U.S. Geological Survey Assessment Model for Continuous (Unconventional) Oil and Gas Accumulations—The "FORSPAN" Model

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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- and engineering-based assessment model developed by the USGS in 1999 for potential additions to reserves of oil, gas, and NGL that reside in continuous (unconventional) accumulations. Potential additions to reserves are those resources in known or in undiscovered accumulations that can be postulated, on the basis of geologic and engineering considerations, to become proved reserves within some specified future time frame. Continuous accumulations, for the purpose of this discussion, are defined as petroleum accumulations that have large spatial dimensions and which lack well-defined downdip petroleum/water contacts: continuous accumulations are not localized by the buoyancy of oil or gas in water (Schmoker, 1995).

As a shorthand notation, the assessment model for continuous accumulations described here is called the "FORSPAN" model, which is a term that expresses the idea of a finite, limited FORecast SPAN for the resource assessment, as opposed to an assessment having an unlimited (or unspecified) time frame. The FORSPAN model has an antecedent in the assessment model for continuous 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).

Geologic Nature of Continuous Accumulations

Continuous petroleum accumulations were defined and quantitatively assessed by the USGS in their 1995 National Assessment (Gautier and others, 1995), under the impetus of the increasing significance of so-called "unconventional" oil and gas resources. Studies emphasizing the geology of continuous oil accumulations and continuous gas accumulations have been published by Schmoker (1996) and Schmoker and others (1996), respectively.

The identification of a continuous accumulation is based upon geologic setting. A geologically grounded definition does not incorporate ephemeral criteria such as special regulatory status or unusual engineering techniques, or arbitrary criteria such as a particular (low) value of matrix permeability or API gravity.

Common geologic characteristics of a continuous accumulation include occurrence downdip from water-saturated rocks, lack of obvious trap and seal, crosscutting of lithologic boundaries, large areal extent, relatively low matrix permeability, abnormal pressure (either high or low), and close association with source rocks. Common production characteristics of a continuous accumulation include large in-place petroleum volume, low recovery factor, absence of truly dry holes, dependence on fracture permeability, and a serendipitous "hit or miss" character for production rates and total recoveries of wells.

As discussed by Schmoker (1995), continuous accumulations are essentially large single fields, having spatial dimensions of many kilometers or miles, that do not owe their existence to the buoyancy of oil or gas in water. Continuous accumulations cannot be counted and analyzed as discrete entities delineated by downdip water contacts, as are conventional fields. Rather, for purposes of resource assessment, the petroleum of a continuous accumulation can be envisioned as residing in cells. From this point of view, a continuous accumulation is a collection of petroleum-containing cells, virtually all of which are capable of producing some oil or gas, but which vary significantly in their production (and thus economic) characteristics.

Resources assessed as continuous accumulations in the USGS 1995 National Assessment (Gautier and others, 1995) included such diverse accumulation categories as tight gas, coalbed gas, oil and gas in shale, oil and gas in chalk, basin-center gas, and shallow biogenic gas.

In the traditional terminology of petroleum resource assessment, undiscovered resources are those postulated to exist outside of known fields, whereas inferred reserves are those forecast to be added to known fields as they are further developed (that is, reserve growth). However, in the case of continuous accumulations, the distinction between undiscovered resources and inferred reserves can be blurred. For example, in the USGS 1995 National Assessment, the existence and location of many of the continuous accumulations were well known, implying that the assessment procedure was an exercise in estimating reserve growth. However, the existence and location of some of the continuous accumulations were not at all certain, but were postulated from geologic knowledge and theory, so that the assessment procedure in these cases was an exercise in estimating undiscovered resources.

Key Aspects of FORSPAN Model

Assessment Units Versus Plays

The USGS 1995 National Assessment (Gautier and others, 1995) used plays as the basic level of assessment, for both conventional and continuous accumulations. A play consists of a group of geologically related fields (conventional accumulations) or geologically related cells (continuous accumulations). Particular emphasis in play analysis is placed on the similarities of the *rocks* in which petroleum occurs.

However, 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 in total-petroleum-system analysis is placed on the similarities of the petroleum *fluids* of fields or cells. 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.

For most continuous accumulations, plays as used in the USGS 1995 National Assessment are equivalent to assessment units, because a continuous accumulation is usually associated with a single pod of active source rocks. The FORSPAN model serves equally well for the assessment of plays or of assessment units. For consistency within this report, FORSPAN is discussed in terms of assessment units.

