

Methodology for the 2005 USGS Assessment of Undiscovered Oil and Gas Resources, Central North Slope, Alaska

By John H. Schuenemeyer¹

¹ Southwest Statistical Consulting, LLC, 960 Sligo St., Cortez, CO 81321

Open-File Report 2005-1410

U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
Gale A. Norton, Secretary

U.S. Geological Survey
P. Patrick Leahy, Acting Director

U.S. Geological Survey, Menlo Park, California: 2005

For more information about the USGS and its products:
Telephone: 1-888-ASK-USGS
World Wide Web: <http://www.usgs.gov/>

Any use of trade, product, or firm names in this publication is
for descriptive purposes only and does not imply
endorsement by the U.S. Government.

Although this report is in the public domain, permission must
be secured from the individual copyright owners to
reproduce any copyrighted materials contained within this report.

Contents

Abstract

Introduction

Specification of the Input

 Minimum accumulation size (MAS)

 Oil accumulation attributes

 Oil accumulation characteristics and estimate of in-place oil

 Gas accumulation attributes, characteristics and estimate of in place gas

 Derivatives

 Correlated attributes

 Risking

 Graphical feedback

The deposit simulation

Aggregation methodology

 Overview

 Specifying the dependency

 Generating a correlated sample

References

Appendix A. Brief description of Splus functions used

Appendix B. Instructions to assessors concerning the protocol

Appendix C. Glossary

Appendix D. Algorithms

Figures

1. Oil formation volume factor vs. trap depth for selected oil gravities.
2. Gas compressibility factor vs. trap depth.
3. Gas formation volume factor vs. trap depth.
4. General flow chart for simulation algorithm.

Tables

- 1a. Oil attribute input sheet.
- 1b. Oil correlation attributes and engineering computations.
- 1c. Number of prospects distributions.
- 1d. Prospect and play risking.
- 1e. Nonassociated gas input sheet.
- 1f. Nonassociated gas correlation attributes and engineering computations.
- 1g. Shapes to be used to specify accumulation attributes, trap depth, and number of prospects.
- 2a. Instantaneous feedback graphs, Beaufortian Cliniform play.
- 2b. Model fitted beta distributions to oil and nonassociated gas attributes, Beaufortian Cliniform play.
- 2c. Oil accumulation distribution, Beaufortian Cliniform play.
- 2d. Oil accumulation distribution, Beaufortian Cliniform play, log units.
3. Play number, name, favorability probability (risk), and file name.
4. Sample simulation output from the Beaufortian Cliniform play.
- 5a. Assessor specified charge dependencies between plays.
- 5b. Assessor specified trap dependencies between plays.
- 5c. Assessor specified timing dependencies between plays.
- 5d. Arithmetic average of assessor specified Charge, Trap, and Timing correlations.
- 5e. Adjusted dependency matrix.
6. Partial aggregation file.
7. Summary statistics for distributions of technically recoverable undiscovered oil, nonassociated gas and derivatives for the central North Slope assessment area.

METHODOLOGY FOR THE 2005 USGS ASSESSMENT OF OIL AND GAS RESOURCES, CENTRAL NORTH SLOPE, ALASKA

By John H. Schuenemeyer

Abstract

Undiscovered oil and gas resources in each of 24 plays (assessment units) within the Alaska Central North Slope were estimated using a deposit simulation analysis in the assessment by the U.S. Geological Survey in 2005. Plays were identified by assessor geologists who specified geologic attributes, risks, and number of prospects for each play. From this information, sizes of oil and gas accumulations were simulated using a Monte Carlo 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 resources from individual plays were then aggregated, and measures of uncertainty computed.

Introduction

The 2005 USGS Central North Slope assessment was performed at the play level (Bird and others, 2005; Garrity and others, 2005). For each play, assessors specified distributions needed to generate accumulations of oil and gas, and distributions of the number of prospects expected to occur. They also specified risk and recovery factors. The methodology used in this assessment was a modified version of the methodology (Schuenemeyer, 2003) used in the U.S. Geological Survey's 2002 assessment of the National Petroleum Reserve Alaska (NPRA) (Bird and Houseknecht, 2002). Improvements included separate specification of numbers of oil and gas prospects, modifications to the input form, expanded graphics, and updated petroleum engineering models. Minimum reservoir sizes for oil and for gas were established to facilitate estimation of the number of prospects. Approximate deposit size distributions were generated at the mean, median, and 5th and 95th levels of uncertainty. The assessment process was based on expert judgment. The final play results were developed by consensus. A detailed discussion of the results is presented in Garrity and others (2005).

This report begins with a discussion of the geologic and engineering input, which was specified by the assessors for each play and entered on assessment forms. Following a discussion of input data and construction of oil and gas accumulation distributions, 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 parameters and assessor-specified distributions and constants. An assessment form, which was a modified version of that used in the 2002 USGS NPRA assessment, was used to capture the distributions and constants for each play. The input for oil, gas, and number of prospects and risk was specified on Excel¹ worksheets. We illustrate input attributes with the Beaufortian Clinoform play forms (table 1a through table 1g). Note that the information on these forms is for illustration only and may not correspond to the final play input. The first worksheet (table 1a) provided for the entry of accumulation attributes for oil, the trap depth distribution, and oil accumulation characteristics. Table 1b displayed a form to specify pairwise correlations between accumulation attributes. It also displayed engineering computations – the gas to oil ratio (*GOR*), and a graph (not shown) of the formation volume factor for oil (*FVF_o*) versus trap depth. In Table 1c the number of prospects was specified for technically recoverable accumulations of at least 5 mm bbl for oil and 100 bcf for gas. Table 1d was used to specify play and prospect risk. Separate prospect risks were given for oil and for gas. Table 1e provided for nonassociated gas volume attributes and gas characteristic values. Table 1f displayed a form to specify pairwise correlations between accumulation attributes for nonassociated gas. It also displayed a graph (not shown) of the formation volume factor for oil (*FVF_g*) versus trap depth.

In addition to specifying fractiles of a distribution, assessors were asked to specify its shape, which could range from highly right skewed to highly left skewed (table 1g). This procedure served as a check on the specification of fractiles and as initial values for the distribution fitting algorithm. General instructions for completing these forms were provide to each assessor in the protocol (Appendix B).

Minimum accumulation size (MAS)

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, the assessment team established a minimum reservoir size or cutoff value for oil and gas. For oil, only deposits of at least 5 mm bbl technically recoverable were considered. For gas, only deposits of at least 100 bcf technically recoverable were considered. These choices of MAS allow for fields, which are now marginally economic, to be considered if the price/cost ratio becomes more favorable.

¹ Mention of a brand name is provided for clarification and does not constitute an endorsement by the U.S. Geological Survey or the author.

Table 1a. Oil attribute input sheet.

Alaskan Assessment Form

Rev: 14-Oct-04

PLAY: **Beaufortian Clinof orm**
 Oil Play Area: **1,447** thousands of acres

OIL ACCUMULATION ATTRIBUTE DISTRIBUTIONS

ATTRIBUTE	Shape	Knowledge Level 1-3 ⁵	LTP	Probability (Attribute ³ with respect to LTP)			Analog/data source	
				0.5	0.05	Max		
NET RESERVOIR THICKNESS	2	3	20	40	60	100		
AREA OF CLOSURE ²	1	3	1	4	15	40		
POROSITY ^{3,4}	4	3	10	13	16	20		
TRAP FILL ³	8	3	75	90	100	100		
			HYDROCARBON PORE VOL ^{3,4}	10	13	16	20	
			POR*Sw					
			In-place mm bbl at median depth	11.6	145.2	1117.2	6206.4	
			6 at median	1.0	17.3	154.7	962.6	

1-thickness in feet, 2-thousands of acres, 3-percent, 4-correlation between Porosity and Water Saturation = -1.0
 5-Knowledge Level: 1=High, 2=Medium, 3=Low; LTP=Lower Truncation Point

	Shape	Level 1-3 ⁵	Min	0.5	0.05	Max	
TRAP DEPTH (in 1000 ft) (from sea level)	5	2	8	10	12	13	Logs & seismic
			Surface to sea level correction (1000 ft):			0.24	OIL

OIL ACCUMULATION CHARACTERISTICS

Oil recovery factor % **40**

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

Water: Depletion: Gas expansion:

FVF (Formation volume factor, rb/stb): **1.81** (at median depth) FVF=0.972+0.000147*F^{1.175}
 (see OilDet sheet)

NGLR (Natural gas liquids to associated gas ratio, bbls/million cu.ft., at stp)= 4.5985*exp(.1711*TD)
25.5 (at median depth)

Oil quality parameters:

API gravity **40**
 Oil Grav (ratio) **0.825**
 Sulfur content of oil **0.10%**

Associated gas quality parameters:

Hydrogen sulfide % **0**
 CO2 contamination % **0**

Other inert gases:

Name: Percent:
 Name: Percent:

TIME OF TRAP DEVELOPMENT

	BEGIN	PEAK	END
STRATIGRAPHIC COMPONENT (Ma)	159	135	130
STRUCTURAL COMPONENT (Ma)	100	65	25

Assessor's Name: **DWH**
 Date of Data Entry MM/DD/YYYY: **9/20/04**
 Date of Simulation Run MM/DD/YYYY: **10/15/04**

Table 1b. Oil correlation attributes and engineering computations

Alaskan Assessment Form

Rev: 14-Oct-04

PLAY: **Beaufortian Cliniform**

OIL ACCUMULATION ATTRIBUTE DEPENDENCIES

Correlations	NET RESERVOIR THICKNESS	AREA OF CLOSURE	TRAP FILL	HYDROCARBO N PORE VOL
NET RESERVOIR THICKNESS	1	0.0	0.0	0.0
AREA OF CLOSURE	0.0	1	0.0	0.0
TRAP FILL	0.0	0.0	1	0.0
HYDROCARBON PORE VOL	0.0	0	0	1

FVF (Formation volume factor, rb/stb):

Median Trap Depth: **10**

Pressure, psi (P)	5000	Pressure=TrapDepth(thous ft)*0.5*1000
Temp, deg F (T)	220	Temp=19*TrapDepth+30
Soution Gas Gr (SGG)	0.767	$SGG = ((0.1402 * LN(P + 14.7) - 0.4227) + (0.1369 * LN(T) + 0.0156) + (0.1704 * LN(API_gravity) + 0.1469)) / 3$
Uncorrected GOR	1555	Uncorrected GOR=SGG*((P+14.7)*10^(0.0125*API_gravity)/(18*10^(0.00091*T)))^(1/0.83)
Final GOR at median depth	1338	Approx final GOR If(Uncorrected GOR <= 1800, 0.86*Un GOR, Un GOR)
F	1565	F= Final GOR*(SGG/OG)^0.5+1.25*T

Notes:

Final GOR at median depth is associated gas to oil ratio, cu.ft./bbl, at stp
LN is log base e

Assessor's Name:

DWH

Date of Data Entry MM/DD/YYYY:

9/20/04

Date of Simulation Run MM/DD/YYYY:

10/15/04

Table 1c. Number of prospects distributions

Alaskan Assessment Form

Rev: 14-Oct-04

PLAY:	Beaufortian Cliniform
Oil Play Area:	1,447 thousands of acres
Gas Play Area:	1,632 thousands of acres

OIL PROSPECTS

MINIMUM ACCUMULATION SIZE, MAS 5 mm bbl, recoverable

	Shape	Knowledge Level 1-3 ⁵	Min	Prob (Num. of		Max
				0.5	0.05	
NUM OF PROSPECTS	2	3	20	40	60	100
5-Knowledge Level: 1=High, 2=Medium, 3=Low						
Size thousands acres (median closure):			80	160	240	400
percent of oil play area			5.5	11.1	16.6	27.7

NONASSOCIATED GAS PROSPECTS

MINIMUM ACCUMULATION SIZE, MAS 100 bcf, recoverable

	Shape	Knowledge Level 1-3 ⁵	Min	Prob (Num. of		Max
				0.5	0.05	
NUM OF PROSPECTS	2	3	20	40	60	100
5-Knowledge Level: 1=High, 2=Medium, 3=Low						
Size thousands acres (median closure):			120	240	360	600
percent of gas play area			7.4	14.7	22.1	36.8

Assessor's Name: DWH
Date of Data Entry MM/DD/YYYY: 9/20/04
Date of Simulation Run MM/DD/YYYY: 10/15/04

Table 1d. Prospect and play risking.

Alaskan Assessment Form

14-Oct-04

Play: **Beaufortian Cliniform**

PROSPECT & PLAY RISKING

ATTRIBUTES OF FAVORABLE

PLAY ATTRIBUTES	CHARGE (C)	Play	
	TRAP/ROCK (T)	1	
	TIMING (F)	0.6	
		1	
<i>Probability that play contains at least 1 reservoir >= minimum accumulation size (CxTxF)</i>			<u>0.6</u>
Note: Specification of both Oil and Gas play risk attributes implies definition of separate oil & gas plays			

PROSPECT ATTRIBUTES	CHARGE (c)	Oil	NA Gas
	TRAP/ROCK (t)	0.90	0.9
	TIMING (f)	0.20	0.2
		1.00	1
<i>Probability that a randomly chosen prospect >= minimum accumulation size is favorable (cxtxf)</i>		<u>0.18</u>	<u>0.18</u>
<i>Play Attributes x Prospect Attributes (CxTxFxcxtf)</i>		<u>0.108</u>	<u>0.108</u>

Allocation (percent):

		Land Area	Oil Vol	Gas Vol
Percent state				
State	Onshore			
	Offshore			
Percent native				
Native	Onshore			
	Offshore			
Total percent				

Assessor's Name: **DWH**

Date of Data Entry MM/DD/YYYY: **9/20/04**

Date of Simulation Run MM/DD/YYYY: **10/15/04**

Table 1e. Nonassociated gas input sheet.

Alaskan Assessment Form

14-Oct-04

PLAY: **Beaufortian Cliniform**

Gas Play Area: 1,632 thousands of acres

NONASSOCIATED GAS ACCUMULATION ATTRIBUTE DISTRIBUTIONS

ATTRIBUTE	Shape	Knowledge Level 1-3 ⁵	LTP	Probability (Attribute ³ with respect to LTP)			Analog/data source
				0.5	0.05	Max	
NET RESERVOIR THICKNESS	2	3	30	50	80	100	
AREA OF CLOSURE ²	2	3	3	6	15	40	
POROSITY ^{3,4}	4	3	10	12	14	18	
TRAP FILL ³	8	3	75	90	100	100	
HYDROCARBON PORE VOL ^{3,4}			10	12	14	18	
POR*Sw	In-place bcf		0.29	1.41	7.32	31.36	
6	depth		0.0	0.0	0.0	0.0	
	depth		0.0	0.0	0.0	0.0	
	depth		0.0	0.0	0.0	0.0	

1-thickness in feet, 2-thousands of acres, 3-percent, 4-correlation between Porosity and Water Saturation = -1.0

5-Knowledge Level: 1=High, 2=Medium, 3=Low; LTP=Lower Truncation Point

	Shape	Level 1-3 ⁵	Min	0.5	0.05	Max	
TRAP DEPTH (in 1000 ft)	5	3	10	14	16	18	
(from sea level)	Enter surface to sea level correction (1000 ft):					0.52	GAS

NONASSOCIATED GAS ACCUMULATION CHARACTERISTICS

NA Gas recovery factor % 70

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=1.785*TD 25.0 (at median)

Nonassociated gas quality parameters:

Hydrogen sulfide % 0

CO2 contamination % 0

Other inert gases:

Name: Percent:

Name: Percent:

Gas fvf 176.7 min depth Gas fvf= 752.2*(1-EXP(-0.05728*TD)) TD<=5.67 thous ft
 281.4 median depth 113.3+21.1*TD-0.812*TD^2+0.0116*TD^3 5.67<TD<=30
 297.7 max depth TD=trap depth (thous ft)

For Nonassociated Gas Accumulation:

TIME OF TRAP DEVELOPMENT

	BEGIN	PEAK	END
STRATIGRAPHIC COMPONENT (Ma)	159	135	130
STRUCTURAL COMPONENT (Ma)	100	65	25

Assessor's Name: DWH Enter this info on Oil sheet

Date of Data Entry MM/DD/YYYY: 9/20/04

Date of Simulation Run MM/DD/YYYY: 10/15/04

Table 1f. Nonassociated gas correlation attributes and engineering computations

Alaskan Assessment Form

14-Oct-04

PLAY: **Beaufortian Cliniform**

GAS ACCUMULATION ATTRIBUTE DEPENDENCIES

Correlations	NET RESERVOIR THICKNESS	AREA OF CLOSURE	TRAP FILL	HYDROCARBO N PORE VOL
NET RESERVOIR THICKNESS	1	0.0	0.0	0.0
AREA OF CLOSURE	0.0	1	0.0	0.0
TRAP FILL	0.0	0.0	1	0.0
HYDROCARBON PORE VOL	0.0	0	0	1

Assessor's Name:

DWH

Date of Data Entry MM/DD/YYYY:

9/20/04

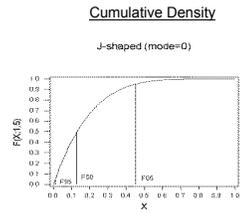
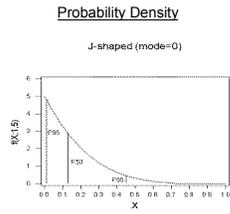
Date of Simulation Run MM/DD/YYYY:

10/15/04

Table 1g. Shapes to be used to specify accumulation attributes, trap depth, and number of prospects.

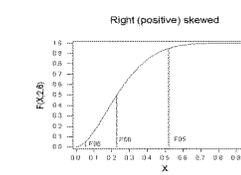
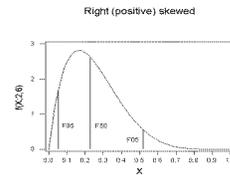
(Domains in these examples are 0 to 1.)

Shape 1



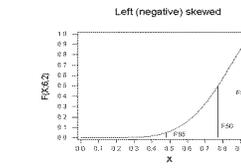
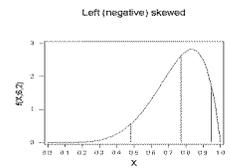
F95	0.01
F50	0.13
F05	0.45
Mean	0.33

Shape 2



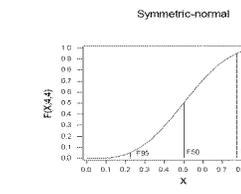
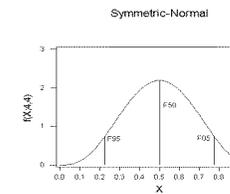
F95	0.05
F50	0.23
F05	0.52
Mean	0.25

Shape 3



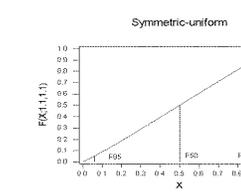
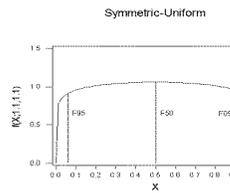
F95	0.48
F50	0.77
F05	0.95
Mean	0.75

Shape 4



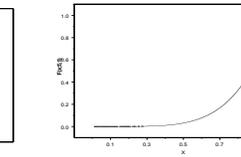
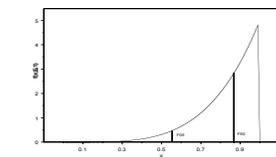
F95	0.23
F50	0.50
F05	0.77
Mean	0.50

Shape 5



F95	0.06
F50	0.50
F05	0.94
Mean	0.50

Shape 6 Complement of J (mirror image of shape 1).



F95	0.99
F50	0.87
F05	0.55
Mean	0.67

Shape 7 Same as shape 6 except with 0.50 probability at maximum (comp j-1).

Reserved for specification of trap fill

i.e.

LTP	0.5	0.05	Max
X	60	100	100

Let X be trap fill
 If $X < 100$ shape is inverted J with Prob ($LTP \leq X < 100$) = 0.5
 Prob ($X=100$) = 0.5

Shape 8 Same as shape 6 except with 0.05 probability at maximum (comp j-2).

Reserved for specification of trap fill

i.e.

LTP	0.5	0.05	Max
X	60	80	100

Let X be trap fill
 If $X < 100$ shape is inverted J with Prob ($LTP \leq X < 100$) = 0.95
 Prob ($X=100$) = 0.05

Oil accumulation attributes

Assessors specified distributions for the following oil accumulation attribute distributions (table 1a):

- net reservoir thickness, *NRT*, in feet,
- area of closure, *AC*, in thousands of acres,
- porosity, *POR*, in percent,
- trap fill, *TF* in percent, and
- trap depth, *TD* in thousands of feet.

Estimates of the lower truncation point (LTP), the 50th (F50), and 5th (F05) fractiles, and the maximum value were entered for *NRT*, *AC*, *POR*, and *TF*.

As specified in the protocol (Appendix B), the LTP was denoted as the minimum size of geologic interest. A principal purpose of the LTP was to eliminate the generation of a container size that would contain a volume of at least the minimum accumulation size (MAS) and have one or more attributes that were *too small* in a geologic sense. For example, in Table 1a, we note that the LTP for net reservoir thickness (*NRT*) was 20 feet. It would clearly be possible to generate a container of at least 5 mm bbl with an *NRT* of 10 feet, however in the judgment of the assessor, such a field would not be technological recoverable in the foreseeable future. (Note that LTP does not represent a specific fractile common to all attributes in a given play.) It was assumed that for *NRT*, *AC*, *POR*, and *TF* the population minimum was zero. Assessors were given plots showing the shape of each histogram of the accumulation attributes.

