Petroleum Systems and Geologic Assessment of Oil and Gas in the San Joaquin Basin Province, California

Chapter 25

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

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Abstract

The U.S. Geological Survey model for undiscovered conventional accumulations is designed to aid in the assessment of crude oil, natural gas, and natural gas liquids (collectively called petroleum) resources. 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. Conventional accumulations are commonly bounded by a down-dip water contact.

The assessment model requires estimates of the number and sizes of undiscovered conventional accumulations. Technically recoverable petroleum resources from undiscovered conventional accumulations are calculated by statistically combining probability distributions of the estimated number and sizes of undiscovered accumulations, 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 U.S. Geological Survey (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 (Schmoker and Klett, 1999, 2000),

SEVENTH APPROXIMATION
DATA FORM FOR CONVENTIONAL ASSESSMENT UNITS (NOGA, Version 5, 6-30-01)

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

Oil (<20,000 cfg/bo overall) **or** Gas (≥20,000 cfg/bo overall):. _____

What is the minimum accumulation size?.... _____ mmboe grown
(the smallest accumulation that has potential to be added to reserves in the next 30 years)

No. of discovered accumulations exceeding minimum size:.... Oil: _____ Gas: _____
Established (>13 accums.) _____ Frontier (1-13 accums.) _____ Hypothetical (no accums.) _____

Median size (grown) of discovered oil accumulation (mmbo):
1st 3rd _____ 2nd 3rd _____ 3rd 3rd _____
Median size (grown) of discovered gas accumulations (bcfg):
1st 3rd _____ 2nd 3rd _____ 3rd 3rd _____

Assessment-Unit Probabilities:

Attribute	Probability of occurrence (0-1.0)
1. **CHARGE:** Adequate petroleum charge for an undiscovered accum. ≥ minimum size.....	
2. **ROCKS:** Adequate reservoirs, traps, and seals for an undiscovered accum. ≥ minimum size..	
3. **TIMING OF GEOLOGIC EVENTS:** Favorable timing for an undiscovered accum. ≥ minimum size	

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

4. **ACCESSIBILITY:** Adequate location to allow exploration for an undiscovered accumulation ≥ minimum size..... _____

UNDISCOVERED ACCUMULATIONS

No. of Undiscovered Accumulations: How many undiscovered accums. exist that are ≥ min. size?:
(uncertainty of fixed but unknown values)

Oil Accumulations:.....min. no. (>0) _____ median no._____ max no. _____
Gas Accumulations:.....min. no. (>0) _____ median no._____ max no. _____

Sizes of Undiscovered Accumulations: What are the sizes (**grown**) of the above accums?:
(variations in the sizes of undiscovered accumulations)

Oil in Oil Accumulations (mmbo):.....min. size _____ median size_____ max. size _____
Gas in Gas Accumulations (bcfg):....min. size _____ median size_____ max. size _____

Figure 25.1. The Seventh Approximation input-data form for conventional assessment units.

and (2) operational procedures developed by the USGS to implement the assessment process for undiscovered conventional accumulations. The input-data form (called the "Seventh Approximation Data Form for Conventional Assessment Units," fig. 25.1) 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. "Seventh Approximation" is a term that expresses the evolution of the input-data form as well as the idea that an exact analysis of undiscovered resources cannot be achieved.

Input-Data Form

As a first step in a petroleum-resource assessment of potential additions to reserves using the USGS assessment model for undiscovered conventional accumulations, discovered and undiscovered accumulations are divided (if necessary) into more homogeneous subunits, termed assessment units. Assessment units are considered and assessed individually and an input-data form is completed for each. The gas volumes used in the assessment model and entered on the input-data form represent total natural gas, both hydrocarbon and nonhydrocarbon. The data form (fig. 25.1) contains six sections, each of which is described herein.

Identification Information

The first section of the data form (fig. 25.1) 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.

