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New U.S. Geological Survey Method for the Assessment of Reserve Growth

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U.S. Department of the Interior
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COVER. Exposures of the Tensleep Sandstone in Sinks Canyon, near Lander, Wyoming (photograph by Christopher J. Schenk, U.S. Geological Survey).

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Conversion Factors

Multiply	By	To obtain
	Length	
barrel (bbl)	0.1590	cubic meter (m^3)
barrel (bbl)	0.136	metric ton (MT), average gravity
cubic foot (ft^3)	0.02832	cubic meter (m^3)
cubic meter (m^3)	35.3147	cubic feet (ft^3)
metric ton (MT)	7.33	barrel (bbl), average gravity

New U.S. Geological Survey Method for the Assessment of Reserve Growth

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Abstract

Reserve growth is defined as the estimated increases in quantities of crude oil, natural gas, and natural gas liquids that have the potential to be added to remaining reserves in discovered accumulations through extension, revision, improved recovery efficiency, and additions of new pools or reservoirs. A new U.S. Geological Survey method was developed to assess the reserve-growth potential of technically recoverable crude oil and natural gas to be added to reserves under proven technology currently in practice within the trend or play, or which reasonably can be extrapolated from geologically similar trends or plays. This method currently is in use to assess potential additions to reserves in discovered fields of the United States. The new approach involves (1) individual analysis of selected large accumulations that contribute most to reserve growth, and (2) conventional statistical modeling of reserve growth in remaining accumulations. This report will focus on the individual accumulation analysis.

In the past, the U.S. Geological Survey estimated reserve growth by statistical methods using historical recoverable-quantity data. Those statistical methods were based on growth rates averaged by the number of years since accumulation discovery. Accumulations in mature petroleum provinces with volumetrically significant reserve growth, however, bias statistical models of the data; therefore, accumulations with significant reserve growth are best analyzed separately from those with less significant reserve growth. Large (greater than 500 million barrels) and older (with respect to year of discovery) oil accumulations increase in size at greater rates late in their development history in contrast to more recently discovered accumulations that achieve most growth early in their development history. Such differences greatly affect the statistical methods commonly used to forecast reserve growth.

The individual accumulation-analysis method involves estimating the in-place petroleum quantity and its uncertainty, as well as the estimated (forecasted) recoverability and its respective uncertainty. These variables are assigned probabilistic distributions and are combined statistically to provide probabilistic estimates of ultimate recoverable quantities. Cumulative production and remaining reserves are then subtracted from the estimated ultimate recoverable quantities to provide potential reserve growth. In practice, results of the two methods are aggregated to various scales, the highest of which includes an entire country or the world total. The aggregated results are reported along with the statistically appropriate uncertainties.

Introduction

Reserve growth is defined as the increased quantities of crude oil, natural gas, and natural gas liquids that have the potential to be added to remaining reserves in discovered accumulations through extension, revision, improved recovery efficiency, and additions of new pools or reservoirs (fig. 1). A new U.S. Geological Survey (USGS) method assesses the reserve growth potential of discovered accumulations. This method currently is in use in a new assessment of potential additions to reserves in discovered fields of the United States.

For the assessment of reserve growth in this study, the additions to reserves are considered to be technically recoverable crude oil and natural gas by use of proven technology that is currently in practice within a given trend or play, or which can reasonably be extrapolated from other geologically similar trends or plays. This study assesses only conventional accumulations and assumes no statistically specific definition of reserves. Only crude oil and nonassociated natural gas that flows to a wellbore are assessed directly. Associated/dissolved natural gas and natural gas liquids are assumed to grow by the same ratio. The overall trend for reserve growth is for higher values through time, owing to volumetrically significant fields. However, many fields show no growth of reserves, and many shrink.

