Chapter 18

U.S. Geological Survey Input-Data Form and Operational Procedure for the Assessment of Continuous Petroleum Accumulations

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Volume Title Page

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By USGS Uinta-Piceance Assessment Team

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Abstract

The USGS FORSPAN model is designed to aid in the assessment of continuous accumulations of crude oil, natural gas, and natural gas liquids (collectively called petroleum). Continuous (sometimes called "unconventional") accumulations have large spatial dimensions and lack well-defined down-dip petroleum/water contacts, thus oil and natural gas are not localized by buoyancy in water. Continuous accumulations include tight gas, coalbed gas, oil and gas in shale, oil and gas in chalk, and shallow biogenic gas.

The FORSPAN model was developed on the premise that continuous accumulations are collections of petroleum-containing cells. Each cell is capable of producing oil or gas, but the cells may vary significantly from one another in their production and, thus, economic characteristics. Technically recoverable petroleum resources from continuous accumulations are calculated by statistically combining probability distributions of the estimated number of untested cells having the potential for the additions to reserves with the estimated volume of oil and natural gas volumes that each of the untested cells may potentially produce, along with associated risks and coproduct ratios. Probabilistic estimates of petroleum resources are given for oil in oil accumulations, gas (associated/dissolved) in oil accumulations, natural gas liquids in oil accumulations, gas (nonassociated) in gas accumulations, and total liquids (oil and natural gas liquids) in gas accumulations.

Introduction

The USGS recognizes two major types of petroleum accumulations based on geology for purposes of resource assessment, conventional and continuous (U.S. Geological Survey National Oil and Gas Resource Assessment Team, 1995; Gautier and others, 1996; Schmoker, 1996; U.S. Geological Survey World Energy Assessment Team, 2000). Conventional accumulations may be described in terms of discrete fields or pools localized in structural and stratigraphic traps by the buoyancy of oil or natural gas in water. In contrast, continuous accumulations are oil or natural gas accumulations that have large spatial dimensions and indistinctly defined boundaries, and which exist more or less independently of the water column (Schmoker, 1996, 1999). Conventional accumulations "float" bubble-like in water; continuous accumulations do not. Because of their fundamental geologic dissimilarities, the USGS assesses conventional and continuous accumulations using different resource-assessment models and methods.

The purpose of this report is to describe (1) the input-data form developed to record data required by the USGS assessment model for continuous accumulations (called the "FORSPAN" model, Schmoker, 1999), and (2) operational procedures developed by the USGS to implement the assessment process for continuous accumulations. The data form (fig. 1) and operational procedures are used as part of the ongoing National Oil and Gas Assessment (NOGA) series of domestic petroleum assessments begun by the USGS in 2000.

Basic Input-Data Form

The FORSPAN model was developed on the premise that continuous accumulations are collections of petroleum-containing cells. The assessment process requires estimates of the number of cells and the volume of oil and natural gas volumes that each cell may potentially produce. Each cell is capable of producing oil or gas, but the cells may vary significantly from one another in their production and, thus, economic characteristics. Although cells are analogous to wells, fundamental differences between the two warrant explanation. Cells differ from wells by having areal properties related to the drainage areas of wells. Cells constitute continuous accumulations. Oil and natural gas volumes contained in cells are expressed as total recoverable volumes. Conversely, wells are considered as points, rather than areas, in the FORSPAN model. Total volumes of oil and natural gas associated with wells, expressed as estimated ultimate recoverable reserves (EUR), are mathematically derived using cumulative production data. The gas volumes used in the FORSPAN model and entered on the input-data form represent total natural gas, both hydrocarbon and nonhydrocarbon.

