STATE OF NORTH DAKOTA POSSIBLE (3P10) OIL RESERVES PROJECT

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Estimation of Sizes and Numbers of Undiscovered Pools, North Dakota Williston Basin

Background

The earliest study to apply what came to be called discovery process modeling was Arps and Roberts (1958), who attempted to characterize the undiscovered reserves in the Cretaceous strata of the east flank of the Denver Basin. Since then, there have been numerous studies estimating undiscovered reserves in various places; much of the work has been done by the U.S. Geological Survey (e.g., Drew et al., 1980; Root and Schuenemeyer, 1980; Drew et al., 1982). Estimation of the undiscovered reserves requires that we know the sizes of the pools, the area of the pools, the area of the basin, the pool discovery dates, and wildcat histories.

Methods and Procedures

Pool Sizes

The pool sizes were taken from the estimates of the ultimate recovery from active pools and units in North Dakota (McCusker and Legerski, 2006). Recoveries were estimated for 613 active pools and units. In addition, pools which are no longer active were added to the list, bringing the total to 1,058 pools and units. As an aid to analysis, the pools were divided into USGS size classes (Table 1). The pool sizes were considered to be the estimated ultimate recovery (EUR) of active pools, and the total production for inactive pools. Only those pools which were class 8 or larger were considered, as smaller pools were considered likely to be affected by economic truncation. There were ten active pools which do not have a long enough production history to allow a normal calculation of EUR; the EUR values for those pools were based on estimates provided by the companies at hearings.

Pools and units as geologic entities

For accurate analysis, the pools should be considered as geologic rather than regulatory entities, with both EUR and area calculated for contiguous reservoirs, regardless of existing field and pool definitions. Where appropriate, in some pools, one of these actions was taken: 1) combining multiple pools into a single pool; or 2) splitting a single pool into multiple entities.

Combination of pools

Pools were combined only if they appeared to be physically contiguous at the same horizon, if the pools or fields were adjacent, and if they were producing from the same stratigraphic horizon, with no dry holes or large gaps between pools. All of the unitized parts of fields were combined with remaining non-unitized parts, provided they met the criteria mentioned above. In addition, pools from different fields were combined using the same criteria. A total of 56 unitized pools were combined with the non-unitized parts (Table 1), and 8 pairs of pools from different fields or pools were combined (Table 2). In all combinations, the combined EUR was obtained by totaling EUR values or total production for the individual parts.

Splitting existing pools

Pools were split into smaller entities only if the parts appeared to be distinct enough to be considered different accumulations. Pools were split if: 1) parts of the pool were on different geologic structures, or greatly different levels on the same structure; or 2) groups of producing wells were geographically distant from one another, or if dry holes existed between the groups. Altogether, 26 pools were split into parts. The EUR values for the split parts were calculated for each part, using the same methods used to calculate the original P1 estimates. If the newly defined split pools were smaller than class 8, they were not considered in the analysis. The total number of pools greater than class 8 for each producing interval, after combining and splitting operations, is given in Table 5.

Pool Areas

The area occupied by each pool was calculated in one of two ways: 1) if a pool had more than three wells, a line was drawn which enclosed but was slightly outside all of the producing wells, and the area covered was measured; 2) if the pool had three or fewer wells, the area was assumed to be the pool spacing multiplied by the number of wells. A summary of pool areas for the analyzed horizons is given in Table 6.

Discovery wells

The discovery well for each pool was considered to be the well which had the earliest production from the pool, regardless of amount. Discoveries were for the field and pool as currently defined. The date of discovery was considered to be the completion date for the discovery well.

Exploratory wells

Exploratory wells include all wells which penetrate a stratigraphic horizon in areas where there is no existing production. This includes all wells labeled as wildcat wells, as well as any wells drilled within existing fields which penetrated horizons which have not produced. Exploratory wells for each producing horizon were tallied separately. For instance, an exploratory well which reached the Madison would be counted as a Madison exploratory well, while one that reached the Red River Fm would be considered an exploratory well for the Madison, Bakken, Birdbear, Duperow, Silurian, Stonewall, and Red River. A well drilled to the Silurian in a field that had Madison and Birdbear production would be an exploratory well only for the Bakken, Duperow, and Silurian. The number of exploratory wells for each horizon analyzed is given in Table 7. As expected, the number of exploratory wells decreases with lower stratigraphic position; the exception to this is the Bakken Formation, which has a more restricted sub crop area than the other units, and thus fewer wildcat wells.

