SPR Draw-Rate Capability Benefits Analysis

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Draft 2

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1.0 Introduction

The choice of draw rate capability and SPR size is guided by budgetary considerations, general facility performance goals, the need to coordinate with other International Energy Agency members, and engineering cost analyses of the SPR facilities. The analysis described here estimates the ranges of economic benefits to the U.S. that could be achieved with alternative maximum drawdown capabilities. Such information can assist in determining the economically preferable (optimal) draw rate capability for a given SPR size.

This brief note provides results from an ongoing analysis of the benefits of alternative SPR draw rates. The results of this analysis are intended to aid in ongoing decisions regarding investments aimed at expanding the SPR's drawdown rate from its current level. This note summarizes the analytical approach used and indicates important recent revisions to the SPR benefits calculation model. It also provides graphical and tabular displays of benefits estimates which highlight the effect of a few key SPR management choices and oil market uncertainties. For drawdown capability analysis, the most important of these are the choice of how fast to draw down once a disruption occurs given uncertainty about its duration, and the availability of market offsets to mitigate the disruption.

All of the estimates reported here are based on changing the maximum draw capability from the current rate of roughly 4.4 million barrels per day (MMBD), given the current SPR size of 563 million barrels. As such, the estimates presented here are the marginal or incremental benefits of changing the drawdown rate from its present level. To provide context, we consider cases with draw capabilities both above and below the current rate, in 0.5 million barrel-per-day increments. The results indicate that if we expect an oil market with disruptions of comparatively short duration (1-6 months), draw rate *expansion* can provide substantial benefits, since it would provide timely access to a valuable asset (the SPR). Conversely, allowing the draw rate to *deteriorate* could markedly reduce the expected benefit of the reserve. No data are yet available on the costs of draw rate expansion, so these draw-rate benefit curves provide only one side of the cost-benefit balancing equation.

2.0 General Conclusions

As Figure 1 and Table 1 show, the discounted expected benefits of expanding the draw rate by 1.5 MMBD (to 6.0 MMBD) *could* be as much as $1.27 billion or as little as $0.00 billion. However the expected benefits probably are within the $0.79 to $0.32 billion range, shown as the solid lines in Figure 1. The range of probable outcomes is shown to emphasize key uncertainties and

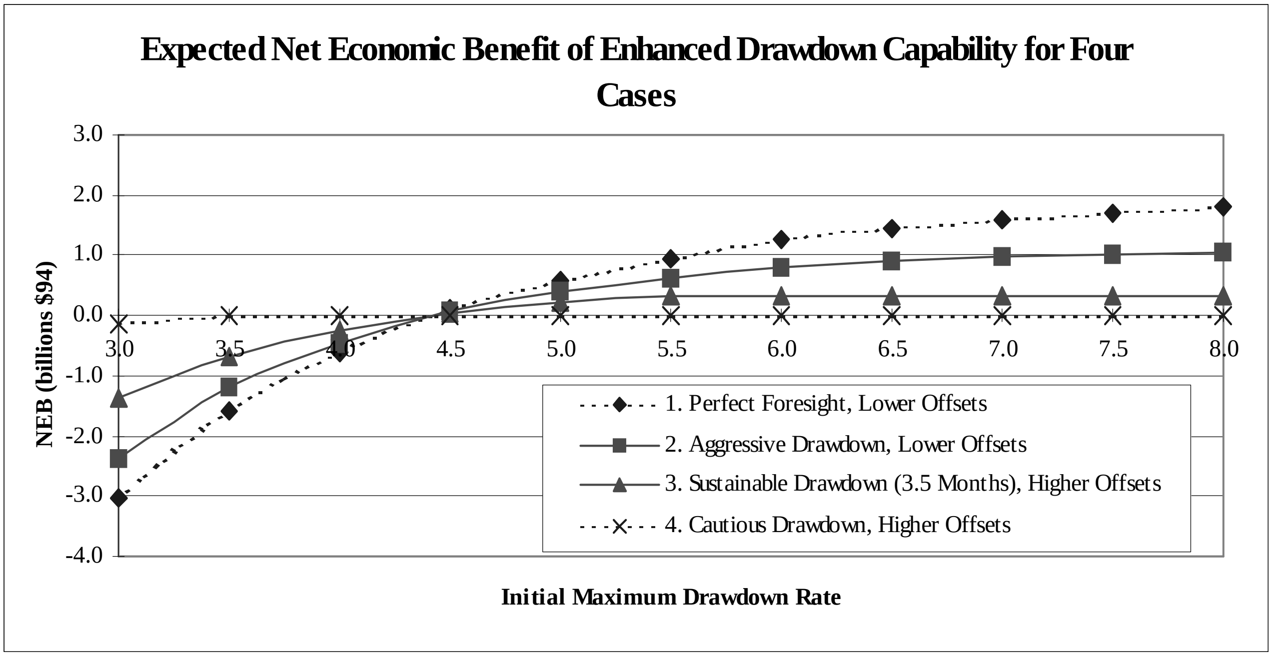

Figure 1 Expected net economic benefit of drawdown capability for four cases (DR97M6L,f,x,h)

opportunities faced by SPR managers. Behind all four curves is the application of a revised GDP elasticity (reflecting the latest research, and higher than the 1990 DOE study) and random disruption lengths which are uniformly distributed over one to six months. The GDP elasticity is an estimate of the percentage GDP change per percentage oil price increase. The revised GDP elasticity estimate of -0.05 is based upon a consensus of experts and recent literature and is considered a fairly accurate account of the linkage between oil price shocks and GDP.[1] The choice of a uniform disruption length distribution (as compared to a normal or triangular perhaps) reflects uncertainty in this area and could be considered a default value in the absence of better information.

[1] See Jones and Leiby 1996 for a survey of pre-1996 studies, and Jones, Bjornstad and Leiby 1997 for a summary of the most recent (1997) research.

Table 1: Expected Net Economic Benefit of Drawdown Capability for Four Cases

	Initial Maximum Drawdown Rate (MMBD)										
	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0
Case 1	-3.01	-1.58	-0.62	0.12	0.59	0.95	1.27	1.46	1.60	1.71	1.81
Case 2	-2.37	-1.20	-0.46	0.08	0.41	0.63	0.79	0.89	0.97	1.01	1.04
Case 3	-1.35	-0.69	-0.26	0.05	0.24	0.32	0.32	0.32	0.32	0.32	0.32
Case 4	-0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Case 1: Perfect Foresight Regarding Disruption Length, Lower Offsets (DR97M6L)
Case 2: Aggressive Drawdown Strategy, Lower Offsets (DR97M6x)
Case 3: Sustainable Drawdown Strategy, Higher Offsets (DR97M6f)
Case 4: Cautious Drawdown Strategy, Higher Offsets (DR97M6h)

The benefit estimates differ in their assumed level of available offsets and drawdown strategies. Offsets include slack production capacity, mostly in the Persian Gulf, and foreign strategic oil stockpiles. Lower levels of available offsets increase the value of the SPR and the value of enhanced drawdown capability. Case 1 of Figure 1 can be considered an upper bound of the benefits of expanding the drawdown rate, approachable but unlikely to be achieved. It combines lower offsets with a drawdown strategy that presumes perfect foresight about disruption length. That is, it presumes the SPR manager knows the length of the disruption and measures out a steady release of crude oil in order of offset as much of the shortfall as possible across its duration. Comparing the results in Case 1 to those of cases 2-4, where the disruption length is uncertain and fixed drawdown rules are used, we see that as the quality of information concerning the actual length of the disruption improves, the benefits of enhanced drawdown increases.

Case 2 in Figure 1 corresponds to lower offset availability and an aggressive drawdown strategy. By an aggressive drawdown strategy we mean releasing as much crude oil as possible (subject to need and ability) as quickly as possible. For larger disruptions this can mean that less oil is available in later months, should the disruption continue. Case 3 is characterized by higher offsets (1990 DOE study assumption) and a more moderate sustainable drawdown path. As defined here, a sustainable drawdown allows for a steady, even release of crude oil assuming that the disruption will be of average length (*expected* duration equals 3.5 months). Both the aggressive strategy and the sustainable strategy are lower than the perfect duration-foresight case due two types of errors associated with less than perfect information. A type 1 error is where the SPR managers drawdown along a path that exhausts the reserve before the disruption ends. This type of error is more often associated with the aggressive drawdown strategy. A type 2 error is where the SPR managers drawdown along a path which results in unused reserves at the end of a disruption. This type of error is more often associated with the more sustainable path. This analysis suggests that given an equal set of assumptions, a type 2 error from excessive caution results in a larger loss of expected benefits than does a type 1 error from excessive zeal. Thus, an aggressive drawdown path is associated with the higher end of the likely range of enhanced drawdown benefits and a more sustainable path is associated with the end of that range.

The extreme lower bound can be characterized by case 4 in Figure 1, which implies no benefits for enhanced drawdown capability. Case 4 represents an even more cautious approach to drawing down the reserve, given uncertainty about the disruption lengths. In this case the SPR manager draws the reserve down at a steady, even rate capable of lasting throughout the maximum *possible* length of the disruption (here set at six months). Since the current drawdown capability is more than adequate to exhaust the existing reserve in 6 months, there is no value to expanding drawdown capability should such a cautious drawdown strategy be adopted. The results of this case are a warning. If meeting each shortfall evenly throughout its possible length of six or more months is the intent, there are no benefits from increasing the draw rate.

3.0 Overview of Analytical Approach Used

3.1 Basic Structure of the Model and Benefits Computation

In examining the benefits of various drawdown rates, ORNL uses an updated version of the model DIS-RISK, developed for DOE. The DIS-Risk Model is a simulation model of SPR activity. It is capable of reproducing the 1990 DOE/Interagency SPR Size Study [DOE 1990] results. It also uses updated parameter estimates and permits extensions such as the analysis of specific, risk-related outcomes. For example, its risk analysis approach reports the expected frequency of disruptions and SPR use, and the probability of SPR exhaustion. It also displays the probability distribution of SPR economic benefits. For more description of the DIS-Risk Model,, see Leiby and Jones [1993] and Leiby and Bowman [1996].

DIS-RISK creates probabilistic simulations of disruptions over the 1997 to 2020 time horizon to examine the benefits of various SPR drawdown rates and/or sizes. In each year a disruption of varying magnitude can occur, according to the specified probability distribution. If the disruption is relatively small, offsets including slack production capacity, demand switching, and foreign stock draws are sufficient to quell the disruption with no noticeable affect on world oil price. If the disruption is not fully offset, the SPR attempts to compensate for any remaining net disruption by drawing down upon its reserves. Provided the disruption is fully offset by the combined contribution of offsets and the SPR, then there is no oil price perturbation and no economic losses occur. Otherwise, the price of oil rises until demand contracts enough to accommodate the net supply shortfall. The price rise imposes costs on the U.S. economy, principally in terms of an increased oil import bill and transitory GDP losses due to the price shock. DIS-RISK also tracks the net revenues to the SPR. The SPR net revenues combined with the costs to society are weighted by the probability of each disruption event considered, and contribute to the expected net benefit of the SPR program. For this study, each SPR program considered is characterized in terms of a reserve size (the current 563 million barrels) and a maximum drawdown rate (3-8 million barrels a day).

