Chapter RG

ESTIMATING POTENTIAL RESERVE GROWTH OF KNOWN (DISCOVERED) FIELDS: A COMPONENT OF THE USGS WORLD PETROLEUM ASSESSMENT 2000

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Table of Contents

INTRODUCTION....................RG-1
KEY ASPECTS OF RESERVE-GROWTH MODEL....................RG-4
Levels of Assessment....................RG-4
Petroleum Volumes Assessed for Reserve Growth....................RG-5
30-Year Time Frame....................RG-7
Dependence of Reserve-Growth Forecasts on Age of Fields....................RG-8
Pros and Cons of an Analog Reserve-Growth Function....................RG-9
Probabilistic Approach to Estimating World Potential Reserve Growth....................RG-13
OVERVIEW OF RESERVE-GROWTH ASSESSMENT PROCEDURE....................RG-16
SUMMARY....................RG-17
REFERENCES CITED....................RG-19
Appendix :Introduction....................RG-21
Retrieve Field Data....................RG-21
Field identification....................RG-21
Calculate Age of Each Field....................RG-22
Adjust Volumes for Reporting Date....................RG-23
Sum Fields and Calculate Differences Between Grown and Known Volumes....................RG-24
Remaining Reserve-Growth Steps....................RG-24
Results....................RG-25

FIGURE AND TABLE CAPTIONS

Figure RG-1. A reserve-growth function (designated the Lower-48-Mean reserve-growth function) derived from the average of the oil reserve-growth function and the gas reserve-growth function used in the USGS

1995 National Assessment of United States Oil and Gas Resources to forecast reserve growth for the Lower 48 United States.

Figure RG-2. Graphical depiction of the forecast strategy for world potential reserve growth, with uncertainty expressed in the form of a symmetrical triangular probability distribution.

Figure RG-3. Simplified flow diagram emphasizing the basic steps used to obtain a forecast of world potential reserve growth for the USGS World Petroleum Assessment 2000.

Appendix figures and tables

Figure RGApp-1. Procedure for adjusting field sizes to the 1995 reference year and then generating a 30-year reserve-growth forecast.

Figure RGApp-2. Forecast for world potential reserve growth of oil (exclusive of the U.S.), with uncertainty expressed in the form of a triangular probability distribution.

Figure RGApp-3. Forecast for world potential reserve growth of gas (exclusive of the U.S.), with uncertainty expressed in the form of a triangular probability distribution.

Figure RGApp-4. Forecast for world potential reserve growth of NGL (exclusive of the U.S.), with uncertainty expressed in the form of a triangular probability distribution.

Table RGApp-1. Known volumes of petroleum and the corresponding grown volumes (excluding the U.S.) estimated for the year 2025.

Table RGApp-2. Fractiles of symmetrical triangular distributions for world potential reserve growth (excluding the U.S.) of oil, gas, and NGL (see also figures A2 to A4).

INTRODUCTION

In the United States and Canada, experience shows that estimates of the sizes (cumulative production plus remaining reserves) of oil and gas fields made at any particular point in time are commonly too low (Arrington, 1960; Attanasi and Root, 1994). As years pass, successive size estimates of groups of fields usually increase in a collective sense, even though the size changes of individual fields through time are extremely variable. The term “reserve growth” as used here, which is synonymous with “field growth”, refers to the increases in estimated sizes of fields that typically occur through time as oil and gas fields are developed and produced. Although only remaining reserves increase in volume, this increase is generally considered to be proportional to the total size of the field.

Reserve growth is a major component—perhaps *the* major component—of remaining U.S. oil and natural-gas resources (Gautier and others, 1995; U.S. Geological Survey National Oil and Gas Resource Assessment Team, 1995; Schmoker and Attanasi, 1997). Projections of the potential reserve growth of known fields have therefore become necessary elements of U.S. petroleum resource assessments.

Such estimates of potential reserve growth usually utilize the age of fields (years since discovery) as a predictive variable, on the assumption that age is a surrogate measure of the various activities, such as infill drilling, water flooding, pressure maintenance, equipment improvement, as well as cumulative production experience, that have been and will continue to be applied to generate reserve growth. A second common assessment assumption is that patterns of past reserve growth form a rationale for modeling patterns of future reserve growth (Lore and others, 1996). These two assumptions are usually adopted out of necessity, because the specific effects of individual contributing factors upon reserve growth are extremely difficult to analyze.

Operators of oil and gas fields in the United States are required to report annually to the U.S. Department of Energy the total production from each of their fields and to provide an estimate of proved reserves. In the United States, proved reserves are rather rigidly defined. Consequently, mathematical models for U.S. potential reserve growth can be developed using good-quality historical data (for examples see Root and others, 1995, and Schmoker and Crovelli, 1998).

Worldwide, however, a set of uniform reporting requirements does not exist. Criteria for the estimation of remaining reserves differ widely from country to country, as do the technical, economic, and political incentives that drive the reserve-growth process. Therefore, patterns of reserve growth for the world as a whole are poorly understood, and the problem of quantitatively estimating world potential reserve growth is formidable.

Nevertheless, reserve growth of significant proportions appears to be occurring in many areas of the world. As a quantitative example, Attanasi and Root (1993) and Root and Attanasi (1993) studied statistics of oil fields and gas fields, respectively, located in the Caribbean, Latin America, South America, Western Europe, the Middle East, Africa, non-Communist Asia, and the southwestern Pacific, and reported clear evidence of reserve growth. Referring to these regions, Attanasi and Root (1993) concluded "not only that recent discoveries are substantially understated, but that field growth could become the dominant source of additions to proved reserves in future years." As a qualitative example, the Oil & Gas Journal (1996, p. 37) introduced a special report on worldwide petroleum production with the observation that "the most important reserves trend in the 1990's has been the additions of large volumes through activities other than new-field exploration" -- that is, through reserve growth.

The authors' ongoing studies of changes through time in field-size estimates of some of the world's large oil and gas fields outside the United States also reveal substantial reserve growth. For example, in the 15 years between 1981 and 1996, the estimated total recoverable oil volume in a data set of 186 non-U.S. oil fields having sizes larger than 500 million barrels of oil increased by 26 percent, or about 160 billion barrels of oil. Similarly, the estimated total recoverable gas volume in a data set of 37 non-U.S. fields with more than 3 trillion cubic feet of gas increased by 21 percent, or about 100 trillion cubic feet of gas. During this 15-year period, 166 of the 223 fields studied increased in estimated size.

It seems reasonable to conclude, based on a considerable volume of qualitative and quantitative evidence, that the World Petroleum Assessment 2000 would be incomplete if an effort was not made to forecast world potential reserve growth. The methodology used in that effort is documented in this report.

The forecast of world potential reserve growth described here is considered to be preliminary. Much work remains to be done on the subject of world potential reserve growth. The present study is an attempt to provide a numerical hypothesis for world potential reserve growth that is valuable in itself, and will perhaps act as a stimulus for discussion and research aimed at reducing the uncertainty of world reserve-growth estimates.

KEY ASPECTS OF RESERVE-GROWTH MODEL

Levels of Assessment

The World Petroleum Assessment 2000 forecast of world potential reserve growth was conducted using fields as the basic level of assessment. Oil and gas fields were considered individually, according to their age (that is, years since discovery). The same reserve-growth function (discussed in a following section) was applied to all oil and gas fields.

