Elicitation of Expert Judgment to Assess Undiscovered Oil and Gas Resources

John H Schuenemeyer

In frontier areas, where well data is sparse, many organizations, including the U.S. Geological Survey (USGS) have used expert judgment to estimate undiscovered resources. In this process, several important issues arise. How should the knowledge be elicited? At what level of aggregation (geologic process model, play, petroleum system, country, etc.) should the assessment be performed? How and at what stage of the estimation process should feedback be given to assessors? Is independent replication of estimates possible? How are issues of dependency dealt with? Which attributes should be specified as point estimates and which should be specified by distributions?

The methodology used in the USGS’s 1002-Artic National Wildlife Refuge assessment in which fractiles were estimated will be discussed together with proposed modifications for the USGS’s National Petroleum Reserve – Alaska assessment.

KEY WORDS: Subjective probability estimation; ANWR; petroleum resource estimation

INTRODUCTION

In the assessment of oil and gas resources, the method used depends on the purpose of the assessment and data. Other factors, such as personnel and budgetary constraints also may influence this choice. The spectrum of methods used to assess oil and gas resources varies from geologic process models, which require detailed knowledge of the geologic environment and data, to curve fitting, which projects historical data into the future without regard to geological considerations. In lightly explored areas, where well drilling data is sparse or non-existent, assessments conducted by the U.S. Geological Survey (USGS) and other organizations have relied, at least in part, on expert judgment to estimate undiscovered resources. Experts used to assess resources rely not only on their general scientific knowledge but augment this information with field studies, hard data, analogy, and examination of previous assessments. Issues involving the use of expert judgment are the focus of this paper.

When planning an assessment, the following issues need to be considered. How should the knowledge be elicited? At what level of aggregation (geologic process model, prospect, play, petroleum system, country, etc.) should the assessment be performed? How and at what stage of the estimation process should feedback of intermediate results be given to assessors? Is independent replication of estimates possible? How should issues of dependency between geologic factors and assessors be addressed? Which attributes should be specified as point estimates and which should be specified by an uncertainty interval, distribution or range?

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2 For presentation at International Association for Mathematical Geology Annual Conference, Cancun, Mexico, September 2001.
THE ANWR ASSESSMENT METHODOLOGY

The 1002 Area, which has not been opened to petroleum exploration, comprises 1.55 million acres of the more than 19 million acres of the Artic National Wildlife Refuge (ANWR). It is approximately 104 miles long with a maximum width of 33 miles and a minimum width of 16 miles (U.S. Department of Interior, 1987). The western border of the 1002 Area is about 50 miles east of the Trans-Alaska pipeline. The 1998 USGS re-assessment of the 1002 Area (ANWR Assessment Team, 1999) was based on information generated by recent nearby discoveries, 1400 miles of reprocessed and reinterpreted seismic data collected within the 1002 Area, and recent geologic field work. Results of previous assessments, which relied heavily upon expert judgment, are described in Mast and others (1980) and Dolton and others (1987). Geologists assessed each of 10 plays for undiscovered conventional oil and gas accumulations having at least 50 million barrels of oil (MMBO) or 300 billion cubic feet of gas (BCFG) in-place. The choice of 50 million barrels of oil equivalent (MMBOE) was somewhat arbitrary and was intended to filter small prospects. It reflected a lower limit on knowledge. Below this value, assessors were not able to detect or formulate component attributes. Assessors specified probability distributions that characterized the play’s reservoir attributes, the number of hydrocarbon prospects, and the risk structure— that is, play and prospect probabilities. For this assessment, the play probability is the likelihood that the play contains at least one accumulation of 50 MMBOE in-place. The prospect probability is the probability that a randomly chosen prospect contains at least 50 MMBOE in-place. (References to the ANWR assessment refer to the 1002 Area of ANWR.)

Assessors were asked to specify an empirical distribution for each of the reservoir attributes and the number of prospects. They initially choose the minimum (100th fractile), the maximum, and the median (50th fractile) values and then fit the distribution to define its shape by estimating values for the 95th, 75th, 25th, and 5th fractiles.

