ESTIMATING THE EFFECT OF FUTURE OIL PRICES ON PETROLEUM ENGINEERING PROJECT INVESTMENT YARDSTICKS

A Thesis

by

ASHISH MENDJOGE

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

December 2003

Major Subject: Petroleum Engineering

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ABSTRACT

Estimating the Effect of Future Oil Prices on Petroleum Engineering Project Investment Yardsticks. (December 2003)

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This study proposes two methods, (1) a probabilistic method based on historical oil prices and (2) a method based on Gaussian simulation, to model future prices of oil. With these methods to model future oil prices, we can calculate the ranges of uncertainty in traditional probability indicators based on cash flow analysis, such as net present values, net present value to investment ratio and internal rate of return.

We found that conventional methods used to quantify uncertainty which use high, low and base prices produce uncertainty ranges far narrower than those observed historically. These methods fail because they do not capture the "shocks" in oil prices that arise from geopolitical events or supply-demand imbalances.

Quantifying uncertainty is becoming increasingly important in the petroleum industry as many current investment opportunities in reservoir development require large investments, many in harsh exploration environments, with intensive technology requirements.

Insight into the range of uncertainty, particularly for downside, may influence our investment decision in these difficult areas.

DEDICATION

To my beloved parents and sister Smita who have always been at my side in any endeavor, supportive and at times critical.

ACKNOWLEDGMENTS

I would like to take this opportunity to express my sincerest appreciation to Dr. John Lee, my advisor, for his help in constructing and completing this thesis. It was a really wonderful opportunity to work with him. His guidance through the discussions and suggestions activated my thought processes and generated a great deal of interest in the thesis work, giving me self-belief and a feeling of responsibility.

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I thank Texas A&M University for educating me in various ways, and for providing me with the very best education. I would like to take the opportunity to thank the faculty and staff for helping me prepare for a life after graduation.

I am going to remember these years of hard work with great pleasure. To all of you, I appreciate what you have done to help me in my scholastic and professional growth.

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CHAPTER I

INTRODUCTION

Exploration and development of oil and gas resources is a fast paced, continually evolving industry that experiences drastic changes due to changes in market conditions. Predicting growth and maintaining competitive advantage by managing cash flows, operating income and resource requirement in a volatile market is a challenge for operating companies. This is due to the inherent risk and uncertainty involved.

Now as we are progressing toward exploration of oil in deeper and harsh environments with harder to find traps involving much greater levels of uncertainty, estimation and quantification of uncertainty is gaining importance.

Begg and Bratvold[1] report that, over the past ten years, oil and gas companies have significantly under performed in the stock market compared to the Dow Jones Industrial Average Index. This is true for both majors and independents. An understanding of the causes of the industry's poor performance is a prerequisite to improving it.

Brashear and Becker[2] have given a similar review; projects undertaken in last two decades had an average return of 7%. This is in spite of improvement of 90% in exploration success rate and of as much as 30% in development success rate due to 3-D seismic technology. These projects were selected on the basis that they surpassed the criteria of internal minimum rate of return of 15% or more.

There are myriad of factors, but dominant among them are the impacts on the value that derive from the existence of uncertainty. If there were no uncertainty then, apart from deliberate misrepresentation, returns would always have been as predicted. The failure of many investments to deliver predicted returns implies over or under estimation of risk or loss.

McMichael[3] stated that oil and gas prices are essential elements in economic and reserves calculation and that the prices have at least as large an impact on project economic performance as the uncertainties in the reservoir and technical data. Forecasts of oil and gas prices are pivotal points in development decisions due to their impact on

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This thesis follows the style and format of *SPE Reservoir Evaluation*.

project economic viability and reserves.

Kokolis and Litvak[4] *et al.* pointed out that the uncertainty is greatest in petroleum exploration and production (E&P) projects at the early or inception stages of the venture. Generally it is during that time frame when bidding decisions have to be made in spite of the available minimum information. To analyze a project effectively, we should come up with a range in investment yardsticks that will have rational upside and down side values scenarios to constrain bid levels to assure at least marginal success in low-end outcomes.

Conventional methods of characterizing uncertainty include methods where forecasts are represented by monotonic increase of inflation indices and corresponding changes on dependent parameters such as crude price and expenses

Underlying correlations existing in the parameters are often overlooked in conventional analysis. Brashear and Becker[5]*et al.* state that people generally estimate the below ground uncertainties in reservoir and geologic parameters but they fell to recognize above ground uncertainties that include future price and costs; changes in demand and transportation storage system, changes in technology for exploration, production and transportation. The formulation and incorporation of these parameters in the analysis gives better estimation of uncertainty associated with it. Correlations have been developed based on historical oil price, production cost and drilling expenditures will make projections more realistic.

Discounted cash flow (DCF) methods described by Downs and Goodman[6] as techniques that calculate value of future expected cash receipts and expenditures using net present value as a factor at a common or starting date are commonly used as part of conventional investment analysis. Surveys made by Dougherty and Sarkar[7] among oil and gas companies, investment advisors and bank engineers have demonstrated that almost 97 percent of respondents use DCF as their primary investment evaluation method.

The focus of this research is on better quantifying the economic uncertainty in petroleum projects caused by uncertainty in future oil prices.

The two broad objectives of this study are:

- To quantify the uncertainty in investment evaluation indicators caused by uncertainty in the future price of oil.
- To develop a model to predict future prices of oil including uncertainty ranges, based on past prices of oil.

These objectives lead to five deliverables listed below:

1. A model for predicting the inflation adjusted future price of oil based on methods used in geostatistics.
2. Comparison of common investment evaluation yardsticks (NPV, NPV/I, IRR) for a typical oil field project determined using
    - Conventional analysis (including most likely, high and low price cases)
    - Actual price trends and operating expenses
3. Comparison of common investment evaluation yardsticks for the same typical oil field project determined using
    - Conventional analysis
    - Oil Price forecasting model

    We will generate sufficient number of cases with the statistically valid sample.
4. Comparison of common investment yardsticks for a representative variety of cash flow profiles reported in literature using
    - Conventional analysis
    - Actual price trends and operating expenses
5. Comparison of common investment evaluation yardsticks for a representative variety of cash flow profiles reported in the literature using
    - Conventional analysis
    - Oil price forecasting model

CHAPTER II

REVIEW OF LITERATURE ON UNCERTAINTY

Introduction

In the literature there appears to have been an informal distinction between the words 'risk' and 'uncertainty' but in many circles these are synonymous. A pioneering work on this subject by Newendorp[8] in 1975 did not draw a distinction between the two terms. Webster's dictionary states, "uncertainty may range from a falling short of certainty to an almost complete lack of conviction or knowledge, especially about an outcome or result," and cites doubt, dubiety, skepticism and mistrust as synonyms. From the Exploration & Production (E&P) industry's view, there is the risk of a dry hole versus making a discovery of undetermined value. The connection between risk and uncertainty is the heart of decision-making. Business or financial uncertainty can be characterized as epistemic uncertainty which is derived from greek word 'episto' relating to knowledge, which is due to lack of information.

Sources of uncertainty

Caldwell and Heather[9] broke down sources of uncertainty as:

- Measurement Inaccuracy
- Computational Approximation
- Incomplete Data
- Stochastic System

Measurement inaccuracy includes random error, a result of factors like a fundamental level of imprecision of instrument and human negligence or error. This error can be rectified with repetition of the observation and by systematic efforts. Another aspect is systematic error. Instruments can generate consistent biased answers due to the poor calibration of the instrument.

Computational approximation arises from use of empirical correlations. These correlations represent a data studied that basically fit a line or curve through experimental measurements or collected data. In the use of correlation the degree of scatter and range of original data is not taken into account and these are used extrapolating beyond the range of original data points that means approximation is imposed on the system.

Caldwell and Heather[9] quote the example of net pay determination in reserves calculation for the source of computer approximation.

The cost factor of data collection gives rise to the third source of uncertainty which is incomplete data. The problem is generally tackled by making suitable assumptions. These assumptions vary according to the experience of the person, and his competence to acknowledge the uncertainty, which gives rise to the bias. Purvis[10] lists ten different types of bias commonly observed in making decisions. The most important one is the overconfidence or pride bias. People get anchored to their first assumption of an uncertain quantity and do not move away from it[11]. Capen[12] exposed this pride bias with a ten item quiz that was based on general knowledge and empirical experiments of bean counting that asked engineers to put down ranges bracketing the answers. He demonstrated engineers are not accustomed to predict the ranges of uncertainty; what they believe to be ninety percent confidence interval frequently turns out to be forty or fifty percent of the actual interval. However with repeated calibration people can be trained to improve their skills in estimating uncertainty. Capen also noted that when, the knowledge of the subject is little, smaller ranges are assigned to uncertainty.

Stochastic parameters are factors which are outside the realm of engineering estimates but are continually at play and affect final answers significantly. Caldwell[13] recognized the stochastic nature of the crude oil prices. His observation was that 94 percent of the time crude prices behave as if they were normally distributed. These stochastic parameters have more significant impact on projects than the ultimate recovery. The cyclical nature of oil prices makes investment patterns in exploration and production industry (E&P) equally cyclical[14]. Oil price volatility correlates with all facets of the business, starting with exploration drilling activity, research and development, employment and labor trends leading to mergers and mega mergers in the industry.

Types of uncertainties

Garb[15] identified three kinds of the uncertainty in E&P projects: (1) technical,
(2) political and (3) economical.

Technical uncertainty relates to whether or not the hydrocarbon volume estimated by geologists and engineers exists in the ground and whether or not the reserves and recovery rates will be as projected by the engineers. Demirmen[16] further described technical uncertainty as a function of how long the property has produced and the maturity and quality of the database from which the reserves determinations were developed and showed technical uncertainty as various forms of reservoir uncertainty. Reservoir uncertainty is the function of three parameters: (1) hydrocarbon in place volume (e.g. structure), (2) recovery factor or productivity (e.g. aquifer strength and reservoir oil saturation) and (3) fluid properties of reservoir fluids, to gas composition and crude viscosity. There is also technical uncertainty in operations such as drilling, number of platforms and their construction time and cost and facility development that relates to gathering and export lines size and cost.

Political uncertainty could materially influence the expected value of a producer's property. It includes not only local and national taxes but environmental regulations, operational restrictions and global concerns including international instability.

Economical uncertainty deals with capital investment, operating expenses, prices, inflation and exchange rates. The investments in E&P projects are frequently medium to long term with high degree of irreversibility. Oil price uncertainty is the chief variable here. The cost of incorrectly anticipating long-term oil price behavior has proved staggering[17]. Sadorsky[18] noted that, "Changes in oil price have an impact on economic activity but changes in economic activity have very little impact on oil prices." He stated that oil price volatility shocks have asymmetric effects on the economy and provided evidence of the importance of oil price movements when explaining movements in stock returns. The real challenge is not try to make forecasts more accurate through technical advances; rather, it is to shift focus to developing better ways to use forecast and to develop planning mechanisms that help to anticipate and prepare for contingent developments.

To manage this price risk effectively and to increase their profitability, E&P companies make use of derivative instruments such as forwards, futures and options. Companies can lock in profits by hedging a portion of their production and through paper trading in adverse price movements. The hedging strategies do not create value but their wise use reduces the variance of earnings or the variance of project profitability[19].

Methods researchers have followed to quantify the economic uncertainties include: Monte Carlo simulation, value at risk (V@R), bootstrap and the fuzzy technique. The Monte Carlo algorithm is a preferred method for risk analysis and uncertainty quantification. It is a powerful yet simple tool for performing complex simulations and is an alternative to deterministic and the conventional "three scenario" (average, high side and low side) approach. The Monte Carlo method dates back to 1940 Manhattan Project when it was used as a code name and suggests its origin to the Mecca of gambling where chance rules. The analysis is carried out by setting a distribution for the variables under consideration. Different sets of scenarios of these variables are created using a random number generator by sampling through the defined distributions. The probability density function is plotted using the sample sets generated. This density function gives the analyst the range of possible outcomes with their probabilities of occurrence. For obtaining the statistically valid results the number of simulations ranges in the thousands. Bordalo *et al.*[20] used this method in decision making in deepwater production system to model the financial risk.

Value at risk or V@R technique is really an extension of Monte Carlo simulation in quantification. V@R is defined in finance as the maximum loss that an institution can be confident it would suffer in a certain time within a particular period. Value at risk is calculated as a difference between the expected value of the economic indicator obtained from cumulative density function of Monte Carlo simulation and the value at a specified low probability often 5%.[21]

The bootstrap method is a statistical valid approach that generates various scenarios of oil prices from the historical sample data by sampling from the original data set with replacement. Sampling with replacement allows recurrence of a particular sample value in the same time sequence. Based on the price predictions generated or on specified scenarios, the analyst evaluates economic indicators and builds the required probability density function.[3]

The fuzzy approach is a fundamentally different method used for uncertainty characterization. Its basis is not linked with probability theory. In this approach we estimate subjective probability for a price shock type of event, the unique and irreplicable nature of which makes determining the probability difficult. Researchers of this discipline include the theory of possibility as an extension of fuzzy sets.[22]

CHAPTER III
METHODOLOGY

We developed two methods in our research to predict the ranges of uncertainty in oil prices. Both methods are based on historical price data.

The price of oil is affected by three major factors demand-supply, inflation and geo-political events. The historical method removes inflation from oil prices and thus makes it a function of the two remaining factors. Major geo-political events are a strong driving factor in the volatility of inflation adjusted crude prices. When we include this event-generated volatility structure in a model that predicts for the future, we assume that the volatility will be repeated in the future.

Scenario generation depends on the year a project is implemented and on project duration. The scenarios are then built as discussed at length in the following pages. The range of values the method predicts for oil prices reflect the actual uncertainty observed in the historical price pattern and the range is directly correlated with the volatility observed in the past.

The second method is based on geostatistical simulation technique of Sequential Gaussian Modeling (SGM). The SGM generates the simulation of future oil prices using a variogram. The algorithm draws a random path through unconditioned cells and, for each cell along the random path; it locates a prespecified number of surrounding conditioned data. This local neighborhood is selected conforming to the range of variogram so the same correlation exists in the predicted price as observed in history. Then, performing ordinary krigging it obtains the mean of Gaussian distribution and the variance which are sufficient to determine the Gaussian function. The procedure is repeated to obtain the desired number of simulations. The use of a price histogram and variogram generates the range of simulated values with same frequency and correlation and so these eqi-probable scenarios represent the historical price pattern and provide a good measure of uncertainty.[23-24]

The first step in this project was of data gathering. We selected West Texas Intermediate (WTI) spot oil price data starting in January 1974 as our price basis. Though abundant data is available for crude oil prices at earlier dates we chose to use data from 1974 onward because prior to 1974 posted prices were common in the oil industry.

Posted oil prices remained stable over long periods while daily prices fluctuated; thus posted price did not reflect the true volatility in crude oil prices. The name posted oil price was derived from a sheet that was posted in a producing field.

The WTI price data were collected from Energy Information Administration (EIA) website[25]. EIA provides daily price data; it was converted to monthly price for use in this study.

Fig.3.1 shows oil price data from 1974 to 2002 (348 months). **Fig. 3.2** shows the historical trend of the consumer price index normalized with respect to 1983. The source for consumer price index (C.P.I) data is U.S. Department of Labor Bureau of Labor Statistics[26]. The data is non-seasonally adjusted data for all urban consumers. The data frequency is monthly.

To account for production and drilling expenses in future projects; we correlated historical expenses data with oil price. **Figs. 3.3** and **3.4** are graphs of the production and drilling costs correlations with oil price. The historical oilfield drilling and production data was taken from EIA website and the Energy Statistics Sourcebook[27-28]. This data is available on yearly basis for 15-year period from 1986 to 2001. A linear trend line with a regression coefficient of 0.30 was fitted for the production data. The drilling expense has a regression coefficient of 0.73 with a power-type trend line.