3.2 Updates to the Model

Recent updates to DIS-RISK were made both for general maintenance and for the purposes of the draw rate issues at hand. General updates include moving the model from a Lotus based system to an Excel format (which eases use of the @Risk simulation program) and updating the market inputs to correspond to the latest version of the Annual Energy Outlook. Updates related to the task at hand include:

- *Monthly analysis*: changing the time interval of the model from quarters to months to allow for finer-grained analysis of disruption lengths from 1-12 months,
- *Allowing for random disruption length*: rather than assuming disruptions are of fixed and known length (in previous studies, 1, 2, or 3 quarters), this provides more flexibility in disruption characterization;
- *Disruption length anticipation* and the SPR management strategy: Since the exact duration of each disruption is not known with certainty at its beginning, the drawdown rate chosen will reflect the anticipated duration (e.g., it can be higher if the anticipated duration is shorter). Clearly, the value of expanded drawdown capability will depend on the whether and how often the drawdown strategy will call for higher draw rates. We consider the result of drawdown "strategies" based on alternative anticipated disruption lengths, which may equal, exceed, or be shorter than the actual length.
- *Consider higher GDP elasticity*: Transitory GDP losses due to oil price shocks are estimated using a parameter called the "GDP Loss Elasticity." The GDP Loss Elasticity indicates the percentage change in GDP per percentage change in oil price during a shock. Based upon recent understanding and new econometric estimates, a GDP loss elasticity due to shocks of -0.05 is considered as an alternative case along with the previously used value of -0.025.

These and other features lead to the sensitivity variables listed in Table 2 below.

Table 2: Sensitivity Variables used in Case Studies	
Variable	**Sensitivity Values**
Maximum Disruption Length	3 months
	6 months
	9 months
	12 months
Distribution of Disruption Lengths	Fixed at 1 month
	Uniform probability distribution, from 1 to Maximum Disruption Length
	Fixed at the Maximum Length
SPR Managers' Anticipation of the Disruption Duration (Drawdown Strategy)	Actual Duration (Perfect Foresight)
	Expected Duration (mean length: sustainable strategy)
	1 month (Aggressive Drawdown)
	Maximum Length (Cautious Strategy)
GDP Elasticity	-0.025 (midcase elasticity estimate from the 1990 DOE study)
	-0.05 (revised elasticity estimate based upon more recent empirical studies)
Availability of Offsets	Higher slack capacity, demand switching, and foreign draw.
	Lower slack capacity, midcase demand switching and foreign draw

3.3 Determination of SPR Draw Rate During a Disruption, and the Arena of Analysis

It is helpful to look at possible SPR draw rates for various disruption sizes and durations. In this way we can see under what conditions the current draw capability might be constraining and identify the "arena" for draw capability analysis. The SPR can be used to fully offset any net supply shortfalls (after offsets) provided the resulting drawdown rate does not exceed either the maximum draw capability <u>or</u> the SPR exhaustion rate. The SPR exhaustion rate is that rate which will deplete the reserve, given the drawdown length and assuming a constant draw rate over the duration of the disruption.

Thus the actual or effective drawdown rate during a disruption is determined by the minimum or binding level the following three constraints: net disruption size (MMBD); maximum programmed drawdown capability; and SPR exhaustion rate.

$$Drawdown\ Rate \le Minimum\ of\ \left\{ \begin{array}{l} Net\ Disruption\ Size\ (MMBD) \\ Maximum\ Programmed\ Drawdown\ Capability \\ SPR\ Exhaustion\ Rate \end{array} \right\}$$

These constraints are in turn functions of three factors: disruption length, disruption size, and maximum programmed drawdown capability (currently at 4.415 MMBD). The combination of these factors can be viewed schematically. Figure 2 displays the resulting drawdown rates for different points on the disruption outcome space. The two axes on the horizontal plane indicate the disruption outcomes, i.e. different values of the two random variables: disruption length and net disruption size. The three flat surfaces on this graph each reflect a set of outcomes where one of the three constraints is binding. The left slope indicates outcomes where the net disruption size is relatively small, and the drawdown rate is thus limited by the net shortfall. The front slope indicates outcomes where the disruptions are relatively long, and the chosen drawdown rate is limited by the exhaustion rate. Finally, the top, flat surface reflects disruption outcomes where the programmed maximum drawdown capability (4.415 MMBD) is binding. These are, naturally, the shorter, larger disruptions.

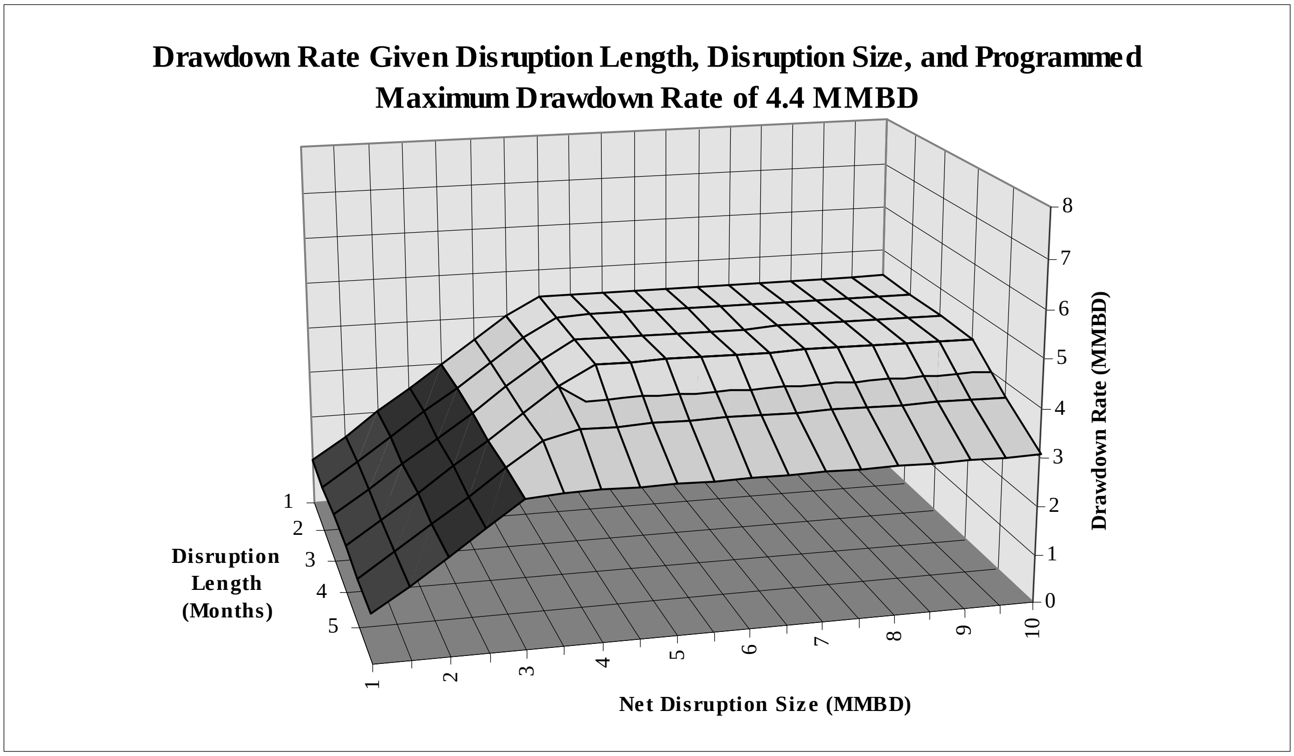

Figure 2 Drawdown rates during disruptions: cases covered by current 4.415 mmbd capability

Generally speaking, if a net disruption is (1) less than 4.415 MMBD or (2) the length of the disruption exceeds four months, then the current programmed maximum drawdown rate of 4.415 is no longer binding. Under the first set of outcomes, some of the drawdown capability is not needed to address the disruption. Under the second set of outcomes, drawdown capability exceeds the SPR exhaustion rate (which falls below 4.4 MMBD after about 128 days). Under these states of the world, additional drawdown capacity is not needed. However, there may also occur disruptions which could be characterized as short-lived but of larger magnitude. Under this regime, the programmed drawdown capability can limit timely access to a valuable resource. As shown in Figure 3, given this state of the world, providing for additional drawdown capacity would increase the effective drawdown rate for some disruption outcomes.

