Vulnerability Assessment for Lake Meredith and Lake Palo Duro

Summary

Flows in the Canadian River Basin have been lower than the historical average for 4 consecutive year since 2000 this condition has established a new drought of record for the Texas Panhandle. Storage in Lake Meredith dropped from 414,000 acre-feet in September 1999 to 134,300 acre-feet (the minimum historical after filling) in February 2004. Lake Palo Duro content dropped from 39,200 acre-feet in May 1999 to 2,300 acre-feet in April 2004. Supplies from Lake Meredith and Lake Palo Duro are not guaranteed under current low storage conditions because it is uncertain if the low storage would be enough to satisfy water demands in the near future.

The analyses developed for the evaluation of the Panhandle Planning Region (Region A) surface water supplies used the period January 1940 through September 2004. The firm yields determined for Lake Meredith and Lake Palo Duro were 69,750 acre-feet per year and 4,000 acre-feet per year respectively. However, the minimum content of the simulation was for September 2004, the last month of the simulation. Therefore, the true firm yield may be lower than the number adopted for the regional water plan if streamflows during the next years are lower than the flows required to meet the demand. Since the drought is still ongoing, truly firm yields cannot be estimated with historical records until there have been enough runoff to refill the reservoirs and produce spills.

The Panhandle Regional Water Planning Group (Region A) authorized Freese and Nichols, Inc. to perform a vulnerability assessment of the reservoirs in the Region (Lake Meredith and Lake Palo Duro) to determine the reliability of water demands under current low storage conditions. The purposes of a vulnerability assessment are:

- To evaluate the ability of Lake Meredith and Lake Palo Duro to supply the assumed firm yield in the short-term (1 to 5 years) under low storage conditions.

- To determine the distribution of storage in the near future (1 to 5 years) given low storage conditions today.

The study was performed using conditional reliability analysis, which forecast future flows based on current storage conditions. The model calculated the expected supply under several conditions of initial storage content that included the current storage as of August 2005 and levels as low as 10% of the conservation storage. The model used in this study is somewhat conservative because it assigns more probability to lower flows under drought conditions than to high flows and it assumes that the lowest annual flow may be repeated during several consecutive years.

The results of these analyses can be summarized as follows:

Lake Meredith

1. The diversion of 69,750 acre-feet per year was determined based on a hydrology ending on September 2004. The conditional model determined that the drought may continue and therefore, the reliable supply may be lower.
2. In the case that the drought continues, the average shortage over the next 5 years would be between 5,700 and 6,200 acre-feet per year, assuming current (August 2005) storage levels, and a diversion of 69,750 acre-feet per year.
3. Under a severe drought, a storage of 160,000 acre-feet in Lake Meredith would likely supply the assumed yield of 69,750 acre-feet per year for the next 12 months. After the second year, shortages may occur.
4. Long term analysis showed that the storage would tend to recover at a slow rate. The long-term average storage is near 325,000 acre-feet.
5. It is recommended to have contingency plans in place that reduce demand or use alternative sources in the case Lake Meredith reaches very low levels. Withdrawals from Lake Meredith should be reduced as the storage content drops. Drought contingency plans to reduce demand or groundwater use as alternative supply during drought are recommended.

Lake Palo Duro

1. Current level of storage (August 2005) is 2,500 acre-feet. Under a severe drought, a storage of 5,000 acre-feet is required to provide a supply of 4,000 acre-feet during 12 month without shortage. Since the current storage is less than 5,000 acre-feet, a shortage for the supply for Region A may occur during the next 12 months if the drought continues.
2. The average shortage of a diversion of 4,000 acre-feet per year for the 12 months following current storage conditions is 213 acre-feet. The maximum shortage of 1,450 acre-feet is expected with a probability of 3%.
3. After 12 months from today, there is a probability of 53% that the storage content would be less than 2,500 acre-feet, and 21 % that the content would be between 2,500 and 5,000 acre-feet.
4. Reservoir content would tend to stay low after 5 years. The average storage after 5 years is 16,114 acre-feet (28% of the conservation capacity).
5. Lake Palo Duro is more vulnerable than Lake Meredith because storage seems to recover more slowly. It is recommended to have alternative sources for water supply during drought conditions, and to reduce demands from Lake Palo Duro under low storage levels.

Conditional Probability Modeling

A conditional probability is defined as the probability of occurrence of an event X given the fact that an event Y (the condition) has occurred. In the context of water resources planning and this study, a conditional probability is used to evaluate the likelihood of meeting certain levels of demand from a reservoir given low storage conditions.

Since the future hydrologic conditions are uncertain, the ability of meeting water supplies during the next years is expressed in terms of probability parameters that represent the forecasted hydrology given current low storage conditions. The model assumes that the average of the future flow depends on the initial storage at the beginning of the year. If the storage is low at the beginning of the year, the average flow under this conditions is lower than the flow that would have occurred under normal or wet years. This represents the assumption that during a drought that induced low storage, low flows are more likely to follow.

Results of the conditional probability model are presented as average or maximum/minimum values. There are 64 years (or sequences) available from historical records from 1940 through 2004. The model assumes that any of the 64 sequences may occur after an assumed initial condition. Each sequence has its own probability of occurrence, where the sum of the probabilities of all sequences equal 1.0. The average value is the probability-weighted average of the results of 64 simulations. The maximum or minimum reflect the extreme values that would occur if severe low or high inflows from historical records follow the initial condition.

For projections longer than 12 months, it is assumed that any of the 64 sequences may be repeated at the end of each year. Therefore, the model considers the possibility of the lowest annual flow to be repeated for several consecutive years (small probability, but possible). A complete description of the conditional probability model is presented in Appendix A.

Inflows in the reservoirs were obtained from the Water Availability Model of the Canadian River Basin (Canadian WAM) developed for Region A. The inflows assumes allocation to other water rights and the reduction of flows entering from New Mexico due to the development of Ute Reservoir.