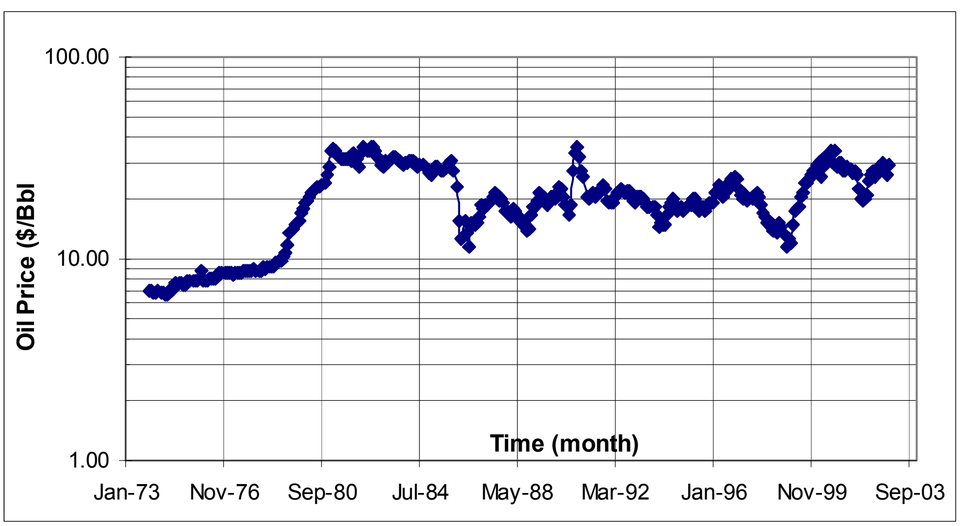

Fig. 3.1- Historical West Texas Intermediate (WTI) crude price profile.

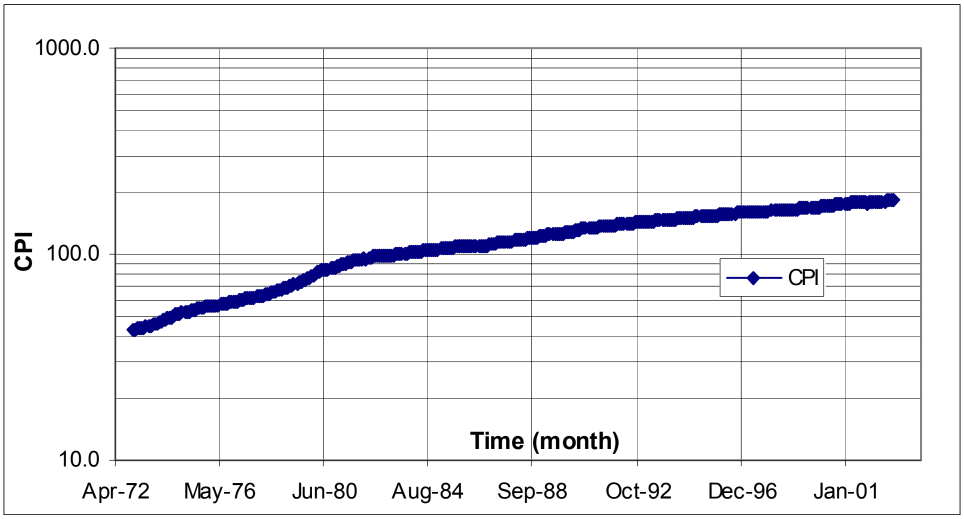

Fig 3.2- Historical trend of consumer price index.

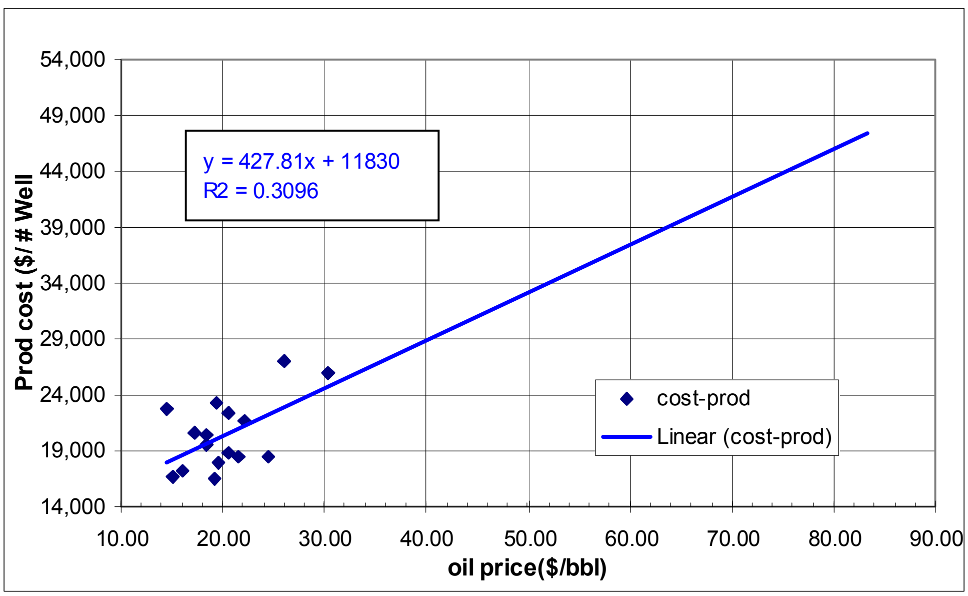

Fig. 3.3- WTI crude price production cost correlation.

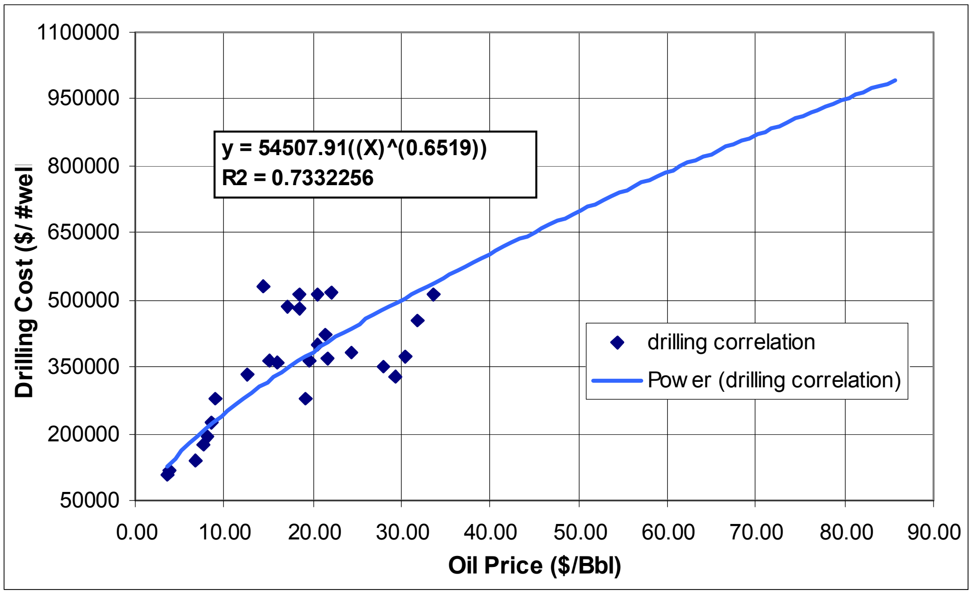

Fig. 3.4- WTI crude price drilling cost correlation.

Economic indicators

For the economic evaluation of exploration and production projects two types of investment yardsticks are used. These two types of economic indicators or yardsticks are differentiated on the basis of time value of money concept. The basic principle of time value of money is that a dollar received today is worth more than a dollar to be received sometime in the future.[29]

Our economic indicator account for the time value of money by 'discounting' future net revenues by a prescribed interest or hurdle rate. Discounted future revenue is the present value, V_p, which for a single cash flow is written as

$$V_p = F_p\,(1+i)^{-n} \qquad (1)$$

and for a cash flow stream is written as

$$V_p = \sum_{j=1}^{n} (F_P)_j \,(1+i)^{-j} \qquad (2)$$

where F_p is the period cash flow "future" value, i is the interest rate and n (or j) is the number of periods in the future.

Discounted net revenue or net present value (NPV) is calculated by replacing the future value in Eqs. 1 and 2 with the net future value. Present value and net present value calculations for investment streams contain both cash inflow and outflow; thus both can be positive or negative. A positive NPV at or above company's hurdle rate is the chief criteria in project selection because it is simply the capital created above the cost of capital to a company.

NPV/I is the ratio of a project's NPV to the present value of the total investment required for the project. It can be written as

$$R_{Di} = \frac{V_{np}}{\left|V_{pi}\right|} \quad \text{...(3)}$$

This indicator may also be viewed as the amount of after tax NPV generated for dollar of discounted investment. NPV/I is derived from NPV and thus bears its all advantages. It is a preferred tool in the ranking of projects when capital requirements exceed the total available capital. Another useful feature of NPV/I is that it is independent of the choice of data to which present values are referred (sometimes called "time zero"). This feature is useful when we compare projects with different starting dates.

Internal Rate of Return (IRR) is the rate that makes the NPV of a project equal zero. This investment criterion is popular because it is independent of discount and hurdle rate. However it is not reliable for ranking projects.

We first examined the uncertainty in typical oilfield project cash flow stream using historical price data and developed our correlations. Capen[30] *et al.* presented the "base case" array of project cash flow streams we examined. We modified the annual cash flow streams as described below and calculated net present value (NPV), net present value to investment ratio (NPV/I) and internal rate of return (IRR) for the base case and for each of the modified cases.

Table 3.1 presents the streams of annual cash flow for the base case (constant oil prices) of our three representative projects, along with economic indicators. **Fig. 3.5** illustrates the cash flows over the 10-year project lives.

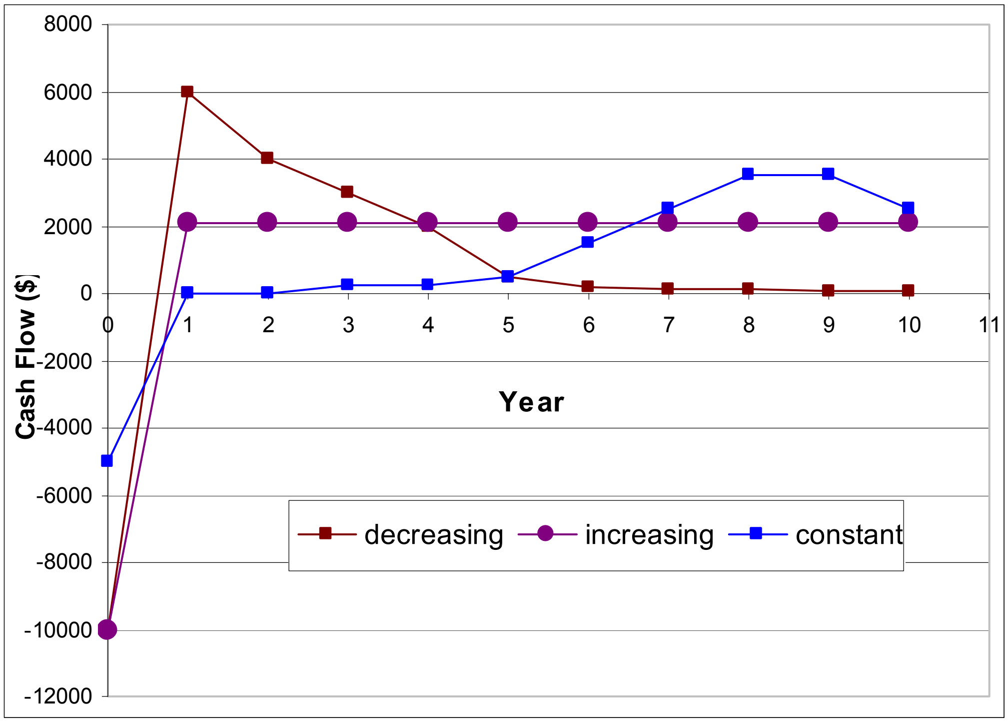

Fig. 3.5- Representative petroleum project annual cash flow profile.

To study the economic uncertainty we then modified the cash flow streams to reflect variable oil prices. First we converted annual cash flows to monthly cash flows and generated monthly oil production schedules. To preserve the original economic indicators (NPV, NPV/I etc.) we generated oil production schedules using an oil price of 20.5 $/STB (any scenario e.g. January 1975 price profile) and set revenues from this production stream equal to 110% of the cash flows proposed by Capen[30], *et al*. Said another way operating expenses were 10% of the total revenues. In these cash flow streams; all investments such as drilling and facilities occurred in year zero.

TABLE 3.1 - Representative Projects with the Economic Indicators

Year	Annual Cash Flow		
	Project-Decreasing	Project-Increasing	Project-Constant
0	-10,000	-5,000	-10,000
1	6,000	0	2,100
2	4,000	0	2,100
3	3,000	250	2,100
4	2,000	250	2,100
5	500	500	2,100
6	200	1,500	2,100
7	100	2,500	2,100
8	100	3,500	2,100
9	50	3,500	2,100
10	50	2,500	2,100
Economic indicators value for most likely case			
IRR (%)	24.8	14.6	16.4
NPV @ 5% ($)	4,322	4,869	6,215
NPV @ 10% ($)	2,942	1,879	2,903
NPV @ 15% ($)	1,789	(98)	539
NPV/I @ 5%	0.43	0.97	0.62
NPV/I @ 10%	0.29	0.38	0.29
NPV/I @ 15%	0.18	(0.02)	0.05

Conventional analysis

Following simple methodology similar to that used in practice by some analysts; we then analyzed each of these projects with high, low and most-likely oil price forecast.

For the most likely case, we assumed that the price of oil would escalate at an annual inflation rate of **5.2%** (compounded monthly). This was the average rate of inflation in CPI over the 348-month period we investigated. The high price case assumed oil price escalated at an annual rate of **10.6%** (compounded monthly). To calculate the escalation in price and in turn to generate the cash flow stream. For the low price case we assumed deflation rate of -5.2% per year (compounded monthly). We also examined a base case with no price change. **Fig. 3.6** shows (on a semi-log scale) price paths we used for conventional analysis.

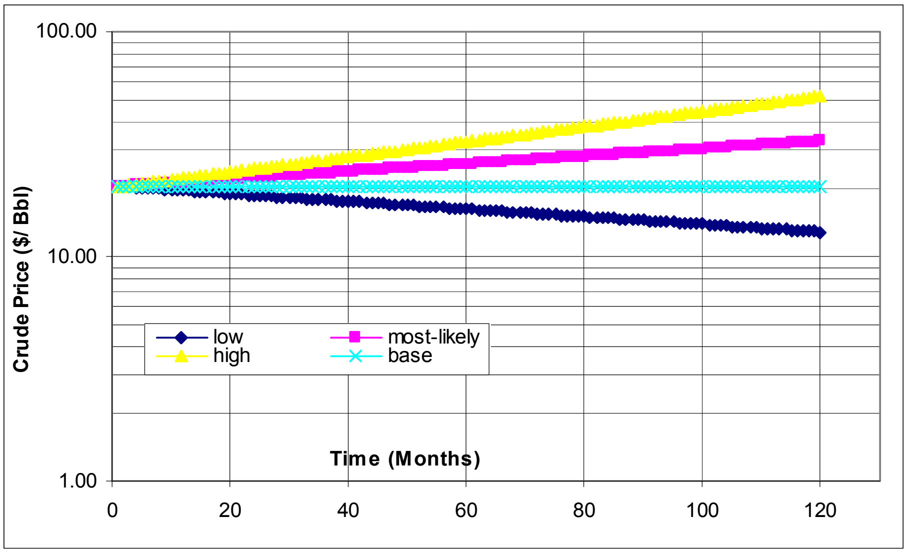

Fig. 3.6- Price scenarios for high, most-likely, low and base cases used in conventional analysis.

Application of historical method to typical cash flow stream

The basic assumption in formulating this method is that the historical price path followed by crude oil in the past will repeat in the future. Application of this method depends on the duration of a project; in this case, the projects have duration of ten years. Here scenario building depends on the starting date of the project.

