Data Mining at the Nebraska Oil & Gas Commission

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Disclaimer

Index

List of Figures

List of Tables

Appendixes

Data Mining at the Nebraska Oil & Gas Commission

Abstract

The purpose of this study of the hearing records is to identify factors that are likely to impact the performance of a waterflood in the Nebraska panhandle. The records consisted of 140 cases. Most of the hearings were held prior to 1980. Many of the records were incomplete, and data believed to be key to estimating waterflood performance such as Dykstra-Parson permeability distribution or relative permeability were absent.

New techniques were applied to analyze the sparse, incomplete dataset. When information is available, but not clearly understood, new computational intelligence tools can decipher correlations in the dataset. Fuzzy ranking and neural networks were the tools used to estimate secondary recovery from the Cliff Farms Unit.

The hearing records include 30 descriptive entries that could influence the success or failure of a waterflood. Success or failure is defined by the ratio of secondary to primary oil recovery (S/P). Primary recovery is defined as cumulative oil produced at the time of the hearing and secondary recovery is defined as the oil produced since the hearing date.

Fuzzy ranking was used to prioritize the relevance of 6 parameters on the outcome of the proposed waterflood. The 6 parameters were universally available in 44 of the case hearings. These 44 cases serve as the database used to correlate the following 6 inputs with the respective S/P.

1. Cumulative Water oil ratio, bbl/bbl
2. Cumulative Gas oil ratio, mcf/bbl
3. Unit area, acres
4. Average Porosity, %
5. Average Permeability, md
6. Initial bottom hole pressure, psi

A 6-3-1 architecture describes the neural network used to develop a correlation between the 6 input parameters and their respective S/P. The network trained to a 85% correlation coefficient. The predicted Cliff Farms Unit S/P is 0.315 or secondary recovery is expected to be 102,700 bbl.

Introduction

The DOE's National Petroleum Technology Office in Tulsa administers a program for *Technology Development with Independents* directed towards small independent oil producers. Coral Production Company was awarded a 3rd round program grant in December 1999.

Coral Production Corporation is a small privately owned company established in May 1986 to purchase and operate producing properties in the Denver-Julesberg Basin. The company's staff consists of 3 employees who currently operate 120 wells producing 14,000 bbl of oil, 500 mcf of gas and 536,000 bbl of water each month.

Coral Production Corporation plans to install a waterflood in the Nebraska Panhandle of the Denver-Julesberg Basin. The Cliff Farms Unit, site of the proposed flood, is located in sections 32&33 of T15N, R52W as seen in Fig. 1.

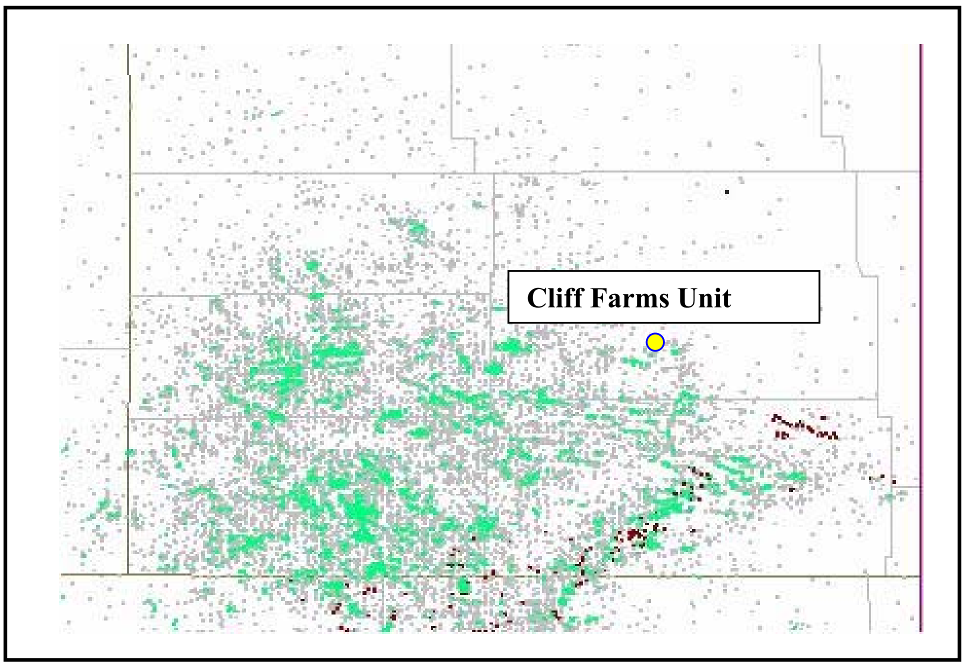


Figure 1. Location of the Cliff Farms Unit in the Nebraska Panhandle. From USGS DD-35. Gray are dry holes, green oil wells, red gas wells.

The success rate of waterfloods in the area is mixed. Waterflood failure is a production problem common to D-J Basin operators. Various reasons are proposed for the nonsuccesses. Depositional channels (geology) and high free gas saturation at the end of primary are the reasons postulated for the failure to form an oil bank. Wettability and fractures are also suggested as reasons for the economic failures. The ratio of secondary barrels produced to barrels produced during primary is frequently a means of defining success. If the ratio is less than 0.25 the project is expected to be marginally economic. There is a need to rapidly and inexpensively estimate secondary recovery reserves as a function of primary recovery. Davis and Chang (AAPG Bulletin 73-8, 8/89) and the API (Bulletin D14, 4/84) attempted with little success to estimate secondary recovery based on readily available public information.

Fields in D-J Basin are generally small (2-20 wells) solution gas drive (with or without water drive) reservoirs. The Davis and Chang AAPG bulletin demonstrates that the median size (estimated ultimate recovery) is about 200,000 bbl that apparently includes secondary oil.

The API bulletin developed empirical correlations for the prediction of recovery efficiency based on actual field performance and special fluid analyses. The "goodness" of the correlations suggested they were of little value in predicting waterflood response.

The D-J Basin is totally the domain of small independent operators without in-house laboratory facilities, such as Coral Production Corporation. For instance information such as special core and fluid analyses is not available. A well defined geological characterization and special rock and fluid properties can be used to numerically model the past performance history of a field. The calibrated simulation model can then be used to predict future performance with a high degree of confidence. The information needed for reservoir simulation is seldom available for the small fields that comprise the majority of the D-J Basin oil accumulations. The required information can be developed at considerable expense. A study of this type exceeds Coral Production Company's requirements. Nevertheless, a great deal of useful field information is available in the public domain. New technology, not available until the 1990s, called computational intelligence, was used to develop new correlations utilizing public information to estimate the secondary to primary ratio (S/P). Given the primary performance history, S/P can be used to estimate secondary recovery reserves.

Discussion

Correlations Company staff spent the week of February 6, 2000 in Sidney, Nebraska at the Oil and Gas Commission. The records of 140 waterflood unitization hearings were reviewed. A generic form, Table I, was developed to record the available information from each case hearing. This information plus the cumulative oil produced at the time of the hearing and the last reported cumulative oil production of each unit was recorded. These data comprise the database, Appendix A, which was used to construct correlations between the secondary to primary ratio.

Table I - Database Form

	Location. Sec T,R	Location. Sec T,R	Location. Sec T,R	Location. Sec T,R
Field				
Case No.				
Unitization Hearing Date				
Discovery Date				
Spacing, Ac/well				
No. Producing Wells				
No. Shut in Wells				
Number dry holes				
Depth to Top of Pay, ft				
Producing Formation				
Producing Mechanism				
Lateral Area, Ac				
Average Net Pay, ft				
Average Porosity, %				
Average Permeability, %				
Connate Water Saturation, %				
Original BHP, Psi				
BHP at Start of Flood, Psi				
Original Oil-Water Contact, SS				
Oil Gravity, ^{o}API				
Original FVF, Vol/Vol				
Original Oil in Place, STB				
Primary Production Hearing Date				
Cumulative Oil, bbl				
Cumulative Gas, mcf				
Cumulative Water, bbl				
Initial Producing Rate, BOPM				
Secondary Production				
Most recent Producing Date				
Cumulative Oil, bbl				
Cumulative Gas, mcf				
Cumulative Water, bbl				

The information available in the unitization case files was not uniform. Nevertheless, a great deal information was obtained that is common to many of the waterfloods. Most of the hearing information was recorded prior to 1980. D-J Basin sandstone floods produce the bulk of the secondary oil during the first five years of operation. Since most of the Units have produced secondary oil for 20 years no effort was made to estimate ultimate recovery. Similarly, no effort was made to estimate ultimate primary recovery because very little primary oil remained at the time the floods were initiated. There are some exceptions to the generality. The prime exception is the secondary gas injection projects initiated by Marathon in the Sidney Nebraska area. The available S/P values are mapped in Fig. 2. The red area near Sidney in SE quadrant locates the early gas injection projects (low primary, high secondary) with the high S/P ratios. The legend to the numbers representing the units is found in Appendix A along with the respective Section-Township-Range location.

