8. Total volume spilled

While it is certainly true, as we have pointed out, that as far as the environmental impact of marine petroleum activity is concerned the frequency and magnitude of individual spills is of considerably more importance than the total volume spilled, the total volume spilled, z, from an activity over its life is of more than passing interest. This section combines our earlier analyses in order to make statements about the total volume spilled.

Like spill incidence and individual spill size, total volume spilled cannot be predicted with certainty. It too is a random variable and as such we must necessarily be content with obtaining information about its density. It is probably obvious to the reader that for any given category and potential development the density of the total amount spilled, z, must depend in some manner on the density of the number of spills, n, and the density of the size of an individual spill, x. And in fact, it is a simple matter to write down the equation relating the density of the total amount spilled to the densities of the number of spills and the size of an individual spill. Since we already have the latter two animals, at least given the assumptions we have been willing to make, obtaining the density of the total volume spilled is merely a numerical computation problem. Unfortunately, for the case at hand, this numerical problem is anything but simple. Therefore, we will have to be satisfied with approximations to this density based on the following approach.

If one is willing to assume, as we have, that the size of an individual spill, x, is independent of the number of spills, n, then the mean and variance of the total amount spilled, z, is related to the means and variances of the number of spills and individual spill size in the following simple manner.

$$\text{MEAN}(z) = \text{MEAN}(n) \cdot \text{MEAN}(x)$$

$$\text{VAR}(z) = \text{MEAN}(n) \cdot \text{VAR}(x) + (\text{MEAN}(x))^2 \cdot \text{VAR}(n)$$

As indicated earlier, over 94% of all the volume spilled is spilled in spills of over 42,000 gallons. Therefore, we will be introducing very little error if in addressing the problem of the total amount of oil spilled, we restrict our attention to spills greater than 42,000 gallons. Under this restriction, Table 8.1 shows the means and variances of n and x, which we computed earlier for production platforms, offshore pipelines and tankers for spills over 42,000 gallons from our hypothetical small, medium and large finds. These particular numbers are based on:

1. All reported U.S. production platform spills from 1964 through 1972 over 42,000 gallons;
2. All reported U.S. offshore pipeline spills, including coastal spills, from 1967 through 1972;
3. All tanker spills on major trade routes over 42,000 gallons worldwide as reported by ECO Inc. for the period 1968 through 1972.

The last two columns show the mean and variances of the total amount spilled for each category and each find as computed

	MEAN(n)	VAR(n)	MEAN(x)	VAR(x)	MEAN(z)	VAR(z)
<u>Small Find</u>						
Platform	2.8×10^{-1}	2.9×10^{-1}	1.08×10^{6}	3.15×10^{12}	3.01×10^{5}	1.2×10^{12}
Pipeline	3.1×10^{-1}	3.2×10^{-1}	1.88×10^{6}	1.50×10^{13}	5.84×10^{5}	5.8×10^{12}
Tanker	4.1×10^{-1}	4.1×10^{-1}	2.03×10^{6}	7.79×10^{12}	8.36×10^{5}	4.9×10^{12}
<u>Medium Find</u>						
Platform	1.3×10^{0}	1.5×10^{0}	1.08×10^{6}	3.15×10^{12}	1.40×10^{6}	5.8×10^{12}
Pipeline	1.4×10^{0}	1.7×10^{0}	1.88×10^{6}	1.50×10^{13}	2.64×10^{6}	2.7×10^{13}
Tanker	1.9×10^{0}	2.0×10^{0}	2.03×10^{6}	7.79×10^{12}	3.88×10^{6}	2.3×10^{13}
<u>Large Find</u>						
Platform	4.7×10^{0}	7.1×10^{0}	1.08×10^{6}	3.15×10^{12}	5.06×10^{6}	2.3×10^{13}
Pipeline	5.2×10^{0}	8.5×10^{0}	1.88×10^{6}	1.50×10^{13}	9.80×10^{6}	10.8×10^{13}
Tanker	6.9×10^{0}	7.4×10^{0}	2.03×10^{6}	7.79×10^{12}	1.41×10^{7}	8.4×10^{13}

TABLE 8.1

MEAN AND VARIANCE OF TOTAL AMOUNT SPILLED BY CATEGORY from the above relationships. In general, the means and variances are of the same order of magnitude. There aren't any really striking differences. Platforms have the lowest means and variances. Tankers have the highest means but variances are lower than the pipeline variances. Once again we observe a situation in which the ratio of the variances to the mean are extremely large but less so for the large find than for the small find. With the large find, we have the law of large numbers beginning to work for us, but only very weakly.

