Chapter ME (Methodology)

METHODOLOGY

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FIGURES

TABLES

TEXT FILES OF COMPUTER CODE

Associated with this chapter ME are seven text files of computer code, located on this CDROM in a data appendix. The seven programs are described in Appendix MEA of this report.

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ABSTRACT

Oil and gas resources in each of the ten plays within the 1002 area of the Arctic National Wildlife Refuge (ANWR) were estimated using a play analysis. Assessors specified geologic attributes, risks, and number of prospects for each play. Some specifications, including porosity and depth, were given in the form of distributions. Other information, including recovery factors, were given as single values. From this information, sizes of oil and gas accumulations were generated using a Monte Carlo simulation algorithm. The number of such accumulations considered in a given simulation run was obtained from the distribution of the number of prospects. Each prospect in each successful simulation run was risked. This process yielded size-frequency distributions and summary statistics for the various petroleum categories. Estimates of remaining resources from individual plays where then aggregated, and measures of uncertainty computed.

INTRODUCTION

There are two major methodologies for assessing undiscovered oil and gas in geologic plays. One is discovery process modeling, a statistical-geological modeling procedure, which is used in mature areas. The other is subjective probability and risking, which is commonly used in frontier areas. Because there were few discoveries in the vicinity of the 1002 area, the latter procedure was used in this assessment. Subjective probability assessments typically involve specifying distributions for input values subjectively, sampling from these distributions, and computing statistics using Monte Carlo simulation.

The level of aggregations chosen for this assessment was the play. For each play, assessors specified distributions needed to generate accumulations of oil and gas, and a distribution of the number of prospects expected to occur. They also specified risk factors. Accumulations of oil and gas were constructed from the product of several factors including porosity, trap fill, thickness, and area of closure. The methodology that was used in this assessment was a modified version of that used in the 1987 ANWR assessment (Dolton, Bird, and Crovelli, 1987). Improvements included modifications of the input form and revised definitions to ensure that the appropriate information was obtained. Also, a minimum reservoir size was established to facilitate estimation of the number of prospects. Deposit size

distributions were generated at the mean and 5th and 95th levels of uncertainty.

Estimates of remaining resources from individual plays were aggregated into distributions of remaining resources for the 1002 play area and selected sub areas. The aggregation procedures were adapted from the 1995 U.S. National assessment of oil and gas resources (Gautier and others, 1995).

The chapter begins with a discussion of the geologic and engineering input, which was specified by the assessors for each play and supplied on the assessment form. Following this, the Monte Carlo simulation is presented. We conclude with a discussion of the aggregation procedure.

SPECIFICATION OF THE INPUT

Information used by the assessment algorithm consisted of statistical models with presest parameters and assessor-specified distributions and constants. An assessment form, which was a modified version of that used in the 1987 ANWR assessment, was used to capture the distributions and constants. The statistical models, with the exception of the oil and gas in place equations, are shown on this form, which consisted of three Microsoft Excel 97 worksheets. The first part (Table ME1a) provided for hydrocarbon volume parameters for oil, the trap depth distribution, oil accumulation characteristics, and the geographic allocation of the resource. The second part (Table ME1b) provided for similar information for non-associated gas. The third part (Table ME1c) was for the specification of the number of prospects, risking information, and the proportional allocation of deposits between oil and gas. Many of the entries on the form are self-explanatory. Those that are not or those of special importance will be discussed here. Tables ME1a, ME1b, and ME1c show the forms that the assessors completed and served as input to the programs MEANWR1.doc and MEANWR1a.doc described in appendix MEA. Input distributions and other parameters are given for each play in Chap. RS (see Tables RS1a and RS1b, RS2a and RS2b, etc.). Definitions for the parameters are given by Charpentier (Chap. DF).

Oil Parameters

The oil hydrocarbon volume parameters and characteristics, Table ME1a, which are used to compute the size of oil accumulations, are the:

net reservoir thickness, NRT, in feet,
area of closure, AC, in thousands of acres,
porosity, φ, in percent,
water saturation, S_w , in percent,
trap fill, TF, in percent, and
formation volume factor, FVF, in reservoir barrels/stock tank barrels, rb/stb.

Estimates of the minimum (100th fractile), the 95th, 75th, 50th , 25th, and 5th fractiles, and the maximum value were entered for NRT, AC, φ, and TF. The fractile values for water saturation, S_w, were computed from $\varphi ? S_w = c$, where c is a constant, which varies by play; it is typically between 300 and 600, as described by Nelson (Chap. PP) and in individual play descriptions, (e.g. Chap. P1 for the Topset play). These distributions were intended to show the variation in characteristics of prospects across a play and not variation within a given prospect. Samples from these distributions and the FVF were combined to estimate oil in place, OIP (in millions of barrels, MMBO), as:

$$OIP = 7.758 \cdot NRT \cdot AC \cdot \varphi \cdot (100 - S_w) \cdot TF \cdot 10^{-6} / FVF$$

The formation volume factor (Table ME1a) is a piecewise linear function of trap depth estimated via a regression model. The distribution of trap depth, TD, in thousands of feet below sea level was also specified by fractiles. The average surface elevation in feet was also specified in Table ME1a. The depth used in oil and gas models was the sum of a randomly chosen depth below sea level plus the average surface elevation. Models for the associated gas to oil ratio, GOR, and natural gas liquids to associated gas ratio, NGLR, are given in Table ME1a.

