CASE STUDY 1

Production Rate Forecast and Evaluation using Monte Carlo Simulation

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Outline

- Summary of active wells
  - Gas wells, oil wells, and gas-condensate wells
- Decline curve analysis of individual wells
  - FAST-RTA used for the analysis
  - Exponential decline, $q=q_i \exp(-Dt)$, (rate-time simultaneously with rate-cumulative)
  - Estimated quantities:
    - Initial flow rate, qi (MMscf/day, or bbl/day)
    - Decline rate, D (1/year)
    - Expected ultimate recovery, EUR (Bscf, or Mbbl)
- Discussion on the Monte Carlo Simulation
  - MC simulation input data and procedure
  - Wildcat case studies
  - Discussion on the field development using MC simulation
  - Report

Active Wells

- Total number of active wells: 154

Active wells to be used in the MC simulation:

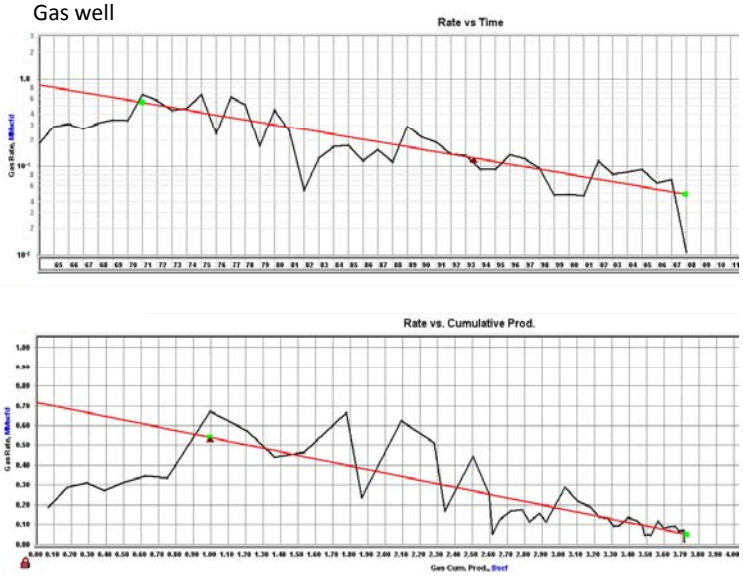
- Dry wells: 0
- Gas wells: 68
- Oil wells: 31
- Gas condensate wells: 28
- Total: 127

Active wells not included:

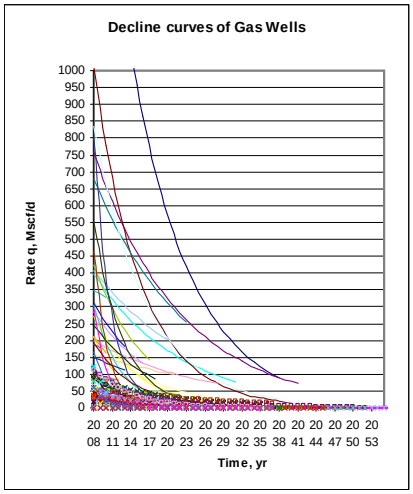
- Gas wells: 3
- Oil wells: 9
- Gas condensate: 15
- Total: 26

Typical Decline Curves

Gas well



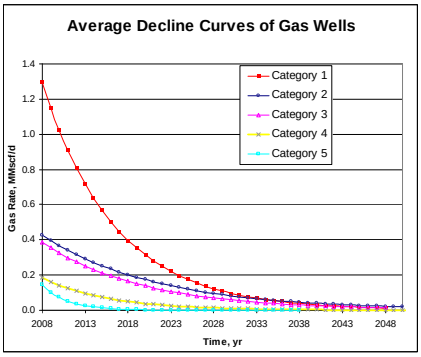
Gas Wells



5 categories for the gas wells are identified based on predicted EUR:

Categ. No	EUR Bscf	Events (# of wells)	Probability	Cumulative Probability
5	<1.0	42	61.76%	61.76%
4	1.0-2.0	12	17.65%	79.41%
3	2.0-3.0	4	5.88%	85.29%
2	3.0-4.0	4	5.88%	91.17%
1	>4.0	6	8.83%	100.00%