In the ANWR methodology, the probability distribution of in-place oil accumulation sizes (volumes) was simulated numerically by sampling reservoir parameter distributions specified by the assessors and applying the following formula:

\[ oil = 7.758 \times 10^{-6} \times nrt \times ac \times por \times (100 - ws) \times tf / (fvf) \]

where oil is oil accumulation size in MMBO, nrt is net reservoir thickness in feet, ac is area of closure in thousands of acres, por is porosity in percent, ws is water saturation in percent, tf is trap fill in percent, and the formation volume factor, fvf, was assumed 1.14 (the value at the estimated Topset median depth). The correlation between por and ws was assumed to be -1.0.

During the entire process, the assessors were required to review periodically the risk probabilities, assessment variable probability distributions, and results to assure that they understood the consequences of each assumption in light of the final results.

The 1998 ANWR assessment was the result of a comprehensive three-year study involving 46 USGS scientists, other federal and Alaska State agencies, contractors, university researchers, and representatives of industry and professional organizations (Bird, 1999). An outline of the steps used in the ANWR assessment follows:

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3 The author developed the methodology as a member of the ANWR Assessment Team, while a mathematical statistician with the U.S. Geological Survey.
1. The type of assessment was specified; in this case, a play assessment of oil and gas resources in the 1002 Area of ANWR. Output was to be amenable to economic analysis. Thus, size-frequency distributions of the in place and recoverable resources were required.

2. The assessment team was constituted.

3. Needs for additional data, studies, and other resources were evaluated.

4. An extensively modified version of the methodology used in a 1987 assessment was chosen.

5. Assessment team members, exchanged ideas, developed protocols, and training in methodology occurred. At intervals of six to nine months, workshops were held in Denver, Colorado and Menlo Park, California.

6. Team members gathered information via site visits, discussion with other experts, literature reviews, and analyses of available data.

7. Practice assessments were performed to familiarize team members with the methodology, identify the need for additional data, or make changes in procedures.

8. Assessment occurred in several stages beginning with individuals responsible for plays completing their assessment forms. Revisions were made at a general assessment meeting and appropriate feedback was given to the assessors.

9. Final play and regional estimates were complete in January 1998.

10. Results were given to team leaders for a final check of reasonableness and internal consistency.

11. Results were disseminated to the public.

12. An informal evaluation of the assessment occurred.

Clearly there were feedback loops. Team members were in contact with each other throughout the assessment process.

We will now address some of the issues that occurred in this and other assessment projects, note how they were addressed in the ANWR assessment, and provide recommendations where appropriate. This paper uses the Topset play in the 1002 Area to illustrate issues of expert judgment.

A FRAMEWORK FOR A SUBJECTIVE ASSESSMENT

Experts

Issues concerning the number and type of experts, calibration of experts and resolving differences among experts will be discussed. The process of eliciting information from experts is presented in the next section.

How many experts should be chosen? Clearly, it is desirable to have independent replication, however, in geologic assessments, usually this is impossible because a limited number of people possess detailed knowledge of a particular geologic environment. Unlike the subjective assessments that occur in Olympic diving or ice dancing, where there may be up to ten judges, in resource assessment there are usually only one or two experts available to assess a petroleum play or system. One or two
experts investigated each play in ANWR but many other members of the assessment team had knowledge of plays other than their own.

Clearly, the type of experts to be chosen is dependent upon the type of resource estimation and level of aggregation at which it is to be conducted. Different expertise is required for a prospect versus a play or some higher level of assessment. Some assessments are essentially Meta analyses, while others require detailed knowledge of a small geographic area. (Meta analysis is a technique to combine smaller studies into a larger one and generally does not involve the collection of new data.) Geologists and geophysicists assigned to the ANWR plays had wide-ranging knowledge of the area and conducted extensive field studies.

Can experts be calibrated? In some applications, this is possible. In Olympic diving, for example, judges can be shown film of dives that have been evaluated by other experts. Sometimes it is possible to construct a realistic simulation; the use of flight simulators to train airline pilots is one such example. A decision theory game is another example. However, the complexity of geologic systems and level of knowledge that would be required to construct an example to challenge experts is formidable and to the best of my knowledge has not been done successfully. A form of calibration can occur by carefully defining terms. It also is necessary to create an environment in which subject matter experts feel comfortable asking questions about the assessment process. Some geologic experts on the ANWR team were relatively new to assessment and it was important that they were at ease with the process of converting geologic information into a quantitative assessment. This subject is addressed more fully in the uncertainty discussion.