In order to obtain some insight on the meaning of these means and variances, we have approximated the density of the total amount spilled by a Gamma with the same mean and variance. This is not completely consistent with our earlier assumptions but the errors introduced will be small. Figure 8.1 shows the results for the small find and Figure 8.2 the results for the large find. The striking feature about Figure 8.1 is the relatively high probability of having no spillage at all in spills over 42,000 gallons, that is, no spills over 42,000 gallons. This is reflected in the height of the vertical portion of the cumulatives to the left of the figure. If the find is landed by tanker the probability of having no spills over 42,000 gallons is .52. If the find is landed by pipeline the probability of no pipeline spills over 42,000 gallons is .75. The probability of no platform spills is .73. The most spread out of the densities is the pipeline. It crosses over both the platform cumulative at the low end and the tanker distribution at the high end. That is, despite

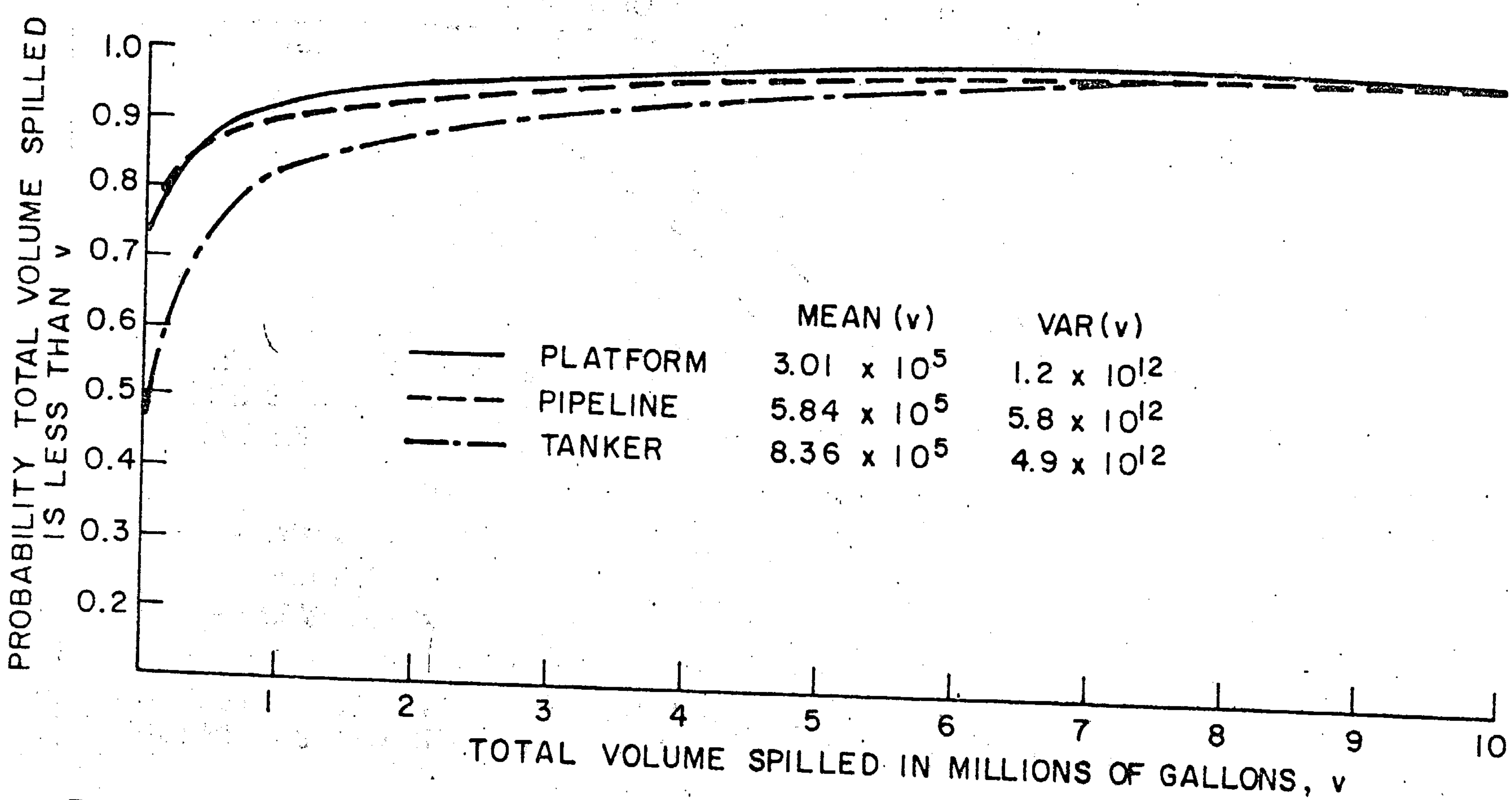

FIGURE 8.1 CUMULATIVE OF TOTAL VOLUME SPILLED FROM SMALL FIND OVER FIELD LIFE IN SPILLS LARGER THAN 42,000 GALLONS

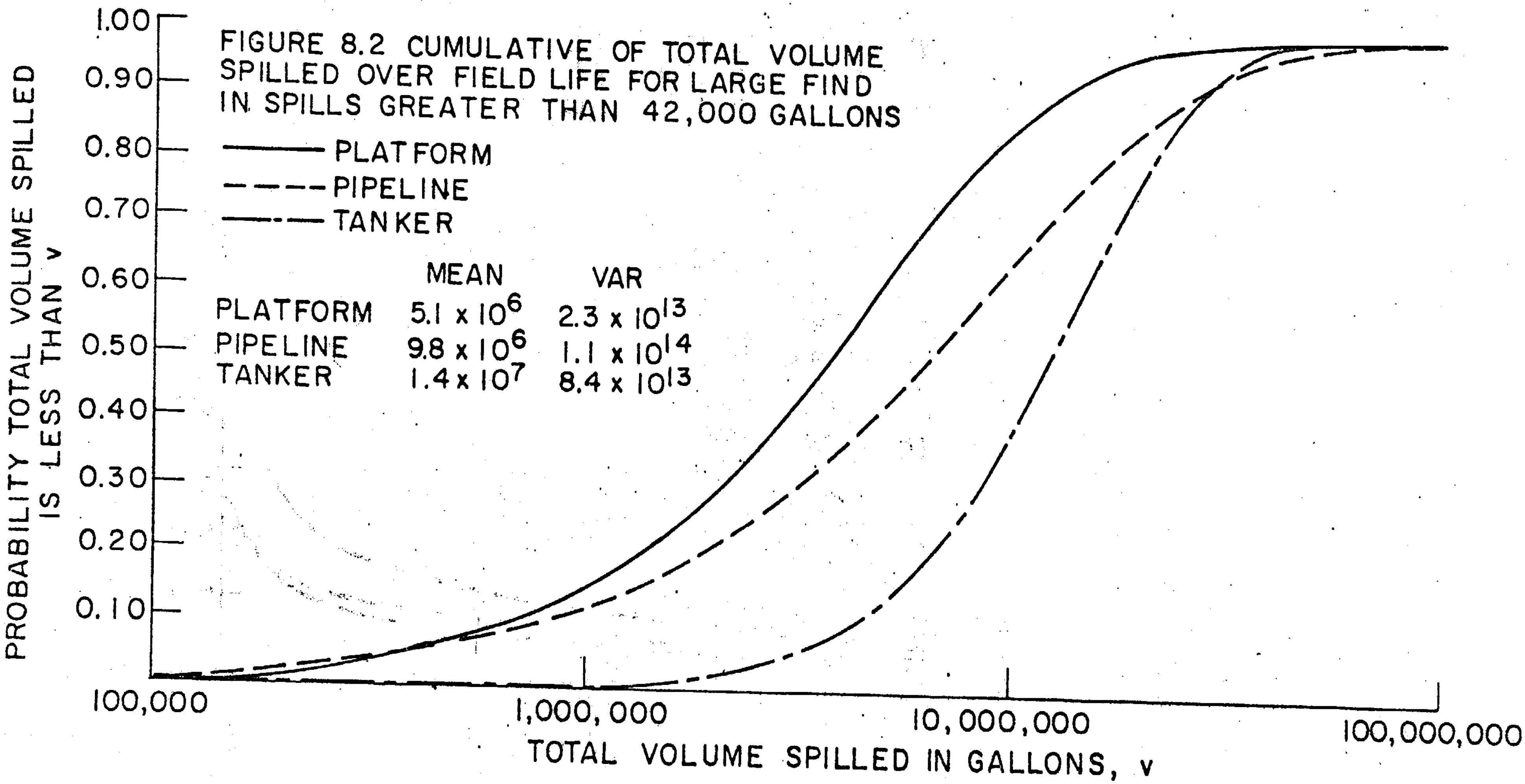

FIGURE 8.2 CUMULATIVE OF TOTAL VOLUME SPILLED OVER FIELD LIFE FOR LARGE FIND IN SPILLS GREATER THAN 42,000 GALLONS

the fact that the pipeline mean is higher than the platform mean there is a higher probability of having no large pipeline spills. Similarly, despite the fact that the pipeline mean is lower than the tanker mean, there is a higher probability of having an extremely large amount of spillage from large pipeline spills than there is from large tanker spills. However, the crossover point is quite high, about 9 million gallons, at which point there is in both cases a very high probability, above .99, that this total amount will not be exceeded. In short, it would take someone who is unusually worried about extremely high volumes of spillage relative to the more likely amounts to prefer the tanker on that account. On the other extreme, someone who is shooting for the highest probability of no spillage, regardless of what happens if there is spillage, would go for the pipeline over platforms if such a choice were possible. Despite these caveats, it is probably safe to say that most people would rank these densities in inverse order of their means. Nonetheless, anyone who expected the actual total spillage to by anywhere close to the mean is quite likely to be disappointed.