As a first step in a petroleum-resource assessment of potential additions to reserves using the FORSPAN assessment model, a continuous accumulation is divided (if necessary) into more homogeneous subunits, termed assessment units

FORSPAN **ASSESSMENT MODEL FOR CONTINUOUS ACCUMULATIONS--BASIC INPUT DATA FORM (NOGA, Version 7, 6-30-00)**

IDENTIFICATION INFORMATION

Assessment Geologist:… ____________ Date: ____
Region:…………………… ____________ Number: ____
Province:………………….. ____________ Number: ____
Total Petroleum System:. ____________ Number: ____
Assessment Unit:………. ____________ Number: ____
Based on Data as of:…… ____________
Notes from Assessor….. ____________

CHARACTERISTICS OF ASSESSMENT UNIT

Assessment-Unit type: **Oil** (<20,000 cfg/bo) **or** **Gas** (≥20,000 cfg/bo) ____
What is the minimum total recovery per cell?… ____ (mmbo for oil A.U.; bcfg for gas A.U.)
Number of tested cells:………… ____
Number of tested cells with total recovery per cell ≥ minimum: ……... ____
Established (>24 cells ≥ min.) ____ Frontier (1-24 cells) ____ Hypothetical (no cells) ____
Median total recovery per cell (for cells ≥ min.): (mmbo for oil A.U.; bcfg for gas A.U.)
1st 3rd discovered ____ 2nd 3rd ____ 3rd 3rd ____

Assessment-Unit Probabilities:

Attribute	Probability of occurrence (0-1.0)
1. **CHARGE:** Adequate petroleum charge for an untested cell with total recovery ≥ minimum ……	____
2. **ROCKS:** Adequate reservoirs, traps, seals for an untested cell with total recovery ≥ minimum.	____
3. **TIMING:** Favorable geologic timing for an untested cell with total recovery ≥ minimum………..	____

Assessment-Unit GEOLOGIC Probability (Product of 1, 2, and 3):……….......……. ____

4. **ACCESS:** Adequate location for necessary petroleum-related activities for an untested cell with total recovery ≥ minimum ………………………………………………………………. ____

NO. OF UNTESTED CELLS WITH POTENTIAL FOR ADDITIONS TO RESERVES IN THE NEXT 30 YEARS

1. Total assessment-unit area (acres): (uncertainty of a fixed value)
   minimum ____ median ____ maximum ____

2. Area per cell of untested cells having potential for additions to reserves in next 30 years (acres):
   (values are inherently variable) minimum ____ median ____ maximum ____

3. Percentage of total assessment-unit area that is untested (%): (uncertainty of a fixed value)
   minimum ____ median ____ maximum ____

4. Percentage of untested assessment-unit area that has potential for additions to reserves in next 30 years (%): (a necessary criterion is that total recovery per cell ≥ minimum)
   (uncertainty of a fixed value) minimum ____ median ____ maximum ____

Figure 1. The input-data form for the FORSPAN assessment model for continuous accumulations.

Assessment Unit (name, no.)

____

TOTAL RECOVERY PER CELL

Total recovery per cell for untested cells having potential for additions to reserves in next 30 years:
(values are inherently variable)
(mmbo for oil A.U.; bcfg for gas A.U.) minimum ________ median ________ maximum ________

AVERAGE COPRODUCT RATIOS FOR UNTESTED CELLS, TO ASSESS COPRODUCTS

(uncertainty of fixed but unknown values)

Oil assessment unit:	minimum	median	maximum
Gas/oil ratio (cfg/bo)………………………..…….	________	________	________
NGL/gas ratio (bngl/mmcfg)…………………..….	________	________	________

Gas assessment unit:			
Liquids/gas ratio (bliq/mmcfg)………………..……	________	________	________

SELECTED ANCILLARY DATA FOR UNTESTED CELLS

(values are inherently variable)

Oil assessment unit:	minimum	median	maximum
API gravity of oil (degrees)…………..………….	________	________	________
Sulfur content of oil (%)………………………...….	________	________	________
Drilling depth (m) ……………...…………….……	________	________	________
Depth (m) of water (if applicable)……………….	________	________	________

Gas assessment unit:			
Inert-gas content (%)……………………….....…..	________	________	________
CO_2 content (%)……………………………….…..	________	________	________
Hydrogen-sulfide content (%)……………...…….	________	________	________
Drilling depth (m)………………………………….	________	________	________
Depth (m) of water (if applicable)……………….	________	________	________

Figure 1—Continued. The input-data form for the FORSPAN assessment model for continuous accumulations.