Exclusions

Many pools were excluded from statistical analysis, for various reasons: 1) those pools whose ultimate recovery placed them below class 8, as described above; 2) producing intervals for which insufficient numbers of pools exist in any size class for analysis. The horizons which fell into this category include Tyler, Spearfish, Dawson Bay, Winnipegosis, and Cambro-Ordovician.; 3) Pools in Mondak Field. All of these pools have unusually large areas for their size class. Moreover, a significant portion of Mondak Field is within Montana, and the ultimate production is difficult to determine with the available information.

The numbers of pools in each size class for the horizons analyzed are given in Table 8. The tallies represent totals after all combination and splitting of pools.

Analysis

Method

The mathematical model used here was developed by the U.S. Geological Survey (see Drew et al., 1982), and considers that the number of pools of a given size to be discovered is a function of the area of the pools, the area of the basin, the total number of wildcat wells drilled, and the total number of pools of the given size which exist in the basin.

$$F_S(w) = F_S(\infty)\left[1 - e^{\frac{-CAw}{B}}\right]$$

where: *w* = cumulative number of wildcat wells
A = average areal extent of pools in given size class
B = area of basin
C = efficiency of discovering pools of size S (random=1, non-random >1)
F_S (*w*) = cumulative number of pools expected to be discovered in size class S by the drilling of *w* wildcat wells
F_S (∞) = ultimate number of pools of size class S that exist in the basin

Application

For each size class, the number of cumulative discovery wells was plotted against the number of wildcat wells which had been drilled at the time of discovery. An example is shown in Figure 1, which depicts the cumulative discoveries and cumulative wildcat wells for Madison class 11 pools (1,024,000-2,048,000 bbls EUR).

For each class and horizon analyzed, the discovery curve was then fit to the theoretical model. The average pool area was assumed to be the average area of the existing pools in that class. The extent of the basin was considered to include only the limits of current and former fields; the basin area was estimated by drawing a convex polygon around the fields. The area of the basin is 22,000 sq mi.

With each analysis, it was necessary to solve the equation above for two unknowns, the ultimate number of pools in the class ($F_S(\infty)$), and the discovery efficiency C. Simple regression techniques are not suitable for the analysis. Instead, nonlinear optimization was used, where the unknowns are initially estimated, and allowed to vary simultaneously to converge on a solution.

An example is shown in Figure 2. The principal solution criterion was the minimum squared distance between the observed discovery values and the equation. In a few cases, the optimization would not converge on a solution; in others, there were too few pools for analysis.

No estimates were generated for those cases. All estimates presented are statistically significant fits at the .05 level or better.

Results

The results of the analyses are presented in Table 9. For the less productive horizons (part B), it was necessary to combine several classes in order to attempt the analysis.

Not surprisingly, the analysis predicts that very few fields remain to be found for size classes 14 or better (> 8,192,000 bbls EUR). For the major producing horizons, the total predicted remaining to be found was about 1,633,000,000 bbls, somewhat less than the current total EUR estimates for active pools (approx. 2,009,000,000 bbls). The majority of the predicted volume is from pools in size class 10 or less (<1,024,000 bbls EUR).

For the less productive horizons, the analysis predicts a total of about 110,800,000 bbls remain to be found. Because of the small number of pools, and the necessity for combining size classes for some of the analyses, the estimates for these horizons may not be as reliable as for the more productive horizons.

One of these less productive horizons is the Bakken Formation, which is currently the subject of intense exploratory activity, which makes extensive use of new drilling technologies.
The new technologies, when successfully applied, can greatly increase production rates and, probably, ultimate recoveries. This makes it difficult to compare some new pools with older ones in the formation, and could also cause an underestimation of the future production capabilities of the unit. The Bakken Formation, and any other units which have been drilled with newer technologies, should be re-evaluated every few years so that significant differences in pool characteristics and production can be identified.

References Cited

Arps, J.J., and Roberts, T.G., 1958, Economics of drilling for Cretaceous oil on east flank of Denver-Julesburg Basin: American Association of Petroleum Geologists Bulletin: v. 42, p. 2549-2566.

Drew, L.J., Schuenemeyer, J.H., and Bawiec, W.J., 1982, Estimation of future rates of oil and gas discoveries in the western Gulf of Mexico: U.S. Geological Survey Professional Paper 1252, 26 p.

