Chapter AM

U.S. GEOLOGICAL SURVEY ASSESSMENT MODEL FOR UNDISCOVERED CONVENTIONAL OIL, GAS, AND NGL RESOURCES—THE SEVENTH APPROXIMATION

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INTRODUCTION

The U.S. Geological Survey (USGS) periodically conducts assessments of the oil, gas, and natural-gas liquids (NGL) resources of areas within the United States and in other regions of the world. The purpose of these assessments is to develop scientifically based estimates of the quantities of petroleum having the potential to be added to proved reserves within some future time frame. Over the years, USGS assessment procedures have not remained static but rather have evolved, as databases, computing power, and geologic knowledge have advanced.

The primary purpose of this report is to document a geology-based assessment model developed by the USGS in1998 for undiscovered oil, gas, and NGL resources that reside in conventional accumulations. Undiscovered resources are those resources postulated from geologic knowledge and theory to exist outside of known fields. Conventional accumulations, for the purpose of this discussion, are defined as discrete, countable deposits commonly delineated by down-dip water contacts. This definition does not incorporate criteria involving factors such as water depth, regulatory status, or engineering techniques

As a shorthand notation, the assessment model developed in 1998 is called here the “Seventh Approximation,” which is a phrase that expresses the evolution of the model as well as the idea that an exact analysis of undiscovered resources cannot be achieved. The Seventh Approximation has an antecedent in the geology-based assessment model for undiscovered conventional accumulations used in the USGS 1995 National Assessment of United States Oil and Gas Resources (Gautier and others, 1995;U.S. Geological Survey National Oil and Gas Resource Assessment Team, 1995).

KEY ASPECTS OF SEVENTH APPROXIMATION

Assessment Units Versus Plays

The USGS 1995 National Assessment (Gautier and others,1995) used plays as the basic level of assessment. A play consists of a group of geologically related petroleum accumulations. Particular emphasis in play analysis is placed on the similarities of the rocks in which the accumulations occur.

Some current USGS petroleum resource assessments are being conducted using subdivisions of the total petroleum system (termed assessment units) as the basic level of assessment. A total petroleum system consists of all genetically related petroleum generated by a pod or closely related pods of mature source rocks. Particular emphasis is placed on the similarities of the fluids of the accumulations. A total petroleum system might equate to a single assessment unit or, if necessary to achieve sufficient homogeneity, be subdivided into two or more assessment units. An assessment unit is thus a mappable volume of rock within the total petroleum system.

The Seventh Approximation serves equally well for the assessment of plays or of assessment units. For consistency, this report is written in terms of assessment units.

Petroleum Volumes Assessed

The objective of the Seventh Approximation assessment model is to provide a means to estimate quantities of undiscovered conventional oil, gas, and natural-gas liquids that have the potential to be added to reserves (proved and inferred) in some specified future time span. These estimated petroleum volumes reside in

fields whose sizes exceed a stated minimum cutoff value for the assessment unit. Terms used in this report such as “undiscovered conventional resources” are understood to be short approximations of this objective.

Note that the geology-based Seventh Approximation does not attempt to predict volumes of conventional resources that will actually be discovered in a given assessment time frame. To do so would require full knowledge of future petroleum economics, exploration technology, and exploration effort at the assessment-unit level. Rather, the Seventh Approximation estimates volumes of conventional resources having the potential to be discovered in the stated time frame.

Computer programs are used in conjunction with the Seventh Approximation to calculate resource estimates. However, assessment results are controlled by geology-based input parameters supplied by assessment geologists who are regional experts, and not by computer-generated statistical projections of historical trends.

Assessment Time Frame (Forecast Span)

For the USGS 1995 National Assessment, forecasts were developed for undiscovered conventional technically recoverable resources without regard for the time span that might be required to realize them. Because the forecast span of the 1995 National Assessment was unlimited, the question of “when?” was not directly addressed. However, the issue of forecast span is incorporated into the Seventh Approximation.

At one extreme, forecast spans in the range of 5–10 years are rather short for geology-based assessments. For such limited time frames, statistical projections of

historical data trends might be the better assessment approach. At the other extreme, forecast spans exceeding 50 years or so seem to be too long when applied to the highly technical petroleum industry. The economic and technical foundations of the industry at that future time will likely be decoupled from the paradigms of the present day.

