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The Value of Expanded SPR Drawdown Capability

SPR Drawdown Capability Study,
Final Report, Draft 2

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The views and opinions expressed here are those of the authors and do not necessary represent the views of the Department of Energy

Executive Summary

Estimated Value of Draw Capability Expansion for Three SPR Sizes, Following 1999 Size Study

- This study estimates the net economic benefits of enhancing the U.S. SPR *drawdown* capability.
- The assessment is done using the DIS-Risk model for probabilistic cost-benefit analysis, following the methods and assumptions used in the 1999 SPR Size study. The model gathers the important quantifiable elements involved in making SPR draw capability and size investment decisions, given uncertainty about the likelihood, size, and duration of future oil market disruptions. It then estimates the *expected* net benefits of alternative SPR sizes or drawdown capabilities.
- The 1999 Size Study examined the net benefits of a range of larger SPR sizes, each with a single pre-specified draw capability (see Figure 1).
- In the current study, gross and net benefits are evaluated over a broad range of drawdown rates between 4.1 and 7.0 million barrels per day (MMBD), in 0.1 MMBD increments. Attention is limited to three different SPR sizes: 590 MMB, 700 MMB, and 800 MMB.

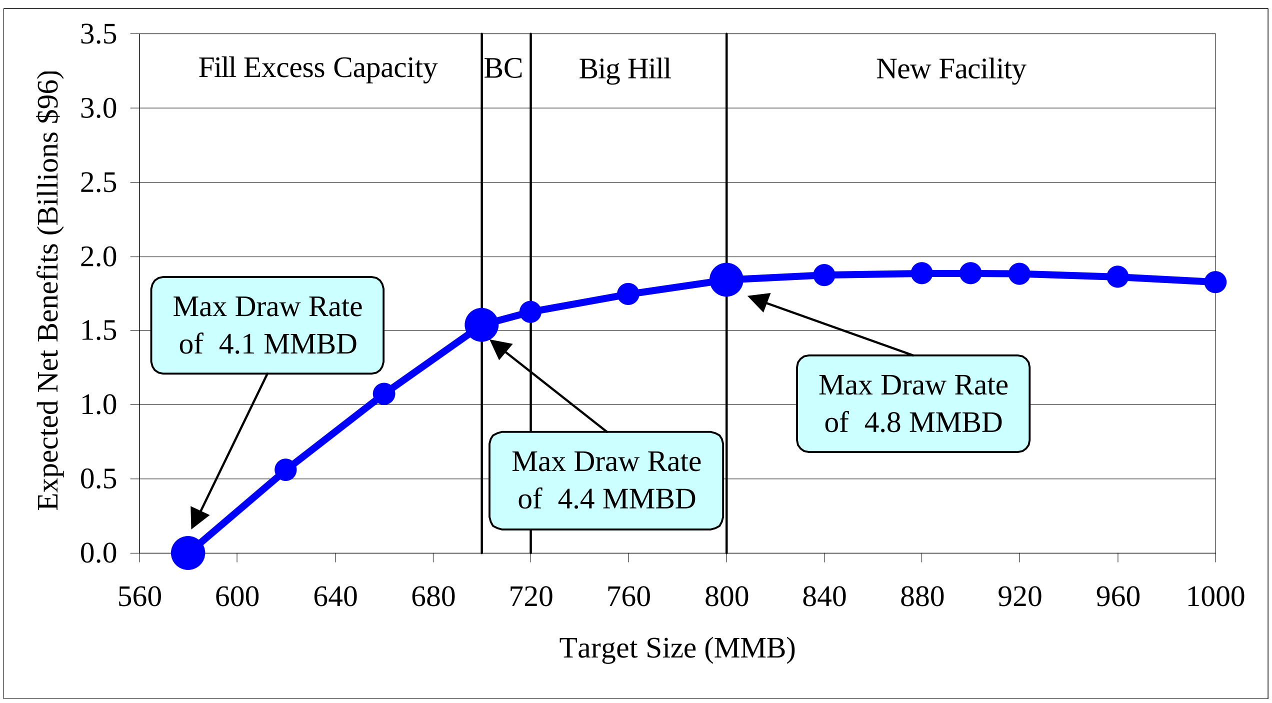

Figure 1: Base Case Results from the 1999 SPR Size Study. In that study a range of new SPR sizes was evaluated, each with a single pre-specified maximum draw capability. The large dots indicate the three corresponding SPR sizes considered in this drawrate study.

Gross and Net Benefits Estimated

! Gross draw capability benefits are computed as the expected reduction in economic losses due to disruptions. Disruption losses stem from reduced GDP and higher oil import costs. For the 700 MMB and 800 MMB reserve, we also subtract the net cost of additional oil and the capital cost of *size* expansion. These gross benefits *exclude* the capital cost of expanding the draw rate.

! Over the range of draw rates the *gross* benefits of expanded draw capability rise steadily, albeit at a diminishing rate. This is because more draw capability can always provide some possible benefit, provided there is some chance of a very large or very short disruption in which it could be used.

! As drawdown capability is increased from the current rate of 4.3 MMBD, gross benefits rise, as shown in Figure 2. For the *Base Case*, the gross benefits of draw capability expansion (excluding size benefits) are:

    $1.4 billion for 590 MMB reserve at 6.0 MMBD;
    $1.8 billion for 700 MMB reserve at 7.0 MMBD; and
    $2.0 billion for 800 MMB reserve at 7.0 MMBD.

! The difference between these gross benefits and net benefits is the capital cost of expanding the draw rate. However, the capital cost of draw capability enhancement is not well-established. It depends upon system design and location, and the possible opportunities for cost sharing with the private sector. Accordingly, draw rate capital costs, and the net benefits of draw rate enhancement, are treated parametrically here. That is, the implications of a range of possible capital costs are considered.

! We find that *net* benefits increase over the full range of draw capabilities considered, provided the discounted cost of draw rate expansion is no more than $400 million per MMBD.

Sensitivity Analysis Reveals Draw Rate Expansion Worthwhile for Wide Range of Conditions

! A large number of sensitivity cases were explored, including sensitivity with respect to:

    " oil market disruption risks (disruption probability and slack oil production capacity);
    " disruption durations;
    " GDP elasticity with respect to oil price shocks;
    " oil price projections;
    " delays in implementing drawdown enhancement; and
    " discount rates.

! IF draw capability can be expanded at a discounted cost of less than $200 million per MMBD (thought to be a reasonable estimate), then expanding to 7.0 MMBD is optimal under all but two sensitivity cases considered (for 700 or 800 MMB reserve).

! Those two cases where 7.0 MMBD is not justified are extreme combinations of high slack production capacity and low disruption probabilities. In those cases, size expansion may not be justified, but even then the optimal draw rate capability is 6.0 - 6.5 MMBD.

! If disruptions are shorter on average than the 3 and 6 month base-case durations, larger reserves are less valuable. However, the marginal value of drawdown capability expansion is greater.

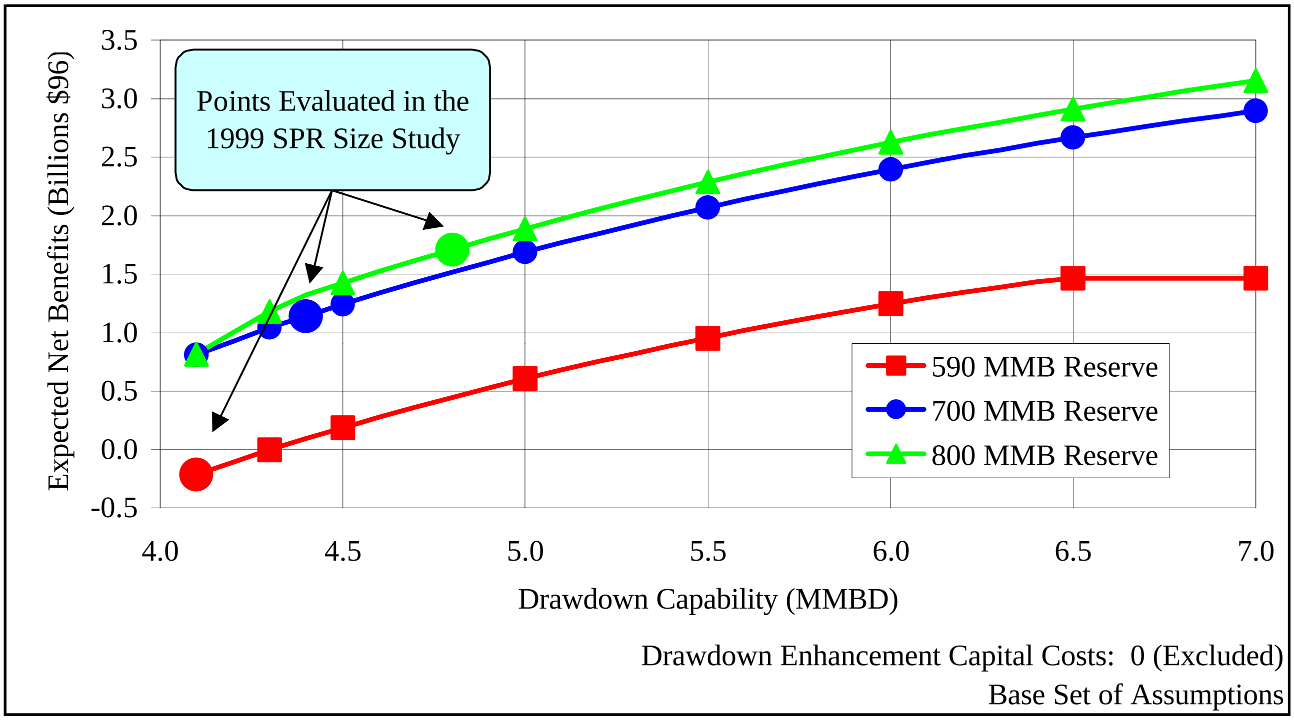

Figure 2: Base Case Results from the 2000 SPR Drawdown. This study estimated the net benefits of a wide range of expanded draw rates, for three different SPR sizes.

Summary Conclusions:

This study leads to some strong conclusions regarding the substantial expected value of enhanced drawdown capability. Despite the large existing strategic stocks and the current 4.3 MMBD draw capability, even larger drawdown capabilities will produce expected benefits. Specifically, over a wide range of conditions, expansion to as much as 7.0 MMBD is worthwhile economically, if it is practical to do so from an engineering perspective.

The net benefits of draw rate expansion are expected to be positive provided the discounted costs of draw capability expansion are less than $400 million/MMBD, which is believed to be a high cost estimate. Even for the relatively high capital cost of $400 million per MMBD of drawrate, the maximum expected net economic benefit is achieved with a 800 MMB reserve and a 7.0 MMBD drawdown rate. Lower estimates of the drawdown capital cost, of course, also reinforce this conclusion, indicating that expanded drawrate capability could be highly valuable. Higher draw capability is especially valuable if future disruptions are expected by be short and intense, rather than protracted and moderate.

These conclusions seem to be robust in the face of sensitivity analysis. IF draw capability can be expanded at a cost of less than $200 million per MMBD, then expanding to 7.0 MMBD is optimal under all but two of the sensitivity cases considered (for a 700 or 800 MMB reserve). For a 590 MMB size SPR, the optimal draw rate is a bit lower than for the larger sizes: between 6.0 and 6.5 MMBD. This is simply because there is less oil in the reserve, and 6.5 MMBD is sufficient to deploy the entire reserve in 90 days.

1.0 Introduction

This report evaluates the net economic benefits of enhancing the U.S. SPR *drawdown* capability. The assessment of alternative U.S. drawdown capabilities was done using a numerical simulation model known as DIS-Risk. Input conditions and sensitivity cases rely heavily on the assumptions in the 1999 Size Study (Leiby and Bowman 1999), with some minor modifications.

The world oil market has endured at least 18 significant oil supply shocks since 1951. The most notable of these, the 4 largest world oil shocks which occurred between 1973 and 1991, are now recognized to have cost the U.S. economy hundreds of billions of dollars. These costs include a loss in GDP as well as higher payments for oil imports. Since oil is traded globally, a major oil price increase spreads quickly throughout the world, with disruptive effects on most energy-using economies. Within each economy, the shock costs are spread through many sectors, the "social aspect" of which is invariably greater than the "private costs". For this reason, oil-using firms and private consumers acting on their own behalf do not have sufficient motivation to adequately insure themselves and the nation against the widespread costs of oil price shocks. That is, the private sector will store oil at a level which is deemed profitable but which is less than socially optimal. Because most of the economy-wide costs of disruptions are "external" to the cost-benefit considerations of private agents, public investment in a program of strategic oil storage is needed.

Strategic oil stocks, by buffering oil supply losses and mitigating sudden major oil price shocks, are a direct and effective means for dealing with the risk to economies of persistent supply and price volatility. Private agents cannot justify holding large oil stocks for the long term as a contingency against unlikely, but potentially dramatic, market upheavals or geopolitical struggles. The private storage costs are too high, the planning time horizons are too long, and the direct benefits to the private agents are too low.[1] Thus, it is incumbent on the public sector to hold strategic oil reserves since private agents are either unwilling or unable to do so.

On the most fundamental level, the five essential attributes of a strategic oil reserve are:

- Size and capacity (in barrels);
- Fill plan (rate in BBL/day, and schedule across years);
- Maximum drawdown capability (rate in BBL/day);
- Drawdown rule or strategy (including triggering events, proportion of shortfall to offset, and coordination with foreign strategic stocks); and
- Refill rate and schedule.

Most analyses of emergency oil stocks have, properly, focused on the first-order issue of the appropriate target size and capacity of the reserve. Naturally, the above five elements of an SPR program configuration are inter-related, and the net benefits of a particular size, or a particular

[1] Unless the government provides incentives for added storage, private oil inventories are principally "working stocks." They are held to ensure reliable plant operations and process flows in the face of routine logistical delays, normal demand fluctuations, and modest short-term price variations.

drawdown capability, will depend on how the rest of the reserve is configured and operated. Consequently, these five elements become integral to a consideration of both optimal size and optimal drawdown capability.

This study shows, perhaps for the first time, how the achievable benefits from any given reserve size depend strongly on the maximum drawdown capability which has been developed. Furthermore, we find that the potential gains from efficient investments in drawdown capability are comparable to the potential net gains from SPR size optimization. This means that the question of how much to invest in drawdown capability and infrastructure is as important as the question of how much to invest in storage capacity and oil. It also means that size and draw decisions are intimately related.

This study summarizes the issues, techniques, and results of estimating the net economic benefits of enhancing the current U.S. SPR *drawdown* capability. ORNL's analytical approach is consistent with that applied in the 1999 SPR size study. As in the 1999 study, we recognize that substantial drawdown capacity already exists, both in the U.S. and elsewhere. The starting point of this analysis is the current U.S. maximum sustainable drawdown rate of 4.3 million barrels a day (MMBD) and a 590 MMB SPR size.[2] The focus of this study is thus placed on the *incremental* net benefits that expanding the current drawdown capacity would provide to the U.S. economy. The assessment of alternative U.S. drawdown capabilities is done using a numerical simulation model known as DIS-Risk. Input conditions and sensitivity cases are drawn heavily from the 1999 SPR size study.

In Section 2 we examine what has been learned so far in the area of efficient SPR size and drawdown capability determination. Past studies and reports are the primary sources for these insights. Also presented is an extensive list of the optimal or preferred drawdown rates from previous analytical studies. Insights concerning trends in these rates are also given. Section 3 describes the model and assumptions used in the analysis. Section 4 presents the results of the analysis and introduces marginal analysis as a tool for weighing costs and benefits. Finally, Section 5 gives the conclusions of the analysis and mentions some issues that merit further attention. The Appendices discuss the different SPR modeling approaches used in the past and in this study, list sensitivity cases performed, and provide extensive tabular reports of the results.

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[2] Expected SPR size and draw rate by the end of the calendar year 2000.

2.0 Lessons from the Past

Important lessons can be learned from past studies and analysis. Many of these insights point towards what factors are truly important in determining the appropriate SPR size and drawdown rate capability and what factors have been set aside as less significant.

2.1 Insights

2.1.1 The effect of key variables on the net benefits of enhanced drawdown rate

While uncertainties remain, past investigations suggest what effect many of the key variables could have on the estimated benefits of enhanced drawdown rate. In some cases, a variable's effect on drawdown enhancement benefits is opposite to what it would be for SPR size increase benefits. For instance, consider the variable "disruption length." If one expects disruptions to be typically longer in duration, then it is probably beneficial to increase the SPR size. However, longer disruptions may tend to reduce the estimated net benefits of drawdown enhancement, since longer disruptions imply a greater chance of reserve exhaustion and less likelihood that a very rapid draw rate could be sustained for the length of the disruption. Table 1 below lists some of the key variables, and our initial expectations regarding how an increase in the magnitude of each key variable will affect the net benefits of drawdown enhancement.

Table 1: Anticipated Effect of Key Variables on the Net Benefits of Enhanced Drawdown Capability

Assumption	2000 Drawdown Capability Study Base Case Values	Directional Effect*	Comment
Likelihood of Disruptions	DOE 1990 Base Case probabilities	⬆	The greater the chance of a disruption, the more likely the increased drawdown rate will be necessary.
Average Disruption Length	4.5 months average (length uniformly distributed over 3 and 6 months)	⬇	For a uniform drawdown over the duration of a disruption, drawdowns are more likely to be limited by stockpile size than by maximum drawdown capability.
Available Slack Production Capacity	EIA IEO 1999 Base Case	⬇	Increased offsets reduce the chance that the drawdown enhancements will be needed.
Effect of Oil Price on GDP (GDP Elasticity)	Base of -5.4% (Mork 1994)	⬆	If the economy is more sensitive to oil price shocks, the benefits of enhanced drawdown rate are greater.
Start Build Yea	2001	⬇	If benefits are greater than costs, then delaying construction delays or reduces discounted net benefits.
Undisrupted Forecasted Oil Price Path	AEO 1999 Base Oil Price Case	⬇	Higher oil prices may mean less domestic oil consumption and less reliance on OPEC.
Foreign Draw Coordination	U.S. and foreign reserves draw down simultaneously	⬇	A greater degree of coordination with foreign reserves implies reduced need for enhanced U.S. draw capability.
Import Demand Elasticities	DOE 1990	⬇	As demand becomes more elastic to price, oil price shocks translate into less oil price increases thus reducing the benefits of enhanced drawdown.
Discount Rate	7% (OMB Circ. A94-B)	⬇	A higher discount rate tends to reduce benefits more than costs, since benefits generally come later.
Fill and Refill Rates	Initial fill and refill rates are sufficient to fill reserve in 5 years.	⬆	A higher fill or refill rate reduces the vulnerability to multiple disruptions, and makes the use of higher draw rates more practical.

*The "directional effect" is the *anticipated* effect on the net benefits of drawdown capacity enhancement from increasing the level of the assumption given in column one. In some cases this is an "educated guess," and the actual direction of effect cannot be reliably determined prior to the numerical analysis.

The effects of other key factors such as drawdown strategy or drawdown timing on drawdown enhancement benefits have yet to be determined. We hope to gain some insight on the direction and magnitudes of these factors in this study.

2.1.2 Delaying drawdown can be beneficial, but often at a cost

In certain circumstances, delaying the drawdown from the reserve during a disruption may be beneficial. Waiting may allow better coordination with allies or help clarify the length and severity of the disruption (Gray 1988). When the disruption duration is uncertain, however, delaying drawdown often results in a missed opportunity to alleviate some or all (in the case of very short duration) of the disruption. Some have seen the hesitancy to draw down during the Gulf War as detrimental to both the economy and the perceived ability of the reserve to capture its full benefits (GAO 1997, p 60).

2.1.3 Privately held crude oil stocks are an uncertain buffer against oil shocks

The majority of IEA emergency stocks counted towards individual country commitments are in fact privately held. While these stocks are counted towards the 90-day net import obligations of member countries, the availability of these stocks during a disruption is in doubt. The reasons for this uncertainty are threefold. First, it is estimated that 70-80 percent of these stocks are needed for the minimum refinery and distribution operating requirements (IEA 1999:9). These stocks probably could not be drawn down without detrimental effects on the refinery industry. Second, much of the public and private stocks use the same delivery systems. Drawing down one type of stock would, in some cases, prevent increased drawdown of the other. Finally it has not been shown that governments have the ability or the will to force private firms to draw down, nor does industry have a proven track record of drawing down stocks during a disruption. Historical evidence suggests that disruptions have an indeterminate aggregate effect on private inventory behavior. Those firms which draw down are often offset by the hoarding of others (DOE 1979:C-1) and the net direction of private inventory flows is ambiguous. In consideration of these factors, this study, the DOE 1990 size study, and the 1999 size study do not count private inventories as an offset.

2.1.4 Shorter disruption lengths translate into higher optimum draw capabilities

For long-lasting disruptions, the drawdown rate is typically limited more by the prospect of reserve exhaustion than it is by the maximum draw capability. Prior studies have confirmed that for disruptions longer than approximately 9 months, there are essentially no benefits of enhancing the drawdown capability (Trumble, Lee and Leiby 1991). A 9-month-long draw at 4 million barrels per day would exhaust even a reserve of 1 billion barrels. It is in the realm of shorter disruptions, where there is little chance of exhausting the reserve, that the choice of a maximum drawrate capability is of more concern. However, increased drawdown capability may still be beneficial for longer disruptions if we consider possible drawdown delays, or possible uneven draw rates over the course of each disruption.

2.1.5 Optimal draw capability increases with SPR size

Past size studies have shown that as the size of the reserve increases, the optimal drawdown capability also increases. One obvious reason is that for any disruption length, a larger reserve can be drawn at a faster rate without exhausting the stock. However, the optimum drawdown capability does not increase in direct proportion to reserve size. While a larger drawdown capability *could* be useful, the probability of it being needed declines as the drawdown rate gets ever-higher, since the assumed probability of a disruption decreases with disruption size. Stated differently, as the drawdown rate capability increases there are fewer and fewer disruption sizes which the drawdown capacity cannot handle, and those disruption sizes become ever-more unlikely.

2.1.6 Historical data is insufficient to estimate disruption probabilities reliably

There have been roughly 13 significant oil supply disruptions in the Middle East and 9 disruptions elsewhere. Statistically, these twenty-two events do not provide enough data to predict future events with any confidence. Most of the historical events involved fairly small shortfalls, certainly of the type that could easily be handled by projected slack oil production capacity and/or the existing reserve drawdown capability. The difficulty comes in estimating not just a single probability, but a distribution of probabilities for disruptions in the larger and rarer size range. An added complication is posed by the need to establish probabilities not only for a range of disruption sizes, but also for a range of disruption *durations*, a matter of some importance for this drawdown capability analysis. Finally, some would argue that the SPR is meant to provide protection against untoward events which may never have happened in the past. In this case, simple recourse to historical data would be inadequate, even if the historical dataset were long and rich enough in a statistical sense.

Given this situation of uncertainty, limited data, and a concern for prospective risk as well as historical risk, the general approach in past studies has been to elicit expert opinion, supplemented with recourse to historical data, to subjectively estimate the appropriate disruption probabilities.

2.1.7 Past studies focused more on refill rates than drawdown rates

Certainly most SPR analyses have focused principally on the question of how large the reserve should be. Perhaps surprisingly, previous studies have concentrated more on refill rate and whether drawing down the reserve would reduce its ability to alleviate future disruptions (DOE 1982, Gray 1988) than on drawdown capability. This past emphasis is understandable, since it reflects both the former perspectives on the oil market and the predominant modeling technique at the time. Many of the previous governmental and academic size studies were conducted in the late seventies and early eighties. At that time, the recent succession of embargoes, wars, and revolutions had led many to conclude that the future of the world oil market was quite bleak. As such, the ability to refill the reserve quickly and address multiple, successive disruptions was seen as paramount. Also, the merits of cautious drawdown, which withholds part of the reserve as a hedge against successive disruptions, seemed more obvious. Incidentally at the time, reserves as large as 1.5 to 2 billion barrels were considered. At the same time, the predominant SPR size and drawdown modeling technique was dynamic programming, as embodied in the Teisberg model. The strength of the Teisberg model was in modeling and preparing for the possibility of multiple disruptions in a relatively short time period. One weakness, however, was the common use of the time increment of one year, long enough to exhaust most reserves for even modest drawdown rates. Thus the nature of the principal SPR model at the time meant that less attention was paid to drawdown capabilities than may have been ideal from our current perspective.

From the time of the 1990 DOE/Interagency study on SPR Size, there has been greater institutional support for the use of disruption probabilities that indicate a substantially lower likelihood of a severe net disruption. Under the midcase disruption probabilities used in the 1990 Size Study, the chances of a disruption large enough to exhaust the reserve are small, and the probability of two such disruptions in rapid succession is remote. This means that when simulating reserve benefits, in any scenario with a large disruption, there is little motivation for drawing down the SPR in a cautious way to preserve oil for future events. Rather, benefits seem to be improved by drawing down rapidly and promptly. The question to be addressed, and which has not received extensive prior attention, is “How rapidly and how promptly?” It is this question that leads to the net-benefits analysis of maximum drawdown capability. It is also worth noting that because of the rarity of multiple large disruptions and the low “hedging value” of cautious drawdown, the dynamic programming approach for optimizing fill-draw used in past analyses is not really appropriate. Rather, the probabilistic risk analysis approach of DIS-Risk, and simulating fill-draw behavior with a variety of pre-specified rules or strategies can be more revealing.

2.2 Results of Previous Drawdown Studies

Table 2 is a compilation of most SPR size and drawdown studies done over the last three decades. The drawdown capability rate reported for each study below is either the recommended rate based on qualitative judgement, or a numerical estimate resulting from an analytical study. High and low estimates are the result of sensitivity analyses. Recommended drawdown rates from these studies were either estimated independently or in conjunction with an evaluation of appropriate SPR size. In many cases, the optimal draw capability could not be clearly determined because the question of draw rate was not fully disentangled from size, and because separate estimates for the capital cost of draw capability expansion were not available.