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Table 1. U.S. Geological Survey EUR classification of pool size

Class	EUR (lower)	EUR (upper)
8	128,000	256,000
9	256,000	512,000
10	512,000	1,024,000
11	1,024,000	2,048,000
12	2,048,000	4,096,000
13	4,096,000	8,192,000
14	8,192,000	16,384,000
15	16,384,000	32,768,000
16	32,768,000	65,536,000
17	65,536,000	131,072,000
18	131,072,000	262,144,000
19	262,144,000	524,288,000

Table 2. Unitized Pools Combined with Non-unitized parts

Field/Unit	Pool
Amor	Red River
Antler	Madison
Baumann Drain	Madison
Bear Creek	Duperow
Beaver Lodge	Silurian
Beaver Lodge	Madison
Beaver Lodge	Ordovician
Big Stick	Madison
Blue Buttes	Madison
Capa	Madison
Cedar Hills	Red River B
Charlson	Madison
Clear Creek	Madison
Coyote Creek	Red River
Dickinson	Lodgepole Unit
Eland	Lodgepole
Flaxton	Madison
Fryburg	Madison
Glass Bluff	Madison
Glenburn	Madison
Grand River	Red River
Haas	Madison
Hofflund	Madison
Horse Creek	Red River
Knutson	Madison
Lake Darling	Madison
Landa	Madison
Little Missouri	Red River
Little Knife	Madison
Lone Tree	Madison
Mackobee Coulee	Madison
Medicine Pole Hills	Red River
Medora	Madison
Mouse River Park	Madison
Newburg	Spearfish/Charles
North Westhope	Madison
North Grano	Madison
Northeast Foothills	Madison
Plaza	Madison
Red Wing Creek	Madison
Rival	Madison
Rocky Ridge	Heath
Rough Rider	Madison

Scotia	Madison
South Westhope	Spearfish/Charles
South Antler Creek	Madison
State Line	Red River
Stoneview	Stonewall
T. R.	Madison
Temple	Winnipegosis
Tioga	Madison
Tracy Mountain	Tyler
Wabek	Madison
Wiley	Madison
Zenith	Heath/Tyler

Table 3. Combined Fields

Field	Pool
Dickinson	Lodgepole
West Dickinson	Lodgepole
Lakeside	Midale/Nesson
Lakeside	Madison
Lost Bridge	Devonian
Lost Bridge	Duperow
Big Stick	Madison
T. R.	Madison
Glass Bluff	Madison
Elk	Madison
Tree Top	Madison
Whiskey Joe	Madison
Haas	Madison
North Haas	Madison
Elkhorn Ranch	Madison
North Elkhorn Ranch	Madison

Table 4. Pools split into separate parts

Field	Pool	No. Parts
Big Stick	Duperow	2
Blue Buttes	Duperow	3
Buckhorn	Madison	2
Camel Butte	Madison	2
Charlson	Madison	2
Charlson	Red River	2
Charlson	Silurian	2
Charlson	Devonian	2
Cherry Creek	Duperow	2
Crooked Creek	Madison	2
Elk	Duperow	2
Elkhorn Ranch/North Elkhorn Ranch	Madison	3
Flat Top Butte	Duperow	2
Fryburg	Madison	3
Glenburn	Madison	3
Hamlet	Madison	2
Lake Darling	Madison	3
Little Knife	Duperow	3
McGregor	Madison	2
Rough Rider	Red River	2
Rough Rider	Duperow	3
Rough Rider	Madison	3
Scotia	Madison	2
T. R./Big Stick	Madison	2
Tioga	Silurian	2
Tioga	Devonian	2

Table 5. Producing intervals and number of pools greater than class 8 from each (after combining and splitting operations)

Interval	No. Pools > Class 8
Madison (incl. Lodgepole, Midale, Mission Canyon, and Ratcliffe pools)	248
Ordovician (incl. Red River, Red River B, West Red River pools)	103
Devonian (incl. Duperow pools)	85
Bakken	30
Birdbear	20
Silurian (incl. Interlake pools)	17
Stonewall	18
Tyler (incl. Heath pools)	15
Spearfish (incl. Spearfish/Madison pools)	10
Dawson Bay	2
Winnipegosis	6
Cambro-Ordovician (incl. Deadwood and Winnipeg pools)	1

Table 6. Average pool areas for size classes (acres)

Size Class	Madison	Devonian	Ordovician	Bakken	Birdbear	Silurian	Stonewall
8	412	499	580	574	616	320	593
9	603	490	692	1,676		640	
10	822	834	933	5,821	2,508	510	3,204
11	1,304	733	1,956				
12	2,390	2,863	4,607	18,081		3,432	
13	4,794	1,555	6,296				
14	6,234						
15	6,935		17,607				
16	16,832						
17	32,283	10,030					
18							
19			146,927				

Table 7. Exploratory wells for horizons analyzed (up to Sept. 1, 2005)

Horizon	Exploratory wells
Madison	4,607
Bakken	1,720
Birdbear	2,534
Duperow	2,177
Silurian	2,124
Stonewall	1,783
Red River	1,065

Table 8. Number of pools in each size class, class 8 and above.