The hydrocarbon pore volume (*HPV*)², expressed in percent, is one of the components of the equation to estimate in place oil. It is computed as

$$HPV = POR - BVW$$

where *BVW*, the bulk volume water, is defined as the product of *POR* and water saturation S_w ($BVW = POR * S_w$). That is, *BVW* is the fraction or percentage of rock volume, which is filled with water. The question we faced was, what fraction of the rock volume is filled with water (the *BVW*) and how much with hydrocarbon (called *hydrocarbon pore volume* or *HPV*)? These two values, given either as a percentage or as a fraction, must sum to the porosity, such that $BVW + HPV = POR$. The porosity distribution is determined by the assessor from available core data, well logs, and analog fields. Because *BVW* is the product of porosity and water saturation, the problem of determining *BVW* reduces to the estimation of water saturation. In this assessment we adopted the same assumption used in the assessment of NPRA and the Arctic National Wildlife Refuge (Nelson, 1999): that *BVW* is constant in a given field. That assumption rests on the concept that *BVW* is constant within a specified lithology above the water-hydrocarbon transition zone and implies that water saturation varies inversely with

² The analysis and text on hydrocarbon pore volume was contributed by Philip Nelson, U.S. Geological Survey.

porosity. The BVW (called $POR * S_w$ on the form) is located in the ATTRIBUTE column of the Oil and Gas attribute assessment sheets (table 1a and table 1e, respectively). The value of BVW is treated as a constant, which is then subtracted from the porosity distribution to yield the distribution of hydrocarbon pore volume. For example, in the Beaufortian Clinoform Play [Oil worksheet], BVW is 6 percent, the median porosity is 13 percent, and consequently the median hydrocarbon pore volume is 7 percent. BVW was between 1 and 6 for the assessed Central North Slope plays.

Low-porosity, fractured reservoirs required a refinement to the estimate of HPV . Porosity in fractures can contribute 1 percent, and in some cases 2 or more percent to total porosity. Fractures are considered to be filled with hydrocarbon, because fracture apertures are greater than pore sizes in low-porosity, unfractured rock. Consequently, BVW_f , the bulk volume water in fractures is zero, and the expression for hydrocarbon pore volume is,

$$HPV = HPV_f + HPV_u = POR_f + POR_u - BVW_u$$

where the subscript f represents pore space in fractures and subscript u represents pore space in unfractured rock. Fracture porosity was included in the porosity distribution and bulk volume water was estimated for the unfractured rock; no modification of the worksheet was required for fractured reservoirs.

For TD and number of prospects (table 1c), the LTP is the minimum value of the population distribution. The TD was adjusted before use in the model by adding an average surface-to-sea level elevation correction factor (table 1a for oil and table 1e for gas). Thus, $TD \leftarrow TD + S_{sl}$, where S_{sl} is the surface to sea level correction factor (0.24×10^3 feet in the Brookian Clinoform oil play, table 1a)

The oil accumulation attribute distributions were intended to reflect the variation in characteristics of prospects across a play and not variation within a given prospect. The values chosen for the fractiles and other estimates were based upon field studies, geophysical and geochemical data, well logs, and analogy. Specific justifications are given in individual play description reports that are currently in preparation.

Oil accumulation characteristics and estimate of in-place oil

Samples from these accumulation distributions and an estimate of the formation volume factor (FVF_o) in reservoir barrels/stock tank barrels, rb/stb were combined to estimate OIP (in millions of barrels, MMBO), as:

$$OIP = 7.758 \times NRT \times AC \times HPV \times TF \times 10^{-4} / FVF_o$$

By repeated Monte Carlo sampling from the distributions for NRT , AC , HPV , TF and TD we generate a distribution of oil in place. An estimate of FVF_o , developed by Mahendra Verma, U.S. Geological Survey, (Verma and Bird, 2005) is computed as follows. Let

$p = 1000TD/2$ and $t = 19TD + 30$ where p is pressure in pounds per square inch (psi) and t is temperature in degrees F. Then the solution specific gravity, sgg is

$$sgg = ((0.1402 \ln(p + 14.7) - 0.4227) + (0.1369 \ln(t) + 0.0156) + (0.1704 \ln(ag) + 0.1469)) / 3$$

where ag is API gravity as specified on the oil worksheet play form (table 1a) and “ln” in the above equation is log base e function. The associated uncorrected gas to oil ratio GOR_u (cu. ft. per barrel at stp) is

$$GOR_u = sgg \left[\frac{(p + 14.7) 10^{0.0125ag}}{18 \times 10^{0.00091t}} \right]^{1/0.83}$$

The corrected GOR is

$$GOR = \begin{cases} 0.86 GOR_u & GOR_u \leq 1200 \\ \left[0.86 + 0.24 \sin^2 \left(\frac{GOR_u - 1200}{2250 - 1200} \frac{\pi}{2} \right) \right] GOR_u & 1200 < GOR_u < 2250 \\ 1.1 GOR_u & GOR_u \geq 2250 \end{cases}$$

Then

$$og = 141.5 / (ag + 131.5)$$

$$F = GOR (sgg / og)^{0.5} + 1.25t$$

where og is the specific gravity of oil.

Finally

$$FVF_o = 0.972 + 0.000147F^{1.175}$$

Oil FVF_o 's are shown for the API gravities of 23, 34, and 39 (fig. 1).

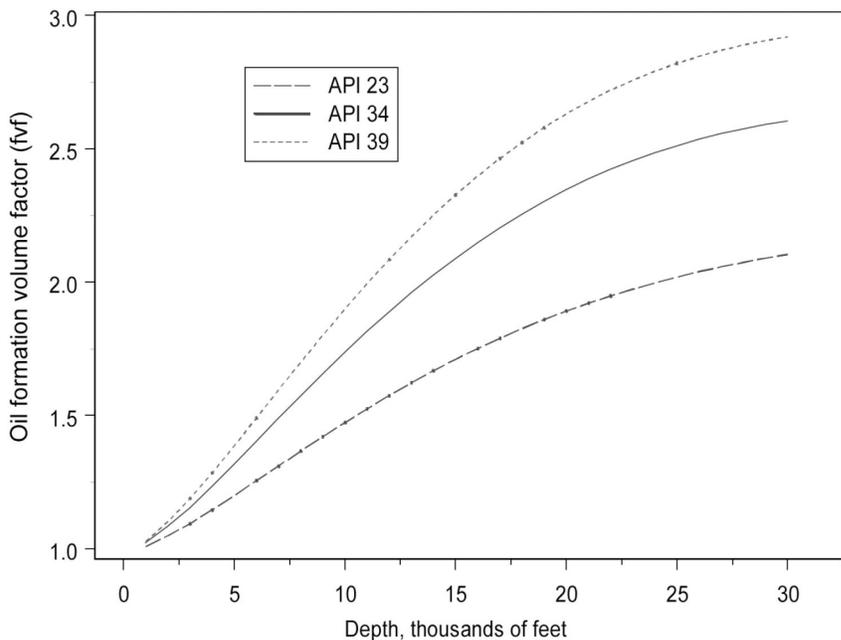


Figure 1. Oil formation volume factor (FVF_o) versus trap depth (TD) for selected API oil gravities.

Gas accumulation attributes, characteristics and estimate of in place gas

The categories of gas oil accumulation attributes and characteristics (table 1e), which were used to compute the accumulation sizes of gas, are the same as for oil, namely NRT , AC , POR , TF , and TD . The equation for the accumulation size of nonassociated gas in place, GIP , (in billions of cubic feet, bcf) is:

$$GIP = 4.356 \times NRT \times AC \times HPV \times TF \times 10^{-6} \times FVF_g$$

where FVF_g is the formation volume factor for gas. By repeated Monte Carlo sampling from the distributions for NRT , AC , HPV , TF and TD we generate a distribution of nonassociated gas in place. The computational algorithm is the same as that used in NPRA (Schuenemeyer, 2003; Standing, 1977; and Verma and Bird, 2005). We begin by obtaining z (the gas compressibility factor) from graphs (Amyx, Bass, and Whiting, 1960) versus TD (fig. 2).

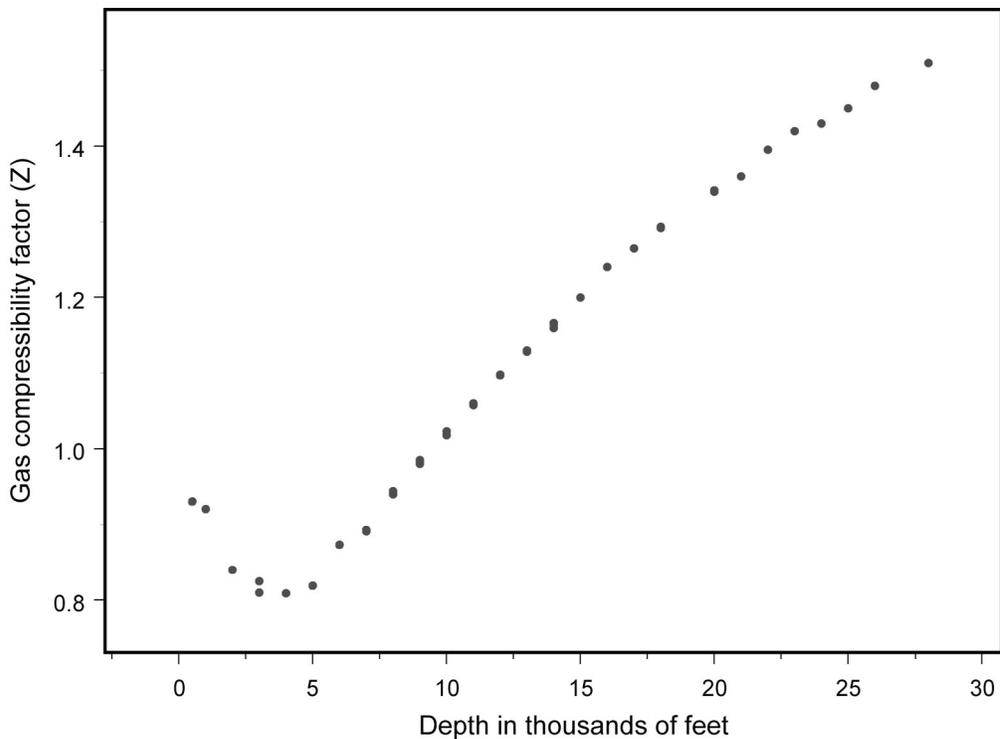


Figure 2. Gas compressibility factor (Z) versus trap depth (TD).

We then compute FVF_g as follows.

$$FVF_g = \frac{35.37415(p + 14.7)}{(t + 460)z}$$

Finally we smooth using the piecewise curve-fitting model:

$$FVF_g \begin{cases} 752.2(1 - e^{-0.05728TD}) & 0 < TD \leq 5.67 \\ 113.3 + 21.1TD - 0.812TD^2 + 0.0116TD^3 & 5.67 < TD \leq 30 \end{cases}$$

The model is illustrated by the solid line in Figure 3.

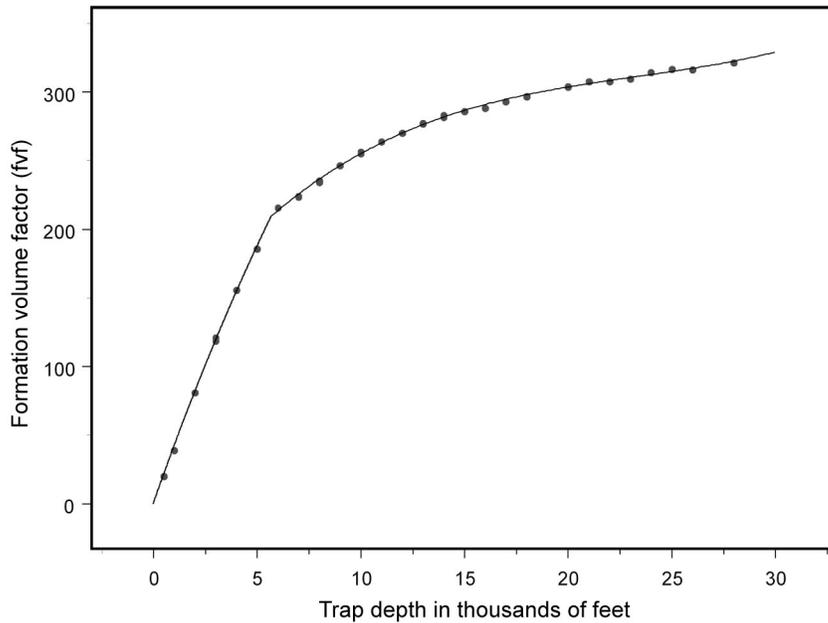


Figure 3. Gas formation volume factor FVF_g versus trap depth TD .

Derivatives

Associated Dissolved Gas (ADG). Given an oil field, it is assumed that associated dissolved gas behaves according to the following model:

$$ADG \text{ (bcfg)} = \text{Corrected GOR (cu.ft/bbl)} * 0.001 * \text{Recov Oil (mm bbl)}$$

Natural Gas Liquid.

For associated gas:

$$NGL-ADG \text{ (mm bbl)} = ADG * NGLR * 0.001$$

where

$$NGLR = 3.3523 \exp(0.1850 TD) \text{ (bbl/million ft}^3 \text{ at STP)} \quad TD \leq 16$$

and TD is trap depth in thousands of feet.

For nonassociated gas:

$$\text{NGL-GAS (mm bbl)} = \text{RNAG} * \text{NGL-NAG} * 0.001$$

where RNAG is recoverable nonassociated natural gas in bcf and

$$\text{NGL-NAG} = \begin{cases} 1.3TD & TD \leq 10 \\ 13 & TD > 10 \end{cases} \text{ (bbl/million ft}^3 \text{ at STP)}$$

Note that the temperature gradients are assumed to be 1.3° F/100 ft for gas plays and 1.9° F/100 ft for oil plays. See Verma and Bird (2005) for details on petroleum engineering models.

Correlated attributes

For some plays assessor chose to specify non-zero pairwise correlations between sets of the attributes *NRT*, *AC*, *POR*, *TF* and *TD* in Table 1b (oil) and/or Table 1f (gas). These correlations, which were specified individually for oil and gas, ranged from -0.75 to 0.30. For example, in the Brookian Clinoform Structural North play, the correlations specified by the assessor were:

Correlations	NET RESERVOIR THICKNESS	AREA OF CLOSURE	TRAP FILL	HYDROCARBON PORE VOL
NET RESERVOIR THICKNESS (NRT)	1	0.3	0.0	-0.5
AREA OF CLOSURE (AC)	0.3	1	0.0	0.0
TRAP FILL (TF)	0.0	0.0	1	0.0
HYDROCARBON PORE VOL (HPV)	-0.5	0	0	1

The positive correlation of 0.3 between NRT and AC would mean that given a high (low) value of NRT we would be slightly more likely to select a high (low) value of AC. The negative correlation between NRT and HPV would mean that given a high (low) value of NRT we would be more likely to select a low (high) value of HPV. Thus, rather than the sampling being independent, when a pairwise correlations is specified, a sample from the second attribute is conditioned on a value from the first. Because some of the user specified distributions were highly skewed, the multivariate sampling was nonparametric and used ranks. So for example, if we were to do 10 simulations, we would draw 10 random variates from the NRT distribution, sort them in ascending order, and assign them ranks from 1 to 10. We repeat the same process for AC, however, the ranks assigned to AC may be {4, 3, 7, 2, 10, 6, 1, 10, 5, 8}. The correlations between the ranks assigned to NRT and those assigned to AC is 0.3, and thus values of AC would be correlated with those of NRT at approximately the same level.

The algorithm used to incorporate these correlations structures into the oil and gas accumulation formulas is as follows:

1. Let R_c be a matrix whose elements are the assessor specified pairwise correlations. We assume R_c to be a 5×5 matrix. Also, let ns be the number of simulation runs.
2. We then see if R_c is permissible. A permissible matrix is one whose determinant is greater than or equal to zero. All assessor defined correlations resulted in permissible matrices. (See additional discussion in the section on Aggregation Methodology.)
3. If R_c is permissible, let $C_h = \text{Cholesky}(R_c)$, be the Cholesky factorization of R_c .
4. Let U_a be a $ns \times 5$ matrix, where each row of U_a is an independent set of uniform random numbers between -1 and 1 .
5. Let $U_{ac} = U_a \times C_h$.
6. Let $Ur_{[i]} = \text{Rank}(U_{ac[i]})$, $i=1, \dots, 5$
7. The ranked values in the columns of Ur represent the sample numbers of the accumulations (with accumulations sorted in ascending order) necessary to achieve the desired correlation structure as specified in R_c .

This methodology was implemented in Splus function `asoga.fnt`, called from Splus function `AMsim.fn`. For additional mathematical and computational details see Kotz, Balakrishnan, and Johnson (2000) and Stewart (1973).

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. A favorability of one implies zero risk.

There are two favorability structures. One is play; the other is prospect. Prospect favorability was further subdivided into oil and gas. Each of these is the product of three attributes, however, play favorability refers to the product of attributes needed for a successful play, whereas, prospect probability refers to the product of those attributes associated with a randomly chosen prospect. The attributes that constitute these structures are charge, trap, and timing formation. Although the names of the attributes are the same at the play and prospect levels, there are nine distinct attributes. They are assumed to be pairwise independent of each other. Prospect attributes were assessed conditional upon the play being successful. Thus, in the Beaufortian Clinoform (table 1d), the play favorability is

$$\begin{aligned}
 F_p &= C \times T \times F \\
 &= 1 \times 0.6 \times 1 \\
 &= 0.6
 \end{aligned}$$

where charge (C), trap/rock (T), and timing (F) are at the play level. In the simulation, if we draw u , a $[0,1]$ uniform random number, and $u \leq F_p = 0.6$, we deem the play successful. Prospect favorability is specified for oil and gas separately. Again in the Beaufortian Clinoform (table 1d), the prospect favorability for oil is

$$\begin{aligned}
F_o &= c_o \times t_o \times f_o \\
&= 0.9 \times 0.2 \times 1 \\
&= 0.18
\end{aligned}$$

where charge (c_o), trap/rock (t_o), and timing (f_o) are at the prospect level for oil. In the Beaufortian Clinoform (table 1d), the prospect favorability for gas is

$$\begin{aligned}
F_g &= c_g \times t_g \times f_g \\
&= 0.9 \times 0.2 \times 1 \\
&= 0.18
\end{aligned}$$

where charge (c_g), trap/rock (t_g), and timing (f_g) are at the prospect level for gas. In this instance both prospect favorability values are the same. In general, they will not be. In the simulation, we draw separately from the number of prospects for oil and gas (table 1c). For each oil prospect, we draw u , a [0,1] uniform random number, and if $u \leq F_o = 0.18$, we deem the prospect successful. Likewise, for each gas prospect we draw u , a [0,1] uniform random number, and if $u \leq F_o = 0.18$, we deem the prospect successful.

A successful play is one in which all three of the play level attributes necessary for a prospect of at least 5 mm bbl technically recoverable oil or 100 bcf technically recoverable nonassociated gas are present. However, there is no guarantee that such a prospect will be found in a “successful play”. A failure to draw at least one deposit in a “successful play” can occur when few prospects are specified and/or the prospect favorability is low.

Assessment definitions (Appendix C) were established and made available to the assessors to provide specific guidelines to allow them to differentiate between these two risks.

Graphical Feedback

Plots of the accumulation attribute distributions, trap depth, and number of prospects distributions, and corresponding fitted values to beta distributions were provided to the assessors. Table 2 shows graphs of area of closure and number of prospects for the oil component of the Beaufortian Clinoform play (table 2a). These graphs could be viewed immediately after data entry. Fitted distributions (Table 2b) from the Splus nonlinear fitting distributions used in the play simulation were provided to the assessors in batch mode. Box plots of accumulation attributes that constituted prospect volumes near the MAS (not shown) were also provided. Finally the oil accumulation distribution was given in original units (table 2c) and in logs (table 2d). In the original units, the accumulation graph only extends to the F05 value in order to allow the assessor

Table 2a. Instantaneous feedback graphs, Beaufortian Cliniform play.