Petroleum Volumes Assessed

The FORSPAN assessment model provides a means to estimate the quantities of oil, gas, and natural-gas liquids in continuous accumulations that have the potential to be added to reserves in some specified future time span. These estimated petroleum volumes reside in cells having total recovery per cell greater than or equal to a stated minimum cutoff value. Terms used in this report such as "potential additions to reserves" are abbreviated expressions of these assessed quantities.

The FORSPAN model does not attempt to predict volumes of petroleum that will actually be added to reserves in a given assessment time frame. To do so would require full knowledge of future petroleum economics and technology, as well as drilling effort at the assessment-unit level. Rather, the FORSPAN model estimates volumes of petroleum in continuous accumulations having the *potential* to be added to reserves in a stated time frame.

Computer programs are used in conjunction with the FORSPAN model to calculate resource estimates. However, assessment results are controlled by geology-based and engineering-based input parameters supplied by geologists and petroleum engineers, 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 potential additions to reserves in continuous accumulations 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 FORSPAN assessment model.

At one extreme, forecast spans in the range of 5–10 years are rather short for assessments that rely heavily on geologic knowledge. For such limited time frames, statistical projections of historical trends might be the better assessment approach. At the other extreme, forecast spans exceeding 50 or 60 years 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.

As an example of a forecast span that appears to represent an acceptable balance with respect to factors such as assessment reliability, long-term planning requirements, financial decisions, and relevance to the human condition, a forecast span of 30 years—approximately one generation—has been adopted for the current USGS World Energy petroleum assessment. A 30-year forecast span is used in this report to help illustrate the FORSPAN model.

A particular forecast span should not be interpreted too literally. An algorithm does not exist for calculating potential additions to reserves in the next 30 years, as opposed to the next 29 or 31 years, for example. It is more appropriate to equate a 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 reasons (for example, an ecologically sensitive area) or physical reasons (for example, extreme water depths). In such cases, the potential additions to reserves postulated to reside in a continuous-type assessment unit on the basis of geologic and engineering considerations might not actually be available to society. In the FORSPAN model, a probability for adequate 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 available for petroleum-related activities.

Cell-Based Approach

A cell is a subdivision or area within an assessment unit having dimensions related to the drainage areas of wells (see last paragraph of this section). A continuous-type assessment unit is thus regarded as a collection of petroleum-containing cells, almost all of which are capable of producing some volume of oil or gas, but which vary significantly in their production characteristics. For purposes of the FORSPAN model, three categories of cells can be identified (fig. 1): (1) cells evaluated by drilling; (2) untested cells; and (3) untested cells having potential to provide additions to reserves within the forecast span of the assessment.

For simplicity, the cells of each category are depicted as contiguous in figure 1, but this is not usually the actual case. Only cells of the third category (those untested cells having potential for additions to reserves within the forecast span) contribute directly to the resource assessment.

Most untested cells having potential for additions to reserves within a forecast span such as 30 years probably will be located in areas where production characteristics are particularly favorable (sweet spots). One or more sweet spots may already be known in an assessment unit. The presence or absence of additional sweet spots might be postulated on the basis of geologic understanding and principles of petroleum engineering.

The specific untested cells having potential for additions to reserves within the forecast span (the equivalent of a "drill here" map) need not be and usually cannot be identified. Instead, the FORSPAN model generates a probabilistic estimate of the number of such cells in the assessment unit.

The area per cell could be equated to drainage area per well. This approach would be well suited for assessment of the remaining potential (including infill drilling) of partially developed sweet spots. In other cases, it might be advantageous to equate the area per cell to larger parcels such as multiple-well development units.

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 FORSPAN assessment model, potential additions to reserves 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 potential additions to reserves in continuous accumulations 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 FORSPAN model are represented by probability distributions rather than by single (point) values. Estimates of potential additions to reserves 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 total assessment-unit area). In other cases, input probability distributions represent values that are inherently variable (such as the probability distribution for total recovery of oil or gas per cell).

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 particular types of probability distributions (lognormal, for example). The choice of probability-distribution types is an operational decision.

Overview of Assessment Procedure

To begin an assessment using the FORSPAN model, a continuous accumulation is divided into reasonably homogeneous assessment units. Assessment units are then considered individually, as outlined by the flow diagram of figure 2*A*.