Table 2: Maximum Drawdown Rate Capabilities from Previous Studies

Study	Recommended or Resulting Drawdown Capabilities (MMBD)			SPR Size (MMB)	Comments
	Low Range	Base Result	High Range		
National Petroleum Council (1974)	NA	3.0	NA	500	Drawdown rate set to provide 180 days of coverage.
National Petroleum Council (1975)	4.0	5.0	6.0	500	For larger reserve sizes, capability should increase at a decreasing rate.
Strategic Petroleum Reserve Plan (1977)	NA	3.3	NA	500	Based upon a single hypothetical 1980 supply disruption.
Strategic Petroleum Reserve Plan Amendment 2 (1978)	NA	5.0	6.0	750	
Balas (1980)	NA	3.7	NA	500	Corresponds to a single hypothetical 1985 disruption. Uses game theory.
	NA	5.5	NA	750	
ICF (1982)	NA	1.0	2.0	300	10 month 5.0 MMBD disruption. Choice of 1.0 MMBD drawdown for 10 months or 2.0 MMBD for 5 months but delayed for 5 months. Uses a modified Verleger simultaneous equations model (Verleger 1982).
SPRO (1984), Temchin and Roemer (1984)	1.5	2.6	3.5	610	Base is an average of disruption probability and length cases. Results from Teisberg model.
	1.6	2.8	3.9	750	
Oren and Wan (1986)	NA	3.3	NA	1570	Uses stationary, continuous time Markov process to characterize OPEC supply.
Leiby and Lee (1990)	2.5	5.0	6.5	750	Results based upon the Teisberg Model
	3.0	5.5	7.0	1000	
Trumble, Lee and Leiby (1991)	3.5	5.5	7.0	1000	Billion barrel reserve. Results from DISSPR and ORNLTEIS models. Does not include capital costs of expansion. Disruption lengths: low, 9 months; base, 6 months; high, 3 months.
Leiby and Jones (1993)	NA	4.5	6.0	750	6 months and longer disruption lengths. Excludes capital costs.
	4.5	6.0	NA	1000	
GAO (1994)	3.0	4.5	6.0	600	Low end from not degassing or performing life extension. Base result is with problems corrected but without further enhancements.
	4.5	6.0	NA	1000	Capital Costs of draw rate expansion is 100 million $94.

Several insights can be gleaned from Table 2 above. First, generally speaking, the older studies considered and recommended lower drawdown rates. This may be due, in part, to the prior expectation that disruptions would be longer-lasting. Second, the preferred drawdown capacity generally increases with size. Most studies which assume a 750 MMB reserve or greater have drawdown rates of 5.0 MMBD or higher.

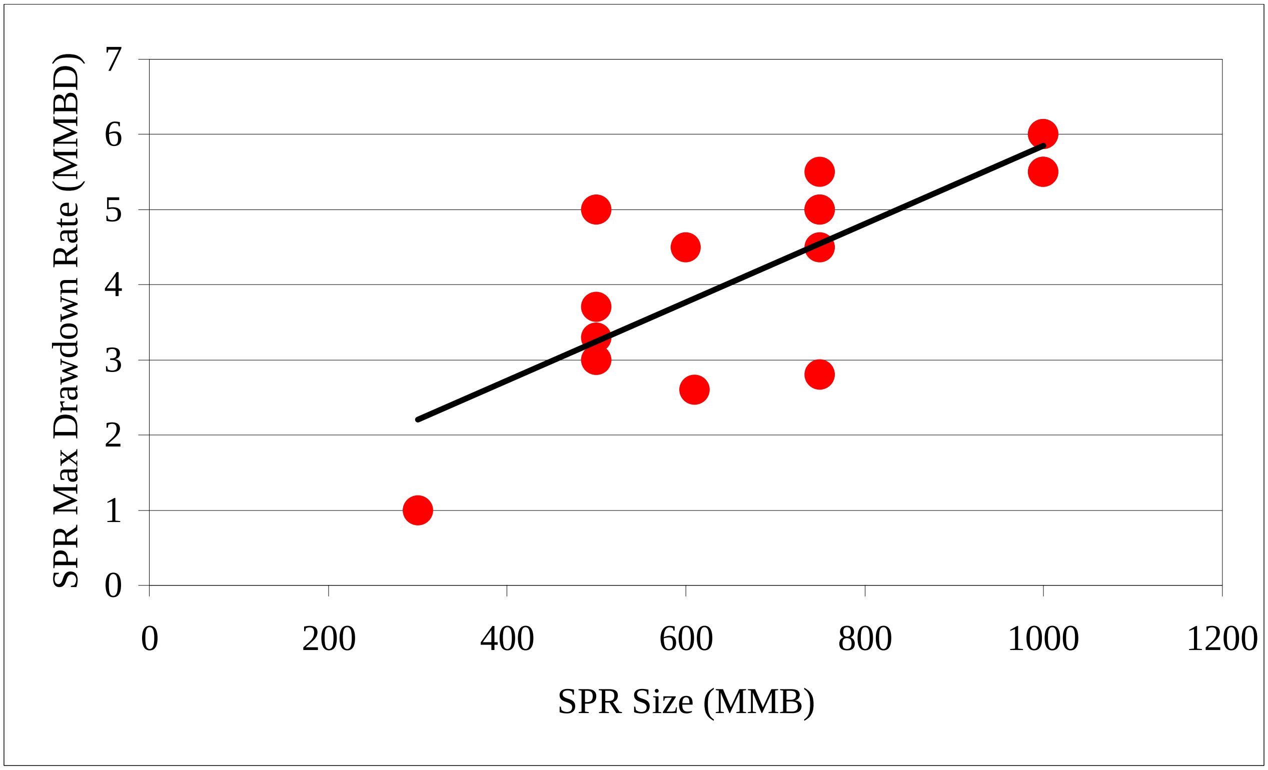

Figure 3: Scatter Diagram of Previous SPR Studies

As Figure 3 graphically displays, recommended drawdown rates generally have increased with planned SPR size.[3] The observation that larger reserves generally call for larger maximum drawdown rates principally reflects the fact that for a given disruption length a higher draw rate would be needed to fully utilize a larger reserve. This is distinct from, yet consistent with, the earlier observation that size and drawrate benefits move in opposite directions as disruptions become longer or shorter.

[3] Excluded from Figure 3 is the results from Oren and Wan (1986) which could be considered an outlier, given its recommended size of 1570 MMB.

3.0 SPR Drawdown Model Description and Assumptions

The DIS-Risk Model is an enhanced version of the DIS-SPR model used in the 1990 DOE/Interagency SPR Size Study (DOE 1990). It allows for reproduction of DOE90 study results, while permitting extensions and the analysis of specific, risk-related outcomes in a simulations format. This risk analysis approach allows, among others, the reporting of the expected frequency of disruptions and SPR use, the probability of SPR exhaustion, and the probability distribution of SPR economic benefits. These distributions are generated in a modest period of computing time using thousands of sample iterations.

3.1 Brief Description of the Model

In DIS-Risk, two SPR configurations are compared side-by-side, generally the current program and an alternative. An alternative program could consist of a higher draw rate capability or a higher reserve size or both. Each SPR configuration is specified in terms of costs (capital, operations, and maintenance), draw rate capabilities, reserve sizes, and fill and refill rates. The two SPR configurations are subject to the same set of random oil supply disruptions. Oil supply disruptions are simulated against reference paths for oil prices, U.S. demands, U.S. supplies, and world demands. Reference paths track low, base, and high oil price path cases from the Annual Energy Outlook of the Energy Information Administration.

Figure 4 below shows a simplified diagram of how the DIS-Risk model works. Within each year over the model time period of 2000 to 2030, an oil supply disruption may occur. The size and the length of the disruption are random outcomes of the underlying probability distributions. This gross oil supply disruption is directly offset by two exogenously specified sources: slack world oil production capacity and short-run demand switching (generally very small). If the net disruption (after offsets) is greater than zero, the SPR, in conjunction with other foreign reserves, attempts to fully offset it. Drawdown rates for each reserve type are limited by the specified maximum drawdown rate for that year, the specified drawdown rule or strategy, and by the rate of exhaustion. After a drawdown, both the U.S. SPR and the foreign reserves are refilled at exogenously specified refill rates.

Oil shortfall is calculated as the size of the remaining disruption after offsets and U.S. SPR and foreign reserve draws. If the oil shortfall is greater than zero, world oil price is affected. World oil price is determined assuming that world demand is elastic in price, non-OPEC supply is essentially fixed, and that the price must increase sufficiently for demand to accommodate the oil shortfall. Oil price increases are then translated into economic costs to society. These costs are composed of Gross Domestic Product (GDP) losses, net oil import costs and deadweight consumer surplus losses (generally very small).

SPR configurations which can draw down more oil are able to alleviate more of the disruption quickly and should provide more benefit. The question is, do the expected benefits outweigh the costs of building greater drawdown capability. Section 3.2 below discusses the key assumptions which influence the outcome of the modeling analysis.

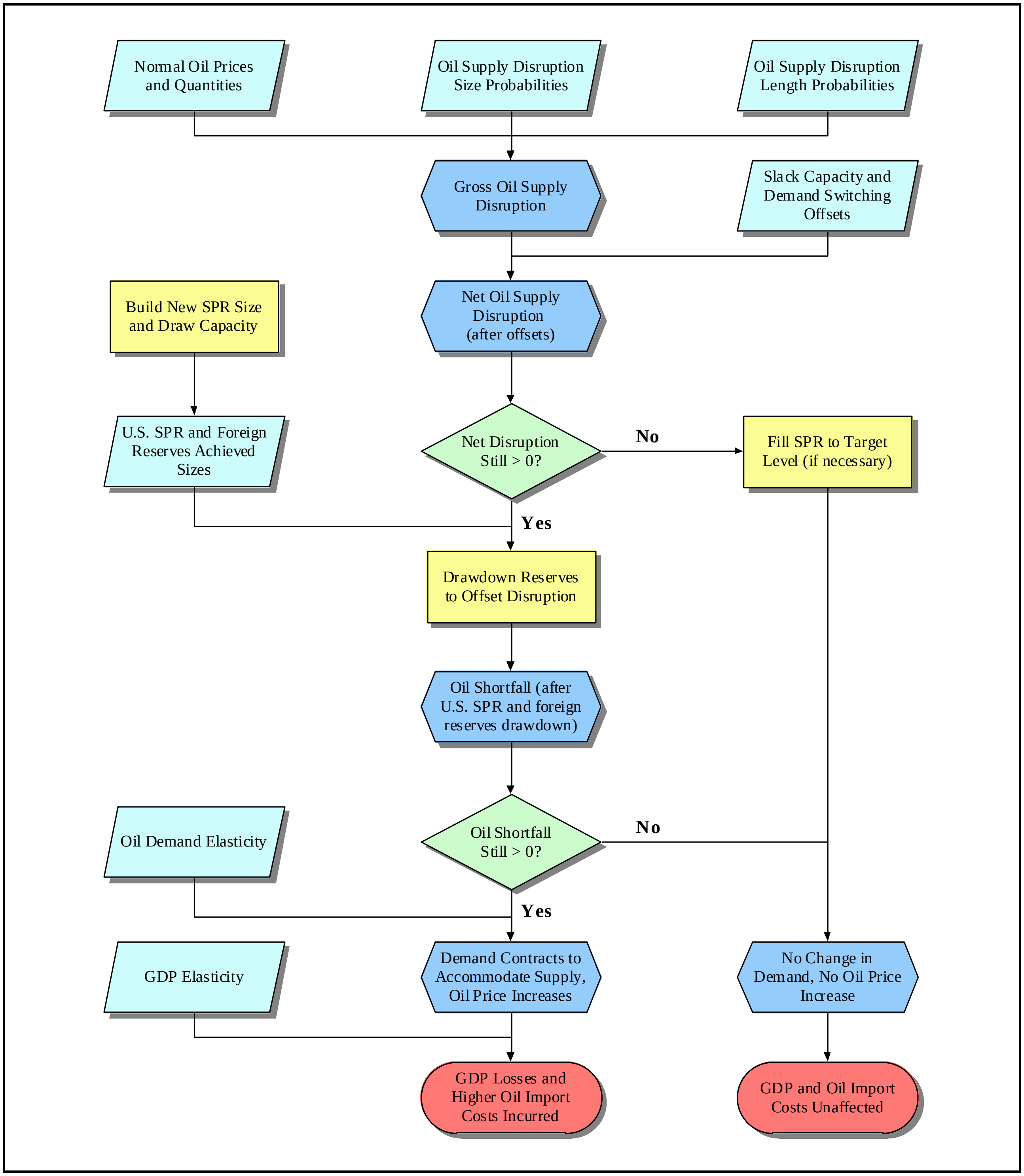

Figure 4: Simplified Diagram of the DIS-Risk Model.

3.2 Brief Description of the Key Model Parameters

The following is a brief description of the key parameters and assumptions used in the model. For a full description, see Leiby and Bowman (2000). Most of the key assumptions used in the 2000 SPR drawdown study are the same as those used in the 1999 SPR size study in order to ensure comparable analysis and results. A few assumptions, however, have been changed since 1999. Those changes are highlighted below.

3.2.1 Normal Oil Market Conditions

The Energy Information Administration (EIA) projections of normal, undisrupted oil markets provide the departure point for determining stockpile net benefits. The assumed projections of world oil price, world oil demand, U.S. demand and supply, and U.S. GDP used in the 2000 SPR drawdown study as well as the 1999 SPR size study are from the 1999 Annual Energy Outlook (EIA 1998). Figure 5 below depicts the historic, forecasted (AEO 1999) and extrapolated (2021-2030) world oil price and world oil demand paths used in both the size and drawdown studies.

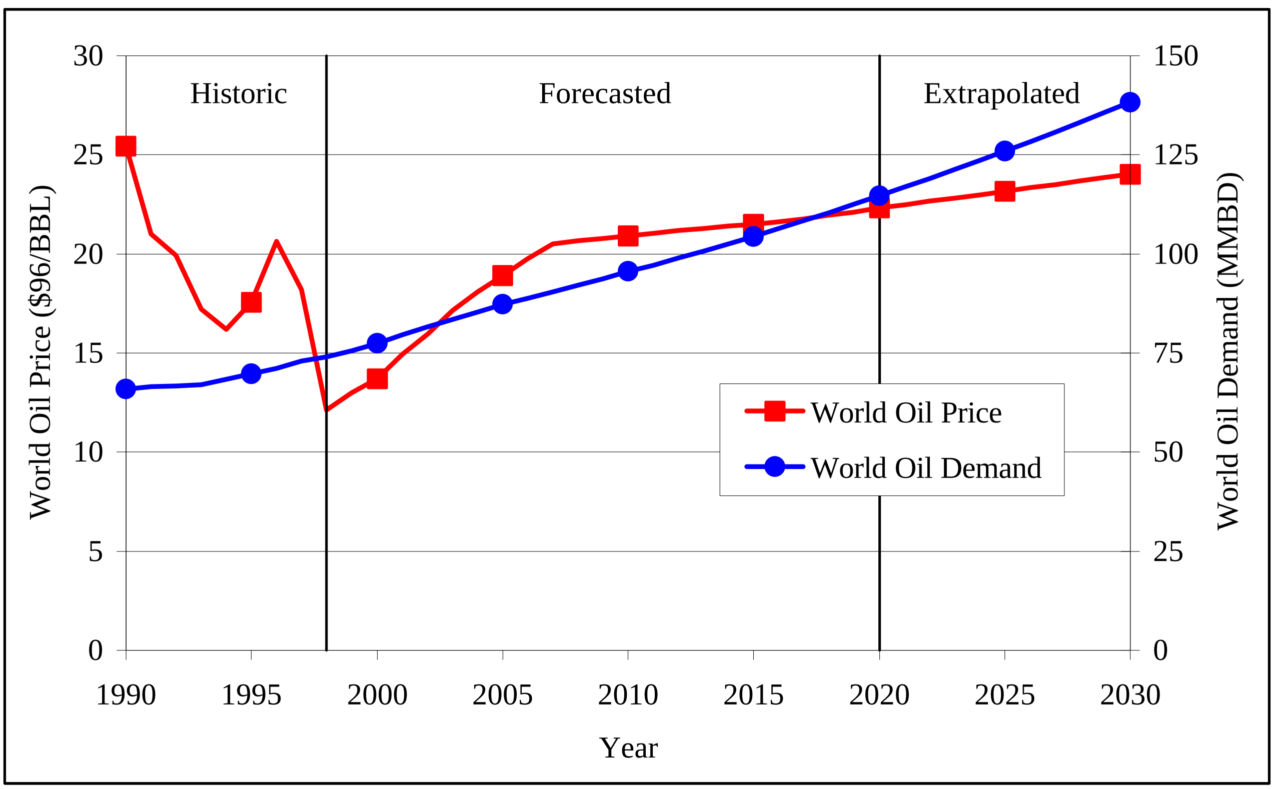

Figure 5: World Oil Price and World Oil Demand Paths.

The 2000 AEO assumptions are also included as a sensitivity case. As shown in Appendix 5, the choice of either AEO 1999 data or AEO 2000 data has little effect on the net expected benefits of drawdown capability expansion.

3.2.2 Oil Supply Disruption Probabilities

Three explicit and careful analyses of the probability of a future world oil supply disruption are currently available: probabilities drawn from the 1990 DOE/Interagency size study, the more recent Energy Modeling Forum (EMF) 1996 analysis, and the unpublished results of a recent expert panel seminar sponsored by the CIA in 1999. The upper-cumulative probability distributions constructed from these three studies, in addition to the high and low probability cases of the 1990 DOE Study, are given in Figure 6 below. While a cumulative probability distribution would show the probability of a disruption event *less than* or equal to a given percent of world supply, the upper-cumulative distribution shows the probability of an event *greater than* or equal a given percent of world supply. From this graph we can, for example, read that the estimated annual probability of a disruption of 15% or more of supply ranges between ½ % to 2.5%.

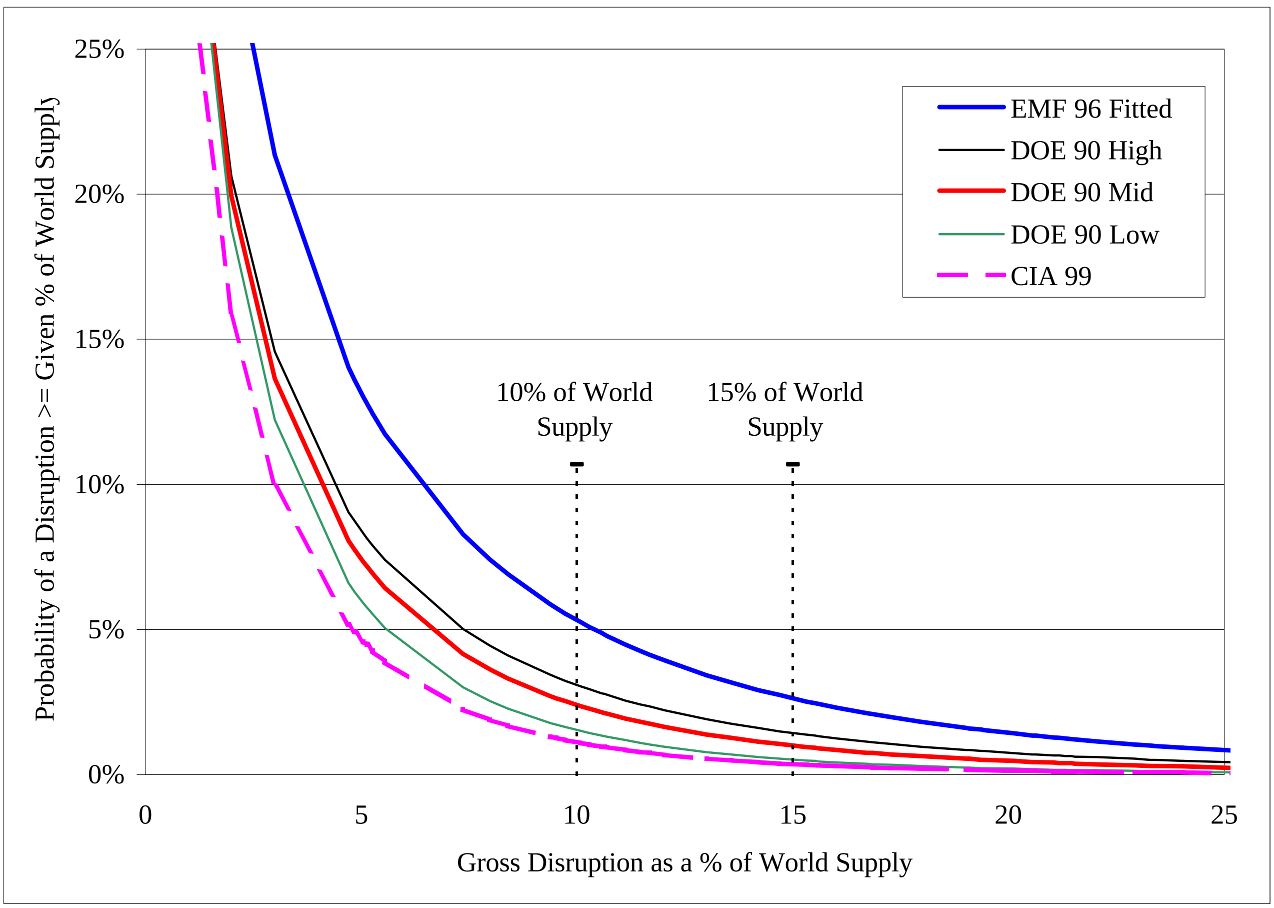

Figure 6: Comparison of Upper Cumulative Probability Distributions of a World Oil Supply Disruption. This graph shows the annual probability of a gross disruption greater-than-or-equal-to a given percentage supply loss

A crucial measure of each disruption probability distribution is the probability it assigns to large but unlikely disruptions, since those are the cases in which available slack production capacity and existing reserves might be inadequate. In such cases additional strategic oil stocks or draw rate capability would be beneficial. Table 3 below shows the annual probabilities corresponding to just two of the many disruption sizes given in Figure 6 and the probability over the entire model time frame of such events occurring.

Table 3: Disruption Probabilities:
Annual Probability of Gross Disruption as a Percent of World Supply*

Disruption Size	Disruption of 10% or more of World Supply		Disruption of 15% or more of World Supply	
Case	Probability of occurring within a given Year	Probability of occurring within the Model Time Period (31 years)	Probability of occurring within a given Year	Probability of occurring within the Model Time Period (31 years)
EMF 1996	5.3%	81.7%	2.5%	56.2%
DOE 1990 Higher	3.1%	62.2%	1.4%	36.2%
DOE 1990 Midcase	2.4%	53.0%	1.0%	26.8%
DOE 1990 Lower	1.5%	38.2%	0.5%	14.9%
CIA 1999	1.1%	29.5%	0.4%	10.7%

*As a guideline, it is helpful to note that the DOE 1990 Study Midcase assessed the annual likelihood of a disruption of 15% or more of world oil supply to be 1%. For the year 1998 this equals about 11 million barrels a day.

Looking at the estimates from the DOE 1990 Midcase, Table 3 shows that the likelihood in any given year of a very large world supply disruption of 15% is 1%. Over the entire model time frame of 31 years the chance increases to 26.8%. While it is true that over the last 48 years (1951-1998) we have not observed a disruption of 15% or more of world supply, this is not inconsistent since under the DOE 1990 Midcase probabilities such an event occurs very rarely (roughly once every 100 years given the 1% annual probability). There has, however, been a gross oil supply disruption of disruption of 11.5% (13% by some measures). Given the 1990 DOE midcase disruption probabilities, the probability of such a disruption is 2% or roughly once every 50 years. This is in line with expectations for a half-century of data.

For this analysis we follow the 1999 SPR Size study and use the DOE 1990 midcase as the base assumption. The four other disruption probability estimates; DOE90 High, DOE90 Low, EMF96 and CIA99 are included as sensitivities.[4]

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[4]Both the EMF and the CIA estimates are drawn from the collective opinions of a group of outside experts, with discussion guided and summarized by the sponsoring organization. The EMF report relied on a lengthy and iterative elicitation methodology conducted in three workshops over two years. The combined results of expert judgement from this group indicate larger disruption probabilities and greater sizes than the DOE 1990 study.

While the CIA one day workshop was more recent than any of the other studies, it was also more informal. The numerical estimates from the CIA study are based on a single informal poll of all attendees in a one-day workshop held in 1999. Unfortunately, while the efforts of the workshop are of interest, they are also less scientifically structured then

3.2.3 Oil Supply Disruption Lengths

An issue even less-studied than the probability of an oil supply disruption is the length of a disruption, given that one has occurred. Given the historical record, no clear evidence points to a direct relationship between the size of a disruption and the length of a disruption. This is illustrated in Figure 7 below which shows that given past history, size and length are only loosely correlated.