Gas Hydrocarbon Volume Parameters

The gas hydrocarbon volume parameters and characteristics, Table ME1b, which are used to compute the accumulation size of gas, are the:

net reservoir thickness, NRT, in feet,
area of closure, AC, in thousands of acres,
porosity, φ, in percent,
water saturation, S_w , in percent,
trap fill, TF, in percent,

original reservoir pressure, P_o , in pounds per square inch (psi),
reservoir temperature, T, in degrees Rankine (°R),
gas compressibility factor, Z,
temperature, T_{sc}, under standard conditions (519.7 °R), and
pressure, P_{sc}, under standard conditions (14.7 psi).

The equation for the accumulation size of gas in place, GIP, (in billions of cubic feet, BCFG) is:

$$GIP = 43560 \cdot NRT \cdot AC \cdot \varphi \cdot (100 - S_w) \cdot TF \cdot 10^{-9} \cdot (P_o / T) \cdot (T_{sc} / P_{sc}) / Z$$

The simulation algorithm permitted specification of separate volume parameters and depth distributions for gas (Table ME1b) and oil accumulations, however, the assessors in this study believed them to be similar and chose to use the same distributions (those in Table ME1a) for both oil and gas accumulations. Equations to estimate the original reservoir pressure, P_o , the reservoir temperature, T, and the gas compressibility factor, Z, are given in Table ME1b. All are a function of depth. For the undeformed areas, P_o is a piecewise linear function split at 10,000 feet and for the deformed areas it is a linear function. For the deformed areas, the parameters for the second P_o equation (depths > 10,000 ft) were set to zero and the first equation was used for all depths. In addition, a model to estimate the natural gas liquids plus condensate to non-associated gas (NGL-NAG) is given in Table ME1b. It is an exponential function of depth. Background information on these models is given in Chap. PA.

Minimum reservoir size

In order to avoid the considerable uncertainties associated with assessing a potentially large number of small prospects, which would be neither technically recoverable nor commercially viable in the foreseeable future, a minimum reservoir size or cutoff value of 50 MMBOE-in place was established and specified in Table ME1c. Initially many of the assessors specified the hydrocarbon volume parameter distributions based on geological considerations without regard to this cutoff.

Once these distributions were obtained, the average[1] values of the hydrocarbon volume parameters necessary to generate a 50 MMBOE-in place accumulation were computed. This information was given to the assessors to provide guidelines concerning the values of thickness, trap fill and the other parameters that "on average" constituted a 50 MMBOE-in place accumulation. Then assessors were given plots showing the shape of each histogram of the hydrocarbon volume parameters. (The computations performed during this phase used Crystal Ball, v. 4.0c (Decisioneering, Inc., 1996), a simulation program used with Microsoft Excel 97 and Microsoft Visual Basic.) Assessors modified their initial distributions, as necessary, so that the minimum accumulation size generated from these distributions would not be too much smaller than the cutoff. A check, made to ensure that the newly specified hydrocarbon distributions resulted in the generation of such size classes, indicated that over 95 percent of the accumulations generated in all plays exceeded the 50 MMBOE-in place minimum reservoir size.

Number of prospects greater than the minimum size

This distribution (Table ME1c) was specified in the same manner as the distributions for depth and hydrocarbon volume. From this distribution, the number of prospects equal to or greater than the 50 MMBOE-in place cutoff are determined that would exist if conditions for the play were favorable. Thus, the assessors have specified a conditional distribution. If the probability of a favorable play or prospect is less than one, then the expected number of deposits will be less than the expected number of prospects.

Risking

Risk in the context of this study is the probability that a play or prospect would be unsuccessful because of the failure of one or more geologic attributes necessary to achieve success. Because it is natural to think of the likelihood of an attribute being present, we used the complement of risk, namely favorability. Thus, a favorability of one implies zero risk.

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[1] Average is defined as follows. Let X_i, i=1, …,5 be the values of the five hydrocarbon volume parameters whose product times a constant k yielded an accumulation of oil A. Let F_i be the cumulative distribution function of X_i and let $p=Pr(X_i \leq x_i)$. Then the "averages" were the values of x_i such that $k\prod_{i=1}^{5} x_i = 50$ MMBOE, where p was constant.

There are two favorability structures. One is called play probability; the other is called prospect probability. Each of these is the product of three attributes, however, play probability refers to the product of attributes thought to be present in the play, whereas, prospect probability refers to the product of those attributes associated with a randomly chosen prospect. The attributes are charge, potential reservoir facies, and timely trap formation (Table ME1c). Although the names of the attributes are the same at the play and prospect levels, there are six distinct attributes. They are assumed to be pairwise independent of each other. See Chap. DF for additional details concerning definitions.