Once experts are selected and provide input, there is a question of how to resolve differences among experts. Procedures include statistical approaches and consensus building through feedback mechanisms. Consensus building may occur in person, via regular mail, email, or telephone with a third party serving as a facilitator. Statistically based approaches need more samples than are usually available in oil and gas resource assessment. The pros and cons of these consensus-building procedures have been well documented and are reviewed in Meyer and Booker (2001). They also provide an excellent general review of subject probability assessment.

In the ANWR assessment, at most two assessors were available for each of 10 plays. When two assessors were assigned a play, they usually reached a consensus before presenting their findings to the entire assessment team. Clearly, these were not independent assessments. At meetings of the assessment team, results for each play were presented and discussed. Team members, not assigned to that play but with a good general understanding of the regional geology served as checks and balances. Differences among assessors were resolved through consensus. More weight was given to opinions expressed by the play experts.

Eliciting Information

There are two aspects to eliciting information. One is the form or other mechanism used to collect information and the other is the process.

Careful consideration needs to be given to the design of a form or other survey instrument. The type of assessment, the structure of the data, and the level of knowledge
dictate the basic type of information required. The manner of elicitation should be highly
dependent on the way in which the assessors can best convey the information they
possess.

The basic forms used in the ANWR assessment to obtain oil, and numbers of deposit
data and risking information are shown in figures 1 and 2. The form for gas (not shown)
is similar to that for oil. The ANWR assessment form evolved over a period of 12-18
months. The oil hydrocarbon volume parameters and risking will be discussed later. An
important aspect of form construction is to consider how the user can best specify the
required information. How assessors view estimation and uncertainty is a critical
element. It is essential that the form be tailored to the user. Certain information,
including some petroleum engineering specifications is known with reasonable certainty
and can be specified as point estimates. The uncertainty associated with some data may
be so large as to make the specification of uncertainty estimates, meaningless. In such
cases, I suggest using point estimates and specifying in the documentation that results be
conditioned upon the specification of a given parameter. Of course, the uncertainty will
be unknown. For many parameters, assessors are able to obtain information from
fieldwork, drill hole data, or analogy. A form may be completed via the telephone, email,
in person interview, or regular mail, or before or during an assessment meeting. Clearly,
the form designer must be cognizant of the proposed data collection method. In the
ANWR assessment, forms were completed prior to the assessment and revised during
assessment meetings.

The quantity and timing of feedback from intermediate model results given to
assessors is an important consideration in reducing bias. The balance is between
providing feedback to assessors so that reasonable changes can be made based upon a
more complete picture of the geology and other factors. For example, it is difficult to
understand fully the consequences of the specification of the net reservoir thickness
distribution (fig. 1) on the resultant accumulation of oil, and reasonable opportunity for
revision should be allowed. A concern is that by having access to this information, the
assessor will consciously or unconsciously tune the results to some pre-selected value and
inappropriately down weight the geologic information. In the ANWR assessment,
assessors were shown accumulation results during practice assessments and during the
final assessment.

Another aspect of subjective probability estimation is anchoring. In the case of an
Olympic diving event, the anchoring is relatively easy with the bounds being 0 and 10.
Although even here, there is concern about an order of presentation effect where early
performers are penalized. In oil and gas resource estimation, it is more difficult.
Anchoring when performed usually takes the form of specifying a left and/or right
truncation value. In some assessments, anchoring on the left is not done, however, this
can result in the generation of thousands of small deposits, which would never be
technically recoverable. A right truncation value is usually established to prevent the
generation in simulation of deposits, which are so large that they could never be realized.
The way truncation points are established is a function of how attribute distributions are
specified and sampled. For example, if as in the 1002-Area study, specification was by

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4 Values of parameters are those of the Topset play in the 1002 Area of ANWR. Neither these nor any
other values, which appear in this paper, are official estimates of the U.S. Geological Survey or any other
organization. Rather they are realistic values intended to illustrate a methodology.
fractile and the resulting sampling was from the specified distribution, the 100th fractile and maximum value constituted lower and upper truncation values. Alternatively, a distribution may be fit to statistics supplied by assessors. If this distribution is lognormal or some other skewed distribution with an infinite right tail, an assessor might select a right tail probability, such as 0.001, to establish the right truncation value. Sometimes the geometry of a play can dictate the upper bound for a deposit, such as by limiting the area of closure or net reservoir thickness. In ANWR, the approach used was to bound the hydrocarbon volume parameters using geologic judgment and then ensure that for a given simulation run of the model, the total area occupied by deposits would not exceed the size of the area of the play. In ANWR a minimum size of 50 millions barrels of oil equivalent was chosen as the smallest accumulation to be generated.