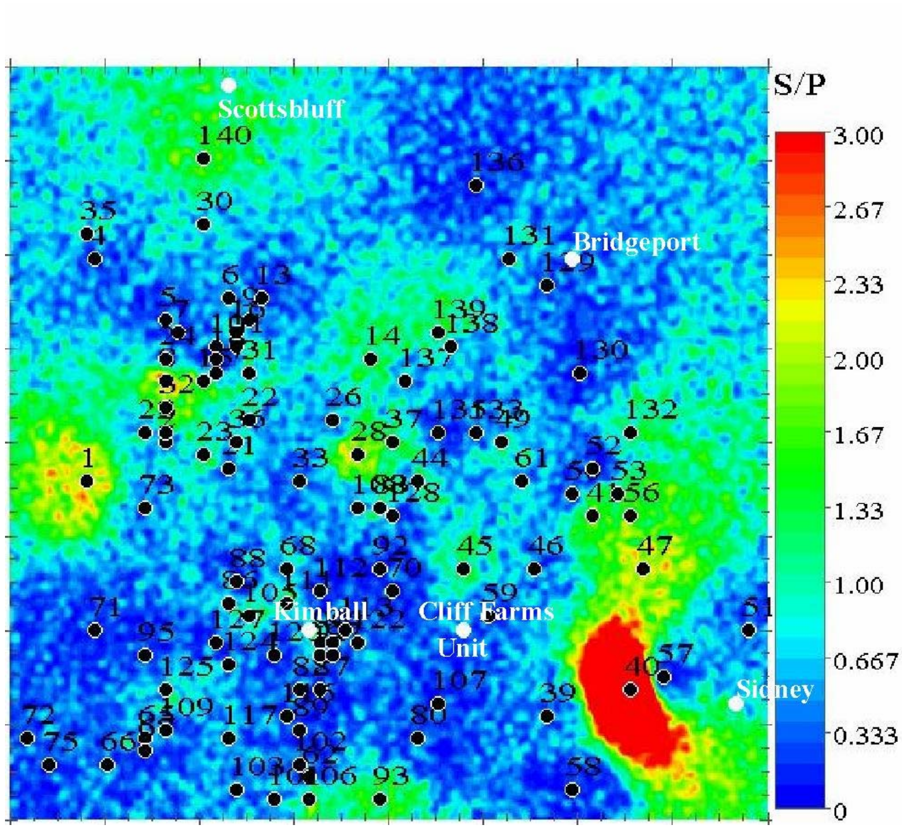


Figure 2. Fractal Distribution of S/P Values.

The value of fuzzy logic as a ranking tool is seen with the procedure used to select the best correlating parameters. The first step in the analysis was to determine which of the 30 entries seen in Table I are relevant to the S/P. Initially conventional cross-plots were constructed. Four of these cross-plots are presented in Fig. 3. Note that the value R^2 (goodness of the correlation between 0 and 1) is low in these examples indicating there is little conventional correlation between Unit acreage, average porosity, average permeability, and initial oil in place and S/P.

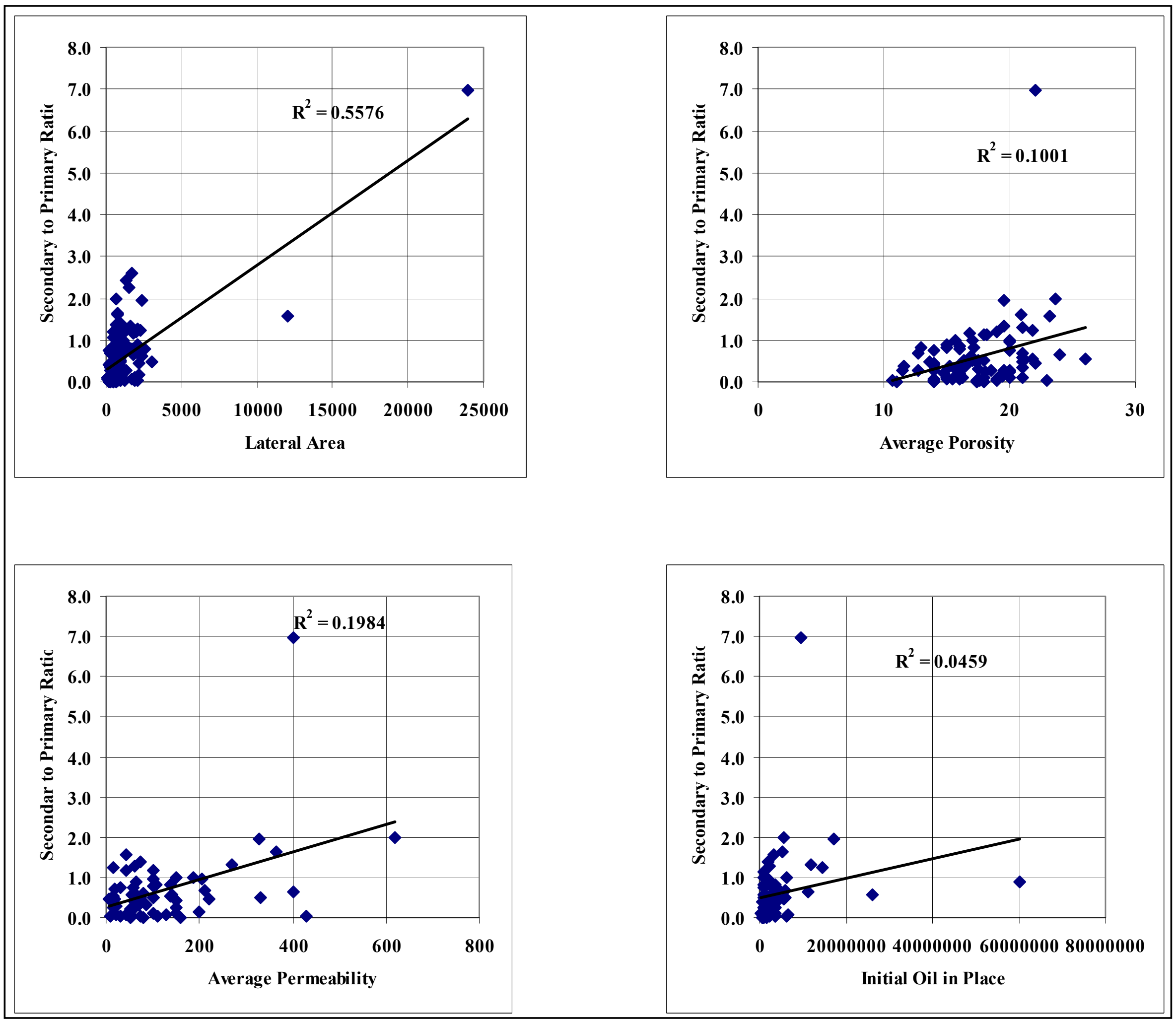


Figure 3. Unit Acreage, Average Porosity, Average Permeability, and Initial Oil in Place vs Secondary to Primary Ratio.

The poor R^2 associated with the conventional cross-plots indicate that there is little reason to continue the analysis. Seen in Fig. 4 are the same four entities normalized between 0-1 and plotted versus the S/P ratio. Again the R^2 values are poor.

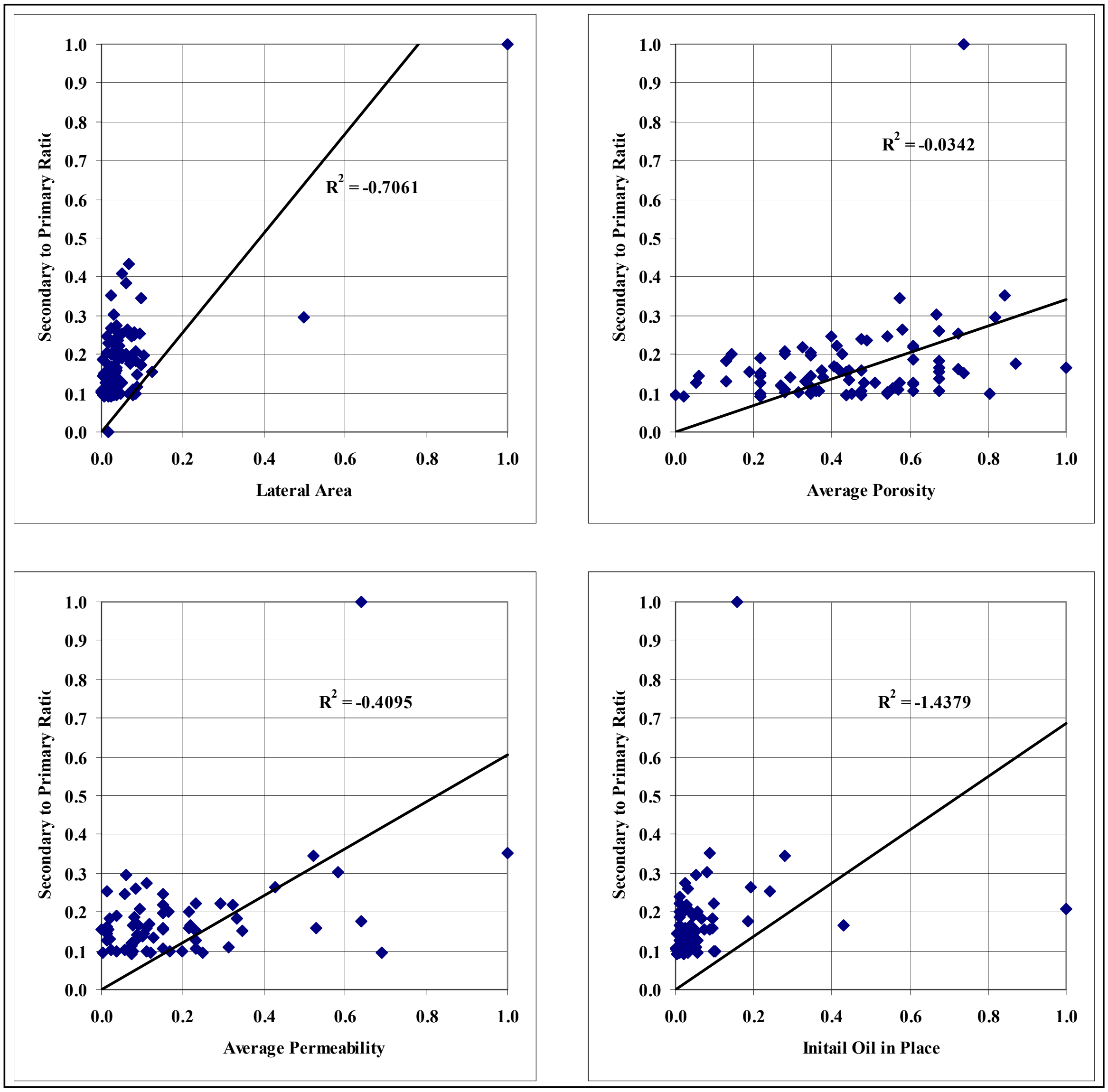


Figure 4. Normalized Unit Acreage, Average Porosity, Average Permeability, and Initial Oil in Place vs Secondary to Primary Ratio.

