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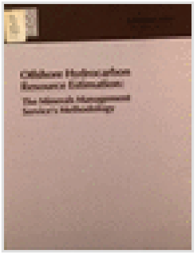

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OFFSHORE HYDROCARBON RESOURCE ESTIMATION: THE MINERALS MANAGEMENT SERVICE'S METHODOLOGY

Committee on Offshore Hydrocarbon Resource Estimation Methodology
Board on Mineral and Energy Resources
Commission on Physical Sciences, Mathematics, and Resources
National Research Council (U.S.).

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The report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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Numerous individuals from both the private and the public sector expressed their views to COHREM regarding not only the need for timely resource estimates, but also the MMS's methodological approaches to developing such estimates. The committee is grateful for the time spent and information shared with it by professionals from the Gas Research Institute (GRI), the Washington law firm of Covington & Burling, the Exxon Production Research Company, the U.S. Geological Survey (USGS) and other branches of the U.S. Department of the Interior, as well as the U.S. Department of Energy (DOE). The committee wishes to recognize the assistance and contribution made by Larry J. Kinler of Pennzoil Exploration and Production Company.

Finally, the committee appreciates the preprint release of information and articles supplied by the various authors contributing to a special edition of the American Association of Petroleum Geologists' (AAPG) Studies in Geology series, Volume 21, entitled Oil and Gas Assessments: Methods and Applications, to be published in 1986.

CONTENTS

EXECUTIVE SUMMARY

Estimating the potential future resources of oil and gas on the Outer Continental Shelf (OCS) is a crucial first step in establishing an OCS leasing program consistent with a prudent national energy policy. Estimates of undiscovered OCS oil and natural gas are referred to during the discussion of numerous policy, political, legal, and environmental issues that arise during the conduct of the federal leasing program. Such estimates also provide the basis for the biennial inventory of offshore undiscovered petroleum resources and are used in drafting areawide environmental impact statements.

At the request of the Minerals Management Service (MMS) of the U.S. Department of the Interior, a 10-member committee of the National Research Council was formed in late 1984 to evaluate the regional resource estimation methodology that MMS has used and is further developing. MMS is charged with the responsibility of estimating the volume of undiscovered recoverable resources in offshore areas. The committee was asked whether the estimation methodology used by MMS, which incorporates geological, geophysical, engineering, and economic data, is particularly suited to meet the goals established by the Outer Continental Shelf Lands Act of 1953, and whether it is useful in meeting other important departmental and national goals.

The central goal of a national energy policy is to foster an adequate supply of energy at reasonable prices. Because much of the 1.1 billion acres within the offshore jurisdiction of the United States is unexplored, the federal government has a pivotal role in the exploration and development of these areas, which may contain undiscovered oil and natural gas resources. MMS personnel at each of its four regional offices, which correspond to the Atlantic, Gulf of Mexico, Pacific, and Alaskan offshore areas, make biennial estimates of undiscovered offshore oil and natural gas resources. These estimates are subsequently reviewed by an MMS committee comprised of regional and headquarters personnel. Realistic estimates of the resource potential of the nation's offshore area are critical to overall planning of the offshore leasing program.

This report discusses the great uncertainties that are involved in these resource assessments, describes the various methods used by MMS and others to generate these assessments, and presents the committee's conclusions and recommendations concerning MMS's assessment procedures.

The committee considers the basic thrust of the MMS assessment methodology to be appropriate but has some concerns about specific procedures and judgments. It is within this context that the committee advances the following conclusions and recommendations for improving MMS's assessments.

Conclusion: The current methodology is excessively detailed for some assessment areas, particularly where few data are available. To be practical and effective, the methodology must deal with thousands of prospects in a timely and consistent manner.

The committee recommends that MMS:

- Approach resource assessment from the perspective of the play, moving to the prospect level as necessary, to the zone level only rarely, and to the basin level only by aggregation of the component plays.

- Develop more fully a grouped-prospect play assessment methodology that is compatible with its current prospect summation approach.

Conclusion: The approach to risking should be revised. Methods for realistically handling the elements of risk are required to provide valid estimates of resources and to sum up resource potentials by area, basin, or region.

The committee recommends that MMS:

- Approach risk evaluation from the perspective of the marginal and conditional probabilities at the play level.

- Develop a systematic analysis of the component geologic dependencies to arrive at probabilities for assessment aggregations.

Conclusion: MMS has not adequately accounted for the likelihood of discoveries of serendipitous hydrocarbon occurrences. Systematic inclusion of postulated prospects and plays reflects historical experience in similar geologic settings or elsewhere and may add significantly to estimates of the resource base.

The committee recommends that MMS:

- Develop a thoroughly systematic process for realistically including potentials from postulated prospects and plays in assessments.

Conclusion: The context in which estimates have been made public has been insufficiently complete in the past. Inclusion of only the attainable potential in MMS's reports limits unduly the horizons of planners and decision makers using the data to the short-term; inclusion of both the attainable potential and the resource base may open up vistas for longer-term planning and more visionary actions.

The committee recommends that MMS:

- Assess and report both the undiscovered resource base and the technologically and economically attainable potential.

- Document critical determinants of the assessment in an appropriate fashion in publicly released data. These determinants should include the ranges of the minimum geologic field size, the minimum economic field size, and, if appropriate, the smallest field size of all that is included in the resource base.

- Report current parameters for both the resource base and the attainable potential; extend the reported probability ranges; and document driving assumptions that affect results, including implied future recovery efficiencies, limits to water and drilling depths considered, and largest expected field size reported by appropriate area.

- Explain to the greatest practicable extent the differences between current and previous assessments.

Conclusion: Adequate safeguards are lacking to ensure internal consistency and reasonableness across the regional offices of MMS. In practice, continued vigilance is required to minimize inconsistencies in assessments made by different groups.

The committee recommends that MMS:

- Establish a review process to provide oversight and to standardize decision-making between regional offices.

- List the hydrocarbon fill fraction along with the results of a prospect assessment and ensure appropriate internal review of this critical parameter.

- Systematically compile historical data from discovered plays to help in making more realistic assessment analogies.

Chapter 1

INTRODUCTION

1.1 OVERVIEW

This report is issued in response to a request by the Minerals Management Service (MMS) of the U.S. Department of the Interior to the National Research Council's (NRC) Board on Mineral and Energy Resources (BMER) within the NRC's Commission on Physical Sciences, Mathematics, and Resources (CPSMR). MMS requested that a committee of the academy "identify the needs for petroleum and natural gas resource information, evaluate the advantages and limitations of existing resource estimation methodologies to address effectively each of the identified needs, assess the adequacy of information available to apply properly each of the existing resource estimation methodologies, and recommend, where possible, new approaches in addressing the needs for petroleum and natural gas resource information."

The Minerals Management Service is charged with maintaining a current estimate of the undiscovered oil and natural gas resources on the Outer Continental Shelf (OCS). Under the OCS Lands Act of 1953, the Secretary of the Interior establishes an OCS leasing schedule, carries out lease sales, monitors exploration, development, and production, and collects royalties on the resources produced. The OCS area should play a critical role in the nation's energy future, as a significant amount of thenation's undiscovered recoverable oil and gas is expected to be found there. At present, offshore oil accounts for about 11 percent of total domestic petroleum production, and offshore natural gas accounts for about 24 percent of total domestic gas production. The potential for increasing the contribution of offshore areas to U.S. energy supplies is substantial.

In 1981, the secretary reorganized the responsibilities for conducting the OCS leasing program. As part of this reorganization, MMS was established, largely from the former Conservation Division of the U.S. Geological Survey (USGS), which previously had been responsible for economic evaluation of tracts offered for lease. The responsibility for estimating the undiscovered oil and natural gas resources throughout the OCS was transferred from the Geologic Division of USGS to MMS in order to consolidate resource estimation and economic evaluation. As fundamentally different methodologies had been used for these two tasks, MMS used this occasion to introduce an improved methodology for preparation of resource estimates.

Current estimates of offshore oil and gas resource information are needed by government for the following purposes: (1) long-term energy policy; (2) forecasting rates of domestic discovery and supply; (3) anticipating environmental impacts of exploration and production; (4) anticipating future technologic and capital requirements; (5) realistically evaluating regulatory options; (6) scheduling lease sales; (7) conducting cost-benefit studies of leasing alternatives; and (8) analyzing the economics of industry's bids on leasable tracts. This report addresses the analytic approach that MMS uses in estimating hydrocarbon potentials of all U.S. offshore areas; it does not address the adequacy of MMS's methods of evaluating bids before acceptance on leasable tracts, or the questions of leasing alternatives.

To address the above needs effectively, the methodology for assessing undiscovered hydrocarbon volumes should be relatable to new geologic concepts as well as historical exploration experience, effective in weighing geologic risks, consistent and updatable, documentable, and flexible in adding or subtracting assessments. Additionally, the methodology should provide a suitable basis for making economic analyses and supply forecasts, while allowing for separation of geologic from economic assumptions and constraints; allow adequate and timely use of a variety of data; and develop and present results in a probability format that reflects all the uncertainties. The committee's recommendations focus on ways to achieve these goals.

Petroleum resources are the quantities of oil and gas believed to be eventually recoverable, by means of known or expected technologies, out of the total volumes in place. Resources include both discovered and undiscovered sources of supply. (See Figure 1.1.) Discovered resources incorporate all the oil and gas that have been found by drilling, including resources that have been produced to date, those that have been found and are economically recoverable but not yet produced (proved and probable reserves), and the theoretically recoverable but currently uneconomic or technologically unattainable (contingent) resources. Undiscovered resources--those estimated by MMS--are those resources that are yet to be found. This total undiscovered resource base consists of economically attainable resources and the remaining nonattainable resources. This report excludes consideration of unconventional oil and gas deposits, such as oil shale, tar sands, and coal gas. The total amount of undiscovered recoverable oil and natural gas is finite but unknown. Geologic, geochemical, and geophysical observations and measurements can establish whether conditions exist that are favorable for accumulation of oil and gas, but there is no known direct means of determining the presence of commercial quantities of hydrocarbons before drilling.

Of the amount of oil and gas that is theoretically recoverable by means of known and expected technologies (the resource base), not all is economically recoverable at any particular time. Whether hydrocarbons are perceived to be economically recoverable depends on current and anticipated price trends, the technology for development and production,

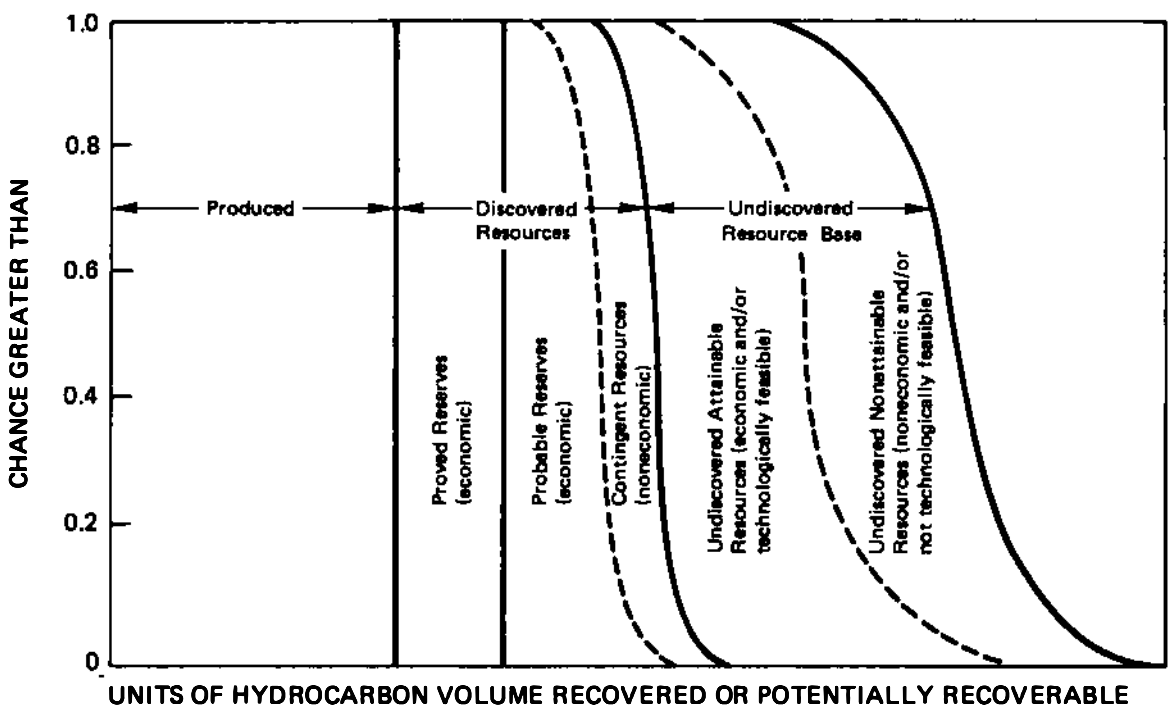


FIGURE 1.1 Ultimately conventionally recoverable petroleum resource base.

the size of the deposit, the proximity to an industrial infrastructure capable of transporting and refining the hydrocarbons, the water depth, the amount of oil versus gas, and many other factors. Obviously, many of these economic and technological factors are not static, but change dynamically as a result of a variety of conditions. For example, economic factors can be dramatically influenced by government policy.