The interpretation of a favorable play is as follows. If the play probability was 0.7, for example, and a large number of plays existed with identical characteristics, we would expect that 7 out of 10 of these would contain the potential for one or more successful prospects. A successful play is one in which all three of the play level attributes necessary for an accumulation of at least 50 MMBOE-in place are present. There is no guarantee that such an accumulation will be found in a successful play. A failure to find at least one deposit in a successful play can occur when few prospects are specified and the prospect probability is low. For a successful play, the number of prospects was drawn at random from the distribution of prospects specified in Table ME1c. The prospect probability was then applied to each of these prospects. The mechanism to do this was to generate a [0,1] continuous uniform pseudo-random number for each prospect selected. When the value of the random number did not exceed the prospect probability, we accepted the prospect and relabeled it a deposit. Thus, the deposits generated in such a manner reflect an unconditional distribution, the risks associated with play and prospect having been applied. Assessment definitions (Chap. DF) were established and made available to the assessors to provide specific guidelines to allow them to differentiate between these two risks. Additional details on the simulation are provided in the following sections. The computational results are presented in Chap. RS.

THE PLAY SIMULATION

Models

The methodology was based upon a Monte Carlo simulation. The simulation program (called MEANWR1 and listed in appendix MEA) was written in Microsoft Visual Basic and operated within the Microsoft Excel

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97 spreadsheets used to record the assessment information. It was run on each of the ten plays, however, the "tenth" play, the Niguanak/Aurora, was partitioned into two scenarios, the many-prospect and two-dome scenarios, as described by Grow and others (Chap. P10). A separate program, which will be discussed later, was required for the Niguanak/Aurora two-dome scenario. Ten thousand simulations were run for each play. These 10,000 simulations were conditioned on the play being potentially favorable. The appropriate divisor used to compute mean unconditional resources for a play was 10,000 divided by the play probability. For example, if the play probability was 0.80, then the divisor would be 12,500 with 2,500 of these being *a priori*, unsuccessful. (Some of the 10,000 simulation runs may of course result in unsuccessful play outcomes.) The additional 2,500 unsuccessful simulations were not run. The reason for choosing to run 10,000 simulations with the play being potentially favorable on all runs was to obtain similar levels of precision on the play summary statistics for all plays, even those that were highly risked.

All sampling occurred from the empirical distributions as specified by the assessors using the inverse probability transformation theorem, i.e., given that F_n is an empirical distribution function, and u is a uniform (0,1) random deviate, we would select an x such that $x = F^{-1}_n(u)$. The uniform random number generator used is Rnd from Microsoft Visual Basic.

Figure ME1 is a flow chart for program MEANWR1. It begins with the major simulation loop, which was executed 10,000 times (box 1). Next, the number of drillable prospects was sampled (box 2). The prospect probability was applied to each prospect (box 4). If it passed this test (box 4), i.e., $P_r \leq u$, where P_r is the probability of a favorable prospect and u is a uniform (0,1) random number, it was randomly classified as oil or gas (box 5) according to the specified proportion (Table ME1c). Next, the hydrocarbon volume parameters and depth were sampled and an in-place oil or non-associated (NA) gas accumulation was computed (boxes 6a, 6b). If this accumulation size was not less than the cutoff (minimum reservoir size), then various co-products were computed (box 7), including associated-dissolved gas and natural gas liquids (NGL) from associated-dissolved gas and from non-associated gas. Technically recoverable quantities of these commodities were also computed by multiplying the in-place volumes by the oil or gas recovery factors (Tables ME1a and b). Detailed information about the prospects was saved. The total oil and/or gas within a simulation run was computed (box 8). This information was used to obtain uncertainty

estimates. After 10,000 simulations, summary statistics for the play were computed (box 11) using a divisor adjusted for the play probability. Summary results are discussed in Chap. RS. A program MERefPr.for (appendix MEA) reformatted the prospect data for later economic analysis.

Members of the assessment team, on the basis of available data, analogy, and theory established the models (Table ME2) used to compute associated-dissolved gas and natural gas liquids. Additional data can be found in Chap. PA.

The Niguanak/Aurora play was partitioned into two scenarios because of the uncertainty as to whether the Niguanak high and Aurora dome should be assessed as two large unique prospects or as a play with many prospects possible. The assessors felt that there was a reasonable chance (a 0.3 probability) that only two very large prospects existed in the eastern 1002 area. These two prospects are the Niguanak high and Aurora dome (referred to as N and A respectively in equations, which follow). Their situation was modeled as the Niguanak/Aurora two-dome scenario. The alternative, thought to occur with a 0.7 probability, which allowed for up to 20 prospects, was called the Niguanak/Aurora many-prospect scenario. (See Chap. P10 for a detailed discussion of the Niguanak/Aurora play.)

The many-prospect scenario was analyzed with the same simulation algorithm (MEANWR1, appendix MEA) that was used for the other plays. However, the two-dome scenario constituted a prospect, as opposed to a play analysis, and required a modified version of the simulation algorithm, namely MEANWR1a (appendix MEA). The difference between this algorithm and MEANWR1 was the way in which prospects were selected. The assessors specified the favorable prospect probability for the Niguanak high and Aurora dome (Table RS10b). The probabilities of success for these two prospects are $P_r(N) = 0.091$ and $P_r(A) = 0.096$ respectively. The model used is analogous to taking a sample of size two with replacement. If neither prospect was found on the first draw, the same set of probabilities was used to determine if either was found on the second draw. If one was found to exist on the first draw then the probabilities that the other prospect existed was modified by the assessor specified conditional probability. These conditional probabilities, $P_r(N_2|A_1)$ and $P_r(A_2|N_1)$ were set to 0.63 by the assessors, where $P_r(N_2|A_1)$ is the probability of a Niguanak deposit given that the Aurora existed. The definition for $P_r(A_2|N_1)$ is parallel. The resultant frequencies of occurrences of the successful prospects for one

10,000 run simulation were: the Niguanak high only, 0.091, the Aurora dome only, 0.103 and both, 0.107. The hydrocarbon volume parameters and depth distributions were judged to be the same for both prospects.