Figure 8.2's results are somewhat similar. Both crossovers still occur. However, because we are now dealing with a mean number of spills in each category in the neighborhood of 5 rather than .3 as in Figure 8.1, the law of large numbers implies the cumulatives are in a real sense tighter. The ratio of the variances to the square of the means has decreased by a factor of almost 10. The means have also increased by a factor of 10. This increase in the means is proportional to the volume produced under our assumptions.

8.1 Postscript

It is the almost universal practice in oil spill analysis, to generate "average spillage rates", usually obtained by simply dividing the total amount observed spilled in some activity over the volume handled. As we have indicated, this practice has very little to recommend itself and by themselves such average spillage rates are almost meaningless, particularly when they are offered as a prediction of the amount which will be spilled.

Nonetheless, it is of some interest to compare our mean spillage rates with the average spillage rates developed by others. The whole concept of a "mean spillage rate" only makes sense because we have assumed that the exposure variable in the Poisson process generating spills is volume handled -- an assumption for which we were able to obtain some empirical evidence in the case of tankers (although number of tanker landings may well be better) but which was simply accepted in the case of pipelines and platforms. In any event, under this assumption, the mean spillage rates for our small, medium and large finds are all the same. By category the ratio of the mean of the total spillage to volume handled is:

Platforms	.00006
Offshore Pipelines	.00011
Tankers	.00016

Except for tankers, these rates are approximately the same as the "high" estimates developed in the Georges Bank report [10], that is, what used to be our high estimates of the mean spillage are now our average estimates. This is due primarily to the additional platform and pipeline spills in the present data base. The mean tanker spillage rate is about 5 times the