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Probabilistic Methodology for GRASS: Gas Resource Assessment Spreadsheet System

by

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INTRODUCTION

Probabilistic methodology is developed for an assessment of the total in-place gas volume in a given study area. A study area is subdivided into a set of geologic plays, and the separate plays are analyzed. Every play is partitioned geologically into parts, called subplays. Each subplay is assessed individually, and then all of the subplays of a play are aggregated to make an assessment of the play. Finally, all of the plays are aggregated for an assessment of the total in-place gas volume in the study area.

Each subplay is assessed individually using a reservoir engineering equation (Garb and Smith, 1987). The hydrocarbon-volume attributes are (1) area of closure, (2) thickness of reservoir rock, (3) effective porosity, (4) trap fill, (5) hydrocarbon saturation, (6) original reservoir pressure, (7) reservoir temperature, and (8) gas compressibility. The hydrocarbon-volume attributes jointly determine the volume of the hydrocarbon accumulation within the subplay. The following reservoir engineering equation is used to calculate the in-place volume of gas in cubic feet:

Gas in-place: $Y = (1.5378)(640)(A)(H)(P)(F)(S_h)(P_e / TZ)$

where A = area of closure (square miles)
H = reservoir thickness (feet)
P = effective porosity (percent)
F = trap fill (percent)
S_h = hydrocarbon saturation (percent)
P_e = original reservoir pressure (psi)
T = reservoir temperature (degrees Rankine)
Z = gas compressibility factor (no units)

The equation consists of a product of factors that are functions of the hydrocarbon-volume attributes. The geologic variables P_e, T, and Z are each taken to be linear functions of reservoir depth D (feet) in the form $a \cdot D + b$. For P_e the parameter a is the pressure gradient (psi/ft), and parameter b is the average ground level atmospheric pressure (psi). For T the parameter a is the temperature gradient (degrees Rankine/ft), and parameter b is the average ground level temperature (degrees Rankine).

To obtain a point estimate of the in-place gas of a subplay, point estimates are made of the six attributes A, H, P, F, S_h, and D which may vary from subplay to subplay within a play. The parameters a and b for each of the variables P_e, T, and Z (i.e., three pairs of a and b) are estimated for a play, and the one set of parameter values is used in all subplays of the play. The point estimate of the in-place gas of a subplay is taken to be a mean estimate.

To obtain an interval estimate of the in-place gas of a subplay, estimates are computed for the ranges of the six attributes A, H, P, F, S_h, and D. The range of an attribute is taken to be $F5$ minus $F95$, i.e., range = $F5 - F95$, where $F5$ denotes the 5th fractile and $F95$ denotes the 95th fractile. However, we initially make one set of estimated range percentages for a play that is used in all subplays of the play. The range percentage of an attribute is defined to be

$$\text{range percentage} = \frac{\text{range}}{\text{mean}} \cdot 100$$

which represents the range expressed as a percentage of the mean. The range percentage is similar to the coefficient of variation which uses the standard deviation in place of the range. Both measures of relative variation are particularly applicable where the variability is a function of the magnitude of the measurements, viz., relative to the means. Thus, for each subplay, the range is computed from the relationship

$$\text{range} = \frac{\text{range percentage}}{100} \cdot \text{mean}$$

Assuming a normal distribution for each attribute, the standard deviation is determined to be

$$\text{standard deviation} = \frac{\text{range}}{3.29}$$

The attributes are treated as independent continuous random variables in order for the methodology to be tractable. The simplifying assumption of independence is made though some dependency exists, e.g., between saturation and porosity. The probabilistic methodology used to process the geologic data is an analytic method derived from probability theory. The analytic methodology is developed by the application of the laws of expectation and variance. The methodology systematically tracks through the geologic model and computes all of the means and variances of the appropriate random variables. An estimate of the standard deviation of the in-place gas of a subplay is computed and varies from subplay to subplay. The lognormal distribution is used as a probability model in order to generate probability fractiles.

All of the means, standard deviations, and fractiles of the subplays of a play are aggregated to make an assessment of the play. Finally, all of the plays are aggregated by applying a separate methodology for an assessment of the total in-place gas resources in the study area. This probabilistic methodology for gas resource assessment lends itself as an ideal application for spreadsheet software. The spreadsheet for making an assessment of a play is called GRASS: Gas Resource Assessment Spreadsheet System. The second spreadsheet for aggregating a set of plays is called GRASSAG: Gas Resource Assessment Spreadsheet System for Aggregation.

THEORY

GRASS probabilistic formulas are in the following columns of the spreadsheet:

(Panel 1)

A
Subplay
No.

B
Closure
(sq.mi.)
Mean or expected value of area of closure: $E(A)$

C
Thicknes
s
(feet)
Mean or expected value of reservoir thickness: $E(H)$

D
Porosity
(%)
Mean or expected value of effective porosity: $E(P)$

E
Trap fill
(%)
Mean or expected value of trap fill: $E(F)$

F
HC Sat.
(%)
Mean or expected value of hydrocarbon saturation: $E(S_h)$

G
Depth
(feet)
Mean or expected value of reservoir depth: $E(D)$

H
Pressure
(PSI)

$$E(P_e) = a_1 E(D) + b_1$$

I
Temp.
(Deg.Rank.)

$$E(T) = a_2 E(D) + b_2$$

J
Gas Comp.
(no units)

$$E(Z) = a_3 E(D) + b_3$$

K
Gas in place
(CF)

$$E(Y) = (1000)(1537.8)(640)E(A)E(H)\frac{E(P)}{100}\frac{E(F)}{100}\frac{E(S_h)}{100}\frac{E(P_e)}{E(T)E(Z)}$$

$$\sum E(Y)$$

(Panel 2)

L
Subplay
No.