In the past, the USGS estimated reserve growth by statistical methods using historical recoverable-quantity data, and the estimates of reserve growth were based on growth rates averaged by number of years since accumulation discovery (Root, 1981, 1988; Root and others, 1997; Schmoker and Klett, 2000) (fig. 2). Accumulations with the most significant reserve growth (in terms of volume) in the most mature petroleum provinces, however, bias statistical models of the

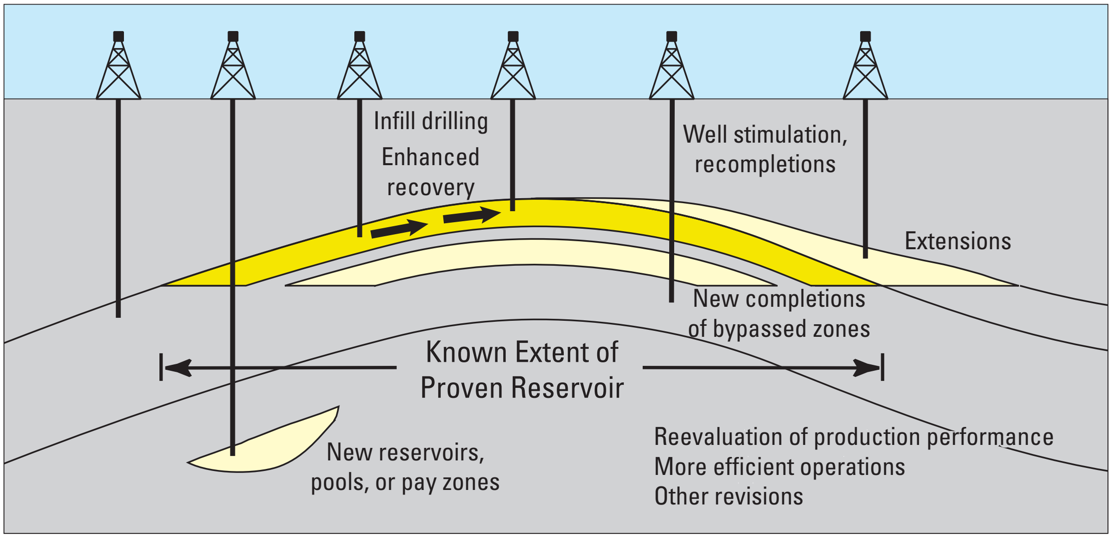


Figure 1. Diagram showing reserve growth defined as increases in successive estimates of recoverable quantities of crude oil, natural gas, and natural gas liquids in discovered fields. Reserve growth can be grouped into three activities: (1) delineation of additional in-place petroleum volumes, which increases the degree of geologic assurance (infill drilling; new reservoirs, pools, or pay zones; extensions); (2) improved recovery efficiency, which increases the degree of technological feasibility (enhanced recovery, well stimulation, recompletions, new completions of bypassed zones); and (3) revisions resulting from recalculation of viable reserves in dynamically changing economic, operating, and regulatory/political conditions, which increases the degree of economical feasibility (reevalution of production performance; more efficient operations). (Entire illustration from Klett, 2005.)

data. Therefore, estimates of reserve growth are more accurate if accumulations with significant reserve growth are analyzed separately.

Large (greater than 500 million barrels) and older (with respect to year of discovery) oil accumulations grow differently than smaller accumulations discovered later—they increase in size at greater rates later in their history rather than early (as occurs for most accumulations), thereby adversely affecting statistical methods commonly used to forecast reserve growth. The accumulations we identified primarily are in large, old oil fields, many of which are in the San Joaquin and Permian Basins (California and Texas, respectively). Removing these large accumulations results in having the less-significant accumulations biasing the estimates, in an onion-layer-like fashion. A point of diminishing returns, however, can be reached. This new assessment of reserve growth involves a two-part approach: (1) individual accumulation analysis of selected largest contributors to reserve growth, and (2) conventional statistical modeling of reserve growth in the remaining accumulations.

