Probabilistic Methodology for Petroleum Resource Appraisal of Wilderness Lands

By Robert A. Crovelli

PETROLEUM POTENTIAL OF WILDERNESS LANDS IN THE WESTERN UNITED STATES

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ABSTRACT

An explanation is provided of the probabilistic methodology developed for the quantitative analysis of the potential petroleum resources of the Wilderness Lands in the Western United States. This approach to the subjective probability procedures allows the geologists to take into account the fact that (a) petroleum resources are not evenly distributed throughout geologic provinces, (b) there usually has been no production of oil and gas in the Wilderness Lands, (c) some States containing Wilderness Lands have been explored heavily, while others have not been, and (d) past exploration and production results in the States provide valuable information to an assessment of the Wilderness Lands. The outcome of all the quantitative resource analyses for the oil and gas potentials in the Wilderness Lands for each State and for the total aggregated results is described by using probability distributions and discussing the results using the range from the 95th fractile (low estimate) to the 5th fractile (high estimate).

INTRODUCTION

Probabilistic methodology was developed for a quantitative assessment of the petroleum potential of Wilderness Lands in the Western United States. The objective was to estimate, in terms of probability distributions, the quantity of undiscovered recoverable conventional crude oil and total natural gas on Wilderness Lands in each of the individual Western States and the total oil and gas resources in all 11 Western States: Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming. Two probability distributions were derived for each of the 11 States, one for oil and one for total gas. Estimates of both the total oil and total gas resources of Wilderness Lands in all 11 Western States were also expressed as two probability distributions.

The approach to the problem that was chosen for this study was to utilize petroleum resource estimates derived from the U.S. Geological Survey Circular 860 study (Dolton and others, 1981; Varnes and others, 1982). These estimates were made at the geologic province level for each province and consist of:

(a) Marginal probability or probability of occurrence.
(b) Conditional probability distribution (log-normal distribution).
(c) Unconditional probability distribution.

A qualitative assessment of the resource potential of the Wilderness Lands involving classifications of high, medium, low, low to zero, zero, and unknown petroleum potential was also utilized and is discussed in chapter A in this circular by B. M. Miller.

METHODOLOGY

The basic methodology is outlined as follows:

1. Partition all of the Wilderness Lands into geologically similar "clusters" of wilderness tracts. A wilderness cluster is a collection of one or more wilderness tracts.
2. For each wilderness cluster within a province
   a. Determine a marginal probability for the cluster.
   b. Determine a conditional probability distribution for the cluster.
   c. Apply the cluster marginal probability to the cluster conditional probability distribution to determine the unconditional probability distribution for the cluster.
3. Aggregate the unconditional probability distributions of resources for the clusters.
   a. Within each State.
   b. Among all States.

MARGINAL PROBABILITY FOR A WILDERNESS CLUSTER

For a wilderness cluster within a province, let the events be defined as

A: Resource is present in cluster

B: Resource is present in province

with corresponding probabilities

P(A): Marginal probability for cluster

P(B): Marginal probability for province.

P(A) and P(B) are related by

$$P(A)=P(B)\,P(A|B)$$

where

P(A|B): Conditional probability of resource is present in cluster *given* that resource is present in province.

There are two marginal probabilities for each Wilderness cluster, one for oil and one for total gas.

PROBABILITY DISTRIBUTION FOR A WILDERNESS CLUSTER

The following relationship is defined

$$Y_c=FX_c$$

where

Y_c: Conditional quantity of undiscovered resource in wilderness cluster

F: Fraction of undiscovered province resource in wilderness cluster

X_c: Conditional quantity of undiscovered resource in province.

The following reasonable and mathematically tractable assumptions are made:

1. F is lognormally distributed.
2. X_c is lognormally distributed.
3. F and X_c are independent.

Under the above assumptions, Y_c is also lognormally distributed.

LOGNORMAL DISTRIBUTION OF F

Let

$$F=f_aR$$

where

f_a: Fraction of total province area that is the wilderness cluster area, i.e., the cluster area fraction.

f_a= Area of wilderness tract(s)/Area of sedimentary basin or province.

R: Rating (or richness factor) of wilderness cluster as to its relative potential compared to the average (mean) quantity of resource per unit area in the province.

Assumptions are that f_a is a fixed value because it is a calculated quantity, and R is a lognormal random variable where $R>0$ because the lognormal distribution is a reasonable judgmental distribution of ratings that will make the mathematics tractable. These assumptions imply that F is lognormally distributed.

The ratings approach allows the geologists to take into account the fact that (a) petroleum resources are not evenly distributed throughout the geologic provinces, (b) there usually has been no production of oil and gas in the Wilderness Lands, (c) some States containing Wilderness Lands have been explored heavily, while others have not been, and (d) past exploration and production results in the States would provide valuable information to an assessment of the Wilderness Lands. See table 1 for a general ratings scale.

TABLE 1.—*General ratings*

Qualitative assessment	Quantitative assessment
High (above average)	$R>1.5$
Medium (average)	$0.5<R\leq 1.5$
Low (below average)	$0<R\leq 0.5$
Zero	$R=0$

Note: $R=1$ assessment implies that the wilderness cluster has average potential compared to the province as a whole.

Two estimates of R are made by geologists for each resource (two estimates for oil and two estimates for total gas):

1. Minimum estimate of R (R_{min})
2. Maximum estimate of R (R_{max})

Example: Rating of oil resource potential of cluster is high, $2 < R < 4$.

That is, the oil resource potential of the wilderness cluster is estimated to be between 2 and 4 times the average oil resource potential of the province (per unit area).