The R^2 values of cross-plots of the fuzzy S/P versus the four parameters, Fig. 5, suggest that S/P can be correlated with the input parameters.

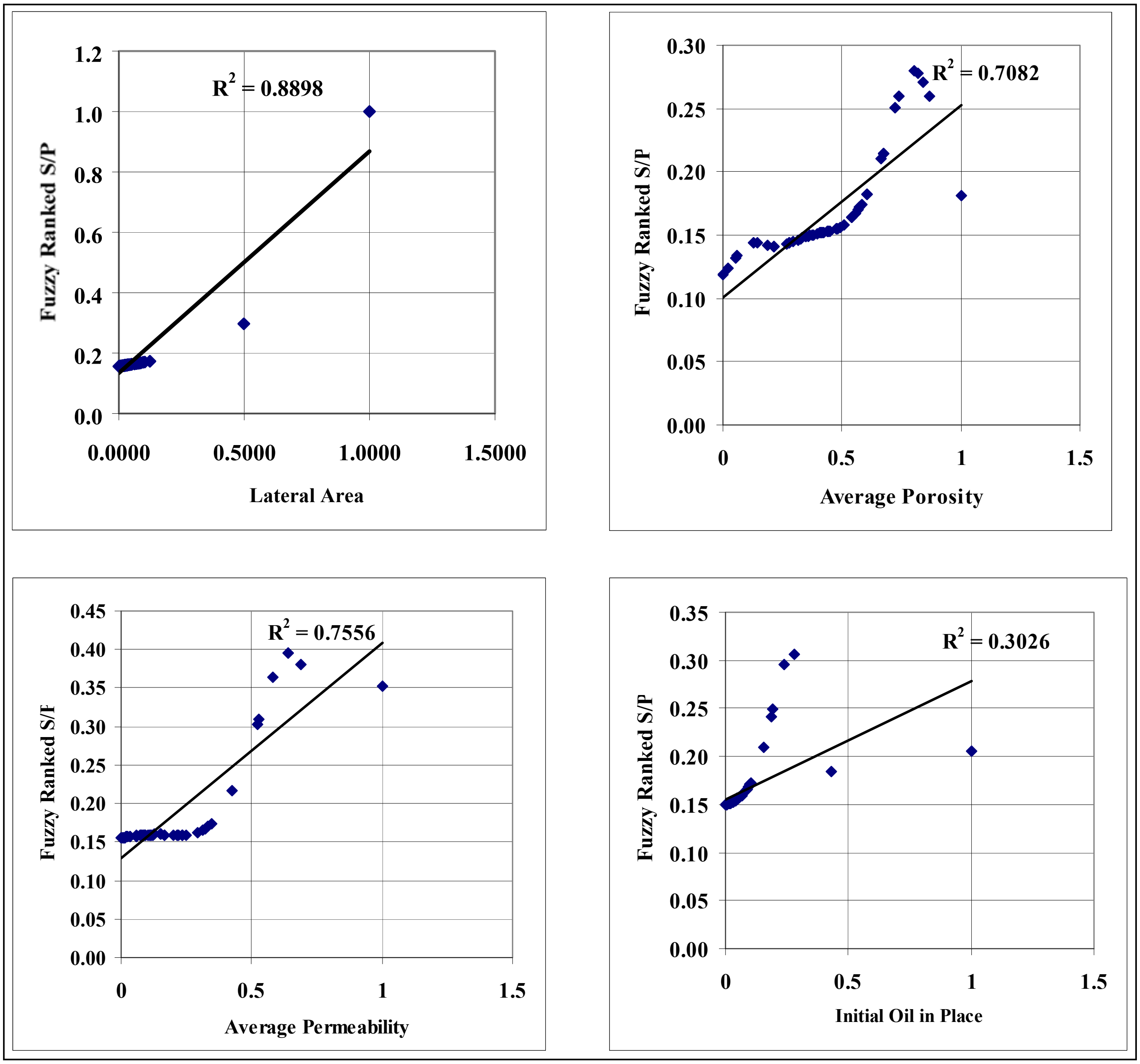


Figure 5. Normalized Unit Acreage, Average Porosity, Average Permeability, and Initial Oil in Place vs Fuzzy Rank Secondary to Primary Ratio.

The average R^2 values of three the types of cross-plots plus the range are defined as a confidence indicator or CI. The confidence indicator increase from 0.22 (average R^2) with the conventional cross-plots to 1.2 with the fuzzy ranking plots. Tabulated in Table II are 6 input parameters that were used to train a 6-3-1 neural network. The table includes the R^2 and CI calculated from the cross-plots of the fuzzy S/P versus each parameter. The average confidence indicator of the 6 input parameters is 0.86. Recorded in the table are the Cliff Farms Unit parameter values that were used to predict S/P.

Table II

Six Correlating Parameters

Parameter	R^2-CI	Cliff Farms Unit
Cumulative Water oil ratio, bbl/bbl	0.835 - 0.935	3.25
Cumulative Gas oil ratio, mcf/bbl	0.240 - 0.290	3.05
Unit area, acres	0.879 - 1.199	580
Average Porosity, %	0.708 - 0.958	15
Average Permeability, md	0.756 - 1.001	35
Initial bottom hole pressure, psi	0.658 - 0.778	1173
Average Confidence Indicator	0.86	

The architecture of the 6-3-1, fully connected, neural network is depicted in Figure 6. The 6 input parameters are in layer 1. Layer 2 consists of 3 hidden nodes (transfer functions) and layer 3 is the output, in this case S/P. Each of the 44 examined waterfloods has a unique set of input values to correlate with the specific S/P value. The weights (represented by lines) are adjusted until an equation is obtained that closely approximates the S/P values given the 6 input values. The desired goodness of the approximation (correlation coefficient) is a function of the number of iterations and the confidence indicator of the individual input variables.

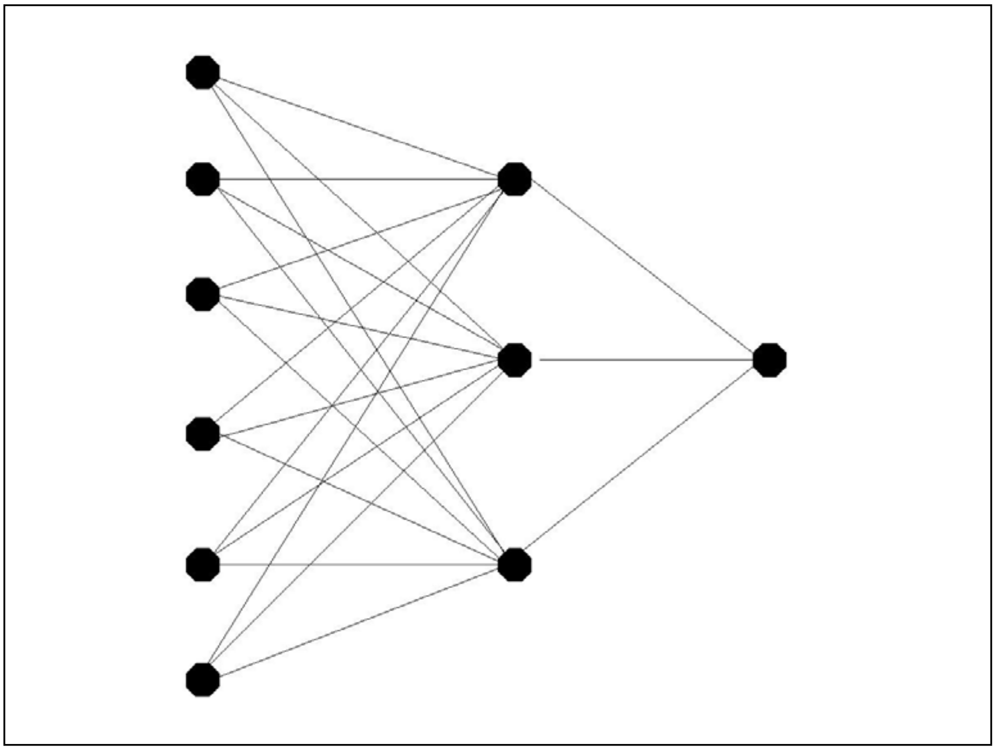


Figure 6. 6-3-2-1 Neural Network used to Correlate Input Parameters with S/P.

The 44 cases, each containing the 6 inputs, were used to train the neural network to a correlation coefficient of 85%. Note that the number of connections is 21 or about half the number of inputs.

The training is seen in Fig. 7. Examination of Fig. 7 provides a visual estimate of the goodness of the neural network training.