The commercialization of new technology for the development and production of resources in harsh environments, such as deep water or arctic conditions, is driven by the discovery of oil and gas and, indeed, by the right to produce them under such conditions. The petroleum industry has little incentive to develop such technology when it does not hold rights to develop a field where these conditions exist, but has a very strong incentive to develop the technology when it does. Therefore, if a resource estimate based on the assumption of current technology is used as the basis for a political decision to exclude environmentally harsh but otherwise prospective areas from the lease sale schedule, then resources may not be found and the technology for the recovery of these resources may not be developed. While a resource base estimate depends almost entirely upon our interpretation of the geology, an estimate of the economically recoverable resources depends upon numerous assumptions related to the present and future economics and technology of development and production, as well as to government policy.

The quality of an estimate of undiscovered resources is highly dependent upon (1) the quantity and quality of the geologic information available; (2) the knowledge, experience, and awareness of the group making the estimate; (3) the appropriateness of the estimation methodology; and, (4) the economic assumptions used. Users of any resource estimate must recognize its probabilistic nature and resulting inherent uncertainty.

1.2 ORGANIZATION OF THE REPORT

This report, prepared by the Committee on Offshore Hydrocarbon Resource Estimation Methodology (COHREM), discusses the great uncertainties that are involved in resource assessments, reviews the various methods normally used to generate these assessments, describes MMS's methodology in particular, presents this committee's conclusions and recommendations concerning MMS's assessment procedures, and provides a detailed glossary and list of references.

Chapter 2

RISK AND UNCERTAINTY IN RESOURCE ASSESSMENT

2.1 PERSPECTIVES

An assessor must ask two basic questions about an undrilled area. First, could any oil or gas fields be present in that area? The answer depends on an analysis of the geologic risks. If, for example, there is a zero chance of adequacy that a hydrocarbon source exists, reservoir rocks are present, or there are trapping conditions for at least one field, the answer is no and the assessor proceeds no further. If there is some chance that the answer is yes, the second question that naturally follows is, how much oil or gas? This question is best answered by multiplying a series of hydrocarbon volume factors, each expressed as a range (reflecting the uncertainties), whose product is a range of possible barrels of oil or cubic feet of gas.

In practice, if the area has enough promise for the finding of hydrocarbons, the assessor tackles the second question first and then ties the formal risk analysis to the result. The assessor estimates a conditional or unrisked range of possible hydrocarbon volumes, assuming the condition that at least one significant field exists. (The meanings of special terms, as used by the committee, are given in the glossary.) In the subsequent risk analysis, the assessor judges the chance that the first assumption of at least one field is right. This estimate is called the chance of success, or the chance of adequacy, or marginal probability; it is 1.0 (unity) minus the risk that no field exists.

The great risks and uncertainties inherent in petroleum exploration must be reflected in any realistic assessment approach. The fact that most wildcat wells are dry shows that geologic risks for this type of drilling activity are high. For assessment purposes, we define geologic risk as the chance that no significant oil or gas field exists. A significant field has a volume of recoverable hydrocarbons that exceeds a specified minimum that is meaningful for the area. Geologic uncertainty is the imprecision in estimating the size range, of recoverable hydrocarbon volumes, for significant fields. Of course, the size range of undiscovered fields is extremely uncertain. Even after discovery, the ultimate size of a field remains uncertain until development and production are complete.

Other terms basic to our discussion include the prospect, which is a potential oil or gas field. A play is a group of geologically related prospects with similar hydrocarbon sources, reservoirs, and traps. A sedimentary basin, which may contain one or more plays, is an area in which thick sediments have accumulated and are preserved.

This discussion focuses on geologic risk, but there are other risks, such as finding risks, producing risks, and additional economic risks. A field in a subtle stratigraphic trap may exist but be very difficult or costly to find. Once found, a field may not be economic to produce because of unfavorable water depths, producing depths, pay thicknesses, producing rates, ice conditions, or other environmental constraints. Even if technically producible, the oil and gas might not be economic to produce or transport. Prices for oil and natural gas may decline to an unforeseen extent. All such factors must ultimately be evaluated in addition to the basic assessment of geologic risk outlined here, particularly in determining the amount of economically recoverable resources.

2.2 PROBABILITY CURVE DISPLAY

The most common convention for presenting probabilistic assessment results is to plot exceedance chance against the range of potentially recoverable hydrocarbon volumes (Figure 2.1). The exceedance chance is the chance that the amount discovered will be equal to or greater than the amount shown. The upper curve shows an example of the unrisked range of estimated potential hydrocarbon volumes, from 10 to 160 units (e.g., 10 to 160 million barrels), conditional on the assumption that significant hydrocarbon volumes (here at least 10 units) do indeed exist. This curve can be created directly by judgment, which is the easy but undocumentable approach, or indirectly in various mechanical ways. One mechanical way is to multiply together several estimated ranges of potential hydrocarbon volume factors (e.g., possible productive areas, net pay thicknesses, and volumetric hydrocarbon yields for a prospect) in a computer simulation.

The unrisked curve shows the uncertainty in the range of significant hydrocarbon volumes as they might exist. The curve may be thought of as a set of possible answers, ordered from smallest to largest. For example, of 100 possible answers, the curve indicates that all 100 (1.0 probability, certain to occur) are equal to or greater than the minimum 10 units of hydrocarbon volume, that 50 (0.5 probability) are equal to or greater than 60 units, that 10 (0.1 probability) are equal to or greater than 110 units, and that none exceeds the maximum of 160 units. The arithmetic average or mean of all 100 points on the curve is 64 units. This average would be the indicated, mechanically generated expected volume of hydrocarbons if the prospect or play were productive; but it might not be productive, so risk-weighting is required.

The lower curve of Figure 2.1 reflects the assessor's judgment that this prospect or play has only a 0.5 chance of success (marginal probability) of containing 10 hydrocarbon volume units or more. This curve, the risked curve, is created by multiplying each probability on

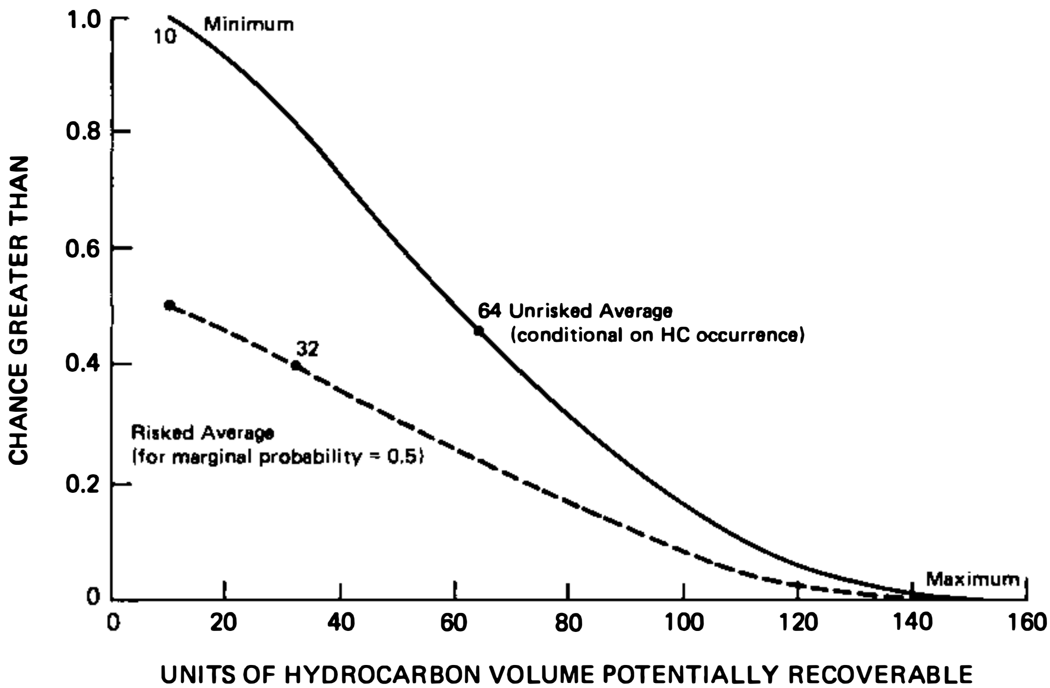


FIGURE 2.1 An example of an unrisked and risked assessment probability curve.

the upper, unrisked curve by the chance of success. If there were 100 prospects or plays like this example, the assessor is estimating that only 50 (50 percent) would have volumes in the unrisked range from 10 to 160 units. The other 50 would be dry or contain less than 10 units. (Ten units or fewer are for practical purposes considered here to be insignificant values to be treated as zeros.) If 100 such prospects or plays were drilled, the average value for expected hydrocarbon volumes would be 32 units, which is the arithmetic mean of 50 zeros and 50 values from the entire unrisked range. Although the probability curve format is not easy to comprehend, it is essential for portraying the uncertainties and risks inherent in resource appraisal.

Because of statistical considerations, aggregation of the results of a composite resource appraisal for several areas is not intuitive. For instance, risked means are additive, but unrisked means are not. Estimates at the 95 percent and 5 percent level are not additive for either curve. Summation of several curves is possible, but only by use of appropriate statistical methods.

2.3 ESTIMATION PROBLEMS

The process of estimating the resource base consists of translating the necessary geologic assumptions into a mathematical model to estimate the amount of hydrocarbons that may be present. The geologic assumptions that go into an assessment are of paramount importance. Overwhelming problems can occur if the wrong geologic concept is modeled, if the right geology is modeled wrongly, or worst of all, if a prospect or play is not modeled at all because the concept is missed entirely. No amount of statistical sophistication can counterbalance erroneous geologic assumptions. With unpredictable geology or poor judgment, an assessor's curve can completely miss the mark. The chief causes of these problems, discussed in detail below, are the complexities of oil and gas occurrence, the inadequacies of data, the judgmental nature of the necessary risk weighting, psychological influences, and modeling pitfalls.

Commercial oil and gas fields result from the complex interplay of various geologic factors. At least 11 factors--source richness, maturation, migration, timing, reservoir thickness, porosity, permeability, trap size, seal, preservation, and recovery--must each be adequate, or no significant volumes of hydrocarbons can accumulate or be produced. Because of the uncommon occurrence of these factors in favorable combination, relatively few prospects become commercial oil and gas fields. Thus, there is a high risk of dry holes associated with exploratory drilling. The difficulty of evaluating the pertinent geologic factors is accentuated by our imperfect knowledge of many of the fundamental processes involved.

Even under ideal conditions, the assessor of undiscovered oil and gas resources must work with incomplete and uncertain data before drilling occurs, for drilling provides the only way to evaluate with confidence all aspects of source, reservoir, and trap. Assessors use all applicable available geologic data concerning the area under consideration. These may include direct observations from wells, seismic reflection profiles, and characteristics of nearby fields. In frontier areas, nearby well and field data are sparse or nonexistent. Therefore, analogies with known areas are commonly used to cope with the substantial uncertainty. However, no two areas are ever exactly alike. Not knowing the right answer in advance, the assessor is forced to play the averages. As the average of many hypothetical possibilities is never the exact actual answer, the assessor is doomed to be wrong on each individual trial. The best that can be done is to bracket the real answer within the range, and to give poor prospects and plays a low chance of adequacy, and good ones a high chance. The assessor's performance realistically can only be gauged over many trials by comparing the sum of the predicted risked means with the sum of the discovered volumes, which should be the same.

The inescapable risking step, which levies a powerful weight on the final assessment product, is and always will be a highly judgmental process. It can be guided by experience, but the future in some way or another will always differ from the past. The risks should be systematically related to the relevant geologic factors, so that the key ones can be further investigated or mapped, and interdependencies established.

Psychological influences, the emotional and motivational factors that may affect the individual or group constructing assessments, are seldom recognized and never acknowledged. An individual's perception of risk is often an intricate mix of actual observations on geology and attitudes toward risk taking. Past experience with unfavorable geology and a cautious attitude can lead to unduly conservative estimates, while some exuberant assessments are brought on by patriotic enthusiasms or jostlings for budgets or the approval to drill. To ask a local expert to assess his area is often like asking a chamber of commerce how good its town is. Other perils include anticipating a desired result rather than what nature has bestowed, or desiring to influence company or national policies for ulterior motives. While such influences are rarely carried to the extremes of malice or conscious deception, their existence argues well for full documentation of the logic and basic assumptions in assessments.

Modeling pitfalls are numerous. They may be simple mathematical errors, input mistakes, incorrect logic, lack of standard definitions and procedures, errors of omission, bad analogies, erroneous assumptions, wrong correlations, or a host of other evils. Significant anomalies are caught where the outcome is irrational, but a constant guard must be posted.

2.4 SUMMARY

In spite of all of these uncertainties and possibilities for error, both government and industry must have systematic, quantitative estimates on which to base policy or investment decisions. It is important to use a method that realistically scales hydrocarbon occurrence in a geologic model. It is then necessary for assessors to document their assumptions and for users to be aware of the limitations. It is very important to consider the whole range of possibilities rather than to focus on only one number, such as the risked mean, which is better viewed in a relative sense than as an absolute value for the final outcome. Assessors generally are more successful at ranking opportunities from relatively good to relatively bad than they are at centering on the correct resource volumes.

Chapter 3

PETROLEUM RESOURCE ASSESSMENT METHODS

3.1 OVERVIEW

Approaches to assessing undiscovered potential include two major classes; those that break the problem down into its logical, practicable, and documentable component volume and risk factors; and those that generate unscaled, direct hydrocarbon-volume estimates, using delphi or analogy techniques. Judgment and analogy are applied at every step of both classes of methodology; however, the assumptions and controlling factors in the second class cannot be adequately documented. Thus, these procedures are not appropriate for the needs of MMS, and are not further considered here. Those methods that fall into the first class require the generation of specific input parameters that can be documented, reviewed, and modified as needed. These methods are described in this chapter.