high estimate developed in the Georges Bank study, reflecting the tremendous amount of spillage in the ECO data which we were not aware of when we wrote the Georges Bank study. The tanker spillage rate above is somewhat above that derived by SCEP and its follow-ons (.0001) [11]. The combined offshore platform and pipeline rate above is approximately the same as that obtained by the University of Oklahoma ($\sim$ .0002)[12]. In short, all analyses which make the assumption that spillage is in some sense proportional to the volume handled and use the same data are going to come up with about the same estimate of the average spillage rate.* However, even accepting the linearity hypothesis, by itself this estimate of the average spillage rate means very little. The variance of the spillage is at least as important and, from a biological point of view, the densities of the frequency and size of individual spills still more important.

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*About the same, but not the same. The mean of our Gamma-based spill size density is higher than the classical estimator for small sample sizes.

9. Summary

1. The size range of an individual spill is extremely large--eight orders of magnitude. The great majority of all spills are at the lower end of this range. But most of the oil is spilled in a few very large spills.

2. For all the reasons given in 1, point estimates of spillage and spillage rates are practically meaningless. Further, from the biological point of view, the frequency and magnitude of individual spills is at least as important as total spillage. Therefore, we have attempted to estimate the probability densities of the number of spills of a given category which will occur from a given hypothetical development and the probability density of the size of these spills. In so doing, we have broken the analysis into six categories:

	> 42,000 gallons	< 42,000 gallons
Tanker/Barge		
Platform		
Offshore Pipeline		

3. In deriving these densities, we have taken a Bayesian approach and assumed spill incidence is generated by a Poisson process in which the exposure variable is volume handled and spill size by a Gamma process. We have used the available data to generate probability densities on the parameters of these processes starting with non-informative conjugate priors.