The essence of the assessment procedure is as follows:

- A minimum total recovery of oil or gas per cell is chosen for the assessment unit. Oil or gas in cells expected to have total recoveries less than the minimum is excluded from the assessment.
- Probabilities for the occurrence of adequate charge, adequate rocks, and adequate timing to form a continuous accumulation with at least one untested cell having total recovery greater than or equal to the minimum are assigned to the assessment unit (geologic risk). The probability that necessary petroleum-related activities for the development of at least one untested cell of sufficient total recovery will be possible is also assigned (access risk).
- The number and the total recovery per cell of untested cells having potential for additions to reserves within the forecast span are estimated.
- For oil accumulations, ratios of gas/oil and NGL/gas are estimated. For gas accumulations, the ratio of liquids/gas is estimated. These ratios are used to assess the coproducts associated with oil in oil accumulations and gas in gas accumulations.
- The combination of geologic and access probabilities, number of untested cells, total recovery per untested cell, and coproduct ratios yields probability distributions for potential additions to reserves of oil, gas, and NGL.
- Potential additions to reserves are allocated by volume percent among various land entities within the assessment unit, and also to the offshore areas of these entities, using allocation percentages estimated by the assessor.

Figure 2*B* provides more detail on the procedure for developing a probability distribution for the number of untested cells in the assessment unit having potential for additions to reserves within the forecast span. This probability distribution results from the combination of three probability distributions (fig. 2*B*): (1) total assessment-unit area; (2) percentage of total assessment-unit area that is untested and has potential for additions to reserves within the forecast span; and (3) area per cell of untested cells having potential for additions to reserves within the forecast span.

Input Data Form

The basic input data form developed to capture data required by the FORSPAN assessment model is shown here as figure 3. This data form can be modified for specific assessments, but its fundamental elements are fixed.

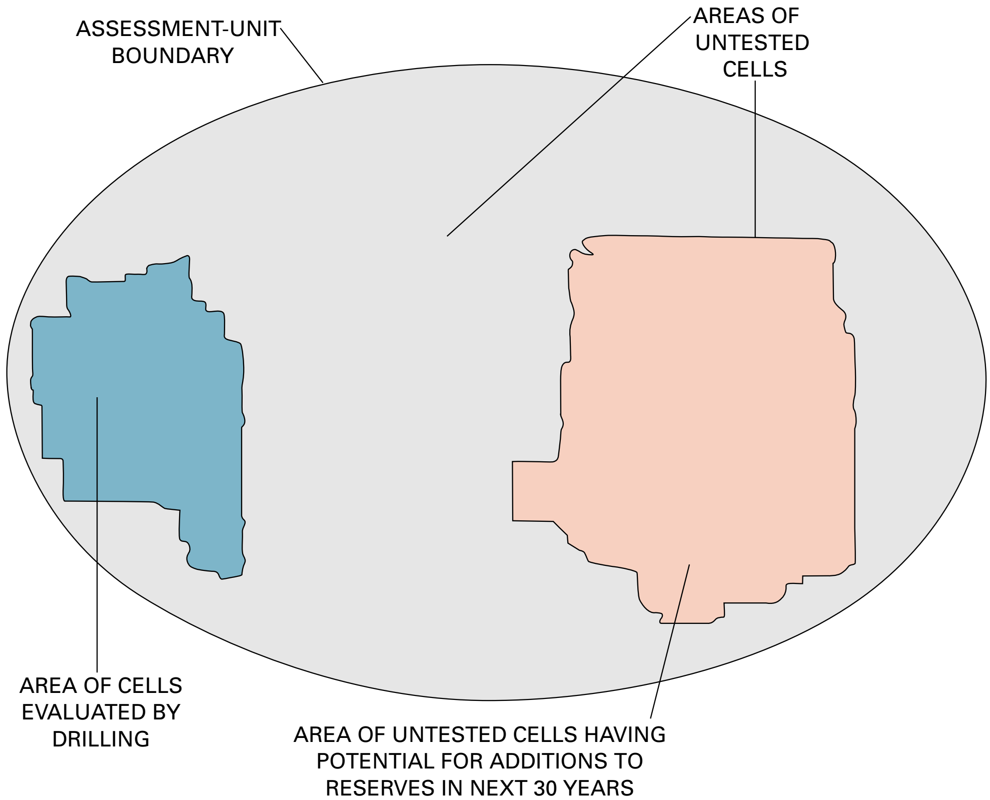

Figure 1. Depiction of three resource-assessment categories for cells of a continuous-type assessment unit. In this example, the forecast span of the resource assessment is 30 years.