The methods of assessing undiscovered potentials under consideration may be practically subdivided into those applied to individual prospects, to plays (groups of prospects), to basins (groups of plays), and to regions (groups of basins). Each method summarized on Table 3.1 is placed at its main level of utility, although some methods have more limited applicability at other levels. The methods are designated by their main volume-factor components, but each method, excepting the regional projections, must ordinarily also incorporate weighting for geologic risk. Methods using areal hydrocarbon yields have generally been superseded by the volumetric approaches listed. Techniques for projecting the reserve growth of discovered fields are not discussed.

The following discussion gives details on the chief characteristics, origins, applications, and limitations of these methods.

3.2 PROSPECT METHODS

3.2.1 Trap Volume

The trap-volume method focuses on the parameters controlling trap volume. The oil or gas content of that volume is introduced with an arbitrary hydrocarbon fill fraction. The detailed volume factors to be multiplied are closure area, corrected average gross reservoir thickness

TABLE 3.1 Outline of Methods for Assessing Undiscovered Petroleum Resources

PROSPECT METHODS

1. Trap Volume: Assessing effective reservoir pore volume under closure, with estimated hydrocarbon fill fraction.

2. Trap and Hydrocarbon Charge Volumes: Assessing trap volume as above, with hydrocarbon fill fraction replaced by estimates of oil and gas volumes generated, migrated, and trapped.

PLAY METHODS

1. Summation of Individual Prospect Assessments.

2. Grouped Geologic Field Numbers and Sizes: Using prospect counts and success ratios with future field-size distributions, or field densities with future field-size distributions.

3. Discovery-Process Models: Projecting future discoveries from statistical analysis of historical field-size distributions in relation to drilling effort.

BASIN METHODS

1. Summation of Play Assessments.

2. Sediment Volumes and Yields: Using total or modified sediment volumes and a hydrocarbon yield per unit volume.

REGIONAL METHODS

1. Summation of Basin Assessments.

2. Life-Cycle Projections: Forecasting discoveries from the historical production record through time.

3. Discovery-Rate Extrapolations: Forecasting discoveries from the historical discovery rate as related to drilling effort.

4. Econometric Methods: Analyzing past and future drilling effort and discoveries from supply, demand, price, and regulatory controls.

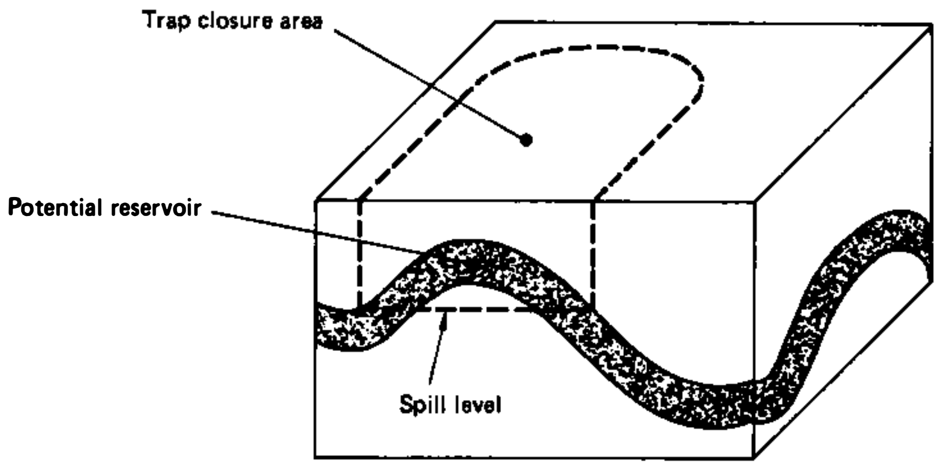
over that area, the reservoir net/gross ratio, average porosity, hydrocarbon saturation, formation volume factor, the hydrocarbon fill fraction, and the recovery efficiency. Figure 3.1 displays the factors that are important in this model. A shortcut is to multiply potentially productive area by an assumed average net pay thickness and by a recoverable yield per unit volume; these three factors include lumped consideration of all the detailed factors, including hydrocarbon fill.

For many years, a single most likely value for each factor was multiplied to produce a single estimate. In the late 1960s, various workers proposed the use of Monte Carlo computer methods to produce a range of estimates reflecting the inherent uncertainties (Stoian, 1965; Walstrom et al., 1967; Smith, 1968). When using the Monte Carlo procedure, probability distributions are determined by running many trials. Each input factor is entered as a range, and the computer multiplies out many different possible combinations that cover all ranges of all factors. The result is a large number of possible answers that can be ordered from smallest to largest to produce an unrisked or conditional probability curve (Figure 2.1). An estimate of the overall chance of adequacy (marginal probability), based on analyzing the geologic controls required to exceed the minimum of each volume factor, is then used to produce the risked curve (Gehman et al., 1981).

This is the fundamental assessment approach used in estimating undiscovered resources and in estimating discovered reserves before appreciable engineering data become available. Its effective use depends on reasonable delineation of the prospect, normally by seismic survey. All key assumptions are laid out, and all interpretations are documented. The most critical and uncertain factor, of course, is the hydrocarbon fill fraction, whose range and central tendency are selected judgmentally. Commonly the range is set from near zero to 1.0, and, in the absence of definitive data on the source rock or where many prospects are being assessed, this may be the only feasible approach. Where data and time are available, however, consideration can be given to the more detailed method discussed next.

3.2.2 Trap and Hydrocarbon Charge Volumes

The trap and hydrocarbon charge volume method uses the same trap-volume analysis described above and also provides, by geochemical material balance calculations, an independent measure of hydrocarbon charge or fill. The charge estimate is based on an analysis of the volumes of oil and gas generated, migrated, and trapped. Many factors must be quantitatively evaluated, including (1) effective source-rock thickness, (2) original organic carbon content, (3) organic matter type, (4) paleodrainage area and continuity, (5) oil and gas yields through time as a function of maturation, (6) oil and gas losses during vertical and lateral migration, (7) all of the trap-reservoir volume factors, (8) trap timing relative to migration, (9) oil and gas losses at the trap related to seal leakage or biodegradation or flushing or overcooking, (10) hydrocarbons spilling out of or into the trap to or from other drainages, and (11) recovery efficiencies. In addition to the usual sophisticated geological, geophysical, and geochemical studies, this approach requires



Hydrocarbon Volume Factors	Hydrocarbon Controls or Geologic Risk Factors
• Closure area	• Existence of fold or fault, facies or unconformity pinchout
• Average reservoir thickness (including net/gross ratio)	• Facies change, truncation, or faulting
• Porosity (including saturation, shrinkage)	• Cementation, fracturing, presence of solution cavities
• Hydrocarbon fill fraction	• Source quality, quantity, maturation, migration; seal and timing; preservation from flushing, overcooking, or biodegradation
• Recovery	• Permeability, viscosity, drive mechanism

FIGURE 3.1 Prospect resource assessment.

detailed analyses of burial, thermal, pressure, and tectonic histories.

Sluijk and Nederlof (1984) presented an elegant calibrated version of this method using a proprietary computer program and data set of some 350 tested and analyzed prospects worldwide. Murris and Demaison (1984) reported that this geochemically based approach has markedly increased forecasting efficiency compared to prospect rankings by trap size only. Demaison (1984) noted higher prospecting success ratios in areas underlain by mature source rocks. Bishop et al. (1984) presented a prospect version of the method depending on a proprietary computer program with individual calibrations of many of the input variables. Other oil companies also have proprietary computer programs that calculate the volumes of hydrocarbons generated by a source rock and migrated to reservoirs. Russian investigators have worked on similar approaches for a long time (Semenovich et al., 1977).

The complexity of this technique is both an advantage and a drawback. It is important to try to understand and quantify all key controls of oil and gas occurrence. It is difficult and time-consuming to do so, however, and the required computer programs and calibrated data sets are beyond the present reach of most assessors. The approach can reduce (but not remove) risk in many areas, and by stages it will ultimately replace some of the short-cut assessment methods.

Various authors have modeled hydrocarbon generation, migration, and entrapment in broader play or basin areas (McDowell, 1975; Momper and Williams, 1979; Welte and Yukler, 1984). Typically, the vast amounts of hydrocarbons thought to be generated must be cut down to size by imposing assumptions of very low expulsion, migration, and/or trapping efficiencies related to hydrocarbon retention in the source or to loss during migration. At the prospect level, the localized trap-volume, drainage, and seal constraints help to keep the method tied to reality. But such factors become an order of magnitude more difficult to analyze on a playwide or basinwide basis. The method today can thus be applied most effectively to prospects, although research is under way on larger-area applications.

3.3 PLAY METHODS

3.3.1 Summation of Individual Prospect Assessments

Summing the risked curves of all component prospects is the most detailed form of play assessment. The sums can be made by Monte Carlo simulation, but care should be taken to isolate any geologic dependencies between prospects (Gehman et al., 1981), or the final marginal probability and highside potential of the summed curve may be seriously misleading. The initial geologic definition and delineation of the prospects to be grouped as a play are absolutely critical to the outcome. Typically, the prospects in a play should share some common elements of risk (Baker et al., 1984), and initially lumping distinctly different prospects from different plays defeats the purposes of probability analysis. Also, in most plays at any given time, it is not possible to identify and delineate all the prospects; thus, additional unidentified ones should be postulated.

The advantage of prospect aggregation is that it preserves the most detailed record of exactly where and in what types of deposits the postulated potentials lie. The disadvantage is that the assessor is so entangled with the details of what he can see that he may fail to grasp the significance of what he cannot see. MMS's computer model called PRESTO, acronym for Probabilistic Resource Estimates-Offshore, is a prospect-summation program; characteristics and qualities will be reviewed in detail in the next chapter.

3.3.2 Grouped Geologic Field Numbers and Sizes

The most common procedure is to take a defined, geologically related group of known and/or postulated prospects, to apply a success ratio in a Monte Carlo simulation to estimate a number of potential fields, and similarly to assign field sizes (volumes of recoverable hydrocarbons) from an appropriate distribution. Separate assessments can be made for oil and for gas prospects and field-size distributions.

Atwater (1956) pioneered the method using single values for each parameter. The Geological Survey of Canada (Roy et al., 1975) used ranges of values for both prospect numbers and field sizes; the field-size distribution was prepared in a prospect-like simulation where the trap-volume and other parameter ranges represented all the prospects rather than just one. L. P. White (1979) in his RASP (Resource Appraisal Simulation for Petroleum) play program expanded the Canadian model to isolate marginal and conditional probabilities and to simulate the exploration process. Baker et al. (1984) had developed a similar approach, offering additional variety in using field densities for estimating field numbers, and known-field reserves for constructing historical field-size distributions.

The strengths are that the method deals with the natural exploration units, prospects and fields, with specified numbers, sizes, and probabilities. The assessment results can readily be used for economic analysis, planning purposes, and discovery forecasting. There is a better perspective on the group than in individual prospect aggregation, particularly in the all-important risking step, and the procedure is much simpler and less time-consuming. On the other hand, the potentials of individual prospects are not specifically identifiable and the field-size distribution can be in serious error if the size of the largest prospect is not known or not properly handled. (The same holds true for prospect summation, of course.) No method is very helpful in assessing subtle stratigraphic traps. It is probably more realistic, however, to treat such traps in a play grouping, using analogies to select the field numbers and sizes, than it is to try to define all individual prospects.

3.3.3 Discovery-Process Models

These methods project future discoveries from statistical analysis of discovered field-size distributions, commonly in relation to drilling effort. Arps and Roberts (1958) first applied this technique to a Cretaceous play in the Denver Basin, clearly recognizing that the study unit should consist of geologically similar fields. The basic assumptions are that the largest fields tend to be found early, and that there is a systematic distribution of successive size classes of fields within a finite area to be explored. Many other investigators have worked with this type of model, as reviewed by Adelman et al. (1983).

This approach is applicable, of course, only in areas where a considerable number of discoveries have been made. It provides a useful view of the future as it might relate to the past, and it serves as a valuable check on the results of geological methods. There is no guarantee, however, that gaps in an existing field-size distribution will be filled. The key question is whether or not actual geologic prospects exist for discovery of the largest postulated fields. Geologic analysis of actual opportunities should be included with the statistical procedures.

3.4 BASIN METHODS

3.4.1 Summation of Play Assessments

Summing the risked curves of all component plays (or prospects) by Monte Carlo simulation is the most detailed form of basin assessment. Again, any geologic dependencies of source, reservoir, or trap conditions between plays should be considered in the summation process, although the importance of interdependencies generally diminishes at higher levels of aggregation. Except in densely drilled basins, it may be desirable to postulate some vaguely identified plays to compensate for serendipity--the discovery surprises, such as subtle traps, that were not conceived at the time of assessment.

3.4.2 Sediment Volumes and Yields

In the simplest form, the total sediment volume in a basin is multiplied by an average recoverable hydrocarbon yield per unit volume taken from a developed basin of apparently similar geologic character (Weeks, 1950). A range of volumes can be multiplied by a range of yields in a Monte Carlo simulation. One modification is to use only the coarse (potential reservoir) facies volumes with corresponding yields (White et al., 1975; Herrington, 1983). Or more complex systems can be devised to modify the volumes and yields to account better for the influence of reservoir, trap, source, and migration factors (Jones, 1975).