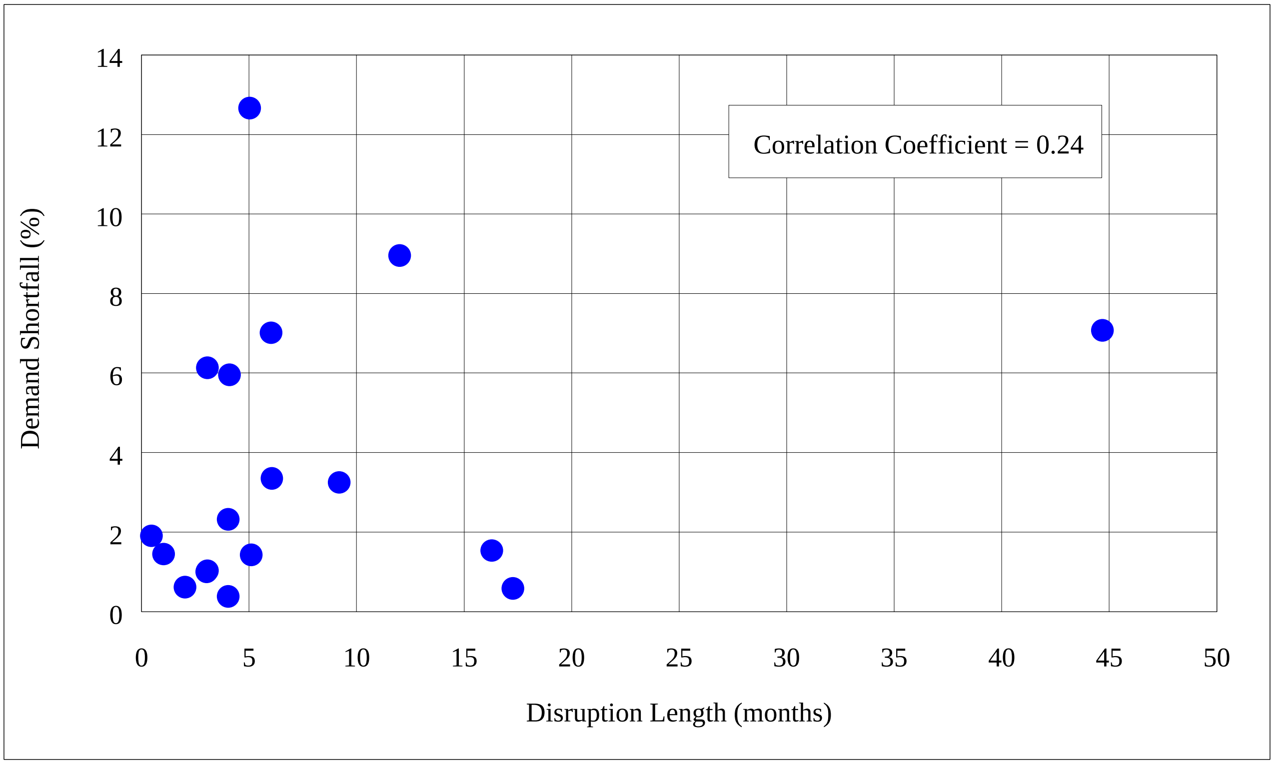

Figure 7: Correlation of Disruption Sizes and Lengths. Historically, Disruption Size and Duration Only Loosely Correlated.

Recognizing this uncertainty, disruption lengths are treated as random and uniformly distributed. That is, all disruption lengths considered are assigned equal probability. We do, however, specify a maximum length to consider for each sensitivity case, with the base case maximum length being 6 months. Also, given the low historical correlation between disruption size and duration, we treat the

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polls of this nature ordinarily are and in some ways conflicting. More specifically, the probabilities were polled without benefit of any of the structured interactive discussion or consistency cross-checks that would be used in a current-practice exercise in probability elicitation (e.g. von Winterfeldt and Edwards, 1986, Chapter 4). Many participants offered a numerical probability estimate only reluctantly. The reason for this brief treatment of the probability poll is that the numerical estimates were not the focal point of the CIA-sponsored workshop. Rather, the workshop focused almost entirely on qualitative discussion of geopolitical issues in the Persian Gulf region. That qualitative discussion emphasized that there is little reason to believe that disruptions are less likely now or in the future than they were 10 years ago. The CIA-sponsored estimates are unpublished in any forum, and have not yet had the benefit of review by peers, agency, or participants. Moreover, there is not yet any written documentation of the workshop, its methods, or its results. Finally, the results of the 1999 CIA workshop do not express the *official* view of the agency.

random size and duration outcomes as independent.

As seen in Figure 8, the median historic disruption length appears to be about five months. In keeping with this historical experience and the 1999 SPR size study, a uniform distribution of disruption lengths of 3 and 6 months is used for the base case, with a mean length of 4.5 months. Sensitivity analysis using disruption lengths of 1 to 6 months; 3, 6 and 9 months; and 3, 6, 9 and 12 months are also performed.

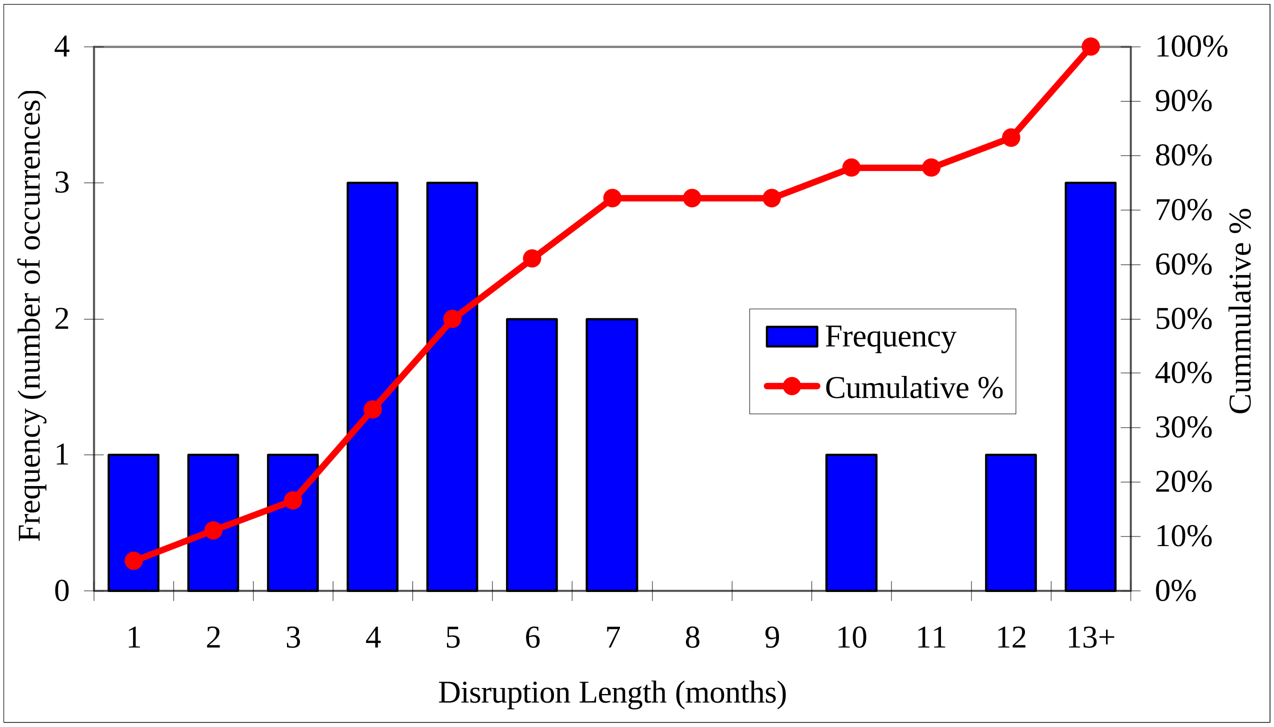

Figure 8: Distribution of Historical Disruption Lengths (Median = 5 Months).

3.2.4 Slack Oil Production Capacity

Disruption probabilities determine the “gross disruption level” or gross loss in oil supply before any market response. The “net disruption level” is defined as the gross disruption level, net of offsets, but excluding U.S. and foreign strategic petroleum reserve drawdowns. Offsets which may partially or fully accommodate a gross disruption include excess oil production capacity (slack capacity), and demand switching (generally modest). Slack capacity is the excess oil production capacity which can go online immediately (within a month) to address a gross disruption. Slack capacity estimates for the 1999 SPR size study and the 2000 SPR drawdown study were drawn from the Energy Information Administration (IEO, 1999). For the 2000 SPR drawdown study, slack capacity estimates from the IEO 2000 are considered in a sensitivity case.[5]

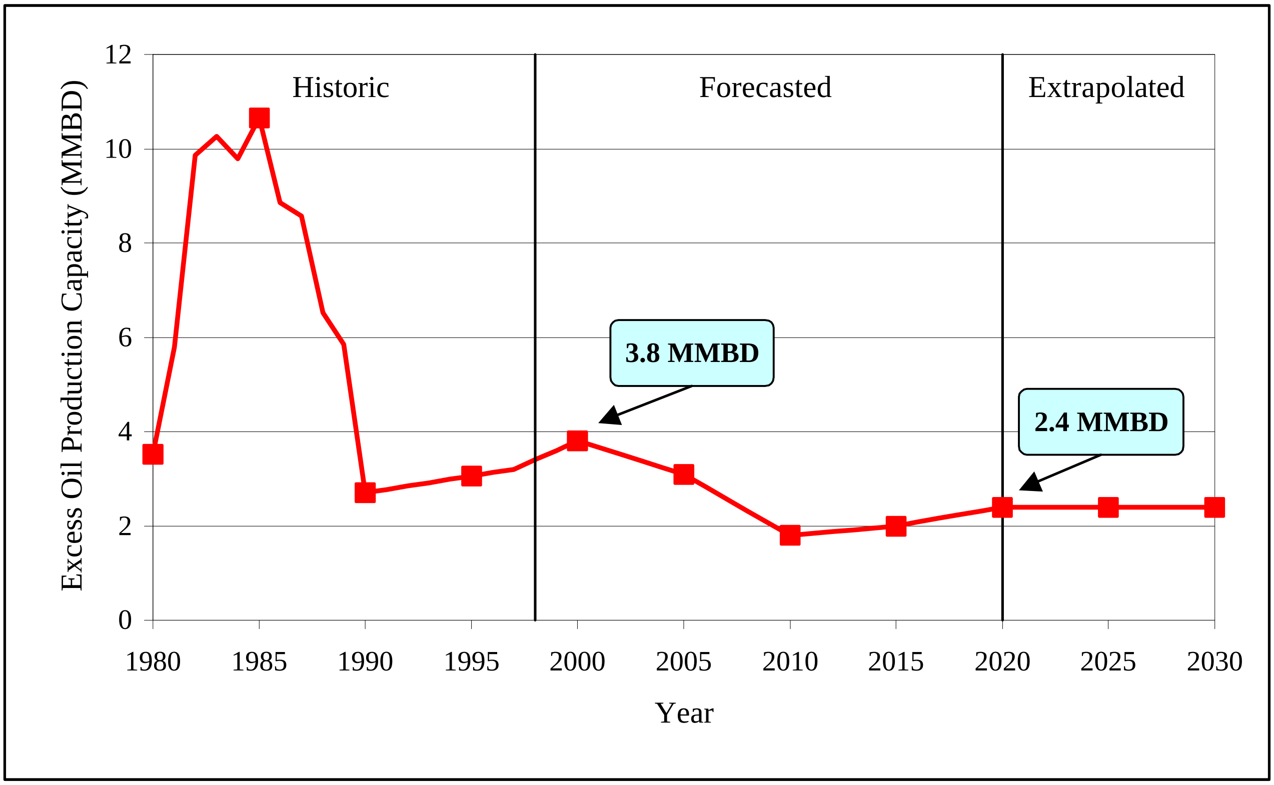

Figure 9: IEO 1999 and IEO 2000 Excess Oil Production Capacity Paths

3.2.5 Import Demand Elasticities

Short-run net import demand elasticities relate import levels to given price changes during an oil shock. In calculating the effect of disruptions, the elasticity of world import demand therefore determines the world oil price change, ΔP, for any given net oil supply shortfall (after supply offsets and the use of the reserve). Following the DOE/Interagency 1990 analysis, U.S. and world net import demand elasticities for 1999 are approximately -0.125 in the short run (first month of a disruption). First-month elasticities increase over time, rising to -0.15 by 2020. Elasticities rise over the duration of the disruption, increasing by 50% after 12 months. Finally net import demand elasticities also increase with the magnitude of oil short fall or price increase.

[5]Note that in the base case we treat the quantity of available slack capacity as independent of disruption size. Perhaps it is more realistic to recognize that supply disruptions may also reduce the amount of slack production capacity available. The amount of slack capacity available may be inversely correlated with disruption size since very large disruptions almost certainly involve the interruption of supply from those countries possessing the bulk of the excess capacity (i.e. Persian Gulf countries).

3.2.6 GDP Elasticity With Respect To Oil Price Shocks

The two principal economic costs to the U.S. due to disruptions, the increased cost of oil imports and the macroeconomic (GDP) adjustment costs, are easily calculated given the changes in world oil price, ΔP. The net import demand elasticity determines import levels I for the given price change ΔP during the shock, and shock import costs ΔC_I are the product of the import level and the price change:

$$\Delta C_I = I \, \Delta P$$

The macroeconomic losses during the shock are summarized by a parameter ó, called the "GDP-elasticity" with respect to oil price shocks. The GDP elasticity essentially specifies the percent GDP change for each percent change in the oil price:

$$\%\Delta GDP \approx ó \; \%\Delta P$$ [6]

Work by Mork, Olsen and Mysen (1994) and a host of other researchers over the past 25 years (Bjornstad, Jones, and Leiby, 1997) sheds considerable light on the macroeconomic cost of oil price shocks. If one were to simply average the estimates of the 26 studies over last 19 years (*neither* a scientific *nor* a recommended approach), one would obtain a GDP elasticity estimate of -6.4% (smallest: -2%, largest: -14%). Instead, we rely on the recent work of Mork et. al., as representative of the current state of the art. The methods used followed the general body of oil shock research and relied on available aggregate macroeconomic data. The results of the Mork et al. empirical study produce a central (mean) GDP elasticity estimate of -5.4%. This implies that a sudden doubling of oil prices causes a decrease in U.S. GDP of approximately 5.4%. As a sensitivity analysis, we consider a variety of elasticities within a 95% confidence interval around the central estimate.

3.2.7 SPR Drawdown Strategies

The value of enhancing drawdown capability will hinge upon the drawdown strategy used. By drawdown strategy we mean the planned drawdown trigger, and the timing and rates of drawdown to be chosen in response to particular market conditions. For good reasons, the U.S. government may avoid making such a strategy explicit. However, for the formal modeling of drawdown net benefits, the specification of one or more such drawdown strategies is essential and unavoidable. Drawdown strategies implemented in DIS-Risk include: drawing at the maximum sustainable rate (base case, same as DOE90), delaying drawdown, maintaining the ability to quickly refill, and drawing down aggressively.

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[6] This is a very close approximation. The actual calculation is done with the elasticity formulation:

$$\left(1 + \frac{\Delta GDP}{GDP}\right) = \left(1 + \frac{\Delta P}{P}\right)^{ó}$$

3.2.8 SPR Drawdown Timing

Delaying drawdown can be considered either as a potential strategy or a manifestation of the circumstances surrounding a drawdown. Decision makers may wish to delay drawdown in order to gain more information concerning the oil disruption or to coordinate action with allies. The base case assumption for drawdown delay is zero, that is no significant delay in drawing down. This assumption is consistent with both current policy and the 1990 and 1999 SPR size studies.

3.2.9 Anticipated Length of Oil Supply Disruption

In a simulation, if a disruption occurs, the actual disruption length is determined by a draw from a random distribution. This length is then known to the model, but may not be known to SPR managers in a real emergency situation. To reflect this uncertainty, the variable "anticipated disruption length"was added to the model. Currently, the base case assumption is that the decision maker has perfect information concerning the length of a disruption. This assumption was implicitly used in both the 1990 and 1999 SPR size studies. Alternatives are to assume that the anticipated disruption length is short (one month), average, long, or random, independent of the actual length. For the random case the average anticipated length would equal the actual length. However, in the random case given any oil supply disruption, the decision maker may underestimate or overestimate the actual disruption length.

3.2.10 Foreign Reserve Draw Coordination

In the 1990 DOE/Interagency Study, the foreign stockpiles were assumed to draw down first. This implicit "Foreign First" rule implied that in certain cases foreign government/strategic stockpiles might be used to fully offset smaller disruptions (if they are sufficient to do so) with NO use at all of the U.S. reserve. This "Foreign First" rule seems somewhat unrealistic, and certainly politically embarrassing. For this reason, we adopted a "coordinated" response of U.S. and foreign reserves as the sequencing assumption for the 1999 SPR size study and the current drawdown study. In the coordinated response, each nation's strategic oil stockpile is used in the same proportion to its size.

3.2.11 Start Build Year

The current base assumption for when the drawdown rate expansion begins is 2001. If benefits are greater than costs, then delaying construction reduces discounted net economic benefits. This hypothesis is tested with alterative start build years of 2005 and 2010.

3.2.12 SPR Fill and Refill Rates

Refill rates are currently set at 0.38 MMBD for a 700 MMB reserve. This refill rate is limited less by technical factors than by budgetary and political considerations. The chosen refill rate is the rate capable of refilling a completely empty reserve in five years. Faster rates (absent capital costs) may result in higher net benefits.

3.2.13 Discount Rate

In these analysis, the discount rate is set at 7% (real terms), the prevailing rate for government projects specified in OMB circular A94-B. A higher discount rate tends to reduce benefits more than costs, since benefits generally come later. Discount rates of 4.5% and 10% are included as sensitivity cases.

4.0 Results

4.1 Recap of the Base Case Assumptions

The "Base Case" for the 2000 SPR drawdown study is comprised of the assumptions given in Table 4 below. These base assumptions are the product of the 1999 SPR size study working group, new additions to the model, and normal model updating.

Table 4: U.S. Strategic Petroleum Reserve Analysis Base Case Assumptions

Normal Oil Market Conditions	EIA Annual Energy Outlook 1999 Base Case
Disruption Probabilities	DOE/Interagency 1990 Base Case (Weibull distribution over disruption sizes, with a 1% annual probability of a disruption equal to 15% or more of world demand).
Disruption Lengths	Length is random. Disruptions last either 3 or 6 months, with equal likelihood (mean length is 4.5 months).
Slack Production Capacity	EIA International Energy Outlook 1999 base path, corresponding to 3.6 MMBD in 1999, declining to 1.8 MMBD by 2010, and then recovering to 2.4 MMBD by 2020. Assumed OPEC production capacity utilization rises from current 90% to 96% by 2010 and beyond.
GDP Elasticity	Midcase, -0.054. Roughly, a sudden oil price doubling causes a 5.4% reduction in GDP.
Import Demand Elasticities	Following the DOE/Interagency 1990 analysis, U.S. and world net import demand elasticities for 1999 are approximately -0.125 in the short run (first month of a disruption). Elasticities rise over the duration of the disruption, increasing by 50% after 12 months. First-month elasticities also increase over time, rising to -0.15 by 2020.
Drawdown Strategy	Maximum sustainable rate. The SPR is drawn down evenly over the course of the disruption.
Drawdown Timing	No delay in drawdown.
Disruption Length Anticipation	Perfect foresight. Decision makers know how long the disruption will last.
Foreign Draw Coordination	U.S. and foreign reserves coordinate drawdowns in proportion to their reserve sizes.
Start Build Year	2001. For drawdown enhancement capital projects, construction begins in 2001 and ends in 2002.
Fill and Refill Rates	Initial fill and refill rates are sufficient to refill the reserve in 5 years.
Discount Rate	7%, per OMB Circular A94-B

4.2 Base Case Results on Expected Net Benefits of Drawdown Enhancement

The primary objective of this study is to determine the expected net economic benefits of increasing the drawdown rate capability beyond its current level of 4.3 MMBD. Included in the net economic benefit calculation is:

- Avoided Costs of Oil Imports,
- Avoided GDP Losses,
- Changes to Net SPR Revenues (oil sales minus purchase costs), and
- Increased Capital Costs (both for size and drawdown) and O&M Costs.

Since we are uncertain about whether and when future oil market disruptions will occur, the modeling approach randomly samples and evaluates many (tens of thousands of) possible futures for the oil market. This is a "probabilistic simulation" approach, as described further in Appendix 1. This analysis yields the "expected" value of drawrate benefits, which is the mean or average benefit over those thousands of simulated outcomes concerning the future.

Enhancing the drawdown rate requires capital expenditures, although some limited degree of drawrate enhancement may accompany an SPR size expansion at no cost. The actual capital cost will depend on the particular situation, location, and system, and is thus difficult to ascertain. Accordingly, for this analysis no exact dollar amount has been placed on the capital cost of drawrate enhancements. Rather the analysis considers a range of costs that might be associated with these improvements. The drawdown capital costs assumed for this analysis exhibit constant marginal costs. For example the costs of going from 4.4 MMBD to 4.5 MMBD are the same for going from 6.0 MMBD to 6.1 MMBD. In reality the marginal costs of drawdown enhancement may rise as cheaper drawdown routes and facilities are developed first, leaving the more difficult and costly alternatives for last. Nevertheless, if costs are unknown, the slope of the marginal cost curve is certainly unknown, and an approximation assuming different levels of constant marginal capital cost may be the best one can do without extensive engineering cost analysis.

Figures 10, 11 and 12 below detail the results of the SPR drawdown capability enhancement analysis for three alternative levels of drawrate capital costs. Each figure shows three curves relating net economic benefit to drawdown rates ranging between 4.1 and 7.0 MMBD, for the three SPR sizes. The three SPR sizes considered in the analysis are 590 MMB (current size), 700 MMB (fill to current capacity), and 800 (fill to current capacity and expand Bayou Choctaw and Big Hill).

Figure 10 shows the benefits of drawrate enhancement for the three different SPR sizes, with drawrate capital costs set to zero. As such, these may be viewed as the *gross* economic benefit curves for drawdown enhancement, rather than the *net* economic benefit curves. The zero dollar value for costs, while not particularly realistic, yields an upper bound on the expected net benefits given the base case assumptions.

Figure 11 reports the same information, assuming that the discounted drawrate enhancement costs $200 million per million barrels-per-day of drawdown capability or $200 per BBL/day. This is proposed as a reasonable, conservative estimate of what the enhancement costs may be. The actual costs of drawrate enhancement will be highly dependent on the project design and the degree to which distribution infrastructure (e.g. pipeline) costs can be shared with private firms who can use that infrastructure for other purposes. The $200 million discounted cost figure is based on a review of the recent PB-KBB size expansion report (PB-KBB 1999, Morgan 2000) and is double the cost estimate adopted in a recent GAO study (GAO 1996).

Figure 12 may be viewed as a possible lower bound of the expected net economic benefits of drawdown enhancement. Here the hypothetical discounted cost of increasing the drawdown capability is taken to be a high value of $400 million per million barrels-per-day or $400/BD.

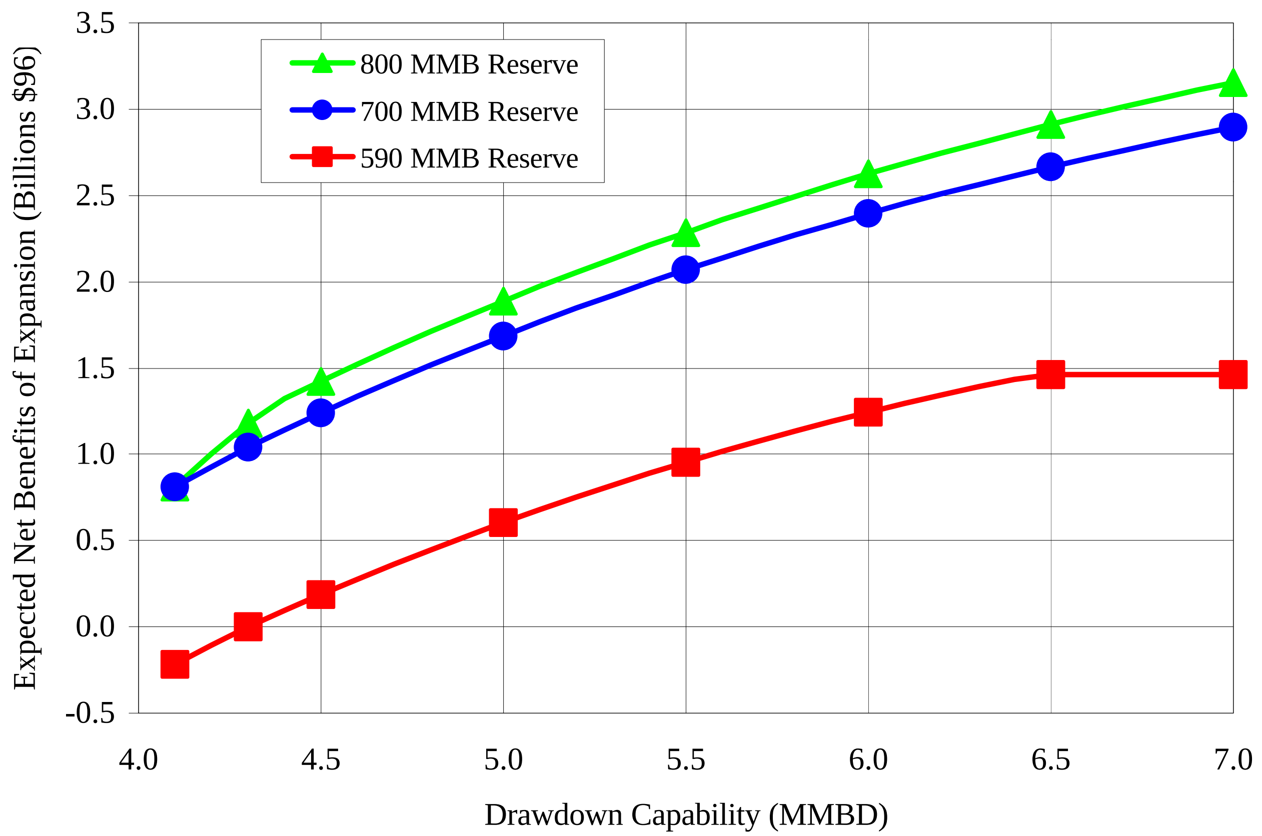

Figure 10: Expected Net Economic Benefits of SPR Size and Drawdown Enhancement. Drawrate capital costs excluded.