We started each project in each year (1974 to 1993) and allowed the same relative price increase each year as were observed historically in the next few years. However, the price pattern followed used historical prices with inflation removed. We used normalized inflation indices to generate uninflated price histories. This approach is necessary as the rate of change of inflation has varied from year to year. **Fig. 3.7** shows historical price profile and normalized index for two cases using cases starting in 1975 and in 1983. After computing oil prices on an uninflated basis, we then escalated the prices at a constant inflation rate equal to the average (5.2% annual rate compounded monthly) rate observed over the 348-month historical period we examined. We then calculated normalized oil price indices for each month during the historical period.

To compare the various scenarios on same basis, the oil price in the first month was fixed at 20.5 $/STB for all starting dates. We then multiplied the starting price by the indexed values appropriate for the starting year we examined and generated monthly oil prices. **Fig**. **3.8** shows the uninflated price scenarios generated using this procedure and compares then with the actual prices for scenarios with starting dates of 1975 and 1983. Depending on project conditions we included drilling and production correlations with oil price in our project cash flow streams. The investments for all projects took place in year zero. The production schedule for project (flat, decrease, increase) was fixed and when oil price forecasts and operating costs were applied, we generated cash flow streams for each project starting in year 1974 to 1993. For each of the generated scenario economic yardsticks are calculated and are evaluated against the base case.

From the economic indicators that we calculated, we generated probability density functions (P.D.F.) and cumulative density functions (C.D.F.) for each project and evaluated the variation in indicator.

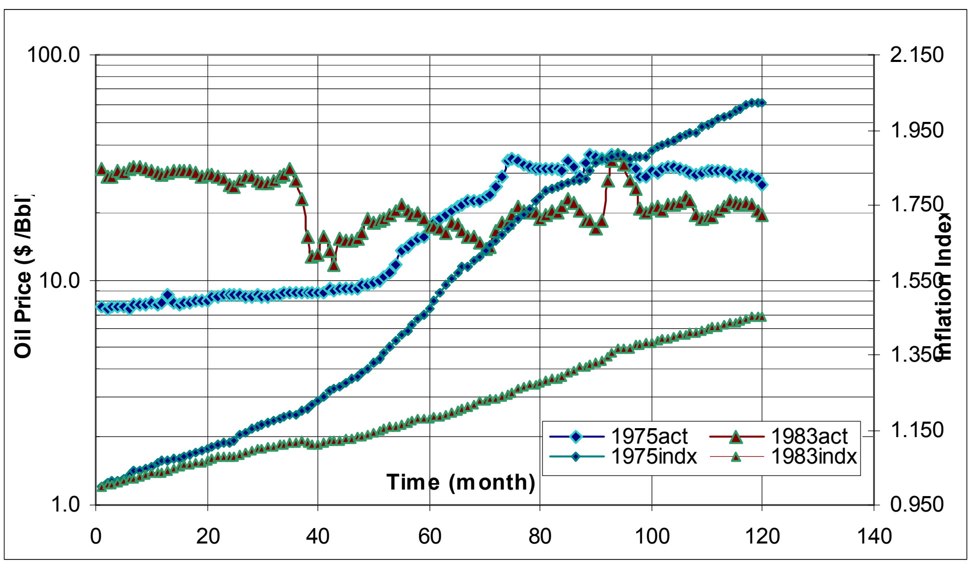

Fig. 3.7- Historical price path and derived inflation indices for 1975 and 1983.

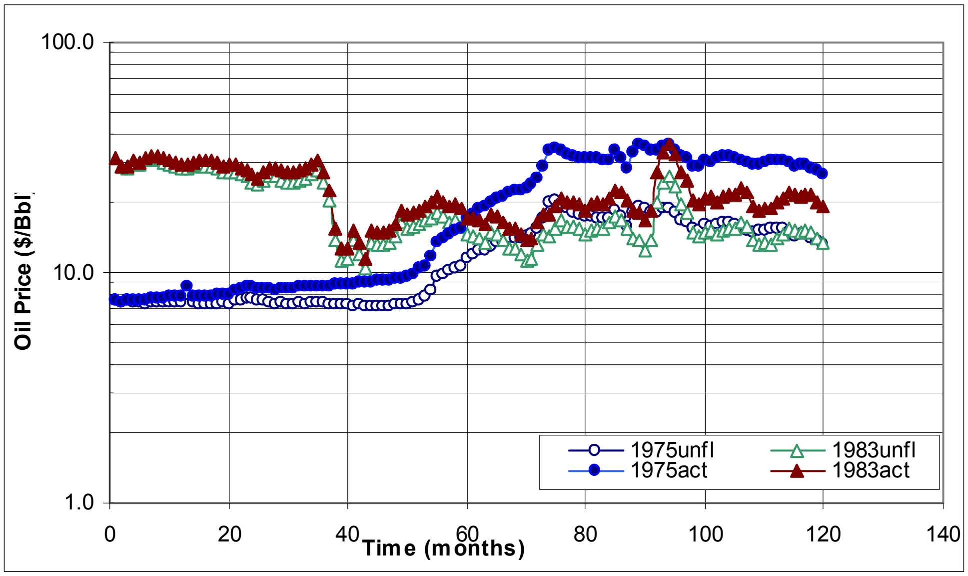

Fig. 3.8- Comparison of historical and uninflated price path for 1975 and 1983.

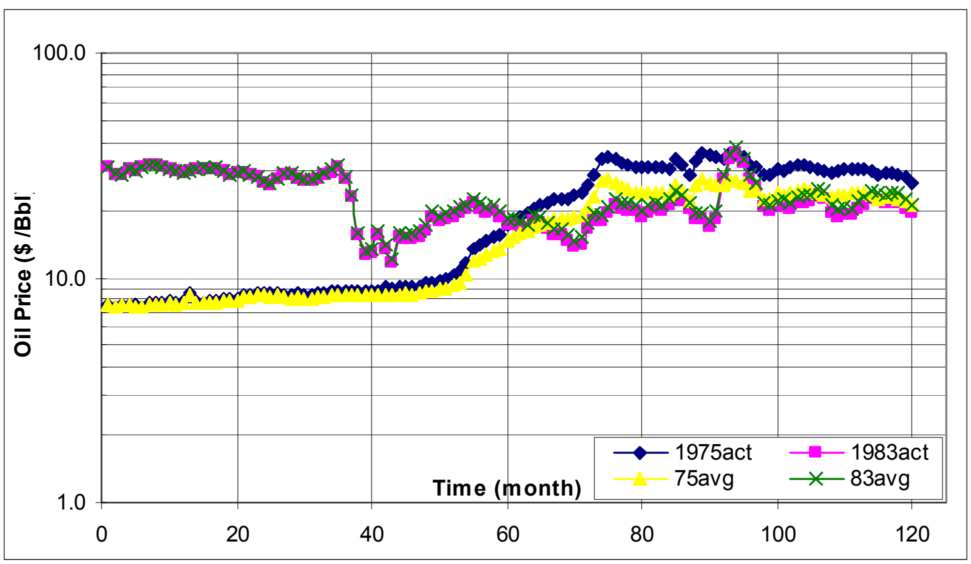

Fig. 3.9- Comparison of actual and average price scenarios for 1975 and 1983.

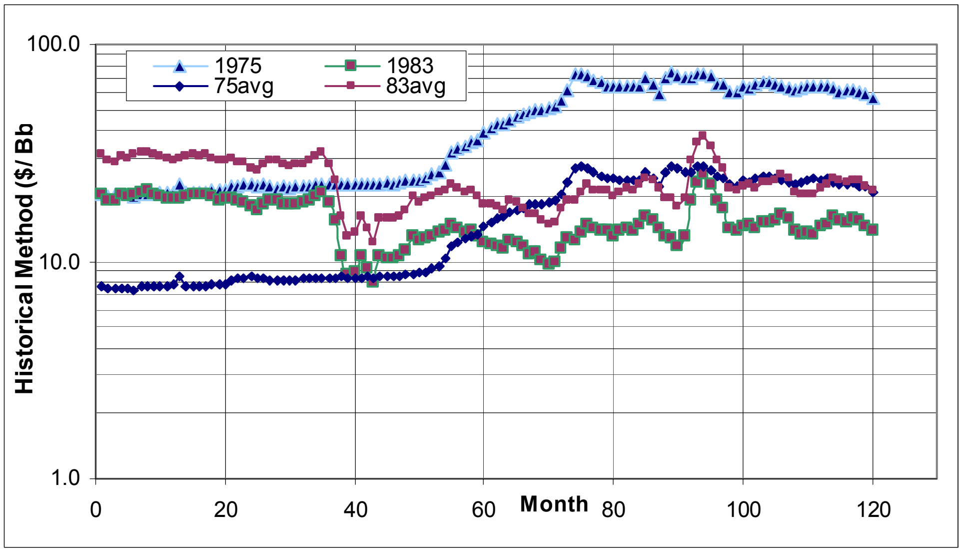

Fig. 3.10- Comparison of historical and average price scenarios for 1975 and 1983.

Application of Gaussian simulation model to typical cash flow streams

We also developed a model to predict future prices of WTI crude oil using Gaussian simulation and used those predictions of oil prices to quantify the uncertainty in the representative oilfield projects (Capen's flat, increasing and decreasing cash flow streams).

The basic requirement was to generate equi-probabable scenarios of future oil prices. To generate these predictions we used the Sequential Gaussian Modeling (SGM) technique. Two available geostatistical software packages; GEOEAS and GSLIB, were used to carry out SGM technique.

SGM requires normally distributed input data. The input data in this case were historical oil prices and its semi variogram from which we obtained correlation matrix. We actually used the inflation adjusted historical oil price data illustrated in **Fig**. **3.11** and tabulated in appendix. The adjusted and uninflated oil prices were generated relative to a inflation index of 1.0 in 1974. The figure shows that the distribution of the prices is multi modal or with more than one peak as the SGM demands input data to be normal a transformation technique had to be used. Using the normal score transform technique from the GEOEAS package, we converted the multi-modal historical oil price data to uni-modal or normally distributed data. The normal score technique accomplishes this by ranking the data and assigning a normal score using the identical quantile of a standard normal distribution. The semi variogram for this normally distributed data was modeled using a spherical model and setting the seal value equal to one. The range obtained by modeling the semi variogram was fed to the simulator with the histogram of the uninflated oil price data to generate the prediction scenarios. A total of fifty uninflated oil price prediction scenarios were generated to analyze the uncertainty range of the typical oil field project. The average inflation index was modeled as function of time in months with a starting value of month set to 348 (the end of historical data). **Fig. 3.12** shows three representative prediction scenarios of the uninflated crude oil price and the same scenarios with inflation added at an annual rate of 5.2 per cent (compounded monthly). We then adjusted these inflated price predictions to a starting value of 20.5$/STB. We then used these results of price forecasts to generate cash-flows for typical petroleum projects and thereby calculated the range of uncertainty based on the reference starting price 20.5$/STB.

Fig. 3.13 shows the price ranges obtained by this method.

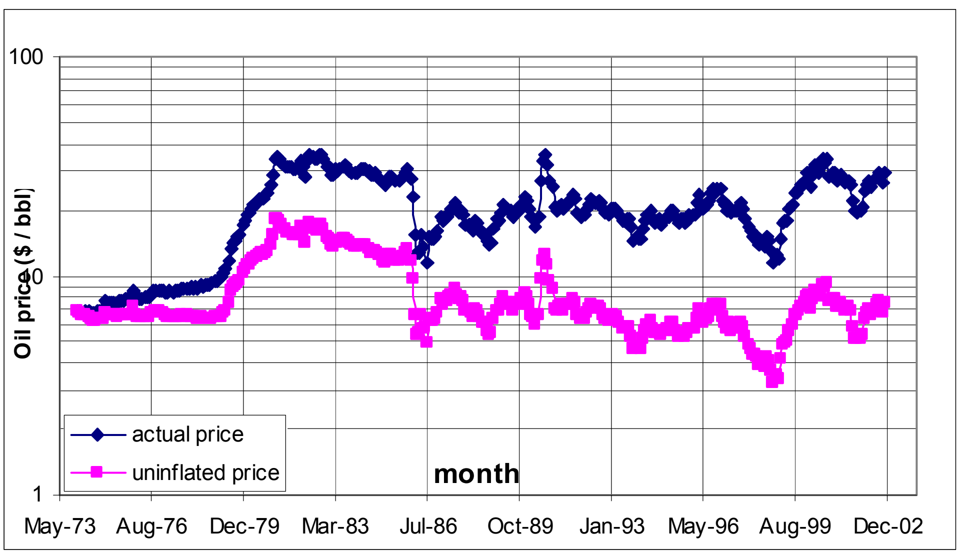

Fig. 3.11- Comparison of actual and uninflated crude prices.

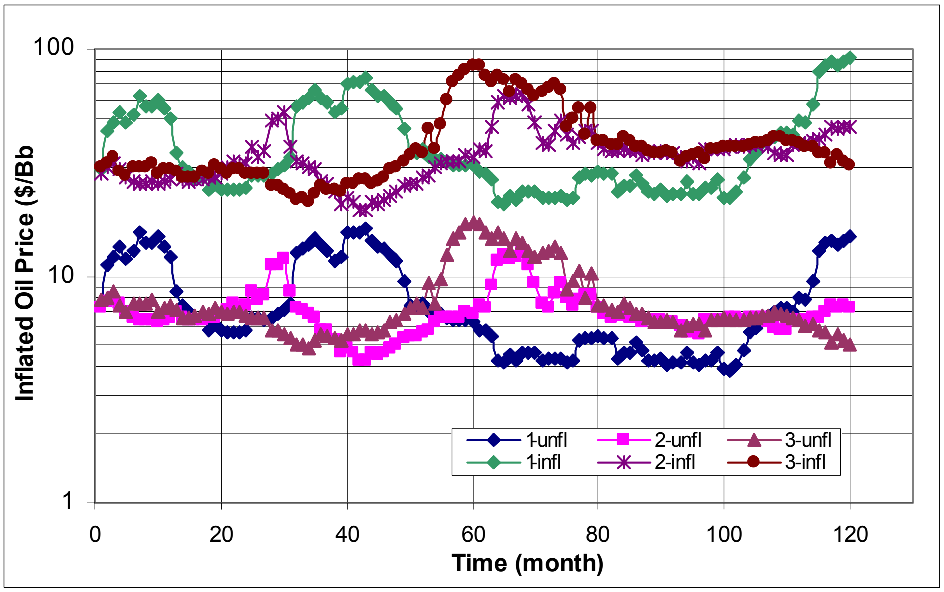

Fig 3.12- Uninflated and inflated scenarios built from G.S. method.

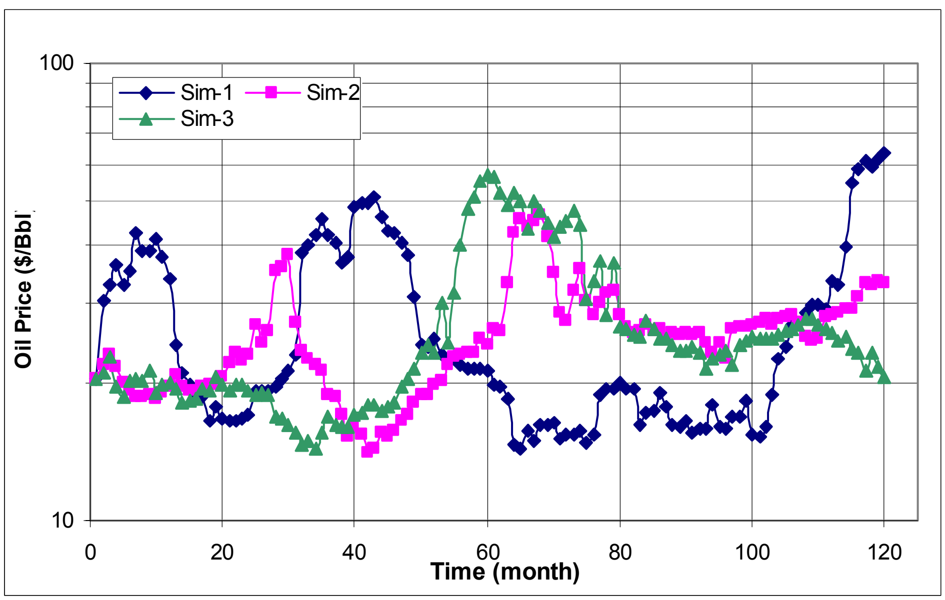

Fig 3.13- Normalized oil price scenarios from G.S. method.