This pioneering method, the forerunner of all quantitative assessments, is now nearly obsolete. The lump-sum result cannot be disaggregated into fields for modern economic and planning analyses. Basins generally are too heterogeneous laterally and vertically to be characterized effectively at one stroke. Systematic, geologically consistent analysis is far more feasible at the play level. About the only remaining common use of basin volumetrics is to verify judgment on aggregations, by comparing the potential hydrocarbon sum, translated into a yield factor, with known basin yields.

3.5 REGIONAL METHODS

3.5.1 Summation of Basin Assessments

Summing the risked curves of all component basins is the most detailed form of regional assessment, especially if the basin assessments are in turn aggregates of play assessments.

3.5.2 Statistical Projections

The three basic types of statistical projections or historical extrapolations outlined below are described in detail by Adelman et al. (1983).

- Life-cycle projections assume a relatively simple functional relation between time and the amounts of oil and gas produced per unit of time. Hubbert (1962) fit the U.S. historical production-rate curve with a logistic function that models the inevitable rise and decline of the exploitation of an exhaustible natural resource. Hubbert's resulting estimates of ultimate production were conservative but were probably closer to the truth than most geologic estimates of the time.

- Discovery-rate extrapolations assume that the oil and gas discovery rate per unit of drilling effort in a mature province where the biggest fields have been found will decline with increasing cumulative drilling effort or cumulative discoveries. Hubbert (1967) tried this approach and got substantially the same results given by his life-cycle projection.

- Econometric methods attempt to analyze past and future drilling effort and discoveries from the standpoint of supply, demand, price, and regulatory controls.

The preceding statistical projections are appropriate only in mature areas. They can provide reality-rooted, lump-sum assessments for comparison with other aggregations. There is often ambiguity about the exact areas and depths truly represented by the projection's results, and locations of the chief potentials cannot be identified. The proper mathematical forms for projections are rarely self-evident. Assessment is fundamentally an analysis of future geologic opportunities, and the future often is not readily predictable from past performance. Statistics do not generate new-play concepts.

Chapter 4

PETROLEUM ASSESSMENT METHODOLOGY OF THE MINERALS MANAGEMENT SERVICE

4.1 OBJECTIVES, REQUIREMENTS, AND DATA

The Minerals Management Service (MMS) has the responsibilities to (1) estimate the technologically and economically recoverable undiscovered petroleum energy resources of the Outer Continental Shelf (OCS) for planning areas and potential lease sales; (2) to analyze economic and engineering parameters for assessing environmental impacts and determining bid adequacy; and (3) to conduct cost-benefit studies of leasing alternatives. To meet these objectives, MMS defined three technical requirements for its resource assessment approach. First, the methodology used must allow areas or tracts to be added or deleted to evaluate the impact of their inclusion or exclusion in a sale. Second, the methodology must be reproducible, allowing estimates to be updated as new information becomes available. Third, the methodology must be flexible, allowing it to address variable states of knowledge from mature leasing areas to frontier basins for which very little information may be available.

The Minerals Management Service has an inventory of identified prospects and their estimated resource potentials. This inventory, which inevitably is incomplete and uncertain, changes over time as knowledge evolves from seismic and geologic evaluation to exploratory drilling. During the search for oil and gas, prospects may be added to or deleted from the inventory as they are identified, condemned, or produced. It is on this changing information base that leasing decisions are made. MMS selectively acquires industry geologic and geophysical data as a condition of lease permits and regulations. To support MMS's leasing decisions, these data are carefully analyzed and interpreted to locate and map geologic features capable of trapping hydrocarbons, and to establish values for geologic parameters necessary for resource assessment and economic evaluation.

By the end of fiscal year 1984, MMS had acquired 874,000 line-miles of common depth point seismic data, about one-third of the total obtained by the petroleum industry. MMS also has access to all offshore proprietary well logs and well information collected by the industry, including the results of Continental Offshore Stratigraphic Test (COST) wells, which are joint ventures sponsored by industry to obtain geologic information in unexplored areas.

4.2 PRESTO METHODOLOGY

The computer model called PRESTO (acronym for Probabilistic Resource Estimates-Offshore) provides for prospect summation by means of a mathematical representation of an area having petroleum potential. It incorporates all relevant available data to derive estimates of undiscovered economically recoverable resources expressed as ranges of values, representing all perceived outcomes. PRESTO simulates exploratory drilling for the area of study. In the simulation, each possible prospect is "drilled" and if hydrocarbons are "discovered," the amount of resources is calculated. PRESTO calculates prospect-specific resources. However, if sufficient stratigraphic information is available to consider geologic zones or horizons within a prospect, PRESTO allows the option of computing zone-level resources.

Figure 4.1 summarizes the steps taken by MMS personnel at the four regional offices to prepare available data for input into the PRESTO model as parameters.

4.3 PRESTO INPUT VARIABLES

The Minerals Management Service regional evaluators have attributed volume factors to each of some 2,400 OCS prospects of variable size identified to date. The seven independent variables that emerge from the mapping efforts, which are input into the PRESTO model to determine potential hydrocarbon volumes, are as follows: (1) productive area, expressed as acres; (2) zone pay thickness, expressed as feet; (3) oil share or the proportion of the zone pay thickness consisting of oil, expressed as a decimal fraction; (4) oil recovery factor for oil reservoirs, expressed as barrels per acre-foot; (5) gas-oil ratio, expressed as cubic feet of natural gas per barrel of oil; (6) gas recovery factor for gas reservoirs, expressed as thousands of cubic feet of nonassociated gas per acre-foot; and (7) condensate yield ratio for liquids produced from gas reservoirs, expressed as barrels per million cubic feet of nonassociated gas. These seven values can be entered either as single points or as ranges described by probability distributions. The seven values or ranges of values are recorded by the MMS evaluator on a Prospect Evaluation Form (Table 4.1).

Three dry risk values quantify the likelihood of no hydrocarbons being present for (1) the zone within the prospect; (2) the prospect within the area; and (3) the area within the basin. There are varying degrees of geologic interdependency between these three levels of assigned risk. Within PRESTO, the risk factors for a level must be made conditional on the risk factors at higher levels. It is the responsibility of the evaluator to decide on the degree of dependence between the dry risk factors at each level, with PRESTO restricting the user to the assumption of independence or positive dependence.

The evaluator must estimate the zone geologic risk for each zone in each prospect. This risk factor represents the overall probability that

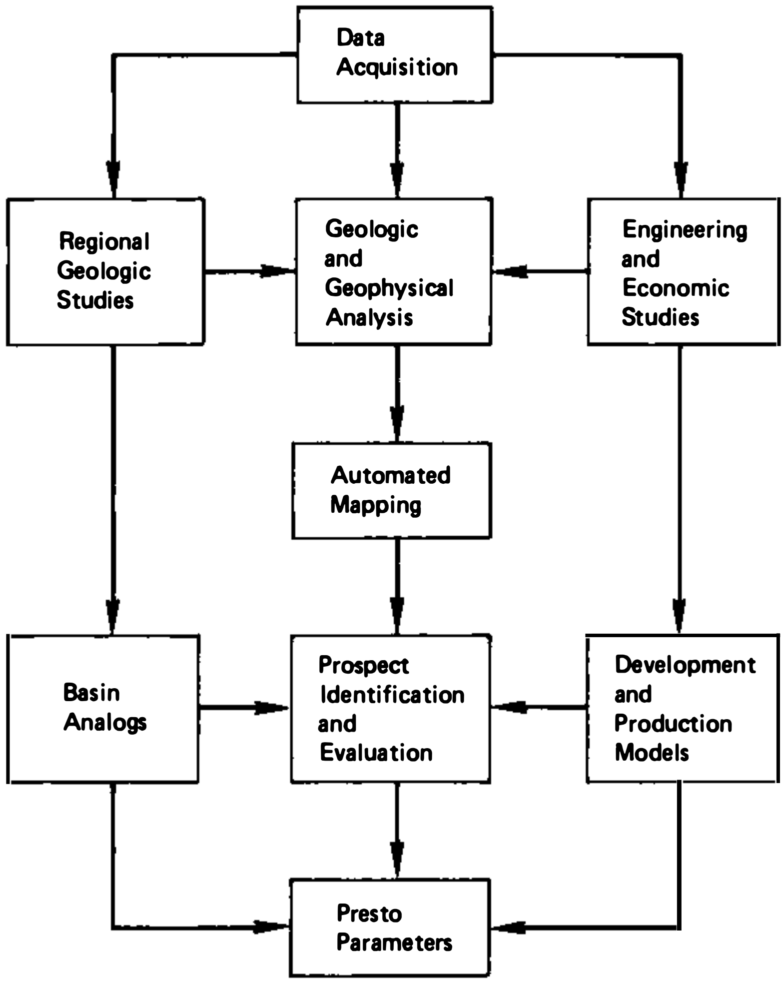


FIGURE 4.1 MMS data gathering and preliminary resource analysis systems.

Source: Ibrahim (1985).

TABLE 4.1 An Example of a Prospect Evaluation Form

BASIC INFORMATION

Prospect ________ Geologist ________ Geophysicist ________
Formation (Age) ________
Water Depth ________
Total Prospect Acreage Min ________ Mp ________ Max ________

TRAP DATA

	% Fill Up	Vertical Closure	Depth	Volume Thickness
Crest Point	____	____	____	
Min Fill Up	____	____	____	____
MP Fill Up	____	____	____	____
Max Fill Up	____	____	____	____
Spill Point	____	____	____	

Located In

	Min Acreage	Mp Acreage	Max Acreage
Tract ____	____	____	____
Tract ____	____	____	____
Tract ____	____	____	____
Tract ____	____	____	____
State Land	____	____	____
Outside Sale			

NET PAY DATA

Formation Thickness ________
% Sand ________

Total porous sand available ________
Net Pay Thickness Min ________ Mp ________ Max ________
Analog ________

RESERVOIR DATA

No. Exploration Wells ____ Depth ____ Depth ____
No. Delineation Wells ____ Depth ____ Depth ____
PVT Depth ____ Temp ____ Pressure gradient ____

Production occurrence: From ____ To ____

	Min	Mp	Max
Recovery Bbl/AF (For oil zones)	____	____	____
Recovery Mcf/AF (For gas zones)	____	____	____
Gas oil Ratio (Ultimate producing)	____	____	____
Yield Condensate (Ultimate producing Bbl/MMCF	____	____	____
Porosity (Avg)	____	____	____
Water Saturation (Avg)	____	____	____
Permeability (Avg)	____	____	____
Fluid properties:			
Oil (API°)	____	____	____
Gas (Sp gravity)	____	____	____
Gas in solution (SCF/bbl)	____	____	____

Chances of "Oil" alone ____
"Oil and Gas" ____ % Oil ____ % Gas ____
"Gas" alone ____

RISK DATA

Zone Success (S_z) = ________ Zone Risk (R_z) = ________

REMARKS: ________________________________

____

Source: Ibrahim (1985).

the zone in the prospect under consideration will be dry. Next, the evaluator must determine the probability that the prospect would not contain hydrocarbons. In addition to the zone and prospect geologic risk factors, a probability that applies to the area as a whole is considered. This area-risk factor represents the likelihood that no prospect as modeled would contain hydrocarbons. Marginal probabilities or chances of adequacy are calculated from these risk factors.

4.4 PRESTO CALCULATIONS

On each of PRESTO's Monte Carlo trials, each prospect is "drilled" to determine whether it is simulated as "productive" by using a sampling technique that compares a computer-generated random number to the conditional risk computed from the dry risk factors. If the prospect is found to contain hydrocarbons in that trial, then oil and gas resources are calculated. Oil and gas resources are calculated for the hydrocarbon-bearing zones using volumetric equations that employ the previously described seven physical properties of a zone within a prospect. The volumes computed are for oil, nonassociated gas, condensate (natural gas liquids), and solution gas. In PRESTO, each of the seven physical variables can be represented as a fixed value; or by one of several distributions of values including uniform, rectangular, triangular, and lognormal distributions. In PRESTO's Monte Carlo computer simulation, one point is randomly selected from the range of values for each variable that the MMS evaluator has specified. The randomly selected values from within the given ranges are used to compute one hydrocarbon volume. For a second trial, new values are randomly selected from the given ranges of values, and another volume is calculated. Each Monte Carlo trial yields one volume and represents one possible outcome. Numerous trials are run using this process until the distribution of volumes has been adequately covered.

After conditional oil and gas resource estimates for a prospect (or zone) have been made, PRESTO determines whether the prospect is commercially viable by comparing the volume of resources for each productive trial to an economic field size volume. To make the comparison, total resources estimated for a prospect on a given trial are converted to barrels of oil equivalent (BOE). Analyses of long-term price trends, and the costs of exploring for, developing, producing, and transporting offshore hydrocarbons are necessary to estimate the minimum economic field size. Estimates of minimum economic field size are derived outside the PRESTO model by a cash flow analysis program, which calculates the amount of resources needed to justify a decision to explore and develop a field, considering specific factors, such as water depth, distance from shore, and depth to the producing horizon. The minimum economic field size reflects the fact that there are lower cost areas, such as the shallower waters of the Gulf of Mexico, where relatively small deposits would be economic, while only larger deposits would be economic at projected oil price ranges in the higher cost areas such as the Beaufort Sea or the deep water Atlantic.

The PRESTO model then compares a prospect's calculated conditional resource potential to the minimum economic field size. If the amount calculated is less than the minimum economic field size, the prospect is considered noneconomic and the resources for the prospect are set equal to zero. If the amount is greater than the minimum economic field size, the prospect is considered productive and the resources that were calculated are stored.