M
Expect
Pe/TZ

$$E(P_e / TZ) = \frac{a_1 E(D) + b_1}{(a_2 E(D) + b_2)(a_3 E(D) + b_3)}$$

N
Depth
Depth range $\% \equiv DR\%$
F95 D.
Pe/TZ

$$(P_e / TZ)_1 = \frac{a_1[E(D) - (DR\% / 100)E(D)/2] + b_1}{\{a_2[E(D) - (DR\% / 100)E(D)/2] + b_2\}\{a_3[E(D) - (DR\% / 100)E(D)/2] + b_3\}}$$

O
F5 D.
Pe/TZ

$$(P_e / TZ)_2 = \frac{a_1[E(D) + (DR\% / 100)E(D) / 2] + b_1}{\{a_2[E(D) + (DR\% / 100)E(D) / 2] + b_2\}\{a_3[E(D) + (DR\% / 100)E(D) / 2] + b_3\}}$$

P
Closure
Closure range % $\equiv AR\%$
Expected value of (Closure)^2

$$E(A^2) = [(AR\% / 100)E(A) / 3.29]^2 + [E(A)]^2$$

Q
Thickness
Thickness range % $\equiv HR\%$
Expected value of (Thickness)^2

$$E(H^2) = [(HR\% / 100)E(H) / 3.29]^2 + [E(H)]^2$$

R
Porosity
Porosity range % $\equiv PR\%$
Expected value of (Porosity)^2

$$E(P^2) = [(PR\% / 100)E(P) / 3.29]^2 + [E(P)]^2$$

S
Trap Fill
Trap fill range % $\equiv FR\%$
Expected value of (Tra Fill)^2

$$E(F^2) = [(FR\% / 100)E(F) / 3.29]^2 + [E(F)]^2$$

T
HC Sat.
Hydrocarbon saturation range % $\equiv S_h R\%$
Expected value of (HC S)^2

$$E(S_h^2) = [(S_h R\% / 100)E(S_h) / 3.29]^2 + [E(S_h)]^2$$

U
Pe/TZ
Expected value of (*Pe/TZ*)^2

$$E[(P_e / TZ)^2] = \left[\left|(P_e / TZ)_1 - (P_e / TZ)_2\right| / 3.29\right]^2 + [E(P_e / TZ)]^2$$

V
Expected value of $(\text{Gas})^2$

$$E(Y^2) = [(1.5378)(640)]^2 E(A^2)E(H^2)E(P^2)E(F^2)E(S_h^2)E[(P_e / TZ)^2]$$

(Panel 3)

W
Subplay
No.

X
In-place
Mean gas
(CF)

$$E(Y) = (1.5378)(640)E(A)E(H)E(P)E(F)E(S_h)\frac{E(P_e)}{E(T)E(Z)}$$

Perfectly Positively Correlated (P.P.C.): $\sum E(Y)$

Independence (Indep.): $\sum E(Y)$

Y
In-place
Var. gas
$(\text{CF})^2$

$$V(Y) = E(Y^2) - [E(Y)]^2$$

P.P.C.: $\left[\sum SD(Y)\right]^2$

Indep.: $\sum V(Y)$

Z
In-place
S.D. gas
(CF)

$$SD(Y) = \sqrt{V(Y)}$$

P.P.C.: $\sum SD(Y)$

Indep.: $\sqrt{\sum V(Y)}$

AA
Mu

$$\mu = \ln \frac{[E(Y)]^2}{\sqrt{[E(Y)]^2 + V(Y)}}$$

Indep.: $$\mu' = \ln \frac{\left[\sum E(Y)\right]^2}{\sqrt{\left[\sum E(Y)\right]^2 + \sum V(Y)}}$$

AB
Sigma

$$\sigma = \sqrt{\ln\left(\frac{V(Y)}{[E(Y)]^2} + 1\right)}$$

Indep.: $$\sigma' = \sqrt{\ln\left(\frac{\sum V(Y)}{\left[\sum E(Y)\right]^2} + 1\right)}$$

AC
In-place Fractiles
*F*95
(CF)

$$F95 = e^{\mu - 1.645\sigma}$$

P.P.C.: $F95' = \sum F95$

Indep.: $F95' = e^{\mu' - 1.645\sigma'}$

AD
*F*75
(CF)

$$F75 = e^{\mu - 0.674\sigma}$$

P.P.C.: $F75' = \sum F75$

Indep.: $F75' = e^{\mu' - 0.674\sigma'}$

AE
*F*50
(CF)

$F50 = e^{\mu}$

P.P.C.: $F50' = \sum F50$

Indep.: $F50' = e^{\mu'}$

AF
*F*25
(CF)

$F25 = e^{\mu+0.674\sigma}$

P.P.C.: $F25' = \sum F25$

Indep.: $F25' = e^{\mu'+0.674\sigma'}$

AG
*F*5
(CF)

$F5 = e^{\mu+1.645\sigma}$

P.P.C.: $F5' = \sum F5$

Indep.: $F5' = e^{\mu'+1.645\sigma'}$

(Panel 4)

AH
Subplay
No.