Application to field case

The third part of this research was to apply the historical method developed earlier to a real field case of incremental oil recovery in a six year duration project. The objective was to determine the feasibility of undertaking incremental recovery by gas and water injection. To do this we selected net present value as the optimization variable. We developed an economics model that would allow us to estimate the net present value using the input and output data from obtained history match run. Major costs, prices and assumptions of this model are presented in **Table 3.2** to **3.5**. Production forecasts with and without gas injection in the field were available. Monthly oil, gas and water production data were available for each well. A gas injection well was proposed to be drilled in the 6th month from start date. The produced gas had to be compressed and the compression cost per MMSCF was available.

For the injection case, installation of the gas compressor and water injection facility costs were added. The produced gas was reinjected along with makeup gas and the compression cost for this operation was calculated on monthly basis. The operating costs for production and gas, water injection with the cost of operation for gas compression for wells were available on monthly basis. A scaling factor of one in **Table 3.2** means that we used a linear relationship between capital facilities costs and actual throughput volumes. The actual cost of capital facilities was calculated according to the following formula.

$$\text{Actual Cost} = \text{Base Cost} * \left(\frac{(\text{Actual Throughput} - \text{Base Throughput})}{\text{Base Throughput}} \right)$$

The operating cost of compression facility was volume constrained. We used the incremental oil produced in the injection case to calculate the revenue stream.

TABLE 3.2-- Capital Costs Summary for Incremental Recovery Project.

Facility	Base Throughput		Base Cost ($M)
Compression Facilities	0.220 m^3x10^6/day	7.77 MMCF/day	350
Water Injection Facilities	2.000 m^3x10^6/day	12.58 MSTB/day	5,000
Additional Gas Handling Facilities[1]	1.000 m^3x10^6/day	35.31 MMCF/day	1,000
[1]in excess of 70.6 MMCF/D (2 MM m^3/day) for all the fields			

TABLE 3.3-- Well Operating Costs Summary for Incremental Recovery Project.

Well Type	Cost per Well	
Production Wells	10,000	$/well/month
Gas Injection Wells	10,000	$/well/month
Water Injection Wells	10,000	$/well/month

TABLE 3.4 – Gas Injection Operating Summary for Incremental Recovery Project.

Type of injection	Volume		Cost ($/month)
Gas re-injection	0.220 m^3x10^6/day	7.77 MMCF/day	32,000
Make-up gas injection	0.382 m^3x10^6/day	13.49 MMCF/day	32,000

TABLE 3.5 – Drilling Cost and Price of Crude for Incremental Recovery Project.

Parameter	Value
Net Oil Price	20.5 $/STB
Cost of Drilling and Completion of a New Well	2.0 $MM/well

The developed drilling and production correlation with the historical price patterns the operation was analyzed for both the cases. We carried out conventional approach using correlation and also without it to see the effects of correlation.

The economic yardstick used here for analysis was NPV only as PV/I and NPV/I are not useful because the investment differs with the injection case and can't be compared on same basis. For IRR in case of incremental recovery projects gives multiple rates. **Fig. 3.14** shows the oil production profile under injection and no injection case.

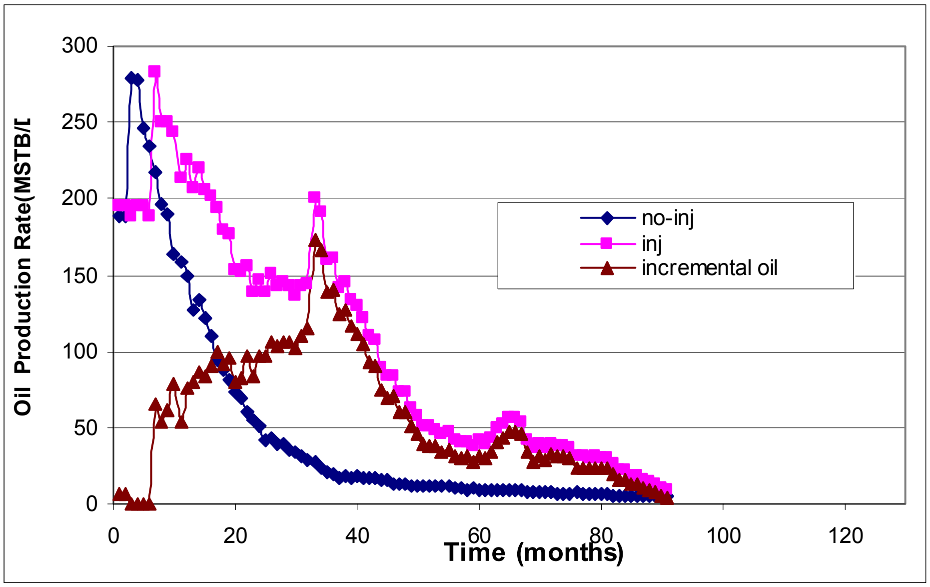

Fig. 3.14- Oil production scenarios with and without injection.

CHAPTER IV

RESULTS

Results for typical cash flow streams

Tables 4.1- 4.3 show the ranges of uncertainty for the three projects with dissimilar cash-flow profiles. The most notable conclusion is that the range of uncertainty for economic indicators determined using conventional analysis is far narrower than that obtained from either historical method or the Gaussian simulation method.

TABLE 4.1 Ranges in Values of Investment Evaluation Indicators, Decreasing Cash Flow Case.

Decreasing Cash Flow Case						
	Conventional Method		Historical Method		Gaussian Simulation Method	
	High	Low	High	Low	High	Low
IRR (%)	33.2	20.2	71.0	8.83	75.0	5.68
NPV@ 5% ($)	6,713	3,126	19,539	873	16,284	145
NPV@ 10% ($)	4,992	1,917	16,230	(239)	13,644	(829)
NPV@ 15% ($)	3,570	899	13,499	(1,162)	11,437	(1640)
NPV/I @ 5%	0.67	0.31	1.95	0.09	1.63	0.01
NPV/I @ 10%	0.50	0.19	1.62	(0.02)	1.36	(0.08)
NPV/I @ 15%	0.36	0.09	1.35	(0.12)	1.14	(0.16)

TABLE 4.2 Ranges in Values of Investment Evaluation Indicators, Increasing Cash Flow Case.

Increasing Cash Flow Case						
	Conventional Method		Historical Method		Gaussian simulation method	
	High	Low	High	Low	High	Low
IRR (%)	22.9	8.2	32.1	7.9	26.1	10.4
NPV@ 5% ($)	12,009	1,299	25,156	1,222	17,216	2,410
NPV@ 10% ($)	6,769	(565)	15,774	(679)	10,110	161
NPV@ 15% ($)	3,321	(1,808)	9,609	(1,931)	5,504	(1,325)
NPV/I @ 5%	2.40	0.26	5.03	0.24	3.44	0.48
NPV/I @ 10%	1.35	(0.11)	3.15	(0.14)	2.02	0.03
NPV/I @ 15%	0.66	(0.36)	1.92	(0.39)	1.10	(0.26)

TABLE 4.3 Ranges in Values of Investment Evaluation Indicators, Constant Cash Flow Case.

Constant Cash Flow Case						
	Conventional Method		**Historical Method**		**Gaussian simulation method**	
	High	Low	High	Low	High	Low
IRR (%)	24.7	10.5	43.9	9.1	36.2	9.310
NPV@ 5% ($)	13,560	2,543	26,501	1,868.5	18,720	2,344
NPV@ 10% ($)	8,629	220	18,513	(343)	12,095	(311)
NPV@ 15% ($)	4,563	(1,472)	12,792	(1,939)	7,535	(2,178)
NPV/I @ 5%	1.36	0.25	2.65	0.19	1.87	0.23
NPV/I @ 10%	0.83	0.02	1.85	0.03	1.21	(0.03)
NPV/I @ 15%	0.46	0.15	1.28	0.19	0.75	(0.21)

Fig. 4.1 to **4.9** show the cash flow profiles obtained for these projects with dissimilar cash flow streams. For the conventional method, **Fig. 4.1** shows the low, most likely, high and base (no inflation) scenarios. The graphs of cash flow profiles for the results using historical and Gaussian simulation method include bounding scenarios that show limits of the ranges in variation of annual cash flow. Note that the ranges for high to low case are much wider than those found using the conventional method. The data series in historical method graph is the scenario modeled according to price profile of that year similarly the number data series in G.S. method charts indicates the particular price scenario generated using the simulator.

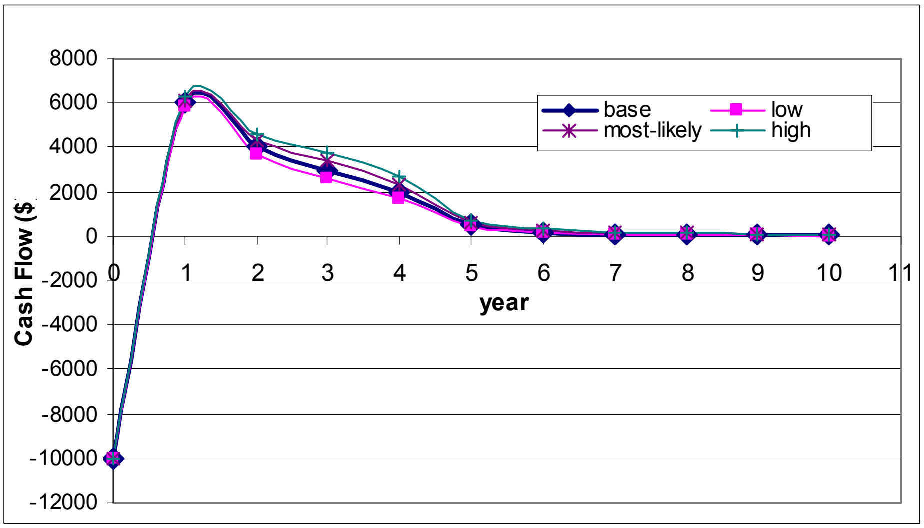

Fig. 4.1- Cash flow ranges obtained for decreasing cash flow case by conventional methods.

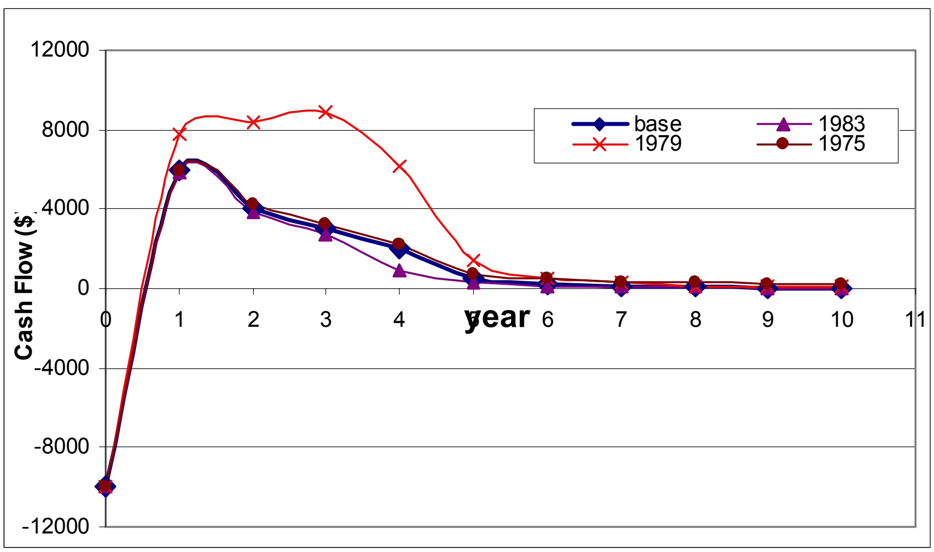

Fig. 4.2- Cash flow ranges obtained for decreasing cash flow case by historical methods.

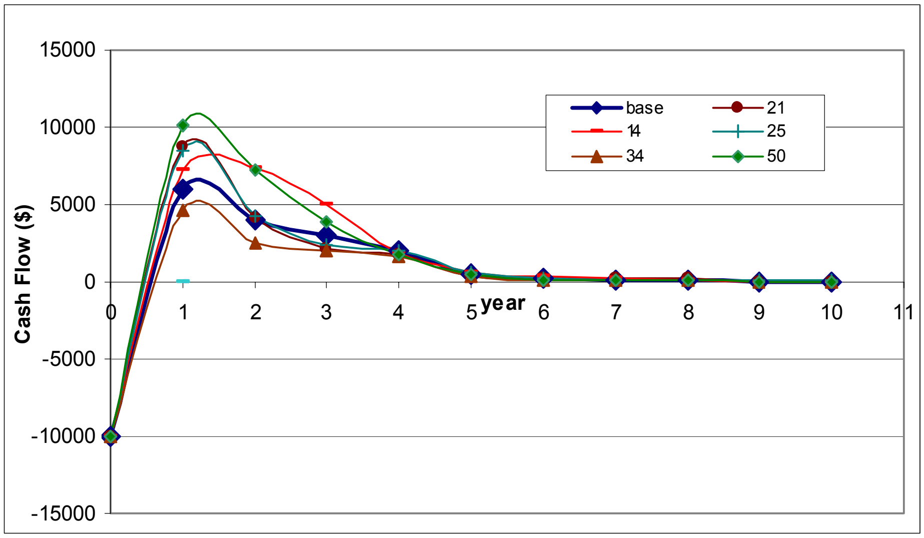

Fig. 4.3- Cash flow ranges obtained for decreasing cash flow case by Gaussian simulation methods.

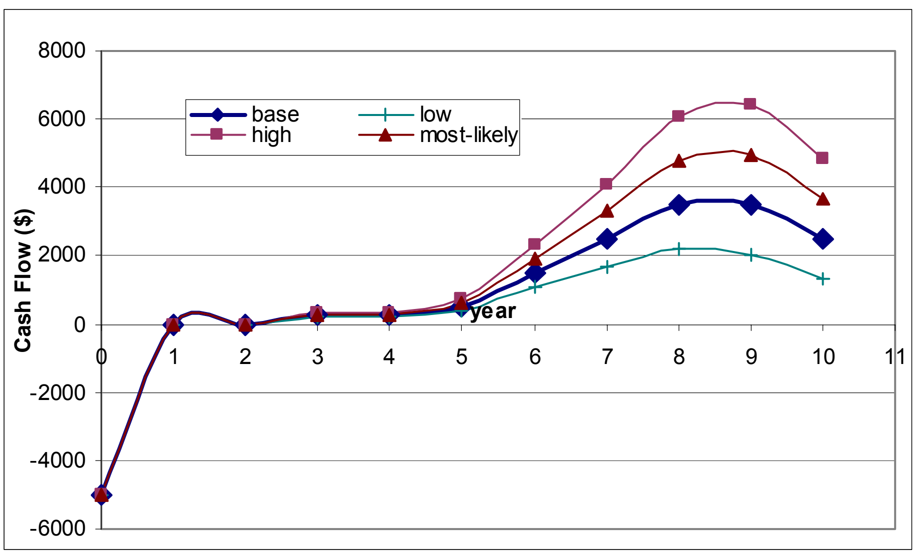

Fig. 4.4- Cash flow ranges obtained for increasing cash flow case by conventional methods.