Applying the same reserve-growth function to all fields implies that account was not made of regional and local variability of reporting systems, reserves definitions, and technical, economic, and political conditions, all of which affect reserve growth. Methodical, worldwide analyses of reserve-growth patterns at regional and local levels offer a way to improve subsequent assessments of world potential reserve growth.

Because the reserve-growth function used was intended to represent world potential reserve growth as a whole and not to reflect the reserve-growth variability of smaller areas, and particularly not the reserve-growth variability of individual fields, forecasts of potential reserve growth are reported only at the world level. Forecasts for lower levels of aggregation were not prepared.

Two different reserve-growth exercises are imbedded in the World Petroleum Assessment 2000. The methodology used to forecast world potential reserve growth is the subject of this report. A somewhat different approach was used to incorporate potential reserve growth into the discovery-history and exploration-history plots generated for each assessment unit (see chapter DS).

Petroleum Volumes Assessed for Reserve Growth

For purposes of the World Petroleum Assessment 2000, potential reserve growth is defined as the quantities of oil, gas, and natural gas liquids (NGL) that have the potential to be added, within 30 years (through 2025), to remaining reserves of known fields, through processes such as field extensions, new-pool discoveries, revisions, and improved recovery efficiencies. For purposes of this assessment, reserve growth is considered only for fields within areas (assessment units) for which forecasts of undiscovered petroleum resources were prepared. Approximately 95 percent of the world's discovered oil and gas (outside the United States) occurs in the defined group of assessment units (chapter RH).

Sources of the field-level data necessary for the reserve-growth assessment were (chapter DS):

- Petroconsultants, Inc., 1996 Petroleum Exploration and Production database (Petroconsultants, 1996).
- NRG Associates, Inc., 1995 Significant Oil and Gas Pools of Canada database (NRG Associates, 1995).

The great majority of the fields included in these databases can be classified as conventional fields, in the sense that they are discrete, countable deposits commonly bounded by downdip water contacts.

The pool-level data of the NRG Associates Canadian database were aggregated to the field level prior to carrying out reserve-growth calculations. The year of discovery for the field was defined as that of the oldest pool in the field.

All fields for which the year of discovery was known, that were not abandoned, and that could be allocated to an assessment unit were grown. (To say that a field was "grown" means that reserve-growth calculations were applied to obtain an estimate for the field's potential size at some stated time in the future, in this case the year 2025.) No minimum field size cutoff was imposed. The volumes of oil, gas, and NGL reported for a field were grown using the same reserve-growth function for each commodity.

The 30-year forecast of world potential reserve growth prepared for the World Petroleum Assessment 2000 was based on reported field sizes as of the end of 1995. However, some fields in the Petroconsultants database and all fields in the NRG Associates Canadian database had a pre-1995 reporting date. In these cases, the reported field size was "adjusted" upward by growing the field from the reporting date to year-end 1995, prior to growing the field an additional 30 years beyond 1995 (see additional discussion in Appendix 1 of this chapter). In a few cases, the reported field size was as of mid-1996; accordingly, these fields were grown for 29 years (rather than 30 years) into the future.

30-Year Time Frame

The forecast span of 30 years that was adopted for reserve-growth estimates in the present study was chosen not only to match that used for estimates of undiscovered resources of the World Petroleum Assessment 2000, but also because it is considered to be a reasonable maximum in its own right. Longer forecast spans for potential reserve growth would seem to be unjustified, given that the economic and technical foundations of the petroleum industry are subject to significant change through time.

The reserve-growth model described here is intended to estimate volumes of petroleum having the *potential* to be added to known fields in the next 30 years. Because of the many indeterminate factors involved, it is not feasible to attempt to predict volumes of petroleum that will *actually* be added to known fields in this time period. To do so would require the ability to predict the future course of the petroleum industry in all of its details.

Dependence of Reserve-Growth Forecasts on Age of Fields

As fields get older, the potential for future reserve growth tends to decrease, as does the sensitivity of reserve growth to field age (fig. RG-1):

- The suite of activities remaining to be employed to generate reserve growth diminishes through time.
- The uncertainty associated with estimates of field size decreases (to zero at the time of field abandonment) as cumulative production increases.

For fields that are only a few years old, the growth multiplier and its rate of change from one year to the next are both relatively high (fig. RG-1). Potential reserve growth for young fields is therefore both large and uncertain on a percentage basis. In contrast, by the time fields reach about 15 years of age, the growth multiplier and its sensitivity to field age have become relatively low (fig. RG-1).

Of the known petroleum volumes assessed for world potential reserve growth, approximately 90 percent of the oil and 84 percent of the gas are in fields more than 15 years old (as of 1995). Thus, most of the world's discovered oil and gas is "old" in the sense of reserve-growth characteristics.

Pros and Cons of an Analog Reserve-Growth Function

A reserve-growth *function* is a numerical model for predicting the future sizes of existing oil and gas fields; it is composed of reserve-growth *factors* that are applied to known field sizes to obtain reserve-growth estimates. Using figure RG-1 as an example, the curve as a whole represents a reserve-growth function and each 30-year growth multiplier is a reserve-growth factor.

The preferred approach to developing a reserve-growth function for the World Petroleum Assessment 2000 forecast of world potential reserve growth would include the following steps:

- Obtain a time series (spanning 10 or more years) of reliable annual estimates of the sizes of world conventional oil and gas fields.
- Arrange these field-size estimates into age classes according to field discovery year.
- Calculate annual fractional changes of the petroleum volumes in each age class.

- Construct a reserve-growth function based on the historical growth patterns established by the sets of annual fractional changes of petroleum volumes.

Detailed descriptions of such an approach have been published by Attanasi and Root (1994) and Attanasi and others (1999) in the context of U.S. reserve-growth functions. For most areas outside the United States and Canada, however, Attanasi and Root (1993) and Root and Attanasi (1993) concluded that successive field-size estimates were not sufficiently reliable and consistent to develop world-level reserve-growth functions.

At the time of the World Petroleum Assessment 2000, available world field-size estimates still appear to be inadequate—in terms of completeness, quality, and internal consistency—to construct a credible world reserve-growth function. That is to say, the preferred approach outlined above to developing a world reserve-growth function cannot be implemented because of data limitations.

Given this conclusion, three reserve-growth options were considered for the World Petroleum Assessment 2000:

1. Defer the forecasting of world potential reserve growth to some future assessment.

2. Forecast potential reserve growth for those relatively few areas of the world where field-size estimates are adequate to establish local reserve-growth functions.
3. Forecast potential reserve growth at the world level by using an analog model that incorporates the reserve-growth experience of the United States.

The third option is the one that has been pursued, on the reasoning that, although the resulting preliminary forecast of world potential reserve growth carries much uncertainty, a greater error would be to not consider world-level reserve growth at all.

The U.S. reserve-growth experience can be found imbedded in sets of annual field-size estimates gathered according to legal reporting mandate by the U.S. Department of Energy from operators of oil and gas fields. These field-level data, which were first collected in 1977, are assembled in an official-use-only database of proprietary information called the Oil and Gas Integrated Field File (OGIFF).