AI
Mean
Percentage (%): U and Mean percentage: $E(U)$
Recoverable gas: $W = (U / 100)Y$
Mean gas
(CF)

$$E(W) = \frac{E(U)}{100} E(Y)$$

P.P.C.: $\sum E(W)$

Indep.: $\sum E(W)$

AJ
Range of U: $R(U) = F5 - F95$
Expect
$(\text{Gas})^2$

$$E(W^2) = \frac{E(U^2)E(Y^2)}{(100)^2} = \left[\left(\frac{R(U)/100}{3.29}\right)^2 + \left(E(U)/100\right)^2\right]E(Y^2)$$

AK
Recoverable
Var. gas
$(\text{CF})^2$

$$V(W) = E(W^2) - [E(W)]^2$$

P.P.C.: $\left[\sum SD(W)\right]^2$

Indep.: $\sum V(W)$

AL
Recoverable
S.D. gas
(CF)

$$SD(W) = \sqrt{V(W)}$$

P.P.C.: $\sum SD(W)$

Indep.: $\sqrt{\sum V(W)}$

AM
Mu

$$\mu = \ln \frac{[E(W)]^2}{\sqrt{[E(W)]^2 + V(W)}}$$

Indep.:

$$\mu' = \ln \frac{\left[\sum E(W)\right]^2}{\sqrt{\left[\sum E(W)\right]^2 + \sum V(W)}}$$

AN
Sigma

$$\sigma = \sqrt{\ln\left(\frac{V(W)}{[E(W)]^2} + 1\right)}$$

Indep.: $$\sigma' = \sqrt{\ln\left(\frac{\sum V(W)}{\left[\sum E(W)\right]^2} + 1\right)}$$

AO
Recoverable Fractiles
*F*95
(CF)

$$F95 = e^{\mu - 1.645\sigma}$$

P.P.C.: $F95' = \sum F95$

Indep.: $F95' = e^{\mu' - 1.645\sigma'}$

AP
*F*75
(CF)

$$F75 = e^{\mu - 0.674\sigma}$$

P.P.C.: $F75' = \sum F75$

Indep.: $F75' = e^{\mu' - 0.674\sigma'}$

AQ
*F*50
(CF)

$$F50 = e^{\mu}$$

P.P.C.: $F50' = \sum F50$

Indep.: $F50' = e^{\mu'}$

AR
$F25$
(CF)

$F25 = e^{\mu+0.674\sigma}$

P.P.C.: $F25' = \sum F25$

Indep.: $F25' = e^{\mu'+0.674\sigma'}$

AS
$F5$
(CF)

$F5 = e^{\mu+1.645\sigma}$

P.P.C.: $F5' = \sum F5$

Indep.: $F5' = e^{\mu'+1.645\sigma'}$

GRASSAG probabilistic formulas are in the following columns of the spreadsheet:

A
Play
Name

B
In-place
Mean gas
(CF)

$E(\cdot)$

Aggregation:
P.P.C.: $\sum E(\cdot)$
Indep.: $\sum E(\cdot)$

C
In-place
Var. gas
$(CF)^2$

$V(\cdot)$

P.P.C.: $\left[\sum SD(\cdot)\right]^2$
Indep.: $\sum V(\cdot)$

D
In-place
S.D. gas
(CF)

$SD(\cdot)$

P.P.C.: $\sum SD(\cdot)$

Indep.: $\sqrt{\sum V(\cdot)}$

E
Mu

$$\mu = \ln \frac{[E(\cdot)]^2}{\sqrt{[E(\cdot)]^2 + V(\cdot)}}$$

Indep.: $$\mu' = \ln \frac{\left[\sum E(\cdot)\right]^2}{\sqrt{\left[\sum E(\cdot)\right]^2 + \sum V(\cdot)}}$$

F
Sigma

$$\sigma = \sqrt{\ln\left(\frac{V(\cdot)}{[E(\cdot)]^2} + 1\right)}$$

Indep.: $$\sigma' = \sqrt{\ln\left(\frac{\sum V(\cdot)}{\left[\sum E(\cdot)\right]^2} + 1\right)}$$

G
In-place Fractiles
*F*95
(CF)

$F95 = e^{\mu - 1.645\sigma}$

P.P.C.: $F95' = \sum F95$

Indep.: $F95' = e^{\mu' - 1.645\sigma'}$

H
F75
(CF)

$F75 = e^{\mu - 0.674\sigma}$

P.P.C.: $F75' = \sum F75$

Indep.: $F75' = e^{\mu' - 0.674\sigma'}$

I
F50
(CF)

$F50 = e^{\mu}$

P.P.C.: $F50' = \sum F50$

Indep.: $F50' = e^{\mu'}$

J
F25
(CF)

$F25 = e^{\mu + 0.674\sigma}$

P.P.C.: $F25' = \sum F25$

Indep.: $F25' = e^{\mu' + 0.674\sigma'}$

K
F5
(CF)