5 Type Curves of Gas Wells



Categ. No	EUR Bscf	D_{ave}	$q_{i,ave}$	EUR_{ave}
5	<1.0	0.3437	0.1448	0.4038
4	1.0-2.0	0.1336	0.1863	1.2792
3	2.0-3.0	0.0855	0.3855	2.4338
2	3.0-4.0	0.0750	0.4260	3.3755
1	>4.0	0.1178	1.2943	5.6560

Oil and Gas-condensate Wells

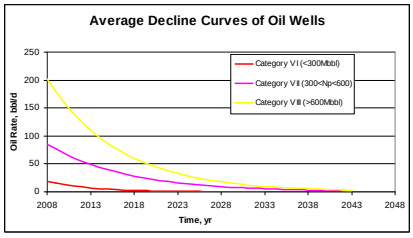
3 categories for the oil wells are identified:

Category Number	EUR Mbbl	Events (# of wells)	Probability	Cumulative Probability
6	<300	20	64.52%	64.52%
7	300-600	5	16.13%	80.65%
8	>600	6	19.35%	100.00%

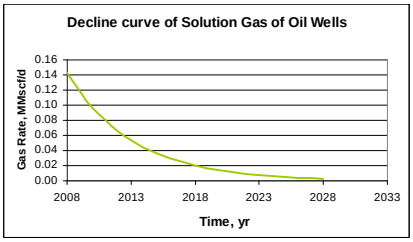
3 categories for the gas condensate wells are identified:

Category Number	EUR Bscf	Events (# of wells)	Probability	Cumulative Probability
9	<3.0	12	42.86%	42.86%
10	3.0-6.0	11	39.29%	82.15%
11	>6.0	5	17.86%	100.00%

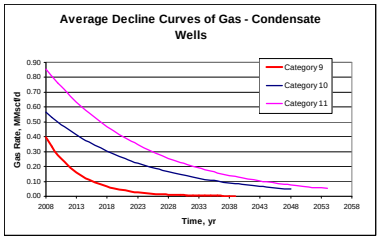
3 Type Curves of Oil Wells



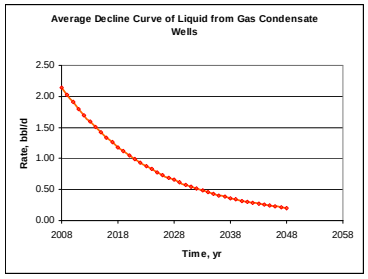
Category Number	EUR Mbbl	D_{ave}	qi_{ave}	EUR_{ave}
6	<300	0.1970	19.14	62.61
7	300-600	0.1102	85.5	409.6
8	>600	0.1210	202.6	1515.8



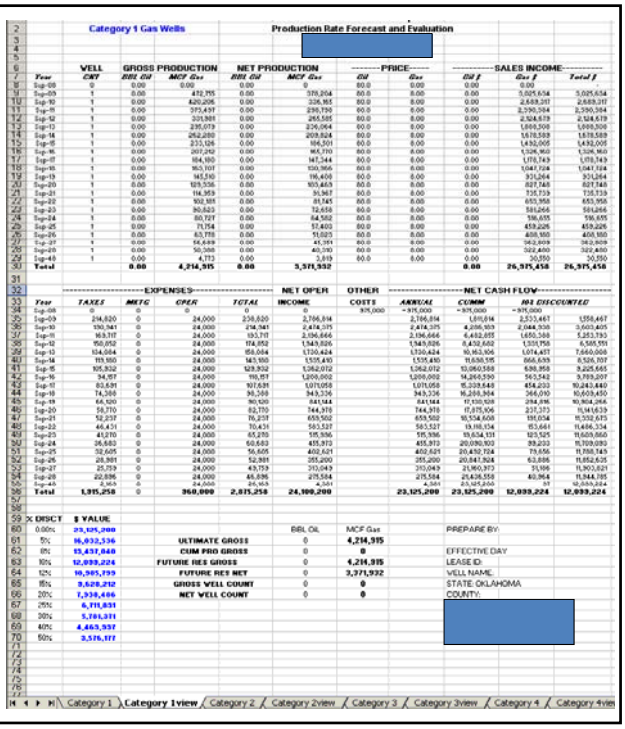
3 Type Curves of Condensate Wells



Category number	EUR Bscf	D_{ave}	qi_{ave}	EUR_{ave}
9	<3.0	0.1805	0.3981	1.7327
10	3.0-6.0	0.0616	0.5639	4.3157
11	>6.0	0.0604	0.8572	6.7070



prepare tabulated results for each category of wells as follows:



MC Simulations

- Wild Cat
  - 20 Wells
- Field Development
  - 120 wells
  - Drill 5 wells each month

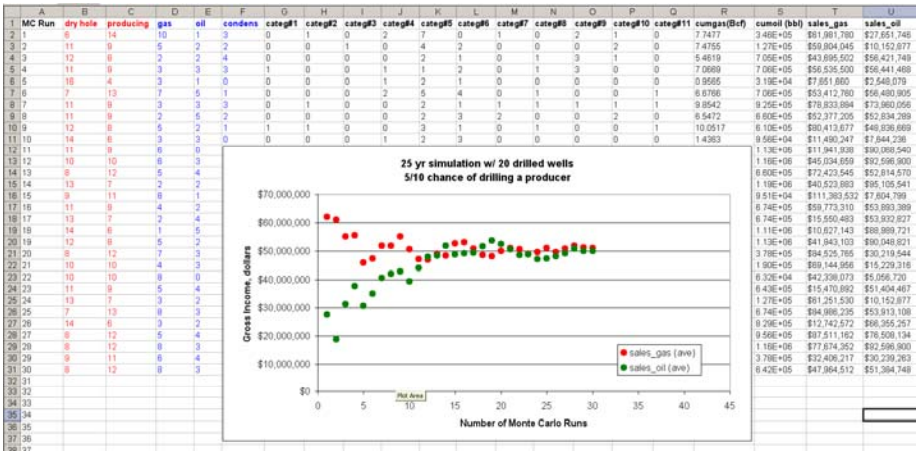
MC Simulation, dataset

- All wells are assumed to be independent events
- Drilling phase for a well: 2 weeks, $700,000
- Completion phase for a well: 1 months, $275,000
- Net production is 80% of gross production
- Price of oil= $87.32/STB
- Price of gas=$3.85 /Mscf
- Taxes= % 7.1 of the total sales income
- Average operational expenses= $2,000/month/well
- 25 years of production
- Number of wells:
  - 20 wells (wildcat simulation)
  - 120 wells (field-scale development)