Since 1977, a ready wellhead market generally has been available for oil and gas throughout the conterminous United States. Concurrently, new-field exploration opportunities in the Lower 48 states have become increasingly limited. As a result of these circumstances, a significant portion of the upstream petroleum effort of the past two decades in the Lower 48 states has been invested in activities designed to generate reserve growth. U.S. reserve-growth trends for the Lower 48 states therefore offer insights into patterns of world reserve growth that could potentially occur if world economic conditions justified the intensive levels of field development that have become typical in many parts of the United States.

There are several reasons why a reserve-growth function that is based on historical trends for oil and gas fields in the Lower 48 states could <u>underestimate</u> world potential reserve growth:

- World oil and gas fields might, in effect, be "younger" than U.S. fields of equivalent calendar age and thus have significantly more reserve-growth potential, because of longer time spans on average from discovery to production to full development, and because of a lack of incentives in some areas to pursue intensive field development.
- Future world reserve growth might benefit from better technology than that which resulted in the U.S. historical reserve-growth record.
- A world petroleum shortage might accelerate activities designed to generate reserve growth as compared to the United States during the past few decades.

There are also several reasons why a reserve-growth function based on the Lower 48 states could <u>overestimate</u> world potential reserve growth:

- Engineering criteria for reporting reserves of world oil and gas fields might, in general, be less restrictive than those for the United States, tending to increase known reserves and decrease the potential for reserve growth.

- Reported reserves might be deliberately overstated in some countries, reducing the potential for future reserve growth.
- Large world oil and gas fields might tend to have more substantial development than U.S. fields prior to release of initial field-size estimates, leading to more accurate initial reserves estimates and reducing the potential for future reserve growth.

The balance that will ultimately emerge from these and other influences upon world reserve growth relative to U.S. reserve growth is unclear.

Probabilistic Approach to Estimating World Potential Reserve Growth

In an effort to express the uncertainty inherent in basing a world reserve-growth forecast upon U.S. analogs, estimates of world potential reserve growth for oil, gas, and NGL are presented in the World Petroleum Assessment 2000 as probability distributions. These probability distributions, which represent the uncertainty of a fixed but unknown value, are developed using a scenario-building approach.

By applying a U.S. reserve-growth function such as shown in figure RG-1 to world oil and gas fields, a point estimate for world potential reserve growth is obtained. More optimistic and less optimistic point estimates can be chosen as representative of the range of U.S. reserve-growth than can be interpreted from the OGIFF database. From point estimates such as these, probability distributions representing one or more scenarios for world potential reserve growth of oil, of gas, and of NGL can be developed. Each reserve-growth scenario is defined by a probability-distribution type (triangular, for example), a set of point estimates for world potential reserve growth, and the distribution parameters such as fractiles, mode, or mean that are assigned to the point estimates.

The reserve-growth scenario reported as part of the World Petroleum Assessment 2000 is illustrated in figure RG-2 and is based on the following three assumptions:

- A symmetrical triangular distribution was the probability-distribution type chosen to represent the forecast of world potential reserve growth. Such a distribution is one of the simplest and most effective ways to quantify data if the number of possible results is broad, and the best estimate and skewness are underlain by much uncertainty.
- The point estimate of world potential reserve growth obtained by applying a U.S. reserve-growth function to world oil and gas fields was set equal to the most likely value of the triangular distribution (which is also the mean value and the median value). This assumption embodies the idea that actual reserve-growth patterns of the past offer the best model for the most likely reserve-growth patterns of the future.
- A point estimate of zero world potential reserve growth was set equal to the minimum value of the triangular distribution. The range of possible net world-level reserve growth in the future is broad, and a choice of zero

as the minimum reserve growth, below which no value can exist, best captures this range.

Choosing the minimum and most likely values of the symmetrical triangular distribution for world potential reserve growth automatically defined the maximum value.

The specific U.S. reserve-growth function that was applied to world oil and gas fields is based on historical reserve-growth trends of the Lower 48 states as shown by the OGIFF database. Two such U.S. reserve-growth functions, one for oil fields and another for gas fields, were originally developed for the USGS 1995 National Assessment of United States Oil and Gas Resources (Gautier and others, 1995; Root and others, 1995; data supplied in digital format by E.D. Attanasi, written commun., 1997). These two functions vary from one another by only minor amounts (Attanasi and others, 1999). For simplicity, a composite reserve-growth function was generated by averaging the oil reserve-growth function and the gas reserve-growth function. This composite function is termed here the Lower-48-Mean reserve-growth function, and is the reserve-growth function applied to world oil and gas fields in the World Petroleum Assessment 2000.

OVERVIEW OF RESERVE-GROWTH ASSESSMENT PROCEDURE

The procedure for estimating world potential reserve growth discussed in previous sections of this paper, amplified in Appendix 1, and outlined in the simplified flow diagram of figure RG-3 requires the management of data for many thousands of oil and gas fields. Calculations and data-handling operations are carried out using commercial database and spreadsheet software, installed on personal computers.

The essential steps in the reserve-growth assessment procedure are as follows:

- Necessary field-level data are retrieved for fields in the Petroconsultants and NRG Associates databases.
- Field-level data are checked for completeness and internal consistency. Fields for which adequate data are reported, that are not abandoned, and that are located in an assessment unit for which undiscovered petroleum resources were estimated are used to assemble a reserve-growth dataset.
- The age (years since discovery) of each field in the reserve-growth dataset is calculated. Known volumes are adjusted upward, where necessary, to compensate for reporting dates prior to the end of 1995.
- A reserve-growth function, such as shown in figure RG-1, is applied to each field of the reserve-growth dataset. Summing yields estimates of total grown volumes of oil, gas, and NGL as of year 2025 and total known volumes. The difference between grown volumes and known

volumes yields a (central-tendency) point estimate of world potential reserve growth, for each commodity.

- More optimistic and less optimistic point estimates of world potential reserve growth are chosen with reference to the central-tendency point estimate.
- Probability distributions for world potential reserve growth of oil, gas, and NGL are constructed by selecting a distribution type and then equating the set of point estimates to parameters of the distribution such as fractiles, mean, or mode. Each probability distribution so constructed depicts a scenario for the magnitude and uncertainty range of world potential reserve growth.

SUMMARY

Reserve growth is well documented in the United States and is a major component of the nation's remaining oil and natural-gas resources. Projections of the potential reserve growth of known fields have therefore become important elements of U.S. petroleum resource assessments. These projections are commonly based on historical growth patterns as established by reliable, consistent, annual estimates of field sizes such as those collected in the OGIFF database.

Worldwide, the issue of reserve growth is considerably less tractable. Although significant reserve growth appears to be occurring in many areas, quantitative patterns of reserve growth for the world as a whole have not been established. A major underlying problem is that the reliability, consistency, and continuity of field-size estimates do not appear adequate to develop sound world-level reserve-growth functions.

Nevertheless, U.S. reserve-growth experience and fragmentary world-level data suggest that world reserve growth might well be large enough to be an issue of near-term societal importance. For this reason, forecasts for world potential reserve growth of oil, gas, and NGL, within a 30-year time frame, have been advanced as part of the World Petroleum Assessment 2000.