$F5 = e^{\mu + 1.645\sigma}$

P.P.C.: $F5' = \sum F5$

Indep.: $F5' = e^{\mu' + 1.645\sigma'}$

APPLICATION

The Gas Resource Assessment Spreadsheet System (GRASS) was used to make an assessment of in-place gas resources in low-permeability Upper Cretaceous and lower Tertiary sandstone reservoirs, Wind River Basin, Wyoming (Johnson and others, 1996). The study consisted of assessing individually 22 plays using GRASS, and then aggregating the play estimates to assess the entire Wind River Basin using GRASSAG. For example, one of these plays is called Nonmarine Kmv >300 (or GKMV4), and the spreadsheet for this play is as follows. Panel 1 of the GRASS spreadsheet for the play GKMV4 in the Wind River Basin consists mainly of input geologic data (Figure 1). Panel 2 gives the intermediate calculations (Figure 2). Panel 3 generates estimates of the in-place gas resources for the subplays and the play GKMV4 (Figure 3). As explained in detail in the previous section, estimates of the recoverable gas resources are arrived at by applying a recovery percentage to the in-place gas resource estimates. Panel 4 is an illustrative hypothetical example of the recoverable gas resource estimates for the subplays and the play GKMV4 (Figure 4). The GRASSAG spreadsheet computes the aggregation of the 22 plays to obtain estimates of the in-place gas resources for the Wind River Basin (Figure 5).

A	B	C	D	E	F	G	H	I	J	K
Play Name :		Nonmarine Kmv > 300				*a* =	0.727	0.016	0.00008	(Panel 1)
						b =	14.7	505	0	
	MEAN									
Subplay No.	Closure (sq.mi.)	Thickness (feet)	Porosity (%)	Trap fill (%)	HC Sat. (%)	Depth (feet)	Pressure (PSI)	Temp. (Deg.Rank.)	Gas Comp. (no units)	Gas in place (CF)
1	2.5	410	6	100	50	19,500	14191	817	1.56	3.37E+11
2	10.2	415	6	100	50	19,000	13828	809	1.52	1.41E+12
3	42.7	370	6	100	50	20,000	14555	825	1.6	5.14E+12
4	69.7	350	6	100	50	19,000	13828	809	1.52	8.10E+12
5	73.9	340	6	100	50	18,000	13101	793	1.44	8.51E+12
6	35.7	320	6	100	50	17,000	12374	777	1.36	3.95E+12
7	5.7	280	6	100	50	19,500	14191	817	1.56	5.25E+11
7a	0.35	200	6	100	50	15,500	11283	753	1.24	2.50E+10
8	20.2	280	6	100	50	19,000	13828	809	1.52	1.88E+12
9	21.1	250	6	100	50	18,000	13101	793	1.44	1.79E+12
10	17.9	250	6	100	50	17,000	12374	777	1.36	1.55E+12
11	0.83	250	6	100	50	18,500	13464	801	1.48	6.96E+10
12	11.2	230	6	100	50	18,000	13101	793	1.44	8.73E+11
13	27.7	250	6	100	50	17,000	12374	777	1.36	2.39E+12
14	1	260	6	100	50	17,500	12737	785	1.4	8.90E+10
15	16.7	320	6	100	50	19,000	13828	809	1.52	1.77E+12
16	0.83	200	6	100	50	16,500	12010	769	1.32	5.80E+10
17	5.2	320	6	100	50	18,000	13101	793	1.44	5.64E+11
18	3.6	310	6	100	50	17,000	12374	777	1.36	3.86E+11
19	3.1	320	6	100	50	18,000	13101	793	1.44	3.36E+11
20	3.8	280	6	100	50	18,000	13101	793	1.44	3.60E+11
21	7.9	250	6	100	50	17,000	12374	777	1.36	6.83E+11
21a	9.3	180	6	100	50	17,000	12374	777	1.36	5.79E+11
22	4.9	230	6	100	50	18,000	13101	793	1.44	3.82E+11
23	24.3	180	6	100	50	18,000	13101	793	1.44	1.48E+12
23a	0.3	200	6	100	50	18,500	13464	801	1.48	2.01E+10
24	31	180	6	100	50	17,000	12374	777	1.36	1.93E+12
25	26	230	6	100	50	19,000	13828	809	1.52	1.99E+12
26	10.4	230	6	100	50	18,000	13101	793	1.44	8.10E+11
27	5.4	220	6	100	50	17,000	12374	777	1.36	4.11E+11
28	5.2	300	6	100	50	17,000	12374	777	1.36	5.39E+11
									Total =	4.89E+13

Figure 1. Panel 1 of GRASS spreadsheet for play GKMV4 in the Wind River Basin.