After resources have been estimated for the first prospect, these procedures are repeated prospect-by-prospect until all have been evaluated. The productive resources for all prospects are added together, yielding a single estimate of undiscovered economically recoverable resources for the basin for one trial. Then, PRESTO goes back to the first prospect, starts the process again, and continues for the number of trials specified by the evaluator.

4.5 PRESTO OUTPUTS

The most important outputs produced by PRESTO for each planning area are (1) the conditional 95 percent, 5 percent, and mean economic resource estimates for hydrocarbons, (2) the marginal probability of economically recoverable hydrocarbons in the area, and (3) the corresponding risked means. Three cases from the conditional distribution are used for environmental impact analyses. A low case, with a 95 percent probability of that amount or more occurring; a high case, with a 5 percent probability of that amount or more occurring; and a mean or average case.

Modifications to PRESTO are being incorporated into two new computer programs, PRESTO II and Model 606. These changes include the following:

1. A fourth level of risk, planning area, in addition to the previous levels, zone, prospect, and basin or subarea.

2. Enhanced sampling capability.

3. Capability to execute on a microcomputer as well as on a mainframe.

4. The option to impose dependency correlations among data variables.

5. Incorporation of postulated prospects in a more systematic fashion.

6. Addition of the risked distribution.

7. Addition of basin and area level checks on economic thresholds.

8. Capability to determine the distribution of resources by prospect, subarea, and area.

Various computational modifications are also planned.

4.6 SUMMARY

The current methodologies were developed to allow MMS to respond to the legal requirements of OCS leasing and development. Volumetric techniques used in the past did not allow consideration of the effect of addition to or removal from specific areas. The ability of the model to disaggregate into area-specific economic and environmental impact assessments is adequately met in this approach. The analysis of individual prospects also allows estimates to be updated as additional information is gathered. The model also meets the need for flexibility in the estimation process, but further improvements are in order. The committee's recommendations, which follow, are made in full cognizance of the planned improvements.

Chapter 5

CONCLUSIONS AND RECOMMENDATIONS

The committee considers the basic thrust of the MMS assessment methodology to be appropriate but has some concerns about specific procedures and judgments. The PRESTO prospect-summation approach is systematic, documentable, and theoretically sound. It is a marked improvement over undocumentable, mainly subjective, delphi-type methods. Unfortunately, the use of a good method does not guarantee good assessment results. The inescapable uncertainties force the use of judgment at every step, and any judgment can be mistaken. The chief benefit of a good method is that its systematic documentation allows others to judge the judgments involved.

The committee has the following conclusions and recommendations for improving MMS's assessments.

5.1 DISCUSSION

Conclusion: The current methodology is excessively detailed for some assessment areas, particularly where few data are available. To be practical and effective, the methodology must deal with thousands of prospects in a timely and consistent manner.

- The committee recommends that MMS approach resource assessment from the perspective of the play, moving to the prospect level as necessary, to the zone level only rarely, and to the basin level only by aggregation of the component plays.

The basic assessment unit should be the play, considered as a group of geologically related prospects with similar hydrocarbon sources, reservoirs, and traps. MMS has approached assessment almost entirely from the perspective of a prospect. The assessment process should be initiated from the perspective of the play. Delimiting a play as a geologically coherent group of prospects both areally and vertically is essential for the proper application of common elements of risk. Lumping geologically disparate prospects destroys the efficacy of the important risking step. The first consideration in defining plays must therefore be the geology. The geologic play entity can then be split into subplays along the planning-area boundaries, water-depth contours, lease-sale lines, or other divisions required for practical purposes. Subplay assessments can later be recombined as necessary, with the proper risk interdependencies taken into account. Assessments of whole planning areas or basins should be made by aggregating the component prospect and/or play assessments.

Where detailed data are available, prospect assessment and summation may be appropriate. However, assessing two or more zones per prospect should be done sparingly. Commonly, the bulk of a field's reserves occur in the single largest zone. If multiple zones are geologically closely related and have the same risk factors, they should be lumped for assessment purposes. Two stratigraphically separated zones having significant potentials and distinctly different risks can be defined as separate plays and assessed separately in a group of prospects. Generally, in view of all the uncertainties, assessment by zones overworks the data and the problem.

- The committee recommends that MMS develop more fully a grouped-prospect play assessment methodology that is compatible with its current prospect summation approach.

Of all the assessment methodologies available (Table 3.1), only two are essentially suited to the needs and present capabilities of MMS, and each should be used where appropriate: (1) prospect summation by play and (2) grouped geological field numbers and sizes by play. All other methods are impractical or unacceptable, either because of excessive data demand or because their results provide insufficient detail on resource distribution. The ideal method would make prospect summations and play assessments of grouped prospects entirely compatible in both mature and frontier exploration plays, would allow ready postulations of prospects, would facilitate updating and reassessment, would allow assessed potentials to be easily split or aggregated for various subplay areas, and would provide a suitable basis for analyses of economic, supply, and environmental issues. As examples, the prospect summation PRESTO program of MMS and the Interior Department's RASP (Resource Assessment Simulation for Petroleum) play program could meet these goals.

Prospect summation gives the most versatile detail on assessed resource distribution, but can be an unnecessarily complicated and time-consuming process where many prospects are involved. In frontier areas where all data are limited, prospect summation depends on the same assumptions as grouped-prospect play assessments and provides the same types of results but does it the hard way, overworking the problem. In intensively drilled areas, where many remaining small but significant prospects are not detected by seismic coverage, grouped-prospect play assessment can often be more effectively applied than prospect summation.

The play approach generally is the most practicable for major regional assessment projects, and the uncertainties in economic as well as geologic prospect parameters ordinarily can be effectively treated by prospect groupings. On the other hand, assessment of individual prospects is the only reasonable tool to use where specific locations are critical or where prospects do not fit a regular size distribution, particularly where there are unusually large sizes.

MMS should have the capability of using either approach, prospect summation or grouped-prospect play assessment, as the needs and data dictate. The two approaches have the same prospect-specific roots and can be made fully compatible, so that it would be possible to switch from one to the other on a play-by-play basis within the same model.

Conclusion: The approach to risking should be revised. Methods for realistically handling the elements of risk are required to provide valid estimates of resources and to sum up resource potentials by area, basin, or region.

- The committee recommends that MMS approach risk evaluation from the perspective of the marginal and conditional probabilities at the play level.

Consideration of risk should first be focused at the play level on marginal and conditional probabilities. The marginal probability or play chance is the geologic existence chance for at least one future significant field in the group of prospects. The play chance reflects the dependent geologic controls that affect all prospects in the group. The conditional probability or success ratio is the expected number of significant fields divided by the number of prospects large enough to hold such fields, given that the dependent geologic controls are favorable. The success ratio reflects the independent geologic controls that affect only certain individual prospects in the group. The average prospect chance for a play with many prospects equals the play chance times the success ratio.

Determining the prospect chance level in this perspective has two important advantages. First, it ties the estimates to experience and historical data, insofar as possible. Second, it clearly separates the group or play-specific levels of risk from the individual or prospect-specific ones. This distinction is critical in aggregating prospect assessments, in determining any geologic interdependencies between plays that may affect their aggregations, and in forecasting discoveries from exploration activity. Of course, known prospects in a play will have chances better or worse than the average, but the average can be used directly for postulated prospects.

- The committee recommends that MMS develop a systematic analysis of the component geologic dependencies to arrive at probabilities for assessment aggregations.

Marginal probabilities for basins or composite areas should not be assigned directly but should be developed by logical aggregations of the component play assessments. Of critical importance in aggregation is the geologic analysis of the dependent versus independent (marginal versus conditional) probabilities discussed above. The dependent factors must be removed for the first step of summation and then reimposed in a second step. The same principles apply to prospect summation.

Subplay assessments could be made in either of two ways or in combination. In the first way, the play is assessed as a series of individual subplays, the prospects being initially divided into subgroups whose areal boundaries are delimited by factors such as the necessary lease-sale lines, or water-depth contours. In the second way, the play is assessed as a whole but an appropriate fraction of the total potential is assigned to each required subplay area. In either way, the subplays or subplay areas would have to be small enough to permit application of the same economic assumptions to all prospects contained in that subplay. Assessment results for subplays could then be reaggregated as required.

Conclusion: MMS has not adequately accounted for the likelihood of discoveries of serendipitous hydrocarbon occurrences. Systematic inclusion of postulated prospects and plays reflects historical experience in similar geologic settings or elsewhere and may add significantly to estimates of the resource base.

- The committee recommends that MMS develop a thoroughly systematic process for realistically including potentials from postulated prospects and plays in assessments.

Unseen prospects should be accounted for in almost every play assessment, and allowances should be made for whole plays that are not yet clearly conceived. Because explorationists at any stage of the search for oil and gas normally cannot identify all future prospects, potentials for unseen prospects in a play should be postulated. The discovery of new plays in old areas has demonstrated again and again that explorationists also cannot generally conceive all play possibilities in early, or sometimes even in late, exploration stages. It is prudent, then, to postulate some whole plays where there currently may be only vague hints. Such postulations apply particularly to stratigraphic or other subtle traps, and they make allowances for the serendipitous or accidental discoveries that have typified many exploration ventures. After carefully reviewing some recently completed regional assessments in which MMS has inserted postulated prospects, it is the committee's opinion that MMS may have underestimated the regions' resource base because of conservative assumptions about the contribution of postulated prospects. Systematic, appropriate inclusion of postulated prospects and plays should be verified in the review process.

Conclusion: The context in which estimates have been made public has been insufficiently complete in the past. Inclusion of only the attainable potential in MMS's reports limits unduly the horizons of planners and decision makers using the data to the short-term; inclusion of both the attainable potential and the resource base may open up vistas for longer-term planning and more visionary actions.

- The committee recommends that MMS assess and report both the undiscovered resource base and the technologically and economically attainable potential.

Both the undiscovered resource-base and the economically and technologically attainable potentials should be reported. The undiscovered oil and gas resource base should be considered as all potentially recoverable volumes postulated to exist, down to some specified minimum field-size limit(s). Offshore, all areas under the jurisdiction or potential jurisdiction of the United States should be assessed, regardless of present accessibility or economics. The estimates of the attainable portion of the undiscovered resource base, deemed economically findable, producible, and marketable, should be derived from these assessments. The most important economic assumptions should be documented.

- The committee recommends that MMS document critical determinants of the assessment in an appropriate fashion in publicly released data. These determinants should include the ranges of the minimum geologic field size, the minimum economic field size, and, if appropriate, the smallest field size of all that is included in the resource base.

Each subplay and play assessment should have a specified minimum geologic field size, a minimum economic field size, and, if necessary, a minimum resource-base field size. The minimum geologic size is the smallest size considered as an observable field in the play assessment. It is of great practical importance in the assessment process as it is the cornerstone upon which geologic risk is evaluated. In a play assessment only those prospects (known or postulated) should be counted that are deemed large enough to hold the specified minimum geologic size.

Selection of an appropriate minimum geologic field size affects every major factor in a play assessment, including the prospect count, the assigned parameters determining the field-size distribution, and the value of the play chance. It is most convenient if the specified minimum size is the same for associated plays in an area, but practical considerations may dictate use of different minimums in different areas.

The minimum economic field size for a prospect or play is the smallest size deemed commercially viable from estimates of future price and cost trends specific to the area. The attainable potential is normally estimated by subtracting from the total assessment the potentials of fields smaller than the minimum economic size but larger than the minimum geologic size. The minimum economic field size is very important and can appreciably influence the attainable potential calculated.

The minimum resource-base field size is the smallest size whose potential is added to a play assessment. If it is the same as the minimum geologic size, no additional potential is assessed. If it is smaller than the minimum geologic size and has some possibility of becoming attainable, its value should be specified, and the potential of all the small fields should be estimated and added to the assessed play potential.

- The committee recommends that MMS report current parameters for both the resource base and the attainable potential; extend the reported probability ranges; and document driving assumptions that affect results, including implied future recovery efficiencies, limits to water and drilling depths considered, and largest expected field size reported by appropriate area.

The MMS practice of reporting conditional and risked assessments for potentially recoverable (not in-place) oil and gas is endorsed. It seems desirable, however, to expand the reported range by giving the 99 and 1 (or even 99.8 and 0.2) percentile values rather than the 95 and 5 for the lowside and highside assessments. In a business as uncertain as assessment, nothing is to be gained by reporting too restricted a range.

It is extremely difficult to present complex assessment results in a simple way. Unrisked and risked cumulative probability curves are the most informative graphical portrayals, but they are hard to understand. The key points from the curves that should be reported are the unrisked lowside, unrisked mean, and unrisked highside, the marginal probability (chance of adequacy), and the risked mean. These parameters are currently reported by MMS for economically attainable oil and gas. They should also be reported for the resource base. The overall oil and gas recovery efficiencies implied for the undiscovered resources should also be reported. In both prospect summation and play assessment, the magnitude of the potential is strongly influenced by the size of the largest field expected. Reporting this value by appropriate area gives a key insight into an assessment.

- The committee recommends that MMS explain to the greatest practicable extent the differences between current and previous assessments.

Great care should be taken to explain fully the causes of differences between a current assessment and previous assessments, and the causes of differences between the resource base and attainable potential. Confusion over the recently released MMS estimates for Alaska's offshore resources illustrates the need for full explanation of such differences when published.

Conclusion: Adequate safeguards are lacking to ensure internal consistency and reasonableness across the regional offices of MMS. In practice, continued vigilance is required to minimize inconsistencies in assessments made by different groups.

- The committee recommends that MMS establish a review process to provide oversight and to standardize decision-making between regional offices.