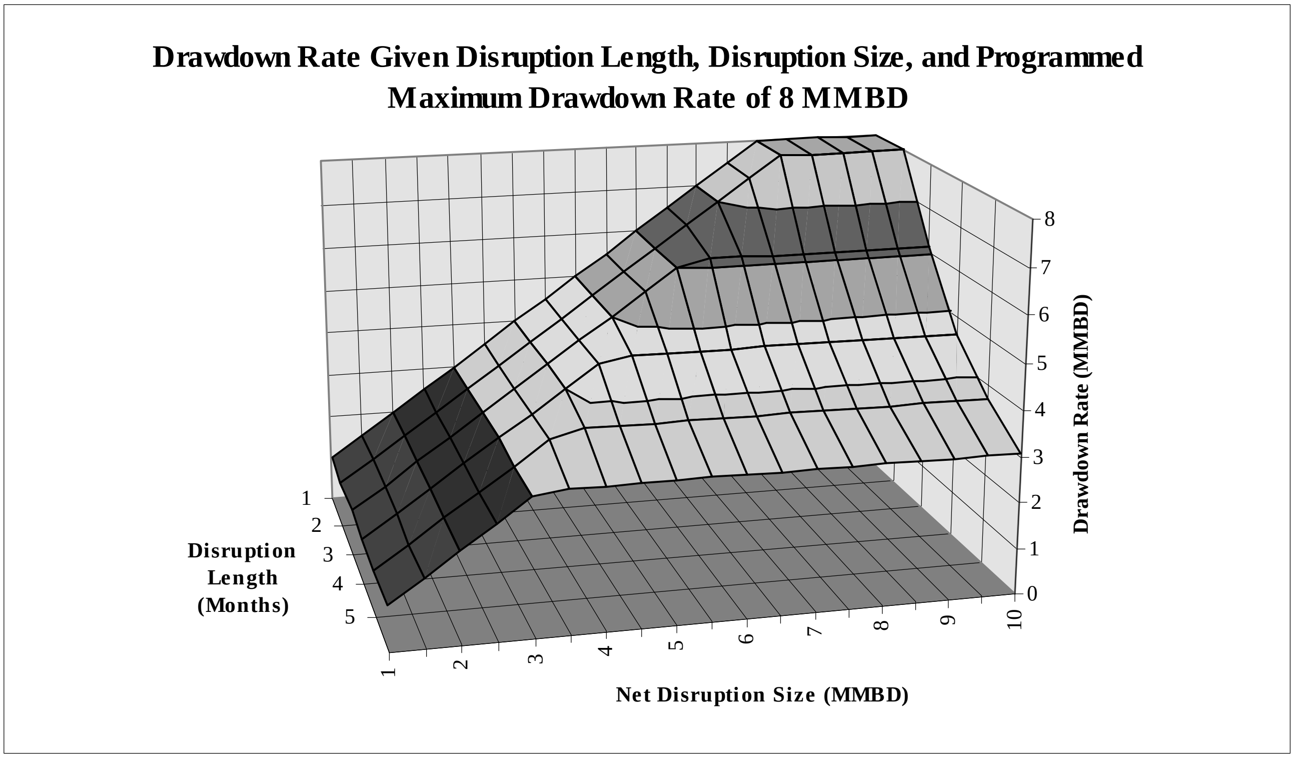

Figure 3 Drawdown rates during disruptions: cases covered by 8 mmbd capability

Figures 4 focuses on the difference between Figure 2 (current capability) and Figure 3 (higher capability) to highlight the incremental coverage provided by a higher drawdown capability. This "incremental drawdown" surface is taken from the 8 MMBD coverage surface in Figure 3, excluding smaller disruption sizes (covered by 4.415 MMBD and higher) and longer duration events (where 4.415 MMBD and higher are ineffective due to exhaustion constraints). This graph indicates the added ability of the reserve to offset some disruptions, i.e. those which are larger and shorter in duration than most. We treat the distribution of random disruption lengths as uniform, i.e., all disruption lengths from 1 to 6 months are equally likely. However, the probability distribution of disruption sizes (the Weibull probability distribution derived from the DOE90 study) shows markedly declining probabilities for larger disruption sizes. Thus the disruption outcomes in Figure 4 which call for the higher draw rates will tend to be lower probability events. Herein lies the arena of analysis for this draw rate study. Given disruptions of randomly varying lengths and sizes producing states of the world where additional capacity may be either redundant or effective, what is the benefit of expanding the drawdown capacity?

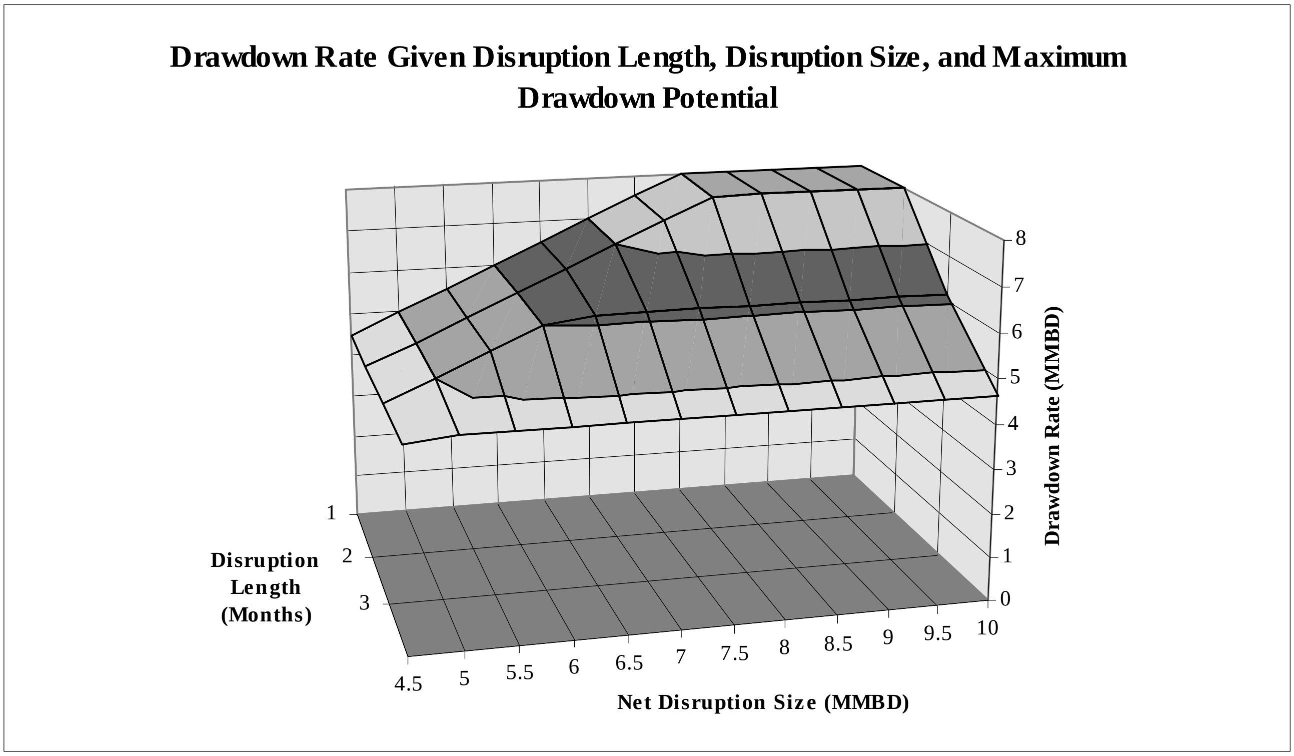

Figure 4 Drawdown rates during disruptions: cases covered by 8 mmbd capability but not by current 4.415 mmbd capability

4.0 Initial Results

4.1 Starting Point Estimates (Departing from 1990 DOE/Interagency Study Assumptions)

We define Net Economic Benefit (NEB) as the incremental benefit of increasing or decreasing the maximum drawdown rate from its current value of 4.415 million barrels a day. Drawdown rates less than the current rate are not considered as policy alternatives, but are included for completeness to examine the potential effects of draw rate deterioration. As a starting point, consider the assumptions used in the 1990 DOE/Interagency Size Study (DOE90). The DOE90 base case reflects a previous conception of the nature of the problem. Specifically, disruptions last 6 months, SPR managers correctly anticipate the disruption length, fairly substantial offsets are available and the GDP elasticity is assumed to be -0.025.

Under the previous DOE90 set of assumptions, there is no benefit of increasing the drawdown capability. There is an obvious and simple explanation for this seemingly unlikely outcome. Since disruptions last six months, and SPR managers, anticipating this, draw at a constant rate throughout the disruption, drawdown rates of roughly 3.3 MMBD are sufficient to exhaust the reserve. Therefore, according to the assumptions of the model, managers of the SPR are never able to drawdown more than 3.3 MMBD. Additional capacity above and beyond 3.3 MMBD thus shows no benefit.

Given the limited suitability of the historical SPR size analysis assumptions for SPR draw rate analysis, we modified the SPR model to reflect the uncertainty about disruption duration, as well as disruption size. In particular, we considered shorter disruptions of fixed length, and random length disruptions whose durations are uniformly distributed between 1 and 6 months. The uniform probability distribution was used because there is insufficient empirical information to support another choice, and it best reflects the state of general uncertainty about duration. Preliminary analysis, as shown in Figure 5, tends to support this approach, since approximately 80 percent of the world's historical disruptions lasted six months or less, with no real discernable pattern. We also assume, absent any better information, that disruption length and disruption size are independent. This assumption is germane to draw rate analysis because, as we saw in section 3, comparatively high draw rates are most useful when the disruption is both short (so that the SPR exhaustion rate is large) *and* large. Assuming that disruption length and size are independent means that a large net disruption is just as likely to be long as it is to be short, but in the former case higher draw rates cannot be sustained and are not useful. Figure 6 shows that historical disruptions had lengths and sizes scattered about with no clear pattern.

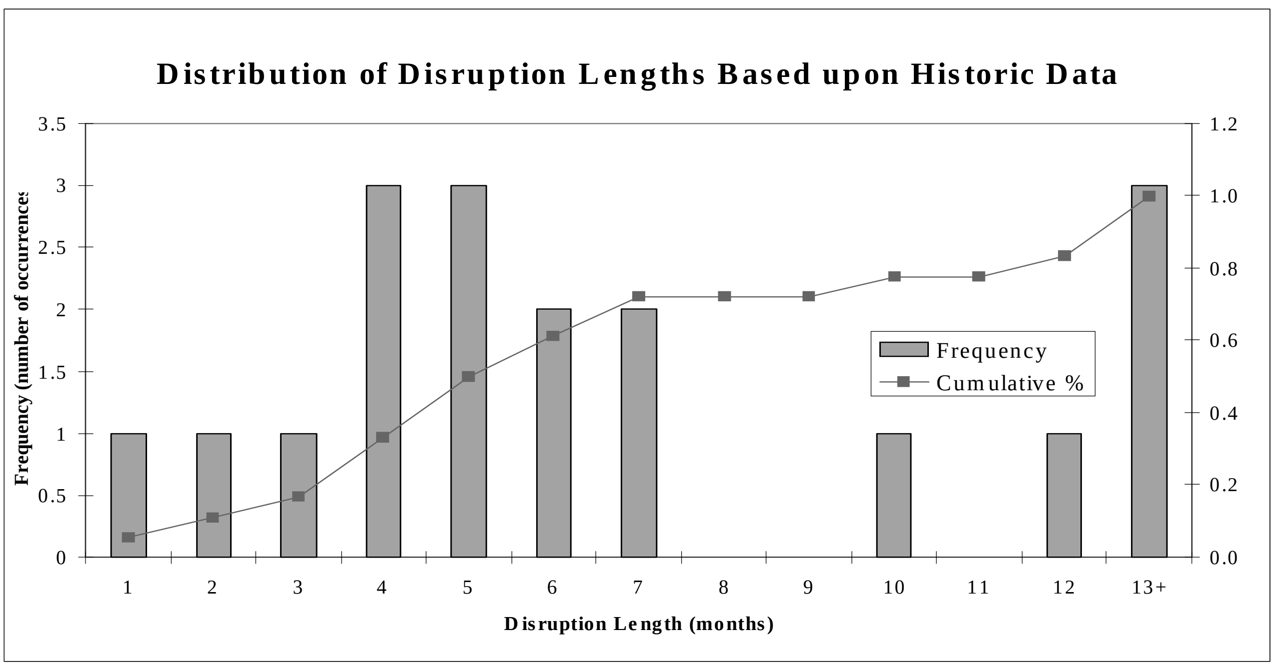

Figure 5: Distribution of disruption lengths for eighteen historical oil supply disruption events ranging from the Iranian field nationalization (1951-1954) to the Gulf Crisis (1990-1991)