L	M	N	O	P	Q	R	S	T	U	V
Play Name :		Nonmarine Kmv > 300								(Panel 2)
		Depth		Closure	Thickness	Porosity	Trap Fill	HC Sat.	*Pe/TZ*	
	Range (%) =	30		30	50	30	20	40		
Subplay	Expect	F95 D.	F5 D.	Expect	Expect	Expect	Expect	Expect	Expect	Expect
No.	*Pe/TZ*	*Pe/TZ*	*Pe/TZ*	(Clo.)^2	(Thick.)^2	(Por.)^2	(Trap)^2	(HC S)^2	(*Pe/TZ*)^2	(Gas)^2
1	11.13	11.81	10.53	6.30	171982.5	36.30	10037.0	2536.95	124.13	1.20E+23
2	11.24	11.92	10.64	104.91	176202.8	36.30	10037.0	2536.95	126.60	2.10E+24
3	11.03	11.71	10.42	1838.45	140061.9	36.30	10037.0	2536.95	121.73	2.81E+25
4	11.24	11.92	10.64	4898.48	125329.3	36.30	10037.0	2536.95	126.60	6.96E+25
5	11.47	12.14	10.88	5506.62	118270.0	36.30	10037.0	2536.95	131.76	7.68E+25
6	11.71	12.36	11.12	1285.09	104765.1	36.30	10037.0	2536.95	137.25	1.65E+25
7	11.13	11.81	10.53	32.76	80210.8	36.30	10037.0	2536.95	124.13	2.92E+23
7a	12.08	12.72	11.51	0.12	40923.9	36.30	10037.0	2536.95	146.16	6.61E+20
8	11.24	11.92	10.64	411.43	80210.8	36.30	10037.0	2536.95	126.60	3.74E+24
9	11.47	12.14	10.88	448.91	63943.5	36.30	10037.0	2536.95	131.76	3.39E+24
10	11.71	12.36	11.12	323.07	63943.5	36.30	10037.0	2536.95	137.25	2.54E+24
11	11.36	12.03	10.76	0.69	63943.5	36.30	10037.0	2536.95	129.14	5.14E+21
12	11.47	12.14	10.88	126.48	54121.8	36.30	10037.0	2536.95	131.76	8.08E+23
13	11.71	12.36	11.12	773.67	63943.5	36.30	10037.0	2536.95	137.25	6.08E+24
14	11.59	12.25	11.00	1.01	69161.3	36.30	10037.0	2536.95	134.47	8.40E+21
15	11.24	11.92	10.64	281.21	104765.1	36.30	10037.0	2536.95	126.60	3.34E+24
16	11.83	12.48	11.25	0.69	40923.9	36.30	10037.0	2536.95	140.13	3.57E+21
17	11.47	12.14	10.88	27.26	104765.1	36.30	10037.0	2536.95	131.76	3.37E+23
18	11.71	12.36	11.12	13.07	98319.6	36.30	10037.0	2536.95	137.25	1.58E+23
19	11.47	12.14	10.88	9.69	104765.1	36.30	10037.0	2536.95	131.76	1.20E+23
20	11.47	12.14	10.88	14.56	80210.8	36.30	10037.0	2536.95	131.76	1.38E+23
21	11.71	12.36	11.12	62.93	63943.5	36.30	10037.0	2536.95	137.25	4.94E+23
21a	11.71	12.36	11.12	87.21	33148.3	36.30	10037.0	2536.95	137.25	3.55E+23
22	11.47	12.14	10.88	24.21	54121.8	36.30	10037.0	2536.95	131.76	1.55E+23
23	11.47	12.14	10.88	595.40	33148.3	36.30	10037.0	2536.95	131.76	2.33E+24
23a	11.36	12.03	10.76	0.09	40923.9	36.30	10037.0	2536.95	129.14	4.29E+20
24	11.71	12.36	11.12	968.99	33148.3	36.30	10037.0	2536.95	137.25	3.95E+24
25	11.24	11.92	10.64	681.62	54121.8	36.30	10037.0	2536.95	126.60	4.18E+24
26	11.47	12.14	10.88	109.06	54121.8	36.30	10037.0	2536.95	131.76	6.96E+23
27	11.71	12.36	11.12	29.40	49517.9	36.30	10037.0	2536.95	137.25	1.79E+23
28	11.71	12.36	11.12	27.26	92078.7	36.30	10037.0	2536.95	137.25	3.09E+23

Figure 2. Panel 2 of GRASS spreadsheet for play GKMV4 in the Wind River Basin.

