9,300	$1,800	$11,100
				$5,183,700	**$680,500**	**$5,864,100**
TANGIBLE COSTS						
			$/FT.			
Drive Pipe	800	30"	220	$72,600	$0	$72,600
Conductor	1,600	20"	60	$96,000	$0	$96,000
Surface Casing	3,500	16"	16	$56,000	$0	$56,000
Intermediate Casing	6,000	9-5/8"	30	$180,000	$0	$180,000
Production Liner	3500	7-5/8"	13.5	$0	$47,250	$47,250
Wellhead Equipment				$120,000	$20,000	$140,000
TOTAL TANGIBLES				**$524,600**	**$67,300**	**$591,900**
TOTAL AFE COSTS				**$5,708,300**	**$747,800**	**$6,456,000**

TABLE 2 – Range of Costs

	Total Cost Base Case	Total Cost Lower Limit	Total Cost Higher Limit
Total Rig Cost	$3,300,000	$3,080,000	$3,960,000
Fuel, Lubes and Water	$74,000	$64,750	$77,700
Rental Equipment	$111,000	$92,500	$122,100
Drilling Mud & Chemicals	$400,000	$350,000	$500,000
Mud Logging	$4,000	$3,250	$4,500
Transportation	$484,700	$299,700	$499,500
Labor + Dock Charges	$74,000	$55,500	$81,400
Supervision	$31,450	$27,750	$33,300
P&A Costs	$600,000	$550,000	$675,000
Insurance	$21,090	$18,500	$22,570
Communications	$11,100	$9,250	$12,210
Drive Pipe	$72,600	$69,300	$75,900
Conductor	$96,000	$80,000	$104,000
Surface Casing	$56,000	$49,000	$59,500
Intermediate Casing	$180,000	$168,000	$198,000
Production Liner	$47,250	$40,250	$52,500