Previous Studies

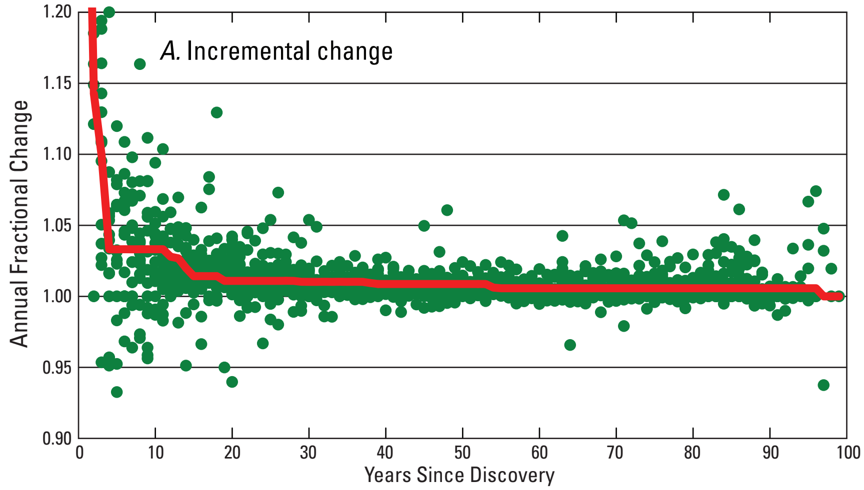
Most published methods used to model and forecast reserve growth are statistical, based on empirical projections of past reserve-growth patterns of crude oil and natural gas fields. Being statistical and based on modeling reserve growth of large populations of accumulations, these methods account for the complex ways that petroleum volumes can be transferred to measured reserves from other reserve and resource classes. Arrington (1960) was the first to develop a method to estimate reserve growth. According to Root and Attanasi (1993), Arrington estimated annual growth of fields between year e and e+1, that is, fields that are one year older, by the growth ratio:

$$\frac{\sum_{d} c\,(d,e+1)}{\sum_{d} c\,(d,e)} \qquad (1)$$

where the variable, $c\,(d,\,e)$, is the volume of crude oil or natural gas discovered in year d as estimated in year e. The same field is represented in both the numerator and denominator.

Root and Attanasi (1993) pointed out that the underlying assumptions are that the amount of growth in any one year is proportional to the size of the field and that this proportionality constant changes as the field ages. They also indicated that field age expressed as years since discovery was used as a degree of field development because it represents a simple index of the various types of field development and also that data are more readily available.

Except for those who developed nonstatistical methods, most subsequent investigators calculated growth ratios and growth factors for fields in much the same way as Arrington (1960). Growth factors are also called “multipliers” and are



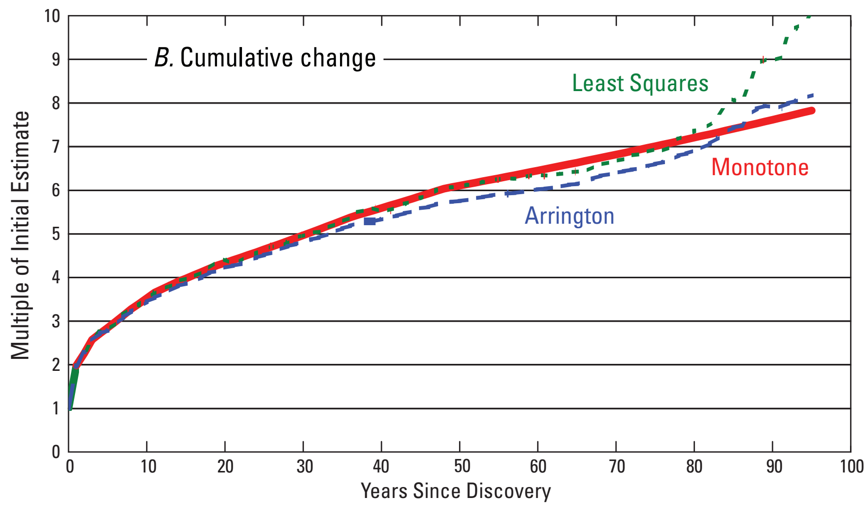


Figure 2. Graphs showing reserve growth as incremental change and cumulative change relative to years since discovery. Reserve growth can be estimated for most petroleum accumulations by statistical methods. In the past, the United States Geological Survey estimated reserve growth by statistical methods using historical recoverable quantity data, and the estimates of reserve growth were based on growth rates averaged by number of years since accumulation discovery. (*A*.) Incremental change of reported recoverable quantities in accumulations of the United States by years since discovery. Green dots represent annual fractional change of the summed recoverable quantities of oil accumulations. This graph was based on 17 consecutive years of data (NRG Associates, 1982 through 1998), from which 16 annual fractional change factors were calculated. Therefore, 16 points representing oil fields (green) are plotted for each year-since-discovery. An incremental reserve-growth model (red line) representing the approximate mean of the individual annual growth factors is shown for reference. (*B*.) Cumulative change of reported recoverable quantities in accumulations by years since discovery (modified from Attanasi, 2001). Points for every year since discovery along the incremental reserve-growth model are consecutively multiplied to construct the cumulative curves shown in this figure. Data for this graph are from production and reserves data reported from 1977 through 1996 by the Energy Information Administration (1998).