Identification Information

The first section of the data form (fig. 3, top of p. 8) is for identification information and brief notes relevant to the assessment. A hierarchy of assessment-related areas can be established that range downward in size to the total petroleum system and then to the assessment unit. The numbering system for these areas can also follow a hierarchical scheme.

Characteristics of Assessment Unit

In the second section of the data form, the assessment unit is classified as representing an oil accumulation or a gas accumulation. Minimum total recovery per cell and assessment-unit probabilities are also entered. Other data requested in this section of the form fall into the category of useful information for the resource-assessment process:

- Number of cells evaluated by drilling.
- Number of evaluated cells having total recovery per cell equal to or exceeding the minimum, and a classification of the exploration and development maturity of the assessment unit according to the number of such cells (established, frontier, or hypothetical).
- Median total recovery per cell for the first-third, second-third, and third-third of cells drilled (“discovery” thirds).

Number of Untested Cells

The third section of the data form (fig. 3, bottom of p. 8) captures the assessor’s hypotheses regarding the variables that lead to 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 the assessment. Minimum, median, and maximum values (F_{100}, F_{50}, and F_0 fractiles) are estimated for each of the following variables:

- *Total assessment-unit area (acres).* The three fractiles represent the uncertainty of a fixed value. Most of this uncertainty reflects geologic problems associated with defining the boundaries of an assessment unit, rather than errors in planimetering an area drawn on a map.
- *Percentage of the total assessment-unit area that is untested.* The three fractiles represent the uncertainty of a fixed value. This percentage is not used directly in FORSPAN calculations, but is a helpful intermediate step in the assessment process.
- *Percentage of the total assessment-unit area that is untested and has potential to provide additions to reserves within the forecast span.* The three fractiles represent the uncertainty of a fixed value. As discussed in a previous section, expectations for this percentage can be linked to geologic and engineering concepts for the existence and producing characteristics of sweet spots.