Uncertainty estimates by play

The 95th, 50th, and 5th fractiles of (unconditional) recoverable oil and recoverable non-associated gas were computed for each play by program MEPU.for (appendix MEA). In order to provide reasonably stable estimates of the size distributions at each of these fractiles, a total of 21 values (the fractile +/- the ten nearest observations) of oil or gas were averaged together to estimate the fractile. The prospect distributions of these 21 simulation runs were averaged to obtain field size distributions at the fractile (e.g., Table RS4e for the Thomson play). Distributions at the 95th and 5th fractiles were needed for subsequent economic analysis. Note that for highly risked prospects and plays, the 95th fractile (or even the 50th fractile) was zero. Of course the interpretation is that 100 percent of the non-zero observations are greater than this fractile.

AGGREGATION METHODOLOGY

Overview

Distributions of resources were computed for each play. From these distributions estimates of means and uncertainty at the 95 and 5 percent fractiles of the distribution were obtained for each play. The next step was to aggregate these resource estimates to higher levels. The mean of the aggregate is simply the sum of the means of the plays to be aggregated. Calculating the fractiles of the aggregate, however, is more complicated. An aggregate distribution was constructed by sampling from the individual plays.

The sampling scheme used to construct an aggregate distribution reflected the dependencies between plays. Often, plays are not independent of each other, and a propensity for a large volume of oil to exist in one play is associated with a large volume in a nearby play. Such a dependency may result from shared sources of charge, reservoir, or trap. The basic concern in aggregating results is the effect that dependency has upon the spread of the aggregate distribution and thus on estimates of uncertainty. For example, if we were to construct uncertainty estimates on the aggregate oil from several

plays based upon the assumption that the amount of resources among pairs of play were independent, these estimates would be narrower than if we had assumed positive dependency. Failure to account for positive dependency would result in estimates of uncertainty that were too narrow and thus would create a higher level of confidence in results than would be warranted if the correct measure of dependency were used. Dependency does not affect the mean of the aggregate distribution, only the spread.

The basic procedure used was to create a correlation matrix from assessor-specified dependencies, generate observations that have the specified correlation structure, rank the correlations, and then choose the samples to form an aggregate distribution. There are ten unique plays in the 1002 assessment area (Table ME3). As previously stated, the Niguanak/Aurora two-dome and Niguanak/Aurora many-prospect are treated as two scenarios of the same play.

Specifying the Dependency

Assessors considered all possible pairs of the ten plays being assessed. For each pair they assigned one of three values (low, medium or high) to the attributes of charge, reservoir, and trap (see Tables ME4-ME6). A high (positive) value assigned to charge between, say plays 1 and 2 might indicate a common mechanism charged both plays. Thus if the value of charge in play 1 was found to be high, the values of charge in play 2 would most likely be high. Each of the three dependency matrices (charge, reservoir, and trap) were converted to correlations by assigning values of 0.1, 0.5, and 0.9 respectively to low, medium, and high entries. A single correlation matrix (Table ME7) was then formed by taking the arithmetic average of the three correlation matrices. For example, the correlations between plays 1 and 2 were specified as 0.9, 0.1, and 0.1 corresponding to charge, reservoir and trap dependencies, and their average is 0.367.

There is a potential inconsistency associated with specifying correlations by pairs of plays, namely, some correlations impose a restriction on others. For example the correlation between plays 1 and 2 is 0.367 and that between plays 1 and 3 is 0.500. Once these are given, the range of correlation between plays 2 and 3 is restricted in that not all values between –1 and +1 are allowed. In order to see if the 10 by 10 correlation matrix given in Table ME7 was internally consistent, a statistical procedure called eigenvalue analysis was performed. The eigenvalues of a consistent

correlation matrix would all be greater than zero. (Stated another way, the matrix would be positive definite.) The minimum eigenvalue of this matrix (Table ME7) is –0.081. Thus, a slight biasing factor, 0.082, was applied to each of the ten eigenvalues. Then the correlation matrix was reconstructed using Fortran program MESample.for (appendix MEA). The resultant correlation matrix, which was used for the remaining part of the analysis, is given in Table ME8. This procedure is similar to that used in the 1995 National Assessment of Oil and Gas Resources (Gautier and Dolton, 1995).

Generating a Correlated Sample

The adjusted correlation matrix (Table ME8) was then used to induce the appropriate correlation structure in the data. A justification for this procedure was given previously. Technical details in the form of an algorithm are given in appendix MEB. The basic idea was to generate a 10-variate continuous uniform distribution with zero mean. This vector was then multiplied by the square root of the correlation matrix. This procedure was repeated 10,000 times to yield a matrix X of size 10,000 rows by 10 columns. The number of rows and columns refer respectively to the number of samples and plays. The numbers in the columns of X were then ranked. Finally, the ranks were adjusted by the total play runs (10,000/play probability). For play 3, the Wedge Play, 13,888 total runs (10,000/0.72) would have been required to generate 10,000 expected potentially successful runs, however, the 3,888 unsuccessful runs were not actually run. They were needed, however, to generate samples for the aggregate distributions. Each element in the matrix X became a sample number. For those plays that consisted of 10,000 runs, such as play 1, the Topset Play, this procedure generated a permutation of the original data that imparted the appropriate correlation structure. The correlation structure based upon ranks is shown in Table ME9. A portion of the matrix X is shown in Table ME10. A rank correlation structure was chosen because the forms of the oil and gas distributions differ widely among the 10 plays. The standard (Pearson) correlation coefficient is only meaningful when distributions are similar and in particular when they are symmetric.