W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG
Play Name :		Nonmarine Kmv > 300								(Panel 3)
	In-place	In-place	In-place			In-place Fractiles				
Subplay	Mean gas	Var. gas	S.D. gas			F95	F75	F50	F25	F5
No.	(CF)	(CF)^2	(CF)	Mu	Sigma	(CF)	(CF)	(CF)	(CF)	(CF)
1	3.37E+11	6.90E+21	8.31E+10	26.514	0.24287	2.19E+11	2.78E+11	3.27E+11	3.85E+11	4.88E+11
2	1.41E+12	1.20E+23	3.46E+11	27.942	0.24279	9.15E+11	1.16E+12	1.36E+12	1.61E+12	2.03E+12
3	5.14E+12	1.61E+24	1.27E+12	29.239	0.24295	3.35E+12	4.24E+12	4.99E+12	5.88E+12	7.45E+12
4	8.10E+12	3.98E+24	2.00E+12	29.693	0.24279	5.27E+12	6.68E+12	7.86E+12	9.26E+12	1.17E+13
5	8.51E+12	4.39E+24	2.10E+12	29.743	0.24262	5.54E+12	7.02E+12	8.26E+12	9.73E+12	1.23E+13
6	3.95E+12	9.45E+23	9.72E+11	28.975	0.24246	2.57E+12	3.26E+12	3.84E+12	4.52E+12	5.71E+12
7	5.25E+11	1.67E+22	1.29E+11	26.957	0.24287	3.42E+11	4.33E+11	5.09E+11	6.00E+11	7.60E+11
7a	2.50E+10	3.77E+19	6.14E+09	23.912	0.24222	1.63E+10	2.06E+10	2.43E+10	2.86E+10	3.61E+10
8	1.88E+12	2.14E+23	4.63E+11	28.232	0.24279	1.22E+12	1.55E+12	1.82E+12	2.15E+12	2.72E+12
9	1.79E+12	1.94E+23	4.40E+11	28.182	0.24262	1.16E+12	1.47E+12	1.74E+12	2.04E+12	2.59E+12
10	1.55E+12	1.45E+23	3.81E+11	28.038	0.24246	1.01E+12	1.28E+12	1.50E+12	1.77E+12	2.24E+12
11	6.96E+10	2.94E+20	1.71E+10	24.936	0.24271	4.53E+10	5.74E+10	6.76E+10	7.96E+10	1.01E+11
12	8.73E+11	4.62E+22	2.15E+11	27.465	0.24262	5.68E+11	7.19E+11	8.47E+11	9.98E+11	1.26E+12
13	2.39E+12	3.47E+23	5.89E+11	28.475	0.24246	1.56E+12	1.97E+12	2.32E+12	2.74E+12	3.46E+12
14	8.90E+10	4.80E+20	2.19E+10	25.182	0.24254	5.80E+10	7.34E+10	8.64E+10	1.02E+11	1.29E+11
15	1.77E+12	1.91E+23	4.37E+11	28.175	0.24279	1.16E+12	1.46E+12	1.72E+12	2.03E+12	2.57E+12
16	5.80E+10	2.03E+20	1.43E+10	24.754	0.24238	3.78E+10	4.78E+10	5.63E+10	6.63E+10	8.39E+10
17	5.64E+11	1.93E+22	1.39E+11	27.028	0.24262	3.67E+11	4.65E+11	5.47E+11	6.45E+11	8.16E+11
18	3.86E+11	9.01E+21	9.49E+10	26.649	0.24246	2.51E+11	3.18E+11	3.75E+11	4.41E+11	5.58E+11
19	3.36E+11	6.85E+21	8.27E+10	26.511	0.24262	2.19E+11	2.77E+11	3.26E+11	3.84E+11	4.86E+11
20	3.60E+11	7.88E+21	8.87E+10	26.581	0.24262	2.35E+11	2.97E+11	3.50E+11	4.12E+11	5.22E+11
21	6.83E+11	2.82E+22	1.68E+11	27.22	0.24246	4.45E+11	5.63E+11	6.63E+11	7.81E+11	9.88E+11
21a	5.79E+11	2.03E+22	1.42E+11	27.055	0.24246	3.77E+11	4.77E+11	5.62E+11	6.62E+11	8.37E+11
22	3.82E+11	8.84E+21	9.40E+10	26.639	0.24262	2.49E+11	3.15E+11	3.71E+11	4.37E+11	5.53E+11
23	1.48E+12	1.33E+23	3.65E+11	27.995	0.24262	9.65E+11	1.22E+12	1.44E+12	1.69E+12	2.14E+12
23a	2.01E+10	2.46E+19	4.96E+09	23.696	0.24271	1.31E+10	1.66E+10	1.95E+10	2.30E+10	2.91E+10
24	1.93E+12	2.25E+23	4.75E+11	28.259	0.24246	1.26E+12	1.59E+12	1.87E+12	2.21E+12	2.79E+12
25	1.99E+12	2.39E+23	4.89E+11	28.287	0.24279	1.29E+12	1.64E+12	1.93E+12	2.27E+12	2.87E+12
26	8.10E+11	3.98E+22	2.00E+11	27.391	0.24262	5.28E+11	6.68E+11	7.87E+11	9.27E+11	1.17E+12
27	4.11E+11	1.02E+22	1.01E+11	26.712	0.24246	2.68E+11	3.39E+11	3.99E+11	4.70E+11	5.94E+11
28	5.39E+11	1.76E+22	1.33E+11	26.984	0.24246	3.51E+11	4.45E+11	5.24E+11	6.17E+11	7.80E+11
P.P.C.	4.89E+13	1.45E+26	1.21E+13			3.19E+13	4.03E+13	4.75E+13	5.60E+13	7.08E+13
Indep.	4.89E+13	1.30E+25	3.60E+12	31.519	0.07352	4.32E+13	4.64E+13	4.88E+13	5.13E+13	5.51E+13

Figure 3. Panel 3 of GRASS spreadsheet for play GKMV4 in the Wind River Basin.