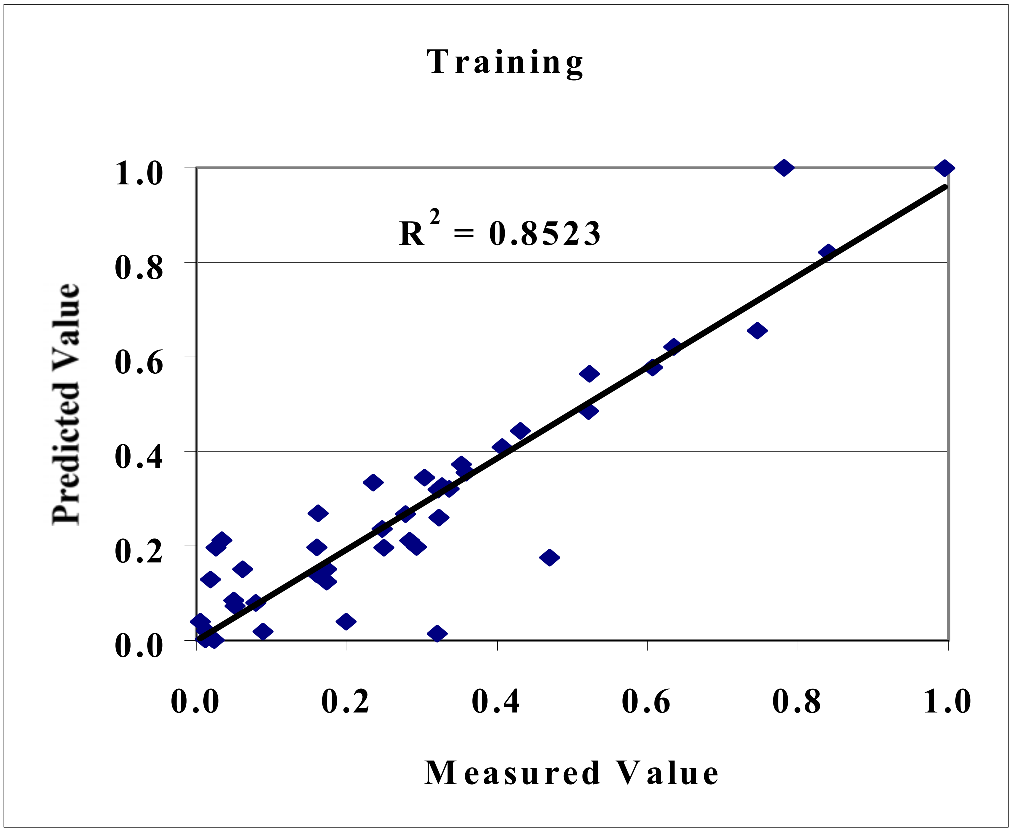


Figure 7. Goodness of the 6-3-1 Neural Network Trained to 85% of the Measured Values.

Conclusion

Computational intelligence was used to correlate public information and predict that the Cliff Farms Unit secondary to primary recovery ratio will be 0.315. Given that the Unit produced 326,000 bbl of primary oil the waterflood is expected to produce 102,700 bbl of secondary oil. The production rate will be monitored for the two years after the start of the flood and ultimate secondary will be calculated with a rate versus cumulative curve as a check of the prediction.

A set of parameters similar to those used to predict the Cliff Farms Unit S/P from any group of D-J sand wells in the Nebraska Panhandle could be used to predict the corresponding S/P. A poster presentation of this report will be made available to the Nebraska Oil & Gas Commission in Sidney, Nebraska.

Appendix A

Sample No.	Field	Case No.	Unitization Hearing Date	Discovery Date	Spacing Ac. /Well	Number Producing Wells	Number Shut-in Wells
1	Barrett	60-9	3/17/1960	Nov-58	40	20	
2	Blake	84-1	Mar-84		40	2	
3	Brinkerhoff	60-15	1960	Jun-59	40	4	
4	Bead Mt. Ranch, Casey	88-3	Mar-88	Apr-65	40	3	
5	Cross	96-5	10/22/1996	1957	40	4	7
6	Davis	61-1	1/18/1961	Apr-58	40	12	
7	Downer, West	61-29	3/24/1961	5/12/1955	40	4	
8	Edwards	64-25	May-59	Mar-57		14	
9	Grant	62-21	8/21/1962	5/14/1959	40	4	1
10	West Harrisburg	61-51				32	4
11	East Harrisburg	61-56	1/13/1961		19	7	
12	Idle Acres	87-1	2/24/1987			10	
13	Joyce	85-2	6/25/1985			7	
14	Kenmac	61-17&18	4/18/1981	Mar-55		23	
15	Lewis	60-10		Mar-58		12	
16	Llano	70-15	1/25/1972	1962		10	
17	Lovercheck	65-20	9/21/1965			7	3
18	North Lovercheck	96-4	6/25/1996			2	
19	Ludden	84-12 86-8				1	
20	McDaniel	61-32				7	
21	McMurray	70-5	5/24/1970	Sep-58	40	6	2
22	Omega	70-18	12/22/1970	6/30/1961	40	3	0
23	Pan American	61-39	9/19/1961			4	1
24	Pet. State (Olsen B)	60-11	3/17/1960	Jul-55	40	18	4
25	Pet. State	60-11					
26	Raymond	68-5	4/29/1968	1857		5	
27	Rocky Hollow	75-19	9/23/1975				
28	Singleton	61-36	9/16/1961				
29	Soule	65-19	7/20/1965	Apr-59		4	
30	Stage Hill	70-13	5/26/1970	Jul-64		12	0
31	Stauffer	66-12	Jul-66	Mar-55		5	8
32	Vedene	65-9	2/22/1966				
33	Vowers (Peterson)	72-18	Nov-72	May-62		8	1
34	Vowers	84-9		Before Records			
35	Warner Ranch	81-1	8/24/1982	Sep-66		6	1
36	Weaver	62-16	6/22/1962	1/6/1959		4	
37	Wilson Ranch	60-35	10/12/1960	1957		13	
38	Wilson Ranch South	94-5	6/30/1994	1959		4	1
39	Bird	92-9	6/30/1992				
40	Doran Farm	64-20	7/21/1964	Apr-53		15	11
41	Eddy	67-8	6/27/1967	Dec-62		11	4
42	Endo	93-5	8/3/1993	73		4	3
43	Foreland	84-2	11/22/1993			2	3

44	Heider	62-34	11/20/1962	Jul-57		7	5
45	Henry	69-6	4/29/1969	Dec-65		7	3
46	Ittner	71-16	11/23/1971	Jun-54		4	7
47	Jomar	75-11	7/22/1975			8	1
48	East Juelf's Gaylord	63-27	7/16/1963	Dec-56		10	1
49	West Juelf's Gaylord	63-13	3/19/1963	1959			
50	Kame	93-2	5/25/1993	1963		12	
51	Kugler	60-44	11/16/1960	1952		6	
52	Leafdale	78-13	7/25/1978	Sep-58		2	
53	Marvel	68-1	1/23/1968	Feb-65		6	1
54	Murfin	64-26	8/18/1964	Apr-57		7	3
55	Potter SW	64-4	2/18/1964				
56	Reimes	61-9	2/15/1961	1951		7	
57	Sidney North	95-2		1951		3	4
58	Sidney SW	96-2		Nov-69		3	1
59	Slama	91-12	8/6/1991	Aug-57		4	3
60	Spearow	91-10	6/4/1991			11	9
61	Winklman	61-16	4/18/1961			4	1
62	Allely	92-4		1953		2	8
63	(Reep) Allely	92-14					
64	Aue-Griffith	61-2	1/18/1961	1956		25	
65	North Baltensperger	63-6	2/1/1963	Jan-56		11	6
66	South Baltensperger	63-10	3/19/1963	1956		6	1
67	North Baltensperger (Roma)	94-7	7/26/1994	1953		3	
68	Barkhoff	63-40	11/19/1963	1958		4	1
69	Bartow	63-2	2/19/1963	1/21/1959		9	1
70	Bean	93-7	8/24/1993	1960's			
71	Benziger	63-47	1/21/1964	Jun-58		7	1
72	Bourlier	88-15	12/17/1968	Jun-57		5	2
73	Brook	62-6	2/16/1962	Oct-58		14	
74	Bukin State	65-48	6/28/1966	1955		3	3
75	Chaney	68-11	9/24/1968			2	2
76	East Chaney	86-1	1982			5	2
77	Claude	94-2				1	
78	Dietz	60-2		Mar-54		9	
79	Divoky	63-26		1959		3	
80	Draw	85-14	10/22/1985	Jun-77		5	
81	Enders		3/26/1996			52	
82	Everton	70-16	11/24/1970			2	
83	Fernquist	64-14	5/19/1964	Jun-56		9	1
84	Gehrke						
85	Goodwin						
86	Heidemann	61-43	10/17/1961			24	
87	Hill	69-18				47	
88	Hilltop	88-1	2/23/1988	Jun-60		3	1
89	Hinshaw	76-1	1/27/1976	Oct-58		2	
90	Houtby	62-22	4/18/1962	Oct-54		15	2

91	South Houtby	82-1	2/23/1982	Aug-71		6	1
92	Hruska	71-14		Jan-56		5	3
93	Ibex	76-22	11/23/1971				
94	Jacinto	60-21	12/28/1960	Apr-55		18	
95	Keefer	83-1	4/26/1983				
96	Kenton	66-5	3/23/1966	Mar-54		6	
97	South Kenton	98-2	6/30/1998	1975		4	
98	Kimball	91-1	5/21/1991				
99	Kimball (Morton)	93-10	9/28/1998	1955		6	
100	KMA	95-1	4/25/1995			9	
101	Long	60-27	6/19/1960	1952		64	
102	North Mintken	62-18	6/22/1962	1958		48	2
103	South Mintken	62-19	6/1/1962	1959	40	6	1
104	Ostgren						
105	Owasco	72-15		Jul-53		6	3
106	Owl	65-27	8/26/1965	Mar-64		7	
107	Western Potter, S.W.	64-4	2/18/1964			7	
108	Pound	86-2	9/11/1986	Feb-85		4	
109	Prairie	62-14	5/15/1962	Jun-55		10	
110	Rodman	61-33	7/18/1961			8	
111	Simpson	61-38	9/19/1961			14	
112	East Simpson	86-12	10/28/1986	Apr-66		6	
113	Skiles	81-8				2	
114	Sloss (Haug)	63-23				2	
115	Sloss	63-23	6/6/1963			79	
116	Spath	67-15	11/21/1967	1959		11	
117	Stevens	63-7	2/19/1963	Aug-57		3	1
118	Sulfide	64-17	3/17/1964			7	
119	Susan	86-13	10/28/1986	1955		14	
120	North Swearingen	65-8	3/16/1965			9	
121	South Swearingen	67-11	9/26/1967			8	
122	Terrace	73-11	10/23/1973	Dec-55		4	1
123	Torgeson (Stanco)	82-6	3/30/1982	1950's		3	17
124	Torgeson	62-23		1950	40	8	12
125	Torgeson (South)	62-8	3/20/1962	1956	40	10	1
126	Vrtatko	63-9	2/1/1963	May-59		5	1
127	Young	70-4	3/24/1970	Apr-55		2	2
128	Zoller State	66-10	1966	1955		5	
129	South Bridgeport	92-2	3/24/1992	Oct-70		4	
130	Duggers Springs	94-4	5/24/1994	Oct-59		15	1
131	Dunlap	78-17				4	3
132	Lane	60-32	9/19/1960	1958		5	2
133	Lindberg	66-14	7/26/1966				
134	Matador	65-22	9/21/1965			4	
135	East Matador	95-5				8	
136	Nike	95-7	9/26/1995			5	
137	Olsen	61-34		Jul-55		31	