Table 5: Expected Net Benefits of Expansion, Base Case Assumptions (Billions $96)

Discounted Drawdown Enhancement Capital Costs: 0 (Excluded)

	Drawdown Capability (MMBD)								
Reserve Size	4.1	4.3	4.4	4.5	5.0	5.5	6.0	6.5	7.0
590 MMB Reserve	-0.22	0.00	0.10	0.19	0.60	0.95	1.24	1.46	1.46
700 MMB Reserve	0.81	1.04	1.14	1.24	1.69	2.07	2.39	2.67	2.89
800 MMB Reserve	0.81	1.18	1.32	1.42	1.89	2.29	2.63	2.91	3.16

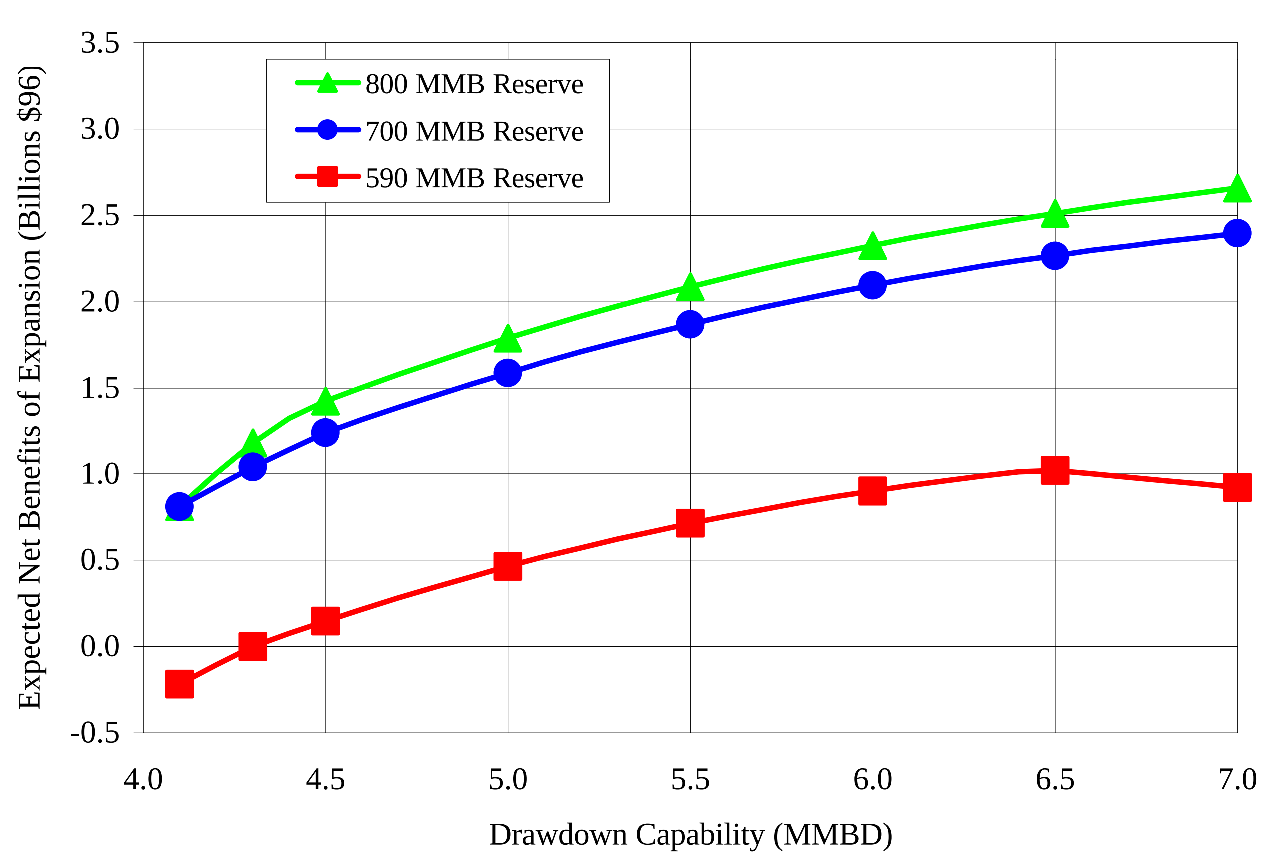

Figure 11: Expected Net Economic Benefits of SPR Size and Drawdown Enhancement. Drawrate capital costs equal to 200 million dollars per million barrels of drawdown capa

Table 6: Expected Net Benefits of Expansion, Base Case Assumptions (Billions $96)

Drawdown Enhancement Capital Costs: $200 mill/MMBD Capability

	Drawdown Capability (MMBD)								
Reserve Size	4.1	4.3	4.4	4.5	5.0	5.5	6.0	6.5	7.0
590 MMB Reserve	-0.22	0.00	0.08	0.15	0.46	0.71	0.90	1.02	0.92
700 MMB Reserve	0.81	1.04	1.14	1.24	1.59	1.87	2.09	2.27	2.39
800 MMB Reserve	0.81	1.18	1.32	1.42	1.79	2.09	2.33	2.51	2.66

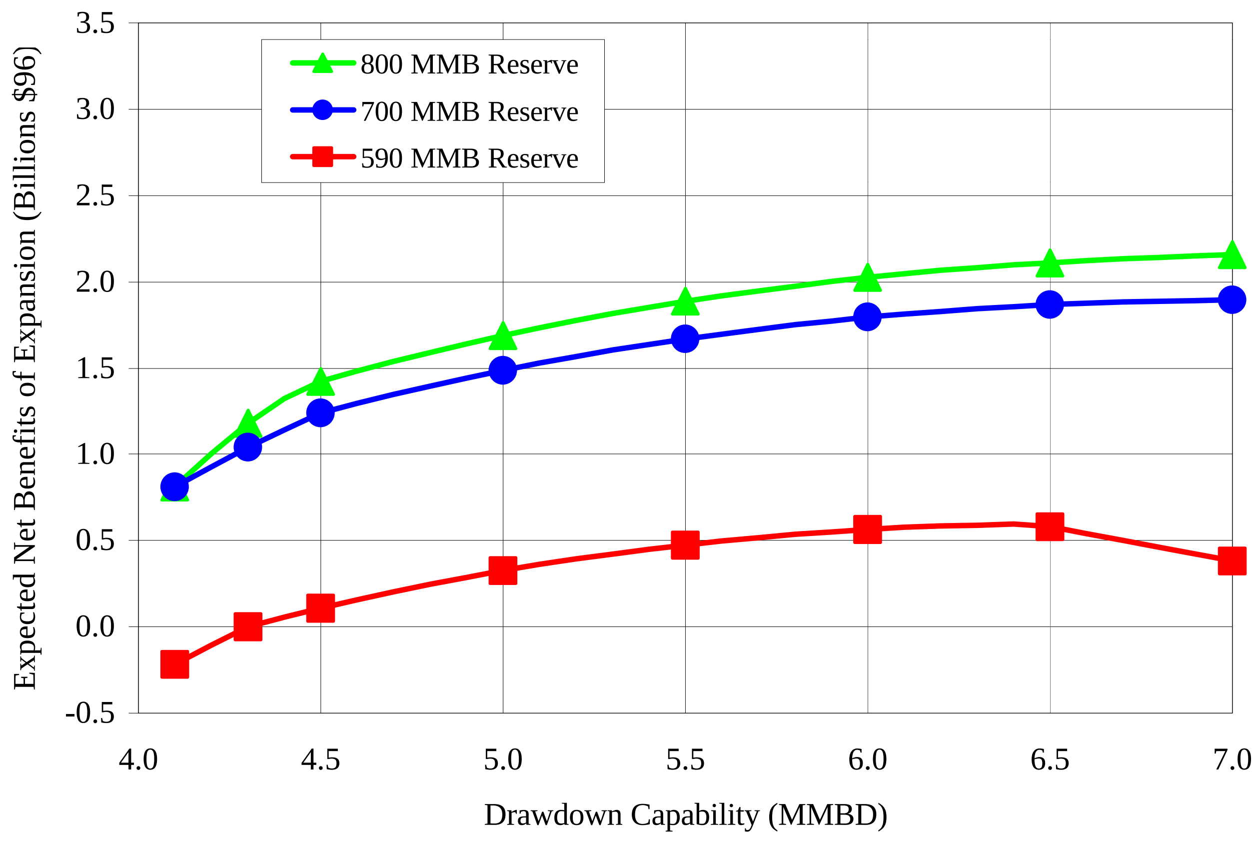

Figure 12: Expected Net Economic Benefits of SPR Size and Drawdown Enhancement. Discounted drawrate capital costs equal $400 million per million barrels of drawdown capability.

Table 7: Expected Net Benefits of Expansion, Base Case Assumptions (Billions $96)

Discounted Drawdown Enhancement Capital Costs: $400 mill/MMBD Capability

	Drawdown Capability (MMBD)								
Reserve Size	4.1	4.3	4.4	4.5	5.0	5.5	6.0	6.5	7.0
590 MMB Reserve	-0.22	0.00	0.06	0.11	0.32	0.47	0.56	0.58	0.38
700 MMB Reserve	0.81	1.04	1.14	1.24	1.49	1.67	1.79	1.87	1.89
800 MMB Reserve	0.81	1.18	1.32	1.42	1.69	1.89	2.03	2.11	2.16

4.3 Insights Gained From the Base Case Results

Over the evaluated range of drawdown rates between 4.3 and 7.0 MMBD, the gross benefits of expanded draw capability are as much as $1.4 billion for the current 590 MMB reserve, $1.8 billion for the 700 MMB, and $2.0 billion for the 800 MMB reserve (Figure 10). These gross benefits exclude the capital cost of expanding the draw rate.

Even for relatively high discounted capital costs of drawrate expansion ($400 million per MMBD, in Figure 12), the maximum or highest level of expected net economic benefit is achieved for a 800 MMB reserve with a 7.0 MMBD drawdown rate. Lower estimates of the capital cost (e.g. Figure 11), logically, also yield this same conclusion, indicating that expanded drawrate capability for most sizes could be highly valuable.

In order to better understand these results, it may be useful to differentiate between net benefits arising from SPR size expansion and net benefits arising from drawdown enhancement. Considering Figure 11, which represents our best guess at what the capital costs may be, we see that much of the achievable net benefits are associated with filling the reserve to its current 700 MMB capacity (moving from the [size, drawdown, net benefits] point of [590, 4.3, 0.0] to [700, 4.4, $\approx$1.25]). As shown by the close proximity of the 700 and 800 curves, very little pure size benefits are garnered by going beyond this size. The substantial remainder of the net benefits can be attributed to drawdown rate enhancements. What Figure 11 shows (as well as Figures 10 and 12) is that there are potentially substantial net benefits that can be realized through enhancing the current drawdown rate, even if we never add another barrel of oil. Of course, this assumes that it is technically possible to construct a system which allows for very high drawdown rates even at current reserve sizes.

This important conclusion, that for the base case assumptions additional drawdown capability can be very valuable, holds true for even high levels of drawdown enhancement capital costs. As Figure 14 below shows, the level of *optimum* drawdown capability is high and does not begin to drop off for the 590 MMB SPR reserve size until capital costs exceed $200 million per MMBD, and $400 million per MMBD for the 700 and 800 SPR reserve sizes. *Some* degree of drawrate expansion beyond the current rate of 4.3 MMBD is optimal so long as capital costs are less than $1000 million per MMBD.

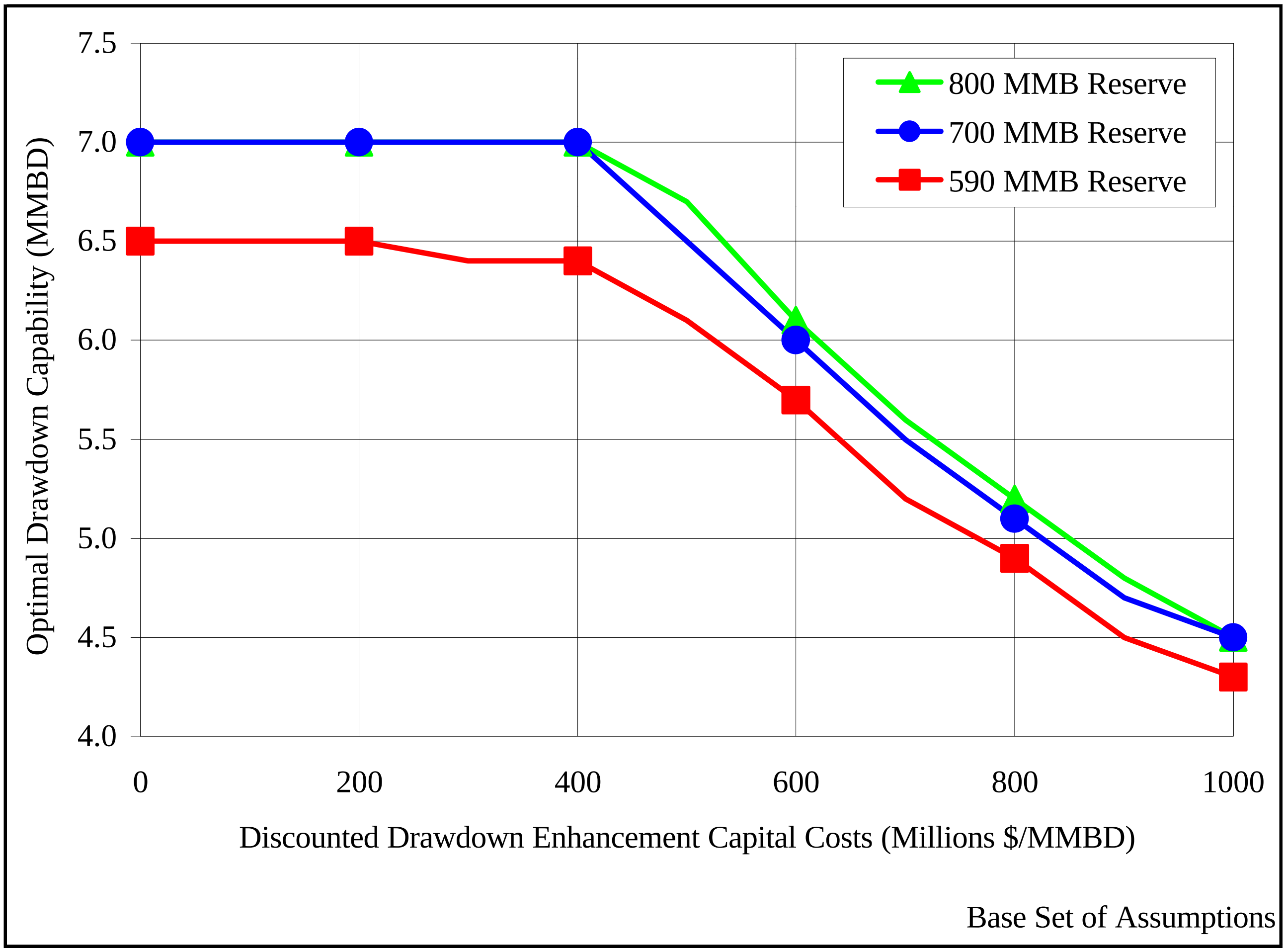

Figure 13: Optimal Drawdown Capability based upon the Expected Net Benefits of Expansion for Various Drawdown Enhancement Capital Costs.

Table 8: Optimal Drawdown Capability based upon the Expected Net Benefits of Expansion

	Discounted Drawdown Enhancement Capital Costs (Millions $/MMBD)											
Reserve Size	0	50	100	200	300	400	500	600	700	800	900	1000
590 MMB Reserve	6.5	6.5	6.5	6.5	6.4	6.4	6.1	5.7	5.2	4.9	4.5	4.3
700 MMB Reserve	7.0	7.0	7.0	7.0	7.0	7.0	6.5	6.0	5.5	5.1	4.7	4.5
800 MMB Reserve	7.0	7.0	7.0	7.0	7.0	7.0	6.7	6.1	5.6	5.2	4.8	4.5

One important, basic insight can be drawn from Figures 10-12. The expected net benefits given in the figures above show that drawdown rate enhancement can be very valuable. Increasing the SPR size can be valuable too (especially to 700 MMB), but much of these benefits are from allowing for even greater drawdown rates and not from the larger stock.

4.4 Marginal Analysis of Draw Capability Benefits

The total benefits reported by this analysis can be used to compute the marginal gains anticipated from increasing the draw capability by a small amount. The "marginal benefits" of draw capability expansion are defined as the change in total benefits for a small increment in draw rate, divided by the size of that draw rate increment. The units of marginal benefits are "millions of dollars per MMBD," or, equivalently, "dollars per barrel-per-day." These values are reported in Tables 9, 10 and 11 below.

The marginal benefit of increasing draw capability by a small increment (e.g. 0.1 MMBD) is approximately $950/BD at the current SPR configuration (4.3 MMBD draw capability and 590 MMB size). However, if instead the reserve size was larger, then the marginal benefit of drawrate expansion from the current 4.3 MMBD draw rate level would be higher, i.e. $1001/BD for the 700 MMB size and $1444/BD for the 800 MMB size.

"Marginal benefit curves" such as those in Figure 14 (which exclude capital costs) are useful for plotting out the declining rate at which draw capability provides benefits, and identifying the likely level of optimal draw capability. Since the capital costs of expanded draw capability remain to be determined from engineering analyses, a practical approach is to compare the estimated marginal *benefits* of draw rate expansion at different draw capability levels to various possible levels of expansion capital *costs*. For each possible level of draw rate capital costs the optimal draw capability can be identified from marginal benefit curves as that rate at which the marginal benefits just equal the marginal capital costs.[7]

Figure 14 shows that the discounted marginal gross benefits of drawrate expansion stay high up to at least 6300 MMB for all three SPR sizes, and exceed $400/BD (discounted) all the way up to 7.0 MMBD for the larger two SPR sizes. This figure, and the associated Table 12 below it, show that over the range of draw rates considered, draw capability expansion is very worthwhile so long as the capital cost of doing so is less than $400/BD. That is for a per barrel cost of $400, the marginal benefits are greater than the marginal costs and continued expansion in worthwhile. At the 7.0 MMBD max draw rate level, marginal benefits just equal marginal costs and expansion should stop.

The optimal draw capability is that level where the marginal benefit of expansion just equals the marginal capital cost of expansion. For example, using Table 12, we see that if the (discounted) marginal capital cost of draw capability expansion is $400 million per MMBD ($400/BD), then the optimal draw capability is about 6.0 MMBD for the 590 MMB reserve, 7.0 MMBD for the 700 MMB size, and 7.0 MMBD for 800 MMB.

[7]Since the marginal benefit curves are given in *discounted* dollars, they should be compared with an estimate of the *discounted* marginal capital costs. For this reason all estimates of drawdown enhancement capital costs are given in discounted terms.

Table 9: Base Case Total and Marginal Net Economic Benefits Associated with Enhancing Drawdown Capability

Drawdown Enhancement Capital Costs: 0 (Excluded)

SPR Size	590 MMB			700 MMB			800 MMB		
Draw Rate Capability	Benefits	Change in Benefits	Marginal Benefits	Benefits	Change in Benefits	Marginal Benefits	Benefits	Change in Benefits	Marginal Benefits
MMBD	Billions $96	Billions $96	$/BBL of Daily Capability	Billions $96	Billions $96	$/BBL of Daily Capability	Billions $96	Billions $96	$/BBL of Daily Capability
4.1	-0.22	0.11	1105.79	0.81	0.12	1179.33	0.81	0.19	1903.84
4.2	-0.11	0.11	1074.47	0.93	0.11	1147.33	1.00	0.18	1758.89
4.3	0.00	0.10	952.51	1.04	0.10	1001.19	1.18	0.14	1443.68
4.4	0.10	0.09	918.87	1.14	0.10	983.60	1.32	0.10	1012.28
4.5	0.19	0.09	887.13	1.24	0.10	956.32	1.42	0.10	984.50
4.6	0.28	0.09	860.64	1.34	0.09	913.65	1.52	0.10	953.04
4.7	0.36	0.08	833.14	1.43	0.09	886.80	1.62	0.09	924.71
4.8	0.45	0.08	809.85	1.52	0.09	863.04	1.71	0.09	899.02
4.9	0.53	0.08	784.59	1.60	0.08	839.38	1.80	0.09	874.59
5.0	0.60	0.08	757.47	1.69	0.08	815.59	1.89	0.08	849.72
5.1	0.68	0.07	727.49	1.77	0.08	789.81	1.97	0.08	823.37
5.2	0.75	0.07	691.37	1.85	0.08	765.90	2.06	0.08	797.33
5.3	0.82	0.07	667.82	1.92	0.07	741.83	2.14	0.08	768.71
5.4	0.89	0.06	647.17	2.00	0.07	715.16	2.21	0.07	744.12
5.5	0.95	0.06	623.52	2.07	0.07	689.85	2.29	0.07	720.32
5.6	1.02	0.06	603.41	2.14	0.07	672.72	2.36	0.07	699.66
5.7	1.08	0.06	583.50	2.21	0.07	652.99	2.43	0.07	677.82
5.8	1.13	0.06	557.91	2.27	0.06	633.82	2.50	0.07	658.21
5.9	1.19	0.05	533.52	2.33	0.06	609.25	2.56	0.06	634.17
6.0	1.24	0.05	508.03	2.39	0.06	584.72	2.63	0.06	607.84
6.1	1.29	0.05	486.94	2.45	0.06	558.53	2.69	0.06	586.94
6.2	1.34	0.05	467.61	2.51	0.05	537.85	2.74	0.06	570.64
6.3	1.39	0.05	450.56	2.56	0.05	521.92	2.80	0.06	554.64
6.4	1.44	0.03	268.05	2.62	0.05	504.00	2.86	0.05	536.47
6.5	1.46	0.00	0.00	2.67	0.05	490.50	2.91	0.05	522.35
6.6	1.46	0.00	0.00	2.71	0.05	474.75	2.96	0.05	506.05
6.7	1.46	0.00	0.00	2.76	0.05	458.49	3.01	0.05	490.29
6.8	1.46	0.00	0.00	2.81	0.04	442.78	3.06	0.05	474.50
6.9	1.46	0.00	0.00	2.85	0.04	422.81	3.11	0.05	459.12
7.0	1.46	0.00	0.00	2.89	0.04	402.84	3.16	0.04	443.74

Table 10: Base Case Total and Marginal Net Economic Benefits Associated with Enhancing Drawdown Capability

Drawdown Enhancement Capital Costs: 200 Million $/MMBD of Capability (undiscounted)

SPR Size	590 MMB			700 MMB			800 MMB		
Draw Rate Capability	Benefits	Change in Benefits	Marginal Benefits	Benefits	Change in Benefits	Marginal Benefits	Benefits	Change in Benefits	Marginal Benefits
MMBD	Billions $96	Billions $96	$/BBL of Daily Capability	Billions $96	Billions $96	$/BBL of Daily Capability	Billions $96	Billions $96	$/BBL of Daily Capability
4.1	-0.22	0.11	1106	0.81	0.12	1179	0.81	0.19	1904
4.2	-0.11	0.11	1074	0.93	0.11	1147	1.00	0.18	1759
4.3	0.00	0.08	753	1.04	0.10	1001	1.18	0.14	1444
4.4	0.08	0.07	719	1.14	0.10	984	1.32	0.10	1012
4.5	0.15	0.07	687	1.24	0.08	756	1.42	0.08	785
4.6	0.22	0.07	661	1.32	0.07	714	1.50	0.08	753
4.7	0.28	0.06	633	1.39	0.07	687	1.58	0.07	725
4.8	0.35	0.06	610	1.46	0.07	663	1.65	0.07	699
4.9	0.41	0.06	585	1.52	0.06	639	1.72	0.07	675
5.0	0.46	0.06	557	1.59	0.06	616	1.79	0.06	650
5.1	0.52	0.05	527	1.65	0.06	590	1.85	0.06	623
5.2	0.57	0.05	491	1.71	0.06	566	1.92	0.06	597
5.3	0.62	0.05	468	1.76	0.05	542	1.98	0.06	569
5.4	0.67	0.04	447	1.82	0.05	515	2.03	0.05	544
5.5	0.71	0.04	424	1.87	0.05	490	2.09	0.05	520
5.6	0.76	0.04	403	1.92	0.05	473	2.14	0.05	500
5.7	0.80	0.04	384	1.97	0.05	453	2.19	0.05	478
5.8	0.83	0.04	358	2.01	0.04	434	2.24	0.05	458
5.9	0.87	0.03	334	2.05	0.04	409	2.28	0.04	434
6.0	0.90	0.03	308	2.09	0.04	385	2.33	0.04	408
6.1	0.93	0.03	287	2.13	0.04	359	2.37	0.04	387
6.2	0.96	0.03	268	2.17	0.03	338	2.40	0.04	371
6.3	0.99	0.03	251	2.20	0.03	322	2.44	0.04	355
6.4	1.02	0.01	68	2.24	0.03	304	2.48	0.03	336
6.5	1.02	-0.02	-200	2.27	0.03	291	2.51	0.03	322
6.6	1.00	-0.02	-200	2.29	0.03	275	2.54	0.03	306
6.7	0.98	-0.02	-200	2.32	0.03	258	2.57	0.03	290
6.8	0.96	-0.02	-200	2.35	0.02	243	2.60	0.03	274
6.9	0.94	-0.02	-200	2.37	0.02	223	2.63	0.03	259
7.0	0.92	-0.02	-200	2.39	0.02	203	2.66	0.02	244

Table 11: Base Case Total and Marginal Net Economic Benefits Associated with Enhancing Drawdown Capability

Drawdown Enhancement Capital Costs: 200 Million $/MMBD of Capability (undiscounted)