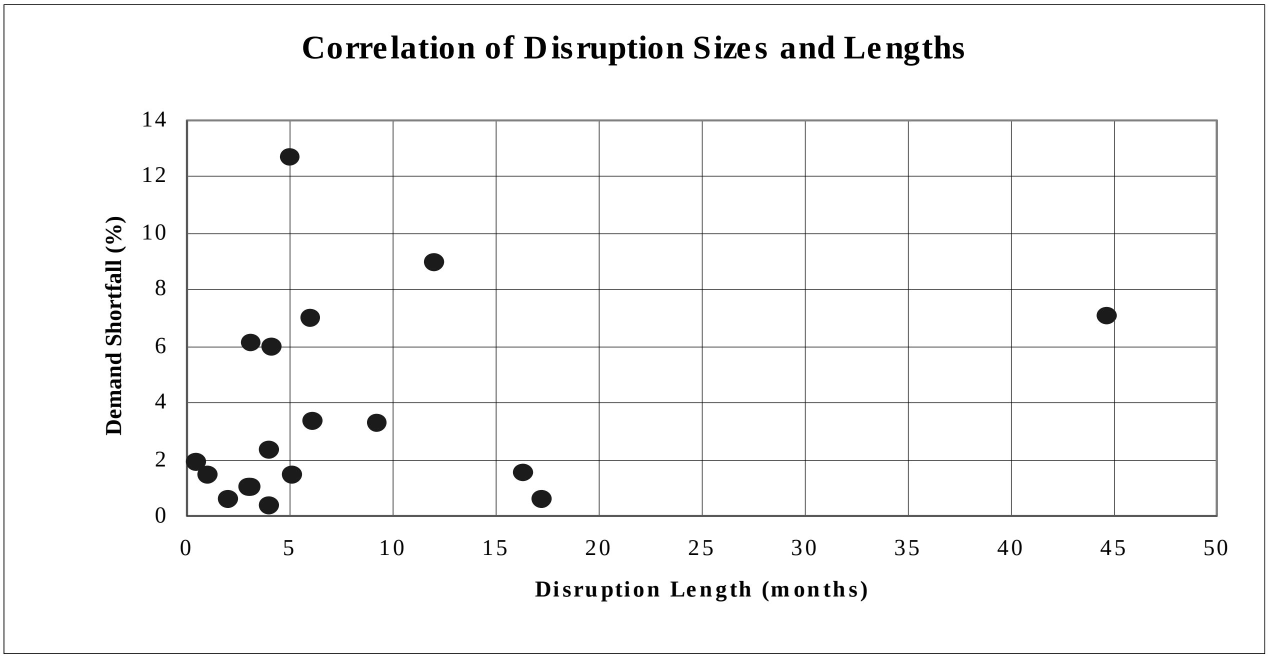

Figure 6 Historical disruptions had sizes and lengths which were loosely correlated at best.

As a starting comparison, we can look at the net economic benefits for drawdown capability enhancement given *random* disruption lengths, but keeping all other assumptions the same as in the DOE90 Base case. Figure 7 graphs the net economic benefits for different drawdown capabilities when disruptions lengths are uniformly distributed from 1 to 6 months. As in the DOE90 study, it uses the lower GDP elasticity of -0.025, and assumes that SPR planners have perfect foresight regarding the length of the disruption, and drawdown accordingly.

Recall that all net economic benefits are measured *relative* to the current size (563 MMB) and drawdown capability (4.4 MMBD) of the reserve. The data for Figure 7 are reported in Table 3. Figure 7 and Table 3 clearly show that when we account for the possibility of disruptions shorter than 6 months, the expected economic benefit of drawdown capability grows for rates above the current level. In this case of lower GDP elasticity the expected economic benefit initially grows quickly, by about one-quarter of a billion dollars for the first increase from 4.4 to 5.0 MMBD, and then more slowly to about three-quarters of a billion dollars for a very large capability increase to 8.0 MMBD.[2] This result contrasts with the conclusion of zero benefits from draw rate expansion if all disruptions were known to last 6 months.

[2]The analogous case presented in section 1, which applies lower offsets and the revised GDP elasticity, shows about double the drawdown expansion benefits. Section 4.3 below sorts out the effects of these two revised assumptions.

The graph in Figure 7 shows both the expected value (probability-weighted average) of NEB as well as the 90% confidence interval, which is delimited by the 5th and 95th percentile. While the mean or average outcome is a common measure of benefits, inclusion of the 5th and 95th percentiles conveys additional information concerning upside and downside. The net economic benefit is determined by random oil market outcomes, and the *expected* net benefit is determined by the average of many (Monte Carlo) samples of possible oil market outcomes. The many individual outcomes are distributed over a range of benefits values rather than at a single point. Specifically, five percent of the time the benefits outcomes are at or below the 5th percentile. Ninety-five percent of the time the net economic benefits are at or below the 95th percentile. On average, the net economic benefit is the mean or expected value. The 5th percentile measure of net benefits displays the "worst case" scenario of potential losses from a change in the drawdown rate. Conversely the 95th percentile reports the upper level of benefits which could be attained 95 percent of the time for a given drawdown rate.

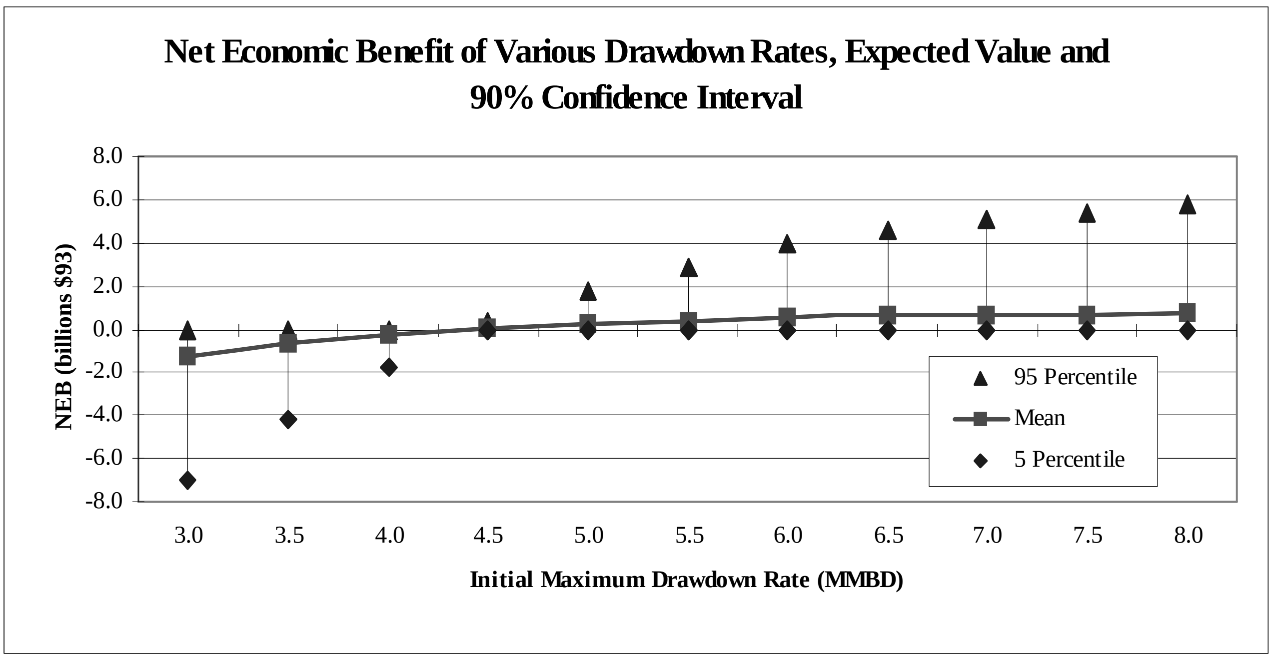

Figure 7 Lower (-0.025) GDP elasticity, higher slack level, disruption length is uniformly distributed over 1 to 6 months, and anticipated disruption length is based on perfect foresight (Case DR97M6a)

Table 3: Net Economic Benefit of Expanded Drawdown Capability - Expected Value and Confidence Interval

	Initial Maximum Drawdown Rate										
	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0
95 Percentile	0.00	0.00	0.00	0.35	1.76	2.91	3.94	4.55	5.04	5.43	5.75
Mean	-1.23	-0.65	-0.25	0.05	0.24	0.40	0.53	0.61	0.66	0.70	0.74
5 Percentile	-7.02	-4.18	-1.78	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Case DR97M6a: Lower (-0.025) GDP Elasticity, Higher Slack Level, Disruption Length is Uniformly Distributed over 1 to 6 Months, and Anticipated Disruption Length is based on Perfect Foresight

The confidence intervals, bracketed by the 5th and 95th percentiles, are informative. The 5th percentile values show that relative to the current draw rate, there is no downside risk to draw capability expansion, at least as long as the SPR managers have good information (perfect foresight) about the length or duration of the disruption.[3] The 95th percentile values show that the possible upside benefit of draw rate expansion could be much greater than the expected value, e.g. there is a 5% chance that benefits could exceed $4 billion for a 6 MMBD draw rate compared to their expected value of $0.53 billion. We also observe from the 5th percentile results that there is a substantial downside risk to allowing the drawdown capability to deteriorate below the current level.

In the next section we relax the assumption that once a disruption occurs, planners will have perfect foresight regarding its duration.

4.2 Effect of Alternative Drawdown Strategies, Given Anticipated Disruption Duration at Time of Shock

The value of expanded SPR draw capability is strongly influenced by the manner in which it will be used. Previous analyses of SPR size and drawdown assumed that the disruption was of some known and fixed duration (usually 3, 6, or 9 months), *and* that the SPR was drawn down to offset as much of the net disruption as possible, subject to the requirement that the drawdown rate must be sustainable throughout the duration of the disruption. The analyses reported here vary these assumptions in two ways:

- The duration of the disruption can be fixed or random (uniformly distributed between 1 and some maximum length);
- SPR managers may or may not know the actual length of the disruption, given that one occurs. They draw down based on an *anticipated*[4] disruption duration

[3] These calculations omit the fixed capital costs of draw capability expansion.

[4] We use the term "anticipated" duration to denote the SPR managers prior beliefs about duration, reserving the term "expected" duration for the statistical expectation, i.e. mean or average duration.

Since we consider random disruption lengths, it is also important to recognize that when a disruption occurs the SPR decision-makers may not know its duration (we assume that they *do* know its size).

To account for this, we considered the consequences of a variety of anticipations about disruption length by SPR managers. While the exact duration of each disruption is not known with certainty at its beginning, the drawdown rate chosen will reflect the anticipated duration. For example, the draw rate might be higher if the anticipated duration is shorter. For the drawdown behavior examined here, the anticipated disruption length determines what drawdown rate the SPR manager believes will exhaust the reserve (i.e., the “anticipated” exhaustion rate). This anticipated exhaustion rate, as Figure 2 showed, can be the limiting factor for longer and larger disruptions. We consider the result of drawdown “strategies” based on alternative anticipated lengths, which may equal, exceed, or be shorter than the actual length. These correspond to a measured, cautious, or aggressive/optimistic drawdown strategy, respectively.

The results of these tests show that benefits are maximized when the SPR planners have good information about disruption duration, and draw down the reserve at a steady rate for the life of the disruption. Not surprisingly, the worst strategy is an overly cautious one in which all disruptions are treated as if they will last for the maximum possible length, 6 months. In this case there is no net benefit to having a draw rate above the anticipated exhaustion rate of 3.5 MMBD. Interestingly, the second best strategy after perfect foresight (which is not so much a strategy as a state of information) is to draw aggressively (as if the disruption could end in one month). If it lasts longer than one month, and there is oil remaining in the reserve, then drawdown can continue along this aggressive path. If the disruption indeed ends after one month, then the reserve will have been used to its best value. In some cases, the disruption may continue for many months, and the aggressive early drawdown may mean the draw rate in the later months must be lower. This causes some loss or “regret” relative to the perfect foresight case (Type 1 error). But still, the simple, aggressive drawdown strategy does reasonably well, and does slightly better than a more cautious strategy of providing for a sustainable drawdown across the expected disruption length (3.5 months). This is seen from the expected benefit curves of Figure 8 and data of Table 4.