For the current USGS World Energy petroleum assessment, a forecast span of 30 years—approximately one generation—has been adopted. For the World Energy assessment, a 30-year forecast span appears to represent a suitable balance among factors such as assessment reliability, long-term planning requirements, financial decisions, and relevance to the human condition.

A particular forecast span, such as 30 years, should not be interpreted too literally. An algorithm does not exist for calculating conventional resources having the potential to be discovered in the next 30 years, as opposed to the next 29 or 31 years, for example. It is more appropriate to equate forecast span to the idea of a societally relevant resource inventory.

In a given time frame, access to a particular assessment unit for petroleum-related activities might not be certain, for political(for example, an ecologically sensitive area) or physical (for example, extreme water depths) reasons. In such cases, undiscovered accumulations hypothesized on the basis of geologic considerations might not actually be available to society. In the Seventh Approximation, a probability for access during the forecast span is assigned to the assessment unit. Such an access probability was not necessary in the 1995 National Assessment because, in an unlimited time frame, all areas are considered eligible for petroleum-related activities.

The specification of a forecast span also impacts estimates of undiscovered conventional resources through the initial choice of petroleum accumulation categories to be assessed (as examples, gas hydrates, heavy oil, small fields, and fields in deepwater). Petroleum resources can be subjectively visualized as forming a pyramid, with a relatively small volume of resources in high-quality accumulation categories near the top of the pyramid and increasing volumes of resources in progressively lower quality accumulation categories towards its base (fig. AM-1). As discussedby McCabe (1998), a particular forecast span can be depicted as a slice through the resource pyramid at some quality level (fig. AM-1). Accumulation categories below the slice are not considered to be viable in the time frame of the forecast span and are excluded from assessment consideration.

Allocations of Assessed Resources

An assessment unit can include within its boundaries a variety of land entities, such as countries, States, surface and mineral ownerships, parks, or wetlands. As part of the Seventh Approximation, undiscovered conventional resources can be allocated by volume percent among various land entities within the assessment unit, as well as to the offshore portion of each entity, if applicable. This allocation component permits customized resource assessments to be compiled. For example, an estimate of undiscovered conventional resources underlying Federal lands in the western United States could be compiled from allocations made at the assessment-unit level.

Probabilistic Approach to Resource Assessment

Many of the numerical parameters that make up the input data set of the Seventh Approximation are represented by probability distributions rather than by single

(point) values. Estimates of undiscovered conventional resources derived from these input data are probability distributions as well.

The probability distributions for some input parameters represent the uncertainty of a fixed value (such as the probability distribution for number of undiscovered fields). In other cases, input probability distributions represent values that are inherently variable (such as the probability distribution for sizes of undiscovered fields).

Minimum (F_{100}), maximum (F_{o}), and median (F_{50}) fractiles are supplied for all input parameters represented by probability distributions. These input fractiles are not specifically linked to a particular type of probability distribution (lognormal, for example).The choice of probability-distribution type is an operational decision that is not constrained by the Seventh Approximation.

OVERVIEW OF ASSESSMENT PROCEDURE

To begin an assessment using the Seventh Approximation, a geologically defined total petroleum system is dividedinto reasonably homogeneous assessment units. Assessment units are then considered individually, as outlined by the flow diagram of figure AM-2.

The essence of the assessment procedure is as follows:

- A minimum field size, which relates in part to the forecast span, is chosen for the assessment unit. Resources in fields smaller than the minimum size are excluded from the assessment.

- Probabilities for the occurrence of adequate charge, adequate rocks, and adequate timing for at least one undiscovered field of minimum size or greater are assigned to the assessment unit (geologic risk). The probability that petroleum-related activities necessary for the discovery of at least one field of sufficient size will be possible in the assessment unit during the forecast span is also assigned (access risk).

- The number of undiscovered oil fields and gas fields in the assessment unit greater than or equal to the minimum field size and the grown sizes of these fields are estimated. Grown undiscovered field size equals reserves estimated at the time of discovery plus any reserves anticipated to be added (or subtracted) as a field is exploited after discovery.