The strategy for these forecasts is outlined in this report. The approach utilizes analog models that incorporate the reserve-growth history of the United States. Forecasts are presented as probability distributions, in order to encompass the large uncertainties that accompany the issue of world potential reserve growth. It is hoped that this initial effort will stimulate discussion, research, and the collection of data aimed at narrowing these uncertainties.

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APPENDIX 1: Details and results of the USGS World Petroleum Assessment 2000 reserve-growth forecast

INTRODUCTION

Details of the steps taken to estimate potential reserve growth for the world are outlined in subsequent sections, following the procedure shown in figure RG-3. All fields for which the discovery year was reported and was prior to 1996, that were not abandoned, and that could be allocated to one of the assessment units used in the World Petroleum Assessment 2000, were used in the potential-reserve-growth procedure. These fields comprise approximately 95 percent of the world's known (discovered) petroleum outside the United States (97 percent of the oil, 94 percent of the gas, and 94 percent of the NGL).

Results of the World Petroleum Assessment 2000 forecast for world potential reserve growth (excluding the U.S.) are given in tables RGApp-1 and 2 and figures RGApp-2 through 4.

Retrieve Field Data

The following field data were retrieved from the Petroconsultants (1996) and NRG Associates (1995) databases:

Field identification

- Field-discovery year
- Year of last report (or update) of field information

- Oil volume
- Gas volume
- NGL volume

Data were checked and edited to ensure that the following criteria were met:

- Fields could be determined to reside within assessment units
- Fields had reported discovery years
- Fields were discovered before 1996
- Fields had a production status other than abandoned
- Fields had a report year equal to or younger than the discovery year (Report year was assumed to be 1995 if not given in the database (2,077 fields without report year))

The resulting dataset, which excluded fields that did not meet these criteria, contained 13,618 fields that were eligible for application of the reserve-growth algorithm. Of these fields, 8,270 were oil fields, 4,464 were gas fields, 1 contained only NGL, and 883 had no reported petroleum volumes. The total volumes of petroleum in the reserve-growth dataset are 1,398 BBO, 5,519 TCFG, and 75 BBNGL (table RGApp-1).

Calculate Age of Each Field

The field age (years since discovery, YSD) was calculated by subtracting discovery year from the report year. For purposes of reserve growth, the age of a field was not calculated relative to some fixed point in time, but rather, relative to the time at which field information was last reported (or updated). Years since discovery was used to determine the appropriate reserve-growth multiplier to be applied to known petroleum volumes.

Adjust Volumes for Reporting Date

Because the effective date of the World Petroleum Assessment 2000 is the end of 1995, sizes of fields having a report year prior to 1995 needed to be "normalized" to a uniform report date -- that is, to the end of 1995. Accordingly, the difference in years between 1995 and the report year was calculated, and as illustrated in figure RGApp-1, this difference was used to determine the number of years of growth that should be applied in order to estimate the field size in the year 2025 (a 30-year forecast span relative to the effective assessment date of 1995). Application of a reserve-growth multiplier for a span other than 30 years (based on the report-year adjustment) had the effect of adjusting the field size to one appropriate for a 1995 reporting date. Such adjustments were made for report years from 1985 through 1996 (fig. RGApp-1). For report years prior to 1985 (691 fields), a 10-year adjustment was assumed, so that reserve growth never exceeded a 40-year span.

Apply Reserve-Growth Function (U.S. Analog)

Spreadsheet tables of growth multipliers based on the Lower-48-Mean reserve-growth function (such as illustrated in figure RG-1) were prepared for report years from 1985 through 1996. Each table contained growth multipliers for fields from 0 to 90 years old. All growth multipliers for fields older than 90 years were equal to 1.00, meaning that fields older than 90 years did not grow. “Grown” oil, gas, and NGL volumes are the product of known (reported) volumes and the growth multiplier that is appropriate for the age and the report year of each field.

Sum Fields and Calculate Differences Between Grown and Known Volumes

The difference between the sum of the grown petroleum volumes and the sum of the known petroleum volumes of individual fields yields a calculated value for world potential reserve growth, as of the year 2025. The known volumes, grown volumes, and potential reserve growth are shown in table RGApp-1. The calculated value for world potential reserve growth, based on the U.S. analog growth function, is here set equal to the expected (mean) value of a probability distribution.

Remaining Reserve-Growth Steps

At this point in the elaboration of the flow diagram of figure RG-3, the reader is referred to the section in the main text labeled “Probabilistic Approach to Estimating World Potential Reserve Growth.” This section describes the choice of a triangular distribution to represent the uncertainty inherent in estimates of world potential reserve growth, and the development of a scenario-based reserve-growth forecast.

Results

The complete World Petroleum Assessment 2000 forecast for world potential reserve growth (excluding the U.S.) is provided in table RGApp-2. Graphical depictions of the reserve-growth estimates for oil, gas, and NGL (excluding the U.S.) are shown in figures RGApp-2, RGApp-3, and RGApp-4, respectively. Implications of the reserve-growth forecast are discussed in the context of the entire world assessment in the chapter on Analysis of Assessment Results (AR).

Table RGApp-1. Known volumes of petroleum and the corresponding grown volumes (excluding the U.S.) estimated for the year 2025. [The expected (mean) potential reserve growth for the 30-year forecast span is the difference between the grown and known volumes]

	Oil (BBO)	Gas (TCFG)	NGL (BBNGL)
Known Volume	1,398	5,519	75
Grown Volume (Expected)	2,010	8,824	117
Potential Reserve Growth (Expected)	612	3,305	42
Percent Increase from Known Volume	44	60	56

Table RGApp-2. Fractiles of symmetrical triangular distributions for world potential reserve growth (excluding the U.S.) of oil, gas, and NGL (see also figures RGApp-2, 3, 4). [Fractiles other than F_{100}, F_{50}, and F_0 were calculated using Monte Carlo simulation with 50,000 trials and do not precisely match those that would be calculated using probability theory]

	World Potential Reserve Growth		
Fractile	Oil (BBO)	Gas (TCFG)	NGL (BBNGL)
F_{100}	0	0	0
F_{95}	192	1,049	13
F_{90}	275	1,457	19
F_{85}	337	1,795	23
F_{80}	390	2,069	26
F_{75}	436	2,316	30
F_{70}	477	2,545	33
F_{65}	514	2,750	35
F_{60}	550	2,942	38
F_{55}	581	3,119	40
F_{50}	612	3,305	42
F_{45}	642	3,462	44
F_{40}	676	3,643	47
F_{35}	712	3,836	49
F_{30}	750	4,036	52
F_{25}	790	4,256	55
F_{20}	836	4,505	58
F_{15}	888	4,784	61
F_{10}	951	5,115	65
F_5	1,031	5,543	71
F_0	1,224	6,610	84