Assessment Unit (name, no.) _____

AVERAGE RATIOS FOR UNDISCOVERED ACCUMS., TO ASSESS COPRODUCTS
(uncertainty of fixed but unknown values)

Oil Accumulations:	minimum	median	maximum
Gas/oil ratio (cfg/bo).....	_____	_____	_____
NGL/gas ratio (bngl/mmcfg).....	_____	_____	_____
Gas Accumulations:	**minimum**	**median**	**maximum**
Liquids/gas ratio (bliq/mmcfg).....	_____	_____	_____
Oil/gas ratio (bo/mmcfg).....	_____	_____	_____

SELECTED ANCILLARY DATA FOR UNDISCOVERED ACCUMULATIONS
(variations in the properties of undiscovered accumulations)

Oil Accumulations:	minimum	median	maximum
API gravity (degrees).....	_____	_____	_____
Sulfur content of oil (%).....	_____	_____	_____
Drilling Depth (m)	_____	_____	_____
Depth (m) of water (if applicable).....	_____	_____	_____
Gas Accumulations:	**minimum**	**median**	**maximum**
Inert gas content (%).....	_____	_____	_____
CO_2 content (%).....	_____	_____	_____
Hydrogen-sulfide content (%).....	_____	_____	_____
Drilling Depth (m).....	_____	_____	_____
Depth (m) of water (if applicable).....	_____	_____	_____

Figure 25.1 Continued. The Seventh Approximation input-data form for conventional assessment units.

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 total assessment unit

Oil in Oil Fields:	minimum	median	maximum
Richness factor (unitless multiplier):.....			
Volume % in parcel (areal % x richness factor):.			
Portion of volume % that is offshore (0-100%)..			

Gas in Gas Fields:	minimum	median	maximum
Richness factor (unitless multiplier):.....			
Volume % in parcel (areal % x richness factor):.			
Portion of volume % that is offshore (0-100%)..			

2. _____ represents _____ areal % of the total assessment unit

Oil in Oil Fields:	minimum	median	maximum
Richness factor (unitless multiplier):.....			
Volume % in parcel (areal % x richness factor):.			
Portion of volume % that is offshore (0-100%)..			

Gas in Gas Fields:	minimum	median	maximum
Richness factor (unitless multiplier):.....			
Volume % in parcel (areal % x richness factor):.			
Portion of volume % that is offshore (0-100%)..			

3. _____ represents _____ areal % of the total assessment unit

Oil in Oil Fields:	minimum	median	maximum
Richness factor (unitless multiplier):.....			
Volume % in parcel (areal % x richness factor):.			
Portion of volume % that is offshore (0-100%)..			

Gas in Gas Fields:	minimum	median	maximum
Richness factor (unitless multiplier):.....			
Volume % in parcel (areal % x richness factor):.			
Portion of volume % that is offshore (0-100%)..			

4. _____ represents _____ areal % of the total assessment unit

Oil in Oil Fields:	minimum	median	maximum
Richness factor (unitless multiplier):.....			
Volume % in parcel (areal % x richness factor):.			
Portion of volume % that is offshore (0-100%)..			

Gas in Gas Fields:	minimum	median	maximum
Richness factor (unitless multiplier):.....			
Volume % in parcel (areal % x richness factor):.			
Portion of volume % that is offshore (0-100%)..			

Figure 25.1 Continued. The Seventh Approximation input-data form for conventional assessment units.

Characteristics of Assessment Unit

In the second section of the data form (fig. 25.1), the assessment-unit type is classified as being either oil prone or gas prone. Assessment-unit type is based on the overall gas/oil ratio (GOR), which includes both discovered and undiscovered petroleum. A conventional assessment unit is characterized as oil prone if the GOR is less than 20,000 cubic feet of gas per barrel of oil (CFG/BO); otherwise, it is gas prone.

A minimum undiscovered accumulation size (volume), which relates in part to the forecast span of 30 years, is chosen for the assessment unit. Petroleum in accumulations expected to contain volumes 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 minimum undiscovered gas-accumulation size is the equivalent size used for oil accumulations, in which 1 barrel of oil equals 6,000 cubic feet of gas.