- Ratios of gas/oil and NGL/gas for undiscovered oil fields and of NGL/gas and oil/gas (or alternatively a single ratio of liquids/gas) for undiscovered gas fields are estimated. These ratios are used to assess the coproducts associated with oil in oil fields and gas in gas fields.

- The combination of geologic and access probabilities, number of undiscovered fields, sizes of undiscovered fields, and coproduct ratios yields probability distributions for undiscovered conventional oil, gas, and NGL resources.

- Undiscovered conventional resources are partitioned among various land entities within the assessment unit, and also their offshore areas, using allocation percentages estimated by the assessment geologist.

INPUT DATA FORM

As a means of providing additional information about the Seventh Approximation, the basic input data form is shown in figure AM-3a and b. This data form can be modified for specific assessments, but its fundamental elements are fixed.

Identification Information

The first section of the data form (fig. AM-3a) is for identification information and brief notes relevant to the assessment. Names and numbers can be established for a hierarchy of areas that range downward in size to the total petroleum system and then to the assessment unit.

Characteristics of Assessment Unit

Minimum field size and assessment-unit probabilities (both discussed in the preceding section) are essential elements of the assessment model and must be specified in the second section of the data form (fig. AM-3a). The additional information requested in this section falls into the category of useful information for the resource-assessment process:

- Classification of the assessment unit as oil prone or gas prone.

- Number of discovered fields in the database(s) exceeding minimum size, and classification of the assessment unit according to exploration maturity.

- Median sizes of discovered fields exceeding minimum size, subdivided into three groups according to date of discovery(discovery thirds).

Established (>13 fields discovered) and frontier (1–13 fields discovered) assessment units are confirmed in that the geologic elements of the total petroleum system are known to be effectual. Established assessment units have enough discovered fields for historic field-level data to be of help in postulating properties of undiscovered fields. For example, the median field sizes of the discovery thirds and their trends through time are factors to consider when estimating the sizes of undiscovered fields.

Undiscovered Fields

The third section of the data form (bottom of fig. AM-3a) represents the core of the Seventh Approximation. This section captures the assessment geologist's hypotheses regarding the number and sizes of undiscovered fields in the assessment unit that are of minimum size and larger. A number of techniques canbe employed to assist in making the required estimates of F_{100}, F_{50}, and F_{0} for the number and sizes of undiscovered fields. These techniques include reservoir-simulation modeling, discovery-process modeling, application of geologic analogs, spatial analysis such as sequence stratigraphy and global tectonics, and study of the total petroleum system.

Average Coproduct Ratios

The next part of the data form (top of fig. AM-3b) is for the ratios necessary to assess coproducts associated with oil in oil fields and gas in gas fields. For oil fields, the necessary ratios are those of gas/oil and NGL/gas. For gas fields, the necessary ratios are those of liquids/gas, or alternatively, NGL/gas and oil/gas. Ratios are expressed as three fractiles (F_{100}, F_{50}, and F_{0}) in recognition of the uncertainty inherent in estimating average properties of undiscovered fields.

Selected Ancillary Data

The fifth section of the data form (fig. AM-3b) establishes a modest set of ancillary data useful for economic and environmental analysis of assessment results. The ancillary data for undiscovered oil fields are API gravity of oil, sulfur content of oil, drilling depth, and water depth. The ancillary data for undiscovered gas fields are inert-gas content, carbon dioxide content, hydrogen sulfide content, drilling depth, and water depth.

ALLOCATION OF UNDISCOVERED RESOURCES

The final section of the data form (fig. AM-3b) is for information necessary to allocate estimates of undiscovered conventional resources to land entities of interest in the assessment unit, and to the offshore portions of these entities. The volume percent of assessed resources assigned to an entity need not match the areal percent of that entity. Because allocated resources should add up to the assessment-unit total, operational considerations might dictate that allocation percentages be supplied as point estimates rather than as fractiles of a probability distribution.

SUMMARY

The Seventh Approximation is a resource-assessment model that provides a strategy for estimating volumes of undiscovered conventional oil, gas, and natural-gas liquids that have the potential to be added to reserves (proved and inferred) within a specified future time frame. These potential resources reside in fields having sizes greater than or equal to a stated minimum field size.