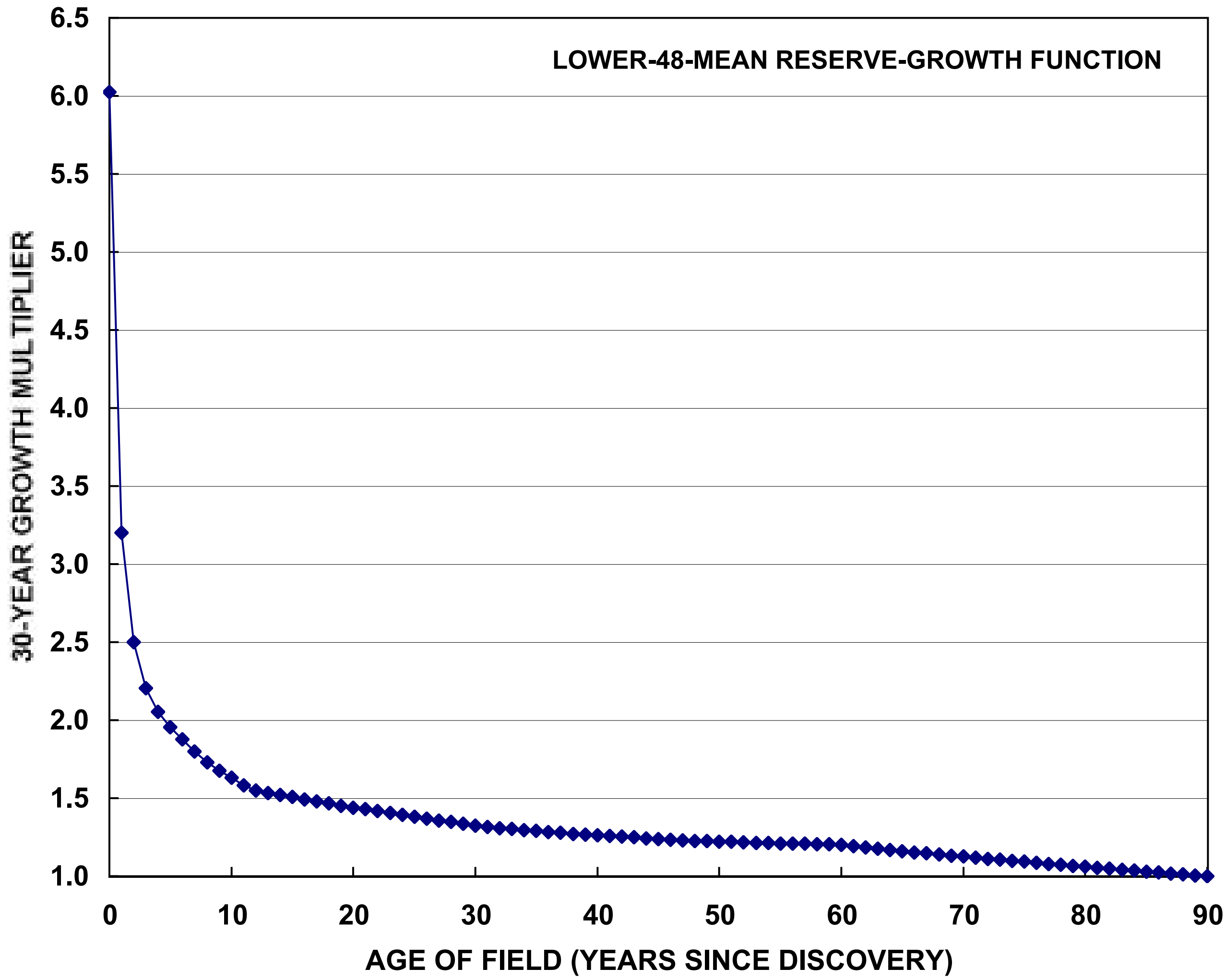


Figure RG-1. A reserve-growth function (designated the Lower-48-Mean reserve-growth function) derived from the average of the oil reserve-growth function and the gas reserve-growth function used in the USGS 1995 National Assessment of United States Oil and Gas Resources to forecast reserve growth for the Lower 48 United States (Gautier and others, 1995; Root and others, 1995; data supplied in digital format by E.D. Attanasi, written commun., 1997). To grow a field for 30 years, known petroleum volumes are multiplied by the appropriate 30-year growth multiplier (or factor), selected according to the age of the field.

World Potential Reserve Growth Model

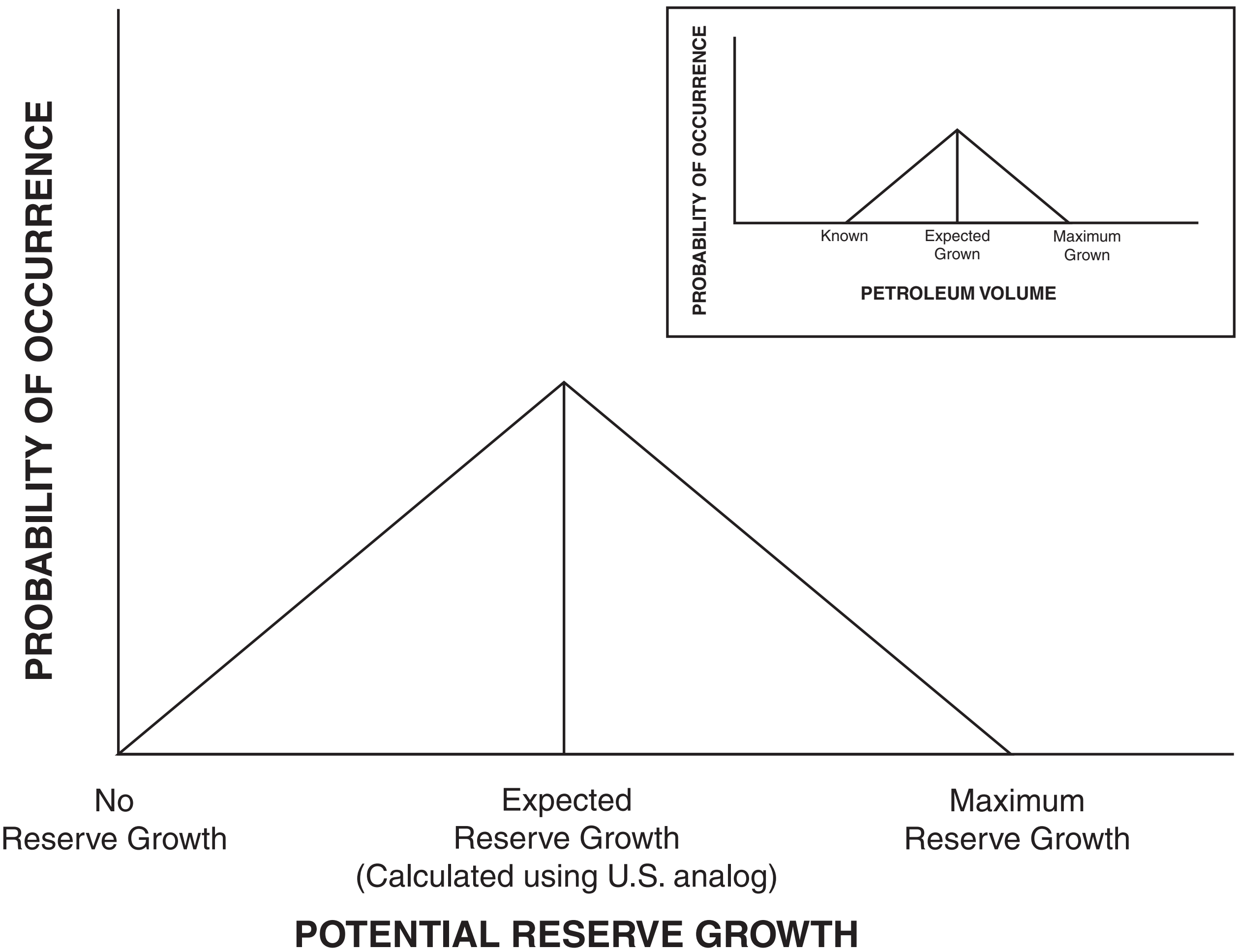


Figure RG-2. Graphical depiction of the forecast strategy for world potential reserve growth, with uncertainty expressed in the form of a symmetrical triangular probability distribution. Inset shows the potential increase in known petroleum volume predicted by the reserve-growth forecast.