SPR Size	590 MMB			700 MMB			800 MMB		
Draw Rate Capability	Benefits	Change in Benefits	Marginal Benefits	Benefits	Change in Benefits	Marginal Benefits	Benefits	Change in Benefits	Marginal Benefits
MMBD	Billions $96	Billions $96	$/BBL of Daily Capability	Billions $96	Billions $96	$/BBL of Daily Capability	Billions $96	Billions $96	$/BBL of Daily Capability
4.1	-0.22	0.11	1106	0.81	0.12	1179	0.81	0.19	1904
4.2	-0.11	0.11	1074	0.93	0.11	1147	1.00	0.18	1759
4.3	0.00	0.06	553	1.04	0.10	1001	1.18	0.14	1444
4.4	0.06	0.05	519	1.14	0.10	984	1.32	0.10	1012
4.5	0.11	0.05	487	1.24	0.06	556	1.42	0.06	585
4.6	0.16	0.05	461	1.30	0.05	514	1.48	0.06	553
4.7	0.20	0.04	433	1.35	0.05	487	1.54	0.05	525
4.8	0.25	0.04	410	1.40	0.05	463	1.59	0.05	499
4.9	0.29	0.04	385	1.44	0.04	439	1.64	0.05	475
5.0	0.32	0.04	357	1.49	0.04	416	1.69	0.04	450
5.1	0.36	0.03	327	1.53	0.04	390	1.73	0.04	423
5.2	0.39	0.03	291	1.57	0.04	366	1.78	0.04	397
5.3	0.42	0.03	268	1.60	0.03	342	1.82	0.04	369
5.4	0.45	0.02	247	1.64	0.03	315	1.85	0.03	344
5.5	0.47	0.02	224	1.67	0.03	290	1.89	0.03	320
5.6	0.50	0.02	203	1.70	0.03	273	1.92	0.03	300
5.7	0.52	0.02	184	1.73	0.03	253	1.95	0.03	278
5.8	0.53	0.02	158	1.75	0.02	234	1.98	0.03	258
5.9	0.55	0.01	134	1.77	0.02	209	2.00	0.02	234
6.0	0.56	0.01	108	1.79	0.02	185	2.03	0.02	208
6.1	0.57	0.01	87	1.81	0.02	159	2.05	0.02	187
6.2	0.58	0.01	68	1.83	0.01	138	2.06	0.02	171
6.3	0.59	0.01	51	1.84	0.01	122	2.08	0.02	155
6.4	0.60	-0.01	-132	1.86	0.01	104	2.10	0.01	136
6.5	0.58	-0.04	-400	1.87	0.01	91	2.11	0.01	122
6.6	0.54	-0.04	-400	1.87	0.01	75	2.12	0.01	106
6.7	0.50	-0.04	-400	1.88	0.01	58	2.13	0.01	90
6.8	0.46	-0.04	-400	1.89	0.00	43	2.14	0.01	74
6.9	0.42	-0.04	-400	1.89	0.00	23	2.15	0.01	59
7.0	0.38	-0.04	-400	1.89	0.00	3	2.16	0.00	44

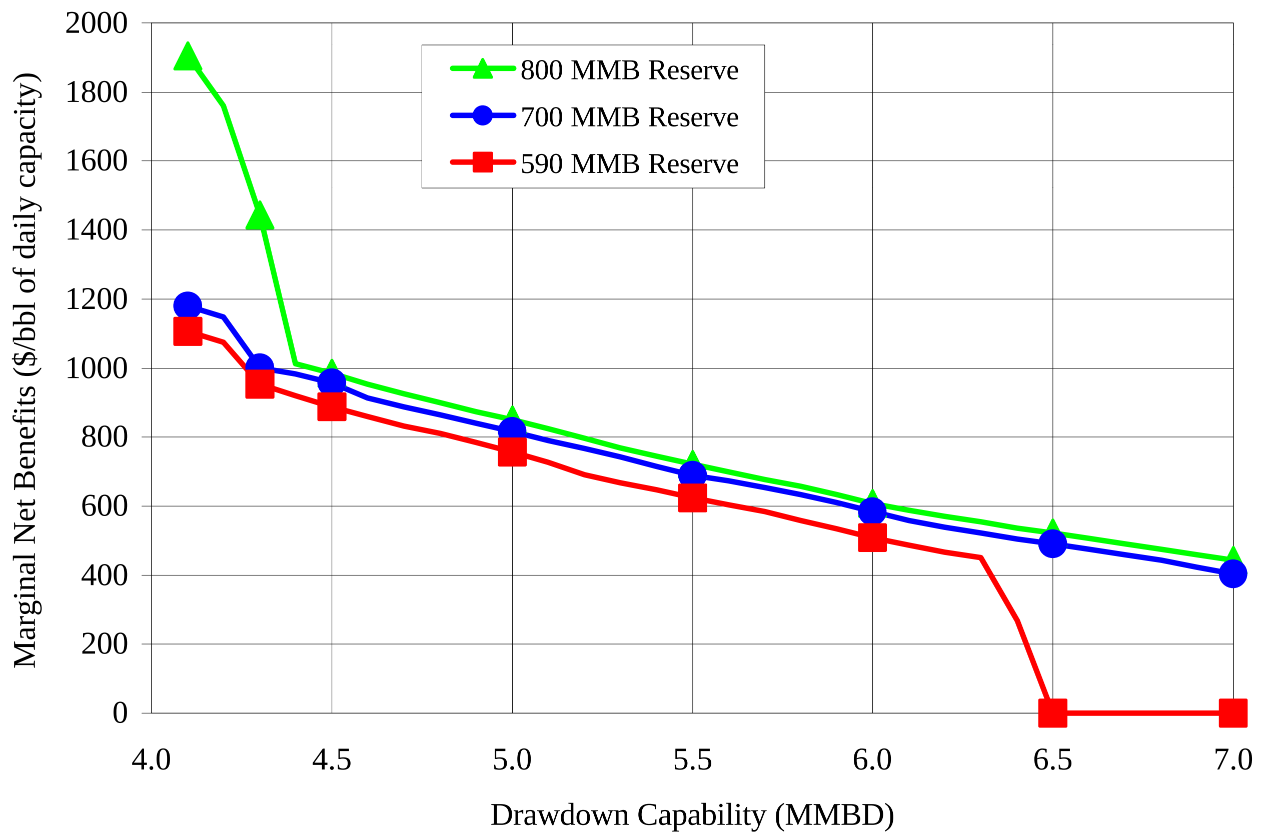

Figure 14: Marginal Change in the Expected Net Benefits of Drawdown Capability Expansion.

Table 12: Marginal Change in Expected Net Benefits of Expansion, Base Case Assumptions ($/(BBL of Daily Capacity)

Discounted Drawdown Enhancement Capital Costs: 0 (Excluded)

	Drawdown Capability (MMBD)								
Reserve Size	4.1	4.3	4.4	4.5	5.0	5.5	6.0	6.5	7.0
590 MMB Reserve	1106	953	919	887	757	624	508	0	0
700 MMB Reserve	1179	1001	984	956	816	690	585	491	403
800 MMB Reserve	1904	1444	1012	985	850	720	608	522	444

4.5 Sensitivity Analysis

The results, presented here for the base case, are a "best guess" at what the future may be. Rigorous analysis oftentimes includes not only one's best guess but also what happens should one's best guess be markedly wrong. Recognizing this, we evaluated SPR size-draw expansion benefits for a set of key sensitivity cases. Figure 15 provides a schematic diagram of the key sensitivity variables of concern and the values explored for each. The figure highlights the combination of conditions used for the base case, as a path through the alternatives connected by arrows. The specific list of sensitivity cases is given in Appendix 4. Numerical results are given in the tables of Appendix 5.

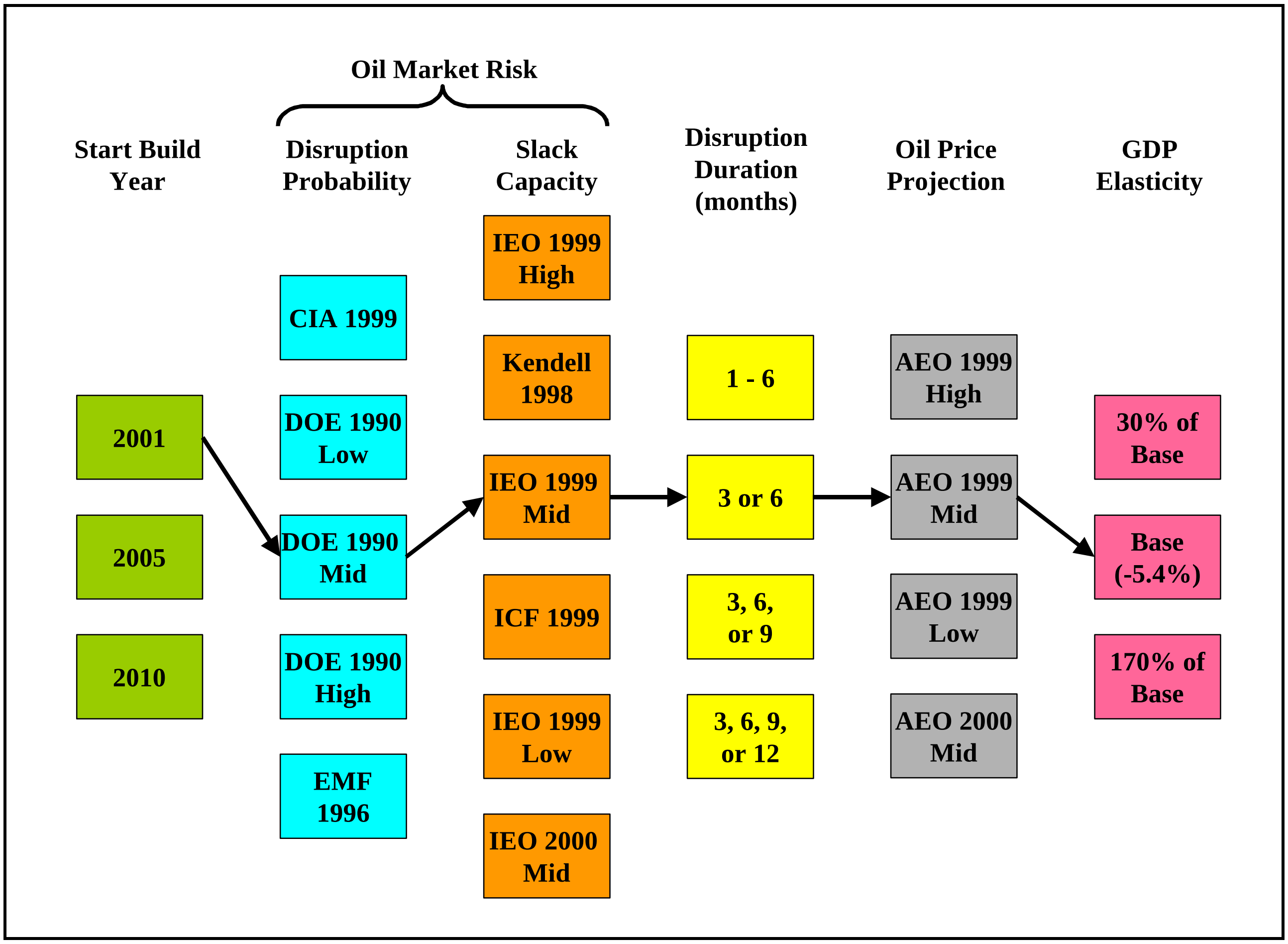

Figure 15: Schematic diagram of the sensitivity cases considered. Key: A case consists of one selection from each column. The arrows connect the selected elements in the "Base" case. Not all combinations of the conditions were examined. See Appendix 3 for a specific list of sensitivity case performed.

Figures 16 through 21 below summarize the essential results of the sensitivity analyses graphically. The sensitivity cases are grouped into sets, in which one or two related inputs are varied. For each set of sensitivity cases, a graph depicts the highest and lowest observed values for the marginal benefits of draw capability expansion, over the range of inputs considered. Marginal benefits are greatest for draw capabilities in the current range of 4.3 MMBD, and decline as higher drawrates are achieved. This declining marginal benefit of draw capability is to be expected, since ever-higher draw capabilities provide protection against an ever-larger fraction of potential disruptions. The likelihood of ever needing further enhancement declines as the level of achieved draw capability grows. Nonetheless, the discounted marginal benefit of draw capability expansion rarely drops below $200/BD for all the sensitivity cases and drawdown rates considered.

Collectively, the sensitivity analysis results lead to the following general conclusions:

- Draw capability benefits are most sensitive to oil market risk (disruption probabilities and slack capacities);
- Sensitivity of marginal drawrate benefits to disruption length is fairly large, with drawrate benefits being higher for shorter disruptions, all else equal;
- Expanding draw rate adds substantial value over a very wide range of GDP elasticities (i.e., within a 95% confidence interval for GDP elasticity);
- Marginal draw benefits show some sensitivity to discount rate;
- Marginal draw benefits decline with a delay in drawdown capability expansion;
- Marginal draw benefits are NOT sensitive to base (undisrupted) oil price projections;

The general conclusion from the sensitivity analyses is that, for the 700 MMB SPR, expansion of the draw rate to 6.0 MMBD and beyond is worthwhile over a wide range of conditions, provided the discounted cost of doing so is $200/BD or less.

A brief discussion of these results is provided in the caption of each sensitivity graph below.

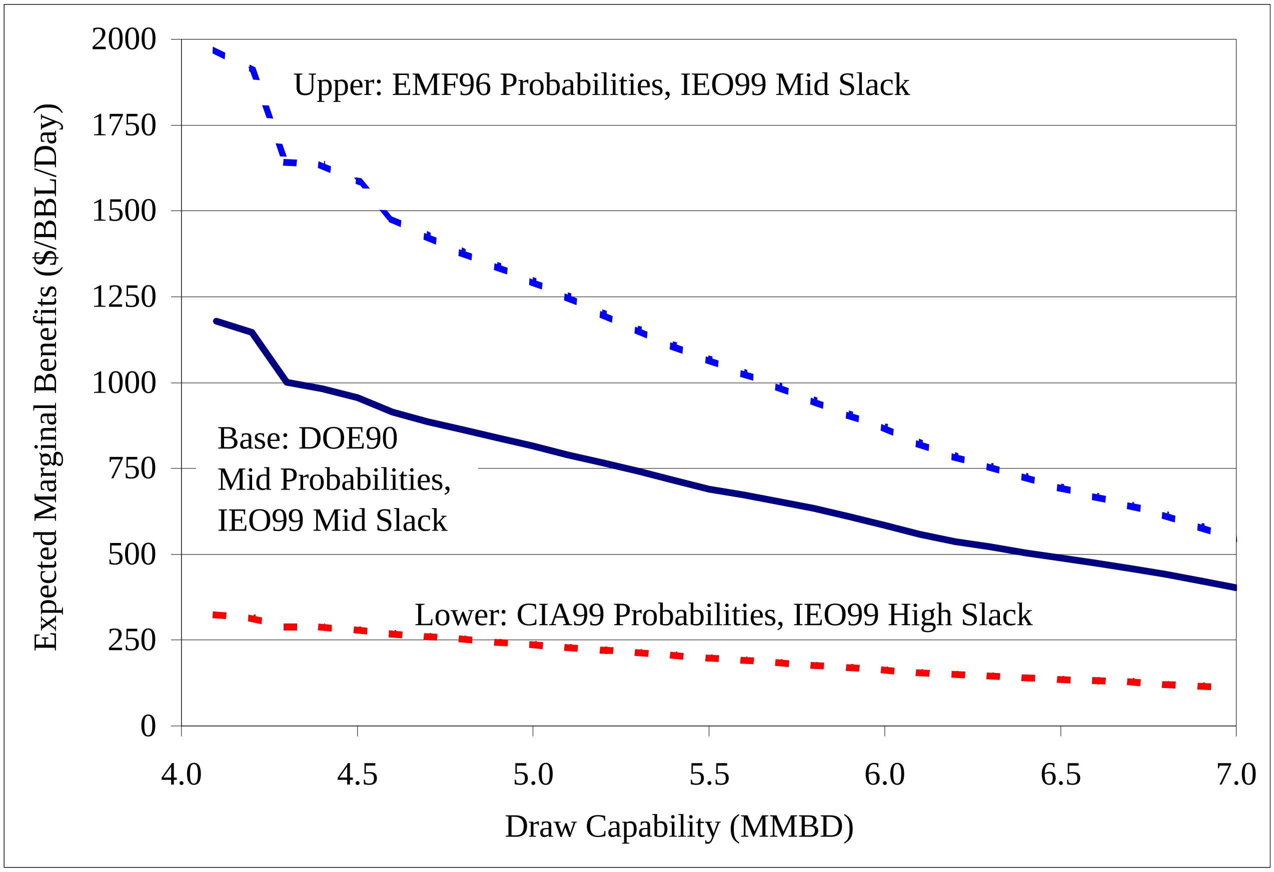

Figure 16: Marginal Draw Capability Benefits: Sensitivity to Oil Market Risk, i.e. Disruption Probability and Slack Oil Production Capacity (700 MMB Size). If disruption probabilities are greater, then the likelihood that the SPR is needed, and the likelihood that an expanded drawdown rate is needed, is naturally greater. Conversely, if disruption probabilities are lower, and if the available slack oil production capacity is expected to be greater, then there is a diminished need for an enhanced draw rate.

Table 13: Marginal Draw Capability Benefits: Sensitivity to Oil Market Risk, i.e. Disruption Probability and Slack Oil Production Capacity (700 MMB Size) (Billions $96)

Drawdown Enhancement Capital Costs: $0 mill/MMBD Capability (Excluded)

	Drawdown Capability (MMBD)								
Sensitivities	4.1	4.3	4.4	4.5	5.0	5.5	6.0	6.5	7.0
Upper: Higher (EMF96) Probabilities, Lower (IEO99 Mid) Slack	1969	1642	1636	1583	1294	1066	870	695	544
Base: DOE90 Mid Probabilities, IEO99 Slack	1179	1001	984	956	816	690	585	491	403
Lower: Lower (CIA99) Probabilities, Higher (IEO99 High) Slack	325	289	288	280	238	198	164	136	110

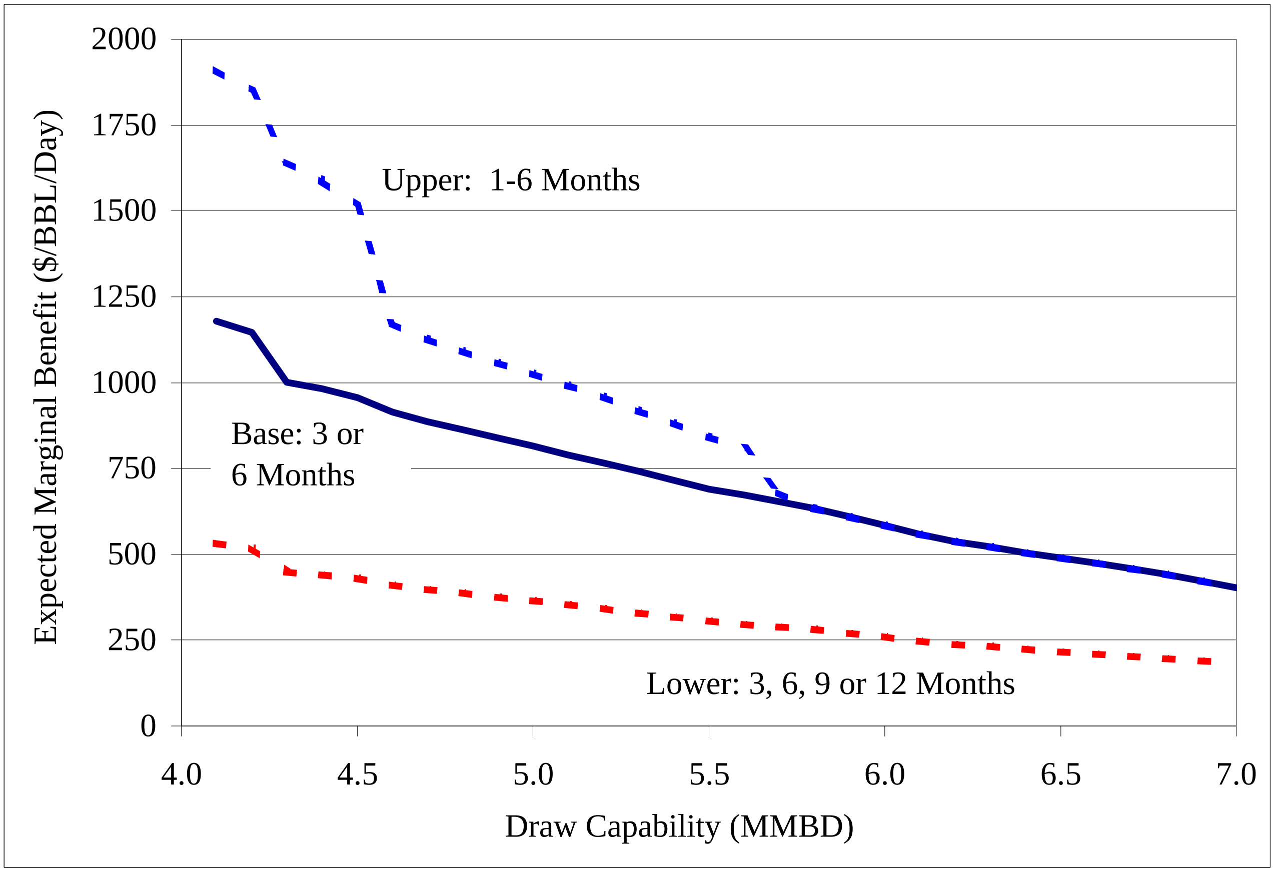

Figure 17: Marginal Draw Capability Benefits: Sensitivity to Disruption Length (700 MMB Size). Disruption length is an important factor influencing marginal drawrate benefits. If there is concern about disruptions which are shorter than 3 months, then drawrate enhancement is markedly more valuable, at least up to 6 MMBD. Alternatively, if half of the disruptions and drawdowns are longer, 9 or 12 months in duration, there is less need for enhanced draw capability. In this latter case, however, the value of expanded SPR *size* is much greater.

Table 14: Marginal Draw Capability Benefits: Sensitivity to Oil Supply Disruption Length (700 MMB Size) (Billions $96)

Drawdown Enhancement Capital Costs: $0 mill/MMBD Capability (Excluded)

	Drawdown Capability (MMBD)								
Sensitivities	4.1	4.3	4.4	4.5	5.0	5.5	6.0	6.5	7.0
Upper: 1-6 Months	1911	1642	1591	1515	1027	842	585	491	403
Base: 3 or 6 Months	1179	1001	984	956	816	690	585	491	403
Lower 3, 6, 9 or 12 Months	533	448	441	430	365	307	260	216	185

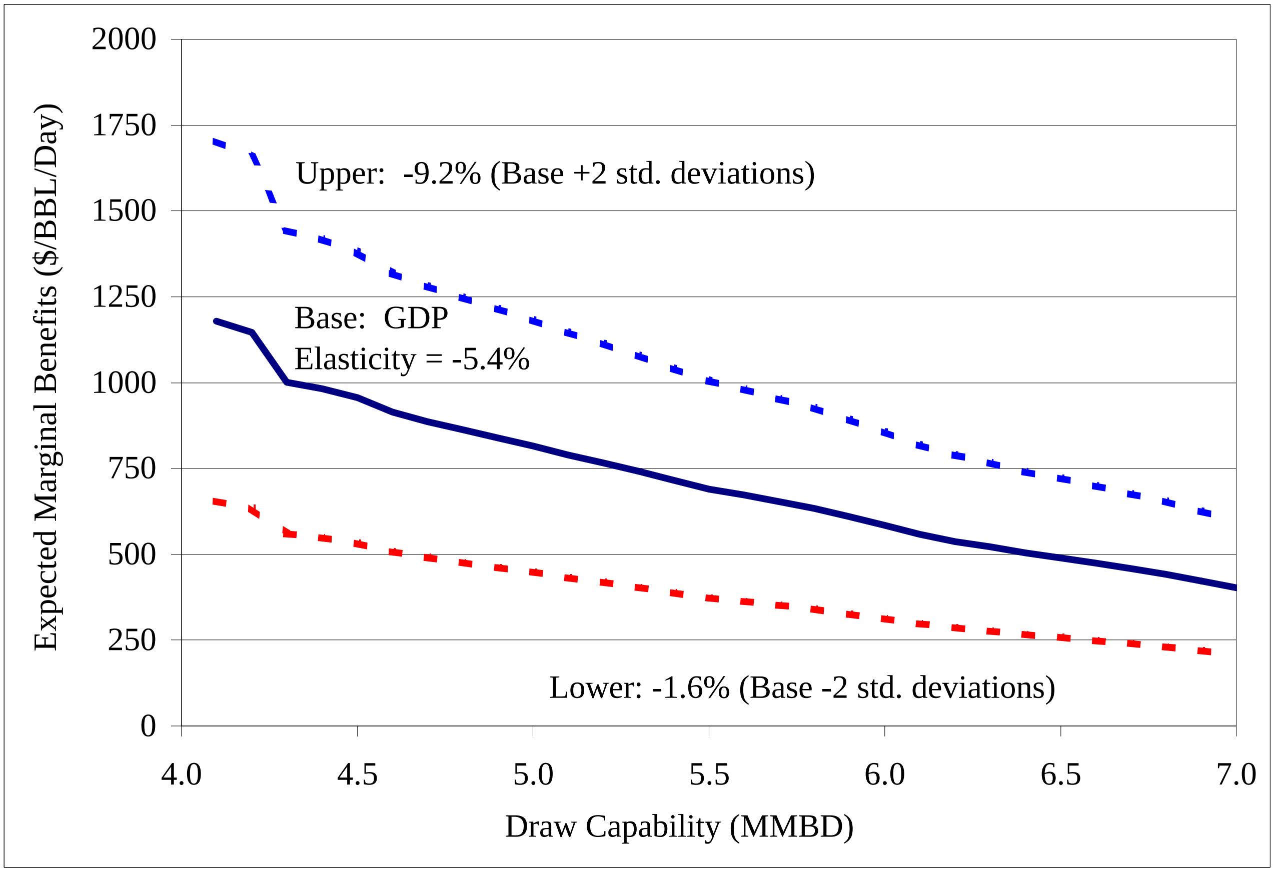

Figure 18: Marginal Draw Capability Benefits: Sensitivity to GDP elasticity (700 MMB Size). Expanding the draw capability adds substantial benefit even for much lower GDP elasticity with respect to oil shocks. (700 MMB Reserve, GDP elasticity varying over base estimate ± two standard deviations, that is between 30% and 170% of the base estimate of -5.4%). This range of GDP elasticities is centered on the mean estimate from the most recent peer-reviewed empirical studies, and encompasses essentially the full spectrum of opinion expressed over the past two decades of research. Even in the lowest extreme, expansion of draw capability to 7.0 MMBD is beneficial if it can be achieved for a discounted cost of $200/BD or less.