Oil Graphs

Density, LTP, and complement cumulative distribution function (ccdf)

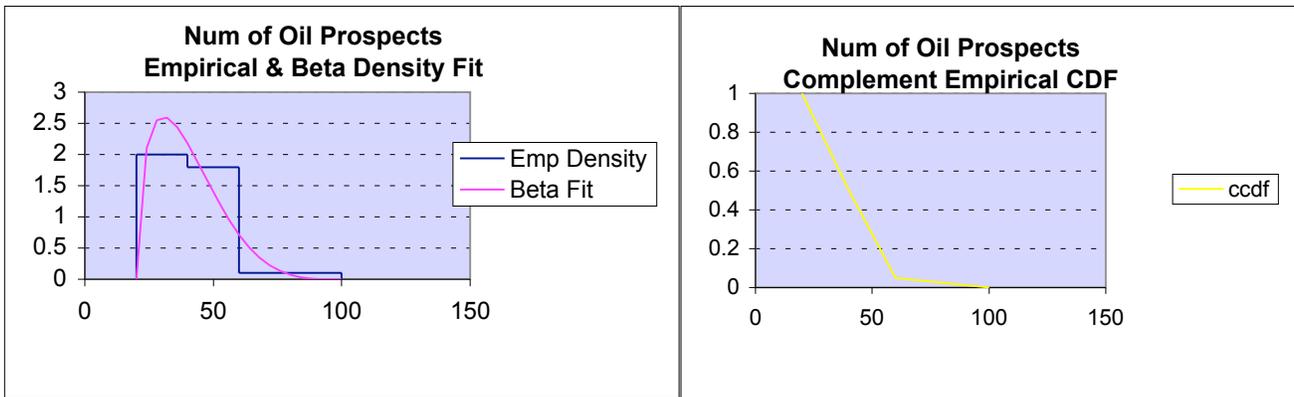
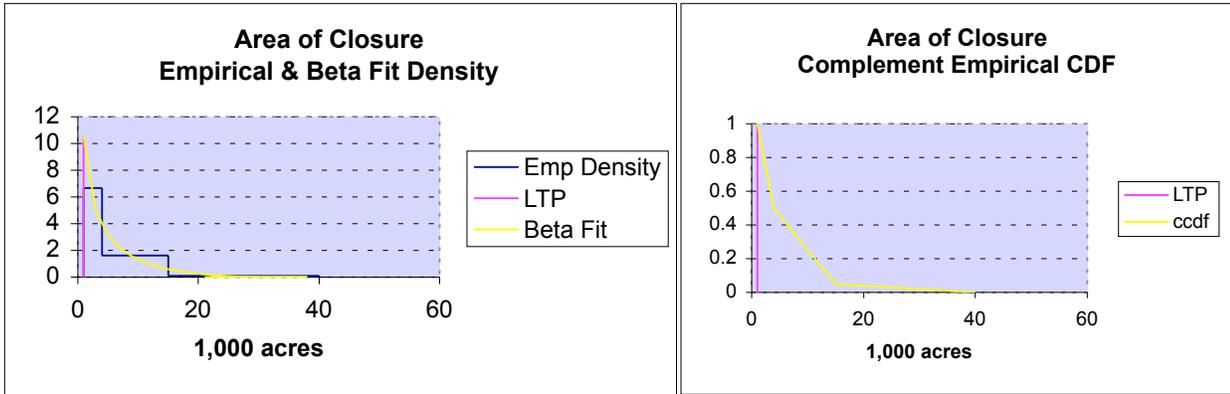


Table 2b. Model fitted beta distributions to oil and nonassociated gas attributes, Beaufortian Cliniform play.

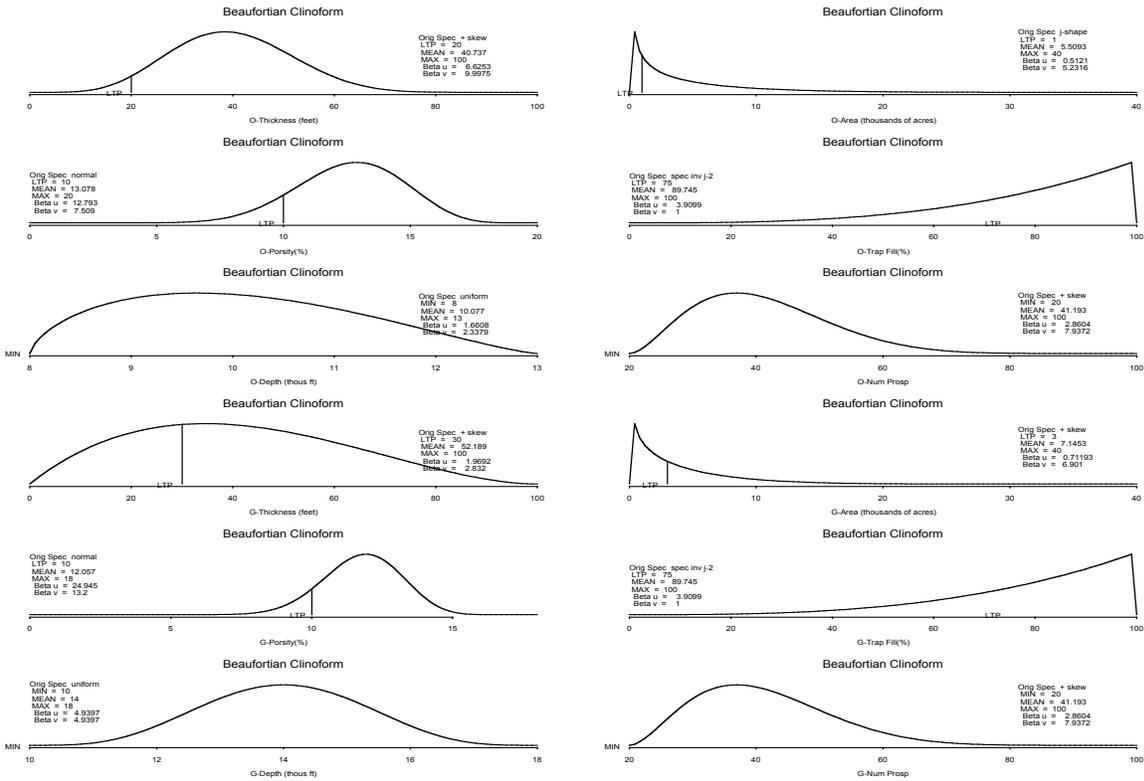


Table 2c. Oil accumulation distribution, Beaufortian Clinoform play.

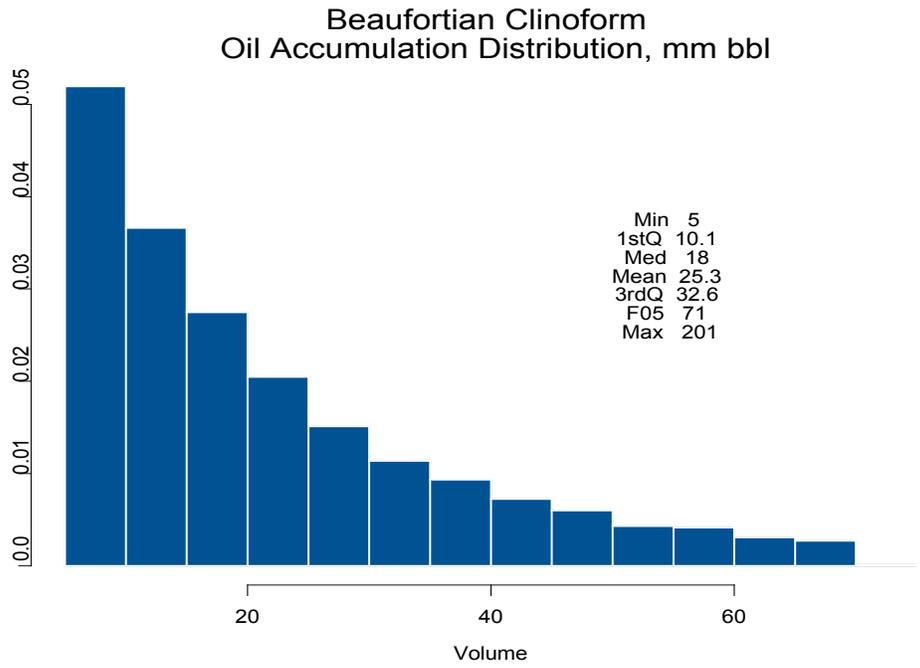
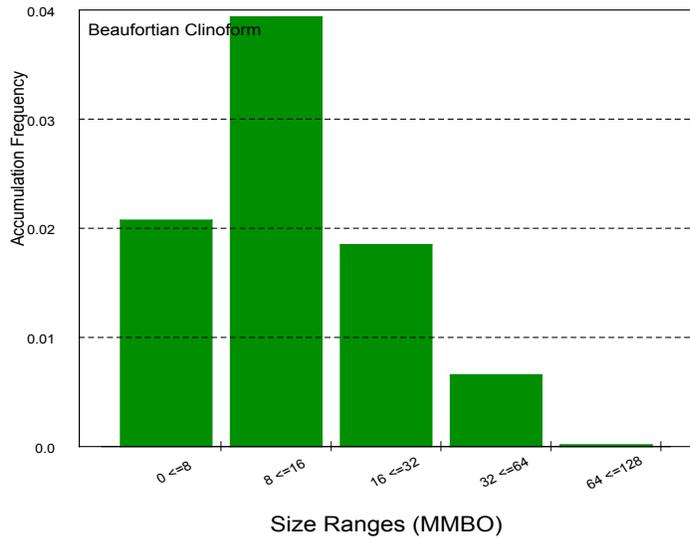


Table 2d. Oil accumulation distribution, Beaufortian Clinoform play, log units.



to focus on the left component of the distribution. The accumulation distribution in log units was presented to help the assessor estimate the number of smaller undiscovered fields.

The Deposit Simulation

The methodology was based upon a Monte Carlo simulation. A series of functions, written in Splus6.1, described in Appendix A, and listed in Appendix D were used to implement the simulation. For each play, 10,000 simulations were run, conditioned on the play being favorable. For example, the Beaufortian Cliniform play favorability probability was 0.60. The expected total number of runs would be 16,667 (10,000 divided by 0.60). However, since the expected number of unsuccessful runs was 6,667, we chose to run only the 10,000 potentially successful runs. The reason for choosing to run 10,000 simulations conditioned on a successful play was to obtain similar levels of precision on the summary statistics for all plays, even those that were highly risked. The uniform random number generator used for the simulations is the Splus6.1 function runif. A list of plays and play favorability probability is given in Table 3 (this is the same as Splus file AMplayr).

Table 3. Play number, name, favorability probability (risk), and file name.

Play number	Play name	Play favorability	Splus file name
1	Brookian Cliniform	1.0	BkC
2	Brookian Topset	1.0	BkT
3	Beaufortian Upper Jurassic Topset East	0.6	BeUJTE
4	Beaufortian Upper Jurassic Topset West	1.0	BeUJTW
5	Beaufortian Cliniform	0.6	BeC
6	Beaufortian Kuparuk Topset	1.0	BeKT
7	Beaufortian Cretaceous Shelf Margin	1.0	BeCSM
8	Triassic Barrow Arch	1.0	BaAT
9	Ivishak Barrow Flank	0.8	BaFI
10	Endicott	0.9	End
11	Endicott Truncation	1.0	EndT
12	Franklinian	1.0	Frk
13	Lisburne Barrow Arch	1.0	LBA
14	Lisburne Barrow Flank	0.9	LBF
15	Kemik-Thompson	1.0	KTh
16	Basement Involved Structural	1.0	BIS
17	Beaufortian Structural	0.9	BeS
18	Brookian Cliniform Structural South	1.0	BkCSS
19	Brookian Cliniform Structural North	1.0	BkCSN
20	Brookian Topset Structural South	1.0	BkTSS
21	Brookian Topset Structural North	1.0	BkTSN
22	Thrust Belt Triangle Zone	1.0	TBTZ
23	Thrust Belt Lisburne	1.0	TBL
24	Ellesmerian structural	0.9	ES

Computation was done with a series of Splus v6.1 functions (Insightful Corp., Seattle, WA). (Splus is a commercially available statistical computing package and programming language, which is functional in form and can be translated into other high level languages, especially R³ statistical software. Input from tables 1a-1f was automatically transferred to an Excel worksheet (WorkS1) (not shown), which provided input to Splus function AMdata.fn.

The fractiles for hydrocarbon accumulation attributes, trap depth, and number of prospects specified by assessors for oil and gas were each fit to a two parameter beta distribution

$$f(x; u, v) = B(u, v)x^u(1-x)^v \quad 0 \leq x \leq 1$$

using Splus function AMpare.fn. The method of fit was the Splus nonlinear estimation function nlmin, which uses a general quasi-Newton optimizer. The function being minimized (fmin) was

$$(qbeta(0.50, p[1], p[2]) - co[1])^2 + (qbeta(0.95, p[1], p[2]) - co[2])^2$$

where *qbeta* is the Splus beta quantile function, *p[1]* and *p[2]* are initial estimates of the beta distribution parameters established from the user specified distribution shape (table 1g), and *c[1]* and *c[2]* are the standardized (to 0 to 1) values of the 0.50 (F50 fractile) and 0.95 (F05 fractile) percentiles specified by the assessors. The result is estimated parameters of the beta distribution. The use of a modified beta distribution only occurred in a few instances for the distribution of trap fill where an assessor specified a) an inverted j-shaped distribution with 0.50 probability occurring at the maximum value (table 1g, shape 7), or b) an inverted j-shaped distribution with 0.05 probability occurring at the maximum value table 1g, shape 8). In case a) the fitted beta density function was

$$f(x; 5, 1) = \begin{cases} 0.5beta(x; 5, 1), & 0 \leq x < 1 \\ 0.5 & x = 1 \end{cases}$$

In case b) the fitted beta distribution was

$$f(x; 1, v) = \begin{cases} 0.95beta(x; 1, v), & 0 \leq x < 1 \\ 0.05 & x = 1 \end{cases}$$

where $v = \ln(0.5) / \ln(1 - x_{0.95})$. Assessors were given the option of choosing other distributions if they did not feel these provided an adequate fit, however, none did.

³ The R-Project for Statistical Computing, <http://www.r-project.org/>. R is open source software.

Assessors were also provided feedback in the form a graphical representation of the beta distribution as fit from their fractile specification. Changes to fractile specifications were allowed, as needed, to properly reflect the geology.

The beta distribution was chosen because assessor specified distribution ranged from highly right skewed to symmetric to left skewed, and from peaked to flat. The beta distribution was able to accommodate this wide range of shapes. In the simulation, all sampling was from the fitted beta distributions. Note assessors could specify that certain beta distributions be correlated. Correlated samples, when specified by assessors, were incorporate into the oil and/or gas in place accumulation distributions, as previously described.

Figure 4 is a flow chart for the simulation algorithm (function AMsim.fn). It begins with the main simulation loop, which was executed 10,000 times for each play; 10,000 being the expected number of potentially favorable plays. Next, a sample was taken from the number of prospects distribution. The number of prospect distribution for oil is independent of that for gas for purposes of sampling. The same assessor typically specified both distributions so in that sense they would not be independent, however, this factor was not incorporated into the simulation. The number of prospects is oil of at least 5 mm bbl technically recoverable, and nonassociated gas of at least 100 bcf technically recoverable. The oil or gas prospect probability was then applied. For a successful prospect, now relabeled a deposit, a value of at least the MAS was obtained via a random sample from the oil or gas in place accumulation distribution. Associated-dissolved gas and natural gas liquids (NGL) from associated-dissolved gas and from nonassociated gas were also computed. Technically recoverable quantities of oil were computed by multiplying the in-place volumes by the oil recovery factor (table 1a and table 1e). Function AMplay.fn totals field level data in each simulation. The output file will contain one line per simulation run. Function AMpsum.fn yields numeric and graphical summary statistics by play. Size-frequency distributions for recoverable oil and nonassociated gas were computed and graphed using functions (AMfreq.fn and AMsf.fn). The purpose of these functions is to allow the assessor to see the result of his/her attribute specification prior to a final simulation run. An example of the detailed output from function AMsim.fn is given in Table 4.

Figure 4. General flow chart for simulation algorithm.

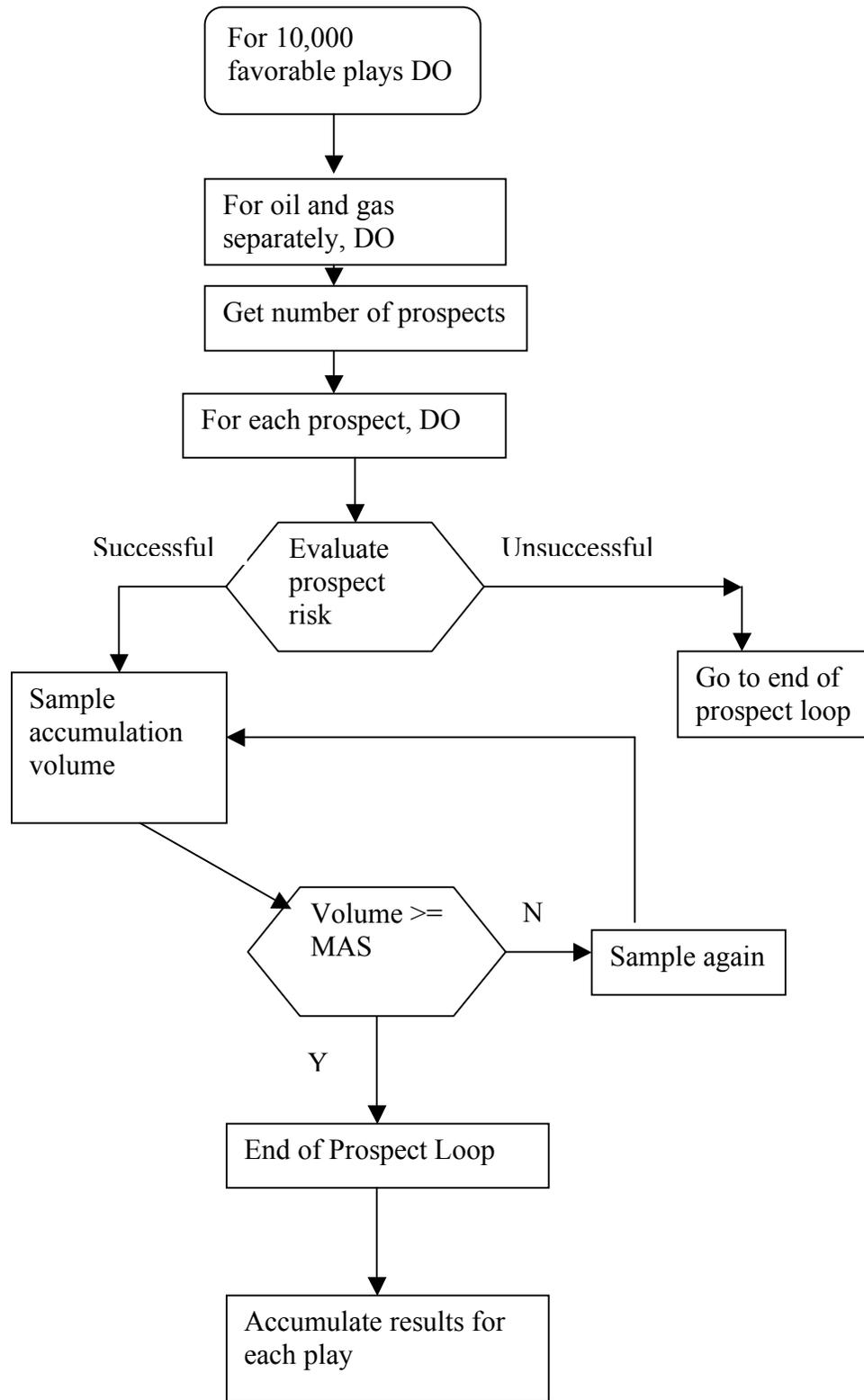


Table 4. Sample simulation output from the Beaufortian Cliniform play.

[run, 1 to number of simulations; numdep, number of deposits this run; depnum, deposit number from 1 to numdep; og.id, 1 for oil, 2 for nonassociated gas; rec.og, technically recoverable oil or gas; nrt, net reservoir thickness in feet; ac, area of closure in thousands of acres; hpv, hydrocarbon pore volume in percent; tf, trap fill in percent; td, trap depth in thousands of feet; fvf, formation volume factor; rec.agas, recoverable associated dissolved gas in billions of cubic feet; rec.NGL, recoverable natural gas liquid in millions of barrels]

run	numdep	depnum	og.id	rec.og	nrt	ac	hpv	tf	td	fvf	rec.agas	rec.NGL
1	14	1	1	34.21	48.31	4.80	9.69	86.82	9.26	1.77	44.53	0.83
1	14	2	1	28.10	52.88	5.53	6.02	96.54	10.10	1.88	40.80	0.89
1	14	3	1	13.01	50.54	3.63	4.56	94.43	10.15	1.88	19.00	0.42
1	14	4	1	32.11	42.55	7.83	6.24	93.28	10.07	1.87	46.44	1.00
1	14	1	2	312.21	66.00	9.91	5.54	99.54	14.50	283.88	NA	4.06
1	14	2	2	163.06	62.81	4.24	8.01	87.24	15.34	287.78	NA	2.12
1	14	3	2	376.85	32.76	22.93	5.87	98.41	14.72	284.97	NA	4.90
1	14	4	2	342.07	60.30	11.90	6.19	90.84	13.41	278.19	NA	4.45
1	14	5	2	409.18	59.78	15.86	5.49	89.93	15.06	286.53	NA	5.32
1	14	6	2	102.54	54.82	3.43	6.60	97.22	13.56	279.05	NA	1.33

To obtain

p (pressure, psi) = $1000 * td / 2$

t (temp, deg F) = $19 * td + 30$

z (gas compressibility, na gas) = $35.37415 * (p + 14.7) / (fvfg * (t + 460))$

where fvfg is fvf nonassociated gas

inplace oil at sea level = $og.id(1) / (oilr * .01)$

inplace nonassociated gas at sea level = $og.id(2) / (gasr * .01)$

where og.id(1) is technically recoverable oil

og.id(2) is technically recoverable gas

oilr is oil recovery factor in percent (from play sheets)

gasr is nonassociated gas recovery factor in percent (from play sheets)

Aggregation Methodology

Overview

Resource estimates from the 24 individual plays were aggregated to total resources in the Central North Slope assessment area. An aggregate distribution was constructed by sampling from the individual plays to estimate assessor specified dependencies between plays. These dependencies result from shared sources of charge, trap and/or timing. Dependency does not affect the mean of the aggregate distribution, only the spread. The mean of the aggregate is simply the sum of the means of the plays to be aggregated. 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. Failure to account for positive dependency would have resulted in estimates of uncertainty that were too narrow and thus would have created a higher level of confidence in results than would be warranted if the correct measure of dependency were used.