The actual process of aggregation, performed by program MEAggre.for, (appendix MEA) is straightforward. Samples are selected by row from matrix X and the corresponding values of oil or gas are obtained from the appropriate play and/or prospect file. Note that there were 10,000 simulation runs in each of the play/prospect files. The unsuccessful runs

resulting from a favorable play probability less than one were assumed to come before the actual 10,000 runs generated from the simulation for purposes of sampling. The sums at the desired levels of aggregation (the entire assessment area, which includes Federal and non-Federal lands, 1002 area, undeformed regions within 1002, and deformed regions within 1002) were written to a file.

The estimates of uncertainty at the aggregate level were performed by program MEUnAgg.for (appendix MEA). The aggregate distributions were read and the observations at the 95th and 5th fractile were identified. The 95th (5th) fractile was the average of the actual observation at the 95th (5th) fractile plus 10 observations on either side of this value. Twenty-one observations were chosen to estimate the fractile to provide some stability for estimates of the field size distributions at these fractiles. The field size distributions were obtained from the prospect files using the same sample numbers that were used to obtain the previously mentioned estimates of uncertainty.

Estimates of the mean at the various levels of aggregation were computed from the actual values in the play/prospect files and were not based upon the additional sampling required in some instance to generate the aggregate distributions. The estimates of uncertainty are presented in Table RS14.

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Appendix MEA. Computer code

The programs are listed in the order they are to be used. The names of the files are listed in bold.

The algorithms used to implement the methodology were written in Microsoft Visual Basic and Fortran 90, however, to the best of the author's knowledge, only standard Fortran 77 statements were used. Each program is described briefly. Code for each program is available as text files elsewhere on this cdrom.

MEANWR1.doc (macro file used in Excel is called ANWR1_VBA)

This is a Visual Basic program operating as an Excel macro. It obtains information from the oil, gas, and risking Excel worksheets (Tables 1a, 1b, and 1c in the ME chapter). When executed, it conducts a 10,000 replication simulation for 10 of the 11 plays (the exception is the Niguanak/Aurora (2 large). It generates summary statistics, and distributions at the mean and at the 95 and 5^{th} fractiles. These consist of an Excel Summary, Distns, and Supple worksheets. This latter sheet contains miscellaneous information needed to critique and replicate the run, including the random number seed. In addition, it creates three ASCII files: (1) HydroData, is a file to test the sampling of hydrocarbon volume parameters, (2) PlayData, contains summary information at the play level for each replication, and (3) ProspData, contains detailed information about each successful prospect. The latter two files will be used to estimate size-frequency distributions. A discussion about the methodology is given in the ME chapter.

MEANWR1a.doc (macro file used in Excel is called ANWR1a_VBA)

This is a Visual Basic program operating as an Excel macro. It operates in a manner similar to ANWR_1 except that it is a prospect analysis for the Niguanak/Aurora (2 large) play. A discussion about this methodology is also given in the ME chapter.

MERefPr.for

This Fortran program edits and reformats the ProspData file created by ANWR1 or ANWR1a for later use in economic analyses programs. The output file contains the play name, description of variables, recoverable oil

and gas and derivatives of the 10,000 potentially successful prospects, area of closure, depth and other parameters.

MEPU.for

This Fortran program estimates the 5th, 50th, and 95th fractiles for the specified play and generates size distributions at these fractiles.

MESamp.for

This Fortran program creates sample numbers needed for aggregation. Specifically, it receives as input a 'correlation' matrix (the average of the charge, reservoir, and trap matrices) and then checks to see if the matrix is indeed a proper correlation matrix. If necessary, it applies an appropriate bias and regenerates the correlation matrix. Then it generates rank order sample numbers that have the proper correlation structure.

MEAggre.for

This Fortran program computes distributions of aggregate totals for all of ANWR, the 1002 area, and undeformed and deformed areas within 1002.

MEUnAgg.for

This Fortran program estimates the 5th, 50th, and 95th fractiles for the in-place or recoverable aggregate distributions. It also outputs the associated sample id numbers of these estimates.

Appendix MEB. Procedure for generating a correlated sample

The adjusted correlation matrix (Table ME8) will now be used to induce the appropriate correlation structure in the data according to the following procedure:

1. Let us refer to the 10 x 10 adjusted correlation matrix as R. We perform a Cholesky decomposition on R to obtain a lower triangular matrix plus the diagonal matrix, call this A, such that AA' = R (where A' is the transpose of A).
2. Generate a 10-variate continuous uniform distribution, i.e., $\{u_i \mid u_i \approx \textit{continuous uniform}\ (-1,+1),\ i=1,10\}$
3. Let $\mathbf{x}=A\mathbf{u}$, where $\mathbf{u}$ is the 10-variate vector of continuous uniforms.
4. Repeat step 3, 10,000 times to obtain a matrix X of size 10,000 rows by 10 columns. (Note that the simulation for each play was performed 10,000 times.) Each row in X will be a vector $\mathbf{x}$' obtained in step 3.
5. Rank each column in X.
6. Because there are two Niguanak/Aurora plays it is necessary to create an 11^{th} column, which will initially be the same as the 10^{th} column of X.
7. Adjust the ranked matrix X by the total number of plays run (10,000/play probability).