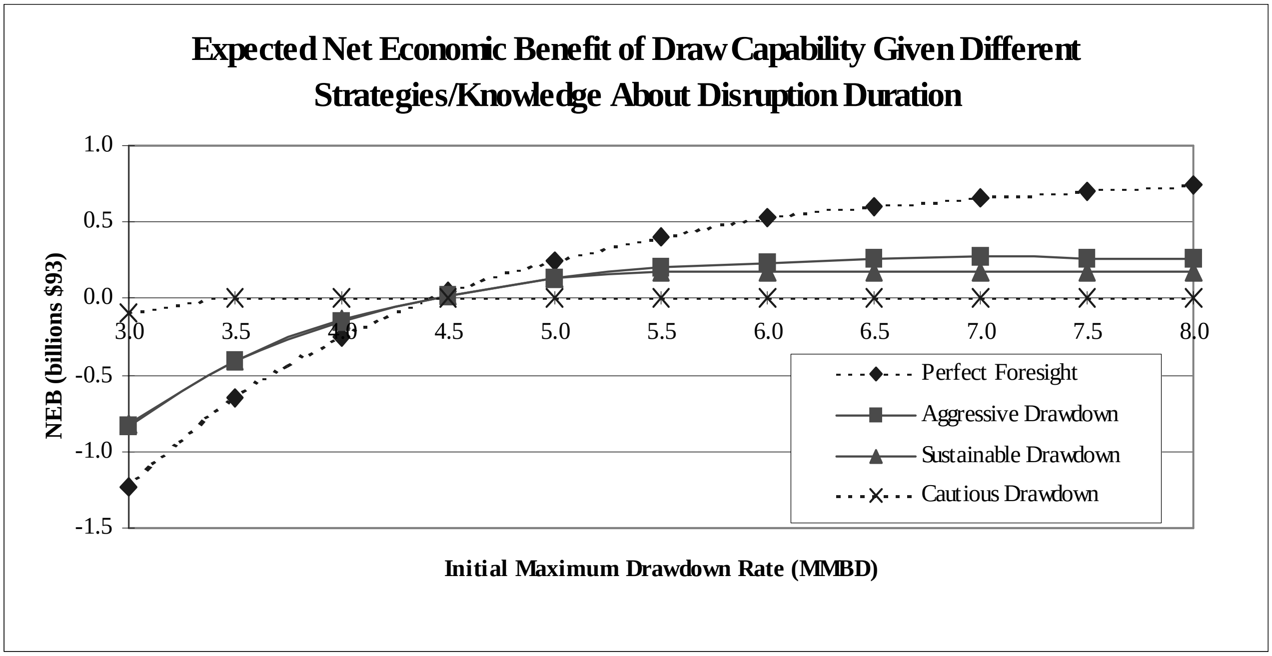

Figure 8 Lower (-0.025) GDP elasticity, higher slack level, disruption length is uniformly distributed from 1 to 6 months, anticipated disruption length differs for each case. (Cases are, respectively, DR97M6a-d)

Table 4: Expected Net Economic Benefit of Draw Capability (Relative to Current 4.415 MMBD) Given Different Strategies/Knowledge About Disruption Duration

	Initial Maximum Drawdown Rate										
Drawdown Strategy/Anticipated Disruption Length	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0
Perfect Foresight	-1.23	-0.65	-0.25	0.05	0.24	0.40	0.53	0.61	0.66	0.70	0.74
Sustainable Strategy/3.5 months	-0.82	-0.40	-0.14	0.02	0.13	0.17	0.17	0.17	0.17	0.17	0.17
Aggressive Strategy/1 month	-0.83	-0.41	-0.15	0.02	0.14	0.21	0.24	0.26	0.27	0.27	0.26
Cautious/6 months	-0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Lower (-0.025) GDP Elasticity, MidCase Slack Level, Disruption Length is Uniformly Distributed from 1 to 6 Months, Anticipated Disruption Length differs for each case. (Cases are, respectively, DR97M6a-d)

While, strictly speaking, the "perfect foresight" condition is not practically attainable, the difference between the perfect foresight results and the results for other simpler assumptions about disruption length indicate the large value of having good information about the actual length of the disruption when planning a drawdown response to a disruption. That is, the differences indicate the expected high value of perfect duration information relative to other anticipatory rules. For large draw capabilities, the Net Economic Benefit (NEB) for perfect foresight is 4 times that achieved by the "sustainable" draw strategy (where the anticipated length equals the average or expected disruption length), a difference of $0.57 billion. The NEB for perfect foresight peaks at 3 times that achieved by the aggressive draw strategy (where the anticipated length equals 1 month), for a difference of $0.48 billion. Given a much-enhanced drawdown capability, it could be worthwhile to spend up to these amounts to develop better information and intelligence about how to gauge disruption durations.

The expected value of perfect information, that is the expected value of perfect foresight about disruption length, tells us how much we should be willing to spend up front before any disruption happens, on a general capability to estimate disruption durations. Then, should a big disruption occur, we would know how fast we could draw the reserve without running out prematurely. This amount could be on the order of $0.5 billion. Alternatively, the amount that we would be willing to pay *once a disruption has started*, to determine that disruption's duration and whether a rapid drawdown is appropriate, is substantially larger. For example, given a 560 million barrel reserve, and draw capability of 6.0 MMBD, we estimate that once a net disruption has occurred, the average value of then learning its duration in order to better plan the draw rate is on the order of $2.5 billion. (Note that this is the value *conditional* on a disruption having occurred. Since a disruption may not occur, the *ex ante expected* value of such foresight is lower.)

On the other hand, another reasonable interpretation of the drawdown benefit curves in Figure 8 is that unless we can hope for good information about disruption duration, (which would be conditional on the available indicators at the inception of each disruption), then there is little *expected* benefit of a drawdown capability much beyond 5.5-6.0 MMBD. This is because if we draw down as if the disruption will be of average duration (3.5 months), then the exhaustion rate becomes binding after 5.5 MMBD. Alternatively, if we draw down aggressively, as if the disruption will be shorter, e.g. 1 month, then the added benefits of higher draw rate are slightly larger than the average-duration strategy. They are partially offset by the costs of occasionally underestimating duration and over-drawing early in the disruption. The downside risks of occasionally over-drawing the SPR under an aggressive drawdown strategy are illustrated in Figure 8a. This figure shows the case where drawdown rates are chosen by treating each disruption as if it will end within one month. For this drawdown strategy, the 5th percentile points indicate a 5% chance that having a higher draw capability could cause system performance to be about $1.5-$2 billion *worse* than the current draw rate of 4.4 MMBD. Note the contrast with Figure 7, for the Perfect Foresight case, which shows no downside risk from draw rate capability expansion (relative to the current draw capability).

It is difficult to ascertain which of these drawdown strategies is most likely to be adopted by future SPR managers. Previous experience suggests that there is an institutional tendency to err more on the side of what is viewed as "caution," and to delay or reduce the drawdown. The tendency may be to hold the reserve as a hedge against a longer or more severe disruption than that which has occurred. The down-side risk of such of go-slow strategy is apparently smaller, and less visible, than the downside risk of too rapid an early drawdown. However, the results here suggest that such a management perspective, while well-intended, may be misguided. Firstly, there are substantial benefits to be gained from a more rapid and early draw during a severe disruption of uncertain length. These can be seen from the up-side (95th percentile) gains in Figure 8a. Secondly, the more aggressive drawdown strategy performs better on average over range of disruptions than the more measured or cautious strategy. This can be seen by its higher average or expected-value benefits over the full range of draw capabilities. The better overall performance of the rapid drawdown strategy is partly due to the basic principle of striking while the iron is hot. Large disruptions are comparatively rare events, and it is generally better to use the reserve when it is needed than to hold it as a last resort against an event which may never occur. The other reason why a drawdown performs well is that the social losses of a disruption grow at a decreasing rate for increasing disruption size. That is, the marginal cost of a disruption declines with increasing disruption size, rather than increases.[5] This means that using a barrel of the SPR against a moderate shortfall now can be at least as valuable as using it against a more severe one later. Finally, there may be other considerations arguing for a prompt and bold drawdown. It may serve to calm markets, show strength to uncooperative oil exporters, and encourage our IEA allies to take similar decisive action.

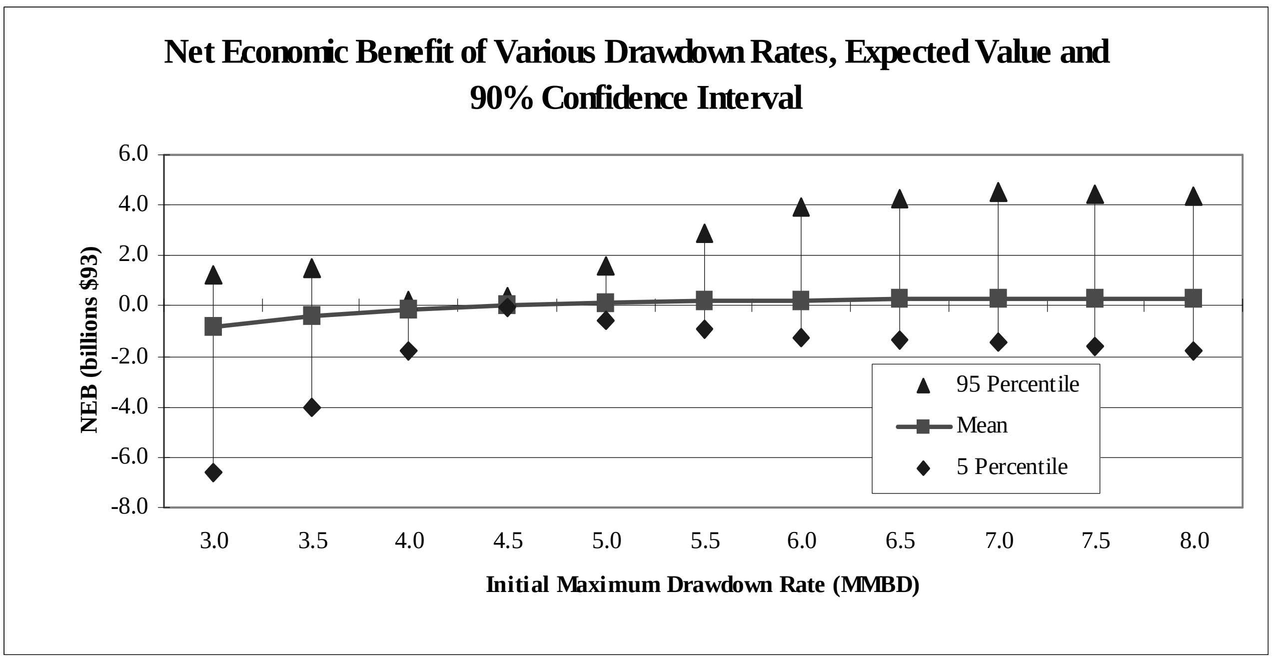

Figure 8a Confidence intervals for drawdown capability net benefit given an aggressive drawdwon strategy (Case DR97M6c).