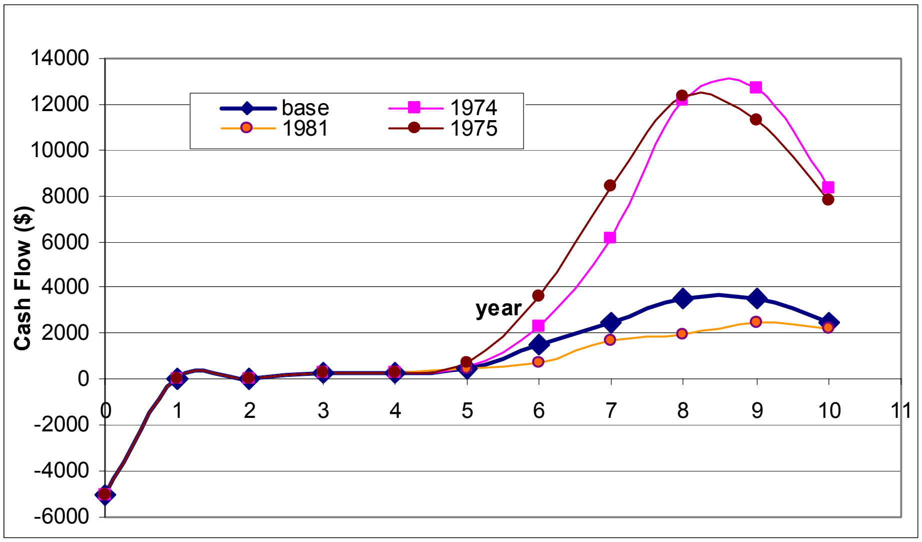

Fig. 4.5- Cash flow ranges obtained for increasing cash flow case by historical methods.

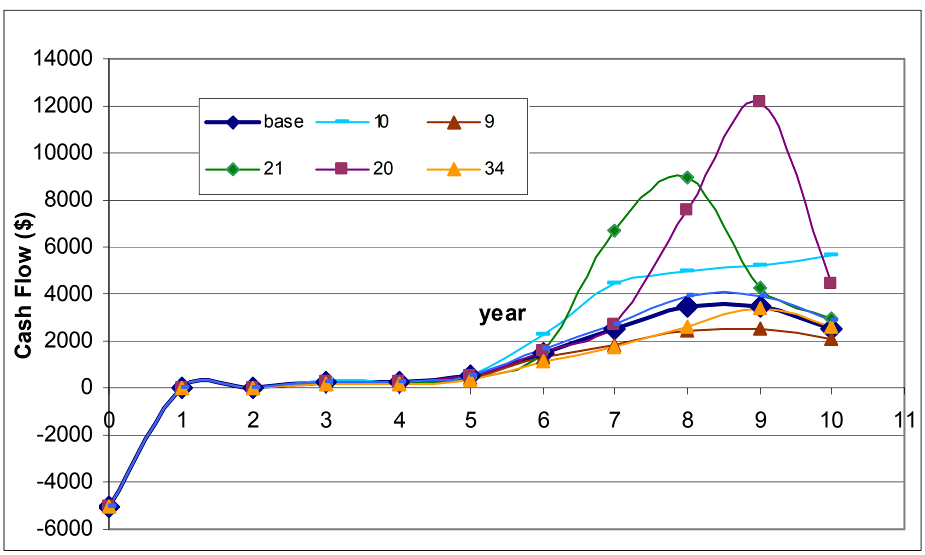

Fig 4.6- Cash flow ranges obtained for increasing cash flow case by Gaussian simulation methods.

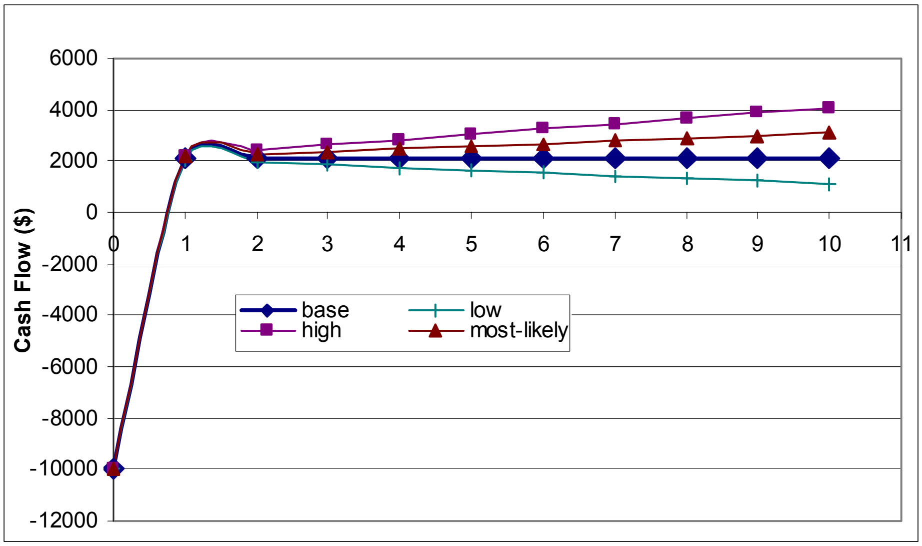

Fig. 4.7- Cash flow ranges obtained for constant cash flow case by conventional methods.

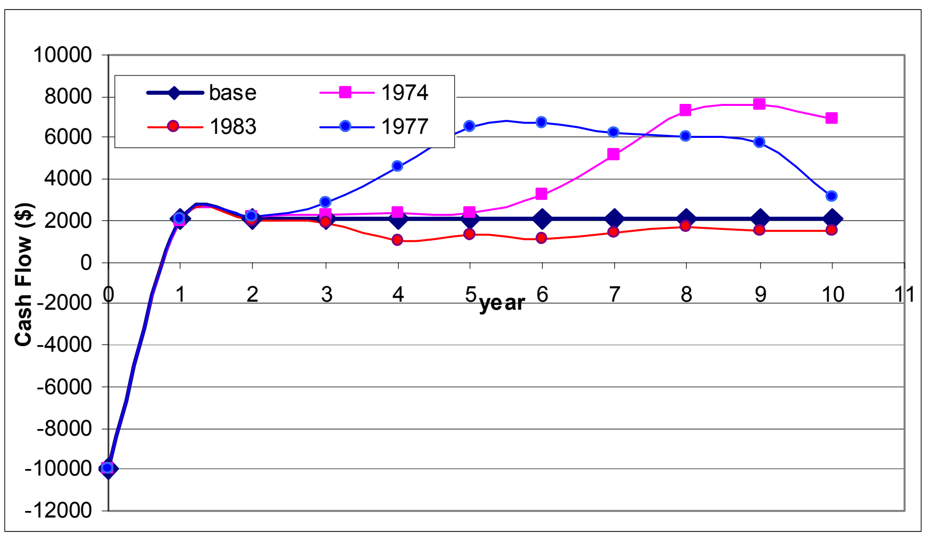

Fig. 4.8- Cash flow ranges obtained for constant cash flow case by historical methods.

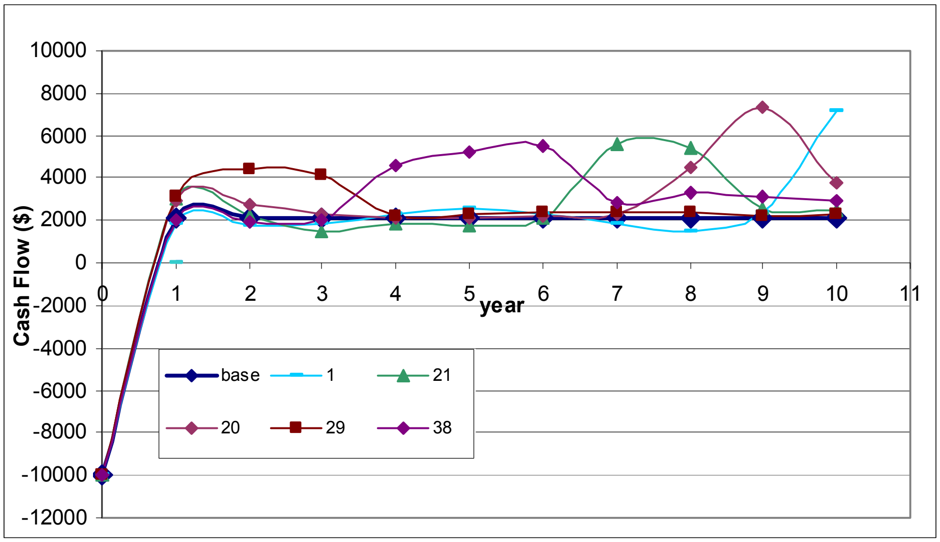

Fig. 4.9- Cash flow ranges obtained for constant cash flow case by Gaussian simulation method.

Fig. 4.10 to **4.18** show the ranges in investment evaluation yardsticks as determined by conventional, historical and Gaussian simulation method. The ranges high to low are much smaller for the conventional method than for the two methods based on actual price histories. The cause of these discrepancies is that the conventional method does not capture the short term volatility in prices that have actually occurred in the past.

TABLE 4.4 -- Ranges of Gaussian Simulation as Percentage of Historical Method.

	Decreasing cash flow case	Increasing cash flow case	Constant cash flow case	Average
IRR (%)	112%	65%	77%	85%
NPV @5% ($)	86%	62%	66%	72%
NPV @10% ($)	88%	60%	66%	71%
NPV @15% ($)	89%	59%	66%	71%
NPV/I @5%	87%	62%	67%	72%
NPV/I @10%	88%	60%	68%	72%
NPV/I @15%	89%	59%	89%	79%

Table 4.4 shows the ranges obtained from Gaussian simulation method calculated as percentage of the ranges calculated for the historical method. The rate averages about

75%. The inability of G.S. method to capture the remaining 30% uncertainty can be attributed to the underlying oil price histogram. In historical method as the scenarios are built with respect to each year, every scenario has its own histogram which gives the variability and effectively captures the uncertainty where as in G.S. method there is only one histogram or price profile used to generate the 50 scenarios.

Fig. **4.10 to 4.18** show the ranges of investment evaluation yardsticks calculated using conventional, historical and G.S. method. For the sensitivity analysis within G.S. method three types of ranges are calculated that are based on underlying scenarios used. To see the effectiveness of the method 15, 35 and 50 scenarios used to calculate the maximum change in values of economic indicator or the range and then these ranges are plotted on the stock market chart. The figures show that there is little difference in the calculated ranges of certainty when we consider 15, 35 and 50 prediction scenarios. The result indicates that 50 scenarios should be more that sufficient.

From the table we can make one more evident conclusion about the relation ship between the ranges of uncertainty by G.S. method and that of historical method. Here in the analysis we selected three projects having entirely different annual cash flow stream. The table shows that G.S. method has obtained ranges greater than 85% of the historical method for the decreasing project where as it predicts the 60% of the range for increasing project. The constant project cash flow gives almost 68% of the range of historical method. The variation in result of ranges with respect to cash flow stream suggests that the method is dependant on the cash flow pattern and there exists high degree of correlation for declining type of project among the both method.

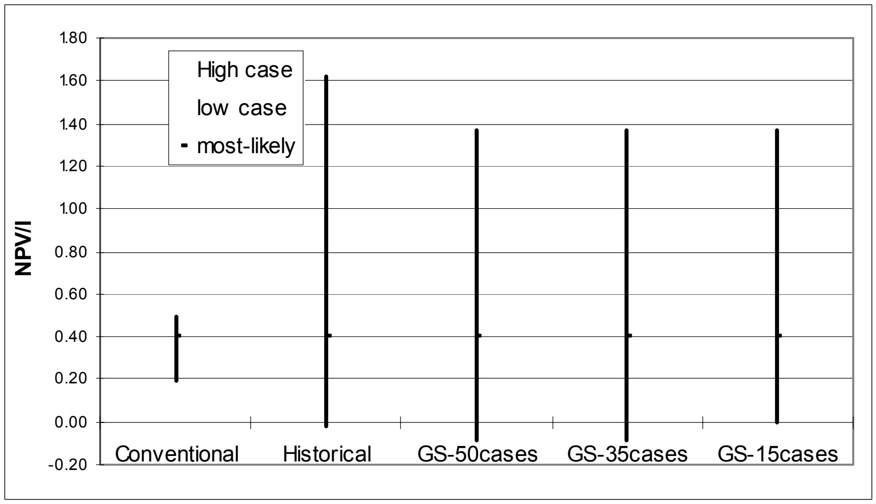

Fig. 4.10- Uncertainty ranges for decreasing cash flow case with NPV/I -10% yardstick.

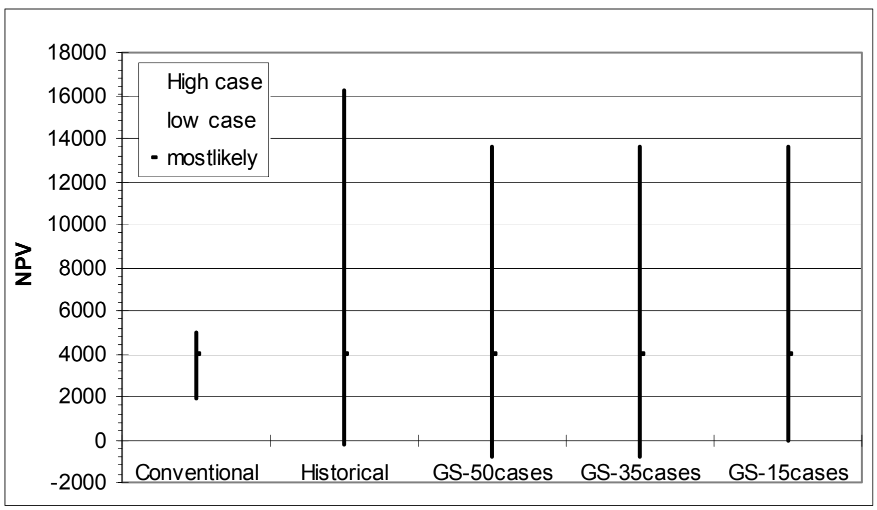

Fig. 4.11- Uncertainty ranges for decreasing cash flow case with NPV-10% yardstick.

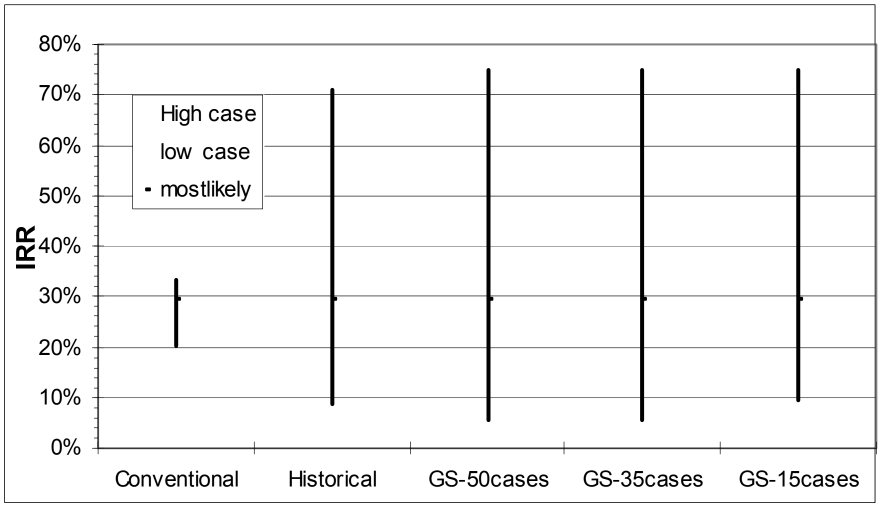

Fig. 4.12- Uncertainty ranges for decreasing cash flow case with internal rate of return yardstick.