Uncertainty, Bias, and Dependencies

Uncertainty, when viewed at a high level can be thought of as consisting of two components. One is the basic uncertainty in the geologic processes. For example, in a play analysis, there is variability in the hydrocarbon volume parameters. Clearly, not all deposits have the same characteristics. This is sometimes called stochastic uncertainty. There is also uncertainty due to lack of knowledge called subjective uncertainty. Helton (1994) discusses a method for treating these two types of uncertainty in performance assessment of complex systems. Unfortunately, these two components often are confounded.

In the ANWR assessment, assessors specified model uncertainty for four of the five hydrocarbon volume parameters (net reservoir thickness, area of closure, porosity, and trap fill), which constituted an oil accumulation (fig. 1). Water saturation was deemed totally dependent upon porosity. Uncertainty estimates also were given for trap depth and the number of containers. The distributions were specified by six fractiles and a maximum value. The assessors were shown the distributions generated by these specifications and modifications were allowed to ensure that they were comfortable with the general form. The distributions for the Topset play are shown in figure 3. The distributions in this and other plays varied in form from slightly left skewed to symmetrical, to highly right skewed. To impose a distribution such as the lognormal would have been inconsistent with the distributions as envisioned by the assessors. Some investigations have advocated the use of the triangular distribution. Although it is easy to specify, the triangular distribution does not represent skewed distributions very well. Attanasi and Schuenemeyer (1999), and Schuenemeyer and Attanasi (1999) examined the effect on uncertainty of misspecifying distributions of hydrocarbon volume parameters. In the ANWR assessment, sampling from the specified hydrocarbon volume empirical distributions generated oil accumulations.

For an upcoming USGS National Petroleum Reserve in Alaska (NPRA) assessment, several modifications to the ANWR methodology have been proposed. One is to ask the assessors to specify their level of knowledge about the hydrocarbon and other attributes. Another is to have the assessor specify the general shape of the distribution (fig. 4) and then specify only the left truncated value, the median, and the maximum for each of the hydrocarbon volume parameters (fig. 5). From these specifications, beta distributions would be fit and the resulting oil accumulation distribution generated. An example of
these distributions using the Topset parameters is shown in figure 6. Note the similarities between these and the empirical distributions shown in figure 4. Distributions of oil accumulations resulting from sampling of the empirical distributions (fig. 7a) and fitted beta distributions (fig. 7b) are quite similar. The means, medians, and standard deviations of oil accumulations for the empirically based sample are 765 MMBO, 396 MMBO, and 1,044 MMBO respectively. Those resulting from sampling from the fitted beta distributions are 686 MMBO, 445 MMBO, and 712 MMBO respectively. The mean and median are remarkably similar. Generating the oil accumulation distribution from the empirical hydrocarbon parameters (fig. 7a) results in a few very large values, which inflate the variance. This requires further investigation. An advantage to the proposed modification is that the assessors are forced to consider the form of the distribution and have fewer parameters to specify.

In my experience and that of others (see for example Rose (1987, 1992)), even scientists making expert judgments in their fields tend to be overconfident about their ability to make precise estimates, and thus usually underestimate true uncertainty. Bias takes several forms. There is statistical bias associated with an estimator. There is sampling bias associated with a failure to either obtain a random sample or make proper adjustments for the sampling scheme that was used to obtain data. In subjective probability estimation, experts may be biased due to information received outside of the scope of their current study. Occasionally, experts may be biased because of pressures to obtain a certain result. In my experience with assessments in the U.S. Geological Survey this later form of bias has not occurred. Biases may result from a poorly designed input form or one that does not permit the necessary data to be recorded. For example, the assessor may be presented with the choice of a triangular distribution when a right skewed beta would be more appropriate. There also are biases associated with the failure to account for important attributes. These two latter cases are examples of system-induced biases.