MC Simulation: procedure

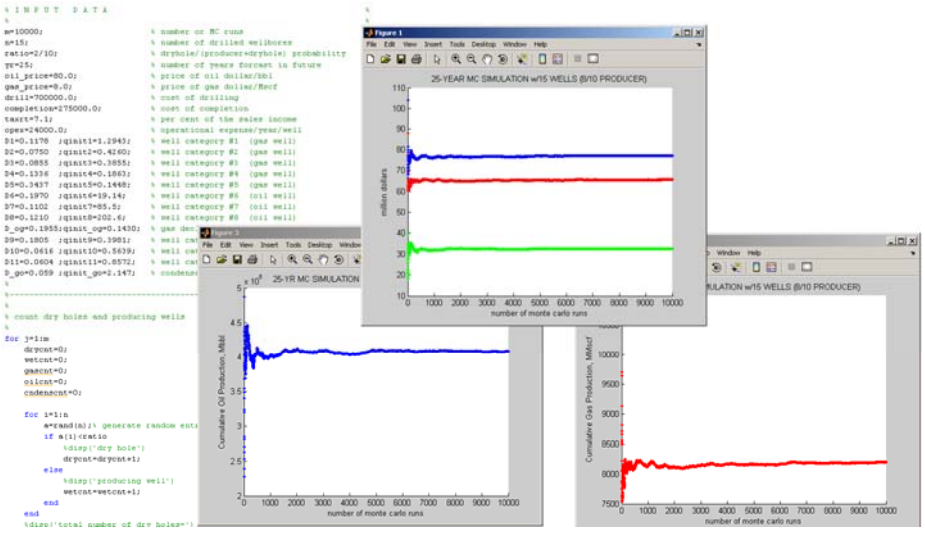
```
% Monte Carlo Simulation
% developed by I.Y. Akkutlu, University of Oklahoma, MPGE
% July 2008
%
clear all
%
%
%-------------------------------------------------------------------------
% I N P U T   D A T A                                                    %
%                                                                        %
m=30;                       % number or MC runs                        %
n=20;                       % number or drilled wellbores              %
ratio=0.5;                  % dryhole/(producer+dryhole) probability   %
yr=25;                      % number of years forcast in future        %
oil_price=80.0;             % price of oil dollar/bbl                  %
gas_price=8.0;              % price of gas dollar/Mscf                 %
drill=700000.0;             % cost of drilling                         %
completion=275000.0;        % cost of completion                       %
taxrt=7.1;                  % per cent of the sales income             %
opex=24000.0;               % operational expense/year/well            %
D1=0.1170  ;qiniti=1.2943;  % well category #1  (gas well)            %
D2=0.0750  ;qiniti2=0.4260; % well category #2  (gas well)            %
D3=0.0855  ;qiniti3=0.3855; % well category #3  (gas well)            %
D4=0.1336  ;qiniti4=0.1063; % well category #4  (gas well)            %
D5=0.3437  ;qiniti5=0.1448; % well category #5  (gas well)            %
D6=0.1970  ;qiniti6=19.14;  % well category #6  (oil well)            %
D7=0.1102  ;qiniti7=85.5;   % well category #7  (oil well)            %
D8=0.1210  ;qiniti8=202.6;  % well category #8  (oil well)            %
D_og=0.1955;qiniti_og=0.1430; % gas decline rate for categs #6 thru #8 %
D9=0.1005  ;qiniti9=0.2994; % well category #9  (gas-condensate well) %
D10=0.0616 ;qiniti10=0.5639; % well category #10 (gas-condensate well) %
D11=0.0604 ;qiniti11=0.0572; % well category #11 (gas-condensate well) %
D_gs=0.059 ;qinit_gs=2.147; % condensate decline for categ #9 thru #11 %
%                                                                        %
%-------------------------------------------------------------------------
%
% count dry holes and producing wells
%
for j=1:m
    drycnt=0;
    wetcnt=0;
    gascnt=0;
    oilcnt=0;
    condencnt=0;

    for i=1:n
        a=rand(n);% generate random entries from uniform distribution [0,1]
```

MC Simulation: procedure (cont.)



MC Run	dry hole	producing	gas	oil	condens	categ#1	categ#2	categ#3	categ#4	categ#5	categ#6	categ#7	categ#8	categ#9	categ#10	categ#11	cumgas(Bcf)	cumoil (bbl)	sales_gas	sales_oil
1	6	14	10	1	3	0	1	0	2	7	0	1	0	2	1	0	7.7477	3.46E+05	$61,981,780	$27,651,746
2	11	9	5	2	2	0	0	1	0	4	2	0	0	0	2	0	7.4755	1.27E+05	$59,804,045	$10,152,877
3	12	8	2	2	4	0	0	0	0	2	1	0	1	3	1	0	5.4619	7.05E+05	$43,695,502	$56,421,749
4	11	9	3	3	3	1	0	0	1	1	2	0	1	3	0	0	7.0689	7.06E+05	$56,535,500	$56,441,468
5	18	4	3	1	0	0	0	0	1	2	1	0	0	0	0	0	0.9585	3.19E+04	$7,651,860	$2,548,079
6	7	13	7	5	1	0	0	0	2	5	4	0	1	0	0	1	6.6766	7.08E+05	$53,412,760	$56,480,905
7	11	9	3	3	3	0	1	0	0	2	1	1	1	1	1	1	9.8542	9.25E+05	$78,833,884	$73,960,056
8	13	7	2	5	2	0	0	0	0	2	3	2	0	0	2	0	6.5472	6.60E+05	$52,377,205	$52,834,289
9	12	8	5	2	1	1	1	0	0	3	1	0	1	0	0	1	10.0517	8.10E+05	$80,413,677	$48,836,669
10	14	6	3	3	0	0	0	0	1	2	3	0	0	0	0	0	1.4383	9.58E+04	$11,490,247	$7,844,236
11	11	9	6	0														1.13E+06	$11,941,938	$90,068,540
12	10	10	6	3														1.16E+06	$45,034,659	$92,596,900
13	9	12	5	4														8.60E+05	$72,423,545	$52,814,570
14	13	7	2	2														1.19E+06	$40,523,883	$95,105,541
15	9	11	8	1														9.51E+04	$111,383,532	$7,604,799
16	11	9	4	2														6.74E+05	$59,773,310	$53,893,389
17	13	7	2	4														6.74E+05	$15,550,483	$53,932,827
18	14	6	1	5														1.11E+06	$10,827,143	$88,989,721
19	12	8	5	2														1.13E+06	$41,943,103	$90,048,821
20	8	12	7	3														3.78E+05	$94,525,765	$30,219,544
21	10	10	4	3														1.90E+05	$89,144,956	$15,229,316
22	10	10	8	0														6.32E+04	$42,338,073	$5,056,720
23	11	9	5	4														6.43E+05	$15,470,892	$51,404,467
24	13	7	3	2														1.27E+05	$81,251,530	$10,152,877
25	7	13	8	3														6.74E+05	$94,886,235	$53,913,108
26	14	6	3	2														8.29E+05	$12,742,572	$66,355,257
27	8	12	5	4														9.56E+05	$87,511,162	$76,508,134
28	8	12	8	3														1.16E+06	$77,674,352	$92,596,900
29	9	11	6	4														3.76E+05	$32,406,217	$30,239,263
30	8	12	8	3														6.42E+05	$47,964,512	$51,384,748
31																				
32																				
33																				
34																				
35																				
36																				
37																				