4. With respect to tanker spills above 42,000 gallons, the results indicate that for a small find (500 MM bbls in place) likelihood of no tanker spills is about .7, the likelihood of 1 such spill is about .25, and it is quite unlikely there would be more than 1 spill. However, for a large find (10,000 MM bbls in place), there will with high probability be somewhere between 4 and 10 spills, with the probability rather equally spread over these possibilities. The density of the size of these spills is spread over three orders of magnitude, with a mean of 2 million gallons and a standard deviation of 2.8 million gallons.

5. With respect to tanker spills below 42,000 gallons, the number of spills is much larger: in the hundreds for the small find and thousands for the large find. However, most of these spills are quite small. The mean size is 318 gallons and it's quite likely that an individual spill will be smaller than the mean. The available data on SBM spills is lacking in both quantity and quality. However, it appears that with respect to small operational spills, we can expect an SBM to have several times the incidence rate of a well-run shoreside fixed berth. However, the SBM may have a substantial effect on the density of large tanker spills by decreasing number of arrivals and decreasing the likelihood of groundings, which account for over 25% of all tanker spills over 42,000 gallons. If the SBM does have this effect, total volume spilled will almost certainly be lower for an SBM installation as opposed to an equivalent shoreside terminal.

6. With respect to platform spills over 42,000 gallons, the analysis indicates that for a small find, there is a .75 probability of no such spill, a .2 chance of 1 such spill, and it is quite unlikely that we will experience 2 or more such spills. For a large find, with high probability we will experience between 1 and 7 such spills with the probability rather equally spread over the possibilities. The density of the size of these spills is spread over two orders of magnitude, with a mean of about 1 million gallons and a standard deviation of 1.8 million gallons. The probability that such a spill will be less than 100,000 gallons is about .2. The probability that it will be greater than 5 million gallons is .05.

7. With respect to offshore pipeline spills over 42,000 gallons, a problem arises whether the coastal spills reported in the Gulf should be included in the data bases. The results aren't all that different, but assuming the coastal spills are included, the probability that we will have no large pipeline spills from a small find landed by pipeline is .75. The probability we will have 1 spill is about .2 and it is rather unlikely we will have more than 1 such spill. For a large find landed by pipeline, with high probability we will have somewhere between 1 and 9 large pipeline spills, with the probability rather equally spread over these possibilities. The density of the size of these spills is dispersed over an extremely large range. We are quite uncertain how large these spills will be. The mean is 1.9 million gallons; the standard deviation is 3.9 million gallons.

8. With respect to offshore production spills less than 42,000 gallons, it is impossible to separate the pipeline and platform spills in the Coast Guard data. The total number of both small platform and small pipeline spills will be in the hundreds for a small find and in the thousands for a large find. According to the EPA data, approximately 90% of these spills will emanate from the platforms. Almost all these spills will be quite small. The mean of these spills is about 100 gallons, and it is quite likely that an individual spill will be less than the mean.

9. With respect to total volume spilled over the field life, the mean for the small find is about 900,000 gallons for the small find landed by pipeline and 1,100,000 gallons for the small find landed by tanker. The variance is quite large and there is a substantial probability in both cases there will be no large spills at all. The standard deviation for the small find landed by pipeline is over 2.65 million gallons; if landed by tanker, 2.45 million gallons. Thus, there is a slightly higher chance of both small total spillage and very large total spillage with the pipeline rather than the tanker, reflecting our greater uncertainty about pipelines.

For a large find, the mean of the total spillage is 15 million gallons for pipeline transport and 19 million gallons for tanker. The ratio of the standard deviation to the mean is not quite so large for the large find as the small find, as the law of large numbers is beginning to work, although weakly. The standard deviation of the total spillage assuming tanker transport for the large find is 10.3 million gallons, and for the pipeline option is 11.5 million gallons.

10. All the above estimates of probabilities can reasonably be regarded as moderately pessimistic. They assume no improvement in technology or operations over the recent past. Also, other assumptions about the exposure variable in the Poisson process, such as platform spill incidence is proportional to number of platforms or tanker spill incidence is proportional to number of landfalls, would decrease the above estimates of spill incidence considerably, given the larger production per platform and vessel sizes are contemplated.

11. Finally, it is extremely important to realize that the above estimates of probabilities do not represent the net effect of OCS development. The net effect will depend on what one assumes about the oil which would be landed in the absence of the development. For example, if one assumes the same amount of crude will be landed on the East Coast with or without a development, then according to our analysis there is a substantial probability that there will be as many large spills without the find as with the find. Such assumptions are outside the scope of the primary effects analysis, and we have not undertaken to estimate these <u>net</u> effects.

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