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[5] There are two technical reasons for this are: (1) demand and supply are assumed to be increasingly elastic (responsive) with increasing disruption size and price, so that each incremental barrel of supply disrupted has a smaller effect on market price, and; (2) the GDP loss elasticity implies a slightly concave relation between oil price change and GDP loss, so each dollar increase in oil price has a smaller effect on GDP.

4.3 Effect of Updated GDP Loss Estimates, and Alternative Assumptions Regarding Slack Capacity

4.3.1 New Evidence on the Relationship Between Oil Price Shocks and the Macroeconomy

Recent studies and new information, including data from the Gulf War crisis, indicate that the elasticity of GDP with respect to oil price is higher than was previously assumed in the DOE90 SPR study. The earliest inquiries into the GDP-oil price relationship indicated a substantial and strong relationship. Many of the values for GDP elasticity in common use then centered around -0.05 (Hamilton 1983, or see EMF 1987 for a sample of early estimates). However, the oil price drop of 1986 did not yield a GDP gain comparable to the GDP losses that had been observed after the price increases of 1973 and 1979. When this observation was included in the statistical studies it led to lower and less significant GDP elasticity estimates. This fact and other doubts which were raised by some researchers (notably Bohi 1989, 1991) about the reliability of the relationship led to the use of a more modest number (-0.025) in the 1990 DOE SPR size study. Since that study two threads of research have restored the credibility of the original -0.05 estimate, if not even higher ones.

First, a series of revised aggregate econometric studies were done to explicitly account for the prospect of a different (asymmetric) response of the economy to positive and negative price shocks, to account for some macroeconomic policy variables, and to include more years of data up to and including the 1991 Persian Gulf event. Examples which estimated the GDP elasticity include Mork (1989), Mory (1993), and Mork, Olsen and Mysen (1994).[6] These studies generally found elasticities consistent with -0.05 or higher. For a survey of the research up to 1995 on the macroeconomic impact of oil shocks, see Jones and Leiby [1996].

Second, in 1996 four new studies were commissioned by Oak Ridge National Laboratory on behalf of the U.S. Department of Energy, to focus specifically on the doubts which had been raised by those who were skeptical about the oil price-GDP relationship. Prior to this research, some doubts had been raised regarding whether historical oil price shocks really *had* substantially contributed to the economic recessions which followed them. The new research shed considerable light on these issues, in each case reinforcing the view that oil price shocks are important influences on macroeconomic activity. The workshop was very successful in resolving a number of key issues and paradoxes

[6]Mork (1989) found, dividing the sample period into segments before and after the 1986 oil price collapse (beginning the second period at 1986:2), that the same model would not fit both periods. This prompted him to examine separate variables for oil price increases and decreases. Otherwise using the same model, the third and fourth quarter lags of the oil price increase variable were negative (both -0.049) and highly significant. The sum of all four coefficients was -0.144. Mory (1993), using a sample period of 1951-1990, obtained a GNP elasticity of -0.0551, highly significant statistically. With separate variables for oil price increases and decreases, he controlled for government purchases and M2 money supply, the GNP elasticity of oil price *increases* was -0.0671, again statistically significant. Also Mork, Olsen and Mysen (1994) applied essentially the same model as Mork (1989) to the experience of seven OECD countries over the period 1967:3-1992:4. For the United States, the contemporaneous price increase and the first and second quarterly lags were significant, and the sum of the coefficients was -0.054.

relating to the macroeconomic consequences of oil price shocks. For example, the research on job creation and destruction showed that indeed we can observe quite significant sectoral dislocations and micro-phenomena in response to oil price shocks. These effects are observable both in individual industries at the 4 digit SIC level (Davis and Haltiwanger 1997) and in state-by-state aggregate employment data (Davis, Mahidhara, and Loungani 1997). The disaggregated results also strongly supported a view of oil price shocks as allocative disturbances, initially causing job losses in some industries and regions, followed later by job creation elsewhere.

The research confirmed that GNP effects are indeed asymmetric with respect to price increases and decreases, but emphasized that this asymmetry is a natural consequence of the way price shocks affect the economy, *not* a paradox. The research also undermined any optimism that structural changes have occurred in the U.S. economy and the oil market which have reduced the importance of oil shocks, or eliminated their significance altogether. If true, this would mean that oil price-GNP models which work well up to the mid-1980s would no longer apply, and we should see evidence of structural instability in the econometric estimates as recent history is added. Hooker (1996) showed that when the oil price movements are transformed to account for the nonlinearity of their effect on GNP, and when the analysis is properly conditioned on macroeconomic policy, the relationship between oil price shocks and GNP is both structurally stable and quite significant all the way through recent history. Overall, however, this research demonstrated beyond any doubt that oil price shocks are important business cycle events, even though key features of how they attain that importance remain to be understood better. For further discussion of the findings of these studies and the Workshop which reviewed them, see Jones, Bjornstad and Leiby, 1997.

For these reasons it now appears that the current state of knowledge is more indicative of a GDP elasticity closer to -0.05 than the previously used -0.025. Table 5 and Figure 9 displays the net expected economic benefit of alternative drawdown rates under different drawdown strategies using the higher GDP estimate. Table 5 also shows the change in economic benefit resulting from using the higher GDP elasticity measure relative to that used in the 1990 DOE SPR size study.

Table 5: Net Expected Economic Benefit for Various Drawdown Strategies Given a Higher GDP Elasticity Estimate (Billions $93)

	Initial Maximum Drawdown Rate (MMBD)										
	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0
Perfect Foresight	-1.72	-0.91	-0.35	0.07	0.34	0.55	0.73	0.84	0.91	0.97	1.02
Sustainable Rate	-1.35	-0.69	-0.26	0.05	0.24	0.32	0.32	0.32	0.32	0.32	0.32
Aggressive Rate	-1.37	-0.70	-0.26	0.05	0.25	0.39	0.49	0.55	0.59	0.61	0.63
Cautious Rate	-0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Change in Net Expected Economic Benefit Due to the Higher GDP elasticity relative to the Lower Estimate (Billions $93)											
	Initial Maximum Drawdown Rate (MMBD)										
	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0
Perfect Foresight	-0.50	-0.26	-0.10	0.02	0.09	0.15	0.20	0.23	0.25	0.26	0.28
Sustainable Rate	-0.53	-0.29	-0.11	0.02	0.11	0.14	0.14	0.14	0.14	0.14	0.14
Aggressive Rate	-0.54	-0.29	-0.12	0.02	0.11	0.19	0.26	0.29	0.32	0.34	0.37
Cautious Rate	-0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

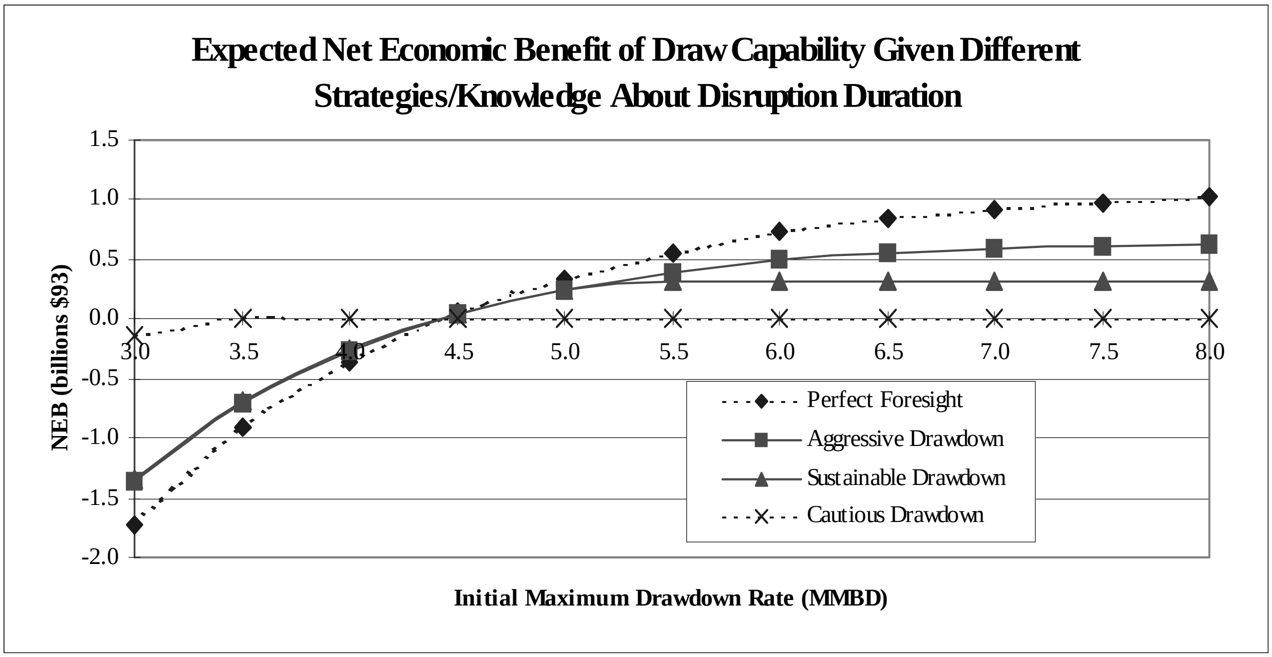

Figure 9 Higher (-0.05) GDP elasticity, higher slack level, disruption length is uniformly distributed from 1 to 6 months, anticipated disruption length differs for each case. (Cases are, respectively, DR97M6e-h)

Under the perfect foresight drawdown strategy and higher GDP elasticity estimate the benefits of increasing the reserve drawdown capabilities from the present rate ranges from 0.34 billion dollars for a 0.5 MMBD day increase to as high as 1.02 billion dollars for a 4.0 MMBD increase in the drawdown rate capability. As the second half of Table 5 suggests the newer GDP measure increases the benefits of draw rate expansion by about one-third in the perfect foresight case (i.e., from 0.02 billion to 0.28 billion above the benefits produced by the lower GDP estimate). As before when the anticipated disruption length is different from the actual length, then the benefits of enhanced drawdown rate are lower. In the cases where the anticipated duration is either the expected disruption length (3.5 months) or 1 month, the higher GDP loss elasticity becomes relatively more important: expansion benefits increase by about 50%-100%.

4.3.2 Revised Perspective on Excess Foreign Production Capacity

In addition to a higher GDP elasticity, there is also reason to believe that the "Base Case" estimate of slack foreign production capacity assumed in the DOE90 study may not be available in future disruptions. This is because the current DOE projections call for rapidly increasing production from OPEC countries, notable Persian Gulf OPEC countries. This means that:

a. The amount of excess capacity that may be used to offset supply disruptions might be diminished, as it is utilized to meet the anticipated normal market demand;

b. Some of the excess capacity that remains under normal market conditions may be unavailable during disruptions either because it too is disrupted along with supply, or because the Persian Gulf or OPEC countries which possess it may not make it available, for political or economic reasons.