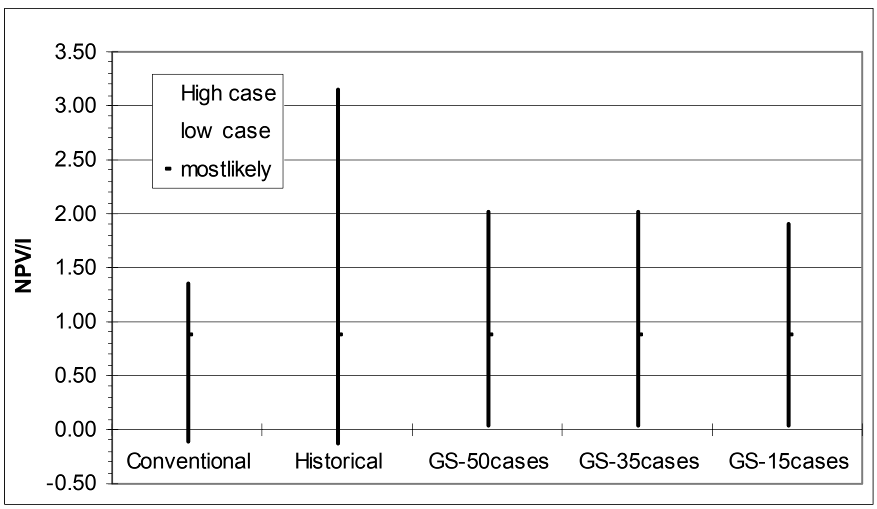

Fig. 4.13- Uncertainty ranges for increasing cash flow case with NPV/I -10% yardstick.

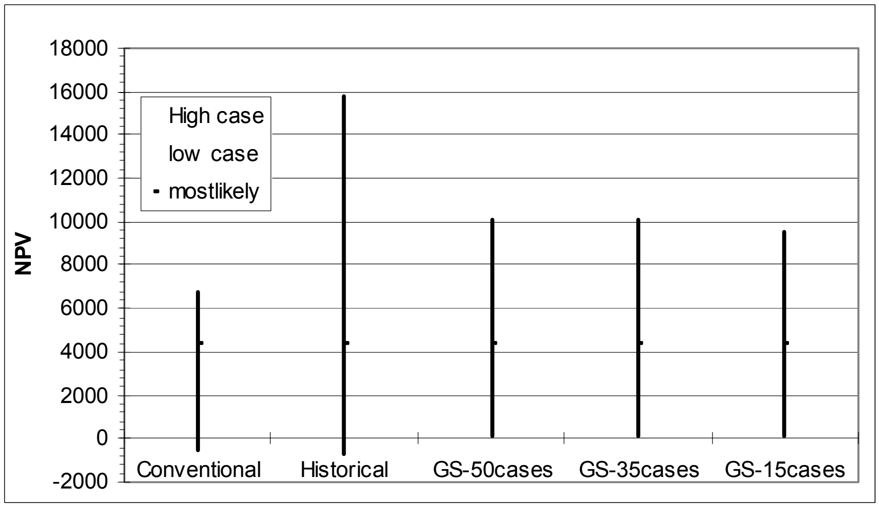

Fig. 4.14- Uncertainty ranges for increasing cash flow case with NPV-10% yardstick.

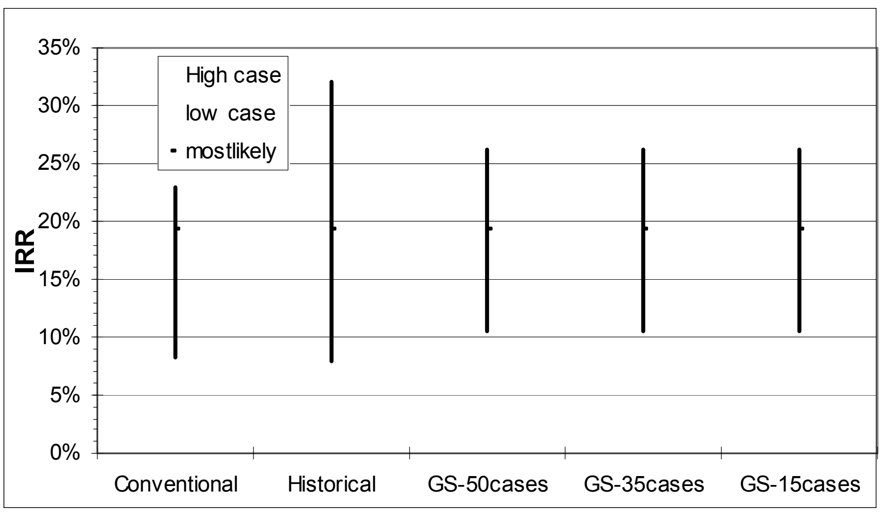

Fig. 4.15- Uncertainty ranges for increasing cash flow case with internal rate of return yardstick.

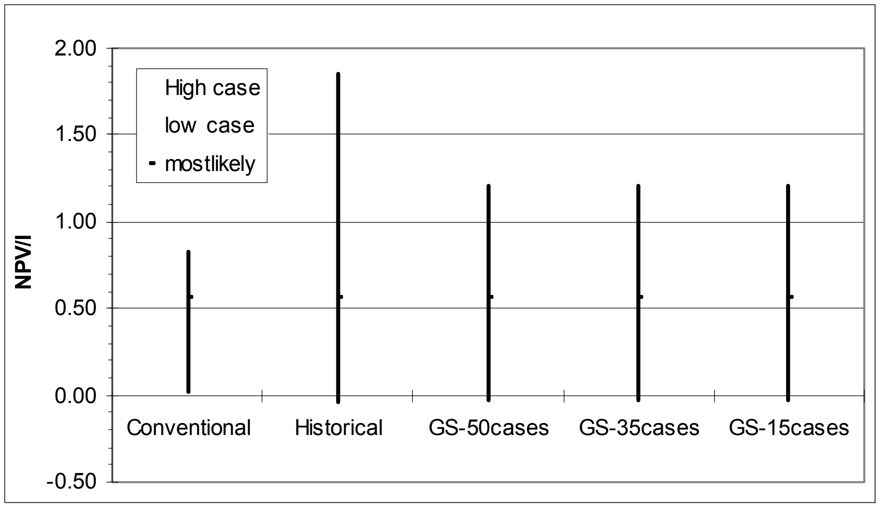

Fig. 4.16- Uncertainty ranges for constant cash flow case with NPV/I -10% yardstick.

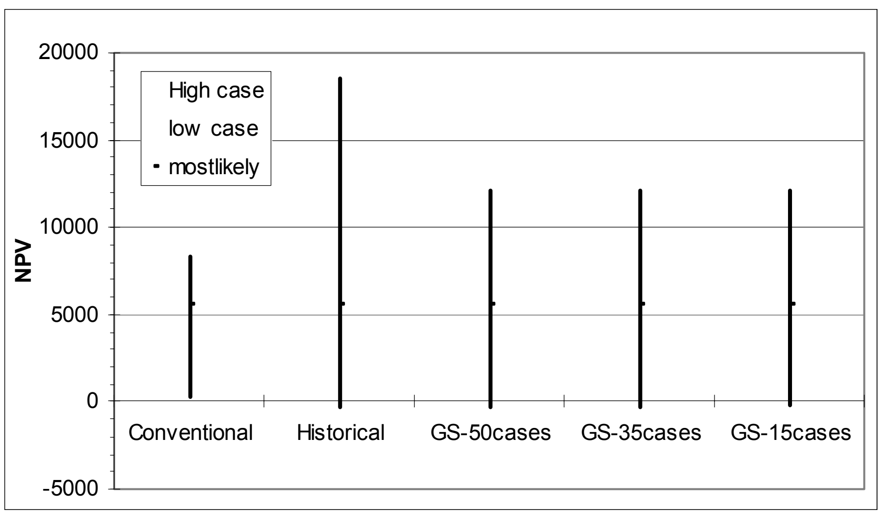

Fig. 4.17- Uncertainty ranges for constant cash flow case with NPV-10% yardstick.

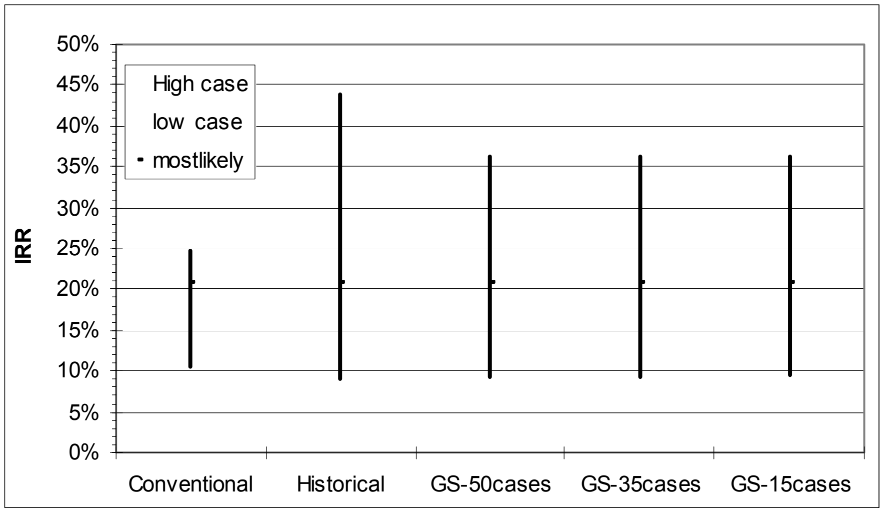

Fig. 4.18- Uncertainty ranges for constant cash flow case with internal rate of return yardstick.

Table 4.5 gives the ranges of uncertainty we obtained for the incremental recovery case with conventional method and historical method. We note that the uncertainty range obtained from the historical method is four times larger than that for the conventional method. We also note that the use of our correlations of operating and drilling costs with oil price .Therefore we can conclude from the results that the conventional method of monotonic increase in price used to obtain future price range is not sufficient to model the uncertainty as the analysis with the historical method that has modeled the scenarios based on historical price profile starting from 1974 suggests there is large uncertainty hiding which is outside of the scope of conventional method and use of these methods will improve the uncertainty estimates and project selection capabilities of the decision makers.

In **Fig. 4.19**, cumulative distribution function (CDF) is generated from the historical method scenarios for the field case of incremental recovery using which P-10, P-50, P-90 values can be calculated. **Fig. 4.20** shows the uncertainty range on the stock market chart obtained from **table 4.5**.

TABLE 4.5 -- Uncertainty Range for Incremental Recovery Project.

NPV @12%			
	Conventional Method	Historical Method	Conventional Method No Correlation used
High Case	$76,996,535	$193,459,369	$76,277,964
Low Case	$49,769,343	$46,229,020	$50,124,589
Most Likely Case	$67,918,074	$67,918,074	$67,560,128
Range	$27,227,192	$147,230,349	$26,153,374

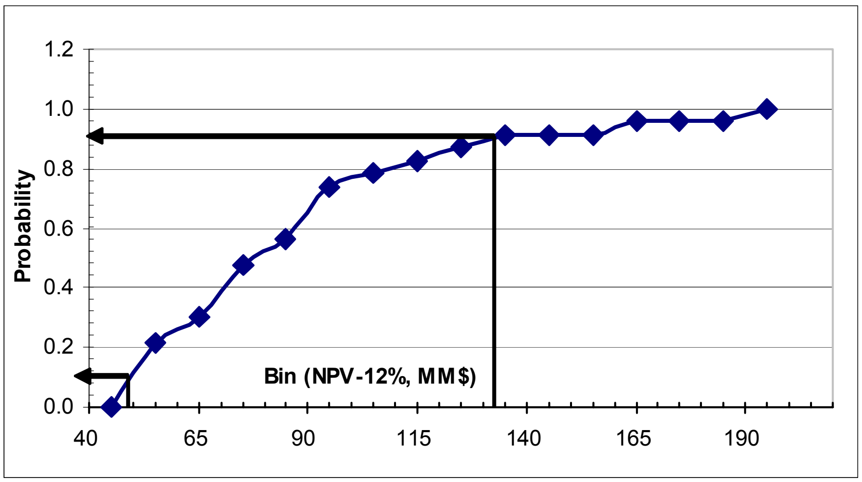

Fig. 4.19- C.D.F. of incremental recovery case showing range of net present value.

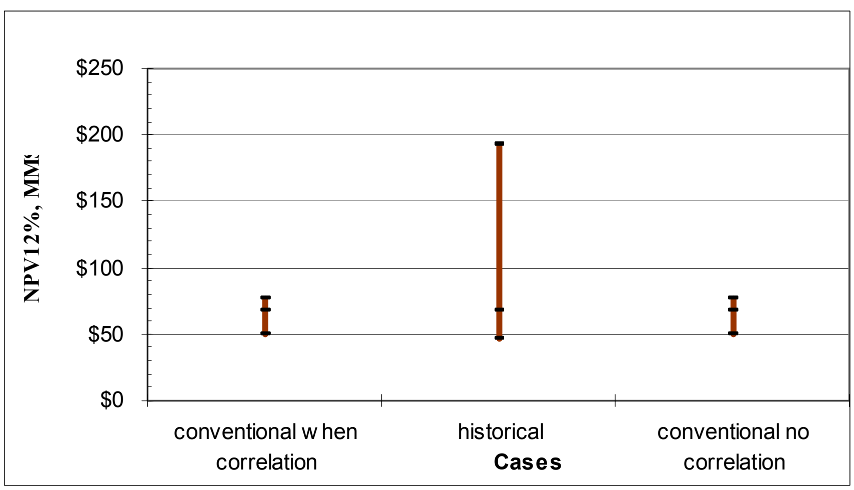

Fig. 4.20- Uncertainty range comparison for incremental recovery case.

CHAPTER V
CONCLUSIONS AND FUTURE WORK

This research applied probabilistic and geostatistical technique to discounted cash flow streams from representative petroleum projects to quantify the economic uncertainty. The results for the model projects allow us to draw the following conclusions.

1. The ranges of uncertainty obtained from conventional analysis are very narrow and are in consistent with that we observed for historical uncertainty ranges captured by historical and Gaussian simulation (G.S.) method using the past three decades oil price data.
2. The reason for the narrow ranges observed in conventional method is caused by the methods exclusion of short period “shocks” or volatility in prices.
3. The historical method represents the observed economic uncertainty in past three decades because it includes the price volatility that occurred for 1974 to 2002.
4. The G.S. method that we proposed has 70 per cent of the range of uncertainty observed in historical method for the economic indicators we used in the study reason being the histogram used for price modeling. The historical method uses histograms generated with varying ranges from the past prices as compared to the G.S. method that has only one underlying histogram.
5. The range of uncertainty produced by the G.S. method is dependant on cash flow pattern as the percentage of range in terms of historical method varies from 59 to almost 90%. For the project having declining cash flow pattern there is high degree of correlation among the both methods compared to other two cash flow patterns.
6. The sensitivity analysis for the G.S. method showed that the range of uncertainty produced by 15 scenarios differs slightly for that produced by 35 scenarios and that there was no further change when 50 prediction scenarios were considered.
7. The field case of incremental recovery using water and gas injection validates the earlier conclusion that conventional method is not sufficient to model the uncertainty as the ranges of uncertainty produced by conventional method and historical method for NPV/I at 12% economic yardstick differ by almost 400%.

Future work could be directed at modifying the conventional method so that it accounts for the price volatility. This might be achieved by using a statistical technique like bootstrap[3]. The sensitivity of the system can be increased by daily spot price for historical method than monthly average price. This change would generate thousands of scenarios similar to the Monte Carlo simulation technique.

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APPENDIX A

Table A-1 gives WTI crude price with the CPI index data used in this research. The following columns describe the values derived from this data to use in methods used in research. The inflation index column for year 1974 is derived from CPI data by normalizing it with January 1974. To give a comparison between deflated price and actual price the next column of deflated oil price is generated using the 1974 inflation index column. The average inflation index is derived analyzing the CPI data the procedure is explained in Appendix B. The historical method uses the average inflated price indices these price profile is generated using the deflated oil price and average inflation index over here we show the average inflation price profile for year 1974.