MC Simulation: procedure (cont.)



15 wildcats, 80% success, 25-year production

	GROSS PRODUCTION	
	Annual Oil, bbl	Annual Gas, Bscf
Sep-08	0.0000	0.0000
Sep-09	63617	1.1600
Sep-10	55906	1.0087
Sep-11	49180	0.8835
Sep-12	43305	0.7790
Sep-13	38167	0.6907
Sep-14	33669	0.6156
Sep-15	29727	0.5511
Sep-16	26269	0.4954
Sep-17	23231	0.4468
Sep-18	20561	0.4043
Sep-19	18211	0.3669
Sep-20	16142	0.3338
Sep-21	14318	0.3044
Sep-22	12709	0.2781
Sep-23	11289	0.2546
Sep-24	10033	0.2335
Sep-25	8924	0.2145
Sep-26	7942	0.1973
Sep-27	7072	0.1817
Sep-28	6302	0.1676
Sep-29	5619	0.1547
Sep-30	5013	0.1430
Sep-31	4475	0.1323
Sep-32	3997	0.1225
Sep-33	3573	0.1135
		10.2335

15 wildcats, 80% success, 10-year production

GROSS PRODUCTION		NET PRODUCTION		PRICE		SALES INCOME		
BBL Oil	MCF Gas	BBL Oil	MCF Gas	Oil	Gas	Oil $	Gas $	Total $
0.00	0.00	0.00	0	80.0	0.00	0.00	0.00	0.00
63,617	1,160,000	50,894	928,000	80.0	8.00	4,071,488	7,424,000	11,495,488
55,906	1,008,700	44,725	806,960	80.0	8.00	3,577,984	6,455,680	10,033,664
49,180	883,500	39,344	706,800	80.0	8.00	3,147,520	5,654,400	8,801,920
43,305	779,000	34,644	623,200	80.0	8.00	2,771,520	4,985,600	7,757,120
38,167	690,700	30,534	552,560	80.0	8.00	2,442,688	4,420,480	6,863,168
33,669	615,600	26,935	492,480	80.0	8.00	2,154,816	3,939,840	6,094,656
29,727	551,100	23,782	440,880	80.0	8.00	1,902,528	3,527,040	5,429,568
26,269	495,400	21,015	396,320	80.0	8.00	1,681,216	3,170,560	4,851,776
23,231	446,800	18,585	357,440	80.0	8.00	1,486,784	2,859,520	4,346,304
20,561	404,300	16,449	323,440	80.0	8.00	1,315,904	2,587,520	3,903,424
383,632	**7,035,100**	**306,906**	**5,628,080**			**24,552,448**	**45,024,640**	**69,577,088**