Assessment Unit (name, no.)

____

ALLOCATIONS OF POTENTIAL ADDITIONS TO RESERVES TO LAND ENTITIES

Surface Allocations (uncertainty of a fixed value)

1. ____________________ represents ________ areal % of the assessment unit

Oil in oil assessment unit:	minimum	median	maximum
Volume % in entity......................................	______	______	______
Portion of volume % that is offshore (0-100%)..	______	______	______

Gas in gas assessment unit:			
Volume % in entity......................................	______	______	______
Portion of volume % that is offshore (0-100%)..	______	______	______

2. ____________________ represents ________ areal % of the assessment unit

Oil in oil assessment unit:	minimum	median	maximum
Volume % in entity......................................	______	______	______
Portion of volume % that is offshore (0-100%)..	______	______	______

Gas in gas assessment unit:			
Volume % in entity......................................	______	______	______
Portion of volume % that is offshore (0-100%)..	______	______	______

3. ____________________ represents ________ areal % of the assessment unit

Oil in oil assessment unit:	minimum	median	maximum
Volume % in entity......................................	______	______	______
Portion of volume % that is offshore (0-100%)..	______	______	______

Gas in gas assessment unit:			
Volume % in entity......................................	______	______	______
Portion of volume % that is offshore (0-100%)..	______	______	______

4. ____________________ represents ________ areal % of the assessment unit

Oil in oil assessment unit:	minimum	median	maximum
Volume % in entity......................................	______	______	______
Portion of volume % that is offshore (0-100%)..	______	______	______

Gas in gas assessment unit:			
Volume % in entity......................................	______	______	______
Portion of volume % that is offshore (0-100%)..	______	______	______

Figure 1—Continued. The input-data form for the FORSPAN assessment model for continuous accumulations.

(Schmoker, 1999). Assessment units are considered and assessed individually; an input-data form is completed for each assessment unit of the continuous accumulation. The data form (fig. 1) contains seven sections, each of which is described herein.

Identification Information

The first section of the data form (fig. 1) is for identification information and brief notes relevant to the assessment. Identification information includes the assessment geologist's name; the date of the assessment meeting at which input data were reviewed and discussed; and the names and numerical codes of the region, province, total petroleum system, and assessment unit. The source and vintage of exploration and production data used to aid in the assessment are also recorded.

Characteristics of Assessment Unit

In the second section of the data form (fig. 1), the assessment unit is classified as representing an oil accumulation or a gas accumulation (assessment-unit type). Assessment-unit type is based on the overall gas/oil ratio (GOR), which includes both discovered petroleum and potential additions to reserves. A continuous assessment unit is characterized as an oil accumulation if the GOR is less than 20,000 cubic feet of gas per barrel of oil (CFG/BO); otherwise, it is a gas accumulation.

A minimum total recovery per cell, which relates in part to the forecast span of 30 years, is chosen for the assessment unit. Petroleum in cells expected to have a total recovery less than the minimum is not considered to be a significant resource in the 30-year forecast span and is excluded from the assessment.

The total number of tested cells and the number of tested cells with total recovery per cell greater than or equal to the minimum are recorded as useful information for the resource-assessment process. A classification of the exploration and development maturity of the assessment unit into one of three categories is also made. An assessment unit is classified as (1) *established* if more than 24 tested cells have total recovery equal to or exceeding the minimum, (2) *frontier* if 1 to 24 such cells have been tested, or (3) *hypothetical* if no such cells have been found. As for the USGS assessment model for undiscovered conventional petroleum, established assessment units have a sufficient number of tested cells for historical cell-level data to be of help in estimating properties of untested cells. At the other extreme, the characteristics of untested cells in hypothetical assessment units must be estimated primarily on the basis of geologic analogs (Klett and others, 2000).