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. The chosen samples are based upon rank order of the BOE in each play.

Specifying the Dependency

Assessors considered all possible pairs of the 24 plays being assessed. For each pair they assigned one of three values (0.1, 0.5, and 0.9), corresponding to low, medium, and high correlation to the attributes of charge, trap, and timing (table 5a–5c). A high (positive) value assigned to charge between, say plays A and B may indicate a common mechanism charged both plays. Thus, if the value of charge in play A was found to be high, the value of charge in play B would most likely be high. A single correlation matrix (table 5d) was then formed by taking the arithmetic average of the three correlation matrices.

There is a potential inconsistency associated with specifying correlations by pairs of plays, namely, some correlations impose restrictions on others. For example, suppose the correlation between plays A and B is 0.367 and that between plays A and C is 0.500. Then the range of the correlation between plays B and C is restricted in that not all values between -1 and $+1$ are permissible. In order to see if the 24 x 24 computed correlation matrix (table 5d) was permissible, a statistical procedure called eigenvalue analysis was performed (function AMcorr.fn). The minimum eigenvalue of a permissible (positive definite) correlation matrix must be greater than zero. The minimum eigenvalue of this matrix was -0.110 . Thus, a slight biasing factor, 0.111, was applied to each of the 24 eigenvalues. Then the correlation matrix was reconstructed (table 5e). The maximum adjustment made to correlations after application of the bias factor was 0.09, however, most pairwise adjustments were 0.01. These adjustments were judged to be within the

Table 5a. Assessor specified Charge dependencies between plays.
 [Correlations: 0.1, low; 0.5, medium; 0.9, high]

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	
1 Brookian Clinoform																								
2 Brookian Topset	0.9																							
3 Beaufortian Upper Jurassic Topset East	0.1	0.1																						
4 Beaufortian Upper Jurassic Topset West	0.1	0.1	0.9																					
5 Beaufortian Clinoform	0.1	0.1	0.9	0.9																				
6 Beaufortian Kuparuk Topset	0.5	0.5	0.9	0.9	0.9																			
7 Beaufortian Cretaceous Shelf Margin	0.1	0.1	0.5	0.5	0.9	0.5																		
8 Triassic Barrow Arch	0.1	0.1	0.1	0.1	0.1	0.5	0.1																	
9 Ivishak Barrow Flank	0.1	0.1	0.1	0.1	0.1	0.5	0.1	0.1																
10 Endicott	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.5															
11 Endicott Truncation	0.5	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.9	0.1	0.1													
12 Franklinian	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.9	0.1	0.1	0.9												
13 Lisburne Barrow Arch	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.9	0.1	0.1	0.9	0.9											
14 Lisburne Barrow Flank	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.5	0.5	0.5	0.1	0.5											
15 Kemik-Thompson	0.5	0.1	0.1	0.1	0.1	0.5	0.1	0.9	0.1	0.1	0.9	0.9	0.9	0.1										
16 Basement Involved Structural	0.1	0.1	0.5	0.1	0.1	0.5	0.5	0.1	0.5	0.5	0.5	0.5	0.1	0.5	0.5									
17 Beaufortian Structural	0.5	0.1	0.5	0.1	0.5	0.5	0.9	0.1	0.5	0.1	0.1	0.1	0.1	0.1	0.1	0.5	0.5							
18 Brookian Clinoform Structural South	0.5	0.5	0.1	0.1	0.1	0.1	0.5	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.9						
19 Brookian Clinoform Structural North	0.9	0.9	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.5	0.1	0.9	0.5					
20 Brookian Topset Structural South	0.5	0.5	0.1	0.1	0.1	0.1	0.5	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.9	0.5				
21 Brookian Topset Structural North	0.9	0.9	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.5	0.9	0.5			
22 Thrust Belt Triangle Zone	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.5	0.5	0.9	0.1	0.5	0.1			
23 Thrust Belt Lisburne	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.5	0.1	0.5	0.1	0.9		
24 Ellesmerian Structural	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.5	0.5	0.5	0.5	0.1	0.5	0.5	0.9	0.5	0.1	0.1	0.1	0.1	0.5	0.1	

Table 5d. Arithmetic average of assessor specified Charge, Trap, and Timing correlations.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1 Brookian Clinoform																							
2 Brookian Topset	0.37																						
3 Beaufortian Upper Jurassic Topset East	0.10	0.10																					
4 Beaufortian Upper Jurassic Topset West	0.10	0.10	0.50																				
5 Beaufortian Clinoform	0.10	0.10	0.37	0.37																			
6 Beaufortian Kuparuk Topset	0.23	0.23	0.37	0.37	0.37																		
7 Beaufortian Cretaceous Shelf Margin	0.10	0.10	0.23	0.23	0.37	0.23																	
8 Triassic Barrow Arch	0.10	0.10	0.10	0.10	0.10	0.23	0.10																
9 Ivishak Barrow Flank	0.10	0.10	0.10	0.10	0.10	0.23	0.10	0.10															
10 Endicott	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.23														
11 Endicott Truncation	0.23	0.10	0.10	0.10	0.10	0.10	0.10	0.63	0.10	0.10													
12 Franklinian	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.50	0.10	0.10	0.50												
13 Lisburne Barrow Arch	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.63	0.10	0.10	0.63	0.50											
14 Lisburne Barrow Flank	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.23	0.23	0.23	0.10	0.23										
15 Kemik-Thompson	0.23	0.10	0.10	0.10	0.10	0.23	0.10	0.37	0.10	0.10	0.50	0.37	0.37	0.10									
16 Basement Involved Structural	0.10	0.10	0.23	0.10	0.10	0.23	0.23	0.10	0.37	0.23	0.23	0.23	0.10	0.37	0.23								
17 Beaufortian Structural	0.23	0.10	0.23	0.10	0.23	0.23	0.50	0.10	0.23	0.10	0.10	0.10	0.10	0.10	0.37	0.23							
18 Brookian Clinoform Structural South	0.37	0.23	0.10	0.10	0.10	0.10	0.23	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.50						
19 Brookian Clinoform Structural North	0.50	0.37	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.23	0.10	0.50	0.63					
20 Brookian Topset Structural South	0.23	0.37	0.10	0.10	0.10	0.10	0.23	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.23	0.63	0.37				
21 Brookian Topset Structural North	0.37	0.50	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.23	0.37	0.63	0.63			
22 Thrust Belt Triangle Zone	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.23	0.37	0.90	0.23	0.50	0.10		
23 Thrust Belt Lisburne	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.23	0.10	0.10	0.37	0.10	0.37	0.10	0.77		
24 Ellesmerian structural	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.37	0.23	0.23	0.23	0.10	0.37	0.23	0.90	0.23	0.10	0.10	0.10	0.10	0.23	0.23

Table 5e. Adjusted dependency matrix.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	
1 Brookian Clinoform																								
2 Brookian Topset	0.33																							
3 Beaufortian Upper Jurassic Topset East	0.09	0.09																						
4 Beaufortian Upper Jurassic Topset West	0.09	0.09	0.45																					
5 Beaufortian Clinoform	0.09	0.09	0.33	0.33																				
6 Beaufortian Kuparuk Topset	0.21	0.21	0.33	0.33	0.33																			
7 Beaufortian Cretaceous Shelf Margin	0.09	0.09	0.21	0.21	0.33	0.21																		
8 Triassic Barrow Arch	0.09	0.09	0.09	0.09	0.09	0.21	0.09																	
9 Ivishak Barrow Flank	0.09	0.09	0.09	0.09	0.09	0.21	0.09	0.09																
10 Endicott	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.21															
11 Endicott Truncation	0.21	0.09	0.09	0.09	0.09	0.09	0.09	0.57	0.09	0.09														
12 Franklinian	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.45	0.09	0.09	0.45													
13 Lisburne Barrow Arch	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.57	0.09	0.09	0.57	0.45												
14 Lisburne Barrow Flank	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.21	0.21	0.21	0.09	0.21											
15 Kemik-Thompson	0.21	0.09	0.09	0.09	0.09	0.21	0.09	0.33	0.09	0.09	0.45	0.33	0.33	0.09										
16 Basement Involved Structural	0.09	0.09	0.21	0.09	0.09	0.21	0.21	0.09	0.33	0.21	0.21	0.21	0.09	0.33	0.21									
17 Beaufortian Structural	0.21	0.09	0.21	0.09	0.21	0.21	0.45	0.09	0.21	0.09	0.09	0.09	0.09	0.09	0.33	0.21								
18 Brookian Clinoform Structural South	0.33	0.21	0.09	0.09	0.09	0.09	0.21	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.45							
19 Brookian Clinoform Structural North	0.45	0.33	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.21	0.09	0.45	0.57						
20 Brookian Topset Structural South	0.21	0.33	0.09	0.09	0.09	0.09	0.21	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.21	0.57	0.33					
21 Brookian Topset Structural North	0.33	0.45	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.21	0.33	0.57	0.57				
22 Thrust Belt Triangle Zone	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.21	0.33	0.81	0.21	0.45	0.09			
23 Thrust Belt Lisburne	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.21	0.09	0.09	0.09	0.33	0.09	0.33	0.09	0.69			
24 Ellesmerian structural	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.33	0.21	0.21	0.21	0.09	0.33	0.21	0.81	0.21	0.09	0.09	0.09	0.09	0.21	0.21	

range of assessor estimated uncertainty. The resultant correlation matrix (table 5e) was used for the remaining part of the analysis. This aggregation procedure is similar to that used in the most recent USGS NPRA assessment (Schuenemeyer, 2003). It is also virtually identical to the dependency scheme used in the USGS 1995 National Assessment (Gautier and other, 1995).

Generating a Correlated Sample

The adjusted correlation matrix (table 5e) was then used to induce the appropriate correlation structure in the data. A justification for this procedure was given previously. The algorithm is essentially the same as that used to generate correlated samples of accumulation attributes. The procedure is outlined below.

1. Let R be the 24 x 24 adjusted (permissible) correlation matrix of play dependencies. Also, let $n_s = 10,000$, where n_s is the number of simulation runs.
2. Perform a Cholesky factorization 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).
3. Let U_a be an $n_s \times 24$ matrix, where each row of U_a is an independent set of continuous uniform random numbers between -1 and 1 .
4. Let $U_{ac} = U_a \times A$.
5. Let $U_{r[i]} = \text{Rank}(U_{ac}[i])$, $i=1, \dots, 24$.
6. Adjust the matrix U_r by the total number of plays run (10,000/play probability).
7. The ranked values in the columns of U_r then represent the sample numbers of the play (with play recoverable barrels of oil equivalent sorted in ascending order) necessary to achieve the desired correlation. (The matrix U_r in the context of the Central North Slope assessment is file AMrand.)

Each element in the matrix U_r became a sample number. As previously discussed, only the expected number of successful plays was generated; however, sample numbers from unsuccessful plays were needed to generate samples for the aggregate distributions. For example, as previously noted, the Beaufortian Cliniform has 16,667 expected number of runs, however, only 10,000 simulation runs were made. In sampling for aggregation, we take a simple random sample of 10,000 from a population of 16,667 runs, 6,667 of which were a priori unsuccessful. For those plays that consisted of 10,000 runs (i.e., the play favorability probability was 1.0), such as the Brookian Topset, this procedure generated a permutation of the original data that imparted the appropriate correlation structure. A rank correlation structure was used because the oil and gas distributions differ widely among the 24 plays. The standard (Pearson) correlation coefficient is only meaningful when distributions are similar and in particular when they are symmetric. The sample numbers to achieve the desired correlation structure were generated by function AMcorr.fn.

The actual process of aggregation, performed by algorithm AMagg.fn, was straightforward. Samples were selected by row from matrix U_r and the corresponding values of oil or gas were obtained from the appropriate play and/or prospect file. 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 follow the actual 10,000 runs generated from the simulation for purposes of sampling. The output file (file AMag) contains aggregate results (one line for each of the 10,000 simulations) plus sample numbers for each play that reference the run numbers in the simulation and play files. A part of this file is given in Table 6.

Table 6. Partial aggregation file.

[roil, oil in millions of barrels; rgas, nonassociated gas in billions of cubic feet; rADG, associated dissolved gas in billions of cubic feet; rNGLadg, natural gas liquids in associated gas in millions of barrels; rNGLnag, natural gas liquids in nonassociated gas in millions of barrels; P1 – P24, play numbers shown in Table 3]

roil	rgas	rADG	rNGLadg	rNGLnag	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P17	P18	P19	P20	P21	P22	P23	P24
4451	22986	4757	102	254	4559	7338	7463	9645	0	7368	9244	5739	2994	8037	4385	3356	800	7990	1857	5613	6964	2838	7356	8555	7909	2998	2182	0
6233	35706	5816	110	424	1805	1337	0	5543	0	7373	2893	3064	9629	8448	4100	9158	1265	7236	8219	7813	3973	4822	7819	1532	64	104	4968	8600
6499	29314	6986	153	339	3389	5313	0	6172	0	3837	4234	8270	0	0	5255	9470	7904	6693	5368	3083	0	7452	7591	4494	6610	7920	4804	7381
3622	26047	3682	72	311	5372	7070	0	4868	0	2641	9856	8182	0	4274	8102	6419	2399	2713	4815	3686	0	3726	8076	9106	5412	5484	3370	2741
2166	29507	2508	63	346	3972	6118	0	5480	6516	7081	893	5015	8883	7969	1922	5047	6543	2668	9134	5053	1664	363	6841	1056	5454	1773	6783	2919
3560	36869	3653	93	433	6278	9157	4751	5445	2703	8705	6993	6039	3875	5822	3485	2717	5103	6593	6700	9624	7661	6951	4411	7788	1819	5138	7971	3301
6139	37950	5417	104	402	6069	5959	4651	2876	4736	6688	3572	8935	5955	6986	5257	8915	6187	7973	3219	3833	6218	3324	8887	5788	5910	5669	907	4754
3520	30924	3078	53	353	4420	4664	5384	9351	7909	9062	4332	5284	2204	2180	3127	1818	8919	7118	1925	418	138	9349	1894	5560	5955	9501	839	1655
3273	23500	3675	85	264	1634	3652	764	862	2259	4586	5435	1739	4043	6411	2621	2695	7846	171	4576	630	3465	1566	1743	7210	4788	3870	1331	394
3381	39630	3497	80	469	4943	2531	0	8039	2958	746	6414	6724	0	5916	758	3619	4869	2624	3885	2066	7270	3245	6124	274	448	8080	5209	3975
3440	31670	3319	56	389	9563	4426	0	1081	0	9137	4236	2739	5958	5068	9393	1178	5000	808	558	5574	5515	1903	3388	5703	4053	4168	1369	1487
4761	36100	4690	93	399	1397	7109	0	6588	0	704	5581	9772	8850	5194	547	9357	3548	5759	1947	3420	5109	7421	1269	1155	8377	7785	9028	1375
4603	36353	5175	116	416	2125	9341	0	4418	2285	6912	6544	8337	0	8146	8228	8805	8690	2492	3193	421	8143	2967	4326	2794	6626	2700	8426	9615
5429	29471	4760	99	343	5215	3902	29	9760	1334	4360	4965	9128	1591	8083	5963	7673	4935	4252	966	198	8919	2153	7277	884	6479	4795	8167	4488
4365	35625	4084	82	420	5552	9937	9351	6831	9864	7244	3655	9382	4901	74	7352	7765	9101	9046	4849	6629	2358	173	6169	3217	9415	15	171	1945
4313	30880	4491	96	357	5163	1500	0	5547	0	3643	4380	8230	0	9284	5038	3085	619	4510	2494	3399	4305	6767	5538	5822	9997	7386	1884	0
4447	37031	4722	102	443	9772	6743	2747	3549	0	8156	3896	952	0	3416	7895	5194	9210	0	3816	9755	5199	3106	3033	5034	139	7948	8765	0
3015	27150	2398	61	311	1692	9953	0	5150	0	9475	9683	1206	9131	7509	9806	9627	4703	6781	9545	163	0	1050	9600	5922	6179	270	1999	5710
4028	29671	4440	95	335	6085	1580	2018	3891	4433	2412	831	5383	2969	1731	2125	4896	1708	266	6894	1607	1012	6178	7175	8761	6365	3224	4875	1170
5089	30519	5245	108	362	5122	4799	0	3953	5453	3260	3934	842	0	0	5610	738	1426	7466	9238	4129	4532	5407	1408	2257	6875	7761	6246	7800
4754	31263	4670	93	348	4958	6450	0	5999	0	2639	4982	5077	1425	7104	2755	5442	3648	7264	4079	1819	5698	4863	1702	3861	5062	7747	6291	4716

The estimates of uncertainty at the aggregate level were performed by function AMsummary.fn from the merged results. Summary results included the mean, standard deviation, and F95, F50, and F05 fractiles for recoverable oil and nonassociated gas (table 7).

Table 7. Summary statistics for distributions of technically recoverable undiscovered oil, nonassociated gas and derivatives for the central North Slope assessment area.

[MMBBL, million barrels; BCF, billion cubic feet; NGL, natural gas liquids]

Statistic	Oil (MMBBL)	Nonassociated Gas (BCF)	Associated Dissolved Gas (BCF)	NGL Associated Gas (MMBBL)	NGL Nonassociated Gas (MMBBL)
Min	1567	16392	1539	26	187
F95	2565	23939	2681	55	278
F75	3249	28806	3444	73	334
F50	3851	32678	4080	88	380
F25	4580	37059	4844	107	431
F05	5854	44873	6092	138	521
Max	10220	71216	9770	231	817
Mean	3984	33318	4198	91	387
Std Dev	1014	6471	1051	26	75
N	10000	10000	10000	10000	10000

For purposes of economic analysis it was desired to obtain an estimate of the field size distributions at each of the fractiles. To accomplish this and reduce sensitivity to the choice of a single fractile, the actual observation at the F95, F50, and F05 fractiles plus 10 observations on either side of this value were extracted and provide USGS economist Emil Attanasi, with data for economic analysis (file AMag). Note that the averages of the

fields in the 24 simulated plays bracketing the fractiles will only be approximately equal to the estimates of the fractiles provided in the summary statistics (file AMss).

References

- Amyx, J.W., D.M. Bass, Jr., and R.L. Whiting, 1960, Petroleum Reservoir Engineering, McGraw-Hill, 610 p.
- Bird, K.J., and Houseknecht, D.W., 2002, U.S. Geological Survey 2002 petroleum resource assessment of the National Petroleum Reserve in Alaska (NPR): USGS Fact Sheet 045-02, 6 p. Also available online at: <http://geopubs.wr.usgs.gov/fact-sheet/fs045-02/>
- Bird, K.J., Houseknecht, D.W., Attanasi, E.D., Moore, T.E., Nelson, P.H., Potter, C.J., Schenk, C.J., Schuenemeyer, J.H., Verma, M.K., Saltus, R.W., Phillips, J.D., Charpentier, R.R., Cook, T.A., Klett, T.R., Pollastro, R.M., 2005, Oil and gas assessment of central North Slope, Alaska, 2005: U. S. Geological Survey Fact Sheet 2005-3043 (available online at <http://pubs.usgs.gov/fs/2005/3043/>), p. 2.
- Garrity, C.P., Houseknecht, D.W., Bird, K.J., Moore, T.E., Potter, C.J., Nelson, P.H., Schenk, C.J., 2005, U.S. Geological Survey 2005 oil and gas resource assessment of the central North Slope, Alaska: Play maps and results: U. S. Geological Survey Open-File Report 2005-1182 (available on-line at <http://pubs.usgs.gov/of/2005/1182/>), p. 29.
- Gautier, D.L., Dolton, G.L., Takahashi, L.I., and Varnes, K.L., eds., 1995, 1995 National Assessment of the United States Oil and Gas Resources-Results, Methodology, and Supporting Data, U.S. Geological Survey Digital Data Series DDS-30.
- Kotz, S., Balakrishnan, N., and Johnson, N.L., 2000, Continuous Multivariate Distributions Volume 1: Models and Applications, 2nd Ed., Wiley. New York.
- Nelson, P.H., 1999, Petrophysical Properties, Chapter PP *in* The oil and gas resource potential of the 1002 Area, Arctic National Wildlife Refuge, Alaska, by ANWR Assessment Team, U. S. Geological Survey Open File Report 98-34.
- Schuenemeyer, J.H., 1999a, Assessment results, in the oil and gas resource potential of the 1002 Area, Arctic National Wildlife Refuge, Alaska, U.S. Geological Survey Open File Report 98-34, CDROM.
- Schuenemeyer, J.H., 1999b, Methodology, in the oil and gas resource potential of the 1002 Area, Arctic National Wildlife Refuge, Alaska, U.S. Geological Survey Open File Report 98-34, CDROM.
- Schuenemeyer, J.H., 2003, Methodology and results from the assessment of oil and gas resources, National Petroleum Reserve, Alaska: U. S. Geological Survey Open-File Report 03-118. Available online at: <http://geopubs.wr.usgs.gov/open-file/of03-118/of03-118.pdf>
- Standing, M.B., 1977, Volumetric and phase behavior of oil field hydrocarbon systems: Society of Petroleum Engineers of AIME, Dallas.
- Stewart, G.W. 1973, Introduction to Matrix Computations, G. W. Stewart, Academic Press, New York (Algorithm 3.9, p. 142.)
- Verma, M.K., and Bird, K.J., 2005, Role of reservoir engineering in the assessment of undiscovered oil and gas resources - in the National Petroleum Reserve, Alaska (NPR): American Association of Petroleum Geologists Bulletin, v. 89, no. 8, p. 1091-1111.