Table 15: Marginal Draw Capability Benefits: Sensitivity to GDP Elasticity (700 MMB Size) (Billions $96)

Drawdown Enhancement Capital Costs: $0 mill/MMBD Capability (Excluded)

	Drawdown Capability (MMBD)								
Sensitivities	4.1	4.3	4.4	4.5	5.0	5.5	6.0	6.5	7.0
Upper: -9.2% (Base +2 std. deviations)	1703	1443	1419	1381	1183	1005	856	722	597
Base: GDP Elasticity = -5.4%	1179	1001	984	956	816	690	585	491	403
Lower: -1.6% (Base -2 std. deviations)	656	560	548	532	448	374	313	259	208

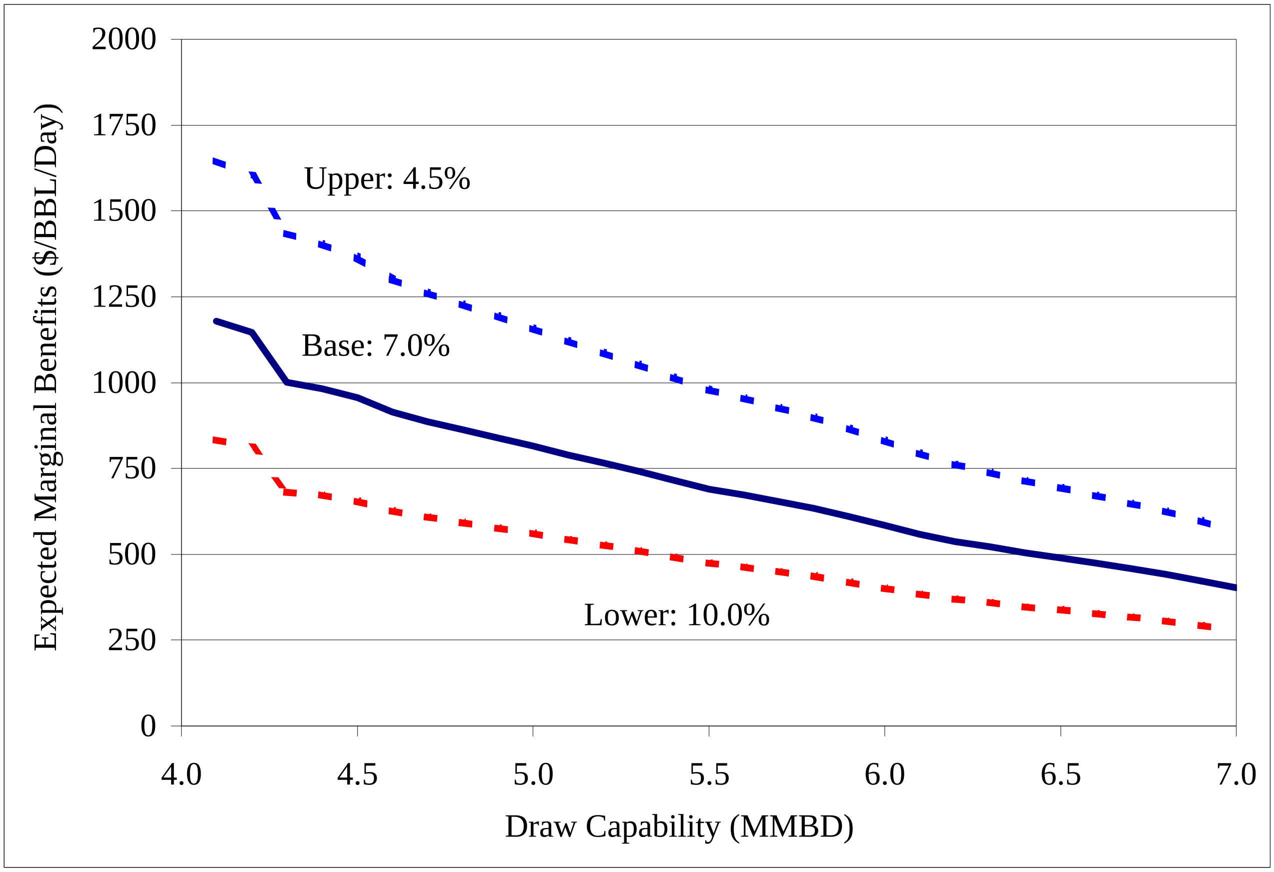

Figure 19: Marginal Draw Benefits: Sensitivity to Discount Rate (700 MMB Size). Higher discount rates reduce the estimated marginal benefit of drawdown capability, since most benefits occur in the future. The converse result occurs for lower discount rates: future benefits have a greater present value.

Table 16: Marginal Draw Capability Benefits: Sensitivity to the Discount Rate (700 MMB Size) (Billions $96)

Drawdown Enhancement Capital Costs: $0 mill/MMBD Capability (Excluded)

	Drawdown Capability (MMBD)								
Sensitivities	4.1	4.3	4.4	4.5	5.0	5.5	6.0	6.5	7.0
Upper: 4.5%	1646	1435	1405	1365	1159	979	832	695	569
Base: 7%	1179	1001	984	956	816	690	585	491	403
Lower: 10%	833	682	674	655	561	475	402	338	279

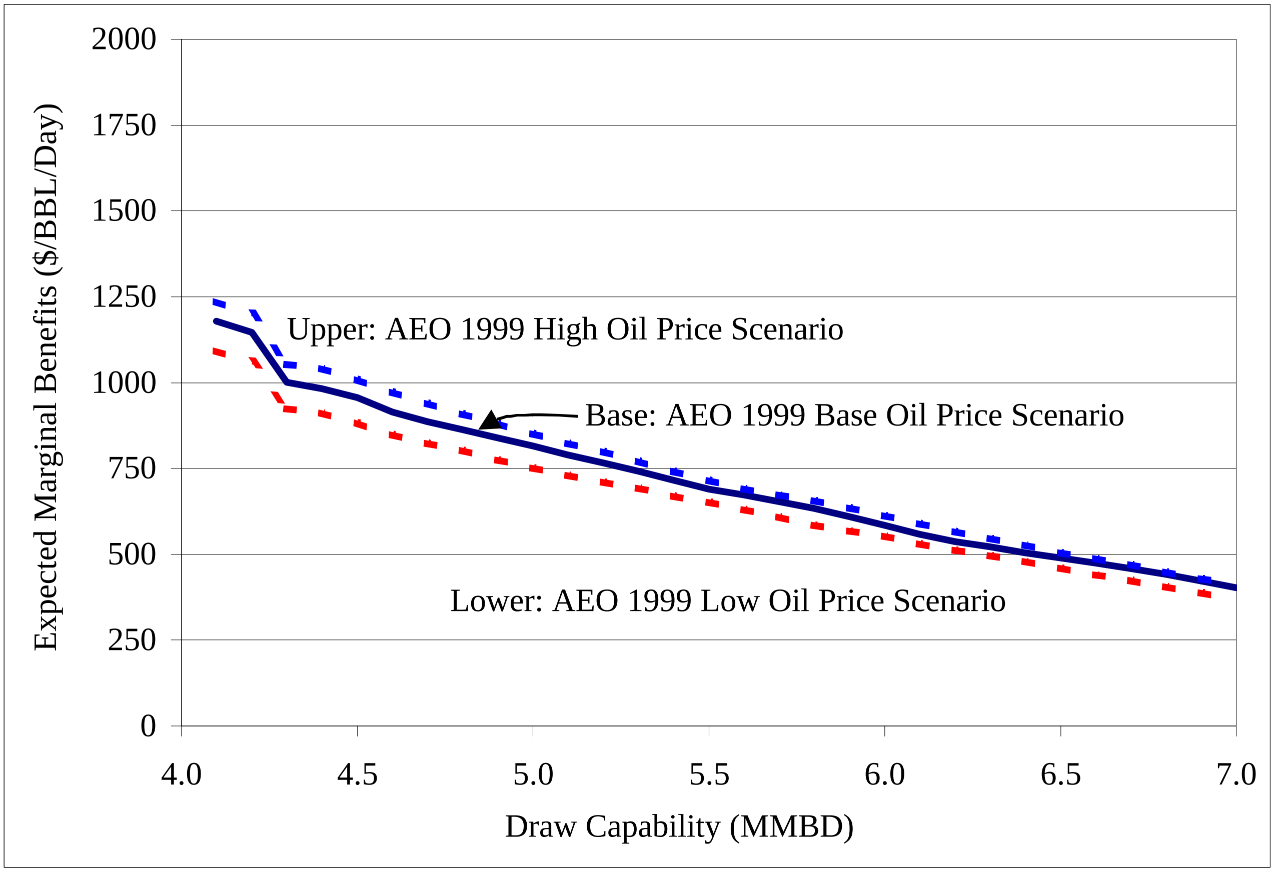

Figure 20: Marginal Draw Benefits: Sensitivity to Oil Price Projections (700 MMB Size). While the benefits of expanded SPR *size* can be sensitive to the projected time path of undisrupted oil prices, the benefits of SPR *drawdown capability* are NOT sensitive to this factor.

Table 17: Marginal Draw Capability Benefits: Sensitivity to Oil Price Projections (700 MMB Size) (Billions $96)

Drawdown Enhancement Capital Costs: $0 mill/MMBD Capability (Excluded)

	Drawdown Capability (MMBD)								
Sensitivities	4.1	4.3	4.4	4.5	5.0	5.5	6.0	6.5	7.0
Upper: AEO 1999 High Oil Price Scenario	1236	1053	1042	1010	851	716	613	505	413
Base: AEO 1999 Base Oil Price Scenario	1179	1001	984	956	816	690	585	491	403
Lower: AEO 1999 Low Oil Price Scenario	1093	924	913	882	752	651	553	461	369

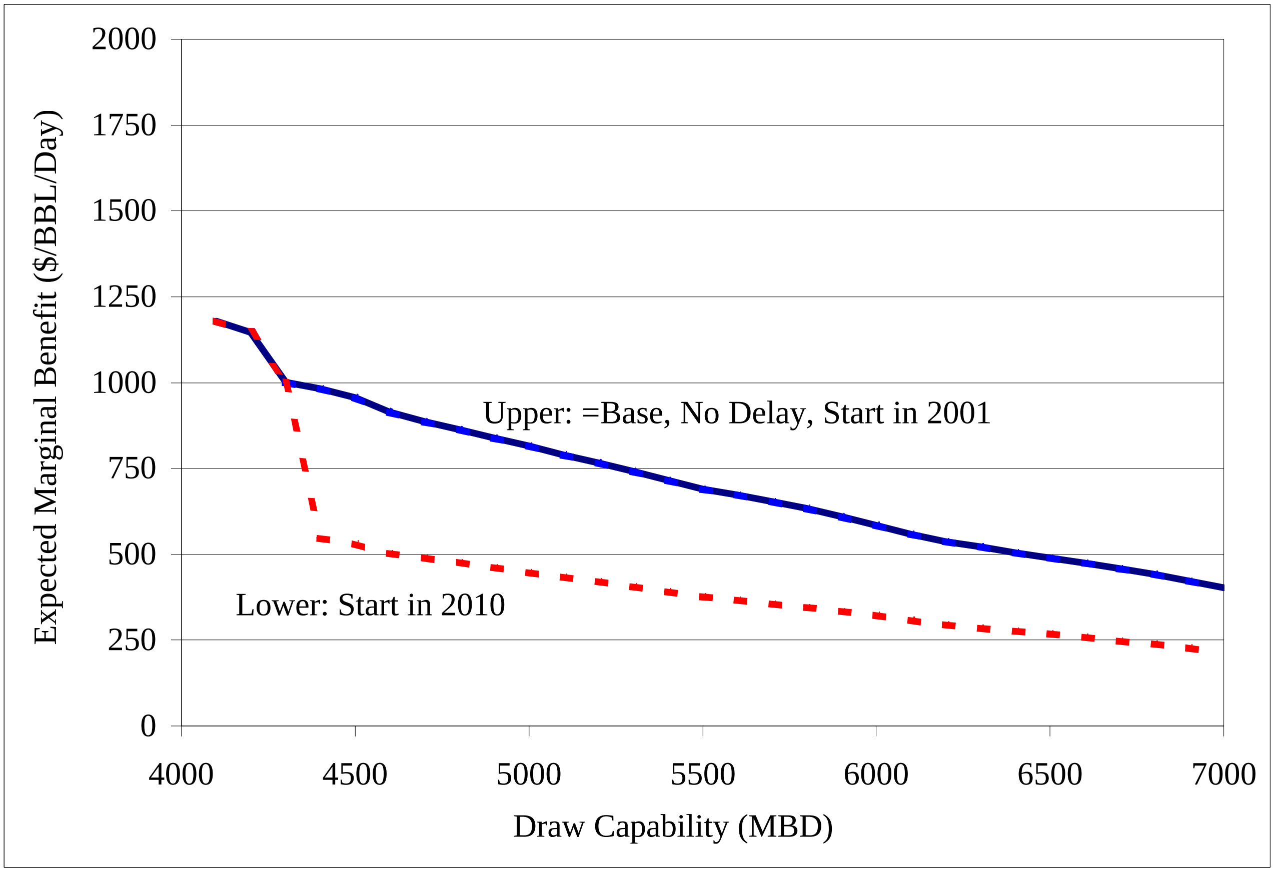

Figure 21: Marginal Draw Benefits: Sensitivity to Delay in Drawdown Capacity Enhancement (700 MMB Size). Lower cases are for 4 and 9 year delays from base. Delaying reduces the present value of marginal benefits in part due to discounting, and in part due to foregone opportunities for greater shock protection in the early years.

Table 18: Marginal Draw Capability Benefits: Sensitivity to Delay in Drawdown Capacity Enhancement (700 MMB Size) (Billions $96)

Drawdown Enhancement Capital Costs: $0 mill/MMBD Capability (Excluded)

	Drawdown Capability (MMBD)								
Sensitivities	4.1	4.3	4.4	4.5	5.0	5.5	6.0	6.5	7.0
Upper: = Base, No Delay, Start in 2001	1179	1001	984	956	816	690	585	491	403
Lower: Start in 2010	1179	1001	546	531	447	376	323	269	215

5.0 Overall Conclusions

It is useful to point out the limits of this analysis. The analysis focuses exclusively on quantitative economic benefits in global market equilibrium. It assumes a rapid drawdown decision can be made, if needed. The analysis omits any possible additional benefit, or cost, due to:

Possible short run transportation/logistical barriers;
Possible deterrence effects of larger draw rate;
Foreign policy considerations; and
SPR insurance value.

Finally, this study does not assess the ability of the private market to assimilate the distributed SPR oil in a timely fashion. Rather, it assumes certain global shortages, and reports the benefits to U.S. society if the market is able utilize large flows originating from the SPR in the U.S. Gulf region over a period of 1 to 6 months.

Bearing these limits in mind, this study leads to some strong conclusions regarding the substantial expected value of enhanced drawdown capability. Despite the large existing strategic stocks and the current 4.3 MMBD draw capability, even larger drawdown capabilities will produce expected benefits. Specifically, over a wide range of conditions, expansion to as much as 7.0 MMBD is worthwhile, if it is practical to do so from an engineering perspective.

The net benefits of draw rate expansion are expected to be positive provided discounted costs of draw capability expansion are less than $400 million/MMBD, which is believed to be a high cost estimate. Higher draw capability is especially valuable if future disruptions are expected by be short and intense, rather than protracted and moderate.

The gross benefits of draw capability expansion (excluding the capital costs of drawdown enhancement, and the benefits of size enhancement) are:

$1.4 billion for 590 MMB reserve at 6.0 MMBD
$1.8 billion for 700 MMB reserve at 7.0 MMBD
$2.0 billion for 800 MMB reserve at 7.0 MMBD

IF draw capability can be expanded at a cost of less than $200 million per MMBD ($200/BD), then expanding to 7.0 MMBD is optimal under all but two of the sensitivity cases considered (for a 700 or 800 MMB reserve). For a 590 MMB size SPR, the optimal draw rate is a bit lower than for the larger sizes: between 6.0 and 6.5 MMBD.

Future Issues For Consideration

Continued research on drawrate planning could usefully focus on some of the factors which were either omitted or taken for granted by this study. We list here some important topics for further consideration.

- Investigation of possible short-run transportation, logistical or institutional barriers which may limit rapid drawdown. Can the market and private infrastructure absorb the large oil flows which are anticipated in the U.S. Gulf region, given an expanded draw capability? What can be done to avoid any potential bottlenecks identified?
- Assessment of the costs of expanding draw capability. What are the promising sites and approaches for expanding draw rates? Are there options for sharing some costs of drawdown and distribution infrastructure with the private sector, *without* sacrificing federal access to that infrastructure in times of oil emergency?
- Analysis of engineering approaches to achieve the economic benefits implied by this drawrate expansion analysis. This includes determining how to translate the drawdown rate expansion into actual engineering parameters – i.e., draw rates for particular sites. It also raises the issue of whether it is more cost effective to focus drawrate expansion efforts on a limited number of sites, with the idea that such an approach could lead to unequal draw rates over time. For example, can we gain more net benefits by making site A draw down very much faster than the others early in the disruption, or is it better to make sites A, B, and C draw down at the same rate (relative to site size) over the course of the disruption? Answering this would require assessing the value of equal versus unequal drawrates over the duration of the disruption.
- Improved characterization of the short-run oil market response to oil supply reductions and SPR surge supplies. While our knowledge of the short-run response of supply and demand to suddenly higher prices during a disruption is imperfect, the nature of that response is important to assessing the benefit of surge drawdown rates. This topic could usefully be revisited, consulting the empirical literature, considering the importance of changed market mechanisms and practices, and assessing whether new data or approaches are available to improve our knowledge of short-run supply-demand response.
- Accounting for risk and uncertainty, and the ability of enhanced draw capability to reduce risk. All of the analysis done here relies on the *average* or expected-value of benefits. But the outcomes in the oil market, and the benefits of SPR capabilities, are necessarily highly uncertain. The comparatively well established capital costs of enhanced SPR capability must be balanced against the remote, but still significant probability of an extremely costly oil market event in which that capability could be of great value. There may also be some risks associated with SPR drawdown performance. A question worth addressing is, “How can we accurately and usefully reflect these risks in our evaluation of SPR costs and benefits?”

Appendix 1: SPR Modeling Techniques

Estimating an appropriate configuration for the SPR is in some ways just like any other project or investment analysis. Capital or money is committed generally in the beginning. Money or benefits are expected sometime in the future. But in some sense SPR projects are also different. For a typical investment one may rely on the expected or normal course of events to take place. For the SPR one focuses on the unexpected or the improbable. A flurry of SPR size and drawdown studies were done in the late seventies and early eighties to deal with just such events. These studies varied in their level of sophistication and complexity. With time, the level of sophistication increased as more focus was given to the topic and computing power increased. Figure 22 below gives a conceptual view of the evolution in SPR modeling techniques.

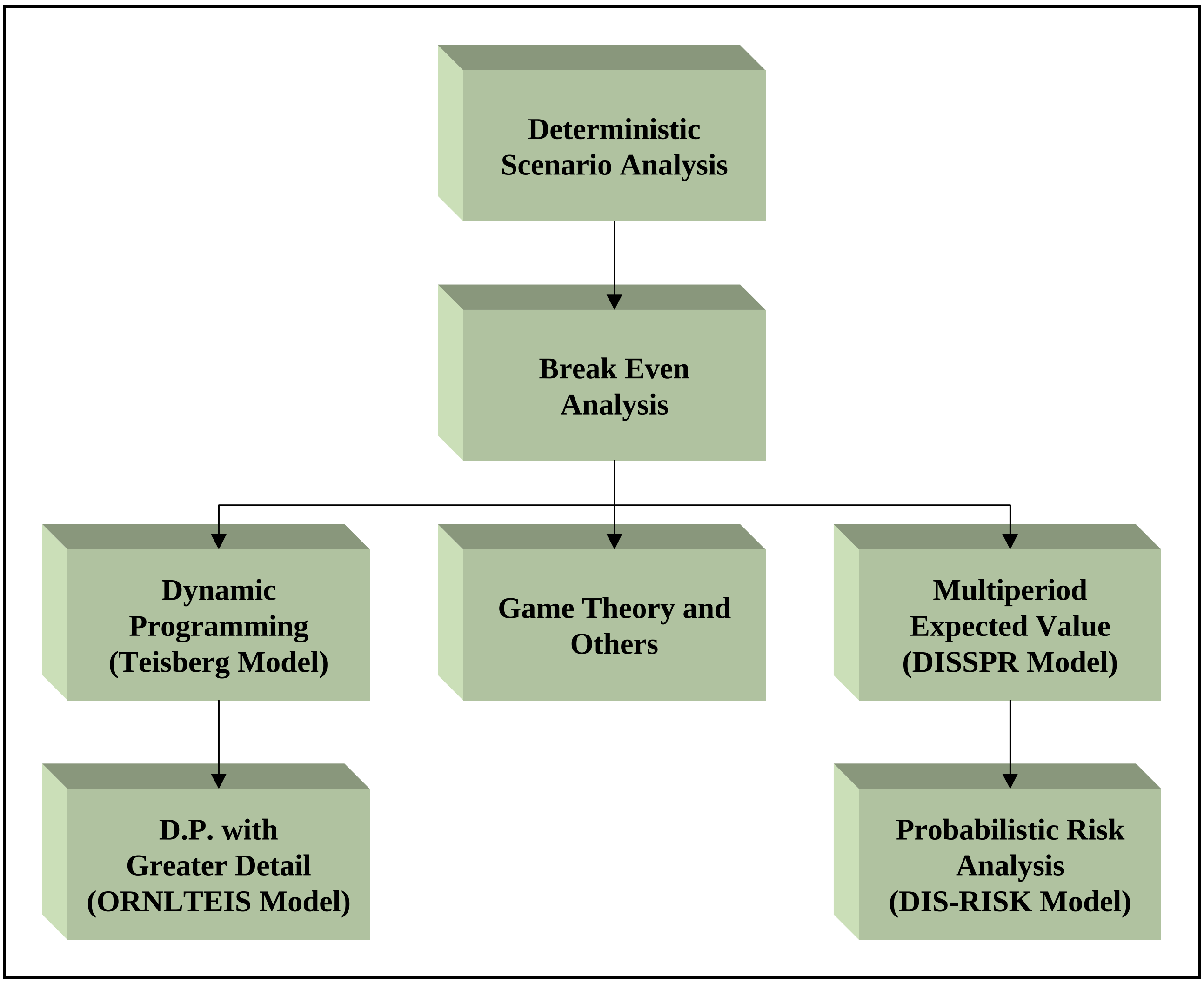

Figure 22: SPR Modeling Techniques; Past and Present.

Deterministic scenario analysis
Many of the early official SPR size and drawdown studies of the late seventies and early eighties used what could be termed deterministic scenario analysis to suggest an appropriate configuration (DOE 1979, 1982). A scenario would consist of a disruption of a predetermined size and in a predetermined year. Cost and national welfare measures would then be computed and compared for various SPR sizes including the assumption of no SPR. Intriguingly, but coincidentally, many of the early studies postulated 1990 as a hypothetical disrupted year. The same year hostilities broke out between Iraq and Kuwait.

Breakeven analysis
To a lesser extent, other studies used breakeven analysis to compute an acceptable SPR size (e.g. Pan Heuristics 1980, CBO 1980). With this analysis tool, decision makers postulate disruption probabilities and determine the probability necessary for a particular size to breakeven. At that disruption probability, total benefits just equal total costs. If the breakeven probabilities are believable, then, the reasoning goes, the size is "acceptable." While this type of analysis was certainly an advancement from the more situational analyses of the past, it was not without its faults. In particular, these analyses often identify the breakeven size in a way that is distinct from the optimal size. To understand this distinction, it is helpful to discriminate between total benefits and marginal benefits, and between total costs and marginal costs. If the breakeven point is defined as that where total benefits just equal total costs, then clearly net benefits (total benefits minus total costs) are zero. The problem with using breakeven analysis in this way is that society is just as well off with the breakeven size as with doing nothing at all. In contrast, the optimal SPR size is where net benefits are maximized and positive, and society is better off. This maximum point occurs where benefits exceed the cost by the greatest amount. This maximum point can be located by applying the following "marginal" rule: provided total benefits exceed total costs and provided benefits grow more slowly with size than costs, continue to add barrels until the expected benefit of adding one more barrel just equals the cost. The same marginal rule applies for evaluating optimal drawdown capability. Despite this comment, a variant of breakeven analysis can play a very useful role, provided the analysis defines the breakeven point as that where *marginal* benefits equal *marginal* costs.

Dynamic programming models
An even larger leap in terms of model sophistication is the dynamic programming approach. The Teisberg (1981) model as well as its successor, ORNLTEIS, uses discrete time dynamic programming to compute the optimal size and drawdown configuration. The "dynamic programming" approach accounts for the interrelatedness of SPR decisions across time. Filling produces a larger SPR to deal with possible future disruptions. Conversely, if a disruption occurs and SPR oil is withdrawn, the method recognizes that less protection will be available at later dates until the reserve is refilled. Acquisition and drawdown decisions are evaluated sequentially in discrete amounts, and the oil market state evolves over time. In each period, the SPR fill and draw choices are constrained by exogenous policy inputs regarding SPR capacity, maximum fill rate, and maximum drawdown rate. SPR capacity inputs reflect possible government investments in pumping equipment, loading docks and pipelines.

The method is "stochastic" in a sense that the market conditions are uncertain. However, in the interests of tractability, uncertainty is represented in a limited way: only a few possible market states (e.g. five disruption sizes) are considered, and it is uncertain which state occurs. The key uncertainty is OPEC behavior. Disrupted prices are determined from a shift in the OPEC supply curve. The SPR effects on oil price and market conditions in each time period are computed, and the total effect are accumulated back to a performance measure in current dollars. Monitored effects of the SPR include: oil acquisition costs, annual holding costs, revenue from the resale of SPR oil, and losses or gains to U.S. producers and consumers from oil market changes.

The dynamic approach allows planners to account for the future implications of SPR fill or draw decisions in each period. However, due to computational burden some simplification in the oil market assumptions must be made. One criticism of the ORNLTEIS model and its predecessor the Teisberg model, is that it can only look at a few distinct market states (disruption sizes), and the oil submodel is necessarily static. In the static oil model the supply and demand equations depend only upon the current market state, and that market state can have one of four or five values. Unlike historical experience, after a disruption period the oil price path and supply and demand quantities immediately return to their normal undisrupted paths (except for minor perturbations resulting from SPR refilling). However, it is unclear whether omitting these dynamic effects bias the benefit estimates up or down and these simplifications are necessary consequences of using a computationally intensive dynamic programming method.