AH	AI	AJ	AK	AL	AM	AN	AO	AP	AQ	AR	AS
Play Name :		Nonmarine Kmv > 300									(Panel 4)
	Mean	Range									
% =	10	6					Recoverable Fractiles				
Sub.	Mean gas	Expect	Var. gas	S.D. gas			F95	F75	F50	F25	F5
No.	(CF)	(Gas)^2	(CF)^2	(CF)	Mu	Sigma	(CF)	(CF)	(CF)	(CF)	(CF)
1	3.37E+10	1.24E+21	1.09E+20	1.04E+10	24.19	0.303	1.96E+10	2.62E+10	3.22E+10	3.95E+10	5.30E+10
2	1.41E+11	2.16E+22	1.90E+21	4.35E+10	25.62	0.303	8.16E+10	1.09E+11	1.34E+11	1.65E+11	2.21E+11
3	5.14E+11	2.90E+23	2.54E+22	1.59E+11	26.92	0.303	2.99E+11	4.01E+11	4.91E+11	6.03E+11	8.09E+11
4	8.10E+11	7.19E+23	6.30E+22	2.51E+11	27.37	0.303	4.70E+11	6.31E+11	7.74E+11	9.49E+11	1.27E+12
5	8.51E+11	7.94E+23	6.95E+22	2.64E+11	27.42	0.303	4.94E+11	6.63E+11	8.13E+11	9.97E+11	1.34E+12
6	3.95E+11	1.71E+23	1.49E+22	1.22E+11	26.66	0.302	2.29E+11	3.08E+11	3.77E+11	4.63E+11	6.21E+11
7	5.25E+10	3.02E+21	2.64E+20	1.63E+10	24.64	0.303	3.05E+10	4.09E+10	5.01E+10	6.15E+10	8.25E+10
7a	2.50E+09	6.83E+18	5.97E+17	7.73E+08	21.59	0.302	1.45E+09	1.95E+09	2.39E+09	2.93E+09	3.92E+09
8	1.88E+11	3.86E+22	3.39E+21	5.82E+10	25.91	0.303	1.09E+11	1.46E+11	1.79E+11	2.20E+11	2.95E+11
9	1.79E+11	3.50E+22	3.06E+21	5.53E+10	25.86	0.303	1.04E+11	1.39E+11	1.71E+11	2.09E+11	2.81E+11
10	1.55E+11	2.62E+22	2.29E+21	4.79E+10	25.72	0.302	8.99E+10	1.21E+11	1.48E+11	1.81E+11	2.43E+11
11	6.96E+09	5.31E+19	4.65E+18	2.16E+09	22.62	0.303	4.04E+09	5.42E+09	6.65E+09	8.15E+09	1.09E+10
12	8.73E+10	8.34E+21	7.30E+20	2.70E+10	25.15	0.303	5.07E+10	6.80E+10	8.34E+10	1.02E+11	1.37E+11
13	2.39E+11	6.28E+22	5.49E+21	7.41E+10	26.16	0.302	1.39E+11	1.87E+11	2.29E+11	2.80E+11	3.76E+11
14	8.90E+09	8.67E+19	7.59E+18	2.75E+09	22.86	0.303	5.17E+09	6.93E+09	8.50E+09	1.04E+10	1.40E+10
15	1.77E+11	3.45E+22	3.02E+21	5.50E+10	25.86	0.303	1.03E+11	1.38E+11	1.69E+11	2.08E+11	2.79E+11
16	5.80E+09	3.69E+19	3.22E+18	1.79E+09	22.44	0.302	3.37E+09	4.52E+09	5.54E+09	6.79E+09	9.11E+09
17	5.64E+10	3.48E+21	3.05E+20	1.75E+10	24.71	0.303	3.27E+10	4.39E+10	5.38E+10	6.60E+10	8.86E+10
18	3.86E+10	1.63E+21	1.43E+20	1.19E+10	24.33	0.302	2.24E+10	3.01E+10	3.69E+10	4.52E+10	6.06E+10
19	3.36E+10	1.24E+21	1.08E+20	1.04E+10	24.19	0.303	1.95E+10	2.62E+10	3.21E+10	3.94E+10	5.28E+10
20	3.60E+10	1.42E+21	1.25E+20	1.12E+10	24.26	0.303	2.09E+10	2.81E+10	3.44E+10	4.22E+10	5.66E+10
21	6.83E+10	5.11E+21	4.47E+20	2.11E+10	24.90	0.302	3.97E+10	5.32E+10	6.52E+10	8.00E+10	1.07E+11
21a	5.79E+10	3.67E+21	3.21E+20	1.79E+10	24.74	0.302	3.36E+10	4.51E+10	5.53E+10	6.78E+10	9.09E+10
22	3.82E+10	1.60E+21	1.40E+20	1.18E+10	24.32	0.303	2.22E+10	2.97E+10	3.65E+10	4.47E+10	6.00E+10
23	1.48E+11	2.41E+22	2.11E+21	4.59E+10	25.68	0.303	8.60E+10	1.15E+11	1.42E+11	1.74E+11	2.33E+11
23a	2.01E+09	4.44E+18	3.88E+17	6.23E+08	21.38	0.303	1.17E+09	1.57E+09	1.92E+09	2.36E+09	3.16E+09
24	1.93E+11	4.08E+22	3.57E+21	5.97E+10	25.94	0.302	1.12E+11	1.50E+11	1.84E+11	2.26E+11	3.03E+11
25	1.99E+11	4.32E+22	3.78E+21	6.15E+10	25.97	0.303	1.15E+11	1.55E+11	1.90E+11	2.33E+11	3.12E+11
26	8.10E+10	7.19E+21	6.30E+20	2.51E+10	25.07	0.303	4.70E+10	6.31E+10	7.74E+10	9.49E+10	1.27E+11
27	4.11E+10	1.85E+21	1.62E+20	1.27E+10	24.39	0.302	2.39E+10	3.20E+10	3.92E+10	4.81E+10	6.45E+10
28	5.39E+10	3.19E+21	2.79E+20	1.67E+10	24.67	0.302	3.13E+10	4.20E+10	5.15E+10	6.32E+10	8.47E+10
PPC	4.89E+12		2.30E+24	1.52E+12			2.84E+12	3.81E+12	4.67E+12	5.73E+12	7.69E+12
Ind.	4.89E+12		2.05E+23	4.53E+11	29.21	0.092	4.19E+12	4.58E+12	4.87E+12	5.19E+12	5.67E+12