EXPENSES			NET OPER	OTHER	NET CASH FLOW			
MKTG	OPER	TOTAL	INCOME	COSTS	ANNUAL	CUM	10% DISCOUNTED	
0	0	0	0	13,800,000	(13,800,000)	(13,800,000)	(13,800,000)	(13,800,000)
0	288,000	1,104,180	10,391,308	0	10,391,308	(3,408,692)	9,446,644	(4,353,356)
0	288,000	1,000,390	9,033,274	0	9,033,274	5,624,582	7,465,516	3,112,160
0	288,000	912,936	7,888,984	0	7,888,984	13,513,566	5,927,110	9,039,270
0	288,000	838,756	6,918,364	0	6,918,364	20,431,930	4,725,336	13,764,606
0	288,000	775,285	6,087,883	0	6,087,883	26,519,813	3,780,096	17,544,702
0	288,000	720,721	5,373,935	0	5,373,935	31,893,749	3,033,446	20,578,149
0	288,000	673,499	4,756,069	0	4,756,069	36,649,818	2,440,615	23,018,764
0	288,000	632,476	4,219,300	0	4,219,300	40,869,117	1,968,335	24,987,098
0	288,000	596,588	3,749,716	0	3,749,716	44,618,834	1,590,246	26,577,344
0	288,000	565,143	3,338,281	0	3,338,281	47,957,115	1,287,052	27,864,396
0	**2,880,000**	**7,819,973**	**61,757,115**	**13,800,000**	**47,957,115**	**47,957,115**	**27,864,396**	**27,864,396**

	BBL Oil	MCF Gas	
ULTIMATE GROSS	383,632	7,035,100	PREPARE BY:
CUM PRO GROSS	0	0	EFFECTIVE DAY
FUTURE RES GROSS	383,632	7,035,100	LEASE ID:
FUTURE RES NET	306,906	5,628,080	WELL NAME:
GROSS WELL COUNT	0	0	STATE: OKLAHOMA
NET WELL COUNT	0	0	COUNTY:

Make comparisons with the traditional (deterministic) approach

Traditional Approach by the Exploration Geologist:

G	H	I	J	K
12 discoveries from 15 wildcats (80% success)				
no development drilling				
LEASEHOLD				
	acres	$/acre		
	100,000	$50.00		$5,000,000.00
SEISMIC				
	sections	$/section		
	781	$65,000.00		$50,765,000.00
DRILLING	80% (Chance of success)			
	wells			
dry	3	$700,000.00		$2,100,000.00
compl.	12	$975,000.00		$11,700,000.00
				$69,565,000.00
RESERVES				
			# of wells	
gas (MCFG)	1,189,000	$8.00	12	$114,144,000.00
oil (bbls)	36,750	$80.00	12	$35,280,000.00
				$149,424,000.00
			ROI	2.15

MC Simulation (25 yr):
net gas produced: 8.20 Bscf
net oil produced: 414.51 Mbbl
gas : 65.60 MM$
oil: 33.16 MM$
total: 98.76 MM$

ROI=1.42
net income=70.46 MM$

MC Simulation, wildcat: case 1

- 25 years of production (Sept 2011→Sept 2036)
- 20 wells (dryhole+producer)
- Each simulation has 10,000 realizations
- Result is an arithmetic average of three simulations

(prod/ dryhole+prod) Ratio:	5/10	4/10	3/10	2/10	1/10
Net gas, Bscf	6.86	5.46	4.11	2.74	1.37
Net oil, Mbbl	341.0	275.0	205.0	137.4	68.2
Gas Sales, MM$	54.89	43.71	32.91	21.89	10.93
Oil Sales, MM$	27.26	22.00	16.40	10.99	5.46
Net Income, MM$	53.60	40.02	26.70	12.90	-0.5146

MC Simulation, wildcat: case 2

- 25 years of production (Sept 2011→Sept 2036)
- 15 wells (dryhole+producer)
- Each simulation has 10,000 realizations
- Result is an arithmetic average of three simulations