Results

Lake Meredith

The probability distribution of storage and average diversion for the next 12 months and five years were computed for several initial conditions, including the current storage as of August 2005 (166,000 acre-feet). A total storage of 120,000 acre-feet (48,000 acre-feet of usable storage plus a dead pool of 72,000 acre-feet) was also included to represent very low storage conditions. This storage level is near 10% of the permitted conservation storage of 500,000 acre-feet.

<u>Ability to supply Region A’s adopted firm yield</u>

Table 1 shows the average and maximum shortage of an annual diversion of 69,750 acre-feet for 12 months following different storage conditions. The current content is highlighted. If the reservoir is at 160,000 acre-feet or more, it would take a little more than one year during the worst-case drought before reaching the minimum level. No shortages are predicted within 12 months after current storage levels. It could be seen that shortages would be possible within 12 months once the reservoir falls below 140,000 acre-feet. The average annual shortage would be 1,039 acre-feet, or 1.5% of the demand. If Lake Meredith falls to 100,000 acre-feet, the average shortage is 16,498 acre-feet per year.

Table 1
Shortages of the Adopted Firm Yield under Different Storage Conditions – Lake Meredith

Initial Storage (acre-feet)	Average shortage in 12 months (acre-feet)	Maximum shortage in 12 months (acre-feet)
80,000	31,712	67,444
100,000	16,498	48,023
120,000	5,954	28,770
140,000	1,039	10,267
> 160,000	0	0

Shortages refer to the adopted firm yield of 69,750 acre-feet per year.

Table 2 shows the expected shortages for a diversion of 69,750 acre-feet per year for years 2 through 5 under different initial conditions. The current storage content is highlighted. This table shows that if the storage is less than 140,000 acre-feet, the average shortage would decrease after year 3. Assuming current (August 2005) storage levels, the average shortage over the next 5 years would be between 5,729 and 6,561 acre-feet per year, with shortages being possible after year 2.

Table 2
Average Shortage for the next 5 Years after Different Initial Conditions – Lake Meredith

	Initial Storage (acre-feet)						
	100,000	**120,000**	**140,000**	160,000 (August 2005)	**180,000**	**220,000**	**260,000**
Average shortage in Year 1	16,498	5,954	1,039	0	0	0	0
Average shortage in Year 2	11,395	9,783	8,170	5,729	3,289	174	0
Average shortage in Year 3	9,435	8,664	7,894	6,561	5,229	2,492	657
Average shortage in Year 4	8,212	7,753	7,295	6,455	5,616	3,663	1,880
Average shortage in Year 5	7,356	7,044	6,731	6,156	5,582	4,150	2,662

Shortages refer to the adopted firm yield of 69,750 acre-feet per year.

Probability of storage after one and five years

Figure 1 presents the probability of storage in August 2006 given the current storage of 166,000 acre-feet in August 2005. Assuming a diversion of 69,750 acre-feet per year, there is a probability of 28% that the reservoir content would be less than 120,000 acre-feet after 12 months. There is a probability of 60% that the storage in Lake Meredith would be more than or equal to the current storage. As mentioned previously, no shortages would occur, but the storage could be low after 12 months, which increases the possibility of shortages after the second year.

Figure 2 is the probability of storage after 5 years from today assuming a sustained diversion of 69,750 acre-feet per year. The probability of going below 120,000 acre-feet during years 2 through 5 is between 35% and 40%. There is a probability of 50% that the storage in Lake Meredith would be less than or equal to the current storage at the end of the fifth year. It seems that storage would have a trend to increase over time, but increases would be at a very small rate. The increase is not enough to eliminate the possibility of shortages during the next 5 years.

Figure 3 shows the probability obtained in the long term, which is independent of the storage conditions at the beginning of the year. The average storage in Figure 3 is 325,000 acre-feet, which is equivalent to the average storage after drought conditions have passed. The content would tend to recover at a slow rate. Even with the increasing trend, Lake Meredith is vulnerable under low storage levels.

Figure 1
Probability Distribution of Storage after 1 Year - Lake Meredith

Initial Storage = 166,000 acre-feet

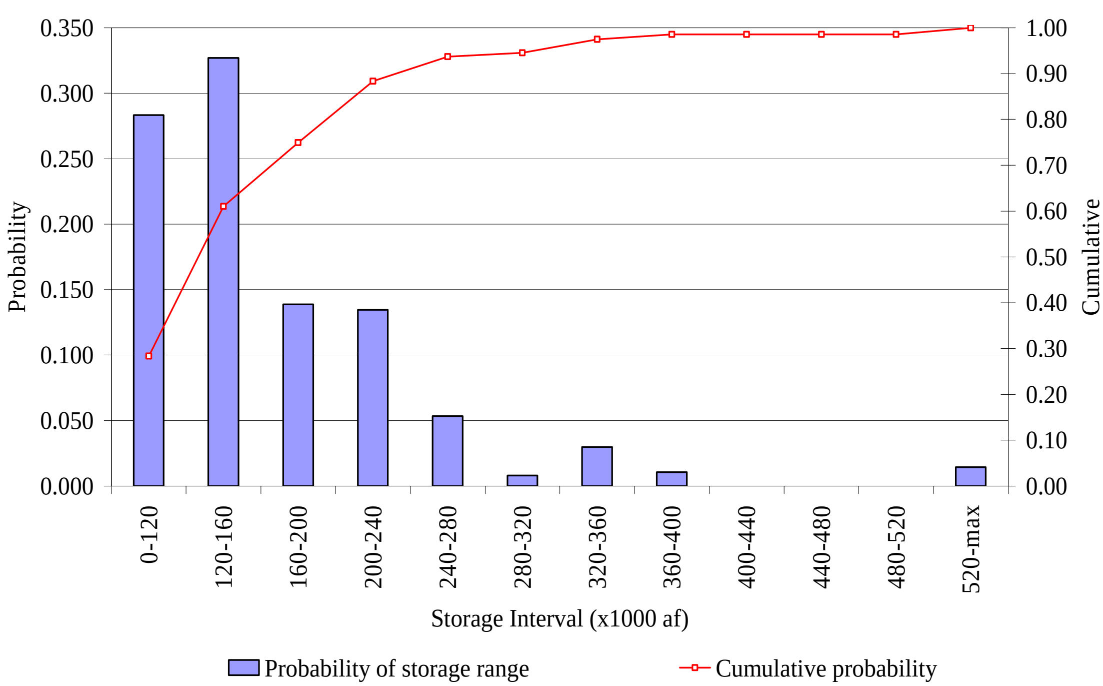


Figure 2
Probability Distribution of Storage after 5 years - Lake Meredith
Initial Storage = 166,000 acre-feet