Appendix A. Brief description of Splus functions used in the 2005 USGS Central North Slope resource assessment

Splus code for each program is available as text files. The file name convention is to use the Splus play file name (table 3) as a prefix for all of the internal play specific files. We refer to the prefix generically as pfn. Also in an Splus file function argument, the equal sign (=) indicates a default values, such as pn = 3 below.

Input data from Excel play form spreadsheet.

Purpose: Reads play parameters from sheet WorkS1 into Splus

Function call: Fndata_AMdata.fn(flin, pn = 3)

Input:

flin is name of Excel file
pn is worksheet page number

Estimate distribution parameters

Purpose: Estimates model parameters (closure, net reservoir thickness, porosity, trap fill, depth, and number of prospects) using a beta distribution.

Function call: Fnpare_AMpare.fn("pfn")

Simulation

Purpose: Simulation of play. Generates oil and gas fields and derivatives.

```
pfnsim_AMsim.fn(pfn, seed = 16, np = 10000)
{
  # seed is random number seed (between 0 and 1023)
  # np = number of simulation runs
```

Simulation summary statistics

Purpose: Summaries field simulation output (pfnsim).

pfnplay_AMplay.fn_(pfn)

Output file contains one line per simulation run.

Play summary statistics:

pfnpss_AMpsum.fn_(pfn, np = 10000)

Size-frequency tables:

```
pfnfreqO_AMfreq.fn(pfn, 1, np = 10000)
```

```
# size-frequency distribution for oil
```

```
pfnfreqG_AMfreq.fn(pfn, 2, np = 10000)
```

```
# size-frequency distribution for nonassociated gas
```

Size-frequency histograms:

```
AMsf.fn_(pfn, og)
```

```
# og = 1 for oil, = 2 for na gas
```

Programs to generate size-frequency accumulation distributions:

```
pfnlnO_AMacc.fn"(pfn, 1, ns = 10000)
```

```
# Also generates oil accumulations
```

```
# ns is number of accumulations to be generated
```

```
pfnlnG_AMacc.fn"(pfn, 2, ns = 10000)
```

```
# Also generates na gas accumulations
```

```
# ns is number of accumulations to be generated
```

Programs to generate size-frequency accumulation plots:

```
AMlogac.fn(pfn, og)
```

```
# Output is in log base 2 size classes.
```

```
# og=1 for oil, =2 for na gas
```

Distributions of accumulation attributes within specified range:

```
AMboxpd.fn(pfn, og)
```

```
{
```

```
#Program reads data file and produces boxplots near specified value of
```

```
# volume
```

```
# og=1 for oil, =2 for na gas
```

Checks play correlation matrix, makes adjustment as necessary and produces sample numbers:

```
AMrand_AMcorr.fn(AMcorrM, AMplayr, seed, cns = 10000)
```

```
# AMrand is sample numbers  
# AMCorrA is alternative output file and is the adjusted correlation matrix  
# AMcorrM is user specified correlation matrix  
# AMplayr contains Splus play names and play risks  
# seed is random number seed; seed between 0 and 1023  
# cns is number of simulations
```

Aggregates play results

```
AMag_AMagg.fn(AMrand, AMplayr)
```

Output file contains aggregate results for oil, na gas, derivatives, and corresponding sample numbers.

Aggregate summary statistics:

```
AMss_AMsummary.fn(AMag)  
Summarizes aggregate file; means, quantiles  
Output is summary file
```

Appendix B. Instructions to assessors concerning the protocol for the 2005 USGS Central North Slope Assessment

By John H. Schuenemeyer

Date: 26-Jul-04

INTRODUCTION

The purpose of this protocol is to provide structure and encourage documentation for the 2005 USGS assessment of the Central North Slope in northern Alaska. It describes the information required on the play assessment form, and suggests input order. Issues of geologic analogs, uncertainty, dependencies, and risking are discussed. The form used in this assessment is a revision of the USGS ANWR-1002 (Schuenemeyer, 1999) and NPRA assessment forms (Schuenemeyer, 2003).

The assessment form is used to specify information needed to estimate recoverable oil, nonassociated gas and derivatives for a play. Statistical distributions for oil and nonassociated gas accumulation attributes, trap depth, and number of prospects are specified. Point estimates for recoverable oil and gas, engineering data, and play and prospect risking also need to be supplied. Pairwise dependencies between accumulation attributes may be specified. In addition, pairwise dependencies between plays need to be specified.

Revisions in the play assessment form include new, lower minimum accumulation sizes, specifying the number of oil and gas prospects separately, enhanced graphics, and additional feedback to assessors.

GEOLOGIC MODEL

Prior to completing a play assessment form, it is necessary to have a well documented geologic model. The model may be based upon geologic observation, analog, or a combination of the two.

Analogues can be used for at least two non-mutually exclusive purposes. The first is to provide guidance in the construction of the geologic model. This should be done first. The second is to supply missing data. Analogues are used to ascertain risking, and supply distributions including accumulation attributes, trap depth and number of prospects. For the remainder of this discussion, we address the issue of using an analog to supply data to a model. There are at least four somewhat separate issues that need to be considered.

1. Comparing an **analog to a frontier area**. The Ulmishek Harrison (1984) paper provides insight into a structured comparison mechanism using ranking of attributes in the analog with those in the frontier area.
2. Often **multiple analogs** are proposed for a given data element or set of elements and a question arises about how to choose among these. In addition to the obvious need for discussion, perhaps a comparison of the ranking of elements as

described above would be useful. We strongly advocate that initially assessors consider multiple analogs. (See Attanasi and Freeman, 2004.)

3. Assessors need to **scale** the analog appropriately.

In many plays, data is derived from a combination of hard data, such as seismic observations, and analog. There is need to carefully document the components of the input that have been derived from analogs and those that are derived from seismic or other direct methods of observation. See for example, Houseknecht and Schenk (1999). I suggest that the following information be obtained and recorded for each data element (or perhaps class of data elements) used in the assessment.

1. **Information source.** Analog or direct observation.
2. **Level of confidence in information.** If analog, how closely does the analog match the frontier (forecast) area?
3. **Multiple analogs.** How are analogs compared? Ranked? How are disagreements, if any, resolved?
4. **Scale.** How is the analog scaled?

Attanasi and Freeman (2004) have prepared analogs using 36 U.S. oil plays and 25 U.S. gas plays, each containing at least 50 accumulations of MAS or greater. The information on each play includes the numbers of accumulations and volume of resource by primary and secondary lithology and trap type. The histogram of the number of accumulations (discovered and undiscovered) versus size class and the complement of the corresponding cumulative size distribution are given. Assessors should review this information for consideration as analogs to plays in northern Alaska.

PLAY FORM SHEETS

A brief description is provided for each of the 14 worksheets in the Excel assessment form.

1. Contents. Lists worksheets comprising the assessment form.
2. Shapes. Lists and describes the shapes of distributions to be used in completing assessment form.
3. WorkS1. Used to transfer information to and from Splus for computation. No user input is permitted.
4. Oil. Input specification for distributions of accumulation attributes and trap depth. Also, oil accumulation characteristics are specified as point estimates.
5. OilGraph. It has two sets of graphs. One set is the empirical density function and a fit to a beta distribution for oil accumulation attributes, trap depth, and number of oil prospects distribution. (The role of the beta distribution will be explained

- shortly.) The second set is the corresponding complementary cumulative distribution functions.
6. OilDet. Assessor may specify pairwise dependencies between the four hydrocarbon attribute distributions. Oil fvf versus trap depth is graphed.
 7. Gas. Input specification for distributions of accumulation attributes and trap depth. Also, gas accumulation characteristics are specified as point estimates.
 8. GasGraph. It has two sets of graphs. One set is the empirical density function and a fit to a beta distribution for oil accumulation attributes, trap depth, and number of oil prospects distribution. The second set is the corresponding complementary cumulative distribution functions.
 9. GasDet. Assessor may specify pairwise dependencies between the four hydrocarbon attribute distributions. Gas fvf versus trap depth is graphed.
 10. Prosp. Specify the number of oil and the number of gas prospect distributions greater than or equal to the minimum accumulation size.
 11. PPR. Specify the oil and gas, play and prospect risks. Specify land, oil, and gas allocation into percents state and native lands, onshore, and offshore.
 12. DistnGr. These illustrate the distributions of the fitted beta distributions and statistics for the accumulation attributes, trap depth, and number of prospects for oil and gas. (Graphs are generated by Splus – no input is required.)
 13. OilAccum. This shows oil accumulation distribution and distribution of accumulation attributes near the MAS. (Graphs are generated by Splus – no input is required.)
 14. GasAccum. This shows nonassociated accumulation distribution and distribution of accumulation attributes near the MAS. (Graphs are generated by Splus – no input is required.)

UNCERTAINTY AND VARIABILITY

In the assessment form, assessors are asked to specify distributions for accumulation attributes, trap depth, and number of prospects for oil and gas. The spread and shape of these distributions reflect two types of uncertainty. One is *aleatory* or irreducible uncertainty. We call this natural variability or just *variability*. It is uncertainty that cannot be reduced by increased knowledge. An example is the variability that exists in area of closure among prospects in a play. The second is *epistemic uncertainty*. This is uncertainty that results from lack of knowledge. This uncertainty may include measurement error, measurement bias, disagreement among assessors, and general lack of knowledge about a physical situation. Epistemic uncertainty can be reduced by additional sampling, improved measurement techniques, field study, and the like.

Input distributions specified for this assessment reflect *variability and uncertainty*. For example, consider area of closure. As previously mentioned, there is natural variability within a play. There is also uncertainty due to measurement error (the geophysics and/or interpretation) and sampling (density of seismic lines).

Usually it is not possible to separate variability and uncertainty. If we possessed perfect knowledge, a distribution spread would comprise only variability. Uncertainty is specified by widening the domain of the data and/or flattening the distribution.

Display 1 is an example of the specification of area of closure that illustrates variability at three levels of uncertainty. Lack of knowledge is reflected by increasing the probability in the right tail of the distributions.

Display 1. Knowledge level - lengthen right tail

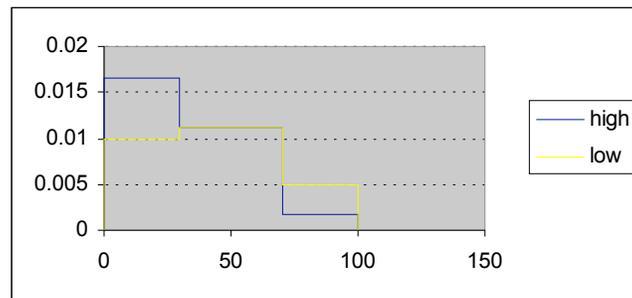
ATTRIBUTE	Shape	Knowledge	LTP	Probability (Attribute >= Value) =		
		Level 1-3 ⁵		0.5	0.05	Max
AREA OF CLOSURE	1	1	2	4	8	10
AREA OF CLOSURE	1	2	2	4	8	12
AREA OF CLOSURE	1	3	2	4	8	14

5-Knowledge Level: 1=High, 2=Medium, 3=Low ; LTP=Lower Truncation Point

Lack of knowledge also may be reflected by increasing the value of the F05 (0.05) value.

When the attribute to be specified has a bounded domain, for example trap fill, which is specified as a percent between 0 and 100, an increasing degree of uncertainty is specified by making the probability more uniform. Display 2 shows how lack of knowledge may be reflected in the situation where the domain is bounded.

Display 2. Trap fill, high and low knowledge levels



In the case of trap fill, the lower level of knowledge is reflected in the probability being more spread out, i.e., more uniform.

ACCUMULATION ATTRIBUTES

Accumulation attributes for oil and gas are input as distributions. Oil distributions are to be specified on the Oil worksheet and nonassociated gas distributions on the Gas worksheet. The suggested order for specifying the probability densities via fractiles is 1) the expected shape of the distribution, 2) knowledge level, and 3) the points on the distribution.

Shapes of Conjectured Distributions

Shapes are described on the Shape worksheet. They may vary from highly right (positively) skewed, including J-shaped and lognormal/gamma looking, to normal, uniform, and left (negatively) skewed. The shape characterizes the overall behavior of the data in a probabilistic sense. Two shapes (7 and 8 on the Shape worksheet), which are mixtures of discrete and continuous, are reserved for trap fill.

The beta distribution serves as a smoothing function. Samples for the simulation used to generate an accumulation distribution and for trap depth and number of prospects will be obtained from the fitted beta distributions. Details are provided in the methodology write up.

Knowledge Level

The knowledge level is an ordinal variable with 1 being a high level of knowledge, 2 a medium level, and 3, a low level. The reason for specifying knowledge level subsequent to the shape is that the distributions (to be specified next) need to reflect the uncertainty (as characterized by lack of knowledge) and variability. An additional reason for specifying knowledge level is to provide a basis for improving future assessments. A way to reduce uncertainty is to put additional effort into those attributes that reflect a lack of knowledge. A summary of knowledge judgments from accumulation attribute distributions in the NPRA assessment (Schuenemeyer, 2003) is presented in the Appendix to this protocol.

Specify fractiles for in-place distributions

My recommendation for the order of specification is as follows:

- i. Maximum value – for area of closure an upper bound may be determined by available space. For porosity and trap fill the upper bound is 100% but of course the maximum may be specified at a lower value if appropriate.
- ii. Lower Truncation Point (LTP). The LTP is specified as the minimum size of geologic interest. One purpose of the LTP is to eliminate the generation of a prospect greater than the specified minimum accumulation size (MAS) that was comprised individual attributes (thickness, closure, porosity, and fill), which were *too small* to generate a prospect. (The MAS will be discussed soon.) For example, without the LTP's, a random sample from the hydrocarbon attribute distribution could retrieve a very small porosity (say < 2 %), coupled with a large area of closure (say > 50,000 acres) that would result in a “prospect” of at least MAS but from a geological viewpoint would not be viable. A second purpose is to eliminate the generation of very small accumulations, which are not judged to be of economic or technological significance in the foreseeable future. The LTP is a geologically based constraint. Only an accumulation attribute at least as large as the LTP will be generated by Monte Carlo sampling and used to generate a distribution of accumulation (prospect) sizes. These distributions are anchored at zero.

- iii. Median value. (The median is the value \tilde{x} such that $\text{Prob}(X \geq \tilde{x}) = 0.5$; it is also known as F50, the 50th fractile.) The median value is with respect to the LTP. Thus, 0.5 probability is between LTP and the median and 0.5 is between the median and the Max value.
- iv. Prob. Attribute ≥ 0.05 – This is a value $x_{0.05}$ such that $P(X \geq x_{0.05}) = 0.05$. It is also known as F05, the 5th fractile. The F05 value is with respect to the LTP.

Should hard data (direct measurements) be available on any attribute, provision will be made to specify as many fractiles as are needed to characterize the distribution.

Porosity * Water Saturation Penalty

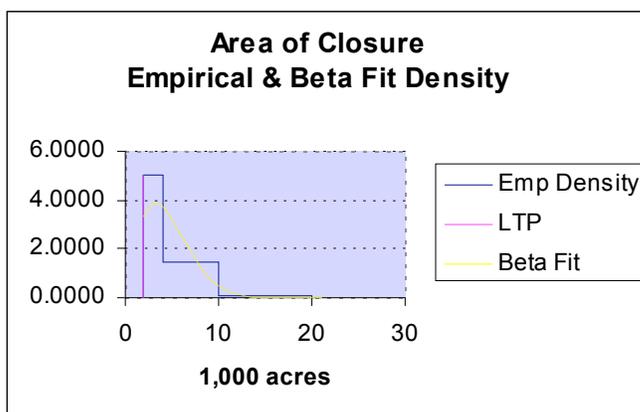
A porosity times water saturation penalty must be entered for oil and nonassociated gas (on the Oil and Gas worksheets respectively) in the POR*Sw box. This number can range between 0 and 6. The Hydrocarbon Pore Volume = Porosity – POR*Sw.

GRAPHICAL FEEDBACK

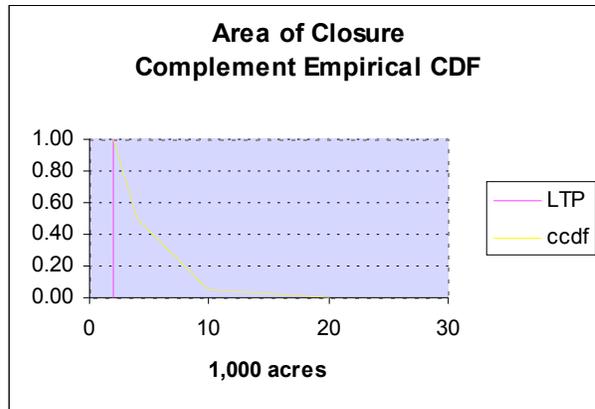
Accumulation attributes, trap depth, and number of prospects

Once the above information is entered in the Oil and Gas spreadsheets of the Alaskan Assessment Form, a graphical representation (Displays 3 is an example) will be given showing the empirical (user specified) density function, the LTP, and beta density function fit to the empirical density function. In addition, a display (Display 4) shows the complementary cumulative distribution function (ccdf). The ccdf is a plot of x versus $\text{Prob}(X \geq x)$; in Display 4, x is area of closure. These graphs are displayed on the assessment form in spreadsheets OilGraph and GasGraph. Assessors will have the opportunity to change input distribution specifications and changes will be reflected on the graphs.

Display 3. Example density plot - area of closure for oil.



Display 4. Example complementary cumulative distribution plot - area of closure for oil.



Complete graphical output is given in Excel spreadsheets OilGraph and GasGraph. To obtain a beta fit to new data requires the execution of Excel Solver (a nonlinear fitting algorithm). Solver can be found under the Tool menu. As an example, for oil Net Reservoir Thickness density graphs (spreadsheet OilGraph), the Solver equation is in cell H7, and the two parameters of the beta distribution are in cells J7 and K7. Solver may be run by clicking on Solver, setting the target cell to H7 and the by changing cells to J7:K7. Reasonable starting values are required for any nonlinear estimation algorithm to converge properly.

Note, that there will be instances when the specified shape is inconsistent with the specified fractiles. For example, an assessor may specify a complementary j-shape (shape 6) but his/her fractiles imply a normal looking distribution (shape 4). It is the assessor's responsibility to check the graph as provided via feedback to insure consistency with specified fractiles and make changes as needed.

fvf graphs

Oil fvf versus depth is graphed in the OilDet spreadsheet. The gas fvf versus depth is graphed in the GasDet spreadsheet.

Accumulation size and attributes

Technically recoverable accumulations of oil and nonassociated gas are given in spreadsheets OilAccum and GasAccum respectively. These are based upon Monte Carlo simulations from the beta distributions fit to accumulation attribute fractiles at or above the LTP's, the beta fitted trap depth distribution, fvf models, and recoverability factors. No MAS has been applied to these distributions.

In addition, distributions (in the form of boxplots) for net reservoir thickness, area of closure, porosity, and trap fill are shown for accumulation sizes near the MAS for oil

and gas. For oil these are boxplots are generated at the F05 (95th percentile) of the depth distribution. Given that the oil fvf is a shrinkage factor which increases with depth, accumulations at shallower depths will be larger. For gas the boxplots are generated at the F95 (5th percentile) of the depth distribution. Given that the gas fvf is an expansion factor which increases with depth, accumulations at deeper depths will be larger. Thus these graphs provide insight into ranges of accumulation attributes that generate MAS or larger.

The graphs on these spreadsheets (OilAccum and GasAccum) are generated by Splus. I am investigating the possibility of have these generated directly in Excel.

SPECIFICATION OF ACCUMULATION ATTRIBUTE DEPENDENCIES

The degree of linear dependency, if any, between accumulation attributes is specified by Pearson correlations on sheets OilDet (Oil Accumulation Attribute Dependencies) and GasDet (Gas Accumulation Attribute Dependencies). Values between -1 and +1 are permitted. A check will be made to ensure that the pairwise correlations are mutually consistent. Sampling to generate accumulations will reflect the specified dependencies. High (near one) positive dependencies will result in a greater spread (range) of accumulation values than smaller positive, zero, or negative correlations. Although nonlinear dependencies may exist, these will be approximated by the specification of linear dependencies.

TRAP DEPTH

Specification of the trap depth distributions for oil (Oil worksheet) and gas (Gas worksheet) is similar to that of the accumulation attribute distributions except that in place of a LTP, a minimum (Min), which typically will be greater than zero, is specified. The resultant distribution will then be *shifted* by the minimum value specified. Depth distributions are with respect to the surface. A surface to sea level correction is required and will be added to equalize depth distributions among plays.