TABLE A.1- Historical Oil Price and Inflation Indices.

	Month	Actual Oil Price ($/STB)	C.P.I. Index	Inflation Index for 1974=1.0	Deflated Oil Price 1974 =6.95	Average Inflation Index	Average Inflated Price ($/STB)
0	Jan-74	6.95	46.6	1.0000	6.95	1.0000	6.95
1	Feb-74	6.87	47.2	1.0129	6.78	1.0039	6.81
2	Mar-74	6.77	47.8	1.0258	6.60	1.0078	6.65
3	Apr-74	6.77	48.0	1.0300	6.57	1.0118	6.65
4	May-74	6.87	48.6	1.0429	6.59	1.0158	6.69
5	Jun-74	6.85	49.0	1.0515	6.51	1.0197	6.64
6	Jul-74	6.80	49.4	1.0601	6.41	1.0237	6.57
7	Aug-74	6.71	50.0	1.0730	6.25	1.0277	6.43
8	Sep-74	6.70	50.6	1.0858	6.17	1.0318	6.37
9	Oct-74	6.97	51.1	1.0966	6.36	1.0358	6.58
10	Nov-74	6.97	51.5	1.1052	6.31	1.0399	6.56
11	Dec-74	7.09	51.9	1.1137	6.37	1.0439	6.65
12	Jan-75	7.61	52.1	1.1180	6.81	1.0480	7.13
13	Feb-75	7.47	52.5	1.1266	6.63	1.0521	6.98
14	Mar-75	7.57	52.7	1.1309	6.69	1.0562	7.07
15	Apr-75	7.55	52.9	1.1352	6.65	1.0604	7.05
16	May-75	7.52	53.2	1.1416	6.59	1.0645	7.01
17	Jun-75	7.49	53.6	1.1502	6.51	1.0687	6.96
18	Jul-75	7.75	54.2	1.1631	6.66	1.0729	7.15
19	Aug-75	7.73	54.3	1.1652	6.63	1.0771	7.15

	Month	Actual Oil Price ($/STB)	C.P.I. Index	Inflation Index for 1974=1.0	Deflated Oil Price 1974 =6.95	Average Inflation Index	Average Inflated Price ($/STB)
20	Sep-75	7.75	54.6	1.1717	6.61	1.0813	7.15
21	Oct-75	7.83	54.9	1.1781	6.65	1.0855	7.21
22	Nov-75	7.80	55.3	1.1867	6.57	1.0898	7.16
23	Dec-75	7.93	55.5	1.1910	6.66	1.0941	7.28
24	Jan-76	8.63	55.6	1.1931	7.23	1.0984	7.94
25	Feb-76	7.87	55.8	1.1974	6.57	1.1027	7.25
26	Mar-76	7.79	55.9	1.1996	6.49	1.1070	7.19
27	Apr-76	7.86	56.1	1.2039	6.53	1.1113	7.26
28	May-76	7.89	56.5	1.2124	6.51	1.1157	7.26
29	Jun-76	7.99	56.8	1.2189	6.56	1.1200	7.34
30	Jul-76	8.04	57.1	1.2253	6.56	1.1244	7.38
31	Aug-76	8.03	57.4	1.2318	6.52	1.1288	7.36
32	Sep-76	8.39	57.6	1.2361	6.79	1.1332	7.69
33	Oct-76	8.46	57.9	1.2425	6.81	1.1377	7.75
34	Nov-76	8.62	58.0	1.2446	6.93	1.1421	7.91
35	Dec-76	8.62	58.2	1.2489	6.90	1.1466	7.91
36	Jan-77	8.50	58.5	1.2554	6.77	1.1511	7.79
37	Feb-77	8.57	59.1	1.2682	6.76	1.1556	7.81
38	Mar-77	8.45	59.5	1.2768	6.62	1.1601	7.68
39	Apr-77	8.40	60.0	1.2876	6.52	1.1647	7.60
40	May-77	8.49	60.3	1.2940	6.56	1.1692	7.67
41	Jun-77	8.44	60.7	1.3026	6.48	1.1738	7.61
42	Jul-77	8.48	61.0	1.3090	6.48	1.1784	7.63
43	Aug-77	8.62	61.2	1.3133	6.56	1.1830	7.76
44	Sep-77	8.63	61.4	1.3176	6.55	1.1877	7.78
45	Oct-77	8.72	61.6	1.3219	6.60	1.1923	7.87
46	Nov-77	8.72	61.9	1.3283	6.56	1.1970	7.86
47	Dec-77	8.77	62.1	1.3326	6.58	1.2017	7.91
48	Jan-78	8.68	62.5	1.3412	6.47	1.2064	7.81
49	Feb-78	8.84	62.9	1.3498	6.55	1.2111	7.93
50	Mar-78	8.80	63.4	1.3605	6.47	1.2158	7.86
51	Apr-78	8.82	63.9	1.3712	6.43	1.2206	7.85
52	May-78	8.81	64.5	1.3841	6.37	1.2254	7.80
53	Jun-78	9.05	65.2	1.3991	6.47	1.2302	7.96
54	Jul-78	8.96	65.7	1.4099	6.36	1.2350	7.85
55	Aug-78	9.05	66.0	1.4163	6.39	1.2398	7.92
56	Sep-78	9.15	66.5	1.4270	6.41	1.2447	7.98
57	Oct-78	9.17	67.1	1.4399	6.37	1.2496	7.96
58	Nov-78	9.20	67.4	1.4464	6.36	1.2545	7.98

	Month	Actual Oil Price ($/STB)	C.P.I. Index	Inflation Index for 1974=1.0	Deflated Oil Price 1974 =6.95	Average Inflation Index	Average Inflated Price ($/STB)
59	Dec-78	9.47	67.7	1.4528	6.52	1.2594	8.21
60	Jan-79	9.46	68.3	1.4657	6.45	1.2643	8.16
61	Feb-79	9.69	69.1	1.4828	6.53	1.2693	8.29
62	Mar-79	9.83	69.8	1.4979	6.56	1.2742	8.36
63	Apr-79	10.33	70.6	1.5150	6.82	1.2792	8.72
64	May-79	10.71	71.5	1.5343	6.98	1.2842	8.96
65	Jun-79	11.70	72.3	1.5515	7.54	1.2893	9.72
66	Jul-79	13.39	73.1	1.5687	8.54	1.2943	11.05
67	Aug-79	14.00	73.8	1.5837	8.84	1.2994	11.49
68	Sep-79	14.57	74.6	1.6009	9.10	1.3045	11.87
69	Oct-79	15.11	75.2	1.6137	9.36	1.3096	12.26
70	Nov-79	15.52	75.9	1.6288	9.53	1.3147	12.53
71	Dec-79	17.03	76.7	1.6459	10.35	1.3199	13.66
72	Jan-80	17.86	77.8	1.6695	10.70	1.3250	14.17
73	Feb-80	18.81	78.9	1.6931	11.11	1.3302	14.78
74	Mar-80	19.34	80.1	1.7189	11.25	1.3354	15.03
75	Apr-80	20.29	81.0	1.7382	11.67	1.3407	15.65
76	May-80	21.01	81.8	1.7554	11.97	1.3459	16.11
77	Jun-80	21.53	82.7	1.7747	12.13	1.3512	16.39
78	Jul-80	22.26	82.7	1.7747	12.54	1.3565	17.01
79	Aug-80	22.63	83.3	1.7876	12.66	1.3618	17.24
80	Sep-80	22.59	84.0	1.8026	12.53	1.3671	17.13
81	Oct-80	23.23	84.8	1.8197	12.77	1.3725	17.52
82	Nov-80	23.92	85.5	1.8348	13.04	1.3778	17.96
83	Dec-80	25.80	86.3	1.8519	13.93	1.3832	19.27
84	Jan-81	28.85	87.0	1.8670	15.45	1.3887	21.46
85	Feb-81	34.14	87.9	1.8863	18.10	1.3941	25.23
86	Mar-81	34.70	88.5	1.8991	18.27	1.3996	25.57
87	Apr-81	34.05	89.1	1.9120	17.81	1.4050	25.02
88	May-81	32.71	89.8	1.9270	16.97	1.4105	23.94
89	Jun-81	31.71	90.6	1.9442	16.31	1.4161	23.10
90	Jul-81	31.13	91.6	1.9657	15.84	1.4216	22.51
91	Aug-81	31.13	92.3	1.9807	15.72	1.4272	22.43
92	Sep-81	31.13	93.2	2.0000	15.57	1.4328	22.30
93	Oct-81	31.00	93.4	2.0043	15.47	1.4384	22.25
94	Nov-81	30.98	93.7	2.0107	15.41	1.4440	22.25
95	Dec-81	30.72	94.0	2.0172	15.23	1.4497	22.08
96	Jan-82	33.85	94.3	2.0236	16.73	1.4553	24.34
97	Feb-82	31.56	94.6	2.0300	15.55	1.4610	22.71

	Month	Actual Oil Price ($/STB)	C.P.I. Index	Inflation Index for 1974=1.0	Deflated Oil Price 1974 =6.95	Average Inflation Index	Average Inflated Price ($/STB)
98	Mar-82	28.48	94.5	2.0279	14.04	1.4668	20.60
99	Apr-82	33.45	94.9	2.0365	16.43	1.4725	24.19
100	May-82	35.93	95.8	2.0558	17.48	1.4783	25.84
101	Jun-82	35.07	97.0	2.0815	16.85	1.4841	25.00
102	Jul-82	34.16	97.5	2.0923	16.33	1.4899	24.32
103	Aug-82	33.95	97.7	2.0966	16.19	1.4957	24.22
104	Sep-82	35.63	97.9	2.1009	16.96	1.5016	25.47
105	Oct-82	35.68	98.2	2.1073	16.93	1.5075	25.52
106	Nov-82	34.15	98.0	2.1030	16.24	1.5134	24.57
107	Dec-82	31.70	97.6	2.0944	15.14	1.5193	23.00
108	Jan-83	31.19	97.8	2.0987	14.86	1.5252	22.67
109	Feb-83	28.95	97.9	2.1009	13.78	1.5312	21.10
110	Mar-83	28.62	97.9	2.1009	13.62	1.5372	20.94
111	Apr-83	30.61	98.6	2.1159	14.47	1.5432	22.33
112	May-83	30.00	99.2	2.1288	14.09	1.5493	21.83
113	Jun-83	31.00	99.5	2.1352	14.52	1.5553	22.58
114	Jul-83	31.66	99.9	2.1438	14.77	1.5614	23.06
115	Aug-83	31.91	100.2	2.1502	14.84	1.5675	23.26
116	Sep-83	31.11	100.7	2.1609	14.40	1.5737	22.66
117	Oct-83	30.41	101.0	2.1674	14.03	1.5798	22.17
118	Nov-83	29.84	101.2	2.1717	13.74	1.5860	21.79
119	Dec-83	29.24	101.3	2.1738	13.45	1.5922	21.42
120	Jan-84	29.74	101.9	2.1867	13.60	1.5985	21.74
121	Feb-84	30.20	102.4	2.1974	13.74	1.6047	22.05
122	Mar-84	30.76	102.6	2.2017	13.97	1.6110	22.51
123	Apr-84	30.60	103.1	2.2124	13.83	1.6173	22.37
124	May-84	30.67	103.4	2.2189	13.82	1.6237	22.44
125	Jun-84	29.86	103.7	2.2253	13.42	1.6300	21.87
126	Jul-84	28.71	104.1	2.2339	12.85	1.6364	21.03
127	Aug-84	29.22	104.5	2.2425	13.03	1.6428	21.41
128	Sep-84	29.38	105.0	2.2532	13.04	1.6493	21.50
129	Oct-84	28.58	105.3	2.2597	12.65	1.6557	20.94
130	Nov-84	27.99	105.3	2.2597	12.39	1.6622	20.59
131	Dec-84	26.65	105.3	2.2597	11.79	1.6687	19.68
132	Jan-85	25.85	105.5	2.2639	11.42	1.6752	19.13
133	Feb-85	27.33	106.0	2.2747	12.01	1.6818	20.21
134	Mar-85	28.53	106.4	2.2833	12.50	1.6884	21.10
135	Apr-85	28.60	106.9	2.2940	12.47	1.6950	21.13
136	May-85	27.61	107.3	2.3026	11.99	1.7016	20.40

137	Jun-85	27.14	107.6	2.3090	11.75	1.7083	20.08
	Month	Actual Oil Price ($/STB)	C.P.I. Index	Inflation Index for 1974=1.0	Deflated Oil Price 1974 =6.95	Average Inflation Index	Average Inflated Price ($/STB)
138	Jul-85	27.23	107.8	2.3133	11.77	1.7150	20.19
139	Aug-85	27.58	108.0	2.3176	11.90	1.7217	20.49
140	Sep-85	28.53	108.3	2.3240	12.28	1.7285	21.22
141	Oct-85	29.54	108.7	2.3326	12.66	1.7352	21.97
142	Nov-85	30.90	109.0	2.3391	13.21	1.7420	23.01
143	Dec-85	27.46	109.3	2.3455	11.71	1.7488	20.47
144	Jan-86	22.93	109.6	2.3519	9.75	1.7557	17.12
145	Feb-86	15.45	109.3	2.3455	6.59	1.7626	11.61
146	Mar-86	12.61	108.8	2.3348	5.40	1.7695	9.56
147	Apr-86	12.84	108.6	2.3305	5.51	1.7764	9.79
148	May-86	15.38	108.9	2.3369	6.58	1.7834	11.74
149	Jun-86	13.43	109.5	2.3498	5.71	1.7903	10.23
150	Jul-86	11.58	109.5	2.3498	4.93	1.7974	8.86
151	Aug-86	15.10	109.7	2.3541	6.41	1.8044	11.57
152	Sep-86	14.87	110.2	2.3648	6.29	1.8115	11.39
153	Oct-86	14.90	110.3	2.3670	6.29	1.8186	11.45
154	Nov-86	15.22	110.4	2.3691	6.43	1.8257	11.73
155	Dec-86	16.11	110.5	2.3712	6.79	1.8328	12.45
156	Jan-87	18.65	111.2	2.3863	7.82	1.8400	14.38
157	Feb-87	17.75	111.6	2.3948	7.41	1.8472	13.69
158	Mar-87	18.30	112.1	2.4056	7.61	1.8544	14.11
159	Apr-87	18.68	112.7	2.4185	7.72	1.8617	14.38
160	May-87	19.44	113.1	2.4270	8.01	1.8690	14.97
161	Jun-87	20.07	113.5	2.4356	8.24	1.8763	15.46
162	Jul-87	21.34	113.8	2.4421	8.74	1.8837	16.46
163	Aug-87	20.31	114.4	2.4549	8.27	1.8910	15.65
164	Sep-87	19.53	115.0	2.4678	7.91	1.8985	15.02
165	Oct-87	19.86	115.3	2.4742	8.03	1.9059	15.30
166	Nov-87	18.85	115.4	2.4764	7.61	1.9134	14.57
167	Dec-87	17.27	115.4	2.4764	6.98	1.9208	13.40
168	Jan-88	17.13	115.7	2.4828	6.90	1.9284	13.30
169	Feb-88	16.80	116.0	2.4893	6.75	1.9359	13.06
170	Mar-88	16.20	116.5	2.5000	6.48	1.9435	12.59
171	Apr-88	17.86	117.1	2.5129	7.11	1.9511	13.87
172	May-88	17.42	117.5	2.5215	6.91	1.9588	13.54
173	Jun-88	16.53	118.0	2.5322	6.53	1.9664	12.83
174	Jul-88	15.50	118.5	2.5429	6.09	1.9741	12.03
175	Aug-88	15.52	119.0	2.5536	6.08	1.9819	12.05