The Seventh Approximation is a geology-based assessment model. The information required for estimation of undiscovered conventional resources is supplied by earth scientists who are knowledgeable about the petroleum geology of

the area under consideration. These regional experts complete a form (fig. AM-3a,b) for each assessment unit of a total petroleum system (or alternatively, for each play of an area). This form is the source of data necessary for assessment calculations.

REFERENCES CITED

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

McCabe, P.J., 1998, Energy resources—Cornucopia or empty barrel?: American Association of Petroleum Geologists Bulletin, v. 82, no. 11,p. 2110–2134.

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.

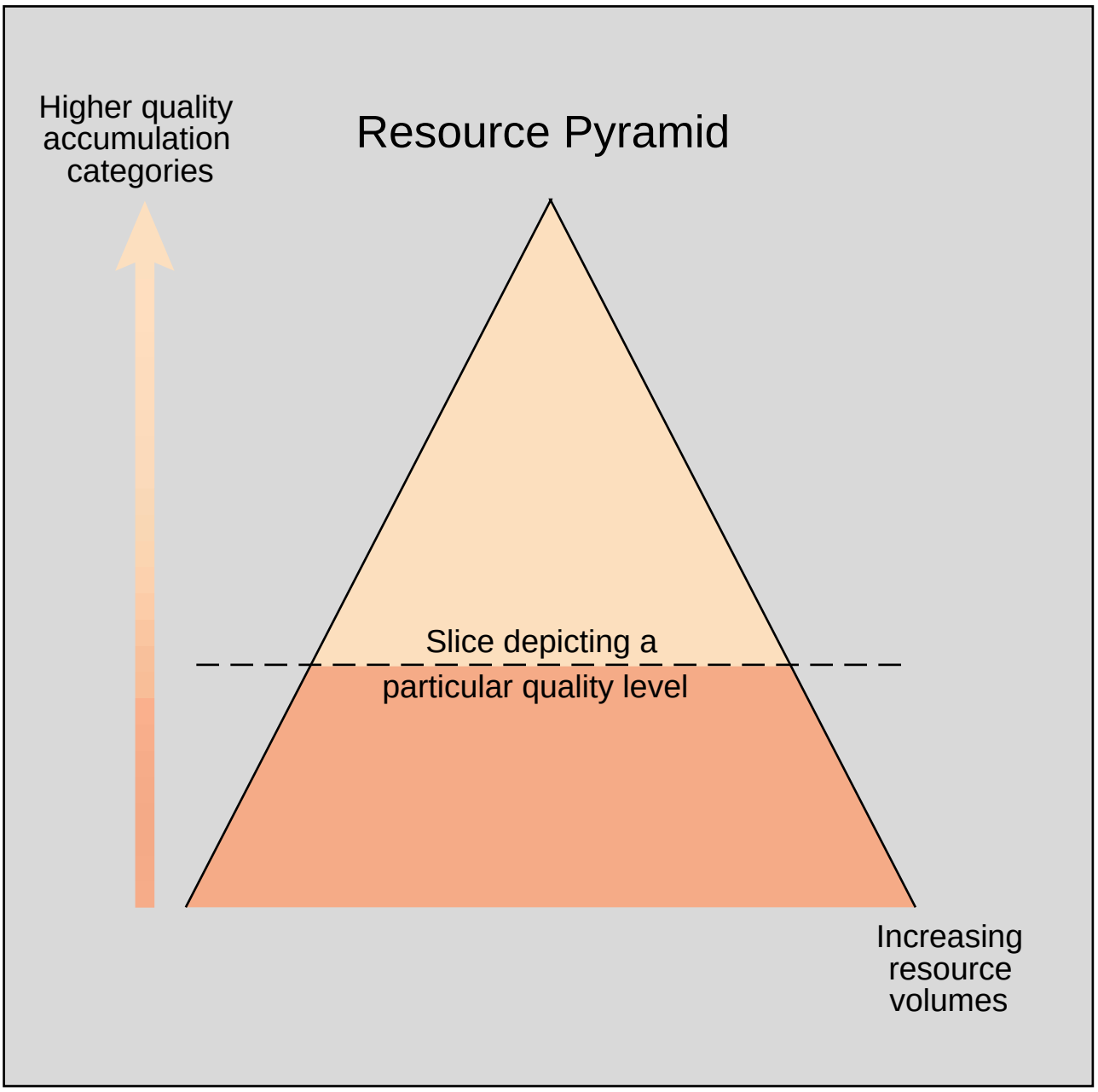

Figure AM-1. Two-dimensional depiction of a petroleum resource pyramid. A given resource-assessment forecast span can be visualized as a slice through the resource pyramid at some quality level. Accumulation categories below the slice are excluded from assessment consideration. (Modified from McCabe, 1998.)