NUMBER OF OIL AND GAS PROSPECTS

The oil and gas prospect distributions are to be specified separately by considering oil and gas as separate subplays whenever possible. These separate distributions are to be entered on the Prosp worksheet. The order of specification of distribution is the same as that for the trap depths.

For oil, the numbers of prospects to be specified are for technically recoverable sizes of at least 5 million barrels *recoverable*. For nonassociated gas, the numbers of prospects to be specified are those at least 100 bcf *recoverable*. These numbers, 5 mm bbl technically recoverable for oil and 100 bcf technically recoverable for nonassociated gas, are the **Minimum Accumulation Sizes** (MAS's). Only prospects of at least these sizes will be generated by the simulation model and become part of the final assessment.

A check is provided, which compares non-overlapping area of closure at the median and F05 for the specified numbers of prospects with the play area. Of course given that prospects occur at varying depths, some stacking may occur making this check conservative.

OIL ACCUMULATION CHARACTERISTICS AND NONASSOCIATED GAS CHARACTERISTICS

Three of the most critically specified point values are the oil and gas *recovery factors* (percent technically recoverable) and the *API gravity* (for oil). A critical computed variable, especially for gas, is the *formation volume factor* (fvf). For oil, the fvf serves to shrink the volume as it moves from in-place to the surface. For gas, it expands it. Equations and graphs of fvf's versus trap depth are given in worksheet OilDet and GasDet for oil and gas respectively. The gas-to-oil ratio (GOR) is a computed value. The equations used to compute the fvf's are those used in the NPRA assessment and were supplied by USGS petroleum engineer Mahendra Verma with input from assessment geologists. The fvf models can be made play specific.

PLAY AND PROSPECT RISKING

The complement of risk, "1-risk" is specified, namely the probability of a favorable outcome. There are two sets of risks – a play risk and a prospect risk. Both are specified on the PPR worksheet. The play and prospect risks, which are assumed to be independent, are a product of three independent factors: charge, trap/rock, and timing. Play favorability means that conditions exist for at least one accumulation of MAS or larger. It does not guarantee the presence of one or more accumulations.

If the play is partitioned into an oil and a gas subplay, separate risking structures can be specified for oil and gas. Play favorability should be specified first and prospect favorability second.

The prospect level favorability also is defined as a prospect of at least MAS. Oil and gas prospects can be risked separately, even when only one play is defined. Care must be taken to avoid double risking.

PLAY AGGREGATION

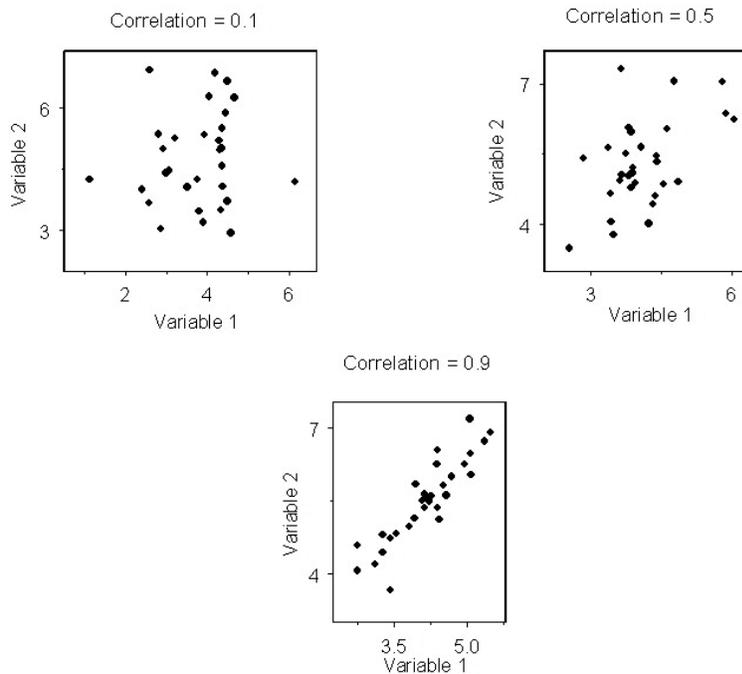
The procedures outlined in the NPRA (and ANWR-1002) methodology section will be used. Assessors will be asked to specify dependencies between each pair of plays. Specifically, assessors will be asked to assign one of three ordinal correlations (low, medium or high) to the attributes of charge, trap, and timing. A high positive correlation assigned to charge between, say plays A and B may indicate that a common mechanism charged both plays. Thus, if charge in play A was found to be high, the charge in play B would most likely be high. High, medium, and low correlations will be assigned values of 0.9, 0.5, and 0.1 respectively. A combined correlation matrix will be formed by taking the arithmetic average of the three correlation matrices. There will be

one matrix each for charge, trap, and timing. Negative dependencies are not allowed. The combined (mean) correlation matrix will be tested for internal consistency (in statistical parlance, this means that the matrix must be positive definite). Should it be inconsistent, small biases will be introduced to make the matrix internally consistent. Results will be provided to the responsible assessors for feedback and confirmation.

When a play *crosses a geopolitical boundary* of interest, the percent of volume allocated to each subdivision of the play is specified. Separate allocations can be made for oil and gas. (See assessment form PPR sheet).

A sample of normal distributions with correlations of 0.1, 0.5 and 0.9 is shown in the following graph (Display 5).

Display 5. Sample scatter plots showing correlations of 0.1, 0.5, and 0.9.



SUMMARY RESULTS

Following the final assessment meeting, I will prepare summary sheets that will include summary input: final accumulation attribute and depth distributions, number of prospects distributions, risking and other key information specified on the assessment forms; and summary output including size-frequency distributions by play. The purpose of these summary sheets will be to allow assessors and other reviews to view the entire suite of plays and thus check for overall consistency.

References

Attanasi, E.D., and Freeman, P.A., 2004, Size-frequency analysis of petroleum accumulations in selected United States plays: Potential analogues for frontier areas: U. S. Geological Survey Open-File Report 2004-1299 (available on-line at <http://pubs.usgs.gov/of/2004/1299/>, 163 p.

Houseknecht, D.W. and Schenk, C.J., 1999, Chapter P1 Topset Play, in The Oil and Gas Resource Potntial of the Arctic National Wildlife Refuge 1002 Area, Alaska, by the ANWR Assessment Team. U.S. Geological Survey Open File Report 98-34, CDROM.

Schuenemeyer, J.H., 1999, Methodology, in the oil and gas resource potential of the 1002 Area, Arctic National Wildlife Refuge, Alaska, U.S. Geological Survey Open File Report 98-34, CDROM.

Schuenemeyer, J.H., 2003, Methodology and results for the assessment of oil and gas resources, National Petroleum Reserve Alaska: U.S. Geological Survey OFR 03-118, available at <http://geopubs.wr.usgs.gov/open-file/of03-118/>.

Ulmishek, G., and Harrison, W., 1984, Quantitative methods for assessment of petroleum resources of poorly known basins, *in* Masters, C.D., ed., Petroleum Resource Assessment: Ottawa, Canada, International Union of Geological Sciences, Publication No. 17, p. 80-94.

Appendix to Protocol. Summary of knowledge level for NPRA accumulation attributes.

The following information is provided to assessors to assist them in gaining insight into uncertainty among attributes in a previous USGS assessment (Schuenemeyer, 2003).

Knowledge level - hydrocarbon volume attributes - NPRA

Oil																			Frequency					
																			1's	2's	3's			
NET RESERVOIR THICKNESS	3	2	2	2	2	2	2	2	2	2	2	2	2	2	2	3	3	2	3	2	2	0	14	4
AREA OF CLOSURE	3	3	3	3	3	3	3	2	2	2	2	2	1	3	3	2	3	2	1	2	5	11		
POROSITY	3	2	2	2	2	2	2	2	2	2	2	2	2	2	1	2	2	2	1	16	1			
TRAP FILL	3	2	2	2	2	2	2	2	2	2	2	3	3	3	2	3	3	3	0	11	7			

Gas																			Frequency		
																			1's	2's	3's
NET RESERVOIR THICKNESS	3	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	2	0	11	7
AREA OF CLOSURE	3	3	3	3	3	2	2	2	2	2	2	3	3	2	3	3	1	2	1	8	9
POROSITY	3	2	2	2	2	2	2	2	2	2	2	2	3	3	2	3	3	2	0	13	5
TRAP FILL	3	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3	3	0	9	9

1 = high knowledge
 2 = medium knowledge
 3 = low knowledge

There appears to be only a slight edge in stated knowledge level of oil over gas attributes. Porosity may be known at a slightly higher level of knowledge than the other attributes, although for two oil plays and one gas play the level of knowledge on area of closure was reported as high.

Appendix C. Glossary

The following definitions were updated by J.H. Schuenemeyer and K. J. Bird, as appropriate, from those by R. Charpentier, Definitions *in* The Oil and Gas Resource Potential of the 1002 Area, Arctic National Wildlife Refuge, Alaska, by ANWR Assessment Team, U.S. Geological Survey Open-File Report 98-34 and used in the 2002 USGS NPRA and the 2005 USGS Central North Slope oil and gas assessments.

Accumulation Attributes: Distributions were specified for five attributes used to calculate the volumes of oil and gas accumulations in the simulation program and in economic scenarios. Because the simulation program calculates an accumulation size using one randomly sampled number from each fitted distribution, spread in the distributions reflect variability between accumulations. Even though some attributes (net reservoir thickness, porosity, and trap fill) could show variation within an individual accumulation, that level of variability is too detailed for this analysis. The distribution of porosity, for example, shows how the average porosity in an accumulation varies from accumulation to accumulation. A sampled value of porosity could be viewed as the mean value in a given accumulation. All of the accumulation attribute distributions are conditional distributions -- conditional on both the play being favorable and the prospect being favorable. The uncertainty expressed in the specification of the accumulation attribute fractiles is not intended to reflect the chance that such an attribute will be present. This is addressed by the risking. The spread in the distributions, however, may reflect geologic uncertainty and lack of knowledge.

Net Reservoir Thickness: A distribution for net reservoir thickness (in feet) in accumulations. The distribution shows how the average net reservoir thickness changes from accumulation to accumulation. It is not the same as the prospect height because it only includes net thickness of reservoir-quality rocks. It is also not the same as net pay thickness, because only some proportion of the reservoir rock contains hydrocarbons. (See trap fill.)

Area of Closure: A distribution for area of trap closure (in thousands of acres) of accumulations.

Porosity: A distribution for average porosity (in percent) in accumulations. The distribution shows how the average porosity changes from accumulation to accumulation.

Trap Fill: A distribution for trap fill (in percent) in accumulations. It is the volumetric percent of the gross reservoir volume (area of closure times net thickness) containing hydrocarbons.

Trap Depth: A distribution for trap depth (in thousands of feet sub sea level) in accumulations. The distribution shows how the average trap depth changes from accumulation to accumulation.

Risking:

Minimum Accumulation Size (MAS) Oil: The smallest accumulation size being assessed, in this case 5 million barrels (MMBO) technically recoverable. Smaller accumulations may exist in the play but are not being assessed.

Minimum Accumulation Size Nonassociated Gas: The smallest accumulation size being assessed, in this case 100 billion cubic feet (BCF) technically recoverable. Smaller accumulations may exist in the play but are not being assessed.

Number of Prospects: A distribution showing uncertainty in the number of prospects for accumulations of the minimum accumulation size or larger. This distribution is conditional on the play being favorable.

Play Attributes: Three probabilities -- Charge (C), Trap/Rock (T), and Timing (F) -- that are used in calculating the Play Probability.

Charge (C): The probability that there has been sufficient source rock, thermal history, and migration to allow for at least one accumulation of minimum reservoir size or larger somewhere within the play.

Trap (T): The probability of the occurrence of rocks containing suitable reservoir characteristics, sealing characteristics, and trap geometry capable of containing at least one accumulation of minimum reservoir size or larger somewhere within the play.

Timing (F): The probability that timing was favorable for an accumulation of minimum reservoir size or larger somewhere within the play.

Play Probability: The probability that the play is favorable, i.e., that the play attributes are adequate to allow at least one accumulation of minimum reservoir size or larger. It is calculated as the product of the three play attributes -- Charge (C), Trap/Rock (T), and Timing (F) -- which are assumed to be pairwise independent. Favorability of the product of the three play attributes is necessary, but not sufficient, for the existence of an accumulation of minimum reservoir size or larger. With a small number of prospects, there is some probability that the play attributes are favorable, but just not present in any one prospect.

Play Risk: The probability that the play is unfavorable, i.e., that the play attributes are not sufficiently favorable to allow any accumulations of minimum reservoir size or larger. It is calculated as 1 minus the Play Probability.

Prospect Attributes: Three probabilities -- Charge (c), Trap/Rock (t), and Timing (f) -- that are used in calculating the Prospect Probability. All of them are conditional probabilities -- conditional on the play being favorable. Probabilities are expressed relative to a randomly chosen prospect. This can also be thought of as giving the proportion of prospects for which a particular condition is favorable. These differ from

the play attributes. For example, one may be certain that there has been sufficient source rock, thermal history, and migration to allow at least one accumulation of minimum reservoir size or larger somewhere within the play ($C = 1.0$) but estimate that only 50% of the prospects have had adequate migration paths open ($c = 0.5$).

Charge (c): The probability (given that the play is favorable) that a randomly chosen prospect has been charged by fluids sufficient for an accumulation of minimum reservoir size or larger.

Trap/Rock (t): The probability (given that the play is favorable) that a randomly chosen prospect has suitable reservoir characteristics, sealing characteristics, and trap geometry capable of containing an accumulation of minimum reservoir size or larger.

Timing (f): The probability (given that the play is favorable) that a randomly chosen prospect has timing favorable for an accumulation of minimum reservoir size or larger.

Prospect Probability: The probability that a randomly chosen prospect is favorable (given that the play is favorable), i.e., that the prospect contains an accumulation of minimum reservoir size or larger. It is calculated as the product of the three prospect attributes -- Charge (c), Trap/Rock (t), and Timing (f) -- which are assumed to be pairwise independent. Favorability of the product of the three prospect attributes is both necessary and sufficient for the existence of an accumulation of minimum reservoir size or larger in a prospect. The prospect probability can also be thought of as giving the proportion of prospects that contain an accumulation of minimum reservoir size or greater.

Prospect Risk: The probability that a randomly chosen prospect is unfavorable, i.e., that the prospect does not contain an accumulation of minimum reservoir size or larger. It is calculated as 1 minus the Prospect Probability.

Fraction of Accumulations Being Oil: That proportion of the accumulations that will be simulated as oil accumulations as opposed to nonassociated gas accumulations.

Miscellaneous:

Accumulation: Trapped hydrocarbons in contiguous pools of a particular play. In this assessment only accumulations of minimum reservoir size or larger are being assessed.

Field: One or more accumulations whose projections on the earth's surface are the same or overlap. All the pools in an accumulation are of the same play, but a field may include pools of different plays. The simulation methodology for plays estimates accumulation sizes. Fields are important principally in the economic part of the analysis.

Play: A play is a set of known or postulated oil or gas accumulations having similar geologic, geographic, and temporal properties, such as source rock, migration pathways, timing, trapping mechanism, and hydrocarbon type.

Play Area: A geographic area that includes all the discovered accumulations (if any) and all the prospects (if any) in a particular play.

Prospect: A feature that may contain trapped hydrocarbons of at least the minimum accumulation size.

Appendix D. Algorithms

"AMdata.fn"<-

```
function(flin, pn = 3)
{
  #Import Alaska oil, gas data from Excel file
  # flin is name of excel file
  # pn is worksheet page number
  # Name Splus output file:
  # xxdata where xx is Splus file name (see PlayNames)
  #Schuenemeyer 2004-06-04
  #
  # Make sure path is correct
  tpa <- paste(
    "C:\\Documents and Settings\\John H Schuenemeyer\\My
    Documents\\OilGas\\AlaskaM\\PlayForms\\",
    flin, sep = "")
  print(tpa)
  importData(tpa, type = "Excel", pageNumber = pn, startRow = 1, endRow
    = 20, startCol = 1, endCol = 5)
}
```

"AMpare.fn"<-

```
function(jrt)
{
  #Estimates beta parameters for oil, gas, and number of prospects
  # assessor specified fractiles and plots resulting distributions
  # Schuenemeyer 2004-10-02
  # jrt is SPlus play name
  # Ndata1 is basic data file (shape, LTP, TF50, TF05, Max)
  # Requires fminb.fn, fminb8.fn, fmino.fn, fminta.fn, fminto.fn
  # (user written minimization functions)
  # Shape of distribution (used for initialization)
  # are given in Excel worksheet
  # Estimation is with Splus nonlinear estimator nlmin.
  # infl <- deparse(substitute(Ndata1))
  PNa <- get("PlayNames")
  PN <- PNa[PNa[, 2] == jrt, 1]
  print(PN)
  infl <- paste(jrt, "data", sep = "")
  Ndata1 <- get(infl)
  betapar <- array(dim = c(15, 5))
  t4 <- array(dim = c(5))
  p <- array(dim = c(2))
  op1 <- seq(0.01, 12, length = 40)
  # op1[1] <- 1.1
```

```

jrn <- c("O-Thickness (feet)", "O-Area (thousands of acres)",
        "O-Porsity(%)", "O-Trap Fill(%)", "O-Depth (thous ft)",
        "O-Num Prosp", "G-Thickness (feet)",
        "G-Area (thousands of acres)", "G-Porsity(%)", "G-Trap Fill(%)",
        "G-Depth (thous ft)", "G-Num Prosp")
vname <- c("LTP/MIN", "TF50", "TF05", "MAX", "beta1", "beta2", "MEAN",
          "ETF50", "ETF05")
dspec <- c("j-shape", "+ skew", "- skew", "normal", "uniform",
          "inverse j", "spec inv j-1", "spec inv j-2")
Ndata <- Ndata1[1:15, 2:5]
shap <- as.numeric(Ndata1[1:12, 1])
par(mfrow = c(6, 2))
for(i in 1:12) {
  if(shap[i] > 0.) {
    # print(c("i", i))
    if(i == 5 | i == 6 | i == 11 | i == 12) {
      # for trap depth [i=5 or 12] and num of prospects [i=6 or 12] distns, LTP is
      minimum
      vname[1.] <- c("MIN")
      mv <- Ndata[i, 4.] - Ndata[i, 1.]
      sv <- (Ndata[i, ] - Ndata[i, 1.])/mv
      sh <- Ndata[i, 1.]
      cc <- 0
    }
    else {
      vname[1.] <- c("LTP")
      mv <- Ndata[i, 4.]
      sv <- Ndata[i, ]/mv
      sh <- 0.
      cc <- 1
    }
  }
  co <- sv[1:3]
  # initial fit is to a beta distribution
  assign("co", co, frame = 1.)
  if(shap[i] == 7.) {
    # 7 is inverted j with 50 % of prob at max
    # note that shapes 7 & 8 are reserved for trap fill
    if(i != 4 & i != 10) stop(
      "Shapes 7 & 8 for trap fill")
    p[1] <- 5.
    p[2] <- 1.
    best$x[1.] <- p[1]
    best$x[2.] <- p[2]
  }
  else if(shap[i] == 8.) {
    # 8 is inverted j with 5 % of prob at max

```

```

if(i != 4 & i != 10) stop(
  "Shapes 7 & 8 for trap fill")
p[1] <- 5.
p[2] <- 1.
best <- nlmin(fminb8.fn, p)
}
else {
  #initial conditions
  if(cc == 0 & shap[i] <= 6) {
    pd <- fminb.fn(op1, op1)
    p[1] <- op1[pd[1]]
    p[2] <- op1[pd[2]]
    best <- nlmin(fminb.fn, p)
  }
  else if(cc == 1 & shap[i] <= 6) {
    pd <- fminb.fn(op1, op1)
    p[1] <- op1[pd[1]]
    p[2] <- op1[pd[2]]
    best <- nlmin(fminb.fn, p)
  }
}
u <- best$x[1.]
v <- best$x[2.]
if(u < 0.001)
  u <- 0.001
if(v < 0.001)
  v <- 0.001
# print(c("shape", shap[i], "int u,v, nlin u,v", p, u, v))
betapar[i, 1.] <- u
betapar[i, 2.] <- v
if(cc == 0) {
  print(c(sh, mv))
  #shifted distns
  # betapar[i,3] is mean
  betapar[i, 3] <- (u/(u + v)) * mv + sh
  betapar[i, 4] <- qbeta(0.5, u, v) * mv + sh
  betapar[i, 5] <- qbeta(0.95, u, v) * mv + sh
}
else if(cc == 1) {
  # truncated distns
  betapar[i, 3] <- mtbeta.fn(u, v, sv[1]) * mv
  betapar[i, 4] <- qtbeta.fn(0.5, u, v, sv[1]) *
    mv
  betapar[i, 5] <- qtbeta.fn(0.95, u, v, sv[
    1]) * mv
}
}

```

```

if(shap[i] == 7.) {
  betapar[i, 3.] <- 0.5 * betapar[i, 3.] + 0.5 *
    mv
  betapar[i, 4] <- Ndata[i, 2]
  betapar[i, 5] <- Ndata[i, 3]
}
else if(shap[i] == 8) {
  betapar[i, 3] <- 0.95 * betapar[i, 3] + 0.05 *
    mv
  betapar[i, 5] <- Ndata[i, 3]
}
#plot distributions
plot(seq(sh, Ndata[i, 4.], length = 100.), dbeta(seq(
  0., 1., length = 100.), u, v), type = "l",
  axes = F, xlab = jrn[i], ylab = "")
axis(1.)
xv <- par("xaxp")
dx <- (xv[2.] - xv[1.])/30.
sn <- 1.
yv <- par("yaxp")
title(PN)
t4[1] <- Ndata[i, 1.]
t4[2] <- betapar[i, 3.]
t4[3] <- Ndata[i, 4.]
t4[4] <- betapar[i, 1]
t4[5] <- betapar[i, 2]
t5 <- format(t4, digits = 5.)
tpa <- paste("Orig Spec ", dspec[shap[i]], "\n", vname[
  1.], " = ", t5[1], "\n", vname[7.], " = ", t5[
  2.], "\n", vname[4.], " = ", t5[3.], "\n",
  " Beta u", " = ", t5[4.], "\n", " Beta v", " = ",
  t5[5])
if(shap[i] == 7.)
  tap <- paste(tpa, "\n", "0.50 prob at max")
if(shap[i] == 8)
  tap <- paste(tpa, "\n", "0.05 prob at max")
if(u > 1. & v > 1.) {
  #mode of beta: u,v > 1 is (u-1)/(u+v-2)
  mde <- (u - 1.)/(u + v - 2.)
  if(mde <= 0.5)
    ixv <- 2.
  else ixv <- 1.
}
else ixv <- 2.
if(shap[i] == 6. | shap[i] == 7 | shap[i] == 8)
  ixv <- 1.