For these reasons we consider the lower-offsets case from the DOE90 study as a reasonable alternative to the higher offsets case previously emphasized. Figure 10 corresponds to lower offsets, and the lower GDP elasticity. Figure 11 is a case where disruptions are more costly: available offsets are lower, and the higher GDP loss elasticity is used. In this case the benefits of draw capability expansion are their largest: $0.6 billion for expansion to 5.0 MMBD, and $1.3 billion for expansion to 6.0 MMBD. The range of variability (relative to the current draw capability's benefits) is also fairly significant

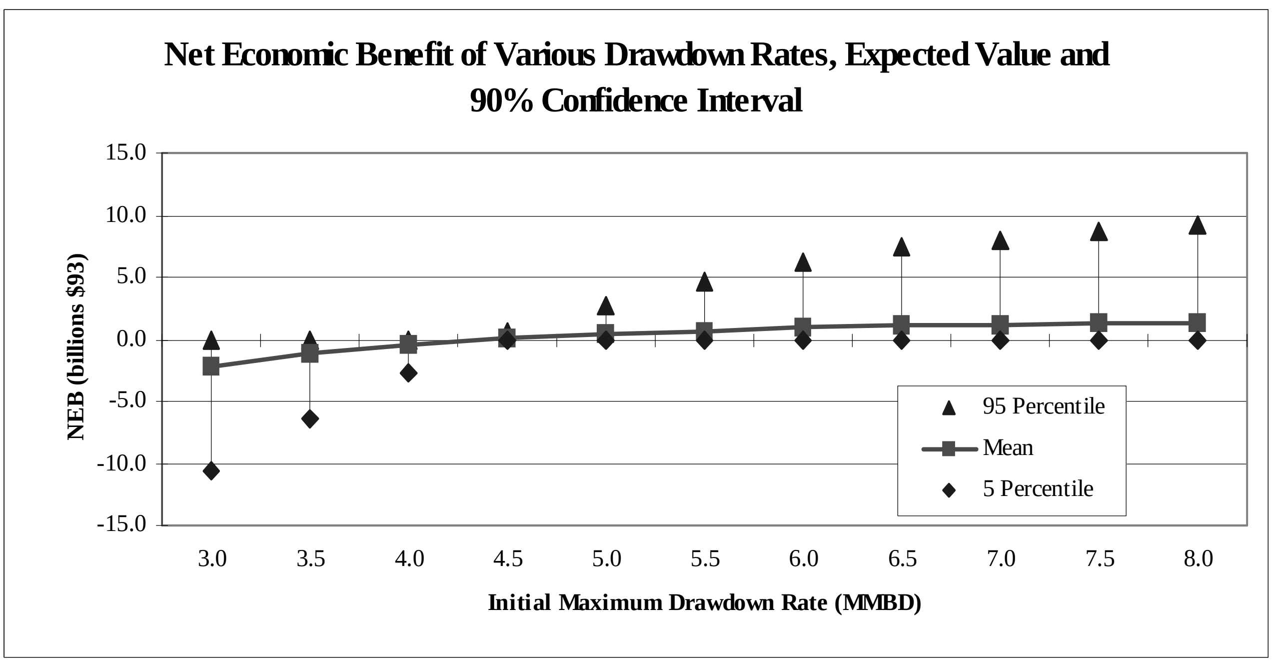

Figure 10 Expected value and 90% confidence interval of net expected benefits of various drawdown rates given a lower GDP elasticity estimate and perfect foresight (Case DR97M6k).

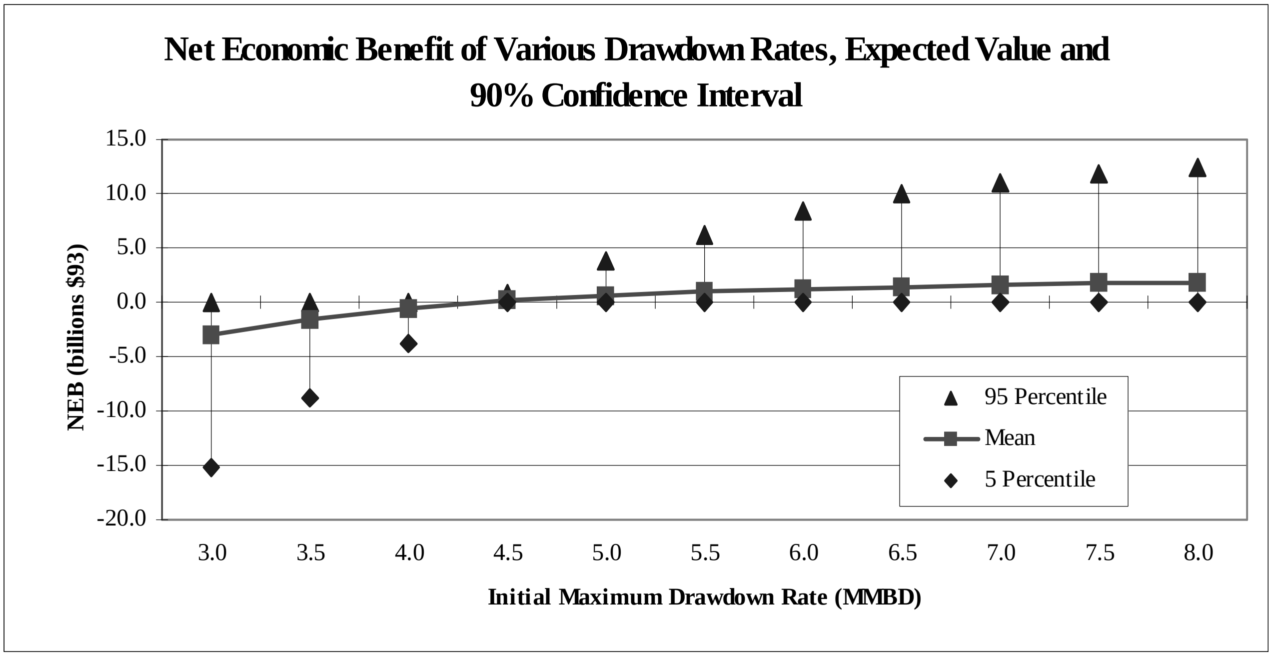

Figure 11 Expected value and 90% confidence interval of the net economic benefits of various drawdown rates given a higher GDP elasticity estimate and perfect foresight (Case DR97M6L).

The results of Table 6 and Figure 12 highlight two key results:

- The GDP loss elasticity is very influential in the estimate of draw capability benefits. Fortunately, this parameter has recently be intensively and well studied, with the conclusion that the larger -0.05 value is justifiable for the estimation of losses from *unexpected* price *increases*.
- The availability of supply offsets (particularly excess production capacity) is of even greater numerical importance than the GDP elasticity. However, little is knows about the actual magnitude of these potential offsets, and whether they are likely to be used during a disruption.

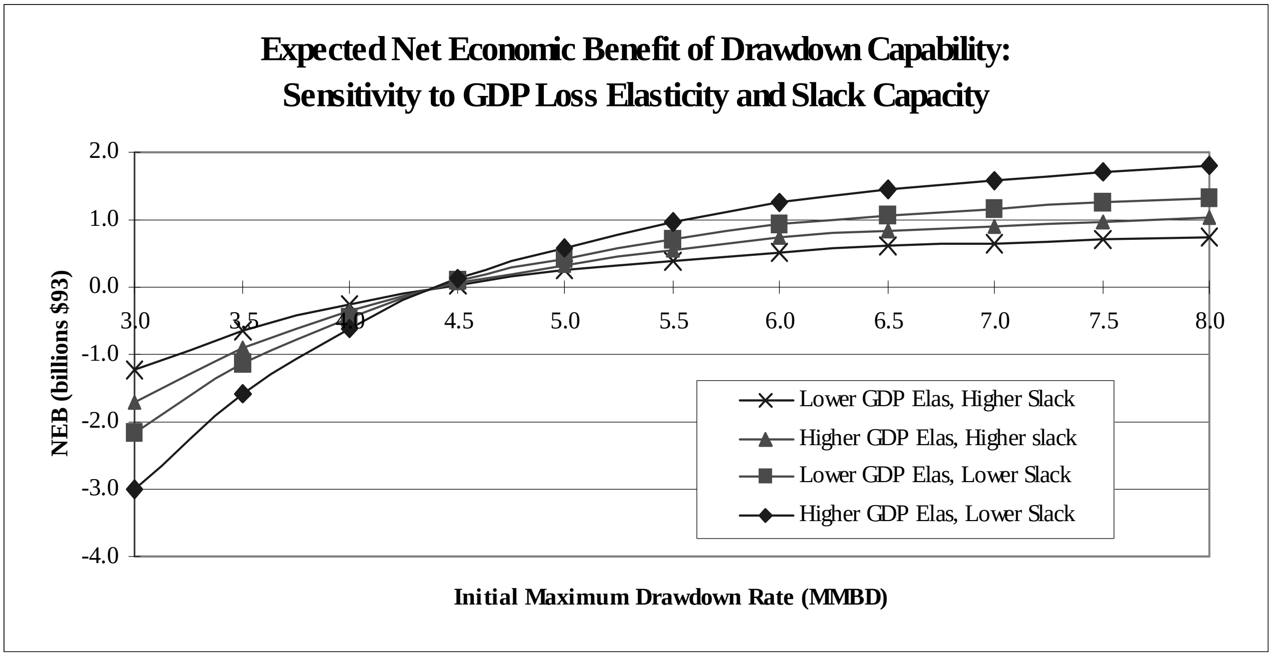

Figure 12 Disruption length is uniformly distributed from 1 to 6 months, and anticipated disruption length is perfect foresight. (Cases are DR97M6a,e,k, and l, respectively).

Table 6: Sensitivity of Expected Net Economic Benefit to GDP Loss Elasticity and Slack Capacity

GDP Loss Elasticity	Slack (Excess Capacity)	Initial Maximum Drawdown Rate										
		3.0	**3.5**	**4.0**	**4.5**	**5.0**	**5.5**	**6.0**	**6.5**	**7.0**	**7.5**	**8.0**
Lower (-0.25)	**Higher**	-1.23	-0.65	-0.25	0.05	0.24	0.40	0.53	0.61	0.66	0.70	0.74
Higher (-0.05)	**Higher**	-1.72	-0.91	-0.35	0.07	0.34	0.55	0.73	0.84	0.91	0.97	1.02
Lower (-0.25)	**Lower**	-2.16	-1.14	-0.45	0.08	0.43	0.70	0.93	1.07	1.17	1.26	1.33
Higher (-0.05)	**Lower**	-3.01	-1.58	-0.62	0.12	0.59	0.95	1.27	1.46	1.60	1.71	1.81

Disruption Length is Uniformly Distributed from 1 to 6 Months, and Anticipated Disruption Length is Perfect Foresight. (Cases are DR97M6a,e,k, and l, respectively).

Since the results in Table 9 assume perfect knowledge about the length of the disruption, they are upper-bound estimates of the value of draw capability enhancement. They indicate, for example, that roughly $1.8 billion is the *maximum* that we should be willing to spend to enhance draw capability to 8.0 MMBD.