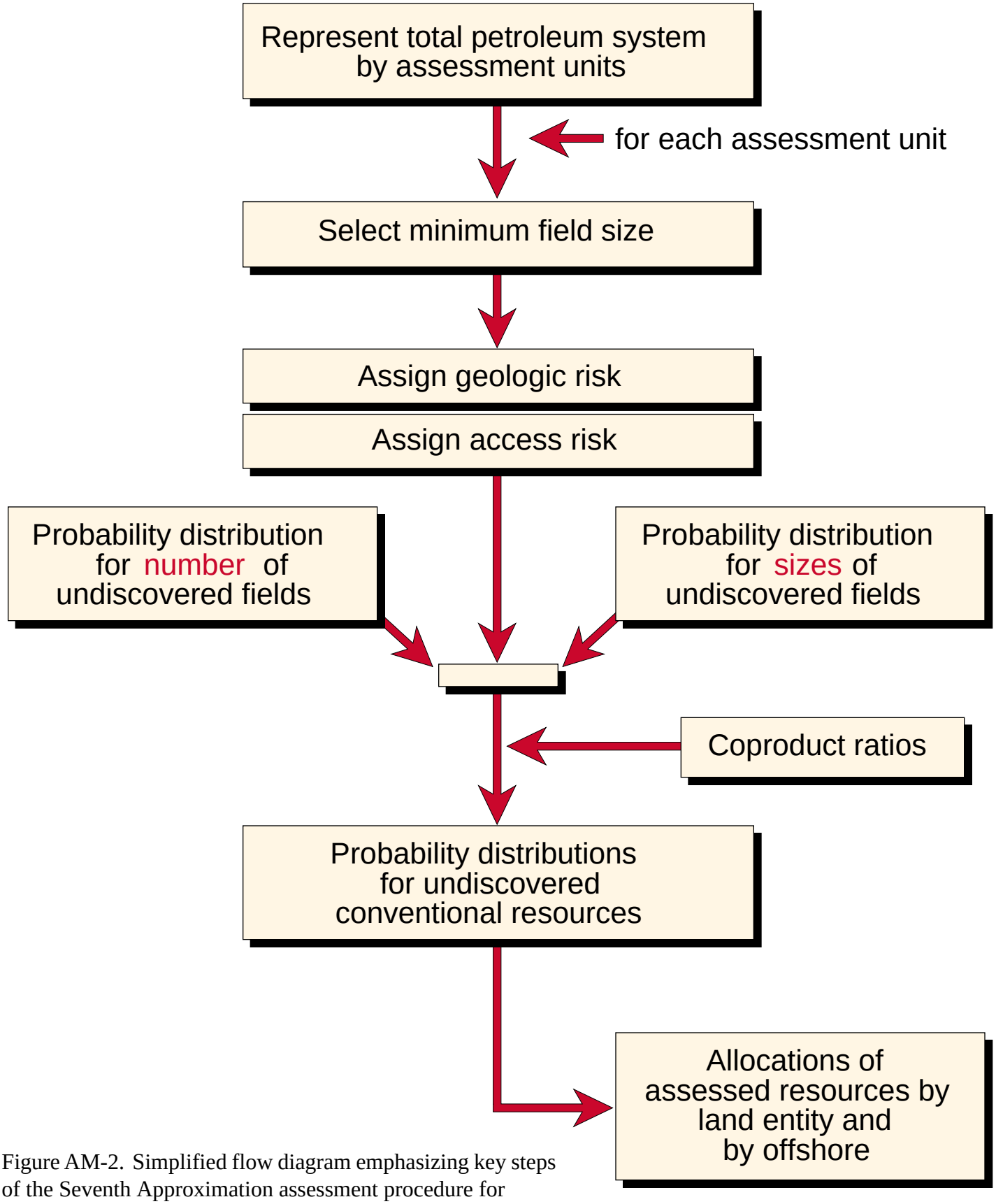

Figure AM-2. Simplified flow diagram emphasizing key steps of the Seventh Approximation assessment procedure for undiscovered conventional resources.