A classification into one of three categories is made of the maturity of the assessment unit, in terms of exploration and development. An assessment unit is considered as (1) established if more than 13 accumulations having volumes equal to or exceeding the minimum have been discovered, (2) frontier if 1 to 13 such accumulations have been discovered, or (3) hypothetical if no such accumulations have been discovered (Klett and others, 2000). Established assessment units have a sufficient number of discovered accumulations for historical discovery data to be of help in estimating properties of undiscovered accumulations (Schmoker and Klett, 1999, 2000). At the other extreme, the characteristics of undiscovered accumulations in hypothetical assessment units must be estimated primarily on the basis of geologic analogs. Hypothetical assessment units carry higher inherent assessment uncertainty than established and frontier assessment units (Klett and others, 2000).

Discovery-history segments are the first-third discovered, second-third discovered, and third-third discovered (or first-half and second-half discovered if data points are few, less than 14) accumulations having volumes greater than or equal to the minimum in an assessment unit. The median accumulation size for each of these discovery-history segments is recorded for informational purposes on the input-data form. These medians and their changes through time are considered when the sizes of undiscovered accumulations are estimated (Klett and others, 2000).

The probability of existence of at least one undiscovered accumulation of minimum size, somewhere in the assessment unit, that has the potential for its volume to be added to reserves in the next 30 years, is estimated (Schmoker and Klett, 1999, 2000). The four risking elements (attributes) of charge, rocks, timing, and access address the question of the probability of occurrence of at least one accumulation of minimum size, 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 analog assessment units in other basins, which is not necessarily P=0.50 (Klett and others, 2000).

Undiscovered Accumulations

The third section of the data form (fig. 25.1) is for recording the number and sizes (upon full development) of undiscovered oil and gas accumulations used to calculate the undiscovered resources 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 variable. The particular type of probability distribution need not be specified in order to estimate these three fractiles, although a triangular distribution is used for the number and a shifted, truncated lognormal distribution is used for the sizes in the NOGA series.

Average Ratios for Undiscovered Accumulations, to Assess Coproducts

The fourth section of the data form (fig. 25.1) is used to record the ratios necessary to assess coproducts associated with oil in oil accumulations or gas in gas accumulations (Schmoker and Klett, 1999, 2000). For oil accumulations, the necessary coproduct ratios are gas/oil (GOR) and natural gas liquids (NGL)/gas. For gas accumulations, the necessary coproduct ratio is total liquids (crude oil, condensate, and NGL)/gas. These ratios represent averages for the potential additions to reserves of the assessment unit. 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 undiscovered accumulations. The coproduct ratios are based on available accumulation-level data for the assessment unit or an analog area and are projected for the undiscovered accumulations. Oil to gas ratios in gas fields were not estimated in the NOGA series.

Selected Ancillary Data for Undiscovered Accumulations

The fifth section of the data form (fig. 25.1) establishes a modest set of ancillary data useful for economic and environ-

mental analyses of assessment results (Schmoker and Klett, 1999, 2000). The ancillary data for undiscovered conventional 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 undiscovered conventional 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 estimated range of values among undiscovered accumulations; that is, they represent values that are inherently variable.

Allocations of Potential Additions to Reserves to Land Entities

The final section of the data form (fig. 25.1) is for the area and volume percentages necessary to allocate assessed volumes of undiscovered accumulations in the assessment unit to various surface and subsurface land entities of interest, and their offshore portions, if applicable. Additionally, a richness factor may be recorded 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 and Klett, 1999, 2000).

The data form allows for richness factors and 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

The number and sizes of undiscovered accumulations in conventional assessment units are generally dependent upon the geologic elements and fundamental processes (such as generation, migration, entrapment, and preservation of petroleum) of the total petroleum system. Conceived geologic models are based on these attributes, and together with the exploration and discovery history of the assessment unit, are used to estimate the variables required for the calculation of technically recoverable undiscovered resources.