```

```

if(ixv == 1.)
  text(xv[ixv], yv[2.], tpa, adj = 0.)
else text(xv[ixv] - 7. * dx, yv[2.], tpa, adj = 0.)
text(Ndata[i, 1.] - sn * dx, 0., vname[1.])
if(shap[i] <= 6) {
  lines(c(Ndata[i, 1.], Ndata[i, 1.]), c(0.,
    dbeta(sv[1.], u, v)))
  # lines(c(Ndata[i, 2], Ndata[i, 2]), c(0, h))
  # lines(c(Ndata[i, 3], Ndata[i, 3]), c(0, h))
  # lines(c(Ndata[i, 2], Ndata[i, 3]), c(h, h))
  h <- 0.45/(sv[3.] - sv[2.])
}
fn <- paste(
  "C:\\Documents and Settings\\John H Schuenemeyer\\My
Documents\\OilGas\\AlaskaM\\PlayForms\\",
  infl, as.character(i), sep = "", collapse = "")
}
}
export.graph(fn, ExportType = "WMF")
# par(mfrow = c(6, 2))
outf <- cbind(Ndata1[1:15, 1:5], betapar)
names(outf) <- c("Shape", vname)
exportData(outf,
  "C:\\Documents and Settings\\John H Schuenemeyer\\My
Documents\\OilGas\\AlaskaM\\PlayForms\\Par.xls",
  type = "Excel")
outf
}

```

"fminb.fn"<-

```

function(p)
{
  # beta fn to be minimized
  (pbeta(co[2], p[1.], p[2.]) - 0.5)^2. + (pbeta(co[3], p[1.], p[2.]) -
    0.95)^2.
}

```

"fminb8.fn"<-

```

function(p)
{
  # beta fn to be minimized for shape 8
  ((pbeta(co[2], p[1], 1) - pbeta(co[1], p[1], 1))/(pbeta(co[3], p[1],
    1) - pbeta(co[1], p[1], 1)) - 0.5)^2.
}

```

"fmino.fn"<-

```

function(t1, t2)
{
  # Schuenemeyer 06-07-2004
  t3 <- outer(t1, t2, FUN = "fminbi.fn")
  t4 <- which(t3 == min(t3))
  pe <- mod.fn(t4, nrow(t3))
  pe
}

```

"fminta.fn"<-

```

function(p)
{
  # Schuenemeyer, 6/25/04 version
  ((pbeta(co[2], p[1], p[2]) - pbeta(co[1], p[1], p[2]))/(1. - pbeta(
    co[1], p[1], p[2])) - 0.5)^2. + ((pbeta(co[3], p[1], p[2]) -
    pbeta(co[1], p[1], p[2]))/(1. - pbeta(co[1], p[1], p[2])) -
    0.95)^2.
}

```

"fminto.fn"<-

```

function(t1, t2)
{
  # Schuenemeyer 06-26-2004
  t3 <- outer(t1, t2, FUN = "fminti.fn")
  t4 <- which(t3 == min(t3))
  pe <- mod.fn(t4, nrow(t3))
  pe
}

```

"AMsim.fn"<-

```

function(fn, seed = 16, np = 10000)
{
  # Schuenemeyer 2004-11-12
  # Big simulation function, which generates
  # recoverable oil and gas accumulations conditioned on
  # successful play, i.e., prospect risk applied.
  # fn is Splus file name
  # seed is random number seed (between 0 and 1023)
  # np = number of simulation runs
  #
  # pfile is Splus parameter file (xxpar, where xx is Splus play name)
  # File xxpare created by AMpare.fn
  # xx is the Splus play name (used to get Excel file).
  #
  iBaFI <- 0
}

```

```

if(fn == "BaFI")
  iBaFI <- 1
set.seed(seed)
print(c("Random number seed", seed))
# pfile is parameter file
tf <- paste(fn, "pare", sep = "")
pfile <- get(tf)
pfile <- as.matrix(pfile)
# ns = number of samples to generate oil and gas accum distns
ns <- 10000
# eps is bias factor for correlation matrix
eps <- 0.001
#rsim number of rows in big simulation array
rsim <- 550000
ra <- array(rep(0, 13 * rsim), dim = c(rsim, 13))
ustat <- array(dim = c(3))
osw <- array(0, dim = 2)
iogc <- array(0, dim = 2)
idep <- array(0, dim = 2)
# prrk is prospect risk for oil [1] and gas [2]
prrk <- array(0, dim = 2)
ib <- 0
# ib - total number of obs in file
# check for oil and gas prospects.
# osw[1]=1 oil, osw[2]=1 gas.
if(pfile[6, 5] > 0) {
  osw[1] <- 1
  prrk[1] <- pfile[15, 2]
  # generate oil accumulation distribution
  acco <- asoga.fnt(ns, 1, fn, pfile)
  acco <- acco[acco[, 1] >= 5, ]
  nsfo <- length(acco[, 1])
}
if(pfile[12, 5] > 0) {
  osw[2] <- 1
  prrk[2] <- pfile[15, 4]
  # generate gas accumulation distribution
  if(iBaFI > 0) accg <- asogBaFI.fn(ns, 2, fn, pfile) else accg <-
    asoga.fnt(ns, 2, fn, pfile)
  accg <- accg[accg[, 1] >= 100, ]
  nsfg <- length(accg[, 1])
}
if(osw[1] + osw[2] == 0) {
  stop("No prospects specified")
}
# simulation loop

```

```

for(j in 1:np) {
  for(ij in 1:2) {
    if(osw[ij] > 0) {
      # pv is number of ij prospects
      kb <- (ij - 1) * 6
      #pv is number of prospects
      pv <- round(rbeta(1, pfile[kb + 6, 6], pfile[
        kb + 6, 7]) * (pfile[kb + 6, 5] - pfile[
        kb + 6, 2]) + pfile[kb + 6, 2])
      # determine number of oil/gas fields
      t2 <- runif(pv, 0, 1)
      # evaluate prospect risk
      t3 <- ifelse(t2 > prrk[ij], 0, 1)
      # idep[ij] is number of fields
      idep[ij] <- sum(t3)
      if(idep[ij] > 0 & ij == 1) {
        # get field size id oil
        ido <- sample(nsfo, idep[ij], replace
          = T)
        depo <- acco[ido, ]
      }
      if(idep[2] > 0 & ij == 2) {
        # get field size id gas
        idg <- sample(nsfg, idep[ij], replace
          = T)
        depg <- accg[idg, ]
      }
    }
  }
  pw <- idep[1] + idep[2]
  # get oil volume and corresponding attributes
  if(idep[1] > 1) {
    for(k in 1:idep[1]) {
      ib <- ib + 1
      if(ib > rsim)
        stop("Increase rsim size")
      t1 <- c(j, pw, k, 1, depo[k, ], NA)
      ra[ib, ] <- t1
    }
  }
  else if(idep[1] == 1) {
    ib <- ib + 1
    if(ib > rsim)
      stop("Increase rsim size")
    ra[ib, ] <- as.vector(c(j, pw, 1, 1, depo, NA))
  }
}

```

```

# get gas volume and corresponding attributes
if(idep[2] > 1) {
  for(k in 1:idep[2]) {
    ib <- ib + 1
    if(ib > rsim)
      stop("Increase rsim size")
    t1 <- c(j, pw, k, 2, depg[k, ], 0, 0)
    ra[ib, ] <- t1
  }
}
else if(idep[2] == 1) {
  ib <- ib + 1
  if(ib > rsim)
    stop("Increase rsim size")
  ra[ib, ] <- c(j, pw, 1, 2, depg, 0, 0)
}
}
ra <- ra[1:ib, ]
ra <- as.data.frame(ra)
names(ra) <- c("run", "numdep", "depnum", "og_id", "rec_og", "nrt",
  "ac", "hvp", "tf", "td", "fvf", "rec_agas", "rec_NGL")
ra[, 12] <- ifelse(ra[, 4] == 1, ra[, 5] * ra[, 12] * 0.001, NA)
rat <- ifelse(ra[, 4] == 2 & ra[, 10] > 10, 13, 1.3 * ra[, 10])
ra[, 13] <- ifelse(ra[, 4] == 1, ra[, 12] * 3.3523 * exp(0.185 * ra[
  , 10]) * 0.001, ra[, 5] * rat * 0.001)
return(ra)
}

```

"AMplay.fn"<-

function(pname)

```

{
  # Summarizes results of output of AMsim.fn (deposit simulation)
  # by play.
  # Schuenemeyer, SWSC, 2004-11-16
  # pname is Splus play name
  # dfile is pnamesim simulation file
  #
  # output - file pnamepss containing play/run totals
  #
  tf <- paste(pname, "sim", sep = "")
  dfile <- get(tf)
  t1 <- length(dfile[, 1])
  nruns <- length(unique((dfile[, 1])))
  ps3 <- matrix(0, nrow = nruns, ncol = 11)
  tmin <- min(dfile[, 4])
  tmax <- max(dfile[, 4])

```

```

ps0 <- unique(dfile[, 1])
#oil only
if(tmax - tmin > 0) {
  #oil & gas fields present
  #recoverable oil & na gas
  ps1 <- tapply(dfile[, 5], list(dfile[, 1], dfile[, 4]), FUN =
    sum)
  ps2 <- tapply(rep(1, t1), list(dfile[, 1], dfile[, 4]), FUN =
    sum)
  #rec assoc dis gas
  ps1b <- tapply(dfile[, 12], list(dfile[, 1]), FUN = sum, na.rm
    = T)
  #rec NGL
  ps1c <- tapply(dfile[, 13], list(dfile[, 1], dfile[, 4]), FUN
    = sum)
  ps3 <- as.data.frame(cbind(ps1[, 1], ps2[, 1], ps1[, 2], ps2[
    , 2], ps1b, ps1c))
}
else if(tmin == 1) {
  #oil only
  ps1 <- tapply(dfile[, 5], list(dfile[, 1]), FUN = sum)
  ps2 <- tapply(rep(1, t1), list(dfile[, 1]), FUN = sum)
  #rec assoc dis gas
  ps1b <- tapply(dfile[, 12], list(dfile[, 1]), FUN = sum, na.rm
    = T)
  #rec NGL
  ps1c <- tapply(dfile[, 13], list(dfile[, 1]), FUN = sum)
  ps3 <- as.data.frame(cbind(ps1, ps2, rep(0, nruns), rep(0,
    nruns), ps1b, ps1c, rep(0, nruns)))
}
else {
  #na gas only
  ps1 <- tapply(dfile[, 5], list(dfile[, 1]), FUN = sum)
  #rec na gas
  ps1a <- tapply(dfile[, 12], list(dfile[, 1]), FUN = sum)
  ps2 <- tapply(rep(1, t1), list(dfile[, 1]), FUN = sum)
  ps1c <- tapply(dfile[, 13], list(dfile[, 1]), FUN = sum)
  ps3 <- as.data.frame(cbind(rep(NA, nruns), rep(NA, nruns),
    ps1, ps2, rep(NA, nruns), ps1a, ps1c))
}
rboe <- ps3[, 1] + ps3[, 3]/6
ps3 <- cbind(ps3, ps0, rboe)
names(ps3) <- c("rec_oil", "ndepoil", "rec_gas", "ndepgas", "rec_ADG",
  "rec_NGLadg", "rec_NGLnag", "run", "rBOR")
ps3 <- as.data.frame(ps3)
print(c(" Number successful plays", length(ps3[, 1])))

```

```
    ps3  
  }
```

```
"AMpsum.fn"<-
```

```
function(pname, np = 10000)
```

```
{  
  # summarizes play results graphically and numerically  
  # output file is xxpss  
  # Schuenemeyer, SWSC, 2004-10-20  
  # pname is play name  
  # dfile is play summary file, xxplay, xx is Splus play name  
  # dataf is basic data file, xxdata  
  #  
  # tplay is total number of plays=num sim runs/play favorability  
  # np is number of simulation runs  
  tf <- paste(pname, "play", sep = "")  
  dfile <- get(tf)  
  tf <- paste(pname, "data", sep = "")  
  dataf <- get(tf)  
  playr <- max(dataf[15, 1], dataf[15, 3], na.rm = T)  
  print(c("Play risk", playr))  
  tplay <- round(np/playr)  
  cv <- c("Rec Oil (mm bbl)", "Num Oil Acc", "Rec NA Gas (bcf)",  
        "Num Gas Acc", "Rec ADG", "Rec NGLadg", "rec_NGLnag")  
  ustat1 <- array(dim = c(7, 7))  
  uf <- array(dim = c(7, 8))  
  #compute recoverable oil and gas  
  #compute summary stats  
  for(i in 1:7) {  
    actog <- na.omit(dfile[, i])  
    actp <- length(actog)  
    if(actp > 0) {  
      if(actp < tplay)  
        actog <- append(actog, rep(0, tplay - actp +  
          1))  
      qo <- quantile(actog, c(0, 0.05, 0.5, 0.95, 1), na.rm  
        = T)  
      qm <- mean(actog)  
      qstd <- sqrt(var(actog))  
      ustat1[i, ] <- as.vector(c(qm, qstd, qo))  
    }  
  }  
  ustat1 <- as.data.frame(ustat1)  
  uf <- cbind(cv, ustat1)  
  names(uf) <- c("Resource", "Mean", "StdDev", "Min", "F95", "Med", "F05",  
    "Max")  
}
```

```

exportData(uf,
  "C:\\Documents and Settings\\John H Schuenemeyer\\My
Documents\\OilGas\\AlaskaM\\PlayForms\\Playss.xls",
  type = "Excel")
uf
}

```

"AMfreq.fn"<-

```

function(pname, og, np = 10000)
{
  # Frequency distribution for size-frequency of oil and/or na gas
  # SWSC 2004-10-20
  # pname is Splus play name
  # og=1(oil) or 2(gas)
  # np is number of play simulation runs
  #
  # Output file:
  #  xxfreqO for oil, xxfreqG for gas
  #  simf is simulation file
  #  dataf is basic data file, xxdata
  tf <- paste(pname, "sim", sep = "")
  simf <- get(tf)
  tf <- paste(pname, "data", sep = "")
  dataf <- get(tf)
  brko <- c(0, 8, 16, 32, 64, 128, 256, 512, 1024, 2048, 4096, 8192,
    16384, 32768, 65536)
  blgn <- length(brko) - 1
  brkg <- 6 * brko
  log2 <- log(2)
  yo <- as.numeric(simf[simf[, 4] == og, 5])
  ylng <- length(yo)
  yog <- array(1, dim = ylng)
  # xoc count
  xoc <- array(0, dim = blgn)
  # xos size (volume)
  xos <- xoc
  mic <- 1
  if(og == 1)
    yos <- round(log(yo)/log2 - 1.5)
  else yos <- round(log(yo/6)/log2 - 1.5)
  yos <- ifelse(yos < 1, 1, yos)
  t2 <- tapply(yo, yos, FUN = length)
  t3 <- names(t2)
  t4 <- as.numeric(t3)
  xoc[t4] <- t2
  xos[t4] <- tapply(yo, yos, FUN = sum)
}

```

```

mic <- max(t4, 1)
div <- np/max(dataf[15, 3], dataf[15, 1], na.rm = T)
xoc <- xoc/div
xos <- xos/div
xcb <- as.data.frame(cbind(xoc[1:mic], xos[1:mic]))
names(xcb) <- c("ndep", "vol")
return(xcb)
}

```

"AMsf.fn"<-

```

function(playn, og)
{
  # barplot of oil or gas, size-freq distns
  #2004-10-20 Mod Schuenemeyer
  # playn is play name
  # oas is histogram file (from AOGfhist.fn)
  # og=1 for oil, =2 for na gas
  #
  PNa <- get("PlayNames")
  PN <- PNa[PNa[, 2] == playn, 1]
  print(PN)
  classg <- c("0 <=48", "48 <=96", "96 <=192", "192 <=384", "384 <=768",
    "768 <=1536", "1536 <=3072", "3072 <=6144", "6144 <=12288",
    "12288 <=24576", "24576 <=49152", "49152 <=98304",
    "98304 <=196608", "196608 <=392316", "392316 <=784632")
  classo <- c("0 <=8", "8 <=16", "16 <=32", "32 <=64", "64 <=128",
    "128 <=256", "256 <=512", "512 <=1024", "1024 <=2048",
    "2048 <=4096", "4096 <=8192", "8192 <=16384", "16384 <=32768",
    "32768 <=65536", "65536 <=131072")
  ato <- "Recoverable Oil (MMBO)"
  atg <- "Recoverable Gas (BCFG)"
  #color is ogc (col) 4 is green, 8 is red
  if(og == 1) {
    class <- classo
    va2 <- ato
    idog <- "o"
    ogc <- 4
    srng <- "Size Ranges (MMBO)"
    infl <- paste(playn, "freqO", sep = "")
  }
  else {
    class <- classg
    va2 <- atg
    idog <- "g"
    ogc <- 8
    srng <- "Size Ranges (BCFG)"
  }
}

```

```

    infl <- paste(playn, "freqG", sep = "")
  }
  par(oma = rep(0, 4))
  #defines outer limits of plot
  par(mar = c(4.9, 4, 4, 2) + 1.1)
  par(fig = c(0, 1, 0, 1))
  par(yaxs = "i")
  oas <- get(infl)
  fn1 <- paste(
    "C:\\Documents and Settings\\John H Schuenemeyer\\My
Documents\\OilGas\\AlaskaM\\PlayForms\\",
    playn, idog, sep = "", collapse = "")
  par(mfrow = c(1, 2), pty = "s")
  for(i in 1:2) {
    if(i == 1)
      at <- "Number of Deposits"
    else at <- va2
    height <- as.data.frame(oas[, i])
    height <- height + 0
    height <- as.numeric(height)
    indx <- index.rowcol(height, height > 0, which = "rows")
    if(length(indx) > 0) {
      mins <- min(indx)
      maxs <- max(indx)
      # print(c(mins, maxs))
      mins <- 1
      # maxs <- 15
      mh <- max(max(height), 1) + 0.1
      # print(mh)
      pv <- pretty(c(0, mh))
      # print(pv)
      mvp <- max(pv)
      if(i == 2 & mvp < 5)
        mvp <- 5
      # print(mvp)
      pts <- barplot(height[mins:maxs], names = class[mins:
        maxs], col = ogc, inside = T, cex = 0.6, crt =
        30, axes = F, ylim = c(0, mvp))
      t0 <- rep(0, length(pts))
      pts <- pts + (pts[2] - pts[1]) * 0.5
      points(pts, t0, pch = "|", cex = 0.5)
      xv <- par("xaxp")
      #print(xv)
      yv <- par("yaxp")
      # print(yv)
      xv[1] <- xv[1] - 1
    }
  }

```

```

#min x
xv[2] <- xv[2] + 1.5
#max x
xinc <- xv[2] - xv[1]
tv <- yv
yv[1] <- yv[2]
yinc <- tv[2] - tv[1]
yl <- as.vector(cbind(0, tv[2]))
axis(side = 2, las = 1, tck = 0, cex = 0.6)
# axis(side = 4, tck = 0)
x1 <- xv[1] + 0.1 * xinc
text(x1, tv[2] - 0.04 * yinc, PN, adj = 0, cex = 0.75)
mtext(side = 1, line = 3, srng, cex = 1., srt = 90)
# title(playn, cex = 0.75)
mtext(side = 2, line = 3, at, cex = 0.75)
xv[2] <- xv[2] + 2
lines(xv[1:2], yv[1:2])
ina <- (tv[2] - tv[1])/tv[3]
for(j in 2:tv[3] - 1) {
  inc <- j * ina
  lines(xv[1:2], cbind(inc, inc), lty = 8)
}
lines(xv[1:2], cbind(0, 0), lty = 1)
lines(c(par())$usr[2], par())$usr[2], tv[1:2], lty = 1)
}
}
export.graph(fn1, Name = "GSD2", ExportType = "WMF")
}