Expected Value and Probabilistic Risk Analysis Models

The DIS-Risk Model is a risk-analysis oriented implementation of the DIS-SPR model, which was used in the 1990 DOE/Interagency SPR Size Study (DOE 1990). It allows for reproduction of DOE90 study results, while permitting extensions and the analysis of specific, risk-related outcomes in a simulation format. The risk analysis approach allows the reporting of the expected frequency of disruptions and SPR use, the probability of SPR exhaustion, and calculates the probability distribution of SPR economic benefits. These distributions are built up in a modest period of computing time using thousands of sample iterations.

In DIS-RISK two alternative SPR programs are compared side-by-side. These programs are subject to the same set of random disruptions, drawn from a continuous probability distribution. Each program is specified in terms of costs (capital, operations, and maintenance), target sizes, normal fill rates, and maximum refill rates. In addition maximum drawdown rates can be set by the user; however, deviations are often constrained by exhaustion rates and technical considerations. Oil supply disruptions are simulated against reference paths for oil price, U.S. demand, U.S. supply, and world demand. In the past reference paths were drawn from the Oil Market Simulations model. Beginning in 1996, reference paths tracked low, base, and high oil price path cases from the National Energy Modeling System (NEMS).

In each year a disruption may occur. Disruptions can be exogenously specified to have a fixed length of 1 to 12 months. Alternatively, disruption length can be a random outcome, distributed uniformly over a specified range. The gross disruption size is a random outcome which, as a percentage of total world demand, follows a smooth, 2-parameter Weibull probability distribution.

The gross disruption size is directly reduced by exogenously specified offsets from two sources: slack production capacity and short-run demand switching. If a net disruption (after offsets) is positive, the SPR attempts to fully offset it, in coordination with drawdowns from foreign strategic stocks. Drawdown rates are limited by the specified maximum drawdown rate for that year, and by the exhaustion rate given the known disruption length. Provided no disruptions has occurred, the SPR is filled toward its target size at the specified normal fill rate. After a drawdown, the SPR is filled at the exogenously specified refill rate until the planned fill path is re-obtained. Fill then reverts to the normal fill rate.

Oil shortfalls are calculated as the remaining disruption after all offsets and SPR draws. During a disruption, non-OPEC supply is assumed to be essentially fixed. World disruption demand equals base world demand minus the net oil shortfall. That is, movement along the demand curve accommodates any shortfall after all offsets. World oil price is determined assuming that world demand is elastic in price, and that price must increase sufficiently for demand to accommodate the net shortfall. Annual elasticities are a linear function of net disruption size. To calculate quarterly elasticities, adjustment factors are applied to annual values. After a disruption, world oil price declines toward the base level according to a fixed quarterly decline factor.

U.S. oil demand is isoelastic in price. U.S. import demand equals U.S. demand minus exogenous U.S. supply, SPR drawdown, and a fixed fraction of world short-run fuel switching. U.S. GNP responds to oil price with a constant GNP-elasticity. GNP loss occurs only during disruptions, not during their after-effects. Total disruption costs are GNP losses, plus incremental import costs, plus deadweight losses of consumer-surplus. The NPV of the disruption costs, capital costs and SPR net revenue streams is calculated, and program differences are reported.

The DIS-Risk model compares oil market outcomes and U.S. economic welfare over the next twenty-five years for two distinct SPR programs. It adopts a risk-analysis methodology by simulating a large number of trajectories for oil prices and SPR activity over the time horizon, and gathering performance statistics. Both expected values and probability distribution information are gathered for: net present value of one program versus the other; incremental SPR utilization; SPR net revenue; and the number and severity of net disruptions. An important feature is that in a given experiment both SPR programs are used to address the same randomly-generated sequence of oil supply shocks. This minimizes the random variation of (differential) program results attributable to the disruption sampling process. Similarly, this same random shock can be applied across the 19 sensitivity cases available in the model and others specified by the user.

Since DIS-RISK is essentially an elaborate spreadsheet model, it avoids the “black box” problem that often thwarts user understanding, or limits the user’s ability to specify changes to the model assumptions. The latest model update added a more user friendly menu system and help reference to further accommodate those less familiar with the model. The comparative transparency of the risk analysis approach makes it easier for the policy maker or policy analyst to observe the analytical process, and effectively guide its direction.

Appendix 2: Required DIS-Risk model changes

In brief, the changes to the DIS-Risk model required for this study are as follows:

- Added *Drawdown Delay* mechanism to model.

- Added *Random Anticipated Disruption Length* capability. Uncertainty in disruption length is reflected through two variables: "actual disruption length" (a random variable) and "anticipated disruption length." In the simulation, if a disruption occurs the actual disruption length is determined by a draw from a random distribution. This length is then known to the model, but would of course be unknown to SPR managers in a real situation at the start of a disruption. The variable "anticipated disruption length"describes the SPR manager's perception of how long the disruption will last, and is important for setting the chosen draw rate.

- Changed model's random seed to conform to previous model results.

- Added engineered drawdown rate capability (more realistic decay of drawdown rate capability as reserve is exhausted).

- Allow for a range of drawdown strategies, including "Surge" and "quick refill" drawdown techniques, using a lookup table.

- Allow for delayed drawdown. This must be reflected both in draw timing and in benefits calculation.

Appendix 3: Comparison of Base Case Assumptions Across DOE Studies

Overall, this study, along with the 1999 SPR Size study, follows the structure, spirit, and assumptions of the 1990 DOE/Interagency size study closely. The DIS-Risk model was originally designed with the ability to replicate the 1990 study, given the same inputs and the choice of certain model settings. However, since then some assumptions have changed as chronicled in Table A1 below. Many changes are minor, but the more important inputs changed are: the GDP elasticity, excess oil production capacity, and the discount rate.

Table A1 summarizes the migration of major assumptions from the 1990 DOE/Interagency size study to the current size study. Included in the table below are the assumptions of the 1993 ORNL size study and the 1999 DOE size study. We include the 1993 study assumptions to provide a brief time line of some the changes in the assumptions. A large portion of the assumption changes in the table below are principally for maintenance of the modeling framework. Changes in the time period, dollars, and discount rate are examples of such changes. Other changes in the assumptions reflect refinements of the current understanding of SPR size analysis. Examples of this include changes to the GDP elasticity and the in-depth cost analysis performed by PB-KBB. Other changes such as variable disruption lengths and treatment of foreign stock are new additions designed to more soundly characterize the issue of SPR size analysis.

Table A1: Comparison of Base Case Assumptions Across Studies

Study / Assumption	1990 DOE/Interagency Size Study (DOE90)	1993 ORNL Size Study	1999 DOE Size Study	2000 DOE Drawdown Study
Time Period of Analysis	1990-2020, quarterly	1993-2020, quarterly	1999-2030, monthly	2000-2030, monthly
Dollars	$88	$90	$96	Same
Discount Rate	10%	7%, OMB Circular A-94	Same	Same
Discount Year	1990	1993	1999	Same
Disruption Probabilities	Developed for Study (DOE90 midcase)	DOE90 midcase	Same	Same
Excess Oil Production Capacity	Developed for Study (DOE90 midcase)	DOE90 midcase	IEO 1999	Same
Foreign Stock Characterization	IEA (1989) Oil Market Report. Foreign Stock divided by 180 days. Inexhaustible Flow. (DOE90 midcase)	DOE90 midcase	IEA (1999) Oil Market Report, APERC (1998) (for South Korea and Chinese Taipei). Exhaustible Stock.	Same
Domestic/Foreign Stock Interaction	Foreign Draws First, U.S. second if necessary.	Foreign Draws First, U.S. second if necessary.	Coordinated (Foreign and U.S. draw at the same time).	Same
Oil Market Prices and Quantities	EIA, International Energy Outlook 1990, 2011-2020 extrapolated.	EIA, Annual Energy Outlook, 1993. 2011-2020 extrapolated.	EIA, Annual Energy Outlook, 1999, 2021-2030 extrapolated.	Same
O&M Costs ($/BBL-Yr of Reserve Capacity)	None	None	0.17 $96 for sizes greater than 700 MMB, PB-KBB (1998).	Same
Capital Costs, Time Path of Expansion, Drawdown Enhancement.	ORNL (1988) Preliminary Results of the SPR Size Cost Benefit Study, Nov 17.	Gray/Borgstrom memo (1993)	PB-KBB (1999)	Size Expansion: PB-KBB (1999), Draw Rate Expansion: variable
U.S. GDP Growth Rate	Fixed at 2%	Fixed at 2%	AEO 1999	Same

Table A1: Comparison of Base Case Assumptions Across Studies

Study / Assumption	1990 DOE/Interagency Size Study (DOE90)	1993 ORNL Size Study	1999 DOE Size Study	2000 DOE Drawdown Study
Fill and Draw Costs ($/BBL)	None	None	0.9 $96 for fill, 0.10 $96 for draw, PB-KBB (1998)	Same
GDP Elasticity	-2.5% from T2/T3 Working Group (1989) Macroeconomic Impacts of Oil Supply Disruptions, Nov 27 (DOE90 midcase).[8]	DOE90 midcase	-5.4% from Mork, Olsen, and Mysen (1994) and others in similar range.	Same
Fill and Refill Rates	Refill Instantaneously and Free.	Refill over time at market prices.	Refill over time at market prices.	Same
Treatment of Uncertain Disruption Sizes	Weibull distribution of supply loss %. Expected value derived from discretized ½% intervals	Weibull distribution of supply loss %. Expected values derived from Monte Carlo risk analysis with 1000 random samples.	Weibull distribution of supply loss %. Expected values derived from Latin Hypercube risk analysis with 10,000 random samples.	Same
Treatment of Uncertain Disruption Lengths	Fixed at 6 months.	Fixed at 6 months.	3 or 6 months uniformly distributed.	Same
Terminal Time Period Evaluation	No valuation of final SPR stock.	Valuation of final SPR stock.	Same	Same
Drawdown Rule	Fixed, draw to completely offset disruption if possible.	Same	Same	Same
SPR Starting Size (MMB)	582	575	580	590

[8] The T2/T3 study group consisted of members of the Department of Treasury, Council of Economic Advisors, and Office of Management and Budget. Based upon a review of Darby (1982) and the EMF-7 study, the group recommended a GDP elasticity range of -2% to -4% with -2.5% as a base or reference case estimate. The base GDP elasticity estimate of -2.5% was chosen based upon the professional judgement of the T2/T3 study group. See EIA 1990 for further details.

Appendix 4: Table Listing Sensitivity Cases Performed

Table A2: Sensitivity Cases Performed	
Oil Market Risk Sensitivity	IEO 1999 Low Case Slack Capacity
	IEO 1999 High Case Slack Capacity
	Kendell 1998 Slack Capacity
	ICF 1999 Slack Capacity
	DOE 1990 Low Case Disruption Probabilities
	DOE 1990 High Case Disruption Probabilities
	EMF 1996 Disruption Probabilities
	CIA 1999 Disruption Probabilities
	IEO 1999 Low Slack & DOE 1990 High Disruption Probabilities
	IEO 1999 Low Slack & EMF 1996 Disruption Probabilities
	IEO 1999 High Slack & DOE 1990 Low Disruption Probabilities
	IEO 1999 High Slack & CIA1999 Disruption Probabilities
	IEO 2000 Mid Case Slack Capacity
	IEO 2000 Mid Slack & AEO 2000 Mid Oil Price Scenario
Oil Price Projection Sensitivity	AEO 1999 Low Oil Price Scenario
	AEO 1999 High Oil Price Scenario
	AEO 2000 Mid Case Oil Price Scenario
Disruption Length Sensitivity	Disruption Lengths of 1-6 Months (3.5 mean)
	Disruption Lengths of 3, 6 & 9 months (6 mean)
	Disruption Lengths of 3, 6, 9 & 12 months (7.5 mean)
Discount Rate Sensitivity	4.5% Discount Rate
	10% Discount Rate
Drawrate Expansion Delay	Start Building Drawdown Capability in 2005
	Start Building Drawdown Capability in 2010

Appendix 5: Tables of Expected Net Benefits of Drawdown Capacity Expansion

Terse numerical results for the sensitivity cases are given in Tables A3-A11 below. Each of the nine tables summarizes the results for one of three SPR reserve sizes (590, 700, or 800) and one of three levels of discounted drawdown enhancement capital costs ($0, $200, or $400 million per $/MMBD of capacity). Highlighted cells identify the level of drawdown capability the yields the maximum net benefits, given the assumed capital costs. Initial inspection of these results suggests this generality: that filling to 700 MMB is generally worthwhile and enhancing the drawdown rate may be even more beneficial.

Table A3: Net Benefits of Expansion for Various Sensitivity Cases (Billions $96): 590 MMB Reserve
Drawdown Enhancement Capital Costs: 0 (Excluded)

	Drawdown Capability (MMBD)								
Sensitivity Case	4.1	4.3	4.4	4.5	5.0	5.5	6.0	6.5	7.0
Base Set of Assumptions	-0.22	0.00	0.10	0.19	0.60	0.95	1.24	**1.46**	**1.46**
4.5% Discount Rate	-0.30	0.00	0.13	0.27	0.86	1.35	1.75	**2.06**	**2.06**
10% Discount Rate	-0.16	0.00	0.07	0.13	0.42	0.66	0.86	**1.01**	**1.01**
AEO 1999 Low Oil Price Scenario	-0.20	0.00	0.09	0.17	0.56	0.88	1.15	**1.35**	**1.35**
AEO 1999 High Oil Price Scenario	-0.23	0.00	0.10	0.20	0.64	1.01	1.31	**1.54**	**1.54**
IEO 1999 Low Case Slack Capacity	-0.19	0.00	0.08	0.15	0.46	0.69	0.87	**0.99**	**0.99**
IEO 1999 High Case Slack Capacity	-0.13	0.00	0.06	0.11	0.36	0.58	0.75	**0.89**	**0.89**
Kendell 1998 Slack Capacity	-0.21	0.00	0.09	0.18	0.57	0.90	1.18	**1.40**	**1.40**
ICF 1999 Slack Capacity	-0.21	0.00	0.09	0.18	0.58	0.92	1.19	**1.41**	**1.41**
DOE 1990 Low Case Disruption Probabilities	-0.15	0.00	0.07	0.14	0.43	0.69	0.90	**1.05**	**1.05**
DOE 1990 High Case Disruption Probabilities	-0.26	0.00	0.11	0.22	0.71	1.12	1.46	**1.71**	**1.71**
EMF 1996 Disruption Probabilities	-0.34	0.00	0.15	0.29	0.91	1.42	1.82	**2.11**	**2.11**
CIA 1999 Disruption Probabilities	-0.12	0.00	0.05	0.11	0.35	0.55	0.71	**0.83**	**0.83**
Disruption Lengths of 1-6 Months (3.5 mean)	-0.28	0.00	0.12	0.24	0.71	1.03	1.30	1.52	**1.65**
Disruption Lengths of 3, 6 & 9 months (6 mean)	-0.14	0.00	0.06	0.12	0.39	0.61	0.79	**0.93**	**0.93**
Disruption Lengths of 3, 6, 9 & 12 months (7.5 mean)	-0.10	0.00	0.04	0.08	0.27	0.43	0.56	**0.66**	**0.66**
Imperfect Disruption Length Anticipation	-0.12	0.00	0.05	0.10	0.32	0.51	0.66	**0.77**	**0.77**
Drawdown Delayed by 1 month	-0.18	0.00	0.08	0.15	0.49	0.79	1.03	**1.22**	**1.22**
Foreign Reserves Used 1st, U.S. 2nd (if needed)	-0.23	0.00	0.10	0.20	0.65	1.03	1.35	**1.61**	**1.61**
Start Building Drawdown Capability in 2005	-0.22	0.00	0.08	0.15	0.49	0.77	1.00	**1.18**	**1.18**
Start Building Drawdown Capability in 2010	-0.22	0.00	0.05	0.10	0.33	0.51	0.67	**0.78**	**0.78**
IEO99 Low Slack & DOE90 High Disruption Probability	-0.22	0.00	0.09	0.17	0.53	0.81	1.02	**1.15**	**1.15**
IEO99 Low Slack & EMF96 Disruption Probability	-0.20	0.00	0.07	0.14	0.44	0.66	0.82	**0.93**	**0.93**
IEO99 High Slack & DOE90 Low Disruption Probability	-0.09	0.00	0.04	0.08	0.25	0.39	0.50	**0.59**	**0.59**
IEO99 High Slack & CIA99 Disruption Probability	-0.06	0.00	0.03	0.06	0.18	0.29	0.38	**0.45**	**0.45**
IEO 2000 Mid Case Slack Capacity	-0.19	0.00	0.08	0.16	0.52	0.82	1.07	**1.27**	**1.27**
AEO 2000 Mid Case Oil Price Scenario	-0.23	0.00	0.10	0.19	0.62	0.98	1.28	**1.50**	**1.50**
IEO 2000 Mid Slack & AEO 2000 Mid Oil Price Scenario	-0.20	0.00	0.08	0.17	0.53	0.84	1.10	**1.30**	**1.30**

Table A4: Net Benefits of Expansion for Various Sensitivity Cases (Billions $96): 590 MMB Reserve
Drawdown Enhancement Capital Costs: 200 Million Dollars per MMBD of Capability

	Drawdown Capability (MMBD)								
Sensitivity Case	4.1	4.3	4.4	4.5	5.0	5.5	6.0	6.5	7.0
Base Set of Assumptions	-0.22	0.00	0.08	0.15	0.46	0.71	0.90	**1.02**	0.92
4.5% Discount Rate	-0.30	0.00	0.11	0.23	0.72	1.11	1.41	**1.62**	1.52
10% Discount Rate	-0.16	0.00	0.05	0.09	0.28	0.42	0.52	**0.57**	0.47
AEO 1999 Low Oil Price Scenario	-0.20	0.00	0.07	0.13	0.42	0.64	0.81	**0.91**	0.81
AEO 1999 High Oil Price Scenario	-0.23	0.00	0.08	0.16	0.50	0.77	0.97	**1.10**	1.00
IEO 1999 Low Case Slack Capacity	-0.19	0.00	0.06	0.11	0.32	0.45	0.53	**0.55**	0.45
IEO 1999 High Case Slack Capacity	-0.13	0.00	0.04	0.07	0.22	0.34	0.41	**0.45**	0.35
Kendell 1998 Slack Capacity	-0.21	0.00	0.07	0.14	0.43	0.66	0.84	**0.96**	0.86
ICF 1999 Slack Capacity	-0.21	0.00	0.07	0.14	0.44	0.68	0.85	**0.97**	0.87
DOE 1990 Low Case Disruption Probabilities	-0.15	0.00	0.05	0.10	0.29	0.45	0.56	**0.61**	0.51
DOE 1990 High Case Disruption Probabilities	-0.26	0.00	0.09	0.18	0.57	0.88	1.12	**1.27**	1.17
EMF 1996 Disruption Probabilities	-0.34	0.00	0.13	0.25	0.77	1.18	1.48	**1.67**	1.57
CIA 1999 Disruption Probabilities	-0.12	0.00	0.03	0.07	0.21	0.31	0.37	**0.39**	0.29
Disruption Lengths of 1-6 Months (3.5 mean)	-0.28	0.00	0.10	0.20	0.57	0.79	0.96	1.08	**1.11**
Disruption Lengths of 3, 6 & 9 months (6 mean)	-0.14	0.00	0.04	0.08	0.25	0.37	0.45	**0.49**	0.39
Disruption Lengths of 3, 6, 9 & 12 months (7.5 mean)	-0.10	0.00	0.02	0.04	0.13	0.19	**0.22**	0.22	0.12
Imperfect Disruption Length Anticipation	-0.12	0.00	0.03	0.06	0.18	0.27	0.32	**0.33**	0.23
Drawdown Delayed by 1 month	-0.18	0.00	0.06	0.11	0.35	0.55	0.69	**0.78**	0.68
Foreign Reserves Used 1st, U.S. 2nd (if needed)	-0.23	0.00	0.08	0.16	0.51	0.79	1.01	**1.17**	1.07
Start Building Drawdown Capability in 2005	-0.22	0.00	0.06	0.11	0.35	0.53	0.66	**0.74**	0.64
Start Building Drawdown Capability in 2010	-0.22	0.00	0.03	0.06	0.19	0.27	0.33	**0.34**	0.24
IEO99 Low Slack & DOE90 High Disruption Probability	-0.22	0.00	0.07	0.13	0.39	0.57	0.68	**0.71**	0.61
IEO99 Low Slack & EMF96 Disruption Probability	-0.20	0.00	0.05	0.10	0.30	0.42	0.48	**0.49**	0.39
IEO99 High Sack & DOE90 Low Disruption Probability	-0.09	0.00	0.02	0.04	0.11	0.15	**0.16**	0.15	0.05
IEO99 High Slack & CIA99 Disruption Probability	-0.06	0.00	0.01	0.02	0.04	**0.05**	0.04	0.01	-0.09
IEO 2000 Mid Case Slack Capacity	-0.19	0.00	0.06	0.12	0.38	0.58	0.73	**0.83**	0.73
AEO 2000 Mid Case Oil Price Scenario	-0.23	0.00	0.08	0.15	0.48	0.74	0.94	**1.06**	0.96
IEO 2000 Mid Slack & AEO 2000 Mid Oil Price Scenario	-0.20	0.00	0.06	0.13	0.39	0.60	0.76	**0.86**	0.76

Table A5: Net Benefits of Expansion for Various Sensitivity Cases (Billions $96): 590 MMB Reserve
Drawdown Enhancement Capital Costs: 400 Million $/MMBD of Capability

	Drawdown Capability (MMBD)								
Sensitivity Case	4.1	4.3	4.4	4.5	5.0	5.5	6.0	6.5	7.0
Base Set of Assumptions	-0.22	0.00	0.06	0.11	0.32	0.47	0.56	**0.58**	0.38
4.5% Discount Rate	-0.30	0.00	0.09	0.19	0.58	0.87	1.07	**1.18**	0.98
10% Discount Rate	-0.16	0.00	0.03	0.05	0.14	0.18	**0.18**	0.13	-0.07
AEO 1999 Low Oil Price Scenario	-0.20	0.00	0.05	0.09	0.28	0.40	0.47	**0.47**	0.27
AEO 1999 High Oil Price Scenario	-0.23	0.00	0.06	0.12	0.36	0.53	0.63	**0.66**	0.46
IEO 1999 Low Case Slack Capacity	-0.19	0.00	0.04	0.07	0.18	**0.21**	0.19	0.11	-0.09
IEO 1999 High Case Slack Capacity	-0.13	0.00	0.02	0.03	0.08	**0.10**	0.07	0.01	-0.19
Kendell 1998 Slack Capacity	-0.21	0.00	0.05	0.10	0.29	0.42	0.50	**0.52**	0.32
ICF 1999 Slack Capacity	-0.21	0.00	0.05	0.10	0.30	0.44	0.51	**0.53**	0.33
DOE 1990 Low Case Disruption Probabilities	-0.15	0.00	0.03	0.06	0.15	0.21	**0.22**	0.17	-0.03
DOE 1990 High Case Disruption Probabilities	-0.26	0.00	0.07	0.14	0.43	0.64	0.78	**0.83**	0.63
EMF 1996 Disruption Probabilities	-0.34	0.00	0.11	0.21	0.63	0.94	1.14	**1.23**	1.03
CIA 1999 Disruption Probabilities	-0.12	0.00	0.01	0.03	**0.07**	0.07	0.03	-0.05	-0.25
Disruption Lengths of 1-6 Months (3.5 mean)	-0.28	0.00	0.08	0.16	0.43	0.55	0.62	**0.64**	0.57
Disruption Lengths of 3, 6 & 9 months (6 mean)	-0.14	0.00	0.02	0.04	0.11	**0.13**	0.11	0.05	-0.15
Disruption Lengths of 3, 6, 9 & 12 months (7.5 mean)	-0.10	0.00	0.00	**0.00**	-0.01	-0.05	-0.12	-0.22	-0.42
Imperfect Disruption Length Anticipation	-0.12	0.00	0.01	0.02	**0.04**	0.03	-0.02	-0.11	-0.31
Drawdown Delayed by 1 month	-0.18	0.00	0.04	0.07	0.21	0.31	**0.35**	0.34	0.14
Foreign Reserves Used 1st, U.S. 2nd (if needed)	-0.23	0.00	0.06	0.12	0.37	0.55	0.67	**0.73**	0.53
Start Building Drawdown Capability in 2005	-0.22	0.00	0.04	0.07	0.21	0.29	**0.32**	0.30	0.10
Start Building Drawdown Capability in 2010	-0.22	0.00	0.01	0.02	**0.05**	0.03	-0.01	-0.10	-0.30
IEO99 Low Slack & DOE90 High Disruption Probability	-0.22	0.00	0.05	0.09	0.25	0.33	**0.34**	0.27	0.07
IEO99 Low Slack & EMF96 Disruption Probability	-0.20	0.00	0.03	0.06	0.16	**0.18**	0.14	0.05	-0.15
IEO99 High Sack & DOE90 Low Disruption Probability	-0.09	**0.00**	0.00	0.00	-0.03	-0.09	-0.18	-0.29	-0.49
IEO99 High Slack & CIA99 Disruption Probability	-0.06	**0.00**	-0.01	-0.02	-0.10	-0.19	-0.30	-0.43	-0.63
IEO 2000 Mid Case Slack Capacity	-0.19	0.00	0.04	0.08	0.24	0.34	**0.39**	0.39	0.19
AEO 2000 Mid Case Oil Price Scenario	-0.23	0.00	0.06	0.11	0.34	0.50	0.60	**0.62**	0.42
IEO 2000 Mid Slack & AEO 2000 Mid Oil Price Scenario	-0.20	0.00	0.04	0.09	0.25	0.36	0.42	**0.42**	0.22

Table A6: Net Benefits of Expansion for Various Sensitivity Cases (Billions $96): 700 MMB Reserve Drawdown Enhancement Capital Costs: 0 (Excluded)