used to calculate future reserve growth. The most current reported recoverable volumes are multiplied by the growth factors to obtain an estimate of future reserve growth. Functional forms (sometimes called “growth functions”) may be assumed to relate annual field growth factors to field age. Growth factors can be given as the ratio of the accumulation size a given number of years after discovery to the size as estimated in the year of its discovery (Root and Attanasi, 1993). These are called cumulative growth factors (Hubbert, 1966; 1967; 1974; Pelto, 1973; Root, 1981; 1982; 1988; Energy Information Administration, 1990a; Lore and others, 1996; 2001; Verma and others, 2001; Verma and Ulmishek, 2003; Verma and Henry, 2004; Verma, 2003, 2005).

As seen in figure 2, from Attanasi (2001) and Klett (2003), both growth factors and functional forms flatten with time indicating that the amount of reserve growth declines as years-since-discovery increases. Statistical methods show that when the growth of reserves in fields is compared to the growth of reserves in reservoirs, growth in fields lasts longer and generally the cumulative growth multiplier is greater than in reservoirs (Attanasi and Root, 1994).

Annual estimates of recoverable volumes used to derive the growth factors are obtained from a variety of datasets. Most report volumes only for fields located in North America. Those datasets include the following: (1) Arrington (1960) used Carter Oil’s in-house estimates and provided an example of a dataset that covered a period from 1940 to 1954; (2) the American Petroleum Institute, American Gas Association, and Canadian Petroleum Association (API/AGA/CGA) (American Petroleum Institute, American Gas Association, and Canadian Petroleum Association, 1967–1980) compiled annual volumetric data in 14 yearly publications that covered the period from 1966 to 1979; (3) the Energy Information Administration compiled the Oil and Gas Integrated Field File (OGIFF), which covered the period from 1977 to 1996 (Energy Information Administration, 1990b, 1998); and (4) Nehring Associates compiled a database for the United States (Nehring Associates, 2008), which covers a period from 1985 to the present, and one for Canada (NRG Associates, 1995). The Nehring Associates’ United States dataset reports annual estimates of recoverable volumes for both fields and reservoirs. IHS Energy’s International Petroleum Exploration and Production Database (IHS Energy, 2009) covers the period from about 1980 to the present and provides estimates of recoverable volumes for fields outside North America. Comparable datasets are also available for the North Sea and parts of Canada.

An excellent history of the development of reserve growth methods is given by Root and Attanasi (1993). Arrington’s method (developed in the early 1960s) was the first attempt to forecast reserve growth (Arrington, 1960; 1966). In the late 1960s and early 1970s, Hubbert developed a method to assess reserve growth by deriving growth factors from the API/AGA/CPA dataset that was used in the first USGS domestic petroleum resource assessment (Hubbert, 1966; 1967; 1974; Mast and Dingler, 1975). Marsh (1971) applied Arrington’s method to the same API/AGA/CPA dataset. Later, Pelto (1973) developed a functional form relating reserve growth to field age much like Hubbert’s. The Alberta Energy Resources Conservation Board (1968) published statistics on the annual growth of reserves, as well as average growth factors for years after discovery. Arps and others (1971) related growth factors to footage drilled since discovery instead of field age, which is an alternate way of expressing the degree of development.

In the early 1980s into the 1990s, personnel of the USGS derived growth factors by applying the Arrington method to datasets of the API/AGA/CGA, OGIFF, NRG Associates, and IHS Energy and constructed a cumulative functional form (growth function) (Root, 1981; 1982; 1988; Root and Attanasi, 1993; Root and Mast, 1993; Root and others, 1997; Attanasi and Root, 1994; Attanasi and others, 1999; Attanasi, 2001). This method was used to forecast reserve growth for subsequent USGS petroleum resource assessments. Other statistical methods were developed by (1) Lore and others (1996, 2001) with the Minerals Management Service, who derived growth factors and a function based on reserve growth of fields in U.S. Federal offshore areas; (2) the Energy Information Administration (1990a), who derived growth factors and a function based on the OGIFF dataset; and (3) the National Petroleum Council (1992; 2003), who derived growth factors and functions to include both field age and well information.