```

"AMacc.fn"<-

```

function(fn, ijc, ns = 10000)
{
  # Schuenemeyer, 2004-10-29
  # Simulation to generate oil/gas accumulations
  # ns is number of accumulations to be generated
  # ijc = 1 for oil, 2 for gas
  # fn is 'Splus' play name
  # Output file:
  # fnlnO for oil or fnlnG for gas
  #
  #ag is API gravity,
  #dcf is surface correction factor
  #qar columns: 1=mmbbl,2=nrt,3=ac,4=por,5=tf,6=td
  #
  # file is parameter file
  set.seed(77)

```

```

par()
brko <- c(0, 8, 16, 32, 64, 128, 256, 512, 1024, 2048, 4096, 8192,
16384, 32768, 65536)
PNa <- get("PlayNames")
PN <- PNa[PNa[, 2] == fn, 1]
tf <- paste(fn, "data", sep = "")
fdat <- get(tf)
tf <- paste(fn, "pare", sep = "")
file <- get(tf)
qar <- array(dim = c(ns, 6))
corsw <- 0
if(ijc == 1) {
  ki <- 0
  tit <- "Oil Accumulation Distribution, mm bbl"
  if(fdat[16, 5] != 0 & !is.na(fdat[16, 5])) {
    #check oil correlation matrix
    tm <- as.matrix(fdat[16:19, 1:4])
    tmo <- tm
    tmo[2, 1] <- tmo[1, 2]
    tmo[3, 1] <- tmo[1, 3]
    tmo[4, 1] <- tmo[1, 4]
    tmo[3, 2] <- tmo[2, 3]
    tmo[4, 2] <- tmo[2, 4]
    tmo[4, 3] <- tmo[3, 4]
    td <- det(tmo)
    print(c("Determinant", td))
    corsw <- 1
    if(td <= 0)
      stop("Not a correlation matrix")
  }
}
else {
  ki <- 6
  tit <- "Gas Accumulation Distribuiton, bcf"
  #check gas correlation matrix
  if(fdat[17, 5] != 0 & !is.na(fdat[17, 5])) {
    if(fn == "BaFI") {
      tmo <- matrix(0, 5, 5)
      tmo[1:5, 1:4] <- as.matrix(fdat[16:20, 1:4])
      tmo[1, 2] <- tmo[2, 1]
      tmo[1, 3] <- tmo[3, 1]
      tmo[1, 4] <- tmo[4, 1]
      tmo[1, 5] <- tmo[5, 1]
      tmo[2, 3] <- tmo[3, 2]
      tmo[2, 4] <- tmo[4, 2]
      tmo[2, 5] <- tmo[5, 2]
    }
  }
}

```

```

        tmo[3, 4] <- tmo[4, 3]
        tmo[3, 5] <- tmo[5, 3]
        tmo[5, 5] <- 1
        print(tmo)
    }
    else {
        tm <- as.matrix(fdat[16:19, 1:4])
        tmo <- tm
        tmo[1, 2] <- tmo[2, 1]
        tmo[1, 3] <- tmo[3, 1]
        tmo[1, 4] <- tmo[4, 1]
        tmo[2, 3] <- tmo[3, 2]
        tmo[2, 4] <- tmo[4, 2]
        tmo[3, 4] <- tmo[4, 3]
    }
    td <- det(tmo)
    print(c("Determinant", td))
    corsw <- 1
    if(td <= 0)
        stop("Not a correlation matrix")
}
}
tit <- paste(PN, "\n", tit)
ag <- file[13, 2]
dcf <- file[12 + ijc, 3]
if(is.na(dcf))
    stop("Surface correction missing")
hpvcf <- file[12 + ijc, 5]
recf <- 0.01 * file[12 + ijc, 1]
k <- 0
for(i in (ki + 1):(ki + 4)) {
    k <- k + 1
    qt <- file[i, 2.]/file[i, 5.]
    pv <- pbeta(qt, file[i, 6.], file[i, 7.])
    u <- runif(ns, min = pv, max = 1)
    qar[, k + 1] <- qbeta(u, file[i, 6.], file[i, 7.]) * file[
        i, 5.]
    if(file[i, 1] > 6) {
        u <- runif(1, 0, 1)
        if(file[i, 1] == 7 & u > 0.5)
            qar[, k + 1] <- file[i, 5]
        else if(file[i, 1] == 8 & u > 0.95)
            qar[, k + 1] <- file[i, 5]
    }
}
}
u <- runif(ns, min = 0, max = 1)

```

```

qar[, 6] <- qbeta(u, file[ki + 5, 6.], file[ki + 5, 7.]) * (file[ki +
  5, 5.] - file[ki + 5, 2]) + file[ki + 5, 2] + dcf
#apply hpv correction factor to porosity
qar[, 4] <- qar[, 4] - hpvcf
if(corsw != 0) {
  #generate correlated rank matrix
  rr <- chol(tmo)
  if(fn == "BaFI") {
    ua <- matrix(runif(5 * ns, -1, 1), ncol = 5)
    uac <- ua %*% rr
    uac[, 1] <- rank(uac[, 1])
    uac[, 2] <- rank(uac[, 2])
    uac[, 3] <- rank(uac[, 3])
    uac[, 4] <- rank(uac[, 4])
    uac[, 5] <- rank(uac[, 5])
    print(cor(uac))
    qar[, 2] <- sort(qar[, 2])
    qar[, 3] <- sort(qar[, 3])
    qar[, 4] <- sort(qar[, 4])
    qar[, 5] <- sort(qar[, 5])
    qar[, 6] <- sort(qar[, 6])
    qar[, 2] <- qar[uac[, 1], 2]
    qar[, 3] <- qar[uac[, 2], 3]
    qar[, 4] <- qar[uac[, 3], 4]
    qar[, 5] <- qar[uac[, 4], 5]
    qar[, 6] <- qar[uac[, 5], 6]
  }
  else {
    ua <- matrix(runif(4 * ns, -1, 1), ncol = 4)
    uac <- ua %*% rr
    uac[, 1] <- rank(uac[, 1])
    uac[, 2] <- rank(uac[, 2])
    uac[, 3] <- rank(uac[, 3])
    uac[, 4] <- rank(uac[, 4])
    print(cor(uac))
    qar[, 2] <- sort(qar[, 2])
    qar[, 3] <- sort(qar[, 3])
    qar[, 4] <- sort(qar[, 4])
    qar[, 5] <- sort(qar[, 5])
    qar[, 2] <- qar[uac[, 1], 2]
    qar[, 3] <- qar[uac[, 2], 3]
    qar[, 4] <- qar[uac[, 3], 4]
    qar[, 5] <- qar[uac[, 4], 5]
  }
}
if(ijc == 1) {

```

```

# oil accumulation
tx <- fvfo.fn(qar[, 6], ag)
qar[, 1] <- (recf * (7.758 * 10.^-4. * qar[, 2] * qar[, 3] *
  qar[, 4] * qar[, 5]))/tx[, 1]
}
else {
# gas accumulation
t1 <- fvfg.fn(qar[, 6])
qar[, 1] <- recf * 0.4356 * 10.^-5 * qar[, 2] * qar[, 3] * qar[
  , 4] * qar[, 5] * t1
}
if(ijc == 1) {
qar <- as.data.frame(qar[qar[, 1] >= 5, ])
q95 <- quantile(qar[, 1], probs = 0.95)
brk <- seq(5, by = 5, round(q95 + 5))
brkln <- brko
}
else {
qar <- as.data.frame(qar[qar[, 1] >= 100, ])
q95 <- quantile(qar[, 1], probs = 0.95)
brk <- seq(100, by = 50, round(q95 + 50))
brkln <- 6 * brko
}
plq <- qar[qar[, 1] <= q95, 1]
names(qar) <- c("vol", "thk", "closure", "porosity", "tf", "depth")
options(digits = 3)
hist(plq, breaks = brk, plot = T, probability = T, include.lowest = T,
  eraseoutline = T, xlab = "Volume", main = tit)
usx <- par("usr")
x1 <- usx[2] * 0.7
y1 <- usx[4] * 0.7
t4 <- round(summary(qar[, 1]), digits = 1)
f05 <- round(quantile(qar[, 1], 0.95))
t4c <- as.character(paste(" Min ", t4[1], "\n", "1stQ ", t4[2], "\n",
  "Med ", t4[3], "\n", "Mean ", t4[4], "\n", "3rdQ ", t4[5],
  "\n", "F05 ", f05, "\n", "Max ", t4[6]))
text(x1, y1, t4c)
fn <- paste(
  "C:\\Documents and Settings\\John H Schuenemeyer\\My
Documents\\OilGas\\AlaskaM\\PlayForms\\",
  fn, "acc", as.character(ijc), sep = "", collapse = "")
export.graph(fn, ExportType = "WMF")
t1 <- hist(plq, breaks = brkln, plot = F, probability = T)
tr <- as.data.frame(t1$counts)
return(tr)
}

```

```

"AMlogac.fn"<-
function(playn, og)
{
  # barplot of oil or gas, accumulation in log 2 units
  #2004-10-20 Mod Schuenemeyer
  # playn is play name
  # og=1 for oil, =2 for na gas
  #
  # oas is histogram file (from AMacc.fn)
  # Input file name
  # xxlnO for oil, xxlnG for gas.
  PNa <- get("PlayNames")
  PN <- PNa[PNa[, 2] == playn, 1]
  print(PN)
  classg <- c("0 <=48", "48 <=96", "96 <=192", "192 <=384", "384 <=768",
    "768 <=1536", "1536 <=3072", "3072 <=6144", "6144 <=12288",
    "12288 <=24576", "24576 <=49152", "49152 <=98304",
    "98304 <=196608", "196608 <=392316", "392316 <=784632")
  classo <- c("0 <=8", "8 <=16", "16 <=32", "32 <=64", "64 <=128",
    "128 <=256", "256 <=512", "512 <=1024", "1024 <=2048",
    "2048 <=4096", "4096 <=8192", "8192 <=16384", "16384 <=32768",
    "32768 <=65536", "65536 <=131072")
  ato <- "Recoverable Oil (MMBO)"
  atg <- "Recoverable Gas (BCFG)"
  #color is ogc (col) 4 is green, 8 is red
  if(og == 1) {
    class <- classo
    va2 <- ato
    idog <- "O"
    ogc <- 4
    srng <- "Size Ranges (MMBO)"
    infl <- paste(playn, "lnO", sep = "")
  }
  else {
    class <- classg
    va2 <- atg
    idog <- "G"
    ogc <- 8
    srng <- "Size Ranges (BCFG)"
    infl <- paste(playn, "lnG", sep = "")
  }
  par(oma = rep(0, 4))
  #defines outer limits of plot
  par(mar = c(4.9, 4, 4, 2) + 1.1)
  par(fig = c(0, 1, 0, 1))
}

```

```

par(yaxs = "i")
oas <- get(infl)
fn1 <- paste(
  "C:\\Documents and Settings\\John H Schuenemeyer\\My
Documents\\OilGas\\AlaskaM\\PlayForms\\",
  infl, sep = "", collapse = "")
par(mfrow = c(1, 1), pty = "s")
for(i in 1:1) {
  if(i == 1)
    at <- "Accumulation Frequency"
  else at <- va2
  height <- as.data.frame(oas[, i])
  height <- height + 0
  height <- as.numeric(height)
  indx <- index.rowcol(height, height > 0, which = "rows")
  if(length(indx) > 0) {
    mins <- min(indx)
    maxs <- max(indx)
    # print(c(mins, maxs))
    mins <- 1
    # maxs <- 15
    mh <- 1.2 * max(height)
    # print(mh)
    pv <- pretty(c(0, mh))
    # print(pv)
   .mvp <- max(pv)
    if(i == 2 &.mvp < 5)
     .mvp <- 5
    # print.mvp)
    pts <- barplot(height[mins:maxs], names = class[mins:
      maxs], col = ogc, inside = T, cex = 0.6, crt =
      30, axes = F, ylim = c(0,.mvp))
    t0 <- rep(0, length(pts))
    pts <- pts + (pts[2] - pts[1]) * 0.5
    points(pts, t0, pch = "|", cex = 0.5)
    xv <- par("xaxp")
    #print(xv)
    yv <- par("yaxp")
    # print(yv)
    xv[1] <- xv[1] - 1
    #min x
    xv[2] <- xv[2] + 1.5
    #max x
    xinc <- xv[2] - xv[1]
    tv <- yv
    yv[1] <- yv[2]

```

```

yinc <- tv[2] - tv[1]
yl <- as.vector(cbind(0, tv[2]))
axis(side = 2, las = 1, tck = 0, cex = 0.6)
# axis(side = 4, tck = 0)
x1 <- xv[1] + 0.1 * xinc
text(x1, tv[2] - 0.04 * yinc, PN, adj = 0, cex = 0.75)
mtext(side = 1, line = 3, srng, cex = 1., srt = 90)
# title(playn, cex = 0.75)
mtext(side = 2, line = 3, at, cex = 0.75)
xv[2] <- xv[2] + 2
lines(xv[1:2], yv[1:2])
ina <- (tv[2] - tv[1])/tv[3]
for(j in 2:tv[3] - 1) {
  inc <- j * ina
  lines(xv[1:2], cbind(inc, inc), lty = 8)
}
lines(xv[1:2], cbind(0, 0), lty = 1)
lines(c(par())$usr[2], par())$usr[2], tv[1:2], lty = 1)
}
}
export.graph(fn1, Name = "GSD2", ExportType = "WMF")
}

```

"AMboxpd.fn"<-

function(fn, ijc)

```

{
  #Schuenemeyer 2004-09-13 (YMD)
  #Program reads data file and produces boxplots near specified value of volume
  # fn is Splus file name
  # ijc = 1 oil, = 2 gas
  #
  # adf = accumulation file
  # file = parameter file (xxpare)
  #
  # for oil depth is F05 (95th percentile)
  # for gas depth is F95 (05th percentile)
  # for oil range is (4.5,5.5 mm bbl)
  # for gas range is (90,110 bcf)
  #
  # ag - specific gravity
  #
  options(digits = 3)
  tf <- paste(fn, "pare", sep = "")
  file <- get(tf)
  if(ijc == 1) {
    ki <- 0

```

```

x1 <- 4.5
x2 <- 5.5
pc <- 0.95
tf <- paste(fn, "acco", sep = "")
}
else {
ki <- 6
x1 <- 90
x2 <- 110
pc <- 0.05
tf <- paste(fn, "accg", sep = "")
}
adf <- get(tf)
b1 <- file[ki + 5, 6]
b2 <- file[ki + 5, 7]
dpth <- file[ki + 5, 2] + (file[ki + 5, 5] - file[ki + 5, 2]) * qbeta(
pc, b1, b2)
miv <- array(0, dim = 4)
t5 <- adf[adf[, 1] >= x1 & adf[, 1] <= x2, ]
nob <- length(t5[, 1])
print(c("Obs in range", nob))
nm <- names(adf)
ag <- file[13, 2]
dcf <- file[13, 3]
hpvcf <- file[12 + ijc, 5]
recf <- 0.01 * file[12 + ijc, 1]
# boxplot(t5)
par(mfrow = c(1, 4))
for(i in 2:5) {
boxplot(t5[, i], main = nm[i])
miv[i - 1] <- median(t5[, i])
}
if(ijc == 1) {
tx <- fvfo.fn(dpth, ag)
qar <- (recf * (7.758 * 10.^-4. * miv[1] * miv[2] * (miv[3] -
hpvcf) * miv[4]))/tx[, 1]
mt <- paste("Oil, range 4.5-5.5 mm bbl, Depth =", round(dpth *
1000), " ft, Num obs =", nob)
}
else {
t1 <- fvfg.fn(dpth)
qar <- recf * 0.4356 * 10.^-5 * miv[1] * miv[2] * (miv[3] -
hpvcf) * miv[4] * t1
mt <- paste("Gas, range 90-110 bcf, Depth =", round(dpth * 1000
), " ft, Num obs =", nob)
}
}

```

```

usx <- par("usr")
print(usx)
text(-100, usx[3], mt, cex = 1.2)
fn <- paste(
  "C:\\Documents and Settings\\John H Schuenemeyer\\My
Documents\\OilGas\\AlaskaM\\PlayForms\\",
  fn, "box", as.character(ijc), sep = "", collapse = "")
export.graph(fn, ExportType = "WMF")
}

```

"AMcorr.fn"<-

```

function(pfile, playr, seed, cns = 10000)
{
  # Generates adjusted correlation matrix and/or
  # corresponding sample numbers
  # Schuenemeyer, SWSC, 2005-12-13
  # pfile is user specified correlation matrix
  # playr contains play risk;
  # seed is random number seed; seed between 0 and 1023
  set.seed(seed)
  # cns is number of simulation runs
  # Note - see last lines of code to change from output of sample
  # numbers (uac) to adjusted correlation matrix (sq).
  # eps is bias factor adjustment
  eps <- 0.001
  pd <- length(pfile[1, ])
  pfile <- as.matrix(pfile)
  sq <- pfile + t(pfile) + diag(pd)
  dts <- eigen(sq)
  eval <- dts$values
  evec <- dts$vectors
  if(eval[pd] <= 0) {
    print(c(" Matrix not PD: min eigenvalue =", eval[pd]))
    bias <- - eval[pd] + eps
    eval <- eval + bias
    sq1 <- sq
    sq <- evec %*% diag(eval) %*% t(evec)
    tri <- sq[1, 1]
    sq <- sq/tri
    for(i in 2:pd) {
      for(j in 1:i - 1)
        sq[i, j] <- sq[j, i]
    }
    dts <- eigen(sq)
    print(dts$values[pd])
  }
}

```

```

ch <- chol(sq)
# print(ch)
#Cholesky factorization
# correlated samples
ua <- array(dim = c(cns, pd))
for(i in 1:pd)
  ua[, i] <- runif(cns, -1, 1)
uac <- ua %*% ch
for(i in 1:pd) {
  uac[, i] <- rank(uac[, i])
  if(playr[i, 3] < 1)
    uac[, i] <- round(uac[, i]/playr[i, 3])
}
#
#save adjusted correlation matrix, sq or
#corresponding correlated sample numbers, uac
# remove and add # as needed
#sq <- as.data.frame(sq)
#sq
uac <- as.data.frame(uac)
uac
}

```

"AMagg.fn"<-

```

function(smpl, playr)
{
  # Aggregate plays
  # Schuenemeyer, SWSC, 2005-03-08
  # smpl is matrix of sample numbers
  # playr contains play risk and play file names
  # Output is aggregation file.
  #
  vp <- c(1, 3, 5, 6, 7)
  pnames <- c("roil", "rgas", "rADG", "rNGLadg", "rNGLnag")
  ppn <- c("P1", "P2", "P3", "P4", "P5", "P6", "P7", "P8", "P9", "P10",
    "P11", "P12", "P13", "P14", "P15", "P16", "P17", "P18", "P19",
    "P20", "P21", "P22", "P23", "P24")
  cns <- 10000
  # np is number of plays to be aggregated.
  np <- length(playr[, 1])
  ur <- array(0, dim = cns)
  erns <- array(0, dim = c(cns, np))
  resa <- array(0, dim = c(cns, length(vp)))
  for(i in 1:np) {
    play <- matrix(0, nrow = 10000, ncol = 9)
    play <- as.data.frame(play)

```

```

fn1 <- paste(playr[i, 4], "play", sep = "")
print(c(i, fn1))
# data for ith play.
play1 <- get(fn1)
# col 8 is run number
t8 <- play1[, 8]
play[t8, ] <- play1
lpo <- length(play[, 1])
lp <- length(play[, 1])
if(playr[i, 3] == 1) {
  # play favorability = 1
  # play[,9] is recov BOE
  po <- order(play[, 9])
  ut <- po[smpl[, i]]
  for(j in 1:5) {
    utt <- play[ut, vp[j]]
    resa[, j] <- resa[, j] + utt
  }
  ut <- ifelse(ut > lpo, 0, ut)
  erns[, i] <- ut
}
else {
  # play favorability < 1.
  tm4 <- cbind(seq(cns), smpl[, i])
  asmp <- tm4[tm4[, 2] <= lp, ]
  playt <- play[tm4[, 2] <= lp, ]
  po <- order(playt[, 9])
  ut <- po[rank(asmp[, 2])]
  ur <- rep(0, cns)
  ur[asmp[, 1]] <- asmp[ut, 1]
  for(j in 1:5) {
    utt <- array(0, dim = cns)
    utt[asmp[, 1]] <- playt[ut, vp[j]]
    resa[, j] <- resa[, j] + utt
  }
  ur <- ifelse(ur > lpo, 0, ur)
  erns[, i] <- ur
}
}
resa <- as.data.frame(resa)
# names(resa) <- pnames
resa <- cbind(resa, erns)
names(resa) <- c(pnames, ppn[1:np])
resa
}

```

```
"AMsummary.fn"<-  
function(dfile)  
{  
  # Summary statistics of aggregation results  
  # dfile is aggregate results (total or Federal lands)  
  #sv is desired percentiles  
  sv <- c(0, 0.05, 0.25, 0.5, 0.75, 0.95, 1)  
  pname <- names(dfile)  
  lc <- 5  
  res <- array(0, dim = c(10, lc))  
  for(i in 1:lc) {  
    res[, i] <- c(quantile(dfile[, i], prob = sv), mean(dfile[,  
      i]), sqrt(var(dfile[, i])), length(dfile[, i]))  
  }  
  res <- as.data.frame(res)  
  names(res) <- pname[1:5]  
  res  
}
```