The group of tested cells having total recovery per cell greater than or equal to the minimum can be divided into the first-third, the second-third, and the third-third that started production (or the first-half and second-half that started production, if data points are few). The median total recovery per cell for each of these discovery-history segments is recorded for informational purposes on the input-data form. The changes in these medians through time are considered when the total recoveries of untested cells having potential for additions to reserves in the next 30 years are estimated.

As for conventional accumulations, assessment-unit probabilities (risk) are estimated for the assessment unit (Schmoker and Klett, 1999, 2000; Klett and others, 2000). The four risking elements (attributes) of charge, rocks, timing, and access address the question of the probability of occurrence of at least one cell of minimum total recovery, somewhere in the assessment unit, that has the potential to be added to reserves in the next 30 years (Schmoker and Klett, 1999, 2000). Each element in this risking structure applies to the assessment unit as a whole and does not equate to the percentage of the assessment unit that might be unfavorable in terms of charge, rocks, timing, or access (Klett and others, 2000).

The geologic portion of the risking structure just described is based on the assumption that assessment units are reasonably homogeneous in terms of charge, rocks, and timing. For example, favorable charge should not occur only in the west half of an assessment unit and favorable rocks only in the east half. Such a situation would suggest that the assessment unit is too large and should be redefined (Klett and others, 2000). If nothing is known about a risking element at the assessment-unit level, the default probability of occurrence (P) should reflect an average probability for similar assessment units in other basins, which is not necessarily P=0.50 (Klett and others, 2000).

Number of Untested Cells with Potential for Additions to Reserves in the Next 30 Years

The third section of the data form (fig. 1) is for recording the variables that are used to calculate a probability distribution for the number of untested cells in the assessment unit that have potential for additions to reserves within the forecast span of 30 years. Minimum, median, and maximum values (F_{100}, F_{50}, and F_0 fractiles) are estimated for each of four variables: (1) total assessment-unit area, (2) area per cell of untested cells having potential for additions to reserves in the next 30 years, (3) percentage of total assessment-unit area that is untested, and (4) percentage of untested assessment-unit area that has potential for additions to reserves in the next 30 years (Schmoker, 1999). The particular type of probability distribution need not be specified in order to estimate the three fractiles for each of these variables, although triangular distributions are used for the NOGA series.

The total assessment-unit area is the area enclosed by the assessment-unit boundaries. The probability distribution for this variable represents the uncertainty of a fixed but unknown value. Most of this uncertainty reflects geologic uncertainty associated with defining the boundaries of the assessment unit, rather than errors in measuring an area on a map (Schmoker, 1999). If the assessment unit is bounded on all sides by other continuous assessment units, the total assessment-unit area is represented by a single (point) value rather than by three fractiles in order to avoid the statistical difficulties of dealing with negative correlations between the areas of two or more assessment units, which are assessed separately and individually.

Area per cell of untested cells having potential for additions to reserves in the next 30 years can generally be equated to the drainage area per well. Drainage area, however, is not necessarily equal to current well spacing. The probability distribution for this variable represents a naturally occurring range of values because the drainage areas of wells in the assessment unit are not constant, but rather change in response to variability in reservoir characteristics.

The percentage of total assessment-unit area that is untested includes areas both within and outside of known “sweet spots.” For example, large blocks of acreage within the assessment unit that are not near a known sweet spot might be untested. Additionally, a sweet spot might be fully drilled at a 160-acre spacing, for example, but if engineering data indicate that drainage area (cell area) is approximately 80 acres, some 50 percent of the sweet spot would remain untested. The probability distribution for this input variable represents the uncertainty of a fixed but unknown value.

The percentage of untested assessment-unit area that has potential for additions to reserves in the next 30 years represents a subset of the untested assessment-unit area. Cells in this subset are forecast to have (1) total recoveries of at least the minimum volume specified in the second section of the data form, and (2) the potential to contribute to reserves in the 30-year time frame of the assessment. Expectations for this input variable are related, at least in part, to geologic and engineering concepts for the existence and reservoir characteristics of sweet spots (Schmoker, 1999). In an unlimited (as opposed to 30-year) assessment time frame, neither of these two conditions could logically be imposed, and the untested area having potential for additions to reserves would equate to the total untested area. The probability distribution for this input variable represents the uncertainty of a fixed but unknown value.