Size Class	Madison	Devonian	Ordovician	Bakken	Birdbear	Silurian	Stonewall
8	32	20	24	6	7	1	6
9	49	23	29	9	3	1	5
10	46	16	20	3	3	3	3
11	40	17	14	6	4	4	1
12	36	3	7	4	2	3	2
13	16	5	6	2	1	2	1
14	11	0	0			3	
15	11	0	2				
16	5	0	0				
17	2	1	0				
18			0				
19			1				

Table 9. Estimated remaining pools and additional ultimate recoveries. Number of existing pools after combination and splitting, and EUR as described above.

A. Major Producing Horizons

Madison

Class	**No.**	**EUR**	**Estimated Remaining**	**Estimated Additional**
8	32	5,704,164	218	38,804,000
9	49	17,910,597	224	81,760,000
10	46	31,153,594	144	97,488,000
11	40	59,254,949	80	118,480,000
12	36	100,274,384	8	22,280,000
13	16	88,669,117	0	0
14	11	134,552,588	0	0
15	11	235,236,997	1	21,385,000
16	5	228,938,137	0	0
17	2	165,953,470	a	a
Total	248	1,067,647,997	675	380,197,000

Devonian

Class	**No.**	**EUR**	**Estimated Remaining**	**Estimated Additional**
8	20	4,009,308	226	45,200,000
9	23	8,393,444	288	105,120,000
10	16	11,758,057	154	115,192,000
11	17	22,539,314	177	234,525,000
12	3	7,051,651	a	a
13	5	32,027,744	*	*
14	0			
15	0			
16	0			
17	1	94,817,475	a	a
Total	85	180,596,993	845	500,037,000

Ordovician

Class	No.	EUR	Estimated Remaining	Estimated Additional
8	24	4,565,531	437	83,030,000
9	29	10,752,300	481	178,451,000
10	20	13,227,658	259	171,199,000
11	14	21,006,324	122	184,342,000
12	7	24,476,664	39	136,344,000
13	6	36,721,366	*	*
14	0			
15	2	54,231,246	a	a
16	0			
17	0			
18	0			
19	1	270,170,239	a	a
Total	103	435,151,328	1,338	753,366,000

[a] too few pools for analysis
*Analysis does not converge

Table 9 (continued)

B. Other Producing Horizons

Birdbear Fm

Class	No.	EUR	Estimated Remaining	Estimated Additional
8 and 9	10	2,317,144	60	13,860,000
10,11,12,13	10	22,845,440	10	23,600,000
Total	20	25,162,584	70	37,460,000

Bakken Fm

Class	No.	EUR	Estimated Remaining	Estimated Additional
8	6	1,089,336	*	*
9	9	2,945,583	25	8,175,000
10 and 11	9	12,039,615	5	6,685,000
12 and 13	6	24,222,535	*	*
Total	30	40,297,069	30	14,860,000

Silurian

Class	No.	EUR	Estimated Remaining	Estimated Additional
8,9	2	666,397	a	a
10,11	7	7,540,289	*	*
12,13,14	8	59,339,608	0	0
Total	17	67,546,294	0	0

Stonewall Fm

Class	No.	EUR	Estimated Remaining	Estimated Additional
8,9	11	2,899,336	122	32,086,000
10,11,12,13	7	2,945,583	11	26,466,000
Total	18	5,844,919	133	58,552,000