138	Stark	67-2	3/28/1967	Sep-56		10	
139	Waitman	64-19	7/21/1964	Aug-57		46	0
140	Cedar Valley	64-3	10/26/1965	Apr-63		16	

Sample No.	Number Dry Holes	Depth to Top of Pay, ft	Producing Formation	Producing Mechanism	Lateral Area, ac. Gross/Net	Ave. Net Pay ft.	Average Porosity, %	Average Perm., md
1	2	6680	J-Sand		1560			
2			J-Sand		240			
3		6660	J-Sand		640			
4	4	6100	J-Sand	Sol. Gas	640/262	4.7	19.2	53
5	4	6080	J-Sand	Sol. Gas	960	10	15	42
6	1		D-sand	Sol. Gas	560/566	5.5	17	63
7	1	5900	D-sand		320	7	21	70
8	3	6420	J-sand	Sol. Gas	1320			
9	2	5540	D-sand	Sol. Gas	2.4	5	20	150
10			D+J sand	Sol. Gas	2200			
11	2	5900	D+J sand	Sol. Gas	1280	15	15	108
12	6	5435	J-Sand		640			
13	8	5370	D-sand		880	7.5	19.4	200
14	5	5200	J-sand	Depletion	1280			
15	3	6750	J-sand	Sol. Gas				
16			J-sand	Sol. Gas				
17	7	5990	D+J sand	Sol. Gas	2100	9	14	56
18	7	5975	D+J sand	Sol. Gas	600			
19			J-Sand					
20			J-Sand					
21	2	6350	J-Sand	Sol. Gas	3054	6	13.6	7.6
22	3	6240	J-Sand	Sol. Gas	927	3.7	17.1	332
23	2		D-sand	Sol. Gas+Water Dr.			15.7	205
24	4	6230	D-sand				14	
25			D-sand					
26	8	5720	J-Sand					
27		6500	D+J sand		240			
28		5630	J-Sand	Sol. Gas	2400		19.5	328
29		6720	J-Sand	Sol. Gas				
30	1	5700	J-Sand	Sol. Gas	2080/660	14	21	212
31	3	6100	J-Sand	Sol. Gas	960/700	5	20	100
32			D+J sand					
33		5800	D-sand		480	5	18.5	
34			J-Sand					
35	7	6150	J-Sand	Sol. Gas	2560/892	2.1	16	100
36	3	6290	J-Sand	Sol. Gas	160	7	20	
37		5260	J-Sand	Sol. Gas	1840	13.4	16.8	42
38	1	5500	J-Sand		520	11	18	160
39			Virgil		640			
40	1	4650	D-sand	Sol. Gas	24000	13	22	400

41	6	4940	J-Sand	Sol. Gas	12000/520	13	23.2	44
42	1	4875	J-Sand		800			
43	4	7000	J-Sand		640			
44	7	5625	J-Sand	Sol. Gas	880/400	8.6	17.2	139
45	5	5200	J-Sand	Sol. Gas	920/134	9.1	18	
46	5	5390	J-Sand	Sol. Gas	880/269	13	22	220
47	5	4800	J-Sand	Sol. Gas&Water Dr.	640		23.6	620
48		5200	J-Sand	Sol. Gas	1080	12.4	18.2	
49		4680	J-Sand		1560			
50	5	5050	J-Sand	Sol. Gas	560	10		
51	1	4600	J-Sand		440	11		
52	5	5050	J-Sand		960	6.5	19	30
53	4		J-Sand		960	10	21	60
54	6	5600	J-Sand	Sol. Gas	840/535	4.8	17.5	139
55		5650	J-Sand		480			
56	3	4875	J-Sand		800	25	20.9	365
57	1	4850	J-Sand		640			
58	2		J-Sand		960	20	17.4	430
59	0	5400	J-Sand	Gas drive	720	11	14.8	53
60	6	4500	J-Sand	Sol gas&water dr.	760			
61	5	5015	J-Sand		280	8		
62	7	6200	J-Sand	Sol. Gas	1680/562	11	16	130
63			J-Sand					
64	8	6200	J-Sand		2000			
65	5	6900	J-Sand	Sol. Gas	1760/882	8.7	12.7	19.3
66	2	6940	J-Sand	Sol. Gas	720/400	7.6	12.7	19.3
67	5	6890	J-Sand		1920	8.75	10.7	10
68	4		J-Sand	Sol. Gas	960/404	8.4	21	56
69	8		J-Sand	Sol. Gas	1100	7	17.5	86
70			J-Sand		560	10	23	110
71	8		J-Sand	Sol. Gas	1200/280	16.4	17.6	75
72	8	7131	J-Sand	Sol. Gas	800/450	12.4	18.1	60
73	5	6750	J-Sand	Sol. Gas	920		17.4	18.6
74	2	5720	J-Sand		280			
75	5	6910	D-sand		160			
76	4	6980	J-Sand		640	15	12.92	
77	3	7270	J-Sand		680		11	
78	2		J-Sand		480	19	15.2	62.2
79	1	6546	J-Sand		150	6.7	15.5	22
80	3	5590	D-sand		240/190		16.3	
81	2		D+J sand					
82	5	6415	J-Sand		80	6		
83	2	5700	J-Sand	Sol. Gas	440/267	17.5	19	100
84			D+J sand					
85			J-Sand					
86	12	6350	J-Sand	Sol. Gas	1680			
87	3	5900	J-Sand		560		20	150

88	9	6410	J-Sand		120		16	
89	5	6180	J-Sand		320			
90	3	6000	J-Sand	Sol. Gas	1120/660	11	20	150
91	2	6020	J-Sand		440		16	
92	4	6000	J-Sand	Sol. Gas	195	4	17.4	81
93		5773	D-sand	Partial Water Drive	2040			
94	8	5856	J-Sand					
95			J-Sand		480			
96	7	6000	J-Sand	Sol. Gas	760	6.23	16.4	101
97	1	6000	J-Sand		360	23	14	
98			J-Sand					
99	7	6200	J-Sand		310	23	14	
100		6450	J-Sand		1000			
101		6100	D-sand				26	142
102	1	6517	J-Sand	Sol. Gas	1280	8.9	11.5	15.5
103	3	6507	J-Sand	Sol. Gas	440	6.4	11.6	15.5
104			J-Sand					
105	6	6050	J-Sand	Sol. Gas		3.2	17	188
106	5	6150	J-Sand	Sol. Gas	960			75
107	2	5650	D+J sand	Sol. Gas	480			
108	2	5794	J-Sand	Sol. Gas	600/350	3.8	21	100
109	1	6780	J-Sand	Sol. Gas	800/500	11.5	15.8	20
110	3	6100	J-Sand		820		16.9	80
111			J-Sand	Sol. Gas	2120		15	65
112	1	5840	J-Sand		520	12	14	52
113	4	6100	J-Sand		640		18	
114			J-Sand					
115	6	6325	J-Sand		1680			
116	4	6280	J-Sand					
117	6	6477	J-Sand	Sol. Gas	160/126	8	16	72
118			J-Sand		800			
119	16	6000	J-Sand		2400			
120	2	5900	J-Sand		640		16	
121			J-Sand		680			
122	6	5800	J-Sand		320/229	8.6	16.5	
123	18		J-Sand		2200			
124		6485	J-Sand		760	10.2	18	75
125	8	6540	J-Sand		1280	9.8	14	30
126	1	6100	J-Sand	Gas depletion	240	16	14	150
127	7	5900	J-Sand		800/412		21	100
128		5700	J-Sand		840		20	
129	6	3900	D-sand		560/172		19.5	
130	9	4350	J-Sand		1920	3	15	
131	1		D-sand			12		
132	2	4587	J-Sand	Fluid Expantion	480			
133		5354	J-Sand		600			
134	4	5160	J-Sand		1040	7		57.8

135	2	5250	J-Sand		560	6	19	
136	8		J-Sand		840		16.2	
137	8	5302	J-Sand		1760/1511	6.6	24	400
138	2	4770	J-Sand		640/470	7.5	21.8	15
139	0	4750	J-Sand	Sol. Gas	2320/1950		21.8	15
140	10	5130	J-Sand		1600	13	19.6	269