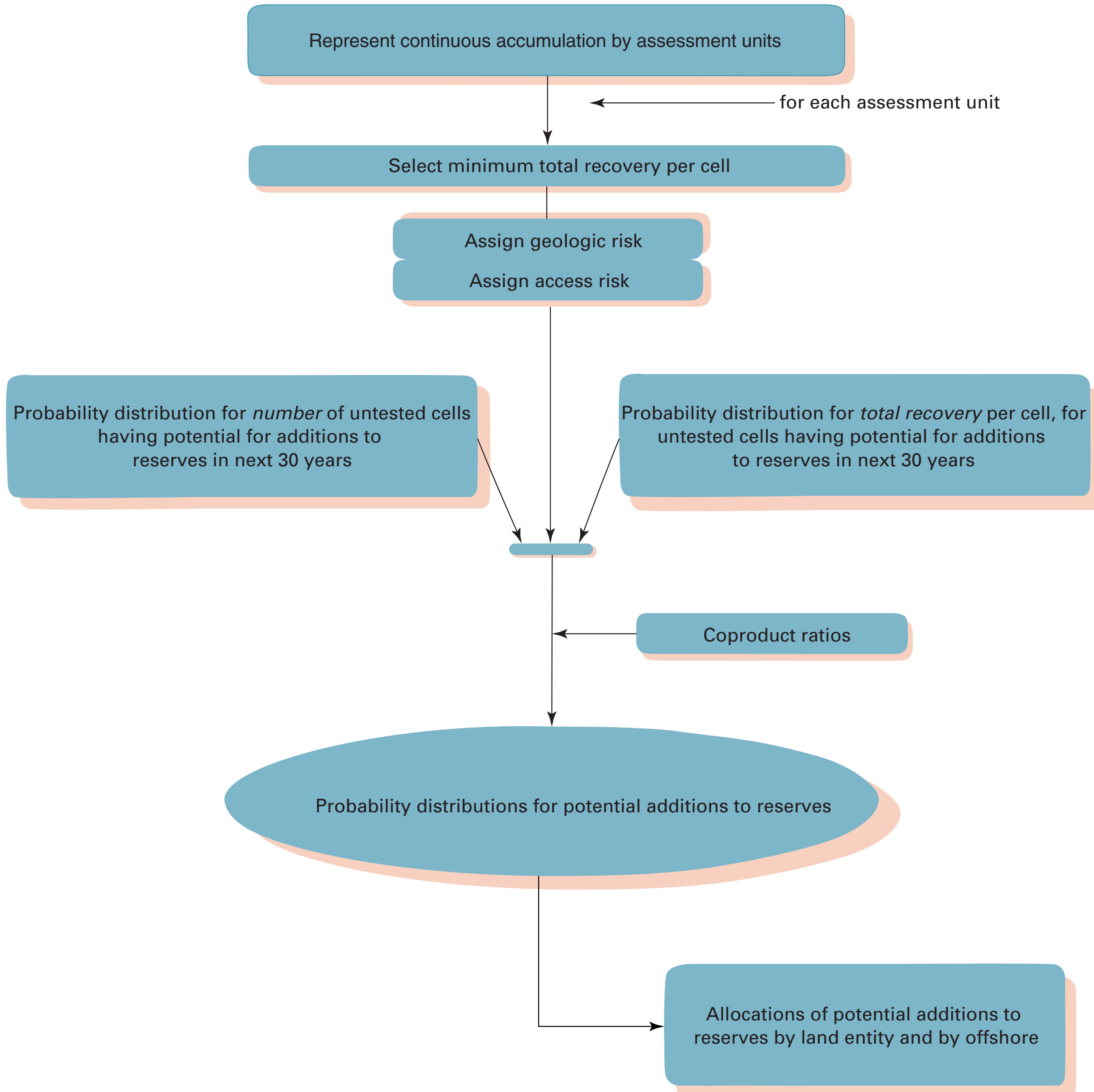

Figure 2. Flow diagram emphasizing key steps of the FORSPAN assessment procedure for continuous oil and gas accumulations. In this example, the forecast span of the resource assessment is 30 years. *A*, Overview of assessment model.

- *Area per cell (acres) of untested cells having potential to provide additions to reserves within the forecast span.* The three fractiles represent values that are inherently variable. Within an assessment unit, area per cell is not likely to be constant, but varies in response to changes in reservoir characteristics.

The three fractiles represent values that are inherently variable. The minimum total recovery per cell (F_{100}) is specified on the first page 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 and (or) in an analog assessment unit.

Total Recovery Per Cell

The fourth section of the data form (fig. 3, top of p. 9) establishes the total recovery (estimated ultimate recovery) of oil or gas per cell, for untested cells having potential to provide additions to reserves within the forecast span of the assessment.

Average Coproduct Ratios

The next section of the data form is for the ratios necessary to assess coproducts associated with oil in oil accumulations or gas in gas accumulations. For oil accumulations, the necessary ratios are those of gas/oil and NGL/gas. For gas accumulations,