(prod/ dryhole+prod) Ratio:	5/10	4/10	3/10	2/10	1/10
Net gas, Bscf	5.09	4.09	3.07	2.04	1.02
Net oil, Mbbl	255.4	207.7	155.1	102.7	51.3
Gas Sales, MM$	40.74	32.75	24.59	16.34	8.14
Oil Sales, MM$	20.43	16.62	12.41	8.22	4.10
Net Income, MM$	40.06	29.93	20.06	9.83	-0.3673

MC Simulation, wildcat: case 3

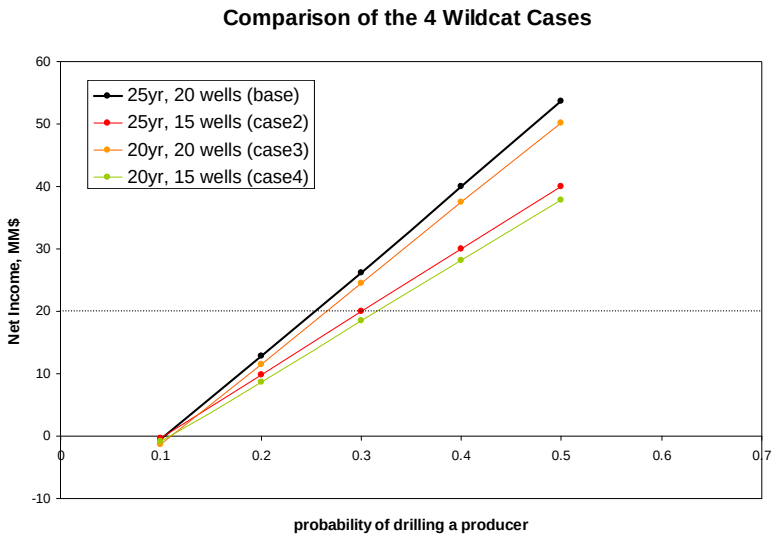
- 20 years of production (Sept 2011→Sept 2031)
- 20 wells (dryhole+producer)
- Each simulation has 10,000 realizations
- Result is an arithmetic average of three simulations

(prod/ dryhole+prod) Ratio:	5/10	4/10	3/10	2/10	1/10
Net gas, Bscf	6.40	5.10	3.83	2.56	1.29
Net oil, Mbbl	327.3	263.2	196.1	131.4	65.39
Gas Sales, MM$	51.21	40.81	30.68	20.46	10.27
Oil Sales, MM$	26.18	21.06	15.69	10.51	5.23
Net Income, MM$	50.20	37.45	24.52	11.58	-1.26

MC Simulation, wildcat: case 4

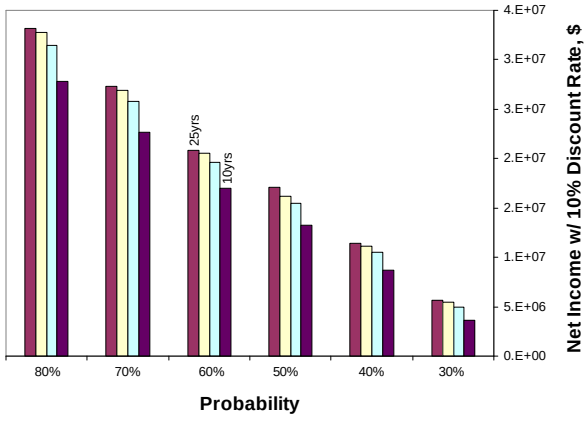
- 20 years of production (Sept 2011→Sept 2031)
- 15 wells (dryhole+producer)
- Each simulation has 10,000 realizations
- Result is an arithmetic average of three simulations

(prod/ dryhole+prod) Ratio:	5/10	4/10	3/10	2/10	1/10
Net gas, Bscf	4.79	3.84	2.88	1.91	0.9531
Net oil, Mbbl	244.7	196.1	147.1	99.4	48.44
Gas Sales, MM$	38.27	30.70	23.07	15.31	7.62
Oil Sales, MM$	19.58	15.69	11.77	7.95	3.88
Net Income, MM$	37.90	28.20	18.51	8.71	-0.9132



Influence of Number of Forecast Years on Net Income

w/ 15 wildcats



MC Simulations homework

- Field Development
  - 120 wells
  - Drill 2 wells each month
  - 10 year economical analysis with 80% chance of dry well
  - 20 year economical analysis with 20% chance of dry well