SEVENTH APPROXIMATION--BASIC INPUT DATA FORM

IDENTIFICATION INFORMATION

Date:……

Assessment Geologist:……..

Region:…… Number:

Province:…… Number:

Total Petroleum System:…… Number:

Assessment Unit:…… Number:

Notes from Assessor:……

CHARACTERISTICS OF ASSESSMENT UNIT

What is the minimum field size?…….. _____ mmboe grown (6000 cfg = 1 bo)

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

Number of discovered fields exceeding minimum size:…… Oil: _____ Gas: _____

Established (>13 fields) _____ Frontier (1-13 fields) _____ Hypothetical (no fields) _____

Median size (grown) of discovered oil fields (mmbo):

1st 3rd discovered _____ 2nd 3rd _____ 3rd 3rd _____

Median size (grown) of discovered gas fields (bcfg):

1st 3rd discovered _____ 2nd 3rd _____ 3rd 3rd _____

Assessment-Unit Probabilities:

Attribute	Probability of occurrence (0-1.0)
1. **CHARGE:** Adequate petroleum charge for an undiscovered field ≥ minimum size……	
2. **ROCKS:** Adequate reservoirs, traps, and seals for an undiscovered field ≥ minimum size.....	
3. **TIMING:** Favorable geologic timing for an undiscovered field ≥ minimum size……	
Assessment-Unit GEOLOGIC Probability (Product of 1, 2, and 3):……	
4. **ACCESS:** Adequate location for necessary petroleum-related activities……	

UNDISCOVERED FIELDS

Number of Undiscovered Fields: How many undiscovered fields exist that are ≥ minimum size?:

(uncertainty of estimating fixed but unknown values)

Oil fields:……min. no. (>0) _____ median no. _____ max no. _____

Gas fields:……min. no. (>0) _____ median no. _____ max no. _____

Sizes of Undiscovered Fields: What are the anticipated sizes (**grown**) of the above fields?:

(inherent natural variability in the sizes of undiscovered fields)

Oil in oil fields (mmbo)…… min. size _____ median size _____ max. size _____

Gas in gas fields (bcfg):…… min. size _____ median size _____ max. size _____

Figure AM-3a. Basic input data form for the Seventh Approximation.

			Assessment Unit (name, no.)					
AVERAGE COPRODUCT RATIOS FOR UNDISCOVERED FIELDS								
(uncertainty of estimating fixed but unknown values)								
Oil fields:				minimum		median		maximum
Gas/oil ratio (cfg/bo)……								
NGL/gas ratio (bngl/mmcfg)……								
Gas fields:								
Liquids/gas ratio (bliq/mmcfg)……								
OR								
NGL/gas ratio (bngl/mmcfg)……								
Oil/gas ratio (bo/mmcfg)……								
SELECTED ANCILLARY DATA FOR UNDISCOVERED FIELDS								
(inherent natural variability in the properties of undiscovered fields)								
Oil fields:				minimum		median		maximum
API gravity of oil (degrees)……								
Sulfur content of oil (%)……								
Drilling depth (m) ……								
Depth (m) of water (if applicable)……								
Gas fields:								
Inert-gas content (%)……								
CO_2 content (%)……								
Hydrogen-sulfide content (%)……								
Drilling depth (m)……								
Depth (m) of water (if applicable)……								
ALLOCATION OF UNDISCOVERED RESOURCES TO LAND ENTITIES								
(uncertainty of estimating fixed but unknown values)								
1. _____ represents _____ areal % of the assessment unit								
Oil in oil fields:				minimum		median		maximum
Volume % in entity……								
Portion of volume % that is offshore (0-100%)……								
Gas in gas fields:								
Volume % in entity……								
Portion of volume % that is offshore (0-100%)……								
(repeat above sequence as necessary to include all land entities of interest)								

Figure AM-3b. Basic input data form for the Seventh Approximation.