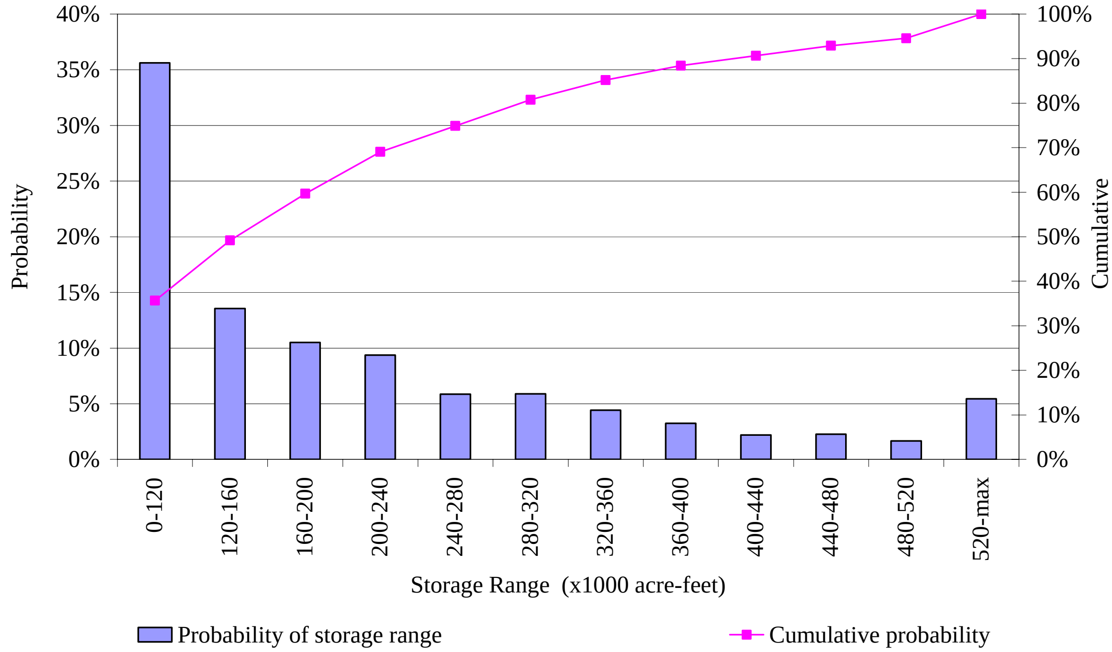
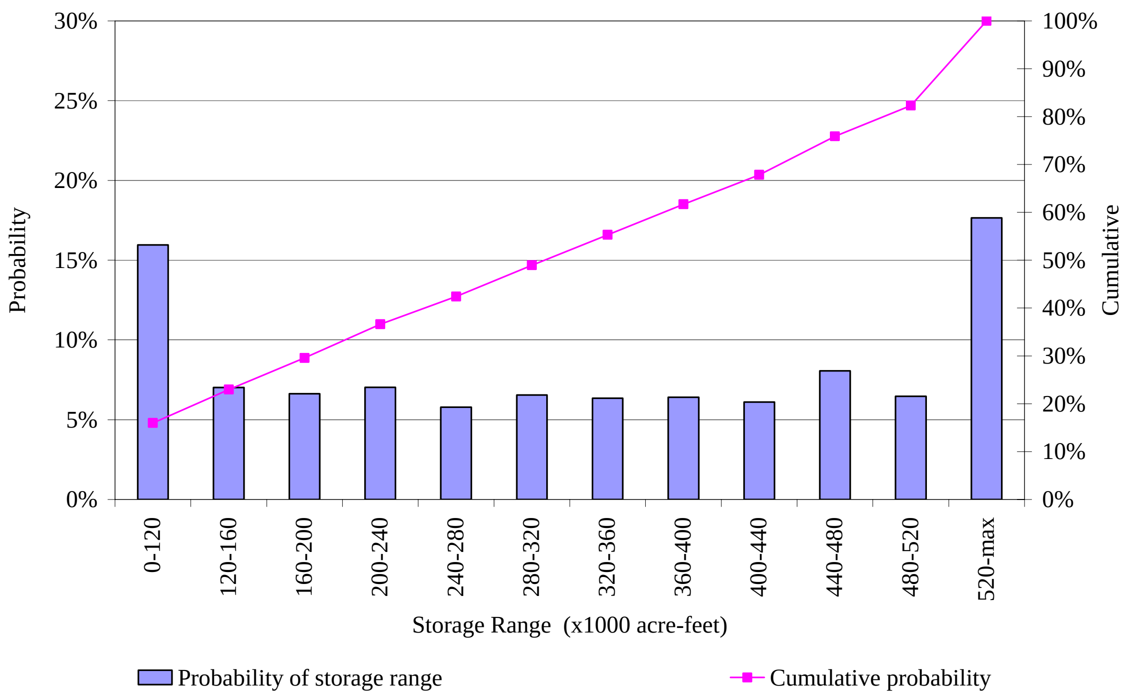


Figure 3
Long Term Probability Distribution of Storage for Lake Meredith



Lake Palo Duro

Ability to Supply Region A's adopted supply

Table 3 shows the average shortages within a 12-month period after several initial storage conditions. The current storage condition is highlighted. Results show that a minimum storage of 5,000 acre-feet is required to provide the adopted supply by the Regional Water Plan without shortage. Table 4 presents the average shortage for the next 5 years. Under current storage conditions, average shortages would be between 4% and 2% of the adopted supply.