			BHP, Psi	Original			Original	Primary
Sample	Connate	BHP, Psi	At Start	Oil-Water	Oil Gravity.	Original	Oil in Place	Cum. Oil
No.	Water Sat. %	Original	Flood	Contact, SS	^{0} API	FVF, vol/vol	bbl	bbl
1								1,050,454
2								538,190
3								558,525
4	40	1722	564		36	1.14	960,000	153,111
5	35	1597			35		2,217,919	549,880
6	22	1328	175	-1150		1.233	2,587,400	458,888
7	28.2							323,486
8								416,067
9	30	1250	250		36		1,086,000	151,583
10								1,875,829
11	20	1723			36	1.305	3,636,450	1,059,465
12								585,252
13	25	1300	100					565,614
14		1300	75					1,602,948
15								668,918
16		1775						289,851
17	30	1500	25		37.65	1.3	1,800,000	821,398
18					37.3			216,622
19								581,412
20								541,748
21	42	1593	100		37	1.2	1,535,000	283,368
22	36.8	1503	150		35	1.15		159,208
23		1300	300					246,930
24	35					1.21		241,153
25								422,998
26		1255					4,729,000	1,120,043
27								
28	20.7				36.6		17,130,006	3,329,275
29								250,350
30	35	1400	170		35.5	1.11	6,000,000	1,015,235
31	35	1300	100		37		2,068,000	473,270
32								1,258,554
33							993,000	272,822
34								764,304
35	30	1489	300		35	1.1	1,386,000	210,256
36	40	1800			39	1.2	875,000	122,092
37	32	1240	100		35.4			3,806,661

38	37.5				38		1,002,000	443,804
39								1,276,775
40	25	1115	633	-445	36.7	1.26	9,641,000	509,026
41	58	1300	400	-603	36	1.2	3,430,000	391,979
42								308,819
43								409,933
44	32.5	1290	200		37	1.156	2,636,400	492,616
45	40	958			37	1.1	922,000	115,127
46	28	1300	250		37	1.2	3,492,500	1,199,715
47	36.6	892				1.1515	5,546,000	783,241
48	35.3							853,506
49								1,557,040
50		1250						531,494
51		1020	180					1,009,553
52	40	1172				1.15	1,764,000	279,727
53							2,200,000	201,424
54	40	1100	150		37	1.23	1,710,000	434,807
55								678,968
56					37		5,200,000	1,262,822
57				-576			3,500,000	76,603
58		1000	700				3,740,000	1,332,050
59		1240	200				3,200,000	544,567
60								2,841,308
61		1175						305,904
62	29	1666	110		37	1.17	6,477,000	660,812
63								104,007
64								1,901,636
65	30	1512	260		39	1.25	4,258,000	718,468
66	30	1512			39	1.25	2,100,000	397,232
67	56	1590	100		39	1.18	2,155,000	611,113
68	48	1355				1.25	917,000	351,810
69	30	1546	250	-1975	39.2	1.2	3,240,000	704,632
70		1249	352	-1035			6,261,250	968,549
71	30	1650	700	-1916	33	1.25	3,530,000	636,794
72	40	1640	327		38.5	1.3	3,604,279	667,700
73	30		1270		38		5,560,000	
74								394,815
75								389,522
76	56.48	1942	300				882,500	106,026
77		1700	200				500,068	110,972
78	25	1600	100			1.27	2,200,000	483,431
79	34	1594	100		38.7		623,000	136,133
80	29.2					1.24	1,268,300	234,844
81								2,915,655
82								119,506
83	24	1240	250	-1000	39	1.174		1,105,885
84								344,323

85								347,307
86		1500	250					1,869,896
87	36				39	1.3	2,100,000	365,453
88						1.13		112,605
89								206,687
90	35	1375	150	-1292	39	1.2	6,276,000	1,351,186
91	35					1.15		291,453
92	20	1380	100		35	1.15	725,000	258,008
93			200					303,909
94				-1785				3,626,529
95								218,134
96	25	1460	100		39	1.13	2,521,000	507,659
97	52	1300	700		38	1.15		270,986
98								2,827,660
99		1300	650				2,635,000	352,121
100								384,924
101	28	1500	150		38	1.25	26,050,000	3,722,269
102	35	1655			38	1.3	1,187,000	204,298
103	35	1525			38	1.3	1,390,000	251,005
104								446,015
105	20	1400	50		37	1.2	926,000	354,919
106		1434	400		36		1,875,000	129,301
107			200					4,062,702
108	35	1200			37	1.25	1,136,670	497,342
109	38	1500	500		38	1.1	2,756,248	167,166
110	32.5							381,662
111			200				60,000,000	968,996
112		1417	100				1,600,000	287,737
113	35						340,000	159,279
114								153,212
115								4,509,192
116							1,900,000	645,229
117	38	1510	200		40	1.3	573,562	173,376
118								169,383
119								649,857
120	44.1							233,841
121							3,604,000	1,188,532
122	41.5	1410				1.2	1,228,800	144,341
123								1,261,337
124	30	1475	85		37	1.33	6,000,000	1,193,818
125	35	1430	100		37		3,000,000	506,111
126	40	1425	210	-1348	39	1.22	1,500,000	279,272
127	27	1410			36	1.25	3,094,000	363,052
128	25					1.12		866,333
129	40	905			34		1,061,000	281,949
130							1,810,800	263,918
131		1090	670					481,455

132								482,360
133								1,385,303
134								234,599
135							2,185,234	657,091
136	40	1100	200			1.098	1,014,015	164,529
137	25	1200	100	-876	36.4	1.2	11,396,000	3,101,320
138	41	1350	300		36	1.3	2,693,000	207,463
139	41	1350	400	-820	36	1.3	14,699,000	927,299
140	23	1259				1.09	11,798,000	934,184

	Primary	Primary		Cum. Prod.	Cum. Prod.	Cum. Prod.		
Sample	Cum. Gas	Cum. Water	Max Prod.	P+S	P+S	P+S	Primary	Primary
No.	mcf	bbl	Rate, BOPM	Cum. Oil	Cum. Gas	Cum. Water	Cum. GOR	Cum. WOR
1	558,793	132,898		3,413,228	1,084,827	6,069,245	1.88	0.13
2	336,123	197,147		538,661	336,726	208,965	1.60	0.37
3	443,803	80,963		1,314,445	738,041	1,274,826	1.26	0.14
4	15,004	94,694		175,022	15,004	178,933	10.20	0.62
5	141,078	795,195		596,576	142,606	826,331	3.90	1.45
6	54,809	10,197	60,000	715,826	100,193	2,519,761	8.37	0.02
7	43,289	1,738		430,775	46,199	111,556	7.47	0.01
8	226,552	26,624		1,422,796	768,193	1,968,888	1.84	0.06
9	57,247	1,996	9,000	190,853	72,435	33,757	2.65	0.01
10	487,234	26,344		2,686,942	1,054,011	2,546,438	3.85	0.01
11	167,644	1,874	64,000	1,934,595	1,100,399	9,851,974	6.32	0.00
12	234,574	257,155		926,710	319,363	8,055,768	2.49	0.44
13	137,765	12,535	19,000	638,003	145,364	55,259	4.11	0.02
14	512,647	100,139		3,607,337	638,456	14,864,084	3.13	0.06
15	337,519	56,258		1,696,426	663,889	2,124,701	1.98	0.08
16	7,781	20,814		533,411	7,781	1,022,466	37.25	0.07
17	568,838	51,446		858,148	606,338	126,868	1.44	0.06
18	123,320	414,237		224,318	123,320	446,265	1.76	1.91
19	86,590	508,708		629,435	86,590	640,311	6.71	0.87
20	108,098	26,866		1,012,874	183,073	1,311,569	5.01	0.05
21	115,638	16,741		415,317	115,638	220,227	2.45	0.06
22	65,987	438,851		240,475	65,987	5,787,026	2.41	2.76
23	139,955	128,248		487,819	250,636	852,026	1.76	0.52
24	128,248	77,580	20,000	338,348	112,843	215,334	1.88	0.32
25	300,702	13,971		589,990	559,285	250,689	1.41	0.03
26	323,888	242,976	28,000	1,653,067	323,888	9,109,507	3.46	0.22
27				872,457	440,397	465,239		
28	1,382,749	71,886	164,000	9,781,926	1,853,302	73,438,165	2.41	0.02
29	166,513	16,081	7,600	391,373	202,018	97,001	1.50	0.06
30	148,079	936,964	1,500	1,709,090	217,861	7,094,093	6.86	0.92
31	1,874	12,469	10,000	927,640	1,874	919,287	252.55	0.03
32	729,591	36,131		3,324,348	1,392,777	3,268,195	1.73	0.03
33	28,059	418,939		343,678	28,059	824,461	9.72	1.54
34	373,050	19,006	4,000	2,842,261	708,638	5,083,931	2.05	0.02