4.4 Value of Draw Capability for Shorter Disruptions (1-3 months)

As Table 7 and Figure 13 show, if we assume that all disruptions are of 3 months in duration, rather than having durations randomly distributed over 1 to 6 months, the expected net benefit of higher draw rates is much larger (up to 80%). The value of draw capability expansion is not as great if we only consider disruptions of 1 month in duration, simply because the economic disruption costs avoided with the reserve are smaller if the disruptions are so short.

Table 7: variation in Draw Capability with Assumed Disruption Duration

Disruption Length	**Initial Maximum Drawdown Rate**										
	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0
Disruption Length is Uniformly Distributed over 1 to 6 Months,	-1.72	-0.91	-0.35	0.07	0.34	0.55	0.73	0.84	0.91	0.97	1.02
Disruption Length is Fixed 3 Months	-2.42	-1.43	-0.59	0.11	0.70	1.20	1.61	1.71	1.71	1.71	1.71
Disruption Length is Fixed at 1 Month	-1.38	-0.83	-0.35	0.07	0.43	0.74	1.01	1.24	1.44	1.61	1.76

Other Assumptions: 560 MMB Size, Higher (-0.05) GDP Elasticity, MidCase Slack Level, and Anticipated Disruption Length is Based on Perfect Foresight (Cases DR97e,i,j)

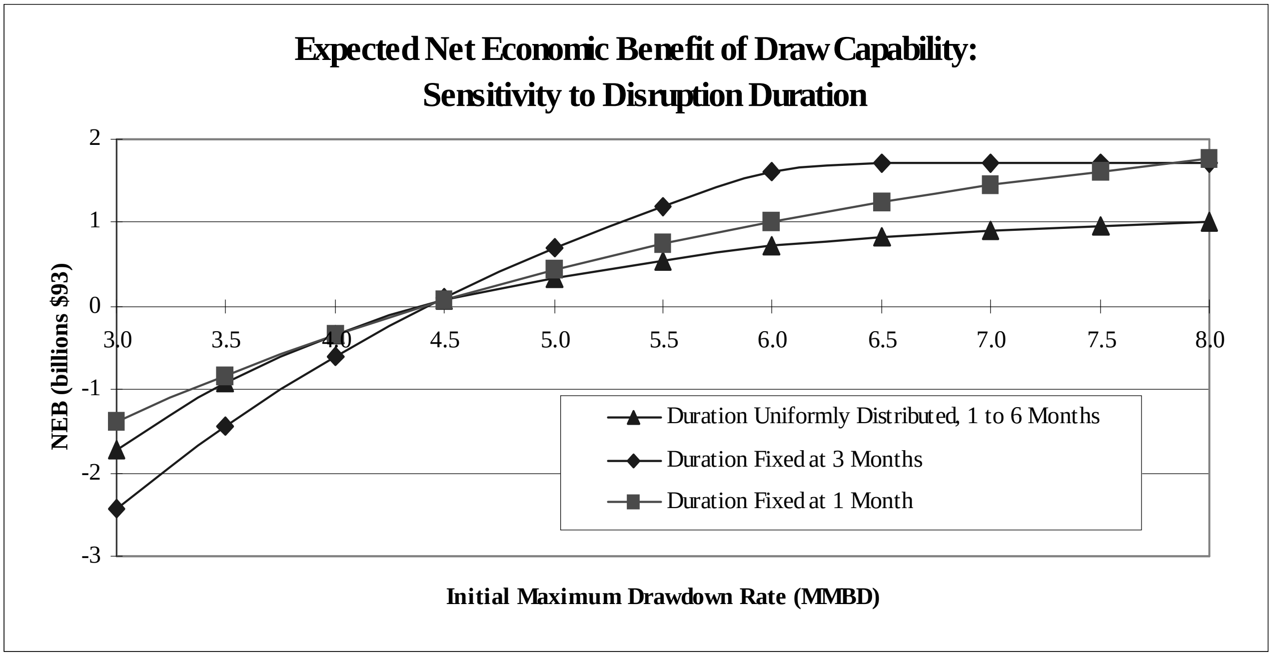

Figure 13 Sensitivity of expected drawdown capability benefits to disruption duration (higher (-0.05) GDP elasticity, higher slack level, and anticipated disruption length is based upon perfect foresight, cases DR97e,i,j).

5.0 General Insights and Next Steps

The analysis so far shows that when we account for the range of possible durations of disruptions, there is some incremental benefit from expanding draw capability up to quite high draw rates. However, it is apparent from the graphs reported here that the marginal benefit of draw capability expansion declines as the draw capability gets larger. When information is available on the cost of draw rate expansion, it will be possible to identify efficient levels of draw capability. For the current size reserve (560 MMB), and for disruption durations uniformly distributed from 1 to 6 months, most of the benefit of draw capability expansion is garnered between 4.5 MMBD and 6.0 MMBD. To gain significant added benefit for much higher rate capabilities, it appears that SPR managers must be able to judge the likely duration of the disruptions at the time they begin. In this way the managers can determine whether or not they should use the available high draw capability. Absent a good way to estimate disruption durations as they occur, the application of general draw rules seems to work reasonably well: drawing as if the disruption will be of average duration; or (slightly better), drawing as if the disruption will end within a month. These simple rules do well for draw rates up to about 6.0 MMBD, and offer little added benefit thereafter. Very “conservative” draw rules, such as assuming that the disruption will endure toward the higher end of the possible durations, appears to be a poor way to use the reserve, and in any case would eliminate any need for, or benefit of, draw capability expansion.

As a corollary to these results, the potential costs of allowing draw capability to deteriorate below the current 4.4 MMBD seem to be quite significant.

The results presented here point the way for some further research. For example, Table 8 indicates the value of more careful thought about slack capacity, a major category of disruption offsets. These offsets turn out to be more important than both disruption probability (at least over the limited range probabilities considered so far), and at least as important as the choice of GDP loss elasticity. What are the causes for slack capacity? How reliable are the estimates of slack capacity and is causes? Can its use in during a disruption be predicted?

Table 8: Summary Sensitivity Table
Expected Net Economic Benefit to GDP Loss Elasticity, Slack Capacity, and Drawdown Strategy

GDP Loss Elasticity	Slack (Excess) Capacity	Drawdown Capability (Million BBL/Day)		
		5.0	**5.5**	**6.0**
Lower (-0.25)	**Higher**	0.13 - 0.24 $bill	0.17-0.40	0.17-0.53
Higher (-0.05)	**Higher**	0.21 - 0.34	0.32-0.55	0.32-0.73
Lower (-0.25)	**Lower**	0.43	0.70	0.93
Higher (-0.05)	**Lower**	0.59	0.95	1.27

Disruption Length is Uniformly Distributed from 1 to 6 Months, and Anticipated Disruption Length is Perfect Foresight. (Cases are DR97M6a,e,k, and l, respectively).

The next steps in this analysis include:

- Examining the Energy Modeling Forum disruption probability case
- Considering U.S. vs foreign draw sequencing or coordination.
- Answering the reverse question: what must we believe for draw rate expansion to be worthwhile?
- Constructing sensitivity analysis diagrams.

References

Bohi, D. R. Energy Price Shocks and Macroeconomic Performance. Washington, D.C.: Resources for the Future, 1989.

Bohi, D. R. "On the Macroeconomic Effects of Energy Price Shocks," Resources and Energy 13 (1991): 145-162.

Davis, S. J., and J. Haltiwanger. 1997. “Sectoral Job Creation and Destruction Responses to Oil Price Changes and Other Shocks.” Paper presented at the DOE Conference, “International Energy Security: Economic Vulnerability to Oil Price Shocks, Washington, D.C., October 1996.

Davis, S. J., P. Loungani, and R. Mahidhara. 1997. “Regional Labor Fluctuations: Oil Shocks, Military Spending and Other Driving Forces. Paper presented at the DOE Conference, “International Energy Security: Economic Vulnerability to Oil Price Shocks, Washington, D.C., October 1996.

Energy Modeling Forum (EMF) 7 Working Group Report, "Macroeconomic Impacts of Energy Shocks: A Summary of Key Results," Hickman, Bert G., Hillard G. Huntington, and James L. Sweeney, eds. Macroeconomic Impacts of Energy Shocks, (Amsterdam: North-Holland) (1987).

Energy Modeling Forum Energy Security Workshop, Marymount University, Arlington, VA. Nov. 12-13, 1996.

Hamilton, J. D. "Oil and the Macroeconomy since World War II," Journal of Political Economy 91 (1983): 228-248.

Hooker, M. A. 1996. “Exploring the Robustness of the Oil Price-Macroeconomy Relationship: Empirical Specifications and the Role of Monetary Policy.” Paper presented at the DOE Conference, “International Energy Security: Economic Vulnerability to Oil Price Shocks, Washington, D.C., October 1996.

"International Energy Security: Economic Vulnerability to Oil Price Shocks,” A Workshop Sponsored by the Department of Energy in Cooperation with the Department of State,” Washington, D.C. October 3-4, 1996.

Jones, Donald W. and Paul N. Leiby (1996). “The Macroeconomic Impacts of Oil price Shocks: a Review of Literature and Issues,” Draft, Oak Ridge National Laboratory, January 5.

Jones, Donald W., David J. Bjornstad, and Paul N. Leiby 1997. The Findings of the DOE Workshop on Economic Vulnerability to Oil Price Shocks: Summary and Integration with Previous Knowledge," Oak Ridge National Laboratory, September 5, 2nd Draft.

Leiby, Paul N. and David C. Bowman, 1996. "Updates to DIS-Risk Model: Model Changes and Results Documentation," REVISED DRAFT, October 10,(Oak Ridge National Laboratory).

Leiby, Paul N. and Donald W. Jones, 1993. "DIS-Risk Model for SPR Analysis: Model Documentation and Benchmarking Results," Revised Draft, Oak Ridge National Laboratory, Prepared for the Office of Management Operations, Strategic Petroleum Reserves Headquarters, U.S. Department of Energy, December 13.

Leiby, Paul N. and David Bowman, "Summary of SPR Planning Models Currently Maintained by ORNL," Working Draft, January 17, 1997.

Mork, K. A. "Oil and the Macroeconomy when Prices Go Up and Down: An Extension of Hamilton's Results," Journal of Political Economy 97 (1989): 740-744.

Mork, K. A. "Business Cycles and the Oil Market," Energy Journal 15 Special Issue (1994): 15-38.

Mork, K. A., Ø. Olsen, and H. T. Mysen. "Macroeconomic Responses to Oil Price Increases and Decreases in Seven OECD Countries," Energy Journal 15(4) (1994): 19-35.

Mory, J. F. "Oil Prices and Economic Activity: Is the Relationship Symmetric?" Energy Journal 14(4) (1993): 151-161.

U.S. Department of Energy/Interagency Working Group. 1990. Strategic Petroleum Reserve Analysis of Size Options. DOE/IE-0016, February.

U.S. Department of Energy, Energy Information Administration. 1997. Annual Energy Outlook 1997. DOE/EIA-0383(97).