Table 3
Shortages of the Adopted Firm Yield under Different Storage Conditions – Lake Palo Duro

Initial Storage (acre-feet)	Average Shortage after 12 months	Maximum predicted shortage after 12 months
500	1,182	3,114
1,000	875	2,687
1,500	602	2,267
2,000	358	1,854
2,500	191	1,455
3,000	86	1,073
3,500	30	724
4,000	10	361
4,500	1	30
>5,000	0	0

Shortages refer to the adopted firm yield of 4,000 acre-feet per year.

Table 4
Average Shortage for the next 5 Years after Different Initial Conditions – Lake Palo Duro

	2,500	5,000	7,500	10,000	12,500	17,500
Average shortage in Year 1	213	0	0	0	0	0
Average shortage in Year 2	156	116	76	38	0	0
Average shortage in Year 3	122	103	84	61	37	2
Average shortage in Year 4	101	90	79	65	50	21
Average shortage in Year 5	86	79	72	63	53	31

Probability of Storage after One and Five Years

Figure 4 is the probability distribution of storage after 12 months starting with the current storage of 2,500 acre-feet. Storage would likely remain below 5,000 acre-feet within the next 12 months. There is very small probability that the reservoir would be above 50% of the conservation capacity.

The probability distribution of storage after 5 years is presented in Figure 5. The most probable range is below 5,000 acre-feet. There is a probability of 50% of having the reservoir above 10,000 acre-feet. The recovery of storage during drought is very slow. Inflows in Lake Palo Duro have not had any extreme flood periods, and therefore, quick recovery due to peak flows is very unlikely.

Figure 4
Probability Distribution of Storage after 1Year - Lake Palo Duro
Initial Storage = 2,500 acre-feet

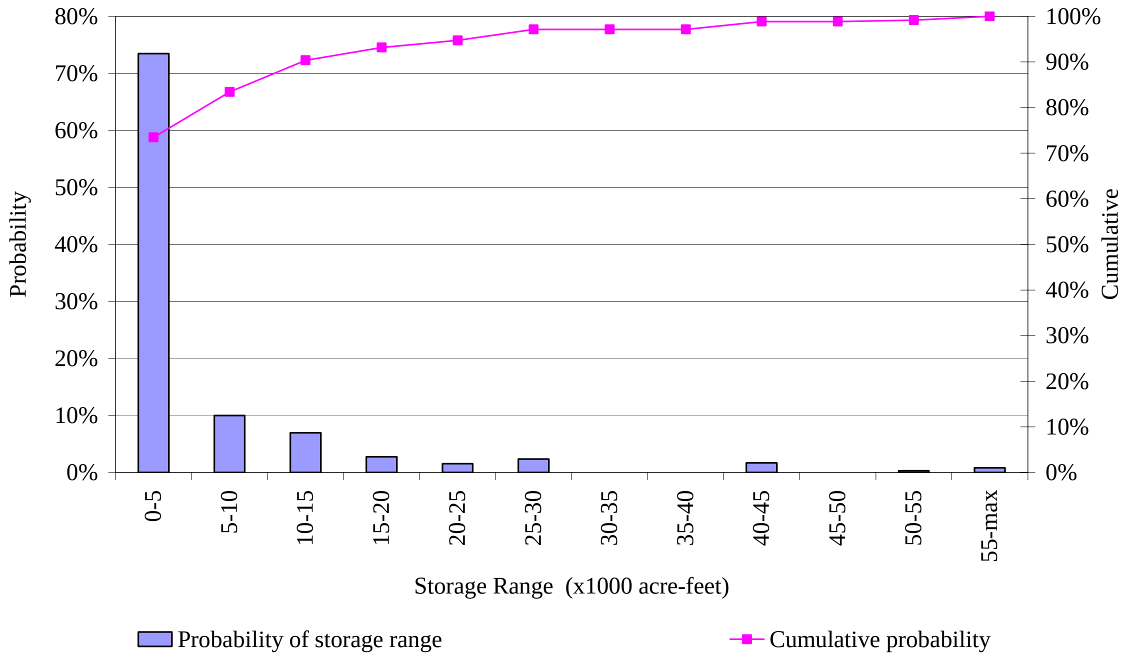
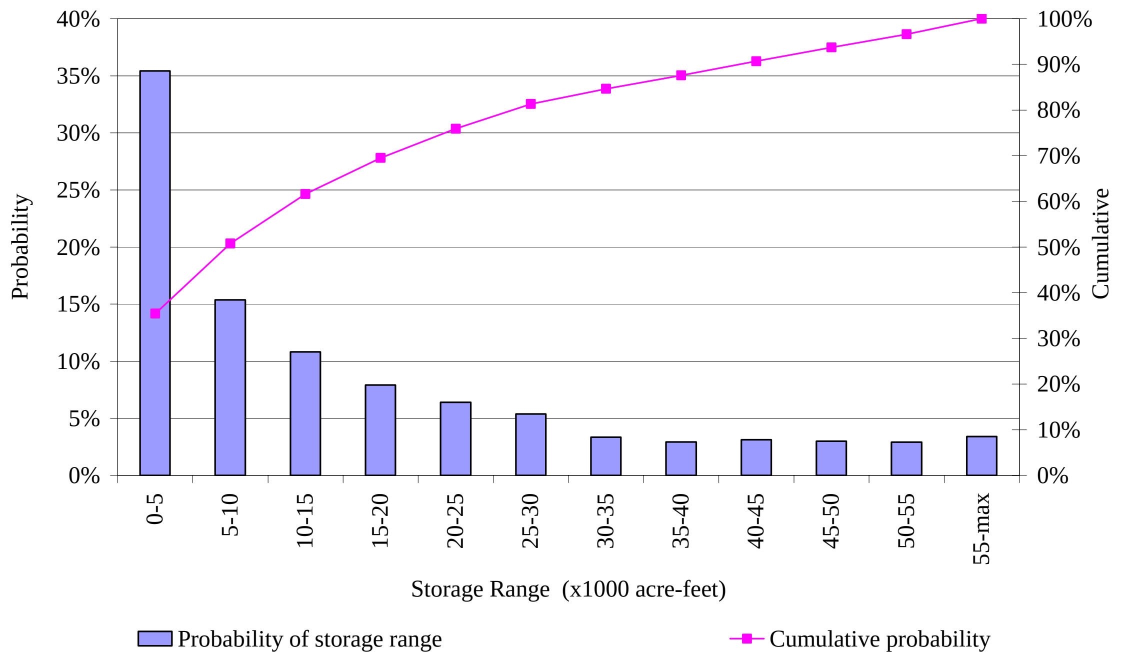