35	0	24,376		376,564	0	330,294		0.12
36	15,332	7,639	6,400	211,922	23,019	95,763	7.96	0.06
37	2,343,081	173,116		8,273,069	2,720,281	37,291,191	1.62	0.05
38	75,087	12,218,177		450,351	75,089	12,210,177	5.91	27.53
39	4,553	3,261,713	27,000	1,718,405	4,553	10,461,303	280.42	2.55
40	624,139	0	60,000	4,061,335	6,721,631	11,450,372	0.82	0.00
41	190,792	216,185		1,008,651	190,792	2,445,317	2.05	0.55
42	18,827	365,157		314,109	18,827	372,364	16.40	1.18
43	64,653	1,403,489		503,127	65,053	4,085,171	6.34	3.42
44	215,942	23,115	15,000	900,303	290,366	2,300,882	2.28	0.05
45	36,761	96,625		244,511	60,332	674,101	3.13	0.84
46	376,493	491,884		1,740,703	376,490	10,341,538	3.19	0.41
47	0	188,083		2,345,466	0	8,010,618		0.24
48	392,167	12,920	21,000	1,802,099	443,404	2,570,881	2.18	0.02
49	913,366	85,353	49,000	2,834,296	1,065,172	7,119,272	1.70	0.05
50	180,659	307,239		665,190	180,659	1,029,431	2.94	0.58
51	70,933	1,143,358	29,000	1,312,423	164,122	5,438,606	14.23	1.13
52	7,832	34,080	5,000	291,269	74,471	134,802	35.72	0.12
53	65,005	126,918	12,000	461,259	360,749	912,736	3.10	0.63
54	201,887	67,256	13,000	660,302	220,266	1,594,714	2.15	0.15
55	285,836	98,309		1,194,924	300,826	2,372,829	2.38	0.14
56	84,057	213,804	24,000	3,312,264	4,375,718	17,184,662	15.02	0.17
57	183,081	2,616,313	15,000	86,092	190,226	3,281,468	0.42	34.15
58	724,858	2,773,427		1,361,781	724,858	3,105,627	1.84	2.08
59	106,036	985,278		664,561	114,019	2,614,455	5.14	1.81
60	2,418,782	12,664,397		2,942,869	2,431,186	16,077,343	1.17	4.46
61	178,791	56,683		515,399	223,861	1,557,578	1.71	0.19
62	251,403	255,282		698,316	279,762	588,734	2.63	0.39
63	0	469,116		151,700	0	1,159,491		4.51
64	795,248	228,509		4,178,477	1,054,679	22,508,694	2.39	0.12
65	243,952	19,927	32,000	1,220,955	251,211	6,653,114	2.95	0.03
66	102,620	6,818		507,323	168,092	200,577	3.87	0.02
67	40,947	6,650,854		625,760	47,890	6,701,823	14.92	10.88
68	264,197	14,050	19,000	551,943	272,155	1,252,145	1.33	0.04
69	118,049	280,094	1,350	928,767	138,012	1,410,473	5.97	0.40
70	61,330	1,318,081		1,005,781	61,330	2,185,321	15.79	1.36
71	143,548	364,448	1,200	657,759	154,198	560,453	4.44	0.57
72	334,247	172,709		838,291	435,150	917,451	2.00	0.26
73	354,655	221,955		1,453,210	543,692	1,078,180	0.00	
74	322,820	12,983		405,561	324,624	124,944	1.22	0.03
75	389,522	41,487		440,930	23,146	524,940	1.00	0.11
76	165,480	11,179		194,076	261,739	347,923	0.64	0.11
77	11,359	390,067		111,179	11,359	406,249	9.77	3.52
78	173,398	5,104	12,120	664,663	218,818	520,323	2.79	0.01
79	79,109	15,243	11,000	147,297	91,554	26,740	1.72	0.11
80	481,716	440,013		258,273	540,417	1,030,061	0.49	1.87
81	320,984	54,824		9,180,887	1,392,728	20,337,563	9.08	0.02

82	1,255	5,539		130,960	1,709	12,086	95.22	0.05
83	372,503	48,479	20,000	2,411,428	605,206	12,409,885	2.97	0.04
84	129,994	1,790		1,402,897	386,953	1,170,384	2.65	0.01
85	138,718	0		808,919	160,726	4,246,554	2.50	0.00
86	703,794	550,127	74,000	3,310,478	796,196	9,156,515	2.66	0.29
87	333,441	137,805	14,000	402,216	353,827	465,376	1.10	0.38
88	14,898	33,567	4,200	121,341	14,898	43,409	7.56	0.30
89	117,618	19,007	800	217,682	131,878	76,080	1.76	0.09
90	217,967	33,869	15,000	2,709,594	217,967	8,047,108	6.20	0.03
91	1,486	110,220	8,000	544,938	15,600	1,336,052	196.13	0.38
92	39,718	3,820	500	261,035	39,718	3,859	6.50	0.01
93	1,736,464	117,586	600	684,830	5,382,913	904,856	0.18	0.39
94	857,884	564,665		6,793,603	1,348,985	31,374,061	4.23	0.16
95	22,057	283,453	7,500	230,629	27,757	428,213	9.89	1.30
96	307,517	19,401	15,000	768,002	93,962	626,316	1.65	0.04
97	11,446	176,585		284,920	11,446	224,466	23.68	0.65
98	882,623	277,807		5,387,714	1,368,677	14,903,283	3.20	0.10
99	11,497	234,003		445,357	11,494	770,875	30.63	0.66
100	4,546	371,437		448,791	4,546	779,696	84.67	0.96
101	2,477,217	376,068	121,500	5,789,839	2,544,440	45,157,015	1.50	0.10
102	91,251	7,458		256,687	128,620	290,167	2.24	0.04
103	156,089	3,254		349,680	210,648	102,291	1.61	0.01
104	74,019	9,665		1,947,743	320,111	4,260,014	6.03	0.02
105	54,666	74,092		703,284	54,666	2,971,951	6.49	0.21
106	152,332	55,455	18,000	308,926	176,601	956,043	0.85	0.43
107	1,079,156	5,459,221		4,386,202	1,145,541	8,725,533	3.76	1.34
108	118,677	52,782	950	737,039	118,677	108,873	4.19	0.11
109	88,473	13,786	5,000	213,408	102,580	104,239	1.89	0.08
110	36,165	103,244		610,883	80,371	1,133,057	10.55	0.27
111	186,005	32,799		1,814,316	388,949	2,437,954	5.21	0.03
112	204,644	349,792		287,737	204,644	349,792	1.41	1.22
113	4,016	162,510	900	173,796	4,016	218,809	39.66	1.02
114	12,728	14,038		188,829	30,061	68,809	12.04	0.09
115	1,422,549	8,615	289,000	16,260,239	4,889,025	42,799,140	3.17	0.00
116	288,584	1,914,845	15,200	854,307	299,006	3,333,391	2.24	2.97
117	108,122	17,620		242,175	126,652	90,115	1.60	0.10
118	44,624	430		444,995	68,923	878,153	3.80	0.00
119	180,625	164,584		1,046,639	180,625	1,800,613	3.60	0.25
120	129,090	52,494		277,960	130,420	68,538	1.81	0.22
121	313,283	41,826		1,496,240	339,366	1,582,965	3.79	0.04
122	13,944	148,648	5,000	196,253	16,973	1,207,659	10.35	1.03
123	126,210	145,478	1,700	1,488,604	126,210	1,208,204	9.99	0.12
124	70,607	28,392	51,000	1,800,899	107,717	2,354,446	16.91	0.02
125	305,769	102,980		882,977	426,523	1,314,596	1.66	0.20
126	74,909	65,821		402,672	76,205	484,173	3.73	0.24
127	68,399	37,958		399,616	68,399	171,462	5.31	0.10
128	3,266	153,725	19,000	1,073,437	58,002	3,631,743	265.26	0.18

129	39,140	2,121,317	5,000	355,115	53,610	3,071,533	7.20	7.52
130	50,307	194,146	1,400	294,974	65,030	217,046	5.25	0.74
131	95,229	44,278	30,000	777,844	114,873	3,794,181	5.06	0.09
132	34,512	175,458	30,000	986,235	94,975	4,663,746	13.98	0.36
133	416,950	486,565		1,752,937	434,602	4,923,540	3.32	0.35
134	104,491	9,405	13,000	407,009	111,882	262,982	2.25	0.04
135	100,282	112,662		697,607	101,572	115,898	6.55	0.17
136	3,988	110,074		181,765	5,552	184,367	41.26	0.67
137	82,916	83,125	125,000	5,101,320	216,641	36,348,769	37.40	0.03
138	58,158	575	6,000	318,196	218,861	153,937	3.57	0.00
139	267,286	13,299	315,000	2,073,435	1,425,787	3,970,320	3.47	0.01
140	233,272	36,044	77,000	2,176,324	307,372	3,967,209	4.00	0.04

Appendix B

A brief overview of the concepts of fuzzy ranking and neural networks was included in the original statement of work. It is repeated for completeness in appendix B.

Fuzzy Ranking & Neural Network Background

Earlier attempts by others to correlate oil recovery with public information focused on the effect of a single variable with recovery. Correlating two variables in this manner with a x-y cross plot is an uni-variant analysis. A uni-variant correlation between API gravity, depth, reservoir thickness, porosity, number of producing wells, number of dry holes, well spacing, formation volume factor, gas-oil ratio, water-oil ratio, original bottom hole pressure, bottom hole pressure at the end of primary, connate water saturation, original oil place, discovery date, unitization date, initial producing rate (gas, oil, water), or cumulative primary production (gas, oil, water) with S/P might be tenuous at best. If a multivariable technique is used to establish the relationships, the correlations can be robust. Neural networks are useful for correlating more than two variables. Neural nets work best when the dependent variables have a real bearing on the independent variable, that is the S/P ratio in this case.

Selecting the strength of the dependent variables (21 are included in the previous paragraph) is objectively accomplished with a fuzzy ranking algorithm. The algorithm develops dimensionless cross plots of each dependent variable versus the S/P ratio. The cross plots are used to evaluate the correlation of each variable with S/P. For example, if the connate water saturation values vary very little with the S/P values from the ? projects it can be assumed that the S_{wc} values are not strong correlating parameters. Similarly, the GOR prior to waterflooding may be inversely proportional to the S/P and GOR would be a strong dependent variable. All dependent variables will be evaluated in this manner.

The fuzzy ranking cartoons in Figs. B1a & B1b illustrate the concept.