World Potential Reserve Growth

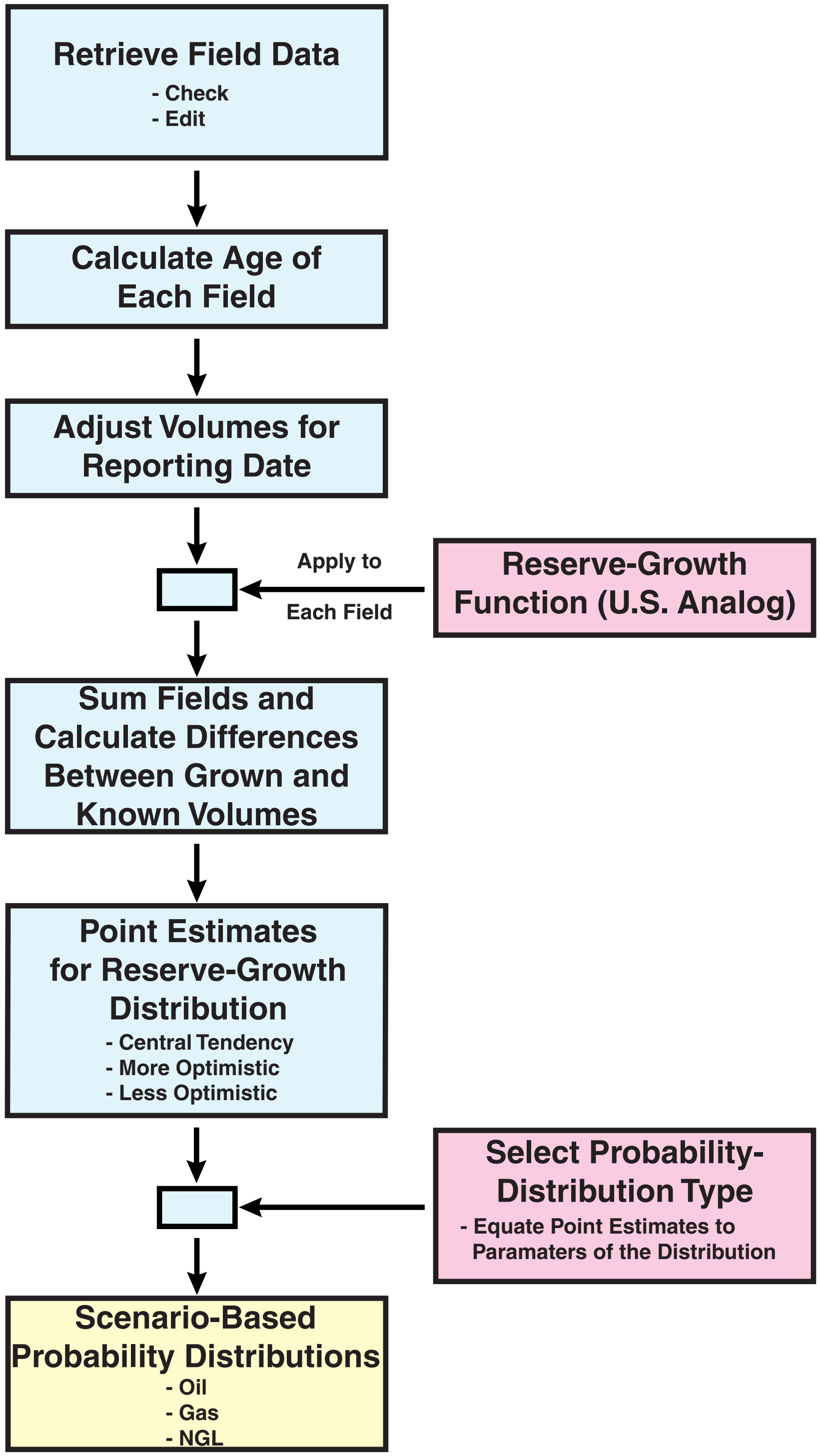


Figure RG-3. Simplified flow diagram emphasizing the basic steps used to obtain a forecast of world potential reserve growth for the USGS World Petroleum Assessment 2000.