Figure 5
Probability Distribution of Storage after 5 Years - Lake Palo Duro
Initial Storage = 2,500 acre-feet



Appendix A

Conditional Probability Modeling

A conditional probability is defined as the probability of occurrence of an event X given the fact that an event Y (the condition) has occurred. The model used in this study finds the likelihood of meeting certain levels of demand from a reservoir given an initial level of storage. The model assumes that any of the 12-month historical naturalized flows from September to August may occur given an initial condition of storage, where the probability of each historical sequence depends on the initial storage at the beginning of the year. For example, if the storage is low at the beginning of the year, those historical sequences with low flow are given higher probability than those high-flow sequences. This represents the assumption that during a drought that induced low storage, low flows are more likely to follow.

Historical inflows in the reservoirs are obtained from a simulation of the Canadian WAM. Therefore, the inflows assume allocation to other water rights and a reduction of flows coming from New Mexico due to the development of Ute Reservoir. The historical inflows are the values that would have been available for impoundment in the past assuming fully development of other rights.

A total of 64 sequences of available inflow (one per calendar year) were created. Each sequence of 12 months was modeled using the OPERATE model. The OPERATE model is an in-house computer model developed by Freese and Nichols for reservoir simulations. Each sequence has its own probability of occurrence based on the initial storage content. The diversions and storage at the end of the 12-month period is calculated as the probability-weighted average of all simulations.

The model is somewhat conservative because:

1. It assigns more probability to lower flows under drought conditions.
2. It assumes that the lowest annual flow may be repeated during several consecutive years.
3. It assumes that Ute Reservoir is at a low level at the beginning of each sequence. This assumption reduces the likelihood of spills from Ute Reservoir and the flow coming from New Mexico.

Some of the concepts presented here are currently being implemented in the Water Rights Analysis Package, the river basin simulation model used in the TCEQ Water Availability Models. The WRAP version with conditional reliability analysis was not available at the time of finishing this study, so the methodology was implemented with the OPERATE model and spreadsheets. A more detailed explanation of this model is expected to be available with the user’s manual of the WRAP version that supports conditional reliability assessments. The steps for the model development are explained next.

1. Expected flow as a function of storage

The connection between past and future annual flows is made through the current reservoir storage content. The model assumes that the reservoir storage level is an indicator of the total amount of inflow during the past. Then, the probability distribution of flows in the next periods can be related to current storage because the storage preserves some "memory" about the previous flows. High storage values are associated with the occurrence of high flows in previous periods, and low storage levels indicate periods of drought.

Using a long-term simulation from the Canadian WAM, a plot of storage at the end of August and the future flows during the next 12 months (September-August) is created. This plot for Lake Meredith is presented as Figure A-1. A relationship between the storage (S) and future flow (Q) is established by the following equation:

$$Q = c * \exp(S/b) \qquad \text{(A.1a)}$$

or

$$\ln(Q) = a + S/b \qquad \text{(A.1b)}$$

Notice that there is linear relationship between ln(Q) and S. The parameters a and b are obtained with a regression. The error (e) of any flow in respect to the average flow is expressed as:

$$e = \ln(Qi) - \ln(Q^*) \qquad \text{(A.2a)}$$

or

$$e = \ln(Qi/Q^*) \qquad \text{(A.2b)}$$

where Qi is the flow of any sequence and Q* is the expected (average) flow after an initial storage condition. A random variable R is defined as

$$R=Qi/Q^* \qquad \text{(A.3)}$$

Therefore, the error (e) of equation (4.2b) can be rewritten as

$$e = \ln(R) \qquad \text{(A.4)}$$

Statistical theory demonstrates that the random variable (e) follows a normal probability distribution with mean zero and known variance. The random variable ln(Qi) also follows a normal probability distribution as:

$$\ln(Qi) = \ln(Q^*) + e \text{ where } e \sim \text{Normal}(0,\sigma^2) \qquad \text{(A.5)}$$

Therefore, a random variable z as defined in (A.6) follows a normal probability distribution with mean zero, and variance equal to 1.0.

$$z = [\ln(Qi)-\ln(Q^*)]/\sigma \sim \text{Normal}(0,1) \qquad \text{(A.6)}$$

Since the logarithm of flow follows normal distribution, the flows follow a probability distribution log-normal. A distribution log-normal is widely accepted for monthly flows in many basins. Figure A-2 illustrates how the probability of the logarithms of the flows changes with storage.

A cumulative probability (the probability that the variable would be less than or equal to a value) can be found from standard tables for a normal distribution. The probability of a sequence is then computed as the difference between the cumulative probability of the average with the next higher flow and the cumulative probability of the average with the next lower flow. The sum of the probabilities of all sequences should equal 1.0.

Table A-1 reproduces the probability of each sequence for an initial storage of 160,000 acre-feet. Figure A-3 is a comparison the duration curves for the naturalized flows expected under an initial storage of 100,000 acre-feet and the duration curve for the naturalized flows under an initial storage of 540,000 acre-feet. A long-term frequency curve obtained from the long-term simulation using the Canadian WAM is also presented. Notice that flows following a low storage are less than the flow after higher storage.

This concept is being implemented in a new version of the Water Rights Analysis Package, along with other options for assigning probabilities to each sequence.