For NOGA, the assessor makes estimates of the number and sizes of undiscovered accumulations which have 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 undiscovered petroleum resources.

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-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, 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 number of undiscovered accumulations and to the estimated average coproduct ratios. A shifted, truncated lognormal distribution is applied to the sizes. These distributions are then statistically combined, along with associated risks (geologic and access probabilities), to provide estimates of potential additions to reserves as technically recoverable undiscovered petroleum resources. For the NOGA series, a computer program developed by the USGS called EMC2 (Energy Monte Carlo Program 2, Charpentier and Klett, 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 Seventh Approximation assessment model for conventional 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. The form consists of six sections, which are:

- Identification information
- Characteristics of assessment unit
- Undiscovered accumulations

- Average ratios for undiscovered accumulations, to assess coproducts
- Selected ancillary data for undiscovered accumulations
- 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 undiscovered accumulation size and geologic and access probabilities (from Characteristics of Assessment Unit), number and sizes of undiscovered accumulations, 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.

References Cited

Charpentier, R.R., and Klett, T.R., 2000, Monte Carlo simulation model, *in* U.S. Geological Survey World Energy Assessment Team, U.S. Geological Survey World Petroleum Assessment 2000: U.S. Geological Survey Digital Data Series DDS–60, 4 CD–ROMs.

Gautier, D.L., Dolton, G.L., Takahashi, K.I., and Varnes, K.L., eds., 1996, 1995 National assessment of United States oil and gas resources—Results, methodology, and supporting data: U.S. Geological Survey Digital Data Series DDS–30, Release 2, 1 CD–ROM.

Klett, T.R., Charpentier, R.R., and Schmoker, J.W., 2000, Assessment operational procedures, in U.S. Geological Survey World Energy Assessment Team, eds., U.S. Geological Survey World Petroleum Assessment 2000: U.S. Geological Survey Digital Data Series DDS–60, 4 CD–ROMS.

Schmoker, J.W., 1996, Method for assessing continuous-type (unconventional) hydrocarbon accumulations, *in* Gautier, D.L., Dolton, G.L., Takahashi, K.I., and Varnes, K.L., eds., 1995 National assessment of United States oil and gas resources—Results, methodology, and supporting data: U.S. Geological Survey Digital Data Series DDS–30, Release 2, 1 CD–ROM.

Schmoker, J.W., 1999, U.S. Geological Survey assessment model for continuous (unconventional) oil and gas accumulations—The "FORSPAN" model: U.S. Geological Survey Bulletin 2168, 9p. [Available only on-line at URL http://geology.cr.usgs.gov/pub/bulletins/b2168/, accessed on January 15, 2002]

Schmoker, J.W., and Klett, T.R., 1999, U.S. Geological Survey assessment model for undiscovered conventional oil, gas, and NGL resources—The Seventh Approximation: U.S. Geological Survey Bulletin 2165, 7 p. [Available on-line at URL http://geology.cr.usgs.gov/pub/bulletins/b2165/, accessed on January 15, 2002]

Schmoker, J.W., and Klett, T.R., 2000, U.S. Geological Survey assessment model for undiscovered conventional oil, gas, and NGL resources—The Seventh Approximation, *in* U.S. Geological Survey World Energy Assessment Team, U.S. Geological Survey World Petroleum Assessment 2000: U.S. Geological Survey Digital Data Series DDS–60, 4 CD–ROMs.

U.S. Geological Survey National Oil and Gas Resource Assessment Team, 1995, 1995 National assessment of United States oil and gas resources: U.S. Geological Survey Circular 1118, 20 p.

U.S. Geological Survey World Energy Assessment Team, 2000, U.S. Geological Survey World Petroleum Assessment 2000: U.S. Geological Survey Digital Data Series DDS–60, 4 CD–ROMs.