Figure 4. Panel 4 of GRASS spreadsheet for play GKMV4 in the Wind River Basin.

A	B	C	D	E	F	G	H	I	J	K
Aggregation Name :			Wind River Basin							
	In-place	In-place	In-place			In-place Fractiles				
Play	Mean gas	Var. gas	S.D. gas			F95	F75	F50	F25	F5
Name	(CF)	(CF)^2	(CF)	Mu	Sigma	(CF)	(CF)	(CF)	(CF)	(CF)
TFU1	8.3E+13	1.39E+27	3.73E+13	0	0	3.74E+13	5.67E+13	7.57E+13	1.01E+14	1.53E+14
TFU2	1.82E+13	7.95E+25	8.92E+12	0	0	7.64E+12	1.20E+13	1.64E+13	2.24E+13	3.51E+13
LANCE1	3.16E+14	6.37E+27	7.98E+13	0	0	2.03E+14	2.59E+14	3.06E+14	3.62E+14	4.61E+14
LANCE2	4.89E+13	5.72E+26	2.39E+13	0	0	2.05E+13	3.22E+13	4.40E+13	6.01E+13	9.41E+13
MEET1	5.13E+13	1.59E+26	1.26E+13	0	0	3.34E+13	4.23E+13	4.98E+13	5.86E+13	7.42E+13
MEET2	5.97E+13	2.27E+26	1.51E+13	0	0	3.84E+13	4.89E+13	5.79E+13	6.84E+13	8.71E+13
MEET3	1.25E+13	3.72E+25	6.1E+12	0	0	5.23E+12	8.20E+12	1.12E+13	1.53E+13	2.40E+13
KMV1	3.47E+13	7.3E+25	8.55E+12	0	0	2.26E+13	2.86E+13	3.37E+13	3.97E+13	5.02E+13
KMV2	1.72E+13	1.89E+25	4.35E+12	0	0	1.11E+13	1.41E+13	1.67E+13	1.98E+13	2.52E+13
KMV3	3.84E+12	3.52E+24	1.88E+12	0	0	1.61E+12	2.52E+12	3.45E+12	4.71E+12	7.38E+12
KMV4	4.89E+13	1.45E+26	1.21E+13	0	0	3.19E+13	4.03E+13	4.75E+13	5.60E+13	7.08E+13
KMV5	7.18E+13	3.28E+26	1.81E+13	0	0	4.63E+13	5.89E+13	6.96E+13	8.23E+13	1.05E+14
KMV6	1.74E+13	7.24E+25	8.51E+12	0	0	7.30E+12	1.14E+13	1.56E+13	2.14E+13	3.35E+13
CODY1	3.06E+13	5.67E+25	7.53E+12	0	0	1.99E+13	2.52E+13	2.97E+13	3.50E+13	4.42E+13
CODY2	1.92E+13	2.34E+25	4.84E+12	0	0	1.24E+13	1.57E+13	1.86E+13	2.20E+13	2.80E+13
CODY3	1.97E+12	9.31E+23	9.65E+11	0	0	8.25E+11	1.29E+12	1.77E+12	2.42E+12	3.79E+12
FRONT1	1.18E+14	8.39E+26	2.9E+13	0	0	7.65E+13	9.69E+13	1.14E+14	1.34E+14	1.70E+14
FRONT2	2.92E+13	5.46E+25	7.39E+12	0	0	1.88E+13	2.39E+13	2.83E+13	3.35E+13	4.26E+13
FRONT3	3.95E+12	3.74E+24	1.93E+12	0	0	1.65E+12	2.60E+12	3.55E+12	4.85E+12	7.60E+12
FALES1	1.18E+12	8.5E+22	2.92E+11	0	0	7.71E+11	9.76E+11	1.15E+12	1.35E+12	1.71E+12
FALES2	7.31E+12	3.42E+24	1.85E+12	0	0	4.70E+12	5.99E+12	7.08E+12	8.38E+12	1.07E+13
FALES3	5.36E+11	6.89E+22	2.62E+11	0	0	2.25E+11	3.53E+11	4.82E+11	6.58E+11	1.03E+12
Aggregation:										
P.P.C.	9.95E+14	8.48E+28	2.91E+14			6.03E+14	7.88E+14	9.52E+14	1.15E+15	1.53E+15
Indep.	9.95E+14	1.05E+28	1.02E+14	34.52829	0.102545	8.36E+14	9.23E+14	9.90E+14	1.06E+15	1.17E+15

Figure 5. GRASSAG spreadsheet for aggregation of 22 plays in the Wind River Basin.

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