2. Computing a Transitional Matrix

The conservation storage of each reservoir was divided in 12 intervals. A transitional matrix represents the probability of having a final storage within one interval when the initial content 12 months before was in another range. For example, one term in the matrix is the probability of ending the simulation with high storage when the content 12 months before was low, or conversely, another element is the probability of having a low storage when the initial content was high. The probabilities for all possible 144 transitions (12 initial intervals x 12 final intervals) were computed to compose the transitional matrix.

The probability of storage after 12 months is computed with simulations of 64 sequences and its probability of occurrence. The probability of being in any of the 12 intervals after 12 months is calculated as the sum of the probabilities of those sequences in which the storage ended the simulation within the interval. Table A-2 shows the transitional matrix, and the computations of the probability of storage with an initial condition between 160,000 and 200,000 acre-feet.

3. Probability of Storage after 12 and 60 months

The probability one year ahead is calculated as the product of the transitional matrix and the probability distribution at the beginning of the year.

For the first year, the probability distribution represents the initial state, with a value of 1 in the interval representing the initial storage, and 0 in the other elements. The probability of storage for successive years computed by multiplying the probability distribution at the beginning of the year by the transitional matrix. The probability 5 years from now is computed by consecutively doing this multiplication five times.[1]

Successive application of the transitional matrix eventually converges to the steady state condition, in which the probability distribution is independent of the state of the previous period.

4. Probability of Diversion Shortages

The average diversion during the 12 months following an initial storage is computed as the probability-weighted average of the diversions of each sequence. It is possible to compute an average diversion in 12 months for each initial storage conditions to produce an array of 12 conditional average diversions.

The average diversion for years 2 through 5 is calculated as the product of the diversion given the initial storage and the probability that the reservoir was in the initial storage at the beginning of the year.

$$\text{Av. diversion} = \Sigma(\text{Diversion under storage S} * \text{Probability of Reservoir content=S})$$

[1] For those with some familiarity with probability concepts, this process is a Markov chain. The transitional matrix method was presented by Moran (1954), “A probability theory of dams and storage systems.” Australian Journal of Applied Science, Volume 5, Number 2, pages 116-124.

Figure A-1
Average Flow as a Function of Storage

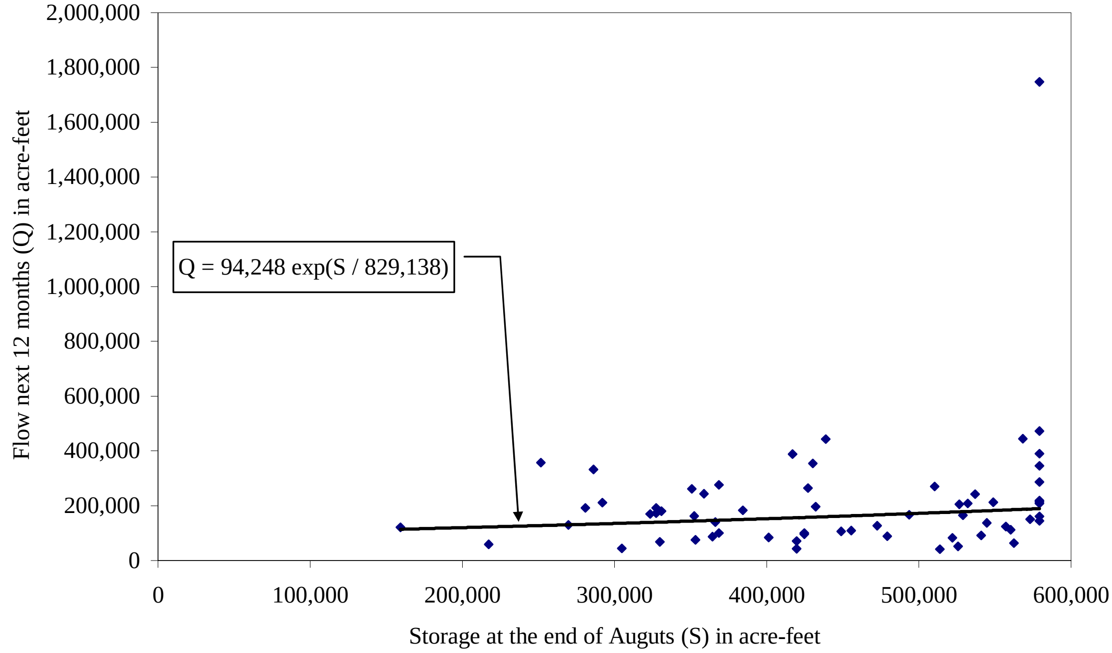


Figure A-2
Probability Distribution of Flows during the Next 12 Months Given an Initial Storage