[a] too few pools for analysis
*Analysis does not converge

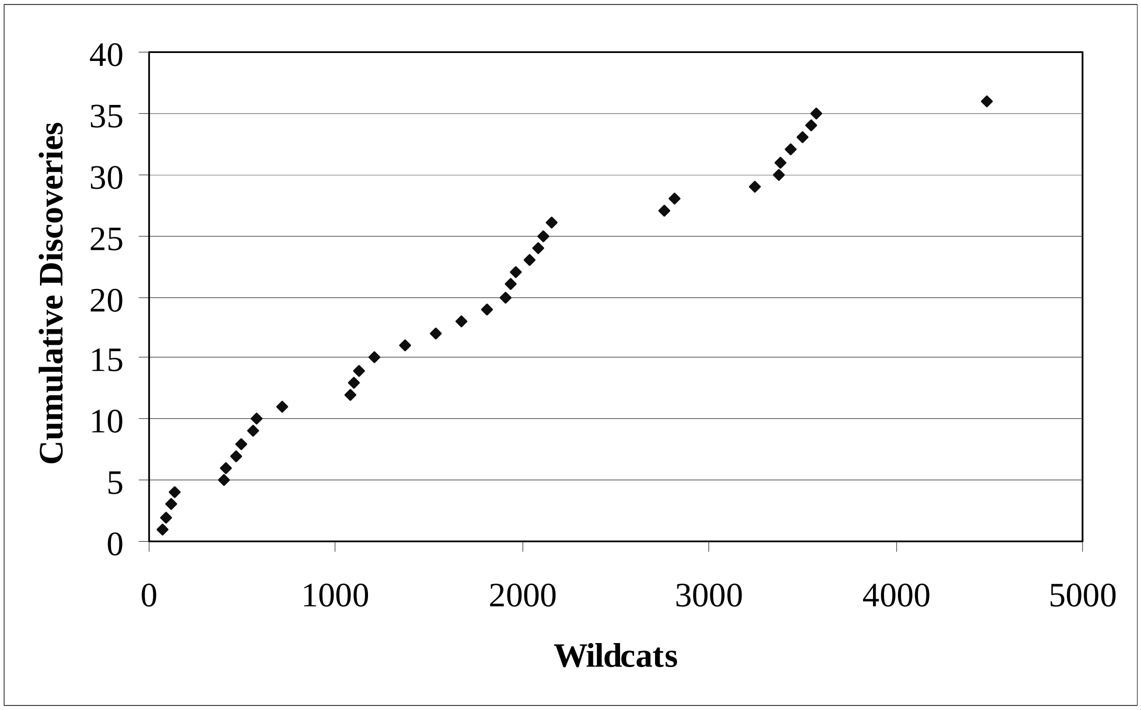

Fig. 1.   Cumulative discoveries versus wildcat wells for Madison class 11 pools

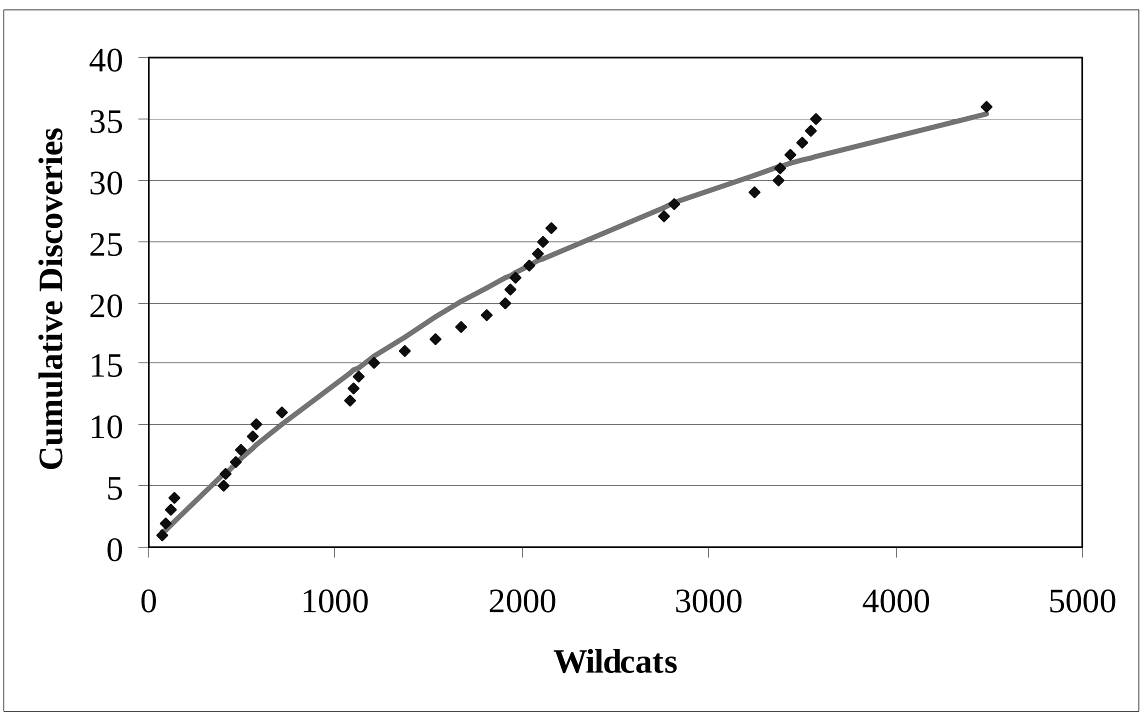

Fig. 2.   Cumulative discoveries versus wildcat wells for Madison class 11 pools, with fitted solution curve.