Figure ME1. Flow chart showing the play methodology. [NA: non-associated]

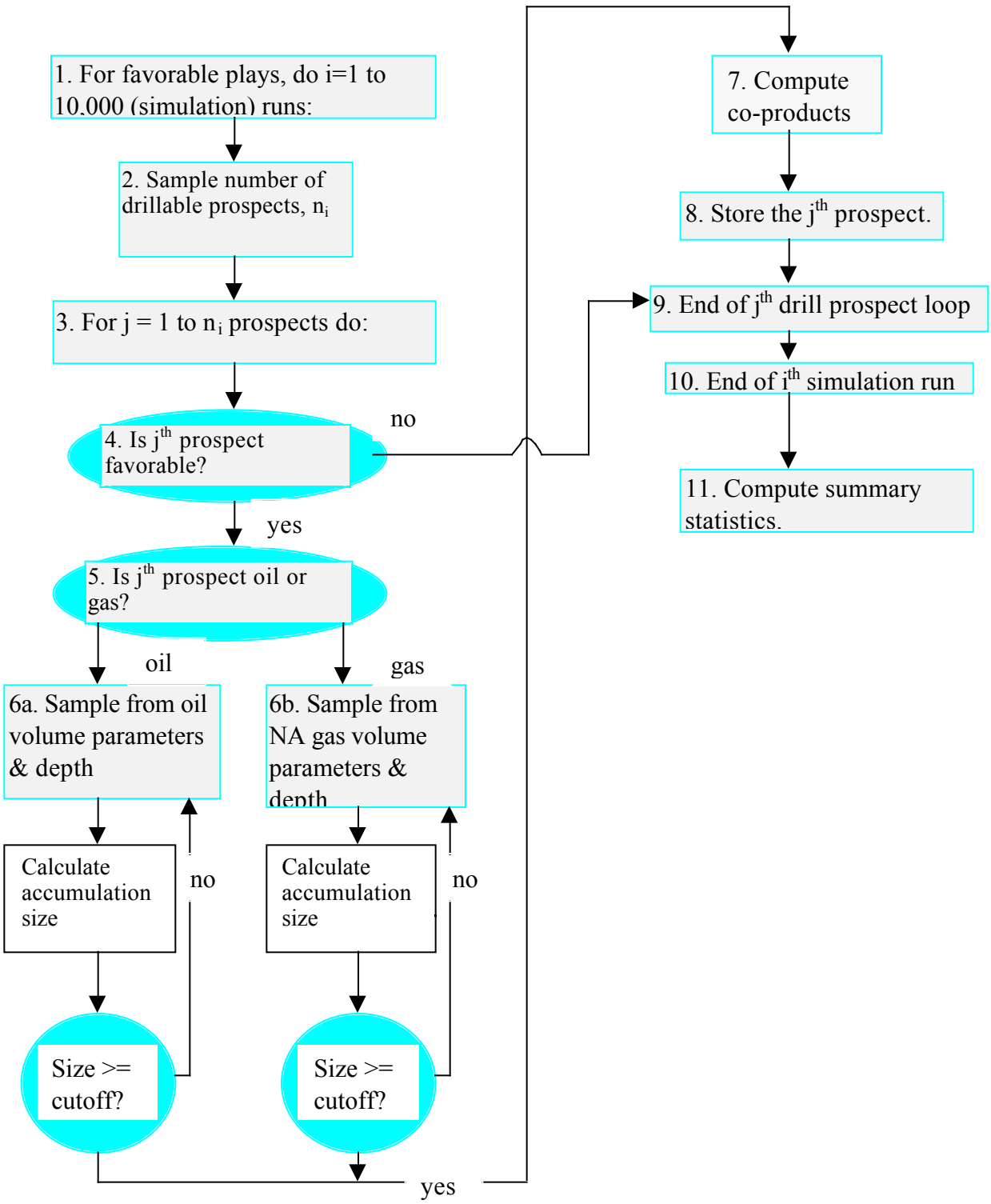

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Table ME1a. ANWR Assessment Form, Oil.

ANWR 1002 Assessment Form-1997

This run:
Program Rev:
Data Rev:

Play Name:
Assessor's Name:
Play area: x1000 acres, within 3-mile boundary

OIL HYDROCARBON VOLUME PARAMETERS

FRACTILES / ATTRIBUTES	PROB OF AND GREATER THAN 100	95	75	50	25	5	Max
NET RESERVOIR THICKNESS[1]							
AREA OF CLOSURE[2]							
POROSITY[3]							
WATER SATURATION[3]							
TRAP FILL[3]							
Approx MMBO							

1-average thickness in feet, 2-thousands of acres, 3-average percent Correlation between Porosity and WaterSaturation = -1

TRAP DEPTH (1000 ft) (below sea level)							

Sea level to surface adjustment (1000 ft):

OIL ACCUMULATION CHARACTERISTICS

Oil recovery factor %

Type of reservoir-drive (check any that apply):
Water: Depletion: Gas expansion:

FVF (Formation volume factor, rb/stb):
FVF= 0.8913 + 5.01E-02 * Depth(1000 ft)) 2170<Depth<12150 ft
FVF=1, Depth <= 2170 ft FVF=1.5, Depth >= 12150

GOR (Associated gas to oil ratio, cu.ft./bbl, at stp):
Log_{10}(GOR)= 2.092 + 0.066906 *Depth(1000 ft)

NGLR (Natural gas liquids to associated gas ratio, bbls/million cu.ft., at stp):
NGLR=1e+06/(5.36E+05 * exp(-0.254 * Depth(1000 ft)))

Oil quality parameters:
API gravity
Sulfur content of oil

Associated gas quality parameters:
Hydrogen sulfide %
CO2 contamination %
Other inert gases:
Name: Percent:
Name: Percent:

Allocation:
Resources in 1002 %
Resources in non-1002 %

Click here or on this symbol in the toolbar to return.

Table ME1b. ANWR Assessment Form, Gas.

GAS HYDROCARBON VOLUME PARAMETERS

This run: 1/0/00

Play:

FRACTILES / ATTRIBUTES	PROB OF AND GREATER THAN 100	95	75	50	25	5	Max
NET RESERVOIR THICKNESS[1]							
AREA OF CLOSURE[2]							
POROSITY[3]							
WATER SATURATION[2]							
TRAP FILL[2,4]							

1-average thickness in feet, 2-thousands of acres, 3-average percent

4-for single value, specify FRACTILE 100 only

TRAP DEPTH (1000 ft) (below sea level)							

NON-ASSOCIATED GAS ACCUMULATION CHARACTERISTICS

NA Gas recovery factor %

Type of reservoir-drive (check any that apply):

Water: Gas expansion:

Natural gas liquids plus condensate to non-associated gas (bbls/million cf) (in place):

NGL-NAG= 0.8595 * exp(0.05217*Depth(1000 ft))

Non-associated gas quality parameters:

Hydrogen sulfide %

CO 2 contamination %

Other inert gases:

Name: Percent:

Name: Percent:

Allocation:

Resources in 1002 %

Resources in non-1002 %

For Gas Accumulation:

Po (Original reservoir pressure, psi):

Po = 14.7 + 470 * Depth(1000 ft)) <=10,000

Po = 14.7 + 700 * Depth(1000 ft)) >10000

T (Temperature, Deg Rankine):

T= 473.7 + 16.458 * Depth(1000 ft)

Z (Gas compressibility factor):

Z =GASPVT, Microcomputer Programs for Petroleum Eng depth>=3000

Z=1-0.11*Depth(1000 ft) + 0.0125*[Depth(1000 ft)]2 depth<3000

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Table ME1c. ANWR Assessment Form, Risking.

RISKING Play: **0** This run: 1/0/00

MINIMUM RESERVOIR SIZE (Millions of BBL in place) 50

	PROB OF AND GREATER THAN						
NUM PROSPECTS > MINIMUM SIZE	100	95	75	50	25	5	Max

	ATTRIBUTES	PROBABILITY OF FAVORABLE
		Computed
PLAY ATTRIBUTES	CHARGE (C)	
	POTENTIAL RESERVOIR FACIES (R)	
	TIMELY TRAP FORMATION (F)	
Probability that the play is favorable (CxRxF)		0
PROSPECT ATTRIBUTES	CHARGE (c)	
	POTENTIAL RESERVOIR FACIES (r)	
	TIMELY TRAP FORMATION (f)	
Probability that a randomly chosen prospect is favorable (cxrxf)		0
Play Attributes x Prospect Attributes (CxRxFxcxrxf)		0
FRACTION OF ACCUMULATIONS BEING OIL		
	Fraction NA Gas=1-Fraction(Oil)	1

Click here or on this symbol in the toolbar to return.

Table ME2. Equations used to compute co-products.

Oil deposit:

ADG (associated-dissolved gas, in BCFG)

$ADG = GOR * Oil * 10^{-3}$

where GOR is the associated gas to oil ratio (see Table ME1a) and the oil is either in-place or recoverable in MMBO.

NGL-ADG (natural gas liquid from ADG, in MMBO)

$NGL\text{-}ADG = NGLR * ADG * 10^{-3}$

where NGLR is the natural gas liquid to associated gas ratio (see Table ME1a).

Non-associated natural gas deposit:

NGL-GAS (natural gas liquid from non-associated gas, in MMBO)

$NGL\text{-}GAS = NGL\text{-}NAG * NAG * 10^{-3}$

where NGL-NAG is the natural gas liquid to non-associated gas ratio (see Table ME1b) and NAG is non-associated gas (in BCFG).

Table ME3. Identification of plays and total number of runs.		
Play number	Play Name	Total Number of Runs
1	Topset	10,000
2	Turbidite	10,000
3	Wedge	13,888
4	Thomson	10,000
5	Kemik	33,333
6	Undeformed Franklinian	15,873
7	Thin-Skinned Thrust Belt	11,111
8	Deformed Franklinian	25,000
9	Ellesmerian Thrust Belt	10,000
10a	Niguanak/Aurora (two-dome)	10,000
10b	Niguanak/Aurora (many-prospect)	15,432

Table ME4. Charge dependencies, high(h), medium(m) and low(l).