Dependencies can occur at several stages of an assessment process. The failure to consider dependencies leads to narrower estimates of uncertainty than would occur had they been incorporated into the model. In ANWR, assessors were asked to specify hydrocarbon volume parameters and other data. The assessors judged the hydrocarbon parameters to be pairwise statistically independent. However, this may not always be true. Dependencies can and do result when assessment results are aggregated, say from a play to an assessment region. See Schuenemeyer (1999) for a discussion of the aggregation methodology used in ANWR. Dependencies also may exist between assessors due to similar training and work experiences, or merely due to conversing with each other. In the ANWR assessment, we recognized that this form of bias but had no way to correct for it.

Evaluating Risk

In oil and gas resource estimation there are risks at the prospect and play levels. There also are investment risks. In ANWR, the two risks we addressed were prospect and play (fig. 2). For both of these attributes, assessors judged that charge, potential reservoir facies, and timely trap formation needed to be favorable in order to transform a prospect into a deposit. For play and prospect risk, these attributes were judged to be
pairwise independent. On this form (fig. 3), the probability of favorability (1 – risk probability) was given. Failure to risk will overstate (bias upward) the expected resource. Too much risk will result in understating (bias downward) the expected resource. An aspect of minimizing bias is to clearly define risk terms and provide training exercises before an assessment. Kaufman (1996) and other authors have addressed risk in the context of subject probability assessment of energy resources.

 COMMENTS

An important aspect of subjective probability assessment, which is often short-changed, is the training of team members prior to an assessment. People from many discipline including geologists, geophysicists, geochemists, engineers, economists, statisticians, and computer specialists constitute an assessment team. Their experience with resource assessments can be varied. Some will not be familiar with the process of translating qualitative geologic into the quantitative format needed to produce an assessment. Even concepts such as mean, median, and mode and how they relate to specific distributions may be unfamiliar. When using truncated distributions, it is important to clarify what quantile is being estimated, that of the truncated or untruncated distribution. Thus, it is important to conduct training sessions in a non-threatening atmosphere in which members of the team feel comfortable asking questions and can see through hands-on experience, the consequences of making estimates. In addition, during this training session, participants can establish and/or review definitions and discuss the general assessment methodology. Terms used in one discipline can have different meanings from those used in another discipline. This training session, however, should not be a practice assessment. That comes later.

Another neglected aspect of resource estimation is the critique. Unfortunately in an oil and gas resource estimate, it may be years, if ever, before its accuracy can be judged. However, a review of the assessment process with an accompanying report is useful. I suggest this be done within one to three months after completion of the assessment. Participants can discuss what worked and where improvement can be made.

Finally it is important to recognize that any forecast is based upon conditions that exist at the time of the assessment, and the exploration for oil and gas is a dynamic process with economic and technological factors, which influence drilling, discovery, extraction, and refining, constantly changing.

REFERENCES


Rose, P.R., 1992, Testimony to Texas Water Commission, June 30.


**ANWR 1002 Assessment Form-1997**

**Play Name:** Topset  
**Program Rev:** 3/31/1998

**Assessor's Name:** Houseknecht-Schenk  
**Data Rev:** 3/23/1998

**Play area:** 735.8 x 1000 acres, within 3-mile boundary

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## OIL HYDROCARBON VOLUME PARAMETERS

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<table>
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<td>18</td>
<td>22</td>
<td>25</td>
<td>28</td>
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<td>40</td>
<td>55</td>
<td>70</td>
<td>83</td>
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- **1-thickness in feet, 2-thousands of acres, 3-percent
- **Correlation between Porosity and Water Saturation = -1

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<tr>
<th>Trap Depth (1000 ft)</th>
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<th>10</th>
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<table>
<thead>
<tr>
<th>Trap Depth (at sea level)</th>
</tr>
</thead>
</table>
| Sea level to surface adjustment (1000 ft): 0.1

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## OIL ACCUMULATION CHARACTERISTICS

**Oil recovery factor %** 40

**Type of reservoir-drive (check any that apply):**

- Water: x
- Depletion: x
- Gas expansion: 