The statistical combination of the four variables specified in terms of three fractiles (F_{100}, F_{50}, and F_0) in this third section of the data form results in a probability distribution for the number of untested cells in the assessment unit having potential for additions to reserves in the next 30 years.

Total Recovery Per Cell

The fourth section of the data form (fig. 1) establishes the total recovery of oil or gas per cell, for untested cells having potential for additions to reserves within the next 30 years (Schmoker, 1999). The probability distribution for this input variable represents a naturally occurring range of values. Again, the particular type of probability distribution need not be specified in order to estimate the three fractiles (F_{100}, F_{50}, and F_0), although a shifted, truncated lognormal distribution is used for the NOGA series.

The minimum total recovery per cell (F_{100}) has been specified in the second section of the data form. Estimates for the median and maximum total recoveries per cell can be guided by decline-curve analysis of wells in the assessment unit or in an analog assessment unit (Schmoker, 1999). However, historical production data serve only as a starting point for estimates of total recoveries from cells yet to be drilled. With past production performance as a guide, input parameters can be chosen to represent perceived impacts of future change, such as improved technologies and newly developed geologic and engineering concepts. However, historical data representing known sweet spots might not be characteristic of all future development.

Average Coproduct Ratios for Untested Cells, to Assess Coproducts

The fifth section of the data form is used to record the ratios necessary to assess coproducts associated with oil in oil accumulations or gas in gas accumulations (Schmoker, 1999). For oil accumulations, gas/oil (GOR) and natural gas liquids (NGL)/gas are required; for gas accumulations, total liquids (crude oil, condensate, and NGL)/gas. These ratios should represent the average of the untested coproducts and are typically derived from the known coproducts. The probability distributions for these input variables depict the uncertainty of a fixed but unknown value (the mean), and not the actual range of coproduct values among untested cells.

Selected Ancillary Data for Untested Cells

The sixth section of the data form establishes a modest set of ancillary data useful for economic and environmental analyses of assessment results (Schmoker, 1999). The ancillary data for untested cells in continuous oil accumulations are estimates of API gravity of oil, sulfur content of oil, drilling depth, and water depth (if part or all of the assessment unit is offshore). The ancillary data for untested cells in continuous gas accumulations are estimates of inert-gas content, carbon dioxide content, and hydrogen sulfide content, as well as drilling depth and water depth, if applicable. These data do not contribute directly to assessment calculations. The probability distributions for the ancillary-data elements represent the range of values among untested cells; that is, they represent values that are inherently variable. Minimum, median, and maximum values are given, but no distribution type is inferred.

Allocations of Potential Additions to Reserves to Land Entities

The final section of the data form (fig. 1) is for the area and volume percentages necessary to allocate assessed potential additions to reserves in the assessment unit to various surface and subsurface land entities of interest, and their offshore portions, if applicable. Examples of such land entities include Federal, State, tribal, and private lands; categories of Federal lands such as wilderness areas, national forests, and national parks; and political units such as States or counties. Allocations can be based on surface ownership, mineral ownership, or both. The volume percent of assessed resources allocated to an entity does not necessarily equal the area percent of that entity (Schmoker, 1999).

The data form allows for allocation percentages to be recorded as three fractiles (F_{100}, F_{50}, and F_0), representing the uncertainty of a fixed but unknown value. A three-fractile input is best suited to the case where an allocation is made to a single land entity (such as a national park) within the assessment unit. However, the requirement that all fractiles of allocated percentages sum to 100 percent becomes a difficult operational problem if several land-entity allocations are each represented by a probability distribution. In the NOGA series, resource allocations are typically made to a number of land entities, and allocation percentages are consequently recorded as point estimates only, the sum of which equals 100 percent.