Hence, two estimates of F are

1. $F_{min} = f_a R_{min}$, minimum estimate of F
2. $F_{max} = f_a R_{max}$, maximum estimate of F

The minimum and maximum estimates of F are used as a 99.73 percent interval estimate to determine a lognormal distribution. There are two sets of minimum and maximum estimates, one for oil and one for total gas.

LOGNORMAL DISTRIBUTION OF X_c

The conditional 95th and 5th fractiles of X_c are used to determine the corresponding lognormal distribution which was assumed in Dolton and others (1981).

CONDITIONAL DISTRIBUTION OF Y_c

The conditional distribution of Y_c is a lognormal distribution since the product of two independent lognormal random variables is lognormally distributed.

UNCONDITIONAL DISTRIBUTION OF Y

The marginal probability for the cluster, P(A), is multiplied times the conditional distribution of Y_c to determine the unconditional distribution of Y, the unconditional quantity of undiscovered recoverable resource in the wilderness cluster. There are two probability distributions for a cluster, one for oil and one for total gas.

AGGREGATIONS OF RESOURCES IN WILDERNESS CLUSTERS

The first three unconditional central moments of Y are computed for each wilderness cluster. There is one set of three moments for oil and another set for total gas.

AGGREGATIONS WITHIN EACH STATE

The estimates of undiscovered recoverable petroleum resources in all of the wilderness clusters in a State are aggregated. An assumption is made that the cluster estimates in a State are perfectly dependent, that is, fractiles are additive. This assumption is made because of the known geologic dependency of the clusters and also because the same geologist(s) assessed all of the clusters in a State. Under this assumption, the sets of three moments for the clusters in a State are combined respectively to produce the first three moments of the probability distribution for the State. A three-parameter lognormal distribution is fitted to the three moments for the State as an approximate aggregate distribution.

AGGREGATIONS AMONG ALL STATES

The estimates of undiscovered recoverable petroleum resources of the Wilderness Lands in all 11 Western States are aggregated. There are two aggregations, one for oil and one for total gas. An assumption is made that the 11 estimates within an aggregation are independent. This assumption is made because of the wide geographic separation of wilderness clusters from State to State, and also because most of the States were assessed by different geologists. Since the dependency within a State is overstated, and the dependency between States is understated, the respective assumptions introduce compensatory effects and, furthermore, do not affect the means. Under the independence assumption, the sets of three moments for the 11 States are combined respectively to produce the first three moments of the probability distribution for the Wilderness Lands. A three-parameter lognormal distribution is fitted to the three moments for the Wilderness Lands as an approximate aggregate distribution.

DESCRIPTION OF AN AGGREGATION

The probability distributions resulting from the 22 State aggregations (both oil and gas) and the two Wilderness Lands' aggregations are described graphically by using the more-than (or complementary) cumulative distribution function that gives the probability of *more than* a specific amount. From this function, all the fractiles can be obtained. Some numerical characteristics (in million barrels for oil and billion cubic feet for gas) of the three-parameter lognormal distribution are also

given on the graph. The mean of the probability distribution is used as a point estimate of the quantity of undiscovered recoverable resource. The range from the 95th fractile (the low estimate) to the 5th fractile (the high estimate) forms the reported interval estimate.

DATA FORMAT

The data collected depend directly upon the methodology and concern each wilderness cluster and the province containing the cluster. One set of data is collected for oil and one set for total gas.

WILDERNESS CLUSTER DATA

The wilderness cluster number, as shown on the data format, is an assigned code number for the respective wilderness cluster. The following quantity is calculated using the data from Varnes and Dolton (1982) and the measured cluster area:

f_a: Cluster area fraction.

The cluster area fraction is the same for both oil and total gas. The following quantities are estimated:

P(A B): Conditional probability of resource is present in cluster *given* that resource is present in province.

R_{min}: Minimum estimate of R, rating or richness factor.

R_{max}: Maximum estimate of R, rating or richness factor.

PROVINCE DATA

The province number, as shown in the data format, is the assigned Resource Appraisal Group (RAG) code number of that province. The following quantities are obtained from the Circular 860 study (Varnes and others, 1982):

P(B): Marginal probability for province.

F_{95}: Conditional 95th fractile for province.

F_5: Conditional 5th fractile for province.

EXAMPLE OF DATA FORMAT

An example of the data format, using only two wilderness clusters in the State of Colorado, is shown in table 2.

SUMMARY

Some special features of the developed methodology are

1. The entire assessment area is partitioned into geologically similar clusters of wilderness tracts.
2. Each wilderness cluster is assessed on the basis of its resource potential compared to the rest of the province.
3. The ratings approach allows the geologists to take into account the fact that (a) petroleum resources are not evenly distributed throughout geologic provinces, (b) there has been little or no production of oil and gas in the Wilderness Lands, (c) some States containing Wilderness Lands have been explored heavily, while others have not been, and (d) past exploration and production results in the States provide valuable information to an assessment of the Wilderness Lands.
4. The aggregation technique has the flexibility to aggregate the estimates for wilderness clusters assuming they are dependent within States and to aggregate the estimates for the States assuming they are independent.
5. Resource potential is described by using a probability distribution.

TABLE 2.—*Data format for assessing petroleum (oil) resources of Wilderness Lands in State of Colorado*

[BB, billions of barrels]

Wilderness cluster					Province			
Cluster no.	Conditional marginal probability P(A|B)	Area fraction f_a	Ratings or Richness Factors		RAG province no.	Marginal probability P(B)	Conditional fractiles (BB)	
			R_{min}	R_{max}			Low F_{95}	High F_5
1	1.0	0.00124	2	4	85	1.0	0.24	3.22
2	0.8	0.00215	0.5	1	85	1.0	0.24	3.22

6. A point estimate using the mean of the distribution is computed along with an interval estimate using the range from the 95th fractile (the low estimate) to the 5th fractile (the high estimate).

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