There is a need for checking the consistency of the assessment procedures used by the respective regional offices. Each area has its special problems, but there should be consistency in the handling of risk, largest field size, hydrocarbon fill, and other key judgments. A small team of perhaps three senior people should review key input, judgments, and results. Some more formal exchange of judgments and ideas among offices would also be desirable.

- The committee recommends that MMS list the hydrocarbon fill fraction along with the results of a prospect assessment and ensure appropriate internal review of this critical parameter.

The judgmental input of the fraction of a prospect's area or volume that is filled with hydrocarbons has a strong impact on the size of the final assessment. The estimated fill fraction therefore should be documented in the assessment results and carefully checked during the review process. MMS prefers to use an areal rather than a volumetric fill fraction. This is acceptable provided that considerable care is used in estimating the related average net pay thickness, and that appropriate dependencies between productive area and net pay thickness are used.

- The committee recommends that MMS systematically compile historical data from discovered plays to help in making more realistic assessment analogies.

Geologic analogies, comparisons of a prospect or play being assessed with similar known productive situations, are important guides in making realistic assessment judgments. MMS has compiled considerable historical data on field parameters useful at the prospect assessment level. To help implement effective play analysis, comparative data should also be compiled for plays, both domestic and worldwide. Examples of such data are geologic characteristics of source, reservoir, and trap; field-size distributions; prospect and field densities by size classes; and historical success ratios and play chances.

5.2 FUTURE DIRECTIONS

Prospect and play assessment methods can be continually improved to reflect the geology more accurately. Ultimately, quantitative models of the processes of petroleum generation, migration, entrapment, and preservation will replace some of our current shortcut empirical approaches. Migration of oil and gas out of the source rocks, through a carrier system, and into (and, unfortunately, often out of) potential traps is a key area for study. Much still remains to be learned about source-rock characterization, reservoir development and continuity, trap leakages, and many other factors.

More advanced computer techniques can also be brought to bear on assessment problems. In particular, comprehensive interactive approaches can help assessors estimate input factors and systematically use comparative data from known hydrocarbon occurrences. Ultimately, sophisticated data-base management systems will also handle and map the enormous volumes of information such as data from seismic records, well logs, and rock samples.

Decision makers need to know how resource assessments translate into potential supplies through time. The answer to this complex question depends on the size, nature, and environment of the resource base; the rates of discovery, development, production, and transport; factors such as politics, competition, new technology, substitution of one fuel type for another, future unconventional sources, national and world supply and demand; and, of course, the all-pervading economic considerations of future costs, prices, inflation, profits, and risks. Play or grouped-prospect assessments are the most effective, available bases upon which to build the necessary assumptions for supply forecasting.

REFERENCES

Adelman, M. A., J. C. Houghton, G. Kaufman, and M. B. Zimmerman. 1983. Energy Resources in an Uncertain Future--Coal, Gas, Oil, and Uranium Supply Forecasting. Ballinger Publishing Co. 434 pages.

Arps, J. J., and T. G. Roberts. 1958. Economics of Drilling for Cretaceous Oil on East Flank of Denver-Julesburg Basin: AAPG Bulletin, v. 42, no. 11, p. 2549-2566.

Atwater, G. I. 1956. Future of Louisiana Offshore Oil Province: AAPG Bulletin, v. 40, p. 2624-2634.

Baker, R. A., H. M. Gehman, W. R. James, and D. A. White. 1984. Geologic Field Number and Size Assessments of Oil and Gas Plays: AAPG Bulletin, v. 68, no. 4, p. 426-437.

Bishop, R. S., H. M. Gehman, Jr., and A. Young. 1984. Concepts for Estimating Hydrocarbon Accumulation and Dispersion, p. 41-52, in Petroleum Geochemistry and Basin Evaluation: G. Demaison and R. J. Murris, eds. AAPG Memoir 35, 426 p.

Demaison, G. 1984. The Generative Basin Concept, p. 1-14, in Petroleum Geochemistry and Basin Evaluation: G. Demaison and R. J. Murris, eds. AAPG Memoir 35, 426 p.

Gehman, H. M., R. A. Baker, and D. A. White. 1981. Assessment Methodology--An Industry Viewpoint, 1981. Proceedings of the Seminar, Kuala Lumpur, p. 114-122.

Herrington, J. C. 1983. Estimation of Potential Gas Resources--Methodology of the Potential Gas Committee, Colorado School of Mines. 15 p.

Hubbert, M. K. 1962. Energy Resources: National Academy of Sciences, National Research Council Publication 1000-D. 141 p.

Hubbert, M. K. 1967. Degree of Advancement of Petroleum Exploration in United States: AAPG Bulletin, v. 51, p. 2207-2227.

Ibrahim, M. 1985. PRESTO: Data Gathering and Preliminary Resource Analysis Systems. Presentation to the Committee on Offshore Hydrocarbon Resource Estimation Methodology, Dallas, May 30, 1985 by the Minerals Management Service.

Jones, R. W. 1975. A Quantitative Geologic Approach to Prediction of Petroleum Resources, in Methods of Estimating the Volume of Undiscovered Oil and Gas Resources: AAPG Studies in Geology 1, p. 186-195.

McDowell, A. N. 1975. What Are the Problems in Estimating the Oil Potential of a Basin?: Oil and Gas Journal, June 9, p. 85-90.

Momper, J. A., and J. A. Williams. 1979. Domestic Oil Reserves Forecasting Method, Regional Potential Assessment, Oil and Gas Journal, v. 77, No. 33, p. 144-149.

Murris, R. J., 1984. Introduction. p. x-xii. In Petroleum Geochemistry and Basin Evaluation: G. Demaison and R. J. Murris, eds. AAPG Memoir 35, 426 p.

Roy, K. J., R. M. Procter, and R. G. McCrossan. 1975. Hydrocarbon Assessment Using Subjective Probability, in J. C. Davis et al, conveners. Probability Methods in Oil Exploration: AAPG Research Symposium. Stanford University, p. 56-60.

Semenovich, V. V., N. I. Bayalov, V. N. Kramarenko, A. E. Kontorovich, A. E. Kuzentosov, S. P. Maksimov, M. Sh. Modelevsky, and I. I. Nesterov. 1977. Methods Used in the USSR for Estimating Potential Petroleum Resources, p. 139-153, in the Future Supply of Nature-Made Petroleum and Gas Technical Reports, R. F. Meyer, ed. The Second IIASA Conference on Energy Resources, July 5-16, 1976. International; Institute for Applied Systems Analysis, Laxenburg, Austria. New York: Pergamon Press.

Sluijk, D. and M. H. Nederlof. 1984. Worldwide Geological Experience as a Systematic Basis for Prospect Appraisal, p. 15-26, in Petroleum Geochemistry and Basin Evaluation: G. Demaison and R. J. Murris, eds. AAPG Memoir 35, 426 p.

Smith, M. B. 1968. Estimate Reserves by Using Computer Simulation Method: Oil and Gas Journal. March 11, p. 81-84.

Stoian, E. 1965. Fundamentals and Applications of the Monte Carlo Method: Journal of Canadian Petroleum Technology, v. 4, p. 120-129.

Walstrom, J. E., T. D. Mueller, and R. C. McFarlane. 1967. Evaluating Uncertainty in Engineering Calculations: Journal Petroleum Technology, v. 19, p. 1595-1603.

Welte, D. H., and M. A. Yukler. 1984. Petroleum Origin and Accumulation in Basin Evolution--A Quantitative Model, p. 27-39, in Petroleum Geochemistry and Basin Evaluation: G. Demaison and R. J. Murris, eds. AAPG Memoir 35, 426 p.

White, D. A., R. W. Garrett, Jr., G. R. March, R. A. Baker, and H. M. Gehman. 1975. Assessing Regional Oil and Gas Potential in Methods of Estimating the Volume of Undiscovered Oil and Gas Resources: AAPG Studies in Geology 1, p. 143-159.

White, L. P. 1979. A Play Approach to Hydrocarbon Resource Assessment and Evaluation: Conference on the Economics of Exploration for Energy Resources. New York University, New York. May 17-18, 1979.

APPENDIX A

THE LETTER REQUESTING STUDY AND THE STATEMENT OF WORK

United States Department of the Interior

MINERALS MANAGEMENT SERVICE
RESTON, VA. 22091

In Reply Refer To:
EMS-Mail Stop 643

EC 14 1983

Dr. Charles J. Mankin
Chairman, Board on Mineral
& Energy Resources
National Academy of Sciences
2101 Constitution Avenue, N.W.
Washington, D.C. 20418

Dear Charles:

Thank you for the opportunity to meet with the Board on November 7, 1983. As you recall, at that meeting we outlined a project concerning regional resource assessment methodology in which the assistance of the Board would be welcome.

The OCS Lands Act, Section 606(d)(2), requires the Secretary of the Interior to maintain an updated estimate of undiscovered crude oil and natural gas resources including hypothetical and speculative resources of the OCS. An assessment of the potential quantities of undiscovered economically recoverable hydrocarbons is fundamental to:

- o establishing leasing/conservation policies, including the 5-Year OCS Leasing Schedule,
- o assessing the impact of possible future energy supply disruptions,
- o determining if sufficient resources are available to fuel the national defense effort,
- o determining if sufficient supplies exist for industries directly dependent on oil and gas supplies,
- o academic supply forecasts.

Previously, estimates of undiscovered recoverable resources were provided by the U.S. Geological Survey's (USGS) Resource Appraisal Group. Secretarial Order No. 3071, Amendment No. 1 (May 10, 1982) transferred responsibility for all offshore resource estimates to the Minerals Management Service (MMS). The provisions of the Order are implemented in a Memorandum of Understanding which further delineates the various responsibilities of MMS and USGS.

Since these regional resource assessments are a new function for MMS, a methodology for assessing the undiscovered recoverable resources that employs geological, geophysical, engineering, and economic data must be developed. We have currently initiated studies to analyze the oil and gas resource assessment methodologies that have been used by industry, other Government agencies, and other countries. We request that the Board provide assistance in identifying and developing a new methodology for the assessment of undiscovered economically recoverable oil and gas resources. Our goal is to develop a flexible methodology that will incorporate inputs from appropriate disciplines (i.e., geology, geophysics, petroleum engineering, economics, statistics) and data sources and yet allow for regional differences in terms of geologic setting, status of exploration and leasing, and status of regional and prospect-specific assessments.

We look forward to working with the Board on this challenging project.

Sincerely,

John B. Rigg
Associate Director for
Offshore Minerals Management

COMMITTEE ON OFFSHORE HYDROCARBON RESOURCE ESTIMATION METHODOLOGY

Statement of Work

The OCS Land Act, Section 606(d)(2), requires the Secretary of the Interior to maintain an updated estimate of undiscovered crude oil and natural gas resources, including hypothetical and speculative resources of the OCS. To assist the Minerals Management Service (MMS) in meeting this responsibility, a Committee under the BMER will conduct a study to:

A. Identify the needs for petroleum and natural gas resource information.

B. Evaluate the advantages and limitations of existing resource estimation methodologies to address effectively each of the identified needs.

C. Assess the adequacy of information available to apply properly each of the existing resource estimation methodologies, and

D. Recommend, where possible, new approaches in addressing the needs for petroleum and natural gas resource information.

APPENDIX B

GLOSSARY

Definitions of the following terms reflect their specialized meanings for oil and gas assessment purposes.

ADEQUACY - See CHANCE.

ANALOGY, ASSESSMENT - Geologic similarity between a known field or productive play or feature and the prospect or play or feature being evaluated. The referenced features are informally called "look-alikes."

ANTICLINE - See FOLD.

ARITHMETIC MEAN - See MEAN.

ASSESSMENT - The estimation of potential amounts of hydrocarbons. The focus normally is on undiscovered resources.

ASSESSMENT CURVE - Exceedance chance (vertical scale) plotted against potential hydrocarbon amounts (horizontal scale). The curve height at any amount is the existence chance for that amount or more. Assessors prefer the "greater than" over the statistician's "lesser than" curve.

UNRISKED ASSESSMENT CURVE - One that is conditional on the assumption that at least a minimum hydrocarbon amount exists; i.e., the adequacy chance is 1.0.

RISKED ASSESSMENT CURVE - The transformation of an unrisked curve, accomplished by multiplying its conditional exceedance chances by the marginal adequacy chance.

DERISKED ASSESSMENT CURVE - The transformation of a risked curve, produced in assessment aggregation, to an "unrisked" curve, accomplished by dividing the risked exceedance chances by the adequacy chance.

ASSOCIATED-DISSOLVED GAS - See GAS.

ATTAINABLE POTENTIAL - See RESOURCE.

AVERAGE - See MEAN.

BASIN, SEDIMENTARY - An area in which thick sedimentary rocks are preserved (sediment thicknesses typically are 1 km or more).

BIODEGRADATION - See CONTROLS (PRESERVATION).

BOE - See OIL-EQUIVALENT BARRELS.

CARRIER BED - See CONTROLS (MIGRATION).

CEMENTATION - The plugging of a rock's pore spaces with minerals.

CHANCE - Synonymous with PROBABILITY.

ADEQUACY CHANCE - Probability that at least a specified significant minimum amount exists. Also called CHANCE OF SUCCESS, EXISTENCE CHANCE, MARGINAL PROBABILITY. Adequacy is one minus risk.

PROSPECT CHANCE - Probability that the prospect contains a field of at least a specified significant minimum size. Also called PROSPECT MARGINAL PROBABILITY. The average prospect chance in a play equals the play chance times the success ratio.