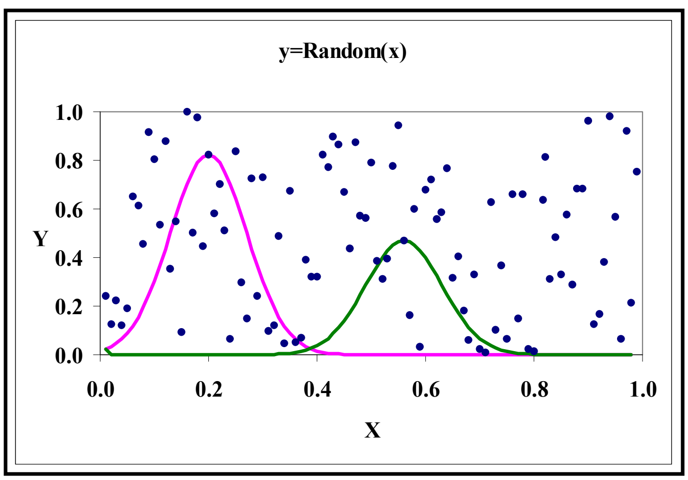


Figure B1a. Conventional cross plot of a random data set (0-1). No correlation between X and Y. The trend is 0.5 (average between 0 and 1) is not evident.

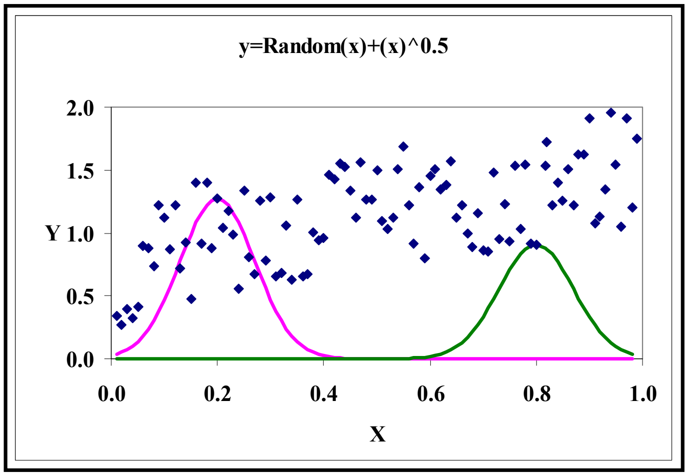


Figure B1b. A Conventional cross plot of a random data set (0-1) plus a square root trend. Note the apparent correlation.

The bell shaped lines are fuzzy membership functions used to identify trends in what can appear to be random data. The fuzzy curves, a type of average of the points encompassed by the curve, are illustrated in Fig. B2 and clearly identify the trends not easily seen in the conventional cross plots. The range, change in Y value, of the random data is about 0.26, indicating no meaningful correlation. The range of the random data plus the square root trend is ~0.9, indicating a correlation between X and Y.

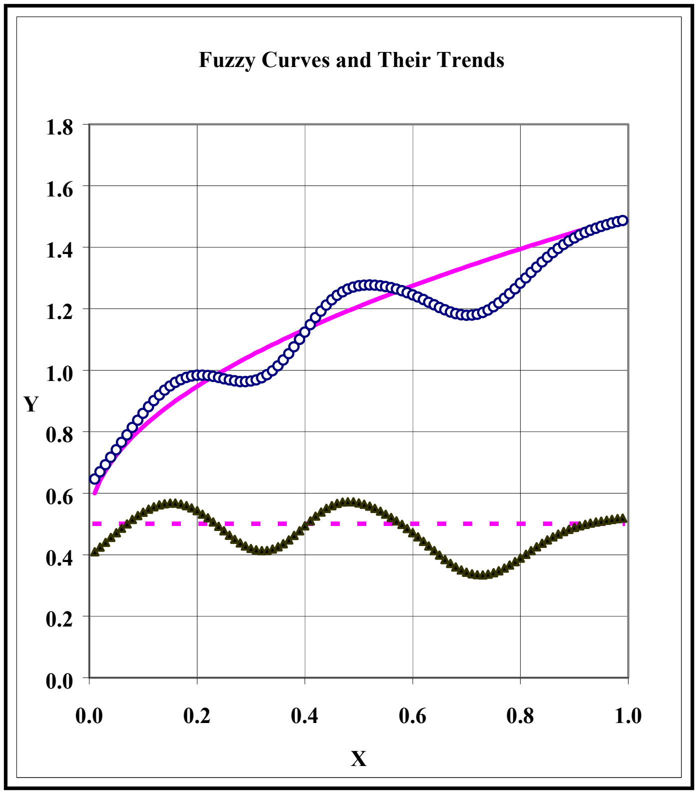


Figure B2. Fuzzy ranking curves. The trends are clearly evident.

Fuzzy ranking technology was used to prioritize the descriptive parameters found in the waterflood hearing files. A neural network was used to correlate the highest-ranking parameters with S/P.

Correlate the highest-ranking parameters with the S/P

Neural networks are useful for correlating more than two variables. They can be viewed as an inverse problem solver where a system of non-linear equations is developed to yield a known value, in this case the S/P ratio. The variables in the equations are the high-ranking parameters. The constants in the equations are called weights. During the training of a neural network, the weights are adjusted to yield the S/P value known from field performance.

A non-linear, feed forward, back propagation, neural network with a fast matrix solver was used to correlate the highest-ranking variables with S/P as the independent variable. Fully connected neural network architectures were evaluated for speed and efficiency. As an example, two different neural network architectures (4-4-2-1 and 4-3-2-1) are seen in Fig. B3. A1, A2, A3, and A4 are the highest ranking input variables, any number of inputs can be used. The tie lines are the weights and circles are the non-linearity functions. Maintaining a satisfactory ratio of training data to weights (coefficients of the regression equation) is assured since there are 42 S/P values for training with perhaps 50 weights depending on the number of high ranking variables selected as input. A good overview of a back propagation neural network is available at http://www.npto.doe.gov/Software/miscindx.html see the Risk Analysis manual.

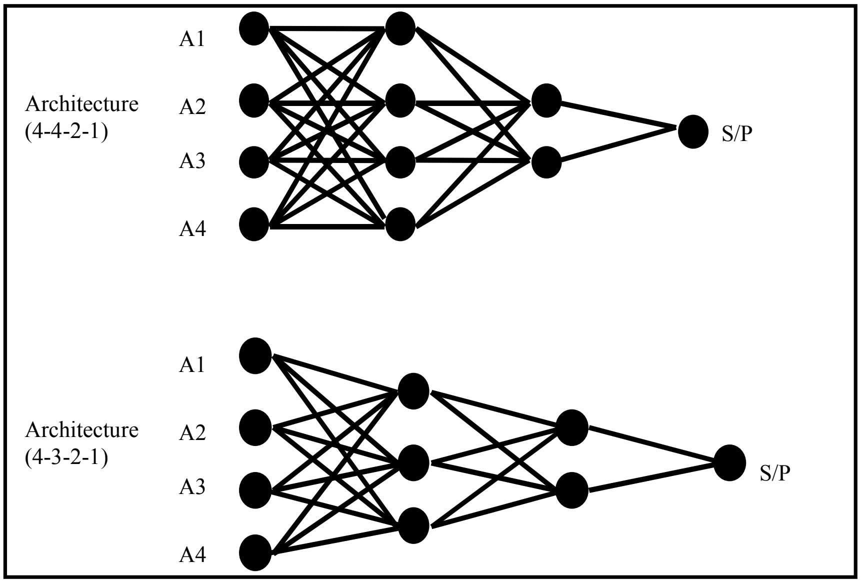
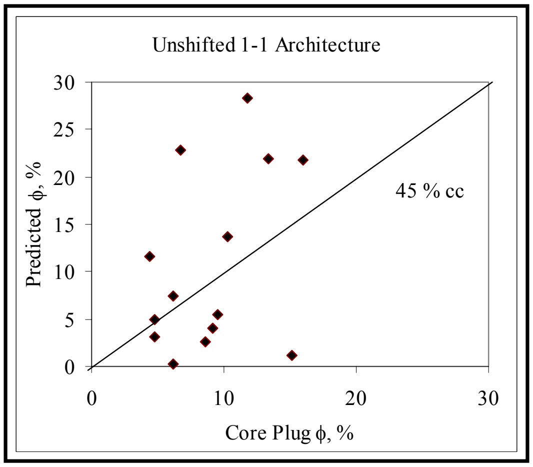


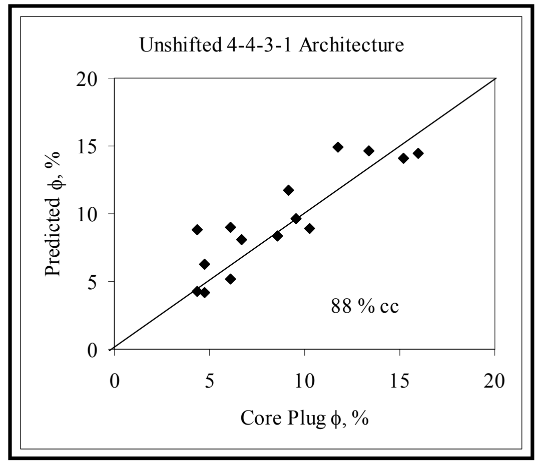
Figure B4. Example of Neural Network Architectures.

Neural networks are trained to yield an output value (S/P in this case). The goodness of the training is expressed as a correlation coefficient with 100% being perfect. In reality networks trained to about 80% are suitable for forecasting. Once a network is trained it can be used to predict the S/P of any non-flooded field given the input parameters. The accuracy of the predictions can be judged with exclusion testing.

A parsed dataset consisting of ? of the known ? S/P values was used to train the best neural network architecture. The ? values dataset network will be used to predict the ? excluded values. The goodness of the predictions will be estimated with a forecast versus actual cross-plot. Exclusion testing provides a means of estimating the validity of the correlations. However, the Cliff Farms Unit waterflood reserves are based on the neural network trained with ? S/P data points.

Fig. B4a&b illustrates exclusion testing as a validation tool. The two variable cross-plot, titled 1-1 Architecture in Fig. B4a, has little value as a forecasting tool. The additional information included in the multi-variable neural network correlation, titled 4-4-3-1 Architecture, resulted in a robust correlation able to forecast with an 88% correlation coefficient.





Figures B5a & b. Exclusion testing with a simple architecture versus a complex architecture on the right.