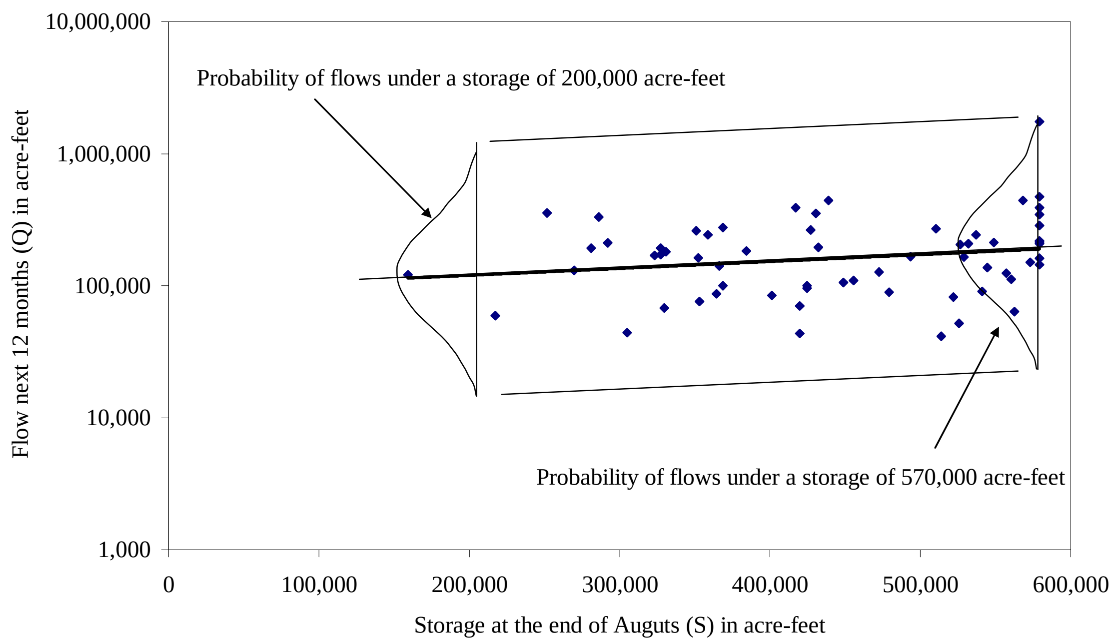


Figure A-3
Exceedance Probability of Naturalized Flows for Different Initial Storage Conditions

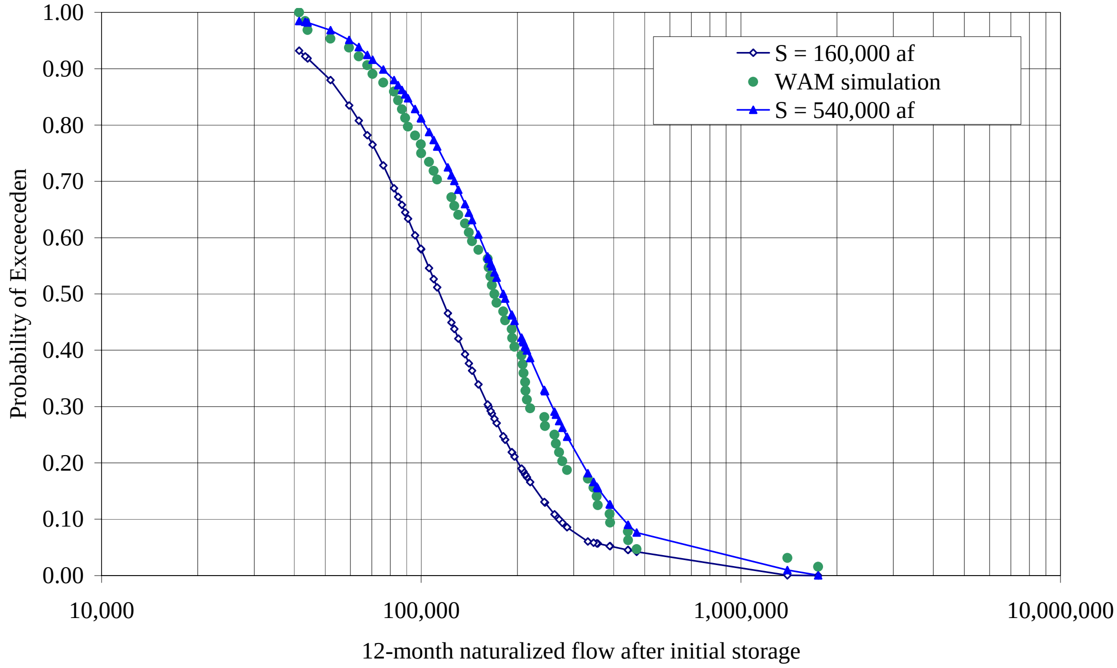


Table A-1
Derivation of the Probability for Each Historical Sequence under an Initial Storage of 160,000 acre-feet in Lake Meredith

Storage August (af): 160,000
Most probable flow (af/yr) under current storage using regression: 114,293

Sequence	From	To	Naturalized Flow [a]	Total inflow Lake Meredith [b]	R	ln (R)	Probability of sequence
1	Sep-40	Aug-41	1398242	1221949	12.234	2.504	0.0137
2	Sep-41	Aug-42	1747414	1556964	15.289	2.727	0.0002
3	Sep-42	Aug-43	472542	294364	4.134	1.419	0.0298
4	Sep-43	Aug-44	205944	99559	1.802	0.589	0.0126
5	Sep-44	Aug-45	137131	76480	1.200	0.182	0.0219
6	Sep-45	Aug-46	82264	34798	0.720	-0.329	0.0282
7	Sep-46	Aug-47	354462	199367	3.101	1.132	0.0008
8	Sep-47	Aug-48	212030	107223	1.855	0.618	0.0026
9	Sep-48	Aug-49	389949	298660	3.412	1.227	0.0034
10	Sep-49	Aug-50	346310	238140	3.030	1.109	0.0017
11	Sep-50	Aug-51	286146	210121	2.504	0.918	0.0197
12	Sep-51	Aug-52	63790	31391	0.558	-0.583	0.0268
13	Sep-52	Aug-53	105790	62835	0.926	-0.077	0.0266
14	Sep-53	Aug-54	141034	122912	1.234	0.210	0.0144
15	Sep-54	Aug-55	276695	176165	2.421	0.884	0.0071
16	Sep-55	Aug-56	99747	58993	0.873	-0.136	0.0126
17	Sep-56	Aug-57	243813	188430	2.133	0.758	0.0114
18	Sep-57	Aug-58	443553	281590	3.881	1.356	0.0034
19	Sep-58	Aug-59	207888	137808	1.819	0.598	0.0029
20	Sep-59	Aug-60	444202	314013	3.887	1.358	0.0016
21	Sep-60	Aug-61	219326	121520	1.919	0.652	0.0225
22	Sep-61	Aug-62	150939	86843	1.321	0.278	0.0304
23	Sep-62	Aug-63	112081	74621	0.981	-0.020	0.0303
24	Sep-63	Aug-64	41470	27745	0.363	-1.014	0.0730
25	Sep-64	Aug-65	389201	309179	3.405	1.225	0.0023
26	Sep-65	Aug-66	144320	89292	1.263	0.233	0.0190
27	Sep-66	Aug-67	208918	153525	1.828	0.603	0.0032
28	Sep-67	Aug-68	124469	102515	1.089	0.085	0.0138
29	Sep-68	Aug-69	242904	167273	2.125	0.754	0.0173
30	Sep-69	Aug-70	214209	147867	1.874	0.628	0.0064
31	Sep-70	Aug-71	164923	121907	1.443	0.367	0.0060
32	Sep-71	Aug-72	270200	215112	2.364	0.860	0.0062
33	Sep-72	Aug-73	161376	120850	1.412	0.345	0.0194
34	Sep-73	Aug-74	90902	81934	0.795	-0.229	0.0201
35	Sep-74	Aug-75	166378	145788	1.456	0.375	0.0069
36	Sep-75	Aug-76	52050	37600	0.455	-0.787	0.0408
37	Sep-76	Aug-77	195833	152176	1.713	0.538	0.0141