World Potential Reserve Growth Forecast Scheme

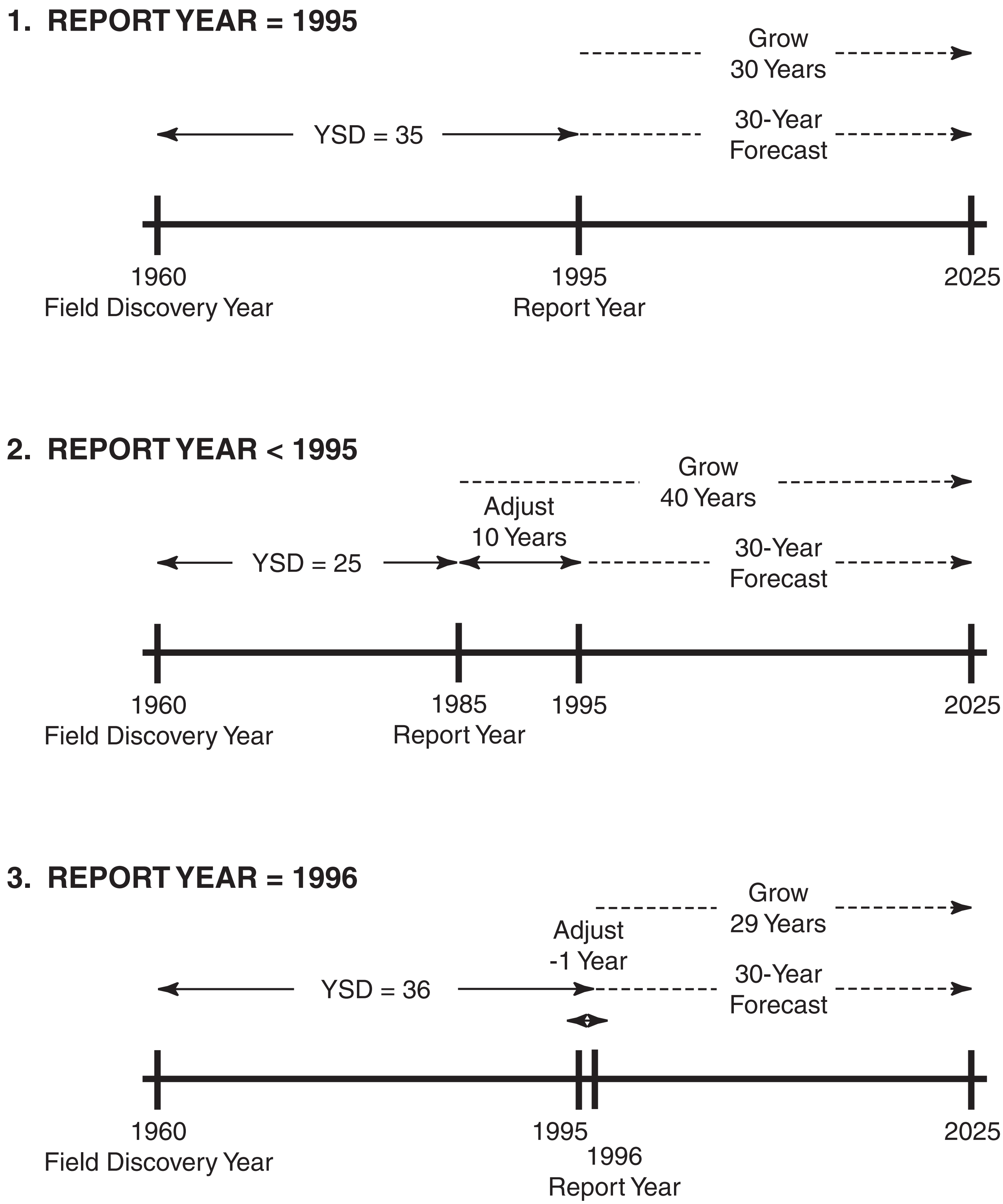


Figure RGApp-1. Procedure for adjusting field sizes to the 1995 reference year and then generating a 30-year reserve-growth forecast.

World Potential Reserve Growth (excluding U.S.) Oil

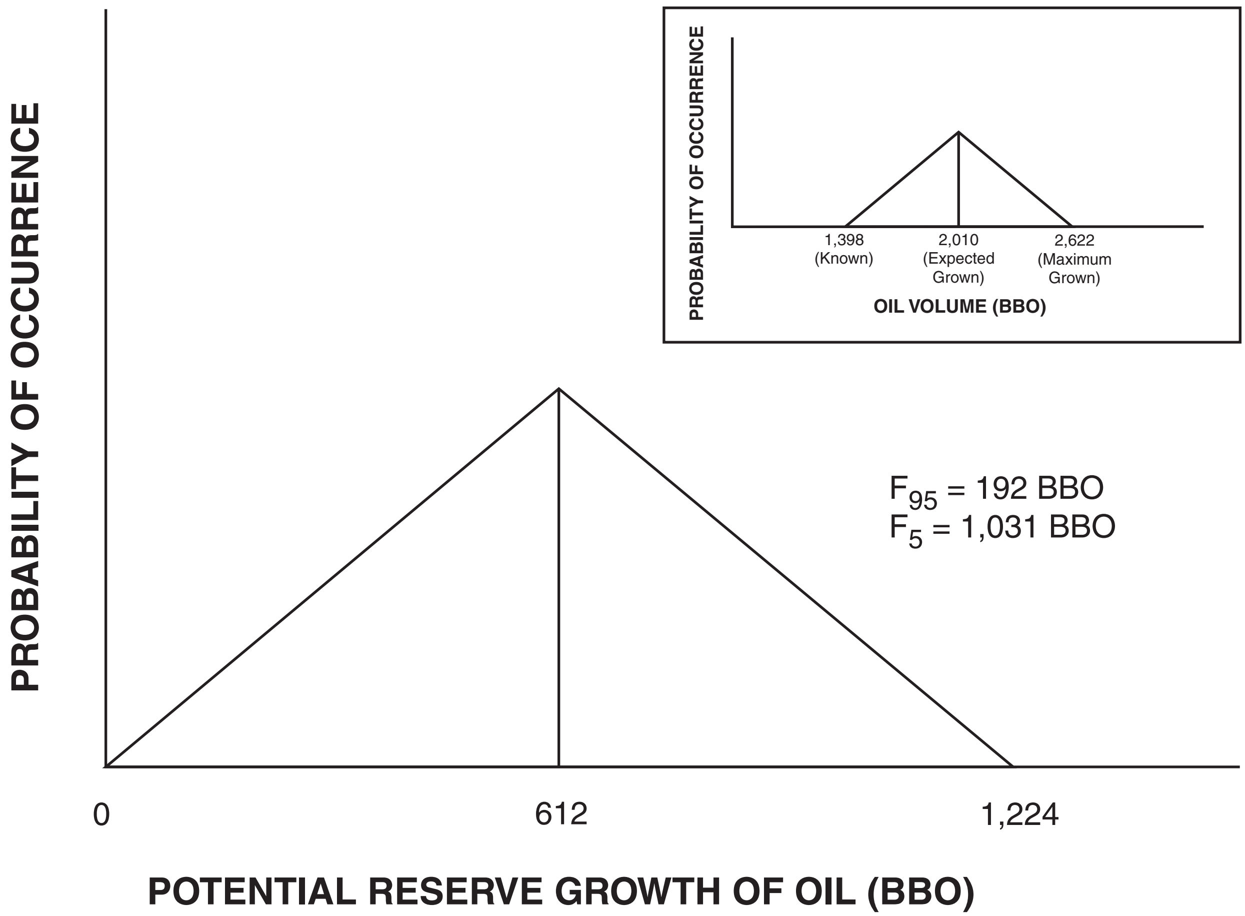
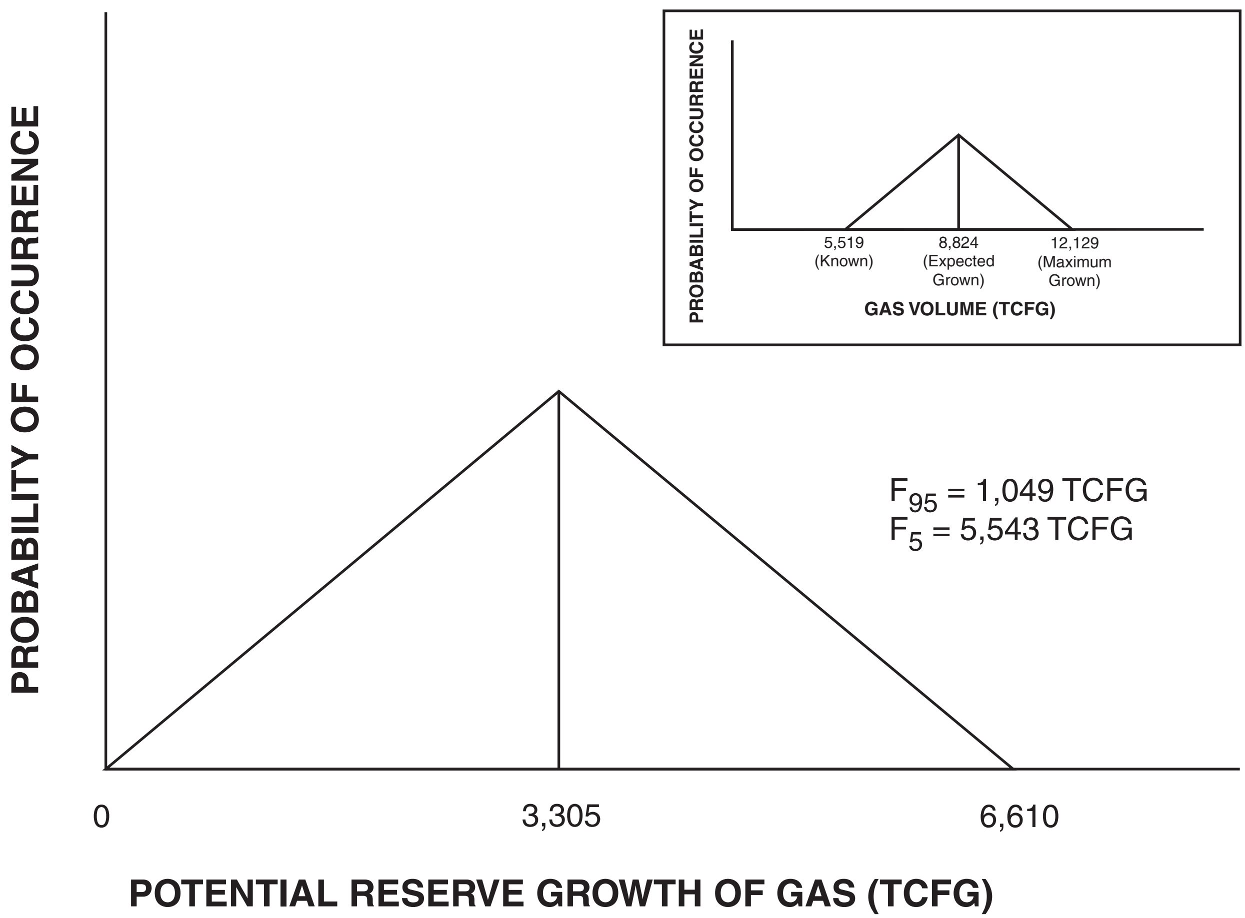