In contrast to statistical methods, in the late 1980s and early 1990s, the Potential Gas Committee (1987) and the Texas Bureau of Economic Geology (Fisher, 1991) estimated reserve growth using nonstatistical methods (Root and Attanasi, 1993). The Potential Gas Committee used a subjective volumetric-yield technique, and the Texas Bureau of Economic Geology used a combined geology and engineering approach to estimate in-place natural gas not in contact with the wellbore (National Petroleum Council, 1992).

Several recent studies have focused on particular regions. Watkins (2000) derived growth factors and functions based on reserve growth of fields of the North Sea using data reported by the United Kingdom Department of Trade and Industry and the Norwegian Petroleum Directorate. In addition, Verma and others (2001), Verma and Ulmishek (2003), Verma and Henry (2004), and Verma (2003, 2005) derived growth factors and functions for pools in Canada and fields in Russia based on data reported by those respective countries. Only a few studies systematically have considered the mechanisms responsible for reserve growth to estimate potential additions to reserves (for example, Tennyson, 2005). This study, however, pursues that approach.

Approach

The primary goal of this assessment of reserve growth is to estimate the amount of potential reserve growth that could occur with current field-development practices. Such estimates represent additions in the foreseeable future rather than recoverable quantities in the sense of what ultimately may be added to reserves. Field and reservoir definitions and production/reserves and ancillary data for the United States primarily are based on the Nehring Associates (2008) Significant Oil and Gas Fields of the United States Database (current through 2006). Well data are derived primarily from the IHS (2010) Petroleum Information/Dwights PLUS™ U.S. Well Database. Field, reservoir, and well data for accumulations outside the United States are taken primarily from the IHS (2009) International Exploration and Production Database. Other published data, such as those from the California Department of Oil, Gas, and Geothermal Resources (available online at *http://www.conservation.ca.gov/dog/*) are also used. Additions to reserves are estimated based on the dataset used to characterize volumetric changes in the given accumulations. For the United States, the starting year for contemporary estimates is 2006.

Aggregated assessment results provide estimates for the United States and the world. For the United States, accumulations are aggregated to national and regional levels. The regional level is scaled to that of the national level. Although accumulations are not aggregated to fields, all conventional accumulations within fields are assessed. This study initially focuses on reserve growth of accumulations within the United States where adequate field and reservoir data are generally available. The methods developed for estimating the nation's reserve growth then are applied to accumulations outside the United States where field and reservoir data commonly are relatively sparse.

Individual Accumulation Analysis

Accumulations that potentially are the largest contributors to reserve growth are selected for individual field analysis. The goal is to account for most of the reserve growth by this method. The individual accumulation analysis method involves estimation of the in-place quantity and its uncertainty, and the forecasted recoverability and its uncertainty (fig. 3). Minimum, median, and maximum estimates are determined for the in-place quantities, which are assigned to a lognormal distribution. The minimum parameter should not be less than the cumulative production. The maximum parameter is the 1 in 99th fractile of the lognormal distribution..

Minimum, mode, and maximum parameters are estimated for the mean recovery factor for the entire accumulation (not the entire range of possible recovery factors), which are assigned to a triangular distribution. The estimates are combined statistically to provide probabilistic estimates of ultimate recoverable quantities. During each iteration of the calculation, reported (known) recoverable quantities are subtracted from the estimated ultimate recoverable quantities to provide potential reserve growth. In some cases, shrinkage of recoverable volumes might occur in some iterations.

A protocol for the assessment of reserve growth in individual large accumulations follows:

1. The U.S. Geological Survey Reserve Growth Assessment team conducts a series of formal assessment meetings, similar to meetings to assess undiscovered petroleum resources. Only USGS personnel may attend the assessment meetings. The project team serves as Reserve Growth Assessment Team (review team) to consider input, reasoning, and supporting data.