Sequence	From	To	Naturalized Flow	Total inflow Lake Meredith	R	ln (R)	Probability of sequence
38	Sep-77	Aug-78	126876	113524	1.110	0.104	0.0144
39	Sep-78	Aug-79	109351	77844	0.957	-0.044	0.0171
40	Sep-79	Aug-80	70413	53075	0.616	-0.484	0.0266
41	Sep-80	Aug-81	261343	188392	2.287	0.827	0.0114
42	Sep-81	Aug-82	264044	160312	2.310	0.837	0.0046
43	Sep-82	Aug-83	89105	59932	0.780	-0.249	0.0123
44	Sep-83	Aug-84	43379	29482	0.380	-0.969	0.0070
45	Sep-84	Aug-85	67825	46676	0.593	-0.522	0.0212
46	Sep-85	Aug-86	130709	85478	1.144	0.134	0.0226
47	Sep-86	Aug-87	356935	179554	3.123	1.139	0.0024
48	Sep-87	Aug-88	192136	162464	1.681	0.519	0.0113
49	Sep-88	Aug-89	183172	134231	1.603	0.472	0.0141
50	Sep-89	Aug-90	84685	50198	0.741	-0.300	0.0146
51	Sep-90	Aug-91	172103	133844	1.506	0.409	0.0158
52	Sep-91	Aug-92	162590	116036	1.423	0.352	0.0057
53	Sep-92	Aug-93	99906	66578	0.874	-0.135	0.0172
54	Sep-93	Aug-94	169441	73170	1.483	0.394	0.0085
55	Sep-94	Aug-95	192565	106859	1.685	0.522	0.0040
56	Sep-95	Aug-96	211323	144102	1.849	0.615	0.0029
57	Sep-96	Aug-97	180679	104070	1.581	0.458	0.0147
58	Sep-97	Aug-98	76057	46572	0.665	-0.407	0.0388
59	Sep-98	Aug-99	332143	146673	2.906	1.067	0.0104
60	Sep-99	Aug-00	95709	64756	0.837	-0.177	0.0266
61	Sep-00	Aug-01	86971	54609	0.761	-0.273	0.0139
62	Sep-01	Aug-02	44092	22836	0.386	-0.952	0.0207
63	Sep-02	Aug-03	59513	42013	0.521	-0.653	0.0369
64	Sep-03	Aug-04	121093	58003	1.059	0.058	0.0311

[a] Naturalized flow is the flow that would have occurred in the absence of water development.
[b] Total inflow is the amount available after Ute Reservoir and senior water rights.

Table A-2

Transitional Matrix for Lake Meredith and Probability Distribution of Storage after 5 years after an Initial Storage inside Interval 3

			Transitional Matrix												**Probability Distribution of Storage**					
			Initial Storage																	
	Storage interval (x 1000 af)		100,000	140,000	180,000	220,000	260,000	300,000	340,000	380,000	420,000	460,000	500,000	540,000	Initial Condition in interval 3	Probability Year 1	Probability Year 2	Probability Year 3	Probability Year 4	Probability Year 5
			1	2	3	4	5	6	7	8	9	10	11	12						
	0-120	1	0.703	0.497	0.188	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.497	0.483	0.446	0.412	0.383
	120-160	2	0.151	0.221	0.282	0.169	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.221	0.172	0.156	0.147	0.140
	160-200	3	0.054	0.125	0.231	0.326	0.183	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.125	0.113	0.107	0.105	0.104
	200-240	4	0.039	0.077	0.146	0.217	0.320	0.235	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.077	0.080	0.088	0.090	0.091
	240-280	5	0.002	0.026	0.069	0.123	0.184	0.260	0.234	0.000	0.000	0.000	0.000	0.000	0.000	0.026	0.039	0.046	0.051	0.055
Final Storage	280-320	6	0.035	0.002	0.027	0.073	0.129	0.167	0.255	0.269	0.015	0.000	0.000	0.000	0.000	0.002	0.041	0.048	0.053	0.056
	320-360	7	0.005	0.039	0.002	0.031	0.109	0.178	0.169	0.192	0.243	0.023	0.000	0.000	0.000	0.039	0.024	0.032	0.037	0.041
	360-400	8	0.000	0.002	0.039	0.033	0.007	0.080	0.174	0.180	0.176	0.232	0.022	0.000	0.000	0.002	0.015	0.020	0.025	0.029
	400-440	9	0.000	0.000	0.002	0.009	0.037	0.015	0.084	0.174	0.181	0.151	0.213	0.021	0.000	0.000	0.006	0.010	0.015	0.019
	440-480	10	0.000	0.000	0.000	0.002	0.009	0.030	0.008	0.091	0.182	0.200	0.145	0.199	0.000	0.000	0.003	0.010	0.015	0.020
	480-520	11	0.000	0.000	0.000	0.000	0.002	0.011	0.030	0.009	0.096	0.169	0.199	0.164	0.000	0.000	0.003	0.007	0.011	0.015
	520-max	12	0.010	0.013	0.015	0.018	0.020	0.024	0.046	0.086	0.108	0.224	0.421	0.616	0.000	0.013	0.021	0.030	0.040	0.049
	Sum		1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000