Figure RGApp-2. Forecast for world potential reserve growth of oil (exclusive of the U.S.), with uncertainty expressed in the form of a triangular probability distribution. See table RGApp-2 for fractile values in 5 percent increments. Inset shows the potential increase in known oil volume predicted by the reserve-growth forecast. Fractiles other than F_{100}, F_{50}, and F_0 were calculated using Monte Carlo simulation with 50,000 trials and do not precisely match those calculated using probability theory.

World Potential Reserve Growth (excluding U.S.) Gas



FigureRGApp-3. Forecast for world potential reserve growth of gas (exclusive of the U.S.), with uncertainty expressed in the form of a triangular probability distribution. See table RGApp- 2 for fractile values in 5 percent increments. Inset shows the potential increase in known gas volume predicted by the reserve-growth forecast. Fractiles other than F_{100}, F_{50}, and F_0 were calculated using Monte Carlo simulation with 50,000 trials and do not precisely match those calculated using probability theory.

World Potential Reserve Growth (excluding U.S.) NGL

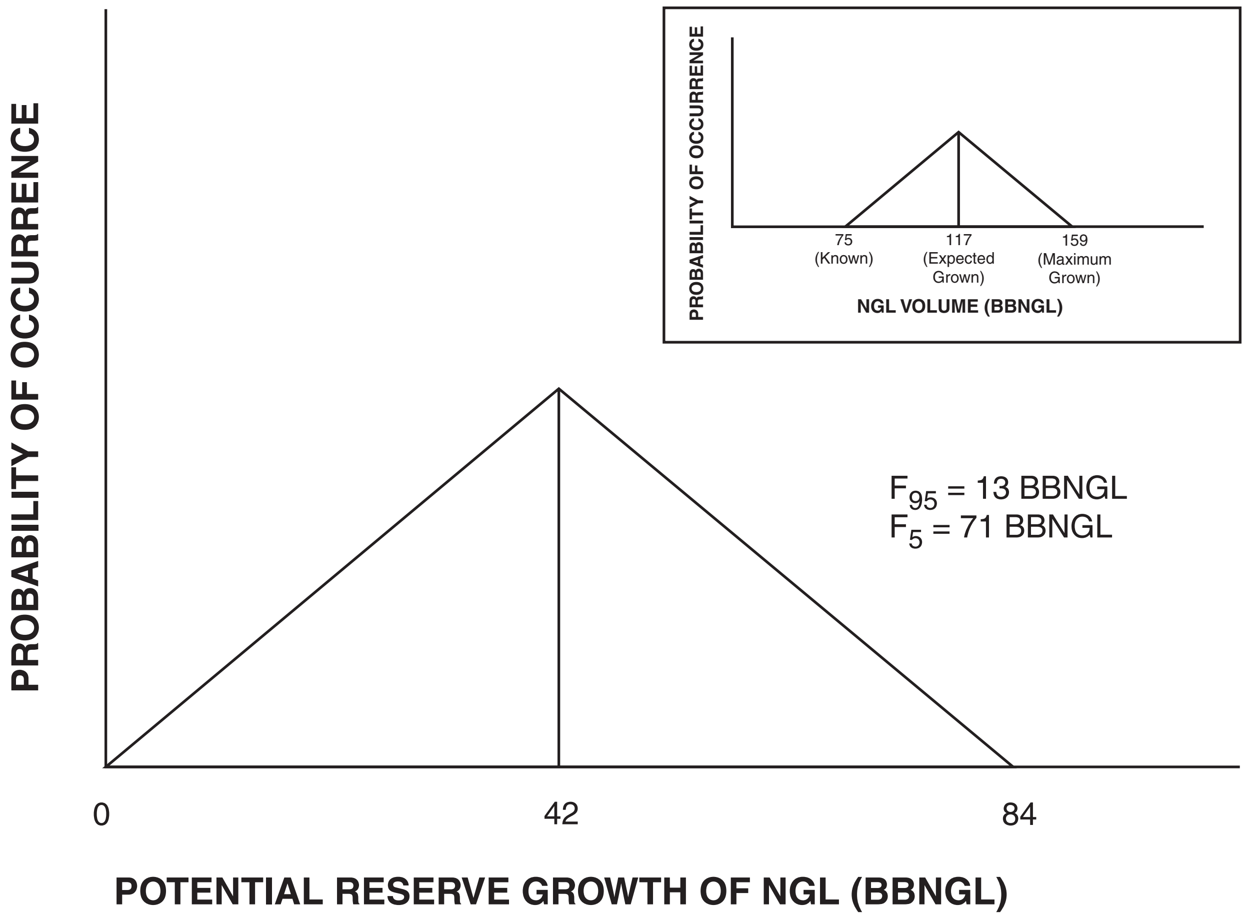


Figure RGApp-4. Forecast for world potential reserve growth of NGL (exclusive of the U.S.), with uncertainty expressed in the form of a triangular probability distribution. See table RGApp-2 for fractile values in 5 percent increments. Inset shows the potential increase in known NGL volume predicted by the reserve-growth forecast. Fractiles other than F_{100}, F_{50}, and F_0 were calculated using Monte Carlo simulation with 50,000 trials and do not precisely match those calculated using probability theory.