PLAY CHANCE - Probability that the play contains at least one field of at least a specified significant minimum size. Also called PLAY MARGINAL PROBABILITY. In historical perspective, play chance is the number of productive plays (each having at least one significant field) divided by the total number of similar plays tested, both productive and nonproductive.

CHARGE, HYDROCARBON - The amount of migrated oil and/or gas available to a trap.

CLOSURE AREA - The area of a trap that could hold oil or gas.

CLOSURE HEIGHT - The vertical distance between a trap's highest point and the lowest level that could hold oil or gas.

COMBINATION TRAP - See CONTROLS (TRAP).

COMMERCIAL FIELD - See FIELD.

CONDENSATE - See NATURAL GAS LIQUIDS.

CONDITIONAL PROBABILITY - See PROBABILITY.

CONTINGENT RESOURCES - See RESOURCE.

CONTROLS, GEOLOGIC - The essential factors controlling significant oil and gas occurrence. All must occur adequately, coevally and contiguously, or else the chances for a field are eliminated. Hence, they are also the key RISK FACTORS to be evaluated in assessment:

SOURCE ROCK - A sedimentary rock (commonly shale or limestone) whose organic matter has been transformed naturally by heat through time and burial into oil and/or gas. This transformation is called GENERATION or MATURATION. The organic matter must be adequate in amount (concentration, areal extent, thickness), type (quality), and maturation.

RESERVOIR ROCK - A rock unit containing or potentially containing recoverable oil or gas in its small open spaces. (POROSITY is the percentage of small open spaces in a rock's bulk volume; PERMEABLILITY is the capacity of a porous rock to transmit fluids.) The reservoir rock must be adequate in thickness, porosity, and permeability. Risks are that the reservoir unit is missing by facies change, unconformity truncation, or faulting, or that the porosity has been cemented or not developed by necessary solution or fracturing.

MIGRATION - The movement of oil and gas through openings in rock. PRIMARY MIGRATION is movement within the source rock to its boundary. SECONDARY MIGRATION is movement from the source-rock boundary to the trap, through permeable rocks (CARRIER BEDS) or faults or fractures. For migration to be effective, permeable paths must be adequate and the trap must be present when the oil and gas migrate (TIMING).

TRAP - A barrier to migration that allows oil and gas to accumulate in a reservoir. The barriers commonly are impervious rock (SEALS) above, below, and/or lateral to the reservoir rock. STRUCTURAL TRAPS result from folding, faulting, or other rock deformation. The most common trap is an anticline or faulted anticline. STRATIGRAPHIC TRAPS result from lithologic (facies) changes sometimes called POROSITY-PERMEABILITY PINCHOUTS. A trap with both structural and stratigraphic aspects is called a COMBINATION TRAP. A trap must have adequate size and seals.

PRESERVATION - Once in the trap, protection of hydrocarbons from flushing, overcooking, or biodegradation. FLUSHING is water washing. OVERCOOKING is overmaturation to less desirable products. BIODEGRADATION is decomposition by micro-organisms.

RECOVERABILITY - The ability to bring underground oil and gas to the surface. Factors that must be adequate are the permeability of the reservoir, low VISCOSITY (resistance to flow) of oil, and reservoir DRIVE (the motive force required to produce hydrocarbons).

CONVENTIONAL HYDROCARBONS - Oil and gas recoverable from wells using standard techniques.

CRUDE OIL - See OIL.

CUMULATIVE PROBABILITY CURVE - See ASSESSMENT CURVE, DISTRIBUTION.

DELINEATION WELL - See WELL.

DELPHI METHOD - A method that utilizes the averaging of several expert opinions of the probability distributions of undiscovered resources.

DENSITY, PROSPECT OR FIELD - The number of prospects or fields per unit area.

DEPENDENT RISK - See RISK.

DEPENDENT VARIABLE - One influenced by changes in another variable.

DERISKED ASSESSMENT CURVE - See ASSESSMENT CURVE.

DEVELOPMENT WELL - See WELL.

DISCOUNT - Reduction of an amount.

DISCOVERED RESERVES - See RESERVES.

DISCOVERED RESOURCES - See RESOURCE.

DISCOVERY RATE - The rate of hydrocarbon discovery expressed as barrels per year, fields per year, barrels per foot of drilling, or the like.

DISSOLVED-ASSOCIATED GAS - See GAS.

DISTRIBUTION, PROBABILITY - A mathematical description of the variation in the relative likelihood of occurrence of possible values of a variable.

FREQUENCY DISTRIBUTION - The count of the number of observations in a sample falling within each of a set of intervals spanning the range of possible values of the variable.

CUMULATIVE FREQUENCY (PROBABILITY) DISTRIBUTION - One in which the frequency counts of each interval are totaled for successive intervals, so that the last interval has the total count of the distribution. The ASSESSMENT CURVE is an example.

NORMAL DISTRIBUTION - An arithmetically symmetrical "bell-shaped" distribution that has no absolute limits. The mean equals both the median and mode.

LOGNORMAL DISTRIBUTION - A symmetrical "bell-shaped" distribution on a log scale with no absolute limits. Plotted on an arithmetic scale it is asymmetrical, or skewed, with a long "tail" toward the higher values. The median value is also the geometric mean. The arithmetic mean is greater than the median, and the median is greater that the mode.

HISTOGRAM - A bar graph in which bar widths represent class intervals, and bar heights are proportional to class frequencies.

EQUAL PROBABILITY DISTRIBUTION - Several discrete values having identical probabilities.

RECTANGULAR DISTRIBUTION - One in which all values between the minimum and maximum have equal likelihood of occurrence.

TRIANGULAR DISTRIBUTION - Represented by a most likely value of greatest probability that lies between designated minimum and maximum values. Probability increases linearly from minimum to most likely, and decreases linearly from most likely to maximum. In a SYMMETRICAL TRIANGULAR DISTRIBUTION the most likely value is arithmetically centered between minimum and maximum and equals both the median and the arithmetic mean.

LOG-TRIANGULAR DISTRIBUTION - A triangular distribution based on the logarithmic scale of the variable. This distribution has more probability associated with the interval on the lower side of the most likely than does the TRIANGULAR DISTRIBUTION. In a SYMMETRICAL LOG-TRIANGULAR DISTRIBUTION the ratio of the most likely value to the minimum is the same as the ratio of the maximum to the most likely. Such a distribution is symmetrical on the log scale but asymmetrical with a long "tail" toward higher values when plotted on the arithmetic scale. The arithmetic mean exceeds the median, which exceeds the mode.

DRIVE - See CONTROLS (RECOVERABILITY).

DRY - Barren of hydrocarbons; nonproductive. See RISK.

DRY GAS - See GAS.

ECONOMETRICS - The application of statistical data to the study of economic data and problems.

ECONOMIC FIELD - See FIELD.

ECONOMIC RISK - See RISK.

ENVIRONMENTAL IMPACT STATEMENT - A report required by law on the effect on the human environment of any major action proposed by the federal government.

EQUAL PROBABILITY DISTRIBUTION - See DISTRIBUTION.

ESTIMATED ULTIMATE RESERVES (EUR) - See RESERVES.

EXCEEDANCE PROBABILITY - The chance that potentials are equal to or greater than a given value.

EXISTENCE CHANCE - See CHANCE.

EXISTENCE RISK - See RISK.

EXTENSIONS - See RESERVES.

FACIES - Distinctive, coeval, adjacent rock units.

FACIES CHANGE - A change in lithology (distinctiveness); e.g., a reservoir sandstone unit changes laterally to shale.

FAULT - A break in the earth's crust across which one side has moved relative to the other.

FAULT LEAK POINT - See FILL FRACTION.

FIELD - A single pool, or multiple pools in one location.

FIELD (ECONOMIC) - One that is profitable to develop and produce; synonymous with COMMERCIAL FIELD.

FIELD DENSITY - See DENSITY.

FIELD SIZE - The estimated ultimate recoverable reserves of oil and/or gas in a field. See also MINIMUM and MAXIMUM.

FIELD-SIZE DISTRIBUTION - Variation in probability associated with the occurrence of possible field sizes. A prospect assessment curve, for example, is a size distribution of potential fields. Field sizes are conveniently represented as truncated lognormal distributions.

FIELD-SIZE PARAMETERS - Factors determining a field-size distribution. A prospect's size distribution can be determined, for example, from productive area, net pay thickness, and recovery factors.

SIGNIFICANT FIELD - One equal to or larger than some minimum size that is meaningful for the area, the available historical data, and the assessment methodology used. LARGEST EXPECTED FIELD SIZE - A field size at some specified exceedance probability (e.g., 5 percent) near the maximum of the field-size distribution, or one equivalent to the mean size of the largest prospect.

FILL FRACTION OR PERCENT - The fraction of total available trap volume (or trap area) that is occupied (or postulated to be occupied) by in-place hydrocarbons. Definitions of trap volume may vary according to the chosen spill or leak point:

> **SYNCLINAL SPILL POINT** - A dip reversal on the reservoir that defines the largest apparent trap.
>
> **FAULT LEAK POINT** - A permeable fault plane that could drain the contiguous part of the reservoir.
>
> **RESERVOIR LEAK POINT** - Leakage across a fault where the reservoir contacts a permeable formation.

FINDING RISK - See RISK.

FLUSHING - See CONTROLS (PRESERVATION).

FOLD - A bending of rock layers.

> **ANTICLINE** - An upfold (convex upward).
>
> **SYNCLINE** - A downfold (concave upward).

FORMATION - A mappable sedimentary rock unit of distinctive lithology.

FORMATION VOLUME FACTOR - For oil, the barrels of fluid in the reservoir required to produce one barrel of stock-tank oil at the surface, i.e., reservoir bbl/stock-tank bbl. The OIL SHRINKAGE FACTOR is the reciprocal, i.e., stock-tank bbl/reservoir bbl. (The decrease in volume is due mainly to removal of dissolved gas during oil production.) The GAS FORMATION VOLUME FACTOR equals reservoir bbl/thousand standard cubic feet. In assessment, its reciprocal is used in calculating surface gas volumes from reservoir volumes.

FRACTURE - Any break in a rock.

FREQUENCY - The number of times a specified event occurs within a specified interval. The percentage frequency of an event relative to the entire distribution is its probability of occurrence.

FREQUENCY DISTRIBUTION - See DISTRIBUTION.

FRONTIER AREA - One in which there has been little or no exploration drilling.

GAS, NATURAL - A mixture of gaseous hydrocarbons (typically methane with lesser amounts of ethane, propane, butanes, pentanes, and possibly some nonhydrocarbon gases).

ASSOCIATED-DISSOLVED GAS - Gas in contact with crude oil either as a free gas cap or in solution with the oil.

NONASSOCIATED GAS - Free gas not in contact with crude oil in the reservoir.

DRY GAS - Gas consisting almost entirely of methane.

GAS/OIL RATIO - Cubic feet of dissolved gas per barrel of oil (SOLUTION GAS/OIL RATIO). More loosely, the ratio to oil of total associated-dissolved gas in a zone or prospect, or of the total associated-dissolved plus nonassociated gas in a prospect, play, or other entity (TOTAL GAS/OIL RATIO).

GENERATION - Synonymous with MATURATION. See CONTROLS (SOURCE).

GEOLOGIC CONTROLS - See CONTROLS.

GEOLOGIC RISK FACTORS - See CONTROLS.

GEOMETRIC MEAN - See MEAN.

GEOMETRY CORRECTION - The reduction of crestal reservoir thickness (thickest potential hydrocarbon column) in an anticline or other trap to an average value representing the entire trap area. This correction accounts for thinning of a hydrocarbon column at the trap edges.

GROUP RISK - See RISK.

HIGHSIDE POTENTIAL - See MAXIMUM.

HISTOGRAM - See DISTRIBUTION.

HYDROCARBONS - Compounds composed of hydrogen and carbon. In general assessment usage, the term includes oil, gas, and natural gas liquids.

INDEPENDENT RISK - See RISK.

INDEPENDENT VARIABLE - One not influenced by changes in another variable.

INDIVIDUAL RISK - See RISK.

IN PLACE - All oil and gas originally in a reservoir, including both recoverable and nonrecoverable volumes. The NONRECOVERABLE volumes are left in the ground after the field is abandoned.

ISOPACH - A line drawn on a map through points of equal thickness of a geologic unit.

LARGEST EXPECTED FIELD SIZE - See FIELD SIZE.

LEAK POINTS - See FILL FRACTION.

LEASE - A contract authorizing oil and gas exploration, development, and production in a given area for a specified time; also, the area or tract covered by such a contract.

LEASE SALE - A competitive auction for leases by sealed bid.

LOG MEAN - See MEAN.

LOGNORMAL DISTRIBUTION - See DISTRIBUTION.

LOG-TRIANGULAR DISTRIBUTION - See DISTRIBUTION.

LOWSIDE POTENTIAL - See MINIMUM.

MARGINAL PROBABILITY - See PROBABILITY.

MATURATION - See CONTROLS (SOURCE).

MATURE AREA - One in which there has been extensive exploration drilling.

MAXIMUM - The largest value of a distribution.

MAXIMUM or HIGHSIDE or UPSIDE POTENTIAL - For an assessment curve, this is the largest value shown at some specified exceedance chance (e.g., 0.05, 0.01, 0.002).

MAXIMUM GEOLOGIC FIELD SIZE - The maximum of a prospect assessment curve, or the largest size included in or resulting from the field-size parameters used to develop the play assessment curve.

MEAN - The arithmetic average, which is the sum of a set of sample values divided by the number of values in the set.

GEOMETRIC MEAN - The _n_th root of the product of _n_ values.