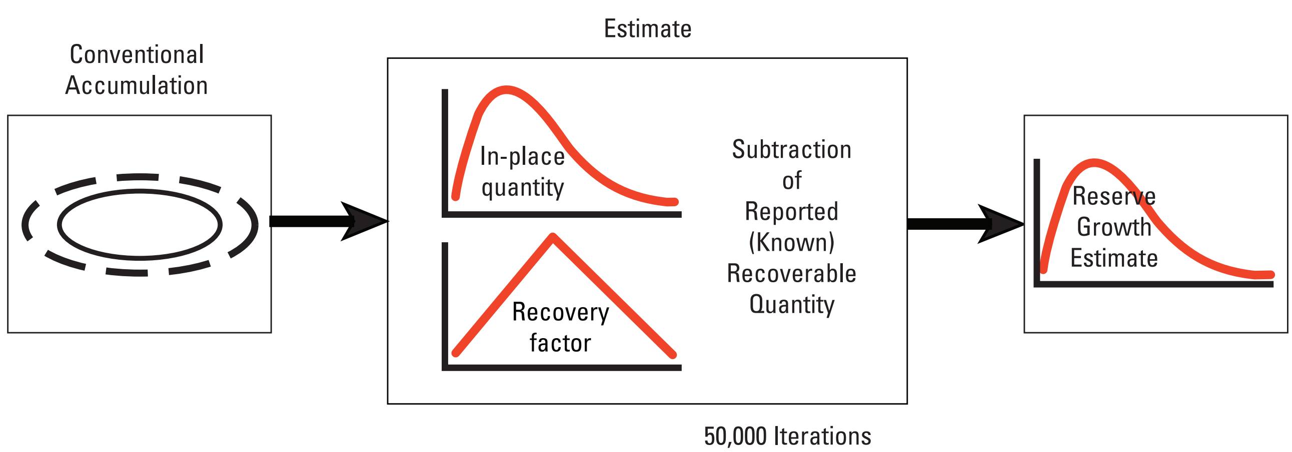


Figure 3. Diagram showing in-place and recovery-factor estimates statistically combined to provide probabilistic estimates of ultimate recoverable quantities. During each iteration of the calculation, recoverable quantities subtracted from the ultimate recoverable quantities provide estimates of potential reserve growth.

2. Two assessment tools are used for individual accumulation analysis: (1) an input form; and (2) a set of graphs, production/reserve statistics, and maps. At the meetings, the assessor provides completed input forms for reserve-growth calculations and identifies the drivers of reserve growth from the set of graphs, statistics, and maps, to justify input.

3. The input form contains estimates of in-place quantities and recovery factors. In-place quantities are based on geologic factors and estimated from reported values. Uncertainties of those values are recorded, as well as the reasoning and justifications for uncertainty. Recovery factors are best based on engineering, reflecting the use of all applicable proven technology and current practices to develop the accumulation. Required information to aid in estimating the recovery factor includes the degree of development and whether current development technology will continue or whether proven new technologies will be implemented. Recovery factors might be greater than those presently reported, depending on the extent of current development. The recovery factors can be determined by development history of the accumulation being studied or from analog accumulations.

4. The set of graphs and statistics should include but are not limited to field-development history; reported in-place quantities and recovery factors; reported production data including cumulative production, remaining reserves, and known recoverable quantities; accumulation area; density and spacing of wells; and numbers of producing wells, injector wells, observation wells, and deeper-pool or shallower-pool wildcat wells. Descriptions of current production practices (primary, secondary, improved, and enhanced, including type of enhanced recovery), the field development history, and assumptions of future field development and recovery are required. In addition, reservoir information, geologic cross sections, maps of accumulation and reservoir boundaries, wells, lease blocks, and a list of operators are useful.

Statistical Methods

Two statistical methods to assess reserve growth, the Monotone Growth Function based on the least-squares fit having a monotonic constraint (Attanasi, 2001) (fig. 2), and a Modified Arrington Function, are used to calculate reserve growth in the accumulations not individually analyzed. In developing this new approach, these two methods were tested using the same accumulation data sets. Projections were made to 2005 and 2030 using Nehring Associates data current through 2000. In addition, reserve growth was estimated in terms of years since accumulation discovery and years since first production. The tests show that the two statistical methods accurately predicted volumes reported in 2005. Estimates of reserve growth by the two methods were similar for the 5-year forecasts, becoming less similar in the longer term (as for the 30-year forecast and beyond).

For this new study, the statistical models are applied to the historical recoverable quantity data for remaining accumulations, and the results are evaluated by the assessment review team. Results from the individual accumulation analysis and the statistical methods are then aggregated.

Conclusions

This project estimates reserve growth, over the foreseeable future, in accumulations that are the largest contributors to reserve growth. The final product is to be a table of reserve-growth estimates for USGS-defined regions and for the United States as a whole. Results from the two methods are to be aggregated at various scales, the highest of which includes country or world scales, and reported along with the largest meaningful uncertainty.

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