	Month	Actual Oil Price ($/STB)	C.P.I. Index	Inflation Index for 1974=1.0	Deflated Oil Price 1974 =6.95	Average Inflation Index	Average Inflated Price ($/STB)
176	Sep-88	14.54	119.8	2.5708	5.65	1.9896	11.25
177	Oct-88	13.77	120.2	2.5794	5.34	1.9974	10.66
178	Nov-88	14.14	120.3	2.5815	5.48	2.0052	10.98
179	Dec-88	16.38	120.5	2.5858	6.34	2.0131	12.75
180	Jan-89	18.02	121.1	2.5987	6.94	2.0210	14.02
181	Feb-89	17.94	121.6	2.6094	6.87	2.0289	13.95
182	Mar-89	19.48	122.3	2.6245	7.42	2.0368	15.12
183	Apr-89	21.07	123.1	2.6416	7.98	2.0448	16.31
184	May-89	20.12	123.8	2.6567	7.57	2.0528	15.55
185	Jun-89	20.05	124.1	2.6631	7.53	2.0609	15.52
186	Jul-89	19.78	124.4	2.6695	7.41	2.0689	15.33
187	Aug-89	18.58	124.6	2.6738	6.95	2.0770	14.43
188	Sep-89	19.59	125.0	2.6824	7.30	2.0852	15.23
189	Oct-89	20.10	125.6	2.6953	7.46	2.0933	15.61
190	Nov-89	19.86	125.9	2.7017	7.35	2.1015	15.44
191	Dec-89	21.10	126.1	2.7060	7.80	2.1098	16.45
192	Jan-90	22.86	127.4	2.7339	8.36	2.1180	17.71
193	Feb-90	22.11	128.0	2.7468	8.05	2.1263	17.12
194	Mar-90	20.39	128.7	2.7618	7.38	2.1346	15.76
195	Apr-90	18.43	128.9	2.7661	6.66	2.1430	14.27
196	May-90	18.20	129.2	2.7725	6.56	2.1514	14.12
197	Jun-90	16.70	129.9	2.7876	5.99	2.1598	12.94
198	Jul-90	18.45	130.4	2.7983	6.59	2.1683	14.30
199	Aug-90	27.31	131.6	2.8240	9.67	2.1768	21.05
200	Sep-90	33.51	132.7	2.8476	11.77	2.1853	25.71
201	Oct-90	36.04	133.5	2.8648	12.58	2.1939	27.60
202	Nov-90	32.33	133.8	2.8712	11.26	2.2025	24.80
203	Dec-90	27.28	133.8	2.8712	9.50	2.2111	21.01
204	Jan-91	25.23	134.6	2.8884	8.73	2.2197	19.39
205	Feb-91	20.48	134.8	2.8927	7.08	2.2284	15.78
206	Mar-91	19.90	135.0	2.8970	6.87	2.2372	15.37
207	Apr-91	20.83	135.2	2.9013	7.18	2.2459	16.12
208	May-91	21.23	135.6	2.9099	7.30	2.2547	16.45
209	Jun-91	20.19	136.0	2.9185	6.92	2.2635	15.66
210	Jul-91	21.40	136.2	2.9227	7.32	2.2724	16.64
211	Aug-91	21.69	136.6	2.9313	7.40	2.2813	16.88
212	Sep-91	21.89	137.2	2.9442	7.43	2.2902	17.03
213	Oct-91	23.23	137.4	2.9485	7.88	2.2992	18.11
214	Nov-91	22.46	137.8	2.9571	7.60	2.3082	17.53

	Month	Actual Oil Price ($/STB)	C.P.I. Index	Inflation Index for 1974=1.0	Deflated Oil Price 1974 =6.95	Average Inflation Index	Average Inflated Price ($/STB)
215	Dec-91	19.50	137.9	2.9592	6.59	2.3173	15.27
216	Jan-92	18.79	138.1	2.9635	6.34	2.3263	14.75
217	Feb-92	19.01	138.6	2.9742	6.39	2.3354	14.93
218	Mar-92	18.92	139.3	2.9893	6.33	2.3446	14.84
219	Apr-92	20.23	139.5	2.9936	6.76	2.3538	15.91
220	May-92	20.98	139.7	2.9979	7.00	2.3630	16.54
221	Jun-92	22.38	140.2	3.0086	7.44	2.3722	17.65
222	Jul-92	21.77	140.5	3.0150	7.22	2.3815	17.20
223	Aug-92	21.34	140.9	3.0236	7.06	2.3909	16.87
224	Sep-92	21.88	141.3	3.0322	7.22	2.4002	17.32
225	Oct-92	21.69	141.8	3.0429	7.13	2.4096	17.18
226	Nov-92	20.34	142.0	3.0472	6.67	2.4191	16.15
227	Dec-92	19.41	141.9	3.0451	6.37	2.4285	15.48
228	Jan-93	19.03	142.6	3.0601	6.22	2.4381	15.16
229	Feb-93	20.09	143.1	3.0708	6.54	2.4476	16.01
230	Mar-93	20.32	143.6	3.0815	6.59	2.4572	16.20
231	Apr-93	20.25	144.0	3.0901	6.55	2.4668	16.17
232	May-93	19.95	144.2	3.0944	6.45	2.4765	15.97
233	Jun-93	19.09	144.4	3.0987	6.16	2.4862	15.32
234	Jul-93	17.89	144.4	3.0987	5.77	2.4959	14.41
235	Aug-93	18.01	144.8	3.1073	5.80	2.5057	14.52
236	Sep-93	18.09	145.1	3.1137	5.81	2.5155	14.61
237	Oct-93	18.15	145.7	3.1266	5.81	2.5253	14.66
238	Nov-93	16.61	145.8	3.1288	5.31	2.5352	13.46
239	Dec-93	14.51	145.8	3.1288	4.64	2.5452	11.80
240	Jan-94	15.03	146.2	3.1373	4.79	2.5551	12.24
241	Feb-94	14.78	146.7	3.1481	4.69	2.5651	12.04
242	Mar-94	14.68	147.2	3.1588	4.65	2.5752	11.97
243	Apr-94	16.42	147.4	3.1631	5.19	2.5853	13.42
244	May-94	17.89	147.5	3.1652	5.65	2.5954	14.67
245	Jun-94	19.06	148.0	3.1760	6.00	2.6056	15.64
246	Jul-94	19.65	148.4	3.1845	6.17	2.6158	16.14
247	Aug-94	18.38	149.0	3.1974	5.75	2.6260	15.10
248	Sep-94	17.45	149.4	3.2060	5.44	2.6363	14.35
249	Oct-94	17.72	149.5	3.2082	5.52	2.6466	14.62
250	Nov-94	18.07	149.7	3.2124	5.62	2.6570	14.95
251	Dec-94	17.16	149.7	3.2124	5.34	2.6674	14.25
252	Jan-95	18.04	150.3	3.2253	5.59	2.6778	14.98
253	Feb-95	18.57	150.9	3.2382	5.73	2.6883	15.42

	Month	Actual Oil Price ($/STB)	C.P.I. Index	Inflation Index for 1974=1.0	Deflated Oil Price 1974 =6.95	Average Inflation Index	Average Inflated Price ($/STB)
254	Mar-95	18.54	151.4	3.2489	5.71	2.6989	15.40
255	Apr-95	19.90	151.9	3.2597	6.10	2.7094	16.54
256	May-95	19.74	152.2	3.2661	6.04	2.7200	16.44
257	Jun-95	18.45	152.5	3.2725	5.64	2.7307	15.40
258	Jul-95	17.33	152.5	3.2725	5.30	2.7414	14.52
259	Aug-95	18.02	152.9	3.2811	5.49	2.7521	15.11
260	Sep-95	18.23	153.2	3.2876	5.55	2.7629	15.32
261	Oct-95	17.43	153.7	3.2983	5.28	2.7737	14.66
262	Nov-95	17.99	153.6	3.2961	5.46	2.7846	15.20
263	Dec-95	19.03	153.5	3.2940	5.78	2.7955	16.15
264	Jan-96	18.85	154.4	3.3133	5.69	2.8064	15.97
265	Feb-96	19.09	154.9	3.3240	5.74	2.8174	16.18
266	Mar-96	21.33	155.7	3.3412	6.38	2.8285	18.06
267	Apr-96	23.50	156.3	3.3541	7.01	2.8395	19.89
268	May-96	21.17	156.6	3.3605	6.30	2.8507	17.96
269	Jun-96	20.42	156.7	3.3627	6.07	2.8618	17.38
270	Jul-96	21.30	157.0	3.3691	6.32	2.8730	18.16
271	Aug-96	21.90	157.3	3.3755	6.49	2.8843	18.71
272	Sep-96	23.97	157.8	3.3863	7.08	2.8956	20.50
273	Oct-96	24.88	158.3	3.3970	7.32	2.9069	21.29
274	Nov-96	23.71	158.6	3.4034	6.97	2.9183	20.33
275	Dec-96	25.22	158.6	3.4034	7.41	2.9297	21.71
276	Jan-97	25.13	159.1	3.4142	7.36	2.9412	21.65
277	Feb-97	22.18	159.6	3.4249	6.48	2.9527	19.12
278	Mar-97	20.97	160.0	3.4335	6.11	2.9643	18.10
279	Apr-97	19.70	160.2	3.4378	5.73	2.9759	17.05
280	May-97	20.82	160.1	3.4356	6.06	2.9876	18.10
281	Jun-97	19.26	160.3	3.4399	5.60	2.9993	16.79
282	Jul-97	19.66	160.5	3.4442	5.71	3.0110	17.19
283	Aug-97	19.95	160.8	3.4506	5.78	3.0228	17.48
284	Sep-97	19.80	161.2	3.4592	5.72	3.0346	17.37
285	Oct-97	21.33	161.6	3.4678	6.15	3.0465	18.74
286	Nov-97	20.19	161.5	3.4657	5.83	3.0585	17.82
287	Dec-97	18.33	161.3	3.4614	5.30	3.0704	16.26
288	Jan-98	16.72	161.6	3.4678	4.82	3.0825	14.86
289	Feb-98	16.06	161.9	3.4742	4.62	3.0945	14.30
290	Mar-98	15.12	162.2	3.4807	4.34	3.1066	13.50
291	Apr-98	15.35	162.5	3.4871	4.40	3.1188	13.73
292	May-98	14.91	162.8	3.4936	4.27	3.1310	13.36

	Month	Actual Oil Price ($/STB)	C.P.I. Index	Inflation Index for 1974=1.0	Deflated Oil Price 1974 =6.95	Average Inflation Index	Average Inflated Price ($/STB)
293	Jun-98	13.72	163.0	3.4979	3.92	3.1433	12.33
294	Jul-98	14.17	163.2	3.5021	4.05	3.1556	12.77
295	Aug-98	13.47	163.4	3.5064	3.84	3.1680	12.17
296	Sep-98	15.03	163.6	3.5107	4.28	3.1804	13.62
297	Oct-98	14.46	164.0	3.5193	4.11	3.1928	13.12
298	Nov-98	13.00	164.0	3.5193	3.69	3.2053	11.84
299	Dec-98	11.35	163.9	3.5172	3.23	3.2179	10.38
300	Jan-99	12.51	164.3	3.5258	3.55	3.2305	11.46
301	Feb-99	12.01	164.5	3.5300	3.40	3.2431	11.03
302	Mar-99	14.68	165.0	3.5408	4.15	3.2558	13.50
303	Apr-99	17.31	166.2	3.5665	4.85	3.2686	15.86
304	May-99	17.72	166.2	3.5665	4.97	3.2814	16.30
305	Jun-99	17.92	166.2	3.5665	5.02	3.2942	16.55
306	Jul-99	20.10	166.7	3.5773	5.62	3.3071	18.58
307	Aug-99	21.28	167.1	3.5858	5.93	3.3201	19.70
308	Sep-99	23.80	167.9	3.6030	6.61	3.3331	22.02
309	Oct-99	23.80	168.2	3.6094	6.59	3.3461	22.06
310	Nov-99	25.00	168.3	3.6116	6.92	3.3593	23.25
311	Dec-99	26.10	168.3	3.6116	7.23	3.3724	24.37
312	Jan-00	27.26	168.8	3.6223	7.53	3.3856	25.48
313	Feb-00	29.36	169.8	3.6438	8.06	3.3989	27.39
314	Mar-00	29.84	171.2	3.6738	8.12	3.4122	27.71
315	Apr-00	25.72	171.3	3.6760	7.00	3.4256	23.97
316	May-00	28.79	171.5	3.6803	7.82	3.4390	26.90
317	Jun-00	31.82	172.4	3.6996	8.60	3.4524	29.69
318	Jul-00	29.70	172.8	3.7082	8.01	3.4660	27.76
319	Aug-00	31.26	172.8	3.7082	8.43	3.4795	29.33
320	Sep-00	33.88	173.7	3.7275	9.09	3.4932	31.75
321	Oct-00	33.11	174.0	3.7339	8.87	3.5068	31.10
322	Nov-00	34.42	174.1	3.7361	9.21	3.5206	32.43
323	Dec-00	28.44	174.0	3.7339	7.62	3.5344	26.92
324	Jan-01	29.59	175.1	3.7575	7.87	3.5482	27.94
325	Feb-01	29.61	175.8	3.7725	7.85	3.5621	27.96
326	Mar-01	27.24	176.2	3.7811	7.20	3.5761	25.76
327	Apr-01	27.49	176.9	3.7961	7.24	3.5901	26.00
328	May-01	28.63	177.7	3.8133	7.51	3.6041	27.06
329	Jun-01	27.64	178.0	3.8197	7.24	3.6182	26.18
330	Jul-01	26.42	177.5	3.8090	6.94	3.6324	25.20
331	Aug-01	27.36	177.5	3.8090	7.18	3.6466	26.19

	Month	Actual Oil Price ($/STB)	C.P.I. Index	Inflation Index for 1974=1.0	Deflated Oil Price 1974 =6.95	Average Inflation Index	Average Inflated Price ($/STB)
332	Sep-01	26.21	178.3	3.8262	6.85	3.6609	25.08
333	Oct-01	22.18	177.7	3.8133	5.82	3.6752	21.38
334	Nov-01	19.80	177.4	3.8069	5.20	3.6896	19.19
335	Dec-01	19.39	176.7	3.7918	5.11	3.7041	18.94
336	Jan-02	19.71	177.1	3.8004	5.19	3.7186	19.29
337	Feb-02	20.72	177.8	3.8155	5.43	3.7332	20.27
338	Mar-02	24.53	178.8	3.8369	6.39	3.7478	23.96
339	Apr-02	26.18	179.8	3.8584	6.79	3.7625	25.53
340	May-02	27.04	179.8	3.8584	7.01	3.7772	26.47
341	Jun-02	25.52	179.9	3.8605	6.61	3.7920	25.07
342	Jul-02	26.97	180.1	3.8648	6.98	3.8068	26.57
343	Aug-02	28.39	180.7	3.8777	7.32	3.8217	27.98
344	Sep-02	29.66	181.0	3.8841	7.64	3.8367	29.30
345	Oct-02	28.84	181.3	3.8906	7.41	3.8517	28.55
346	Nov-02	26.35	181.3	3.8906	6.77	3.8668	26.19
347	Dec-02	29.46	180.9	3.8820	7.59	3.8820	29.46

APPENDIX B

Basis for the average annual inflation rate of 5.2 percent (compounded monthly) in the generation of scenarios.

The CPI index for the starting month of January 1974 is 46.6

The CPI index for the starting month of December 2002 is 180.9

Total number of months starting with January 1974 = 347

Then

$$(\text{Inflation Index})_{\text{Last Month}} = (\text{Inflation Index})_{\text{First Month}} \times (1+\text{i})^{\text{Total number of months}}$$
$$(180.9) = (46.6) \times (1+i)^{347}$$

where i equals to the monthly inflation rate.

The monthly inflation rate is 0.003905 i.e. 0.39 per cent when this is compounded monthly, the annual rate is 5.2 percent. For the high price conventional analysis scenario, we used inflation rate twice the historical monthly rate and the value is 0.00781, i.e., 0.78 per cent per month when compounded, the annual rate is 10.64 percent.

VITA

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