LOG MEAN - The arithmetic mean of the logarithms of sample values. Its antilog is equivalent to the geometric mean.

MEDIAN - The middle value of a distribution; the median is the point with 0.5 probability of being exceeded.

MIGRATION - See CONTROLS.

MINIMUM - The smallest value of a distribution.

MINIMUM or LOWSIDE POTENTIAL - For an assessment curve, this is the smallest value shown at some specified exceedance chance (e.g., 0.95, 0.99, 0.998).

MINIMUM GEOLOGIC FIELD SIZE - The minimum of a prospect assessment curve, or the smallest size included in or resulting from the field-size parameters used to develop the play assessment curve.

MINIMUM ECONOMIC FIELD SIZE - The smallest size needed to assure profitable production.

MINIMUM RESOURCE-BASE FIELD SIZE - The smallest size whose potential is included in the resource base.

MODE - The most frequently occurring value (or interval) in a frequency distribution. Synonymous with MOST LIKELY.

MONTE CARLO - A procedure to simulate probability distributions by running many trials to obtain a range of possible answers reflecting different combinations of values selected at random from within specified ranges of input parameters.

MOST LIKELY - In a probability distribution of a variable, the value associated with the highest probability. Synonymous with MODE.

NATURAL GAS - See GAS.

NATURAL GAS LIQUIDS (NGL) - Generally propane and heavier hydrocarbons that are separated from natural gas as liquids in field separators or in processing plants. Also commonly referred to as CONDENSATE. NGL yields are reported as bbl/million cu ft of gas.

NET/GROSS RATIO - The thickness of effective reservoir (having adequate porosity and permeability) divided by the thickness of the gross reservoir formation. The non-net portion typically consists of interbedded shales, siltstones, low permeability limestones, etc.

NET PAY THICKNESS - The thickness of a reservoir containing producible oil or gas, or the postulated such thickness for a prospect. In assessments this should be an average thickness for the potentially productive area (see GEOMETRY CORRECTION).

NONASSOCIATED GAS - See GAS.

NONRECOVERABLE HYDROCARBON - See IN PLACE.

NORMAL DISTRIBUTION - See DISTRIBUTION.

OIL - A mixture of liquid hydrocarbons.

OIL-EQUIVALENT BARRELS (OEB or BOE) - Amounts of gas expressed as the energy-equivalent of oil, generally at 5600 to 6000 cubic feet per barrel. This ratio does not reflect the volume equivalency of the two fluids in reservoirs.

OUTER CONTINENTAL SHELF (OCS) - The part of offshore areas under federal jurisdiction.

OVERCOOKING - See CONTROLS (PRESERVATION).

PALEODRAINAGE AREA - The area being drained of hydrocarbons during the time of migration from source to trap.

PAY ZONE - Productive zone. See also NET PAY THICKNESS.

PERMEABILITY - See CONTROLS (RESERVOIR).

PETROLEUM - Synonymous with HYDROCARBONS.

PINCHOUT (PERMEABILITY-POROSITY) - See CONTROLS (TRAP).

PLANNING AREA -- One of 26 subdivisions of U.S. offshore regions used as the initial basis for considering blocks to be offered for lease in the Department of Interior's areawide offshore oil and gas leasing program.

PLAY - A group of geologically related prospects with similar hydrocarbon sources, reservoirs, and traps.

PLAY CHANCE - See CHANCE.

POOL - An underground accumulation of petroleum in a single and separate reservoir.

POROSITY - See CONTROLS (RESERVOIR).

PRESERVATION - See CONTROLS.

PRIMARY MIGRATION - See CONTROLS.

PROBABILITY - The perceived likelihood of occurrence of an event, i.e., the ratio of outcomes producing the event to the total outcomes considered possible. Probability values range from 1.0 (certain to occur) to zero (certain not to occur).

CONDITIONAL PROBABILITY - The probability of an event given that some other event has already occurred, e.g., the chance for a field given that the geologic controls of oil and gas are favorable. (See SUCCESS RATIO.)

MARGINAL PROBABILITY - The chance for at least a significant minimum amount. Synonymous with ADEQUACY CHANCE. For prospects it is the PROSPECT CHANCE, and for plays it is the PLAY CHANCE.

PROBABLE FINAL RESERVES - See RESERVES.

PROBABLE RESERVES - See RESERVES.

PRODUCING RATE, WELL - The number of barrels of oil (or cubic feet of gas) that can be produced from a well in a day.

PRODUCTIVE AREA - The area of a pool or field containing producible oil or gas, or the postulated such area for a prospect.

PROSPECT - A potential oil or gas field.

PROSPECT CHANCE - See CHANCE.

PROSPECT DENSITY - See DENSITY.

PROVED RESERVES - See RESERVES.

RECOVERABILITY - See CONTROLS.

RECOVERY - The fraction of oil or gas volumes in place in the reservoir that can be brought to the surface is called RECOVERY EFFICIENCY. Related RECOVERY FACTORS are expressed as barrels of stock-tank oil per acre-foot of reservoir, or thousands of standard cubic feet of gas per acre-foot of reservoir, or standard cubic meters of oil or gas per cubic meter of reservoir.

RECTANGULAR DISTRIBUTION - See DISTRIBUTION.

RESERVES, DISCOVERED -

PROVED RESERVES - The estimated remaining quantities of petroleum that geologic and engineering studies demonstrate with reasonable certainty will be recoverable from known reservoirs under existing economic and operating conditions.

PROBABLE RESERVES - The estimated quantities of petroleum, in addition to proved reserves, that geologic and engineering studies indicate will likely be recovered from partially defined reservoirs under existing economic and operating conditions. Reserve additions to known reservoirs may come from EXTENSIONS (increased proved area) and/or REVISIONS (changed estimates based on new information or improved recovery techniques).

ESTIMATED ULTIMATE RESERVES (EUR) - Cumulative production plus proved reserves.

PROBABLE FINAL RESERVES - Estimated ultimate plus proved plus probable reserves.

RESERVOIR LEAK POINT - See FILL FRACTION.

RESERVOIR ROCK - See CONTROLS.

RESOURCE - A new or reserve source of potential petroleum supply, including both discovered and undiscovered sources.

CONTINGENT (STATIC) RESOURCES - Discovered petroleum that is potentially recoverable but currently noncommercial.

DISCOVERED RESOURCES - Proved plus probable reserves, plus contingent resources. Past plus future sources of supply would also include past production.

UNDISCOVERED RESOURCE BASE (UNDISCOVERED RECOVERABLE RESOURCES) - Potentially recoverable petroleum volumes postulated to exist, regardless of present accessibility or economics, in fields larger than some specified minimum size (MINIMUM RESOURCE-BASE FIELD SIZE).

UNDISCOVERED ATTAINABLE POTENTIAL - That part of the undiscovered resource base deemed accessible and economically and technologically findable, producible, and marketable.

UNDISCOVERED NONATTAINABLE (NONECONOMIC) POTENTIAL - That part of the undiscovered resource base deemed accessible and not economically and technologically findable, producible, and marketable.

REVISIONS - See RESERVES.

RISK FACTORS, GEOLOGIC - See CONTROLS.

RISK, GEOLOGIC - The chance that no significant oil or gas field exists. Also called EXISTENCE RISK or CHANCE OF FAILURE or DRY RISK. Risk is one minus adequacy.

RISK (ECONOMIC) - The chance that no commercial oil or gas field exists.

RISK (FINDING) - The chance that an existing field might not be discovered.

RISK (DEPENDENT OR GROUP) - The chance that all related zones (or prospects or plays) are dry if one is dry.

RISK (INDEPENDENT OR INDIVIDUAL) - The chance that one zone (or prospect or play) is dry regardless of the status of others.

RISKED ASSESSMENT CURVE - See ASSESSMENT CURVE.

ROYALTY - Lease payment based on percentage of gross income or of total value of oil and gas produced.

SATURATION, HYDROCARBON - The hydrocarbon-bearing fraction of the pore volume of a reservoir. WATER SATURATION is one minus hydrocarbon saturation.

SEAL - See CONTROLS (TRAP).

SECONDARY MIGRATION - See CONTROLS.

SHRINKAGE FACTOR, OIL - See FORMATION VOLUME FACTOR.

SIGNIFICANT FIELD - See FIELD SIZE.

SOURCE ROCK - See CONTROLS.

SPILL LEVEL - The lowest level to which oil or gas can be held in a trap before spilling out.

STATIC RESOURCES - See RESOURCE.

STRATIGRAPHIC TRAP - See CONTROLS (TRAP).

STRUCTURAL TRAP - See CONTROLS (TRAP).

SUCCESS RATIO - In a play, the conditional probability that some prospect is indeed a field, given that the geologic controls of oil and gas are favorable. The success ratio may be estimated as the expected number of fields exceeding a specified minimum significant size divided by the number of prospects large enough to hold such fields.

SYMMETRICAL DISTRIBUTION - See DISTRIBUTION.

SYNCLINAL SPILL POINT - See FILL FRACTION.

SYNCLINE - See FOLD.

TIMING - See CONTROLS (MIGRATION).

TRAP - See CONTROLS (TRAP).

TRIANGULAR DISTRIBUTION - See DISTRIBUTION.

TRUNCATION - See UNCONFORMITY.

UNCERTAINTY, GEOLOGIC - Specifically, the imprecision in estimating the size range of significant fields. In the broader sense of being unsure or in doubt, uncertainty also encompasses risk.

UNCONFORMITY - A buried erosion surface.

TRUNCATION - The beveling of rock strata by erosion at an unconformity.

UNDISCOVERED ATTAINABLE POTENTIAL - See RESOURCE.

UNDISCOVERED RESOURCE BASE - See RESOURCE.

UNRISKED ASSESSMENT CURVE - See ASSESSMENT CURVE.

UPSIDE POTENTIAL - See MAXIMUM.

VISCOSITY - See CONTROLS (RECOVERABILITY).

VOLUME FACTOR - One of several parameters required to assess potential hydrocarbon volumes. Examples are net pay thickness, productive area, and recovery factor for prospect assessment.

WATER SATURATION - See SATURATION.

WELL -

NEW-FIELD WILDCAT - a hole drilled on a geologic feature never before productive.

DELINEATION WELL - a hole drilled to outline a new discovery.

DEVELOPMENT WELL - a hole drilled for producing a field.

WELL LOGS - Records obtained by lowering instruments in wells and recording continuously some physical property of the rocks.

WILDCAT - See WELL.

ZONE - One of multiple pools (or postulated pools) in a field (or prospect).

APPENDIX C

ADDITIONAL SOURCES OF TECHNICAL INFORMATION REGARDING RESOURCE ESTIMATION

Anderson, R. O., and H. A. Slack. 1981. Guidelines for NPC Assessment of Arctic Oil and Gas Potential in the U.S. National Petroleum Reserve. National Petroleum Council. Washington, D.C.

Bugg, P., and S. Miller. 1981. Policy Applications of the NPRA Model. Office of Minerals Policy and Research Analysis. U.S. Department of the Interior. Presented at the Symposium on the Evaluation of Petroleum Resources of the Canadian Society of Petroleum Geologists, Calgary, Alberta, January 20-21, 1981. 24 pp.

Crovelli, R. A. 1981. Probabilistic Methodology for Oil and Gas Resource Appraisal. Washington, D.C.: U.S. Department of the Interior. 77 pp.

Dolton, G. L., K. H. Carlson, R. R. Charpentier, A. B. Coury, R. A. Crovelli, S. E. Frezon, A. S. Khan, J. H. Lister, R. H. McMullin, R. S. Pike, R. B. Powers, E. W. Scott, and K. L. Varnes. 1982. Estimates of Undiscovered Recoverable Conventional Resources of Oil and Gas in the United States. U.S. Geological Survey Circular 860. 87 pp.

ICF, Inc. 1979. A Review of the Methodology of Selected U.S. Oil and Gas Supply Models. Prepared for the Energy Information Administration, U.S. Department of Energy. Washington, D.C. 143 pp.

INTERA Petroleum Consultants and INTERA Technologies, Inc. Undated. PRESTO II: Probabilistic Resource Estimates Offshore Code Documentation. 119 pp. (plus Appendix A1-A27).

INTERA Technologies, Inc. 1984. Development of 606 Model. A Technical Proposal (RFP No. 3187). Submitted to the Minerals Management Service. 52 pp.

Resource Planning Associates. 1984. Guide for Using the Leasing Simulation Computer Program TSL80 (version October 16). Prepared for Minerals Management Service, U.S. Department of the Interior. Cambridge, Massachusetts.

U.S. Department of the Interior, Office of Minerals Policy and Research Analysis. 1979. Final Report of the 105(b) Economic and Policy Analysis. Appendix A. p. 117-125.

U.S. Department of the Interior, Secretarial Issue Document. 1985. Appendix F, Economic Considerations of the Five Year OCS Leasing Program. 72 pp.

U.S. Minerals Management Service. 1984. Resource Evaluation Program Report: Geological and Geophysical Data Acquisition in the Outer Continental Shelf. Reston, Virginia: Department of the Interior.

U.S. Minerals Management Service. 1985. Estimates of Undiscovered Oil and Gas Resources for the Outer Continental Shelf. Washington, D.C.: Department of the Interior.

U.S. Minerals Management Service. 1985. Outer Continental Shelf Oil and Gas Leasing and Production Program: Annual Report Fiscal Year 1984. Washington, D.C.: U.S. Department of the Interior.

U.S. Office of Technology Assessment. 1985. Oil and Gas Technologies for the Arctic and Deepwater. Washington, D.C. 227 pp.