**FVF (Formation volume factor, rb/stb):**

- FVF= 0.8913 + 5.01E-02 * Depth(1000 ft)  
- FVF=1, Depth <= 2170 ft
- FVF=1.5, Depth >= 12150 ft

**GOR (Associated gas to oil ratio, cu.ft./bbl, at stp):**

- \[ \log_{10}(GOR) = 2.092 + 0.066906 \times \text{Depth}(1000 \text{ ft}) \]

**NGLR (Natural gas liquids to associated gas ratio, bbls/million cu.ft., at stp):**

- \[ \text{NGLR} = 1 + 0.0056 \times \text{Depth}(1000 \text{ ft}) \]

**Oil quality parameters:**

- API gravity: 30
- Sulfur content of oil: 

**Associated gas quality parameters:**

- Hydrogen sulfide %: 
- CO₂ contamination %: 5
- Other inert gases:

**Allocation:**

- Resources in 1002 %: 70
- Resources in non-1002 %: 30
### Figure 2. Number of prospects and risk information, Topset Play

**RISKING**  
**Play: Topset**  
**Date: 3/31/1998**

**MINIMUM RESERVOIR SIZE (Millions of BBL in place):** 50

<table>
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<tr>
<th>NUM CONTAINERS</th>
<th>100</th>
<th>95</th>
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<th>50</th>
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<td>49</td>
<td>65</td>
<td>80</td>
<td>97</td>
<td>116</td>
<td>125</td>
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**PROBABILITY OF FAVORABLE ATTRIBUTES**

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<tr>
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<td></td>
</tr>
<tr>
<td>TIMELY TRAP FORMATION (F)</td>
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<td></td>
</tr>
</tbody>
</table>

Probability that play contains at least 1 reservoir >= minimum size (CxRxF) = 1

<table>
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<th>PROBABILITY</th>
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<td>PROSPECT CHARGE (c)</td>
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<td>POTENTIAL RESERVOIR FACIES (r)</td>
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</tr>
<tr>
<td>TIMELY TRAP FORMATION (f)</td>
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<td></td>
</tr>
</tbody>
</table>

Probability that a randomly chosen prospect is favorable (cxrf) = 0.27

Play Attributes x Prospect Attributes (CxRxFcxrxf) = 0.27

**FRACTION OF ACCUMULATIONS BEING OIL**

Fraction NA Gas = 1 - Fraction(Oil) = 1

FRACTION OF ACCUMULATIONS BEING OIL = 0
Figure 3. The distributions of net reservoir thickness, area of closure, porosity and trap fill for the Topset play.
Figure 4. Possible shapes of distributions proposed for the NPRA assessment.
Figure 5. A modified assessment form with Topset oil accumulation volume parameters.

**Modified ANWR Assessment Form-2001**

**PLAY:** Topset  
**Play area:** 735.8 x 10³ Acres within 3-mile boundary

**OIL ACCUMULATION VOLUME PARAMETERS**

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<td>4</td>
<td>40</td>
<td>33</td>
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</tbody>
</table>

**OIL ACCUMULATION CHARACTERISTICS**

- **Oil recovery factor %**: 40
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  - FVF = 1.5, Depth >= 12150 ft
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  - Log₁₀(GOR) = 2.092 + 0.066906 * Depth(1000 ft)
- **NGLR (Natural gas liquids to associated gas ratio, bbls/million cu.ft., at stp)**:
  - NGLR = 1 + 0.36E+08 * exp(-0.254 * Depth(1000 ft))
- **Oil quality parameters**: API gravity 30
- **Associated gas quality parameters**: Hydrogen sulfide % 0, CO₂ contamination % 5

**Allocation**:  
- Resources in NPRA % 70  
- Resources in State Offshore % 15  
- Resources in Native Lands % 15

**TIME OF TRAP DEVELOPMENT**

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**Assessor’s Name:**  
**Date of Data Entry MM/DD/YYYY:**  
**Date of Simulation Run MM/DD/YYYY:**
Figure 6. Beta distributions fit to the Topset oil accumulation parameters given in figure 5.
Figure 7. A comparison between Topset oil accumulation distributions, generated by sampling from the empirical distribution of hydrocarbon parameters (fig. 7a) and that obtained by first fitting beta distributions (fig. 7b).