Play Number	1	2	3	4	5	6	7	8	9
2	h								
3	h	h							
4	h	h	h						
5	h	h	h	h					
6	h	h	h	h	h				
7	h	h	h	h	h	h			
8	m	m	m	m	m	h	h		
9	m	m	m	m	m	m	m	m	
10	m	m	m	m	m	h	h	h	m

Table ME5. Reservoir dependencies, high(h), medium(m) and low(l).

Play Number	1	2	3	4	5	6	7	8	9
2	l								
3	m	h							
4	l	l	l						
5	l	l	l	m					
6	l	l	l	m	m				
7	m	h	m	l	l	l			
8	l	l	l	m	m	h	l		
9	l	l	l	l	l	l	m	m	
10	l	l	l	m	m	h	l	h	m

Table ME6. Trap dependencies, high(h), medium(m) and low(l).

Play Number	1	2	3	4	5	6	7	8	9
2	l								
3	l	l							
4	l	l	l						
5	l	l	l	m					
6	l	l	l	h	h				
7	m	m	l	l	l	l			
8	l	l	l	l	l	l	m		
9	l	l	l	l	l	l	m	m	
10	l	l	l	h	h	l	h	h	m

Table ME7. Average play dependencies of charge, reservoir and trap.

Play Number	1	2	3	4	5	6	7	8	9	10
1	1.000									
2	0.367	1.000								
3	0.500	0.633	1.000							
4	0.367	0.367	0.367	1.000						
5	0.367	0.367	0.367	0.633	1.000					
6	0.367	0.367	0.367	0.767	0.767	1.000				
7	0.633	0.767	0.500	0.367	0.367	0.367	1.000			
8	0.233	0.233	0.233	0.367	0.367	0.633	0.500	1.000		
9	0.233	0.233	0.233	0.233	0.233	0.233	0.500	0.500	1.000	
10	0.233	0.233	0.233	0.633	0.633	0.633	0.633	0.900	0.500	1.000

Table ME8. Correlation matrix after bias factor of 0.082 was applied.

Play Number	1	2	3	4	5	6	7	8	9	10
1	1.000									
2	0.339	1.000								
3	0.462	0.585	1.000							
4	0.339	0.339	0.339	1.000						
5	0.339	0.339	0.339	0.585	1.000					
6	0.339	0.339	0.339	0.708	0.708	1.000				
7	0.585	0.708	0.462	0.339	0.339	0.339	1.000			
8	0.216	0.216	0.216	0.339	0.339	0.585	0.462	1.000		
9	0.216	0.216	0.216	0.216	0.216	0.216	0.462	0.462	1.000	
10	0.216	0.216	0.216	0.585	0.585	0.585	0.585	0.831	0.462	1.000

Table ME9. Rank correlations of samples to be aggregated.

Play Number	1	2	3	4	5	6	7	8	9	10
1	1.000									
2	0.322	1.000								
3	0.442	0.556	1.000							
4	0.332	0.326	0.311	1.000						
5	0.317	0.322	0.314	0.554	1.000					
6	0.333	0.330	0.319	0.695	0.678	1.000				
7	0.574	0.694	0.441	0.330	0.325	0.333	1.000			
8	0.204	0.202	0.195	0.326	0.323	0.565	0.441	1.000		
9	0.216	0.201	0.208	0.198	0.201	0.203	0.439	0.433	1.000	
10	0.206	0.206	0.203	0.575	0.565	0.564	0.575	0.815	0.430	1.000

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Table ME10. A portion of the sample table.

	Play Number										
Sample	1	2	3	4	5	6	7	8	9	10a	10b
1	220	71	3452	3264	1046	687	401	6825	8219	2623	4047
2	9956	2761	2999	1793	13323	7368	7311	18900	6111	5161	7964
3	7748	1923	5439	7486	12586	9196	4424	8657	7790	3802	5867
4	4731	1495	6119	3880	10406	10598	1143	4300	6666	832	1283
5	8612	6239	5952	9571	32719	12890	8208	5335	7457	6771	10449
6	1382	8172	3073	3755	26989	10638	4107	18370	5954	5491	8473
7	6233	8173	8909	7555	32519	13190	6237	3135	6129	3179	4905
8	1301	387	668	181	1349	47	281	822	354	271	418
9	8961	9975	13850	6463	32853	15528	11033	24977	9064	9875	15239
10	8756	6736	13531	8571	24563	13514	6374	16495	5272	5988	9240
11	9521	9067	10811	6815	31986	9711	7427	2880	404	2769	4273
12	3248	7664	9228	7853	11886	10469	3904	20100	5620	6087	9393
13	212	916	3287	3202	13373	5376	2209	21605	3951	8729	13470
14	5732	8712	12356	6617	30429	11612	9004	21530	7834	8979	13856
15	2695	1176	663	897	343	723	4476	13607	8453	3562	5496
16	8678	1601	1833	7902	19533	5263	5842	12685	6999	7257	11199
17	992	8105	8266	4522	3363	9234	6679	17142	1161	4966	7663
18	199	559	2973	5634	20223	4334	582	4685	1933	5102	7873
19	407	5459	10456	1950	5053	3982	5326	5442	1553	2815	4344
20	1437	8624	11163	9177	31013	15553	7559	24172	4552	9761	15063