	Drawdown Capability (MMBD)								
Sensitivity Case	4.1	4.3	4.4	4.5	5.0	5.5	6.0	6.5	7.0
Base Set of Assumptions	0.81	1.04	1.14	1.24	1.69	2.07	2.39	2.67	**2.89**
4.5% Discount Rate	1.95	2.27	2.42	2.56	3.19	3.74	4.20	4.58	**4.91**
10% Discount Rate	0.10	0.26	0.33	0.40	0.71	0.97	1.19	1.38	**1.54**
AEO 1999 Low Oil Price Scenario	0.96	1.18	1.27	1.36	1.77	2.13	2.43	2.69	**2.90**
AEO 1999 High Oil Price Scenario	0.50	0.74	0.85	0.95	1.42	1.82	2.16	2.44	**2.67**
IEO 1999 Low Case Slack Capacity	4.86	5.08	5.16	5.25	5.64	5.94	6.18	6.37	**6.51**
IEO 1999 High Case Slack Capacity	-0.31	-0.18	-0.12	-0.06	0.20	0.42	0.61	0.77	**0.90**
Kendell 1998 Slack Capacity	0.47	0.69	0.79	0.88	1.30	1.65	1.96	2.21	**2.43**
ICF 1999 Slack Capacity	0.64	0.87	0.96	1.06	1.49	1.85	2.16	2.42	**2.64**
DOE 1990 Low Case Disruption Probabilities	0.23	0.40	0.47	0.54	0.86	1.14	1.36	1.56	**1.72**
DOE 1990 High Case Disruption Probabilities	1.18	1.46	1.57	1.69	2.22	2.67	3.06	3.38	**3.65**
EMF 1996 Disruption Probabilities	3.18	3.56	3.73	3.89	4.61	5.21	5.71	6.10	**6.42**
CIA 1999 Disruption Probabilities	-0.18	-0.06	0.00	0.06	0.31	0.52	0.70	0.85	**0.98**
Disruption Lengths of 1-6 Months (3.5 mean)	-0.26	0.12	0.28	0.44	1.04	1.52	1.86	2.11	**2.32**
Disruption Lengths of 3, 6 & 9 months (6 mean)	2.10	2.25	2.31	2.37	2.66	2.91	3.11	3.28	**3.43**
Disruption Lengths of 3, 6, 9 & 12 months (7.5 mean)	3.01	3.11	3.16	3.20	3.40	3.57	3.72	3.84	**3.94**
Imperfect Disruption Length Anticipation	1.49	1.52	1.53	1.54	1.74	1.94	2.12	2.26	**2.37**
Drawdown Delayed by 1 month	0.30	0.49	0.57	0.65	1.01	1.32	1.59	1.81	**2.00**
Foreign Reserves Used 1st, U.S. 2nd (if needed)	0.72	0.97	1.08	1.18	1.66	2.07	2.42	2.72	**2.97**
Start Building Drawdown Capability in 2005	0.81	1.04	1.14	1.22	1.59	1.90	2.16	2.39	**2.58**
Start Building Drawdown Capability in 2010	0.81	1.04	1.14	1.20	1.44	1.65	1.83	1.98	**2.10**
IEO99 Low Slack & DOE90 High Disruption Probability	5.21	5.47	5.57	5.67	6.11	6.47	6.75	6.97	**7.14**
IEO99 Low Slack & EMF96 Disruption Probability	8.58	8.83	8.92	9.01	9.39	9.69	9.92	10.10	**10.24**
IEO99 High Slack & DOE90 Low Disruption Probability	-0.63	-0.54	-0.50	-0.46	-0.28	-0.14	-0.01	0.09	**0.17**
IEO99 High Slack & CIA99 Disruption Probability	-0.77	-0.71	-0.68	-0.65	-0.52	-0.41	-0.32	-0.24	**-0.18**
IEO 2000 Mid Case Slack Capacity	0.31	0.52	0.60	0.69	1.07	1.40	1.67	1.91	**2.10**
AEO 2000 Mid Case Oil Price Scenario	0.53	0.77	0.87	0.98	1.43	1.83	2.16	2.44	**2.67**
IEO 2000 Mid Slack & AEO 2000 Mid Oil Price Scenario	0.03	0.24	0.33	0.41	0.81	1.14	1.42	1.66	**1.86**

Table A7: Net Benefits of Expansion for Various Sensitivity Cases (Billions $96): 700 MMB Reserve
Drawdown Enhancement Capital Costs: 200 Million Dollars per MMBD of Capability

	Drawdown Capability (MMBD)								
Sensitivity Case	4.1	4.3	4.4	4.5	5.0	5.5	6.0	6.5	7.0
Base Set of Assumptions	0.81	1.04	1.14	1.24	1.59	1.87	2.09	2.27	**2.39**
4.5% Discount Rate	1.95	2.27	2.42	2.56	3.09	3.54	3.90	4.18	**4.41**
10% Discount Rate	0.10	0.26	0.33	0.40	0.61	0.77	0.89	0.98	**1.04**
AEO 1999 Low Oil Price Scenario	0.96	1.18	1.27	1.36	1.67	1.93	2.13	2.29	**2.40**
AEO 1999 High Oil Price Scenario	0.50	0.74	0.85	0.95	1.32	1.62	1.86	2.04	**2.17**
IEO 1999 Low Case Slack Capacity	4.86	5.08	5.16	5.25	5.54	5.74	5.88	5.97	**6.01**
IEO 1999 High Case Slack Capacity	-0.31	-0.18	-0.12	-0.06	0.10	0.22	0.31	0.37	**0.40**
Kendell 1998 Slack Capacity	0.47	0.69	0.79	0.88	1.20	1.45	1.66	1.81	**1.93**
ICF 1999 Slack Capacity	0.64	0.87	0.96	1.06	1.39	1.65	1.86	2.02	**2.14**
DOE 1990 Low Case Disruption Probabilities	0.23	0.40	0.47	0.54	0.76	0.94	1.06	1.16	**1.22**
DOE 1990 High Case Disruption Probabilities	1.18	1.46	1.57	1.69	2.12	2.47	2.76	2.98	**3.15**
EMF 1996 Disruption Probabilities	3.18	3.56	3.73	3.89	4.51	5.01	5.41	5.70	**5.92**
CIA 1999 Disruption Probabilities	-0.18	-0.06	0.00	0.06	0.21	0.32	0.40	0.45	**0.48**
Disruption Lengths of 1-6 Months (3.5 mean)	-0.26	0.12	0.28	0.44	0.94	1.32	1.56	1.71	**1.82**
Disruption Lengths of 3, 6 & 9 months (6 mean)	2.10	2.25	2.31	2.37	2.56	2.71	2.81	2.88	**2.93**
Disruption Lengths of 3, 6, 9 & 12 months (7.5 mean)	3.01	3.11	3.16	3.20	3.30	3.37	3.42	3.44	**3.44**
Imperfect Disruption Length Anticipation	1.49	1.52	1.53	1.54	1.64	1.74	1.82	1.86	**1.87**
Drawdown Delayed by 1 month	0.30	0.49	0.57	0.65	0.91	1.12	1.29	1.41	**1.50**
Foreign Reserves Used 1st, U.S. 2nd (if needed)	0.72	0.97	1.08	1.18	1.56	1.87	2.12	2.32	**2.47**
Start Building Drawdown Capability in 2005	0.81	1.04	1.14	1.22	1.49	1.70	1.86	1.99	**2.08**
Start Building Drawdown Capability in 2010	0.81	1.04	1.14	1.20	1.34	1.45	1.53	1.58	**1.60**
IEO99 Low Slack & DOE90 High Disruption Probability	5.21	5.47	5.57	5.67	6.01	6.27	6.45	6.57	**6.64**
IEO99 Low Slack & EMF96 Disruption Probability	8.58	8.83	8.92	9.01	9.29	9.49	9.62	9.70	**9.74**
IEO99 High Sack & DOE90 Low Disruption Probability	-0.63	-0.54	-0.50	-0.46	-0.38	-0.34	-0.31	**-0.31**	-0.33
IEO99 High Slack & CIA99 Disruption Probability	-0.77	-0.71	-0.68	-0.65	-0.62	**-0.61**	-0.62	-0.64	-0.68
IEO 2000 Mid Case Slack Capacity	0.31	0.52	0.60	0.69	0.97	1.20	1.37	1.51	**1.60**
AEO 2000 Mid Case Oil Price Scenario	0.53	0.77	0.87	0.98	1.33	1.63	1.86	2.04	**2.17**
IEO 2000 Mid Slack & AEO 2000 Mid Oil Price Scenario	0.03	0.24	0.33	0.41	0.71	0.94	1.12	1.26	**1.36**

Table A8: Net Benefits of Expansion for Various Sensitivity Cases (Billions $96): 700 MMB Reserve Drawdown Enhancement Capital Costs: 400 Million Dollars per MMBD of Capability

	Drawdown Capability (MMBD)								
Sensitivity Case	4.1	4.3	4.4	4.5	5.0	5.5	6.0	6.5	7.0
Base Set of Assumptions	0.81	1.04	1.14	1.24	1.49	1.67	1.79	1.87	**1.89**
4.5% Discount Rate	1.95	2.27	2.42	2.56	2.99	3.34	3.60	3.78	**3.91**
10% Discount Rate	0.10	0.26	0.33	0.40	0.51	0.57	**0.59**	0.58	0.54
AEO 1999 Low Oil Price Scenario	0.96	1.18	1.27	1.36	1.57	1.73	1.83	1.89	**1.90**
AEO 1999 High Oil Price Scenario	0.50	0.74	0.85	0.95	1.22	1.42	1.56	1.64	**1.67**
IEO 1999 Low Case Slack Capacity	4.86	5.08	5.16	5.25	5.44	5.54	**5.58**	5.57	5.51
IEO 1999 High Case Slack Capacity	-0.31	-0.18	-0.12	-0.06	0.00	**0.02**	0.01	-0.03	-0.10
Kendell 1998 Slack Capacity	0.47	0.69	0.79	0.88	1.10	1.25	1.36	1.41	**1.43**
ICF 1999 Slack Capacity	0.64	0.87	0.96	1.06	1.29	1.45	1.56	1.62	**1.64**
DOE 1990 Low Case Disruption Probabilities	0.23	0.40	0.47	0.54	0.66	0.74	**0.76**	0.76	0.72
DOE 1990 High Case Disruption Probabilities	1.18	1.46	1.57	1.69	2.02	2.27	2.46	2.58	**2.65**
EMF 1996 Disruption Probabilities	3.18	3.56	3.73	3.89	4.41	4.81	5.11	5.30	**5.42**
CIA 1999 Disruption Probabilities	-0.18	-0.06	0.00	0.06	0.11	**0.12**	0.10	0.05	-0.02
Disruption Lengths of 1-6 Months (3.5 mean)	-0.26	0.12	0.28	0.44	0.84	1.12	1.26	1.31	**1.32**
Disruption Lengths of 3, 6 & 9 months (6 mean)	2.10	2.25	2.31	2.37	2.46	2.51	**2.51**	2.48	2.43
Disruption Lengths of 3, 6, 9 & 12 months (7.5 mean)	3.01	3.11	3.16	3.20	**3.20**	3.17	3.12	3.04	2.94
Imperfect Disruption Length Anticipation	1.49	1.52	1.53	1.54	1.54	**1.54**	1.52	1.46	1.37
Drawdown Delayed by 1 month	0.30	0.49	0.57	0.65	0.81	0.92	0.99	**1.01**	1.00
Foreign Reserves Used 1st, U.S. 2nd (if needed)	0.72	0.97	1.08	1.18	1.46	1.67	1.82	1.92	**1.97**
Start Building Drawdown Capability in 2005	0.81	1.04	1.14	1.22	1.39	1.50	1.56	**1.59**	1.58
Start Building Drawdown Capability in 2010	0.81	1.04	1.14	1.20	1.24	**1.25**	1.23	1.18	1.10
IEO99 Low Slack & DOE90 High Disruption Probability	5.21	5.47	5.57	5.67	5.91	6.07	6.15	**6.17**	6.14
IEO99 Low Slack & EMF96 Disruption Probability	8.58	8.83	8.92	9.01	9.19	9.29	**9.32**	9.30	9.24
IEO99 High Sack & DOE90 Low Disruption Probability	-0.63	-0.54	-0.50	**-0.46**	-0.48	-0.54	-0.61	-0.71	-0.83
IEO99 High Slack & CIA99 Disruption Probability	-0.77	-0.71	-0.68	**-0.65**	-0.72	-0.81	-0.92	-1.04	-1.18
IEO 2000 Mid Case Slack Capacity	0.31	0.52	0.60	0.69	0.87	1.00	1.07	**1.11**	1.10
AEO 2000 Mid Case Oil Price Scenario	0.53	0.77	0.87	0.98	1.23	1.43	1.56	1.64	**1.67**
IEO 2000 Mid Slack & AEO 2000 Mid Oil Price Scenario	0.03	0.24	0.33	0.41	0.61	0.74	0.82	**0.86**	0.86

Table A9: Net Benefits of Expansion for Various Sensitivity Cases (Billions $96): 800 MMB Reserve Drawdown Enhancement Capital Costs: 0 (Excluded)

	Drawdown Capability (MMBD)								
Sensitivity Case	4.1	4.3	4.4	4.5	5.0	5.5	6.0	6.5	7.0
Base Set of Assumptions	0.81	1.18	1.32	1.42	1.89	2.29	2.63	2.91	**3.16**
4.5% Discount Rate	2.50	3.04	3.25	3.40	4.06	4.63	5.11	5.52	**5.87**
10% Discount Rate	-0.16	0.08	0.17	0.24	0.56	0.83	1.06	1.26	**1.43**
AEO 1999 Low Oil Price Scenario	1.15	1.49	1.62	1.71	2.15	2.52	2.83	3.11	**3.34**
AEO 1999 High Oil Price Scenario	0.29	0.68	0.83	0.93	1.42	1.84	2.19	2.49	**2.74**
IEO 1999 Low Case Slack Capacity	7.12	7.38	7.48	7.57	7.99	8.33	8.60	8.82	**8.98**
IEO 1999 High Case Slack Capacity	-0.94	-0.71	-0.62	-0.56	-0.30	-0.07	0.12	0.28	**0.42**
Kendell 1998 Slack Capacity	0.23	0.58	0.72	0.81	1.24	1.61	1.93	2.20	**2.42**
ICF 1999 Slack Capacity	0.58	0.94	1.08	1.17	1.62	2.01	2.33	2.60	**2.83**
DOE 1990 Low Case Disruption Probabilities	-0.04	0.22	0.33	0.40	0.73	1.02	1.26	1.46	**1.63**
DOE 1990 High Case Disruption Probabilities	1.38	1.80	1.97	2.09	2.65	3.12	3.52	3.87	**4.16**
EMF 1996 Disruption Probabilities	4.46	5.02	5.24	5.41	6.18	6.82	7.35	7.79	**8.15**
CIA 1999 Disruption Probabilities	-0.69	-0.48	-0.40	-0.34	-0.08	0.14	0.33	0.48	**0.61**
Disruption Lengths of 1-6 Months (3.5 mean)	-0.77	-0.33	-0.15	0.02	0.74	1.28	1.69	2.00	**2.23**
Disruption Lengths of 3, 6 & 9 months (6 mean)	2.87	3.11	3.20	3.26	3.56	3.82	4.03	4.21	**4.36**
Disruption Lengths of 3, 6, 9 & 12 months (7.5 mean)	4.31	4.48	4.55	4.59	4.80	4.98	5.13	5.26	**5.37**
Imperfect Disruption Length Anticipation	1.74	1.99	2.08	2.09	2.18	2.35	2.53	2.67	**2.80**
Drawdown Delayed by 1 month	-0.02	0.31	0.44	0.52	0.89	1.22	1.49	1.72	**1.92**
Foreign Reserves Used 1st, U.S. 2nd (if needed)	0.64	1.06	1.23	1.33	1.83	2.26	2.63	2.94	**3.20**
Start Building Drawdown Capability in 2005	0.81	1.18	1.32	1.41	1.79	2.11	2.39	2.63	**2.84**
Start Building Drawdown Capability in 2010	0.81	1.18	1.32	1.38	1.64	1.87	2.06	2.22	**2.36**
IEO99 Low Slack & DOE90 High Disruption Probability	7.65	7.95	8.07	8.18	8.66	9.06	9.37	9.63	**9.83**
IEO99 Low Slack & EMF96 Disruption Probability	12.50	12.77	12.87	12.97	13.39	13.72	13.99	14.19	**14.35**
IEO99 High Slack & DOE90 Low Disruption Probability	-1.40	-1.24	-1.17	-1.13	-0.96	-0.81	-0.68	-0.58	**-0.49**
IEO99 High Slack & CIA99 Disruption Probability	-1.62	-1.50	-1.45	-1.43	-1.29	-1.18	-1.09	-1.01	**-0.94**
IEO 2000 Mid Case Slack Capacity	0.07	0.40	0.53	0.62	1.02	1.36	1.65	1.89	**2.10**
AEO 2000 Mid Case Oil Price Scenario	0.53	0.90	1.05	1.15	1.63	2.04	2.39	2.68	**2.93**
IEO 2000 Mid Slack & AEO 2000 Mid Oil Price Scenario	-0.22	0.12	0.26	0.35	0.75	1.10	1.40	1.65	**1.86**

Table A10: Net Benefits of Expansion for Various Sensitivity Cases (Billions $96): 800 MMB Reserve
Drawdown Enhancement Capital Costs: 200 Million Dollars per MMBD of Capability

	Drawdown Capability (MMBD)								
Sensitivity Case	4.1	4.3	4.4	4.5	5.0	5.5	6.0	6.5	7.0
Base Set of Assumptions	0.81	1.18	1.32	1.42	1.79	2.09	2.33	2.51	**2.66**
4.5% Discount Rate	2.50	3.04	3.25	3.40	3.96	4.43	4.81	5.12	**5.37**
10% Discount Rate	-0.16	0.08	0.17	0.24	0.46	0.63	0.76	0.86	**0.93**
AEO 1999 Low Oil Price Scenario	1.15	1.49	1.62	1.71	2.05	2.32	2.53	2.71	**2.84**
AEO 1999 High Oil Price Scenario	0.29	0.68	0.83	0.93	1.32	1.64	1.89	2.09	**2.24**
IEO 1999 Low Case Slack Capacity	7.12	7.38	7.48	7.57	7.89	8.13	8.30	8.42	**8.48**
IEO 1999 High Case Slack Capacity	-0.94	-0.71	-0.62	-0.56	-0.40	-0.27	-0.18	-0.12	**-0.08**
Kendell 1998 Slack Capacity	0.23	0.58	0.72	0.81	1.14	1.41	1.63	1.80	**1.92**
ICF 1999 Slack Capacity	0.58	0.94	1.08	1.17	1.52	1.81	2.03	2.20	**2.33**
DOE 1990 Low Case Disruption Probabilities	-0.04	0.22	0.33	0.40	0.63	0.82	0.96	1.06	**1.13**
DOE 1990 High Case Disruption Probabilities	1.38	1.80	1.97	2.09	2.55	2.92	3.22	3.47	**3.66**
EMF 1996 Disruption Probabilities	4.46	5.02	5.24	5.41	6.08	6.62	7.05	7.39	**7.65**
CIA 1999 Disruption Probabilities	-0.69	-0.48	-0.40	-0.34	-0.18	-0.06	0.03	0.08	**0.11**
Disruption Lengths of 1-6 Months (3.5 mean)	-0.77	-0.33	-0.15	0.02	0.64	1.08	1.39	1.60	**1.73**
Disruption Lengths of 3, 6 & 9 months (6 mean)	2.87	3.11	3.20	3.26	3.46	3.62	3.73	3.81	**3.86**
Disruption Lengths of 3, 6, 9 & 12 months (7.5 mean)	4.31	4.48	4.55	4.59	4.70	4.78	4.83	4.86	**4.87**
Imperfect Disruption Length Anticipation	1.74	1.99	2.08	2.09	2.08	2.15	2.23	2.27	**2.30**
Drawdown Delayed by 1 month	-0.02	0.31	0.44	0.52	0.79	1.02	1.19	1.32	**1.42**
Foreign Reserves Used 1st, U.S. 2nd (if needed)	0.64	1.06	1.23	1.33	1.73	2.06	2.33	2.54	**2.70**
Start Building Drawdown Capability in 2005	0.81	1.18	1.32	1.41	1.69	1.91	2.09	2.23	**2.34**
Start Building Drawdown Capability in 2010	0.81	1.18	1.32	1.38	1.54	1.67	1.76	1.82	**1.86**
IEO99 Low Slack & DOE90 High Disruption Probability	7.65	7.95	8.07	8.18	8.56	8.86	9.07	9.23	**9.33**
IEO99 Low Slack & EMF96 Disruption Probability	12.50	12.77	12.87	12.97	13.29	13.52	13.69	13.79	**13.85**
IEO99 High Sack & DOE90 Low Disruption Probability	-1.40	-1.24	-1.17	-1.13	-1.06	-1.01	-0.98	**-0.98**	-0.99
IEO99 High Slack & CIA99 Disruption Probability	-1.62	-1.50	-1.45	-1.43	-1.39	**-1.38**	-1.39	-1.41	-1.44
IEO 2000 Mid Case Slack Capacity	0.07	0.40	0.53	0.62	0.92	1.16	1.35	1.49	**1.60**
AEO 2000 Mid Case Oil Price Scenario	0.53	0.90	1.05	1.15	1.53	1.84	2.09	2.28	**2.43**
IEO 2000 Mid Slack & AEO 2000 Mid Oil Price Scenario	-0.22	0.12	0.26	0.35	0.65	0.90	1.10	1.25	**1.36**

Table A11: Net Benefits of Expansion for Various Sensitivity Cases (Billions $96): 800 MMB Reserve
Drawdown Enhancement Capital Costs: 400 Million Dollars per MMBD of Capability

	Drawdown Capability (MMBD)								
Sensitivity Case	4.1	4.3	4.4	4.5	5.0	5.5	6.0	6.5	7.0
Base Set of Assumptions	0.81	1.18	1.32	1.42	1.69	1.89	2.03	2.11	**2.16**
4.5% Discount Rate	2.50	3.04	3.25	3.40	3.86	4.23	4.51	4.72	**4.87**
10% Discount Rate	-0.16	0.08	0.17	0.24	0.36	0.43	**0.46**	0.46	0.43
AEO 1999 Low Oil Price Scenario	1.15	1.49	1.62	1.71	1.95	2.12	2.23	2.31	**2.34**
AEO 1999 High Oil Price Scenario	0.29	0.68	0.83	0.93	1.22	1.44	1.59	1.69	**1.74**
IEO 1999 Low Case Slack Capacity	7.12	7.38	7.48	7.57	7.79	7.93	8.00	**8.02**	7.98
IEO 1999 High Case Slack Capacity	-0.94	-0.71	-0.62	-0.56	-0.50	**-0.47**	-0.48	-0.52	-0.58
Kendell 1998 Slack Capacity	0.23	0.58	0.72	0.81	1.04	1.21	1.33	1.40	**1.42**
ICF 1999 Slack Capacity	0.58	0.94	1.08	1.17	1.42	1.61	1.73	1.80	**1.83**
DOE 1990 Low Case Disruption Probabilities	-0.04	0.22	0.33	0.40	0.53	0.62	0.66	**0.66**	0.63
DOE 1990 High Case Disruption Probabilities	1.38	1.80	1.97	2.09	2.45	2.72	2.92	3.07	**3.16**
EMF 1996 Disruption Probabilities	4.46	5.02	5.24	5.41	5.98	6.42	6.75	6.99	**7.15**
CIA 1999 Disruption Probabilities	-0.69	-0.48	-0.40	-0.34	-0.28	**-0.26**	-0.27	-0.32	-0.39
Disruption Lengths of 1-6 Months (3.5 mean)	-0.77	-0.33	-0.15	0.02	0.54	0.88	1.09	1.20	**1.23**
Disruption Lengths of 3, 6 & 9 months (6 mean)	2.87	3.11	3.20	3.26	3.36	3.42	**3.43**	3.41	3.36
Disruption Lengths of 3, 6, 9 & 12 months (7.5 mean)	4.31	4.48	4.55	4.59	**4.60**	4.58	4.53	4.46	4.37
Imperfect Disruption Length Anticipation	1.74	1.99	2.08	**2.09**	1.98	1.95	1.93	1.87	1.80
Drawdown Delayed by 1 month	-0.02	0.31	0.44	0.52	0.69	0.82	0.89	**0.92**	0.92
Foreign Reserves Used 1st, U.S. 2nd (if needed)	0.64	1.06	1.23	1.33	1.63	1.86	2.03	2.14	**2.20**
Start Building Drawdown Capability in 2005	0.81	1.18	1.32	1.41	1.59	1.71	1.79	1.83	**1.84**
Start Building Drawdown Capability in 2010	0.81	1.18	1.32	1.38	1.44	**1.47**	1.46	1.42	1.36
IEO99 Low Slack & DOE90 High Disruption Probability	7.65	7.95	8.07	8.18	8.46	8.66	8.77	8.83	**8.83**
IEO99 Low Slack & EMF96 Disruption Probability	12.50	12.77	12.87	12.97	13.19	13.32	13.39	**13.39**	13.35
IEO99 High Sack & DOE90 Low Disruption Probability	-1.40	-1.24	-1.17	**-1.13**	-1.16	-1.21	-1.28	-1.38	-1.49
IEO99 High Slack & CIA99 Disruption Probability	-1.62	-1.50	-1.45	**-1.43**	-1.49	-1.58	-1.69	-1.81	-1.94
IEO 2000 Mid Case Slack Capacity	0.07	0.40	0.53	0.62	0.82	0.96	1.05	1.09	**1.10**
AEO 2000 Mid Case Oil Price Scenario	0.53	0.90	1.05	1.15	1.43	1.64	1.79	1.88	**1.93**
IEO 2000 Mid Slack & AEO 2000 Mid Oil Price Scenario	-0.22	0.12	0.26	0.35	0.55	0.70	0.80	0.85	**0.86**

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