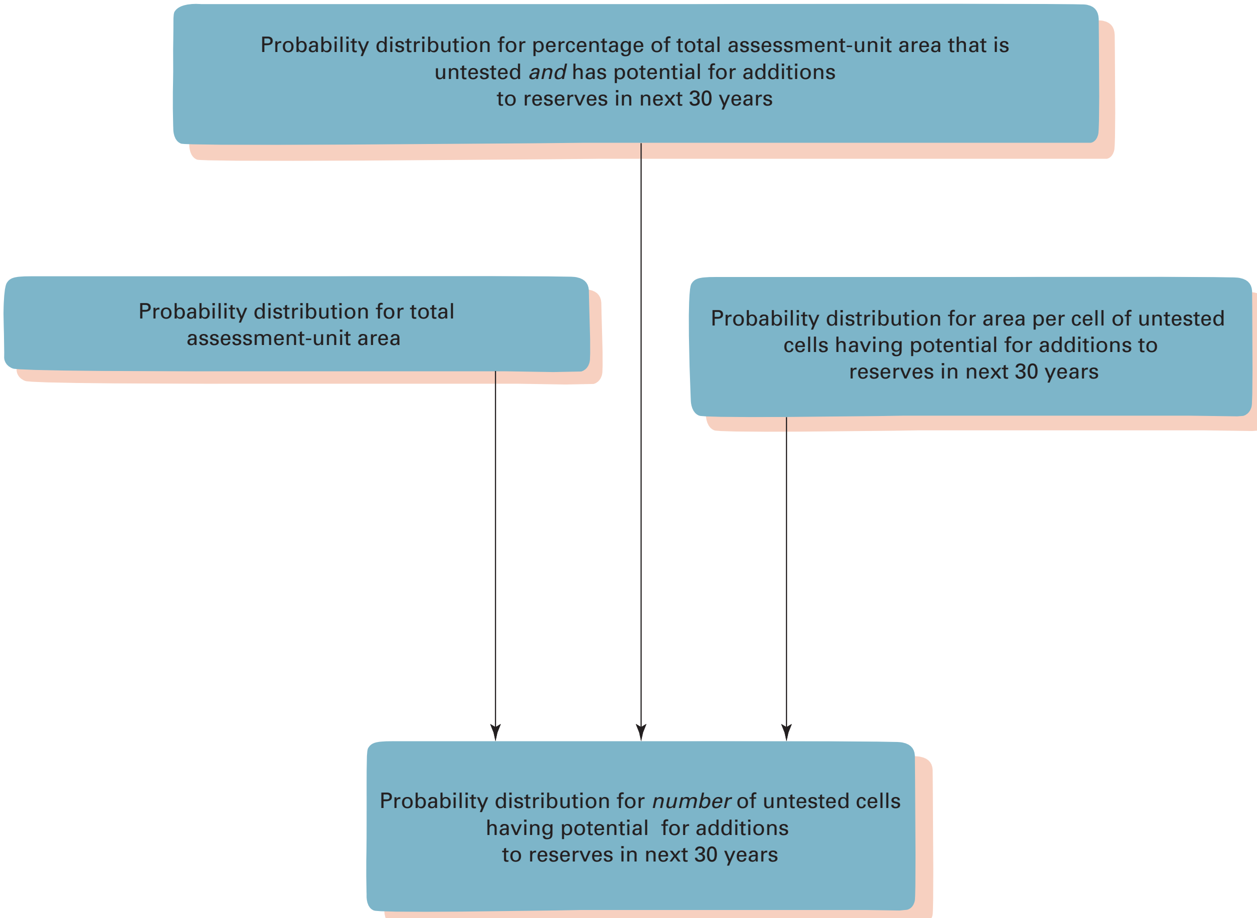

Figure 2—Continued. Flow diagram of the FORSPAN assessment procedure. *B*, Elaboration of part of flow diagram of *A*, showing the data used to develop a probability distribution for number of untested cells having potential for additions to reserves.

the necessary ratio is that of liquids/gas. These ratios are averages for the assessment unit. The three fractiles thus represent the uncertainty of fixed values.

Selected Ancillary Data

The sixth section of the data form establishes a modest set of ancillary data useful for economic and environmental analyses of assessment results. The ancillary data for untested cells in oil accumulations are API gravity of oil, sulfur content of oil, true vertical drilling depth, and water depth. The ancillary data for untested cells in gas accumulations are inert-gas content, carbon dioxide content, hydrogen sulfide content, true vertical drilling depth, and water depth.

Allocations of Potential Additions to Reserves

The final section of the data form (bottom of p. 9) is for information necessary to allocate estimates of potential additions to reserves 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 a land entity does not necessarily 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 (the medians only) rather than as three fractiles.

Summary

FORSPAN is a geology- and engineering-based resource-assessment model for estimating volumes of oil, gas, and natural-gas liquids in continuous accumulations that have the potential to be added to reserves within a specified future time frame. The information required to generate resource forecasts using FORSPAN is supplied by geologists and petroleum engineers who are knowledgeable about the area under consideration. These experts complete an input-data form (fig. 3) for each assessment unit of a continuous accumulation. This form is the source of data necessary for assessment calculations.

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FORSPAN ASSESSMENT MODEL FOR CONTINUOUS ACCUMULATIONS--BASIC INPUT DATA FORM

IDENTIFICATION INFORMATION

Assessment Geologist:........ ______________ Date: ______
Region:........................... ______________ Number: ______
Province:.......................... ______________ Number: ______
Total Petroleum System:...... ______________ Number: ______
Assessment Unit:............... ______________ Number: ______
Notes from Assessor ______________

CHARACTERISTICS OF ASSESSMENT UNIT (A.U.)

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 evaluated cells: ... ______
Number of evaluated 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 NEXT 30 YEARS

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

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

Percentage of total assessment-unit area that is untested **and** 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 ______

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

Figure 3. Basic input data form for FORSPAN assessment model. In this example, the forecast span of the resource assessment is 30 years.

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
(uncertainty of a fixed value)

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)………………….	________	________	________

ALLOCATIONS OF POTENTIAL ADDITIONS TO RESERVES TO LAND ENTITIES
(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%)……	________	________	________

*Repeat above sequence as necessary to include all land entities of interest.

Figure 3—Continued. Basic input data form for FORSPAN assessment model. In this example, the forecast span of the resource assessment is 30 years.