Operational Procedures

As with the number and sizes of undiscovered accumulations in conventional assessment units, the area, number, and total recoverable volumes of untested cells in continuous assessment units are generally dependent on the geologic elements and fundamental processes (such as generation, migration, entrapment, and preservation of petroleum) of the total petroleum system. Additionally, producing cells in continuous assessment units are typically clustered, existing as sweet spots. Conceived geologic models are based on these attributes, and together with the exploration and discovery history and performance of production wells of the assessment unit, are used to estimate the variables required for the calculation of potential additions to reserves.

For NOGA, the assessor makes estimates of the areas and percentages of untested cells having the potential for addition to reserves within the given time span for the assessment. The parameters of these variables (input data) are evaluated and typically adjusted during a formal assessment meeting. The final variables are then statistically combined to provide estimates of the petroleum resources.

Most of the potential additions to reserves in continuous assessment units are expected to come from infill drilling and expansion of existing sweet spots, and from undiscovered sweet spots. The density of tested cells, total recoverable volumes, and success ratio for discovery of tested cells within an assessment unit are examined and used in conjunction with the geologic knowledge of migration pathways and reservoir and trap distribution to identify those cells having the potential for reserve additions in the untested portions of the unit. Tested-cell data from analog assessment units are used for under-explored or unexplored assessment units.

An Assessment Review Team scrutinizes and evaluates the estimated input data during the formal assessment meetings, in order to maintain the accuracy and consistency of the assessment procedure. At each assessment meeting, the assessing geologists present a description of the assessment-unit geology, including regional setting, structural evolution, source-rock properties, depositional history, and potential petroleum-rich areas, horizons, or plays for future exploration. Each of the estimates made by the assessor on the initial data-input form is systematically addressed. As the assessment meeting progresses, a digital version of the final input form is constructed. Commonly, revisions are made to the initial input data upon analysis of the geology, well-production data, and exploration and discovery history. Upon final consensus of the Assessment Review Team and the assessor, the digital input form is saved, printed, and initialed by each of the team members.

A resource-calculation procedure mathematically applies triangular distributions to the variables used to calculate the number of untested cells having the potential for additions to reserves and applies triangular distributions to the estimated average coproduct ratios. The procedure also applies a shifted, truncated lognormal distribution to the total recoverable volumes per untested cell. These distributions are then statistically combined, along with associated risks (geologic and access probabilities), to provide estimates of technically recoverable petroleum resources. For NOGA, a computer program developed by the USGS called ACCESS (Analytic Cell-based Continuous Energy Spreadsheet System; Crovelli, 2000) is used for this operation. Probabilistic estimates of petroleum resources are given for oil in oil accumulations, gas (associated/dissolved) in oil accumulations, natural gas liquids in oil accumulations, gas (nonassociated) in gas accumulations, and total liquids (oil and natural gas liquids) in gas accumulations.

Summary

The USGS FORSPAN assessment model for continuous petroleum accumulations requires geology- and engineering-based input data. Necessary input data are recorded on the form described in this report, which is completed for each assessment unit of a continuous accumulation. The form consists of seven sections, which are:

- Identification information
- Characteristics of assessment unit

- Number of untested cells with potential for additions to reserves in the next 30 years
- Total recovery per cell
- Average coproduct ratios for untested cells, to assess coproducts
- Selected ancillary data for untested cells
- Allocations of potential additions to reserves to land entities.

Identification information supplies the data necessary for record keeping and assessment organization. Statistical combination of the minimum total recovery per cell and geologic and access probabilities (from Characteristics of assessment unit), number of untested cells, total recovery per cell, and coproduct ratios yields probability distributions for quantities of petroleum having the potential to be added to reserves within a forecast span of 30 years. Ancillary data provide a set of information (not used directly in assessment calculations) that is useful for economic and environmental analyses. Allocation percentages allow the apportionment of assessed potential additions to reserves to various land entities of interest within the assessment unit.

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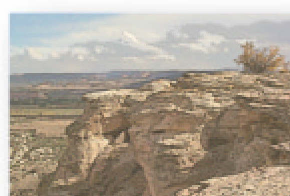

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